TRAVAUX

International Association of Geodesy
Volume 32

General and technical reports
1999 – 2001

Established at the IAG Scientific Assembly
Budapest, Hungary, September 2001

Editor: O. B. Andersen

International Association of Geodesy
TRAVAUX 2001

TABLE OF CONTENTS

SECTION I: POSITIONING

SECTION II: ADVANCED SPACE TECHNOLOGY

Special Commissions of Section II:

SC7: Satellite Gravity Field Missions	**Karl-Heinz Ilk**

Special Study Groups of Section II:

SSG 2.162: Precise Orbits Using Multiple Space Techniques	**R. Scharroo**
SSG 2.183: Spaceborne Interferometry Techniques	**Ramon Hanssen**
SSG 2.192: Spaceborne GNS Atmosphere Sounding	**Rob Kursinski**
SSG 2.193: Gravity field missions: calibration and validation	**Pieter Visser**
SSG 2.194: GPS Water Level Measurements	**Gerry Mader**

International Services of Section II:

IGS : International GPS Service	**C. Reigber**
ILRS: The International Laser Ranging Service	**John Degnan**
IVS: International VLBI Service for Geodesy and Astrometry	**W. Schlüter**

SECTION III: DETERMINATION OF THE GRAVITY FIELD

Report by the President	**Michael G. Sideris**

Commissions of Section III:

Comm XIII: International Gravity and Geoid Commission	**Martin Vermeer**

Special Study Groups of Section 3:

SSG 3.167: Regional Land and Marine Geoid Modelling	**I.N. Tziavos**
SSG 3.177: Synthetic Modelling of the Earth's Gravity Field	**Will Featherstone**
SSG 3.184: Use of Remote Sensing Techniques for Validating Heights and Depths	**Philippa Berry**
SSG 3.185: Merging data from dedicated satellite missions with other gravimetric data	**Nico Sneeuw**
SSG 3.186: Altimetry data processing for gravity, geoid and sea surface topography determination	**C. Hwang**

International Services of Section III:

BGI - International Gravimetric Bureau	**J-P. Barriot**
IGeS - International Geoid Service	**F. Sansò**

SECTION IV: GENERAL THEORY AND METHODOLOGY

Report by the president	**Bernhard Heck**

Special Commissions of Section IV:

SC1: Mathematical and Physical Foundations of Geodesy	**P. Holota**

Special Study Groups of Section IV:

SSG 4.187: Wavelets in Geodesy and Geodynamics	**W. Keller**
SSG 4.188: Mass Density from Joint Inverse Gravity Modelling	**G. Strykowski**
SSG 4.189: Dynamic theories of deformation and gravity fields	**D. Wolf**
SSG 4.190: Non-probabilistic assessment in geodetic data analysis	**H. Kutterer**
SSG 4.191: Theory of Fundamental Height Systems	**C.Jekeli**

SECTION V: GEODYNAMICS

Report by the president	**Clark Wilson**

Commissions of Section V:

Comm V: Earth tides	**Shuzo Takemoto**
Comm XIV: Crustal Deformation	**S. Zerbini**

Special Commissions of Section V:

SC3: Fundamental Parameters	**E. Groten**
SC8: Sea Level and Ice Sheets	**Michael Bevis**

Joint Working Groups of Section V:

IAG/IAPSO: Joint Working Group Geodetic Effects of Non-Tidal Oceanic Processes	**R. S. Gross**

International Services of Section V:

IERS: International Earth Rotation Service	**Jan Vondrak**
PSMSL: Permanent Service For Mean Sea Level	**P. L. Woodworth**
BIPM: Bureau International des Poids et Mesures - Time Section	**E.F. Arias**
International Center for Earth Tides	**B.Ducarme**

OUT OF SECTION

GALOS: Geodetic Aspect of the law of the sea	**Bjorn G. Harsson**
IAG WG: Working Group on Eduction	**C. C. Tscherning**
IAG-CDC: Committee for Developing Countries (CDC)	**D. Blitzkow**
IAU/IAG: Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites	**P.K. Seidelmann**

MEETINGS

Minutes of the IAG - Executive Committee meeting at the XXII IAG/IUGG General Assembly, Birmingham, July, 1999

Minutes of the EC meeting in Nice, 28-29th April, 2000, held in connection with the EGS XXV general assembly**.**

Minutes of the EC meeting in Nice, 30-31th March, 2001

Report on the South America Geoid 2000

Report of the 14th Int. Symposium on Earth Tides (ETS2000)

IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes

First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS, Zurich, Switzerland, March 12-16, 2001

The 11th Symposium of the EUREF Subcommission

Second International Symposium: Geodynamics of the Alps-Adria Area by means of Terrestrial and Satellite Methods

Report on the International Conference on Technical Aspects of Maritime Boundary Delineation and Delimitation, Including Unclos Article 76 Issues (ABLOS), Monace, 9-10 September, 1999

Meeting Report of the IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes held in conjugation with the EGS XXV General Assembly, Nice, France, April, 2000

Working Meeting of the IAG SSG 4.190 on non-probabilistic assessment in geodetic data analysis

Minutes of the Organizational Meeting for African Reference System "AFREF"

Report on the 2nd International Workshop on Airborne Gravimetry and Polar Gravity

ARCGP – Arctic Gravity Project

TOP

FOREWORD.

Every four year the International Association of Geodesy (IAG) publishes its reports for the past four year period, called the "Travaux de l'Association Internationale de Geodesie".

The "Travaux " is normally published shortly after the General Assembly of the International association of Geodesy held as a part of the General Assembly of the International Union of Geodesy and Geophysics (IUGG).

In light og the possible restructuring of the IAG within the upcoming two years, the IAG decided to publish a new version of the IAG Travaux covering reports for the past two years (1999-2001). The Travaux will be published in association with the IAG scientific Assembly in Budapest, Hungary, 2-8 september, 2001 so that scientific information can be disseminated rapidly throughout the geodetic community.

The Travaux is the complete collection of all the reports of all the bodies constituting the Association and in the current version it. This version of the Travaux is very successful in that it contains as many as 47 reports. Hereby this version of the Travaux is complete in the sense that all bodies of the IAG have reported.

Each of the 5 sections within the IAG has their own chapter in the Travaux. In these chapters the sections report on their commissions, services, special commissions, special study groups and working groups. Finally a number out of sections reports are found. In this version also meeting reports have been added to the Travaux.

It is an instantaneous picture of the work performed the last two years by a large number of individuals and groups through international coorporation under the auspices of the International Association of Geodesy.

I would like to thank all the contributors who did a very good job in collecting the individual reports of their sections. I would also like to thank Anne Louise Vest for her very fine work in preparing the individual documents in the Travaux for publication.

The IAG homepage on the Internet (www.gfy.ku.dk/~iag) is an open up-to-date forum for communication. Through this electronic address, all members of the IAG are now able to have almost real time access to all information related to the IAG. An electronic version of the "Travaux" can also be found here

Ole B. Andersen

MID-TERM REPORT IAG SECTION 1

"POSITIONING"

President's Report

Alan Dodson, President

The University of Nottingham,

Institute of Engineering Surveying & Space Geodesy (IESSG,

University park

Nottingham NG7 2RD

Great Britain

The structure of Section I in the period 1999-2003, established during the IUGG General Assembly in Birmingham, is similar to that for the previous four-year period, in that it consists of one Commission, one Special Commission and four Special Study Groups. These are:

Commission X "Global and Regional Geodetic Networks"
President: Claude Bocher

Special Commission 4 "Application of Geodesy to Engineering"
President: Heribert Kahmen

SSG 1.179 "Wide Area Modelling for Precise Satellite Positioning"
Chair: Shaowei Han

SSG 1.180 "GPS as an Atmospheric Remote Sensing Tool"
Chair: Hans van der Marel
Co-Chair: (ionosphere) Susan Skone

SSG 1.181 "Permanent Regional Arrays"
Chair: Robert Weber

SSG 1.182 "Multipath Mitigation"
Chair: Mike Stewart

The Commissions and SSGs have all been very productive during the period 1999-2001, and details of their activity are reported below. In particular, there has substantial activity in the topic of SSG 1.180, where GPS is proving to be of significant importance in a number of atmospheric research and operational applications.

Section I has also played a major part in several scientific meetings during the last two years, of particular note perhaps were the Mobile Mapping Technology workshop in Cairo, Egypt in January 2001, and the symposium on Vertical Reference Systems in Cartagena, Colombia in February 2001. In addition the Section will be playing a full role in the forthcoming IAG Scientific Assembly in Budapest, and has several meetings planned for the period between then and the next IUGG General Assembly in 2003.

It is increasingly apparent that there has been growing interaction and overlap between the Sections of the IAG (Section I and Section II in particular) as well as between the Sections and the IAG services. This is no more apparent than in Section I with for example the subject of global and regional networks being of primary importance to both Commission X and the IGS.

The IAG review of its structure, which will be presented for discussion and approval at the forthcoming IAG Scientific Assembly in Budapest, in September 2001, addresses the growing importance of the IAG Services, whilst also redefining the Section/Commission structure in an attempt to recognise the changing geodetic scene. In the proposed structure the present five sections and their associated commissions and special commissions, will be abolished, to be replaced by four topic-related Commissions (each with a sub-structure of SSGs etc.). Under this new structure it is proposed that a Commission on “Positioning and Applications” be established, largely taking on the role of the current Section I, but recognising the growing involvement of geodesists in the application of geodesy.

Previously this application role in the field of engineering has been addressed through SC4. Under the new proposal, applications in a much wider sense will in future have more substantial recognition in the work of the IAG. Furthermore the IAG Services, such as the IGS, will have a more explicit role in IAG activities, as together with the new Commissions, they will form the main components of the new IAG structure.

COMMISSION X:

"GLOBAL AND REGIONAL GEODETIC NETWORKS"

Introduction

The goal of the Commission is to focus on the variety of existing control networks (horizontal or vertical, national or continental, global from space techniques) as well as their connections and evolutions.

The Commission has two types of subdivisions: Sub-Commissions and Working Groups:

1) Sub-Commissions for large geographic areas: Europe, North America, South America, Africa, South East Asia and Pacific. Such Sub-Commissions will deal with all types of networks (horizontal, vertical and three-dimensional), and all related projects which belong to that geographical area.

2) Working Groups for specific technical topics which would be relevant to the Commission's activities. Such Working Groups are not substitutes for a SSG of the IAG, but rather look at technical and practical problems, in particular by establishing specifications for the countries, and also possibly sponsoring training seminars.

In addition, Commission X has a Steering Committee (SC) consisting of:

- President of the Commission
- Presidents of the Sub-commissions
- Chairs of the Working Groups

Each country member of the IAG is permitted to appoint one representative to Commission X. If the country belongs to an area where a Sub-Commission has been already established, the representative will be a de facto member of that Sub-Commission. Each country not yet a full member of the IAG is welcomed to appoint an observer to the Commission. Members of Working Groups will be selected by the Chairs, and approved by the SC after consultation with relevant people and representatives of countries. The web site for the Commission is at: http://lareg.ensg.ign.fr/GRGN/.

Objectives of the Commission

1. To expand the present GRGN web site in order to give a proper source of information of relevant activities, including Sub-Commissions and Working Groups, but also related activities at national or international level, such as survey agencies, international programs or projects, services such as IGS, IERS or others. This site should also provide informations on standards and terminology, catalogue of datums and cartographic coordinate systems.

2. To expand the list of national representatives and involve them more in the Commission activities (for instance updates of the web system).

3. To stimulate the formation of new Sub-Commissions.

4. To update the list and charters of the Working Groups.

5. To stimulate the development of a modern geodetic framework for Africa (AFREF).

6. To stimulate the organisation of a training school related to the GRGN field (modern networks, ITRF, GPS, etc.).

7. To promote ITRF as the international framework, and to realise its densification for all type of uses, help to remove misunderstandings with respect to WGS84, and promote ITRF for the new global navigation satellite systems such as the European Galileo program.

Organisation of Sub-Commissions and Working Groups

Sub-Commission for Europe (EUREF)
President: Jose Agria Torres (PORTUGAL)

Sub-Commission for North America
President: Dennis Milbert (USA)

Sub-Commission for South America
President: Luiz Paolo Souto Fortes (BRAZIL)

Sub-Commission for Antarctica
President (co-chairs): John Manning (AUSTRALIA), Reinhard Dietrich (GERMANY)

Sub-Commission for South East Asia and Pacific
President(co-chairs): John Manning (AUSTRALIA), Jun Yong Chen (CHINA)

Working Group on Datums and Coordinate Systems (WG1)
Chairman: Bjorn Geir Harrson (NORWAY)

Working Group on the Worldwide Unification of Vertical Datums (WG3)
Chairman:William Kearsley (AUSTRALIA)

National Representatives

Australia: John Manning
Austria: E Erker
Belgium: Carine Bruyninx
Brazil: Sonia Maria Alves Costa
Canada: Michael Craeymer
China: Yan Ping Zhang
Croatia: Damir Medak
Czech Republic: Jan Kostelecky
Egypt: A Tealeb
Estonia: Artu Ellmann
Finland: Matti Ollikainen
France: Michel Kasser
Germany: Ewald Reinhart
Hungary: Jozsef Adam
Israel: Yossi Melzer
Italy: Maurizio Barbarella
Japan: Hiromichi Tsuji
Luxembourg: Andre Majerus
Malaysia: Samad Bin Haji Abu
New Zealand: Graeme Blick
Norway: Oddgeir Kristiansen
Poland: L W Baran
Portugal: Luisa Bastos
Russia: G Demyanov
South Africa: Richard T Wonnacott
Switzerland: D Schneider
United Kingdom: Peter Dare
USA: Dennis Milbert
Yugoslavia: Dragan Blagojevic

SPECIAL COMMISSION 4:

"APPLICATION OF GEODESY TO ENGINEERING"

Introduction

Rapid developments in engineering, microelectronics and the computer sciences have greatly changed both the instrumentation and methodology in Engineering Geodesy. The objectives of the Special Commission are on the one hand to document the body of knowledge in this field, and on the other hand to encourage new developments and present them in a consistent framework. Symposia and workshops are planned to document the current state of development in engineering applications of geodesy. Working Groups were established in areas of current research interest which will have specific goals to ensure that their research work can be accomplished in a four year period. In addition, there is considerable collaboration with other international organisations such as the ISPRS, FIG, and the ION.

SC4 WG 1: "Real-Time Mobile Multi-sensor Systems and Their Applications in GIS and Mapping"

To fulfil the need for up-do-date inventory and geometric data along transportation routes (e.g. roads, railways, rivers, pipelines, etc.) Mobile Multi-sensor Systems (MMS) are being operated. In general, MMS have in common that they integrate a set of sensors mounted on a single platform, and synchronized to a common time base. They are typically operated in kinematic mode. In principle, they are capable of operating only with the data measured on the platform, that is, no other information (such as external ground control) is needed, although it may be included as redundant information. Systems of this type:

- Can be immediately deployed anywhere on the Earth without the need for identifying existing ground control.
- Employ a task-oriented system design through integration at the measurement level, and hence data flow optimisation can be a built-in feature.
- Can be equipped with real-time quality control features by including data redundancies in the system design, and by using a combination of real-time data processing and Expert Knowledge to generate homogeneous results.
- Generally use software geo-referencing to transform the time-dependent measurement process into a sequence of geo-referenced images, which can be considered as independent geometric units in post-mission processing.

The objectives of the Working Group are:
Identify and promote new developments in MMS.
Identify and promoted new applications for MMS.
Encourage and document emerging processing techniques for MMS.

Chairman: Naser El-Sheimy (Canada)
Co-chairman: Jan Skalou (Switzerland)
(18 members)

SC4 WG 2: “Dynamic Monitoring of Buildings and System Analysis”

The world records for bridge span and building height have increased more than tenfold in the second millennium. In the 20th century alone, the record height for a building has increased from 118m to 452m, while the record for a bridge span has increased from 521m to 1991m.

As can be seen from these records, quality control of these structures is a challenging task. The goals of the monitoring methods are: assessment of the structural behaviour (safety inspection) and improvement of maintenance (optimization of repair, early detection of damage, etc.). The input for the monitoring methodes can be forced or ambient vibrations. Then "Forced Vibration Testing" (FVT) and "Ambient Vibration Testing" (AVT) can be applied.

Instruments, used to monitor the motions, are often fixed to the object under motion. That means that their dynamic parameters change depending on the frequencies of the motions. The goal of this Working Group is, to study dynamic monitoring methods, sensor systems and system analysis models for quality control of large manmade structures. Interdisciplinary collaboration will be necessary.

Chairman: Wolfgang Niemeier (Germany)
Co-Chairman: Rainer Flesch (Austria)
(8 members)

SC 4 WG 3: “Monitoring of Local Geodynamic Processes and System Analysis”

Monitoring and system analysis of landslides, mudflows and rockslides has become of great importance, since the population of the world is increasing dramatically and, as in many cases, housing estates and industrial sites were erected without taking these geodynamic processes into consideration.

In mountainous areas, for instance, as in the European Alps, it is estimated that about 6% of the country is affected by landslides. Along the Yangtze River in China, in the vicinity of the Three Gorges Dam Reservoir, for instance, about 100 landslide sites have to be monitored. Their average velocities can vary from 1 to 200mm/year, and in general the movements are fairly regular, especially on large slopes. In some cases there are reactions according to the climate conditions. However, sometimes instabilities are possible, which cause the velocities to be multiplied by a factor 100 and greater, sometimes resulting a disaster failure.

The main goals of the Working Group are to study:

Computer-controlled MMS recording geodetic,
geophysical and meteorological data.
Different models of system analysis.
Models for disaster/failure prediction.

Chairman: Gyula Mentes (Hungary)
Co-Chairman: Ewald Brückl (Austria)
(14 members)

SC 4 WG 4: “Geodesy on Large Construction Sites”

The growing world population and the globalization of the economy demands improved traffic systems, power stations and construction of dwellings and bureau centres. Therefore in the future large construction sites will have to be managed. Geodetic methods and techniques can contribute to do this management in a most economical way. There will be large construction sites for high speed railway lines, tunnels, bridges, power dams, airports, and so on.

The main goals of the Working Group will be to study:
1. The design of networks based on permanent GPS stations.
2. The navigation of construction machines.
3. High precision alignment methods.
4. Information systems based on geodetic-geotechnical-geological data.

Chairman: A new chairman will be nominated within two months.

SC 4 WG 5: “Pseudolite Application in Engineering Geodesy”

In satellite-based precise positioning, the dominant factors are the number *and* geometric distribution of the satellites tracked by the receivers. In the case of global navigation satellite systems (GNSS) such as GPS, Glonass, and the planned Galileo system, four visible satellites are the minimum requirement for precise three-dimensional positioning. In general, the more satellites that are tracked, the more reliable the positioning solutions. However, in some situations, such as in downtown urban canyons, engineering construction sites, and in deep open-cut pits and mines, the number of visible satellites may not be sufficient. In the worst situations, such as in underground tunnels and inside buildings, the satellite signals may be completely lost. Such problems with existing GNSS systems can be addressed by the inclusion of additional ranging signals transmitted from ground-based "pseudo-satellites" (pseudolites). Pseudolites are an exciting technology that can be used for a wide range of positioning and navigation applications, either as a substantial augmentation tool of spaceborne systems, or as an independent system for indoor positioning applications.

The goal of this proposed Working Group is to study new concepts of pseudolite-related positioning and, in particular, applications of pseudolites in engineering geodesy. Major objectives of the research activities are to study:
1. Pseudolite augmentation of GPS system.
2. Pseudolite-only positioning scenarios.
3. Integration of pseudolites with other sensors, such as INS.

These objectives will be achieved by:
- Promoting discussions between Working Group members.
- Setting up a Working Group website providing a focus for pseudolite research and applications with the relevant links. The web site is located at: http://129.94.250.108/iag-sc4-wg5/index.html.
- Developing a comprehensive bibliography dealing with pseudolite research and applications.

Chairman: Jinling Wang (12 members)

SC 4 WG 6: “Application of Knowledge-Based Systems in Engineering Geodesy”

For many geo-(but also non-geo-)disciplines the results of geodetic measurements (coordinates, displacements, etc.) serve as a basis for solving problems such as interpretation, documentation, recognition, control, design, prediction, diagnose, alarming, simulation, and so on. Examples are the (intelligent) control of measurement or guidance systems, the detection of outliers, or the early recognition of noticeable patterns in the displacement data of tunnels under construction, etc. For these tasks geodetic data often must be considered incomplete and uncertain, and in most cases additional knowledge from experts of the specific application field is needed.

Nowadays there is a growing demand for geodesists to work in interdisciplinary teams and to contribute to the development of appropriate systems and techniques that help to solve these problems in a more 'intelligent' and 'automatic' manner. The application of AI-methods, such as Knowledge-based Systems, seems to be a promising approach, gence this research for, and applicability in, Engineering Geodesy will be the main objective of the Working Group.

Chairman: Klaus Chmelina (5 members)

Conference Activities

WG 1 was organiser of the conference "3rd International Workshop on Mobile Mapping Technology", 3-5 January, 2001 in Cairo, Egypt. A report on the conference can be downloaded from the SC4 websites.

Websites: http://info.tuwien.ac.at/ingeo/sc4/sc4_99-03.htm, http://www.sc4.de.vu/

Working Groups WG 2 and WG 3 have organised a workshop on "Monitoring of Constructions and Local Geodynamic Processes", held in Wuhan, P.R. China, from 22-24 May, 2001.

Websites: http://info.tuwien.ac.at/ingeo/sc4/wuhan01.htm
http://www.wtusm.edu.cn/wuhan01.htm

The Special Commission is co-sponsor of the "5th Conference on Optical 3-D Measurement Techniques", which will be held in Vienna, Austria, 1-4 October, 2001.

Websites: http://info.tuwien.ac.at/ingeo/optical3d/o3d.htm
http://www.optical3d.de.vu/

The Special Commission is organising the "2nd Conference on Geodesy for Geotechnical and Structural Engineering", which will be held in Berlin, Germany, 21-24 May, 2002. This will be the meeting where all the WGs will come together to present their scientific programs and report on their current research work.

Websites: http://info.tuwien.ac.at/ingeo/sc4/berlin.html
http://www.sc4-berlin2002.de.vu/

SPECIAL STUDY GROUP 1.179:

"WIDE AREA MODELLING FOR PRECISE SATELLITE POSITIONING"

Introduction

Precise satellite positioning requires that carrier phase data be used and that the integer ambiguities associated with the carrier phase measurements be resolved in some way. However, the distance from the user receiver to the nearest reference receiver may range from a few kilometres to hundreds of kilometres. As the receiver separation increases, the problems of accounting for distance-dependent biases increase, and reliable ambiguity resolution for carrier phase-based satellite positioning becomes an even greater challenge.

'Wide area modelling' for precise satellite positioning requires either long observation spans to estimate all biases in the functional model, or multiple reference stations. For the first approach, all error sources, such as orbit bias, atmospheric parameters, receiver inter-channel biases, along with the user's trajectory, should be estimated simultaneously. This is the approach used for geodetic static positioning (e.g., IGS-based site coordinate determination, and precise GPS orbit determination). The second approach provides more opportunities to either estimate the different biases individually and then apply interpolated biases (at the user location) to the measurements, *or* generate a so-called 'virtual reference station', by using the data from a multiple reference station network. Some of the concepts have been studied in the past by previous IAG SSGs, both separately and in combination, and with respect to various applications. In 1999 the IAG established SSG 1.1.79 to focus on investigations of the GPS functional model, the stochastic model, and ambiguity resolution procedures. The website of the Special Study Group 1.179 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1179.htm.

Objectives of the SSG 1.179

1. Error modelling through the improvement of functional models for medium-range, and long-range high precision satellite positioning using multiple reference stations, including:

- multipath mitigation algorithms,
- troposphere model refinement,
- regional ionosphere modelling algorithms,
- orbit bias modelling,
- parametric modelling algorithms (for each error source), and
- integer bias estimation and validation, e.g. cycle slip detection/repair and ambiguity resolution.

2. Error modelling through stochastic model refinement, including:

- correlation analysis of carrier phase measurements from satellite positioning systems,
- stochastic modelling algorithms suitable for post-processing applications, and
- stochastic modelling algorithms suitable for real-time applications.

3. The continued study of ambiguity resolution techniques in order to develop:

- more efficient means of searching integer ambiguities, and
- validation procedures for ambiguity resolution.

4. The application of these improvements to:

- short-range satellite positioning applications,
- differential correction generation from multiple reference GNSS receiver network, in support of medium-range high precision navigation,
- precise long-range GPS kinematic positioning, and
- sub-centimetre engineering applications, e.g. construction deformation monitoring, volcano monitoring, etc.

Members and Corresponding Members

Members: Shaowei Han (Chair, USA), Oscar Colombo (USA), Paul Cross (UK), Paul de Jonge (U.S.A), Hans-Jürgen Euler (SWITZERLAND), Yanming Feng (AUSTRALIA), Yang Gao (CANADA), Yongil Kim (KOREA), Donghyun Kim (CANADA), Dennis Odijk (THE NETHERLANDS), Günter Seeber (GERMANY), Dariusz Lapucha (USA), Jingnan Liu (CHINA), Nigel Penna (AUSTRALIA), Rock Santerre (CANADA), Julia Talaya (SPAIN), Jinling Wang (AUSTRALIA), Xinhua Qin (USA), Peiliang Xu (JAPAN).

Corresponding Members: Changdon Kee (KOREA)

Activities of the SSG1.179

Error Modelling Through Improvement of Functional Models

Error modelling through the improvement of functional models for medium-range, and long-range high precision satellite positioning using multiple reference stations includes the study of topics such as multipath mitigation, troposphere modelling, regional ionosphere modelling, and orbit bias modelling. These biases could be estimated individually through some special approaches, or by setting different parameters in the functional model for the different error biases.

Absolute field calibration of GPS antennas is based on the controlled antenna motion of a robotic arm, and is now a mature calibration technique. The technique can be used to calibrate all antennas in a multiple reference station network. With (absolutely) calibrated antennas it is possible to separate phase centre variations and multipath. An approach for multipath calibration based on controlled antenna motion was proposed.

Investigations into the use of 'semi-parametric least squares' for the mitigation of systematic errors in GPS processing have been conducted. Current focus is the lumping together of all systematic errors as a single smoothing function, estimated over the processing session. Initial results from a 'short' 30km baseline are encouraging, and tests have commenced on more data sets.

An adaptive Finite-duration Impulse Response filter, based on a least-mean-squares algorithm, has been developed to derive a relatively noise-free time series from continuous GPS results. This algorithm is suitable for real time applications. Numerical simulation studies indicate that the adaptive filter is a powerful signal decomposer, which can significantly mitigate multipath effects.

Increased use has been made of ionospheric regional modelling to improvement on-the-fly ambiguity resolution over long distances, as part of initiatives within the GEOIDE project (website: www.scg.ulaval.ca/gps-rs/). Ionospheric tomography has also been used to help resolve GPS ambiguities on-the-fly at distances of hundreds of kilometres during increased geomagnetic activity. An approach, referred to as the "grand solution", which estimates orbit, refraction, and local bias error states, along with the uer's trajectory, was proposed. The modelling and estimation of the tropospheric zenith delay, both for more accurate real time and post-processed navigation, and for rapid and precise meteorological updates, has been implemented.

With respect to Real-Time Kinematic (RTK) positioning using multiple reference stations, the results of a survey conducted by Dr. Euler, Chair of the RTCM SC104 Working Group "Network RTK", of working group members found:

The expected RTK accuracy could be at sub-decimetre to centimetre level (one sigma).

The reference station distances should be of the order of 50-70 km for centimetre accuracy, or about 200 km and above for decimetre accuracy.

The size of a reference station area should be of the order of 500 km x 500 km. However, target could be nationwide to continentwide coverage.

The medium for distribution of data could be unidirectional techniques (Broadcast like UHF, VHF, TV, DARC, etc) or bi-directional techniques (GSM, UTMS, etc.).

The baud rates for transmission are from 2400 Baud upwards, including 1Hz observation data.

The tolerated latency is up to 10 seconds without SA, or up to 2 seconds with SA. However, the orbit information can be delayed by up to 120 seconds, ionosphere by up to 10 to 60 seconds, troposphere by up to 30 seconds. The real-time positioning output is expected within 100 milliseconds.

The requirement for reference station equipment is dual-frequency receivers with clear sky view.

With regards to GPS/Glonass surveying and navigation applications using multiple reference stations, a new method was proposed, in which the distance-dependent biases have been separated into the frequency-dependent errors (ionospheric bias) and frequency-independent errors (e.g. troposphere bias and orbit bias). The separate estimates of the two types of errors, which are generated from the carrier phase measurements using the multiple reference stations, can be used to model the user distance-dependent biases for L1, L2 carrier phase and pseudo-range measurements in different ways.

Error Modelling Through Stochastic Model Refinement

High quality estimation results using least squares require the correct selection of the functional *and* stochastic models. The stochastic model should represent the statistical characteristics of the modelling errors. It is dependent on the choice of observation functional model, hence for a different choice of functional model, a different stochastic model may be needed. For example, if the ionospheric delay is considered an unknown parameter in the functional model, the modelling errors will not include the residual (double-differenced) ionospheric bias, and hence they will more likely have random properties.

The SIGMA-D model has been developed for stochastic modelling of GPS signal diffraction errors in high precision GPS surveys. The basic information used in the SIGMA-D model is the measured carrier-to-noise power-density ratio (C/N0). Using the C/N0 data and a template technique, the proper variances are derived for all phase observations. Thus the quality of the measured phase is automatically assessed and if phase observations are suspected of being contaminated by diffraction effects they are downweighted in the least-squares adjustment. An extended weight model for GPS phase observations was also proposed.

Mathematical and statistical modelling has also been investigated. Using a multipath estimation method based on the signal-to-noise ratio and an elevation-dependent stochastic model, the height accuracy of a typical RTK session has been improved by approximately 44% and the fidelity of quality measures has been increased.

A stochastic assessment procedure has been developed to take into account the heteroscedastic, space- and time-correlated error structure of the GPS measurements. Test results indicate that by applying the stochastic assessment procedure developed , the reliability of the estimated positioning results is improved. In addition, the quality of ambiguity resolution can be more realistically evaluated.

Magellan's new product Instant-RTK™ has reportedly overcome the functional and stochastic modelling problem through empirical knowledge and a real-time learning procedure which can used to adapt the model when the environment is changing.

On the other hand, the stochastic modelling approach has been applied to the parameters in the functional model. For example, the residual ionospheric delay after applying ionospheric delay corrections could be accounted for through processing the residual ionospheric delay correction as stochastic observables. The stochastic model to be applied for the corrections could be provided by multiple reference stations. First results show indeed an enormous improvement in the success rate of ambiguity resolution.

Continued Study of Ambiguity Resolution Techniques

GPS ambiguity resolution (AR) techniques have been intensively investigated. The integer ambiguity searching techniques have been dramatically improved over the last decade, especially by the contribution of the LAMBDA method. However, it has to be recognised that all search algorithms are likely to result in identical integer ambiguity candidates under comparable setups, e.g. using like search windows/volumes and similar parameters. Continued study is now focused on AR in integrated systems: GPS, Glonass, pseudolite or other systems, and more powerful validation criteria to ensure correct ambiguity resolution.

For example, Magellan's new product Instant-RTK™ appears to have successfully addressed the functional and stochastic modelling problem through empirical knowledge and a real-time learning procedure. A series of validation criteria have been implemented, in addition to the commonly used ratio test, which can be adapted based on the reliability requirements, number of satellites, observation time and baseline length. The Instant-RTK validation criteria have successfully traded off the requirements of observation span on the one hand, and RTK solution reliability on the other. Moreover, the algorithm to detect, identify and adapt the outliers to guard against incorrect integer ambiguity determination has been implemented, and the success rate of AR has been increased significantly.

Leica Geosystems' System 500 has implemented a repeated search processing technique to shorten ambiguity initialisation time and to improve AR reliability, especially in difficult environments. This method repeats its internal determination of the integer ambiguity using significantly shorter observation times. Once the AR algorithm has verified that they are identical, the system can output its coordinates.

On the theoretical side, a method was proposed to evaluate the probabilities of correct integer estimation based on the variance matrix of the (real-valued) least-squares ambiguities. These success rates are given for the ambiguity estimator that follows from integer bootstrapping. Although less optimal than integer least-squares, integer bootstrapping provides useful and easy-to-compute approximations to the integer least-squares solution. In a similar manner, the bootstrapped success rates provide bounds for the probability of correct integer least-squares estimation.

New Development and Future Trends

In the next few years, more commercial system will be developed to generate corrections from multiple reference stations for surveying and precise navigation applications. RTCM SC104 Working Group "Network RTK" will propose a new format to transmit correction information from multiple reference station networks. This is not only beneficial to RTK systems, but also to single-frequency, low-cost GPS systems. Moreover, once the additional civilian frequency is transmitted by Block IIF satellites, the wide area error modelling for precise satellite positioning will be significantly improved.

SPECIAL STUDY GROUP 1.180:

"GPS AS AN ATMOSPHERIC REMOTE SENSING TOOL"

Introduction

Using networks of ground-based GPS receivers it is possible to observe the integrated water vapour (IWV) and the total electron content (TEC) of the Earth's atmosphere. While at first these parameters were considered a mere nuisance, it is nowadays considered to be an important signal for atmospheric sciences.

Water vapour is one of the most important constituents of the atmosphere. It plays a crucial role in many atmospheric processes covering a wide range of temporal and spatial scales. Furthermore, it is also the most important greenhouse gas and highly variable. Climate research and monitoring, as well as operational weather forecasting, need accurate and sufficiently dense and frequent sampling of the water vapour, to which existing GPS networks could contribute significantly. In order to be of any use for operational weather forecasting, firstly GPS networks must be able to provide integrated water vapour in near real-time (NRT) (with a typical delay of one hour), and secondly GPS observations must be assimilated into Numerical Weather Prediction (NWP) models.

Dual-frequency GPS receivers enable the estimation of total electron content (TEC) along a given satellite-receiver signal path. By combining observations from regional and global networks of continuously operating dual-frequency receivers, parameters describing the spatial and temporal distribution of total electron content can be derived. Such observations of TEC, available globally on a near real-time basis, allow an excellent opportunity for monitoring ionospheric signatures associated with space weather. For example, the development of ionospheric storms can be observed in global patterns of TEC, while small-scale irregularities in electron density (associated with scintillation) can be observed in short-term variations of TEC and/or spectral analysis of GPS phase observations. The website of the Special Study Group 1.180 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1180.htm.

Objectives of the SSG 1.180

The focus of the SSG is to explore the issues related to the derivation of water vapour and TEC in NRT using GPS, the assimilation of GPS water vapour data into weather forecasting models, use of GPS water vapour data for climate applications and the integration of GPS-derived TEC estimates and scintillation indices into space weather applications. The main objectives of the special study group are:

Identify key signatures observed in GPS-derived estimates of TEC, as associated with phenomena such as ionospheric and geomagnetic storms, scintillation, travelling ionospheric disturbances, magnetospheric substorms and auroral activity.

Assess methods to quantify the level and nature of ionospheric activity, based on TEC estimates.

Explore key issues related to the feasibility of integrating TEC estimates, and TEC-based indices, into space weather forecasting and nowcasting - such issues include real-time requirements, and the temporal and spatial resolution necessary for reliable detection and prediction of ionospheric phenomena.

Identify key problems in GPS-derived integrated water vapour, as associated with phenomena related to the near field of the antenna, such as multipath and phase centre variations, and local weather (gradients, mapping to the vertical), reprocessing and archiving of data, in relation to climate applications.

Explore key issues related to the assimilation of GPS-derived integrated water vapour observations into NWP models - such issues include real-time requirements, temporal and spatial resolution, slant or vertical delays, temporal and spatial correlation and quality insurance issues.

Assess the potential impact of tropospheric tomography using GPS-estimated slant delays.

The activities of the SSG consist of compiling a database of relevant literature and research groups, and to facilitate discussions of key issues though email between members, and describe the products of the research through periodic progress reports. Due to the large number of meetings, sessions and symposia in relation to the work of the SSG it was not necessary to organise a special working group meeting.

Members

Hans van der Marel (Co-chair, THE NETHERLANDS), Susan Skone (Co-chair, CANADA), Helen Baker (UK), Michael Bevis (USA), Steven Businger (USA), Galina Dick (GERMANY), Mark Falvey (NEW ZEALAND), Manuel Hernandez-Pajares (SPAIN), Per Hoeg (DENMARK), Tetsuya Iwabuchi (JAPAN), Mark Knight (AUSTRALIA), Tony Mannucci (USA), Christian Rocken (USA), Akinori Saito (JAPAN), Peter Stewart (CANADA), Rene Warnant (BELGIUM).

Activities of the SSG1.180

TEC Estimation and Monitoring

Networks of permanent GPS receivers are an excellent tool to compute the Total Electron Content (TEC) of the ionosphere. The International GPS Service (IGS) has set up an Ionospheric Pilot Project in June 1998, involving several International Associate Analysis Centers (CODE, EMR (NRCAN), ESA, JPL, UPC). Estimates of TEC are available on a daily basis in the form of IONEX files. Special campaigns were organised during the solar eclipse in August 2000 and during the solar maximum in 2001 involving high-rate (1ssec) observations of many GPS receivers.

The precise determination of TEC in real-time is important for DGPS and GPS-RTK applications with the closest reference station at several hundred kilometres. Several improvements of ionospheric models with GPS have been made involving tomographic and adaptative approaches.

A real-time ionospheric TEC model for the Australian region, based on a network of semi-codeless receivers extending from Northern Australia to the Antarctic, has been developed by the Ionospheric Prediction Services (IPS) in Australia. The purpose of this work is to provide broadcast corrections for single-frequency users as part of a proposed Wide Area DGPS system. More recent work has involved the use of GPS to monitor ionospheric disturbances during magnetic storm events, for ionospheric TEC and scintillation monitoring in low, mid and high (Southern) latitudes, including the Antarctic, and the use of GPS to measure the Earth's plasmasphere.

In Canada an ionospheric warning and alert system for Canadian Coast Guard DGPS users was developed.

Ionospheric Scintillation Monitoring and Effects of Scintillations on GPS

The Australian Defence Science & Technology Organisation (DSTO) has been developing models of the effects of ionospheric scintillations on GPS with the intention of quantifying losses in navigational accuracy and acquisition performance. The scintillation model they use is essentially a stochastic model in which the amplitude and phase distribution functions are assumed to be Nakagami-m and Gaussian respectively, and the power spectral densities are assumed to follow an inverse power-law relationship. This is based on measurements taken from numerous sources, in particular the Defense Nuclear Agency Wideband satellite experiment from the 1970s. It is also consistent with the Wide Band Scintillation Model, WBMOD, which was developed by Northwest Research Associates and enables key scintillation parameters such S_4 and σ_ϕ to be predicted. By linking WBMOD with the receiver performance models, predictions can be made about the likely impact of scintillations on a GPS receiver at a given time and location under a specified set of solar and geomagnetic conditions. In parallel with this work it has been attempted to validate the WBMOD model for the Northern Australia / South East Asia region using a network of Ionospheric Scintillation Monitoring receivers (ISMs which provide S_4 and σ_ϕ measurements etc.) and semi-codeless NovAtel Millennium receivers (used to measure TEC). These receivers have been in place for several years in locations close to both the magnetic equator and the crests of the equatorial anomaly in Indonesia, Malaysia and Papua New Guinea. This work has compared WBMOD predictions with regional measurements of the diurnal, seasonal and solar cycle variations in S_4 and σ_ϕ. Various groups within these countries have been actively involved with DSTO in this effort.

A high latitude scintillation monitoring network has also been established for Northern Canada.

GPS Radio Occultation Measurements

GPS and LEO satellites are used to carry out radio occultation studies of the ionosphere and for ionospheric tomography to reveal vertical density profiles.

The GeoForschungsZentrum (GFZ) has commenced, together with other research centres of German Helmholtz Society, a new strategic project GASP ("GPS Atmosphere Sounding") using ground-based and space-based GPS techniques for applications in numerical weather predictions, climate research and space weather monitoring. One of the two sub-projects of GASP focuses on water vapour estimation, and temperature and pressure profiles from radio occultation measurements.

Development of a 6-satellite constellation for GPS occultation and space weather measurements (COSMIC) has commenced. An occultation data analysis centre is being developed at UCAR (COSMIC Data Analysis and Archive Center), for the processing of data from COSMIC and other occultation missions.

Use of Ground-Based GPS for Numerical Weather Prediction (NWP) and Climate Research Applications

Requirements for the use of ground-based GPS for Numerical Weather Prediction (NWP) have been formulated by the European COST-716 project "Exploitation of Ground Based GPS for NWP and Climate Applications". The upper limit for the latency of the GPS data is 1h 45m. Also, it has been established that it is best to use Zenith Total Delays in NWP applications, without converting to Integrated Water Vapour first. It is expected that GPS may improve the forecast of precipitation under certain conditions.

To gather experience with a NRT system, and to assess the quality of tropospheric estimates in the framework of the GASP project, a small test network of ten GPS receivers was installed by the GFZ at the synoptic sites of the DWD in 1999. The NRT network established for the test campaign has been expanded by existing German DGPS sites (SAPOS network) and by an additional 12 GFZ GPS receivers installed at the synoptic sites of the DWD during the year 2000. The total number of sites in the analysis is presently 70, with an expected increase to about 90 sites. A new analysis strategy has been developed to make possible the automatic operation of 100 and more stations, a ZTD estimation interval of 15 minutes, as well as the estimation of gradients.

New Zealand has an operational system in which estimates of PW are obtained with a delay of 1-3 hours (http://www.gns.cri.nz/earthact/crustal/precip/gpspw.html). The website also shows radiosonde and global weather model PW for comparison. The use of GPS PW in mesoscale models was found to positively influence rainfall simulation during a storm observed during SALPEX'96 (Southern ALPS EXperiment).

Several groups have started investigating true real-time water vapour determination. A network of over 100 GPS stations, and the real-time analysis facility for these data to generate PW, called the SuomiNet, is currently being established.

GPS Water Vapour Tomography and Slant-Delay Estimation

UCAR has initiated the development of ground-based GPS slant measurement techniques to obtain refractivity profile and signal bending information from a mobile platform. In Oklahoma a dense 25-site GPS network for water vapour tomography is operating (ARM-Tomography).

List of Meetings Relevant to the SSG 1.180

XXII General Assembly IUGG, July 18-30, 1999 Birmingham, UK (HM, GD)

COST 716 Workshop, Soria Moria, Oslo, 10-12 July 2000. (HM)

COST 716 Management Committee and Working Group Meetings. (HM, GD)

ION-GPS'99, Nashville, USA, September 1999. (HP, MK)

GPS'99, Tsukuba, Japan, October 1999. (HP)

PLANS 2000, San Diego, USA, March 2000. (HP)

EGS'2000, Nice, France, April 2000. (HP)

IRI workshop 2000, Warsaw, Poland, July 2000. (HP)

ION-GPS'2000, Salt Lake, USA, September 2000. (HP)

AMS meeting Albuquerque Jan 2001 (CR). Special session on GPS slant and Special session on SuomiNet

COSPAR meeting, Green Bay, Taiwan, Sept. 27-29 2001 (CR). Special meeting on COSMIC mission.

URSI meeting Boulder, CO, Jan 2001 (CR). Special Session on GPS remote sensing.

IAIN World congress, San Diego, June 2000. (MK)

ION National Technical Meeting, Anaheim, USA, January 2000.

URSI National Radio Science Meeting, Boulder, USA, January, 2000.

S-RAMP Conference (Solar-Terrestrial Energy Program for Space Weather), Sapporo, Japan, October, 2000.

Fall Meeting of the American Geophysical Union, San Francisco, California, December, 2000.

EGS'2001, Nice, France, March 2001. (HM,HP) Special session on GPS Meteorology.

GNSS'2001, Seville, Spain, May 2001.

Beacon Satellite Symposium 2001, Boston, USA, June 2001.

IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting, Boston, Massachusetts, July 8-13, 2001.

ION meeting SLC, Sept. 2001 (Session on GPS meteorology.

IAG Scientific Meeting, September 2001

Special Study Group 1.181:

"REGIONAL PERMANENT ARRAYS"

Introduction

In recent years an increasing number of GPS reference stations have been established on both global and regional scales. Ideally, the latter should represent local densifications of the International Terrestrial Reference Frame (ITRF) polyhedron. While at the outset these stations were built up in most cases to monitor active tectonic regions, recently the augmentation of real-time surveying and probing of the atmosphere have become important applications. The website of the Special Study Group 1.181 is http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1181.htm.

Objectives of the SSG 1.181

The work of this SSG aims at the tie of regional GPS networks to the International Terrestrial Reference Frame (ITRF), as well as to study the ambiguity resolution within a network of multiple reference stations at baselines with lengths of up to several tens of kilometres. In particular, the appropriate modelling of ionosphere and troposphere path delays as the limiting factors for ambiguity resolution, and the influence of antenna phase centre variations, will be studied. Concepts and realisations of "virtual reference stations" will be compared. Real-time kinematic (RTK) solutions within active reference station networks, the benefits of using combined GPS/Glonass receivers, as well as the use of predicted IGS orbits will also be subjects of investigation. Last, but not least, in cooperation with SSG 1.179, reliable error models of the baseline solutions have to be formulated. To achieve these goals the SSG will focus on:

1. Studying the atmospheric modelling part within a network of multiple reference stations.
2. Maintaining a website providing SSG related information.
3. Studying in-depth the concept of "vitual reference stations".
4. Providing test data sets from regional GPS/Glonass arrays for case studies.
5. Investigating the influence of antenna phase centre variations.
6. Encouraging participation in related symposia.
7. Reporting achievements at the IAG Conference in Budapest in 2001, and the next IUGG General Meeting in 2003.
8. Preparing recommendations and a final report on the SSG's activities.

Members and Corresponding Members

Members: Robert Weber (Chair, AUSTRIA), Richard Bindley (UK), Heike Bock (SWITZERLAND), Carine Bruyninx (BELGIUM), Peter CLARKE (UK), Herb Dragert (CANADA), Galera Monico (BRAZIL), Tom Herring (USA), Horst Hartinger (AUSTRIA), Paul de Jonge (USA), Ambrus Kenyeres (HUNGARY), Jan Johnasson (SWEDEN), Lambert Wanninger (GERMANY), Teriyuki Kato (JAPAN), Elena Ostrovsky (ISRAEL).

Corresponding Members: Manuel Hernandez-Pajares (SPAIN), Helmut Titz (AUSTRIA), Leos Mervart (CZECH REPUBLIC)

Activities of the SSG1.181

A Work Program has been proposed by the Chair. Topics of this WP are:

Reference Frame Issues - how to tie the regional network to the ITRF.

Impact of the Atmosphere - apriori models / height correlation.

Satellite Orbits - errors in satellite orbits, differences Broadcast and IGS precise/rapid/ultra-rapid orbits.

Parametrisation of Error Sources within a GNSS Real-Time Network.

Concept of 'Virtual Reference Stations'.

GPS/Glonass integration.

Signal Diffraction and Multipath.

Currently substantial contributions to this Working Program (including manuscripts and presentations) cover the topics 1, 3, 4, 5 and 6. The Impact of the Atmosphere, and Multipath (as well as Signal Diffraction) have not been dealt withdue to a only moderate response of the members to these issues. This might change within the next two years at least for the atmosphere modelling because of the upcoming ‘COST Action 716 Demonstration Experiment (troposphere wet delay) and the ‘Solar Max Campaign (ionosphere). (Although other SSGs are also active in these areas.)

Test data sets are available from the Chair and several WG members covering small regional networks in Austria, Switzerland and parts of the EUREF network. Data sets contain GPS as well as combined GPS/Glonass data.

A SSG web page has been established primarily for communication and information of the WG members (for details see http://luna.tuwien.ac.at/ssg1181/ssg1181.htm).

A meeting of the SSG members will take place at the next IAG Scientific Assembly in Budapest, as well as one meeting in the USA (AGU Fall Meeting 2001).

Future plans comprise include the detailed study of the quality of quasi real-time orbits, as well as their influence on ambiguity resolution and troposphere modelling. Synergy effects of using data from dual system (GPS/Glonass) / dual-frequency receivers are also under investigation.

The final goal over the next two years is to prepare recommendations and a comprehensive final report on the SSG's activities.

Special Study Group 1.182:

"MULTIPATH MITIGATION"

Introduction

The precision of raw carrier phase observations recorded by modern GNSS receivers is generally at the sub-millimetre level. However, in all but the most benign environments, the achievable resolution of GNSS positioning is one or more orders of magnitude worse. This discrepancy between the theoretical hardware-dependent precision of the raw observations and the practical accuracy of GNSS position solutions can, in part, be attributed to the effects of site-dependent electromagnetic scattering of incoming GNSS signals. If millimetre level (or better) GNSS accuracies are to be routinely achieved in the future, these electromagnetic scattering effects (commonly referred to as multipath and diffraction) must be eliminated. The website of the Special Study Group 1.182 is
http://www.gmat.unsw.edu.au/snap/gps/iag_section1/ssg1182.htm

Objectives of the SSG 1.182

The goal of the SSG 1.182 is to study GNSS multipath detection and mitigation techniques with the aim of improving existing high precision positioning accuracies. In the context of this SSG, multipath is loosely defined as the systematic errors in raw GNSS observations that are due to any signal scattering effect caused by the local environment surrounding an antenna. Furthermore, this SSG will focus on carrier phase and code-based multipath in terms of effects on receiver operation for high precision applications. Finally, within the scope of the group, the term GNSS is defined to encompass any type of global positioning system (for example, GPS, Glonass-GPS and Galileo-GPS), or systems simulating GNSS signals (such as in the case of pseudolites). The objectives of the group can be summarised as:

Evaluate and compare existing and developing algorithms and techniques for multipath detection and mitigation.
Quantify and document the effectiveness of commercial receiver-based multipath mitigation techniques for high precision positioning.
Investigate and document the properties of multipath in a variety of environments (particularly high risk environments).
Provide information and guidelines for multipath detection and elimination for high precision applications.

Members and Corresponding Members

Members: Mike Stewart (Chair, AUSTRALIA), Penina Axelrad (USA), David Betaille (UK), Mike Braasch (USA), Luisella Giulicchi (THE NETHERLANDS), Cythia Junqueira (BRAZIL), Guillermo Ortega (THE NETHERLANDS), Jayanta Ray (CANADA), Angela Reichert (USA), Rodney Walker (AUSTRALIA), Andreas Weiser (AUSTRIA).

Corresponding Members: Joao Batista (BRAZIL), Paul Cross (UK), Xiali Ding (HONG KONG), Minghai Jia (AUSTRALIA), Domenico Sguerso (ITALY).

Activities of the SSG 1.182

The primary activities of the group since its inception in January 2000 have been:

a. Define the terms of reference and objectives.

b. Compile review of relevant and available literature. A list of some 120 multipath related papers is located at: http://www.cage.curtin.edu.au/~mike/ssg1.182/biblio.htm.

c. Compile review of relevant web sites. A set of links to relevant web sites can be found at: http://www.cage.curtin.edu.au/~mike/ssg1.182/links.htm.

d. Compilation of data archive for multipath data. The SSG is in the process of compiling a data archive to provide multipath researchers with easy access to a variety of different data types from different environments. The archive will also provide reference to the multipath analysis performed by the group who supplied the data, enabling direct comparison between different techniques and different research groups. The archive should be on-line by late 2001.

e. Define core research areas within the SSG's terms of reference. As the terms of reference are rather broad, a number of core research sub-sections have been defined. Individual group members have been encouraged to monitor developments in the sub-sections relevant to their personal fields of expertise. These include:

- multipath characterisation and attitude determination;
- multipath mitigation developments in receiver hardware;
- semiparametric and parametric multipath modelling techniques;
- weighting and SIGMA models for multipath mitigation;
- multipath in space-based applications;
- multipath mitigation using multi-antenna arrays, time stacking and crossing points; and
- electromagnetic propagation modelling for multipath analysis.

Below is a brief summary of the technical developments being covered by this SSG. Full reports from group members can be found at the SSG 1.182 own website: http://www.cage.curtin.edu.au/~mike/ssg1.182/recent_reports.htm.

Multipath Mitigation Developments in Receiver Hardware

A variety of so-called multipath-mitigating receiver architectures have been developed over the past decade.

Narrow-correlator (NovAtel); Edge correlator (Ashtech) - The narrow-correlator concept involves moving the traditional 'early' and 'late' correlators closer together. The peak of the pseudo-range multipath error envelope is reduced in direct proportion to the correlator spacing. Ultimately the finite bandwidth of the GPS signal places a practical lower bound on the correlator spacing. Correlator spacings of 0.1

and 0.05 chips are commercially available, thus providing approximately a factor of 10 to 20 reduction in the peak of the error envelope.

Multipath-Estimating Delay-Lock Loop (MEDLL) (NovAtel)- The MEDLL uses multiple correlators (6 – 10) per channel in order to determine the shape of the multipath-corrupted correlation function. The MEDLL software determines the best combination of direct and multipath signals (that is, amplitudes, delays, and phases) which could have produced the measured correlation function.

Strobe correlator (Ashtech*)* - The strobe correlator was developed by Ashtech in 1996 and involves a linear combination of two narrow correlator discriminator functions. The result is a discriminator function which is very narrow and thus is significantly less susceptible to medium and long delay multipath.

Enhanced strobe correlator (Ashtech); Pulse-Aperture Correlator (NovAtel) - For most practical purposes the Enhanced Strobe Correlator exhibits true P-code-like multipath characteristics. Specifically, it is virtually insensitive to multipath with delays longer than 50 metres. More recently, NovAtel has released the Pulse Aperture Correlator which has very similar performance. Other manufacturers (Leica, Navcomm) have similar architecture.

Multipath mitigation through modified antenna design is also an important field of research. The most recent developments include adaptive array techniques in which two classes of solutions have been proposed. A first is based on the joint utilisation of a direction-of-arrival (DOA) estimation technique together with a constrained adaptive algorithm. A second approach uses a self-adaptive constant modules technique, eliminating the need of a pilot signal and DOA estimator.

Multipath Mitigation Using Functional and Stochastic Modelling

One of the most important developments to date in this field are the SIGMA models which were developed to overcome artificially introduced periods of weak satellite geometry by proper weighting of phase observations (SIGMA-e model) and to reduce signal diffraction effects of the phase observations (SIGMA-D model). The main parameter of these models is the ratio of the power of the GPS carrier wave C [dBW] to the noise power density N0 [dBW-Hz], in short C/N0 [dB-Hz]. Usually, geodetic receivers provide the C/N0 measurement in the receiver internal binary format or in the NMEA $GPGSV message. There are currently discussions in progress to standardise and include the C/N0 observation in a future RINEX format of the GPS observation files. Recently, researchers from Leica Geosystems have proposed a self-calibrating SIGMA-D weight model.

A different approach to the SIGMA models also uses signal quality indicators such as signal-to-noise ratio (SNR) to reduce the errors due to multipath. Work is concentrating on direct estimation of the size and sign of multipath errors and subsequent correction of the raw phase measurements, and the estimation of the elements of a full covariance matrix for the raw GPS phase data according to the likely size of the multipath contamination and the amount of correlation of errors between satellites.

An alternative to traditional least squares modelling of systematic errors in GPS data has also been proposed. The semiparametric model and penalised least squares method describe multipath by a complex but smoothly varying function with time. The functions, and estimated parameters such as station coordinates and ambiguities, are decomposed using the penalised least squares method. Multipath mitigation using the repeatability of SNR ratios over the sidereal day at permanent GPS receivers is based on using a residual stacking algorithm. Others separate multipath from the carrier phase observations. The University of Colorado has developed an algorithm to utilise the spatially-correlated characteristics of multipath to reduce multipath in ground and space-based applications. This algorithm will be used to mitigate multipath in ground-based GPS reference stations.

Electromagnetic Propagation Modelling for Multipath Analysis

The European Space Agency (ESA) is using a software tool "Multipath Virtual Laboratory" (MVL) to compute multipath effects on the GPS observables having satellite constellation location, receiver antenna location, positioning of surrounding structures and antenna information as input parameters. The computation of signal propagation uses a ray-tracing angular Z-buffer algorithm, followed by an electromagnetic field computation using the Geometric Theory of Diffraction (GTD). The MVL tool was used to pre-compute the presence of multipath for the rendezvous of the shuttle Atlantis with the Russian space station MIR.

Work on modelling the multipath environment of the International Space Station is currently underway at the Jet Propulsion Laboratory (JPL) using a multipath simulator previously developed in 1990. In this recent application of the simulation model, the measurement error due to multipath has been computed for a number of different antenna locations. Once the multipath error for each antenna is computed, the corresponding orbit error due to multipath is determined using JPL's GIPSY-OASIS II orbit determination software.

A relatively new technique that involves a numerical solution to the Parabolic Equation (PE) has been used to solve for two-dimensional propagation over any type of terrain. The PE provides a direct solution of Maxwell's wave equations by approximating the Helmholtz scalar wave equation. This technique does not rely on the study of individual ray paths as used in the GTD. Propagation simulations from the model accurately provide the amplitude and phase of the propagated plane wave at all points within the model domain. The PE model was used to study the effects of diffraction and multipath caused by various types of terrain commonly found in an open cut mining environment.

Multipath Characterisation and Attitude Determination

Both ESA and the NASA Johnson Space Center group have been studying multipath effects on attitude determination in the particularly severe environment of the International Space Station (ISS). NASA has compared space shuttle GPS flight data to predicted results from geometrical diffraction prediction. ESA has analysed data from on-ground experiments and in-flight demonstrations for the rendezvous and docking of ESA's Automatic Transfer Vehicle with the ISS. Researchers at ESA have also studied the design of a modified patch antenna that provides low elevation and LHCP signal rejection. Size, weight, and other characteristics are designed for space applications with the goal of improving attitude accuracy below 1°.

Two academic research groups specialise in multipath mitigation for attitude determination. One group have looked at phase map corrections for using simulations and satellite data from the CRISTA-SPAS Experiment. Another group proposes the use of non-dedicated receivers for attitude determination, including using a group of closely spaced antennas for multipath correction in RTK. Attitude accuracy is quite poor because antenna separation is very small. Multipath reduction with the multi-antenna array has been studied in various environments, such as in urban canyons and under foliage. Improvement due to multipath corrections is reported to be approximately 50%.

MID-TERM REPORT OF THE INTERNATIONAL ASSOCIATION OF GEODESY SECTION II: ADVANCED SPACE TECHNOLOGY

http://geodesy.eng.ohio-state.edu/iag_sectionII

President: C.K. Shum (USA), ckshum@osu.edu
Secretary: Pascal Willis (France), pascal.willis@ensg.ign.fr
September 1999 – August 2001
5 July, 2001

Summary

Section II, Advanced Space Technology of the International Association of Geodesy, is engaged in new space techniques for geodesy, geodynamics, atmospheric, oceanographic and other areas of Earth science studies. Its objectives include the participation and promotion of the research and applications using the modern space technologies for a wide variety of interdisciplinary studies in Earth and planetary sciences. Section II organizes Commissions and Special Commissions, Special Study Groups and various Services to fulfill its objectives. This report summarizes the progress for the first half of the four-year term (1999-2003) of Section II activities.

Commission, Special Commissions, and Special Study Groups

The structure of Section II during 1999-2003 has been organized at the IUGG General Assembly in Birmingham in 1999. It consists of:

1. **Commission VIII**, International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG), http://www.dgfi.badw.de/~cstg/, Chair: Hermann Drewes (Germany), Secretary: Wolfgang Bosch (Germany). The Mid-Term report of CSTG is on: http://geodesy.eng.ohio-state.edu/iag_sectionII/CSTGmid-termreport.htm. Sub commissions are:

   (i) Coordination and Combination of the Analysis in Space Geodesy, Chair: Tom Herring (USA), http://bowie.mit.edu/~tah/cstg_comb/.
   (ii) Precise Satellite Microwave Systems, Chair: Pascal Willis (France).
   (iii) Multi-mission Satellite Altimetry, Chair: Wolfgang Bosch (Germany), http://dgfi2.dgfi.badw-muenchen.de/cstg/SCOMMSA/.
   (iv) Precise Orbit Determination for Low Earth Orbiting Satellites, Chair: Markus Rothacher (Germany), http://ww.iapg.bv.tum.de/cstg/index.html.
   (v) Project on DORIS, Chair: Gilles Tavernier (France).

2. **Special Commission VII**, Satellite Gravity Field Missions, Chair: Karl-Heinz Ilk (Germany), Scientific Secretary: Jürgen Kusche (Germany), http://www.geod.uni-bonn.de/SC7/index.html. The Mid-Term report is on: http://www.geod.uni-bonn.de/SC7/index.html.

3. **Special Study Groups**. There are five Special Study Groups (SSG), two could be considered as continuation from the previous 4-year period, three SSGs are newly established. They are:

(i) SSG 2.162, Precise Orbits Using Multiple Space Techniques, Chair: Remko Scharoo (The Netherlands), http://www.deos.tudelft.nl/~remko/ssg2.162. Mid-Term report is on http://www.deos.tudelft.nl/~remko/ssg2.162/report2000.pdf.
(ii) SSG 2.183: Spaceborne Interferometry Techniques, Chair: Ramon Hanssen (The Netherlands), http://www.geo.tudelft.nl/fmr/research/insar/ssg/ssg2183.html. The Mid-Term report is on http://geodesy.eng.ohio-state.edu/iag_sectionII/ssg2.183.htm.
(iii) SSG 2.192: Spaceborne Atmospheric GNS Soundings, Chairs: Rob Kursinski (USA), Klemens Hocke (Germnay), http://www.gfz-potsdam.de/pb1/IAG/SSG_RO/SSG_RO.htm. The Mid-Term report is on http://www.gfz-potsdam.de/pb1/IAG/SSG_RO/ssg_news.html.
(iv) SSG 2.193: Gravity Field Mission: Calibration and Validation, Chairs: Pieter N.A.M. Visser (The Netherlands), Christopher Jekeli (USA), http://www.deos.tudelft.nl/~pieter/IAG.SSG. The Mid-Term report is on http://www.deos.tudelft.nl/~pieter/IAG.SSG/REPORTS/ReportSSG2.193_2000.html.
(v) SSG 2.194: GPS Water Level Measurements, Chairs: Gerry Mader (USA), Tilo Schone (Germany), Doug Martin (USA), http://op.gfz-potsdam.de/altimetry/SSG_buoys/index.html. The Mid-Term report is on http://op.gfz-potsdam.de/altimetry/SSG_buoys/SSG_notes.html.

4. **Services. There are three Services under Section II:**

(i) International GPS Service (IGS), Chair: Christopher Reigber, Director of the Central Bureau: Ruth Neilan, http://igscb.jpl.nasa.gov. The Mid-Term report is on http://geodesy.eng.ohio-state.edu/iag_sectionII/ruthiag.html.
(ii) International Laser Ranging Service (ILRS), Chair: John J. Degnan, Secretary: Mike Pearlman, Director of the ILRS Central Bureau: John M. Bosworth, http://ilrs.gsfc.nasa.gov. The Mid-Term report is on http://geodesy.eng.ohio-state.edu/iag_sectionII/ilrs.htm.
(iii) International VLBI Service for Geodesy and Astrometry (IVS), Chair: Wolfgang Schlueter, Director of the Coordinating Center: Nancy Vandenberg, http://ivscc.gsfc.nasa.gov. The Mid-Term report is on http://geodesy.eng.ohio-state.edu/iag_sectionII/IVS-midterm.htm.

Progress

July 2000 marked the first satellite gravity mission launch in the decade, CHAMP, for the beginning of a series of spaceborne gravity measurement sensors, to be followed by GRACE in late 2001 and GOCE in 2005. For the first time ever, high-low GPS-LEO tracking, low-low LEO-LEO Doppler ranging, spacebrone gradiometer and with 3-axis accelerometers will be flown and represent new space technologies at the frontier of geodetic measurements. SAC-C (2000), CHAMP, GRACE and COSMIC (2004) represent new and abundant missions using GPS limb-sounding or occultation for measuring atmospheric water vapor (integrated water vapor and precipitable water vapor profiles). Together with ground based GPS, spaceborne GPS occultation measurements are beginning to have a major impact on space weather, meteorology and climate studies. Use of GPS on buoys for water level measurements represents another innovative use of GPS. GPS reflection or GPS altimeter measurements, which are being tested (e.g., using CHAMP), represents another new space technology to be potentially promising. Synthetic Aperture Radar interferometry (InSAR) is continuing to be studied as another cutting-edge space geodetic technology. Special Commission and SSGs under Section II have made progress in studying in each of these new space geodetic techniques.

Conferences

During 1999-2001, Section II contributed to various scientific conferences including the following:

IAG Scientific Assembly, Vistas for Geodesy in the New Millennium, Budapest, Hungary, September 2-7, 2001.

American Geophysical Union Spring Meeting, Boston, Massachusetts, USA, June, 2001.

Fifth Symposium on Integrated Observing Systems, American Meteorological Society Symposium, Albuquerque, New Mexico January 15-19, 2001.

26th General Assembly of the EGS in Nice, France, March 25-30, 2001.

GNSS-2001, Sevilla, Spain, 2001.

American Geophysical Union Fall Meeting, San Francisco, California, USA, December, 2000.

ERS-ENVISAT Symposium, Gothenbury, Sweden, October 2000.

COSPAR Symposia, Taipei, Taiwan, Sept., 2000.

14th International Symposium on Earth Tides, Mizusawa, Japan, August 8-Septemeber 1, 2000.

IAG International Symposium on Gravity, Geoid, and Geodynamics 2000, July 31-August 4, Canada, 2000.

COSPAR Symposia, Warsaw, Poland, July 16-23, 2000.

IGARSS2000, Honolulu, July 2000.

Spring AGU Meeting, Washington D.C. May 30-June 3, 2000.

ERIM 2000, Remote Sensing for Marine and Coastal Environments, Charleston, May 1-3, 2000.

Pacific Islands Conference on Climate Change, Rarotonga, Cook Islands, April 2-7, 2000.

25th General Assembly of the EGS in Nice, France, April 24-29, 2000.

ISRSE, Cape Town, 27-31 March 2000.

6th International Conference on Applications of High-Performance Computers in Engineering, 26-28 January, 2000, Maui, Hawaii, 2000.

American Geophysical Union Spring meeting, Washington, USA, 2000.

TOPEX/POSEIDON/Jason-1 Science Working Team Meeting, Miami, USA, 2000.

ION GPS 2000, Salt Lake City, Utah, USA, 2000.

Sixth International Symposium on Land Subsidence,volume CNR, 2000.

Fall AGU Meeting, San Francisco, December 13-17, 1999.

Second International Workshop on ERS SAR Interferometry, `FRINGE99', Belgium, 10-12 Nov 1999.

TOPEX side B altimeter calibration campaigns, Jason SWT Meeting, St. Raphael, France, October 25-27, 1999.

EGS' First Vening Meinesz Conference on "Global and Regional Sea-Level Changes and the Hydrological Cycle", Loiri-Porto San Paolo, Sardinia, Italy, October 4-7, 1999.

GPS99 meeting, Tsukuba, Japan, October, 1999.

IUGG Symposia, Birmingham, UK, July, 1999.

EGS 24th General Assembly, The Hague, The Netherlands, April 1999.

ALT-B Calibration Workshop, Goddard Space Flight Center, Greenbelt, Maryland, USA, 1999.

The Ocean Observing System for Climate, OCEANOBS 99, St Raphael, France, 1999.

Conclusions

On the eve of the evolution of the IAG structure, Section II would be in its last 4-year term under the current organization. While mathematics and technology may considered by many as the foundation of Geodesy, the new IAG structure would reflect the prominence of applications and services in terms of Commissions (Reference Frame, Gravity Field, Earth Rotation and Geodynamics, and Positioning and Applications). It is envisioned that the development and studies of space technologies, while no long would be at the highest level of the IAG new structure, would and should still be playing a critical part in its evolved role to continue to contribute as one of the foundations of contemporary geodesy.

MID-TERM REPORT OF COMMISSION VIII

INTERNATIONAL COORDINATION OF SPACE TECHNIQUES FOR GEODESY AND GEODYNAMICS (CSTG)

1. Introduction

A new structure was given to the Commission VIII CSTG during the 35th IUGG General Assembly in Birmingham, UK, July 1999. The new president elected at this assembly is *Hermann Drewes*, and there were installed five subcommissions and one project:

- Subcommission on the International Space Geodetic Network (ISGN),

  Chair: *John Bosworth*
- Subcommission on the Coordination and Combination of the Analysis in Space Geodesy,

  Chair: *Tom Herring*
- Subcommission on Precise Satellite Microwave Systems,

  Chair: *Pascal Willis*
- Subcommission on Multi-Mission Satellite Altimetry (SCOMMSA),

  Chair: *Wolfgang Bosch*
- Subcommission on Precise Orbit Determination for Low Earth Orbiting Satellites (POD/LEO),

  Chair: *Markus Rothacher*
- Project on Doris,

  Chair: *Gilles Tavernier*

Besides of the subcommission and project chairmen, there are also four IAG Services and the ICSU Commission on Space Research represented in the CSTG Executive Committee:

- International Earth Rotation Service (IERS), Representative: *Claude Boucher*
- International GPS Service (IGS), Representative: *Ruth Neilan*
- International Laser Ranging Service (ILRS), Representative: *John Degnan*
- International VLBI Service for Geodesy and Astrometry (IVS), Representative: *Wolfgang Schlüter*
- ICSU Commission on Space Research (COSPAR), Liaison: *John Dow*

Furthermore, the past president, *Gerhard Beutler*, is a member of the CSTG Executive Committee.

2. Activities of the Commission

The CSTG Executive Committee met three times after its constituting meeting in Birmingham, namely in San Francisco, December 1999, in Warsaw, July 2000 and in Nice, March 2001. We'll give just the most important highlight of each meeting:

The main topics at the San Francisco meeting were the setup and detailed discussions of the terms of reference of the subcommissions. Emphasis was laid on the cooperation of the CSTG subcommissions and other IAG entities, in particular the Special Study Groups (SSG) and Working Groups of the Services.

During the Warsaw meeting, there was a fundamental discussion on the relationship to COSPAR, in particular to its Panel on Satellite Dynamics (PSD). A variety of mutual interests of CSTG and PSD were seen which should be focussed on in the future work.

In Nice, there was an important topic on the role of CSTG in view of the new structure of IERS, in particular with respect to the CSTG Subcommission on Coordination and Combination of the Analysis in Space Geodesy. This subcommission coincides very much with the new IERS Combination Research Centers and the IERS Analysis Coordinator. A close cooperation and clear separation of the objectives was discussed.

The commission CSTG organized one joint symposium on "New Trends in Space Geodesy" together with POD during the 33rd Scientific Assembly of COSPAR in Warsaw, July 2000. More than 70 contributions (oral and poster) were presented in six thematic sessions during three complete days. The proceedings of this symposium will be published in the reviewed journal "Advances in Space Research".

Two CSTG Bulletins, No. 15 (80 pages) and No. 16 (86 pages), were edited in 1999 and 2000, another one is in preparation (2001). The Bulletins include reports of the subcommissions and services as well as individual contributions. More than 400 copies are printed and distributed of each edition of the CSTG Bulletins.

3. Activities of the Subcommissions

3.1 Subcommission on the International Space Geodetic Network (ISGN)

The ISGN seeks to carry on the role of the GGSS in setting standards, documenting and disseminating best practice site criteria for all space geodetic sites. Of great importance in this work are the local survey ties between various techniques. In addition, the ISGN, working with the international space geodesy services, seeks to recognize and certify a "super-set" of multi-technique space geodesy sites that meet a set of rigorous criteria for the purpose of enhancing their long-term sustainability. These sites are and would continue to provide a wealth of high quality data for comparison of techniques, combined solutions and the underpinning for the International Terrestrial Reference Frame and the International Celestial Reference Frame.

The ISGN Chair has developed the following near term activities for the subcommission:

- The ISGN Criteria document has been approved and will be distributed to all potential ISGN sites. A draft charter for the ISGN is being prepared.
- The first set of candidate sites, meeting the ISGN criteria, has been selected. Letters of invitation to become part of the ISGN will be signed by the ISGN and CSTG chairs and sent to the organizations responsible for the certified candidate sites.
- Letters to other potential space geodetic sites that are deficient in some areas of the ISGN Criteria will be prepared and sent to the organizations responsible for the sites. The letters will review the concerns and encourage the sites to take the necessary remedial actions.
- Work with the IERS, the space geodetic services and other CSTG elements to resolve a list of survey tie discrepancies. At a splinter meeting at the EGS meeting in March 2001, the ISGN began the organization of an international team of geodetic surveyors to assist in resolving outstanding site survey omissions and inaccuracies. The team members agreed to work on local survey tie issues within their areas of responsibility and report back to ISGN.
- The ISGN will prepare and distribute a recommended set of survey field procedures and analysis procedures to be reviewed by the membership.
- The ISGN will continue to maintain the Global Space Geodetic Site Information Summary within the NASA GSFC CDDIS and will continue to disseminate information on the best practices for site selection, layout, monumentation, surveying and documentation.

3.2 Subcommission on Coordination and Combination of the Analysis in Space Geodesy

The objective of the subcommission is to study the algorithms and procedures for optimally combining measurements of space geodetic techniques. Main topics for the actual period are

- the updating of the SINEX format to include information appropriate for all space geodetic systems,
- investigations of strategies for combining geodetic results and data,
- analysis of results from combinations with emphasis on results that are unexpected.

The subcommission participated in two international meetings which had sessions associated with combination issues:

- GPS 99, Tsukuba, Japan (see CSTG Bulletin No. 16)
- GEMSTONE, Tokyo, Japan (see Proceedings CRL, Koganei)

3.3 Subcommission on Precise Satellite Microwave Systems

The role of the subcommission is seen in supporting new and emerging techniques. Emphasis will be laid on the advocacy of geodetic interests in the discussion on the GALILEO mission. Contacts have been made to individuals who are represented in the bodies of the mission development. The important meetings on the European level are intensively followed.

3.4 Subcommission on Multi-Mission Satellite Altimetry (SCOMMSA)

The main objectives of the subcommission are

- to promote free access to all altimeter data for scientific investigations,
- to study synergies among different altimeter missions and other remote sensing techniques,
- to set up the requirements for altimeter data structures, standards etc.
- investigate the establishment of an international altimeter service.

An international discussion on the organization, functionality, content and structure of a multi-mission altimeter data base system was started. This data base will be the first step towards a better access and use of altimetry for scientific research.

3.5 Subcommission on Precise Orbit Determination for Low Earth Orbiting Satellites

The primary scientific goals of the subcommission are the studies of

- different LEO orbit modeling approaches,
- the impact of global parameters on LEO orbits,
- mission-dependent data structures and standards
- LEO orbits derived from different observation techniques.

Different data sets of LEO GPS data are made available for groups that are interested to test their software packages, e.g., those from TOPEX/Poseidon, GPS/MET, CHAMP, SAC-C. The data format issue has been discussed in various meetings.

The subcommission participated in the following international meetings:

- IGS network Workshop, Oslo, June 2000;
- IGS Analysis Workshop, Washington, September 2000;
- LEO Workshop, Potsdam, February 2001.

3.6 Project on Doris

The project shall coordinate the activities towards the installation of an International Doris Service (IDS). For this purpose, a joint CSTG/IERS Doris Pilot Experiment was carried out. The project prepared and released the Terms of Reference of the experiment, which were discussed during the AGU Fall Meeting, San Francisco, December 1999. The chairman of the CSTG Subcommission is simultaneously the chairman of the Pilot Experiment and strongly involved in its realization.
The project was very well represented and involved in the organization of the Doris Days, Toulouse, May 2000. A considerable step forward to an international operational product generation was achieved. The individual components of a future service and its interaction, however, have still to be improved. The project is on the way, but still not completely mature for the installation of a service.

4 Conclusion

The Commission CSTG and its Subcommissions have been active in the international coordination of space techniques by organizing of and participating in several research projects and international meetings. They are publishing their results in international journals and CSTG Bulletins. The Commission and most of the Subcommissions have their own web home pages in the internet (www.dgfi.badw.de/cstg). There is a frequent interaction and cooperation of the individual components of the Commission focused in the annual Executive Committee meetings.

IAG SPECIAL COMMISSION VII 'SATELLITE GRAVITY FIELD MISSIONS' (IAG SECTION II)

Mid-term Report

http://www.geod.uni-bonn.de/SC7.html

K.H. Ilk[1] (chair), P. Visser[2] (co-chair), J. Kusche[3] (scientific secretary)

[1] Institute of Theoretical Geodesy, University Bonn, Nussallee 17, D-53115 Bonn, Germany, Email: ilk@theor.geod.uni-bonn.de
[2] Delft Institute for Earth-Oriented Space Research, Kluyverweg 1, 2629 HS, Delft, The Netherlands, Email: Pieter.Visser@lr.tudelft.nl
[3] Delft Institute for Earth-Oriented Space Research, Thijsseweg 11, 2629 JA, Delft, The Netherlands, Email: j.kusche@citg.tudelft.nl

Abstract

This mid-term report describes the activities of the Special Commission VII "Satellite Gravity Field Missions" during the past one and a half years since the IAG General Assembly 1999 in Birmingham, UK. The tremendous progress in preparing and realizing satellite-borne gravity field missions in the past years made it necessary to redefine the objectives of SCVII slightly, especially in view of the dedicated tasks of various Special Study and Working Groups established in Birmingham. Satellite-borne gravity measurements can provide unprecedented views of the earth's gravity field and its changes with time. Together with complementary geophysical data, satellite gravity data represent a "new frontier" in studies of the system earth. It can be expected that the work of Special Commission VII can be more successful in the coming years than in the past. Indeed, the data available in the next future will attract many groups with different analysis concepts and with various ideas to investigate scientific and commercial applications of a very precise high resolution gravity field. This is the reason that SCVII has the chance to support the international exchange of ideas and to draw the greatest possible benefit out of these data.

1. Introduction and background

SCVII is a continuation of a Special Commission that existed already the four years period before 1999 and had been established on the occasion of the IAG General Assembly in Boulder, USA, in the year 1995. The task at that time was to create a platform that integrates all international activities related to gravity field determination by satellite gravity gradiometry and to prepare the conditions for a future mission. Around the year 1995 the common opinion was that only a dedicated satellite gravity gradiometry mission could provide a gravity field which meets the demands of the community. In the upcoming years since 1995 the situation changed in so far as the cheaper satellite-to-satellite tracking concept gained again more interest. This situation is also reflected in the change of the title of SCVII is involved. Before 1999 it was dedicated to the “Gravity Field Determination by Satellite Gravity Gradiometry” and in the follow-on period to the more general topics of “Satellite Gravity Field Missions”. The last six years since 1995 showed a tremendous progress in preparing satellite-borne gravity missions: today we not only have an accepted satellite gravity gradiometry mission but, additionally, two satellite-to-satellite gravity missions already realized or immediately before realization. The multi-purpose high-low satellite-to-satellite mission, CHAMP, has been launched in July 2000. The low-low satellite-to-satellite mission, GRACE, is in the final preparation phase and will be launched end of 2001 and the satellite gravity gradiometry mission GOCE, at present in the scientific and industrial preparation phase, will be realized in 2005. CHAMP, GRACE and GOCE have the potential to revolutionize the knowledge of the system earth. Not only the static part of the gravity field can be determined with unprecedented accuracy, but also an eventual time dependency can be derived. Despite the fact that all three missions have the potential to measure the gravity field by sort of relative measurements between free falling sensors, they are not redundant. Indeed, the characteristics of high-low SST, low-low SST and SGG are rather complementary than competitive. SST is superior in the lower harmonics below degree and order 50 to 60. A mission like GRACE, therefore, is optimal for studying time-varying gravity effects at moderate wavelengths. The static part of the gravity field up to approximately degree 50 can be expected with high accuracy. A condition to detect temporal effects is a corresponding mission duration of several years. Satellite gradiometry is superior for obtaining high spatial resolution from a moderate mission period. Various studies showed that increase of measurement precision or decrease of altitude result in a clear gain of spatial resolution in case of SGG, while this effect is very moderate in case of SST. A SGG mission like GOCE is superior in the short wavelengths parts of the gravity field up to a spherical harmonics degree of 250. The results of a mission like GOCE start to be better than those of a low-low SST mission from degree 60 to 80 on. A high-low SST mission like CHAMP can provide an improvement in the knowledge of the gravity field of approximately one order of magnitude over present models for wavelengths between 400 to 2000km. The coming years, sometimes defined as the “Decade of Geopotential Research” will represent an enormous challenge for the geo-scientific community. This fact is reflected also in the activities of IAG, especially by Section II, which is dedicated to “Advanced Space Technology”, within its scope several Special Study and Working Groups have been established.

2. Objectives

The Special Commission VII can act as a platform of discussion and information exchange related to these various missions. A discussion board should promote discussions related to various topics. National and international activities related to the gravity field missions are being distributed to the interested community. Links to the most important addresses related to these missions are given in the SCVII web page. There are three main problem areas; each of them consists of several sub topics. It is indicated whether specific problems are treated within a Special Study Group. Cooperation started between some of these groups and SCVII:

- Analysis of the observation system:

- on the flight validation and calibration of satellite data of various mission types – connections to SSG 2.193 "Cal/val of new gravity mission instruments" (P. Visser, C. Jekeli) and the Working Group "Preparation of Standard Procedures for Global Gravity Field Validation" (Th. Gruber),
- integrated sensor analysis - connections to SSG 2.162 "Precise orbits using multiple space techniques" (R. Scharroo),
- new sensors (laser interferometers, alternative gradiometers and accelerometers),
- Modeling and data analysis aspects:
- comparison of analysis techniques (global and regional),
- gravity field modeling aspects with view to the time dependency of the gravity field – connections to SSG 4.187 "Wavelets in geodesy and geodynamics" (W. Keller),
- combination of satellite data and (inhomogeneous) terrestrial data – connections to SSG 3.185 "Merging data from dedicated satellite missions with other gravimetric data" (N. Sneeuw),
- calibration of satellite derived data – connections to SSG 2.193 "Cal/val of new gravity mision instruments" (P. Visser, C. Jekeli) and the Working Group "Preparation of Standard Procedures for Global Gravity Field Validation" (Th. Gruber),
- downward continuation aspects,
- Applications in geo sciences, oceanography, climate change studies and other interdisciplinary research topics in earth sciences:
- oceanographic aspects - connections to SSG 2.194 "GPS water level measurements" (C. Jekeli),
- inversion of the gravity field,
- structure of atmosphere and ionosphere - connections to SSG 2.192 "Spaceborne atmospheric GNS soundings" (R. Hanssen),
- temporal variations of the gravity field and the cryosphere,
- temporal variations of the gravity field and the hydrosphere.

Besides these topics the Special Commission should also act as a brain pool for ideas of future developments in gravity field research. This encompasses not only applications to various fields of geo sciences but also developments of future satellite borne techniques to measure the gravity field. Any idea is welcome even when it sounds unrealistic at the present time. Examples are the mission proposals presented for discussion a couple of years ago: COLIBRI (Hummingbird), a multi low-low satellite-to-satellite tracking experiment or TIDES (Tidal Interferometric Detector in Space) which was considered to be based on laser doppler interferometry using ultra-stable lasers. Another example was GEOID, a mission based at that time on the University of Maryland’s Superconducting Gravity Gradiometer. While these ideas were still realistic because they are based on more or less available technology one could think also of completely new proposals as for example the measurement of the earth's gravity gradient with an atom interferometer-based gravity gradiometer, recently proposed by Snadden et al., published e.g. in the Physical Review Letters.

3. Members

SCVII has 56 members and corresponding members, respectively, including the chair, co-chair and scientific secretary. The names of the members and corresponding members that expressed their interest in the work of SCVII are given in the following list.

Chair/co-chair/scientific secretary:
Karl Heinz Ilk, Pieter Visser, Jürgen Kusche

Members/corresponding members:

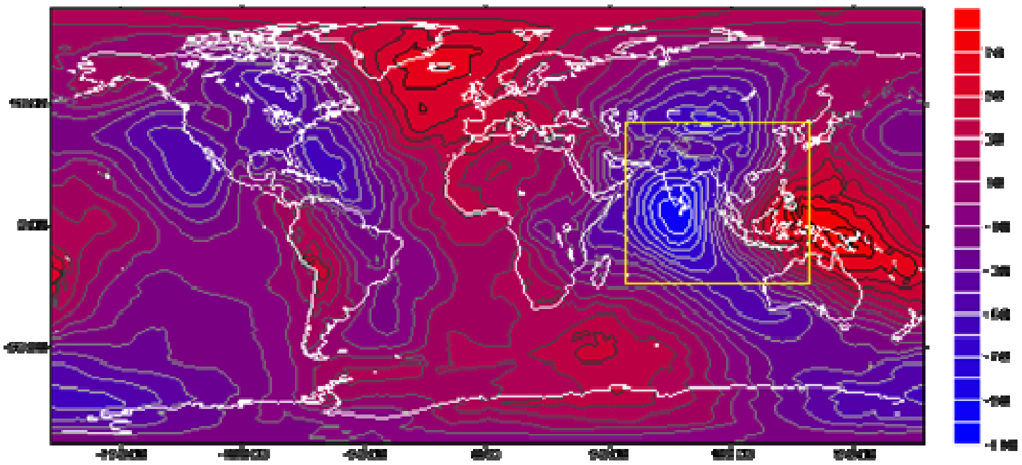
Dimitri Arabelos (Greece), Georges Balmino (France), Srinivas Bettadpur (USA), Johannes Bouman (The Netherlands), Ben F. Chao (USA), Jean Dickey (USA), René Forsberg (Denmark), Willi Freeden (Germany), Yoichi Fukuda (Japan), Martin van Gelderen (The Netherlands), Erik Grafarend (Germany), Richard S. Gross (UK), Thomas Gruber (Germany), Roger Haagmans (Norway), Bernhard Heck (Germany), Cheinway Hwang (Taiwan), Chris Jekeli (USA), Steve Kenyon (UK), Wolfgang Keller (Germany), Roland Klees (The Netherlands), Rolf König (Germany), Radboud Koop (The Netherlands), Ulrich Meyer (Germany), Federica Migliaccio (Italy), Jerry X. Mitrovica (USA), Philip Moore (UK), Jürgen Müller (Germany), Steve Nerem (USA), Helmut Oberndorfer (Germany), Erricos Pavlis (USA), Margarita Petrovskaya (Russia), Dan Roman (USA), Reiner Rummel (Germany), Fernando Sansò (Italy), E.J.O. Schrama (The Netherlands), Wolf-Dieter Schuh (Germany), Avri Selig (The Netherlands), Abdel Sellal (Algeria), Peter Schwintzer (Germany), C.K. Shum (USA), Martijn Smit (The Netherlands), Dru Smith (USA), Nico Sneeuw (Germany), Hans Sünkel (Austria), Byron Tapley (USA), Pierre Touboul (France), Christian C. Tscherning (Denmark), Illias Tziavos (Greece), John Wahr (USA), Michael Watkins (USA), Martin Vermeer (Finland), Janusz Zielinski (Poland), Peiliang Xu (Japan).

4. Specific accomplishments

From the various activities the members of SCVII were involved, we especially want to mention an initiative of SCVII in close cooperation with Pieter Visser and his SSG 2.193, related to the generation of a data set of simulated CHAMP, GRACE, GOCE and 24 GPS satellite orbits. The data set covers a time period of 30 days and includes the velocities, accelerations, and for GOCE the tensor components for specified gravity fields and reference frame specifications. For the beginning, the models are very simplified, e.g. there is no noise on the data. It is intended to provide more specific error models in the upcoming months. The data set should be used for investigations related to satellite borne gravity field missions, especially to compare

- global and/or regional recovery techniques,
- spherical harmonics (each parameter and degree variances) and gravity functionals in (geographic) blocks (center point and mean block values),
- gravity functionals in (geographic) blocks (center point and mean block) values in the region specified in the data sheet.

The simulation material is available in packed form on two CD-roms. It can be received after demand or downloaded together with additional information material from the SCVII web page. The computation comparisons should be done for global and regional analysis techniques. As regional example an area with a rough gravity field in the South-East-Asian area has been selected (fig, geoid heights in m):



Besides this acitivity the bibliography of SGG and SST related references has been improved. Up to now the bibliography contains about 370 different references covering the last three decades. But this list is far from being complete. Even key papers may be missing and a lot of work has to be done to complete this bibliography.

Investigations have been performed and are still under way concerning the development of analysis techniques (global and regional) of SST and SGG observations as well as the downward continuation problem (see references in the SST/SGG bibliography within the last two years). This work has been performed within the frame of SCVII, but also outside of it.

5. Conclusions and outlook

The response to the offer to provide the simulation scenarios so far are very encouraging. The CD-roms have been sent to 15 members of various institutions and countries on demand and some may have downloaded the data set or part of it. We will extend our simulations to include error models for gravity gradients but also to the other mission scenarios. To come up with realistic error models we will establish a group of scientists that should discuss appropriate models in the coming weeks. Many groups around the world are working hard to develop software for analyzing satellite born gravity field observations, as satellite gravity gradiometry observations, satellite-to-satellite tracking data, either in the high-low or in the low-low mode. A large part of the groups that will be responsible for the data processing of these missions are already quite well prepared, but still need to extend and fine tune processing methods and software. In addition, many groups are working on new analysis methods and processing algorithms that are of different maturity level. For these activities, data sets of realistic simulated observations including error models will be of great help. Indeed, there will be only a couple of years and we are confronted with a huge number of data. There are various approaches for global and regional gravity recovery procedures, space-wise, time-wise, etc. some of them are using spherical harmonics, wavelets, covariance functions or any other space-localizing gravity field representations etc.. Another problem closely related to the recovery procedure are the topics "calibration" and "validation", but also data combination with terrestrial data or any already existing data set. To provide a simple platform for any scientist or for groups of scientists of the international community with the task to check and to improve his/their own developments or to compare the effectiveness of their procedures to the procedures of others it seems to be useful to use a unique data set.

IAG Special Study Group 2.162
PRECISE ORBITS USING MULTIPLE SPACE TECHNIQUES
IAG Section II

Remko Scharroo (Chair)

Delft Institute for Earth-Oriented Space Research,
Kluyverweg 1, 2629 HS, Delft, The Netherlands,
e-mail: remko@deos.tudelft.nl

Abstract

The IAG Special Study Group 2.162 “Precise Orbits Using Multiple Space Techniques”' got a reincarnation in 2000, after having a bit of a dormant state. During 2000 members of the Special Study Group have been developing and improving techniques to better determine the orbits of satellites, mainly of low-earth orbiters that carry remote sensing equipment that require high precision orbits.

These activities are focusing particularly on current and upcoming satellite missions that require precise orbit determination and have more than one tracking data type available, such as SLR, DORIS, radar altimeter, GPS and/or GLONASS. To be launched in 2001 are Envisat and Jason-1, Cryosat in 2003. \ers1, \ers2, TOPEX/Poseidon and GFO are used currently.

Orbit determination of GPS and GLONASS satellites using its microwave instruments in connection with SLR shows still some complications with the definition of the phase and optical centres.

1 Introduction and background

Modern satellites that require precise positioning are equipped with several independent tracking devices. The ERS satellites were the first to combine Satellite Laser Ranging (SLR) and Doppler tracking with the Precise Range And Range-rate Equipment (PRARE) for precise orbit determination in support of the radar altimeter (RA). It was soon shown that the RA itself proves an important tracking device. Interferometric Synthetic Aperture Radiometry (InSAR) has recently developed to become another demanding consumer of precise satellite orbits.

TOPEX/POSEIDON (T/P) carries, apart from its RA, four independent tracking systems including SLR, Doppler Orbitography and Radio Positioning Integrated by Satellite (DORIS), Global Positioning System (GPS), and the Tracking and Data Relay Satellite System (TDRSS). For the first time, the force model errors, especially gravity, have been reduced to a point where a comparison of the various satellite tracking systems at or near their noise level is possible.

Results, as expected, show that each system has its own strengths and weaknesses. Therefore, recent precise orbit determination improvements for \ers2 and T/P have been obtained using a combination of multiple tracking techniques.

With PRARE on ERS-1 and GPS on Geosat Follow-On (GFO) on the limb, orbits for these satellites will likely remain to be based partly on altimeter tracking data.

The next generation of altimeter satellites (Jason-1, Envisat and Cryosat) will also be equipped with several tracking systems to support their altimeter, either DORIS or GPS in combination with SLR. There are great expectations for achieving orbits with sub-centimeter precision with a latency of about a month. Operational near real-time orbit determination is rapidly gaining interest and precision. With the approach of DIODE real-time orbits will be at hand.

In the future navigation and tracking satellites (GPS, GLONASS, and TDRSS) will start demanding higher precision orbit determination, because they are and will be used as reference for Low Earth Orbiters (LEOs) in high- low satellite-to-satellite tracking configurations (cf. IAG Subcommission on Precise Orbit Determination for Low Earth Orbiting Satellites). Some of these navigation satellites are equipped with more than one tracking system. An important aspect is also to assess the respective tracking station coordinate solutions and evaluate misfits between the solutions.

GRACE will provide precise satellite-to-satellite tracking in a low-low configuration. Since precise orbit information for this satellite is so important, it will be wise to combine this tracking data type with e.g. the readings of the accelerometers. This is a joint research topic with SSG 2.193 (chaired by Pieter Visser)

The focus of this study group will be to further evaluate and characterize the various tracking systems, develop and assess new tracking techniques, and apply the products to improve the state-of-the-art in precision orbit determination.

2 SSG 2.162 members

The IAG Special Study Group 2.162 consists of 22 members, including the chair and 1 corresponding member. The names and affiliation of the members is listed below:

Chair:Remko Scharroo (TU Delft, The Netherlands)

Members: Boudewijn Ambrosius (TU Delft, The Netherlands), Per-Helge Andersen (FFI, Norway), Jean-Paul Berthias (CNES, France), Willy Bertiger (JPL, USA), John Dow (ESA, Germany), Ramesh Govind Coleman (AUSLIG, Australia), Bruce Haines (JPL, USA), Jaroslav Klokocnik (Czech Academy of Sciences, Czech Republic), Scott Luthcke (GSFC, USA), Franz-Heinrich Massmann (GFZ, Germany), Francois Nouel (CNES, France), Erricos Pavlis (UMD, USA), John Ries (UT/CSR, USA), Markus Rothacher (AIUB, Switzerland), Ernst Schrama (TU Delft, The Netherlands), Ladislav Senhal (Czech Academy of Sciences, Czech Republic), C.K. Shum (OSU, USA), Tim Springer (AIUB, Switzerland), Mike Watkins (JPL, USA), René Zandbergen (ESOC, Germany), Shengyuan Zhu (GFZ, Germany)

Corresponding member: Pieter Visser (TU Delft, The Netherlands)

The members have all been active in satellite orbit determination and have contributed to the improvement of orbit precision in various ways: by the development of accurate measurement models and techniques to combine various types of tracking data, or by the comparison of orbits based on different tracking data. Results of these activities have been presented at various international conferences and symposia like those of EGS, AGU, and IAG, and satellite-specific symposia and workshops like the T/P Science Working Team meetings and the ERS-Envisat Symposium.

3 Specific results and outlook

Most efforts currently focus at the improvement of LEO satellites with remote-sensing instrumentation that requires highly accurate orbit determination, such as ERS1, ERS2, T/P, and Envisat. Ground breaking work has been conducted in the past combining SLR and altimeter data for the orbit determination of ERS1 and ERS2, in the absence of a more precise microwave tracking instrument. When PRARE became available, the combination of the three tracking data types became an important issue. However, the intricacies of the differences between the various orbits computed with the different tracking instruments are not yet understood.

The GLONASS and GPS satellites also obtain more attention. Attempts have been made to combine GPS/GLONASS and SLR tracking data for the orbit determination. Here, it was found that the position and the phase centers and the optical centre of the laser reflector array are often less known than expected. More research is to be expected in this field.

Operational, near-real time orbit determination appears feasible now using only SLR and altimeter tracking data. Accuracies of near realtime ERS2 orbits are in the neighbourhood of 10 cm in radial direction.

DORIS is getting more attention as it matures into the most effective microwave tracking instrument ever developed. The next generation will provide real-time orbit information. Next studies will have to identify to which extend DORIS and SLR tracking data are compatible or complementary. The same holds for these tracking types with respect to GPS. Unfortunately, the later issue is still under-researched.

During the next phase, the study group will be extended with experts in the area of GLONASS and GPS orbit determination. A proper database of all relevant papers and presentations will be gathered and be available through the web page of the special study group.

References

Berthias, J.-P., P. Cauquil, C. Jayles, D. Laurichesse, and S. Nordine (2000), Real-time on-board precise orbit determination with doris, Paper presented at the European Geophysical Society XXV General Assembly, Nice, France, 25-29 April 2000.

Lemoine, F. G., N. P. Zelensky, D. D. Rowlands, G. C. Marr, S. B. Luthcke, and D. S. Chinn (2000), Precise orbit determination for the geosat follow-on spacecraft, Paper presented at the European Geophysical Society XXV General Assembly, Nice, France, 25-29 April 2000.

Massmann, F.-H., J. C. Raimundo, C. Reigber, C. Falck, F. Flechtner, and A. Scherbatschenko (2000), The prare system onboard ers-2: Status and results, in “Proceedings of the ERS-ENVISAT Symposium, Gothenburg, Sweden, 16-20 October 2000, Eur. Space Agency Spec. Publ., ESA SP-461”.

Scharroo, R., P. N. A. M. Visser, and N. R. Peacock (2000), ERS orbit determination and gravity field model tailoring: Recent developments, poster presented at the European Geophysical Society XXV General Assembly, Nice, France, 25-29 April 2000.

Vincent, P., B. Duesmann, and R. Scharroo (2000), The validation of envisat orbits, in “Proceedings of the ERS-ENVISAT Symposium, Gothenburg, Sweden, 16-20 October 2000, Eur.\ Space Agency Spec.\ Publ., ESA SP-461”.

SPECIAL STUDY GROUP 2.183 SPACEBORNE INTERFEROMETRY TECHNIQUES

MID-TERM REPORT (R.HANSSEN)

This mid-term report gives a brief overview of the developments in radar interferometry since the IAG General Assembly 1999 in Birmingham, UK. The members of the Special Study Group on Spaceborne Interferometry Techniques have been working on a variety of topics related to the terms of reference. The objectives of the group are

- to develop techniques and algorithms that allow extracting unambiguously topographic, deformation, and atmospheric signal from spaceborne repeat-pass radar interferometry,
- to develop methods that allow describing the quality, in terms of accuracy and reliability, of the interferometric products taking the most significant error sources into account, and
- to validate topographic and deformation maps for various applications and under various environmental conditions.

Members

Falk Amelung	(University of Hawaii, USA)	amelung@pgd.hawaii.edu
Richard Bamler	(German Aerospace Center (DLR), Germany)	Richard.Bamler@dlr.de
Alessandro Ferretti	(Politecnico di Milano, Italy)	aferre@elet.polimi.it
Satoshi Fujiwara	(Geographical Survey Institute, Japan)	
Linlin GE	(University of New South Wales, Australia)	l.ge@student.unsw.edu.au
Rick Guritz	(Alaska SAR Facility, USA)	rguritz@images.alaska.edu
Ramon Hanssen (chair)	(Delft University of Technology, The Netherlands)	hanssen@geo.tudelft.nl
Johan Mohr	(Technical University of Denmark)	jm@emi.dtu.dk
David Sandwell	(Scripps Institution of Oceanography, USA)	sandwell@geosat.ucsd.edu
Andrew Wilkinson	(University of Cape Town, South Africa)	ajw@eng.uct.ac.za
Howard Zebker	(Stanford University, USA)	zebker@jakey.stanford.edu

Progress in radar interferometry

Spaceborne radar interferometry has developped considerably during the last two years. The experience with the repeat pass missions for topographic mapping, especially the problem of temporal decorrelation and atmospheric disturbances, culminated in the Shuttle Radar Topography Mission (SRTM) [17]. This Space Shuttle mission was performed between 11 and 23 February 2000 and used a single-pass configuration with a fixed 60 m boom to carry the two radar antennas. It mapped all land masses between 60°N and 58°S using C-band, and tiles of this area with a higher accuracy using X-band [5,22]. Currently, data calibration and processing is still in progress.

Progress in the field of the phase unwrapping problem focussed mainly on the application of network flow algorithms and the unwrapping of sparsely distributed, isolated resolution cells in interferograms [8,6,7].

An important development is the development of a procedure to use many or all available SAR images of a specific area in order to obtain topography or deformation measurements [10] [11] [9] [12] . This method, using Permanent Scatterers (image pixels which remain coherent over long time intervals and for wide baselines) is a successful attempt to overcome the temporal decorrelation problem as well as atmospheric disturbances. Single coherent pixels, which would not be identified using conventional methods are analyzed as time-series of deformation.

The influence of the atmospheric signal, which hampered quantitative quality statements of interferometric data, has been analyzed and modeled as a stochastic signal. [13] Scaling characteristics enable the construction of covariance functions to model the behavior of turbulent mixing in the atmosphere.

A new application of repeat-pass interferometry is atmospheric water vapor mapping [15,14]. If coherent interferograms are available over areas where topography is known, and surface deformation is absent, the phase variations mainly reflect the lateral atmospheric delay differences. For distances less than, say, 50 km these delay differences are mainly caused by water vapor heterogeneities, giving a new high-resolution perspective on radio propagation for space-geodetic methods.

To facilitate investigations, synthetic simulations of SAR data as well as of interferometric data were reported by [23].
[
18] reported on the geometric calibration of ERS data. Using an algorithm which extracts SAR parameters and a method for raw data preparation, this calibration results in slant range images that have an accuracy that corresponds to 10 m horizontally on the ground. Their results also demonstrate the high stability of the ERS satellites.

Stacking methodologies as well as phase-gradient methods have been developped to improve DEM generation [19,20].

For the analysis of earthquakes using remote sensing, the combination of radar with optical imagery has been improved, using alternative (optical) correlation techniques.

The fast-track analysis of SAR data for e.g. earthquake research is demonstrated by [21], where ERS data of Hector Mine earthquake where received by a local groundstation and used to form an interferogram within 20 hours of the second overflight.

New insights in volcano monitoring were reported, see [24,4,1]. Volcanic uplift, caused by the accumulation of magma in subsurface reservoirs, is a common precursor to eruptions. But, for some volcanoes, uplift of metres or more has not yet led to an eruption. [3] present displacement maps of volcanoes in the Galápagos Islands, constructed using satellite radar interferometry, that might help explain this dichotomy. Subsidence studies have been reported by [2] and [16].

Conclusion

Members of the special studygroup are active in a wide range of research fields, spanning from electrotechnics to geodesy and geophysics. Due to this broad scale of interests, it is not feasible to arrange specific meetings where the entire group could come together. Nevertheless, several members meet regularly at a number of international symposia, allowing for interaction and cooperation. Progress in radar interferometry has been considerable in the last couple of years, and the members of the studygroup will continue to pursue the objectives mentioned above.

Publications by the members

1. F Amelung, C Oppenheimer, P Segall, and H Zebker.
   Ground deformation near Gada 'Ale volcano, Afar, observed by radar interferometry.
   Geophysical Research Letters, 27(19):3093-3097, 2000.
2. Falk Amelung, Devin L Galloway, John W Bell, Howard A Zebker, and Randell J Laczniak.
   Sensing the ups and downs of Las Vegas: InSAR reveals structural control of land subsidence and aquifer-system deformation.
   Geology, 27(6):483-486, June 1999.
3. Falk Amelung, Sigurjón Jónssen, Howard Zebker, and Paul Segall.
   Widespread uplift and trap door faulting on Galápagos volcanoes observed with radar interferometry.
   Nature, 407(6807):993-996, October-26 2000.
4. Falk Amelung, Sigurjon Jonsson, Howard Zebker, and Paul Segall.
   Prospects of volcano geodesy with ERS radar interferometry.
   In *Second International Workshop on ERS SAR Interferometry, `FRINGE99', Liège, Belgium, 10-12 Nov 1999*, pages 1-9. ESA, 1999.
5. R Bamler, M Eineder, and H Breit.
   The X-SAR single-pass interferometer on SRTM: Expected perfomance and processing concept.
   In *EUSAR'96, Königswinter, Germany*, pages 181-184, 1996.
6. Curtis W Chen and Howard A Zebker.
   Network approaches to two-dimensional phase unwrapping: intractability and two new algorithms.
   Journal of the Optical Society of America A., 17(3):401-414, March 2000.
7. Curtis W Chen and Howard A Zebker.
   Two-dimensional phase unwrapping using statistical models for cost functions in

nonlinear optimization.
Journal of the Optical Society of America A., in press, 2000.

8. Mario Costantini.
A novel phase unwrapping method based on network programming.
IEEE Transactions on Geoscience and Remote Sensing, 36(3):813-821, May 1998.

9. A Ferretti, C Prati, and F Rocca.
Measuring subsidence with SAR interferometry: Applications of the permanent scatterers technique.
In L Carbognin, G Gambolati, and A I Johnson, editors, *Land subsidence; Proceedings of the Sixth International Symposium on Land Subsidence*, volume 2, pages 67-79. CNR, 2000.

10. Alessandro Ferretti, Claudio Prati, and Fabio Rocca.
Multibaseline InSAR DEM reconstruction: The wavelet approach.
IEEE Transactions on Geoscience and Remote Sensing, 37(2):705-715, March 1999.

11. Alessandro Ferretti, Claudio Prati, and Fabio Rocca.
Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry.
IEEE Transactions on Geoscience and Remote Sensing, 38(5):2202-2212, September 2000.

12. Alessandro Ferretti, Claudio Prati, and Fabio Rocca.
Permanent scatterers in SAR interferometry.
IEEE Transactions on Geoscience and Remote Sensing, 39(1):8-20, January 2001.

13. Ramon F Hanssen.
Radar Interferometry: Data Interpretation and Error Analysis.
Kluwer Academic Publishers, Dordrecht, 2001.

14. Ramon F Hanssen, Arnout J Feijt, and Roland Klees.
Comparison of precipitable water vapor observations by spaceborne radar interferometry and Meteosat 6.7-μm radiometry.
Journal of Atmospheric and Oceanic Technology, 18(5):756-764, May 2001.

15. Ramon F Hanssen, Tammy M Weckwerth, Howard A Zebker, and Roland Klees.
High-resolution water vapor mapping from interferometric radar measurements.
Science, 283:1295-1297, February-26 1999.

16. Jörn Hoffmann, Howard A Zebker, Devin L Galloway, and Falk Amelung.
Seasonal subsidence and rebound in Las Vegas Valley, Nevada, observed by synthetic aperture radar interferometry.
Water Resources Research, 37(6):1551-1566, June 2001.

17. Rolando L Jordan, Edward R Caro, Yunjin Kim, Michael Kobrick, Yuhsyen Shen, Frederick V Stuhr, and Marian U Werner.
Shuttle radar topography mapper (SRTM).
In Giorgio Franceschetti, Christopher J Oliver, James C Shiue, and Shahram Tajbakhsh, editors, *Microwave Sensing and Synthetic Aperture Radar*, pages 412-422. SPIE, Bellingham, 1996.

18. Johan Jacob Mohr and Søren Nørvan Madsen.
Geometric calibration of ERS satellite SAR images.
IEEE Transactions on Geoscience and Remote Sensing, 39(4):842-850, 2001.

19. David T Sandwell and Evelyn J Price.
Phase gradient approach to stacking interferograms.
Journal of Geophysical Research, 103(B12):30183-30204, December 1998.

20. David T Sandwell and Lydie Sichoix.
Topographic phase recovery from stacked ERS interferometry and a low resolution digital elevation model.
Journal of Geophysical Research, 105(B12):28211-28222, 2000.

21. David T Sandwell, Lydie Sichoix, Duncan Agnew, Yehuda Bock, and Jean-Bernard Minster.
Near real-time radar interferometry of the Mw 7.1 Hector Mine earthquake.
Geophysical Research Letters, 27(19):3101-3104, 2000.

22. Marian Werner.
Shuttle radar topography mission (SRTM). the X-Band SAR interferometer.
In *28th EuMC workshop proceedings*. EuMW Amsterdam, 9 October 1998, 1998.

23. L S Wray, A J Wilkinson, and M R Inggs.
Synthetic aperture radar image simulator for interferometry.
In *ISRSE, Cape Town, 27-31 March 2000*, 2000.

24. Howard A Zebker, Falk Amelung, and Sjonni Jonsson.
Remote sensing of volcano surface and internal processes using radar interferometry.
In Peter J Mouginis-Mark, Joy A Crisp, and Jonathan H Fink, editors, *Remote sensing of active volcanism*, Geophysical Monographs 116, pages 179-205. American Geophysical Union, Washington, DC, 2000.

IAG/SSG 2.192
"SPACEBORNE GNS ATMOSPHERE SOUNDING"

Report from the members (in alphabetic order):

Georg Beyerle (on behalf of him):
Radio holographic analysis shows that around 1/3 of the GPS/MET occultation events have multibeam propagation in the lower troposphere. Raytracing simulation of the time history of the direction of arrival of direct (GPS--LEO) and reflected (GPS -- earth's surface --LEO) signal explains the observed multipath structure in detail. This finding may improve refractivity retrieval in the lower troposphere and may indicate a future application of radio occultation for sounding of boundary layer, ocean and ice surface.

Ben Chao:
A loosely defined "geodesy team" for the COSMIC Mission intend to use COSMIC (2004 launch) orbit data (from GPS) to infer Earth's gravity field and its temporal variations. Strawman simulations have indicated possible great improvements over our present solutions.

Jennifer Haase:
GNSS RADIO OCCULTATION FOR AIRBORNE SOUNDING OF THE TROPOSPHERE

The usual geometry for GNSS (Global Navigation Satellite System) based on radio occultation sounding has the receiver placed on a LEO (Low Earth Orbit) satellite.

We investigated a new geometric approach, assuming an airborne rather than a spaceborne receiver. Information on the refractivity structure and, in turn, on atmospheric variables (most notably temperature and humidity) can be retrieved from accurate airborne measurements of the amplitude and phase delay of the signals occulted by the troposphere. We present advantages and disadvantages of making measurements from commercial aircraft equipped with proper GNSS receivers and antennae. Using the EGOPS4 software (see Kirchengast et al. paper in this session), we simulated realistic airborne occultation observations and assessed their characteristics, such as geometric properties, dynamic range, and error sources.

Findings include that an airborne system has the potential to provide many more profiles below 10 km height than LEO systems (though not with similar global coverage), that the profile characteristics are much more sensitive to the geometry determined by the GNSS satellites than in the LEO case, and that horizontal refractivity structures are expected to be a main error source. Finally, planned future work on the topic is outlined. The project is supported by the European Space Agency.

George Hajj, Manuel de la Torre Juarez, Rob Kursinski, Tony Mannucci, et al.:
Occultation Research at JPL

The GPS receiver on CHAMP has recently begun producing a limited amount of occultation data. Working with the German occultation team and the U.S. GPS Earth Observatory (GEO) occultation team, the receiver group at JPL is assessing the performance of the receiver and updating the receiver software on the GPS receiver on the CHAMP satellite to fix various bugs and improve performance overall. The GEO group at JPL has begun deriving occultation profiles from CHAMP and assessing the performance of the CHAMP GPS receiver. Initial results are promising in that the Signal to Noise Ratios (SNR) are higher than in previous receivers, particularly the L2 SNR with AS-on. The receiver appears to be tracking occulted GPS signals very deep into the troposphere. Initial retrieval results will be reported on at the Spring AGU meeting in Boston.

The GEO group is developing a retrieval scheme that uses only the GPS CA signal. The work is driven by the very poor L2 data quality of most of the Oersted and GPS/MET occultation data sets. As a result, the ionospheric effects could not be estimated and removed using the normal L1 versus L2 approach. By using the group delay minus phase delay both derived from the GPS CA signal, the effect of the ionosphere can be estimated and removed. The penalty is of course that the ionosphere estimated this way is quite noisy because the group delay estimates are roughly two orders of magnitude noisier than the phase delay estimates. Results and an assessment of the utility of this approach will be presented at the Spring AGU.

Research is proceeding on assimilating GPS occultation data into ionospheric models to study the upper atmosphere.

Yunck et al. (2000) described the Atmospheric Moisture and Ocean Reflection Experiment (AMORE) using high frequency occultation observations and GPS surfaces reflections.

A collaborative research effort is proceeding with Toshi Tsuda et al. in Japan on profiling the atmosphere using occultation observations from mountain tops based on the Zuffada et al. (1999) concept.

NOTE Spring AGU session: there will be a special session at the AGU in Boston at the end of May chaired by Tony Mannucci and John LaBrecque where many new GPS occultation results will be presented.

Sean Healy:
Work at the Met Office for the GRAS-SAF:

We have been deriving the statistics bending angle and impact parameter errors caused by horizontal gradient errors by simulating occultations within the domain of the Met Office mesoscale model. In addition, we are developing a fast bending angle forward model for the direct assimilation of bending angle into numerical weather prediction systems.

Ben Herman:
We are working on an advanced radio occultation experiment to independently monitor water vapor and ozone, as well as refractivity, temperature, pressure, and geopotential height. This will be accomplished with transmitters in space which will have transmitting capbilities at ozone and water vapor absorbing frequencies, as well as the standard L1 and L2 frequencies. We are completing software development and working with JPL on breadboarding the hardware. The experiment, when completed,will operate in a cross-link mode with each space instrument having a transmitter and a receiver.

Klemens Hocke:
By means of the GPS/MET data base and statistical analysis, the 4-D small-scale fluctuation field of the earth's atmosphere and ionosphere has been preliminary inspected. In particular the detection of thin ionization layers in the lower ionosphere by GPS radio occultation seems to be promising. First results indicate a relationship between earth's topography, atmospheric and ionospheric fluctuations, suggesting a coupling of the whole atmosphere by upward energy/momentum flux of atmospheric waves and showing the potential of GPS radio occultation for correlative studies of lower, middle and upper atmosphere.

Gottfried Kirchengast:
Please see for publications and ARSCliSys Research Group:
http://www.uni-graz.at/igam

Rob Kursinski:
We looked at initial results of combining GPS and ECMWF analysis information within a 1Dvar framework (Kursinski et al., 2000). We are working with Paul Poli and Joanna Joiner at the GSFC Data Assimilation Office (DAO) on assimilating the GPS occultation data into the DAO analyses. In Kursinski and Hajj (2001) we report on initial results of deriving water vapor from GPS/MET data. Comparisons with ECMWF and NCEP analyses and the classic climatology of Peixoto and Oort revealed general similarity but also some important systematic biases. In particular the rounding off of the tradewind inversion in the analyses was very apparent in the comparisons.

At the fall AGU we reported on the dryness of subtropical free troposphere derived from GPS/Met occultations and some implications regarding the water vapor feedback in climate. A manuscript is in preparation.

We have been able to observe the mixed layer in the Planetary Boundary Layer using GPS/MET data. This represents the first time this layer has been observed from space. We will report on this at the Spring AGU and a manuscript is in preparation.

We are evaluating the accuracy of water vapor and temperature derived from high frequency (10 - 200 GHz) occultations and determining the optimum frequencies (see Ben Herman's report above).

NOTE: The special March 2000 issue of TAO dedicated to the COSMIC mission is now out as a book from Springer. (see Lee et al., 2001 in references below)

Christian Marquardt:
Development of variational retrieval schemes of RO soundings in the neutral stratosphere; validation of meteorological products from RO measurements; application of RO data in upper tropospheric and stratospheric dynamics
----

Manuel Martin-Neira:
The European Space Agency, within the Payload Systems Division (Directorate of Technical and Operational Support), is researching on the use of reflected GPS or generally, GNSS signals, for altimetry, wind, wave height and TEC retrievals over ocean. We conduct this research through contracts with external institutes, universities or industries, as well as through experiments we perform ourselves at ESTEC (ESA center in Holland). We proposed the use of GNSS ocean reflected signals for ocean altimetry for the first time in 1993, under a concept called "PARIS" [Martin-Neira, 1993]. The main contracts we have had in the recent past were dedicated to model the ocean surface as well as the reflected GNSS signals. Right now we finished a study on the use of carrier phase for ocean altimetry and there is an on-going activity to develop algorithms for signal processing from aircraft altititude.

On the experimental side we carried out an experiment from a bridge were an rms height accuracy of 1% of the chip length was achieved (3 m for C/A code) [Martin-Neira et al. 2001].

Last year we also performed a test on a pond to investigate on the use of carrier phase for altimetry and obtained millimetric height error [Martin-Neira et al., 2000]. As for the future we intend to place industrial contracts to define a "PARIS" instrument for Earth remote sensing from space.

Alexander Pavelyev:
The efficiency of radio holography has been confirmed by direct observation of multi beam propagation and reflected from the sea signal using MIR/GEO and GPS/MET radio occultation data. This demonstrates high-technology level of the radio holography approach and opened new perspectives for radio occultation experiments: observation natural processes in the atmosphere, mesosphere and ionosphere, measurements of the parameters of the sea surface by means of analysis of reflected signal. The radio holograms of D-layer of the ionosphere revealed wave structures with vertical periods about of 1-2 km in the altitude dependence of the vertical gradient of electron density. Observation of wave structures in D-layer and E-layer of the ionosphere is important for understanding the momentum and energy interchange between lower and upper atmosphere and study fine structure of mesopause region. The main conclusion consists in possibility of qualitative measurements of wind velocity in the lower ionosphere using radio occultation data. Directions of the future progress is outlined. These directions are:

bistatic scatterometry using combined phase and amplitude radio occultation data; this may be considered also in the context of elaborating new international small satellite system for observation of the effect of radiowave propagation on the telecommunication link between two satellite (K. Igarashi et al. 2000);

measurements of parameters of the boundary layer disposed near the sea surface, using reflected signal for more precise evaluation parameters of the lower troposphere, revealing features in the humidity distribution;

elaboration of models for revealing wave phenomena in the upper atmosphere on the phone on more powerful contribution of the F-layer of the ionosphere;

measurements of parameters of natural processes in the upper ionosphere using combined amplitude and phase data analysis;

development of special models to account for ionospheric influence on the atmospheric refractivity restoration and temperature measurements.

Giulio Ruffini:

I am now working at Starlab (www.starlab.net), and continuing my previous activities in the area of GNSS-R at the newly created company and with a new group (5 people are now in this group). We are working on several aspects of GNSS-R, researching applications in scatterometry as well as in altimetry (using code and phase ranging). Starlab is officially involved in Paris-Alpha, and is responsible for the science aspects of the project. Paris-alpha (ESA project, technical officer is M. Martin-Neira) is interested in retrieving GNSS-R altimetric data from aircraft, and we are considering both code and phase ranging aspects of the problem.

We are also leading Paris-Beta (ESA project, technical officer is P. Silvestrin) which is researching the applications of PARIS for spaceborne bistatic altimetry.

We have also participated in several experimental campaign related to GNSS-R: MEATEX (MEditerranean Aircraft Tracking EXperiment), MEBEX (MEditerranean Balloon EXperiment), and Zeeland II.

Sergey Sokolovskiy:

At UCAR/GST we looked into the GPS/MET data and found that almost 1/2 of the occultations are affected by receiver tracking errors at the end (sometimes those errors are very large).

"Worst case" RO signals were simulated based on high-resolution radiosondes and forward wave propagation model.

An open loop tracking technique was outlined and tested by the simulated "worst case" RO signals. The "worst case" signals can be tracked without the corruption common for PLL tracking.

For the radio optics (sliding spectral) inversion method an option which overcome the problem of identification and selection of the local maxima in the spectrum of RO signal (which can be very complicated), was introduced and tested by the simulated "worst case" signals.

Additionally: The sliding window Fourier analysis detects reflected signals in the GPS/MET data identically to the MUSIC reported by Beyerle and Hocke.

Andrea Steiner :

EMPIRICAL ERROR ANALYSIS OF GNSS RADIO OCCULTATION DATA

A.K. Steiner and G. Kirchengast

Radio occultation observations using the Global Navigation Satellite System (GNSS) have great potential to contribute to the Global Climate Observing System (GCOS).

Besides such benefit for climate monitoring and modeling, the assimilation of high-quality GNSS occultation data into numerical weather prediction (NWP) models could lead to improved weather forecasts and analyses.

In this context we present results of an empirical error analysis of GNSS radio occultation data, which is based on a realistically simulated occultation dataset produced by the End-to-end GNSS Occultation Performance Simulator (EGOPS).

In order to involve realistic atmospheric profiles and error characteristics we used a T213L50 ECMWF analysis field. The ionosphere was prescribed with the NeUoG model, a global empirical 3D model of the ionospheric electron density field.

Radio occultation observations were simulated for one observational day adopting the planned European Meteorological Operational satellite (METOP) as Low Earth Orbit (LEO) platform and its GNSS Receiver for Atmospheric Sounding (GRAS) as sensor. Involving a sub-millimetric precision 3D ray tracer, excess phase path profiles were computed for an ensemble of 300 occultation events equally distributed over the globe and in time. With an rms error of ~2 mm at 10 Hz sampling rate they closely mimic the expected METOP/GRAS sensor performance. Atmospheric (troposphere/stratosphere) profiles were retrieved with a state-of-the-art occultation data processing chain and were compared to the "true" co-located profiles. An error analysis was performed at each retrieval step to empirically obtain realistic bias profiles and covariance matrices. We show biases, standard deviations, and correlation functions for each main retrieval product, including bending angle, refractivity, pressure, geopotential height, temperature, and specific humidity. We compare our empirical results with theoretical results and discuss the utility of the empirical covariance matrices for specifying observation error covariance matrices in data assimilation systems ingesting GNSS occultation data.

Jens Wickert:

First occultation measurements of CHAMP have been taken during measurement intervals since February 11, 2001. Vertical profiles of dry temperature and specific humidity were derived and compared with meteorological analyses of ECMWF and NCEP. They show a good agreement. In spite of anti-spoofing on mode of the GPS satellite system, the new BlackJack GPS receiver allows for atmospheric sounding with high accuracy and vertical resolution. It is found that the CHAMP measurements have the potential to reach the Earth's surface.

It is expected, that "AS on" will have no limiting influence on the data processing, Therefore it is expected that CHAMP will provide about 200 vertical profiles of atmospheric parameters daily after the commissioning phase.

Development of automatically working occultation processing system at GFZ Potsdam.

Xiaolei Zou:

Following is a short statement from us: With a raytracing procedure and variational data assimilation techniques, hundreds of GPS/MET bending angle profiles were assimilated into the global atmospheric analysis. A small but consistent improvement in the short-range (6-h) and medium-range (1-5 days) forecast skills, especially in the Southern Hemisphere, were obtained.

References:

Beyerle, G., K. Hocke:
Observation and simulation of direct and reflected GPS signals in radio occultation experiments, Geophysical Research Letters, in press, 2001

Engeln, A.v., S. Buehler, G. Kirchengast, and K. Kuenzi,
Temperature profile retrieval from surface to mesopause by combining GNSS radio occultation
and passive microwave limb sounder data, Geophys. Res. Lett., 28, 775-778, 2001.

Foelsche, U., and G. Kirchengast,
An improved mapping function for the hydrostatic delay at GPS frequencies, Phys. Chem. Earth (A), 26, 153-157, 2001.

Garrison, J.L, G. Ruffini, A. Rius, E. Cardellach, D. Masters, M. Armatys, V.U Zavorotny,
Preliminary results from the GPSR Mediterranean Balloon Experiment (GPSR-MEBEX), Proceedings of ERIM 2000,
Remote Sensing for Marine and Coastal Environments, Charleston, 1-3 May 2000.

Hartmann, G.K., G. Kirchengast, A. von Engeln, M.L. Richards, J. Ramsauer,and Ch. Jarchow,
MAS-GRAS sensor combination and optimal estimation retrieval of temperature and HO profiles, Phys. Chem. Earth (A), 25, 625-628, 2000.

S. B. Healy and J. R. Eyre, 2000,
Retrieving temperature, water vapour and surface pressure information from refractive-index profiles derived by
radio occultation: A simulation study. Q. J. R. Met. Soc., 126, pp. 1661-1683.

S.B. Healy, 2001,
Radio occultation bending angle and impact parameter errors caused by horizontal refractive index gradients in the troposphere: A simulation study. J. Geophys. Res. (In press).

S. B. Healy, 2001,
Smoothing radio occultation bending angles above 40km. Annales Geophysicae (In press).

Hocke, K., A.G. Pavelyev:
General aspect of GPS data use for atmospheric science, Advances in Space Research, in press, 2001

Igarashi, K., A. Pavelyev, K. Hocke, O. Yakovlev:
Radio holographic principle for observing natural processes in the atmosphere and retrieving meteorological parameters from radio occultation data, Earth, Planets and Space 52, 893-899, 2000

Kursinski, E.R., S. B. Healy and L. J. Romans, 2000,
Initial results of combining GPS occultations with ECMWF global analyses within a 1DVar framework, Earth Planets Space, 52, 885-892.

Kursinski and Hajj, 2001,
A comparison of water vapor derived from GPS occultations and global weather analyses, J. Geophys. Res., 106, D1, p. 1113-1138, anuary 16, 2001.

L.-C. Lee, C. Rocken and E.R. Kursinski Eds.,
Applications of Constellation Observing System for Meteorology, Ionosphere and Climate, Springer-Verlag, Hong Kong, 2001, 384 pp.

Liu, H., X. Zou, R. A. Anthes, J. C. Chang, J.-H. Tseng, and B.Wang,
2000: Extended assimilation and forecast experiments using hundreds of GPS/MET bending angle profiles. J. Geoph. Res., Atmosphere,
(submitted), pp22.

Marquardt C., K. Labitzke, Ch. Reigber, T. Schmidt and J. Wickert,
An assessment of the quality of GPS/MET radio limb soundings during February 1997, Phys. Chem. Earth, 26, 125-130, 2001.

Martin-Neira,
"A Passive Reflectometry and Interferometric System (PARIS): Application to Ocean Altimetry", ESA Journal, Vol.17, pp. 331-355, Dec 1993.

Martin-Neira et al,
"The PARIS Concept: An Experimental Demonstration of Sea Surface Altimetry Using GPS Reflected Signals", TGARS Vol.39, No.1,
pp.142-150, January 2001.

Martin-Neira et al,
"Ocean Altimetry Using the Carrier Phase of GNSS Reflected Signals", CERSAT Bulletin, Issue 11, Scientific Topic 22, November 2000.

Pavelyev, A.G., K. Igarashi, K. Hocke, S.S. Matugov, a.I. Kucherjavenkov, D.A. Pavelyev, O.I. Yakovlev:
First application of radioholographic method to wave observations in the upper atmosphere, Radio Science, in press, 2001

Rieder, M.J., and G. Kirchengast,
Error analysis for mesospheric temperature profiling by absorptive occultation sensors, Ann. Geophys., 19, 71-81, 2001.

Rieder, M.J., and G. Kirchengast,
An inversion algorithm for nonlinear retrieval problems extending Bayesian optimal estimation, Radio Sci., 35,45-56, 2000.

(References for G. Ruffini: (see http://foobar.starlab.net/~giulio)

Ruffini, G., Soulat, F,
Paris Interferometric Processor Theoretical Feasibility Study part I and Part II. , for ESA's PIPAER-IEEC-TN-1100/2100,
ESTEC Contract No. 14071/99/NL/MM, August 2000. Courtesy of ESA. The authors wish to thank Manuel Martin-Neira for very useful comments. The best site to dowload this is http://arXiv.org/ps/physics/0011027
IGARSS 2000 slides: G. Ruffini(1), J.L. Garrison(2), E. Cardellach(1), A. Rius(1), M. Armatys(3), D. Masters(3) , Inversion of GPSR
Delay-Doppler Mapping Waveforms for wind retrieval, Honolulu, July 2000.

Ruffini, G., J.L Garrison, E. Cardellach, A. Rius, M. Armatys, D. Masters,
Inversion of GPSR Delay-Doppler Mapping Waveforms for wind retrieval, transparencies of talk presented at IGARSS2000, Honolulu, July
2000.

Ruffini, G.,
GNSS-OPPSCAT WP1000 ESA Report : Remote Sensing of the Ocean by Bistatic

Radar Observations: a Review here:WP1000.ps.Z The author wishes to thank Pierluigi Silvestrin for very useful comments. Courtesy of ESA, GNSS-OPPSCAT project.

Sokolovskiy, S.V.,
Modeling and inverting radio occultation signals in the moist troposphere, Radio Science, accepted, 2001.

Sokolovskiy, S.V., Tracking tropospheric radio occultation signals from low Earth orbit, Radio Science, accepted, 2001.

Steiner, A.K., and G. Kirchengast,
Gravity wave spectra from GPS/MET occultation observations, J. Atmos. Oceanic Technology, 17, 495-503, 2000.

Steiner, A.K., G. Kirchengast, and H.-P. Ladreiter,
Inversion, error analysis, and validation of GPS/MET occultation data, Ann. Geophys., 17, 122-138, 1999.

Steiner, A.K., G. Kirchengast, U. Foelsche, L. Kornblueh, E. Manzini, and L. Bengtsson,
GNSS occultation sounding for climate monitoring, Phys. Chem. Earth (A), 26, 113-124, 2001.

Wickert, J., R. Galas, G. Beyerle, R. König, Ch. Reigber,
GPS Ground Station Data for CHAMP Radio Occultation Measurements,
Phys. and Chem. of the Earth, in press, 2001.

Wickert J., Reigber C., Beyerle G., König R., Marquardt C., Schmidt T., Grunwaldt L., Galas R., Meehan T.K, Melbourne W.G., Hocke K.,
Atmosphere sounding by GPS radio occultation: First Results from CHAMP, submitted to GRL, 2001.

Yunck TP, Hajj GA, Kursinski ER, LaBrecque JA, Lowe ST, Watkins MM, McCormick C,
AMORE: An autonomous constellation concept for atmospheric and ocean observation,
ACTA ASTRONAUTICA, 46: (2-6) 355-364 JAN-MAR 2000

Zou, X., F. Vandenberghe, B. Wang, M. E. Gorbunov, Y.-H. Kuo, S. Sokolovskiy, J. C. Chang, J. G. Sela, and R. Anthes, 1999:
A raytracing operator and its adjoint for the use of GPS/MET refraction angle measurements. J. Geoph. Res., Atmosphere, 104, 22,301-22,318.

Zou, X., B. Wang, H. Liu, R. A. Anthes, T. Matsumura, and Y.-J. Zhu, 2000:
Use of GPS/MET refraction angles in 3D variational analysis. Quart. J. Roy. Meteor. Soc., (in press), pp29.

Zou, X., H. Liu, and R. A. Anthes, 2000:
A Statistical Estimate of Forward Model Errors and Observational Errors Caused by the Calculation of Radio Occultation Bending Angle from Doppler Shift. J. A. S., (submitted), pp25.

Zuffada, C., G. A. Hajj and E. R. Kursinski (1999),
A novel approach to atmospheric profiling with a mountain-based or airborne GPS receiver, J. Geophys. Res., 104, D20, 24435-24447, October 27, 1999.

IAG SPECIAL STUDY GROUP 2.193
GRAVITY FIELD MISSIONS: CALIBRATION AND VALIDATION
(IAG SECTION II)

Report 2000
http://www.deos.tudelft.nl/~pieter/IAG.SSG/index.shtml

P.N.A.M. Visser[1] (chair) and C. Jekeli[2] (co-chair)

[1] Delft Institute for Earth-Oriented Space Research, Kluyverweg 1, 2629 HS, Delft, The Netherlands, Email: Pieter.Visser@lr.tudelft.nl
[2] Civil & Environmental Engineering and Geodetic Science, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210, Email: jekeli@osu.edu

Abstract

This report describes the activities and the achievements of the IAG Special Study Group (SSG) 2.193 "Gravity field missions: calibration and validation" in its founding year 2000. The objective of the study group is to define, evaluate and characterize possibilities and methods for calibration and validation (Cal/Val) of observations taken by gravity field missions and the derived gravity field model products. These activities have become very relevant with the launch of the German CHAMP satellite in July 2000 and the upcoming launch of GRACE in the fall of 2001, and GOCE in 2005. These missions make use of new generations of GPS receivers and new technologies like ultra-sensitive accelerometers, a gradiometer and drag-free control system. Many questions in the field of calibrating the several types of observations are open and need to be addressed. In addition, new concepts for validation derived gravity field products have to considered, designed and developed, and old concepts reviewed due to the unprecedented demands in accuracy and both spatial and temporal resolution. In 2000, several studies have been carried out to assess and review many Cal/Val possibilities. In addition, several institutes and organizations are preparing for ground and airborne campaigns to support Cal/Val activities. Finally, a joint effort with the Special Commission "SC7: Gravity Field Determination by Satellites" has resulted in a first set of simulated observations made available to the scientific community. This data set can be used for testing purposes.

1. Introduction and background

The recent launch of the German CHAMP satellite in July 2000 can be seen as the starting point of what can be defined as the "Decade of Geopotential Research", with two more missions to come: the U.S./German/French GRACE in 2001 and the European Space Agency (ESA) GOCE in 2005. These satellites make use of advanced technologies that will enable global gravity field mapping with unprecedented accuracy and resolution in space and time.

CHAMP is currently providing observations that will enable the production of the first consistent long-wavelength mean gravity field model employing a geodetic-quality GPS receiver for high-low Satellite-to-Satellite Tracking (SST) in combination with an ultra-sensitive accelerometer measuring non-conservative forces. GRACE aims at monitoring long- to medium-wavelength gravity field variations, but will also enable the mapping of the mean global gravity field with a resolution significantly surpassing existing models. To this aim GRACE will consist of two low-flyers enabling high-accuracy low-low SST tracking in combination with GPS high-low SST and accelerometers, that are even more sensitive than the one on board of CHAMP. Finally, GOCE will be the first satellite equipped with a space-borne gravity gradiometer (SGG) together with a high-quality GPS/GLONASS receiver and a drag-free control system. GOCE aims at recovering the global mean gravity field with unprecedented resolution.

The observations that will be produced by the satellites need to be properly calibrated and reduced to gravity field model products that need to be validated. The calibration entails the conversion of the raw instrument measurements into engineering units within known limits of accuracy and precision, for example cm and mm/s for the SST measurements, m/s2 for the accelerometer and Eötvös units (E or 10-9 m/s2/m) for the differential accelerometer measurements by the gradiometer. The validation concerns the conversion of these engineering quantities into geophysical units with sufficient accuracy, for example cm for geoid undulations, mgal for gravity anomalies and E for the gravity gradients.

The satellites will provide new types of observations never used before in gravity field modeling and the spectral (error) characteristics of these are not well understood. Several calibration methods need to be reviewed, assessed, enhanced and/or designed in order to retrieve these characteristics and guarantee a proper calibration. Due to the required accuracy and resolution, the same can be said about validation methods for the gravity field products.

A number of different categories of possibilities for Cal/Val are considered and subject of the activities of this SSG :

1. pre-flight calibration of the science instruments;
2. on-the-fly calibration and validation;
3. use of ground truth data;
4. comparison with existing state-of-the-art gravity field models;
5. intercomparison between gravity field products from different missions, but also based on different instruments within one mission.

2. SSG 2.193 - members

SSG 2.193 has 20 regular members, including the chair and co-chair and 18 corresponding members. The SGG started its activities in January 2000. The names of the members of the SGG and countries are given in the following list:

Chair/co-chair:
Pieter Visser (The Netherlands)/Chris Jekeli (USA)

Members:
Miguel Aguirre (The Netherlands), Dimitri Arabelos (Greece), Srinivas Bettadpur (USA), Richard Coleman (Australia), Rene Forsberg (Denmark), Cheng Huang (China), Cheinway Hwang (Taiwan), Karl-Heinz Ilk (Germany), Steve Kenyon (USA),

Gerard Kruizinga (USA), Jürgen Müller (Germany), Felix Perosanz (France), Tadahiro Sato (Japan), Martijn Smit (The Netherlands), Dru Smith (USA), Hans Suenkel (TU-Graz/Austria), Peter Schwintzer (Germany), John Wahr (USA)

Corresponding members:
Alberto Anselmi (Italy), Georges Balmino (France), Stefano Cesare (Italy), Reinhard Dietrich (Germany), Yoichi Fukuda (Japan), Johnny Johannessen (Norway), Helmut Oberndorfer (Germany), Christian LeProvost (France), John Manning (Australia), Reiner Rummel (Germany), Jens Schroeter (Germany), Avri Selig (The Netherlands), C.K. Shum (USA), Christian Tscherning (Denmark), Pierre Touboul (France), Phil Woodworth (Great-Britain), Changyin Zhao (USA), Yaozhong Zhu (China)

Most of the members have been involved very actively in the (partly) final preparation stages for CHAMP and GRACE and preparatory stages of GOCE leading to activities relevant but not under coordination of this SSG. Many of the members met informally during several international conferences and symposia in 2000, e.g. the EGS, AGU and IAG GGG2000 meetings. Many of them also contributed to national and international studies and research programs that include preparations for Cal/Val activities, and also acted as consultants to instrument manufacturers and industry in general.

Due to changes in positions and obligations, it may become necessary to revise the membership lists of this SSG.

3. Specific accomplishments

Some of the members formed part of a study team that investigated and assessed a number of Cal/Val methods and possibilities summarized in [Albertella et al., 2000; Visser et al., 2000]. Moreover, several preparatory activities took place by members in preparation of gravity field modeling from future satellite missions that might be beneficial to Cal/Val [Kusche et al., 2000; Oberndorfer et al., 2000; SID, 2000]. These activities included closed-loop simulations and full-scale modeling of satellite (sub)systems required to understand instrument and satellite behavior, helping in establishing realistic error models and procedures for Cal/Val. Also a study was conducted to assess gravity field modeling possibilities from arrays of GPS-carrying low-flying satellites [Hwang, 2000].

The launch of CHAMP and the final preparatory phase for GRACE triggered many efforts and activities related to observation data processing and quality control in general and Cal/Val of both observations and gravity field model products in general. Cal/Val possibilities and capabilities were demonstrated based on both supporting satellite observations, e.g. SLR observations in case of CHAMP, and ground support data [AGU, 2000].

Several members participated in both national and international cooperations for setting up ground and airborne (gravimetry) campaigns to support Cal/Val of the future gravity missions GRACE and GOCE. Certain members also cooperate with members of the related SSG 2.162 "Precise Orbits Using Multiple Space Techniques", chaired by Remko Scharroo, and the Working Group " Preparation of Standard Procedures for Global Gravity Field Validation", chaired by Th. Gruber, partly in the framework of Science Working Teams (e.g. JASON-1) and Precise Orbit Determination teams (e.g. ENVISAT). Finally, this SSG contributed to the generation of a data set of simulated CHAMP, GRACE and GOCE observations that was made available to the scientific community. This activity was coordinated by Special Commission SC7, chaired by Karl-Heinz Ilk.

4. Conclusions and outlook

Many activities have been undertaken by colleagues, members of this SSG in particular, related to Cal/Val of gravity field mission observations and gravity field model products. Most of the efforts were carried out in the framework of ongoing programs related to specific satellite missions, namely CHAMP, GRACE and GOCE, and not specifically in the framework of this SSG. It is foreseen that these activities will be extended and intensified in the years to come. It is the aim of this SSG to serve in the future as a means for exchanging and distributing information relevant to these efforts, and trigger cooperation between different colleagues at both national and international level. In light of this, it is intended to promote and continue cooperation with SC7, SSG 2.162 and the above mentioned Working Group.

5. References

AGU (2000), 2000 Fall Meeting, American Geophysical Union, San Fransisco, December 15-19, 2000, Published as a Supplement to EOS, Transactions, AGU, Vol. 81. No. 48, pp. F307-F311, November 28

Albertella, A., F. Migliaccio, F. Sanso, and C.C. Tscherning (2000), From Eötvös to mGal, WP4: Scientific Data Production Quality Assessment using Local Space-wise Preprocessing, Contribution to Final Report, ESA/ESTEC Contract No. 13392/98/NL/GD, 313-329, SID/DEOS, April 2000.

Hwang, C. (2000) Gravity recovery using COSMIC GPS data: application of orbital perturbation theory, Journal of Geodesy, in press

Kusche, J., K.H. Ilk, and S. Rudolph (2000) Impact of terrestrial data on future satellite gravity field solutions, Towards an Integrated Global Geodetic Observing System (IGGOS), R. Rummel, H. Drewes, W. Bosch, and H. Hornik (Eds.), IAG Symposium 120, pp. 189-192, Springer.

Oberndorfer, H., J. Müller, R. Dorobantu, C. Gerlach, R. Rummel, N. Sneeuw, R. Koop, P. Visser, P. Hoyng, A. Selig, and M. Smit (2000) Simulation of the GOCE Gravity Field Mission, Towards an Integrated Global Geodetic Observing System (IGGOS), R. Rummel, H. Drewes, W. Bosch, and H. Hornik (Eds.), IAG Symposium 120, pp. 201-204, Springer.

SID (2000), GOCE End-to-end Closed Loop Simulation, Final Report, ESTEC Contract No. 12735/98/NL/GD, SRON/IAPG/DEOS, January 2000.

Visser, P.N.A.M., R. Koop, and R. Klees (2000), From Eötvös to mGal, WP4: Scientific data production quality assessment, Contribution to Final Report, ESA/ESTEC Contract No. 13392/98/NL/GD, 157-176, SID/DEOS, April 2000.

MID-TERM REPORT SSG 2.194

"GPS WATER LEVEL MEASUREMENTS"

Chairman: Gerry Mader (USA)
Co-chairs: Doug Martin (USA) & Tilo Schöne (Germany)

Introduction

The SSG acts as a forum to exchange information about using GPS-buoys primarily for measuring the instantaneous sea level. Originally the establishment of the SSG was a request of the community to calibrate and monitor the satellite radar altimetry (RA) measurements of recent and forthcoming RA missions. Beside this, members of the group are using the techniques also for river or lake level monitoring.

The GPS buoy technique is very new and not yet well established. Different groups are using different types of buoys and concepts. Members from the US (OSU/Ohio or JPL) and the colleagues from Spain are using life-saver types of buoys. The concept is very straight forward and gives good results. Another concept is using ruggedized types of buoys, which are more suitable for harsh conditions and long-term deployment. Unfortunately this concept is very expensive. For example, for the absolute calibration campaign of ENVISAT, the European Space Agency ESA favorite a dual concept: ruggedized buoys for the long-term measurements and using life-saver types of buoys in a leapfrog scenario to get more calibration values, if the weather permits operations.

WEB Server

(http://op.gfz-potsdam.de/altimetry/SSG_buoys/index.html)

A web page was established for Special Study Group 2.194 "GPS Water Level Measurements" on the GFZ web server in Potsdam. In addition to the Terms of reference for SSG 2.194, the web site provides a list of the members with contact information, information activities and news of pending conferences and workshops, an electronic library, and an opportunity for members to submit a Technical Note on research and development activities to create a forum for discussing technical issues related to GPS water level measurements. Unfortunately, this feature has not been as active as the Chairs had hoped. The electronic library is widely used but needs updating

.

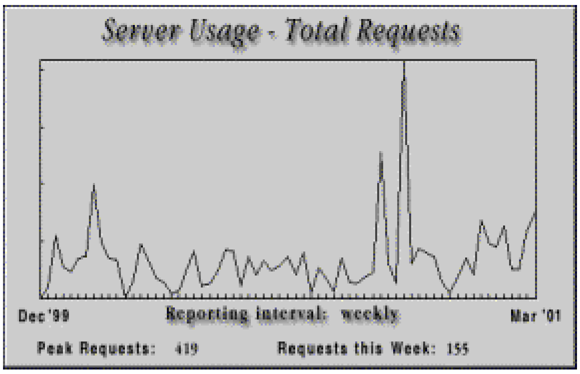


Figure1: Access Statistics

RECENT MEETINGS AND ACTIVITIES

A meeting was held at the EGS in Nice (April 2000). Here, mostly colleagues from Europe attended the meeting. In total 5 presentations were given (for the full report, see the SSG WEB-page: http://op.gfz-potsdam.de/altimetry/SSG_buoys/ssg_meeting_nice.html).

1Tilo Schöne reported about the planned GPS-buoy activities at GFZ. Within a larger project, which now founded, a ruggedized buoy will be deployed in the North Sea. A triple crossover is selected, for which a crossover of ERS-2/ENVISAT intersects with a GFO and Topex/JASON-1 track. The lifetime of the buoy will be several years in order to monitor a bias and drift of the respective radar altimeter. The buoy will be equipped with additional sensors (e.g. wind speed, air pressure, etc.) and may serve as a basis for additional studies. The internal accelerometers and the wind speed sensor will be used for calibrating the respective altimeter measurements. To account for the sea surface slope, several water level recorders will be deployed in the surroundings.

1Etienne Favey reported about a project at lake Lac Leman. A special buoy design (Plexiglas ball, which protects batteries, receiver and antenna) was deployed and the results were compared to a airborne laser profiling. Three time series were acquired, which have a good agreement with the laser profiles. A second campaign was carried out in Greece, using the same setup. A third campaign was to profile the river Rhine. A Trimble 4600 LS was used, which is water proof and can be put to water without protection.

1Juan José Martinez-Benjamin reported about a campaign for TOPEX (TP239, 18.3.1999). The campaign (near Begur Cape, Llafrance) has successfully used 2 GPS reference stations, 2 tide gauges and compared it to a lightweight buoy. A similar campaign will repeated in near future.

1Antonio Rius reported about the GRAC campaign. 3 lightweight buoys were deployed, keeping the distance between the buoys as constant as possible. GIPSY was used for GPS processing, problems occurred with the tropospheric influence to the GPS data.

1C.K. Shum reported about campaigns at Lake Michigan for GFO-1 and TOPEX calibration.

REPORTS OF THE MEMBERS

The Ohio State University (OSU), College of Engineering

The OSU floater buoy consists of a choke ring mounted on a standard 30" life ring with a plexiglas dome for protection. Over the past several years the buoy has been used to look at problems ranging from altimeter calibration to mapping regional sea level. It has also been used in conjunction with tide gauge and altimeter data to collect data to look at problems associated with sea level mapping, positioning of tide gauges, waves, combining GPS measurements with bathymetry and other traditional hydrographic measurements, combining GPS water level measurements with numerical models, and studying GPS sampling requirements. Much of this data is still being analyzed and will hopefully be useful in designing future experiments. This summer it is hoped to return to Lake Michigan to look at regional water level mapping combining GPS, tide gauge, and altimetry. It is planned to position tide gauges along the coast of the Gulf of Mexico for use with calibrating aircraft altimetric measurements.

National Oceanic and Atmospheric Administration, National Ocean Service (NOS)

Precise orbits, improved antenna and receiver design, antenna phase center models, and more robust kinematic software all contribute to obtaining centimeter-level precision in the vertical component of GPS measurements from floating platforms (buoys, barges, or ships). This new high level of precision makes it possible to obtain GPS-derived water level time series suitable for the determination of tidal datums to support hydrographic surveys and maintenance dredging projects, mapping sea surface topography, satellite altimeter calibration, and the determination of boundary conditions for numerical models and model verification.

NOS, in general, relies on "buoys of opportunity" to conduct GPS buoy applied research activities. Partnering primarily with the US Coast Guard (USCG) and at least one time with the National Data Buoy Center. The USCG buoys were existing navigation buoys located in the Upper Chesapeake Bay, San Francisco Bay, and Lake Huron. NOS used the USCG batteries and solar panels for power and installed a GPS chokering antenna, a radio antenna and a radio modem on the buoys to retrieve the GPS data in real-time. There was no attempt obtain an absolute GPS-derived water level time series for determining tidal datums for harmonic constituents during the Upper Chesapeake Bay and Lake Huron deployments. The objectives of these deployments were to investigate power consumption, communication links, and baseline lengths for future projects. The antenna height relative to the plane of floatation of the San Francisco buoy was measured and the vertical component of the GPS kinematic solutions was adjusted to plane of floatation of the buoy and averaged into a 6 minute GPS-derived water level height. These data were subsequently processed to provide tidal datums and harmonic constituents for the San Francisco buoy.

NOS, in partnership with the USCG, is currently designing a new GPS Buoy System specifically to improve the boundary conditions for the NOS Coastal Forecast System and conduct model verification. The buoy will be deployed about 20 km off the East Coast of the US. In addition to the GPS and radio antenna, other components will be a tilt meter, a water level measurement system, and a micro controller to integrate the GPS data and ancillary sensor data into the radio transmission to shore.
NOS also working on the development of a small GPS buoy system to support NOS hydrographic survey and other missions in the US estuarine and coastal waters. The buoy will be able to measure water levels using precise DGPS to an accuracy of within 5 cm or better. Relative buoy motions should be properly compensated and sampling rate should be adequate to obtain the true averaged water level without aliasing. Averaged water level data are typically recorded at 6-minute intervals. The buoy data measuring system will be self-contained and operated up to 3 months with remote access of data from buoy via line-of-sight radio at convenient time intervals. This buoy system will be handled from a small survey vessel of approximately10 m length.

Navy Oceanographic Office

Summary of GPS Buoy Exercises for the Northern Gulf of Mexico Littoral Initiative (NGLI).

The Northern Gulf of Mexico Littoral Initiative (NGLI) was established to provide reliable, timely meteorological and oceanographic mesoscale models of the Gulf of Mexico littoral region through development and operation of a sustainable comprehensive nowcasting/forecasting system. *In situ* observations and remote sensing measurements such as turbidity, currents, sea surface height, temperature, salinity and optics will be collected for model validation via an extensive data collection network. The NGLI system is designed to sustain high-volume data availability, providing rapid access to information by a broad range of users.

The goal of NGLI is to become a sustained cooperative effort among federal and state agencies who will use *in situ* observations, remote sensing, and models to monitor and forecast ocean circulation, waves, sediment transport, and water properties. It is sponsored by the Department of Navy (CNMOC) and the Environmental Protection Agency/Gulf of Mexico Program (EPA/GOMP). The Naval Oceanographic Office (NAVOCEANO) has established a test bed in the Mississippi Bight, which is bordered on the west by the Mississippi River outflow and on the east by Mobile Bay. NGLI will initially support demonstrations in the littoral regions bordering the Northern Gulf of Mexico coastline, however, these demonstrations will ultimately be used to test, improve and validate models and capabilities in oceanographic regions likely to be encountered in overseas Navy operations. The NGLI can also provide the Army Corps of Engineers the capability to manage sediment transport and civil authorities the means to consider habitat loss and environmental impacts from increased pollution caused by amplified population, hotel and casino development, and industry.

One of the primary shallow-water measurements required by the NGLI is sea surface elevation. Present day applications require *in situ* measurements of these quantities either by themselves or in conjunction with remotely sensed measurements. In particular, the increased use of ocean forecasting models by NAVOCEANO and numerical forecasting centers requires these measurement data in real-time or near real-time, either for boundary condition specification or data assimilation.

NGLI will develop a communication buoy as a platform for DGPS water level determination on satellite altimeter ground tracks. This buoy will be capable of supporting a GPS receiver for differential (DGPS) water level determination. GPS measurements will, in principle, aid in supporting forecasting of multiple circulation processes across the shelf. GPS measurements assist in enabling the buoy platform to support forecasting of multiple circulation processes across the shelf.

This effort will be presented in three phases:

The goal of Phase 1 is to determine the processing, timing, and communication requirements for measuring water level using a buoy. A NAVO/WHOI buoy will be outfitted with an RTK Dual Frequency GPS receiver, a suite of buoy motion sensors, and a data acquisition/storage system. A "Reference Station" will record RTK GPS data simultaneously. This reference station data will be used to process the buoy GPS data and simulate "on-the-fly" RTK measurements of the GPS antenna position.

The RTK corrected buoy antenna position will then be corrected for short-term, wave induced, buoy motion. The outcome will be a clearer understanding of the requirements for computing centimeter level antenna positions in real time, correcting the buoy antenna position for wave motion, and for supporting the RTK link needed between a reference station GPS and the buoy mounted RTK "rover" GPS.

The goal of Phase 2 is to prototype the buoy processing required to support "on-board" real time RTK processing of the antenna position and correct it for wave induced buoy motion. Through this effort "on board" algorithms for the buoy system will be developed. Once the processor and buoy sensor systems are developed sufficiently to support the prototype algorithms, a buoy system will be integrated to support short term and local testing. This will include integration of a communications link allowing the buoy RTK GPS to receive real time RTK corrections from the reference station. The outcome of this phase will be prototype buoy hardware and software for real time resolution of RTK GPS and wave motion and empirical data for comparison to known water level data for direct comparison and for optimizing buoy systems in preparation for offshore testing

The goal of Phase 3 is to deploy a buoy capable of measuring and reporting water level measurements. The expected deployment site is in Mississippi Sound between 88.48 W 29.56 N and -88.62 W 29.84 N, which are the GFO satellite track positions. The system will operate at-sea for 6-months, with the data being received through the communications link.

GeoForschungsZentrum Potsdam (GFZ)

Activities at GFZ are still in the development stage. The GFZ buoy program is in support of the large scale program SEAL of the German Helmholtz Association aiming at an integrated approach for quantifying sea level on various space and time scales. The project is based on new observing techniques and recent high resolution models of the processes governing the system ocean-ice-earth.

A ruggedized GPS equipped buoy will be developed and deployed in the North Sea. A toroid buoy was already selected and tested. This surface rider type of buoy will not only permit the observation of the instantaneous sea level during the satellite pass, but also an estimation of the significant wave height will be performed. In addition, the buoy will be equipped with supplementary sensors, like wind speed, humidity and air pressure sensors, allowing a broader use for calibration, e.g. of the backscatter / wind speed relationship. Meteo data may also be used by German Authorities in their forcasting models. The buoy will be deployed at a crossover location of ERS-2 (and ENVISAT). A nearby crossover with TOPEX and GFO (less than 5 km) makes this site even more suitable for multi-mission calibration. In addition, up to three bottom mounted tide gauges will be deployed to account for the sea surface slope between the crossovers. The lifetime of the buoy is expected to be several years. Based on this experience, a second buoy will be deployed in cooperation with OSU.

In the next month the integration will be done and first in-situ test with the fully equipped buoy will be starting right before the start of ENVISAT. In the first test phase high rate data of the GPS and the buoy motion sensors will be aquired. The data set will be tested in order to find a optimal sampling scenario.

Universitat Politècnica de Catalunya (Spain)

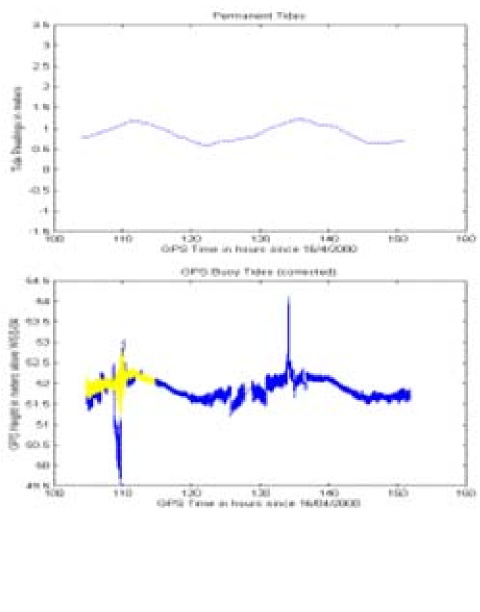
Experience in calibration campaigns has been obtained in the Cape of Begur area, NE Spain.The first campaign made on March 1999 consisted of two reference stations on shore and two GPS buoys underneath the TOPEX/POSEIDON groundtrack to get the instantaneous sea level. The GPS buoys were designed at the Cartographic Institute of Catalonia using GPS antennas placed inside floats of toroidal form following a design from the University of Colorado. Data from L'Estartit tide gauge has been used as data from two specific tidegauges, float and pressure, under supervision from Clima Maritimo-Puertos del Estado. It was performed the absolute calibration of Topex altimeter Side B.

A second campaign with an advanced GPS buoy has been made on July 2000 with an estimation of the altimeter bias that hints at the level of accuracy that might be achievable for JASON-1 and ENVISAT.One other objective has been to GPS map the Mean Sea Surface (MSS) and to lay the foundation for a general indirect calibration site which allows to calibrate altimeters from different satellites crossing the area. These and future campaigns could contribute to calibration of emerging global sea-level records from TOPEX/POSEIDON and its successors.

These campaigns and their data processing have been made under a CICYT (Comision Interministerial de Ciencia y Tecnologia) National Coordinated R+D Project in Space Research, ref: ESP97-1816-CO4, that includes several govermental/research Institutes and Universities from Spain with International participation of France and the United States.

GPS Buoy Activities in Indonesia

(Imam Mudita wrote): Starting from the research topic I have chosen for my doctoral study program, GPS observation for sea level measurement on a floating buoy is being investigated. During the investigation period, a GPS buoy sea level measurements were taken on an in-house project campaign, as part of the UPT Baruna Jaya research activities, in April in the Bay of Jakarta. Figure 1 shows the buoy while collecting data during the campaign.



The data set were 15 days of continuous GPS observation in 0.5 seconds interval. Coincident tides data during the campaign from a near tide gauges station of PERUM PELABUHAN II were also taken. The result shows that GPS could be used as a tool for sea level measurement if a careful correction applied in the data processing (see Figure 2. in yellow color)

Currently, we are trying to integrate GPS measurement with Motion Reference Unit (MRU-5) as attitude sensor of the GPS antenna movement. We will deploy this system in April 2001.

For the next stage, we are going to make the system in a real time mode of observation with a reliable radio data communication and a more sophisticated buoy construction.

Instituto de Ciencias del Espacio (CSIC), Institut d'Estudis Espacials de Catalunya (IEEC)

The recent GPS buoy acitivies carried out at the Institute for the Space Studies of Catalonia (IEEC) are the "GPS Radar Altimeter Calibration" campaigns GRAC99 and GRAC2000. They had been conducted in June 1999 and September 2000 on board a research vessel to follow different Radar Altimeter (RA) tracks where to perform GPS buoy and oceanographic measurements. The combined GPS and oceanographic measurements were though to calibrate the RA sea level estimates with the emphasis on the geostrophic currents observation application.

In GRAC99, the GPS observations were gathered through a three-buoy structure, specially designed for the campaign. Four time series of GPS buoy measurements were conduceted under the ERS-1, ERS-2 and TOPEX/POSEIDON tracks when these RA were over-flying the area. The description of this campaign and the results are published in [1].

In GRAC2000, a new buoy structure was constructed. It was a two-buoy system thought to allow for a double checking approach of the solution: on one hand the sea level form both antennas (after phase center corrections) should be the same. On the other hand, the distance between the buoys was constant, and its value should be recovered from the positioning of the antennas.

In terms of data processing, the main characteristic of such GRAC campaigns were the distance of the GPS observation from the Reference Ground Stations, more than 80 km. Dedicated strategies to accurately solve the vertical position were developed. GRAC99 yielded a publication, while there is a internal-project report about GRAC2000:

[1] The Use of GPS buoys in the determination of oceanic variables, Cardellach, E., D.Behrend, G.Ruffini, A.Rius, Earth Planets and Space, Vol.52, pp 1113-1116, 2000.

[2] GRAC 2000 GPS Buoy Report, included in the GRAC Report, Cardellach, E., April 2001. Contact Jordi Font, jfont@icm.csic.es for GRAC reports.

SEA LEVEL STUDIES IN TASMANIA USING GPS BUOYS

Christopher Watson (CW), Richard Coleman (RC), Tony Sprent (AS)
Centre for Spatial Information Science, University of Tasmania
John Hunter (JH), John Church (JC), il White (NW)
Antarctic CRC, University of Tasmania

Sea Level work (CW, RC, JH)

The application of GPS to localised oceanographic and geodetic experiments has been investigated with the design and construction of a series of GPS buoys. The buoys have been deployed at Port Arthur on Tasmania's southeast coast as part of a long term sea level study. The GPS buoys have be used in the determination of a precise marine geoid and they have also been instrumental in understanding local oceanographic phenomena (seiching) acting within the Port Arthur bay. A 1-2 day experiment was undertaken using two GPS buoys, 6 pressure sensors and the Port Arthur tide gauge as a way of verifying the performance of the GPS buoys.

Buoy Design and Operation (CW, AS, RC)

The first buoy system was constructed for the Port Arthur experiment by Chris Watson (Watson, 1999) and the buoys were simple 'wave rider' designs similar to those developed by Kelecy et al. (1994) and Key et al. (1997). The buoys were designed to only support the GPS antenna and hence needed to operate close to shore or be tethered to a boat where the GPS receiver is stored and operated. The floating platform consisted of a section cut from a heavy-duty plastic drum, which was braced and partially filled with polystyrene foam for buoyancy. Leica AT202+GP antennas and custom-made perspex antenna domes were fitted to the buoys. The buoy design is shown in Figure 1.

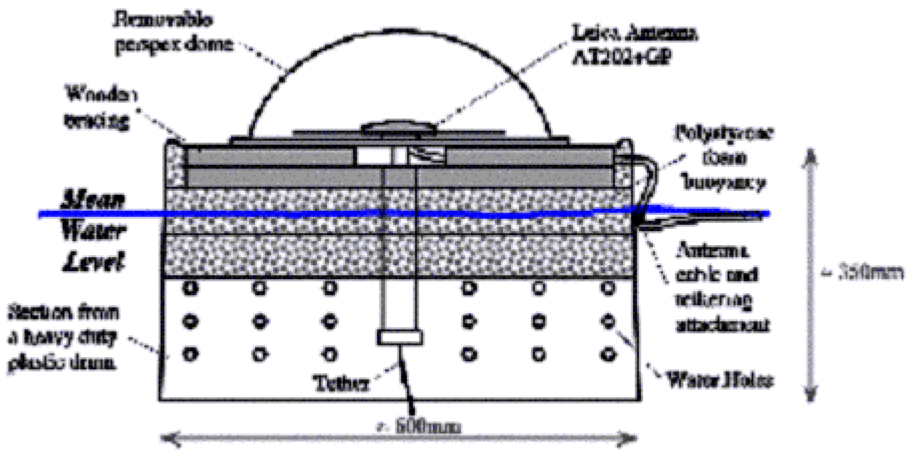


Figure 1. The prototype buoy design

The buoys performed well, however were limited due to their restriction of being operated close to shore or from a boat. The design was also quite susceptible to small surface wave activity.

Following the success of the prototype buoy, a more ruggedised version was designed and constructed by Tony Sprent. The buoys were utilised for further experiments at the Port Arthur site and will be used for satellite altimeter verification experiments at the Burnie verification site (see later). As it was aimed to measure the instantaneous sea surface at high sampling frequencies, a wave-rider style of buoy was still required. This will allow measurement of wave spectra and current velocity with the ability to filter the results to obtain the mean sea surface.

The newer buoy system was designed as a self-contained unit, with battery power, a GPS receiver and a choke ring antenna. This removes the previous restriction of operating the GPS from a tethered boat or from land. The design remains readily transportable for use in local experiments, whilst rugged enough for ocean based experiments. The buoy consists of a central water tight, cylindrical vessel which contains all the GPS equipment and batteries. All pieces of hardware inside the vessel are centrally constrained to ensure the overall construction is balanced about the central vertical axis. A removable stainless steel frame with three Ø300mm polystyrene floats is used to support the GPS equipment. A plan view of the buoy design with the antenna dome removed is shown in Figure 2.

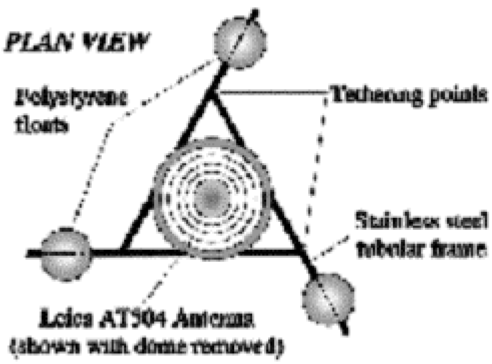


Figure 2. Plan view of the latest buoy design.

The overall radius of the buoy is 850mm. The larger weight and lower centre of mass prevents any high frequency oscillation caused by small wind induced surface waves. The buoy is shown in section in Figure 3.

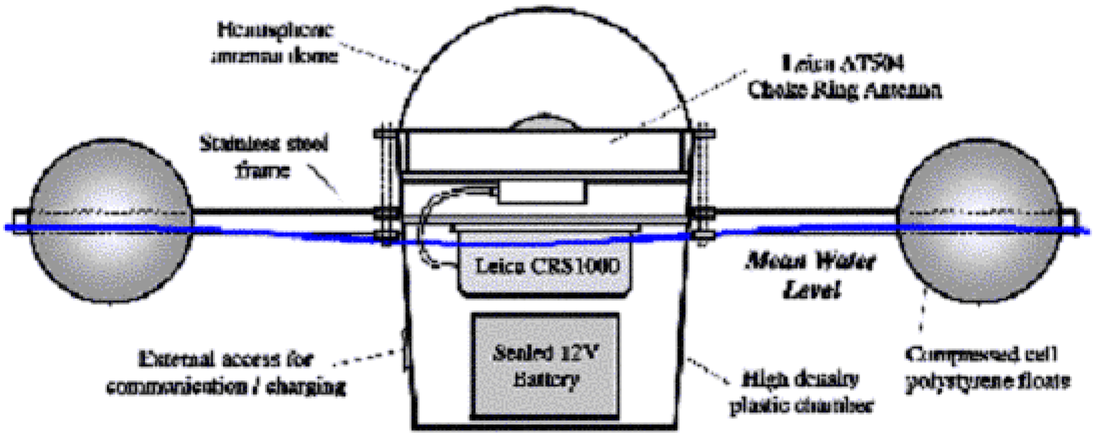


Figure 3. The latest buoy design for the Tasmanian experiments.

The buoys have been designed to accommodate Leica CRS1000 receivers and choke ring antennas (AT504). The dome is custom made out of 3mm 'Sunloid KD' which is an acrylic polyvinyl chloride material. The receivers have 64 Mb of internal memory and allow sampling rates of up to 10 Hz allowing for most experiment scenarios.

Altimeter Calibration (JC, RC, NW, CW)

The buoys will also be deployed as part of the Jason-1 and ENVISAT altimeter calibration activities - as well as cross-calibration with T/P and ERS-2. Both GPS buoys will be utilised off the north west coast of Tasmania, in Bass Strait as part of work towards a southern hemisphere altimeter verification experiment (see White et al., 1994). The two buoys will be positioned between 12 and 40 km from three static GPS reference sites and an acoustic tide gauge site in Burnie harbour. The position of the antenna phase centre relative to the mean level surrounding the buoy is of fundamental importance for this experiment - requirement is for accuracies at the 1 cm level. The effect of the plastic antenna radomes needs to be further investigated as absolute height is required. Accuracy of kinematic processing over medium to long baselines remains the principal difficulty for these applications. Software development has been started which is aimed at developing algorithms specifically tuned to processing on a floating platform.

Kelecy, T., Born, G., Parke, M. and Rocken, C. (1994). 'Precise mean sea level measurements using the Global Positioning System', Journal of Geophysical Research, 99(C4), **pp. 7951-7959**.

Key, K., Parke, M. and Born, G. (1998). 'Mapping the Sea Surface Using a GPS Buoy', Marine Geodesy, 21, **pp. 67-79**.

Watson, C. (1999). 'A Contribution to Absolute Sea Level in Tasmania', Thesis for Bachelor of Surveying with Honours, Centre for Spaital Information Science (CenSIS), University of Tasmania, Hobart, **p. 197**.

White, N., Coleman, R., Church, J., Morgan, P. and Walker, S. (1994). 'A southern hemisphere verification for the TOPEX/POSEIDON satellite altimeter mission', Journal of Geophysical Research, 99(C12), pp. 24505-24516.

Publications by the Members

Cardellach, E., D. Behrend, G. Ruffini, A. Rius: The Use of GPS buoys in the determination of oceanic variables, Earth Planets and Space, Vol.52, pp 1113-1116, 2000.

Cardellach, E.: GRAC 2000 GPS Buoy Report, included in the GRAC Report, Cardellach, E., April 2001. Contact Jordi Font, jfont@icm.csic.es for GRAC reports.

Cheng, K., C.K. Shum, M. Parke, K. Snow, S.C. Han, J.J. Benjamin, D. Martin, G. Mader: "GPS-Buoy water level instrument:Applications for radar altimeter calibration", oral presentation, GGG2000, Canada, 2000.

Colombo, O.L., A.G. Evans, M.I. Vigo, J.M. Ferrandiz, J.J. Benjamin: "Long-baseline (>1000km), sub-decimeter kinematic positioning of buoys at sea, with potential application to deep-sea studies", oral presentation, ION GPS 2000, Salt Lake City, Utah, USA, 2000.

Kruizinga, G.L.H., B. Haines, J.J. Martinez-Benjamin, M. Martinez-Garcia, J. Talaya, M.A. Ortiz, B. Perez: "The CATALA experiment, preliminary results of ALT-B calibration using GPS buoys off the Catalonian Coast (Spain)", ALT-B Calibration Workshop, Goddard Space Flight Center, Greenbelt, Maryland, USA, 1999.

Martinez-Benjamin, J.J., M. Martinez-Garcia, G.L.H. Kruizinga, B. Haines, M.A. Ortiz, J. Talaya, B. Perez, E. Alvarez, J. Garate, J.M. Davila, J.M. Ferrandiz, M.I. Vigo-Aguiar: "The CATALA campaigns: indirect calibration technique for ENVISAT altimeter calibration", ERS-ENVISAT SYMPOSIUM, Gothenburg, Sweden, 2000.

Martinez-Benjamin, J.J., M. Martinez-Garcia, G.L.H. Kruizinga, B. Haines, M. Ortiz, J. Talaya, J. Garate, J. Davila, J. Ferrandiz, M. Vigo-Aguiar, B. Perez, E. Alvarez: "The CATALA Experiment: Absolute Calibration of TOPEX Altimeter-B using GPS buoys in the NW-Mediterranena sea", POSTER, The Ocean Observing System for Climate, OCEANOBS 99, St Raphael, France, 1999.

Martinez-Benjamin, J.J., M. Martinez-Garcia, M.A. Ortiz, J. Talaya, G.L.H. Kruizinga, B. Haines, J. Garate, M. Davila, JM. Ferrandiz, M.I. Vigo-Aguiar, B. Perez, E. Alvarez, O. Colombo, B. Chao, CK. Shum: "The TOPEX/POSEIDON CATALA Altimeter Calibration Campaign", POSTER, American Geophysical Union, AGU-2000 Spring meeting, Washington, USA, 2000.

Martinez-Benjamin, J.J., M. Martinez-Garcia, M.A. Ortiz: "Validation of TOPEX/POSEIDON GDR by independent techniques", POSTER, XXVI General Assembly of the European Geophysical Society (EGS), Nice, France, 2001.

Martinez-Benjamin, J.J., M. Martinez-Garcia, M. Ortiz, J. Talaya, J.Garate, J. Davila, J. Ferrandiz, M. Vigo-Aguiar, B. Perez, E. Alvarez: "The TOPEX/POSEIDON and JASON-1 Calibration Campaigns in the Cape of Begur and Ibiza Island Regions", POSTER, TOPEX/POSEIDON/Jason-1 Science Working Team Meeting, Miami, USA, 2000.

Martinez-Garcia, M., G.L.H. Kruizinga, B. Haines, J.J. Martinez-Benjamin, M.A. Ortiz, J. Talaya, J. Garate, M. Davila: "PRELIMINARY RESULTS OF THE GPS BUOYS DATA PROCESSING IN THE NORTH WESTERN MEDITERRANEAN SEA", POSTER, International Union of Geodesy and Geophysiscs, IUGG, 18-30 July 1999, Birmingham.

Martinez-Garcia, M., G.L.H. Kruizinga, J.J. Martinez-Benjamin, M.A. Ortiz, J. Talaya: "Preliminary experience and technical aspects on the JASON-1 validation and calibration radar altimeter by using GPS buoys", oral presentation, XXV General Assembly of the European Geophysical Society (EGS), Nice, France, 2000.

Martinez-Garcia, M., J.J. Martinez-Benjamin, M.A. Ortiz: "Analysis and Strategies applied to the GPS buoys data for the TOPEX ALT-B Absolute Calibration in the NW-Mediterranean", POSTER, TOPEX/POSEIDON/Jason-1 Science Working Team Meeting, Miami, USA, 2000.

Martinez-Garcia, M., J.J. Martinez-Benjamin, M.A. Ortiz: "Strategies with GPS for the navigation of buoys", POSTER, GNSS-2001, Sevilla, Spain, 2001.

Martinez-Garcia, M., J.J. Martinez-Benjamin, M.A. Ortiz-Castellon: "Calibration techniques applied to satellite altimeter", oral presentation, XXVI General Assembly of the European Geophysical Society (EGS), Nice, France, 2001.

Ortiz, M.A., M. Martinez-Garcia, J.J. Martinez-Benjamin: "GPS buoys for altimeter calibration campaigns", POSTER, GNSS-2001, Sevilla, Spain, 2001.

Watson, C. (1999). "A Contribution to Absolute Sea Level in Tasmania", Thesis for Bachelor of Surveying with Honours, Centre for Spaital Information Science (CenSIS), University of Tasmania, Hobart, p. 197.

INTERNATIONAL GPS SERVICE

This report provides an outline of the IGS activities and interim progress report to the International Association of Geodesy for the year 2001. The past two years have been exciting for the IGS involving many new activities and applications in addition to the continued support to the scientific community through GPS data and data products. The current status and availability of IGS products is listed in the table below.

Key Activities in 2000-2001

The main focus in has been promoting the use of IGS data and products as the accepted international standard and expanded outreach to developing countries. This is evidenced by the IGS tutorial development, exhibits at conference and workshop venues and developing the IGS User Forums. A main activity of the IGS Governing Board (GB) since late 1999 is a strategic planning effort. The motion to develop a plan was approved at the June 2000 meeting of the GB and resulted in the establishment of a strategic planning committee. This committee worked with an experienced facilitator retained by the Central Bureau (CB). This committee followed a planning process and prepared necessary information for the full retreat of the GB in December, 2000. This was a very worthwhile effort and the final documents will be complete by June of 2001. Issues addressed by the GB include a review of the IGS Mission, IGS long-term goals and the key strategic actions to accomplish these goals. It is expected that there will be consensus to obtain an official recommitment to the IGS from participating organizations and to attempt to gain stable support from sponsoring agencies. The IGS seeks IAG support of the IGS plan and its implementation.

Increasing involvement in realizing a modern continental geodetic reference system for Africa, 'AFREF'. This will be of great benefit to the African nations and may enable greater geodetic GPS densification of this vast area, The most effective way to achieve such continental reference system that is robust and globally consistent is through GPS technology and the economics of GPS make this the technique of choice for sustainable geodetic operations within Africa. This activity is advocated by the IAG, IAG Commissions X and the IGS.

Chair of the IGS GB since 1994, Prof. Gerhard Beutler of the University of Bern, Switzerland was succeeded by Prof. Christoph Reigber of theGeoForschunZentrum, Postdam Germany at the December 1999 meeting. In 1999 the IGS Governing Board also established the position of the IGS Reference Frame Coordinator, filled by Dr. Remi Ferland of the Natural Resources of Canada. 1999 saw the retirement of Governing Board members who had each been instrumental in the early orgnization of the IGS and its rapid growth: Prof. Yehuda Bock, Dr. Jan Kouba, IGS Analysis Coordinator from 1993 - 1998, Dr. Bill Melbourne, and Prof. Ivan Mueller. Mueller and Melbourne were involved in the IGS planning Committee, led by Mueller and established in 1990.

IGS Working Groups, Pilot Projects

Applications of GPS extend beyond the fundamental processes of the IGS. These activities which are very reliant on the IGS for realization, but are not yet a core compnent of the IGS are organized into working groups, pilot projects or committees.

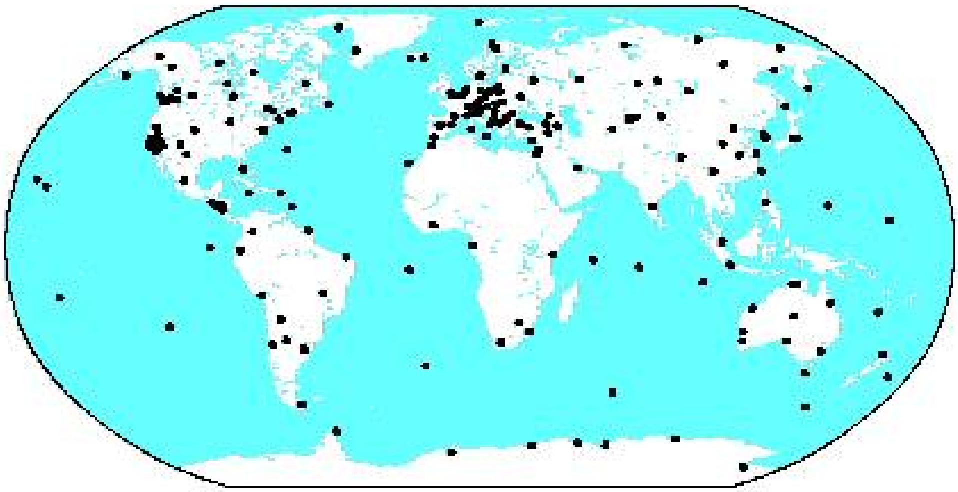
These currently include:

- Precise Time and Frequency Pilot Project, joint with the BIPM
- IGS Densification of the Reference Frame Working Group
- Ionosphere Working Group
- Troposphere Working Group
- Low Earth Orbiter Pilot Project International GLONASS Pilot Project
- Real-Time Working Group
- Tide Gauge Benchmark Monitoring Project (for sea-level and altimeter calibration)

More details on each of these activities can be found in the Annual and Technical Report Series of the IGS, and workshop proceedings, all available at the IGS website or through the IGS Central Bureau.

IGS Network

- The network of the IGS grows each year, and contributing organizations also increase. The IGS has over 250 stations within the cooperative network and lists over 100 participating organizations. However distribution and geographic coverage of the stations remain sub-optimal, especially in remote regions of the world, oceanic areas, and developing countries.



During the past two years, the International GLONASS Pilot Project (IGLOS-PP) has been developing and is now officially recognized within the IGS adding an additional class of station and processes to the IGS infrastructure. GLONASS is being moved towards full integration into the GPS-based IGS. This is a key extension of the IGS and establishes a precedent that the service is poised to unify observations and product development of similar satellite microwave techniques, including the future Galileo & potential GNSS.

Another growing strength in IGS is utilizing the increasing number of stations providing hourly uploads of data files to the IGS data centers. Now approximately 60 stations provide data hourly to the data centers, permitting the IGS analysis centers to processing observations more rapidly and to successfully move from daily orbit generation to sub-daily generation. This is currently twice daily and moving towards 3 to 4 times daily in the near future. This is vital for providing more rapid products to users, and decreasing the time to access ultrarapid orbits. This more rapid turn around results in less aging of the predicts, and thus the available precision now approaches 25 cm 3-dimensional weighted rms. level (3d-wrms) a great improvement over daily products for time critical applications. In any case, IGS Final orbits remain consistent at the 5cm 3d-wrms..

Outreach and Exhibit

The Central Bureau completed design of an exhibit booth in early 2000 for displaying and providing information to attendees of scientific forums and conferences. All publications of the IGS are displayed. Publication requests are available at each venue and accessible on the web as well. The new IGS exhibit is also designed to be extremely portable so that it can be shipped to other IGS colleagues who can host the exhibit at various venues. During the past two years the exhibit was displayed at the 28th International Symposium on Remote Sensing of the Environment (ISRSE) in Capetown, South Africa; INTERGEO Conference in Berlin, Germany; at the GPS Annual Conference of the Institute of Navigation (ION) in Salt Lake City, USA; AGU 2000 Fall meeting in San Francisco, USA, CONSAS, South Africa, and the EGS in Nice, March 2001.

In 1999 and 2000 a great deal of time and effort were devoted to developing a tutorial of the IGS describing in details all components. A number of people were responsible for contributing to the contents of this tutorial. The tutorial was divided into the following sections reflecting the various components of the IGS:

- Why IGS?
- Introduction to Basics of GPS
- IGS Overview — Organization and Resources
- Network, GPS Stations and Data Flow
- Data Centers, Accessing Data Products
- Product Generation, Quality and Applications
- Reference Frame Issues
- Discussion

It requires nearly six hours to provide the tutorial in present scope. Evaluations indicate that this has been very well received and we intend to keep it current and further develop the contents. Two areas yet to be developed include a section on ‘How to Use IGS Products’ and additional subsections on the key applications — the focus of the working groups and pilot project in the IGS (atmospherics, ionosphere, time transfer, sea level, etc.).

IGS Meetings and Workshops 2000-2001

July 2000: IGS Network Workshop, Oslo, Norway was organized joint with COST Action 716, ‘Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications’ hosted locally by Statens Kartverk, the Norwegian Mapping Authority. This was a key workshop to review state of IGS infrastructure and plan future actions based on directions of the IGS analysis requirements and projects.

September 2000: IGS Analysis Center Workshop US Naval Observatory, Washington DC, first two days devoted to aspects of the IGS Pilot Project on Precise Time and Frequency joint with BIPM. Analysis workshop devoted to the technical details of maintaining state of the art products. Also September, ION GPS 2000 Salt Lake City, CB hosted an Exhibit, and a Users Forum .

December 2000: Organized IGS Strategic Planning session and Governing Board meeting in Napa Valley, California, hosted IGS Exhibit and other meetings at the AGU in San Francisco.

February 2001: Low Earth Orbiter Pilot Project Organization Workshop, held at GeoForschungsZentrum, Potsdam, Germany.

October 2001: "Towards Real Time", IGS Workshop to be held in Ottawa Canada,

October 15-18, hosted by Natural Resources of Canada.

IGS Product Table [GPS Broadcast values included for comparison]				
	Latency	Updates	Sample Interval	Accuracy
GPS Satellite Ephemerides				
Broadcast	real time	--	daily	~260 cm
Predicted (Ultra-Rapid)	real time	twice daily	15 min	~25 cm
Rapid	17 hours	daily	15 min	5 cm
Final	~13 days	weekly	15 min	<5 cm
	(Note: IGS accuracy limit based on comparisons with independent laser ranging results. The precision of Rapid and Final orbits is better.)			
GLONASS Satellite Ephemerides				
Final	~4 weeks	weekly	15 min	30 cm

GPS Satellite & Tracking Station Clocks				
Broadcast	real time	--	daily	~7 ns
Predicted (Ultra-Rapid)	real time	twice daily	15 min	~5 ns
Rapid	17 hours	daily	5 min	0.2 ns
Final	~13 days	weekly	5 min	0.1 ns
	(Note: The precision of IGS Rapid and Final clocks are shown above, relative to the IGS timescale, which is linearly aligned to GPS time in one-day segments. The Broadcast and Ultrarapid clocks refer only to the GPS satellites.)			
Geocentric Coordinates of IGS Tracking Stations (>130 sites)				
Final horizontal positions	12 days	weekly	weekly	3 mm
Final vertical positions	12 days	weekly	weekly	6 mm
Final horizontal velocities	12 days	weekly	weekly	2 mm/yr
Final vertical velocities	12 days	weekly	weekly	3 mm/yr
Earth Rotation Parameters				
Rapid polar motion	17 hours	daily	daily	0.2 mas
Final polar motion	~13 days	weekly	daily	0.1 mas
Rapid pm rates	17 hours	daily	daily	0.4 mas/d
Final pm rates	~13 days	weekly	daily	0.2 mas/d
Rapid length-of-day	17 hours	daily	daily	0.030 ms
Final length-of-day	~13 days	weekly	daily	0.020 ms
	(Note: The IGS uses VLBI results to calibrate for the long-term behavior of LOD estimates.)			
Atmospheric Parameters				
Final tropospheric	< 4 weeks	weekly	2 hours	4 mm zenith path delay
Ionospheric TEC grid	(under development)			

Related Links
http://igscb.jpl.nasa.gov/
http://www.cx.unibe.ch/aiub/acc.html
http://igscb.jpl.nasa.gov/organization/centers.html
http://igscb.jpl.nasa.gov/overview/links.html

INTERNATIONAL LASER RANGING SERVICE (ILRS)

J. J. Degnan[1] and M. R. Pearlman[2]

[1] NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

[2]Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA USA 02138, USA

CONTRIBUTIONS OF THE ILRS

The ILRS collects, merges, analyzes, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets of sufficient accuracy to satisfy the objectives of a wide range of scientific, engineering, and operational applications and experimentation. The basic observable is the precise time-of-flight of an ultrashort laser pulse to and from a satellite, corrected for atmospheric delays. These data sets are used by the ILRS to generate a number of fundamental data products, including: centimeter accuracy satellite ephemerides, Earth orientation parameters, three-dimensional coordinates and velocities of the ILRS tracking stations; time-varying geocenter coordinates, static and time-varying coefficients of the Earth's gravity field, fundamental physical constants, lunar ephemerides and librations, and lunar orientation parameters

ORGANIZATION AND ROLE OF THE ILRS

The ILRS Tracking Stations range to a constellation of artificial satellites and the Moon with state-of-the-art laser ranging systems and transmit their data on a rapid basis (at least daily) to an Operations or Data Center. Stations are expected to meet ILRS data accuracy, quantity, and timeliness requirements, and their data must be regularly and continuously analyzed by at least one Analysis or mission-specific Associate Analysis Center. Each Tracking Station is typically associated with one of the three regional subnetworks (National Aeronautics and Space Administration (NASA), EUROpean LASer Network (EUROLAS), or the Western Pacific Laser Tracking Network (WPLTN).

Operations Centers collect and merge the data from the tracking sites, provide initial quality checks, reformat and compress the data if necessary, maintain a local archive of the tracking data, and relay the data to a Data Center. Operational Centers may also provide the Tracking Stations with sustaining engineering, communications links, and other technical support. Tracking Stations may perform part or all of the tasks of an Operational Center themselves.

Global Data Centers are the primary interfaces between the Analysis Centers and the outside users. They receive and archive ranging data and supporting information from the Operations and Regional Data Centers, and provide this data on-line to the Analysis Centers. They also receive and archive ILRS scientific data products from the Analysis Centers and provide these products on-line to users. Regional Data Centers reduce traffic on electronic networks and provide a local data archive.

Analysis Centers receive and process tracking data to produce ILRS data products. They are committed to produce the products on a routine basis for delivery to the Global Data Centers and the IERS using designated standards. Full Analysis Centers routinely process the global LAGEOS-1 and LAGEOS-2 data and provide Earth orientation parameters on a weekly or sub-weekly basis. They also produce other products such as station coordinates and velocities and geocenter coordinates on a schedule consistent with IERS requirements and provide a second level of data quality assurance in the network. Associate Analysis Centers produce specialized products, such as time-varying gravity field measurements, fundamental constants, satellite predictions, precision orbits for special-purpose satellites, regional geodetic measurements, and data products of a mission-specific nature. Associate Analysis Centers are also encouraged to perform quality control functions through the direct comparison of Analysis Center products and the creation of "combined" solutions using data from other space geodetic techniques. Lunar Analysis Centers produce LLR products such as lunar ephemeris, lunar libration, and Earth rotation (UT0 -UT1). In the field of relativity, LLR is used for the verification of the equivalence principle, estimation of geodetic precession, and examination of the relative change in G.

CENTRAL BUREAU

The ILRS Central Bureau (CB) is responsible for the daily coordination and management of ILRS activities. It facilitates communications and information transfer and promotes compliance with ILRS network standards. The CB monitors network operations and quality assurance of the data, maintains all ILRS documentation and databases, and organizes meetings and workshops. In order to strengthen the ILRS interface with the scientific community, a Science Coordinator and an Analysis Specialist within the CB take a proactive role to enhance dialogue, to promote SLR goals and capabilities, and to educate and advise the ILRS entities on current and future science requirements related to SLR. The Science Coordinator leads efforts to ensure that ILRS data products meet the needs of the scientific community and there is easy online access to all published material (via Abstracts) relevant to SLR science and technology objectives.

The CB has been actively providing new conveniences (such as targeted email exploders) and adding to the technical and scientific database. The information available via the ILRS Web Site has grown enormously since its inception, and many new links to related organizations and sites have been established. The site provides details and photographic material on the ILRS, the satellites and campaigns, individual SLR station characteristics, a scientific and technical bibliography on SLR and its applications, current activities of the Governing Board Working Groups and Central Bureau, meeting minutes and reports (including annual reports), tracking plans, etc. In the future, much more material will be made available online along with an enhanced search capability to quickly isolate specific material of interest. Due to the impending retirement of the CB's first Director, John Bosworth of NASA , Dr. Michael Pearlman of SAO has assumed the role of CB Director and Ms. Carey Noll of NASA will assume Dr. Pearlman's previous role of ILRS Secretary.

The Central Bureau maintains a comprehensive web site as the primary vehicle for the distribution of information within the ILRS community. The site, which can be accessed at: http://ilrs.gsfc.nasa.gov/

includes the following major topic titles: About the ILRS, Current Events, Working Groups, Satellite Missions, Network Stations, Data Products, Science/Analysis, Engineering/Technology, Reports, Frequently Asked Questions (FAQs), and Links. Mirrored sites are also available at the Communications Research Laboratory (CRL) in Tokyo and the European Data Center (EDC) in Munich. The site also includes SLR related bibliographies, Earth science links, historical information, collocation histories, and mail exploders. An on-line brochure provides charts for SLR presentations. A hard copy library of early documentation has been assembled and is listed in the on-line bibliography.A new ILRS Reference Card was recently developed to provide easy online access to much of this material and to targeted email exploders.

GOVERNING BOARD AND WORKING GROUPS

The Governing Board (GB) is responsible for the general direction of the service. It defines official ILRS policy and products, determines satellite tracking priorities, develops standards and procedures, and interacts with other services and organizations. There are 16 members of the Governing Board (GB) - three are ex-officio, seven are appointed, and six are elected by their peer groups (see Table 2). The first GB completed its two year term in Fall 2000. A new Board was elected over the summer and installed in November 2000 at the 12th International Workshop in Matera, Italy. John Degnan was elected by the current GB to serve a second two year term as Chairperson.

Hermann Drewes	Ex-Officio, CSTG President	Germany
Michael Pearlman	Ex-Officio, Director ILRS Central Bureau	USA
Carey Noll	Ex-Officio, Secretary, ILRS Central Bureau	USA
Werner Gurtner	Appointed, EUROLAS , Networks & Eng. WG Coordinator	Switzerland
Wolfgang Schlueter	Appointed, EUROLAS, Networks & Eng. WG Deputy Coord.	Germany
David Carter	Appointed, NASA	USA
John Degnan	Appointed, NASA, Governing Board Chairperson	USA
Yang FuMin	Appointed, WPLTN	PRC
Hiroo Kunimori	Appointed, WPLTN, Missions WG Coordinator	Japan
Bob Schutz	Appointed, IERS Representative to ILRS	USA
Graham Appleby	Elected, Analysis Rep.	UK
Ron Noomen	Elected, Analysis Rep. , Analysis WG Coordinator	Netherlands
Wolfgang Seemueller	Elected, Data Centers Rep. , Data Formats & Procedures WG Deputy Coordinator	Germany
Peter Shelus	Elected, Lunar Rep., Analysis WG Deputy Coordinator	USA
Georg Kirchner	Elected, At-Large, Missions WG Deputy Coordinator	Austria
John Luck	Elected, At-Large, Data Formats & Procedures WG Coordinator	Australia

Table 1. ILRS Governing Board (as of May 2001)

Within the GB, permanent (Standing) or temporary (Ad-Hoc) Working Groups (WG's) carry out policy formulation for the ILRS. At its creation, the ILRS established four Standing WG's: (1) Missions, (2) Data Formats and Procedures, (3) Networks and Engineering, and (4) Analysis. In 1999, an Ad-Hoc Signal Processing WG was organized to provide improved satellite range correction models to the analysts. The Working Groups are intended to provide the expertise necessary to make technical decisions, to plan programmatic courses of action, and are responsible for reviewing and approving the content of technical and scientific databases maintained by the Central Bureau. All GB members serve on at least one of the four Standing Working Groups, led by a Coordinator and Deputy Coordinator. Table 1 lists the current GB membership, their nationality, and special function (if any) on the GB.

Fortunately, the WG's have attracted talented people from the general ILRS membership who have contributed greatly to the success of these efforts. The Missions WG has formalized and standardized the mission documentation required to obtain ILRS approval for new missions and campaigns. They continue to work with new missions and campaign sponsors to develop and finalize tracking plans and to establish recommended tracking priorities. The Data Formats and Procedures WG has been tightening up existing formats and procedures, rectifying anomalies, providing standardized documentation through the web site, and setting up study subgroups and teams to deal with more complicated or interdisciplinary issues. The Networks and Engineering WG has (1) developed the new ILRS Site and System Information Form which is being distributed to the stations to keep the engineering database current, (2) provided a new online satellite-link analysis capability for system design and performance evaluation, and (3) initiated the development of the ILRS technology database. The Analysis WG has been working with the ILRS Analysis Centers to develop a unified set of analysis products presented in the internationally accepted SINEX format. Three associated pilot programs are underway to assess differences among analysis products from the different centers. The Signal Processing Ad-Hoc WG is working on improved center-of-mass corrections and signal processing techniques for SLR satellites.

ILRS NETWORK

The ILRS Network as of May 2001 is shown in Figure 1. Traditionally the network has been strong in the US, Europe, and Australia. Through international partnerships, the global distribution of SLR stations is now improving, especially in the Southern Hemisphere. NASA, working in cooperation with CNES and the University of French Polynesia has established SLR operations on the island of Tahiti with MOBLAS-8. In cooperation with the South African Foundation for Research Development (FDR), NASA has relocated MOBLAS-6 to Hartebeesthoek (which already has VLBI, GPS, and DORIS facilities) to create the first permanent Fundamental Station on the African continent. Both systems are operational. . Operations at the new Australian station on Mt. Stromlo, which replaced the older Orroral site near Canberra, are going extremely well in terms of both data quantity and quality.

The NASA TLRS-3 system at Universidad de San Agustin in Arequipa, Peru, has carried the total SLR tracking load for South America in recent years. However, BKG (Germany) has selected Concepcion, Chile, for the site of its newly developed multi-technique Totally Integrated Geodetic Observatory (TIGO). The TIGO- with SLR, VLBI, GPS and absolute gravimetry techniques - will provide a Fundamental Station in South America when it becomes operational in late 2001. In Argentina, NASA has been negotiating a possible transfer of TLRS-4 to the University of La Plata. A possible joint Chinese-Argentine SLR station at the San Juan Observatory in western Argentina, with SLR equipment furnished by the Beijing Astronomical Observatory, is also being discussed .

The Peoples' Republic of China has made substantial investment in SLR stations and technology over the past two years. The SLR station in Kunming was recently re-established, bringing the total number of Chinese permanent sites to five (Shanghai, Changchun, Wuhan, Beijing, and Kunming. The data quality and quantity from the permanent Chinese stations continue to improve, most notably at Changchun. The Wuhan SLR station has been recently moved to a site outside the city where there is significantly better atmospheric seeing, and construction is nearing completion on two mobile Chinese SLR stations which will occupy additional sites within China, as part of a national geodetic program. The new Russian SLR station started operations near Moscow in 1999, and permission is being requested from the Russian government to integrate it into international SLR operations. A Russian SLR station in Novosobirsk has recently applied for ILRS membership. In Japan, The Communications Research Laboratory (CRL) in Tokyo continues to operate two of its four Keystone sites at Kashima and Tateyama in the Tokyo area. The future of the Koganei and Miura sites is unclear. The Simosato site, operated by the Japanese Hydrographic Institute, will continue to provide data in this technically highly interesting region. The Japanese Space Agency, NASDA, is also negotiating for the construction of a new state-of-the-art SLR station.

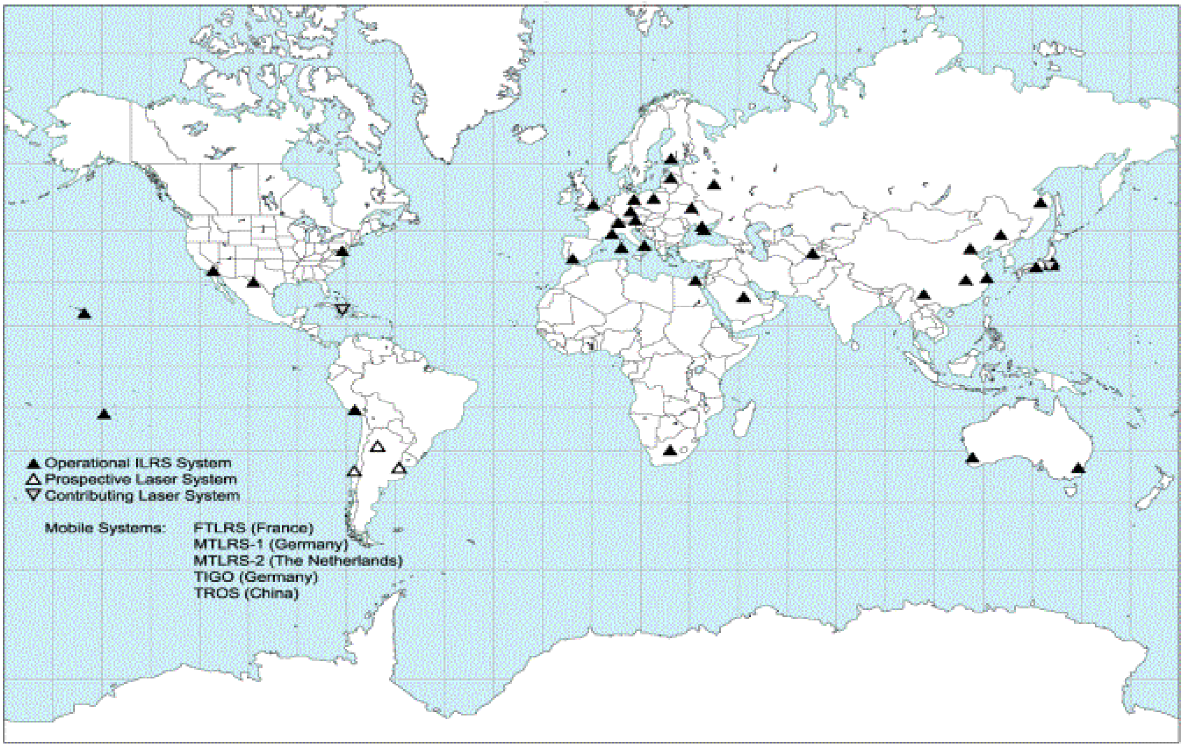


Figure 1. ILRS Network (as of May 2001)

Sites in the United States and Europe have been relatively stable over the past several years, with efforts continuing to improve overall performance or reducing the cost of SLR operations. The new state-of-the-art Matera Laser Ranging Observatory (MLRO) with both SLR and lunar ranging capability has now been installed at Matera and is presently undergoing final acceptance testing. The new French Transportable Laser Ranging System (FTLRS) is undergoing checkout in preparation for tracking support of JASON and other active satellite missions from a site in the Mediterranean region. The unmanned SLR2000 prototype is nearing completion at NASA and field tests are scheduled to begin in Fall 2001.

ILRS TRACKING PRIORITIES AND CAMPAIGNS

The ILRS is currently tracking about two dozen targets, including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, engineering missions, and lunar reflectors (see Table 2). The newest missions include the German CHAMP mission (GFZ), which was added in July 2000, and the oceanography mission, GFO-1 (US Navy), which was recently elevated from campaign status to permanent tracking. In addition, three new GLONASS (72, 79, and 80) satellites are being tracked in support of the IGLOS campaign. Recently, Etalon 1 and 2 were elevated in priority at the request of the ILRS Analysis Working Group in order to ascertain whether or nor SLR's determination of Earth Orientation Parameters (EOP) could be improved.

The ILRS assigns satellite priorities in an attempt to maximize data yield on the full satellite complex while at the same time placing greatest emphasis on the most immediate data needs. Priorities provide guidelines for the network stations, but stations may occasionally deviate from the priorities to support regional activities or national initiatives and to expand tracking coverage in regions with multiple stations. Tracking priorities are set by the Governing Board, based on application to the Central Bureau and recommendation of the Missions Working Group.

During the past year, tracking campaigns have included: (1) ERS-1 to support tandem Synthetic Aperture Radar (SAR) experiments with ERS-2; (2) the GEOSAT Follow-on (GFO-1) altimetric mission, (3) the South African SUNSAT remote sensing satellite, and (4) revived GEOS-3 and Beacon-C tracking for gravity field improvement .

Since several remote sensing missions have suffered failures in their active tracking systems or have required in-flight recalibration, the ILRS has encouraged new missions with high precision orbit requirements to include retroreflectors as a fail-safe backup tracking system, to improve or strengthen overall orbit precision, and to provide important intercomparison and calibration data with onboard microwave navigation systems.

UPCOMING MISSIONS

At one time, the main task of the international SLR Network was the tracking of dedicated geodetic satellites (LAGEOS, Starlette, etc.). Although we have had requests to revive tracking on older satellites already in orbit (e.g. Beacon-C) to further refine the gravity field with improved accuracy laser data, new requests for tracking are now coming mainly for active satellites. The tracking approval process begins with the submission of a Missions Support Request Form, which is accessible through the ILRS web site. The form provides the ILRS with the following information: a description of the mission objectives; mission requirements; responsible individuals, organizations, and contact information; timeline; satellite subsystems; and details of the retroreflector array and its placement on the satellite. This form also outlines the early stages of intensive support that may be required during the initial orbital acquisition and stabilization and spacecraft checkout phases. A list of upcoming space missions that have requested ILRS tracking support is summarized in Table 3 along with their sponsors, intended application, and projected launch dates.

Priority	**Satellite**	**Sponsor**	**Altitude (Km)**	**Inclination**	**Campaign Ends**
1	CHAMP	GFZ	470	87.3	
2	GFO-1	US Navy	790	108.0	
3	ERS-2	ESA	800	98.6	
4	TOPEX/Poseidon	NASA.CNES	1,350	66.0	
5	Starlette	CNES	815 - 1,100	49.8	
6	WESTPAC	WPLTN	835	98	
7	Stella	CNES	815	98.6	
8	Beacon-C	NASA	950 - 1,300	41	31 December 2001
9	Ajisai	NASDA	1,485	50	
10	LAGEOS-2	ASI/NASA	5,625	52.6	
11	LAGEOS-1	NASA	5,850	109.8	
12	Etalon 1	RSA	19,100	65.3	
13	Etalon 2	RSA	19,100	65.2	
14	GLONASS 80	RSA/IGLOS	19,100	65	
15	GLONASS 72	RSA/IGLOS	19,100	65	
16	GLONASS 79	RSA/IGLOS	19,100	65	
17	GPS 35	US Air Force	20,100	54.2	
18	GPS 36	US Air Force	20,100	55.0	
	Lunar Targets	**Sponsor**			
1	Apollo 15	NASA			
2	Apollo 11	NASA			
3	Apollo 14	NASA			
4	Luna 21	RSA			

Table 2. ILRS Tracking Priorities (as of April 2001)

Once tracking support is approved by the Governing Board, the Central Bureau works with the new missions to develop a Mission Support Plan detailing the level of tracking, the schedule, the points of contact, and the channels of communication. New missions normally receive very high priority during the acquisition and checkout phases and are then placed at a routine priority based on the satellite category and orbital parameters. After launch, New Mission Reports with network tracking statistics and operational comments are issued weekly. The Central Bureau monitors progress to determine if adequate support is being provided. New mission sponsors (users) are requested to report at the ILRS Plenary meetings on the status of ongoing campaigns, including the responsiveness of the ILRS to their needs and on progress towards achieving the desired science or engineering results.

MEETINGS AND REPORTS

The ILRS organizes semiannual meetings of the Governing Board and General Assembly, which is open to all ILRS Associates and Correspondents. The 5th ILRS General Assembly was held in November 2000 in Matera, Italy, in conjunction with the 12th International Workshop on Laser Ranging. The 6th ILRS General Assembly was held in March 2001 in conjunction with the EGS Symposium in Nice, France. Detailed reports from past meetings can be found at the ILRS web site.

Mission Name	Support Requester	Mission Type	Planned Launch Date	Mission Duration	Altitude (km)	Inclination (deg)	Mission Request Form Received
nvisat-1	ESA Europe	Oceans, Atmosphere	June 2001	5 years	800	98.5	yes
Starshine 3	NRL/USA	Atmosphere, Educational	August 2001	3-5 years	470	67	yes
JASON-1	CNES/NASA France/USA	Oceans, Atmosphere	October 2001	5 years	1336	66	yes
Starshine 2	NRL/USA	Atmosphere, Educational	December 2001	3-5 years	360	39	yes
Icesat (GLAS)	NASA USA	Ice Balance, Oceans	January 2002	3-5 years	600	94	yes
ADEOS-II	NASDA Japan	Oceans, Atmosphere	February 2002	3 years	803	98.6	yes
GP-B	NASA-JPL USA	Relativity	October 2002	1-2 years	400	90	yes

Table 3. Upcoming Missions (as of April 2001)

The 7th ILRS General Assembly will be held at the Centre de Congres Pierre Baudis in Toulouse, France, on Friday morning, 21 September 2001. The meeting is held in conjunction with the SPIE/Europto Symposium on Remote Sensing (September 17-

21, 2001), which includes a session on Laser Radar Techniques (Sept. 17-18) as well as open ILRS -sponsored Working Group sessions and calibration workshops A special Joint ILRS/WPLTN symposium will be held in Riyadh, Saudi Arabia, on the following Sunday and Monday (September 23-24).

The first ILRS Annual Report (1999) was published last year It is available as hard copy from the CB or online at the ILRS Web Site. The 2000 ILRS Annual Report is in preparation.

ILRS Analysis Center reports and inputs are used by the Central Bureau for weekly review of station performance and to provide feedback to the stations when necessary. Special weekly reports on on-going campaigns are issued by email. The CB also generates Quarterly Performance Report Cards and posts them on the ILRS web site. The Report Cards evaluate data quantity, data quality, and operational compliance for each tracking station relative to ILRS minimum performance standards. A catalogue of diagnostic methods, for use along the entire data chain starting with data collection at the stations, has emerged from this process and will be made available on the ILRS web site. The evaluation process has been helpful in comparing results from different Analysis and Associate Analysis Centers, a role soon to be assumed by the Analysis Working Group.

MIDTERM REPORT OF THE INTERNATIONAL VLBI SERVICE FOR GEODESY AND ASTROMETRY (IVS)

Wolfgang Schlüter [1], Ed Himwich[2], Axel Nothnagel[3], Alan Whitney[4] and Nancy Vandenberg [2]

1. General Remarks

The IVS (International VLBI Service for Geodesy and Astrometry) was established in February 1999 in order to support VLBI programs for geodetic, geophysical and astrometric research and operational activities. IVS coordinates the observations, the data flow, the correlation, the data analysis and the technology developments.
IVS is recognized as a Service of the International Association of Geodesy (IAG) since July 1999 when the General Assembly was held in Birmingham/England and is also recognized as a Service of the IAU since the XXIVth General Assembly, Manchester/England, August 2000. Thus, acting within the frame of IAG and IAU, IVS has to guarantee provision of the required results on a regular and timely basis. Nowadays the IVS is a Technique Center for the International Earth Rotation Service (IERS) and has close interactions with IERS. The VLBI technique uniquely provides the parameters for the CRF and is the only technique to determine the celestial pole. IVS is producing Earth Orientation Parameters (EOP) from 24h observation sessions regularly and periodically carried out such as NEOS and IRIS. The parameters in particular are the celestial pole coordinates dj, de polar motion parameter xp, yp, and DUT1. In addition DUT1 is derived from 2h observation sessions carried out quasi daily by Wettzell and Green Bank, nowadays Wettzell and Kokee Park. CRF solutions are regularly derived in order to determine quasar positions or to detect proper motions of quasars. Station positions and velocities are derived from all the observations and are a strong contribution to the ITRF. It is planned to provide EOP with subdaily resolution and baseline length evolutions. The products are available via data centers at NASA GSFC/Greenbelt, USA ftp://cddisa.gsfc.nasa.gov or BKG-Leipzig, Germany ftp://ftp.leipzig.ifag.de or Observatoire Paris, France ftp://ivsopar.obspm.fr. Access to IVS Homepage is available via http://ivscc.gsfc.nasa.gov/ mirrored at BKG http://www.leipzig.ifag.de/IVS and CRL http://ivs.crl.go.jp/mirror

2. Summary of the IVS Components

A Call for Participation was released jointly by CSTG and IERS on June 1, 1998. The proposals were evaluated and accepted by the Steering Committee. In summary IVS has today

- 30 Network Stations, concentrated in USA, Europe, Japan and a deficit in the southern hemisphere,
- 3 Operation Centers namely NASA-GSFC, NEOS, Geodetic Institute of the University of Bonn,
- 7 Correlators operated by NEOS (Washington)/USA, NASA(Haystack)/USA, BKG-MPI/Germany, GSI/Japan, CRL/Japan, IAA/Russia, JIVE/Netherlands,
- 6 Data Centers established at NASA-GSFC/USA, Observ. Paris/France, BKG/Germany, CNR/Italy, CRL/Japan and Agenzia Spaziale/Italy,

- 21 Analysis Centers , four of them are gloabal Analysis Centers which provide solutions for a combinations of the IVS core products (IAA/Ru, Univ. St. Petersburg/Ru, GSFC/US, BKG/D, OP/F) and 17 Associate AC perform investigations or provide related products,
- 9 Technology Development Centers supporting the recording techniques MK III and MK IV, K4 and S2, and
- 1 Coordinating Center operated by NEOS, a cooperation of USNO and GSFC.

All together there are 77 components representing 30 Member Organizations in 15 countries and more than 230 individual Associate Members. IVS has 31 Member organizations, and 6 Affiliated Member organizations.

Fig. 1. Overview of the distribution of the IVS components

3. IVS Activities

The 1st Directing Board meeting was held in Wettzell on February 11, 1999 in order to establish the Service and to initiate activities under the flag of the IVS. As of the inauguration date of IVS, on March 1, 1999, its web site was available at http://ivs.gsfc.nasa.gov.

Soon thereafter, a solicitation for IVS data and analysis was released to obtain proposals from the Operation and Analysis Centers on the provision of products such as correlation results, EOPs, and combined analysis. Those products derived by the Analysis Centers were designed to become “official” IVS products. In the same solicitation the call for an Analysis Coordinator was released.

The **IVS Annual Report 1999** was published in August 1999 (electronically) and September 1999 (printed) [1]. The intention of the Analysis Report was to provide a document on the status of all components. A procedure was created to standardize the layout, which supported and accelerated the publication of the Annual Report 1999.

The **2000 IVS General Meeting** was organized and held in Kötzting, Germany, during February 21-24, 2000. It was a successful meeting with more than 120 participants registered. The goals of the meeting were determined by a program committee. The main character of the 1st General Meeting was addressed towards young researchers. Overview talks and tutorials were held before the sessions, in order to introduce the session topic to those who work in different areas. It has to be mentioned that the proceedings of 2000 IVS General Meeting [2] were published in June 2000. The proceedings published nearly all the papers and tutorials and are a very valuable tool, especially for people starting to work in VLBI.

At the 3rd Directing Board Meeting, held in Wettzell before the General Meeting, slight modifications to the Terms of References were made in order to clarify the status of the Analysis Centers and to include Affiliated Members. Affiliated Members will be informed about IVS activities without having obligations to IVS.

During the IVS 2000 General Meeting, a first meeting was held of the **IVS Working group on "GPS phase centers Mapping"** , which is a joint Working Group of the International GPS Service (IGS) and International Laser Ranging Service (ILRS). The objectives were "to study the feasibility equipment, time required, and if it could be done with accuracy sufficient to make it worthwhile". The members of the WG are Brian Corey/ MIT-Haystack, Ed Himwich/NVI, Inc./GSFC for the IVS, Tom Herring/MIT-Boston, Tim Springer/AIUB for the IGS and Graham Appleby/ and Richard Biancale/CNES for the ILRS. The activity and the status of the work could be seen on the IVS-homepage http://ivs.gsfc.nasa.gov.

On the last day of the 2000 General Meeting, February 24, the **first Analysis Workshop** has been held. Axel Nothnagel, who became IVS Analysis Coordinator on October 1, 1999, invited to the meeting. Standards, analysis models and contributions of the various Analysis Centers were discussed, five Working groups have been established in order to share the workload. Access to all the information is made available via http://ivs.gsfc.nasa.gov and its link to the Analysis Coordinator homepage.

A **regular combination procedure for the VLBI derived EOP series**, provided from the four Analysis Centers, NASA Goddard Space Flight Center/Greenbelt, USA, Bundesamt fuer Kartographie und Geodäsie/Leipzig, Germany, Institut for Applied Astronomie /St. Petersburg, Russia and University of St. Petersburg, Russia has been developed by Axel Nothnagel and Christoph Steinforth of the Geodetic Institute of the University of Bonn. The combined results have been released as IVS products and are now used from IERS for further combination with the other techniques.

In 2000 the first **Analysis Pilot Project** has been started by the Analysis Coordinator in order to encourage more Analysis Centers to perform data analysis. A common set of data covering a period of one year has been released for the pilot project which allows to compare the results of the individual analyses, to unify the data reduction procedures and to exchange experience. In addition to the 4 global Analysis Centers, 9 more Analysis Centers participated in the Pilot Project. 17 different solutions have been derived using 6 different analysis software packages. The results have been discussed at **the Second VLBI Analysis Workshop** held at the Goddard Space Flight Center/Greenbelt, USA in the period from February 12-14, 2001. These activities are very encouraging and a second pilot project is going to be started soon.

In September 2000 the hardware **VLBI Standard Interface (VSI-H)** specification has been released (more detailed information: http://ivs.gsfc.nasa.gov). VSI-H specification was developed by an international committee of experts in VLBI instrumentation, led by Alan Whitney/MIT-Haystack, IVS Technology Coordinator, in a concerted effort to standardize interfaces to/from VLBI data recording and playback systems. Adherence to the VSI-H specification will allow data collected on heterogeneous VLBI data systems to be processed directly on VLBI correlators. A standardized software interface, VSI-S, is expected to follow within the next year. Thanks to the committee especially Alan Whitney/MIT-Haystack-USA as the chair, Wayne Cannon and Richard Worsfold/CRESTech-Canada, Ralph Spencer/ Jodrell Bank Observatory-UK, Richard Ferris/CSIRO Telescope National Facility-Australia, John Romney, George Peck/NRAO-USA, Brent Carlson/Herzberg Institut of Astrophysics NRCC-Canada, Tetsuro Kondo, Junichi Nakajima, Yasuhiro Koyama, Mamorou Sekido and Hitoshi Kiuchi/CRL-Japan and Mickael Popov/Astro Space Center of Lebedev Physical Institute Moscow-Russia the specification have been set up in a short period of time with a broad international acceptance.

The 4th Directing Board meeting was held on September 17, 2001 in Paris-F and the 5th Directing Board Meeting was held in Greenbelt-USA. In order to improve the IVS products and to optimize the resources within IVS a **Working Group for the evaluation of the existing observing programs** was created with the following task:

- Review the usefulness and appropriateness of the current definition of IVS products and suggest modifications.
- Recommend guidelines for accuracy, timeliness, and redundancy of products.
- Review the quality and appropriateness of existing observing programs with respect to the desired products.
- Suggest a realistic set of observing programs which should result in achieving the desired products, taking into account existing agency programs.
- Set goals for improvements in IVS products and suggest how these may possibly be achieved in the future.
- Present a written report to the IVS Directing Board at its next meeting.

Harald Schuh is the chair of this group and experienced members are invited to contribute.

The **First IVS Technology and Operations Workshop (TOW)** was held at Haystack Observatory during March 12-14, 2001. The program committee for the meeting was lead by Ed Himwich, NVI Inc/GSFC. The workshop provided detailed training on VLBI technology and operations and was attended by over 60 people. This meeting will be repeated every two years. The material covered was adapted to meet people's interests as well as important issues. A notebook covering details of the training sessions and talks were provided to all attendees. This notebook should prove to be useful a reference for all involved.

4. Personal fluctuations in the Directing Board

Some personal fluctuations in the Directing Board (DB) have to be mentioned. The representative of the IAG, Gerhard Beutler, when he was elected as Vice President of IAG, withdrew from the board after the 2nd DB meeting, held in Birmingham, July 19, 1999. He was the initiator of the IVS and we have to express our thanks to him. James Campbell, one of the most experienced VLBI experts, was nominated by IAG to be the new IAG representative. Axel Nothnagel, representing the Analysis Centers on the DB, started his work as Analysis Coordinator (AC) as of October 1, 1999. Up to October, 1999 the function of the AC was jointly carried out by Marshall Eubanks, Chopo Ma and Nancy Vandenberg. Marshall Eubanks, representative of the Operations Centers and Correlators, has founded a new e-business, which demands his full attention. He withdrew from the DB and was replaced by Kerry Kingham.

In accordance with the ToR, elections have carried out for the positions of the Analysis and Data Center representative and of the Technology Development Center representative. Both positions have been occupied for the first two years term only, starting at the initiation date of the IVS. Since Axel Nothnagel became the Analysis Coordinator in October 1999 the position of the Analysis Representative became vacant. The position of the representative for the Technology Development Centers was held by Tesuro Kondo, CRL-Japan. In addition one of the At Large positions, that position held by Wayne Cannon, was set for a two years term only. The election has been held in December 2000. Harald Schuh, Austria was elected as the representative for the Analysis and Data Centers, Arthur Neill, USA was elected to represent the Technology Development Centers and Yasuhiro Koyama, Japan was elected as AT Large Member. After the election, it turns out that the Directing Board is strongly dominated by US and European representatives and improvements for the balance of representatives from different agencies, nations and groups have been discussed at the 5th Directing Board meeting. The enlargement of the board by a 3rd At Large Member was decided and the ToR have been modified.

The current members of the DB and their functions are:

Ex Officio:

IAG representative	James Campbell;
IAU representative	Nicole Capitaine
IERS representative	Chopo Ma
Coordinating Center	Nancy Vandenberg

Coordinators:

Analysis Coordinator	Axel Nothnagel
Network Coordinator	Ed Himwich
Technology Coordinator	Alan Whitney

Representatives:

Analysis and Data Centers	Harald Schuh
Operation Centers and Correlators	Kerry Kingham
Networks	Shigeru Matsuzaka
Networks	Wolfgang Schlüter (chair)
Technology Development Centers	Arthur Neill
At Large Members:	Yasuhiro Koyama Paolo Tomasi NN

Literature

[1] Vandenberg, N.R. (editor): Annual Report 1999, NASA/TP-1999-209243, Greenbelt-MD, August,1999

[2] Vandenberg, N.R. and Baver K.D. (editors), 2000 General Meeting Proceedings February 21-24, 2000 Kötzting, NASA/CP – 2000 – 209893, Greenbelt MD, June 2000

---

[1]Bundesamt für Kartographie und Geodäsie, Fundamentalstation Wettzell, D-93444 Kötzting, Germany

[2] NVI, Inc./NASA Goddard Space Flight Center, Code 920.1, Greenbelt, MD 20771,USA

[3] Geodätisches Institut, Universität Bonn, Nussallee 17, D-53115 Bonn, Germany

[4] MIT-Haystack Observatory, Off Route 40, Westford, MA 01886-1299, USA

SECTION III:
DETERMINATION OF THE GRAVITY FIELD

REPORT OF THE PRESIDENT OF FOR THE PERIOD 1999-2001

President: Michael G. Sideris
University of Calgary
Department of Geomatics Engineering
2500 University Drive N.W.
Calgary Alberta T2N 1N4
Canada

1. Introduction and Objectives

This report describes very briefly the activities of Section III for the period 1999-2001. Given the numerous activities and large number of significant accomplishment during the last two years, this report should be used only as a “road map” of Section III’s activities and, for completeness and detailed information, the interested reader should consult the reports of the study groups, commissions and services for the same period. These reports also provide web site addresses, where recent results, data sets, publications and other relevant information can be found.

The developments in the gravity field determination expressed in the formal IAG by-laws, for which Section III is responsible, are:

1. absolute and relative terrestrial gravity measurements;
2. gravity networks and control stations;
3. non-tidal gravity variations;
4. determination of the external gravity field and geoid from different gravity field data types; and
5. reduction and estimation of gravity field quantities.

2. Structure

In order to achieve its objectives, the Section has established the following Structure:

President: Michael G. Sideris (Canada)

Secretary: Gerd Boedecker (Germany)

Commission XIII: International Gravity and Geoid Commission

President: Martin Vermeer (Finland)

Special Study Groups:

- SSG 3.167: Regional Land and Marine Geoid Modelling
  Chair: I.N. Tziavos (Greece)
- SSG 3.177: Synthetic Modelling of the Earth's Gravity Field
  Chair: Will Featherstone (Australia)
- SSG 3.184: Use of Remote Sensing Techniques for Validating Heights and Depths
  Chair: Philippa Berry (UK)
- SSG 3.185: Merging Data from Dedicated Satellite Missions with Other Gravimetric Data
  Chair: Nico Sneeuw (Germany)
- SSG 3.186: Altimetry Data Processing for Gravity, Geoid and Sea Surface Topography Determination
  Chair: C. Hwang (Taiwan)

International Services:

- BGI: International Gravimetric Bureau
  Director: J-P. Barriot (France)
- IGeS: International Geoid Service
  Director: F. Sansò (Italy)

A substructure is also in place, whereby the above bodies establish sub-commissions and working groups as needed, to tackle specific problems or research areas. These include:

- The Working Group on Inter-comparison of Absolute Gravimeters
- The Working Group on World Gravity Standards
- The Working Group on the Global Gravity Monitoring Networks
- The Arctic Gravity Project
- The Antarctic Gravity Project
- The Sub-commission for Europe
- The Sub-commission for North America
- The Sub-commission for South America
- The Sub-commission of South East Asia

3. Major Meetings and Schools

Section III was involved directly or indirectly in the organization of many scientific meetings, workshops and international schools. Also, the various bodies within SectionIII held many business meetings and/or workshops, usually during the major conferences. Of particular important for their service to our colleagues in developing countries are the international schools for the determination and use of the geoid, organized by the International Geoid Service. A non-exhaustive list is given below.

- 4th International School on the Determination and Use of the Geoid, February 21-25, 2000, Johor, Malaysia.
- South America Geoid Workshop, May 17-19, 2000, São Paulo, Brazil.
- IAG Symposium on Gravity, Geoid, and Geodynamics 2000 (GGG2000), July 31 - August 4, 2000, Banff, Alberta, Canada.
- IAG Symposium on Vertical Reference Systems, February 20 - 23, 2001, Cartagena, Colombia.
- Annual Meetings of the European Geophysical Society, and American and Canadian Geophysical Unions, 1999, 2000, 2001.

4. Summary and Outlook

All bodies of Section III have been operating very successfully and are meeting or exceeding the objectives they have set for themselves. This is evident from the list of publications, scientific exchanges, and meetings and workshops organized. Congratulations are due not only to the chairs and secretaries of the various bodies but also to the individual members contributing to the work of the Section.

With IAG being in the process of reorganising its operations and internal structure, it is of course possible that many changes will take place in the near future. For example, with leadership from IGeS and the consent of BGI, NIMA, ICET and GFZ, the Section is proposing the creation of a new IAG service named International Gravity Field Service (IGFS). IGFS is being proposed as a unified structure aiming at collecting, validating and distributing data and software for the purpose of determining the gravity potential and the surface of the Earth a accurately as possibly. The publication of a joint Information Bulletin is envisaged, as well.

After the IAG assembly in Budapest this fall, we will all be awaiting with great anticipation the new structure of IAG, and are looking forward to seeing the new place the Determination of the Gravity Field will have in it.

Michael G. Sideris
IAG Section III President Calgary, June 2001

THE INTERNATIONAL GRAVITY AND GEOID COMMISSION OF IAG

Report on Activities
by

Martin Vermeer
Chairman

1. Establisment and Terms of Reference

The decision to establish this IAG Commission was taken in July 1999 in Birmingham, UK, at the IUGG/IAG General Assembly, merging the activities of the International Gravity Commission and the International Geoid commission. The objective was to establish a stronger focus for the scientific study of the gravity field of the Earth.

Terms of Reference were drawn up to guide the work of the Commission. They can be found at the Web address http://www.iag-iggc.org/Trms0001.htm.

2. The working groups of the Commission

2.1 The WG on Intercomparison of Absolute Gravimeters

The Working Group on Intercomparison of Absolute Gravimeters, headed by Leonid Vitushkin, has been particularly active. Dr. Vitushkin has worked to establish not only the IGGC's Working group, but a similar working group involving the same scientific community, but belonging to the sphere of international metrology under the auspices of the Bureau International des Poids et Mesures (BIPM, http://www.bipm.org) in Paris, France.

For this purpose the creation of a new Consultative Committee has been proposed for absolute gravimetry. The impetus for this was a letter (July 15, 1999) by three leading Russian geophysicists representing the National Geophysical Committee and its Geodesy Section, addressed to the President of IAG explaining the need to bring absolute gravimetric work within a metrological framework. The precise organizational arrangement is yet to be decided in October 2001 (Letter November 23, 2000, Jean Kovalevsky, Comité International des Poids et mesures).

The objective is to establish a close collaboration between the metrological community on the one hand, and the geodetic-geophysical community on the other.

In preparing these initiatives, Dr. Vitushkin visited Helsinki, Finland in October 4 - 6, 2000 on the invitation of the Director-General of the Finnish Centre for Metrology and Accreditation, Ulla Lähteenmäki. The undersigned participated in the discussions that took place.

2.2 The Arctic Gravity project

Also the Arctic Gravity Project (ArcGP), another working group within IGGC, was very active under the leadership of René Forsberg and the contructive attitudes of several circumarctic countries, among which Russia, the United States, Canada, Denmark and Norway.

In spite of the obvious political sensitivity of the stated objective of producing a gravity survey map of the Arctic Ocean at 5' resolution, good progress was made. Gravimetric data appears to exist from a large number of sources and techniques (shipborne, airborne, submarine, ice surface, satellite altimetry…) to cover all of the target area with the possible exception of a small banana shaped region.

The first meeting of the Working Group took place in St Petersburg, Russia, in a small mansion outside the city. The meeting, in which the undersigned participated, was both productive and pleasant.

A second meeting in Canada is to be convened these days.

The ArcGP has its own web site, address http://www.nima.mil/GandG/agp/.

2.3 The Antarctic Gravity Project

The Working Group on Antarctica of the IGGC has been headed by Alessandro Capra of the University of Bologna. Dr. Capra also heads the Physical Geodesy project within the Geodesy program (GIANT) of the Geodesy and Geographic Information group of SCAR, the Scientific Committee on Arctic Research.
The purpose of this WG is, similarly to ArcGP. the compilation of a gravimetric data base with a view of determining a high resolution geoid model of the Antarctic area. See the Web site http://www.scar-ggi.org.au/geodesy/physgeod/index.htm.

2.4 Other Working Groups

The creation of the following WG's was decided at the first IGGC Assembly meeting in Banff, Canada, cf. section 5.1

- WG on World Gravity Standards, chair Gerd Boedecker
- WG on the Global Gravity Monitoring Network, chair Berndt Richter

3 The Subcommissions

The following Subcommissions have been established at the outset of the IGGC:

3.1 North America

The Subcommission for North America, chaired by Marc Véronneau, was off for a good start, with gravity and DEM measurement and compilation and geoid determination going on in several member countries. Meetings held include:

- At the Canadian Geophysical Union meeting, Banff, May 2000;
- At the GGG2000 meeting in Banff, Canada, see section 5.1
- At the IAG Symposium in Cartagena, Colombia, see section 5.2or attendance.
- The next official meeting is planned for May 2000 in connection again with the CGU meeting in Ottawa, Canada.

This Subcommission has also the Caribbean and Central America within its field of operations and letters of invitation were sent to all the countries of Central America, Cuba, The Bahamas and the Dominican Republic, which have not yet responded.

The Subcommission's Web site is at: http://www2.geod.nrcan.gc.ca/~marc/GGSCNA/GGSCNA.html (requires a password).

3.2 Europe

The Subcommission for Europe, chaired by Ambrus Kenyeres. A report on its activities was presented at the GGG2000 meeting. It can be found at http://www.iag-iggc.org/SC_Europe2000.htm.

The Computing Centre for the European Geoid at the University of Hannover (Heiner Denker) has expressed an interest in continued involvement in this computational effort. It is intended, in close co-operation with EUREF, to use a highly reliable GPS/levelling data set as fiducial control for future geoid model determinations.

3.3 South America

The Subcommission for South America, headed by Denizar Blitzkow. A meeting has been held in Cartagena, Colombia, see section 5.2. Geoid determination activities for the area are ongoing, as are gravity surveys and establishment of digital terrain models.

3.4 South-East Asia

The Subcommission for South-East Asia, headed by Bill Kearsley. Activities in this area are hampered by the lack of an existing IAG framework for co-ordinating activities in the region. Nevertheless, as a success can be reported the IAG Geoid School in Johor, Malaysia, in February 2000.

4 Services

The Services currenty under the auspices of the IGGC are:

- The Bureau Gravimétrique International, Toulouse, France. Director: Jean-Pierre Barriot (taking office 1999).
- The International Geoid Service, Milano, Italy. Director: Fernando Sansó.

Both services have been active in their mandated fields of activity. It should be stressed that the operations of both are made possible mostly by national sources of financing within France and Italy, respectively. The IGGC can only play a co-ordinating role for both in order to enable them to better execute their mandates.

A first Directing Board meeting of both services was held during the Banff meeting, cf. section 5.1.

Web sites of both services are:

- BGI: http://bgi.cnes.fr:8110/.
- IGeS: http://www.iges.polimi.it.

5 Meetings

5.1 Banff

At the GGG2000 (Gravity, Geoid, and Geodynamics) meeting, July 31 - August 4, 2000, in Banff, Canada, the Assembly of the IGGC met for the first time, on the first of August. A number of decisions was taken, mainly confirming the proposed study groups and subcommissions and their chairpersons, as well as the terms of Reference. The Minutes are found here: http://www.iag-iggc.org/minutes2000.htm.

5.2 Cartagena

A symposium called the IAG Symposium on Vertical Reference Systems was convened February 20 - 23, 2001 in Cartagena, Colombia, where besides the Subcommission for South America, also the Subcommission for South America met in a splinter meeting.

Unfortunately the undersigned was unable to attend, but a letter was sent to the organizers expressing the support of the IGGC to the symposiom, and expressing good wishes for its success.

5.3 Nice

In preparation for the 2001 meeting of the IAG Executive Commmittee, a proposal was circulated drafted by several people within the Executive, aimed at the creation of a GFFS, "Gravity Field and Figure of the Earth Service", which would serve as a formal umbrella for

- The BGI
- The International Geoid Service
- The Service International des Marées Terrestes

and a couple of services to be newly established. One such service, for which official support was promised by the GeoForschungsZentrum in Potsdam, Germany (Letter Ch. Reigber , March 23, 2001), was a Service for the Intercomparison of Global Spherical Harmonic Expansions.

The publication of a joint Information Bulletin is envisaged.

The undersigned asked the proposal to be placed on the agenda for discussion; unfortunately again such discussion took place in his absence forced by other commitments.

6 Web site

A web site, http://www.iag-iggc.org for the Commission was set up and is being maintained by the Secretary, Jacques Liard at his affiliation, Natural Resources Canada. Their provision of hosting facility and bandwidth is gratefully acknowledged.

REPORT OF IAG SPECIAL GROUP 3.167

"REGIONAL LAND AND MARINE GEOID MODELLING" (1999-2001)

http://olimpia.topo.auth.gr/ssg3167

Ilias N. Tziavos

Aristotle University of Thessaloniki, Department of Geodesy and Surveying, Univ. Box 440, 54006 Thessaloniki, Greece, e-mail: tziavos@olimpia.topo.auth.gr

INTRODUCTION

This report summarizes the main work and activities of the IAG Special Study Group (SSG) 3.167 "Regional Land and Marine Geoid Modelling" between August 1999 and April 2001. This SSG was established for the period 1999-2003 during the 1999 General Assembly of IUGG in Birmingham, the UK. It is a continuation of a previous SSG of IAG (1995-1999) under the same title and the same objectives, since IAG has recognized the importance of the geoid modelling on a regional scale in land and marine areas.

The primary objective of this SSG is the accurate regional-scale land and marine geoid determination mainly emphasizing on the following directions: (a) Investigation of modelling procedures for land and marine geoid, differences between methods and difficulties when working across the land/sea boundary; (b) new efficient ways of working with heterogeneous data for geoid determination; (c) the use of numerical techniques and the possibilities to prescribe or recommend the extent of a standard procedure; (d) revision of procedures for calculating the errors of geoid/quasi-geoids; (e) the impact of GPS - heights not only to validation procedures but also to common adjustments with geoid heights; (f) the contribution of high accuracy and resolution marine geoid to sea surface topography determination and other related oceanographic studies; (g) modelling of long-wavelength errors in regional geoid/quasi-geoid computations by the new satellite gravity missions CHAMP, GRACE and GOCE; (h) the contribution of airborne gravimetry to geoid modelling in combination procedures.

It is worth mentioning that the work and activities included in this report belong to those members of the SSG who sent me in time their contributions. These contributions are available via the SSG's website at the following URL (http://olimpia.topo.auth.gr/ssg3167). Due to space limitations I describe below that part of the work which mainly reflects the leading tasks and goals of SSG. Additionally, scientific work by other colleagues is also briefly presented and reference is given to several recent papers published in geodetic journals or in papers presented in geodetic symposia during the last two years. Some results reported in recent dissertations are also discussed. A more complete list of references can be found in the above mentioned web page.

MEMBERSHIP

SSG 3.167 had, primarily, thirty regular members, including the president and ten corresponding members. After the IAG GGG2000 meeting held in Banff (August 2001) eleven colleagues joined SSG as corresponding members. The geographical spread of the SSG members is quite satisfactory. The members expertise range from mathematical and physical geodesy to gravity field applications in different branches of geosciences. The names of the members of the SSG and countries are given below:

Full Members*:*

I.N. Tziavos	(Greece, chairman)	H. Abd-Elmotaal	(Egypt)	R. Barzaghi	(Italy)
J. Catalao	(Portugal)	J.Y. Chen	(China)	O.C. Dahl	(Norway)
H. Denker	(Germany)	W. Featherstone	(Australia)	R. Hipkin	(United Kingdom)
R. Haagmans	(The Netherlands)	Z. Jiang	(France)	J. Kaminskis	(Latvia)
N. Kuehtreiber	(Austria)	Y. Kuroishi	(Japan)	U. Marti	(Switzerland)
C. Merry	(South Africa)	D. Smith	(USA)	J. Toth	(Hungary)
G.C. Tsuei	(Taiwan)	M. Veronneau	(Canada)		

Corresponding Members*:*

H. Duquenne	(France)	J. Fernandes	(Portugal)	Y. Fukuda	(Japan)
C. Hwang	(Taiwan)	C. Jekeli	(USA)	W. Kearsley	(Australia)
P. Knudsen	(Denmark)	J. Krynski	(Poland)	M. Kuhn	(Germany)
D. Milbert	(USA)	G. Papp	(Hungary)	K. Prijanta	(Indonesia)
L. Sanchez	(Colombia)	K. Zhang	(Australia)		

Corresponding Members (after the meeting in Banff):

V. Andritsanos	(Greece)	M.E. Ayhan	(Turkey)	A. Bayoud	(Canada)
L. Biagi	(Italy)	J. Brozena	(Canada)	G. Fotopoulos	(Canada)
A. Kenyeres	(Hungary)	C. Kotsakis	(Canada)	M. Pearse	(N. Zealand)
D.R. Roman	(USA)	G.S. Vergos	(Canada)		

LAND/MARINE GEOID MODELLING - SPECIFIC ACCOMPLISHMENTS

Different geoid or quasi-geoid determinations on a local or regional scale have been carried out by members of the SSG in different sea/land test areas using combinations of heterogeneous data sources referred to high degree and order geopotential solutions. The methods employed range from the classical numerical integration procedures, the spectral FFT techniques and the stochastic least-squares collocation algorithms to the input/output system theory algorithms in the frequency domain (Abd-Elmotaal 2000, Andritsanos and Tziavos 2000, Fotopoulos et al. 2000, Duquenne 2000, Rodriguez 1999, Toth et al. 2000, Tziavos 2000). The results obtained meet the today accuracy demands of a wide number of applications related to surveying, geodesy, geophysics and other disciplines of geosciences. The quality of the geoid heights produced in land areas was assessed by comparisons with corresponding heights at GPS benchmarks (see, e.g., Featherstone 2001, Marti et al. 2000, Toth et al. 2000). The use of GPS in combined adjustments with gravimetric geoid heights is discussed by Kotsakis and Sideris (2000). The estimated accuracy of the determined geoid/quasi-geoid heights reached in some cases the level of one decimeter and in pure marine geoid solutions found close to one centimeter (Fernandes et al. 2000, Rodriguez 2000, Vergos et al. 2001, Andritsanos 2000, Andritsanos et al. 2000). Gravimetric geoid solutions were also computed on a national scale by different authors and attempts were made to the direction of datum unification (see, e.g., Featherstone 2000, Marti et al. 2001, Fotopoulos et al. 2000, Toth et al. 2000).

Kotsakis (2000) discussed problems occurring in linear signal estimation from discrete gridded data and has drawn interesting conclusions related to modern operational geodesy and practical applications like local/regional geoid determination. Hwang and Lih-Shinn Hwang (2001) computed an improved geoid model for Taiwan with an accuracy ranging from 2 cm to 10 cm in order to assess the accuracy of orthometric heights and detect vertical rates of land motion. Toth et al. (2001) investigated the recovery of gravity and geoid in Hungary from torsion balance data using collocation and spectral techniques. A thorough comparative analysis on regional high-frequency geoid computations in Canada using a synthetic gravity field is given by Novak et al. (2000).

Several simulation studies were carried out in the frame of modelling the long wavelength part of the Earth’s gravity field taking advantage from the new satellite gravity missions of CHAMP, GRACE and GOCE. Tscherning (2001) has illustrated the advent of pure satellite gravity models by the new missions. These models will considerably improve our possibilities for computing precise quasi-geoidal differences. The expected accuracy could be better enough than that obtained by EGM96.

The effects of density variations on terrain corrections and the handling of topography in practical geoid determination were studied by several authors (see, e.g., Kuhn 2000, Omang and Forsberg 2000, Tziavos and Featherstone 2000, Biagi and Sanso 2000). The geophysical dimension of a regional quasi-geoid determination and its correlations with Moho depths and other geophysical parameters have been studied in several papers (see, e.g., Abd-Elmotaal 2000, Kuehtreiber and Abd-Elmotaal 2000, Toth et al. 2000). In the same frame and according to Molodensky theory efficient ways of computing the G1 term and the influence of the grid size of digital elevation models on quasi-geoid contribution has been also investigated (Merry 2001, Amod 2001). Tsoulis (2000) studied the spherical harmonic analysis of a global digital elevation model using the Airy/Heiskanen and Pratt/Hayford isostatic models.

The essential role of airborne gravimetry in combination solutions with marine gravity observations, satellite altimetry derived and land gravity for high resolution geoid computations is demonstrated in several studies (Bastos et al. 2000, Olesen et al. 2000). The increasing interest for new airborne gravity surveys during the last two years contributed to the better knowledge of the geoid and sea surface topography in different areas (Greenland, eastern Mediterranean and Crete island, Azores islands, Corsica). The geoid results reached the level of one decimeter or better in several cases in terms of standard deviation of the differences between the computed geoid heights and the corresponding heights derived from satellite altimetry (Andritsanos et al. 2000, Fernandes et al. 2000, Rodriguez 1999, Rodriguez and Sevilla 2000). Several authors discussed the role of satellite altimetry in gravity field modelling in self-seas and coastal areas and pointed out inherent problems when working across the land/sea boundary (see, e.g., Andersen and Knudsen 2000, Andritsanos 2000, Hipkin 2000, Vergos et al. 2001). Pure altimetric geoid solutions were carried out taking advantage from the most accurate mission of TOPEX/Poseidon and the high resolution geodetic missions of GEOSAT and ERS-1 (see, e.g., Fernandes et al. 2000, Vergos et al. 2000, Andritsanos et al. 2000). Moreover, marine geoid solutions were computed by combining altimetric data with shipborne gravity data in areas presenting geodynamic and oceanographic interest (see, e.g., Rodriguez 1999, Andritsanos 2000, Fernandez et al. 2000, Vergos et al. 2000).

FUTURE WORK

The geographical distribution of the members of the SSG made difficult their close cooperation and common research. However there was a collaboration between different members on an individual basis. The research carried out by the members of SSG during the last two years was mainly addressed in its different targets, promising results were reported and important conclusions were drawn with respect to regional geoid modelling. However, additional work should be done within the next two years until the General Assembly of IUGG in Saporo, Japan, in 1993. Some suggestions for future work are summarized as follows:

- Refinement of the procedures used for the computation and evaluation of the regional geoid/quasi-geoid solutions and their errors.

- Investigation of the comparison and combination techniques between geoid heights and GPS/levelling heights.

- More systematic analysis on the contribution of the new satellite gravity missions to the improvement of the long-wavelength part of a geoid/quasi-geoid determination.

- High-resolution marine geoid solutions by combining satellite altimetry, airborne and sea gravimetry data for oceanographic applications.

REFERENCES

Abd-Elmotaal, H.: A gravimetric geoid for Egypt derived by FFT techniques. Presented at *Gravity, Geoid and Geodynamics 2000,* Banff, Canada, July 31-August 4, 2000.

Abd-Elmotaal, H.: Vening Meinesz inverse isostatic problem with local and global Bouguer anomalies. *Journal of Geodesy*, 74/5, 390-398, 2000.

Amod, A.: *The use of spectral methods in quasi-geoid determination*. Ph.D. Thesis, Dept. of Geomatics, University of Cape Town, 2001.

Andersen, O.B. and P. Knudsen: The role of satellite altimetry in gravity field modelling in coastal areas. *Phys. Chem. Earth (A),* vol. 25, No. 1, 17-24, 2000.

Andritsanos, V.D., and I.N. Tziavos: Estimation of gravity field parameters by a multiple input/output system. *Phys. Chem. Earth (A),* vol. 25, No. 1, 39-46, 2000.

Andritsanos, V.D., G.S. Vergos, I.N. Tziavos, E.C. Pavlis and S.P. Mertikas: A high-resolution geoid for the establishment of the GAVDOS multi-satellite calibration site. *Proceedings of Gravity, Geoid and Geodynamics 2000,* Banff, Canada, July 31-August 4, 2000.

Andritsanos, V.D., M.G. Sideris and I.N. Tziavos: Quasi-stationary sea surface topography estimation using input/output method and error analysis of satellite altimetry. Accepted for publication in *Journal of Geodesy*.

Andritsanos, V.D.: *Optimal combination of terrestrial and satellite data using spectral methods for applications to geodesy and oceanography*. Ph.D. Thesis, Dept. of Geodesy and Surveying, Aristotle Univ. of Thessaloniki, 2000.

Bastos, L., C. Cunha, R. Forsberg, A. Olesen, A. Gidskehaug, L. Timmen and U. Meyer: On the use of airborne gravimetry in gravity field modelling: experiences from the AGMASCO project. *Phys. Chem. Earth (A),* vol. 25, No. 1, 1-8, 2000.

Biagi, L. and F. Sanso: A new algorithm for fast RTC computation. Presented at *Gravity, Geoid and Geodynamics 2000,* Banff, Canada, July 31-August 4, 2000.

Duquenne, H.: The geoid in New Caledonia. *Private communication*, 2001.

Featherstone W.E.: Towards unification of the Australian height datum between the mainland and Tasmania using GPS and the AUSgeoid98 geoid model. *Geomatics Research Australasia*, 73, 30-40, 2000.

Featherstone W.E.: Absolute and relative testing of gravimetric geoid models using GPS and orthometric height data. Accepted for publication in *Computers and Geosciences*, 2001.

Fernandes, M.J., L. Bastos, J. Catalao: The role of multi-mission ERS altimetry in the determination of the marine geoid in the Azores, *Marine Geodesy,* 23, 1-16, 2000.

Fotopoulos, G., C. Kotsakis and M.G. Sideris: A new Canadian geoid model in support of levelling by GPS. *Geomatica,* 54.1, 53-62, 2000.

Hipkin, R.: Modelling the geoid and sea-surface topography in coastal areas. *Phys. Chem. Earth (A),* vol. 25, No. 1, 9-16, 2000.

Hwang , C. and L.S. Hwang: Use of geoid for assessing trigonometric height accuracy and detecting vertical land motion. Draft, 2001.

Kotsakis, C.: *Multiresolution aspects of linear approximation methods in Hilbert spaces using gridded data*. Ph.D. Thesis, Dept. of Geomatics Eng., University of Calgary, *UCGE Rep. Nr. 20138,* 2000.

Kotsakis, C. and M.G. Sideris: On the adjustment of combined GPS/levelling/geoid networks. *Journal of Geodesy*, 73/8, 412-421, 1999.

Kuehtreiber, N. and H.A. Abd-Elmotaal: Gravimetric geoid computation for Austria using seismic Moho data. Presented at *Gravity, Geoid and Geodynamics 2000,* Banff, Canada, July 31-August 4, 2000.

Kuhn, M.: Geoidbestimmung unter Verwendung verschiedener Dichtehypothesen. Ph.D. Thesis, *DGK, Reihe C,* Heft Nr. 520, Munich 2000.

Marti, U., A. Schlatter and E. Brockmann: The possibilities of combining levelling with GPS measurements and geoid information. Presented at the *EGS XXVI Gen. Assembly*, Nice, France, 26-30 March, 2001.

Merry, C.L.: *Personal communication*, 2001.

Novak, P., P. Vanicek, M. Veronneau, S. Holmes, W.E. Featherstone: On the accuracy of modified Stokes's integration in high-frequency gravimetric geoid determination. *Journal of Geodesy*, 74/9, 644-654, 2000.

Olesen, A.V., R. Forsberg, K. Keller, A. Gidskehaug: Airborne gravity survey of Linkoln Sea and Wandel Sea, north Greenland, *Phys. Chem. Earth (A),* vol. 25, No. 1, 25-30, 2000.

Omang, O.C.D. and R. Forsberg: How to handle topography in practical geoid determination: three examples. *Journal of Geodesy*, 74/6, 458-466, 2000.

Rodriguez, G., M.J. Sevilla, C. de Toro: Crossover analysis in the Canary-Azores region of ERS-1 altimetric data. *Bollettino di Geofisica Teorica ed Applicata,* 40, 3-4, 1999.

Rodriguez, G.: *Geoid studies using terrestrial and marine gravity data (in Spanish).* Ph.D. Thesis, Universitad Complutense de Madrid, 1999.

Toth, Gy., Sz. Rosza, V.D. Andritsanos, J. Adam and I.N. Tziavos: Towards a cm-geoid for Hungary: recent efforts and results. *Phys. Chem. Earth (A),* vol. 25, No. 1, 47-52, 2000.

Toth, Gy., Sz. Rosza, J. Adam and I.N. Tziavos: Gravity field recovery from torsion balance data using collocation and spectral methods. Presented at the *EGS XXVI Gen. Assembly*, Nice, France, 26-30 March, 2001.

Tscherning, C.C.: Geoid determination after the first satellite gravity missions (draft version). To appear in the Festschrift volume for Prof. Torge, 2001.

Tsoulis, D.: A comparison between the Airy/Heiskanen and the Pratt/Hayford isostatic models for the computation of potential harmonic coefficients. *Journal of Geodesy*, 74/9, 637-643, 2000.

Tziavos, I.N. and W. Featherstone: First results of using digital density data in gravimetric geoid computation in Australia. Proceedings of *Geodynamic, Gravity and Geoid 2000*, Banff, Canada, July 31-August 4, 2000.

Tziavos, I.N.: The geoid in the Mediterranean-Recent results and future plans. Invited paper, presented at the *FIG Symposium "Mediterranean Surveyors in the new millennium",* Malta, Sept. 18-21, 2000.

Vergos, G.S., F.A. Bayoud, M.G. Sideris and I.N. Tziavos: High-resolution geoid computation by combining shipborne and multi-satellite altimetry data in the eastern Mediterranean sea. Presented at the *EGS XXVI Gen. Assembly*, Nice, France, 26-30 March, 2001.

REPORT OF IAG SPECIAL STUDY GROUP 3.177

"SYNTHETIC MODELLING OF THE EARTH'S GRAVITY FIELD" (1999-2001)

http://www.cage.curtin.edu.au/~will/iagssg3177.html

W.E. Featherstone

Curtin University of Technology, Western Australia

INTRODUCTION

This report gives the Chair's perspective of work undertaken by IAG SSG 3.177 between August 1999 and April 2001. It is important to acknowledge that, due to time and space constraints, not all SSG members' activities have been included; for this I apologise.

The primary objective of this SSG is to construct *synthetic models of the Earth's gravity field* for use in geodesy. Such models were not widely available to the geodetic research community, which is at odds with some other areas of the Earth sciences. Instead, geodetic gravity field researchers tended to rely on empirical methods to validate their results. The availability of a synthetic gravity field model avoids this undesirable scenario and can give a more independent and objective validation of the procedures used.

The ultimate outcome of this SSG will be theories, methodologies/software and synthetic models, which will probably be distributed via the IAG or IGGC. It is anticipated that these will allow for objective testing of the theories and methodologies used in gravity field determination and modelling. Indeed, they may even contribute to the resolution of some of the procedural differences currently encountered between gravity field researchers around the world.

A significant progression since the last report to the IAG is that new synthetic gravity fields (including grids of self-consistent gravity anomalies, geoid heights and vertical deflections at the geoid) and software packages for constructing synthetic gravity fields have been made available via the SSG's web-page (http://www.cage.curtin.edu.au/~will/iagssg3177.html).

MEMBERSHIP

Full Members

Will Featherstone (Australia, Chair)
Erik Grafarend (Germany)
Roger Hipkin (United Kingdom)
Christopher Jekeli (USA)
Zdenek Martinec (The Czech Republic)
Yoichi Fukuda (Japan)
Roger Haagmans (Norway)
Simon Holmes (Australia)
Rüdiger Lehman (Germany)
Yuri Neyman (Russia)

Roland Pail (Austria)
Gabor Papp (Hungary)
Doug Robertson (USA)
Walter Schuh (Austria)
Gabriel Strykowski (Denmark)
Gyula Toth (Hungary)
Ilias Tziavos (Greece)
Petr Vanicek (Canada)
Peter Vajda (The Slovak Republic)
Martin Vermeer (Finland)

Corresponding Members

Giampietro Allasia (Italy)
Sten Claessens (The Netherlands)
Hans Engels (Germany)
Jonathan Evans (United Kingdom)
Rene Forsberg (Denmark)
Jonathan Kirby (Australia)
Michael Kuhn (Germany)
Gabi Laske (USA)
Adam Dziewonski (USA)
Marcel Mojzes (The Slovak Republic)
Edward Osada (Poland)
Mensur Omerbasie (Canada)
Spiros Pagiatakis (Canada)
Dean Provins (Canada)
Michael Sideris (Canada)
Dru Smith (USA)
Hans Sünkel (Austria)
Christian Tscherning (Denmark)
Judit Benedek (Hungary)

SYNTHETIC FIELDS BASED ON SPHERICAL HARMONICS - EFFECTS MODELS

Some members have used ultra-high-degree spherical harmonics to construct synthetic gravity field models. One such model, computed at Curtin University of Technology, Australia, extends to degree 5400 (to 45 degrees latitude) and to degree 2700 (over the whole Earth). These limits are set by computer underflow and overflow errors in IEEE double precision. The ultra-high-degree coefficients have been created artificially by scaling and recycling EGM96 and GPM98 coefficients (ie. an 'effects' model). Fully normalised associated Legendre functions have been modified to avoid numerical instabilities (Holmes and Featherstone, 2001). The degree-variance of this synthetic model has been constrained to follow that of the Tscherning-Rapp model beyond degree-1800.

This synthetic gravity field has been used to construct self-consistent geoid heights and gravity anomalies at the geoid, which can then be used to test geoid-computation algorithms and software as follows. The synthetic spherical harmonics are used to compute the magnitude of gravity at the geoid (defined by the synthetic model), then normal gravity at the ellipsoid subtracted to yield gravity anomalies. These synthetic gravity anomalies are used as input into geoid computation algorithms and software, then the geoid output is compared with the self-consistent, synthetic geoid heights. Any differences between the computed and synthetic geoid can then be attributed to algorithmic and/or software errors.

Featherstone (1999) has used this approach and an earlier version of this synthetic model over Western Australia to test the theories and software used to produce AUSGeoid98. This study shows that, when using error-free gravity data (which, of course, is not the case in practice), the standard deviation of the error committed due to the algorithms and computer software is ±0.008m (max=0.035m, min=–0.035m, mean=0.000m).

A similar study was conducted by Novak *et al*. (2001) to validate the Stokes-Helmert and modified kernel theories used at the University of New Brunswick, Canada. This shows that the theory and software, used for some recent Canadian geoid models, is capable of producing a geoid with centimetre accuracy. The standard deviation of the error committed when using quadrature-based numerical integration of the modified Stokes's formula is ±0.010m (max=0.039m, min=–0.030m, mean=0.003m) and when using the fast Fourier transform is ±0.011m (max=0.045m, min=–0.036m, mean=0.003m). Recent work at the University of New Brunswick shows that extreme care must be used when dealing with terrain corrections during the construction of mean Helmert anomalies in mountainous regions.

Experiments, due to be reported at the 2001 IAG General Assembly, will use a refinement of the above synthetic gravity field to test the gravimetric computation of vertical deflections using modifications of Vening-Meinesz's formulae. Regular geographic grids of self-consistent geoid heights, gravity anomalies and vertical deflections (at the geoid) over Greece (18E-30E, 34N-42N) and Australia (108E-160E, 8S-45S) are available at the SSG's web-site. The Greek data are given on a 5' by 5' grid (degree 2160), and the Australian synthetic data are given on a 2' by 2' grid (degree 5400).

SYNTHETIC FIELDS BASED ON MASS-DENSITY - SOURCE MODELS

Point-mass models continue to be a useful means of modelling the external gravity field. Through the numerical (or even analytic; see later) integration of Newton's integrals, self-consistent values of the gravitational potential and acceleration can be generated (ie. a 'source' model).

Claessens *et al*. (2001) use 500 free-positioned point masses beneath the Perth region of Western Australia to construct a geoid model consistent with gravity observations. This study led to the identification of some quite serious errors in the Australian marine gravity database, as well as confirming the misfit between satellite-altimeter-derived gravity anomalies in near-coastal regions. As such, this synthetic gravity field has indirectly found an additional application in detecting errors in regional gravity data.

During the same study, an issue relevant to generating a synthetic gravity field from free-positioned point masses was identified. Specifically, if gravity observations are used to attempt to construct a synthetic field that is as realistic as possible, large masses may be positioned in areas devoid of observations. These subsequently cause very large synthetic gravity and geoid values to be produced in these areas, which are not necessarily realistic. This study implies that such synthetic fields should use fixed-positioned masses, which also reduces the computational burden.

Allasia (2001) has developed analytic solutions of Newton's integral for a continuous mass-density distribution. This paper has set a theoretical framework, but no practical application of this method has yet been made. It is thus recommended that SSG members begin to collaborate with Allasia to undertake practical computations to generate a synthetic gravity field. This method appears to have the potential to generate a completely error-free (ie. with no approximations) synthetic gravity field. It may also be possible to generate gravity field quantities inside the topographic masses, but further work is probably required.

Lehmann (2000) has produced a synthetic gravity field model using MATLAB (version 4.2 or later) script files, principally to test altimetry-gravimetry problems. However, this synthetic field can also be adapted, or used directly, to generate other gravity field quantities, such as spherical harmonics between degrees 11 and 2160. This synthetic field is based on an axisymmetric model of the Earth that is made as realistic as possible. Pseudo-random, un-correlated noise can be introduced into this model. A copy of the 'user manual' and the MATLAB script files are available via the SSG's web-site.

Haagmans (2000) has constructed a global synthetic gravity field model that can generate gravity field quantities exterior to the Earth's surface at various spatial resolutions, and at aircraft and satellite altitudes. The model is based on a spherical harmonic expansion of an isostatically compensated topography and the EGM96 global geopotential model. The maximum degree is 2160, which corresponds to a spatial resolution of 5' by 5'. This synthetic field is available directly from the author.

Work on forward gravity field modelling of prism-based mass-density models continues. Papp and Benedek (2000) have used Newtonian integration of a three-dimensional topographic mass-density model to determine curvature of the plumblines. Nagy *et al*. (2000) have published a review-type paper on determining gravity field quantities from prisms. Papp (2000), Benedek (2000) and Kuhn (2000) have presented papers related to the use of mass-density data in synthetic modelling of the gravity field and to geoid computation.

Papp and his group continue to develop the three-dimensional model of the lithosphere in Central Europe. The depth-density model of the sediments has been modified according to the research results of the Eötvös Loránd Geophysical Institute by separating the sediments into two groups (Transdanube/West Hungary and Great Hungarian Plane/East Hungary). The lithospheric model was also extended towards the East (Romania), where the Transylvanian Basin and the Vrancea region (plate subduction) are dominant.

The geophysical community is conducting work relevant to the construction of a synthetic gravity field for use in geodesy. These studies are based on forward modelling to generate gravity and magnetic fields due to reasonably sophisticated geological structures. One of these software packages, *Noddy*, uses Hjelt's dipping prism equations and frequency domain methods to calculate the potential field response from a three-dimensional geological model. Other geological forward modelling software, some of which is in the public domain, is given at http://www.earth.monash.edu.au/~mark/strmodlinks.html.

Work on the Reference Earth Model (REM), the follow-on from Dziewonski and Anderson's PREM, also continues, but that group seems to be focussing more on the seismic properties of the Earth.

SUGGESTED FUTURE WORK (2001-onwards)

In order not be too prescriptive over the future activities of SSG 3.177, the following are suggested directions to the Group. Firstly, it is important to recognise that different authors are investigating different, yet complementary, approaches to the construction of the synthetic gravity field. This in itself is essential so that there is cross fertilisation of ideas and, moreover, tests on the synthetic field(s) that may eventually be used as control.

It is realistic to expect that preliminary synthetic fields will continue to be customised to accommodate a specific area of study. For example, comparisons of approaches to Stokesian integration on a regional scale (eg. Novak *et al*., 2000) probably require a synthetic field of different functionality to that used for, say, detailed investigation of plumbline geometry (eg. Papp and Benedek, 2000). Of course, a 'complete' synthetic field could be used for both, but separate synthetic fields are more convenient initially. With this qualification, the following are offered as a list of characteristics and features that a complete synthetic gravity field model could contain.

For a complete synthetic gravity field model, which is constructed from geophysical forward modelling, the following should be considered:

- Realistic models of the Earth’s topography by the densest available digital elevation models, which can be extended artificially to higher resolutions.

- Realistic models of the mass-density distribution within the deep Earth, crust and topography, probably using *a priori* geophysical models from other disciplines.

- Realistic models of the modes and depths of isostatic compensation and other boundaries that are characterised by large mass-density contrasts.

- Realistic models of noise and systematic errors (correlated and un-correlated), which can be varied by the user for sensitivity analyses.

Most importantly, the model should rely on as few assumptions as possible so that it can be used to test the assumptions currently in use. In addition, the use of realistic and accepted models of the Earth should guarantee that the results from the synthetic field can be applied to the real Earth.

It is envisaged that complete synthetic gravity field models should at least offer the following features:

- Generation of the synthetic field in different formats; these being point, grid or mean values of geoid, gravity anomalies, gravity gradients and vertical deflections.
- A spherical harmonic series expansion with various spectral error characteristics.
- Generation of point, grid and mean gravity data with various error characteristics.
- Generation of vector gravity data above and within the Earth’s physical surfaces.

Ideally, the model will generate gravity to <1microGal and the geoid to <1mm at all frequencies, though this aim may prove to be over-optimistic; but let us try!

REFERENCES

Allasia G (2001) Approximating potential integrals by cardinal basis interpolants on multivariate scattered data , *Computers and Mathematics with Applications* (in press)

Benedek (2000) The effect of point density of gravity data on the accuracy of geoid undulations investigated by 3D forward modelling. Presented to *Gravity Geoid and Geodynamics 2000*, Banff, Canada.

Claessens S, Featherstone WE, Barthelmes F (2001) Experiments with free-positioned point-mass geoid modelling in the Perth region of Western Australia, *Geomatics Research Australasia*, (submitted in 2000)

Featherstone WE (1999) Tests of two forms of Stokes's integral using a synthetic gravity field based on spherical harmonics, in: *Festschrift Erik Grafarend*, University of Stuttgart, Germany.

Haagmans R (2000) A synthetic Earth model for use in geodesy, *Journal of Geodesy* 74: 503-511.

Holmes SA, Featherstone WE (2001) A generalised approach to the Clenshaw summation and the recursive computation of very-high degree and order normalised associated Legendre functions, *Journal of Geodesy* (submitted in 1999).

Kuhn M (2000) Density modelling for geoid determination. Presented to *Gravity Geoid and Geodynamics 2000*, Banff, Canada.

Lehmann, R. (2000) Technical description of the axisymmetric experiment for the study of the altimetry-gravimetry problems of geodesy, (publications details unknown)

Nagy D, Papp G, Benedek J (2000) The gravitational potential and its derivatives for the prism, *Journal of Geodesy*, 74 (7/8): 552-560.

Novak P, Vanicek P, Veronneau M, Holmes S, Featherstone WE (2001) On the accuracy of modified Stokes's integration in high-frequency gravimetric geoid determination, *Journal of Geodesy*, 74(11): 644-654.

Papp G (2000) On some error sources of geoid determination investigated by forward gravitational modelling. Presented to *Gravity Geoid and Geodynamics 2000*, Banff, Canada.

Papp G, Benedek J (2000) Numerical modelling of gravitational field lines – the effect of mass attraction on horizontal coordinates, *Journal of Geodesy*, 73(12): 648-659.

USE OF REMOTE SENSING TECHNIQUES FOR VALIDATING HEIGHTS AND DEPTHS

MIDTERM REPORT FOR SSG 3.184

Philippa Berry

Meetings have been held on an ad-hoc basis at conferences, supplemented by email correspondence. Work on several different radar based techniques for remotely sensed height determination is being carried out by members of this study group.

A global scale assessment of current Global Digital Elevation Models has been performed using an independently derived height dataset, containing over 100 million points. These data were calculated from satellite altimeter data from the ERS-1 Geodetic Mission. Models evaluated include GLOBE v1., GTOPO30, JGP95E, Terrain Base and ETOPO5. The results confirm the presence of substantial errors common to all models tested. These errors have been attributed to reliance on a common stock of a small number of data sources. The most consistent agreement was obtained where data were sourced from DTED; poor results were generally obtained where the source was Digital Chart of the World or the International Map of the World.

Because these errors were found to be contaminating existing GDEMs very significantly, it was decided to create a new GDEM, ACE (Altimeter Corrected Elevations, produced at De Montfort University) by fusing the best of the available ground truth with a DEM derived from the satellite-based dataset. The first release of this new GDEM has just been made. Globally, 28% of values have been outright replaced with new altimeter based data, and a further 17% corrected for vertical misplacement. The new model is currently being evaluated by members of this group.

However, this approach does not enable detailed mapping, nor mapping over mountainous regions where altimeters to date have lost lock. Several different techniques and missions have been deployed to create accurate detailed DEM data on a global scale. The recently flown Shuttle Topographic Mission created a huge dataset which is currently being processed. Data post-processing has proved very complex, resulting in some delays to the original schedule. However, results should be released soon, enabling assessment of these vital new DEM data to be carried out within the next two years. Additionally, work on InSAR and stereo SAR derived DEMs continues, forming another increasingly important datastream as the application of these techniques to mapping becomes more widespread.

The launch of Envisat within the next few months should further increase the available data pool, both by providing an additional source of SAR data and by deploying the RA-2, an altimeter configured with an additional tracking mode to allow the instrument to remain in lock over more extreme terrain.

All indications are that within the life of this working group, a considerable advance will have been made in the mapping of the earth’s topographic surfaces.

Mid-Term Report of SSG 3.185 (1999–2001)

MERGING DATA FROM DEDICATED SATELLITE MISSIONS WITH OTHER GRAVIMETRIC DATA

Nico Sneeuw

Institut für Astronomische und Physikalische Geodäsie
Technische Universität München
sneeuw@bv.tum.de

This report describes the activities and accomplishments of the special study group (SSG) 3.185, Merging data from dedicated satellite missions with other gravimetric data, in the time-frame 1999-2001. The general objectives of SSG 3.185 are to investigate issues related to merging (spatial domain, spec-trally and/or normal matrix combination) and to come up with results and proposals that may support CHAMP/GRACE/GOCE communities in their data processing and merging strategies.

1 Members

The special study group 3.185 consists of the following members:

Sneeuw N (president)	IAPG, TU Munich	Germany
Albertella A	DIIAR, Politecnico Milano	Italy
Bettadpur SV	CSR, Univ. Texas	USA
Bouman J	SRON, Utrecht	The Netherlands
Bruton AM	AGEM, Univ. Calgary	Canada
Gruber T	GFZ Potsdam	Germany
Kenyon S	NIMA	USA
Kusche J	DEOS, Delft Univ. Technology	The Netherlands
Lemoine JM	CNES, GRGS	France
Pavlis NK	Raytheon ITSS Corp	USA
Schuh WD	TG, Univ. Bonn	Germany

At the beginning of the study group activities Bouman's affiliation was the Delft University of Technology, The Netherlands, whereas Kusche was at the University Bonn, Germany. Sneeuw will start at the University of Calgary in the course of 2001.

2 Activities

E-mail discussion: Interaction between the members of SSG 3.185 has been stimulated by putting forward certain questions through e-mail. There have been two provocative questions so far:

1. In view of the expected accuracy of the gravity field missions CHAMP and GOCE: why would we need old satellite data? This question was discussed from several viewpoints:

    a) reprocessing of orbits, e.g. for altimetry

    b) decorrelation of gravity field parameters

    c) a priori information and regularization

    d) calibration

    e) time-varying gravity field, especially low degrees

2. When merging satellite data with terrestrial data: how does the inhomogeneity of the terrestrial database affect the satellite results? This discussion hasn't been closed yet. Partial answers to this question are found in the work by Pavlis and by Kusche, cf. references.

Validation working group Gruber chairs the IGeS working group Preparation of Standard Procedures for Global Gravity Field Validation. Members areamongst others Albertella, Kenyon, Pavlis and Sneeuw. Objective of the working group is the definition of standard test procedures for global gravity field evaluation. These activities entail the validation of satellite gravity field solutions with terrestrial data and hence cover many aspects of SSG 3.185.

Simulation data set Kusche has strongly been involved in the provision of simulated data sets for CHAMP, GRACE and GOCE. This was a joint activity with Special Commission SC7 Satellite Gravity Field Missions, chaired by K.-H. Ilk, and SSG 2.193 Gravity field missions: calibration and validation, chaired by P. Visser. These data are available on CD and on-line through http://www.geod.uni-bonn.de/SC7-data/. They are of tremendous help in validating gravity recovery software, merging schemes and so on.

Ph.D. theses Four members of the SSG finished their Ph.D. theses on areas relevant to the SSG: Bouman, Bruton, Gruber and Sneeuw. See the list of references.

GRACE Bettadpur and Gruber are GRACE project team members. In particular they are involved in the GRACE science data processing system, which touches on many aspects of the SSG's goals.

GOCE Albertella, Bouman, Gruber, Kusche, Schuh and Sneeuw actively participate in the GOCE project and in studies of the European Space Agency (ESA) on GOCE-related issues, e.g. (Sünkel, 2000). Especially issues like merging SST with SGG, regularization, local data in polar gaps and other SSG-related objectives are addressed.

3 Selected meetings

The members of SSG 3.185 participated at several meetings, giving presentations and contributing to the proceedings. Participation of SSG-members was never high enough, though, to warrant a formal SSG-meeting. Discussion of the relevant SSG-topics was therefore—beside the aforementioned e-mail discussions—restricted to informal contacts. The following list of meetings contains the highlights, although it is certainly not com-plete:

EGS 2000 Nice, France. In particular session G3.01 The Earth gravity field (joint EGS/AGU): Global high-resolution geopotential modelling

GGG 2000 Banff, Canada. Gravity, Geoid and Geodynamics 2000

AGU 2000 Fall Meeting San Francisco, USA

German Geodetic Week 2000 Potsdam, Germany

EGS 2001 Nice, France. In particular session G1 The new gravity missions (CHAMP GRACE, GOCE)

4 Relevant publications by members of the SSG

Albertella A, F Sans`o, N Sneeuw (1999). Band-limited functions on a bounded spherical domain: the Slepian problem on the sphere, J. Geodesy 73:436-447

Albertella A, N Sneeuw (2000). The Analysis of Gradiometric Data with Slepian Functions, Phys. Chem. Earth (A) 25(9–11):667–672

Bouman J (2000). Quality assessment of satellite-based global gravity field models, NCG Publications on Geodesy 48

Bruton AM (2000). Improving the Accuracy and Resolution of SINS/DGPS Airborne Gravimetry,UCGE Report 20145

Glennie CL, KP Schwarz, AM Bruton, R Forsberg, AV Olesen, K Keller (2000). A comparison of stable platform and strapdown airborne gravity, J. Geodesy 74:383–389

Gruber T (1999). Global Gravity Field Modelling, in: National Report of the Federal Republic of Germany on the Geodetic Activities in the Years 1995-1999, compiled by: B Heck, R Rummel, E Groten, H Hornik; DGK Reihe B, Heft Nr 308, München 1999

Gruber T, C Reigber, P Schwintzer (2000). The 1999 GFZ pre-CHAMP high resolution gravity model, in: K.P. Schwarz (Ed.) Proceedings of IAG Symposium 121, Geodesy Beyond 2000 –The Challenges of the First Decade, pp 89–95

Gruber T, A Bode, C Reigber, P Schwintzer, G Balmino, R Biancale, J-M Lemoine (2000). GRIM5-C1: Combination solution of the global gravity field to degree and order 120, Geophys. Res. Letters 27(24):4005-4008

Gruber T (2000). Hochau oesende Schwerefeldbestimmung aus Kombination von terrestrischen Messungen und Satellitendaten ueber Kugelfunktionen, Scientific Technical Report STR00/16, GeoForschungsZentrum Potsdam

Gruber T (2001). High Reslution Gravity Field Modeling with Full Variance-Covariance Matrices, submitted to J. Geodesy , 7-2000

Kusche J, KH Ilk, S Rudolph (2000). Impact of terrestrial data on future satellite gravity field solutions, in: Towards an Integrated Global Geodetic Observing System (IGGOS), R Rummel, H Drewes, W Bosch, H Hornik (eds.), IAG symposium 120, pp. 189–192, Springer

Kusche J, R Klees (2001). Regularization for GOCE, submitted

Kusche J (2001). Implementation of multigrid solvers for satellite gravity anomaly recovery, J. Geodesy 74:773–782

Pavlis NK (2000). On the modeling of long wavelength systematic errors in surface gravimetric data, in: K.P. Schwarz (Ed.) Proceedings of IAG Symposium 121, Geodesy Beyond 2000 –The Challenges of the First Decade, pp 131–136

Sneeuw N (2000). A semi-analytical approach to gravity field analysis from satellite observations, Deutsche Geodätische Kommission, Reihe C, Heft Nr. 527 see also: http://tumb1.biblio.tu-muenchen.de/publ/diss/bv/2000/sneeuw.html

Sünkel H (ed.) (2000). From Eötvös to mGal, ESA/ESTEC contract No. 13392/98/NL/GD

MIDTERM REPORT OF SPECIAL STUDY GROUP 3.186:

ALTIMETRY DATA PROCESSING FOR GRAVITY, GEOID AND SEA SURFACE TOPOGRAPHY DETERMINATION

Cheinway Hwang

Department of Civil Engineering, National Chiao Tung University, 1001 Ta Hsueh Road, Hsinchu 300, Taiwan, ROC

1. Introduction

This midterm report summarizes the background, research goals, members and current results of IAG SSG 3.186. Since the Seasat mission of 1978, satellite altimetry has found its wide applications in geodesy, geophysics and oceanography. As new satellite missions such as GFO-1, ENVISAT JASON-1, and CRYOSAT will contribute more to the existing data sets of Seasat, Geosat, ERS-1/2, and TOPEX/POSEDION, these applications will continue to grow. But there are still many applications to be explored, many problems to be solved, and many data processing techniques to be improved. For example, coastal geoids, gravity anomalies tide models and bathymetry models derived from satellite altimetry have important engineering applications, which did not receive much attention in the past. But exploiting satellite altimetry in coastal areas requires much more sophisticated correction models and data processing techniques than in the open oceans. The data and coordinate systems of different satellite missions should be properly weighted/corrected and unified in order to obtain an optimal multi-satellite data set for subsequent analyses. Shipborne gravity data are abundant in many areas of the oceans, and have high quality and good spatial resolution. They should be combined with altimetry data for global gravity and geoid computation and estimation of high-degree geopotential model. Bathymetry model is an important element in, e.g., the general circulation model of the world oceans and the hydrodynamic tide model, and should be optimally derived with altimetry and other data. Eddies in coastal areas are associated with coastal upwellings, which are extremely important for marine production.

SSG 3.186 encourages members to tackle the following problems:

(1) improving the quality of coastal altimeter data by improving geophysical corrections, retracking waveforms and "tuning" altimeter measurements.

(2) promoting engineering applications of coastal altimetry with high quality coastal geoid, gravity anomaly, bathymetry, ocean tide and sea surface topography models from altimetry.

(3) investigating the best method and the best altimeter data type for computing gravity anomalies, mean sea surface heights from multi-satellite altimeter data

(4) developing a best technique to compute bathymetry from altimeter-derived geoids or gravity anomalies, with emphasis on the downward continuation and filtering problems.

(5) finding a best strategy and data sources to combine shipborne gravity/airborne gravity and altimeter data for generating global and regional gravity anomalies and geoids.

(6) improving orbit accuracies of altimetric satellites and accuracies of the long wavelength gravity field by crossover and other methods.

(7) unifying the coordinate systems between two or more satellite missions for determining long-term time series of oceanographic parameters.

2. Members

Currently there are 21 members from 12 countries in SSG 3.186. They are mostly university professors, doctoral students and research scientists. For doctoral students, their research topics more or less fit the recommended research topics of SSG 3.186 (see above). A list of members and their email addresses is shown in the following table.

Name (country)	Email address
V. D. Andritsanos (Greece)	bandrit@edessa.topo.auth.gr
O. Andersen (Denmark)	oa@kms.dk
D. Chao (China)	dbchao@wtusm.edu.cn
S. A. Chen (Taiwan)	chen@geodesy.cv.nctu.edu.tw
X. Deng (Australia)	xiaolid@vesta.curtin.edu.au
C. Hwang (Taiwan)	hwang@geodesy.cv.nctu.edu.tw
Y. Fukuda (Japan)	fukuda@kugi.kyoto-u.ac.jp
J. W. Kim (Korea)	jwkim@kunja.sejong.ac.kr
J. Klokocnik (Czech Republic)	jklokocn@asu.cas.cz
P. Knudsen (Denmark)	pk@kms.dk
J. Li (China)	jcli@wtusm.edu.cn
P. Hsu (Taiwan)	patri@geodesy.cv.nctu.edu.tw
P. Medevedev (Russia)	pmedv@wdcb.rssi.ru
P. Moore (UK)	moorep@aston.ac.uk
M. Rentsch (Germany)	rentsch@gfz-potsdam.de
T. Schoene (Germany)	tschoene@gfz-potsdam.de
C. K. Shum (USA)	ckshum@osu.edu
G. S. Vergos (Canada)	gsvergos@ucalgary.ca
G. Venuti (Italy)	giove@ipmtf4.topo.polimi.it
Y. Wang (USA)	ywang@magus.stx.com
Y. Yi (USA)	yi.3@osu.edu

3. A summary of current activities and results of members

The geodesy group in the Civil Engineering, National Chiao Tung University (lead by C. Hwang) and the group in the Ohio State University (lead by CK Shum and Y. Yi) are jointly testing algorithms for retracking ERS-1 waveforms over the continental shelf of east Asia. This is an attempt to see the effect of retracked altimeter data in improving accuracy and resolution of geoid and gravity anomaly determination in the shallow waters. Furthermore, Hwang and Hsu (2001) derive global mean sea surface heights (SSHs) on a 2´×2´ grid using Seasat, Geosat (ERM and GM), ERS-1 (1.5-year mean of 35-day, and GM) and TOPEX/POSEIDON (T/P) (5.6-year mean), ERS-2 (2-year mean) and Geosat-Follow-On (GFO) (18-month mean) altimeter data over the regions 0°-360° longitude and -82°-82° latitude. Hwang and Chen (2000a) use TOPEX/Poseidon (T/P) altimeter data to compute time-varying circulation and eddies over the South China Sea (SCS) for 1993-1999. Hwang and Chen (2000b) use 5.6 year of T/P sea level time series to identify important signals of the South China Sea by Fourier and wavelet analyses.

Deng and Featherstone (2000) analyze Poseidon (January 1998 to January 1999) and ERS-2 (March 1999 to April 1999) altimeter data in an area extending up to 350km from the Australian coasts (Deng and Featherstone, 2000). They investigate the behavior of the altimeter data in coastal regions and estimate a possible boundary around Australia's coasts in which the altimeter range may be estimated poorly. Using the standard deviation of the mean power of the returned waveforms as an indication of the general variability of the altimeter returns, shows obvious coastal contamination out to ~4km, and less obvious contamination out to ~8km. The results from individual waveforms indicate that the data contamination varies with the type of shoreline topography, which in turn leads to a distance-varying contamination around Australia.

Vergos and Sideris (2001) investigate the possibility of improving the estimation of the bottom topography of the Earth's oceans using gravity data in two extended test areas. The first area is located in the Mediterranean Sea, and the other one is across the mid Atlantic ridge bounded by 40^{o} £ f £ 50^{o} and 330^{o} £ l £ 340^{o}.

The Danish group (lead by Andersen and Knudsen) is continuing to improve the accuracy of gravity and mean sea surface determination, as well as the accuracy of global ocean tide model. Their recent results can be found in Andersen et al (2000) and Andersen and Knudsen (2000).

The Danish group (lead by Andersen and Knudsen) is continuing to improve the accuracy of gravity and mean sea surface determination, as well as the accuracy of global ocean tide model. Their recent results can be found in Andersen et al (2000) and Andersen and Knudsen (2000).

Rentsch et al. (2000) generate a global 2' by 2' high-resolution grid of marine gravity anomalies by processing upgraded altimeter data from the Geodetic Missions of Geosat and ERS-1. They also retrack ERS-2 waveforms in the Chinese Sea. A much higher along-track resolution is achieved from the retracked altimeter profiles and has improved the accuracy of the marine gravity field model. However, new problems arise by using such data, e.g. a higher noise level and the absence of convenient corrections like ocean tide and wet tropospheric path delay.

Klokonick et al. (2000) investigate the single- and dual-satellite Crossover (SSC and DSC) residuals between and among Geosat, T/P, and ERS 1 or 2. They present the theory and give various examples of certain combinations of SSC and DSC that test for residual altimetry data errors.

Wang (2000) compute a global set of mean SSH using TOPEX, ERS-1 and Geosat data. Inter-comparisons show that the root mean square values of the difference in mean SSH are 6.8, 6.8 and 7.2 between GSFC98/OSU95, GSFC98/CRS95, and OSU95/CSR95.

Andritsanos and Tziavos (2000) investigated the method of multiple input and output for gravity parameter recovery.

4. Challenges and future works

One challenge is in the shallow waters, where altimeter data quality is seriously degraded. Here waveform retracking can improve the situation, but more work is still needed. In particular, tide model accuracy must be significantly improved in order to have the possibility of coastal applications of satellite altimetry. Another challenge is the combination of data from multi-sensors, such as satellite/air-borne altimeters, ship/air-borne gravimeters, for marine geoid/gravity determination. Different sensors have different noise levels and spatial resolutions, which make the combination a difficult task. To the SSG3.186 members, the determination of oceanic dynamic topography, which is important for determining ocean circulations, is a subject not well studied at the current stage, especially in the coastal areas. It is indeed very desired to see if coastal oceanography can benefit from satellite altimetry. Finally, many of the groups have computed global sets of marine gravity and mean SSH, so it will be necessary to perform an inter-comparison of these results and compute an optimal set from these various sets using a weighted average method, something like the method for combing the IGS orbit of GPS. SSG3.186 may then presents this optimal set of marine gravity and mean SSH to the world scientific community for various applications.

5. SSG3.186-related publications of members

Andritsanos, V.D., and I.N. Tziavos, 2000. Estimation of gravity field parameters by a multiple input/output system. Phys. Chem. Earth (A), 25 (1), 39-46.

Andersen, O.B., and P. Knudsen, 2000. The role of satellite altimetry in gravity field modeling in coastal areas, Phys. Chem. Earth, 25 (10), 17-24.

Andersen, O.B., P. Knudsen and R. Trimmer, 2000. The KMS99 global gravity field from ERS and Geosat altimetry, Proc. ERS-Envisat Symp. 2000, Göteborg, Sweden.

Deng, X. and W. Featherstone, 2000. Analysis of ERS-2 satellite altimeter waveform data around Australian coasts, paper presented to the Annual Research Seminar, The University of New South Wales, Sydney, Australia, 20-21 November, 2000.

Hwang, C, and S.-A. Chen, 2000a. Circulations and eddies over the South China Sea derived from TOPEX/Poseidon altimetry, J. Geophys. Res.,105, 23,943-23,965, Hwang, C., and S.-A Chen, 2000b. Fourier and wavelet analyses of TOPEX/Poseidon-derived sea level anomaly over the South China Sea: A contribution to the South China Sea Monsoon Experiment, J. Geophys. Res., 105, 28,785-28,804.

Hwang, C, and H.-Y. Hsu, 2001. A global mean sea surface grid from Seasat, Geosat, ERS-1, and TOPEX/POSEIDON altimetry: application of deflection-geoid formula, abstract submitted to the IAG Scientific Assembly, Budapest, 2-9 September, 2001.

Klokonick, J., C.A. Wagner and J. Kostelecky, 2000. Residual errors in altimetry data detected by combinations of single- and dual-satellite crossovers, J. Geod., 73, 671-683.

Medvedev, P., 2001. The use of the satellite altimetry data for Sea of Okhotsk and Caspian Sea studies and the plans of GPS and GLONASS applications, abstract submitted to the IAG Scientific Assembly, Budapest, Sep 2-9, 2001.

Rentsch, M., A. Braun, T. Schöne, T. Gruber, and P. Schwintzer, 2000. Recent results and applications from GFZ marine gravity grids, EGS XXV General Assembly, Nice, France, 26 April, 2000.

Vergos, G.S., and M.G. Sideris, 2001. Improving the estimation of bottom ocean topography with satellite altimetry derived gravity data using the integrated inverse method, abstract submitted to the IAG Scientific Assembly, Budapest, 2-9 September, 2001.

Wang, Y., 2000. The satellite altimeter data derived mean sea surface GSFC98, Geophys. Res. Lett., 27 (5), 701-704, 2000.

BGI ACTIVITIES 1999-2000

- scanning of entire BGI database of gravity reference stations (about 5000 stations). The corresponding database will be on line in March 2001 (the BGI is completing tests).

- updating of the literature database. About 2000 recent publications (period of the 90's) have been re-entered into the database. For each publication, it has been addressed up to 5 key words chosen from an updated list. The literature database will be on line in June 2001 and the list of keywords will be published in the BGI Bulletin.

- rebuilding of the database of addresses (more than 2000 addresses or list of contacts are currently under review).

- complete rewriting of the query procedures on the BGI gravity database under Oracle Developer/forms, the TSO procedures being no longer supported.

- BGI involvement to the new gravimetric networks of North Africa, with O.S.S. (Observatoire du Sahara et du Sahel), O.A.C.T. (Organisation Africaine de Cartographie et de télédetection, O.T.C. (Office de Topographie et de Cartographie Tunisien).

- BGI participation to IGeS Geoid School in Johor (Malaysia). Presentation of validation techniques.

- new software for the detection of systematic errors on gravity data sets (shifts on coordinates). A poster has been presented during the Banff

Conference in July-August 2000 (BGI Bulletin n°87).

- Rewriting in Java (platform-independent language) of the validation software DIVA. Beta-tests are currently performed, and the software will be avalaible for downloading on the BGI server.

INTERNATIONAL GEOID SERVICE REPORT
(1999 - 2001)

Since the IAG/IUGG General Assembly held in Birmingham, IGeS has developed several activities, both on the international and the Italian side.

One of the main tasks of IGeS was to promote and to organize schools on geoid determination, focussed on theoretical and practical aspects.

On February 2000, a geoid school was held in Johor Bahru (Malaysia) in cooperation with the Department of Survey and Mapping Malaysia (DSMM), acting as local organiser.

This was the fourth international school organised by IGeS in the last six years. The general purpose of this school was to prepare new graduate students, young scientists or employees of national agencies and services or industry staff, to use and, when necessary, to compute gravimetric geoids for the many scientific and technical applications.

The topics discussed during the five lectures were: a general introduction to physical geodesy with special emphasis on geoid computation and collocation theory; the computation and use of high degree and ultra-high degree geopotential models; the geoid computation using Stokes' integral; terrain effetcs in geoid estimation; FFT techniques in geodesy.

Forty-one students coming from Australia, Chile, China, Ethiopia, France, Hong Kong, Indonesia, Malaysia, Nepal, Singapore, Sweden, Republic of Maldives and USA attended the school. Lecture Notes and IGeS software have been provided as well as numerical exercises which have been made available to the students.

A further geoid school was planned on January 2001 in Cairo, Egypt. However, due to organisational problems, this school wasn't held and was rescheduled for February 2002. A geoid school in the Unites States is also planned on December 2001 in San Francisco.

Furthermore, IGeS was actively involved in a relevant project for geoid determination in South America.

This project was carried out in strict cooperation with NIMA and the Escola Politécnica, Universitade de São Paulo and led to two new estimates of the quasi-geoid over an area covering the whole South America. These results were presented during the South America Geoid 2000 Workshop held at the Escola Politécnica, Universidade de São Paulo, from May 17 to 19, 2000. This meeting was organized by IGeS (International Geoid Service), SCGGSA (Sub-Commission for Gravity and Geoid in South America), CDC (Committee for Developing Countries) and it was also supported by IAPSO (International Association of the Physical Science of the Ocean). The workshop aimed at encouraging cooperation in data delivery among South American nations in the framework of the SCGGSA activities and also at promoting national and regional geoid estimates in South America. Furthermore, cooperation between oceanographers and geodesists for the computation of the geoid in coastal areas was encouraged.

Seventeen participants attended the workshop and the South America nations involved were Argentina, Brazil, Chile, Ecuador, Paraguay and Uruguay. The new quasi-geoid solutions were also presented at the IAG Symposium on Vertical Reference Systems (VeReS), Cartagena, (February 2001) and during the last EGS Assembly in Nice (March, 2001).

Future projects will involve IGeS in geoid estimation activities in Antarctica and in South Africa: a preliminary data analysis on gravity data in an area of Antarctica has been presented at the Nice EGS Assembly in the G7 Session on “Regional and local gravity field approximation”.

IGeS web has been also updated during these two years and contains at present 23 geoid data files and a collection of 11 global geopotential models. In the near future, software on terrain correction and GIS for geoid update will be made freely available through the IGeS web.

Another important activity which started in 1993, namely the publication of the IGeS Bulletin, was continued and improved. The Bulletin number 10 was published on May 2000 and the next issue is going to be published within May 2001: starting from the tenth issue, the Bulletin became a reviewed scientific journal. The next important change will start with the future issues that will be published almost entirely on CD .

IGeS also actively participated, together with BGI, NIMA, ICET and GFZ, in the creation of a new IAG service named International Gravity Field Service (IGFS). IGFS has been proposed as a unified structure aiming at collecting, validating and distributing data and software for the purpose of determining, with various degrees of accuracy and resolution, the gravity potential of the Earth, or any of its functional, and the surface of the Earth.

In Italy, IGeS worked at estimating and refining the Italian geoid and is cooperating with the Italian Space Agency (ASI), the Istituto Geografico Militare (IGM) and the Agenzia del Territorio (Italian National Cadastre).

Also in this context, IGeS has organised schools on theory and practice for geoid computation. They were held at the IGeS Main Centre (DIIAR, Politecnico di Milano) on February 2000, at IGM in Florence on October 2000 and in Rome at the Agenzia del Territorio on January 2001.

Report Of IAG Section IV

-GENERAL THEORY AND METHODOLOGY-
ON THE ACTIVITIES BETWEEN 1999 AND 2001

Bernhard Heck, Section President
University of Karlsruhe
Geodetic Institute
Englerstrasse 7
D-76128 Karlsruhe
Germany

The structure of Section IV in the period 1999 - 2003 is essentially the same as in the former four-year period. It consists of the Special Commission

SC1 : Mathematical and Physical Foundations of Geodesy
Chair: P. Holota

covering broader and long-term items of geodetic theory and methodology in its sub-commissions and working groups, and of the five Special Study Groups

SSG 4.187 : Wavelets in Geodesy and Geodynamics
Chair: W. Keller

SSG 4.188: Mass Density from Joint Inverse Gravity Modelling
Chair: G. Strykowski

SSG 4.189: Dynamic Theories of Deformation and Gravity Fields
Chair: D. Wolf

SSG 4.190: Non-Probabilistic Assessment in Geodetic Data Analysis
Chair: H. Kutterer

SSG 4.191: Theory of Fundamental Height Systems
Chair: C. Jekeli

This structure has been set up on the occasion of the IUGG General Assembly in Birmingham 1999 in order to cover the most important aspects of contemporary geodetic theory, and has proven to be highly efficient in the first half of the working period.

Besides the thematical work done in the various bodies of Section IV - which is reported below in detail - the planned changes of the IAG structure have played a central role in the past bi-annual period. In contrast to other IAG sections, the scope of Section IV is not confined to a specific topic in Geodesy such as positioning, or gravity field determination, or geodynamics; the accent here is rather on the systematic (mathematical) treatment of groups of problems. Therefore it is quite natural that most topics treated by the bodies in Section IV are shared in one way or another with other IAG sections, adding sometimes a different, more general point of view, but without just duplicating the work. Ideally, the mathematical problems occurring in the topic-oriented sections should be reflected upon in Section IV and solved on a general basis. Another principal scope of Section IV is to develop mathematical tools and to take up available approaches already developed in other fields of Science and to adept them to Geodetic Science; a prominent historical example is Least Squares Collocation which was developed in the seventies mainly in Section IV and nowadays is a basic tool in many branches of Geodesy. In recent years, e.g. spatial statistics, robust statistical methods, fuzzy theory and the use of wavelets have been thoroughly investigated in Section IV for applications in Geodesy; some of these approaches seem to be rather promising and to become highly efficient tools in geodetic data analysis. Concerning the plans for a new IAG structure it is scheduled to abolish the present sections and to replace them by four topic-oriented commissions, dealing with

1) Geometric Reference Frames
2) Gravity Field
3) Earth Rotation and Geodynamics
4) Positioning and Applications.

The task of these new commissions is to promote the advancement of science, technology and international cooperation in their field. Besides the services, the commissions will form the main components of the new IAG structure.

In the new structure an entity like the present section IV is no more foreseen and visible at the highest level of organization below the EC, the level of the commissions and services. But this does not mean at all that geodetic theory and methodology will not play a fundamental role anymore. Since one of the major tasks of the new commissions is the promotion of science, these bodies will be responsible for the development of theory and modelling in their respective fields, too. Of course, this procedure cannot include the development of general, topic-independent approaches of data analysis and mathematical-physical foundations, methodology and "general" theory of Geodesy. After many discussions a solution of this problem could be found, consisting of the creation of an inter-commission committee on general theory and methodology, reporting directly to the EC. It is expected that the existence of such a committee will make sure that e.g. mathematically interested geodesists and application-oriented mathematicians and physicists furthermore will find a home and meeting-place within IAG. The implementation of the new structure, to be approved during the IAG Scientific Meeting in Budapest in September 2001, is still a heavy task and a challenge for Section IV in the next two years.

In the past bi-annual period 1999 - 2001 Section IV contributed to different scientific meetings such as

- Seventh International Winter Seminar in Sopron/Hungary, February 19-23, 2001,
- International Symposium on Vertical Reference Systems, Cartagena/Columbia, February 20-23, 2001,
- First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS, Zurich/Switzerland, March 12-16, 2001, and
- EGS General Assembly, Nice/France, March 25-30, 2001.

A strong input from Section IV will also be given to the IAG Scientific Meeting in Budapest/Hungary, September 2-8, 2001. Finally it is planned to continue the series of Hotine-Marussi Symposia on Mathematical Geodesy in 2002; traditionally Section IV has been strongly involved in these symposia, organized in Italy.

Mid-term Report of IAG Special Commission 1

MATHEMATICAL AND PHYSICAL FOUNDATIONS OF GEODESY

for the period 1999-2001

by
Petr Holota
Research Institute of Geodesy, Topography and Cartography
250 66 Zdiby 98, Praha-vychod, Czech Republic
e-mail: holota@pecny.asu.cas.cz

1. Introduction

The Special Commission on Mathematical and Physical Foundations of Geodesy (CMPFG) was established by the International Association of Geodesy on the occasion of the 20th General Assembly of the International Union of Geodesy and Geophysics in Vienna in 1991. **It expresses the need for a permanent structure working on the foundations of geodesy**. The establishment of the special commission is essentially associated with the preparatory work done by K.-P. Schwarz (the president of Section IV at that time) and the Section IV Steering Committee.

The main objectives of the special commission are the following:

- to encourage and promote research on the foundations of geodesy in any way possible;
- to publish, at least once every four years, comprehensive reviews of specific areas of active research in a form suitable for use in teaching as well as research reference;
- to actively promote interaction with other sciences;

to closely cooperate with the special study groups in Section IV - General Theory and Methodology. (As an IAG structure the CMPFG belongs particularly to this section).

This formulation is short in its form but in reality it represents a challenging program that may be also found in the 2000 issue of The Geodesist's Handbook [Journal of Geodesy (2000), Volume 74, No. 1]. In addition one can read information and details concerning the CMPFG (including the bibliography) on the website of this special commission at the address: http://pecny.asu.cas.cz/IAG_SC1/

It is natural that the research program of the CMPFG represents a continuation of the activities developed already in the period of the last 8 years when E.W. Grafarend successfully chaired the special commission. The research program of the CMPFG mainly focuses on *statistical problems in geodesy, numerical and approximation methods, geodetic boundary value problems, on problems in geometry and differential geodesy, relativity, cartography, on equilibrium reference models and also on the theory of orbits and dynamics of systems.*

In this field the CMPFG derives important driving impulses especially from the work of the IAG itself. As a minimum let us mention two problems that were discussed at a special plenary session held in Birmingham on the occasion of the 22nd General Assembly of the International Union of Geodesy and Geophysics in 1999: *1) "Are our contemporary theoretical and computer models sufficient to handle the 1:*10^9 *accuracy in frame realization, Earth rotation, positioning etc. consistently?"; - 2) "Can we be sure that sensor and/or model deficiencies do not enter into geophysical interpretation?"*

The broad spectrum of research objectives is connected with a subdivision of the research program into specific tasks. In 1999 immediately upon approval of the CMPFG program by the IAG the following subcommissions were established:

- *Subcommission 1 "Statistic and Optimization"*
  Chair: P. Xu (Japan)
- *Working Group "Spatial statistics for geodetic science"*
  Chair: B. Schaffrin (USA)
- *Subcommission 2 "Numerical and Approximation Methods"*
  Chair: W. Freeden (Germany)
- *Subcommission 3 "Boundary Value Problems"*
  Chair: R. Lehmann (Germany)
- *Subcommission 4 "Geometry, Relativity, Cartography and GIS"*
  Chair: V. Schwarze (Germany)
- *Subcommission 5 "Hydrostatic/isostatic Earth's Reference Models"*
  Chair: A.N. Marchenko (Ukraine)

The theory of orbits and dynamics of systems is an exception. In general problems that by nature have a tie to this topic are given a considerable attention in many branches of science. Here the topic was left within the framework of the special commission itself. It focuses on the interplay between mathematics (especially analysis) and applications that together with problems related to methods of integration, modelling, analysis of perturbations and qualitative aspects in the evolution of trajectories reach the field of space geodetic methods and inertial systems. After two years the original intention is associated with visible achievements. The work of the CMPFG members resulted in a number of very valuable contributions. They concern e.g. dynamic satellite geodesy on the torus; the relation between analytical and numerical integration in satellite geodesy; energy relations for the motion of satellites within the gravity field; asymptotic series in mathematics, celestial mechanics and physical geodesy; satellite geodesy on curved space-time manifolds; differential equations in inertial navigation systems etc. Considerable activities of members develop also in the filed of dedicated satellite mission and in a contact with IAG Special Commission 7.

2. Subcommissions

Also the subcommissions are very productive. It can be immediately seen from the **bibliography** of the CMPFG that is directly accessible **on the website** of the special commission (at the address given above and in the References). It contains a rich list of entries that document the research done by the members of the special commission in the reported period. (On the website the bibliography is an open material that is under a process of a permanent completion.)

For page limit let us mention some highlights only. ***Subcommission 1*** placed emphasis on areas such as the theory of (geo)inverse problems, nonconventional models for space applications, spatial information theory, global optimization methods and also the advancement of traditional topics. The IAG Executive Committee at its meeting in Nice, 2000 have decided to give Dr. Peiliang Xu (the chair of the subcommission) the IAG young authors award for his paper "Biases and the accuracy of, and an alternative to, discrete nonlinear filters", published in the Journal of Geodesy, Vol. 73(2000), pp. 35-46. Within the general discipline of statistics, methods which relate each "data point" to a location allow for an analysis with a spatial resolution that might otherwise be lost. The data do not need to be point data themselves, but could have been derived from a certain area by averaging. Key is that we have to deal with both probabilistic and spatial distributions. This in short is the field of research of the ***Working Group*** that develops its activities in a close cooperation with Subcommission 1. Members of the subcommission and the working group brought significant contributions to the IAG 1st International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS in Zurich, March, 2001.

An intensive mathematical research oriented to problems in the representation and approximation of the Earth's gravitational potential, to problems in physical geodesy and in the treatment of modern space geodetic data was in the focus of ***Subcommission 2*.** The season is that one has to think of the geopotential as a "signal" in which the spectrum evolves over space in significant way. This space-evolution of the frequencies is not reflected in the Fourier transform in terms of non-space localizing spherical harmonics. Wavelet transforms are a counterpart. Therefore, aspects of constructive approximation, decorrelation, data compression etc. were treated within the wavelet theory. Moreover, an uncertainty principle was formulated and used as it gives an appropriate bound for the quantification of space and frequency properties of trial functions in geodesy. In the focus there were also combined models, where expansions in terms of spherical harmonics are combined with local methods, e.g. radial base function techniques as splines, wavelets, mass-points, finite elements etc. In the limited time span of the first two years the subcommission also significantly progressed in the methodology of the treatment of spaceborn observations. In addition to a number of presentations and entries in the bibliography an important contribution on "Multiscale modelling of GOCE data products" was prepared for the ESA International GOCE User Workshop held in Noordwijk in April, 2001.

Subcommission 3 focused on boundary value problems (BVP) in physical geodesy. They are essentially connected with the use of potential theory and the theory of partial differential equations in the determination of the gravity field and figure of the Earth. In the reported period the research carried out by the subcommission concentrated on the refinement of the solution of the standard problems and new mathematical models, on free-datum and multi-datum BVPs, as they arise from unknown height datums; on mixed BVPs and especially various types of altimetry-gravimetry problems with their capability to give a mathematical model for a combined use of different data on the boundary; on stochastic BVPs; overdetermined and constraint BVPs; BVPs on special surfaces and also on pseudo BVPs. The research covered also non-classical methods in the solution of BVPs, as variational methods with their close tie to the concept of the so-called weak solution, boundary element techniques, various aspects in the use of ellipsoidal harmonics and other function bases. Within traditional concepts the role of the BVPs is rather well-known in physical geodesy, but nowadays the work of the subcommission is strongly influenced by new striking impulses. Among others they reflect the progress in the data collection, data accuracy, higher requirements on the accuracy of the solution and also a need for mathematical modelling associated with the use of modern technologies, as e.g. airborn gravimetry and dedicated satellite missions (a spacewise approach, Slepian's problem etc.). The results of the subcommission were clearly visible at the IAG International Symposium on Gravity, Geoid and Geodynamics 2000 in Banff, July/August, 2000 and also at the 26th General Assembly of the EGS in Nice, March, 2001.

Geometry oriented problems, relativity aspects, cartography and GIS define the field of interest of ***Subcommission 4.*** Here under geometry one understands the Marussi-Hotine approach to differential geodesy, foundations of Gaussian differential geodesy, geometry of plumblines as geodesics in conformal 3-manifould, Fermi's coordinates etc. Nevertheless the main progress was achieved in the use of the theory of relativity, in particular in the reformulation of geodetic measurement processes within the framework of general relativity. Here the metric tensor plays an important role and it was represented with respect to a set of appropriate charts. Using the words of the chairman, we knew that almost every quantity of interest in geodetic and geophysical applications refers to a geocentric, Earth-fixed coordinate system (chart). Therefore, the space-time metric with respect to an Earth-fixed chart was derived at first post Newtonian order. The field equations determining the terrestrial gravitational field were derived and its explicit representation was outlined. On this basis the impact of the results on the modelling of geodetic measurement process including space-time positioning scenarios as well as the high-precision gravitational filed estimation was discussed. Finally, results achieved in cartography and GIS were presented at the IAG 1st International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS in Zurich, March, 2001.

Subcommission 5 is a completely new substructure of the CMPFG. Nevertheless it proved to be very active. In the reported period it attacked the construction of piecewise radial density models, stable determination of parameters of radial density models, variational problems and the interpretation of some reproducing kernels, it focused on the low-frequency Earth's gravity field and the evolution of the Earth's principal axes and moments of inertia completed with a canonical form of the solution. Some research was also oriented to incompressible fluid Earth, compressibility and vicoelestic perturbations. For the density recovery from seismic velocities the solution was based on three differential equations and the density function was separated into a hydrostatic (main) part and an additional small part due to chemical/phase inhomogenieties or superadiabatic temperatures. Some famous laws (Legendre-Laplace, Roche, Darwin, Gauss) were considered for radial density distribution in connection with the solution of the famous Clairaut, Poisson and Williamson-Adams differential equations. In the interpretation of reproducing kernels it was shown that the set of all suitable kernel functions may be interpreted as a finite sum of two point singularities (pole and dipole) and also straight line singularities. In addition an optimum point mass model of the global gravitational filed was compiled.

3. Business Meeting in Banff

The CMPFG is an important discussion forum. This was evident from *the business meeting of the special commission* organized in Banff on the occasion of the IAG International symposium "Gravity, Geoid and Geodynamics 2000". A circular letter distributed by the special commission chairman well before the meeting proved to be a stimulus that met with a good response. *"What you think is the most urgent problem to be solved related to the foundations of geodesy"* this was a key question formulated by C.C. Tscherning and circulated with the letter. It turned out that what is natural. The response reflects the impact of the future or up-coming satellite missions. *In particular the following urgent problems were mentioned* (in the formulations by R. Rummel):

- How to deal in a proper way with the actual Earth boundary when bringing down the high resolution gravity information from GOCE from satellite altitude to the Earth's surface? Should one simply apply some kind of topographic correction or are there better and/or more correct ways?
- A mission like GRACE drifts (in the course of the entire mission length) down from, say 500 km to 300 km. While going down the gravity field is sampled in a changing manner and at the same time it drifts through several regimes of resonance. At the same time one tries to recover the temporal variations of the gravity field. Thus one is faced with a very complicated sampling/aliasing problem, which to my best knowledge is not sorted out so far.
- A similar problem in altimetry which certainly affects, for example, estimates of sea level change. Again the satellite samples time variable effects such as tides in a very complicated time and space pattern. What is the aliasing situation there, what could be done to improve it?
- In real world satellite sensors such as accelerometers or gradiometers do not show a normally distributed noise behavior but drifts and a similar effects cause systematic distortions which result in e.g. 1/f (f = frequency) behavior. We have taken into account these things but in an ad hoc manner. Could one work on stochastic models on the sphere for processes with less favorable error behavior?
- Currently several groups try to determine center-of-mass changes of the Earth from the analysis of global tracking data. What is the proper formulation of datum definition and S-transformation for a real deformable earth with moving plates, how should a center-of-mass change determination be correctly formulated from the theoretical point of view?

K.-H. Ilk expressed another view. He pointed out **three problem areas related to the satellite missions** CHAMP, GRACE and COCE: - analysis of the observation system; - modelling and data analysis aspects; - applications in geosciences, oceanography, climate change studies and other interdisciplinary research topics.

In addition M. Vermeer suggested, loosely speaking "best practices" and the use of **common sense** in connection with the use of modern techniques in geodesy. Using his words, we know that in traditional geodesy there were these common sense rules such as "working from the large to the small" and many many more. With new techniques, and the availability of fast computers and complex theories, sometimes it seems that common sense has been a bit forgotten.

The subsequent discussion at the business meeting concerned some reflections on the running process towards the new structure of the IAG. B. Heck, the president of IAG Section IV outlined the key aspects that motivate this initiative. His information were then amplified by F. Sanso, the IAG president who first paid a considerable attention to the work of the CMPFG itself and than focused on a detailed explanation of the principles and actions that are most frequently discussed within the IAG executive in preparing the concepts for the new IAG structure. The business meeting of the CMPFG was well attended, not only by the members, but also by a number of participants of the Banff symposium on Gravity, Geoid and Geodynamics 2000. The CMPFG will hold its **future business meeting** in Budapest, concurrently with the IAG Scientific Assembly, 2-8 September 2001. For 2002 the CMPFG prepares an active participation in the Hotine-Marussi symposium on mathematical geodesy which by tradition will be held in Italy under the sponsorship of the IAG.

References: see please http://pecny.asu.cas.cz/IAG_SC1/

Acknowledgements. Concluding this brief report, I wish to express my sincere thanks to all my colleagues from IAG Special Commission SC1 for excellent cooperation and all the results achieved that often mean months or years of a great endeavor and devoted work. Much success in your further work!

REPORT OF THE SSG 4.187

WAVELETS IN GEODESY AND GEODYNAMICS

Chair: W. Keller

The main fields of the SSG activities have been

1. publications
2. software development
3. education
4. comparison of different wavelet based algorithms

1 Publications

The members of the SSG have published so far 22 papers in scientific journals and on conferences. These contributions can be divided into four groups

1. pattern recognition,
2. spherical wavelets,
3. filtering and prediction,
4. enhancement of numerical processes.

1.1 Pattern recognition

Most of the publications about wavelet applications belong to this field. The goal is to find certain signatures which, on different scales, are hidden in the signal.

One group of pattern recognition techniques deals with the interpretation of signal registration from different geodetic measuring systems : Superconducting gravimeters, airborne gravimeters and so on.The publications [3],[9],[19] and [21] can be counted to this group.

A more exotic application of pattern recognition using wavelets is the study of atmospheric turbulence and seafloor topography as reported in [2] and [4].

Last but not least, wavelets are frequently used for gravity field modeling. A topic which is discussed in the contributions [5] and [10].

1.2 Spherical wavelets

This topic is the main focus of the Kaiserslautern University Group with W. Freeden as its head. The group aims at a construction of a wavelet analysis on the sphere. Among the many publications of this group the contributions [1], [6]and [7] should be mentioned.

1.3 Filtering and prediction

The ability of wavelets to decompose a given signal into a sequence of non-overlapping (or slightly overlapping) frequency bands can be used for an optimization of prediction and filtering algorithms. The publications [13], [14], [15], [16] and [17] deal with this problem.

The time-frequency resolution property of wavelets is the key for the extension of the known filtering algorithms from the stationary to the non-stationary case. These questions are discussed in the publications [11] and [12].

1.4 Enhancement of numerical processes

Numerical algorithms do not take effect uniformly on all scales. Usually their main effect is concentrated on a certain scale-range. Wavelets can be used to decompose the numerical process in a number of sub-processes, each of them operating on a certain scale-range. Neglecting the minor effective sub-processes can improve the numerical performance of the whole process considerably. This idea is studied in the contributions [8] and [20].

2 Software development

In order to provide the geodetic community with ready-to-use tools for wavelet analysis the most important wavelet-related algorithms as

- windowed Fourier transformation
- continuous wavelet transformation
- discrete wavelet transformation
- 2D-discrete wavelet transformation

were coded in ANSI-C and tested with the GNU compiler collection gcc. These programs are command-line driven. In order to facilitate the use of these algorithms Tck/Tk graphical user interfaces and utilities for the visualization of the results using the GMT tools were supplied. Since gcc, Tcl/Tk and GMT are not available on every platform a transformation to the platform independent JAVA system is currently going on. Both the C and the JAVA versions of the algorithms can be downloaded from the SSG 4.187 home-page

http://www.uni-stuttgart.de/iag

3 Education

In order to provide young scientists a basic knowledge in wavelet theory SSG members were involved as lecturers in two summer courses on wavelets:

- School of Wavelets in the Geosciences , Delft October 4-9, 1998
- graduate course Wavelets in Geodesy and Geodynamics , University of Calgary, August 4-21, 2000

4 Comparison of algorithms

In order to provide a scale for comparison of different wavelet algorithms a synthetic polar motion test data-set was created by Dr. Schmidt and was made available to the SSG via the SSG home-page. The members of the SSG were requested to analyze the data with their own algorithms and to submit the results. From the results conclusions about the strength and the weakness of different algorithms should be drawn. Unfortunately, the resonance to this project was disappointingly low.

References

[1] Bayer M. , Freeden W., Maier T.: WAVELET ANALYSIS OF THE GEOMAGNETIC FIELD WITHIN SOURCE REGIONS OF IONOSPHERIC AND MAGNETOSPHERIC CURRENTS Berichte der Arbeitsgruppe Technomathematik, N0.: 217 University of Kaiserslautern, September 1999

[2] Beth, S. ;Boos, T.; Freeden, W.; Casott, N.; Deussen, D.; Witte, B: On the wavelet determination of scale exponents in energy spectra and structure functions and their application to CCD camera data In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 221 - 226 Springer-Verlag Berlin Heidelberg 2000

[3] Bruton, A.M.; Schwarz, K.-P.,Skaloud,J.: The use of wavelets for the analysis and de-noising of kinematic geodetic measurements In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 227 - 232 Springer-Verlag Berlin Heidelberg 2000

[4] Dreher, S.; Lalancette, M.F.: Estimating Lithosphere Characteristics With Wavelet Admittance and Coherence of Gravity and Seafloor Topography. paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[5] Doufexopopolou, M.G. ; Bartha, G.C.: A Strategy to Approach a Multi-scale Space/Time Problem by Only data Information.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[6] Freeden W. , Michel V. : LEAST SQUARES GEOPOTENTIAL APPROXIMATIONBY WINDOWED FOURIER TRANSFORM AND WAVELET TRANSFORM Berichte der Arbeitsgruppe Technomathematik, N0.: 216 University of Kaiserslautern, September 1999

[7] Freeden W.: Multiscale Modelling of Spaceborne Geodata B.G. Teubner Verlag, Stuttgart, 1999

[8] Gilbert A., Keller W.: Deconvolution with Wavelets Journal of Geodesy. Journal of Geodesy 2000(74) pp. 306-320

[9] Haagmans,R.H.N.; Dorst, L.L.; Francis, O.: Wavelets and Statistical Testing for Improved Analysis of Super Conducting Gravimeter Data at the main Tidal Frequencies.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[10] Horowitz, F.G., Strykowski, P.; Hornby, P.; Boschetti, F.; Cox, S.J.D.: A Multiskale Skeletonization of The EGM96 Gravity Disturbances, Locally Compared with Australian Geophysical data.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[11] Keller W.: A Wavelet Approach to Non-Stationary Collocation In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 208 - 213 Springer-Verlag Berlin Heidelberg 2000

[12] Keller, W.: A Wavelet Solution to Non-stationary 2D Collocation. data.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[13] Keller, W.: Wavelets in Geodesy and Geodynamics Lecture Notes, Universtity of Calgary 2000

[13] Kotsakis C.: The Multiresolution Character of Collocation Journal of Geodesy in print

[14] Kotsakis C.: The Role of Statistical Collocation as a Tool for Constructing Generalized Multiresolution Analyses in the L2(R) Hilbert Space Bolletina di Geodesia e Scienze Affini in press

[15] Kotsakis C.: Wavelets and Collocation: An Interesting Similarity In: K.-P. Schwarz (Ed.) Geodesy Beyond 2000: The Challenges of the First Decade Birmingham, 1999 IAG General Assembly Birmingham , July 19 - 30, 1999 pp. 227 - 232 Springer-Verlag Berlin Heidelberg 2000

[16] Kotsakis, C.: Multiresolution Aspects of Linear Approximation Methods in Hilbert Spaces Using Gridded Data Department of Geomatics Engineering UCGE Reports Number 20138

[17] Kotsakis, C.; Sideris M.G.: Aliasing Error Modelling in Single-input Single-output Linear Estimation Systems. paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[19] Liu, L.T.; Hsu, H.T. ; Sun H.P.: Wavelet-characterized Approach to Harmonic Analysis of Tide Gravity Observations.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[20] Salamonowitcz, P.H.: A Wavelet Based Gravity Model with Application to the Evaluation of Stoke's Integral.paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[21] Liu,L.T.;Hsu,H.T.: Wavelet application in Airborne Gravimetry..paper given at the IAG International Symposium on Gravity, Geodesy and Geodynamics held in Banff, July 31 - August 4, 2000

[22] Klees, R.; Haagmanns,R.: Wavelets in the Geosciences. Lecture Notes in Earth Sciences, Springer-Verlag, Berlin, Heidelberg, New York, 2000

SSG 4.188 MASS DENSITY FROM JOINT INVERSE GRAVITY MODELLING

Introduction

The special study group SSG 4.188 of IAG was established for the period 1999-2003 during the1999 General Assembly of IUGG in Birmingham, the UK. Its main role within IAG is to provide an official forum for research directed towards mass density modelling. The importance of this topic goes far beyond the narrow scope of work of the study group. There are clear affinities between these research topics in Geology, Geodesy and Solid Earth's Geophysics. Furthermore, IAG has since many years recognized the importance of this field of research. The present study group is a continuation of previous study groups SSG 4.141 (1991-1995) and SSG 4.170 (1995-1999). This report is a mid-term biannual report on the activities of SSG 4.188.
The members of the study group, both full members and the corresponding members, are spread geographically and with regard to the research interests. Their expertise ranges from mathematical geodesy to geophysics with geological applications. The common point of interest is, however, the realization of the importance in modelling of addressing directly the source of the gravitational signal, the mass density.

Members

Gabriel Strykowski (chairman, Denmark)	gs@kms.dk
Ludwig Ballani (Germany)	bal@gfz-potsdam.de
Riccardo Barzaghi (Italy)	GEOIDE@IPMTF4.TOPO.POLIMI.IT
Fabio Boschetti (Australia)	Fabio.Boschetti@ned.dem.csiro.au
Gottfried Gerstbach (Austria)	ggerstb@terra.tuwien.ac.at
Petr Holota (chairman of Special Commission of Section IV, Czech Republic)	gope@asu.cas.cz
Bruno Meurers (Austria)	bruno.meurers@univie.ac.at
Ove Christian Dahl Omang (Norway)	ove@omang.com
Spiros Pagiatakis (Canada)	spagiatakis@gsc.NRCan.gc.ca
Gabor Papp (Hungary)	papp@ggki.hu
Ilya L. Prutkin (Russia)	prutkin@igeoph.mplik.ru
Tatiana Romanyuk (Russia)	t.romanyuk@relcom.ru
Sabine Schmidt (Germany)	sabine@geophysik.fu-berlin.de
Dan Sharni (Israel)	sharni@techunix.technion.ac.il
Vitaly Starostenko (The Ukraine)	vstar@igph.kiev.ua
Ilias Tziavos (Greece)	tziavos@eng.auth.gr
Marc Veronneau (Canada)	marc@geod.nrcan.gc.ca

Corresponding members

Will Featherstone (chairman of IAG's SSG 3.177, Australia)	Featherstone_WE@cc.curtin.edu.au
Olga Legostayeva (The Ukraine)	olgal@igph.kiev.ua
Michael Kuhn (Germany)	kuhn@dgfi.badw.de
Irina Makarenko (The Ukraine)	irinam@igph.kiev.ua
Dimitrios Rossikopoulos (Greece)	rossi@topo.auth.gr
Tamara Yegorova (The Ukraine)	egorova@igph.kiev.ua

Practical work of the study group (1999-2001):

a. New members

Since its creation in 1999 two new members joined SSG 4.188:
Spiros Pagiatakis (Canada) joined as a full member;
Michael Kuhn (Germany) joined as a corresponding member.

b. Website of SSG 4.188

The study group has its own website with the following URL:
http://research.kms.dk/~ssg4188/study_group/index.html

c. SSG 4.188 in 1999-2001

The work of the study group as a team suffers from problems that are not uncommon to other study groups. The geographical spread of the members as well as the spread research-wise makes it difficult to collaborate closely on a daily basis. However, such collaboration exists on individual basis between different members of the study group. Also, for all members, it is useful to know about others with similar research interests.

Right from the start we knew that it would be difficult to arrange a meeting for all members of the study group. Not all of us attend necessarily the same conferences, and it would be unfair to arrange a meeting for only part of the study group. Thus, in order to provide means of communication between the members, the idea was to establish and to use the official website of SSG 4.188. Initially we thought that such website could be used for discussions and for exchange of ideas. Regrettably, the website came up only few months ago, and at the present the need for discussions seems to be rather limited. However, this can change in the future and we keep this option open in case somebody takes the initiative. The situation described above is probably very typical and reflects the working conditions of many special study groups. Firstly, it is difficult to share the ideas prior to publishing. Secondly, it takes time to get involved in discussions.

Fortunately, in recent years it became more common for various research groups to promote their work via the Internet. This is also the case for some members of the study group. It is here that we see a realistic possibility in the future of extending the website of SSG 4.188 and to get a realistic picture of the research covered by the study group. All it takes is to provide links from the website of SSG 4.188 to the member's URL and, possibly, to other related sites. Such procedure will not involve the members with unnecessary additional work, and seem to be a good way of utilizing the Internet without going into trouble of writing special reports.

Scientific results in brief

The website of SSG 4.188 contains a list of relevant recent publications (not necessarily exclusively by the members of the study group) published in 1999-2001 in Journal of Geodesy, Geophysics, Journal of Geophysical Research (volume B), Geophysical Research Letters, Geophysical Journal International, Pure and Applied Geophysics, Physics and Chemistry of the Earth, Tectonophysics and others. Furthermore, this list of publications includes references to relevant presentations and papers at three major conferences: IAG International Symposium on Gravity, Geoid and Geodynamics in Banff in 2000; 70th Annual Meeting of SEG in Calgary 2000, and the 26th General Assembly of EGS in Nice 2001.

The overall impression is, that mass density directly/indirectly still plays an important role in Geodesy, Solid Earth's Geophysics and Geology. The research activity seems to be spread over the whole spectrum of topics ranging from e.g. the studies of the mathematical structure of the ambiguity domain (i.e. the null-space of the inverse gravimetric problem) to the practical modelling of the regional geology in e.g. the Ukraine or in the United States. Even the old and well-established concepts, e.g. such as the homogenous prism formula for gravitational attraction or similar formulas for other elementary bodies, is still the object of research. The goal is to modify the formulas in order to increase the flexibility (i.e. to use them for more complex mass density modelling) and to improve the speed of computations.

In Geophysics and Geology most of the papers involve mass density models, which are fully 3D. In Geodesy the refinement of terrain corrections, an important step in improving the geoid model, seem still to be a hot topic. Furthermore, the goal of 1-cm geoid makes it worthwhile to investigate the necessity of using more refined mass density models, especially in mountainous areas. Not all countries are like e.g. Switzerland prepared to introduce the refined mass density models into the construction of their national geoids, but more and more countries consider the possibility. In most countries the geoid accuracy of 1-cm is still not achievable. Therefore, the efforts should be concentrated on improving the fundamental data (Digital Elevation Models, gravity information, vertical datum problems) rather than on complicating the geoid modelling by introducing refined mass density information. However, the use of refined mass density models for geoid modelling is without doubt on the agenda for future high accuracy geoids.

Also, in recent years, the launching of CHAMP and the preparations for the new gravity missions GRACE and GOCE boosted the interest not only in gravity and mass density, but also as a mean of studying geophysical phenomena related to e.g. climate changes and similar (oceanography, polar ice melting, postglacial rebound). The expected high accuracy of the new gravity missions seems to make studies of these time-varying phenomena a realistic possibility.

SSG 4.189 DYNAMIC THEORIES OF DEFORMATION AND GRAVITY FIELDS

Detlef Wolf, GeoForschungsZentrum Potsdam, Germany

1. Scientific program

SSG 4.189 `Dynamic theories of deformation and gravity fields' was established in response to the continuing need to develop improved dynamical models for the interpretation of time-dependent deformation and gravity fields as better data become available from GPS, VLBI and absolute gravity measurements or are expected from the satellite gravity missions CHAMP and GRACE. Whereas the development of improved theoretical models for the different types of forcing responsible for the deformation and gravity fields is defined as the principal activity of SSG 4.189, a substantial portion of its research during the period 1999-2001 also involved the application of existing theory.

2. Regular members

H. Abd-Elmotaal (University of Minia, Egypt)
J.-P. Boy (Louis Pasteur University, France)
V. Dehant (Royal Observatory of Belgium, Belgium)
R. Eanes (University of Texas, USA)
J. Engels (University of Stuttgart, Germany)
J. Fernández (Ciudad University, Spain)
G. Kaufmann (University of Göttingen, Germany)
Z. Martinec (Charles University, Czech Rebublic)
G. Milne (University of Durham, UK)
H.-P. Plag (Norwegian Mapping Authority, Norway)
G. Spada (University of Urbino, Italy)
W. Sun (University of Tokyo, Japan)
P. Varga (Geodetic and Geophysical Research Institute, Hungary)
K. Wieczerkowski (GeoForschungsZentrum, Potsdam, Germany)
D. Wolf (GeoForschungsZentrum Potsdam, Germany)
P. Wu (University of Calgary, Canada)

3. Associate members

P. Gegout (Louis Pasteur University, France)
E. Grafarend (University of Stuttgart, Germany)
J. Hinderer (Louis Pasteur University, France)
L. Sjöberg (Royal Institute of Technology, Sweden)

4. Scientific results

4.1. Fundamental theory

Sun and Sjöberg (1999a) revisited the classical problem of surface loading of a radially symmetric elastic body and studied the radial dependence of the load Love numbers and the Green functions for displacement, potential and gravity perturbations. Grafarend (2000) computed the gravity field of an arbitrary deformable body under the assumption that the topographic surface, the interfaces and the internal mass distribution vary over time. Grafarend et al. (2000) studied the relationship between the incremental Cartesian moments of the mass density, the incremental moments of inertia and the incremental gravitational potential coefficients for an arbitrary deformable body. As excitation, they considered tidal forcing, normal and tangential surface forcings and rotational variations. Dehant et al. (1999) calculated tidal Love numbers for rotating aspherical earth models. In addition to elastic earth models, they also investigated effects caused by assuming an inelastic convecting mantle.

In two papers, the problem of load-induced, viscoelastic perturbations of a compressible earth initially in hydrostatic equilibrium was considered. Whereas Wolf and Kaufmann (2000) were concerned with the plane-earth approximation of the problem, Martinec et al. (2001) considered the generalized problem for a spherical earth consisting of compositionally homogeneous shells. The density stratification was given by Darwin's law, which can be shown to satisfy the field equations governing the initial state. In another study, a systematic comparison between the solutions for load-induced perturbations of spherical, incompressible earth models with Maxwell or Burgers rheology was carried out (Göbell et al., 1999).
Attempts were also made to obtain solutions of the field equations for 2-D and 3-D incompressible viscoelastic earth models. Whereas Kaufmann and Wolf (1999) obtained an approximate analytical solution for a 2-D plane earth, Martinec and Wolf (1999) derived the exact analytical solution for two axially nested spheres. The analytical solutions are required to test more general numerical solutions for arbitrary 2-D or 3-D viscoelastic earth models (Martinec, 1999, 2000).

4.2. Glacial loading

Th oma and Wolf (1999) interpreted a subset of the glacial-isostatic adjustment data available for Fennoscandia in terms of 1-D earth models and proposed improved bounds for the viscosity stratification. An alternative approach was followed by Wieczerkowski et al. (1999), who employed formal inverse theory to infer the viscosity stratification below Fennoscandia. More recently, Milne et al. (2001) considered GPS data from Fennoscandia. They showed that lithosphere thicknesses and asthenospere viscosities inferred from this type of data are consistent with those obtained using relative sea-level data. Kaufmann and Amelung (2000) used subsidence data from the artifical Lake Mead, Nevada, to infer the viscosity stratification in this region and found very low viscosity values. Thoma and Wolf (2001) interpreted land uplift induced by the recent melting of the Vatnajökull ice cap, Iceland, and found anomalously low values for the lithosphere thickness and asthenosphere viscosity in this region. Kaufmann and Lambeck (2000) interpreted convectively supported geoid perturbations as well as glacially induced changes of sea level, rotation and the gravity field and inferred global average values of the upper- and lower-mantle viscosities.

Wu (1999) raised the question of whether relative sea-level changes in Hudson Bay and along the Atlantic coast of North America can also be explained in terms of the glacial-isostatic adjustment of a flat earth with non-Newtonian rheology. His results show that reconciling all sea-level data is difficult for non-Newtonian rheologies. Subsequently, Wu (2001) incorporated tectonic stress and found that this modification makes the assumption of a non-Newtonian rheology more reasonable. Giunchi and Spada (2000) developed a spherical earth model with non-Newtonian rheology and concluded that, in this case, the long-wavelength signatures of glacial-isostatic adjustment become largely insensitive to the viscosity of the lower mantle.

Wu et al. (1999) discussed the question of whether deglaciation-induced stresses are sufficiently strong to have triggered paleo-earthquakes in Fennoscandia. They found that glacial-isostatic adjustment is probably the cause of the large postglacial faults observed but is unlikely to be responsible for the current seismicity in this region. Wu and Johnston (2000) studied a similar problem for North America and concluded that stresses are sufficiently strong for triggering earthquakes at locations not too far from the former ice-sheet margin. Klemann and Wolf (1999) investigated the consequences of a ductile layer inside an otherwise elastic lithosphere for glacial-isostatic adjustment. Their results show that the stress pattern is significantly affected by the presence of a ductile layer.

Milne et al. (1999) developed an improved method of accounting for the influx of ocean water to once ice-covered marine regions after melting and analyzed the implications of this effect for the interpretation of glacial-isostatic adjustment. Kaufmann (2000) predicted glacially induced variations of the gravity field due to Late-Pleistocene and present-day changes in glaciation and discussed the question of their detectability by the satellite missions CHAMP and GRACE.
Kaufmann et al. (2000) revisited the issue of glacial-isostatic adjustment in Fennoscandia. In particular, they investigated whether lateral variations in lithosphere thickness and viscosity may be resolved from the observational record. Their results show that predictions of relative sea level, uplift rates and gravity anomalies differ significantly if lateral variations are taken into account.

4.3. Surface, internal and tidal loading

Abd-Elmotaal (1999a) calculated Moho depths for a test area in Austria using the Vening Meinesz and the Airy-Heiskanen isostatic models and compared the results with seismic Moho depths. Abd-Elmotaal (1999b, 2000) reviewed the inverse Vening Meinesz isostatic problem defined as finding the Moho depth for which the isostatic gravity anomalies become zero. Sun and Sjöberg (1999b) calculated global geoid perturbations on the assumption that the topographic loads are compensated by elastic deformation only. They found positive correlations between the calculated and observed perturbations, although large differences remained for long wavelengths due to the neglect of dynamic processes. Dehant et al. (2000) computed the response of Mars to nutational, tidal and loading excitation and studied the influence of the planet's assumed material properties on its response. Arnoso et al. (2001) analyzed tidal gravity observations from Lanzarote, Canary Islands, and discussed whether they can be used to resolve structural details of the upper crust below the island. Neumeyer et al. (1999) and Hagedoorn et al. (2000) investigated the total atmospheric contribution to gravity perturbations using an elastic earth model. They found that their results are superior to those obtained by simply using empirical relationships between pressure and gravity changes.

4.4. Seismo-volcanic forcing

Nostro et al. (1999) compared spherical and flat earth models for computing co- and postseismic deformations in order to assess in which cases the neglect of sphericity and self-gravitation is justified. In a related study, Boschi et al. (2000) calculated the global deformation caused by a shear dislocation located in the mantle. Important points of their study were the consideration of sources below the lithosphere and effects due the presence of a low-viscosity asthenosphere. Folch et al. (2000) considered the viscoelastic deformation caused by an inflated magma chamber and investigated the errors introduced by neglecting the finite dimension of the chamber or the topography of the region. In a related study, Fernández et al. (2001) interpreted deformation and gravity change data from Long Valley Caldera, California. They showed that incorrect interpretations may result if only one type of data is used.

5. Other activities

The research carried out in SSG 4.189 was reported by several of its members and invited guests during the 7th International Winter Seminar on Geodynamics on `Viscoelastic Theories in Geodynamics' held in Sopron, Hungary, February 19-23, 2001. The meeting was financially supported by the Hungarian Academy of Science.

6. Selected publications of members: 1999-2001

Abd-Elmotaal, H., 1999a.
Inverse Vening Meinesz isostatic problem: theory and practice.
Boll. Geod. Sci. Aff., 58, 53-70.

Abd-Elmotaal, H., 1999b.
Moho depths versus gravity anomalies.
Surv. Rev., 35, 175-186.

Abd-Elmotaal, H., 2000.
Vening Meinesz inverse isostatic problem with local and global Bouguer anomalies.
J. Geod., 74, 390-398.

Arnoso, J., Fernández, J., Vieira, R., 2001.
Interpretation of tidal gravity anomalies in Lanzarote, Canary Islands.
J. Geodyn., 31, 341-354.

Boschi, L., Piersanti, A., Spada, G., 2000.
Global postseismic deformation: deep earthquakes,
J. Geophys. Res., 105, 631-652.

Dehant, V., Defraigne, P., Wahr, J.M., 1999.
Tides for a convective earth.
J. Geophys. Res., 104, 1035-1058.

Dehant V., Defraigne P., Van Hoolst T., 2000.
Computation of Mars' transfer function for nutation tides and surface loading.
Phys. Earth Planet. Inter., 117, 385-395.

Fernández, J., Charco, M., Tiampo, K. F., Jentzsch, G., Rundle, J. B., 2001.
Joint interpretation of displacements and gravity changes in volcanic
areas. A test example: Long Valley Caldera, California.
Geophys. Res. Lett., 28, 1063-1066.

Folch, A., Fernández, J., Rundle, J.B., Martí, J., 2000.
Ground deformation in a viscoelastic medium composed of a layer
overlying a half space. A comparison between point and extended sources.
Geophys. J. Int., 140, 37-50.

Giunchi, C., Spada, G., 2000.
Postglacial rebound in a non-Newtonian spherical earth.
Geophys. Res. Lett., 27, 2065-2068.

Göbell, S., Thoma, M., Wolf, D., Grafarend, E.W., 1999.
Berechnung auflastinduzierter Vertikalverschiebungen, Geoidhöhen und
Freiluft-Schwereanomalien für ein selbstgravitierendes, sphärisches Erdmodell
und unterschiedliche Rheologien.
Sci. Techn. Rep. GFZ Potsdam, STR99/24, 76 pp.

Grafarend, E.W., 2000.
The time-varying gravitational potential field of a massive, deformable body.
Stud. Geophys. Geod., 44, 364-373

Grafarend, E.W., Engels, J., Varga, P., 2000.
The temporal variation of the spherical and Cartesian multipoles of the
gravity field: the generalized MacCullagh representation.
J. Geod., 74, 519-530.

Hagedoorn, J.M., Wolf, D., Neumeyer, J., 2000.
Modellierung von atmosphärischen Einflüssen auf hochgenaue Schweremessungen
mit Hilfe elastischer Erdmodelle.
Sci. Techn. Rep. GFZ Potsdam, STR00/15, 87 pp.

Kaufmann, G., 2000.

Ice-ocean mass balance during the Late Pleistocene glacial cycles in view
of CHAMP and GRACE satellite missions.
Geophys. J. Int., 143, 142-156.

Kaufmann, G., Amelung, F., 2000.
Reservoir-induced deformation and continental rheology in vicinity of Lake Mead,
Nevada.
J. Geophys. Res., 105, 16341-16358.

Kaufmann, G., Lambeck, K., 2000.
Mantle dynamics, postglacial rebound and the radial viscosity profile.
Phys. Earth Planet. Inter., 121, 301-327.

Kaufmann, G., Wolf, D., 1999.
Effects of lateral viscosity variations on postglacial rebound: an analytical approach.
Geophys. J. Int., 137, 489-500.

Kaufmann, G., Wu, P., Li, G., 2000.
Glacial isostatic adjustment in Fennoscandia for a laterally heterogeneous earth.
Geophys. J. Int., 143, 262-273.

Klemann, V., Wolf, D., 1999.
Implications of a ductile crustal layer for the deformation caused by the Fennoscandian ice sheet.
Geophys. J. Int., 139, 216-226.

Martinec, Z., 1999.
Spectral, initial value approach for viscoelastic relaxation of a spherical earth with a three-dimensional viscosity - I. Theory.
Geophys. J. Int., 137, 469-488.

Martinec, Z., 2000.
Spectral-finite element approach to three-dimensional viscoelastic relaxation in a spherical earth.
Geophys. J. Int., 142, 117-141.

Martinec, Z., Wolf, D., 1999.
Gravitational viscoelastic relaxation of eccentrically nested spheres.
Geophys. J. Int., 138, 45-66.

Martinec, Z., Thoma, M., Wolf, D., 2000.
Material versus local incompressibility and its influence on glacial-isostatic adjustment.
Geophys. J. Int., 143, 1-25.

Milne, G.A., Mitrovica, J.X., Davis, J.L., 1999.
Near-field hydro-isostasy: the implementation of a revised sea-level equation.
Geophys. J. Int., 139, 464 -483.

Milne, G.A., Davis, J.L., Mitrovica, J.X., Scherneck, H.-G., Johansson, J.M., Vermeer, M., Koivula, H., 2001.
Space-geodetic constraints on glacial isostatic adjustment in Fennoscandia.
Science, 291, 2381-2385.

Neumeyer, J., Barthelmes, F., Wolf, D., 1999.
Estimates of environmental effects in superconducting gravimeter data,
Bull. Inf. Mare 'es Terr., 131, 10153-10159.

Nostro, C., Piersanti, A., Antonioli, A., Spada, G., 1999.
Spherical versus flat models of coseismic and postseismic deformations.
J. Geophys. Res., 104, 13115-13134.

Sun, W., Sjöberg, L.E., 1999a.
Gravitational potential changes of a spherically symmetric earth model caused by a surface load.
Geophys. J. Int., 137, 449-468.

Sun, W., Sjöberg, L.E., 1999b.
A new global topographic-isostatic model.
Phys. Chem. Earth, 24, 27-32.

Thoma, M., Wolf, D., 1999.
Bestimmung der Mantelviskosität aus Beobachtungen der Landhebung und Schwere in Fennoskandien,
Sci. Techn. Rep. GFZ Potsdam, STR99/02, 101 pp.

Thoma, M., Wolf, D., 2001.
Inverting land uplift near Vatnajökull, Iceland, in terms of lithosphere thickness and viscosity stratification.
in: Gravity, Geoid and Geodynamics 2000, Springer, Berlin, in press.

Wieczerkowski, K., Mitrovica, J., Wolf, D., 1999.
A revised relaxation-time spectrum for Fennoscandia,
Geophys. J. Int., 139, 69-86.

Wolf, D., Kaufmann, G., 2000.
Effects due to compressional and compositional density stratification on load-induced Maxwell-viscoelastic perturbation.
Geophys. J. Int., 140, 51-62.

Wu, P., 1999.
Modeling postglacial sea-levels with power law rheology and realistic ice model in the absence of ambient tectonic stress.
Geophys. J. Int., 139, 691-702.

Wu, P., 2001.
Postglacial induced surface motion and gravity in Laurentia for uniform mantle with power-law rheology and ambient tectonic stress.
Earth Planet. Sci. Lett., 186, 427-435.

Wu, P., Johnston, P., 2000.
Can deglaciation trigger earthquakes in N. America?
Geophys. Res. Lett., 27, 1323-1326.

Wu, P., Johnston, P., Lambeck, K., 1999.
Postglacial rebound and fault instability in Fennoscandia.
Geophys. J. Int., 139, 657-670.

REPORT OF THE IAG SSG 4.190:

'NON-PROBABILISTIC ASSESSMENT IN GEODETIC DATA ANALYSIS'

IAG SCIENTIFIC ASSEMBLY 2001, BUDAPEST

Hansjörg Kutterer
DGFI Munich
Marstallplatz 8
D-80539 Munich
E-Mail: kutterer@dgfi.badw.de

1. Introduction

Geometrical and physical models can only be approximations of the reality. Hence the difference between the chosen model and the data remains uncertain. In Geodesy, these differences are - after some pre-processing - exclusively considered as random. Mathematically they are treated by means of stochastics. As a consequence, this proceeding is normative since the use of stochastic methods restricts in turn the considered type of uncertainty to random variability of the data. Contrary to the classical approach there are cases when stochastics is not the adequate theoretical basis to handle all problem-immanent uncertainties. Two examples may give an idea. In applications like, e.g., Real-Time Kinematic Differential GPS, imprecision due to unknown systematic effects is the most relevant type of uncertainty. Besides, the common empirics-based formulation of the stochastic model in adjustment calculus implies a source of non-random uncertainty. Thus, it is not recommended to consider only random-type uncertainties.

To establish a general methodology for the comprehensive assessment of uncertainty in geodetic data analysis it is necessary to identify and to classify the occuring uncertainties in typical geodetic applications (qualification of uncertainty in observation, modelling, and inference). In addition, the elaboration of a proper terminology and the compilation of a bibliography are required. Within the work of the IAG SSG 4.190 (SSG) at least three fields of application are considered: GPS data processing, deformation analysis, and GIS. The relevant uncertainties have to be quantified regarding the respective application. The main points of interest are the data handling in the acquisition and preprocessing steps and the corresponding setup of models. As an example the uncertainty of GPS results introduced by different operators and different software packages is mentioned.

Furtheron it is necessary to collect and to characterize different non-standard approaches to deal with uncertainty and to infer under uncertainty like robust statistics, fuzzy theory, possibility theory, evidential reasoning, etc, in addition to the well-known concepts of approximation theory and stochastics. The applicability of the different approaches to the data analysis in the mentioned fields of geodetic interest needs to be discussed. Looking at the possible scientific interpretations of the quantities resulting from the data analysis it is essential to assess the corresponding (types of) uncertainty qualitatively and numerically.

Undoubtedly, there is in several cases a competition between the different approaches. In other cases with a clear distinction between the immanent uncertainties it is worthwhile to study the combination of the mathematical approaches for a more adequate use in geodetic practice. Statistics with data which are both random and imprecise can be mentioned as an example.

2. Organizational notes

Up to now (April 2001) two working meetings of the SSG have been held. The first meeting took place on April 7, 2000 in Karlsruhe, Germany. Eleven SSG members participated with oral presentations of their SSG-related work and discussions. The participation of E. A. Shyllon was funded by the IAG. This is gratefully acknowledged. On this occasion it was decided to organize an international symposium on the main topics of the SSGs work, i.e. robust estimation and fuzzy techniques. This symposium took place in Zurich, Switzerland, from March 12 to March 16, 2001. A proceedings volume is edited by Carosio and Kutterer (2001). A second SSG working meeting was held during this symposium. Further working meetings will take place on a half-annual or annual basis.

3. SSG website and mailing list

The SSG maintains the website www.dgfi.badw.de/ssg4.190 which is updated regularly. The site contains formal details (terms of reference, objectives, list of members), information on the work of the SSG (notes, papers, minutes of the working meetings, Zurich symposium report, bibliography) and a SSG mailing list. Feedback and criticism concerning the web presentation of the SSG and the contents of the website are highly appreciated.

4. Membership structure

Chairman:	H. Kutterer (Germany)	
Members:	O. Akyilmaz (Turkey)	M. Brovelli (Italy)
	A. Brunn (Germany)	A. Carosio (Switzerland)
	B. Crippa (Italy)	G. Joos (Germany)
	K. Heine (Germany)	S. Leinen (Germany)
	B. Merminod (Switzerland)	F. Neitzel (Germany)
	W. Niemeier (Germany)	J. Ou (China)
	D. Rossikopoulos (Greece)	B. Schaffrin (U.S.A.)
	E. A. Shyllon (Nigeria)	A. Stein (The Netherlands)
	J. Wang (Australia)	Y. Yang (China)
	J. Zavoti (Hungary)	

Corresponding Members:

R. Fletling (Germany)	J. B. Miima (Germany)
M. Molenaar (The Netherlands)	S. Schön (Germany)
R. Viertl (Austria)	A. Wieser (Austria)

5. Classification of uncertainty

It is well-known that the complete procedure of (geodetic) data management consists of *data aquisition*, *data pre-processing* (reduction of the 'raw' data to fit the geodetic observables which serve as an interface to the scientific models), *inference* (estimation and prediction of model parameters and derived quantities). Finally, regarding the general objectives of geodetic work the obtained results are interpreted in a scientific framework. For a general starting point of uncertainty assessment and management in the complete procedure, several types of uncertainty have to be distinguished. In the following, uncertainty is used as a generic expression. For more details see Kutterer (2001).

The modelling part of data analysis has to be separated into the set-up of the measurement or observation model (e.g., application of atmospheric corrections) and into the set-up of the model of main scientific interest (e.g., plate-kinematic model). A global distinction is between uncertainties of the model (or of the concept), uncertainties of the data (measurements, observations) and uncertainties introduced by the estimation or inference procedures.

The classical uncertainty concept in Geodesy is based on three classes of errors: gross errors, systematic errors, and random errors. Gross errors have to be avoided or detected by control methods, whereas systematic errors have to be eliminated by the observation set-up and correction methods. The remaining errors are considered as random. Thus, the distinction between randomness and systematics is based on the observation frame: Only those systematic errors are eliminated that can be modelled mathematically, whereas the others are neglected.

The decision about an observation value being biased by a gross error is usually based on human experiences, machine threshold values, or critical values of statistical tests. Therefore, there is some imprecision or fuzziness in the concept of gross errors. It should be noticed that the uncertainty of models or concepts is not considered in classical Geodesy. Nevertheless, there are uncertainties of the model because of the incomplete (human) knowledge (modelling of the 'state of the art'), necessary simplifications due to the complexity of the real world (naming of and restriction to the relevant characteristics), modelling of a substitute situation (discretization of continuous objects and processes), fuzziness or imprecision of linguistic expressions or descriptions ('gross error', 'high temperature'), imprecision or inaccuracy of some 'known' model parameters, ambiguity (non-uniqueness in a crisp sense), or vagueness (non-uniqueness in a fuzzy sense, non-specificity).

Uncertainties of the data are due to the random selection of the data, the random variability of the data (central limit theorems), imprecision of the observation procedure and instruments (round-off errors, recording of correction data), lacking reliability of the data, reduced credibility of the data (data are recorded reliably, but their adequacy for the modelled situation is questionable), data gaps, or lacking consistency of data coming from different sources.

Uncertainties of the estimation or inference procedures result from simplifications for (convenient) mathematical treatment (e.g., linearized models), (ambiguous) choice of the optimum principle of parameter estimation, or decisions based on discrete alternatives and on threshold values.

As a pragmatic matter of fact, the uncertainty of the uncertainties (uncertainty modelling) can additionally be taken into account. This comprises the uncertainty model for the observed values, the uncertainty model for the introduced prior information and the uncertainty model for the scientific (geodetic) model.

6. Mathematical theories for the assessment of uncertainty

Mathematical theories which are adequate for (at least) some parts of uncertainty modelling and handling can be separated into theories which are more or less based on the theory of probability and into theories which are not. The approximation theory is the most fundamental approach since uncertainty is considered in terms of approximation errors which are minimized by minimizing a suitable measure for the distance between model and data. Probabilistic theories are the theory of stochastics with uncertainty modelled by means of random variables, the Bayes theory allowing the use of stochastic (sometimes subjective) prior knowledge (Koch, 1990), and the evidence theory (Shafer, 1976) or theory of hints (Kohlas and Monney, 1995), repectively. These last two theories are more or less identical. They can be understood as a generalization of the Bayes theory; uncertain prior knowledge is modelled and assessed using credibility and plausibility measures. Finally, robust statistics has to be settled between pure approximation theory and stochastics.

Non-probabilistic theories are interval mathematics (Alefeld and Herzberger, 1983), fuzzy theory (Dubois and Prade, 1980), possibility theory (Dubois and Prade, 1988), the theory of rough sets or artificial neural networks. Interval mathematics allows to consider imprecise data whereas fuzzy theory comprises both fuzziness (or imprecision) of the model and of the data. The main branches of fuzzy theory are fuzzy logic and fuzzy data analysis. The latter can be understood as generalization of interval mathematics. As a perspective, there are approaches to combine probabilistic and non -probabilistic approaches like, e.g., by Viertl (1996) who develops a statistics for imprecise data with extensions to Bayesian statistics.

The above-mentioned mathematical theories are (partly) different in the way of modelling and assessing the specific uncertainty. For example, there is no difference between approximation theory and stochastics or robust statistics, respectively, if only a best-fit is needed. But there is a big difference if an inference-based decision (like e.g., outlier rejection) is required because a criterion has to be specified. Thus, there is a need in geodetic data analysis for the selection of the adequate kind of mathematics, for the definition of particular measures of uncertainty, and for the combination of the most suitable mathematical theories if several types of uncertainty occur in the applications. For further information and for a extended list of references see the SSG website. Within the SSG the main focus is on robust statistics and on geodetic applications of both fuzzy logic and fuzzy data analysis to handle classical model-data deviations in general and to consider (non-random) data and model imprecision.

7. Registration of uncertainty

Aiming at the assessment and management of uncertainty in typical geodetic data analysis it is indispensable to register, to characterize, and to categorize the essential components and steps. The set-up of a corresponding questionnaire is the key to the assessment of uncertainty. It can serve as a basis for the improvement of particular procedures in use and for the comparison of procedures.

The main steps of each geodetic data analysis are data acquisition, data pre-processing, and inference. Besides the analysis, a general description is needed as a frame for the questionnaire to identify the specific application and to make the results comparable with others. Finally, conclusions have to be drawn on the consistency of the data processing and analysis, on the adequate treatment of the existing types of uncertainty, and on the assessment of the data acquisition and analysis procedure in use. Usually, the results of a data analysis are interpreted scientifically. Thus, their genesis has to be understood thoroughly. This means particularly the sources for and the propagation of the immanent and the introduced types of uncertainty.

A proposed questionnaire can be found on the SSG webpages. Such a questionnaire is recommended as a basis for the assessment of routine data analysis like in the IAG data services. This could help to get a deeper understanding of the data products to be used or interpreted.

8. Status quo and future work

Information concerning the first two items of the SSG objectives is now available: The relevant types of uncertainty are characterized; a variety of mathematical methods exists which are more or less elaborated for use in geodetic data analysis. The 'First Symposium on Robust Statistics and Fuzzy Techniques' in March 2001 in Zurich which was organized by the SSG showed improvements of robust estimation techniques mainly for geodetic networks but also for the analysis of real time GPS phase data. Applications of fuzzy theory to deformation analysis, to GPS ambiguity resolution and to modelling in GIS were presented; see the proceedings for details. Within the SSG there will be further application directed studies on robust statistics, Bayes theory, interval mathematics, fuzzy theory, and artificial neural networks. A prominent task of the SSG for the period from 2001 to 2003 is the comparison of the applicability of different mathematical theories for uncertainty assessment to particular data analytical problems like, e.g., temporal or spatial prediction.

References

Alefeld G.; Herzberger J. (1983): Introduction to Interval Computations. Academic Press, New York.

Carosio A.; Kutterer H. (Ed.) (2001): Proceedings of the First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS. Swiss Federal Institute of Technology Zurich, Institute of Geodesy and Photogrammetry - Report No. 295.

Dubois D.; Prade H. (1980): Fuzzy Sets and Systems. Academic Press, New York.

Dubois D.; Prade H. (1988): Possibility Theory, Plenum Press, New York.

Koch K. R. (1990): Bayesian Inference with Geodetic Applications. Springer, Berlin Heidelberg New York.

Kohlas J.; Monney P.-A. (1995): A Mathematical Theory of Hints. Springer, Berlin Heidelberg.

Kutterer H. (2001): Uncertainty assessment in geodetic data analysis. In: Carosio, A. und H. Kutterer (Ed.) (2001)

Shafer G. (1976): A Mathematical Theory of Evidence. Princeton University Press, Princeton.

Viertl R. (1996): Statistical Methods for Non-Precise Data. CRC Press, Boca Raton New York London Tokyo.

PROGRESS REPORT OF SPECIAL STUDY GROUP 4.191
THEORY OF FUNDAMENTAL HEIGHTS SYSTEMS

September 1999 - April 2001

During this reporting period, the SSG organized its membership, created an internet web site, had one official meeting, and was represented at a number of conferences and workshops dedicated to vertical reference systems. The group is heavily interrelated with other structural entities of the International Association of Geodesy, including special study groups and commissions and special commissions of other sections. In fact many important works related to the theory of height systems have been accomplished by individuals outside the group.

Internet Web site: www-ceg.eng.ohio-state.edu/~cjekeli/ssg4-191.htm

This site includes several pages describing

Objectives
Members
Meetings
Bibliography
Reports
Links

These pages are largely self-explanatory, but it is noted that the page listing the members has several links to web pages maintained by regular and corresponding members who themselves are leading specific related areas of research or services. The bibliography is extensive, though not complete, and includes references to past works related to the theory of vertical datums and height systems. The web page for Reports includes circular letters and reports from the president of the group, as well as other relevant documents.

To provide further insight to the variety of vertical datums existing around the world, a questionnaire was distributed to national representatives of the IAG asking them to furnish information on their height system, including the availability GPS/leveling data. A compilation of this information will shortly also be accessible on the SSG web site.

Meetings

On the occasion of the International Symposium on Gravity, Geoid and Geodynamics 2000, held in Banff, 31 July - 4 August 2000, the SSG met to introduce its activities and request improvements and other input from the geodetic community to make the group more productive and informative. Most of the suggestions concerned obtaining basic information such as definitions and data on height systems; these have been and are being incorporated in the web site, as exemplified by the compilation of vertical datums.

Other symposia and workshops of special interest to the SSG include the following and were (will be) attended by members of the SSG:

1. World Height System Workshop, Prague, 7-9 November, 2000; organized by the Geographic Service of the Czech Armed Forces. A partial set of contributions, titled "The way forward to come to an improved world height system," may be obtained from Villiam Vatrt (e-mail: vatrt@vtopu.army.cz) or Marie Vojtiskova (e-mail: vojtiskova@vtopu.army.cz). The program is also available on the SSG web site.

2. IAG Symposium, Vertical Reference Systems, Cartagena, Columbia, 20-23 February 2001; organized by the Instituto Geográfico Agustín Codazzi. The proceedings of the symposium will be published in the Springer IAG Symposia series. The program of the symposium is also found on the SSG web site.

3. IAG Scientific Assembly, IAG-2001, Budapest, Hungary, 2-8 September 2001; organized by the IAG and the Hungarian Academy of Sciences. This Assembly features a session (A4) titled "Vertical Datums: Determination Techniques and Unification" and is chaired by the President of the SSG. The program will also be posted on the SSG web site and it is planned to produce a proceedings of the presented papers.

Bibliography

Besides the bibliography provided on the SSG web site, other extensive lists of relevant publications may be found in the links related to the activities of the European and South American Reference System projects.

Summary

While the work of the group has been rather inhomogeneous we have tried to provide at least a focus for activities via the internet site which is being updated periodically. Major projects in Europe and South America currently in progress to modernize the corresponding geodetic reference systems, including the vertical datums, have overshadowed work in this Study Group, and much activity is consequently seen in other relevant structures of the IAG. It is hoped that this SSG can, at least, provide a point of common interest.

Christopher Jekeli
President, SSG 4.191

IAG SECTION V: GEODYNAMICS

Report to the General Assembly, Budapest, 2001

1. Overview

Clark R. Wilson, President Section V

This document describes the activities of various commissions and services organized within IAG Section V. A description of these activities, including links to websites, is at the Section V website http://www.astro.oma.be/IAG/index.html Sections of this report are therefore summaries of the more complete information to be found at the website.

2. Commision V: Earth Tides

Shuzo Takemoto, President

Program of Activities

The objective of the Commission is to promote international cooperation and coordination of investigations related to the observation, preprocessing, analysis and interpretation of earth tides. By earth tides, we understand all phenomena related to the variation of the Earth's gravity field and to the deformation of the Earth's body induced by the tide generating forces, i.e. the forces acting on the Earth due to differential gravitation of the celestial bodies as the Moon, the Sun and the nearby planets. The Commission makes standard software for the prediction of earth tide phenomena and for the processing of earth tide observations available to the scientific community by an Electronic Information Service, started in November 1st 1995. Note that the ftp information service is no longer available, because since May 1997, the Electronic Information Service of the Earth Tide Commission is directly accessible from the www home page. The Commission supports the activities of the International Center for Earth Tides (ICET) in collecting, analyzing and distributing earth tide observations. The ICET is considered as the executive office of the Earth Tide Commission. The Commission provides an Electronic Information Service with data and software files on its website.

International Symposium on Earth Tides

The 14th International Symposium on Earth Tides (ETC2000) was held in Mizusawa, Iwate, Japan from August 28th to September 1st, 2000. The Symposium sessions were: Tidal instrumentation; Results of ground based observations; Tidal observations using space techniques; Modeling of solid earth tides and related problems; Atmospheric and oceanic loading effects; Data processing; Superconducting gravimeters; Tidal studies in tectonic active regions; Tides on planet; Proceedings were published in the Journal of the Geodetic Society of Japan V. 47, No. 1, 2001.

The Earth Tide Commission Medal

The Earth Tide Commission normally awards the Earth Tide Commission Medal to a scientist for her/his outstanding contribution to international cooperation in earth tide research, on the occasion of the International Symposium on Earth Tides. At the opening session of the 13th International Symposium on Earth Tides on July 22nd, 1997, the Earth Tide Commission Medal was awarded for the first time to Baron Paul Melchior for his outstanding contribution to international cooperation in earth tide research. In May 2000, the ETC steering committee decided to award the ETC Medal 2000 to the late Prof. H.- G. Wenzel for his outstanding contribution to international cooperation in earth tide research. The ETC awarded the Medal to Ms Marion Wenzel at the Opening Session of ETS2000 on August 28 2000 at Mizusawa, Japan.

Working Groups:

Working Group 4: Calibration of Gravimeters (Michel Van Ruymbeke, Closed in 2000)

Working Group 5: Global Gravity Monitoring Network (Bernd Richter, Closed in 2000)

Working Group 6: Earth Tides in Geodetic Space Techniques (Harald Schuh / Wu Bin)

Working Group 7: Analysis of Environmental Data for the Interpretation of Gravity Measurements (Gerhard Jentzsch / Corinna Kroner)

Working Group 8: Gravitational Physics (Lalu Manshinha)

3. Commission XIV: Crustal Deformation

Suzanna Zerbini, Chairperson

The primary general objectives of the Commission XIV, Crustal Deformation, as confirmed by the Commission Bureau Meeting in San Fernando in September 2000, are: to study 3-D motions, in active tectonic regions, post-glacial rebound and sea-level fluctuations and changes in relation to vertical tectonics along many parts of the coastlines and in relation to environmental fluctuations/changes affecting the geodetic observations; to promote, develop and coordinate international programs related to observations, analysis and data interpretation for the three fields of investigation mentioned above; to promote the development of appropriate models. The structure of Commission XIV is entirely new because the Commission was created at the General Assembly in Birmingham. Details are at web site http://www.df.unibo.it/commXIV/ Generally, Commission XIV coordinates the activities of the IAG related to crustal deformation, including the work through its regional commissions for Africa, North America, Central and South America and the Caribbean, Antarctica, Asia via APSG, Geodetic and Geodynamics programs of the Central European Initiative (CEI), and WEGENER.

Commission XIV held 4 meetings during this period: San Fernando, Spain, September 21, 2000, San Francisco, CA, U.S.A., December 17, 2000, Miami, FL., U.S.A., December 15, 2000, Nice, France, March 29, 2001. Reports for these are given on the Commission XIV website noted above. In addition, two upcoming meetings related to Commission activities are scheduled for May 14 in Shanghai (APSG), and the end of August 2001 (Helsinki, Finland)

4. Special Commission 3: Fundamental Parameters

Erwin Groten, Chairman

There are two fundamental aspects which affect the policies of SC-3 and will subsequently also affect IAG and IUGG: The first is the recently adopted IAU reference systems which are fully relativistic and are based on accuracy assumptions of the sub-microarcsecond range which implies that actions has to be taken by us. In Birmingham IAG was still hesitating. Consequently, the existing reference systems of IAG, such as the inconsistent WGS 84 (updated in 1997) and the GRS 80, no longer represent the present state of the art. The roles of ellipsoidal systems, as those by Somigliana-Pizzetti, have to be discussed in detail and their use and applications together with other reference frames, such as ITRF, ICRF etc., have to be clarified. SC-3 has delivered a variety of studies and investigations. The second aspect is the progress in measurement techniques and the feasibility studies on forthcoming high-precision gravity and other space projects, such as GRACE, GOCE, CHAMP, JASON, ENVISAT etc., give way to more detailed investigations of the gravity field and its regional and temporal variations as well as variations of the shape and structure of the earth. Substantial improvements of tidal and other time-dependent variations of the earth (solid, load and fluid models) justify deeper and far reaching studies of those space-time variations, also in view of the aforementioned relativistic aspects.

One particular aspect of those variations is global vertical changes which demand unified global vertical reference systems or frames. In the past, global tectonics and geodynamics were dominated by horizontal motion and movement. SC-3 has produced and published impressive and far reaching studies and results in this connection which are not yet incorporated into IAG products and standards. All significant global trends and well documented variations need to be incorporated in the associated reference models. Variability of earth's rotation, global sea level changes, variations in the ocean-ice-atmosphere budget as well as recent crustal movements are only a small part of global geodynamics where precise unified reference frames are now needed and where physical and dynamical aspects need to be incorporated in (partly) kinematic reference frames such as IGS, ITRF etc. Two recently discussed details are the incorporation of a unified vertical global datum in ITRF and the addition of physical and dynamical aspects to IGS. With almost three quarters of the earth's surface being of oceanic type, long periodic dynamics, such as El Nino, La Nina etc. besides shorter periodic and even shortest periodic (subdiurnal etc.) variations deserve more attention than in the past.

From the triaxiality of the earth, to core-mantle-boundary effects and earth's core dynamics SC-3 has substantially contributed to recent developments. The same holds true for surface phenomena. Recently, also critical reviews of the newly adopted IAU-systems in view of their consequences for geodesy were formulated by SC-3. It appears that IAG has not properly involved SC-3 in badly needed discussions on improved reference systems and consistent systems of fundamental constants and parameters in strictly relativistic frames and systems. Nevertheless, SC-3 is continuing its contributions to and studies of highly-precise reference frames and systems and related theoretical investigations. The titles of numerous studies and publications of SC-3 since 1999 can be found in the circular letters of SC-3 from that time on. The most important contributions were presented at various meetings and appeared in international journals such as J. of Geodesy, Studia Geophysica et Geodaetica etc. The main contributions to the Somigliana-Pizzetti field originated from Prof. Grafarend and associates, the principal studies on unified vertical datums were published by Prof. Bursa and his group.

5. Special Commission 8: Sea Level and Ice Sheets

Michael Bevis, Chairman

IAG SC 8 has so far focused on continuous geodetic positioning of tide gauges. It led the formation of the CGPS@TG Working Group, which is a joint working group of IAG (SC 8), IAPSO, PSMSL, and the IGS, to provide a technical forum to discuss and disseminate technical standards, and to promote the transition from studying the problem to actual operational activity. The main vehicle for doing this is the CGPS@TG website http://www.soest.hawaii.edu/cgps_tg.

The CGPS@TG group also ran a one day Workshop at the Hawaii GLOSS GE7 meeting in Hawaii on 26 April, 2000. Here The IGS announced the imminent formation of a new pilot project, called TIGA, that will take on operational responsibility for collecting and processing CGPS data obtained at tide gauges.

6. Joint Working Group on Geodetic effects of non-tidal oceanic processes

Richard Gross, Chairman

The IAG/IAPSO Joint Working Group (JWG) on Geodetic Effects of Nontidal Oceanic Processes was formed at the XXII General Assembly of the IUGG held in Birmingham during July, 1999 for the purpose of: (1) promoting investigations of the effects of nontidal oceanic processes on the Earth's rotation, deformation, gravitational field, and geocenter; and (2) fostering interactions between the geodetic and oceanographic communities in order to gain greater understanding of these effects. In the two years since it was formed, three meetings-of-opportunity of the JWG have been held: (1) on December 15, 1999 in conjunction with the 1999 Fall Meeting of the AGU held in San Francisco, California; (2) on April 27, 2000 in conjunction with the XXV General Assembly of the EGS held in Nice, France; and (3) on March 29, 2001 in conjunction with the XXVI General Assembly of the EGS held in Nice, France. Summaries of the latter two meetings have been or will soon be published in the IAG Newsletter (J. Geodesy, 74, 500-501, 2000; J. Geodesy, 75, in press, 2001). In the last few years a number of exciting developments have occurred in the area of ocean / solid Earth interactions. As global ocean general circulation models continue to improve, and as ocean data assimilation systems are developed, even more progress can be expected to be made in this field in the future. In the last few years the effect of oceanic mass redistribution on the orbits of satellites have also been studied. The launch of CHAMP and the imminent launch of GRACE will enable even more detailed studies of the influence of the oceans on the Earth's gravitational field. Furthermore, CHAMP and GRACE will directly measure the mass term of the Earth rotation excitation functions (Gross 2001) as well as fluctuations in ocean-bottom pressure (Ponte 1999). Thus, the next few years should prove as exciting as the last few years in studying the geodetic effects of nontidal oceanic processes. Reports from individual JWG members on their activities are given below.

Report from S. Dickman: Continued work on the dynamic barometer to include pressure forcing of the oceans by harmonics of higher degrees and orders. The goal is to produce a more accurate 'DB' correction for analysis of tidal signals in l.o.d., and the expansion should be useful for applications of greater interest to the JWG, relating to the removal of a barometric pressure-driven component from GRACE data. A master's student of mine has just begun investigating the correlations between atmospheric/oceanic processes and rapid polar motion. Our goal is to develop a more efficient and optimal correction to rotational data for the effects of AAM. The differences between such a correction and the traditional AAM subtraction has implications for oceanic excitation of polar motion.

Report from J. Nastula: Velocity and mass fields from a constant-density ocean model driven by observed surface wind stresses and atmospheric pressure were used to estimate the equatorial excitation functions for the ocean for the period 1993-1995. The results of this paper confirm findings that oceanic excitation when added to atmospheric excitation, leads to substantial improvements in the agreement with observed polar motion excitation at seasonal and intraseasonal periods. In addition the results point to the role of Oceanic Angular Momentum (OAM) signals in exciting polar motion at period between 5 and 10 days. The combined oceanic-atmospheric excitation does not explain, however, all the observed polar motion excitation, especially for c2. It is also clear that there is still a drop in coherence between geophysical and geodetic excitation series at about 8 or 9 days. The similarity in the OAM series calculated from the barotropic and full stratified ocean models indicates the relevance of barotropic dynamics to the treatment of the variable vertically integrated circulation and associated mass fluxes. The comparisons of geophysical and geodetic excitations at rapid time scales seem to favour an ocean with stronger friction.

To better understand the nature of the high frequency Atmospheric Angular Momentum (AAM) and OAM signals and to try to reduce the uncertainties in their estimated values, it is useful to analyse their regional variability characteristics and how different regions may contribute to the globally-integrated values. Regional analysis of AAM and OAM signals have been performed for monthly and longer periods and for periods shorter than 10 days (Nastula et al. 2000b) and have revealed the importance of specific areas for polar motion excitation. The results also confirm findings that oceans supplement the atmosphere as an important source of polar motion excitation. Regional characteristics of short period excitation are generally in agreement with those obtained from analyses performed for signals at monthly and longer periods. The AAM and OAM signals associated with pressure terms were found to be of the same order of magnitude while signals associated with winds were substantially larger then those associated with ocean currents. The strongest polar motion excitation due to variability of atmospheric pressure, oceanic pressure and wind terms is connected with areas over northern and southern midlatitudes. The spatial pattern of pressure + inverted barometer (IB) term is dominated, however, by maxima over land areas. Oceanic excitation due to currents is strong in the North Pacific and the Southern Oceans. For ocean current terms, maxima in variability and fractional covariances do not strictly coincide, indicating that areas of large variability may not always contribute the most to the variability in the global excitation function.

Report from R. Ponte: In two papers, Ponte and Stammer successfully demonstrated the important ocean role on polar motion excitation at seasonal and Chandler periods, and confirmed the measurable but weak oceanic influence on LOD at seasonal and shorter timescales. Seasonal signals in OAM were traced to changes in the oceanic gyre and circumpolar circulation and mass fields. Positive impact of data assimilation on the estimation of OAM was examined by Ponte et al. (2001). Analysis by Ponte and Rosen of a newly available 40-year torque data set revealed strong atmospheric stress torques on the ocean and a truly three-way interaction among atmosphere, oceans, and solid Earth at seasonal periods. Short delays expected in the transfer to the solid Earth of the angular momentum exchanged with the atmosphere could not explain the observed phase lead of LOD over AAM at monthly and longer periods. Besides continuing to examine possible non-isostatic signals in the oceanic response to atmospheric pressure at high frequencies, other ongoing efforts have focused on extending the coverage and temporal resolution of existing OAM series.

7. International Earth Rotation Service

Jan Vondrak, Chairman of the Directing Board

During past years the International Earth Rotation Service (IERS) has undergone a fundamental re-organization that was led by its Directing Board under the efficient chairmanship of Chris Reigber (1995-2000). The re-organization of the IERS was initiated at the IERS Workshop, Paris 1996, that endorsed corresponding recommendations, and the discussions that followed at the next IERS Workshop at Potsdam, 1998, namely during the 'IERS Retreat'. Shortly afterwards, the new IERS Terms of Reference were formulated and endorsed in March 1999 by the IERS Directing Board; the document is available on the IERS web site (www.iers.org). The main 'driving force' of the proposed changes was the ever increasing complexity of the service since its establishment in 1988, and the efforts to make it less centralized and even more international, with tasks and responsibilities clearly defined and distributed among many institutions all over the world.

New IERS Terms of Reference define the following components of the new IERS: Technique Centers (TC) that are generally autonomous independent services, cooperating with the IERS. There is typically only one TC per technique, and it provides its operational products to the IERS. At the moment, these are the following: International VLBI Service (IVS); International GPS Service (IGS); International Laser Ranging Service (ILRS); International DORIS Service (IDS) that has not yet been formed, and the technique serves as a Pilot Experiment of the CSTG.

Product Centers (PC) that are responsible for the products of the IERS. They are as follows: Earth Orientation PC, responsible for monitoring longterm orientation parameters, publications for time dissemination and announcements of leap seconds. It is placed at Observatoire de Paris, under the leadership of Daniel Gambis. Rapid Service/Prediction PC, responsible for providing Earth orientation parameters on a rapid basis, primarily for realtime users. It is placed at U.S. Naval Observatory, Washington D.C., and is headed by Jim Ray. Conventions PC is responsible for the maintenance of the IERS conventional models, constants and standards. Joint proposal of U.S. Naval Observatory (Washington D.C.) and Bureau International des Poids et Mesures (Sevres) was accepted, under the guidance of Dennis McCarthy and Gerard Petit, respectively. International Celestial Reference System PC, responsible for the maintenance of ICRS and its realization, ICRF. Joint proposal of Observatoire de Paris and U.S. Naval Observatory was accepted, both groups being represented by Jean Souchay and Ralph Gaume, respectively. IGN was designed to become the ITRS Product Center, with Claude Boucher as its representative, and both IGN and DGFI as ITRF Combination Centers. The IERS is open for additional ITRF Combination Centers. Global Geophysical Fluids PC, responsible for providing relevant geophysical data sets and related results. This center, having seven subcenters, was established only in 1998, and consequently no new Call for Participation was issued. It is headed by Ben Chao of GSFC.

Combination Research Centers that are responsible for the development of combinations from data (or products) coming from different techniques. They are expected to provide their solutions to Analysis Coordinator. There are ten of them (the names of leading scientists are given in brackets):

- AICAS & CTU, Prague (J. Vondrak);
- FGS & DGFI, Munich (D. Angermann);
- FGS & FESG, Munich (M. Rothacher);
- FGS & GIUB, Bonn (A. Nothnagel);
- GFZ, Potsdam (S.Y. Zhu);
- FFI, Kjeller (P.H. Andersen);
- GRGS, Toulouse (R. Biancale);
- IGN, Marne-la-Vallee (P. Sillard);
- JPL, Pasadena (R. Gross);
- IAA, St. Petersburg (Z. Malkin).

Analysis Coordinator that is responsible for long-term and internal consistency of the IERS reference frames and other products, for ensuring the appropriate combination of the TC products into a single set of official IERS products and for archiving them.

The designated Analysis Coordinator is Markus Rothacher but, because of his new position and teaching responsibilitie at the Technical University Munich, he will be able to take over his new IERS office only in summer 2001. Therefore Tom Herring (MIT) was appointed as the interim Analysis Coordinator.

Central Bureau that is the administrative center of the IERS; it is responsible for the general management (according to the directives given by the Directing Board), for coordinating the activities, IERS publications, archiving the products and it also serves as its communication center with the users. It is placed at Bundesamt fuer Kartographie und Geodaesie in Frankfurt, under the direction of Bernd Richter.

Directing Board that exercises general control over the activities of the IERS; its chairperson (elected by the Board from its members) is the official representative of the IERS to external organizations. It consists of two representatives of each of the Technique Centers, one for each of the Product Centers, one for all Combination Research Centers together, a representative of the Central Bureau, Analysis Coordinator, and representatives of the IAU, IAG/IUGG and FAGS. Most of the new IERS components were operational by the end of 2000, and the new IERS as a whole will be fully operational in summer 2001.

8. Permanent Service for Mean Sea Level (PSMSL)

Phil Woodworth, Director

Introduction

This year the Permanent Service for Mean Sea Level (PSMSL) has continued with its primary task of assembly of the global data set of sea level change information and its dissemination to the research community. It has also contributed strongly to the further development of the Global Sea Level Observing System (GLOSS), and has participated in important international conferences and working groups concerned with sea level and climate change. These and other activities are reviewed briefly in the following report. In the period since the last Annual Report (i.e. since mid-December 1999), almost 1300 station-years of data were entered into the PSMSL database which is approximately 400 more than in 1999. This is a creditable achievement, given the local difficulties referred to in last year's PSMSL Report, with the number of station-years this year similar to those obtained on average prior to 1999.

GLOSS

The Global Sea Level Observing System (GLOSS) is an Intergovernmental Oceanographic Commission (IOC) project, one of the aims of which is to improve the quality and quantity of data supplied to the PSMSL. GLOSS can be considered as one of the first components of the Global Ocean Observing System (GOOS). In brief, the status of the programme at the present time is near-identical to that one year ago. GLOSS can be considered approximately two-thirds operational, if one uses data receipts by the PSMSL as a guide to operational status, or somewhat better if one considers several factors discussed in detail in the PSMSL 1999 Report. However, these status summaries hide major problems in several regions, with expenditure in new tide gauge equipment in a number of countries, and the network improvements which result, balanced against the fact that many GLOSS stations in other countries are being terminated or require major upgrades. In addition, the investments made in gauges for international programs (notably WOCE) are unlikely to be repeated in future. Consequently, it is possible that GLOSS status, measured in terms of PSMSL receipts, may have reached a plateau. This pessimism is contradicted to some extent by the stated requirements for investment in regional networks of coastal tide gauges by, for example, the GOOS COOP (Coastal Oceans Observations Panel). Therefore, GLOSS status may receive a boost in the long term from 'coastal', rather than 'climate' or 'oceanographic', applications. The PSMSL maintains a list of reports relevant to the development of GLOSS http://www.pol.ac.uk/psmsl/training/gloss.pub.html An updated version of the third volume of the IOC Manuals and Guides No.14 on sea level measurement and interpretation has been completed and can be down-loaded from the PSMSL training web page: http://www.pol.ac.uk/psmsl/training/training.html

New WOCE Sea Level Data CD-ROM Version 2.0 of the WOCE Sea Level Data set is now available. In addition to the 'Fast-delivery' and 'Delayed-mode' WOCE sea level data sets, the CD-ROM contains tidal constants from the WOCE sea level data set, PSMSL monthly and annual mean sea level data set, and the GLOSS Station Handbook (Version 4.1). Copies are available from PSMSL, BODC or the University of Hawaii Sea Level Center. At the recent IOC International Oceanographic Data and Information Exchange (IODE) XVI Committee meeting several extensions to the Global Ocean Data Archaeology and Rescue (GODAR) project led by Mr. Syd Levitus (Ocean Climate Laboratory, WDC-A) were suggested. Dr. Lesley Rickards represented the PSMSL at this meeting and proposed a data archaeology project for historical sea level records with the aim of extending existing time series and gaining access to observations which are not in digital form. In many countries there are considerable amounts of historical sea level data in paper form such as charts or tabulations. These need to be computerised to provide electronic access, as backup for data security, and so that they can be subject to modern quality control and analysis. The original records would not be destroyed, as they may contain further information which is not captured by the computerised version (for example, charts digitised to hourly values might miss tsunami or seiche information) and also, in some cases, they are historic documents.

GLOUP

The PSMSL is responsible to the IAPSO Commission on Mean Sea Level and Tides for the maintenance of the database of pelagic (bottom pressure recorder) information. This data base, now called GLOUP (Global Undersea Pressures), was significantly enhanced during the year by Dr. Chris Hughes and can be inspected at: http://www.pol.ac.uk/psmslh/gloup/gloup.html.

Current holdings consist of 279 records at 149 sites, of which 62 are deeper than 200 m and longer than 25 days (20 longer than 300 days). Currently, all sites are in the Atlantic and Indian Ocean sectors, with none in the Pacific, and work is underway to acquire Pacific records. High frequency and daily data are available from the web site, as well as tidal analyses. The latter will be input to the IAPSO Pelagic Tidal Constants data set, which is also maintained by Dr. Hughes on behalf of the PSMSL and IAPSO.

9. BIPM Time Section

Felicitas Arias, Head

International time scales

Reference time scales International Atomic Time (TAI) and Universal Coordinated Time (UTC) have been computed regularly and have been published in the monthly Circular T. Definitive results for 1999 and 2000 have been available, in the form of computer-readable files in the BIPM home-page and on printed volumes of the respective Annual Reports of the BIPM Time Section. Work is done to automate the calculation of TAI and UTC, this allowing a shorter delay in the publication of Circular T.

Algorithms for time scales

Research concerning time scale algorithms includes studies to improve the long-term stability of the free atomic time scale EAL and the accuracy of TAI. Studies are undertaken to evaluate the feasibility of providing a prediction of UTC in quasi-real time. Some 80 % of the clocks are now either commercial caesium clocks of the type HP5071A or active, auto-tuned active hydrogen masers, and together they contribute 86 % of the total weight with consequent improvement in the stability of EAL. Since most HP5071A clocks have at present the maximum relative weight, the weighting procedure of clocks in TAI is under revision. The medium-term stability of EAL, expressed in terms of the Allan deviation, is estimated to be 0.6 ´ 10-15 for averaging times of 20 to 40 days over the period. Nine primary frequency standards reported their measures to the BIPM. The global treatment of these individual measurements led to a relative departure of the duration of the TAI scale unit from the SI second on the geoid ranging, in the last year, from +2 ´ 10-15 to +6 ´ 10-15, with an uncertainty of 4 ´ 10-15. Following the recommendations of the Consultative Committee on Time and Frequency, changes were implemented to render the data used in TAI, as well as the results, more accessible to the users and to make the procedures of calculation even more transparent and traceable. Since April 2000 two modifications were implemented: a new model to characterise the instability of the free atomic scale EAL, and a more complete representation of the uncertainty of the deviation of the TAI scale interval relative to that of the Terrestrial Time TT.

Time links

In the last decade the time links computed at the BIPM used the classical GPS common-view technique based on C/A-code measurements obtained from one-channel receivers. The commercial availability of newly developed receivers has stimulated interest in extending the classical common-view technique for use of multichannel dual-code dual-system (GPS and GLONASS) observations, with the aim of improving the accuracy of time transfer. The two-way time and frequency transfer via geostationary satellites (TWSTFT) has a performance comparable to that of GPS. Since July 1999 GPS multichannel links and TWSFTF links are being progressively introduced in TAI. Even if the calculation of TAI relies mostly on single channel GPS links , GPS multichannel and TWSTFT links are also included. Ionospheric parameters and precise ephemerides provided by the IGS (International GPS Service) are routinely used to correct all links in regular TAI calculations since May 2000. In addition, the BIPM Time section carries on research on new techniques of time transfer, such as the utilisation of geodetic type receivers. These activities are developed in the frame of the IGS/BIPM pilot project to study accurate time and frequency comparison using GPS phase and code measurements.

Space-time references

The BIPM/IAU Joint Committee on general relativity for space-time reference systems and metrology (JCR), created in 1997, continued its work. Two studies have been conducted at the BIPM in collaboration with other members of the JCR. One concerns the extension of the relativistic framework to allow a correct treatment for time transformations and the realisation of barycentric coordinate time at the full post Newtonian level. The second study concerns the realisation of geocentric coordinate times. Following a Call for Participation of the IERS, the BIPM, jointly with the USNO, will provide its Conventions Product Centre since January 2001.

10. International Center for Earth Tides

B.Ducarme, Director

The staff of ICET, which is completely supported by the Royal Observatory of Belgium, is composed as follows: Prof. B.Ducarme, Director (part time) Mrs. L.Vandercoilden, technician (full time), Mr. M.Hendrickx, technician (part time). The Royal Observatory of Belgium is hosting ICET since 1958 and continues to provides numerous administrative and scientific facilities especially for the publication of the " Bulletin d'Information des Marées Terrestres" , for the tidal data processing and more recently for the maintenance of the ICET/GGP data base.

Ongoing activities

The tasks of the Centre are continuously updated and ICET decided : to become the computing centre and the data bank of the Global Geodynamics Project (GGP) which is a six years world wide campaign of tidal gravity observations using a network of more than 15 cryogenic gravimeters, to organise training sessions in tidal data preprocessing and analysis using up to date software and procedures, and to improve the diffusion of these software, to develop its web page www.astro.oma.be/ICET/

As the groups interested by tidal phenomena are always very small and often only marginally involved in tidal research and as the papers dealing specifically with tidal studies are not fitting so well to international journals, it is still very important to keep a specialised diffusion and information medium. It is the vocation of the "Bulletin d'Information des Marées Terrestres" (BIM). ICET is publishing two eighty-pages issues per year. Starting from BIM 133 an electronic version is available from ICET web site.

We receive regularly requests for information. The most common requests concerns tidal predictions or general information. We receive more or less one request per week. Since ICET is charged, thanks to Marion Wenzel courtesy, to distribute freely the ETERNA34 tidal analysis package we had to sent 40 copies of the CD-rom within the first year. ICET web site has been updated and developed. Besides general information including historical aspect and last ICET reports, it proposes to the visitors an access to: the general bibliography on Earth Tides from 1870-1997 either by alphabetical order of the first author or following the decimal classification introduced by Prof. P.Melchior, the table of content of the most recent issues of the BIM and, starting from BIM 133, an electronic version of the papers, tidal analysis and preprocessing software available from different web sites or on request from ICET.

The 14th International Symposium on Earth Tides

ICET Director presented his report to the Earth Tides Commission (ETC) at the 14th International Symposium on Earth Tides (ETS2000) which took place at Mizusawa (Japan) from August 28 to September 1st. The ICET Directing Board met on August 29 under the chairmanship of Prof. S. Takemoto, ETC President. Unhappily several members were not present. Following the decease of Prof. H.G.Wenzel, it was decided to propose the cooptation of additional members i.e. Prof. R.Vieira Diaz from Spain and Dr. H. Schuh from Austria. The main subject of discussion was the proposal of creating a new confederated service inside IAG, discussed below.

Data processing

Several Institutes continue to send regularly earth tides data to ICET. All data received have been checked and recompiled. East European countries are still sending clinometric and extensometric records but most of the activity is now devoted to gravity tides. Most of our computing activities are now connected to the GGP project. According to the internal GGP rules we produced already the 4 CD-ROMS containing the raw (#1 and #2) and processed (#1a and #2a) minute data of the two first years, 97/07 to 99/07, of the project. The CD-ROM of the third year is due on July 2001.

Proposed New structures inside IAG

In the framework of the reorganisation of the IAG structures a proposal has been put forward by Prof. F. Sanso, Director of the IGeS to create a confederation of the IAG Services dealing with the gravity vector i.e. the International Centre for Earth Tides (ICET), the International Gravimetric Bureau (IGB) and the International Geoid Service (IGeS). A draft proposal was established during meetings of the three directors in Milan on May 3, 2000 and on March 22nd in Nice. Other entities could join this group. The proposed name of this new composite body is Gravity Field and Figure of the Earth Service (GFFS). As the statutes of the contributing entities are very different, some being FAGS member or WDC other not, each partner will keep his own governing bodies and structures. There will be an « Advisory board » organising the co-operation between Centres and their representation at IAG level. Individuals wishing to contribute actively to the GFFS may obtain the status of « Fellows » and will be represented inside the Advisory Board. The Directing board of ICET agreed on the principle of joining GFFS. The same holds for IGB and IGeS. The IAG Executive Committee set up a provisory board to report at the General Assembly in Budapest. As a first action ICET was decided to organise jointly with IGB a summer school on gravity measurements and data processing, including the tidal signal.

GEODETIC ASPECT OF THE LAW OF THE SEA (GALOS)

Chairman : B. G. Harsson (Norway)

I- Mandate

The mandate of GALOS is to formulate recommendations concerning geodetic aspects of international maritime boundary delimitation within the framework of the Law of the Sea Convention 1982 for the IAG member countries. The geodetic tasks involved in the delimitation are:

1) Accurate area determination.
2) Definition of offshore limits, both geometrical and as continental shelf limits.
3) Definition of equidistant boundaries.
4) Definition of partial effect boundaries.
5) Determination of base points.

II- Program of work since 1999

At the international ABLOS conference in Monaco 1999, under the title “Technical aspects of Maritime Boundary delineation and delimitation” GALOS was offered to convene the session for geodetic aspects. Seven presentations were given in this session. All together the conference had four sessions during two days in September. The proceedings were published by the International Hydrographic Bureau in Monaco.

After the ABLOS conference a GALOS business meeting was held in Monaco.

A new GALOS web-site is finished at the address: www.gdiv.statkart.no/galos

Also for the next international ABLOS conference “Accuracies and Uncertainties in Maritime Boundaries and Outer Limits”, which will be held in Monaco 18 – 19 October 2001, GALOS is offered to convene one session.

III- Members

Members are:

G. Carrera	(Canada/Mexico)	
E. W. Grafarend	(Germany)	
D. Grant	(New Zealand)	
E. Groten	(Germany)	
B. G. Harsson	(Norway) -	Chairman
H. G. Henneberg	(Venezuela)	
K. de Jong	(The Netherlands)	
F. Madsen	(Denmark)	
S. Mira	(Indonesia)	
B. Murphy	(Australia)	
S. Nichols	(Canada)	
S. Oszczak	(Poland)	

C. Rizos	(Australia)
G. Seeber	(Germany)
M. Sasaki	(Japan)
A. B. H. Salem	(Tunisia)
L. E. Sjöberg	(Sweden)
W. A. van Gein	(The Netherlands)
P. Vanicek	(Canada)
J. D. Zund	(USA)

Observer:

T. Katsura	(Japan)
N. R. Guy	(South Africa)

The relation GALOS - ABLOS

The chairman of GALOS is appointed as one of the three IAG-members in ABLOS, which has all together 10 members. ABLOS is the Advisory Board on Hydrographic, Geodetic and Marine Geo-Scientific Aspects of the Law of the Sea. The other seven members of ABLOS are: 3 appointed from the International Hydrographic Organization (IHO), 3 from the Intergovernmental Oceanographic Commission (IOC) and the Division for Ocean Affairs and the Law of the Sea of the UN Office of Legal Affairs (DOALOS) has one representative in an ex-officio capacity.
The web-address to ABLOS is: http://www.gmat.unsw.edu.au/ablos/

GALOS-member Jack Weightman dead.

It is with the deepest regret that we had to announce the passing away of our colleague Jack Weightman the 15th January 2001 after a short illness. He had been an active member of GALOS since GALOS started up in 1988.

REPORT FROM THE WORKING GROUP ON EDUCATION

Presented at the meeting of the IAG Executive Committee, April 2000.

Authors: B.Heck (Karlsruhe), M.Sideris (Calgary), C.C.Tscherning (Copenhagen).

At the meeting of the Executive Commmittee in November 1999 a proposal by C.C.Tscherning for creating an Education Commission was presented http://www.gfy.ku.dk/~iag/educcom.htm

The proposal was discussed briefly at the meeting and it was decided to form a Working Group with the authors of this report as members to consider the proposal, and report at the EC meeting in April 2000.

The committee agrees that it is important that IAG plays an even stronger role in geodetic education. This could primarily be done by facilitating the exchange of information about teaching material and courses and by helping in organizing international courses at different levels.

In order to study the problem of exchanging educational information, an experimental home-page was established associated with the IAG home-page: http://www.gfy.ku.dk/~iag/eduwg.htm

This home-page shows which kinds of material could be made available in different categories.

The committee has discussed whether a "Commission" should be established, but consider it sufficient to establish a smaller Special Commission (SC) of active teachers from the different continents directly reporting to the EC. In a new structure it might be merged with another commission.

The SC should have the following tasks:

(1) Collect and distribute information about existing courses, educational material (lecture noters, powerpoint presentations, www-material) and curricula. This should be done using a home-page much like the experimental one mentioned above. The maintenance of this home-page should be done by an institution after an announcement of opportunity. (The IAG Education Service (?)). This institution should also be responsible for checking the quality of the material posted on the home-page.
(2) Review proposals for courses and contingently propose courses in areas (both geographical and topical) where there are no identified activities (and a need, obviously).
(3) Foster cooperation between institutions offering PhD-training, cf. the DOGE proposal. The EU framework programs gives possibilities at least within Europe.
(4) Investigate the use of new educational tools. Especially tools for distance learning.
Also this should be done after an announcement of opportunity.
(5) The SC should not try to establish a standard curriculum, but inform of the various ways geodesy is taught at different places. The SC may however on request evaluate curricula.

IAG - CDC (International Association of Geodesy / Committee for Developing Countries)

IAG Scientific Assembly - Budapest, September 2 - 8, 2001.

1. History

During the General Assembly in Vienna, August 1991, the IUGG (International Union of Geodesy and Geophysics) requested to each of its constituent associations to reinforce actions towards Developing Countries. For this reason the IAG Executive Committee, at its meeting in Columbus, March 1992, set up an IAG Committee for Developing Countries (IAG - CDC). The committee had several activities on the coordination of Michael Louis. With his retirement the activities have been discontinued. At the EC meeting in Como, November 1999, a proposal by the president has been approved to restart the activities of IAG - CDC under the coordination of Denizar Blitzkow.

2. Objectives

2.1 To encourage and to facilitate present participation of developing countries in geodetic activities with a significant contribution to their own development as well as to the development of geodesy in general.
2.2 To request all IAG bodies and organizations to take into account, in their activities, the needs and capabilities of developing countries in order to ensure a profitable participation of them.

3. IAG - CDC Membership

Denizar Blitzkow (Brazil) - Chairman
Edvaldo Simões da Fonseca Junior (Brazil)
J.Y. Chen (China)
Charles Merry (South Africa)
Salah Mahmoud (Egypt)
Salem Kahlouche (Algeria)
José Napoleon Hernandez (Venezuela)
John Manning (Australia).

4. Activities

IAG - CDC has been involved directly or indirectly with different projects in South America and Africa.

4.1 South America

4.1.1 Gravity surveys for densification of national network have been carried out in several countries for the last few years. The following countries have improved the gravity coverage due to this action: Argentina, Brazil, Chile, and Paraguay.

This initiative has been coordinated by D. Blitzkow and supported by NIMA(USA), GETECH (University of Leeds – UK), and many national organizations in the different countries. As a consequence, several improved versions of the geoid have been derived for the continent in a joint cooperation of EPUSP and IGeS.

4.1.2 Workshop: South America Geoid 2000;

The South America Geoid 2000 workshop held at Escola Politécnica, Universidade de São Paulo, May 17 - 19, 2000, was organized by IGeS (International Geoid Service), SCGGSA (Sub-Commission for Gravity and Geoid in South America), CDC (Committee for Developing Countries) and it was also supported by IAPSO (International Association of the Physical Science of the Ocean). The workshop had the following objectives:

- To assemble as many countries as possible from South America to compute a geoid model.
- To encourage every country to cooperate with SCGGSA for data delivery.
- To encourage every country to compute a local geoid model with the data available.
- To discuss different efforts for data acquisition in the continent.

The countries that participated to the activities were the following: Argentina, Brazil, Chile, Ecuador, Paraguay and Uruguay.

IAG - CDC Participation: D. Blitzkow, R. Barzaghi, O. Andersen, R. Forsberg.

4.2 Africa

4.2.1 African Reference System (AFREF): Southern Africa

Representatives of 8 countries in Southern Africa met in Cape Town on the 13th and 14th of March 2001 to discuss a regional project within the broader ‘AFREF’ project to create a uniform geodetic reference system for Africa. The 8 countries present were: Botswana, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe.

IAG - CDC Participation: Sansò, F., Neilan, R..

4.2.2 Organization of Africa gravity data for geoid computation

The purpose of this project is to carry out a determination of the geoid in Africa. A major part of the project will be to collate and merge gravity anomaly data sets for Africa. Because of the paucity of these data and their poor distribution, the geoid that will result won’t be very precise, but it should still be a substantial improvement over the global EGM96 model. An equally important part of the project will be to develop geoid computation expertise within Africa.

To do the African Geoid was created a working group with the following objectives:

- Identifying and acquiring data sets - gravity anomalies, DEM's, GPS/leveling;
- Training African geodesists in geoid computation;
- Merging and validation of gravity data sets, producing 5' gridded and mean Dg;
- Computation of African geoid, and evaluation using GPS/leveling data.
  IAG - CDC Coordination: C. Merry, D. Blitzkow.

4.2.3 2nd Workshop on the definition of the North African Reference Frame (2° Atelier Nord Africain de Géodésie)

Representatives of the following countries participated to the workshop: Algeria, Libya, Morocco, Mauritania and Tunisia.

During the workshop a project was created to unify the Geodetic Reference Frame in North Africa (NAFREF).

To do the unification 3 working groups were created:

WG I: Definition and establishment of a Terrestrial Reference System for North Africa.

WG II: Unified Geoid Determination.

WG III: Establishment of a General Committee for the realization of NAFREF. It was created two committees: Coordination Committee and Scientific Committee.

IAG - CDC Participation: F. Sansò, Z. Altamimi, M. Sarrailh, S. M. Alves Costa.

(Report prepared by D. Blitzkow and E.S. Fonseca Junior)

REPORT OF THE IAU/IAG WORKING GROUP ON CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS OF THE PLANETS AND SATELLITES: 2000

P.K. SEIDELMANN (CHAIR)
U.S. Naval Observatory, Washington, DC, U.S.A.

V.K. ABALAKIN
Institute for Theoretical Astronomy, St. Petersburg, Russia

M. BURSA
Astronomical Institute, Prague, Czech Republic

M.E. DAVIES
RAND, Santa Monica, CA, U.S.A.

C. de BERGH
Observatoire de Paris, Paris, France

J.H. LIESKE
Jet Propulsion Laboratory, Pasadena, CA, U.S.A.

J. OBERST
DLR Berlin Adlershof, Berlin, Germany

J.L. SIMON
Institut de Mecanique Celeste, Paris, France

E.M. STANDISH
Jet Propulsion Laboratory, Pasadena, Ca, USA

P. STOOKE
Univ. of Western Ontario, London, Canada

P.C. THOMAS
Cornell Univ., Ithaca, NY, USA

Abstract. Every three years the IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites revises tables giving the directions of the north poles of rotation and the prime meridians of the planets, satellites, and asteroids. Also presented are revised tables giving their sizes and shapes. Changes since the previous report are summarized in the Appendix.

Key words: Cartographic coordinates, rotation axes, rotation periods, sizes, shapes

1. Introduction

The IAU Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites was established as a consequence of resolutions adopted by Commissions 4 and 16 at the IAU General Assembly at Grenoble in 1976. The first report of the Working Group was presented to the General Assembly at Montreal in 1979 and published in the Trans. IAU 17B, 72-79, 1980. The report with appendices was published in Celestial Mechanics 22, 205-230, 1980. The guiding principles and conventions that were adopted by the Group and the rationale for their acceptance were presented in that report and its appendices will not be reviewed here. The second report of the Working Group was presented to the General Assembly at Patras in 1982 and published in the Trans. IAU 18B, 15 1 162, 1983, and also in Celestial Mechanics 29, 309-321, 1983. The third report on the Working Group was presented to the General Assembly at New Delhi in 1985 and published in Celestial Mechanics 39, 103-113, 1986. The fourth report of the Working Group was presented to the General Assembly at Baltimore in 1988 and was published in Celestial Mechanics and Dynamical Astronomy 46,187-204, 1989. The fifth report of the Working Group was presented to the General Assembly at Buenos Aires in 1991 and was published in Celestial Mechanics and Dynamical Astronomy 53, 377-397, 1992. The sixth report of the Working Group was presented to the General Assembly at the Hague in 1994 and was published in Celestial Mechanics and Dynamical Astronomy 63, 127-148, 1996. The seventh report of the Working Group was presented to the General Assembly at Kyoto, but the changes were sufficiently minor that the report was not published.

In 1984 the International Association of Geodesy (IAG) and the Committee on Space Research (COSPAR) expressed interest in the activities of the Working Group, and after reviewing alternatives, the Executive Committees of all three organizations decided to jointly sponsor the Working Group. In 1998 COSPAR informed the Working Group that, while the reports and expertise of the Working Group are appreciated, the Working Group does not follow the scientific structure of COSPAR and they wish to terminate the formal affiliation.

This report incorporates revisions to the tables giving the directions of the north poles of rotation and the prime meridians of the planets and satellites since the last report. Also, tables giving the sizes and shapes of the planets, satellites, and asteroids are presented.

2. Definition of Rotational Elements

Planetary coordinate systems are defined relative to their mean axis of rotation and various definitions of longitude depending on the body. The longitude systems of most of those bodies with observable rigid surfaces have been defined by references to a surface feature such as a crater. Approximate expressions for these rotational elements with respect to the J2000 inertial coordinate system have been derived. The J2000 coordinate system is defined by the FK5 star catalog and has the standard epoch of 2000 January 1.5 (JD 2451545.0), TCB. The variable quantities are expressed in units of days (86400 SI seconds) or Julian centuries of 36525 days.

The north pole is that pole of rotation that lies on the north side of the invariable plane of the solar system. The direction of the north pole is specified by the value of its right ascension a0 and declination d0, whereas the location of the prime meridian is specified by the angle that is measured along the planet's equator in an easterly direction with respect to the planet's north pole from the node Q (located at right ascension 90° + a0) of the planet's equator on the standard equator to the point B where the prime meridian crosses the planet's equator. The right ascension of the point Q is 90° + a0 and the inclination of the planet's equator to the standard equator is 90° - d0. Because the prime meridian is assumed to rotate uniformly with the planet, W accordingly varies linearly with time. In addition, a0, d0, and W may vary with time due to a precession of the axis of rotation of the planet (or satellite). If W increases with time, the planet has a direct (or prograde) rotation and if W decreases with time, the rotation is said to be retrograde.

In the absence of other information, the axis of rotation is assumed to be normal to the mean orbital plane; Mercury and most of the satellites are in this category. For many of the satellites, it is assumed that the rotation rate is equal to the mean orbital period.

The angle W specifies the ephemeris position of the prime meridian, and for planets or satellites without any accurately observable fixed surface features, the adopted expression for W defines the prime meridian and is not subject to correction. Where possible, however, the cartographic position of the prime meridian is defined by a suitable observable feature, and so the constants in the expression W = W0 + Wd, where d is the interval in days from the standard epoch, are chosen so that the ephemeris position follows the motion of the cartographic position as closely as possible; in these cases the expression for W may require emendation in the future.

Recommended values of the constants in the expressions for a0,d0, and W, in standard equatorial coordinates with equinox J2000 at epoch J2000, are given for the planets, satellites, and asteroids in Tables I, II, and III. In general, these expressions should be accurate to one-tenth of a degree; however, two decimal places are given to assure consistency when changing coordinates systems. Zeros are added to rate values (W) for computational consistency and are not an indication of significant accuracy. Additional decimal places are given in the expressions for the Moon, Mars, Saturn, and Uranus, reflecting the greater confidence in their accuracy. Expressions for the Sun and Earth are given to a similar precision as those of the other bodies of the solar system and are for comparative purposes only. The recommended coordinate system for the Moon is the mean Earth/polar axis system (in contrast to the principal axis system).

3. Definition of Cartographic Coordinate Systems

In mathematical and geodetic terminology, the terms 'latitude' and 'longitude' refer to a right-hand spherical coordinate system in which latitude is defined as the angle between a vector and the equator, and longitude is the angle between the vector and the plane of the prime meridian measured in an eastern direction. This coordinate system, together with Cartesian coordinates, is used in most planetary computations, and is sometimes called the planetocentric coordinate system. The origin is the center of mass.

Because of astronomical tradition, planetographic coordinates (those used on maps) may or may not be identical with traditional spherical coordinates. Planetographic coordinates are defined by guiding principles contained in a resolution passed at the fourteenth General Assembly of the IAU in 1970. These guiding principles state that:

(1) The rotational pole of a planet or satellite which lies on the north side of the invariable plane will be called north, and northern latitudes will be designated as positive.

(2) The planetographic longitude of the central meridian, as observed from a direction fixed with respect to an inertial system, will increase with time. The range of longitudes shall extend from 0° to 360°.

Thus, west longitudes (i.e., longitudes measured positively to the west) will be used when the rotation is prograde and east longitudes (i.e., longitudes measured positively to the east) when the rotation is retrograde. The origin is the center of mass. Also because of tradition, the Earth, Sun, and Moon do not conform with this definition. Their rotations are prograde and longitudes run both east and west 180° instead of the usual 360°.

Latitude is measured north and south of the equator; north latitudes are designated as positive. The planetographic latitude of a point on the reference surface is the angle between the equatorial plane and the normal to the reference surface at the point. In the planetographic system, the position of a point (P) not on the reference surface is specified by the planetographic latitude of the point (P') on the reference surface at which the normal passes through P and by the height (h) of P above P'.

The reference surfaces for some planets (such as Earth and Mars) are ellipsoids of revolution for which the radius at the equator (A) is larger than the polar semiaxis (C).

Calculations of the hydrostatic shapes of some of the satellites (Io, Mimas, Enceladus, and Miranda) indicate that their reference surfaces should be triaxial ellipsoids. Triaxial ellipsoids would render many computations more complicated, especially those related to map projections. Many projections would loose their elegant and popular properties. For this reason spherical reference surfaces are frequently used in mapping programs.

Many small bodies of the solar system (satellites, asteroids, and comet nuclei) have very irregular shapes. Sometimes spherical reference surfaces are used for computational convenience, but this approach does not preserve the area or shape characteristics of common map projections. Orthographic projections often are adopted for cartographic portrayal as these preserve the irregular appearance of the body without artificial distortion.

With the introduction of large mass storage to computer systems, digital cartography has become increasingly popular. These databases are important to irregularly shaped bodies and other bodies where the surface can be described by a file containing planetographic longitude, latitude, and radius for each pixel. In this case the reference sphere has shrunk to a point. Other parameters such as brightness, gravity, etc., if known, can be associated with each pixel. With proper programming, pictorial and projected views of the body can then be displayed by introducing a suitable reference surface.

Table IV contains data on the size and shapes of the planets. The first column gives the mean radius of the body (i.e., the radius of a sphere of approximately the same volume as the spheroid). The standard errors of the mean radii are indications of the accuracy of determination of these parameters due to inaccuracies of the observational data. Because the shape of a rotating body in hydrostatic equilibrium is approximately a spheroid, this is frequently a good approximation to the shape of planets, and so the second and third columns give equatorial and polar radii for 'best-fit' spheroids. The origin of these coordinates is the center-of-mass with the polar axis coincident with the spin axis. The fourth column is the root-mean-square (RMS) of the radii residuals from the spheroid and is an indication of the variations of the surface from the spheroid due to topography. The last two columns give the maximum positive and negative residuals to bracket the spread.

Table V contains data on the size and shape of the satellites. The first column gives the mean radius of the body. The standard errors of the mean radii are indications of the accuracy of determination of these parameters due to inaccuracies of the observational data. Because the hydrostatic shape of a body in synchronous rotation about a larger body is approximately an ellipsoid, that shape has been selected to describe the shape of the satellites. The next three columns (2-4) give the axes of the best-fit ellipsoids in the order equatorial subplanetary, equatorial along orbit, and polar. The origin of these coordinates is the center-of-mass with the polar axis coincident with the spin axis. The fifth column is the RMS of the radii residuals from the ellipsoid and is an indication of the variations of the surface from the ellipsoid due to topography. The last two columns give the maximum positive and negative residuals to bracket the spread.

Table I. Recommended values for the direction of the north pole of rotation and the prime meridian of the Sun and planets (2000)

a_0, d_0 are standard equatorial coordinates with equinox J2000 at epoch J2000.

Approximate coordinates of the north pole of the invariable plane are
a0 = 273 °.85, d0= 66°.99.

T = interval in Julian centuries (of 36525 days) from the standard epoch

d = interval in days from the standard epoch.

The standard epoch is 2000 January 1.5, i.e., JD 2451545.0 TCB.

Sun	a0	=	286°. 13	
	d0	=	63°.87	
	W	=	84°.10 + 14°.1844000d	
Mercury	a0	=	281.01 - 0.033T	
	d0	=	61.45 - 0.005T	
	W	=	329.548 + 6.1385025d	(a)
Venus	a0	=	272.76	
	d0	=	67.16	
	W	=	160.20 - 1.4813688d	(b)
Earth	a0	=	0.00 - 0.641T	
	d0	=	90.00 - 0.557T	
	W	=	190.16 + 360.9856235d	(c)
Mars	a0	=	317.68143 - 0.1061T	
	d0	=	52.88650 - 0.0609T	
	W	=	176.753 + 350.89198226d	(d)
Jupiter	a0	=	268.05 - 0.009T	
	d0	=	64.49 + 0.003T	
	W	=	284.95 + 870.5366420d	(e)
Saturn	a0	=	40.589 - 0.036T	
	d0	=	83.537 - 0.004T	
	W	=	38.90 + 810.7939024d	(e)
Uranus	a0	=	257.311	
	d0	=	-15.175	
	W	=	203.81 - 501.1600928d	(e)
Neptune	a0	=	299.36 + 0.70 sin N	
	d0	=	43.46 - 0.51 cos N	
	W	=	253.18 + 536.3128492d-0.48sin N	(e)
	N	=	357.85 + 52.316T	
Pluto	a0	=	313.02	
	d0	=	9.09	
	W	=	236.77 - 56.3623195d	(f)

(a) The 20° meridian is defined by the crater Hun Kal.

(b) The 0° meridian is defined by the central peak in the crater Ariadne.

(c) The expression for W might be in error by as much as 0°.2 because of uncertainty in the length of the UT day and the TT UT on 1 January 2000.

(d) The 0° meridian is defined by the crater Airy-0.

(e) The equations for W for Jupiter, Saturn, Uranus and Neptune refer to the rotation of their magnetic fields (System III). On Jupiter, System I ($WI = 67°.1 + 877°.900d$) refers to the mean atmospheric equatorial rotation; System II ($WII = 43°.3 + 870°.270d$) refers to the mean atmospheric rotation north of the south component of the north equatorial belt, and south of the north component of the south equatorial belt.

(f) The 0° meridian is defined as the mean sub-Charon meridian.

Table II. Recommended values for the direction of the north pole of rotation and the prime meridian of the satellites (2000)

---

a0, d0, T, and d have the same meanings as in Table I (epoch 2000 January 1.5, i.e., JD 2451545.0 TCB).

Earth: Moon

$$a0 = 269°.9949 + 0°.0031T - 3°.8787 \sin El - 0°.1204 \sin E2 + 0.0700 \sin E3 - 0.0172 \sin E4 + 0.0072 \sin E6 - 0.0052 \sin El0 + 0.0043 \sin E13$$

$$d0 = 66.5392 + 0.0130T + 1.5419 \cos E1 + 0.0239 \cos E2 - 0.0278 \cos E3 + 0.0068 \cos E4 - 0.0029 \cos E6 + 0.0009 \cos E7 + 0.0008 \cos E10 - 0.0009 \cos E13$$

$$W = 38.3213 + 13.17635815\, d - 1.4 \times 10^{-12}\, d^2 + 3.5610 \sin E1 + 0.1208 \sin E2 - 0.0642 \sin E3 + 0.0158 \sin E4 + 0.0252 \sin E5 - 0.0066 \sin E6 - 0.0047 \sin E7 - 0.0046 \sin E8 + 0.0028 \sin E9 + 0.0052 \sin E10 + 0.0040 \sin E11 + 0.0019 \sin E12 - 0.0044 \sin El3$$

where $El = 125°.045 - 0°.0529921d$, $E2 = 250°.089 - 0°.1059842d$, $E3 = 260°.008 + 13°.0120009d$,

$E4 = 176.625 + 13.3407154d$, $E5 = 357.529 + 0.9856003d$, $E6 = 311.589 + 26.4057084d$,

$E7 = 134.963 + 13.0649930d$, $E8 = 276.617 + 0.3287146d$, $E9 = 34.226 + 1.7484877d$,

$E10 = 15.134 - 0.1589763d$, $E11 = 119.743 + 0.0036096d$, $E12 = 239.961 + 0.1643573d$,

$E13 = 25.053 + 12.9590088d$

Mars:	I	Phobos	a0 = 317.68	- 0.108T	+ 1.79 sin Ml	
			d0 = 52.90	- 0.061T	- 1.08 cos M1	
			W = 35.06	+ 1128.8445850d	+ 8.864T 2	
				- 1.42 sin M1	- 0.78 sin M2	
	II	Deimos	a0 = 316.65	- 0.108T	+ 2.98 sin M3	
			d0 = 53.52	- 0.061T	- 1.78 cos M3	
			W = 79.41	+ 285.1618970d	- 0.520T2	
				- 2.58 sin M3	+ 0.19 cosM3	

where M1 = 169°.51 - 0°.4357640d, M2 = 192°.93 + 1128 °.4096700d + 8°.864T2,

M3 = 53°.47 - 0°.0181510d

Jupiter:	XVI	Metis	a0 = 268.05	- 0.009T		
			d0 = 64.49	+ 0.003T		
			W = 346.09	+ 1221.2547301d		
	XV	Adrastea	a0 = 268.05	- 0.009T		
			d0 = 64.49	+ 0.003T		
			W = 33.29	+ 1206.9986602d		
	V	Amalthea	a0 = 268.05	- 0.009T	- 0.84 sin J1	+ 0.01 sin 2J1
			d0 = 64.49	+ 0.003T	- 0.36 cos J1	
			W = 231.67	+ 722.6314560d	+ 0.76 sin J1	- 0.01 sin 2J1
	XIV	Thebe	a0 = 268.05	- 0.009T	- 2.11 sin J2	+ 0.04 sin2J2
			d0 = 64.49	+ 0.003T	- 0.91 cos J2	+ 0.01 cos 2J2
			W = 8.56	+ 533.7004100d	+ 1.91 sin J2	- 0.04 sin 2J2
	I	Io	a0 = 268.05	- 0.009T	+ 0.094 sin J3	+ 0.024 sin J4
			d0 = 64.50	+ 0.003T	+ 0.040 cos J3	+ 0.011 cos J4
			W = 200.39	+ 203.4889538d	- 0.085 sin J3	- 0. 022 sin J4
	II	Europa	a0 = 268.08	- 0.009T	+ 1.086 sin J4	+ 0.060 sin J5
					+ 0.015 sin J6	+ 0. 009 sin J7
			d0 = 64.51	+ 0.003T	+ 0.468 cos J4	+ 0.026 cos J5
					+ 0.007 cos J6	+ 0.002 cos J7
			W = 35.67	+ 101.3747235d	- 0.980 sin J4	- 0.054 sin J5
(a)					- 0.014 sin J6	- 0.008 sin J7

	III	Ganymede	a0 = 268.20	- 0.009T	- 0.037 sin J4	+ 0.431 sin J5
						+ 0.091 sin J6
			d0 = 64.57	+ 0.003T	- 0.016 cos J4	+ 0.186 cos J5
						+ 0.039 cos J6
			W = 44.04	+ 50.3176081d	+ 0.033 sin J4	- 0.389 sin J5
(b)						- 0.082 sin J6
	IV	Callisto	a0 = 268.72	- 0.009T	- 0.068 sin J5	+ 0.590 sin J6
						+ 0.010 sin J8
			d0 = 64.83	+ 0.003T	- 0.029 cos J5	+ 0.254 cos J6
						- 0.004 cos J8
(c)			W = 259.73	+ 21.5710715d	+ 0.061 sin J5	- 0.533 sin J6
						- 0.009 sin J8

where J l = 73°.32 + 91472°.9T, J 2 = 24°.62 + 45137°.2T, J 3 = 283°.90 + 4850°.7T,

J 4 = 355.80 + 1191.3T, J 5 = 119.90 + 262.1T, J 6 = 229.80 + 64.3T,

J 7 = 352.25 + 2382.6T, J 8 = 113.35 + 6070.0T

Saturn:	XVIII	Pan	a0 = 40.6	- 0.036T
			d0 = 83.5	- 0.004T
			W = 48.8	+ 626.0440000d
	XV	Atlas	a0 = 40.58	- 0.036T
			d0 = 83.53	- 0.004T
			W = 137.88	+ 598.3060000d
	XVI	Prometheus	a0 = 40.58	- 0.036T
			d0 = 83.53	- 0.004T
			W = 296.14	+ 587.289000d
	XVII	Pandora	a0 = 40.58	- 0.036T
			d0 = 83.53	- 0.004T
			W = 162.92	+ 572.7891000d

	XI	Epimetheus	a0 = 40.58	- 0.036T	- 3.153 sin S1	+ 0.086 sin 2Sl
			d0 = 83.52	- 0.004T	- 0.356 cos S1	+ 0.005 cos 2SI
(j)	n		W = 293.87	+ 518.4907239d	+ 3.133 sin S1	- 0.086 sin 2S1
	X	Janus	a0 = 40.58	- 0.036T	- 1.623 sin S2	+ 0.023 sin 2S2
			d0 = 83.52	- 0.004T	- 0. 183 cos S2	+ 0.001 cos 2S2
(j)			W = 58.83	+ 518.2359876d	+ 1.613 sin S2	- 0.023 sin 2S2
	I	Mimas	a0 = 40.66	- 0.036T	+ 13.56 sin S3	
			d0 = 83.52	- 0.004T	- 1.53 cos S3	
(d)			W = 337.46	+ 381.9945550d	- 13.48 sin S3	- 44.85 sin S5
	II	Enceladus	a0 = 40.66	- 0.036T		
			d0 = 83.52	- 0.004T		
(e)			W = 2.82	+ 262.7318996d		
	III	Tethys	a0 = 40.66	- 0.036T	+ 9.66 sin S4	
			d0 = 83.52	- 0.004T	- 1.09 cos S4	
(f)			W = 10.45	+ 190.6979085d	- 9.60 sin S4	+ 2.23 sin S5
	XIII	Telesto	a0 = 50.51	- 0.036T		
			d0 = 84.06	- 0.004T		
(j)			W = 56.88	+ 190.6979332d		
	XIV	Calypso	a0 = 36.41	- 0.036T		
			d0 = 85.04	- 0.004T		
(j)			W = 153.51	+ 190.6742373d		
	IV	Dione	a0 = 40.66	- 0.036T		
			d0 = 83.52	- 0.004T		
(g)			W = 357.00	+ 131.5349316d		
	XII	Helene	a0 = 40.85	- 0.036T		
			d0 = 83.34	- 0.004T		
			W = 245.12	+ 131.6174056d		

	V	Rhea	a0 = 40.38	- 0.036T	+ 3. 10 sin S6
			d0 = 83.55	- 0.004T	- 0.35 cos S6
(h)			W = 235.16	+ 79.6900478d	- 3.08 sin S6
	VI	Titan	a0 = 36.41	- 0.036T	+ 2.66 sin S7
			d0 = 83.94	- 0.004T	- 0. 30 cos S7
			W = 189.64	+ 22.5769768d	- 2.64 sin S7
	VIII	Iapetus	a0 = 318.16	- 3.949T	
			d0 = 75.03	- 1.143T	
			W = 350.20	+ 4.5379572d	
	IX	Phoebe	a0 = 355.00		
			d0 = 68.70		
			W = 304.70	+ 930.8338720d	

where Sl = 353°.32 + 75706°.7T, S2 = 28°.72 + 75706°.7T, S3 = 177°.40 - 36505°.5T

S4 = 300.00 - 7225.9T, S5 = 316.45 + 506.2T, S6 = 345.20 - 1016.3T,

S7 = 29.80 - 52.1T

Uranus:	VI	Cordelia	a0 = 257.31	- 0. 15 sin U1	
			d0 = -15.18	+ 0.14 cos U 1	
			W = 127.69	- 1074.5205730d	- 0.04 sinUl
	VII	Ophelia	a0 = 257.31	- 0.09 sin U2	
			d0 = - 15.18	+ 0.09 cos U2	
			W = 130.35	- 956.4068150d	- 0.03 sin U2
	VIII	Bianca	a0 = 257.31	- 0.16 sin U3	
			d0 = -15.18	+ 0. 16 cos U3	
			W = 105.46	- 828.3914760d	- 0.04 sin U3
	IX	Cressida	a0 = 257.31	- 0.04 sin U4	
			d0 = - 15.18	+ 0. 04 cos U4	
			W = 59.16	- 776.5816320d	- 0.01 sin U4

X	Desdemona	a0 = 257.31	- 0. 17 sin U5		
		d0 = -15.18	+ 0. 16 cos U5		
		W = 95.08	- 760.0531690d	- 0.04 sin U5	
XI	Juliet	a0 = 257.31	- 0.06 sin U6		
		d0 = - 15.18	+ 0.06 cos U6		
		W = 302.56	- 730.1253660d	- 0.02 sin U6	
XII	Portia	a0 = 257.31	- 0.09 sin U7		
		d0 = - 15.18 + 0.09 cos U7			
		W = 25.03	- 701.4865870d	- 0.02 sin U7	
XIII	Rosalind	a0 = 257.31	- 0.29 sin U8		
		d0 = -15.18	+ 0.28 cos U8		
		W = 314.90	- 644.6311260d	- 0.08 sin U8	
XIV	Belinda	a0 = 257.31	- 0.03 sin U9		
		d0 = -15.18	+ 0.03 cos U9		
		W = 297.46	- 577.3628170d	- 0.01 sin U9	
XV	Puck	a0 = 257.31	- 0.33 sin U10		
		d0 = -15.18	+ 0.31 cos U10		
		W = 91.24	- 472.5450690d	- 0.09 sin Ul0	
V	Miranda	a0 = 257.43	+ 4.41 sin U11	- 0.04 sin 2U11	
		d0 = -15.08	+ 4.25 cos U11	- 0.02 cos 2U11	
		W = 30.70	- 254.6906892d + 1.15 sin U 11	- 1.27 sin U12	+ 0.15 sin 2Ul2 - 0.09 sin 2U11
I	Ariel	a0 = 257.43	+ 0.29 sin U13		
		d0 = -15.10	+ 0.28 cos U13		
		W = 156.22	- 142.8356681d	+ 0.05 sin U12	+ 0.08 sin U13
II	Umbriel	a0 = 257.43	+ 0.21 sin U14		
		d0 = -15.10	+ 0.20 cos U14		
		W = 108.05	- 86.8688923d	- 0.09 sin U12	+ 0.06 sin U14

III Titania a0 = 257.43 + 0.29 sin U15

d0 = -15.10 + 0.28 cos U15

W = 77.74 - 41.3514316d + 0.08 sin U15

IV Oberon a0 = 257.43 + 0.16 sin U16

d0 = -15.10 + 0.16 cos U16

W = 6.77 - 26.7394932d + 0.04 sin U16

where Ul = 115°.75 + 54991°.87T, U2 = 141°.69 + 41887°.66T, U3 = 135°.03 + 29927°.35T,

U4 = 61.77 + 25733.59T, U5 = 249.32 + 24471.46T, U6 = 43.86 + 22278.41T,

U7 = 77.66 + 20289.42T U8 = 157.36 + 16652.76T, U9 = 101.81 + 12872.63T,

U10 = 138.64 + 8061.81T, U11 = 102.23 - 2024.22T, U12 = 316.41 + 2863.96T,

U13 = 304.01 - 51.94T, U14 = 308.71 - 93.17T, U15 = 340.82 - 75.32T,

U16 = 259.14 - 504.81T

Neptune III Naiad a0 = 299°.36 + 0°.70 sin N - 6.49 sin N1 + 0°.25 sin 2Nl

d0 = 43.36 - 0.51 cos N - 4.75 cos Nl. + 0.09 cos 2Nl

W = 254.06 + 1222.8441209d - 0.48 sin N + 4.40 sin N1 - 0.27 sin 2N1

IV Thalassa a0 = 299.36 + 0.70 sin N - 0.28 sin N2

d0 = 43.45 - 0.51 cos N - 0.21 cos N2

W = 102.06 + 1155.7555612d - 0.48 sin N + 0. 19 sin N2

V Despina a0 = 299.36 + 0.70 sin N - 0.09 sin N3

d0 = 43.45 - 0.51 cos N - 0.07 cos N3

W = 306.51 + 1075.7341562d - 0.49 sin N + 0.06 sin N3

VI Galatea a0 = 299.36 + 0.70 sin N - 0.07 sin N4

d0 = 43.43 - 0.51 cos N - 0.05 cos N4

W = 258.09 + 839.6597686d - 0.48 sin N + 0.05 sin N4

VII Larissa a0 = 299.36 + 0.70 sin N - 0.27 sin N5

d0 = 43.41 - 0.51 cos N - 0.20 cos N5

W = 179.41 + 649.0534470d - 0.48 sin N + 0. 19 sin N5

VIII	Proteus	a0 = 299.27	+ 0.70 sin N	- 0.05 sin N6		
		d0 = 42.91	- 0.51 cos N	- 0.04 cos N6		
		W = 93.38	+ 320.7654228d	- 0.48 sin N	+ 0.04 sin N6	
I	Triton	a0 = 299.36	- 32.35 sin N7	- 6.28 sin 2N7	- 2.08 sin 3N7	
			- 0.74 sin 4N7	- 0.28 sin 5N7	- 0.11 sin 6N7	
			- 0.07 sin 7N7	- 0.02 sin 8N7	- 0.01 sin 9N7	
		d0 = 41.17	+ 22.55 cos N7	+ 2.10 cos 2N7	+ 0.55 cos 3N7	
			+ 0.16 cos 4N7	+ 0.05 cos 5N7	+ 0.02 cos 6N7	
			+ 0.01 cos 7N7			
		W = 296.53	- 61.2572637d m	+ 22.25 sin N7	+ 6.73 sin 2N7	
			+ 2.05 sin 3N7	+ 0.74 sin 4N7	+ 0.28 sin 5N7	
			+ 0.11 sin 6N7	+ 0.05 sin 7N7	+ 0.02 sin 8N7	
			+ 0.01 sin 9N7			

where N = 357°.85 + 52.316T, N I = 323°.92+62606°.6T, N2 = 220°.51+55064°.2T,

N3 = 354.27 + 46564.5T, N4 = 75.31 + 26109.4T, N5 = 35.36 + 14325.4T,

N6 = 142.61 + 2824.6T, N7 = 177.85 + 52.316T

Pluto	I	Charon	a0 = 313.02	
			d0 = 9.09	
			W = 56.77	- 56.3623195d

(a) The 182° meridian is defined by the crater Cilix.

(b) The 128° meridian is defined by the crater Anat.

(c) The 326° meridian is defined by the crater Saga.

(d) The 162° meridian is defined by the crater Palomides.

(e) The 5° meridian is defined by the crater Salih.

(f) The 299° meridian is defined by the crater Arete.

(g) The 63° meridian is defined by the crater Palinurus.

(h) The 340° meridian is defined by the crater Tore.

(i) The 276° meridian is defined by the crater Almeric.

(j) These equations are correct for the period of the Voyager encounters. Because of precession they may not be accurate at other time periods.

Satellites for which no suitable data are yet available have been omitted from this table. Nereid is not included in this table because it is not in synchronous rotation.

Table III. Recommended rotation values for the direction of the north pole of rotation and the prime meridian of selected asteroids (2000)

a0, d0, W, and d have the same meanings as in the Table I (epoch 2000 January 1.5, i.e., JD 2451545.0 TCB).

243 Ida	a0 = 348°.76
	d0 = 87°.12
	W = 265°.95 - 1864°.6280070d (a)
951 Gaspra	a0 = 9°.47
	d0 = 26°.70
	W = 83°.67 + 1226°.9114850d (b)
4 Vesta	a0 = 301°
	d0 = 41 °
	W = 292° + 1617°.332776d
433 Eros	a0 = 11°.9
	d0 = 20°.8
	W = 324°.08 + 1639°.3922d

(a) The 0° meridian is defined by the crater Afon.

(b) The 0° meridian is defined by the crater Charax.

Table VI contains data on the size and shape of selected asteroids. The first column gives the mean radius of the body and an estimate of the accuracy of this measurement. The next three columns give estimates of the radii measured along the three principal axes. The fifth column gives the radii of a best-fit ellipsoid. These are given because an ellipsoid is a common reference shape for photometric analyses. The last column gives an estimate of the maximum deviation of the body from the ellipsoid and is an estimate of the goodness of fit.

The values of the radii and axes in Tables IV, V, and VI are derived by various methods and do not always refer to common definitions. Some use star or spacecraft occultation measurements, some use limb fitting, others use altimetry measurements from orbiting spacecraft, and some use control network computations. For the Earth, the spheroid refers to mean sea level, clearly a very different definition from other bodies in the Solar System.

The uncertainties in the values for the radii and axes in Tables IV, V, and VI are generally those of the authors, and, as such, frequently have different meanings. Sometimes they are standard errors of a particular data set, sometimes simply an estimate or expression of confidence.

The radii and axes of the large gaseous planets, Jupiter, Saturn, Uranus, and Neptune in Table IV refer to a one-bar-pressure surface.

The radii given in the tables are not necessarily the appropriate values to be used in dynamical studies; the radius actually used to derive a value of J2 (for example) should always be used in conjunction with it.

Table IV Size and shape parameters of the planets

Planet	Mean radius (km)	Equatorial radius (km)	Polar radius (km)	RMS deviation from spheroid (km)	Maximum elevation (km)	Maximum depression (km)
Mercury	2439.7 ± 1.0	same	same	1	4.6	2.5
Venus	6051.8 ± 1.0	same	same	1	11	2
Earth	6371.00 ± 0.01	6378.14 ± 0.01	6356.75 ± 0.01	3.57	8.85	11.52
Mars	3389.508 ± 0.003	3396.200 ± 0.16	N 3376.189 ± 0.05 S 3382.582 ± 0.05	3.3	21.183 ± 0.005	7.825 ± 0.005
Jupiter*	69911 ± 6	71492 ± 4	66854 ± 10	62.1	31	102
Saturn*	58232 ± 6	60268 ± 4	54364 ± 10	102.9	8	205
Uranus*	25362 ± 7	25559 ± 4	24973 ± 20	16.8	28	0
Neptune*	24622 ± 19	24764 ± 15	24341 ± 30	8	14	0
Pluto	1195 + 5	same	same			

*The radii correspond to a one-bar surface.

Table V. Size and shape parameters of the satellites

Planet	Satellite	Mean Radius (km)	Subplanetary equatorial radius (km)	Along Orbit equatorial radius (km)	Polar radius (km)	RMS deviation from ellipsoid (km)	Maximum elevation (km)	Maximum depression (km)
Earth	Moon	1737.4 ± 1	same	same	same	2.5	7.5	5.6
Mars I	Phobos	11.1 ± 0.15	13.4	11.2	9.2	0.5		
II	Deimos	6.2 ± 0.18	7.5	6.1	5.2	0.2		

Jupiter	XVI	Metis	21.5 ± 4	30	20	17			
	XV	Adrastea	8.2 ± 4	10	8	7			
	V	Amalthea	83.5 ± 3	125	73	64	3.2		
	XIV	Thebe	49.3 ± 4	58	49	42			
	I	Io	1818.1 ± 0.1	1826.5	1815.7	1812.2	1.4	5-10	3
	II	Europa	1561	same	same	same	0.5		
	III	Ganymede	2634	same	same	same	0.6		
	IV	Callisto	2408	same	same	same	0.6		
	XIII	Leda	5						
	VI	Himalia	85 ± 10						
	X	Lysithea	12						
	VII	Elara	40 ± 10						
	XII	Ananke	10						
	XI	Carme	15						
	VIII	Pasiphae	18						
	IX	Sinope	14						
Saturn	XVIII	Pan	10 ± 3						
	XV	Atlas	16 ± 4	18.5	17.2	13.5			
	XVI	Prometheus	50.1 ± 3	74.0	50.0	34.0	4.1		
	XVII	Pandora	41.9 ± 2	55.0	44.0	31.0	1.3		
	XI	Epimetheus	59.5 ± 3	69.0	55.0	55.0	3.1		
	X	Janus	88.8 ± 4	97.0	95.0	77.0	4.2		
	I	Mimas	198.6 ± 0.6	209.1 ± 0.5	196.2 ± 0.5	191.4 ± 0.5	0.6		
	II	Enceladus	249.4 ± 0.3	256.3 ± 0.3	247.3 ± 0.3	244.6 ± 0.5	0.4		
	III	Tethys	529.8 ± 1.5	535.6 ± 1.2	528.2 ± 1.2	525.8 ± 1.2	1.7		
	XIII	Telesto	11± 4	15 ± 2.5	12.5 ± 5	7.5 ± 2.5			
	XIV	Calypso	9.5 ± 4	15.0	8.0	8.0	0.6		
	IV	Dione	560 ± 5	same	same	same	0.5		
	XII	Helene	16	17.5 ± 2.5			0.7		
	V	Rhea	764 ±4	same	same	same			

VI	Titan	2575 ± 2	same	same	same			
VII	Hyperion	141.5 ± 20	180 ± 20	140 ± 20	112.5 ± 20	7.4		
VIII	Iapetus	718 ± 8	same	same	same	6.1	12	
IX	Phoebe	110 ± 10	115 ± 10	110 ± 10	105 ±10	2.7		
Uranus VI	Cordelia	13 ± 2						
VII	Ophelia	15 ± 2						
VIII	Bianca	21 ± 3						
IX	Cressida	31 ± 4						
X	Desdemona	27 ± 3						
XI	Juliet	42 ± 5						
XII	Portia	54 ± 6						
XIII	Rosalind	27 ± 4						
XIV	Belinda	33 ± 4						
XV	Puck	77 ± 5					1.9	
V	Miranda	235.8 ± 0.7	240.4 ± 0.6	234.2 ± 0.9	232.9 ± 1.2	1.6	5	8
I	Ariel	578.9 ± 0.6	581.1 ± 0.9	577.9 ± 0.6	577.7 ± 1.0	0.9	4	4
II	Umbriel	584.7 ± 2.8	same	same	same	2.6		6
III	Titania	788.9 ± 1.8	same	same	same	1.3	4	
IV	Oberon	761.4 ± 2.6	same	same	same	1.5	12	2
Neptune III	Naiad	29 ± 6						
IV	Thalassa	40 ± 8						
V	Despina	74 ± 10						
VI	Galatea	79 ± 12						
VII	Larissa	96 ± 7	104	89		2.9	6	5
VIII	Proteus	208 ± 8	218	208	201	7.9	18	13
I	Triton	1352.6 ± 2.4						
II	Nereid	170 ± 25						
Pluto I	Charon	593 ± 13						

Table VI. Size and shape parameters of selected asteroids

Asteroid	Mean radius (km)	Radii measured along principal axes (km)	(km)	(km)	Radii of best-fit Ellipsoid (km)	Maximum deviation from ellipsoid (km)
243 Ida	15.65 ± 0.6	26.8	12.0	7.6	30.0, 12.6, 9.3	8.4
951 Gaspra	6.1 ± 0.4	9.1	5.2	4.4	9.1, 5.2, 4.7	2.1
216 Kleopatra		108.5	47	40.5		

4. Appendix

This appendix summarizes the changes that have been made to the tables since the 1994 report (Celestial Mechanics and Dynamical Astronomy 63, 127-148, 1996).

In Table I, the new value for the W0 of Mercury was the result of a new control network computation by Robinson et al. (1999). The new values of a0 and d0 for Mars are due to Folkner et al (1997). The new value for W of Mars was the result of a control network computation by Davies et al (1999). The value for the d term in W for Jupiter is from Higgins et al. (1996).

The new value for the d term in W for Jupiter is a new radio rotation period by Higgins et al. (1996).

In Table II the value of W for Metis is from Lieske (1997).

In Table III the value for Vesta are from Thomas et al. (1997) and the values of Eros are from Thomas et al. (2000).

In Table IV the Mars model is that determined by the Mars Orbiter Laser Altimeter (MOLA) group from Smith et al. 1999.

In Table V the sizes of the inner satellites of Jupiter are from Thomas et al. (1998). The sizes of th Galilean satellites are from Davies et al (1998).

In Table VI the parameters for 216 Kleopatia are from Ostro et al 2000.

References

Davies, M. E., Colvin, T. R., Belton, M. J. S., Veverka, J. and Thomas, P. C.: 1994, 'The direction of the north pole and the control network of Asteroid 951 Gaspra', Icarus **107**, 18-22.

Davies, M. E., Colvin, T. R., Belton, M. J. S., Veverka, J. and Thomas, P. C.: 1996, 'The direction of the north pole and the control network of Asteroid 243 Ida', Icarus **120**, 33-37.

Davies,M.E., Colvin,T.R., Oberst,J., Zeitler, W., Schuster, P., Neukum, G., McEwen, A.S., Phillips, C.B., Thomas, P.C., Veverka, J., Belton, M.J.S., Schubert, G.:1998,'The Control Networks of the Galilean Satellites and Implications for Global Shape',Icarus **135**, 372-376.

Davies, M., Colvin, T., Kirk, R., Lee, E., Sucharski, R.:1999,'Status of the RAND-USGS Control Network of Mars', Fifth International Conference on Mars, July 19-24, 1999, Pasadena, California.

Dermott, S. F. and Thomas, P. C.: 1988, 'The Shape and Internal Structure of Mimas', Icarus **73**, 25-65.

Dermott, S. F. and Thomas, P. C.: 1994, 'The determination of the mass and mean density of Enceladus from its observed shape', Icarus **109**, 241-257.

de Vaucouleurs, G., Davies, M. E., and Sturms Jr., F. M.: 1973, 'Mariner 9 areographic coordinate system', J. Geophys. Res. 78 (20), 4395-4404.

Folkner, W. M., Yoder, C. F., Yuan, D. N., Standish, E. M., and Preston, R. A.: 1997, 'Interior Structure and Seasonal Mass Redistribution of Mars from Radio Tracking of Mars Pathfinder ', Science **278**, 1749-1752.

French R. G., Nicholson, P. D., Cooke, M. L., Elliott, J. L., Matthews, K., Perkovic, O., Tollestrup, E., Harvey, P., Chanover, N. J., Clark, M. A., Dunham, E. W., Foffest, W., Har-rington, J., Pipher, J., Brahic, A., Grenier, I., Roques, F., and Arndt, M.: 1993, 'Geometry of the Saturn system from the 3 July 1989 occultation of 28 Sgr and Voyager observations', Icarus **103**, 163-214.

Higgins, C. A., Carr, T. D. and Reyes, F.: 1996,' A new Determination of Jupiter's radio rotation Period', Geoophys. Res Letters **23,** 2653-2656.

Hubbard, W. B., Porco, C. C., Hunten, D. M. Rieke, G. H., Rieke, M. J., McCarthy, D. W., Haemmerle, V, Clark, R., Turtle, E. R, Haller, J., McLeod, B., Lebofsky, L. A., Marcialis, R., Holberg, J. B., Landau, R., Caffasco, L., Elias, J., Buie, M. W., Persson, S. E., Boroson, T, West, S., and Mink, D. J.: 1993, 'The occultation of 28 Sgr by Saturn: Saturn pole position and astrometry', Icarus **103**, 215-234.

Lieske, J. H.: 1997, 'Revised rotation angle for Jupiter satellite 516 Metis ', JPL Interoffice Memorandum **312.F-97-059**.

Mason, E. C., French, R. G., and Buie, M. W.: 1992, 'Uranus pole and ring orbits from 1977-1991 stellar occultation and Voyager 2 observations', BULL Am. Astron. Soc. **24**, 103 1.

Millis, R. L., Wasserman, L. H., Franz, O. G., Nye, R. A., Elliot, J. L., Dunham, E. W., Bosh, A. S., Young, L. A., Slivan, S. M., Gilmore, A. C., Kilmartin, P. M., Allen, W. H., Watson, R. D., Dieters, S. W., Hill, K. M., Giles, A. B., Blow, G., Priestley, J., Kissling, W. M., Walker, W. S. G., Marino, B. F., Dix, D. G., Page, A. A., Ross, J. E., Avey, H. P., Hickey, D., Kennedy, H. D., Mottram, K. A., Moyland, G., Murphy, T, Dahn, C. C., and Klemola, A. R.: 1993, 'Pluto's radius and atmosphere: Results from the Entire 9 June 1988 occultation data set', Icarus **105**, 282-297.

Nicholson, P. D. and Matthews, K.: 1991, 'Near-infrared observations of the Jovian ring and small satellites', Icarus **93**, 331-346.

Ostro, S. J., Hudson, R. S., Nolan, M. C., Margot, J-L., Scheeres, D. J., Campbell, D. B., Magri, C., Giosini, J. D., Yeomans, D. K.: 2000, 'Radar Observations of Asteroid 216 Kleopatra', Science, **288**, 836-839, 5 May.

Robinson, M.S.,Davies,M.E., Calvin, T.R., Edwards,K.: 1999,'A revised control network for Mercury' JGR **104**, E12 30, 847-852

Smith, D. E., Lerch, R J., Nerem, R. S., Zuber, M. T, Patel, G. B., Fricke, S. K., and Lemoine, F. G.: 1993, 'An improved gravity model for Mars: Goddard Mars model-I', J. Geophys. Res. **98**, 20,871-20,889.

Smith, D. E., Zuber, M. T., Solomon, S. C., Phillips, R. J., Head, J. W., Garvin, J. B., Banerdt, W. B., Muhleman, D. O., Pettengill, G. H., Neumann, G. A., Lemoine, F. G., Abshire, J. B., Aharonson, O., Brown, C. D., Hauck, S. A., Ivanov, A. B., McGovern, P. J., Zwally, H. J., and Duxbury, T. C.: 1999, 'The global topography of Mars and implications for surface evolution ', Science, **284**, 1495-1503.

Thomas, P. C., Veverka, J., Simonelli, D., Helfenstein, P., Carcich, B., Belton, M. J. S., Davies, M. E., and Chapman, C.: 1994, 'The shape of Gaspra', Icarus **107**, 23-36.

Thomas, P. C., Veverka, J., Carcich, B., Belton, M. J. S., Sullivan, R., and Davies, M. E.: 1996, 'The shape of Ida', Icarus.**120**, 20-32.

Thomas, P. C., Binzel, R. P., Gaffey, M. J., Zellner, B. H., Storrs, A. D., and Wells, E. 1997 “Vesta: Spin, pole, size, and shape from HST images, Icarus **128**, 88-94.

Thomas, P. C., Burns, J. A., Rossier, L., Simonelli, D., Veverka, J. Chapman, C., Klaasan, K., Johnson, T. V., and Belton, M. J. S.: 1998 “The small inner satellites of Jupiter” Icarus **135**, 360-371.

Thomas, P. C., Joseph, J., Carcich, B., Veverka, J., Miller, J. K., Owen, W., Williams, B., Robinson, M.: 2000 “The shape of Eros from NEAR imaging data”, Icarus, **145**, in press.

MINUTES OF THE IAG - EXECUTIVE COMMITTEE MEETING AT THE XXII IAG/IUGG GENERAL ASSEMBLY, BIRMINGHAM, JULY, 1999.

Three meeting were held during the IUGG GA in Birmingham. For each meeting the agenda items treated as well as participants is listed below.

1. Meeting. Monday, July 19, 1999, 11.00-12.45.

Agenda Items treated: 2,3,4,5,6,8

Present were: K.P. Schwarz, (President), F.Sanso (1. Vice President), J.O.Dickey (2. Vice President), C.C.Tscherning (Secretary General), F.Brunner (President Section 1), R.Forsberg (President Section 3), P. Holota (President Section 4), M.Feissel (President Section 5), C.Boucher (President Commission X), P.Willis (Secretary Section 2), G.Beutler (President Commission XII), M.Sideris (secretary Section 3), B.Heck (Secretary section 4), C.Wilson (Secretary section 5), T.Tanaka (President Commission VII), W.Torge (Past president), I.I.Mueller (Honorary President), H.Moritz (Honorary President).

Note: Titles refer to old EC.

2. Meeting. Saturday, July 24, 9.00 - 16.00.

Agenda Items treated: 1,7,8,9,10,11,12,13,14,15,16,17,18,19

Present were: G. Beutler, C. Boucher, F.-K. Brunner, M. Feissel, R. Forsberg, B. Heck, C. Jekeli, R. Rummel, F. Sansò, K.-P. Schwarz, M. Sideris, H. Sünkel, T. Tanaka, W. Torge, C.C. Tscherning, P. Willis.

3. Meeting. Monday, July 26, 1999, 19.00 - 20.30

Agenda Items treated: 20,21,22,23

Present were: Y.Yuanxi (Secretary sec 4), C. Boucher, M. Feissel, W. Torge, T. Tanaka, B. Heck, P. Holota, P. Willis, R. Rummel, M. Sideris (President Sec 3), G. Beutler (First vice president), M. Vermeer (President of Commision), F. Brunner, C. C. Tscherning, K.-P. Schwarz, J. O. Dickey, F. Sanso (President), O. Andersen.

The new Executive Committee members (elected at the previous Council meeting) were invited to participate in this meeting. Note: Titles of new members of the EC.

Minutes.

1. Adoption of the minutes of the EC meeting in Paris.

The minutes were adopted without change.

2. Birmingham Organisation*.*

The organisation and program of the General Assembly were presented by the Secretary General.

3. Proposals for new nominations.

The list of nominations, prepared by the Nomination Committee, was presented by the president of the Nomination Committee, W.Torge. The CVs of the nominated persons were made available for inspection at the IAG office. Further nominations may be submitted according to the by-laws.

4. Proposal for members of the audit committee.

The Bureau proposed the following persons: G.Harsson (Norway), J.Adam, (Hungary) and R.Wonnacott (South Africa).

5. Nomination of the members of the resolution committee.

The following persons were nominated for the Resolution Committee: F.Sanso', J.Dickey, A.Dodson and C.Merry.

6. New fellows.

The procedure for appointing fellows was discussed. Officers who end their term during the General Assembly are eligible. It was discussed whether presidents of sub-commissions should be elected fellows. G.Beutler also pointed out that members of Scientific Bodies of some services also were eligible. It was decided to ask the section presidents to give recommendations that would be discussed at the next session. Here the following Fellows were elected:

O. Balt. Andersen, (Denmark), D.Arabelos (Greece), L.Ballani (Germany), B.Benciolini (Italy), M.Bevis (USA), G.Blewitt (UK), J.Bosworth (USA), A.Cazenave (France), T.Clark (USA), J.Degnan (USA), V.Dehant (Belgium), H.Drewes (Germany), B.Ducarme (Belgium), W.Featherstone (Australia), W.Freeden (Germany), T.Herring (USA),K.-H. Ilk (Germany), P. de Jonge (The Netherlands), J.Johanssen (Sweden), P.Knudsen (Denmark), Z-X Li (PRC), J.Manning (Australia), N.Pavlis (USA), C.Rizos (Australia), C.Rocken (USA), I.Tziavos (Greece), M.Vermeer (Finland), M.Wei (Canada), D.Wolf (Germany), S.Zerbini (Italy).

7. Venue of IAG Scientific Assembly 2001.

Applications had been received from Budapest (Hungary), Copenhagen (Denmark), Sopron (Hungary), Warsaw (Poland). After presentation of each venue by the country representatives and a comparison of the different venues, Budapest was selected.

The contact between the Executive Committee and the Local Organizing Committee to be finally decided Monday 26th.

8. IAG representatives to external bodies

BGI Directing Board: Dr. M.Vermeer (Finland), President of the Gravity /Geoid Commission.

IAPSO Commission on Mean Sea Level and Tides: M.Bevis to be contacted.

IAU Working Group on Astronomical Standards (WGAS): E. Groten (Germany), continuing.

IAU ICRS Working Group: T. Herring (USA), continuing.

ICET Directing Board: Dr. S.Takemoto, (Japan), President Earth Tide Commission.

ICL: S.Zerbini, (Italy)..

IERS Directing Board: C. Reigber (Germany), continuing, or his nominee.

IGS Governing Board: G. Beutler (CH), (ex-officio), T. Herring (USA), IAG Representative. ISO TC 211: J.Ihde (Germany), continuing.

IUGG Inter-Association Committee for Mathematical Geophysics: M. Vermeer (Finland), continuing.

IUSM Executive Board: I.I. Mueller (USA) K.-P. Schwarz (Canada), continuing to next meeting. New representatives will be nominated if there is a need after the next meeting.

PAIGH (PanAmerican Institute for Geography and History): W. Torge (Germany), continuing.

SIRGAS: H. Drewes (Germany), continuing.

WMO/IUGG Working Group on data exchange for forecast of natural disasters. S.Zerbini.

SCAR WG-GGI.: R.Dietrich (Germany).

The procedure for further elections were discussed, and it was proposed that in several cases the sections could make the appointment. It was decided to ask the representatives for bi-annual reports. The Bureau will review the reports. The Bureau may prepare a few questions to be answered in the report.

9. Adoption of new SSG.

It was decided that all special study group and special commissions should deliver complete description and member-list to the section presidents by the end of

September. Section presidents should then compile and forward the complete list to the Central Bureau for inclusion on the IAG web page.

EC members will be asked to comment on the descriptions before the end of October. Adoption of the descriptions of the SSG's (and SC) would then be carried out via e-mail vote. Subsequently discussion can be held at the EC meeting in November. The President stressed that the special study groups should be international in membership and focussed in their research. If possible the research objectives should be agreed upon by the SSG membership.

The following SSG were then established and the president appointed:

Section I: Positioning

SSG 1.179: Wide area modelling for precise satellite positioning - S. Han (Australia)

SSG 1.180: GPS as an atmospheric remotesensing tool - H. Van der Marel (The Netherlands),

SSG 1.181: Regional permanent arrays - R.Weber (Austria),

SSG 1.182: Multipath mitigation - M.Steward (Australia)

Section II: Advanced Space Technology

SSG2.162: Precise orbits using multiple space techniques - R. Scharroo (USA) to continue until decision is made at first EC meeting.

SSG 2.183: Spaceborne INSAR technology - R.Hanson (The Netherlands).

Section III: Determination of the gravity field

SSG 3.167: Regional land and marine gravity field modelling. - I.Tziavos (Greece) Continuing.

SSG 3.177: Synthetic Modelling of the Earths gravity field - W. Featherstone (Australia), continuing.

SSG 3.178: Arctic Gravity Project R. Forsberg, was to become a working group within the new IGGC.

SSG 3.184: Use of remote sensing techniques for validating heights and depths - P. Berry (UK)

SSG 3.185: Merging data from dedicated satellite missions with other gravimetric data- N. Sneeuw (Germany).

SSG 3.186: Altimetry data processing for gravity, geoid and sea surface topography determination - C. Hwang (Taiwan).

Section IV: General theory and methodology

SSG 4.187: Wavelets in Geodesy and geodynamics- W. Keller (Germany)

SSG 4.188: Mass density from integrated inverse gravity modelling - G. Strykowski (Denmark)

SSG 4.189: Dynamic theories of deformation and gravity field - D. Wolf (Germany)

SSG 4.190: Non-probabilistic assessment in geodetic data analysis - H. Kutterer (Germany)

SSG 4.191: Theory of Fundamental Height Systems - C.Jekeli (USA).

Section V: Geodynamics

IAG/IAPSO working group: Geodetic effects of non-tidal oceanic processes - R. Gross (USA)

SC8 should establish contacts with an IAPSO commission on Geodetic fixing of tide gauges. Mike Bevis will be contacted on this.

K.P.Schwarz and J.Dickey expressed concerns about the overwhelming number of SSG Chairpersons from Europe.

10. New IAG Structure - program / procedure of work.

The resolution on the restructuring process was adopted with one modification.

The following members were proposed for the steering committee:

G. Balmino (France), G. Beutler (Switzerland), F.K. Brunner (Austria), J.O. Dickey (USA), M. Feissel (France), R. Forsberg (Denmark), R. Rummel (Germany), K.-P. Schwarz (Canada), and ex-officio, F.Sanso'. G.Beutler was proposed as chairperson of the Steering Committee.

The steering committee is responsible for contacting a large group of experts and users and to develop a proposal by the end of 2000.

The proposal must be adopted at an extraordinary council meeting at the Scientific Assembly in 2001 and implemented at the General Assembly in 2003.

11. Sponsorship of Symposia.

Sponsorship of the following meetings were given:

XIII International Course on Engineering Surveying - Munich (Germany) - March 13-17, 2000.

International Workshop on "Perspectives of Geodesy in South-East Europe" - Dubrovnik (Croatia) - May 2-6, 2000.

International Congress on Geodesy and Cartography - Caracas (Venezuela) - December 2000.

12. JofG Editorial Board proposal.

The proposal from the Editor-in-Chief was adopted:

Editor-in-Chief: P.J. G. Teunissen (The Netherlands), Assistant Editor-in-Chief: F.H.Schroeder (The Netherlands), IAG Information Editor: O.B.Andersen (Denmark), Book-review editor: C.C.J.M.Tiberius (The Netherlands).

Editors: R.Barzaghi (Italy), C.Brunini (Argentine), F.K.Brunner (Austria), A.Dodson (UK), W.E.Featherstone (Australia), W.Fredeen (Germany), T.A.Herring (USA), P.Holota (Czech rep.), H.T.Hsu (PRC), K.H.Ilk (Germany), A.Kleusberg (Germany), R.B.Langley (Canada), S.Okubo (Japan), B.Schaffrin (USA), I.N.Tziavos (Greece), M.Vermeer (Finland), P.Willis (France), P.Xu (Japan).

13. IAG Budget.

K.-P.Schwarz proposed that not more than the equivalent of half of the quadrennial IUGG contribution is kept as a bank reserve. As a consequence of this the following budget was approved: (Amounts in USD).

	Receipts			Expenditures	
15	IUGG Allocation	100000	11	Administration	50000
2	UNESCO grants	0	12	Publications	12000
3	OTHER grants	0	13	Assemblies	60000
4	Contracts	0	14	Symposia & meetings	30000
5	Sales of publications	12000	16	Grants	25000
6	Miscellaneous	35000	18	Miscellaneous	6000
7	Total receipts	147000	19	Total Expenditures	183000
8	Banks (Jan. 1, 1999)	94000	20	Banks (Dec. 31, 2003)	58000

14. IAG Fund.

The fund will be included in the IAG accounts following the advice of the Audit Committee.

The new Assistant Secretary General (K.Keller (Denmark)), will make a special effort to raise more money, contacting fellows, associates, institutions and private companies.

15. Proposal for Joint IUGG/BIPM Commmittee on a CTRS.

C. Boucher presented the proposal received via IUGG from BIPM.

C. Boucher, G. Beutler (rep IAG), and a IUGG representative to IERS (C. Reigber or his successor) were appointed as members of a committee to propose procedures for the adoption of an ITRF within IAG/IUGG and its dissemination to other agencies. The name of the committee should be decided by the committee themselves.

16. Journal Artificial Satellites.

CSTG recommended that the Polish Journal Artificial Satellites is not made the official journal of an IAG body. The EC agreed with the arguments given in their letter.

K.-P. Schwarz and C.C. Tscherning will send a letter to the Polish Space Research Centre explaining the IAG position.

17. Rules for IAG Young Author Award.

The rules proposed by the President were adopted. The revised rules are available from the IAG home page

18. Proposals for new IAG Services: ILRS, IVS, DORIS, EOSS.

The proposal for ILRS and IVS were adopted. CSTG was thanked for their work with these proposals.

A more developed proposal will be expected from DORIS. The EOSS proposal was not acceptable since it was a regional and not an international service proposed. The group is invited to work inside IAG (Comm. X and SC 8).

19. Rules for Bomford Prize.

The proposal by K.P.Schwarz was accepted. The revised rules are available from the IAG home page

20. Status of Handbook and Travaux.

O.Andersen reported on the preparations of the Travaux and the Handbook. 80% of the material has been received or promised before mid August for the Travaux. The remaining 20% will not come. 50% of the representatives of IAG to other bodies have responded.

Publication is foreseen on a CD in late September. The Travaux will also be available on the web. With the CD an order list for the Travaux as a book will be distributed.

The Handbook has a final deadline after the next EC meeting (finalising SSG descriptions). This will result in a publication in February of 2000. Parts of the Handbook will be available on the web as soon as the material is ready.

21. Audit Committee report.

CCT presented the report that had been distributed. The outgoing president will write to the three members to thank them for their work.

The Central Bureau got a mandate to merge the IAG general account with the account for the IAG fund to limit costs and facilitate administration.

22. Resolution Committee Report.

FS presented the resolutions. The resolutions were adopted after revision for presentation at the Council.

23. Miscellaneous.

A. Birmingham proceedings.

At present there are nearly 90 pre-orders in hand. Springer has required a minimum of 150 pre-orders in order to publish the proceedings. It was decided to publish proceeding with the number of pre-orders we are getting even though this might result in a 3000$ expense for IAG. It was mentioned that we might be saving a corresponding amount on the Travaux. The President proposed that e-mails are written to all IAG participants at the IUGG shortly after the meeting to ask once more for pre-orders.

B. Earth Science Focus on Urban Issues.

During the last four years the IUGG has drawn attention to what earth sciences can do to urban regions in the future. Its was discussed in which manner IAG can contribute to solving urban problems. The issued was postponed to the next EC meeting.

C. Advertising IAG

W. Torge strongly recommended that the next EC take up the issue of advertising the IAG in the next 4-year period.

MINUTES OF THE EC MEETING IN NICE, 28-29TH APRIL, 2000, HELD IN CONNECTION WITH THE EGS XXV GENERAL ASSEMBLY.

The following were present.

F. Sanso	President
G. Beutler	First Vice President.
D. Blitzkow	Second Vice President
C. C. Tscherning	Secretary General
O. Andersen	Ass. Sec. General
K. Keller	Ass. Sec. General
C. Rizos	Secretary Sec 1.
C. K. Shum	President Sec 2.
M. Sideris	President Sec 3.
G. Boedecker	Secretary Sec 3.
B. Heck	President Sec 4.
C. Wilson	President Sec 5.
V. Dehant	Secretary Sec 5.
H. Drewes	President Comm VIII.
C. Boucher	President Comm X
M. Vermeer	President Comm XIII
S. Zerbini	President Comm XIV.
I. Mueller	Past President
K. P. Schwarz	Past President

1. Approval of agenda

F. Sanso presented the agenda containing several additions, and this was approved.

2. Adoption of minutes of Como EC meeting

The Minutes of the EC meeting on 28-29th November, 1999, in Como, Italy, had been distributed by e-mail and were published as part of the IAG newsletter in JoG 74/02. They were adopted by the EC without corrections.

3. Proposal for an IAG retiree association.

I. Mueller had distributed a proposal for establishing an association of IAG retiree/seniors/past officers as a forum to contribute expertise of value to IAG. The association would be open to all IAG fellows and associates, and have meetings at Scientific Assemblies and an electronic newsletter. The EC agreed on the general idea of having such an association, and awaits the formal proposal from I. Mueller at the SA in Budapest.

4. IAG Scientific Assembly in Budapest 2001.

I. Mueller presented the status of the preparation of the Local Organizing Committee (LOC) for the SA in Budapest (3-7 Sept 2001). The preparations are under control and the LOC has established a web page for communication. The Academy of Sciences, where the SA will be held, has 11 meeting rooms of various sizes (max 320 persons). The LOC requests that IAG specify requirements with respect to rooms and sizes at least 3-5 weeks before the SA. Details on the scientific program are given under item 8.

5. Feedback on Travaux/Handbook and IAG newsletter.

O. Andersen informed that the Travaux was distributed on CD and is also available from the Central Bureau (CB) as a book. The Geodesist's Handbook is published, but only a few members of the EC had received it so far. O. Andersen reported that Springer takes up to 2-3 month in printing issues, and also sometimes merges issues which delays publication of the IAG newsletter. This is problematic, and EC stressed that it should be avoided in the future. The IAG Secretary will contact the Editor-in-chief on this issue.
Possible distribution of an electronic quarter-annual newsletter via e-mail was considered.

6. Collaboration with ION. (Institute of Navigation).

The president of ION has approached IAG for coorporation on a GPS book jointly written by authors from IAG and ION. The EC decided to ask F. Sanso to contact R. Neilan, P.Willis, G. Hein or W. Gurtner to establish liaison and to define a fruitful coorporation with ION, based on areas where IAG has strength

7. Report from the review committee (herinafter RC)

G. Beutler presented the report of the IAG review committee (RC) and went through the Executive summary available at ftp://ubecx.unibe.ch/aiub/iag Only part 5(IAG mission and objectives) and part 6 (IAG structure) were subsequently discussed in detail. Once the comments made below have been given to the RC they have the mandate to create the proposal that should be presented to the EC in March 2001 and subsequent to council at the SA in 2001.

IAG mission and objectives.
A revision of the suggested IAG mission and objectives was carried out, and it was recommended that two more points should be added: a preamble on the usefulness of geodesy for society and another bullet on emerging technologies.

IAG structure.
It was decided by vote that the IAG structure should have commissions, services, and a communication/outreach branch and a few projects represented on the same level. Projects on this top level will be established by the EC. GIGGOS may be one of them, but has not been selected at this point in time.
There was agreement on establishing a communication and outreach branch, and that a call for participation should be drafted. It was recommended by the EC that the review committee consider the flexibility within the IAG structure and allows for

establishment of inter-commission/service bodies (i.e., for geodetic theory or techniques, which presently resides within commissions)

Structure of the IAG Central bureau, IAG bureau, EC and Council. G. Beutler pointed out that the commission names were not fixed by the proposal, and that he would appreciate input from EC members on this.

It was strongly stressed that there should be no appointed members in the EC. Services, commissions and members can nominate members, which will subsequently be elected by the Council.
The importance of the Council was stressed. A suggestion for improved communication between the EC and the Council would be to initiate informative meetings at the SA.

Individual Membership and Nominations/Voting.
K. P. Schwarz introduced possible scenarios for IAG personal membership based on the IAVCEI model. It was clarified that the issue of personal membership is not necessarily linked to the review process, but that it would be advantageous to introduce it at the same time if the EC agrees to go this route. In the IAVCEI model, personal members have benefits (i.e. discounts on participation in General Assemblies and journal subscription, voting rights). The EC gave its approval in principle to develop a proposal for personal membership that has different levels of membership fees (developing countries) and benefits. It also decided that voting rights should not be given to individual members. The proposal will have to be approved by the EC.

Finally the EC agreed to invite I. Mueller and J. Kauba to join the review committee for finalising the proposal for IAG restructuring.

8. Scientific program for the IAG Scientific Assembly (SA) in Budapest.

K. P. Schwarz had prepared and distributed a proposal for the scientific program for the SA in Budapest in 2001. Four symposia are proposed, two of them will run in parallel every day. Friday will be devoted to the IAG restructuring. The possibility of awarding a prize for the best student presentation using the IAG fund was discussed. It was decided to publish all presented and poster papers whose mauscripts are available at the meeting on a CD without review. A selected number of representative papers will be reviewed for publication in the IAG/Springer symposia series. The registration fees will be increased to include the cost of producing the proceedings. The review process should be strict to be representative of the quality of science that IAG stands for. J. Adam will be asked to serve as editor of the proceedings. It was left to the convenors to accept/reject abstracts and carry out the review process. Besides the CD containing all abstracts and remaining un-reviewed papers, there will be an official IAG CD containing mid term reports of the bodies (especially the SSG) of the IAG.

9. Collaboration with sister societies (FIG, ISPRS, etc) after IUSM

It was stressed that the collaboration should be on the working level and as concrete as possible. Obvious collaboration should be co-sponsoring of each other?s symposia.

10. ISPRS has requested support for becoming a member of ICSU

The Bureau has issued a positive response to the ISPRS request for ICSU membership.

11. Report from the WG on Education

The report of the WG was presented by C. Tscherning. It was questioned whether there should be any "checking" of teaching material, and it was agreed that only the functionality of the links from the homepage to the proposed material will be checked. C. Tscherning was elected as president of the Committee on Education.

12. Report from the Committee for Developing Countries (CDC).

D. Blitzkow had found it difficult to make progress in the work. The goals of the former CDC had been reviewed, and a number of concrete activities were taking place in South America. Despite IAG had allocated USD 4000 to the CDC it was not at all sufficient to start any meaningful activity due to the large cost of air-travel within Africa.
A workshop will be organized in May 2000 in Sao Paulo on the South-American geoid cosponsored by the Int. Geoid Service (IgeS). G. Beutler referred to the position paper of J. Manning, which contained useful considerations concerning the developing countries. J.Manning had also pointed to the activities of the UN regional Cartographic Conferences. It was concluded that we have to start with local geodesists, and in this sense the schools were a good entry point.

13. Discussion of IAU recommendation.

E. Groten had informed the Bureau about the IAU request of having a reference value of the gravity potential for time-corrections. It was recommended to use the best current value.

14. Request from GALOS to Recognize Galo Carrera as an IAG Fellow

GALOS had requested that the work of Galo Carrera was recoginzed by IAG. The EC decided to award him the fellowship of IAG.

15. IAU request of IAG representative to IAU Commission 19.

Clark Wilson was proposed, and accepted.

16 IAG Sponsored meetings.

To be summarized from the IAG homepage. J. Manning has requested the IAG endorsement of a regional workshop in Mongolia. An IAG representative was requested. The meeting is recognized as a fine initiative, and J.Manning will be asked to represent IAG. A meeting on Recent Crustal Movements in Helsingfors in August has been organized, and could be in conflict with the Scientific Assembly. It was felt that the way in which the first announcement of this meeting used the IAG name was inappropriate.

This was conveyed to the organizers by M.Vermeer. S.Zerbini is advising the LOC with respect to the program. Com. XIV will sponsor the meeting.

17. IAG collaboration with EGS and AGU.

IAG SSG co-sponsorship is possible together with AGU/EGS at international meetings. This would be a way to achieve~~d~~ IAG goals. IAG SSG could be used as a bridge between AGU and EGS. IAG ought to be visible, by co-sponsering sessions etc. F. Sanso will contact AGU and EGS concerning collaboration.

18.Young author's award

F. Sanso refered to the letter of P. Teunissen, editor-in-chief of the JofG, which had been distributed in advance. Of the four candidates proposed. Dr. Xu. was unanimously chosen for his paper "Biases and the accuracy of, and an alternative to, discrete nonlinear filters", Published in JoG, Vol. 73, pp. 35-46, 1999.

19. Gravity field service.

A meeting will be held in Milan concerning unification of the three gravity services. BGI, IGS, IETC. NIMA might provide a new GDEM (SRTM (100-200m)) to improve global gravity. The EC encouraged this initiative.

20. Next meetings.

Next EC meeting: (EGS 2001 26-30 of March) 30-31/3 2001. Major items will be IAG restructuring, and SA planning.

MINUTES OF THE EC MEETING IN NICE, 30-31TH MARCH, 2001.

The following were present.

F. Sanso	President
G. Beutler	First Vice President.
D. Blitzkow	Second Vice President
C. C. Tscherning	Secretary General
O. Andersen	Ass. Sec. General
A. Dodson	President Sec 1
C. K. Shum	President Sec 2
M. Sideris	President Sec 3
B. Heck	President Sec 4
C. Jekeli	Secretary Sec 4
Y. Yang	Secretary Sec 4
C. Wilson	President Sec 5
H. Drewes	President Comm. VIII
C. Boucher	President Comm X
S. Zerbini	President Comm XIV
K. P. Schwarz	Past President
J. Adam	LOC of IAG SA meeting in Budapest.

1. Approval of agenda

FS presented the agenda containing several additions, and this was approved.

2. Confirmation of adoption of minutes of the 2000 IAG meeting in Nice, France

The Minutes of the EC meeting in Nice, 28-29th April, 2000 were published as part of the IAG newsletter in JoG 74/06 and on the IAG web page. The Minutes were adopted by the EC with the following correction under item 7 (Report from the review committee, IAG structure): Inter-commission/service bodies reside within sections and not within commissions.

3. Report from the Review Committee.

G. Beutler presented the IAG review 2000-2001 Executive Summary and went through the IAG Missions and Objectives. These were adopted with minor revisions.

The key elements of the IAG structure were presented. EC adopted the following titles for commissions with the provisional content specified in the proposal for new Statutes and By-laws.

Comm 1. Geometric reference frames

Comm 2. Gravity field

Comm 3. Earth Rotation and Geodynamics

Comm 4. Positioning and Applications.

The Bureau will distribute the adopted executive summary to the National Representatives within two weeks of the EC.

The review committee was thanked and the committee was dissolved. G. Beutler was asked to present the executive summary in Budapest.

It was decided that if the Council in Budapest passes the change of structure, a committee for the realization of the new IAG structure should be established. G. Beutler assisted by the section presidents should lead this committee. The committee should have the freedom to invite additional committee members.

A procedure for handling amendments to the Statutes and By-laws was established by the EC:

It was underlined that amendments should be send through the National representatives and should be send to the Secretary General before the end of June.

All amendments will be presented to the Council in Budapest. Amendments will be mailed to the EC prior to the Council meeting for possible support. The Amendments will be posted on the IAG internet site and distributed to the National Representatives before the Council meeting.

4. Proposal for new statutes and by-laws.

The Secretary General received the proposal for new statues and by-laws 6 months ahead of the Council meeting Budapest, which is why they can be considered at this meeting.

According to the new Statutes a review committee shall review the Statutes and Bylaws every eight years to ensure an up-to-date structure IAG. The first review shall take place in 2007.

The proposals for new Statutes and By-laws with the amendments made at the EC meeting were unanimously adopted by the EC for presentation to the Council in Budapest. The Bureau will distribute the proposal to the National Representatives within two weeks of the EC.

IAG Guidelines for the Establishment of Sub-commissions, Study Groups, Commission Projects, Inter-commission Committees and IAG Projects were distributed for information at the EC meeting. It was decided that they should not be included to the By-laws.

C. Jekeli put forward a motion for a mechanism to change the status of the inter-commission committees. B. Heck supported the motion. The motion reads: “The EC may recommend to the council and seek its approval to grant full commission status to an inter-commission committee”. The motion was not adopted by the EC.

5. 20001 IAG Scientific Assembly in Budapest.

K.-P. Schwarz and J. Adam presented the status of the preparation for the IAG meeting. Presently 274 have pre-registrated representing 58 countries.

Advertising was discussed. IAG agreed to advertise GPS World and Galileo World at the meeting in Budapest by distributing free sample copies. O. Andersen was asked to contact Springer with respect to similar arrangement with the Journal of Geodesy. C.C. Tscherning should explore the possibilities of advertisement in EOS, and C. K. Shum agreed to announce the meeting at the upcoming spring AGU.

The meeting arrangement proceeds as planned and the second circular had been distributed. The list of symposium convenors and session chairs was distributed for information.

K.-P. Scwartz will establish a small committee to elect best poster and oral presentation among young scientist.

Financial support has been obtained from ESA and NASA, and IAG will be able to support a substantial number of scientists.

6. Bi-annual report.

Bi-annual reports from all the entities within IAG will form an official IAG publication. This publication will be distributed on CD in Budapest and will published on the IAG Internet site. The section presidents are responsible for compiling the material within their sections. Status were:

Sec 1. All entities have been contacted and have responded positively

Sec 2. All entities have been contacted. Reports are already available on the Section web site.

Sec 3. All entities have been contacted. Most have responded positively

Sec 4. All entities have promised to send material at end of April.

Sec 5. All entities have been contacted and have responded. The section will report via the section website.

7. Collaboration with sister societies.

F. Sanso reported on a meeting with ISPRS, IUG, FIG, IHO, ICA and IAG at the ISPRS meeting in Amsterdam, July 2000.

A proposal for establishing a joint board of spatial information societies will be addressed at the next meeting with the societies, which will take place 2. Sept. 2001 in Budapest.

It was decided to discuss how the collaboration could be enlarged with other organizations/societies at the EC meeting in Budapest.

FIG has drafted a memorandum of understanding, which had been distributed prior to the meeting. The EC adopted the memorandum of understanding.

It was decided that F. Sanso should ask R. Neilan to become IAG representative to the Institute of Navigation (ION).

C. Boucher was asked to prepare a proposal for establishing a group to look into implementation of ITRF including communication between the involved organizations.

8. Report from the Committee for Developing Countries

D. Blitzkow presented the work of the CDC. A South American geoid workshop was successfully held in Sao Paolo in 2000 with participation from most South America countries. The committee’s work in South America is very successful.

Meeting was held with C. Merry (S. Africa) on establishing a working group on creating an African geoid.

Commission X and the IGS central Bureau suggested the establishment of an African continental reference system (AFREF). The “Interest and motivation for establishing AFREF” document was distributed prior to the meeting and presented by C. Boucher.

9. Report on the Journal of Geodesy.

P. Teunissen reported on the Journal of Geodesy. Printed and online versions are available. Volume 74 contains ten issues (two double issues) and the Geodesists Handbook and will be finished shortly. Volume 75 will be finished in 2001 and will contain three double issues).

Review process has been lowered from 10 to 9 month on average, but the production time has been increased from 4 to 5 month.

Special issues on “GLONASS” (guest editor P. Willis) and on “New parameters for Earth orientation” (guest editor T. Herring) are foreseen, and review papers are also planned. It was stressed that interaction with the section presidents is important in defining special issues.

The IAG newsletter suffers from Springers production time. Springer has agreed that IAG can issue electronic news on a regular basis.

10. Gravity Field and Figure of the Earth Service. (GFFS)

M. Sideris presented a suggestion for establishment of a new IAG service “Gravity Field and Figure of the Earth Service (GFFS)” formed by joining the following services (BGI, ICET, IGeS) supplemented with the following centers/services (PSMSL, ICGEM (international center for global earth gravity models)). The EC agreed to set up a coordination group headed by M. Sideris to create/prepare the terms of reference for the service. The coordination group should prepare the material for establishment of the service at the Budapest meeting.

11. IAPSO Scientific Assembly (Mar de la Plata, Argentina, October 2001*)*

The EC approved to co-sponsor the IAPSO meeting in October and to have a joint IAG/IAPSO symposium called "Gravity, geodesy and the ocean circulation as inferred from altimetry".

12. IUGG General Assembly in Sapporo 2003.

C. C. Tsherning asked for input on themes for the IUGG GA as well as names of union symposia for the IUGG GA by the end of July.

13. Next meeting.

The next EC meeting will be held in Budapest, Tuesday 4. September 2001. The subsequent meeting will be held 26-27th April, 2002 in association with the next EGS meeting.

Ole B. Andersen

REPORT ON THE SOUTH AMERICA GEOID 2000

The South America Geoid 2000 workshop held at Escola Politécnica, Universidade de São Paulo, from May 17 to19, 2000, was organized by IGeS (International Geoid Service), SCGGSA (Sub-Commission for Gravity and Geoid in South America), CDC (Committee for Developing Countries) and it was also supported by IAPSO (International Association of the Physical Science of the Ocean). The workshop had the following objectives:

- To assemble as many countries as possible from South America to compute a geoid model.

- To encourage cooperation between oceanographers and geodesists for the computation od geoid in coastal areas.

- To encourage every country to cooperate with SCGGSA for data delivery.

- To encourage every country to compute a local geoid model with the data available.

- To discuss different efforts for data acquisition in the continent.

The countries that participated to the activities were the following:

Argentina, Brazil, Chile, Ecuador, Paraguay and Uruguay.

REPORT OF THE 14TH INT. SYMPOSIUM ON EARTH TIDES (ETS2000)

The 14th International Symposium on Earth Tides (ETS2000) was successfully held in Mizusawa, Japan, during the period from August 28 to September 1, 2000. 137 participants from 21 countries reported fully on their results of continuing researches on Earth tides and thus contributed to the progress of further research of Earth and Planetary Tides.

1. Officers of the Commission

The President of the IAG Commission V (Earth Tides) was elected by the Council of IAG at the IUGG/IAG General Assembly held in Birmingham, UK, in July 1999.Before the opening session of the ETS2000, the President consulted opinion of the National Representatives of the Commission on proposal to ask Jacques Hinderer and Olivier Francis to continue their office until the next IUGG/IAG General Assembly to be held in Sapporo, Japan, in July 2003, and obtained their approval.

At the opening session of ETS2000, the Commission elected J. Hinderer as Vice-President and Francis as Secretary without a dissenting voice. Congratulation to Jacques Hinderer and Olivier Francis, and the best wishes for their future work.

3. ETC Homepage

Now, the ETC Homepage can be seen through the following address,

http://www-geod.kugi.kyoto-u.ac.jp/iag-etc/

4. 2nd ETC Medal

The ETC steering committee decided to award the 2nd ETC Medal (ETC Medal 2000) to the late Prof. Hans-Georg Wenzel for his outstanding contribution to international cooperation in earth tide research. His contribution to gravity and Earth tides researches is so well known through the papers more than 150. He is famous by development of a new tidal potential catalogue, a worldwide synthetic gravity tides model, and the Earth tides data processing package so called ETERNA. With grateful appreciation for the numerous services rendered by Prof. Hans-Georg Wenzel during his lifetime, all participants of ETS2000 paid one-minute's tribute to him with deepest sympathy. The ETC awarded the 2nd ETC Medal to Ms Marion Wenzel at the Opening Session of ETS2000 on August 28 2000 at Mizusawa, Japan.

5. ETC Working Groups

At the opening session of ETS2000, chairpersons of following Working Groups reported their activities,

Working Group 4 "Calibration of Gravimeters", (M.van Ruymbeke),

Working Group 5 "Global Gravity Monitoring", (B. Richter), Working Group 6 "Earth Tides in Geodetic Space Techniques, (H. Schuh),

Working Group 7 "Analysis of Environmental data for the interpretation of gravity measurements", (G. Jentzsch).

The Earth Tide Commission thanks all members and chairpersons of WGs which have been active during the last period, for their fruitful work.

ETC accepted the conclusions of the reports of the Working Groups and decided according to their wishes:

To close Working Group 4 (Calibration of Gravimeters, Chairperson: M.van Ruymbeke).

To close Working Group 5 (Global Gravity Monitoring, Chairperson: B. Richter).

To extend for another 4 year term the activities of the Working Group 6 (Earth Tides in Geodetic Space Techniques) under the new chairperson-ship.

To extend for another 4 year term the activities of the Working Group 7 (Analysis of Environmental data for the interpretation of gravity measurements) under the new chairperson-ship.

To create Working Group 8 on "Gravitational Physics" under the chairperson-ship of Prof. Lalu Manshinha to tackle among others the following scientific problems: The Problem of Aberration: Modern tidal position catalogs assume that the true position of the tide causing body is responsible for the tidal forces, rather than the apparent position, as in optical astronomy. The problem may have consequences, as it may imply relative velocities between the gravity and optical signals. This is a case for experts in Celestial Mechanics and in Earth Tides. The Gravitational Shielding:There is currently no accepted theory of gravity that incorporates or predicts gravitational shielding. The problem is possibly different from the absorption of gravitational radiation by matter. The Earth Tide community should think about, and search for, the consequences of shielding.

6. Directing Board of the International Center for Earth Tides (ICET)

The ICET Directing Board (S.Takemoto (Chair), B.Ducarme, T.F.Baker, D.Crossley, H.T.Hsu and O. Francis (Non-voting member)) met together on August 29, 2000 at the Z-hall in Mizusawa. The main subject for discussion was "Future activity of ICET and re-organization of the IAG services". ICET-DB discussed on the GFFS (Gravity Field and Figure of the Earth Service) proposed by Prof. F. Sanso, which is a new Service including activities of BGI, IGeS and ICET.

Because of a restriction of time, ICET-DB could not draw a conclusion at Mizusawa and decided to continue our discussion by E-mail. ICET-DB will draw a conclusion not later than the end of October 2000.

7. RESOLUTIONS adopted by the Earth Tide Commission

The Earth Tide Commission has adopted the following resolutions at the closing session of the 14th International Symposium on Earth Tides, August 28 - September 1, 2000, Mizusawa, Japan.

1/ Recognizing the importance of the observation of tidal effects and of the determination of tidal parameters by space geodetic techniques,

the ETC recommends

to continue this observational effort;

to compare the results obtained by different space geodetic techniques between each other and with the results of ground based tidal measurements.

2/ Recognizing the importance of the new international services on space geodetic techniques

the ETC recommends

that WG6 establishes or intensifies the cooperation with the analysis coordinators of these international services concerning the tidal modelling.

3/ Considering the new fields of tidal research in lunar and planetary geodesy

the ETC recommends

that the tidal community should take an active part in space missions related to lunar and planetary geodesy ;

requests a proper archiving of the data and metadata acquired during those missions and normal access to the world-wide geodetic community.

4/ Considering the increasing interest of the tidal community to lunar and planetary researches

the ETC recommends

that a session on tides on the planets should be included in the future earth tides symposia.

5/ Recognizing the importance of a global Earth coverage with superconducting gravimeters

for the study of weak geophysical signals,

for the determination of the liquid core resonance parameters,

for the study of the polar motion effects on gravity, for the intercomparison of the load vectors derived from recent ocean tides models,

for the study of global and regional gravity changes to validate the results of the dedicated satellite missions,

the ETC recommends

to extend the GGP observation period for an additional 6 year period starting July 2003, to maintain the existing sites and to encourage the installation of new GGP stations especially in the Southern hemisphere and in polar regions.

6/ Recognizing the fact that presently the calibration of the superconducting gravimeters participating to the world-wide GGP project is not homogeneous

the ETC recommends

that systematic calibration campaigns with absolute gravimeters should be planned and realized before the end of the current GGP observation period, through an international cooperative effort.

7/ Recognizing the importance to keep in operation several calibration techniques for gravimeters to allow a mutual accuracy control,

the ETC recommends

that inertial calibration platforms and moving mass calibration devices should continue to be developed or maintained besides more usual calibration methods such as intercomparison with absolute or well-calibrated relative instruments.

8/ Recognizing the importance of environmental data for the interpretation of tidal measurements the ETC recommends:

a/ to record the following parameters:

- The barometric pressure, temperature, precipitation, and ground water level. The sampling rate for the recording of environmental parameters should correspond to the sampling rate of the geodynamic data observed. A sufficient resolution and accuracy of the measurements of the environmental parameters should be granted.

- Although the difficulties of monitoring soil moisture are recognized, its is recommended to undertake efforts to realize a continuous monitoring of this parameter.

- The monitoring of wind is also recommended because wind might produce short-period noise as well as long-period modulations.

b/ to correct gravity data in long term studies for local (diameter 100 km), regional (diameter 2000 km), and global atmospheric pressure signals as all three produce significant effects.

c/ to develop correction models for gravity, tilt, and strain related to:

- ground water table variations

- snow, rain and soil moisture

- stress resulting from temperature variations

9/ Noting the importance for tidal measurements of accurate error estimates

and appreciating that such estimates can be made only if the power spectral density of the noise is known

the ETC recommends

to show noise spectra as Power Spectral Density expressed in unit 2/ frequency.

10/ On behalf of all participants of the 14th International Symposium on Earth Tides, the ETC thanks the Japanese National Committee for Geodesy, the Science Council of Japan, the Geodetic Society of Japan, the National Astronomical Observatory of Japan, the City of Mizusawa and the Iwate Prefecture for their generous support to the Symposium.

11/ ETC thanks the Local Organising Committee : Masatsugu Ooe (Chairman), Tadehiro Sato (Secretary) , Jiro Segawa (President of Geodetic Society of Japan) and the staff, for their wonderful welcome and their many efforts in making the 14th International Symposium on Earth Tides a great scientific success.

8. IAG Travel Awards

The following 5 persons are winners of IAG Travel Award.

Alexander Kopaev, (Moscow, Russia), Janusz Bogusz, (Warsaw, Poland), Carla Braitenberg, (Trieste, Italy), Sun He-Ping (Wuhan, P.R. China), Zhigen Yang (Shanghai, P.R. Chin)

9. Publication of the ETS2000

Proceedings of scientific papers will be published as a special issue of the Jour. Geod. Soc. Japan. Other Report on the ETS2000 including the list of participants will be appeared in the next issue of BIM

10. Next Symposium

During the ETS2000, Canadian Colleagues (Profs. D. Smylie, L. Mansinha and S. Pagiatakis) kindly offered to have the next (15th) International Symposium on Earth Tides in Canada in 2004. The Earth Tide Commission acknowledges the receipt of this invitation.

Shuzo Takemoto

IAG/IAPSO JOINT WORKING GROUP ON GEODETIC EFFECTS OF NONTIDAL OCEANIC PROCESSES

Meeting held on March 29, 2001 in Nice, France in conjunction with the XXVI General Assembly of the European Geophysical Society (EGS) during which presentations were given by R. Gross, T. Sato, B. Chao, and A. Brzezinski.

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans.

Recognizing the important role that nontidal oceanic processes play in Earth rotation dynamics, an IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes was formed at the XXII General Assembly of the IUGG in Birmingham. The objective of this IAG/IAPSO Joint Working Group is to investigate the effects of nontidal oceanic processes on the Earths rotation, deformation, gravitational field, and geocenter, and to foster interactions between the geodetic and oceanographic communities in order to promote greater understanding of these effects. R. Gross described the International Earth Rotation Service (IERS) Special Bureau for the Oceans (SBO). The IERS Special Bureau for the Oceans is one of seven Special Bureaus of the IERS Global Geophysical Fluids Center

(GGFC) which was established on January 1, 1998 in order to help relate dynamical properties of the atmosphere, oceans, mantle, and core to motions of the Earth, including its rotation. In particular, the IERS Special Bureau for the Oceans is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, bottom pressure, and torques. Through the IERS SBO web site at http://euler.jpl.nasa.gov/sbo, oceanic data can be downloaded and a bibliography of publications pertaining to the effect of the oceans on the solid Earth can be obtained. Currently, two different oceanic angular momentum data sets are available. The IERS SBO is one possible source of data that can be used by the IAG/IAPSO Joint Working Group in their investigations on the geodetic effects of nontidal oceanic processes.

T. Sato discussed the effect of sea surface height variations on superconducting gravimeter measurements. Good agreement with gravity measurements at 3 different sites were obtained using results from both an ocean model and from TOPEX/POSEIDON measurements which had been corrected for the steric changes in sea surface height that have no gravitational signature. This study of the results of gravity observations clearly shows that gravity measurements from satellites and on the ground have an important role to play when studying the effects of oceanic variability on the local and global geophysical processes of the Earth. He then presented plans for deploying ocean- bottom pressure recorders off the coast of Japan at TOPEX and Jason-1 crossover points.

As the mission scientist for the GRACE Mission Office, B. Chao discussed the use of oceanic general circulation models to dealias GRACE gravitational field measurements. The GRACE project is currently planning on producing gravitational field solutions at monthly intervals. Since the distribution of mass within the oceans changes more rapidly than this, the gravitational effect of this rapid oceanic mass movement will be aliased in the monthly solutions unless it is modeled and removed from the GRACE measurements. A barotropic, or perhaps a baroclinic, ocean model driven by either NCEP or ECMWF surface winds and fluxes will likely be operated by the GRACE project in order to model and remove the high frequency variations in oceanic mass distribution that will not be sampled by the GRACE monthly gravitational field solutions. Since this scheme will most likely not be able to perfectly remove the aliased signals, the user community should be cognizant of the uncertainties that will be introduced by this procedure. Similar aliasing effects are also expected to occur due to rapid atmospheric, hydrologic, and ocean-tidal mass movement, and the GRACE project is also planning to use atmospheric and ocean tide models to similarly remove these effects.

A. Brzezinski summarized the results on the oceanic excitation of the Chandler wobble that he and J. Nastula presented at the 33rd COSPAR Scientific Assembly held in Warsaw, Poland during July 16-23, 2000 (to appear in Advances in Space Research). Using the POLE98 polar motion series, the NCEP/NCAR reanalysis atmospheric angular momentum series obtained from the IERS Special Bureau for the Atmosphere, and the 11-year-long oceanic angular momentum (OAM) series of Ponte et al. (J.Geophys. Res., vol. 104, pp. 23393-23409, 1999) obtained from the IERS SBO, they demonstrated that the OAM series is highly coherent with the lacking non-atmospheric excitation of the observed Chandler wobble signal. In terms of the excitation power, the combined effect of the atmosphere and ocean explains about 80% of the free wobble, which agrees to within 1-sigma uncertainty with the result recently published by R. Gross (Geophys. Res.Lett., vol. 27, pp. 2329-2332, 2000).

The next meeting is scheduled to be held in conjunction with the XXVII General Assembly of the EGS that will be held in Nice, France during April 22-26, 2002. The exact date and time of this meeting will be announced later. In order to receive announcements of this and all future meetings, please contact Richard Gross at richard.Gross@jpl.nasa.gov.

R. Gross

FIRST INTERNATIONAL SYMPOSIUM ON ROBUST STATISTICS AND FUZZY TECHNIQUES IN GEODESY AND GIS, ZURICH, SWITZERLAND, MARCH 12-16, 2001

The 'First International Symposium on Robust Statistics and Fuzzy Techniques in Geodesy and GIS' took place at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland, from March 12-16, 2001. It was initiated by the members of the Special Study Group (SSG) 4.190 of the International Association of Geodesy (IAG) on 'Non-probabilistic assessment in geodetic data analysis'. It was organized by Prof. A. Carosio, ETH Zurich,, and Dr. H. Kutterer, DGFI Munich, chairman of the SSG. Nearly 60 participants from 15 countries attended the symposium.

The program of the meeting consisted of applications of robust statistics and fuzzy theory, mainly in the fields of geodetic engineering, deformation analysis, geographic information systems, satellite-based positioning (GPS),

and photogrammetry. Therefore five technical sessions and a panel discussion were organized. In advance, two tutorials were given on robust statistics (A. Carosio) and on fuzzy logic (H. Kutterer, S. Schön) on monday, March 12.

The symposium was opened on tuesday, March 13, with a welcome address by Prof. B. Heck, University of Karlsruhe, president of the IAG section IV. Two invited lectures followed. The first one was presented by Prof. F. Hampel, ETH Zurich, who considered both the historical development of robust statistics and recent mathematical problems. The second one was given by Prof. R. Viertl, Technical University of Vienna, who motivated the non-precision approach and showed the application of statistical methods to non-precise data based on the extension principle of fuzzy theory. H. Kutterer gave the last lecture in this session on a general viewpoint of uncertainty assessment.

In the technical session on geodetic engineering four talks were focussed on robust statistics: kinematic positioning (Y. Yang), the BIBER estimator (F. Wicki), and the reliability of robust estimators (M. Berber, S. Hekimoglu). One talk considered the use of interval mathematics for the measurement uncertainties (S. Schön). L. Soukup discussed 'least squares without minimization'.

The second technical session on deformation analysis showed a variety of different assessment methods: a conic fitting algorithm (O. Akyilmaz), inference on deformation measures like strain tensors (J. Cai), fuzzy deformation analysis (K. Heine), Plucker coordinates (R. Jurisch), artificial neural networks (J. B. Miima), modelling alternatives in deformation measurements (D. Rossikopoulos), and maximum correlation adjustment (F. Neitzel).

The third session which was on Geographic Information Systems (GIS) consisted of four talks, three using fuzzy logic (G. Joos, S. Keller, E. Stefanakis) and one on robust estimation techniques (E. Kanani). The following session was dedicated to GPS data processing and analysis: real-time prediction of failures (C. Dacheng), robust techniques (A. Wieser, Y. Yang), and fuzzy methods (S. Leinen, H. Kutterer).

The last technical session of the symposium was on photogrammetry, remote sensing, and image processing. F. Sanso discussed the Wiener-Kolmogorov prediction problem with the application to digital terrain models. L. Mussio considered semantic ambiguity questions for pattern recognition. M. Scaioni showed the use of the LMS estimator for outlier rejection in automatic aerial triangulation.

The last day of the symposium started with an introductory talk by F. Sanso on the challenges for the IAG in data analysis in the fields of geodesy and GIS, especially regarding the modelling of uncertainty by probabilistic and non-probabilistic techniques. A panel discussion on data analysis within IAG closed the symposium.

The proceedings of the symposium are published as Report No. 295 of the Institute of Geodesy and Photogrammetry of the Swiss Federal Institute of Technology Zurich (ETH). Further information can be found on the website of the IAG SSG 4.190. The address is www.dgfi.badw.de/ssg4.190. Last but not least a warm thanks goes to the local committee around A. Carosio at the ETH Zurich for the excellent organization of the symposium.

H. Kutterer

THE 11TH SYMPOSIUM OF THE EUREF SUBCOMMISSION

The 11th symposium of the EUREF Subcommission was held in Dubrovnik from 16. - 19.5.2001. Proceedings will be published in AMitteilungen des Bundesamtes für Kartographie und Geodäsie@.

On this symposium the following resolutions were adopted:

Resolution No. 1

The IAG Subcommission for Europe (EUREF)

recognising that

-in May/June 1994 the EUREF-SLOCRO-94 campaign in Slovenia and Croatia was observed,

-in September/October 1995 the Slovenia-95 and CROREF-95 campaigns in Slovenia and Croatia were observed,

-in August/September 1996 the CROREF-96 campaign in Croatia was observed,

and all the results were submitted to the EUREF Technical Working Group as a combined EUREF-CRO-94/95/96 solution, where it was accepted as class B standard (about 1 cm at the epoch of observations)

endorses the subsets of points for Croatia submitted to the EUREF Technical Working Group as improvements and extensions of EUREF89,

but considering that two points in Croatia observed during the EUREF-CROSLO-94 campaign were destroyed,

recommends that all old Croatian points should be deleted from the EUREF database and replaced by the subset of points selected from the EUREF-CRO-94/95/96 solution.

Resolution No. 2

The IAG Subcommission for Europe (EUREF)

considering

-the availability of the ITRF2000 as an improved and accurate realisation of the ITRS,

-the improved determination of the rotation of the Eurasian plate using ITRF2000 site velocities,

recommends to replace the NNR-NUVEL-1A rotation rate values by the ones derived from ITRF2000 in the transformation formula linking ETRS89 to ITRS.

Resolution No. 3

The IAG Subcommission for Europe (EUREF)

recognising the significant practical and scientific value of the EVRS

noting the usefulness of improving its realisation EVRF2000

asks national levelling data providers to UELN/EUVN to inform the Technical Working Group on the tidal system and other corrections used,

recommends that in the future levelling data be submitted in the zero tidal system according to the EVRS definition and corresponding IAG resolution 16, 1983.

Resolution No. 4

The IAG Subcommission for Europe (EUREF)

recognising

-the European Vertical GPS Reference Network (EUVN) with its GPS-derived ellipsoidal heights and levelled connections to UELN,

-the definition of the European Vertical Reference System EVRS with its first realisation UELN 95/98, called EVRF2000,

considering

-this implicit pointwise realisation of a European geoid consistent with both ETRS89 and EVRS,

-the existence of a large number of regional and local geoids in Europe,

-the urgent need by the navigation community for a height reference surface,

asks its Technical Working Group and the European Subcommission of the IAG IGGC (International Gravity and Geoid Commission) to take all necessary steps to generate a European geoid model of decimetre accuracy consistent with ETRS89 and EVRS.

Resolution No. 5

The IAG Subcommission for Europe (EUREF), which held its eleventh EUREF symposium in Dubrovnik from May 16-18, 2001, expresses its heartfelt thanks to the Local Organising Committee, its chairman ZELJKO BACIC and the State Geodetic Administration, as well as the Cadastre Office in Dubrovnik and the International Centre of Croatian Universities, for organising the symposium and for the excellent arrangements resulting in a very successful meeting.

Joao Agria Torres, Lisbon: jatorres@ipcc.pt

Helmut Hornik, Munich: hornik@dgfi.badw.de

SECOND INTERNATIONAL SYMPOSIUM: GEODYNAMICS OF THE ALPS-ADRIA AREA BY MEANS OF TERRESTRIAL AND SATELLITE METHODS

Last autumn the beautiful city of Dubrovnik became a meeting point of the international geodetic community again. It was after a long interruption lasting almost exactly 9 years. In 1989 the participants of the First International Symposium on Gravity Field Determination and GPS-Positioning in the Alps-Adria Area left the Dubrovnik Inter-University Centre, the venue of the symposium, with a believe that they will reconvene at the same place in four years. However, the reality and the difficult time in this area prepared another development.

Only last year the reconstructed Inter-University Centre of Dubrovnik became the venue of the Second International Symposium: Geodynamics of the Alps-Adria Area by means of Terrestrial and Satellite Methods which was held here between September 28 and October 2, 1998. The symposium was sponsored by the International Association of Geodesy and it also had a generous local support. In total 43 interesting papers were presented by scientists coming from 9 different countries to the audience of over 70 participants. The meeting was organized by Prof. K. Èoliæ (as the local organizer, University of Zagreb) and Prof. H. Moritz (as the international co-organizer).

At the opening session a number of addresses was presented by local and international representatives. Then the participants of the symposium heard a very interesting lecture by K. Èoliæ and H. Moritz on Rudjer Boškoviæ (1711-1787), a native of Dubrovnik and a remarkable figure in the history of modern European science who also made considerable contributions to geodesy and geophysics.

The symposium itself was subdivided into 10 session: 3 sessions were devoted to Geodynamics and chaired subsequently by H. Seeger, G. Rossi and C. Marchesini. Then G. Schmitt chaired a session on Geoid, F. Vodopivec a session on GPS, P. Holota a session on Positioning and Gravity, P. Pesec chaired a session on CERGOP, E. Groten a session on the Theory and finally two session devoted to practical works were chaired by A. Zeman and K. Kaniuth.

The first session on Geodynamics started with a paper by Hussein A. Abd-Elmotaal who discussed inverse Vening Meinesz Moho depths for the Eastern Alps. Then Z. Altiner et al. presented a talk on crustal deformations in the Adriatic sea area as inferred on the basis of GPS observations. Subsequently, E. Groten and St. Leinen treated deformation monitoring around a large viaduct close to Istambul using GPS and levelling. Finally, F. Vodopivec and D. Kogoj discussed the geodynamics in Slovenia and A. Zeman approached a problem of estimating vertical dynamics on the territory of former Austro-Hungarian empire on the bases of results of historical levellings.

The second session on Geodynamics was opened by A. Caporali who in his talk attacked a problem of constraining the rheology of continental lithosphere near Orogens with the use of Bouguer gravity anomalies. The programme of the session continued with a paper by D. Miškoviæ on problems of national reference frame and geodynamic investigations in Slovenia. Then B. Richter et al.

discussed absolute gravity measurements in Croatia approached as a standardized base net for geodynamic, height and gravity studies. Finally, G. Schmitt and C. Marchesini informed about geodetic activities with respect to geokinematics in Friuli and the Eastern Alps.

At the last session on Geodynamics E. Prelogiæ et al. treated recent tectonic movements and earthquakes in Croatia and then G. Rossi and M. Zadro discussed geodynamic processes at the northern boundary of Adria plate, especially strain-tilt measurements and modelling. The session was closed with a paper by P. Vyskoèil (presented in absentia by H. Moritz) on the map of vertical movements of Dinaridies Eastern Alps, Pannonian Basin and the Bohemian Massif.

As already mentioned, together with geodynamics oriented sessions there were also sessions on closely related topics in Dubrovnik.

The paper by H. Abd-Elmotaal et al. *stared the Geoid session*. The talk was devoted to the influence of implementing the seismic Moho depths in geoid computation. K. Arsov and H. Sünkel approached the problem of influence of the resolution of DEM in gravity reduction. They used fractal models of the topography for their analyses. E. Groten and K. Seitz discussed a detailed geoid of Germany based on EGM96. N. Kühtreiber presented a recent geoid computation for Audtria and N. Kühtreiber et al. then concluded the session with results of a geoid computation for the central part of the Alps-Adria area.

At the GPS session A. Caporali devoted his talk to an analysis of a GPS network along the Alpine Arc. K. Kaniuth and Stuber attacked the problem of accuracy and reliability of height estimates in regional GPS networks. H. Seeger et al. contributed with results of a re-computation of the EUREF GPS campaigns in Croatia and Slovenia. Finally, M. Marjanoviæ and Lj. Rašiæ discussed the results of the EUREF 1997 GPS campaign in Croatia.

Also the Gravity was discussed at a separate session. Here J. Flury brought an information on a local gravity filed determination in the Estergebirge. E. Gueguen and C. Doglioni discussed the geodynamic evolution of the Appeninic subduction. R. Marjanoviæ-Kavanagh contributed with experiences with a new digital tiltmeter and G. and G.K. Walach presented a Bouguer gravity map of Styria.

The session on CERGOP was opened by D. Miškoviæ et al. They presented results of the GPS-measurements in the Bovec-Tolmin earthquake region. H. Düller and P. Pesec contributed with information on the Austrian permanent GPS-network. P. Pesec then summarized the current status of the Austrian IDNDR project (Crustal dynamics of the Adriatic microplate and the adjacent East-Alpine area). Finally, J. Šimek discussed possible topics for the international cooperation within CEI/CERGOP on the background of current European project.

Within theory oriented session the audience heard a contribution by P. Holota on Galerkin's method in the determination of the disturbing potential. Then an analysis of a straight line equation by M. Lapaine and new concepts of boundary value problems of physical geodesy after GPS presented by H. Moritz.

Finally, *two working sessions were devoted to practical works*. Here K. Èoliæ et al. contributed with two talks: on the survey of the Plitvice-lakes (the phenomenon in the Karst of the Dinaric Alps with satellite and terrestrial measurements) and on the 3-D geodynamic network of broader area of the city of Zagreb. Then Z. Kapoviæ et al. presented results of the geodynamic research of the historical center in the city of Dubrovnik with precise geometric levelling. Subsequently M. Plazibat approached linear transformation between old and new national networks by means of finite elements and M. Solariæ discussed a visibility analysis of GPS satellites in Central Europe.

At the closing session (chaired by B. Gajèeta) the participants adopted a number of important resolutions. They are as follows:

Resolution 1 - The Symposium,

recognizing the need of a regular exchange of ideas and research results in the field of the 'tectonic scenario' in the wider Alps-Adriatic region and

having in mind the hospitality of the Croatian colleagues,

recommends regular meetings in a four years cycle in the city of Dubrovnik, with one intermediate meeting at a different place between two of these symposia.

Resolution 2 - The Symposium,

recognizing the need of further research concerning the 'tectonic scenario' in the wider Alps-Adriatic region and of studies concerning earthquake disaster prevention in this region,

recommends the establishment of a corresponding Special Study Group in Section V 'Geodynamics' of IAG, with due relation to CERGOP.

Resolution 3 - The Symposium,

considering that the area of the Plitvice Lakes is not only a National Heritage under the patronage of UNESCO (No. 148), but also very important for different reasons such as Dinaric Karst geology, effect of tourism etc. and

considering that important geodetic and geodynamical studies have already been performed by the Geodetic Faculty of Zagreb University,

recommends that this area be declared an *International Geodynamic Test Area* in which all relevant geodetic methods are to be applied.

Resolution 4 - The Symposium,

recognizing the need of permanent GPS stations and

considering the existence of such stations e.g. in Croatia and Slovenia.

recommends the establishment of at least one permanent GPS station on the territory of Bosnia and Herzegovina.

Resolution 5 - The Symposium,

> *recognizing* the great and successful efforts of Prof. Èoliæ and Prof. Moritz and their staff in preparing and organizing this symposium and
>
> *appreciating* the importance of the topics under consideration for applied and theoretical surveying, geodesy, geodynamics and related practical activities by universities and state organizations in and around the Alpine-Adriatic Area up to the Panonnian Basin,
>
> *expresses* its sincere thanks for the wonderful days in the beautiful city of Dubrovnik, which is under the patronage of UNESCO (No. 149), and in the stimulating environment of IUC in free Croatia.

The scientific programme of the symposium was enriched by the presentation of the book by H. Horitz: Science, Mind and the Universe (U. Wichmann Vlg., Heidelberg, 1995) and its translation into Croatian. On this occasion an introductory lecture was held by Acad. N. Trinajstiæ who gave an interesting outline of philosophy and discussed its contemporary trends.

The participants of the symposium spent nice and well organized time together and during an interesting excursion had a possibility to learn more about the marvelous city of Dubrobnik and its beautiful surrounding. The symposium was a clear success. The Proceedings will be published by the Geodetic Survey of Croatia.

P. Holota

REPORT ON THE INTERNATIONAL CONFERENCE ON TECHNICAL ASPECTS OF MARITIME BOUNDARY DELINEATION AND DELIMITATION, INCLUDING UNCLOS ARTICLE 76 ISSUES (ABLOS), MONACE, 9-10 SEPTEMBER, 1999.

Seventy-six attendees from twenty-nine countries were present at the Conference. In addition the International Hydrographic Bureau (IHB) personnel, members of the UN Commission on the Outer Limits of the Continental Shelf and the UN Division of Ocean Affairs and Law of the Sea participated. The sessions and papers were organised by the Conference Committee chaired by P. Vaniçek, chairman of ABLOS, and the Conference Proceedings, containing the 26 paper presented, will be produced by the IHB.

The Conference was divided into four sessions over a span of two days. In the first session, “Issues concerning the UN Commission on the Limits of the Continental Shelf”, convened by G. Carrera, topics related to the approach of the UN CLCS to submissions made by coastal states were considered in contributions presented by members of the Commission. The following papers were delivered: CROKER, Peter, CLCS Member (Ireland), “The mandate and work of the Commission on the Limits of the Continental Shelf”.HINZ, Karl, CLCS Member (Germany), “A review of continental margins of the world”. LAMONT Iain, CLCS Member (New Zealand), “Formulating the New Zealand Continental Shelf Claim: A First Step”. BREKKE, Harald, CLCS Member (Norway), "Uncertainties and errors in sediment thickness”. CARRERA, Galo, CLCS Member (Mexico) “Wide continental margins of the world: a survey of marine scientific requirements and international regional cooperation needs posed by the implementation of Article 76 of UNCLOS”. ALBUQUERQUE, Alexandre and CARRERA, Galo, CLCS Members (Brazil and Mexico) “Information on the outer limits of the extended continental shelf”.

The second session, “Geodetic issues, with emphasis on errors in maritime boundaries and how to reduce them”, convened by B.G. Harsson, dealt with specifically geodetic problems of delineation and delimitation of maritime boundaries. The following papers were delivered: CARRERA, Galo, (Canada) "The impact of the seabed roughness on the location of the outer limits of the extended continental shelf". GROTEN, Erwin, (Germany) "Coastal Boundaries and Vertical Datums. VANIÇEK, Petr, (Canada) "Propagation of errors from shore baselines seaward”.SJOBERG, Lars, M Fan and Milan Horemuz, (Sweden) "Accuracy of computed points on a median line, factors to be considered", MURPHY, Brian, Philip Collier, David Mitchel andl Bill Hirst., (Australia) "Maritime zone boundary generation from straight baselines defined as geodesics”. OSZCZAK, Stanislaw, A.Wasilewski, Z.Rzepecka (Poland) " RTK/ DGPS service in maritime boundary delimitations". ELEMA, I. and Kees de JONG, (The Netherlands) "The determination of boundaries at sea between Belgium and The Netherlands".

The third session, “Tools needed for boundary delimitations”, convened by R. Macnab, dealt specifically with hardware and software that would be necessary to obtain the data to substantiate a continental shelf claim. The following papers were delivered: PALMER, Hal, Lorin Pruett, and Kurt Christensen, (USA), "GIS applications to maritime limit and boundary delimitation". MONAHAN, David, Michael S. Loughridge, Meirion T Jones, Larry Mayer, (Canada, USA, UK)   "A model for using publicly available data and methodologies to begin preparing a claim to an extended continental shelf under article 76 of the United Nations Convention on Law of the Sea (UNCLOS)". MONAHAN, David and Larry Mayer, (Canada) "An examination of publicly available bathymetry data sets using digital mapping tools to determine their applicability to Article 76 of UNCLOS". HIRST, Bill, Brian Murphy and Phil Collier, (Australia) "An Overview of Australian Maritime Zone Boundary Definition". BORISSOVA, Irina Philip A. Symonds, Robin Gallagher, Bruce C. Cotton and Gail Hill, (Australia) "A set of integrated tools based on ArcView for defining the outer limit of Australia's continental shelf". BENNETT, John, (USA) "Contrast of the 'Surface of Directed Gradients' with the 'Surface of Maximum Curvature' to compute the foot of the continental slope". HARDING, Jennifer, Herman Varma, John Hart and Ron Macnab, (Canada) "The HH code: facilitating the management, manipulation, and visualization of bathymetric data".

In the last session, "Other issues and case studies (not necessarily related to Article 76)", convened by C. Rizos, specific issues and case studies were the subjects of discussion. The following papers were delivered: MONAHAN, David and David Wells, (Canada) "Achievable uncertainties in the depiction of the 2500m contour and their possible impact on continental shelf delimitation". MACNAB, Ron, (Canada)

"Article 76 in the Arctic - a catalyst for international collaboration". CHERKASHOV, Georgi, A., Gramberg I.S. Makorta A.P., Kaminsky V.D., Naryshkin G.D., Poselov V.A., Sorokin M.Yu. (Russia) "Bathymetry and Deep Structure of the Arctic Continental Margin of Russia in the context of article 76 UN Convention on the Law of the Sea". COAKLEY, Bernard, (USA) "Contribution of the SCICEX Project Towards the Implementation of Article 76 of the UN Convention on the Law of the Sea in the Arctic Ocean". SYMONDS, Phil, (Australia) "Austalia's approach to defining its extended continental shelf: progress and issues arising".

The Conference, staged in the beautiful new offices of IHB, was considered a great success and a possibility that a bi-annual ABLOS-sponsored conference could become a regular international venture in Monaco was discussed. It was the first time that the IHB offices have been utilised for a conference of this format and it was evident that the facilities would not be adequate to support a conference wit a larger number of participants. It is anticipated that the assistance of the Principality of Monaco will have to be sought if this was to become a regular venture.

P. Vaniçek

MEETING REPORT OF THE IAG/IAPSO JOINT WORKING GROUP ON GEODETIC EFFECTS OF NONTIDAL OCEANIC PROCESSES HELD IN CONJUGATION WITH THE EGS XXV GENERAL ASSEMBLY, NICE, FRANCE, APRIL, 2000.

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans. Products of oceanic general circulation models (OGCMs) have been used to study these and other geodetic effects of nontidal oceanic processes. Data assimilation systems similar to those employed in numerical weather prediction are beginning to be used with OGCMs to improve their fidelity. In the near future, time-varying gravitational field measurements, which over the oceans can be interpreted as time-varying ocean-bottom pressure measurements, will be available from the CHAMP and GRACE satellites. The assimilation of these new data types into OGCMs can be expected to further improve the accuracy of global ocean models, and hence the accuracy of the predicted effects of oceanic processes on the Earth's rotation, deformation, gravitational field, and geocenter.

Recognizing the important role that nontidal oceanic processes play in Earth rotation dynamics, an IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes was formed at the XXII General Assembly of the IUGG in Birmingham. The objective of this IAG/IAPSO Joint Working Group is to investigate the effects of nontidal oceanic processes on the Earth_s rotation, deformation, gravitational field, and geocenter, and to foster interactions between the geodetic and oceanographic communities in order to promote greater understanding of these effects. A meeting of this IAG/IAPSO Joint Working Group was held on April 27, 2000 in Nice, France in conjunction with the 25th General Assembly of the European Geophysical Society during which presentations were given by Rui Ponte, Chris Hughes, and Richard Gross.

Rui Ponte discussed an oceanographic data assimilation system being created by collaborators from the Massachusetts Institute of Technology (MIT), the Scripps Institution of Oceanography, and the Jet Propulsion Laboratory. The ocean model component of the data assimilation system, originally developed at MIT, is currently run on a 2x2 degree horizontal grid with constant mixing coefficients and a simple convective adjustment scheme. Future improvements will include finer resolution, more realistic mixed layer physics and eddy parameterizations, and relaxation of the volume conserving formulation. The oceanographic data currently being assimilated include altimetric measurements of sea surface height, hydrographic sections, and sea surface temperature measurements. Other types of data (e.g., floats, XBT profiles) will also be included in the future. Routine calculation of oceanic angular momentum and torque quantities from the output of the assimilation system is envisioned.

Chris Hughes described the GLObal Undersea Pressure (GLOUP) data bank. For more information about GLOUP and/or to obtain the series of historical ocean-bottom pressure measurements see the GLOUP home page at http://www.pol.ac.uk/psmslh/gloup/gloup.html.

Richard Gross described the International Earth Rotation Service (IERS) Special Bureau for the Oceans (SBO). The IERS Special Bureau for the Oceans is one of seven Special Bureaus of the IERS Global Geophysical Fluids Center (GGFC) which was established on January 1, 1998 in order to help relate dynamical properties of the atmosphere, oceans, mantle, and core to motions of the Earth, including its rotation. In particular, the IERS Special Bureau for the Oceans is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, bottom pressure, and torques. Through the IERS SBO web site at http://euler.jpl.nasa.gov/sbo, oceanic data can be downloaded and a bibliography of publications pertaining to the effect of the oceans on the solid Earth can be obtained. Currently, two different oceanic angular momentum data sets are available. The IERS SBO is therefore one possible source of data that can be used by the IAG/IAPSO Joint Working Group in their investigations on the geodetic effects of nontidal oceanic processes.

Meetings of the IAG/IAPSO Joint Working Group on Geodetic Effects of Nontidal Oceanic Processes are planned to be held twice-per-year in conjunction with major conferences in order to foster interactions on this topic between the geodetic and oceanographic communities. These meetings, which are open to all interested individuals, will generally be held in the Spring in conjunction with the EGS conference in Europe and in the Fall in conjunction with the Fall AGU conference in the United States. The next meeting will be held in conjunction with the Fall 2000 AGU conference in San Francisco, California during December 15-19, 2000 with the exact date and time to be announced later. In order to receive announcements about this and all future meetings, please contact Richard Gross by sending an email message to him at Richard.Gross@jpl.nasa.gov.

WORKING MEETING OF THE IAG SSG 4.190 ON NON-PROBABILISTIC ASSESSMENT IN GEODETIC DATA ANALYSIS

The first working meeting of the IAG SSG 4.190 took place at the Geodetic Institute, University of Karlsruhe (GIK), on April 7, 2000. 11 members and corresponding members were participating. The meeting was opened with a welcome note by B. Heck, president of the IAG Section IV on General Theory and Methodology. H. Kutterer, chairman of the SSG, continued with a short review of the terms of reference and objectives. The main part of the meeting consisted of oral presentations by members of the SSG on the topics fuzzy-theory (E. A. Shyllon, K. Heine), robust estimation (A. Carosio), artificial neural networks (J. B. Miima), interval mathematics (S. Schön), GIS for local geoid computation (M. Brovelli), and on general uncertainty theory (H. Kutterer).

It was decided to have annual closed working meetings of the SSG. Besides, it is planned to organize an open international workshop on robust and fuzzy techniques in March 2001 in Zürich.

The financial support of the stay of E. A. Shyllon by the IAG is gratefully acknowledged as well as the sponsoring of the organization of the meeting by the GIK.

H. Kutterer

MINUTES OF THE ORGANIZATIONAL MEETING FOR AFRICAN REFERENCE SYSTEM "AFREF"

Held April 27, 2000, Centre Universitaire Mediterranean (CUM), Nice, France

Meeting Objective:

Discuss possible organization of a project to establish a common geodetic reference system throughout Africa compatible with the International Terrestrial Reference System (ITRF). Discuss ways to involve the international geodesy community to work with African nations to develop a single, uniform, continental geodetic reference

system meeting international standards to replace the myriad national reference systems, many of which have not been maintained, and are out of date and inaccurate.

Meeting Organization:

Called by Claude Boucher, head of Commission X of the International Association of Geodesy (IAG) "Global and Regional Networks", also head of the ITRF and the representative of the International Earth Rotation Service (IERS) to the International GPS Service (IGS). The IGS is active globally in supporting the mission of the IAG & IERS/ITRF through the techniques and applications of the Global Positioning System (GPS). GPS is the most economical and widely accessible modern geodetic technology for realizing a continental reference network throughout Africa.

Executive Summary

The decision was taken at this preliminary meeting to pursue the coordination of a project designated "AFREF", the objective of which is to establish a continental, robust and homogenous geodetic reference system throughout Africa. Africa remains the only continent with paucity of satellite geodetic measurements, especially GPS observations, either episodic, or continuous. There are a few notable exceptions: locations in South Africa, single stations in Malindi, Kenya; Mas Palomas, Canary Islands, Spain; Libreville, Gabon and at previous times a station each in Ghana and Cote 'd Ivorie.

Difficulties of in-country support, communications, reliable infrastructure and lack of resources hinder permanent, high quality GPS station implementations a Helwan, Egypt; Adis Ababa, Ethiopia; Rabat, Morocco; and Kampala, Uganda, for example, where equipment have been installed.

This meeting and earlier ad-hoc discussions have highlighted the importance of a renewed effort to realize a reference system for this continent through international collaboration directly with the African nations. It was emphasized that the must truly be a joint effort with Africans to be successful and that it must focus on the

transfer of appropriate technology to sustain the references with modern instrumentation, e.g. GPS and other satellite techniques. It is also noted that resources will be required to enable organizational participation and project activities (e.g. travel, equipment, technical support, etc.)

The meeting attendees agreed to further explore and pursue a joint project 'AFREF' with the Africans and other international partners, and that such a project should:

1. Support and ensure the fundamental basis for the national 3-d reference networks for today and in the future through a continental African geodetic network fully consistent and homogeneous with the global reference frame of the ITRF.
2. Establish continuous, permanent GPS stations such that each nation or each user has free access (and at least within 1000km) of such stations.
3. Provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks and numerous applications with readily available technology
4. Understand the necessary geodetic requirements of participating national and international agencies.
5. Assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

Ruth Neilan, acknowledging contributions from Jim Slater

REPORT ON THE 2ND INTERNATIONAL WORKSHOP ON AIRBORNE GRAVIMETRY AND POLAR GRAVITY

Field, Svalbard, Norway, August 7, 1999.

Twenty participants from six countries gathered to an informal workshop on the Arctic gravity field, held at UNIS (University of Svalbard), Longyearbyen, Norway. The workshop was called at short notice to take advantage of several airborne gravity survey activities taking place at the same time from this high-Arctic location. The meeting was called to follow up a similar workshop held in Kangerlussuaq, Greenland, June 2-4, 1998. The workshop was sponsored by IAG section III.

The workshop was organized by KMS (National Survey and Cadastre, Denmark) and University of Bergen. R. Forsberg, KMS initiated the workshop with a presentation on the Arctic Gravity Project, an international effort to compile a gravity grid of the Arctic region, a.o. to support the planned gravity field satellite missions. The Arctic Ocean is currently the object of intense gravity survey activities from both aircraft, submarines and icebreakers, and additionally the relaxation of historical tensions in the region have meant that comprehensive Russian data are now being presented also to western researchers. Sergei Maschenkov (VNIIO, Russia) gave an overview of results of the intensive Russian program by the presentation Arctic Gravity and Magnetic Compilation, in part carried out within a US/Russian bilateral coopeation. Most of the Arctic is covered with gravity observations, with many surveys carried out from numerous ice camps of the former Soviet Union. John Brozena (Naval Research Lab., USA) gave an overview talk of current US airborne activities in the Arctic. Since 1992 major parts of the western and central Arctic basins have been covered by long-range airborne gravimetry, in a program sponsored by NIMA. The data have provided significant new insight into the major tectonic elements of the Arctic Ocean. More technical talks included presentations by V. Childers (NRL) and A. V.Olesen (KMS) on details of aerogravity measurements and processing, and by K. Keller (KMS) and B. Nelson (DRE, Canada) on hardware setup for aerogravity and magnetic measurement systems. The later paper illustrated the high accuracy of modern magnetometer systems (.05 nT), as well as gave the point that magnetic measurements should referably always be made alongside aerogravity in such operationally difficult areas like the Arctic.

Regional project talks included presentation on German icebreaker and aerogeophysical activities in the Fram Strait region by U. Meyer (AWI, Germany), on ongoing KMS survey activities around Greenland (A. Olesen), Norwegian aerogravity activities in Greenland (D. Solheim/SK, A. Gidskehaug/UiB), and on Russian aerogravity activities around Frans Josef Land carried out in recent years. The different projects, based on many different kinds of aircraft (smaller Twin-Otters or Do-228s, or long-range P-3s or IL-38s) shows that aerogravity has now become an operational tool, although there still is room for much research and development on both improving gravity sensor performance as well as improving accuracy of long-range kinematic GPS.

Rene Forsberg

ARCGP – ARCTIC GRAVITY PROJECT

International Association of Geodesy – International Gravity and Geoid Commission

Minutes of Workshop and WG Meeting, St. Petersburg, Russia, June 7-8, 2000

The 2nd working group meeting of the IAG-IGGC Working Group ”Arctic Gravity Project” was held at Znamenka, outside St. Petersburg, Russia, on June 7-8, 2000, as part of an ”Arctic Science Week”. The meeting was arranged by VNIIOkeangeologia, Ministery of National Ressources, St. Petersburg. Local organizing committee was headed by A. Zayonchek of VNIIO.

The meeting was split in two parts: A workshop on the polar gravity field (June 7), and a business meeting of ArcGP (June 8). During the workshop the data status of different countries and projects in the Arctic region were highlighted, data quality discussed for various methods for gravity surveys, and a brief of some Antarctic activities was also included.

1. **Report on workshop day, June 7**

The meeting was opened by a welcome address by *V. Kaminsky*, Deputy Director of VNIIO.

The chairman of ArcGP, *R. Forsberg,* then opened the meeting by giving a brief overview of the background of the Arctic Gravity Project. The ArcGP was initiated based on discussions held at meetings in Celle, Germany, and Kangerlussuaq, Greenland, 1998. ArcGP has at the IUGG 1999 General Assembly in Birmingham, England, been adopted by International Association of Geodesy as an official Working Group of the International Gravity and Geoid Commission. The rationale for the ArcGP is especially the developments in global gravity field mapping, where new satellite missions such as CHAMP, GRACE and GOCE in the coming years will improve the global gravity field significantly, except for the polar regions due to orbit restrictions. But also improved insight into the tectonics, geodynamics, and geoid of the Arctic Ocean region will be an important outcome of ArcGP.

The president of the International Geoid and Gravity Commission, *M. Vermeer*, then gave welcoming remarks on behalf of IAG and IGGC, and outlined the basic structure of IAG and the links to ArcGP. The ArcGP is in status similar to the IGGC regional subcommissions, albeit time-limited. He stressed that interest in ArcGP is both geodetical and geophysical, and that geodetic services like International Geoid Service and Bureau Gravimetrique will benefit from this initiative. He also welcomed a similar initiative for Antarctica.

The scientific contribution included the following presentations (presenting author shown) – summary made primarily from notes taken by S. Kenyon:

S. Kenyon: EGM96 global gravity field model and ArcGP data status.

Outlined the current status of the joint NIMA/NASA/Ohio State Univ. Model EGM96, a global sherical harmonic expansion of the geopotential to degree 360. Gave then an overview of the current data status for data constributed to the ArcGP, and some comparisons of different data sets.

G. Demianov: GAO98 global gravity field model and Russian geodetic activities.

A main goal is to construct a precise geoid. Current global Russian spherical harmonic model is GAO98, based a.o. on gravity data from TSNIIGAIK and the GEODAS CD-ROM global gravity data, satellite altimetry and satellite orbit models to degree and order 60. A GPS/Glonass satellite geodesy network in Russia is being established to support global activities and provide basic geodetic infrastructure for Russia. Differences between PZ-90 (Glonass) and WGS84 (GPS) coordinates were illustrated. ArcGP will improve Russian geoid and solve important geodetic problems related to geoid determination. GPS/levelling will be the means to compare geoid models.

S. Maschenkov: Regional tectonic interpretation of gravity and other geodata in the Arctic.

Showed Arctic Ocean gravity compilation made from VNIIO data, Canadian and NRL data sets, as well as similar bathymetric and magnetic compilations. All fields highlight the main features of the Arctic Ocean such as Gakkel and Lomonossov Ridges. Showed depth to Moho estimate based on 3-D gravity modelling and seismic data. Showed data on extension of continental shelf up to Lomonossov ridge and showed profile examples in Canada Basin and north of Russia. Concluded an the Arctic gravity compilation project is important for understanding geologic and tectonic structure.

V. Childers: NRL aerogravity program 1992-1999.

The US Naval Research Lab has, under the leadership of J. Brozena, carried out airborne gravity measurements over the high Arctic since 1992, and over Greenland 1991-92, using long-range P-3 aircraft, equipped with numerous GPS receivers and 2 gravimeters. Major campaigns have included the Canada and Amerasian Basins. Operations have been based out of Alaska, Greenland and – since 1998 – Svalbard, in cooperation with other US and foreign scientific groups. Over the years quality of surveys has improved, primarily due to advances in GPS technology and processing. Greenland was flown 1991-92 as a high-altitude survey at 4100 m elev. The Arctic has been flown since 1992 as low-level flights with 10 n.m. line spacing. Internal cross-over errors have decreased from 4 mGal for the oldest surveys to ca. 2 mGal since 1996. Results have shown new tectonic features, such as extinct spreading axis in Canada Basin. Comparisons to satellite altimetry were around 3 mGal r.m.s. in smooth areas, 7.5 mGal in rough areas, resolution somewhat higher for airborne gravity. Raised question of a common way to define resolution.

V. O. Leonov: Russian aerogeophysical surveys of Frans Josef Land region and Antarctica.

Outlined Russian airborne activities of ”Polar Marine Geological Expeditions” in Arctic and Antarctica. Airborne mapping program is based on IL-38 aircraft system with aerogravity, aeromagnetism and radio-echo sounding channels. Navigation is by INS, radionavigation/Doppler radar and altimeter/barometer. GPS MX-4400 recently installed. Horizontal navigation accuracy better than 100 m. Gravimeter is of vibrating-string type. Standard deviation of measurements is 4-6 mGal, in future 3-3.5 mGal. Magnetic results better than 5 nT. Surveys over Frans Josef Land region in three campaigns since 1993, flying out of Murmansk. Line pattern of 5 km spacing, 20 km cross-lines were flown. Operational costs of aircraft around 2000 USD/hr. Illustrated results by anomaly plots and explained tectonic interpretation/structure. Data to be made available to ArcGP on same conditions as other Russian data.

- Antarctica: Surveys since 1989 in the Weddel Sea, Queen Maud Land, and Enderby Land. Programme suspended at the moment due to lack of funds. Line spacing 20 km, accuracy 4-7 mGal, slightly higher in the interior due to lack of satellites.

B. Coakley: SCICEX submarine geophysics and bathymetry programme.

The US Navy has made a nuclear-powered submarine available for yearly scientific cruises of the SCICEX programme since 1993. More than 100,000 km of narrow-beam bathymetry and gravity have been collected. Since 1998 wide-swath bathymetry has been collected as well. SCICEX has collected data outside 200 nm limits except north of Alaska and Svalbard. Submarine traverses at 400-750 ft depth at 15 knots. Gravity is measured with a Bell gravimeter and reduced to surface, employing a 2 min filter to the data. Vertical accelerations are corrected from depth sensor information. Some errors are expected due to errors in navigation (submersion periods up to 2 weeks give INS drift). R.m.s. cross-over errors are at 2 mGal. Base ties made in origin ports (Hawaii, England, east coast US). Examples were shown of side-scan bathymetry and gravity from recent surveys (Chukchi Borderlands, Alaska Shelf, Lomonossov and Gakkel Ridges, Yermak Plateau). SCICEX programme is now suspended, but negotiations are underway with the US Navy for more cruises.

M. Veronneau: Geoid modelling of the Arctic Region.

Explained gravity status of Canadian territory. National gravity program with spacing up to 10 km completed except for a few small voids (Foxe Basin, Great Bear Lake). GSD has contributed 105,000 surface measurements and 9,500 airborne data (1998 PMAP survey north of Ellesmere Island) for ArcGP. Showed complete free-air anomaly map for North America including Greenland as part of effort to make joint North American geoid under IGGC Subcommission on North American Geoid. ArcGP data will help this project. Showed results of geoid computations and compared to other geoid models of US and Greenland, and compared geoid accuracy to data from GPS/levelling over various areas.

R. Forsberg: Greenland aerogravity project 1998-2000.

KMS has operated an airborne gravity system in a Twin-Otter since 1998, as a spin-off from the EU project AGMASCO. System is based on custom-developed INS, laser altimetry, GPS and a Lacoste and Romberg gravimeter, owned by University of

Bergen, Norway. Survey program 1998-2000 to map coastal areas around Greenland, with support from NIMA. The program complements earlier NRL airborne measurements of the interior of Greenland and recent surface measurements of the ice-free parts. Cross-overs with independent ship and ice surface data indicate performance at 2 mGal r.m.s. and resolution of 6 km at airspeed 130 knots, with no bias offsets, making data very well suited for geoid computations and check of older marine data. Showed improvements of new airborne data on the geoid in region north of Greenland.

D. Solheim: *Svalbard gravity project.*

The Norwegian Mapping Authority has made airborne gravity measurements around Svalbard 1998-99 (SAG98 and SAG99), to complete the coverage over land and the surrounding shelf regions. Land gravity program suspended since 1986 due to fatal helicopter crash. New airborne measurements have been made with support from Norsk Hydro, Oliedirektoratet, and KMS/NIMA. The same system setup and airplane were used as in the KMS Greenland airborne survey. Russian participants joined 1999 flights in ocean region between Frans Josef Land and Svalbard. Comparisons of airborne to marine gravity data are good (2.6 mGal r.m.s.), over land large discrepancies between surface and airborne data exist due to problems in upward continuation of point data in rugged topography with glaciers of unknown thickness, airborne data could be inverted to infer glacial thicknesses. Compiled data set of land and downward continued airborne data to be made available to ArcGP.

T. Boebel: *AWI airborne geophysics in the Arctic and Antarctic 1997-1999.*

Described AWI aerogravity and aeromag campaign in the Arctic since 1997. Surveys are based on AWI Do-228 aircraft, aerogravity system spin-off from AGMASCO project, using own S-56 LCR gravimeter. Measurements made in Fram Strait region between Greenland and Svalbard, operating from Longyearbyen and Station Nord. Primary purpose of measurements to map plate boundary features between Spitsbergen and Greenland. Showed free-air plots from 1997-98 showing Gakkel Ridge anomaly, and corresponding bathymetry and magnetics. AWI also makes shipboard gravity in region by icebreaker Polarstern.

- Antarctica: EMAGE aerogeophysical program 1996-2000..2003 to map offshore gravity and magnetics on the shelf in region around German Neymeyer station at a spacing down to 5 n.m.. Scientific objectives are to study the type of continental margin and spreading anomalies. Aerogeophysics data to be collected along with support for EPICA European drilling project in Queen Maud Land, 1999-2004. New project WEGA proposed to map larger parts of East Antarctica 2003-?. AWI activities will complement existing Russian data, AWI has these data.

M. Vermeer: *Gravity surveys of Finland and the Baltic Sea.*

Showed Finnish gravity coverage. Finland has very dense coverage of gravity (2-3 km spacing) over all of its national territory. A subset of these data at 5 km resolution provided for ArcGP. Data include winter ice measurements off the coasts. Joint Nordic airborne survey using KMS Twin-Otter system has completed coverage of Baltic Sea. Airborne data versus recent ship data showed 1.8 mGal r.m.s. difference. Data to be used for updated geoid model of Nordic region.

R. Forsberg: *Gravity from satellite altimetry over the Arctic Ocean – status and future possibilities*.

The principle of gravity recovery from satellite altimetry was outlined. Advances in retracking of satellite altimetry waveforms have made data more exact. On behalf of S. Laxon, UCL and D. McAdoo, NOAA, recent ERS ice-satellite altimetry results from the Arctic Ocean south of 81N were presented, included a detailed gravity map of the Russian shelf. Two other solutions covering the Arctic Ocean are the solution by BGI, France (G. Balmino and M. Sarrailh), based on two retracked ERS-1 repeats only, and the KMS99 field of O. Andersen, which is based on non-retracked ocean-mode ERS-1 and ERS-2 data 1993-99, giving many return in leads and over thin ice in the Arctic. Comparisons over ice-free areas show r.m.s. gravity errors of 5-8 mGal, and 5-15 mGal for comparisons to ice-breaker data off NE Greenland. KMS99 seem to be best in open ocean region, UCL/NOAA most recent field best over ice. Comparisons of this field and NRL data in the Canada basin have given fits at 3-4 mGal r.m.s. Gravity from satellite altimetry up to 88N will be possible using new satellite missions: The NASA ICESAT/GLAS laser altimetry mission, to be launched 2001, and ESA's CRYOSAT radar mission 2003. With these data all current data voids in the Arctic will be covered.

A. Zayonchek: *Integrated Interpretation of Gravity and Other Geodata in the North Eurasian Shelf for Russian State Regional Geological Mapping Program.*

Showed plots of the Bouguer gravity and magnetic anomaly for region north of Russia, to study structure of continental shelf. Complex geophysical models shown along seismic profiles. Showed estimated depth to Moho and tectonic scheme/zonation map, and showed geophysical model along Gakkel Ridge seismic line collected by BGR.

R. Macnabb: *The new International Bathymetric Chart of the Arctic Ocean – building a DEM for calculating Bouguer corrections over ocean and continent*.

Outlined current status for a new grid of Arctic Bathymetry. Primary purpose to make new GEBCO map, to replace existing arctic bathymetry map GEBCO sheet 5.17 from 1979, based on very limited data. 11 organizations from 8 countries involved in geographically allocated data collections and grid preparation. Significant new data from SCICEX and older US/British submarine cruises as well as from Russian maps. New map product developed on GIS system at University of Stockholm (M. Jakobsson), based on internal 2.5 x 2.5 km grid. A prototype ”beta-version” map displayed. Plans for 2000+ to incorporate additional data sets and complete project documentation prior to formal distribution of grid. Data well suited for ArcGP to convert from Free-air to Bouguer anomalies, and grid manipulation and visualisation tools already set up to handle this.

The chairman closed the session of workshop session by thanking the presenters, and gave a special thanks to the hard work of the professional simultanous Russian/English translators.

2. Minutes of the ArcGP business meeting, June 8

The agenda for the business meeting was:

- Status of data submitted to date

- Comparisons of different data sources

- Strategy for data merging of data sets with highly different noise characteristics

- Grid specification issues, final formats

- Strategy for obtaining missing data

- Time schedule

- Publication policy of joint papers and reports

- Web site issues and data distribution

- Auxillary grid issues: Bouguer anomalies, ice thickness DEMs

The business meeting started with an outline of the ArcGP goal: To collect the necessary data to compile a public-domain 5' free-air gravity grid for the area north of 64N by 2001. Original data are not to be made available, to avoid problems with national secrecy requirements. A website and ftp box have been set up at the ArcGP processing center at NIMA. Parts of the contributed data also reside at KMS, notably for comparisons and data merging method development.

Status of submitted data:

National agency contributions:

Finland – OK, 2.5' data for making 5' mean values provided.

Sweden – OK, 5' grid data computed at KMS from data in joint Nordic geoid data base.

Iceland – OK, original data provided to KMS.

Norway – OK, data to be provided, problems with downward continuation over Svalbard.

Greenland – August 2000 survey along coast to be included, new downward continued 5' data grid available late 2000. Otherwise all data available.

Canada – point data provided to ArcGP web site, need to redo recent Ellesmere Island survey to update processing of orthometric heights.

Alaska – covered from NIMA archives, including USGS helicopter surveys.

Russia – collected marine Arctic data 1960-1992 through aircraft-supported ice surveys. Data are high-quality point measurments using 3 gravimeters and 2-3 base stations, positioned by differential navigation, lately satellite navigation, navigation accuracy 50 m to 1 km. Colocated with depth measurements. Some limited submarine data also exist. Most surveys have been carried out by Russian Navy (HDNO/GUNIO), with additional activities by ministeries. Land data for continental Russia exist throughout, and 10' mean data for European Russia have already been provided for ArcGP by G. Demianov.

Rear-admiral A. Makorta, HDNO stressed the monumental effort involved in the many decades of Russian gravity work across the entire Arctic Ocean basin. Admiral Makorta offered that HDNO would make available their data to compile the final ArcGP grid product, and at the same time incorporate all western available gravity data into the product. HDNO would in addition to compiling the final ArcGP grid product also be willing to print the final gravity map.

The chairman (R. Forsberg) thanked A. Makorta for the offer to take over the ArcGP processing and welcomed the initiative, which would be a major step forward in the cooperation between Russia and the international scientific community on gravity field matters. The chairman suggested that with the well-advanced progress of ArcGP, the current grid product be finished at NIMA/KMS in the short term, by incorporating available 5' data in the last data voids. This interim "beta-version" grid could then be transferred to HDNO for comparisons with the superior-quality original russian data, especially to quantify errors in satellite altimetry and airborne gravity, and to isolate possible problems in base ties with SCICEX submarine data. Updated original data (or compiled subgrids) could then be transferred to HDNO for production of the final ArcGP grid and map. The scheme would be subject to negotiations with the major data holders, notably NIMA.

The status of other major data providers:

Alfred Wegener Institute, Germany – four seasons of airborne gravity available, 1997-98 already provided, 1999-2000 to be processed this fall. Polarstern data also provided.

SCICEX data – all data up to 1998 have been provided through ArcGP ftp box, 1999 data have some small residual problems. B. Coakley would reprocess the last data and forward to ArcGP soon. He would also make an effort to check base ties of earlier submitted data sets.

Naval Research Lab – all Arctic Ocean data 1992-99 provided, Greenland 1991-92 data to be downward continued and merged with surface data. With current improvements of NRL processing, the 1991-92 Greenland airborne data could be improved by reprocessing. No decision has been taken on this issue yet.

Other data sources discussed were Sweden (plans cruise to North Pole with icebreaker ”Oden” 2001. Might be too late to incorporate gravimeter onboard, and get data to ArcGP), incorporation and check of historical ice-island data (e.g, T-3, Arlis and Fram).

Comparisons of different data sets

R. Forsberg presented a number of comparisons between SCICEX, NRL, Danish/Norwegian, German and airborne Russian (PMGE) gravity data in the Greenland-Svalbard-Frans Josef Land region, and around the North Pole. Surface data (high-quality marine gravimetry, Lincoln Sea ice data and LOREX ice-camp data) show good agreement to NRL and other airborne data, with no major bias differences (< 2 mGal) and r.m.s. differences mostly in range 2-4 mGal. PMGE and KMS data compare well (4 mGal r.m.s.) in overlap region west of Frans Josef Land, when transforming Russian gravity reference system to absolute/GRS80 western system using transformation parameters provided by Tsniigaik. Some problems were encountered with SCICEX data, suspected to be due to base tie errors.

Stategy for merging different data sources

The method of least squares collocation/Kringing was discussed, and generally agreed to be suitable, since it allows different standard deviations to be assigned to data. Data sets displaying bias problems would be ”draped” top other data sets using related methods. It was recommended that GIS visualisation methods be utilized in the data preparation process to identify errors and problems.

Grid specification and formats

It was accepted that the decision of the Birmingham WG meeting is in force: The basic grid will be a 5’ free-air grid, displaced 2.5’ relative to the integer degrees, so that the final grid from 64N to the North Pole will consist of even number of points in both directions. An expansion of the grid will be made in the Atlantic region to include all of Greenland and Iceland.

It was discussed if a cartesian x-y grid should be adopted instead, e.g. on a polar stereographic projection. It was agreed that an internal working x-y grid would be a good idea, especially for GIS applications, but that the final grid should be given as a geographic grid, to easily merge the ArcGP grid into other regional or global grids, which are more or less invariably in geographic coordinates. A geographic grid is also natural due to the decision of a southern limit of 64N.

Strategy for obtaining missing data

Since the main data voids are covered by Russian data, negotiations should be undertaken to fill these voids. With the new HDNO offer to prepare the final ArcGP grid, it is hoped that good progress be made in talks to Russian data holders. Western data holders should eventually give permission for direct data exhange with Russia, preferably giving HDNO permission to use the original point data as part of an exchange agreement.

No other major data sources are likely existing. S. Kenyon would investigate to what degree major oil companies could make data off Alaska available.

Time schedule

Early 2001 would be deadline for submission of data for inclusion in the ArcGP initial ”beta” grid. Flexibility would be essential, if new data surfaces, and the developments in the HDNO cooperation. Grid and initial publications to be made ready by mid-2001. Final grid and map compilation by late 2001/early 2002, likely by HDNO.

Publication policy

The ArcGP results should be presented at the major international meetings by the active members of the ArcGP WG, and not just the chairman or co-chairman. On the recommendation of R. Macnabb it was decided to make available a set of ”standard overheads” for such presentations. Major benchmark meetings would include the IAG General Assembly in Budapest, AGU and EGS meetings, and the IAGA General Assembly in Vietnam, all 2001. A main joint paper could be submitted to Journal of Geodesy. An article in EOS would also be desirable.

Web site issues and data distribution

The publication of the final grid product would be made both on the web and on CD-ROM. A printed report and map would follow, with all members of ArcGP acknowledged.

The current ArcGP website is maintained by NIMA at *http://www.nima.mil/GandG/agp.*

The web site will be updated with minutes and status reports as the project progresses. The web site will also be used as main distribution channel for distributions of the final grid.

Auxillary grid issues: Bouguer anomalies, ice thickness DEM

It was decided that auxillary grids of Bouguer anomalies and geoid heights should be included on the final web/CD-ROM distributed product.

To compute Bouguer anomalies the IBCAO project bathymetric grid may readily be used on the ocean. Available 5’ land DEM heights are similarly available on land, both at NIMA and from international databases. However, a 5’ grid of glacier thicknesses would be required to produce reliable Bouguer anomalies over glaciers. Thickness data are available over Greenland and Iceland, but for other regions such as Svalbard and Ellesmere Island no data are available. Data exist for part of Russia (Frans Josef Land), but is not yet available. It was decided to start a subproject to compile a 5’ ice thickness grid to be used for the compilation of the Bouguer anomaly grid. 5’ grid cells on glaciers with unknown thickness will be specially flagged. KMS will take the lead on this special task.

It was similarly decided to include an Arctic geoid model based on the free-air gravity grid, using spherical FFT methods. GSD, KMS, and Tsniigaik will cooperate on this subproject when basic freeair grid is ready, including comparisons to GPS on tide gauges.

Next ArcGP meeting

It was decided to have a next ArcGP working group meeting in Ottawa, Canada, in connection with the meeting of the Canadian Geophysical Union and Subcommission of the Geoid of North America, May 14-18, 2001. The ArcGP business meeting will take place on one of the days of the week, and it will be attemted to organize a special ”Arctic Geophysics” session during the CGU meeting, where many ArcGP relevant presentations will be possible. Organizer will be Marc Veronneau, GSD.

Thanks

The particpants in the ArcGP express a great thanks to VNIIO and the organizing committee under the leadership of A. Zayonchek for arranging an efficient meeting, and an excellent general programme of the visit.

Copenhagen, July 5, 2000
Rene Forsberg, KMS

Encl.:

Participant list (addresses of ArcGP members available on ArcGP homepage).

A preliminary free-air grid plot and coverage map of different sources underlying free-air map.

Participants in ArcGP meeting, St. Petersburg, June 7-8, 2000:

Canada:

W. Roest (Geological Survey of Canada, Ottawa)

R. Macnabb (Geological Survey of Canada, Halifax)

M. Veronneau (Geodetic Survey Division, Ottawa)

Denmark:

R. Forsberg (KMS; chairman of ArcGP)

Finland:

M. Vermeer (Finnish Geodetic Institute; president of International Gravity and Geoid Commission)

Germany:

T. Boebel (Alfred Wegener Institute)

Latvia:

J. Kaminskis (State Land Survey)

Norway:

D. Solheim (Statens Kartverk)

Harald Brekke, Oddny Svendsen (Oliedirektoratet)

USA:

V. Childers (Naval Research Lab, Washington DC)

B. Coakley (Tulane Univ., Luisiana)

S. Kenyon (NIMA, St. Louis; co-chairman of ArcGP)

Russia:

G. Demianov (Tsniigaik, Moscow)

K. Astafurova , A. Cheruych, V. Glebovski, V. Kaminsky, S. Paukki, S. Mashenkov, A. Zayonchek (VNIIO, St. Petersburg)

A. Makorta, A. Oparin, N. Nesterov (Head Department of Navigation and Oceanography, Russian Navy, St. Petersburg)

V.O. Leonov (Marine Geological Research Expedition, Lomonossov)

V. Kamyanskoy (Min. of National Ressources, Moscow)

V. Polikepov (All-Russian Inst. For Exploration Geophysics, Moscow).