Perugia, Italy July 2-13, 2007

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EARTH: OUR CHANGING PLANET

IAG

INTERNATIONAL ASSOCIATION OF GEODESY

INTER-ASSOCIATION SYMPOSIA AND WORKSHOPS

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Perugia, Italy **July 2-13, 2007**

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EARTH: OUR CHANGING PLANET

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Abbreviations

IAG	International Association of Geodesy
IAGA	International Association of Geomagnetism and Aeronomy
IAHS	International Association of Hydrological Sciences
IAMAS	International Association of Meteorology and Atmospheric Sciences
IAPSO	International Association for the Physical Sciences of the Oceans
IASPEI	International Association of Seismology and Physics of the Earth's Interior
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
CliC	Climate and Cryosphere
Ev-K2-CNR	Everest-K2 CNR Committee
GEWEX	Global Energy and Water Experiment
HKH-FRIEND	Hindu Kush-Himalayan Flow Regimes from International Experimental and Network Data
IABO	International Association for Biological Oceanography
IACS	International Association of Cryospheric Sciences
ICACGP	International Commission on Atmospheric Chemistry and Global Pollution
ICASVR	International Commission on Atmosphere-Soil-Vegetation Relations
ICCE	International Commission on Continental Erosion
ICCL	International Commission on Climate
ICCLAS	International Commission on the Coupled Land-Atmosphere System
ICCP	International Commission on Clouds and Precipitation
ICDM	International Commission on Dynamic Meteorology
ICGW	International Commission on Groundwater
ICIMOD	International Center for Integrated Mountain Development
ICMA	International Commission on the Middle Atmosphere
ICRS	International Celestial Reference System
ICSIH	International Commission on Snow and Ice Hydrology
ICSW	International Commission on Surface Water
ICT	International Commission on Trac
ICWQ	International Commission on Water Quality
ICWRS	International Commission on Water Resources Systems
IGAC	International Global Atmospheric Chemistry
IGS	International Glaciological Society
ILP	International Lithosphere Program
INQUA	International Union for Quaternary Research
ION	International Ocean Network

IRC	International Radiation Commission
PUB	Prediction in Ungauged Basins
SCAR	Scientific Committee on Antartic Research
SEDI	Study of the Earth's Deep Interior
SPARC	Stratospheric Processes and their Role in Climate
UCCS	Union Commission for the Cryospheric Sciences
UNESCO	United Nation Educational, Scienti. c and Cultural Organization
UNITAR	United Nations Institute for Training and Research
WMO	World Meteorological Organization

Session code naming

The first letter of the session codes indicates whether the session is a Union, a Joint Interassociation or a single Association sponsored event, the second letter indicates the type of event: Symposium (S) or Workshop (W). For Joint events, the second letter indicates the Lead Association (with the abbreviations listed below) and the third indicates whether a session is a Symposium (S) or a Workshop (W). In some cases (namely IAGA, IAHS) Association session codes have an extra codi. cation referring to a speci. c Theme or Division.

U	UNION
J	JOINT
G	IAG
A	IAGA
H	IAHS
M	IAMAS
P	IAPSO
S	IASPEI
V	IAVCEI

Some examples:

US002

is a **U**nion **S**ymposium; **JGW**001 is a **J**oint IA**G** **W**orkshop with IAG as the Lead Association;

MS003

is an Association (IA**M**AS) **S**ymposium. **AS III** 020 is an Association (IAG**A**) **S**ymposium sponsored by its **III** Division.

JGS001 **Symposium** **(97 - 120)**

Convener : Dr. Don Chambers, Dr. Victor Zlotnicki

Ocean Circulation and contributions from new satellite missions

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JGS002 **Symposium** **(121 - 159)**

Convener : Prof. Richard Coleman, Prof. Steve Nerem

Global sea-level change: Altimetry, GNSS and tide gauge measurements

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JGS003 **Symposium** **(160 - 233)**

Convener : Dr. Jeff Freymueller

Earthquake and Volcano Geodesy

JGS005 **Symposium** **(234 - 282)**

Convener : Dr. Isabella Velicogna, Prof. Konrad Steffen, Dr. Mark Drinkwater

Observations of the Cryosphere from Space (IAG and UCCS Symposium hosted by IAG - merged with JGS004)

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JGS001 **97 - 120**

Symposium
Ocean Circulation and contributions from new satellite missions

Convener : Dr. Don Chambers, Dr. Victor Zlotnicki

Data from the new gravity missions (CHAMP, GRACE, and the upcoming GOCE) combined with altimetric sea surface height open up a wealth of opportunities for new observables applicable to ocean circulation, including: absolute surface geostrophic currents, time variable ocean bottom pressure, time changes in deep ocean currents, and time changes in heat content. This session will be devoted to original results using data from CHAMP and/or GRACE for ocean circulation studies, as well as estimates of what can be expected from GOCE. Results showing effects of assimilating gravity data products into general ocean circulation models are also welcome.

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JGS001 **Oral Presentation** **97**

Return of the Arctic Ocean to Pre-1990s Circulation as Suggested by GRACE and In Situ Bottom Pressure Measurements

Dr. James Morison
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John Wahr, Ron Kwok, Cecilia Peralta-Ferriz

In the late 1980s and through the 1990s there were major shifts in the Arctic Ocean circulation. With the aim of helping to track such changes, we have undertaken in situ ocean bottom pressure measurements and the analysis of Gravity Recovery and Climate Experiment (GRACE) data. For the in situ measurements we have developed an Arctic Bottom Pressure Recorder (ABPR), which is suitable for deployment through pack ice. The ABPRs are equipped with acoustic modems to allow annual data recovery while leaving the instruments undisturbed on the bottom for up to 3 years. Recovery of the first year of data from gauges installed near the North Pole was achieved in April 2006. The two ABPR records are highly correlated and the comparison between GRACE-derived bottom pressure at the North Pole and the ABPR data is quite good. Both GRACE and the ABPRs show a declining bottom pressure trend in 2005-2006. The complete GRACE record indicates this has been going on since the start of the GRACE record and amounts to about a 10 cm decrease in bottom pressure from 2002 to 2006. We believe this trend is associated with a steric change due to a drop in upper ocean salinity in the central Arctic Ocean. The change in hydrography near the Pole has been tracked for the last 6 years by the North Pole Environmental Observatory (NPEO). The NPEO record shows a reduction in upper ocean salinity to near the pre-1990s climatology. We have averaged all the NPEO hydrographic casts taken each year since 2000 within 400 km of the Pole, and computed the average bottom pressure change associated with the average density changes in each year. The agreement with the GRACE and ABPR trends is good through 2005. We have also investigated the effect on bottom pressure of a hypothetical return to pre-1990s hydrography over a larger area of the Arctic Ocean. We find reasonable agreement with the spatial distribution of bottom pressure trends from GRACE, especially a decrease in bottom pressure in the Makarov Basin associated presumably with the return of less saline, Pacific-derived upper ocean water to that region. The hypothetical trends in sea surface height indicated by the difference between GRACE and the hypothetical steric changes is in qualitative agreement with the changes in sea ice drift over the past 6 years. The bottom pressure trends indicate the Arctic Ocean circulation has nearly returned to pre-1990s conditions.

Keywords: arctic ocean, grace, bottom pressure

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JGS001 **Oral Presentation** **98**

Eddy propagation velocity in the global oceans determined from satellite altimetry and numerical models

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Energetic variability of ocean currents at scales of 100 km and 30 days accounts for a major portion of the kinetic energy of ocean circulation. It is often referred to as the mesoscale variability, or eddy variability of the ocean. Ocean eddy variability was the first oceanic feature detected by satellite altimeters in their formative years in the 1980s. Maps of the standard deviation of sea surface height (SSH) representing the ocean eddy variability became a signature product of altimetry. The relatively small scales of ocean eddies, however, had prevented observations made by a single altimeter from resolving the details of the movement of ocean eddies. The long and simultaneous data records from TOPEX/Poseidon and ERS-1/2 and their respective follow-ons, Jason and ENVISAT, are now making it feasible to study the movement of eddies and determine their propagation velocity. Analysis of the data merged from the aforementioned satellite missions revealed detailed patterns of the propagation of ocean eddies in the global oceans. These patterns show high correlation with the mean flow of the global ocean circulation. They also reflect the effects of bottom topography which steers the mean flow that in turn affects the eddy propagation. These effects are most visible in the Southern Ocean where the Antarctic Circumpolar Current (ACC) is heavily influenced by bottom topography. In a narrow band along the equator, the eddy propagation is fast and eastward, reaching speed over 60 km/day. The propagation turns westward outside the tropics with speed on the order of 20 km/day. The westward speed gradually diminishes at mid latitudes. Only when the mean flow has a substantial eastward component (e.g., ACC) the eddy propagation has a finite eastward component. The meridional component of eddy propagation has substantial speed in the tropical regions, as well in regions where the mean flow has a substantial meridional component. There is little significant meridional propagation elsewhere. In the tropics, the meridional eddy propagation is divergent away from the equator at the eastern boundaries of the ocean and convergent towards the equator at the western boundaries. At mid and high latitudes, barotropic mean circulation is apparently most effective in affecting the eddy propagation; for example, in the recirculation gyre south of the Gulf Stream as well as in the center of the Argentine Basin. The observed global patterns of eddy propagation are generally well simulated by an eddy-permitting ocean general circulation model. The comparison of zonally averaged speed of propagation between model simulations and observations shows excellent agreement. There are also regions of significant discrepancies, revealing places where the ocean model needs improvement.

Keywords: ocean eddy, satelite altimetry, ocean currents

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JGS001 **Oral Presentation** **99**

Observing Steric Sea Level Variations with a Combination of Jason-1, GRACE, and Argo

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Josh K. Willis

The Gravity Recovery and Climate Experiment (GRACE) has provided unprecedented capability for measuring the Earths time-variable gravity, which is predominantly caused by redistribution of water mass. Although the signal is much larger over land, there are still significant gravity changes over the ocean that cause measurable sea level variations, either from redistribution of mass within the ocean or exchange of water between the land and ocean. Satellite altimeters such as Jason-1 measure the sea level changes related to these mass variations, as well as large density (or steric) variations that do not cause a gravity variation. Argo profiling floats measure temperature/salinity to a depth of 2000m. Since 2003, there has been nearly global coverage of the oceans from these three observing systems. In this study, we will compare the steric sea level calculated from a combination of Jason-1 and GRACE with steric sea level derived from the Argo temperature/salinity profiles on both global and local scales for the period from January 2003 to December 2006. An EOF analysis will be used to study common modes of variability. Differences, particularly in the trend of the global average over the 4-year interval, will be discussed. We will also examine early estimates of a combination of Jason-1, GRACE, and Argo data into monthly maps of steric sea level. The Jason-1/GRACE combination is arguably most accurate at long-wavelengths due the more uniform global coverage and consistent data from the satellites, while the Argo data give more accurate information about shorter wavelength signals since they represent measurements of a single profile. By combining the three data sets, we expect to produce maps of steric sea level that are accurate over a much broader wavelength spectrum than from either Jason-1/GRACE or Argo alone.

Keywords: grace, argo, steric sea level

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JGS001 **Oral Presentation** **100**

Seasonal changes in global ocean currents from GRACE gravity field observations

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Henryk Dobslaw

Monthly mean gravity fields solely based on GRACE satellite tracking data are found to provide reliable ocean mass anomalies down to 500 km regional averages when comparing them to mass observations obtained from sterically corrected Jason 1 altimetry and simulated mass anomalies derived from the Ocean Model for Circulation and Tides (OMCT). Beside the assessment of systematic shortcomings of GRACE, Jason 1 and OMCT estimates, robust signals of mass anomalies in the North Pacific and in various regions of the Southern Ocean are identified in all three independent datasets. Correlations of up to 0.8 and rms values of differences of around 2 hPa indicate that uncertainties are well below the expected monthly mean mass signals of up to 6 hPa rms in these regions. By means of output of the numerical ocean model, mass anomalies are related to changes in barotropic ocean currents, providing in turn the opportunity to infer barotropic current anomalies from GRACE observations, and therefore principally allowing to monitor climate relevant changes of ocean currents from satellite observations.

Keywords: circulation, gravity, modeling

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JGS001 **Oral Presentation** **101**

GOCE : ESA's Earth Gravity Mission

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Rune Floberghagen

The Gravity field and steady-state Ocean Circulation Explorer (GOCE) Missionwill be the first Earth Explorer Core mission of the Living Planet programme of the European Space Agency (ESA). The satellite is scheduled for launch by the end of 2007. The primary objective of the GOCE mission is to provide global and regional models of the Earth gravity field and the geoid, its reference equipotential surface, with high spatial resolution and accuracy. The high resolution static gravity field and gravimetric geoid measured by GOCE will stimulate research in a wide range of disciplines spanning studies of ocean circulation, cryosphere, solid-earth physics, natural hazards, geodesy and surveying.In this paper we will present the status of the GOCE development activities, including the status of the tests of the satellite flight model and payload. Furthermore, the main technical features of the satellite and of the ground segment will be presented.

Keywords: goce, gravity, gradiometer

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JGS001 **Oral Presentation** **102**

Mass variation in the Mediterranean and Black Seas and in their catchments areas

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Juergen Kusche, Matthias Becker, Emil Stanev, Sebastian Grayek

The seasonal and interannual mass variation in the Mediterranean and Black Seas and in their catchment areas is estimated from GRACE, altimetry data and from hydrological and oceanographic models. The steric component of sea level change is estimated in the Mediterranean Sea from the MFSTEP and the ECCO oceanographic models and in the Black Sea from climatic data sets and numerical simulations with MOM. A smoothed spatial averaging kernel is applied to each field to obtain comparable basin averaged monthly time-series. To restore the magnitude of the GRACE-derived water mass signal a scaling factor is applied. In addition, a de-correlation filter is applied to the GRACE fields in order to remove the effect of stripes. GRACE is able to detect water mass variations in the Mediterranean Sea. It is crucial that variations in land water storage, which inevitably contribute to GRACE-based estimates of water mass, are taken into account. The GRACE seawater mass corrected for the leakage of land hydrology and the filtered steric-corrected altimetry are in good agreement (correlation of 0.8 and rms of 29 mm). The error of the GRACE estimate is probably still larger than the error of the estimate derived from the steric-corrected altimeter data, however the quality of the GRACE products is continuously improving and a further reduction of the errors in the water mass estimation from GRACE is expected. This will further contribute to the understanding of the water mass balance in the Mediterranean-Black sea and catchment areas. In the Black Sea the use of advanced filtering techniques is crucial for the detection of mass variations in this relatively small area, where, however, the annual non-steric sea level variation is considerably larger than in the neighboring Mediterranean Sea.

Keywords: grace, masschange, sealevel

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JGS001 **Oral Presentation** **103**

Estimating the sea surface topography the profile approach with error examination

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IAG

Roman Savcenko

The considerable gravity field improvements achieved through the GRACE mission essentially increase the capability to obtain a reliable signature of the sea surface topography. Two issues remain to be considered: Even the latest gravity field solution from GRACE still exhibit a meridian or track dependent pattern and require a smoothing. In addition, altimetry surveys details of the sea level with much shorter wavelength than resolved by the band limited spherical harmonic representation of the Earth gravity field. In the present paper we therefore follow a profile approach by (i) merging sufficiently smoothed geoid profiles with the along-track sea level measurements of satellite altimetry. As altimetry observes much more details than any geoid profile we (ii) use the autocovariance function of the smoothed geoid profile to apply (iii) a low pass filter to the altimetric sea surface heights such that the filtered heights obtain the same statistical properties as the geoid profile. The along track differences between filtered sea level and filtered geoid are taken as best estimates of sea surface topography profiles which subsequently can be extrapolated or densified by profiles of other altimeter satellites. The approach is completed by considering the error budget of both, geoid and altimetric sea surface heights.

Keywords: sea surface topography, grace, altimetry

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JGS001 **Oral Presentation** **104**

Combining new GRACE-based Geoids with Satellite Altimetry to Estimate Arctic Dynamic Ocean Topography

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Sinead L. Farrell, Seymour W. Laxon, Andy L. Ridout, Carl A. Wagner

We have constructed accurate, high-resolution hybrid geoids for the Arctic to properly estimate the dynamic ocean topography (DOT) in these ice covered seas. Our hybrid geoids have been computed using a combination of new geopotential information from the Gravity Recovery and Climate Experiment (GRACE) satellites and surface gravimetry. We use mean geopotential fields (e.g., GGM02S and recent RL04 updates) derived exclusively from GRACE data in order to provide the long-wavelength (>600 km) geoidal component. Then, by combining - or actually differencing - altimetric sea surface heights recovered from near-polar satellites such as ICESat and ERS-2 with the hybrid geoid(s) we can estimate mean Arctic DOT and ocean circulation for the decade 1995 to 2005. Circulation features such as the Beaufort Gyre have an apparent DOT amplitude of ~20 cm. Comparisons with numerical models and ocean bottom pressure observations will be shown. The mission-specific techniques by which altimetric sea surface heights are estimated from ICESat and ERS-2 waveforms will be described. These techniques are designed to minimize effects of sea-ice (freeboard) noise on sea surface height estimates.

Keywords: grace, arctic ocean

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JGS001 **Oral Presentation** **105**

Ocean bottom pressure from model and GRACE estimates

Dr. Rui M. Ponte
IAPSO

Katherine J. Quinn, Patrick Heimbach, Carl Wunsch

Large-scale low frequency variability in ocean bottom pressure is analyzed using GRACE (Gravity Recovery and Climate Experiment) data products and an optimized model solution from the ECCO-GODAE (Estimating Circulation and Climate of the Ocean-Global Ocean Data Assimilation Experiment) project. The optimized ECCO-GODAE estimate is obtained by fitting most available ocean data in a least-squares sense, using best known statistics of model and data errors. Variability in the spatial mean is a substantial part of the observed bottom pressure signal, particularly at the seasonal timescale; net freshwater input and atmospheric pressure effects are both important. For the residual spatially-varying patterns, GRACE and model results agree well over the Southern Ocean where strongest variability at annual and semiannual periods is present. Phase patterns tend to match well, although model amplitudes are generally weaker. We experiment with various GRACE products and model solutions to derive estimates of uncertainty for the bottom pressure estimates and discuss the use of time-varying GRACE data to constrain the model solutions.

Keywords: gravity, ocean, bottom pressure

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JGS001 **Oral Presentation** **106**

Mean dynamic topography of the Arctic Ocean from altimetry and geoid compared to oceanographic models

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Henriette Skourup, Helge Drange, Johnny Johannessen, Seymour Laxon, Wieslaw Maslowski, Mike Steele, Jinlun Zhang

The combination of GRACE-based precise geoid models and a mean sea surface from altimetry allows the direct determination of ocean MDT, and thus give possibility for independent validation of oceanographic models. In the Arctic Ocean this MDT estimation is complicated by the sea-ice cover, as well as the limited latitude extent of altimetry missions. Ocean circulation models are similarly uncertain due to the sparseness of oceanographic in-situ data, and there is a large different between models. In the paper we present new methods for estimation of ocean sea surface topography and sea ice freeboard heights from ICESat, and use 2 years of ICESat data in combination with an mean sea surface based on 8 years of retracked ERS data, to produce a seamless, consistent Arctic Ocean mean sea surface. This MSS is subsequently combined with a new Arctic geoid model based on GRACE and terrestrial gravity data, to give an estimate of the MDT from remote sensing. This model is subsequently compared to a number of current oceanographic circulation models, each differing in resolution, forcing and implementation of sea-ice interaction. The MDT fields from models and remote sensing is seen to give good qualitative agreements, with characteristic features such as the Beaufort Gyre and the low in the Norwegian-Greenland Sea consistently mapped. This thus shows the potential use of remote sensing data to provide independent constraints on Arctic Ocean circulation models, especially in the future with the availability of improved altimetry and geoid data from CryoSat and GOCE.

Keywords: mdt, arctic ocean, geoid

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JGS001 **Poster presentation** **107**

Spatial and temporal variations of the Kuroshio derived from altimetry, GRACE and hydrological data

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Yang Lu, Houtse Hsu

The Kuroshio Current, originating from the North Equatorial Current, is one of the worlds major western boundary currents. As it is so important for scientific research, climate and socioeconomic consequences, extensive studies have been carried out from oceanographic viewpoints. With the development of the satellite gravity missions and the satellite altimetry missions, the geoid models and sea surface height models have been improved greatly, which gives us a good opportunity to study the space-time variations of the Kuroshio from space more accurately than previously. Using the altimeter data and a geoid recovered from GRACE, the Kuroshio surface currents are derived in China Sea and adjacent sea. With this independent knowledge of Kuroshio surface currents from altimetry/geoid, combining with the temperature and salinity profiles from NOAAs WOA01, the Kuroshio currents as a function of depth are retrieved. The spatial and temporal variations of the Kuroshios transport, axis velocity, width and path fluctuation of Kuroshio in the East China Sea (ECS) from 1993 to 2005 are discussed. A wavelet filter method is used to remove the short-wavelength and noise signal in the SSH and geoid. The results show that the wavelet filter is more efficient than Gauss filter on showing the details and branches of the Kuroshio. The cross wavelet spectrum and wavelet coherence analysis are performed to reveal the relationship between the Kuroshio and the sea surface temperature data in the NINO3 region.

Keywords: kuroshio, altimetry grace, hydrology

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JGS001 **Poster presentation** **108**

Assessment of Geoid Models off Western Australia Using In-Situ Measurements

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R. Coleman, K.R. Ridgway

The recently released Earth geoid models from the Gravity Recovery and Climate Experiment (GRACE) have reached 20 cm accuracy at the spatial scale of 350 km. Data from Gravity field and steady-state Ocean Circulation Explorer (GOCE), scheduled for launch in 2007, should further improve the geoid at the level of 1 cm accuracy with spatial scales down to 160 km. Thus, the ocean mean dynamic topography (MDT) and the corresponding mean geostrophic circulation can be estimated by satellite altimetry. s coastal dynamics are influenced by two major ocean boundary current systems: the East Australian Current and the Leeuwin Current, which are characterised by mesoscale features. Of these currents, the Leeuwin Current flows poleward over the continental shelf along the Western Australian coastline. To understand these ocean currents, a precise and full spatial scale of geoid is crucial. In this paper, we estimate ocean MDTs off Western Australia bounded by 20S to 45S and 108E to 130E using available geoid models (e.g., GGM02, and EIGEN-GL04C) and the time-averaging mean sea surface estimated by multi-satellite altimetry. Estimates are then compared to independent ocean climatologies, such as the Climatology of the Australasian Regional Seas (CARS) (cf. Ridgway and Dunn, 2002). In quantifying the impact of using a particular geoid model to compute the ocean MDT, we directly assess the accuracy of the geoid model in the Western Australian coastal regions by statistical comparison.

Keywords: geoid, mean dynamic topograpgy, altimetry

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JGS001 **Poster presentation** **109**

Integration of Altimetry and GOCE geoid for Ocean Modeling: Results from the GOCINA and the GUTS projects.

Dr. Per Knudsen
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The Gocina And Guts Teams

One of the major goals of the recently completed EU project GOCINA (Geoid and Ocean Circulation In the North Atlantic) was to determine the following three quantities; an accurate mean dynamic topography model, an accurate mean sea surface and an accurate geoid for the GOCINA region between Greenland and the UK and to use the common relationship between the three quantities for mutual improvement. The improved MDT was used for the assimilation of altimetry into the FOAM, MERCATOR, and the TOPAZ model systems. The results demonstrated that the use of the improved MDT improved the modeling of the transports and increased the agreement with observations. The modeling of the heat transport through the straits was changed accordingly, showing the importance of including proper MDTs in climate predictions. Hence, the potential of GOCE to improve future global ocean and climate modeling is evident. No ocean circulation products are planned to be delivered as level-2 products as part of the GOCE project so that a strong need exists, for oceanographers, to further process the GOCE level-2 geoid and merge it with Radar Altimetry. The primary requirement of oceanographers is to have access to a geoid and its error covariance at the highest spatial resolution and accuracy possible, although required resolution depends on application. For effective use of the geoid data, knowledge of the error covariance is mandatory. Within the ESA supported GUTS project the user requirements for GOCE User Toolbox associated with geodetic, oceanographic and solid earth applications are consolidated.

Keywords: goce, meandynamictopography, oceancirculation

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JGS001 **Poster presentation** **110**

GRACE mass variations and ocean bottom pressure fluctuations in the South Atlantic

Mrs. Carmen Boening

Ralph Timmermann, Jens Schrter, Andreas Macrander

The GRACE satellite mission provides time-variable gravity field solutions on a monthly time scale. In contrast to earlier systems, the accuracy of these data is expected to be good enough to derive ocean mass variations from the GRACE gravity anomalies. Since ocean bottom pressure (OBP) fluctuations are an excellent proxy for ocean mass variations an analysis of OBP anomalies in the South Atlantic has been performed. For this purpose we utilize a global ocean circulation model and compare the simulated monthly mean OBP anomalies with in situ data measured by bottom pressure recorders (e.g. PIES) and fields derived from GRACE data. The ocean model is a 1.5 global version of the 3D Finite Element Sea Ice--Ocean Model (FESOM) which has been developed at the Alfred Wegener Institute for Polar and Marine Research (AWI). In situ data from two AWI PIES in the South Atlantic are available for the period 2002-2005. First results indicate a strong correlation between FESOM and GRACE OBP anomalies on a global and regional scale. On smaller, synoptic scales the correlation weakens. Due to spurious elongated meridional patterns in the monthly gravity field anomalies, gravity fluctuations on scales less than 1000 km are difficult to detect. Since the in situ measurements are point measurements by nature, it is essential to identify the area for which their time series are representative. A cross-correlation analysis of FESOM data indicates that regions of spatially coherent patterns of OBP are separated by major features of bottom topography. Averaging GRACE data over these patterns improves agreement with the in situ data. Simulated and observed pressure gradient time series between the two PIES positions are compared to each other, to the simulated volume transports across the line between them, and to total ACC transport variations.

Keywords: ocean bottom pressure, grace, finite element model

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JGS001 **Poster presentation** **111**

High Resolution Ocean Topography from Satellite Gravimetry and Altimetry

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IAPG TUM Muenchen Scientific Associates IAG

Reiner Rummel

The precise geoid models from GRACE and soon GOCE in combination with sea surface geometry data from satellite altimetry allow to obtain a precise estimate of the absolute dynamic sea surface topography with rather high spatial resolution. However this implies combination of data with fundamentally different characteristics and different spatial resolution. One of the central problems is to get altimetric data and the geoid spectrally consistent without loss of precision and/or resolution. We try to design a filter for the altimetric data, using the spectral characteristics of the satellite gravimetric geoid. The area considered is an ocean box (latitude [-65; -45]; longitude [40W; 20E]), with a regular equiangular grid. On the grid points, the values of the sea surface height (altimetric data) are evaluated by interpolation and compared with geoid undulations derived from a spherical harmonic series. To find a suitable filter of the data, we analyze the bi-dimensional Fourier spectrum of the geoid undulation for different maximum degrees. In a second step the error statistics will be analyzed in terms of their variance-covariance structure. An alternative method the use of the least square collocation is investigated: the choice of the maximum degree in the covariance matrix could to operate like a filter.

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JGS001 **Poster presentation** **112**

Ocean circulation with a focus on the importance of a high precision mean sea surface model

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C.K. Shum, Yuchan Yi, Ove Omang, Dag Solheim

In the ocean circulation studies, the aim is to determine - in an integrated approach using multiple space borne, in situ and ocean general circulation model data - the Mean Dynamic sea surface Topography (MDT). MDT isthe difference between the Mean Sea Surface (MSS) and the geoid. The MDT provides the absolute reference surface for the ocean circulation and is, in particular, expected to improve the determination of the mean ocean circulation. This, in turn, will advance the understanding of the role of the ocean mass and heat transport in climate change. The main purpose of this study is to provide detailed assessment and validation of the geoid, MSS, and MDT for the north Atlantic and the Arctic sea region. Synthetic MDTs were computed by the simple formula MDT = MSS- Geoid. In this study, several synthetic MDT models have been computed using available regional and global MSS and geoid models. A low-pass filtering process was applied to provide the major oceanographic features of the MDT in the region. For the validation of MSS and geoid models, the MDTs based on ocean hydrographic data were compared with the synthetic MDTs. Several MDTs based on ocean hydrographic data were studied. The OCCAM and FOAM models provided best results andthe OCCAM model was used for the final assessments of the models. The synthetic MDTs showed similar major oceanographic features as the OCCAM MDT. A mean of approximately 10.1 cm for the differences between synthetic and OCCAM models was estimated. Further, the three models of geoid, MDT and MSS have been inter-compared and the residuals were determined by the simple formula R =MSS-Geoid-MDT. This was done for the different models in the region. The residuals R for OCTAS07 MSS, OCTAS_02 geoid and OCCAM MDT provide a standard deviation mismatch of 13.1 cm. Multiple high-latitude observing satellite radar altimetry data, including ENVISAT, ERS-2, ERS-1 ERM, ERS-1 GM and GFO data, are used to determine the OCTAS07 MSS model in the north Atlantic and the Arctic sea region. These data have been cross-validated and using the multiple altimetry data base (the so-called stack files) generated at the Ohio State University. The OCTAS07 MSS model is developed with the mean tracks of TOPEX/POSEIDON as a reference. In this model, the annual, semi-annual as well as sea surface trends were removed. The OCTAS_02 is a gravimetric geoid computed in the same region. Long-wavelength portion of this geoid model is determined from global geopotential model GGM01C up to degree and order 200. The OCTAS_02 is calculated using the remove-restore technique and the Wong-Gore modified Stokess function with truncation at degree 80.

Keywords: ocean circulation, mean sea surface, altimetry

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JGS001 **Poster presentation** **113**

Altimetric mean sea surface for the North Atlantic and the Arctic Sea

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The Mean Dynamic sea surface Topography (MDT) is a crucial input for ocean circulation and ocean mass transport studies in the polar region. Determination of an accurate geoid and a high precision Mean Sea Surface (MSS) model, towards an improved MDT model for the North Atlantic and the Arctic sea, is the main goals of this study. This paper describes the integrated approach for the determination and evaluation of the MSS models using multiple space borne, in situ and ocean general circulation model data. Multiple high-latitude observing satellite radar altimetry data, including ENVISAT (cycles 10-52), ERS-2 (cycles 1-85), ERS-1 ERM (phases C and G), ERS-1 GM (phases E and F) and GFO (cycles 37-168) data, are used to determine the MSS model, called OCTAS07. These data have been cross-validated and using the multiple altimetry data base (the so-called stack files) generated at the Ohio State University. In this study, several experiment models have been derived and their respectively consistency and accuracy evaluated. The OCTAS07 MSS model is developed with the mean tracks of TOPEX/POSEIDON as a reference. In this model, the annual, semi-annual as well as sea surface trends were removed. The resolution of the OCTAS07 MSS model is 3 minutes in latitude and 6 minutes in longitudes. All computations have been performed relative to the available regional geoid model called OCTAS_02. Note that OCTAS_02 is a gravimetric geoid computed in the region in 2004. Long-wavelength portion of this geoid model is determined from global geopotential model GGM01C up to degree and order 200. The OCTAS_02 is calculated using the remove-restore technique and the Wong-Gore modified Stokess function with truncation at degree 80. The OCTAS07 MSS model ranges between 15 and 70 m in the study region. The internal consistency or the quality estimate for the OCTAS07 MSS model ranges from 2 to 5 cm over the study region. This quality estimate is based on the residual from fitting the data to the model using least squares collocation. The OCTAS07 MSS model was also further validated using available global and regional models (KMS01, KMS03, KMS04, CLS01, CLS04, GSFC00, OCTAS06 and OSU95). Mean and standard deviation of differences between OCTAS07 and KMS04 MSS models are 0.5 cm and 10.4 cm, respectively. Compared to OCTAS06 MSS model, these values are 0.8 cm and 7.2 cm, respectively.

Keywords: altimetry, envisat, octas

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JGS001 **Poster presentation** **114**

Combining Altimeter and Satellite Gravity to Compute Quasi-stable Dynamic Ocean Topography

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The new gravity explore mission GRACE, which provides significant improvement in global gravity field model of the Earth, makes separating precise mean dynamic ocean topography (MDOT) from altimeter-derived mean sea surface (MSS) possible and efficient. In this study, a new mean sea surface height model from T/P and JASON-1 altimeter data is formed with 30x30 grid. By combining it with the latest GRACE-geoid model computed from gravity model WHU-GM-05, the mean ocean dynamic topography is determined. From the derived model, several comparisons are processed with that from earlier models (EGM96, Rio05, ECCO and GGM02). Respecting to previous models, the results show improvement of the derived MDOT is significant.

Keywords: altimeter, grace, mean dynamic ocean topography

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JGS001 **Poster presentation** **115**

Empirical ocean tide analysis of cross-calibrated multi-mission altimeter data

Mr. Roman Savcenko

Dr. Wolfgang Bosch

The capability to empirically estimate ocean tides from satellite altimetry data suffers from the large ground track spacing and the satellites repeat cycles leading to severe alias effects. The spatial sampling can be improved by combining data from altimeter satellites with different ground track pattern. Different orbit configurations imply however different capability to de-alias and separate dominant tidal constituents. This becomes an advantage if the tidal analysis includes multi-mission altimeter data carefully cross-calibrated in advance by a global adjustment of nearly simultaneous crossover events. We consider the tidal analysis on a dense system of grid points and investigate to what extend it is possible to de-correlate major tidal constituents.

Keywords: altimetry, tides

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JGS001 **Poster presentation** **116**

Regional high resolution geoid determination by a combination of GRACE data and in-situ altimetry observations

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The new satellite missions have improved our knowledge of the Earth's gravity field in the recent years. Especially the satellite mission GRACE has recovered the low and medium wavelength part of the gravity field spectrum with unprecedented accuracy. From satellite altimetry data on the other hand the small wavelength gravity field details can be determined over the deep oceans. Therefore a combination of both datasets is highly demanded. The present paper investigates a new approach to combine data from satellite altimetry and satellite gravity missions. Altimetry observations will be used in-situ without gridding and without calculating gravity anomalies first. The combination approach is applied to regional areas covered by both, altimetry and gravity data in order to avoid the data gap problem on continental areas. This approach requires a regional analysis of the GRACE data as well. Therefore the processing strategy has to be based on the analysis of short arcs of the satellite's orbit selected over the respective area, and the gravity field has to be parameterized by space localizing basis functions. First results based on real GRACE, Topex/Poseidon and ERS data are presented. The specific contribution of altimetry is assessed and the combined gravity field is compared to independent high resolution gravity data.

Keywords: geoid determination, grace, altimetry

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JGS001 **Poster presentation** **117**

GOCE Mission Products and Performance

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Danilo Muzi

This paper focuses on the performance of the GOCE mission products. Level 1b products include calibrated and corrected time series of measurements from the Gradiometer instrument as well as from the Satellite-to-Satellite Tracking instrument, while Level 2 products include all precise orbit and gravity field information. In particular, the Level 2 geoid (error) products are expected to be of primary importance for the oceanographic community. In addition, the overall lay-out of the ground segment and the role of the GOCE ground segment elements in the quality assurance of the products to be delivered to end users will be discussed.

Keywords: goce, geoid, performance

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JGS001 **Poster presentation** **118**

Gravity field and mean sea level determination in the North Atlantic using a combination of laser and radar satellite altimetry

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Cross-over adjusted stacked radar altimetry data from Geosat and Topex/Poseidon satellites is used to define a precise reference frame of satellite tracks where Icesat data and Geosat geodetic mission data with dense coverage are merged, allowing a detailed recovery of the marine gravity field. Laser altimetry from Icesat has different characteristics compared to radar altimetry: the repetition rate is faster and the footprint is much smaller (data can be used until the transition ocean-land), providing an alog-track high resolution mapping of the ocean surface. A remove-restore procedure is used to obtain residual sea surface heights by removing the low and high frequencies (the global geopotential model EGM96 is used as reference field and the effects of the topography/bathymetry are computed using the RTM correction with the local accurate bathymetric model AZDTM98 and the global model JGP95E. A validation procedure is applied using least squares collocation, followed by a grid generation of residual geoid undulations, that is inverted using an efficient method based on Fast Fourier Transform to obtain residual gravity anomalies. After adding the contributions to the gravity field from the global model and from the topography/bathymetry, the results are compared with adjusted gravity data obtained from gravimetric surveys. A similar procedure is used to obtain the mean sea level surface in the same area.

Keywords: laser radar altimetry, gravity field

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JGS001 **Poster presentation** **119**

Global and Regional Trends in Ocean Mass (Bottom Pressure) from GRACE

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Ocean signals are among the weakest that GRACE observes, and trends are the most difficult such signals to isolate accurately. Glacial Isostatic Adjustment, errors in atmospheric models, and drifting signals from adjacent continental landmasses, and trends in spherical harmonic degree 1, all complicate the interpretation. However such trends are important evidence of decadal and longer variability in the oceans.Many numerical models are incapable of simulating trends because they do not conserve mass due to the Boussinesq approximation. Others, while non-Boussinesq, depend critically on highly suspect ocean-atmospheric fluxes of freshwater from atmospheric models and equally uncertain global river runoff.Here we analyze a handful of regions of the world oceans where such signals are stronger: the subpolar and subtropical gyres of the N. Atlantic and N. Pacific, and the broad Antarctic Circupolar region.For validation we use region-averages of the difference between altimetric sea surface heights and steric height from a combination of ARGO float, XBT and shipboard hydrography data.

Keywords: ocean, bottom pressure

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JGS001 **Poster presentation** **120**

Mean dynamic topography by an iterative combination method

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Mean dynamic ocean topography (MDT) can be found by measuring the mean sea surface height and computing a gravimetric geoid. The three independent quantities: mean sea surface height , geoid and mean dynamic topography , are related by the equation . However, it is misleading to see the task as optimal estimation of two quantities from three, with one constraint, because the geoid is not directly observable. Computing a geoid involves an integral of gravity over the Earth's surface. To complete this integral at sea, gravity must be continuously available though interpolation into the gaps between ship-tracks. We have shown that analytical interpolation is insufficient and results in geoid errors of many decimetres over the gaps. Thus, data gaps make the initial concept involving the three data streams, , and non-viable. Patching the gaps directly with altimetric 'pseudo-gravity' anomalies is logically inconsistent. Our Iterative Combination Technique (ICM) generates mutually compatible grids of gravity and MDT. The ICM solution converges rapidly: the rms MDT modification between iterations falls below 3mm after 10 iterations. We test the ICM MDT against an average of six high resolution global circulation models that assimilate hydrographic data, having first adjusted this composite MDT to a compatible with the verified part of the GRACE gravity model. After GRACE correction, the difference ICM MDT and the composite MDT has a standard deviation of 4.2 cm.

Keywords: mean dynamic ocean topography, iterative combination method, geoid

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JGS002 **121 - 159**

Symposium
Global sea-level change: Altimetry, GNSS and tide gauge measurements

Convener : Prof. Richard Coleman, Prof. Steve Nerem

One of the current priorities in the scientific world is to understand changes in global sea-level and its effect on coastal populations. Recent improvements in understanding the contributions of ice sheets and glaciers, continental water storage, thermal expansion of the oceans as well as advances in the analysis of the observation of sea-level from altimetry, tide gauges and ground motion from GPS/levelling must be assimilated in order to provide the best possible estimates of present-day sea-level change. In this session we invite contributions from all disciplines associated with the measurement of changes in sea-level including satellite altimetry and gravity missions, studies of tide-gauge records, monitoring of the local ground movement of tide gauges by space geodetic techniques (e.g. GPS) as well as long-term estimates of sea-level change. Presentations related to the IGS TIGA Pilot Project are most welcome.

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JGS002 **Oral Presentation** **121**

Global sea level reconstruction 1807-2002

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We present reconstruction of global sea level from 1023 tide gauge records. All previous assessments of global sea level rise have been done estimating linear trends from limited number of individual long-term time series. We have developed a new virtual station method to overcome geographical bias and which can quantify the uncertainties due to representativity issues of the used stations. How good is the reconstruction? Our global sea level trend estimate of 2.4 1.0 mm/yr for the period from 1993 to 2000 is comparable with the 2.6 0.7 mm/yr sea level rise calculated from TOPEX/Poseidon altimeter measurements. However, we show that over the last 100 years the rate of 2.5 1.0 mm/yr occurred between 1920 and 1945, is likely to be as large as the 1990s, and resulted in a mean sea level rise of 48 mm. What is new? We demonstrate that advanced statistical methods improve error estimations and reduce uncertainties for calculation of regional and global sea level rise. In contrast with linear trends, where the rate of mean sea level rise is constant, our results reveal the evolution of global and regional sea level rise during the past 200 years. We show as well that changes in sea level are not uniformed; smoothed by the 30 year SSA window, the trends from the different ocean regions show slightly dissimilar patterns and still demonstrate some low-frequency variability. We also show that variability in sea level records over periods 2-14 years has increased during the past 50 years for the most of the ocean basins. We provide evidence that this increase in 2.2-13.9 year variability is associated with the greater influence of the large scale atmospheric circulation represented by the Southern Oscillation, North Atlantic Oscillation, Arctic Oscillation and Pacific Decadal Oscillation indices.

Keywords: sea, level, changes

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JGS002 **Oral Presentation** **122**

Combining ICESat Altimetry and Tide Gauges for Coastal Water Surface Determination in the Great Lakes

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Dr. Alexander Braun, Dr. Michael G. Sideris

One of the outcomes of the determination of the Sea Surface Height (SSH) is the Sea Surface Topography (SST) which is of great interest to the geodetic communities especially for defining a highly accurate, globally consistent, and integrated reference height system. A unique global height system definition must be related to a common (global) geopotential surface, which is the geoid. Thus, knowing the SST, especially along the coastal areas, will help to unify height systems with inconsistent zero points. In coastal areas, tide gauges have been providing us for decades with sea-level records at individual points, with the inherent problems of limited spatial distribution and suboptimal coastal locations. The satellite radar altimetry missions (e.g., TOPEX, Jason, etc.) determine the SSH with high degree of accuracy (few centimeters) in open water (global scale). In the coastal areas, however, the determination of SSH with these satellite missions is more complicated and the measurement accuracy is degraded due to inherent limitations, namely, the large footprint diameter (2-20 km) and the large spacing between along-track and cross-track measurements. Therefore, a new technique is needed to provide us with an accurate SSH in coastal areas, by which we can overcome the limitations that exist in both satellite altimetry and tide gauges. The Ice, Cloud and Land Elevation Satellite laser altimetry mission (ICESat), was launched on Jan, 12, 2003, with a primary goal to measure ice sheet elevations and changes in the polar regions. The laser altimeter on-board, the Geoscience Laser Altimeter System (GLAS) emits approximately 3.4 million laser pulses per day with about 1 million valid ocean elevations per day. Unlike radar altimetry, ICESat, with a data rate of 40 Hz and a footprint diameter of 65 m, is capable of measuring precise topography near the coast and therefore ICESat measurements can be directly compared with coastal tide gauge data. The main objective of this work is to validate the ICESat measurements near coast with the tide gauges data over the Great Lakes in order to examine the potential of combining ICESat altimetry over water and tide gauge data in order to improve the accuracy of SSH determination. The Great Lakes were initially chosen as a network of 52 tide gauges (25 Canadian MEDS station and 27 US NOAA stations) is available, and because tides, waves and swell are greatly diminished which may introduce a high noise in ICESat measurements. To compare with each individual tide gauge, ICESat data within a specific radius from the tide gauge is selected and then we checked which tide gauges are co-located with ICESat observations in the operation period, then, the lake level time series of the specific tide gauge is compared with the resulting ICESat data points. The bias between tide gauge and ICESat is determined from averaging the data of the ICESat closest footprints to the tide gauge.

Keywords: icesat, water, greatlakes

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JGS002 **Oral Presentation** **123**

Study of the mean sea level and its time variations

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The mean sea level is studied by applying on tide gauge data a sophisticated regression model. The latter takes into account the following elements. (i) The tidal signal, including the non-common long period tides and the shallow water tides. (ii) Non-tidal quasi-periodic low frequencies, namely annual waves, effects of the polar motion (Chandler waves) and, for very large series of data, the effect of the solar activity. (iii) Determination and elimination of perturbations, including finding and estimation of jumps or very fast changing of the water level. (iv) Polynomial approximation, free of the effect of the constituents, enumerated above. The idea is that the mean sea level can be considered as a polynomial of as low as possible power, in the best case as a linear function of the time. The analysis is applied in a series of iterations, which may deal separately by the elements (i) through (iv), looking by optimal parameters with the help of statistical criteria. However finally, a model including all elements is treated according to the least squares rules by using appropriate options of the tidal program VAV. The analysis has been applied on data from the tide gauges in the Pacific Ocean, namely 8 tidal stations in Chile and the Atlantic Ocean, namely data from the Cananeia (Brazil), the port of Ostende (Belgium) and the Geodynamic Observatory in Lanzarote (Canary Islands).

Keywords: mean sea level, ocean tides, pole tide

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JGS002 **Oral Presentation** **124**

GRACE-based water volume change in major river basins over 2002-2006 and contribution to sea level

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Cazenave Anny, Ramillien Guillaume, Guentner Andreas

W. Llovel, A. Cazenave, G. Ramillien and A. Guentner. We have analysed temporal variations of integrated water volume in the 27 largest river basins worldwide using different sources of GRACE geoid data over 2002-2006. The land water storage changes are based on a generalized least-squares inversion of original GRACE geoids. Over each basin, we compare water volume change estimates from different geoid data sources. Although the inversion process allows some resonant harmonics seen in the geoid solutions to be significantly attenuated, analysis of the power spectrum (degree variance) of the land water solutions still reveal spurious peaks clearly associated with these resonances. Tests have been performed to evaluate the effect of corresponding harmonic coefficients on the water volume solution (by comparing solutions with and without these harmonics). In other tests, we have removed the long-wavelength part of the land water solutions before computing the river basin averaged water volume. We also compare water volume time series using global land surface model outputs. These series of tests allow us to quantify, at river basin-scale, water volume errors associated with spherical harmonics truncature, leakage effects, geoid data source, etc. The results are further analysed to place bounds on the contribution of land waters to sea level change over recent years.

Keywords: grace satellite gravity, global hydrology

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JGS002 **Oral Presentation** **125**

Looking for acceleration in the rate of global sea level change

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Measurements of global sea level change over the past decade using altimetry have found a rate of increase of 3.2 mm/yr which is significantly larger than the mean rate for the 20th Century, calculated from a sparse set of tide gauges (~1.8 mm/yr). This larger rate of increase over the past decade has led to suggestions that the rate of sea level rise may be accelerating. Here the decadal rates of global sea level change through the twentieth century, reconstructed from tide gauge records, are analysed to explore whether the last decade of sea level change is unusual. Twentieth century decadal rates of global sea level change from two reconstructions are compared with the rate from altimetry. Both the reconstruction of Holgate (2007) and Church and White (2006) are based on tide gauges but use different methodologies. It is found that while the rate of sea level change during the altimetry period is higher than average, it is not especially so, and it is not the highest rate of increase during the twentieth century. No evidence for an increase in the rate of sea level change during the century is identified.

Keywords: tide gauge, sea level, altimetry

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JGS002 **Oral Presentation** **126**

Comparing the sea level response to pressure and wind forcing of two barotropic models: validation with tide gauge and altimetry data

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Marta Marcos

The sea level outputs of two barotropic ocean models (MOG2D and HAMSOM) are intercompared and validated against tide gauge and TOPEX/Poseidon data. Nine years (1993-2001) of data are used in an area covering the Mediterranean Seaand the Iberian Atlantic coast. In average, both models provide better results than the classical inverted barometer correction (IB) in terms of reducing the sea level variance observed by tide gauge and altimetry. However, the skill of MOG2D and HAMSOM varies considerably with temporal scales and location. In coastal areas, the validation with tide gauge data has shown that the largest improvement is achieved using HAMSOM, where the variance reduction with respect IB is 19.3 % to be compared to with the 12 % obtained with MOG2D. This impact is larger for large long periods (> 20 days) where HAMSOM provides a correction of 24 % in contrast of about 0% given by MOG2D. On the contrary, MOG2D improves performs better than HAMSOM at high frequencies (< 20 days), with a capability of reducing tide gauge variance with respect IB of 22% in front of 19 % obtained with HAMSOM. In the open ocean, the application of both models to altimetry data has demonstrated that, in average, MOG2D and HAMSOM have very similar skills reducing the aliasing of high-frequency signals. Nevertheless, in the Atlantic Basin, MOG2D clearly provides better results than HAMSOM, and the opposite happens in the Eastern Mediterranean Sea. In conclusion, it is not possible to draw a single recommendation for the selection of one of the models. Instead, depending on the spatial domain and frequency of the spectra, HAMSOM or MOG2D models should be used. Results may have relevant implications in the analysis of sea level variations aiming at separating the steric, atmospheric and mass contributions

Keywords: satellite altimetry, tide gauge data, barotropic numerical models

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JGS002 **Oral Presentation** **127**

Hydrologic Contributions to Global Mean Sea Level Change

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D. P. Chambers, J. Famiglietti, E. Leuliette

Time series of variations in global mean sea level from TOPEX/Poseidon and Jason show a large amount of interannual variability, especially during ENSO events. Analysis of thermosteric sea level suggests that not all of the interannual variability is related to changes in the ocean heat storage, which implies that it may be explained by interannual variations in the exchange of freshwater mass with the continents. Unfortunately, observations of the hydrologic contributions to sea level change are sparse at best, and thus assessing the contributions to sea level change is difficult. Nevertheless, we have embarked on an effort to quantify these contributions using the available river gauge, precipitation, and evaporation data, as well as model output that incorporates these measurements. In addition, GRACE time variable gravity measurements provide a way to directly determine the hydrologic contributions to sea level change, but only over the last 4 years. We will review the results of our analysis of these datasets, but on the whole, they suggest that the exchange of freshwater between the continents and the oceans is a significant driver of interannual variability in global mean sea level.

Keywords: global, sea, level

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JGS002 **Oral Presentation** **128**

Towards more Accurate Estimates of the Thermosteric Sea Level Rise

Dr. Catia Domingues
IAPSO

John A. Church, Neij J. White, Susan E. Wijffels

Ocean thermal expansion is a significant component of global mean sea level rise. Estimates of thermal expansion (thermosteric sea level) are based on ocean temperature profiles collected since the 1950s using a variety of instruments with different technologies (eg., bottles, MBTs, XBTs, CTDs, profiling floats). Historically, more temperature observations have been collected in the Northern Hemisphere, and truly global coverage was only achieved very recently as part of the Argo program. As the number of temperature observations is larger in the upper ocean, most of the profiles are for the upper 300 db, with a much smaller number down to 700/750 db. Below these depth levels, temperature profiles are sparse. Studies are now reporting systematic biases in the ocean temperature measurements related to both changes in the technology and relative spatial coverage of the observing system. Spatial coverage is especially poor in the Southern Ocean. In this work, we attempt to address the above issues and minimise their impact on our estimates of thermal expansion. Our thermal expansion estimates are reconstructed for the 1970-2005 period and are based on a reduced space optimal interpolation scheme using quality-controlled temperature observations from the ENACT (EN3) dataset. By performing various reconstruction tests we will be able to examine the impact of the reported observational biases. We also investigate the potential of confidently extending the vertical integration of the estimates to depth levels greater than 700/750 db. Our aim is to provide greater accuracy and understanding of the thermal expansion contribution to sea level rise and climate change.

Keywords: thermal expansion, sea level rise, climate change

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JGS002 **Oral Presentation** **129**

Global Coastal Sea Level Change on Decadal and Century Timescales

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Simon Holgate, Svetlana Jevrejeva, Roland Gehrels

Several papers have been published recently which have made use of the global mean sea level data set (of the Permanent Service for Mean Sea Level) to study rates of global sea level change on decadal and longer timescales. tudies have indicated a high rate of rise in the 1990s broadly consistent with the rate observed from TOPEX/Poseidon/Jason altimetry, but similarly large decadal rates have been found in other parts of the historical record. On century timescales the data indicate almost no acceleration, or even a small deceleration, of sea level rise for the 20th century alone in most station records, but a small acceleration between the 19th and 20th centuries. This presentation will provide an overview of these recent findings and comment on the uncertainties and their various sources. It will also point to the methods (e.g. tide gauge data archaeology, archaeological surveys, salt marsh data acquisition) by which information on century-timescale change might be better understood.

Keywords: sea level changes

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JGS002 **Oral Presentation** **130**

Validation of the thermosteric sea level sensitivity of climate models based on observations

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In a recent paper, Rahmstorf (2007) used a semi-empirical approach to estimate future sea level rise. Given the large response time of the ocean with respect to changes in atmospheric conditions, it is assumed that the twenty-first century rate of sea level rise is proportional to the atmospheric temperature increase over its pre-industrial value. The constant of proportionality is determined from the twentieth century observations. This relationship is then used to estimate future sea level rise based on projections for the atmospheric temperature rise. The resulting estimate (50 to 140 cm) is much higher than the projections recently presented by the IPCC (Summary for Policy Makers, IPCC AR4, 2007). This raises the question whether the current generation of climate models is capable of correctly reproducing the observed sea level rise in response to atmospheric temperature changes, so that we can have confidence in the projections.Here, the semi-empirical relation between the rate of sea level rise and changes in atmospheric temperature based proposed by Rahmstorf (2007) on observations is validated for a suite of climate model simulations performed in preparation of the IPCC Fourth Assessment Report. To this end, the thermosteric sea level sensitivity (defined as the rate of global mean thermosteric sea level rise given a certain temperature rise) of the models is analyzed. The results are compared to estimates of the rate of thermosteric sea level rise derived from hydrographic data over the twentieth century. It is discussed that the rate of thermosteric sea level rise projected by climate models for the early twenty-first century is (well) below currently observed rates, with possible implications for the IPCC projections.

Keywords: sea level rise, observations, model simulations

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JGS002 **Oral Presentation** **131**

Assessment of the 20th Century Sea Level Rise

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Sea level rise has been widely recognized as a measurable signal as one of the consequences of the anthropogenic effect resulting from global climate change. The current and post-IPCC Third Assessment Report (TAR, 2001) determination of the 20th Century sea level rise is estimated to be around 1.7-1.8 mm/yr. While the observations could not be explained by plausible geophysical causes during TAR (2001) by ~40%, the assessment during the IPCC Fourth Assessment Report (FAR, 2007) effort implicates a much closer budget in that the geophysical explanations largely accounts for the observed sea level rise. However, the agreement could potentially be accidental due to largely unknown geophysical factors including anthropogenic water impoundment and potential hydrologic imbalance. This paper discusses contemporary results for the determination and explanation of the causes of the 20th century global sea level rise, using data and models including tide gauges (1900-2004), multiple satellite altimetry (1984-2005), hydrographic data (1948-2005), GRACE (2002-2006) and radar altimetry (1992-2004) observed mass changes of large ice sheets, and GIA models (radial and laterally heterogeneous), with an attempted assessment of the current sea level budget.

Keywords: sealevel, climatechange, satellitealtimetry

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JGS002 **Oral Presentation** **132**

A decade of tide gauge monitoring using continuous GPS and absolute gravimetry in the UK: new estimates of vertical land motion and sea-level change

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Over the last ten years a network of ten continuous GPS (CGPS) stations co-located with tide gauges of the UK Tide Gauge Network has been established in collaboration between the Institute of Engineering Surveying and Space Geodesy (IESSG) and the Proudman Oceanographic Laboratory (POL). Over the same period, POL has carried out absolute gravimetry (AG) measurements at nearly annual intervals at sites close to the tide gauges at Newlyn, Aberdeen and Lerwick.In contrast to North America or Fennoscandia, where the maximum vertical land movements (VLM) due to glacial isostatic adjustment is at the cm/yr level, the British Isles undergo motions of few mm/yr, placing tight constraints on any measurement techniques applied to reliably detect such small changes. Although, continuous GPS has been demonstrated as being a very useful tool for this purpose in North America or Fennoscandia, it remains a challenge to accurately determine the VLMs at the magnitudes expected for the British Isles, given the current limitations in the accuracies associated with the International Terrestrial Reference Frame (ITRF), the modelling of systematic biases in the processing of GPS measurements, and/or GPS processing strategies themselves. In this study we discuss present-day VLM of the British Isles inferred from recent results from AG and CGPS measurements and compare these with geological information and sea level records, and conclude that only a combination of these give a reliable picture of the VLM observed in the British Isles.

Keywords: absolute gravimetry, continuous gps, tide gauge

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JGS002 **Poster presentation** **133**

Estimation of the ocean tide effect on the altimetric measurements

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The oceanic tide is a periodic phenomenon of rise and fallen of the sea level. It is governed by the gravitational action of the solar system bodies essentially the moon and the sun, it translates by a transport of water masses. The evaluation of the oceanic tide is calculated using two global models GOT99.2 and FES99; the comparison of the results obtained with the ocean tide value transmitted in the message of Jason-1 and Topex/Poseidon satellites allowed us the validation of the methodological approach developed. The proximity of the results obtained is sufficient for the most altimetric applications as the determination of the mean sea level which was calculated on the western Mediterranean Sea during a 72 cycles period.

Keywords: estimation, ocean tide, sea level

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JGS002 **Poster presentation** **134**

Sea level trend in Gulf of Thailand and South China Sea

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Sea level change is an index of global change especially the global warming. Global sea level is rising at 2-3 mm/yr (IPCC,2001), but few studies have been conducted regarding local sea level change and there is virtually no systematic study in the Gulf of Thailand and South China Sea. The objective of this research is to determine the rate of sea level change in the Gulf of Thailand and South China Sea using annual average sea-level data from 12 tide gauge stations namely Ko Sichang, Sattahip, Ko Lak and Ko Mattaphon station from Thailand, Geting, Cendering, Tanjung Gelang, Palua Tioman and Tanjung Sedili station from Malaysia, Danang, Hondau and Quinhon station from Vietnam. The results shows no agreements among the rates determined from different stations. Analysis of data of Sattahip, Ko Mattapone, Ko Sichang, Hondau, Danang, Palua Tioman , Geting, Tanjung Gelang, Tanjung Sedili and Cendering station yield the rising rate of 0.22, 0.51, 0.81, 2.2, 2.5, 2.5, 2.6, 2.6, 2.9 and 2.9 mm/yr respectively whereas data from Ko Lak and Quinhon station gives a falling rate of 0.52 and 0.82 mm/yr respectively. The conflicted results indicate the need of further investigation of local factors before actual rate of sea level change in the Gulf of Thailand and South China Sea could be determined.

Keywords: sea level, tide guage, gulf of thailand

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JGS002 **Poster presentation** **135**

Surface Elevation Change of Ice Sheet from Crossover of ENVISAT Data

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Jiangcheng Li

The satellite radar altimeters are nadir-pointing active microwave sensors initially developed to operate over ocean surface and make precise measurements of the sea surface topography. Moreover, it has been used for many years to analyze the elevation, snow precipitation/accumulation, snow compaction, snow melting, and ice flow over the ice caps and the level changes over inland water bodies. Understanding the current state of the polar ice sheets is critical for determining their contribution to sea-level rise and predicting their response to climate change. Especially, the time series of surface elevations can be used to study ice sheet dynamics and the mass or volume balance of the ice sheets which are relevant to global climate change and sea level rise. Surface elevations over the ice sheets have traditionally been determined by pressure altimetry, geometrical leveling, and by combined airborne barometric altimetry and radar distance measurement. But these methods had a precision of typically several tens of meters at best and had only a limited coverage. Gains in accuracy by at least an order of magnitude have been accomplished during the last two decades from satellite radar altimetry and airborne laser altimetry. The widest coverage has come from satellites, especially from ENVISAT, which extends to 81.5 of latitude, covering almost all of Greenland and mostly Antarctica. In this paper, an algorithm for time series analysis based on crossover (Davis C.H et al., 2001) was used to obtain 4(2003-2006) years elevation changes from ENVISAT data. From the time series, the seasonal and annual signal could be clearly found. Moreover, many elevations profile and its anomalies along longitude direction could be obtained using the crossover results.

Keywords: satellite altimetry, ices heet, time series

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JGS002 **Poster presentation** **136**

Ocean loading tidal corrections of GPS stations in Antarctica

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This paper describes the ocean loading tides corrections of GPS stations in Antarctica, such as the Great Wall station, Zhongshan station. Based on the theory of ocean loading tides, the displacement corrections of ocean loading tides on GPS stations in Antarctica are calculated by using CRS4.0 ocean loading tides model. These corrections are also applied to GPS data processing. The GPS data are analyzed by the GAMIT software with and without these corrections. We compared and analyzed the GPS baseline components to get the differences. The results show that the ocean tidal displacement corrections have obvious effects upon GPS baseline components. The average effect is about 6mm. Therefore, we should not ignore the ocean loading tides corrections of GPS stations in Antarctica to obtain precise and reliable results.

Keywords: gps, ocean loading tides, correction

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JGS002 **Poster presentation** **137**

Beyond variations in mean: searching for trends in sea-level quantiles from global tide gauge records

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Maria Eduarda Silva

Tide gauge records constitute a precious repository of information on 20th century sea-level variability. The analysis of sea-level observations from tide gauges is often focused on the estimation of linear trends by ordinary least squares regression, yielding the rate of change in the mean of sea level. However, sea-level variability can include not only changes in the central tendency (mean) but also changes in the spread and shape of the sea-level distribution over time; the rate of change of upper (or lower) quantiles of sea-level can be very different from the rate for the corresponding mean. In this study, we address this issue by investigating the rates of change of sea-level at different parts of the distribution using quantile regression. A total of 177 tide gauge records (the same data set as in Holgate and Woodworth, 2004) are analysed. For each record, the ordinary least squares trend is computed, as well as the quantile regression trends for quantiles 0.1, 0.25, 0.5, 0.75 and 0.9 (corresponding, respectively, to lowest 10%, 25%, 50% 75% and 90% of the sorted observations). Furthermore, taking into account that sampling variation increases with the distance to the center of the distribution, a statistical test is used to assess whether the differences in the slopes for the different quantiles are statistically significant. For most tide gauge records the slope estimated by ordinary least squares is very similar to the slope for quantile 0.5, indicating that the distribution of sea level observations is approximately symmetric and that the ordinary least squares estimate is robust. However, slopes from upper and lower quantiles are distinct from the mean rate, with the rate of the upper quantile being, for some records, nearly twice the ordinary least squares rate for the mean.

Keywords: sea level, tide gauges, extremes

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JGS002 **Poster presentation** **138**

The work of the permanent service for mean sea level

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Since 1933, the Permanent Service for Mean Sea Level (PSMSL) has been the global data centre for the collection, publication, analysis and interpretation of monthly mean sea level data from a worldwide network of tide gauge. In 2008, we will be celebrating our 75th birthday. Based at the Proudman Oceanographic Laboratory (POL), the PSMSL is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) established by the International Council of Scientific Unions (ICSU). The mission of the PSMSL is to provide the community with a full service for the acquisition, analysis and interpretation of sea level data. Alongside its main focus as the global sea level data bank, the PSMSL provides advice to tide gauge operators and analysts. It plays a central role in the development of the Global Sea Level Observing System (GLOSS), including the provision of tide gauges to Africa under the auspices of the IOC (through the ODINAFRICA project). The PSMSL database contains more than 54000 station-years of monthly and annual mean values of sea level from over 2000 tide gauge stations around the world received from almost 200 national authorities. On average, approximately 1500 station-years of data are entered into the database each year. This data set is used in all analyses of recent regional and global sea level changes, including those which inform the Intergovernmental Panel on Climate Change.

Keywords: sea, level, databank

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JGS002 **Poster presentation** **139**

Mechanisms of the mean global sea level rise and solution of

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The mechanism of perturbed relative small displacements (and rotations) of the Earth shells (the core, the mantle etc.) under of a differential gravitational attraction of external celestial bodies is responsible for formation of qualitatively new oceanic and atmospheric tides caused by a gravitational attraction of a displaced core and deformable mantle (Barkin, 2005). These tides are characterized by a wide spectrum of frequencies and various style of displays in opposite hemispheres of the Earth (in particular in northern and southern). The mentioned mechanism has allowed to explain divergences between the theory and the observations which have been found out by Blewitt et al. (2001) at studying of a style of global seasonal deformation of the Earth. The annual polar oscillation of the outer core and accompanying deformations of the mantle give the significant contribution to value of the observable load moment and to observable annual oscillation of the Earth centre of mass. On the other hand the gravitational attraction of displaced core substantially determines (and organizes) redistribution of atmospheric and oceanic masses between northern and southern hemispheres, i.e. determines process and cyclicity of formation of load on the Earth surface. From here it follows, that any other oscillations of the core (with other frequencies and form) and its linear trend will determine also the related phenomena of redistribution of oceanic and atmospheric masses, loading planetary deformations of the mantle, and also the appropriate variations of sea level. Here we obtain some upper evaluations of mean sea level rise on the base of value of velocity of linear trend of the Earth centre of mass in 6.69 mm/yr (Tatevian et al., 2004). The component of this drift caused by the polar trend of the core and by corresponding deformation of the mantle characterizes slow redistribution of water masses from a southern hemisphere in northern which leads to increasing of mean sea level with small velocity 0.33 mm/yr. The velocity of secular increasing of load on the mantle has been evaluated approximately on the known value of amplitude of the appropriate load moment making annual oscillation (for atmospheric and oceanic masses). It results in inversion of radial deformations of the mantle (similar and proportional to the annual mode), but increasing linearly in the time with velocity 1.81 mm/yr on South Pole and decreasing with the same velocity on North Pole. On equator radial displacements are equal to zero. The mentioned displacements of the Earth surface determine deformations of the ocean bottom and finally result in rise of mean sea level with velocity about 0.18 mm/yr. One more component in slow change of mean sea level is caused by the trend of the centre of mass, due to linearly increasing oceanic and atmospheric masses in northern hemisphere. By our evaluations it makes 0.40 mm/yr. Thus, the total effect results in rising of mean sea level with velocity consists about 0.91 mm/yr, that gives some additional positive arguments to solution of "attribution problem" about the unknown (lost) mechanism of increasing of mean sea level (Miller, Douglas, 2004). References Barkin Yu.V. (2005) Oscillations of the Earth core, new oceanic tides and dynamical consequences. Materials of XI International Scientific Conference "Structure, geodynamics and mineral genetic processes in lithosphere" (September, 20-22 2005, Syktyvkar, Russia), Publisher of Geology Institute of Komi SC of Ural Section of RAS, Syktyvkar, pp. 26-28. In Russian. Blewitt G., Lavallee D., Clarke P., Nurutdinov K. (2001) New global mode of Earth deformation: seasonal cycle detected. Science, V. 294. pp. 2342-2345. Miller L. and Douglas B. C. (2004) Mass and volume contributions to twentieth-century global sea level rise. Nature, v. 428, 25 March 2004, pp. 406-409.

Keywords: meansealevel, attributionproblems, climate

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JGS002 **Poster presentation** **140**

To explanation of increasing of sea mean level in 20th century

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On the basis of geodynamic model of the forced swing and drift of the Earth core relatively to the elastic mantle (Barkin, 2001, 2002) the secular variations of surface of geoid and the corresponding slow changes of the ocean surface have been analyzed. The secular drift of the Earth core predicted by author along geocentric axis OP in direction to a geographical point 70.0 N, 104.3 E, leads to the directed slow redistribution of atmospheric, oceanic and others fluid masses (and to corresponding deformations of the elastic mantle) from the southern hemisphere to the northern hemisphere. OP is an axis of the specified hemispheres. In result all coefficients of geopotential test the certain secular changes which have been evaluated by us on a basis of simple model of two points with variable masses located at poles of inclined axis OP (Barkin, 2001). Masses of points vary with velocities 0.179x10 (15) kg/yr (point situated in Northern hemisphere) and 0.043x10 (15) kg /yr (point in Southern hemisphere) at respective change of masses of the top spherical layer. On our geodynamic model the secular drift of a geocenter is a reflection of the identical drift of the Earth core relatively to the elastic mantle along axis OP in northern direction. The gravitational influence of superfluous mass of the core by its displacements leads to formation of inversion atmospheric and oceanic tides. The asymmetric position of continents and inclined character of displacement of the core cause the complex redistribution of masses of the Earth and, accordingly, cause variations of all geopotential coefficients. As secular variations of a geopotential determine secular changes of a surface of ocean, as geoid's surface, so on the values of variations of geopotential coefficients we can determine coefficients of development of velocity of increasing of a ocean surface in series on spherical functions. In result, on the basis of offered point model of secular redistribution of masses the coefficients of the first and second harmonics of secular velocity of change of ocean surface have been determined (in mm/yr): A10 =-1.36 (-0.24 +/-0.52); A11=0.12 (0.12 +/-0.47); B11 =-0.48 (-0.42 +/-0.45); A20 =-1.95 (-1.92 +/-0.56); A21=0.19 (-0.01 +/0.30); B21 =-0.74 (-0.70 +/-0.30); A22=0.08 (0.08 +/-0.13); B22=0.07 (0.17 +/-0.14). For comparison the experimental values of coefficients obtained according to data of observations at tidal stations of all world approximately for hundred years are specified in brackets (Nakiboglu, Lambeck, 1991). Secular increasing of the mean sea level has made 1.15 +/-0.39 mm/yr. Formation of a relief surface of ocean according to the mentioned solution found above leads to additional increasing of the sea mean level with velocity about 0.23 mm/yr. Thus, velocity of change of the mean sea level according to observations at tidal stations and on variations of geopotential coefficients makes about 1.4 mm/yr. It is known that satellite observations (Topex-Poseidon data) show the more high values of velocity of increasing of mean sea level about 2.5 mm/yr (Cazenave et al., 2003). This discrepancy can be explained as result of the pure geometrical effect of satellite observations. In reality, the motion of satellites is connected dynamically with center of mass of the Earth. Therefore the drift of the centre of mass of the Earth in northern direction formally is reflected in reduction of distances from the satellite up to the ocean surface in southern hemisphere and to their increase in northern hemisphere. At averaging of measurements on the surface of all ocean there will be an effect of apparent additional increase of the mean sea level. By our estimation this effect makes about 0.69 mm/yr at velocity of the drift of the center of mass of the Earth 6.69 mm/yr. Therefore satellite velocity of increase of the mean sea level accepts the greater value of 2.2 mm/yr that is rather close to the data of observations. So on the data of altimetric observations of Topex-Poseidon satellites in 1990 the rising of the sea level with velocity 2.5 mm/yr was observed (Cazenave et al., 2003). The small divergence in the given values of velocity of increase of sea level can be explained by particularities of trajectory measurements. In this case thermal and climatic effects can not apply for a big component attributed to observed increasing of sea level. References Nakiboglu S.M. and Lambeck K. (1991) "Secular sea-level change". In: Glacial Isostasy, Sea-Level and Mantle Rheology (Eds. R. Sabadini et al.) Kluwer Academic Publishers. p. 237-258. Barkin, Yu.V. (2001) Explanation and prediction of the secular variations of the Earth rotation, geopotential, force of gravity and geocenter drift. Proceedings of International Conference "AstroKazan-2001". Astronomy and geodesy in new millennium (24-29 September 2001), Kazan State University: Publisher "DAS", pp. 73-79. Cheng M., Tapley B.D. Variations in the Earth's oblateness during the past 28 years. Journal of geophysical Research, V. 109, B09402 Cazenave A., Cabanes C., Dominh K., Gennero M.C., Le Provost C. (2003) Present-day sea level change: observations and causes. Space Science Reviews, V. 108, Issue 1, pp. 131-144.

Keywords: mean, sea, level

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JGS002 **Poster presentation** **141**

Residual Geoid and topography of Ninety East Ridge in Northeastern (above 5o N) Indian Ocean: Inference on the nature of Ridge crustal compensation

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The Ninetyeast Ridge is a major submerged aseismic (?) ridge extended roughly in north-south direction between 18o N and 34o S in the Bay of Bengal oceanic lithosphere. Earlier studies carried out mainly at the southern latitudes shows that the ridge system was formed between 82-38 My as an hotspot trail during the northward movement of the Indian plate over the Kerguelen hotspot. The crustal compensation mechanisms of major ridge systems are usually studied through the correlation of marine gravity and topography. But the marine geoid, being a potential surface, could effectively reflect the basement undulation signals stronger in sediment thick environment. In this study, we first discuss about the processing methodology for deriving marine geoid/gravity from the satellite altimeter derived instantaneous sea surface height (SSH) data. The SSH data obtained from the Exact Repeat Mission (ERM) paths of five satellites were processed and the residual geoid anomalies were obtained after removing the deeper earth effects through spherical harmonic analysis using EGM96 potential coefficients. Then we computed the residual geoid to topography ratio (GTR) over the northern (between 11o N to 17o N) and southern (5o to 11o N) portions of the ridge and obtained the apparent isostatic compensation depths. Analysis of the results obtained through geoid to topography ratio over the ridge system suggests that the ridge is in multiple state of isostatic compensation of Pratt type at its northern and southern latitudinal regions. At the northern region GTR varies from 0.63 0.05 to 0.44 0.03 while at southern region it ranges from 1.34 0.09 to 1.31 0.07. The apparent compensation depth decreases roughly from 28 km to 9 km from southern to the northern portion of the ridge. Finally we present the results obtained through the harmonic analysis of gravity anomaly over the ridge which also shows the role of upper mantle in determining the compensation depths beneath the ridge system.

Keywords: altimetry isostasy, ninetyeastridge marinegeoid, topography

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JGS002 **Poster presentation** **142**

New combination models of GNSS observations for precise oribt determination of LEOs with undifferenced geometric strategy

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At the present, with the technique of PPP(precise point positioning), decimeters to centimeters accuracy is achievable at the ground station. Considering the characteristics of the PPP, this technique can also be used in the LEOs orbit determination, but the accuracy and stability cant be guaranteed owing to the fast speed of the LEOs and the fast variability of ionosphere. But with the operation of the new generation Global Navigation Satellite Systems(GNSS), such as modernized GPS and Galieo, more obervations can be used to determine more accurate and reliable orbits. Firstly, the effects of positioning accuracy are analyzed in detail and it is concluded that the ratio of noise to wavelength of combined observation determines the ambiguity accuracy. Then, according to the analysis, three criteria are outlined to determine the best combinations: 1) The noise of combination should be smaller; 2) The ratio of noise to wavelength of combination should be smaller; 3) The ionoshpheric effects of combination should be smaller. With the above criteria, a group of new ionosphere-free combinations are found out. With these new models better accuracy and more stability of LEOs orbits is expected to achieve.

Keywords: gnss, orbit, determination

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JGS002 **Poster presentation** **143**

Regional characteristics of long-term sea level variations from sea level and sea surface temperature data

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TOPEX/POSEIDON and JASON-1 sea level observations over the most recent 12 years have qualitatively been used to study regional characteristics in sea level variations over this period. EOFs of annual anomalies have been derived using different periods of time and compared. Furthermore, spatial characteristics have been derived for sea level slopes computed over different time intervals. Finally, correlations between long-term changes in sea level and sea surface temperature have been analyzed to deduce the steric contribution to sea level change. Consistent increases in both sea level and sea surface temperatures are found in most parts of the Atlantic Ocean over this period. In the Indian Ocean and particularly the Pacific Ocean, the trends in both sea level and temperature are still dominated by the large changes associated with the large El Nin Southern Oscillation in 1997-1998.

Keywords: sealevelchanges, satellitedata

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JGS002 **Poster presentation** **144**

Attribution of global sea level variations from the ECMWF ocean reanalysis

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The question of attributing variations of global sea level to thermal expansion and/or mass increase over the oceans is addressed by using the information from the new ECMWF historical ocean reanalysis. By combining model first guess with subsurface data, the ocean re-analysis can yield a better estimate of changes in the dynamic height. By comparing the total trend in sea level given by the altimeter data with the trend in steric height given by the ocean analysis, it is possible to estimate the component of the trend due to mass variations. Results show that until 2002 the global trend in sea level was mainly due to thermal expansion. After 2002, the contribution to sea level due to mass increase starts being substantial. Observing system experiments have been conducted to test the sensitivity of the results to changes in the observing system.

Keywords: sea level, trends, attribution

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JGS002 **Poster presentation** **145**

JASON-1 absolute calibration results from the Eastern Mediterranean Gavdos project

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S. P. Mertikas

The Gavdos permanent absolute calibration facility, initially established with joint EU, NASA, and Swiss Federal Government funding in 2002, while fully operational at the moment, it is also being expanded to a regional absolute sea level monitoring and altimeter calibration facility applicable to many missions, in the Eastern Mediterranean. The main site is still at Karave, located under a crossing point of the Jason-1 ground-tracks (passes 018 and 109), and adjacent to an ENVISAT pass, on the isle of Gavdos, about 50 km to the south of the main island of Crete, Greece. The project is now continuing under the OSTM program with funding from NASA and the Greek government. The current plans include the relocation of the Gavdos Karave facility to the final and originally intended location, on a new pier (finally constructed!), a move that will improve vastly the protection of the facility from heavy winter storms and minimize the need for maintenance. The Karave GPS receiver operated continuously throughout the past years, the tide gauges however were placed in storage to avoid damage during the construction period, and they have been redeployed as of last fall. The facility now has off the wall electric power at all times, and it will be upgraded to include an ISDN line and a computer, so that we will be able to download all of the data, including GPS observations, on a hourly/daily basis. This is expected to happen in early 2007. We have already selected the location for the establishment of an identical setup at a site on the main island of Crete, at Kastelli, near the TUC site (60 km west of TUC), on a TUC-owned area and situated exactly under the descending Jason-1 pass 018. We have selected a radar gauge as well as a backup system of similar type for the new location. Once tested and calibrated, we plan to replace the Karave system with one of these since they are much less demanding in terms of maintenance, always a concern during the winter months. This gives us access to a second site and use of the altimeter measurements made to the north of Crete, in the Aegean Sea. It will thus allow the collection of additional information on the circulation and currents of the area between the Cape Maleas and Western Crete (e.g. Cretan cyclone). The project is now producing results on the basis of the new GDRs and extending our efforts to include the ENVISAT and GFO missions. We are also planning to repeat the co-location at the TUC facility site with the French Transportable Laser Ranging System (FTLRS) that established an initial link of the entire GAVDOS network of sites with the ITRF2000 frame, in order to update the link to the global TRF. This is contingent on FTLRS availability, which in turn is tied to its deployment in Australia and the launch of JASON-2.

Keywords: gavdos, sea level, altimeter calibration

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JGS002 **Poster presentation** **146**

Sea-level Rise in the Northeast Pacific from a Combined Tide Gauge, GPS, and Absolute Gravity Analysis

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Sea-level rise in the northeast Pacific is a significant source of hazard to the large coastal urban centers and infrastructures in the U.S. Pacific Northwest and western . Crustal uplift, and hence relative sea-level (RSL), are expected to vary considerably along the 2000 km-long coast as a result of changes in active tectonics and Holocene postglacial rebound. Thus, tide gauge data from this region have so far been rejected from most global analyses to avoid the effects of uncorrected vertical motions. In light of recent studies suggesting large spatial variations in the 20th Century rates of sea-level rise, this raises the issue of applicability of global mean eustatic estimates to the northeast Pacific region. To address this question, we analyze data from a subset of 14 nearby GPS and tide gauge sites. Data from Canadian and tide gauges are quality controlled to derive robust monthly RSL time series. In particular, we estimate linear trends and associated standard errors that account for the spatially and temporally correlated characteristics of the RSL data. Vertical velocities at the GPS sites are derived in the ITRF2000 reference frame. Alternative reference frames (e.g., IGb00, ITRF2005) are considered as part of the overall uncertainty in the absolute GPS vertical velocities. The combined tide gauge/GPS analyses indicate a 20th Century regional rate of sea-level rise of 1.5 to 2.0 mm/yr, in good agreement with global average eustatic estimates. As an alternative to the global GPS reference frame alignment, we use absolute gravity data at 4 collocated sites to provide an independent tie to the Earth center of mass reference. The joint tide gauge/GPS/absolute gravity analyses indicate a 20th Century regional rate of sea-level rise of -1.0 to 0.0 mm/yr, inconsistent with most global and regional estimates. These results point to a possible issue in using absolute gravity as a tie to the Earth center of mass reference in regions of active tectonics, such as the Cascadia subduction zone. However, the discrepancy between the GPS, absolute gravity, and tide gauge data is not yet resolved, indicating that more ground truth work is required to resolve regional uplift and sea-level rise in the northeast Pacific.

Keywords: tide gauge, gps, northeast pacific

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JGS002 **Poster presentation** **147**

Vertical motion control of tide gauges in the Atlantic as a part of the TIGA Project

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DGFI participates in the IGS TIGA Project operating continuously observing GPS stations at six tide gauges in the Atlantic and processing a network of about sixty GNSS sites in the same area as a TIGA Analysis Centre. The weekly processing of this network leads to a seven year time series starting in January 2000 for each station, and a multi year solution of epoch station coordinates with linear and periodic velocities. These results are analyzed together with the corresponding tide gauge registrations to confront mean sea level rise (or fall) derived from the historical tide gauge records with the vertical movement of the sites where these tide gauges are embedded. This analysis is complemented by including the sea surface variations obtained from satellite altimetry in the surrounding marine areas at the same sites. We validate the balance between GPS, tide gauge, and altimetry derived trends and conclude that the sea level trend derived from tide gauge registrations must be corrected (in space and time) by vertical crustal movements. The reliability of these corrections is guaranteed by the adequate combination of GNSS positioning, tide gauge registrations, and satellite altimetry data analysis. The results of this kind of studies are especially useful for monitoring the global sea level change and for the reliable unification of classical vertical datums.

Keywords: tiga project, global sea level change, vertical crustal movements

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JGS002 **Poster presentation** **148**

Seavar - sea level anomalies from combined satellite altimetry and GPS-corrected Tiga tide gauge data

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The SEAVAR project aims at the recovery of consistent time series of sea level change by combining satellite altimetry data - with its global coverage - and the longer time series available from tide gauge measurements. For a better separation of land movement signals from sea level change in the tide gauge data, GPS corrections are applied. Tide gauges are located on land and, therefore, subject to land movement induced by miscellaneous sources. Since almost all global coasts are affected by various geological processes, it is crucial that these processes be taken into account in order not to mistake tide gauge movements for actual sea level change. Making use of results of the IGS TIGA project, corrections for tide gauge measurements can be obtained by evaluating vertical land movement from co-located or nearly co-located GPS stations. Usually, only the Glacial Isostatic Adjustment (GIA) - accounting for the post-glacial rebound of land masses after melting of ice sheets - is applied to tide gauge measurements by use of global models. However, this signal is predominant only in the Fennoscandia and Canada region; and a determination of land movements based solely on GIA models dramatically underestimates the influence of local geological effects at individual stations. These effects (e.g., regional subsidence caused by groundwater extraction, or sudden disruptions from earthquakes) cannot be captured by models and must be determined separately for each tide gauge station. GPS site position series in a global reference frame make it possible to quantify these effects and establish a long-term height reference to obtain the 'true' sea level change signal from the formerly mixed signals in the tide gauge data. This paper features an Optimal Interpolation-based reconstruction of global sea level anomalies for the last 50 years from a combination of TOPEX/Poseidon satellite altimetry data with GPS-corrected tide gauge measurements. We present a selection of over 110 TIGA stations which provide high-quality GPS time series, and for which long-term local land movement trends have been calculated. All time series have been carefully corrected for spurious jumps arising from perturbing events such as, i.e., antenna changes. More than 50 of these stations, for which Revised Local Reference (RLR) data is available from the Permanent Service for Mean Sea Level (PSMSL), were included in the combined reconstruction. A comparison with GIA-only corrected tide gauge data is provided.

Keywords: sea level, tiga, gps

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JGS002 **Poster presentation** **149**

Changes in ocean heat content in the twentieth century: a comparison between climate model simulations and observations

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It is expected that changes in ocean heat content, and the resulting thermal expansion of the ocean, will be the major contributor to sea level rise over thetwenty-first century (IPCC AR4, Summary for Policymakers, 2007). It needs to be verified, though, that the climate models on which these projections are based are capable of reproducing the observed thermosteric sea level rise over the twentieth century, not only in terms of the global mean but also on a regional scale. In addition, there is much debate on the impacts of limited data coverage on the estimated changes in ocean heat content based on hydrographic data sets. It has been suggested that the contribution of the thermal expansion may be underestimated because of this limited spatial and depth coverage. Within this project, changes in ocean heat content over the second half of the twentieth century are calculated from a suite of state-of-the-art climate model simulations that were made available to the scientific community in preparation for the Fourth Assessment Report of the IPCC. The results are compared to estimates of the thermosteric sea level rise derived from hydrographic data over the same period. The analysis focuses not only on global mean values but also on separate ocean basins, both for changes in heat content over the upper ocean and over the full depth. The question whether limited data coverageresults in an underestimation of changes in ocean heat content from hydrographyis addressed based on these model simulations.

Keywords: heat content, model

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JGS002 **Poster presentation** **150**

Geocenter motions and geodynamic consequences due to dynamics of sea surface topography from TOPEX/POSEIDON altimetry 1993 2004

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The T/P altimeter data for twelve years 1993-2004, cycles 11 453 were used to compute the seasonal variations in the first degree Stokes geopotential coefficients$\delta J1(0)$, $\delta J1(1)$ and $\delta S1(1)$ and their annual and semi-annual parts. These variations represent the motions of Earth's mass center with respect to the mean ocean surface or vice versa. The solution has used 2381 054 T/P altimeter discrete points. The effect of the above first degree harmonics on the Earth-Moon-Sun force function was also estimated, as well as the resulting variations in the torque due to the ocean surface dynamics. The effect of seasonal variation, i.e. the annual and semi-annual terms, were estimated, and the remaining non-seasonal variations were also determined. The same procedure was also applied to the ocean temperature data. The contribution of the pure steric effect to the typical global mean sea level rise was determined and is also discussed.

Keywords: earthsinertiatensor, earthsmasscenter, tpaltimetry

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JGS002 **Poster presentation** **151**

GIA signatures on Holocene and present-day vertical movements along the coasts of Italy

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Solving the sea level equation for a spherically symmetric Maxwell Earth, we investigate the effects of the melting of remote Pleistocene ice sheets on past and present-day relative sea level variations and vertical movements of geoid and solid Earth along the Italian coasts. For a suite of plausible viscosity profiles we compare predictions of different global ice chronologies (ICE, ICE3G and ICE5G) that have been previously tested on different Mediterranean Holocene relative sea level sites. In particular, on the basis of the sensitivity of North African relative sea level curves to the Holocene melting of the Antarctic ice sheet, we study the effects of different assumptions regarding the time-history of this remote glacier. By considering the catastrophic melting of Antarctica at 8,000 years BP, as suggested by the rsl data from Djerba (Tunisia), we compare the effects of a sudden deglaciation to those ascribed to the smooth and linear melting phase considered in previous works. Finally we predict bounds on the GIA-related signal at Italian PSMSL tide-gauge stations and derive a revised mean value for the ongoing climate-related eustatic sea level rise in the Mediterranean.

Keywords: sea level, glacio hydro isostasy

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JGS002 **Poster presentation** **152**

Observations of the sea level in the geodynamics laboratory of Lanzarote (Canary Islands)

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Vlez Emilio, Venedikov Angel

The Laboratory of Geodynamics of Lanzarote (Canary Islands), it is a scientific installationdepending on the Institute of Astronomy and Geodesy of Spain.This Laboratory is consequence of a wide national and international collaboration and practically it extends for the whole surface of the Lanzarote Island. One of the three modules of permanent observation, the one located in the well-known area as Jameos del Agua to the north of the island, is specially dedicated to the continuous observation of the ocean level and the study of their possible variations. This laboratory, how we expose in this communication, is an exeptional place to observe the variations of the sea level. The multiparametric observations: sea level, meteorological parameters, gravity, earth tides, deformations, GPS etc.. began in the year 1988. Among the years 2004 and 2006, has been renewed most of those more than 25 sensors in operation, in the frame of an European project of the program INTERREG IIIB. Likewise, the systems of acquisition and transmission of data have been modernized and potent programs of analysis of the observations have been developed. In this section we point out the program VAV, of analysis of time series that we are using for the analysis of theoceanic, earthand atmospheric tides, registered in a continuous way in the Laboratory. In this communication we make a presentation of the laboratory and very especially of the part of the same related with the observation of the sea level.

Keywords: sea level, gps tidalgauges, canary islands

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JGS002 **Poster presentation** **153**

The role of altimeter data processing on global sea level studies

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Susana Barbosa

In spite of the relatively short altimetric records, satellite altimetry has been playing a major role in the study of sea level variation, both in terms of the spatial and temporal trend. Since the absolute value of sea level anomalies is relatively small it is affected by many factors such as instrument drifts, geophysical corrections and satellite ephemeris.This study focuses on the impact of the major geophysical corrections and orbit field on the spatial pattern of sea level trend and on the structure of the interannual signals and derived sea level trend of global altimetric series. Global data for the whole TOPEX/Poseidon (T/P) mission have been analysed. The effects of using the most recent GRACE orbits and state-of-the-art models for the sea state bias (SSB), inverse barometer (IB), radiometer wet tropospheric (Wet_cor) corrections and satellite ephemeris have been analysed.Results show that all the studied geophysical corrections have an effect on the interannual signal and on the linear trends derived from the TOPEX global time series. Clear geographically correlated spatial patterns of sea level trend can be identified when using different SSB models or different orbit fields. The meaning of these patterns is investigated. Also, IB-corrected time series and non IB-corrected ones reveal significantly different regional patterns of sea level trend, although it is difficult to ascertain causes to these results.

Keywords: sea level change, geophysical corrections, satellite orbit

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JGS002 **Poster presentation** **154**

Improvement of satellite altimetry data sets in the coastal regions

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In the coastal regions the altimeter data are degraded due to the following main reasons: the altimeter measurement itself is degraded due to land contamination; the wet tropospheric correction computed from the on board Microwave Radiometer (MWR) measurements becomes invalid due to the large footprint of the instrument; the global ocean tide models do not properly account for local tide effects. In addition, other geophysical corrections might have local effects such as the inverse barometer (IB) and the sea state bias (SSB). Solutions for overcoming some of these problems are presented. Data sets of the major present and past altimeter missions are analysed and algorithms for improving data accuracy and spatial coverage near the coast are implemented. This study focuses on two main aspects: the improvement of the range recovery both by retracking and by using the high frequency data (10-20Hz) present on the Geophysical Data Records (GDR); on the correction of the path delay due to the wet troposphere by a global implementation of the so-called dynamically linked method to the ECMWF model correction. Results are cross-validated and, whenever possible, compared to independent data such as tide gauges.

Keywords: coastal altimetry, wet tropospheric corretion, range recovery

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JGS002 **Poster presentation** **155**

New tide gauge technologies at Lestartit for monitoring sea level and altimeter calibration campaigns

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LEstartit tide gauge is a classical floating tide gauge set up in lEstartit harbour (NE Spain) in 1990. Data are taken in graphics registers from which each two hours the mean value is recorded in an electronic support. L'Estartit tide gauge serie provides good quality information about the changes in the sea heights at centimer level, that is the magnitude of the common tides in the Mediterranean. The data from l'Estartit has been used to compute the Mean Sea Surface MSS using GPS buoys along an ascending track of TOPEX/Poseidon (July 2000) and JASON-1 (August 2002). In the framework of a Spanish Space Project, the instrumentation of sea level measurements has been improved by providing this site with a radar tide gauge and with a continuous GPS station nearby. This will have a significant incidence in the satellite altimeter calibration activities as in the past campaigns on 1999, 2000 and 2002. The main objective will be the estimation from the time series ofsea level change in the area. The radar tide gauge is a Datamar 3000C, with 26 GHz frequency, 1 mm resolution, 8 beam with incorporating a GPS receiver for automatic clock synchronization and a Thales Navigation Internet-Enabled GPS Continuous Geodetic Reference Station (iCGRS) with a choke ring antenna. It is intended that the overall system will constitute a CGPS Station of the TIGA (GPS Tide Gauge Benchmark Monitoring) networks. It is the main scientific objective of the cGPS installation.

Keywords: tidegauge, gps, altimetry

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JGS002 **Poster presentation** **156**

Determination of sea-level change and vertical crustal motion in the Canadian Arctic from GPS and tide gauges

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Donald L. Forbes, Joseph A. Henton, Mieczyslaw Piraszewski

Projections of relative sea-level rise and the resulting risks of flooding and coastal erosion require a good understanding of sea-level change and vertical crustal motion. Consequently, beginning in 2001 a network of several continuous GPS stations co-located with tide gauges has been established in the Canadian Arctic with the aim of directly measuring changes in sea level and vertical crustal motion. The tide-gauge data provide measurements of relative sea level with respect to the crust upon which the tide gauge is anchored while the GPS data enable us to determine the absolute vertical velocity of the crust with respect to a global reference frame. Combining the two allows us to determine absolute changes in Arctic sea level with respect to the global frame. Several factors affect our ability to obtain reliable estimates from these measurements, including monumentation, various kinds of noise and systematic biases, equipment type and changes, and (most importantly) the length of the time series. We discuss each of these factors in relation to our experiences from the past several years. Although based only on three to five years of data, we provide some preliminary results of crustal motion and sea-level change and compare these to estimates reported by others, including geological and model results. We also make use of older tide-gauge data extending over the last few decades and estimate the level of accuracy we might expect with longer time series.

Keywords: sea level, gps, tide gauges

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JGS002 **Poster presentation** **157**

Evaluating the Brazilian Vertical Reference System and Frame through Improved Coastal Satellite Altimetry Data

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The benchmarks (BMs) of the Brazilian Fundamental Vertical Network (BFVN) have heights which are referred to the Brazilian Vertical Datum at Imbituba (BVD-I), defined by the mean sea level (MSL) established with tide gauge data collected from 1949 to 1957 at Imbituba Harbour in southern Brazil. Several tide gauges were tied to BFVN since the beginning of its establishment in 1945, but the comparison of each local MSL to BVD-I is very problematic, mainly because of two main sources of errors. On one hand, BFVN's heights are computed without gravity measurements only normal-orthometric corrections are applied. On the other hand, the sea surface topography (SSTop) has very distinctive behaviour at each location along the coast, depending on local water temperature, prevailing winds, geostrophic effects, types of equipments etc. Nowadaysstudies are under development towards theimprovement of Brazilian heights. The integration of satellite altimetry data, multiple tide gauges referencesand BFVN is one of the ways for an independent validation of such an improvement. Satellite altimetry gives highly precise information on SSTop over a great part of the oceans. However, SSTop is characterized by strong differences at deep, open sea and at coastal or shallow waters. Besides the natural phenomenon by itself, the processing strategies also show degraded performance at coastal areas e.g. the standard waveform used for selecting or discarding the returning radar pulses, or the global tide models used for reduction of altimeter observations. Thus, SSTop derived from satellite altimetry missions must be suitably propagated, or extrapolated, along the satellite tracks towards the coastal tide gauges. This extrapolation must consider the specific hydrodynamical processes present at such regions. In addition, to take advantage of the diverse temporal and spatial sampling characteristics of each altimetry mission (T/P+Jason-1, ERS-2+Envisat etc), they should be harmonized through a process including a regional multi-mission cross-over analysis. The evaluation/validation of the studies on BFVN could be achieved through the connection of the reference levels from tide gauge and satellite altimetry data, allowing the SSTop correction at some selected tide gauges along the Brazilian coast. This is performed through the integration of multiple satellite altimetry missions, local/regional hydrodynamical models when available , tide gauge data, and leveling+gravity+GPS information. Initial procedures including extrapolation of altimetry results towards the coast are tested at the Salvador site of the Permanent Geodetic Tide Gauge Network, RMPG. Besides having the narrowest shelf, its sea level observations show almost no meteorological effects, both contributing to an optimal performance of the residual tide analysis (RTA), an essential step when working with satellite altimetry data in shallow waters.

Keywords: sea surface topography, residual tide analysis, vertical reference

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JGS002 **Poster presentation** **158**

HYDROWEB : an on-line database from space altimetry for lake and river levels

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HYDROWEB is an on-line database of water level time series for major rivers, lakes and floodplains. These time series are based on altimetry data from Topex/Poseidon, ERS1, ERS2, ENVISAT, GFO and JASON1. Data from altimetry are available from 1993 up to 2006. Presently, the database includes 150 lakes and reservoirs and 160 virtual stations over major rivers. These data demonstrate variabilities due to climatic and anthropic factors and could participate to water management activities. Data from the gravimetry mission GRACE will be soon included in HYDROWEB. These data are time series of water quantities over about 20 large rivers basins.

Keywords: altimetry, lakes rivers, database

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JGS002 **Poster presentation** **159**

A Fast Improvement of Sea Level Change Monitoring in Indonesia Archipelago after the Indian Ocean Tsunami 26 December 2004

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The ongoing program to improve the Indonesia Tide Gauge Network into a real time data transmission, as part of the establishment of Indonesia Tsunami Early Warning System (InaTEWS) capable of detecting tsunami generated both in Indian Ocean and Indonesia internal sea waters, this will greatly contribute to a better quality and spatially distributed long term sea level change detection in the Indonesia Archipelago. The program has to be completed by end of 2008 and the network will consists of 120 stations, originally 60 stations before the event, of which 80 digital stations will be equipped with a real time satellite based data communication, 25 digital stations with weekly data downloading via GSM-GPRS communication and the remaining are analog stations. Datum stability of sea level measurement should always be one of the main concerned in quality checking of a long term mean sea level time series. We improve the stability by the following standard i.e. i) each station will be equipped with a strong fiberglass tide staff with accurately graduated numerals and the surface is coated with a special enamel porcelain, protecting from rust and decolonization. This is expected will last over many years under normal condition, ii) regular high precision leveling measurements forming a small close loop network from the tide staff to bench mark with minimum four witness points, and iii) there are 10 stations will be equipped with GPS time and auto switch level for minimizing time and height drifts, respectively, iv) installing continuous GPS stations at more than 10 tide gauge and the remaining will be measured periodically. In this paper, a wavelet analysis of monthly mean sea level data time series showing a clear indication of sea level change from 10 sampling stations of the network will be included.

Keywords: real time, tide, guage

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JGS003 **160 - 233**

Symposium
Earthquake and Volcano Geodesy

Convener : Dr. Jeff Freymueller

Large earthquakes produce significant static and dynamic displacements that can be measured easily by modern space geodesy. The largest earthquakes, such as the 2004 Sumatra-Andaman Islands earthquake or the much older but even larger 1964 Great Alaska earthquake and 1960 Chile earthquake, may produce dynamic and static displacements detectable around the entire globe. A particular area of newly-recognized importance is the intermediate range between the seismic frequency band and the static displacements, for example the role of slow slip and early postseismic transients. High-rate GPS provides a new tool to investigate such phenomena. While volcanic eruptions and intrusions cause deformation that is more localized than for the largest earthquakes, displacements can be substantial and geodesy can provide critical information about the movement and accumulation of magma in the subsurface. Volcanoes display remarkable dynamism and variation in displacements, with a rich array of geodetically observable signals at a wide range of timescales. This session will cover topics ranging from the use of geodetic data to study earthquake and volcanic sources and related effects such as postseismic deformation, to the impact of earthquakes or volcanic unrest on geodetic observables such as gravity, displacements, and the terrestrial reference frame.

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JGS003 **Oral Presentation** **160**

Determining 3D displacement due to QESHM 2005 earthquake using satellite radar interferometry

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Behzad Vosooghi, Maryam Dehghani

An earthquake with the magnitute of 5.6 occurred in west of Qeshm in November 27th , 2005. Qeshm is an Island located in the Persian Gulf in south of Iran. Interferometric SAR was applied in order to calculate the surface deformation due to the earthquake. However, the earth surface deformation can be achieved along the Line_Of_Site (LOS) direction. Therefore multiple interferograms with different geometries were used to obtain the deformation in three dimensions. The north component is difficult to determine because the satellites have near-polar orbits. In this paper it was tried to resolve the north component by computing azimuth offsets for both pair of images. This measurement produces displacement field in range and azimuth direction that can be converted into displacement in north and east directions. The deformation field was then analysis to find more about this earthquake behavior in the area.

Keywords: insar, interferogram, azimuthoffset

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JGS003 **Oral Presentation** **161**

Seismicity and Crustal Deformation along Indo Myanmar Region

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Sunil Lashram

The present paper deals with seismic and crustal deformation studies are carried in Indo Myanmar Ranges (IMR), which displays recent and active slip beside the seismicity in region. It displays an active and recent slip of India along western margin of Indo china. The IMR tectonic province represents a typical arc setting extending from East Himalayan Syntaxis in the north to Andaman Sea in the south. The Indo Myanmar plate boundary is believed to be locked up for the centuries. The seismicity is concentrated along the eastern flank of IMR, Sagang Fault and along northern Shan Platue, suggesting that the motion is accommodated on localized structures rather than distributed by seismic sources in strike slip deformation. The depth distribution of seismicity possibly coincides with partial melting of subducting slab. The occurrence of active volcanoes in the southern part of the IMR in Indian Ocean after the 26 December 2004 mega earthquake and mega tsunami of Indian Ocean also provides the evidence of volcanic activity along this arc. The crustal deformation studies based on the GPS campaigns (1996-2000 and 2004-06) indicate that the deformation along the Indian plate in this region is approximately 3.0-4.6 cm/yr and the Sagang fault accommodates 2.0-2.3 cm/yr in a right lateral strike slip motion. The comparison of crustal velocities from Sundaland and India plate with respect to IMR and Sagang fault indicates that the slip is being accommodated by strike slip motion is approximately 10 mm/yr along the west of the Sagang fault. The localized deformation is entirely due to stress resulting from India collision with Eurasia. Therefore, IMR are believed to be locked up for the centuries this may trigger an earthquake of approximately 8.5(??) in the future.

Keywords: seismicity, crustaldeformation, indomyanmarregion

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JGS003 **Oral Presentation** **162**

Spatiospectral localization of global geopotential fields from GRACE reveals the coseismic gravity change due to the 2004 Sumatra-Andaman earthquake

Prof. Frederik Simons

Shin-Chan Han

Regional mass fluxes due to transport and adjustment within the Earth system that are implicitly contained in the monthly GRACE global geopotential coefficients are revealed by localizing global spectra using spatiospectrally concentrated window functions. The data provided to the science community by the GRACE team consist of time series of spherical harmonic coefficients and their noise estimates. Extracting high-quality, uncontaminated, space-dependent signals from such data proves to be a real challenge, as by definition, spherical harmonics are non-localized basis functions. A new method of spatiospectral localization, recently developed by Wieczorek, Simons and Dahlen, is the ideal candidate to address this problem. In our approach, a bandlimited basis of spatially localized spherical functions is constructed by optimizing a spatio-spectral concentration criterion, in the sense of Slepian. Among the unique features of this method are that the shape of the region of interest may be completely arbitrary; that the solution is optimal and maximizes an energy concentration criterion; and that a whole family of functions is obtained from which estimates may be formed with desirable statistical qualities. We have analyzed 45 monthly global GRACE harmonic coefficient series in order to find the coseismic signature associated with the 2004 great Sumatra-Andaman earthquake. A significant gravity change after the earthquake is found in the time-series of the GRACE coefficients after localization with the best concentrated band-limited window centered near the north of the island of Sumatra. This change is undetectable from the original global coefficients or from coefficients localized elsewhere on the globe. A step function with its discontinuity at 26 December 2004 usefully models the coseismic gravity change. The localized GRACE coefficients contain the jumps (associated with the earthquake) up to degree and order 55, although not all of them within this band produce changes that are statistically significant. The gravity change calculated from the localized GRACE coefficients displays 30 Gal peak-to-peak variations which are very well correlated with an independently derived seismic model based on elastic dislocation theory.

Keywords: earthquakes, gravity, localization

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JGS003 **Oral Presentation** **163**

Postseismic deformation following the 2005 Kashmir earthquake as observed by GPS measurements

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C D Reddy

The October 8, 2005 Kashmir earthquake in Indus Kohistan Seismic Zone (IKSZ) (M = 7.4, depth = 20 km, Seismic Moment = 1x 1020 Nm, Epicenter = 34.43 N, 73.53 E (120 km WNW of Srinagar, on Hazara- Kashmir Syntaxis), Origin time = 3:50:38.63 (UTC)) is a major seismic event in the Himalayan region. The earthquake occurred along a tectonic boundary, which is characterized by high seismic activity. Understanding of the earthquake process requires detailed insights into how the tectonic stresses are accumulated and released on seismogenic faults. In terms of crustal deformation, the loading cycle is divided into four phases viz. pre-seismic, co-seismic, post-seismic, and inter-seismic. Particularly the Analysis of post-seismic deformation provides information on rheological and constitutional properties of the lower crust and upper mantle. There are many possible mechanisms of postseismic deformation. Three of the most accepted are: afterslip, viscoelastic relaxation, and poroelastic relaxation. GPS studies have been initiated for studying the post-seismic deformation. Three continuous GPS sties have been set up at Gulmarg, Amritsar and Jaipur. Following the Kashmir earthquake, about 16 months of GPS data starting from October 2005 have been analyzed from three sites. Significant near field post-seismic deformation observed in EW, NS and UD components from GPS time series. Logarithmic function fits well to post-seismic time series and agree with characteristics of after-slip. This paper describes the characteristics of post-seismic crustal deformation and its mechanism following the Kashmir earthquake.

Keywords: gps, postseismicdeformation, after slip

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JGS003 **Oral Presentation** **164**

Blind and surface earthquakes ruptures deduced from INSAR in Algeria and Morocco: insights for the active deformation along the plate boundary in North Africa

Prof. Mustapha Meghraoui
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We study recent earthquakes along the plate boundary in North Africa using InSAR. The selected large to moderate earthquakes of Mascara (18 August 1994, Mw 5.8), Ain Temouchent (22 December 1999, Mw 5.7), Zemmouri (21 May 2003, Mw 6.8) and Al Hoceima (26 May 1994, Mw 6.0; 24 February 2004, Mw 6.5) belong to a narrow strip, parallel to the plate boundary, in the Tell Atlas and Rif Mountain ranges. The surface deformation of earthquakes mapped by InSAR, and related rupture at depth obtained from elastic models of dislocation, are consistent with late Quaternary tectonic investigations. We constructed numerous interferograms using Radarsat, Envisat and ERS SAR data acquired both in the ascending and descending passes of the satellites with SRTM digital elevation model for the removal of the topographic contribution. Interferograms of the coastal 2003 Zemmouri earthquake and related offshore fault rupture display high gradient of fringes near the shoreline. We invert the coseismic slip on a more realistic curving surface constructed from triangular elements (using Poly3Dinv) and a damped least square minimization. The obtained slip distribution is similar to that on rectangular fault surface (Okada), but the fault locates 5 to 10 km from the coast, dips about 45 SE with a smooth change in strike north of Boumerdes from N45E to N70W in the SW fault section. The same procedure is applied to the Al Hoceima earthquakes area where conjugate blind ruptures induce a complex pattern of surface deformation. Although the possibility of obtaining fringes associated with moderate magnitudes (Mw<6) is low, the selection of image pairs and the fold-related faulting allowed us to obtain interferograms with up to 4 fringes across the epicentral region of the Ain Temouchent earthquake. In the absence of surface faulting InSAR results contribute significantly to the identification and characterisation of seismogenic faulting.

Keywords: insar, faulting, earthquakes

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JGS003 **Oral Presentation** **165**

Afterslip of the Sumatra-Andaman Earthquake Detected by Continuous GPS Observations and Their Tectonic Implications

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The 2004 Sumatra-Andaman earthquake is the first M9 event after the implementation of the global continuous GPS observation networks. Many groups have been conducting researches using data from IGS and other networks established in the surrounding regions. I would like to discuss afterslip distributions and their tectonic implications on the basis of some representative studies. Analyzing these data with data from IGS and other continuous networks, we have obtained postseismic displacements following the 2004 Sumatra-Andaman earthquake. We used continuous GPS data from 6 sites operated by Chulalongkorn Univ. and Kyoto Univ. or JAMSTEC, 2 sites by Shizuoka Univ. and JAMSTEC, 3 sites by NICT in and , 1 site by STE-Lab, Nagoya Univ. and IGS and other continuous networks in East Asia and countries surrounding the Indian Ocean. An about 25cm SW-ward motion was detected at Phuket, southern Thailand, since right after the mainshock, which is as large as the coseismic displacement there (Figure 1). Bangkok also experienced about 9cm SW-ward displacement, which is somewhat larger than its coseismic displacement. In 2006, displacements at sites in were rotated clockwise and became more westward. There is a possibility that heavy rain in northern in summer of 2005 may have affected coordinate solutions. It is noteworthy that Yangong in and Padang in Sumatra do not show any significant postseismic displacements, although they are much closer than sites in Indochina peninsula such as Chiangmai. It is also interesting that transient displacement can be recognized at Padang after the March 28, 2005, Nias earthquake, though its coseismic displacement was not detected. We adopted the Yabuki and Matsuuras(1992) method for the inversion of observed postseismic displacements to reveal temporal and spatial afterslip distribution on the plate interface. Afterslip beneath the Andaman Islands seems to have continued till 2006, while that in the Nias region quickly decayed. Total moment released by afterslip is estimated to 1.581022Nm (Mw8.73). Coseismic slip on the plate interface is the largest SW off Sumatra and rapid decay of afterslip is obtained in its vicinity. These results suggest that lateral variation in frictional properties on the plate interface along the trench may exist. On the other hand, distance between the trench and the pivot line along which is the boundary between coseismic uplift and subsidence is almost constant (Suito et al., 2005). Therefore strain/stress must have large spatial variation along the strike before the mainshock and we must pay more attention to the cause of ~30m slip. These speculations may result in importance of hard asperities on plate interfaces for possible M9 earthquakes along subduction zones.

Keywords: gps, afterslip, sumatra earthquake

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JGS003 **Oral Presentation** **166**

Looking rise and fall of magma through a volcano by decoding gravity record

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Mt Asama, an andesitic volcano in central Japan, erupted on Sept. 1, 2004. Three major eruptions during the following month produced ~120,000 tons of volcanic ejecta, including volcanic ash that fell as far as 150 km from the volcano in central Tokyo. A week after the first eruption, we started continuous absolute gravity measurement to an accuracy of better than 0.3 microgal. Significantly, a correlation is evident between variation in recorded gravity and volcanic activity. That is, all the three major eruptions occurred within a few days after local gravity reached maxima, i.e., during the gravity decreasing phase. This relationship strongly suggests that continuous gravity monitoring may enable the prediction of volcanic eruption. Eruption during the gravity decreasing phase, however, was not anticipated by ourselves because gravity decrease often occurs when magma starts retreating deep within the earth. This apparent paradox is easily resolved by considering a rising and falling magma column within the conduit. Notice that the recorded gravity maxima occurs when the magma head is of equal elevation to the observation station on the volcano flank. The gravity readings change dramatically once the elevation of the magma head exceeded that of the observation point. Increased magma elevation above the observation point results in greater upward attraction at the observation point. This effect acts to counter the Earths regular downward gravitational force, resulting in a decrease in measured gravity. The surface gravity is therefore minimized when the magma head reaches the top of the conduit. Given that the radius of the conduit is much smaller than the horizontal distance between the conduit and observation point, the attraction of the magma is most easily computed using a line mass model with geophysically reasonable parameters. In other words, we can quantitatively estimate the magma head height by applying an inversion technique to the gravity data. We confirmed that the estimates on the head height are consistent with both seismological and volcanic gas observations.

Keywords: absolute gravity, eruption, magma head

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JGS003 **Oral Presentation** **167**

New insights of the magma system under the Hekla volcano in Iceland, reveled by strain and other deformation data

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Hekla is one of the most frequently erupting volcanoes in Iceland, with at least 18 eruptions in the past 1000 years. During the last 40 years it has erupted about every 10 years. Hekla shows very few long-term precursors to eruptions; optical tilt, GPS and InSAR gives indications of upcoming eruptions. The short-time precursors, spanning less than 80 minutes before the eruption, are seismic unrest and strain changes. The most recent eruption occurred on February 26 - March 8, 2000. A 6.6 km long eruptive fissure opened along Hekla summit. The network of volumetric six strainmeters spans an azimuthal range of 180 degrees around Hekla at distance 45-50 km and one station (BUR) located 11 km from the summit perpendicular to the strike of the eruptive fissure. BUR initially experienced a large rapid negative excursion due to growth of a feeder dike. Data from other strainmeters, show expansion allowing monitoring of the pressure change in the magma chamber as the eruption progresses. As the feeder dike grows it uses material from an inferred magma chamber. This reduces the pressure from the magma chamber at 10 km deep that can be monitored by the distant stations, which are less affected by the dike itself. Diking associated with the 2000 eruption of Hekla appears to be limited to very shallow depth, suggesting that the dike is completely within the topographic edifice of Hekla (about 1.5 km height). The horizontal displacements measured by GPS between 1993-2000 consist of the pre-eruptive, the co-eruptive and the plate spreading signals. However, the co-eruptive signal dominates the closest GPS sites; these data also demand a very shallow dike. A time series of ground tilt at a station 11 km west of Helkas summit indicates magma pressure of the same scale as prior to the two most recent eruptions. Strain changes during dike formation immediately prior to the eruption allow estimates of reservoir bulk modulus and hence of gas phase content.

Keywords: hekla, strain, tilt

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JGS003 **Oral Presentation** **168**

Precursors to Great Earthquakes along the Nankai Trough; Slow Earthquakes, Non-volcanic Deep Tremor and Slow Slip

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Just before (and during) the December 1944 Tonankai great earthquake, the Military Survey Institute of Japan carried out leveling surveys in the anticipated region of the earthquake. Mogi (1985) pointed out that large closure errors, for line segments measured on the day before and the morning of the earthquake, could be indicative of continuing tilting due to precursory slip. Before the 1946 Nankaido great earthquake there were level changes recorded by tide gauges and also large changes in water levels in wells. We have shown (Linde and Sacks 2002) that the pre-earthquake changes for both events are indicative of slow slip on the down-dip extension of the seismogenic zone, a region that can store strain energy but fails with slow slip. The coseismic slip for both earthquakes averages about 4 meters; the down-dip slow slip was determined to be about half the seismogenic value. In his most recent studies of the same area, Obara (2006) reports that small (~cm) slow slip events and non-volcanic tremor occur on the upper surface of the subducting plate. The locations for these events correspond rather closely to the areas we proposed as having slow slip precursory to the great earthquakes. Additionally the slip rate from Obaras work would result in about 2 meters being released in 100 years, the approximate return interval for the great earthquakes. This is consistent with the deficit being released as a large slow event just before those great earthquakes.

Keywords: slow earthquakes, grea earthquakes, precursory slip

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JGS003 **Oral Presentation** **169**

GPS-derived deformation from two years continuous and campaign observation in Sumatra

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The existence of pre-event GPS data along the west coast of Aceh, provided a relatively dense coverage close to the rupture zone. Since February 2005 we reobserved this GPS network. We also constructed more than ten new GPS pillars and one continue GPS station. Three different deformation processes have been considered for modeling the measured displacements (1) coseismic strain release during the 2004 Sumatra earthquake, (2) postseismic deformation of the 2004 earthquake and (3) slip along the Sumatra Fault Zone (SFZ). With time series generated from CGPS sites as well as dense campaign-mode repeat measurements from very close to the ruptures, we attempt to separate the effects. The result of campaign-style GPS measurements gives a first order indication of heterogeneities in slip distribution of the coseismic displacement. The latitudinal variation of geodetic displacement shows two distinct regions, region 1 around 4- 4.5 and region 2 around 4.5 5.5. Significant afterslip appears to have occurred updip of the ruptured around west coast of Aceh.

Keywords: sumatra, 2004 earthquake, dense gps

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JGS003 **Oral Presentation** **170**

Slow slip events and interseismic coupling on the Hikurangi subduction zone, New Zealand

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The Hikurangi subduction zone accommodates underthrusting of the Pacific Plate beneath the North Island, New Zealand. Modelling of campaign GPS velocities there indicates that large portions of the subduction thrust are coupled during the interseismic period, suggesting that large subduction thrust earthquakes are possible at this margin. The down-dip limit of the seismogenic zone beneath the southern North Island is deeper (~35-50 km deep) compared to the northern and central North Island (where interseismic coupling terminates at ~10-15 km depth). Increased use of continuous GPS data in since 2002 has led to the observation of several slow slip events on the Hikurangi subduction zone. In all cases, these slow slip events occur near the down-dip transition from interseismic coupling to aseismic creep, supporting our interpretation of the campaign GPS data. We observe a rich variety of slow slip events in New Zealand,with widely varying durations, depths, magnitudes and recurrence intervals. Thus far in the North Island, we have observed that deeper slow slip events (25-60 km depth) have longer durations (~1-2 years), and longer recurrence intervals, while shallower slow slip events (~10-15 km) occur more rapidly (within weeks), and recur more frequently. In a few locations where the configuration of the seismogenic zone inferred from campaign GPS is less certain, slow slip events can be used to refine our knowledge of the down-dip termination of interseismic coupling. In particular, we will show results from the most recent slow slip event observed in the Hawkes Bay region (June/August 2006), and discuss implications of this event for delineating the down-dip termination of the seismogenic zone beneath the central Hikurangi margin.

Keywords: gps, tectonics, crustal deformation

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InSAR measurements of subsidence and eruption model for the mud volcano in Sidoarjo, East Java

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On 29 May 2006, a mixture of mud, steam, gas and water started to erupt at a gas exploration site in East Java, Indonesia. More than 0.012 cubic kilometers of mud had been erupted as of November 2006, and the activity is still ongoing. There have been 13 fatalities, and more than 11,000 people are being evacuated. Therefore there is a social importance to understand the current state of the activity and to forecast the future evolution of the eruption. A synthetic aperture radar (SAR), named PALSAR, equipped on the Japanese ALOS satellite launched in January 2006, has captured several images at the eruption site. We have performed SAR interferometric analyses using four images acquired between 19 May 2006 and 4 January 2007. All the computed interferograms indicate ellipsoidal fringes in an area of 4 km (north-south) x 3 km (east-west), centered at the eruptive vent. The signals in the area closest to the eruptive vent (spatial extention of about 1.5 km) cannot be obtained because of the erupted mud. The interferogram of 19 May - 4 October 2006 shows 7 cycles of phase change, indicating that displacements of at least 80 cm away from the satellite occurred in the first four months. The displacement amplitudes in the following 46 days, as indicated by the interferogram of 4 October - 11 November 2006, are found to be approximately the same amount as those observed during the first four months. This is consistent with the increase in the observed eruption rate. The interferograms computed using the image of 4 January 2007 exhibit a loss of coherency in the area of interest, which perhaps indicate that the increase of the subsidence rate is persistent. In the modeling, we first assumed a horizontal planar ellipsoidal crack whose longer axis lies in the north-south direction. Inverting for the location, lengths of the longer and shorter axes, and overpressure of the source found a model having its center close to the vent, its longer and shorter axes are 2.5 km and 1.5 km, respectively, and its depth at 0.36 km The sum of the squared residuals was 7 percent of that of the observed data. Next, we assumed an oblate spheroid having its shortest axis in the vertical direction. This assumption predicted a model having its smallest depth about 0.1 km and greatest depth 1 km. The sum of the squared residuals was 5 percent of that of the observed data. Geologic analyses of the mud and information from the drilling suggest that some of the material is coming from depths of 1 to 3 km. On the other hand, our analysis indicates that the deformation source lies at several hundred meters beneath the ground. Our results are consistent with Davies et al. (2007, GSA Today, 17, 4-9) who conclude from their consideration based mainly on geologic data that fluid coming from depth entrains mud at a shallower depth. Our boundary element models, however, predict that the subsurface volume decrease is of the same order as the erupted mud volume. This suggests that the possibility of a caldera collapse, proposed by Davies et al. (2007), is low.

Keywords: mud volcano, sar interferometry, java

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JGS003 **Oral Presentation** **172**

Clues on the recent unrest episode of the Campi Flegrei Caldera (italy) from ground deformation data

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Luca Crescentini, Alan Trevor Linde, Ivor Selwyn Sacks, Roberto Scarpa, Pierdomenico Romano

Modeling of deformation measurements before and during eruptions is a powerful tool to study active volcanoes. Source depth, of critical importance for understanding volcanic processes, is often the least well constrained.The Campi Flegrei caldera (Southern Italy) is a volcano-tectonic depression, bounded on the east by Vesuvius and on the west by the volcanic islands of Ischia and Procida. It is a highly populated area (about 400000 people) located 15 km west of Naples inside the Campanian Plain.Since the last eruption (Monte Nuovo, 1538 A.D.) the Campi Flegrei caldera has suffered notable unrest episodes, including large ground deformation, seismic swarms and increases in degassing activity.The caldera had been continously subsiding (at about 1 cm per year), from 1538 till 1970. A substantial ground uplift, more than 1 m, occurred in the period 1970-1972 and, after a small subsidence of about 30 cm after 1972, a very strong uplift (about 2 m) occurred in the period 1982-1984 having a nearly symmetrical pattern. Starting from the beginning of 1985, a still continuing subsidence began, superimposed by some short uplift phases, the last one being presently going on.Leveling and strain data are available for all recent events. CGPS data are available since year 2000.Here we use all horizontal and vertical components of the GPS data as well as the strain and leveling data. The modeling is done with a layered crust and various source shapes are considered. We achieve a robust estimate of the source position and depth, as well as a suggestion of the reservoir oblateness.

Keywords: ground deformation, inflation sources, layering

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Inversion of deformation and gravity data in a layered medium with an application to the Campi Flegrei caldera (Italy)

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We have developed a C-code for the inversion of deformation and gravity data in a layered medium, with respect to various point and finite sources (approximated by a suitable discrete distribution of point sources). Source parameter values are optimized using Adaptive Simulated Annealing (Ingber 1993) or Neighbourhood Algorithm (Sambridge 1999). Parameter uncertainties are estimated using bootstrapping and NAB (Sambridge 1999). Forward modelling (generation of expected measurement values given a set of model parameters) is performed by means of a set of Green's functions, generated using PSGRN (Wang et al. 2006) for what relates to massless expanding sources and double-couple sources and GRAVW4 (Fernandez et al., 1997) for what relates to point mass intrusions. The code has been validated inverting several synthetic datasets with noise. As a first application, we model deformation and gravity data collected at Campi Flegrei caldera (Italy) during the 1980-1984 inflation, assuming that the source is a finite spheroid embedded in a layered half space. Sensitivity of results on layering details is assessed. Interesting differences with respect to published results, always obtained in homogeneous media, will be shown.

Keywords: geodetic data inversion, crustal layering, campi flegrei

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JGS003 **Oral Presentation** **174**

Absolute gravity surveys in Chile: a contribution to earthquake and volcano geodesy

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High precision gravity measurements in active tectonic or volcanic areas are likely to provide complementary information to geodetic studies on crustal deformation processes and their possible associated mass or density changes. The continental margin of Chile belongs to the most active subduction zones where such processes can be studied. As crustal deformation processes are also well documented by previous geodetic studies based on GPS or InSAR data, this area represents a suitable natural laboratory for investigating gravity changes of geodynamic origin.Since 2002, we carried out several field surveys in north and central with the aim to set up co-located networks of absolute gravity and GPS/CGPS stations. The main objective is to better constrain the static displacements (vertical motions for instance) and gravity changes along the Andean subduction margin associated with the earthquake cycle. A second objective is to contribute to the determination of reference gravity/geodetic base stations in South America for other scientific purposes (monitoring of local volcanic deformations, gravity calibration lines, geodesy, etc.). Our absolute gravity measurements are acquired with the laboratory micro-g FG5 meter when the highest accuracy is required and with the new micro-g A10 portable meter that is used for network densification. A total number of 15 FG5 and 60 A10 absolute gravity stations have been established in north and centralduring 3 field surveys spanned between 2002 and 2006.The data acquired on this network allowed us first to estimate the inner accuracy of the Chilean absolute gravity network and to evaluate the consistency of gravity (FG5, A10) and GPS measurements. The FG5 observations carried out in 2002 and 2005 also provided the first evidence of local gravity changes associated with the co-seismic displacement for the June 13, 2005 Tarapaca subduction earthquake (Mw 7,7). Those observations are consistent with the predicted values computed from an elastic dislocation model and with other geodetic measurements (CGPS, INSAR data) also available for this event. We present here the results of these absolute gravity experiments and discuss their implications for the study of earthquake and volcanic processes along the south-American plate margin

Keywords: temporal gravity change, crustal deformation, andes

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Integration of SAR and geodetic techniques for the analisys of volcanic deformations Crespi Mattia, Calcagni laura, Luzietti Lucia DITS Area di Geodesia e Geomatica, Sapienza Universit di Roma, v. Eudossiana, 18 - 00184 Roma

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This work is focused on the study about the absidence phenomenon of the Colli Albani volcanic complex (Roma District, Central Italy), in the frame of a INGV project to understand the phenomenon and to define a hazard level. A deformation study, to obtain a detailed modelling of the phenomenon, is normally realized through the analysis of different geodetic measurements, in this case SAR and high precision levelling. The problem to face is to search a procedure able to integrate data obtained from different techniques generally relative to different points no placed on a regular grid. Two different statistic are chosen to overcome these problems: the collocation, a statistic theory well known in Geodesy to estimate the geoid and the kriging. If SAR data are interpreted like a stochastic signal known in a particular set of points, with collocation theory its possible to obtain the signal in different points (prediction) and to eliminate measurement error (filtration). In this way, beginning from SAR velocities its possible to predict displacements velocity on levelling benchmarks, so to do a comparison between the two different techniques. To apply this method its necessary to know the covariance function of starting data (SAR data); since this function it wasnt known, its built in two different steps, it was computed an empiric estimate of covariance function, which was interpolated by an appropriate covariance functions model. The empiric model of covariance function was estimated on the basis of the characteristics of the phenomenon: because from previous surveys it was detected that the absidenceof Colli Albani area was characterized by a simmetry respect a central area with more consistent displacements, its used an empiric covariance function in which its underlined a radial and an angular dependence. The kriging theory is a different approach to deal with the problem, with this method its possible to obtain an estimation of the deformation using the observation, unlike the collocation, in addition to detection of measurements error its also possible to filter other any biases, due, for example to residual errors from elaboration. As well as in collocation theory its necessary to know data correlation to perform prediction and filtering, in this case its necessary to compute the variogram relevant to SAR data, that define their spatial correlation.The obtained results show that both collocation theory and kriging are effective methods to integrate different types of data, but its important to underline that these methodologies are influenced in significant way by the modelling of the phenomenon under investigation, so its essential to known as deep as possible its characteristics in order to carry out a suited covariance/variogram model.

Keywords: deformation integration sar

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JGS003 **Poster presentation** **176**

Extraction of 2D Deformation Field Caused by 2005 Qeshm Earthquake By SAR interferometry

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An earthquake with the magnitude of 5.6 occurred at 10:22:19 (UTC) on Sunday, November 27, 2005 in west of Qeshm. Qeshm is an Island located in the Persian Gulf in south of Iran . The field observations represented a great amount of deformation after the earthquake. In order to calculate the surface deformation due to the earthquake interferometry SAR method was applied. Interferometry SAR technology is a method mostly used to achieve the amount of surface displacement caused by earthquake, landslide and subsidence. However, the earth surface deformation can be obtained along the Line_Of_Site (LOS) direction using interferometry. In order to calculate the deformation in three dimensions, multiple interferograms with different geometries are used. The north component is difficult to determine because the satellites have near-polar orbits. In this paper it was tried to resolve the 2D surface deformation. The two-dimensional displacement field on the earths surface associated with the earthquake was calculated by combining satellite radar interferometry images from two different look directions. The available data sets used in this study are four ENVISAT images acquired in descending as well as ascending mode with the temporal baseline of one month.

Keywords: insar deformationfield los

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CO-Seismic Deformation of the 2006 Jogyakarta earthquake

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The 27 May 2006 earthquake hit the provinces of Yogyakarta and Central Java of Indonesia at 5:54 a.m. local time, with its epicenter estimated around 25 km south-southwest of the Indonesian city of Yogyakarta and 17.1 km below the seabed. The USGS-estimated magnitude of first earthquake is Mw 6.3. Subsequently, about 750 aftershocks have been reported, with the largest intensity recorded at Mw 5.2. The 2006 Jogyakarta earthquake occurred along the active Opak fault, which runs about NE from Parang Tritis area to Bantul area then continue northward to Klaten region. A week after the earthquake, 1.e. 4 to 8 June 2006, GPS surveys were conducted on 48 GPS points belonging to the 2nd order GPS network around Jogyakarta and Central Java. GPS surveys were conducted using 14 geodetic-type dual-frequency GPS receivers. GPS data processing is done using Bernesse 4.2 software. GPS results show that horizontal coseismic displacement around Bantul and Jogyakarta are mostly less then 10 cm, with mostly south and south-west directions. Derived GPS displacements and the depths of aftershocks indicated the existence of left-lateral fault with dip-angle of about 50 degrees. GPS displacements and location of aftershocks also indicate that this fault is located in the east of Opak fault indicated in the geology map. The surface expressions of the rupture are generally not represented by clear principal shear zones, but are revealed by complex assemblages of rupture webs. The observed fault offset is 28 cm, measured from a tectonically sheared bridge construction in Segoroyoso Village, Pleret.

Keywords: jogyakarta, earthquake, co seismic

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JGS003 **Poster presentation** **178**

On the termination of the 2000 Tokai slow earthquake observed by GPS measurements

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Based on continuous GPS observations, the velocity of surface deformation due to slow earthquake in the Tokai area continuing since mid-2000 has terminated after the South Coast of Honshu (SCH) earthquake in September 2004 in the local reference frame. The recent horizontal crustal movement after the 2004 SCH earthquake appears to return to same as the secular motion observed before the beginning of the slow event. The uplift observed during the slow event period has terminated before the beginning of 2006 in the area. Looking at the overall deformation pattern in the Tokai region within global reference frame, there are changes in three periods: before the beginning of the slow event, during the slow event, and after the 2004 SCH earthquake.

Keywords: slow earthquake, tokai area, gps measurements

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JGS003 **Poster presentation** **179**

The focal mechanism solutions and earthquake activities of

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The Sichuan-Yunnan Block is located on the southeaster fringe of Qinghai-Tibet plateau. The geotectonic deformation and earthquake activity are very strong in the place where is the most active region of strong earthquakes with high intensity and frequency. The strong earthquake activity distributes along the border fault zone of the Sichuan-Yunnan active block. The huge fault zones, such as the north-west fault, the north-east fault and the north-south fault are developed. The Sichuan-Yunnan region and its adjacent areas are divided into several blocks. This is north Sichuan block, west Sichuan block, mid Sichuan block, mid Yunnan block, southwest Yunnan block. The digital waveform data from Chengdu and Kunming telemetric seismic networks (2000~2005) are collected and systematically processed, which serve as the basis for this study. The seismic data were selected from the earthquakes with clear first motion directions, which took place in several blocks. The biggest amplitudes of P and S waves and clear first motion directions are marked on the seismograms. We obtained focal mechanism solutions of small earthquakes by inversion of waveform data from the regional seismic networks, using a point-source dislocation model in the layered medium. We use the quick calculation method of the generalized transmission coefficients and the theoretic seismic figures to fit the maximum amplitude ratio of direct waves. Based on P- and S-wave amplitudes and some clear initial P-wave motion data, we calculated focal mechanism solutions of 928 M 2.5 earthquakes (1994~2005) in 4 sub-blocks of Sichuan and Yunnan Provinces, namely Sichuan-Qinghai, Yajiang, Central Sichuan and Central Yunnan blocks. Combining these calculation results with those of the focal mechanism solutions of moderately strong earthquakes, we analyzed the stress field characteristics and dislocation types of seismogenic faults that are distributed in the 4 sub-blocks. The orientation of principal compressive stress for each block is: EW in Sichuan-Qinghai, ESE or SE in Yajiang, Central Sichuan and Central Yunnan blocks. Based on a great deal of focal mechanism data, we designed a program and calculated the directions of the principal stress tensors, 1, 2 and 3, for the 4 blocks. Meanwhile, we estimated the difference (also referred to as consistency parameter) between the force axis direction of focal mechanism solution and the direction of the mean stress tensor of each block. Then we further analyzed the variation of versus time and the dislocation types of seismogenic faults. Through determination of focal mechanism solutions for each block, we present information on the variation in value and dislocation types of seismogenic faults.

Keywords: focal mechanism solution, stress field, consistency parameter

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Coseismic displacements and slip distribution inferred from gps geodetic observations for the 1 April 2006 Peinan, Southeastern Taiwan, earthquake

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We have set up 52 campaign-mode stations combined with 6 continuously recording GPS stations (CORS) in an area of 15x15 km2 which located in southeastern Taiwan since 2001, complemented with the precise leveling to detect the near fault deformations. On the 1st April 2006 occurred a moderate (ML 6.35) shallow earthquake, near Peinan township, Taitung, and the epicenter is located at 22.88N 121.08E (CWB earthquake report, 2006). This event provides a good opportunity to study the detail geological structures of the Longitudinal Valley Fault (LVF) near the Taitung area. According to the GPS and precise leveling results, the displacements show three different deformation types, which are with about 35 mm westward and 30 mm subsidence in the southernmost part of the Coastal Range, with about 45 mm southward and 20 mm uplift in the east margin of the Central Range, and about 10 mm northward and 15 mm uplift near the Luyeh area on the west side of the Coastal Range. This unique coseismic deformation pattern can be used to realize the collision characteristics of the suture zone between the Philippine Sea plate and Eurasian plate at the southernmost Longitudinal Valley.

Keywords: cors, coseismic deformation, dislocation model

Simulation of crustal velocity field of Chuandian by spherical numerical manifold method and GPS data

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Results from geophysical and geological data are in terms of hundred years and millions years respectively. They can not provide continuous current crustal movement field. The coverage of GPS stations is not enough compared with the big area of plate and block. For the observation networks are mainly set up to monitor earthquake and tectonic activity, GPS stations are mostly deployed along faults. So the distribution of GPS stations is not as even as desired. In order to map the velocity field and stress field of crustal movement, numerical tools are used to simulate the movement and deformation of the district without geodetic data and geophysical observation. Among the simulation tools Finite Element Method, which is based on the idea of dividing a complicated domain into small and manageable pieces, has been used in many fields. It can deal with continuous deformation very well. Discontinuous Deformation Analysis is capable of dealing with discontinuity, but it requires that all blocks be totally separated by faults. In this paper Numerical Manifold Method is proposed to simulate crustal deformation. Here, the most important work is developing spherical Numerical Manifold Method from plane Numerical Manifold Method. A set of formulae is deduced in order that large scale crustal movement could be properly simulated with this method. GPS station velocities relative to Euroasia plate in Chuandian district are derived from twice observations of Crustal Movement Observation Network of China and NUVEL1A model. The main faults framework is established according to Chuandians geological materials. The fields of velocity, maximum and minimum stress change and maximum shear stress change of whole Chuandian district are simulated with spherical numerical manifold method. Finally result analysis is fully made.

Keywords: crustal deformation, velocity field, simulation

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Geodetic constraint on slip distribution of three megathrust earthquakes along the Kuril trench, northern Japan

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Geological evidence, historical documents, and modern geophysical observation manifests couple of large earthquakes repeated along the Kuril (Chishima) trench southeast off Hokkaido, Japan. The Kuril trench is known as one of the most active region of large earthquakes where the Pacific plate is subducting beneath Hokkaido with 8 cm/yr. Recurrence interval of M~8 megathrust earthquakes is 50 100 years and their segmentation along the trench such as Tokachi-oki and Nemuro-oki is proposed by Utsu(1972). In Tokachi-oki segment, the 1952 M8.1 and 2003 M8.0 Tokachi-Oki earthquakes occurred. In Nemuro-oki segment, the 1894 M~8.0 and 1973 M7.4 Nemuro-Oki earthquakes may be the largest earthquakes. Although the 1952 and 2003 earthquakes have very similar aftershock distribution and seismic intensity in Hokkaido, their tsunamis are different on the southeastern coast of Hokkaido (Hirata et al., 2003). Because modern geodetic measurements started in Hokkaido at the end of 19th century, geodetic data can resolve how different slip distribution of these earthquakes are. In this study, I collected the geodetic data including triangulation, trilateration, leveling, and GPS data to estimate coseismic slip distribution of the 1952, 1973, and 2003 earthquakes. Triangulation and leveling started in Hokkaido in 1890s were used to measure horizontal and vertical positions of benchmarks, respectively. The first measurements near the source region of the 1952 Tokachi-oki earthquake were conducted in 1902-1913. The measurements after the 1952 event were conducted in 1952- 1967. The trilateration conducted in 1982-84 substituted for triangulation to measure horizontal positions of benchmarks after the 1973 Nemuro-oki earthquake. The permanent GPS (GEONET) observation started in 1994. The coseismic and postseismic displacement of the 2003 earthquake is precisely measured by continuous GPS. However, the geodetic measurements before the continuous GPS are not often so that the difference between preseismic and postseismic measurements include not only the coseismic deformation of the 1952 and 1973 earthquakes but also its postseismic deformation, interseismic deformation, deformation associated with other earthquakes. Assuming the GPS site velocity during 1999-2003 is average of interseismic one, I removed the interseismic deformation from observed data. In addition to triangulation, trilateration, leveling and GPS data, I used data of tide gauge and local distance measurements to detect coseismic deformation. The observed deformation is assumed to attribute to slip on the subducting Pacific plate along the Kuril trench. The geometry of the plate boundary is approximated by dozens of rectangular faults. The rake of slip is fixed to the direction opposite to the relative plate motion(N65W) and slip amount on each rectangular fault is a parameter to estimate. In the inversion, constraint on the smoothness of the slip distribution and non-negative of slip amount is applied. The 1952 and 2003 Tokachi-oki earthquakes are estimated to have similar slip distribution (Fig. 1a and 1c). The location of the slip peak (e.g. asperity) is almost identical. Although large slip (~8m) east of the Kushiro submarine canyon near the trench was estimated by the tsunami study of the 1952 event (Hirata et al., 2003), geodetic inversion shows only 1-2m of slip near the coast. Although the resolving power of the geodetic data is poor near the trench, they do not accept large slip such as 8 m. The coseismic slip of the 2003 earthquake is limited west of the submarine canyon and the postseismic one expanded into the eastern region of the canyon. The estimated moment magnitude of the 2003 events (Mw8.1) is little larger than that of the 1952 event (Mw8.0). The postseismic slip is attribute of the afterslip and slip of 2004 Kushiro-oki doublets (M6.9 and 7.1). The result suggests that the 2003 events are the recurrence of the 1952 earthquake. The slip region of the 1973 Nemuro-oki

earthquake does not reach the submarine canyon. It implies that the large slip areas (e.g. asperities) of the Tokachi-oki and Nemuro-oki earthquakes are separated and that afterslip fills their gap.

Keywords: gps, leveling, subduction

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Relatiuonship between local and regional deformation study

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Currently in many tectonicaly active regions of the Earth have been developed the permanent GPS networks with the distances between points of the order 100-500 kilometers. These networks provide the study of the general problems of regional geodynamics, however, because of large distances between points, have a little information for solving of the tasks, where the local deformation features are required. Amongst them we shall select the problems, connected with deformation forerunners of the earthquakes, study of the contact zones adjacent tectonic plates, detailed study of specific areas large faults, where the strong earthquakes are often occurred, seismic real-time zoning and etc. On economic considerations it is difficult to expect that in the near future the development on large areas local permanent GPS networks with distances between sites 5 25 km. for solving the above mentioned problems will be made. This consideration give justification for searching of analytical description of the relationship between regional and local deformations to convert the first to second ones. The empirical formula was received on the base of the data on GPS regional networks of tectonically active region of the Caucasus, Pamiro-Tyanshan, Alpine regions of West Europe. For local deformation were used the data gathered by the laser geodimeters on the Caucasus, Kamchatka, Pamir and California regions. The comparison of real observed and analytically calculated deformations allow us to make the conclusion about typical size of blocks in tectonically active regions under study: dominating sizes of blocks are 10-20 km, that well complies with the block size derived using seismic data. It is worse to mention that though the main data on deformation is gathered for collision zones, the size of areas with extension and compression approximately equal. The empirical formula were used also for analysis of the deformation processes in regional network GPS permanent stations, assymmetricaly covered epicentral area of Izmit earthquake in Turky (M 7.6 17.08.1999). Observed regional deformation, because of larger distances between points [300-1500 km,] have an order 1 10-8-5 10-9 and does not characterized at all the deformation condition during the last stages of the earthquake preparing. Where as the calculated local deformation for this region have the values ~ 2 10-5 that correspond match better to usually observed deformation before the seismic events with magnitude 7.5-7.8 on the Richter scale.

Keywords: earthquake, deformation, gps

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Effect of Subducting Plate on Postseismic Deformation in a Viscoelastic Self-gravitating Spherical Earth

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Postseismic crustal deformation and gravity change associated with great earthquakes have been detected with advanced space geodetic techniques such as GPS and GRACE. Viscoelastic relaxation is the dominant mechanism of postseismic deformation on decadal time scales. Several theories of global postseismic deformation of spherical Earth have been proposed so far to deal with the far-field deformation considering self-gravitation in a consistent way (Piersanti et al., 1995; Pollitz, 1997; Wang, 1999; Pollitz, 2003; Tanaka et al., 2006). In these models, however, lateral heterogeneity in viscosity due to a subducting plate and time variation in the gravity have not been considered, simultaneously. Therefore, for interpreting GPS and GRACE data, it is worth constructing a viscoelastic model that incorporates these two effects at the same time. In this study, we apply a spectral finite element method (Martinec, 2000), which was originally developed for surface loading of a self-gravitating spherical Earth, to the dislocation one. This method allows to consider much larger deviations in the viscosity profile in magnitude than those in perturbation methods, which makes it suitable for simulating relaxation process in presence of a subducting elastic plate. We employ 2-D (i.e. rotationally symmetric) viscoelastic structure with ring sources allocated along latitude lines. This corresponds to an infinitely long fault in a half-space model, which can be applied to deformations caused by the Sumatra-Andaman and the Chile events whose fault lengths reach approximately 1,000 km. We prescribe the boundary conditions at the source in form of double couple forces equivalent to a considered dislocation. To validate this formulation, we compare the computed results with those by Tanaka et al. (2006) for a special case of 1-D (i.e. spherically symmetric) viscoelastic structure. Good agreements are obtained for the fault mechanisms of strike-slip, vertical dip-slip and dip-slip with dip angle of 45 degrees. Using this method, we calculate the viscoelastic relaxation in the following two cases: (I) spherically symmetric viscosity structure with an elastic lithosphere of thickness 40 km and (II) a subducting plate with dip angle of 20 degrees and width of 100 km. The result for a ring source with an infinitesimal width at depth 30 km shows that by the presence of the subducting plate the vertical displacement rate is increased by 30 to 80 % and the horizontal displacement rate is decreased by 50 % in the epicentral distance from one to two degrees at the continental side. The spatial pattern of this increase in the vertical displacement is consistent with the known feature for a flat-Earth model (Suito and Hirahara, 1999).

Keywords: postseismic, deformation, viscoelasticity

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Strain analysis of Eastern Turkey with GPS data obtained from geodetic GPS campaigns

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Eastern NAFZ is one of the most tectonically active regions in Turkey. Yedisu segment of the North Anatolian Fault (NAF) has not been broken entirely since the 1784 earthquake. After the 1992 Erzincan and 2003 Pulumur Earthquakes, the coulomb stress loading on the Yedisu segment of the NAF has been increased significantly and the region needs to be monitored. Seismic hazard and risk for the cities around these regions are extremely high. Determination of strain accumulation is the essential part of seismic hazard analysis. One of the major data types of estimating strain rates is geodetic velocities. Importantly, the spatial and time scale of geodetic data availability affects making reliable estimates of earthquake occurence rates. Geodetic data used in this study were obtained from the GPS campaigns at the Eastern part of Turkey performed by Bogazici University Kandilli Observatory and Earthquake Research Institute between the years of 2003 and 2006. Geodetic observations were realized in three times in an area of 350x200 km square with 12-month intervals. 14 new GPS stations were constructed far from elastic and plastic deformation areas. Additionally, 2 of TUTGA (Turkish National Fundamental GPS Network) points exist in the region were used in the study. The aim of the study is to model the present-day deformation field by means of a continuous strain rate field based on GPS velocity observations.

Keywords: nafz, gps, strain

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A Large Scale Deformation Monitoring Study with Network Design Strategies on an Active Fault at Western Anatolia-Izmir

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Aegean Region, which comprises the Hellenic Arc, Greek mainland and the western Turkey, is a seismically active region because of the convergence of Eurasian and African lithospheric plates, which forces a westward motion on the Anatolian plate relative to the Eurasia. Western Anatolia with its remarkable deforming structure has always draw scientists' interest because of its complex geologic features. Unfortunately, geodynamic studies performed in this region are insufficient or small scaled. Izmir the biggest metropolitan city of the western Anatolia with a 2.5 million population covered by several active faults, and has a great risk about big earthquakes. This project aims to perform a large scale investigation on Tuzla Fault-Izmir and its vicinity. A geodetic network design, optimization, and observations are being performed on Izmir Bay-Tuzla Fault, which forms the lineament trending NESW between Menderes Town and Doganbey Cape, in order to contribute new and detailed information to the region tectonics. This study is also a combination of space techniques and conventional geodetic techniques (i.e. GPS and precise levelling). The observation time, monument structure, processing alternatives, and the evaluation of results are introduced in terms of optimization strategies. Therefore a detailed geodetic deformation schedule tried to be documented including network optimization and design stages.

Keywords: geodetic network design, deformation monitoring, western anatolia

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Structural deformation determinations for strong motions

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The North Anatolian Fault (NAF) is one of the active faults that cross over Turkey. 17 August İzmit and 12 November Dzce earthquakes are caused by the rapture of the NAF fault. These earthquakes gave serious damage to the engineering structures like the viaduct located in Bolu, the north center of Turkey, where the NAF cross the motorway line. The Bolu viaduct is a part of the Transport European Motorway (TEM) that connects İstanbul to Ankara. Especially the earthquake occurred in 12th November caused the piers of the Bolu viaduct to move as a result the viaduct structure is seriously damaged. Thereafter some precise geodetic surveys were carried out in the region and on the viaduct piers in order to determine the severity of the displacements caused by the earthquake. The methods used for understanding the damages on the structure and in the region will be explained in details. The results obtained from the geodetic measurements will be discussed and conclusion will be drawn.

Keywords: transformation, earthquake, viaduct

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Modeling deformation of the Colli Albani Volcanic Area by integration of different geodetic techniques

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Working Group R.U.8 Project V3_1 Colli Albani

The Colli Albani is a quiescent Volcanic District that belongs to the potassic and ultrapotassic Roman Magmatic Province, a northwest-trending chain of volcanoes that developed along the Tyrrhenian Sea margin of Italy during middle and late Pleistocene time. The volcanic history of the Colli Albani Volcanic District is dominated by recurrent eruptive histories started about 561 ka and ending with the most recent and voluminous activity of the Albano maar (<70 ka) phase, that cannot be considered extinguished yet. At present, the Colli Albani are characterized by recurrent seismic activity having swarm character, temperature and composition water variations, gas emissions and significant ground deformations. The Dept. of Civil Protection financed a project to evaluate the potential level of hazard of the area; in this framework we present the results of the Research Unit 8 having the aim to integrate different geodetic techniques and to estimate reliable spatial and temporal distribution of the deformation of the area. A methodology of integration of GPS, high precision leveling, DInSAR time series and gravity surveys has been developed to assess a deformation model of the Colli Albani. First field surveys detected significant ground deformation and gravity changes in the whole Colli Albani area. In this work we present the relevant steps followed from the observations of each single technique toward the unified model.

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Studies of intraplate deformation resulting seismicity in the Northern Indian Plate

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Abstract: Seismicity map prepared from earthquake studies shows a widely diffuse intraplate seismicity in the Bay of Bengal and adjoining peninsular India in comp- arison with the clearly defined higher seismicity at the eastern plate boundary. Several geophysical evidences and observations indicate that that the northern Indian plate including the Bay of Bengal and peninsular India has experienced extensive deformation.Brief account of various causes of intraplate stresses and deformation is presented and nature of ongoing intraplate stresses and deformation in the Bay of Bengal and Peninsular India is discussed.Fault plane solution studies reveal that almost all intraplate earthquake in the Bay of Bengal and coastal areas of peninsular India exhibit thurst faulting mechanism having consisting north dipping fault and more or less N-S directed pressure or compression axis.Composite plot of pressure and tension axes of focal mechanism of solution of intraplate earthquake of this region also suggest that this region is also experiencing N-S compression.Small scale seismic profiling in southern Bay of Bengal also suggest N-S compressive deformation apparently by folding of upper sedimentary layer and high angle reverse faulting of acoustic basement of oceanic crust having E-W orientation.The intraplate region of peninsular India and Bay of Bengal becomes seismically active in response to continuous northward push of Indian lithosphere from Ridge push at Carlsberg Ridge.

Keywords: seismicity, intraplate deformation, composite plot

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Determining displacement and rupture direction of new fault, DEC 26, 2003, Bam, Iran with INSAR method

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The power of SAR Interferometry in earthquake monitoring has been demonstrated with the Bam earthquake, where the movement of coseismic features has been measured with a typical accuracy of 2 to 10 millimeter over a 35000 area surrounding the event. Using two images obtained in same time with spatial parallax Digital Elevation Model (DEM) can be generated while by two images acquired in same place with time parallax height changes in earth surface can be generated. Since there is always a time delay, and usually parallax as well, a processing must be done to remove the unwanted component. For removing, the unwanted component of topography there must be three images or DEM of area. On 26 December 2003, a large earthquake struck the small city of Bam in the Kerman province of southeast Iran. The epicenter of this earthquake was in a new fault at the south of Bam while the old fault is at east. In this study, three images of Envisat satellite acquired before and after the Bam earthquake and provided by ESA were used for calculating the displacement and rupture direction of new fault in Bam. All processing steps were done by Doris software in Linux workstation. The results of this research show the magnitude of Bam earthquake and its moment are 6.4 and respectively. These results were compared with other works like USGS and Harvard that show the magnitude 6.5 and 6.6 respectively. Since the results are almost similar, InSAR can be successfully used in earthquake analyzing.

Keywords: sar interferometry, bam earthquake, envisat

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Using SAR interferometry in fault ruptures observation: Izmit (Turkey) earthquake, August 17, 1999

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A major earthquake ( ) occurred in the small town Izmit in Turkey on August 17, 1999. We use Synthetic Aperture Radar interferometry (InSAR) to map the displacement field of this earthquake. We show the fault ruptures occurred by this event. Using five images obtained by ERS1 and ERS2 satellites, imaged before and after event, we can obtain the fault parameters. The ~80 km of surface rupture on land has been mapped. In this study, all processing steps were done by Doris software in Linux workstation. Consequently, InSAR can be successfully used for analyzing the parameters of an earthquake. Additionally, we hope it can be used for predicting the main earthquakes in the future.

Keywords: sar interferometry, izmit earthquake, ers1 ers2

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Detailed Ground Deformation around the Volcanoes Detected by Precise Leveling in Japan

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We repeated the precise leveling around Asama volcano, Kozu volcano and Ontake Volcano in Central Japan to discuss the pressure source based on the vertical deformation every year since 2000. We also established levering routes consisting of many benchmarks with a distance every 300 to 500 m to detect the vertical deformation more precisely. Large earthquake swarm including six magnitude 6 earthquakes was observed in Miyake-Kozu region and Miyake volcano was erupted on July August, 2000. At the time of the earthquake swarm large vertical deformation of 20 cm was observed by the precise leveling around Kozu volcano. It suggests the huge dike intrusion between Kozu and Miyake Islands. Depression deformation is detected in Kozu Island after the 2000 event and it suggests the some dike intrusion beneath the island. At the 2003 Asama volcano eruption, one dike intrusion was estimated in the westward of Asama creator from the GPS measurements. We are repeating the precise leveling along the route to the estimated dike intrusion area after the 2003 eruption and depression deformation is detected above the estimated dike intrusion until May 2006. Around the Ontake volcano, lasting earthquake swarm was observed for the last 30 years since 1976. We repeat the precise leveling across the earthquake swarm region every year since 2001. The convex uplift deformations are detected from the precise leveling across the earthquake swarm, and the large uplift was observed in the period of 2002-2003, which is the most active period of the seismic activity. As referred to above, detailed precise leveling give us the ground deformation precisely, and it should suggest the new steps for discussion about the pressure source model beneath the volcano.

Keywords: precise leveling, vertical deformation, pressure source

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Postseismic Deformation Seven Years After the 1999 Chi-Chi, Taiwan, Earthquake

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The 1999 Chi-Chi, Taiwan, earthquake (Mw 7.6) is a large inland low-angle thrusting event. It produced a remarkable 100-km-long surface rupture and caused serious damage in central Taiwan. Inversions of geodetic and seismic data show a maximum co-seismic slip of about 10-15 m concentrated at the northern bend of the seismogenic fault, and extending about 10 km down-dip from the ground surface. Significant transient postseismic deformation was observed by frequent GPS campaign surveys in central Taiwan and a new densely-deployed continuous GPS array in Taiwan installed after the Chi-Chi earthquake. The first 15-month (September 1999 to December 2000) postseismic GPS data reveal the postseismic displacement field resembles that due to the main shock, with maximum displacements of 25 and 23 cm in the horizontal and vertical components. Afterslip is the dominant mechanism in the first 15-month period. Based on these data, Hsu et al. (2007) inverted for the space-time distribution of afterslip, using the Extended Network Inversion Filter. The results indicate high slip rates surrounding the region of greatest coseismic slip. The slip-rate distribution remains roughly stationary over the 15-month period. Maximum afterslip of 0.57 m occurs down-dip and to the east of the hypocentral region. Afterslip at hypocentral depths is limited to the southern part of the main shock rupture, with little or no slip on the northern section where coseismic slip was greatest. A major part of the postseismic deformation is aseismic. In this study, velocity field from 2001 to 2003 and 2004 to 2006 are estimated, respectively, from both the campaign-surveyed and continuous GPS data in central Taiwan. The patterns of postseismic displacement fields during those two periods will be compared with that in the first 15-month period. These GPS data will also be utilized to study if afterslip is still the dominant mechanism of postseismic deformation seven years after the Chi-Chi earthquake, or the viscoelastic relaxation of the lower crust and upper mantle has become more prominent.

Keywords: postseismic deformation, afterslip, viscoelastic relaxation

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Implications for the magnitude of background stress field from GPS measurements and focal mechanisms

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We use GPS data and earthquake focal mechanisms before and after the Chi-Chi earthquake to estimate the magnitude of deviatoric stress in shallow crust. Inferred Chi-Chi postseismic slip shows a significant 15 counter-clockwise rotation relative to the interseismic slip. The rotation of the postseismic slip vectors suggests that the background stress is of the order of the coseismic stress drop. Assuming the direction of shear stress is parallel to inferred slip direction on the dcollement. We use the interseismic kinematic slip model, the coseismic stress field, as well as the postseismic stress field from focal mechanisms to derive the magnitude of deviatoric stress. Our results suggest the deviatoric stress is about 5 MPa on the dcollement, implying a low basal shear stress and a low friction of about 0.01. Such a low friction is consistent with the lack of internal deformation in the crustal wedge. In addition, we consider two rheologies including power law creep as well as velocity-strengthening friction. Using laboratory estimates of rock flow properties, we find the resulting thickness of the shear zone is huge and may be due to poor constrains of rock flow properties. The rheology with frictional sliding provides more reasonable parameters. Given lithostatic and hydrostatic pore pressures on the dcollement, we estimate the frictional parameter (a-b) of about 3.310-2 ~ 5.010-2, comparable to laboratory estimates.

Keywords: stress, postseismic, rheology

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The 2006 slow slip event in the Guerrero gap, Mexico: Insight into the time evolution of the slow slip from daily to sub-daily GPS position estimations.

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Since a few years, some geodetic deformation measurements, mostly in subduction zones (e.g., Canada, Japan, Mexico), have revealed a new particular type of transient deformation, the so-called silent earthquake. These events last from days to months and probably affect the subduction interface. They occur without any seismic signature but the energy they release can reach the one release during a Mw≥6.8 earthquake. Their occurrence significantly modifies our understanding of the elastic seismic cycle and of the mechanics of faulting. First order questions about silent earthquakes (size, location, repetition, periodicity, associated mechanisms) remain unsolved at the moment. We contribute to the understanding of these events thanks to permanent GPS measurements (1997-2007, currently 18 stations) of the surface deformation in the Guerrero gap zone in central Mexico. We present new results on the last silent earthquake occurring from March to December 2006. We test and set up several processing strategies to increase the time resolution of the position estimations without strongly increasing the position uncertainties. We provide some daily, sub-daily and 30 second position time series in order to better describe the kinematics of the silent slip. We expect to constrain its time evolution, and in particular to detect some slip velocity variations at the beginning, during or at the end of the event if they exist. This work will provide a new comprehensive data set of observations to test new hypotheses on the fault friction parameter related to slow slip events, and to test some new time dependent kinematic rupture models.

Keywords: slow earthquake, gps, mexico

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Modelling of the surface displacement, stress, strain and gravity change due to the underground heat source

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Thermo-elastic strains and stresses play a considerable role in the stress state of the lithosphere and its dynamics, especially at pronounced positive geothermal anomalies. Topography has a significant effect on ground deformation. In this paper we describe two methods for including the topographic effects in the thermo-viscoelastic model. First we use an approximate methodology which assumes that the main effect of the topography is due to distance from the source to the free surface and permits to have an analytical solution very attractive for solving the inverse problem. A numerical solution is also computed using finite element method (FEM). The numerical method allows include the local shape of the topography in the modeling. In the numerical model the buried magmatic body is represented by a finite volume thermal source of variable power density. The temperature distribution is computed by the higher-degree FEM. For analytical as well as numerical model solution only the forces of thermal origin are considered. The comparison of the results obtained using both, analytical and numerical techniques shows the qualitative agreement of the vertical displacements. In the numerical values small differences were obtained. The results show that for the volcanic areas with an important relief the perturbation of the thermo-viscoelastic solution (deformation and total gravity anomaly) due to the topography can be quite significant. In consequence, neglecting topography could give erroneous results in the estimated source parameters.

Keywords: deformation, thermoelasticity, modelling

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Ions, vapors and/or nanoparticles penetrating volcanic edifices?

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A top-sealed plastic tube with a diameter of ca. 15 cm had been buried ca. 70 cm deep vertically at the base of La Fossa volcano, Vulcano island, Italy, next to the front of the obsidian flow. The tube had been filled with layered rock and quartz wool to condense vapors emanating from the soil. At ca. 75 cm below the surface the sample had been exposed to vapors from Sept. 2005 to April 2006. The leached sample had not been in touch with the ground. 2 other glass wool cushions (ca. 10 cm thick, uncompacted) had been underneath to minimize capillary effects. A rock wool layer not touching ground revealed nucleated sylvite (KCl ~10 µm in size) and barite ($BaSO_4$ ~5-10 µm in size) crystals by SEM/EDS in its basal portion. Other very small (< 2 µm) particles were observed on the rock wool fibers but we could not identify them because they were suddenly volatilized by the electron beam. The bright appearance in backscattered images suggests that these particles may be metal compounds. The nucleation of sylvite and barite documents the presence of ions. Leaching of the quartz wool at room temperature with deionized H_2O and ICP-MS analysis documented 4 groups of elements: 1. positive signal: Mg, K, Ca, Cr, Mn, Ni, (Ba); low to moderate volatility at magmatic conditions. 2. unclear signal: Al, Si, P, Fe; low volatility at magmatic conditions. 3. no signal: V, As, Se, Mo, Co. As, Se, Mo, V are considered to be highly volatile, Co got a low volatiliy. 4. positive signal: Cu, Zn, Cd, Sn, Pb, W; high volatility at magmatic conditions. Leaching with nitric acid documented also V and Fe, and produced higher values for all elements, except K and Sn. This experiment documents for the first time an unknown element transport by vapors/gases through a volcanic edifice interacting with hydrothermal and magmatic gases. Charging, and to a lesser degree ions, in volcanic environments had been documented after fracture-charging in eruptive plumes and in phreatomagmatic and steam plumes (James et al., 2000). The heating events 2005/2006 (Granieri et al., 2006) might have shifted anomalous CO_2 degassing in the vicinity of the site. No acidic alteration at the site is detectable. Ground temperatures at 092005, 042006 and 092006 had been 19-21°C. All ions, vapors or nanoparticles have to go through porous systems to nucleate or getting deposited on the glass wool. Halocarbons and chlorinated benzenes are reported from the base of La Fossa v. (Schwandner et al., 2004). The origin of ions, the question if ions or nanoparticles are responsible for ICP-MS detected elements, are crucial if there will be future approaches to develop new chemical or physical sensors to monitor active volcanoes. It remains unknown if elements detected are entering the atmosphere or are getting adsorbed onto the volcanic ash/soil particles. Theoretical and empirical studies exist if particles from the lithosphere can reach the ionosphere and cause disturbances (Liperovsky et al., 2005; Dautermann et al. 2007). Geochemical data on recent rock coatings suggest that metals and trace elements are at least partially fixed on the surface of the ground (Fulignati et al., 2002). Ref: Dautermann et al., 2007. J. Geophys. Res., Vol. 112, B02106, doi: 10.1029/2006JB004447. Fulignati et al., 2002. JVGR, 115, 397-410. James et al., 2000. J. Geophys. Res., 105, B7, 16641-16649. Granieri et al.,2006. GRL, 33, L13316, doi:10.1029/2006GL026460. Liperovsky et al., 2005. Natural Hazards and Earth System Sciences, 5, 783-789. Schwandner et al., 2004. J. Geophys. Res., 109, D04301.

Keywords: vapor, ion, volcano

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JGS003 **Poster presentation** **198**

Study on Jiashi Strong Earthquake Swarm Region, Xinjiang of China by InSAR

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Located in the boundary of west Kunlun-Pamir Plateau, rigid Tarim basin and Tianshan mountain, Jiashi and its adjacent region, Xinjiang Uygur Autonomous Region of China presents a complicated tectonics background which is apt to induce strong earthquake for example several strong earthquakes with magnitude >Ms6.0 have hit the area of Jiashi since 1996 and caused lots of deads and property loss especially for the envent of 2003. It is noticeable that so much strong earthquakes occurred in a region within such short time. Many efforts such as GPS, gravity and seismic tomography have been used to study the geodynamics of the earthquake swarm, but we do not understand which silent fault(s) triggered the strong erathquake swarm and the relationship of these silent faults so far.On the basis of ERS-1/2 SAR images from ESA, the DInSAR interferograms of Jiashi strong earthquake swarm area during 1996-1999 are obtained by using SRTM DEM released by NASA. The results show that the seismic activities and crustal deformation in this region during 1996-1999 were affected by EW and NEE faults. The velocity difference between the soutjern and northern blocks of Tuotegongbaizi fault is about 5mm/a along LOS. The jiashi Ms6.0 earthquake on Aug.2, 19998 and mS6.6 earthquake on Aug.27 may not be related to silent faults.

Keywords: insar, tienshan mountain, jiashi earthquake swarm

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JGS003 **Poster presentation** **199**

Establishment of a permanent GPS network in Canary Islands and its initial results

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In April 2004, sudden increase of seismicity occurred beneath Mt. Teide of Tenerife, Canary Islands. The long-resting volcano was suspected to be reactivated but there was essentially no continuous monitoring system for the volcanic deformation. In response to this volcanic crisis, we established a continuous GPS array in Tenerife, La Palma, and El Hierro islands in order to monitor deformation of the volcano. The network consists of 9 permanent sites, of which 7 stations are on the Tenerife Island. Acquired GPS phase data are processed with the Bernese GPS software, using precise orbit and earth rotation parameters determined by the International GNSS Service (IGS). Precise estimate of daily coordinates of each site shows that no significant crustal deformation occurred even during the most active stage of the seismicity beneath Mt. Teide in the middle of 2004. Although we have not detected any sign of magma intrusion at depth, geodetic monitoring is an indispensable part of volcano monitoring. We conducted a numerical test to examine the detectability of the present GPS network for magma intrusion beneath the Mt. Teide. Calculation results demonstrate that, with the present GPS network, we will be able to detect deformation signals associated with a magma intrusion of 1107m3 beneath Teide, which is common to moderate size eruption or magma intrusion events.

Keywords: gps, mount teide, crustal deformation

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JGS003 **Poster presentation** **200**

Ground ruptures and seismic faulting at depth: the case of the Kalamata, Greece, 1986 earthquakes

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The 1986, Ms=5.8 Kalamata (S. Greece) earthquake was one of the most destructive but least studied earthquakes in is the last 30 years. Based on the limited available seismological data and certain discontinuous minor ground ruptures, this event was assigned to a normal fault cutting through to the surface and correlating with a major range-front fault. A refinement of this fault model was attempted on the basis of an elastic dislocation analysis of pre-seismic and post-seismic leveling data. These data reveal that the 1986 earthquake reflects reactivation of a segmented, blind normal fault, part of a major broad left-stepping fault zone associated with several earthquakes during the last 200 years; a result consistent with seismological evidence (clustered aftershocks, absence of very shallow aftershocks and waveform complexities). Widespread minor surface ruptures associated with the 1986 earthquake are not regarded as tectonic, shear fractures, but as extensional (secondary) fractures produced by the very strong ground motion produced by this earthquake in intensively pre-fractured rocks, while seismic accelerations were amplified in high gradient slopes (topography effect). Still, the differences between these models are small, and some years ago would have been dismissed as noise in the data used.

Keywords: greece, surface faulting, elastic dislocation

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JGS003 **Poster presentation** **201**

Crustal deformation in Baitoushan volcano detected by SAR interferoemtry

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Baitoushan is a stratovolcano with a 5km wide summit caldera which is located on - border. According to historical documents, eruptions have occurred in 1413, 1597, 1668, and 1702 AD, and volcanic activity after the last eruption had been inactive. However intermittent seismic swarm has started under Baitoushan volcano from 2002, and a relation with an increase of a volcanic activity has been pointed out. Then we applied SAR interferometry to investigate crustal deformation around Baitoushan volcano. First, we analyzed ENVISAT SAR data acquired on October 2004 and November 2005, and obtained concentric shaped fringe with about 10km diameter. Its fringe shows that a slant range has been shortened 3cm. Estimating parameter of Mogis model (Mogi, 1958) from obtained crustal deformation, an inflation source located in 2200m depth (under the sea level) under Baitoushan volcano was obtained. Estimated volume change was 1.510^6 m^3. Its location is roughly consistent with a location where a seismic swarm has occurred. This result suggests that seismic swarm has been induced by a movement of magma. Next, we analyzed JERS-1 SAR data acquired in 1992-1998, and crustal deformation around Baitoushan volcano was negligible, less than 1cm/yr.

Keywords: insar, baitoushan, volcano

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JGS003 **Poster presentation** **202**

Inflation of Kilauea volcano, Hawaii: Boundary element modeling of ALOS/PALSAR interferometric data

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The summit of Kilauea volcano has experienced a relatively rapid inflation in the period of January to October 2006. The distance between two Global Positioning System (GPS) stations located on opposite sides of Kilaueas caldera increased more than 20 cm in the period (Hawaiian Volcano Observatory website). An L-band synthetic aperture radar (SAR) PALSAR, equipped on the Japanese ALOS satellite that was launched in January 2006, has captured several SAR images on the volcano. An interferometric analysis of the pair of 2 May and 2 August 2006 images shows a signal consistent with an inflation in the summit area.In order to quantitatively explain the observed signal, boundary element computations are performed. The summit inflation source is modelled with an oblate spheroid that inflates in response to a constant overpressure. Preliminary results indicate that a vertically elongated spheroid of 1 km height located at about 3.5 km beneath the summit well explains the observed signal. The location of this source is consistent with that of a deflation source determined previously by GPS data for a period before 2003. The interferogram also shows a signal of several centimeters along the southwest rift zone of the volcano. While this signal corresponds perhaps to a noise caused by atmospheric perturbations, a boundary element computation found that it could be explained by an intrusion of a vertical dike beneath the southwest riftzone.

Keywords: sar interferometry, kilauea, boundary element modelling

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JGS003 **Poster presentation** **203**

GPS determination of ongoing ground deformation at Santorini Caldera, Greece

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Santorini Caldera in the southern Aegean , is part of a well developed but still very active volcanic system fueled by subduction along the Hellenic arc. The caldera is partially submerged, with only pieces of caldera wall, flanks and central post-caldera lavas exposed above the sea level, comprising a grouping of five small islands. The system had its most recent caldera-forming event around 1650 B.C. in a massive series of Plinean eruptions that expelled some 60 km3 of volcanic material, burying the previous island surface, and according to certain investigators, contributing to the demise of the Minoan civilization. Additionally, the eruption likely caused wide-spread and locally large tsunami waves across the Aegean and Mediterranean Seas . The system remains active with ongoing smaller pyroclastic and phreatic eruptions, the most recent in the 1950s, forming the central islets atop of the submerged caldera floor. In late-spring 2006, with UNAVCO engineer support and support from the Santorini Volcano Observatory, we established a network of two continuous GPS across the caldera, and will soon finish a third site atop one of the young central islets. Thus we covered the area for which there is geodetic evidence of limited inflation some years ago. In addition to continuous measurements we performed a first GPS campaign of 18 previously established and new sites across the 5-island group. Currently, we are planning a second set of measurements for spring-summer 2007. Through the continuous and campaign measurements we hope to establish the rate of ongoing deformation in the volcanic complex, and determine if there exists any significant transient deformation that would yield valuable information about near source rheology and pressure history. This information may additionally be useful for understanding the early post-caldera resurgence in a mostly submerged environment. This information may be useful for early hazard awareness and mitigation during future regional volcanic crises.

Keywords: santorini, volcano, gps

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JGS003 **Poster presentation** **204**

iGeoPS, a Matlab tool for High Rate GPS data analysis: application to the Mt.Etna network

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geodesy agu

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In these last years, an increasing interest in high rate GPS is clearly showed by the numbers of papers where this methodology is applied in seismology (Larson et al., 2003; Bock and Prawirodirdjo, 2004; Ji et al., 2004; Miyazaki et al., 2004; Elosegui et al., 2006.), in volcanology (Mattia et al., 2004), and in tsunami hazard evaluation (Blewitt et al., 2006). Sometime this technique is applied in a posteriori, meaning that the data collected by the GPS stations are reprocessed and analysed, but the great potential of HRGPS is surely related to its application in the field of real time processing and to the big interest of the civil protection authorities in following dynamic processes related, for example, to the opening of a fracture field or to a dome extrusion during a volcanic eruption. Since 2002, the INGV (Istituto Nazionale di Geofisica e Vulcanologia) section of Catania () manage two real time high rate GPS networks in Stromboli and Etna volcanoes. In order to improve our capability to evaluate the volcanic risk and our knowledge of the deformative processes linked to magma movements at shallow depths, we developed a software tool finalised to the analysis of HRGPS data. This software tool, named iGeoPS, runs in Matlab framework and permits to analyze long series of HRGPS data sampled with any frequency. In particular, the tool can visualize raw data, statistically filter the raw data, sidereally filter the data, calculate power spectrum for specified windows (both in time and frequency content), display spectrograms of the signal, calculate statistics and RMS of the scatter of the data, and perform cross-correlation and trend analysis for different series. Moreover, iGeoPS allows to do advanced non linear analysis such as fractal and chaotic analysis and integrates different non linear modelling techniques such as neural networks, fuzzy systems and wavelets. In this paper, after a brief introduction to the features of the developed tool, we summarize the main results related to the characteristics of the HRGPS signal and to the main volcanic events observed using this approach. Furthermore we show an analysis of data collected since 2003 on Mt.Etna where phenomena related to explosive activity, opening of fractures, tidal effects etc, clearly define the potential of this technique in volcano monitoring.

Keywords: ground deformations, etna, gps

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JGS003 **Poster presentation** **205**

New geodetic techniques and analytical tools to study ground deformation in volcanic areas: the example of sicilian volcanoes

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After decades of rapid evolution of geodetic techniques, Volcano Geodesy now represents a fundamental tool to investigate the structure and dynamics of volcanoes. Not only are geodetic data suitable to follow the effects of magma movements beneath volcanoes at different time and space scales, but they are also valuable in assessing the dynamics of active structures in a volcanic area. These features imply that volcano geodesy has a growing importance in risk mitigation. Active volcanoes of Sicily (South Italy) are located in highly populated regions, giving rise to considerable volcanic risk. The almost continuous activity of the Sicilian volcanoes (e.g. Mt. Etna and Stromboli) urge scientists to assess new approaches to retrieve data and/or devise tools to analyze them. Volcano geodesy embraced this challenge and the study of ground deformations on Sicilian volcanoes offers a useful example of applying both new surveying modes and developing mathematical tools to analyze the new data sets. A review of applications of geodesy for monitoring recent volcanic eruptions or for understanding the current dynamics of Sicilian volcanoes is here presented. Particular emphasis is devoted to the potential of volcano geodesy to cover a wide range of phenomena from slight slowly evolving deformations due to deep magmatic sources up to very fast large movements related to volcanic flank failures or dyke intrusions.

Keywords: deformations, volcanicrisk, sicilianvolcanoes

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JGS003 **Poster presentation** **206**

Slow Earthquakes Triggered by Typhoons

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Taiwan experiences very high deformation rates, particularly along its eastern margins. To investigate this region, we have started (in 2003) to install several small networks of Sacks-Evertson strainmeters. The initial data from all sites show characteristics of good quality: tidal signals with very high signal to noise ratio and large (~10,000 counts on 24 bit ADC system) amplitudes; strains trending into contraction with rates that decrease exponentially with time and earthquakes clearly recorded. Additionally the instruments have recorded a number of slow strain changes with durations ranging from about an hour up to a few days; we interpret these signals in terms of slow earthquakes. All of the slow events identified to date occur at the times of typhoons passing over or very close to the study area, but not all typhoons are associated with slow strain events (9 typhoons in 2004 were accompanied by 5 slow events). Seismicity for the area deliniates a roughly north-south striking steeply dipping (to the west) zone with reverse slip; the shallowest extent of the zone is just inland. We look for source solutions consistent with that tectonic setting. The slow events exhibit a considerable range of amplitude and complexity; small, short amplitude events have a quite simple and smooth waveform; the longest (2 days) and largest (100 to 350 nanostrain at 3 sites) has waveforms with a lot of structure. The similarity among the stations (located in an ~isosceles triangular array with spacing ~10 km and 4 km) is indicative of rupture propagation of a slow slip source (equivalent magnitude about 5).We are able to match the essential character of the data with a very simple model of a downward propagating line source with uniform slip; the largest slow event appears to be comprised of 3 sub-events all starting at a depth of ~3 km with the final sub-event propagating to a depth ~10 km. Typhoon activity produces a large increase in short period (~ sec) energy so it is not possible to determine whether these slow events are accompanied by non-volcanic tremor, as has been reported for the Nankai subduction and Cascadia slow events. We hypothesize that the slow earthquakes are triggered by the typhoon activity due to the resultant low air pressure over land reducing the locking force on the fault zone. Such repeated slow events may explain why this area of high deformation does not experience very large earthquakes.

Keywords: slow earthquake, borehole strain, typhoon

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JGS003 **Poster presentation** **207**

Nonlinear effects during post-seismic visco-elastic deformation

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Evidences of power law during post-seismic deformation are recently identified. A part of the total deformation is elastic andan investigation nto the nonlinear elastic effects is carried out. The geometrically nonlinear effects are included by taking into account the nonlinear part of the elastic strain tensor.This can predict the deformation more accurately, in particular, close to irregularities of fault boundaries where stress concentrations appear. The governing quasi-static FEM equationand the effective viscosity coefficient are of the form(Kev + Kct + Kg)Δq = Q - F, η = A(-1/n)dot(E)(1/n-1)exp(H/nRT)where Kevis the elasto-viscous stiffness matrix, Kctis the current contact stiffness andKg the "geometric" stiffness which includes the effect of the (linearized) nonlinear part of the strain tensor,Δq is the displacement increment,Q is the external loading vector and F is the internal forces vector.The visco-elastic model employs power law viscosity function where dot(E)is the second strain rate invariant, T is the temperature, R is the universal gas constant, A and H are the experimental material constants. The numerical examples that will be presented concern the displacements applied along the fault and observations of the displacements on the surface.The computational model is 3D and includes contact relations between the moving plates in the fault. The problem is described in the updated Lagrangian frame and the FE equation is solved using Newton-Raphson technique. The calculations are performed using the newly developed visco-elastic version of the program "Oregano". We examine a simplified conceptualmodel in which a surface traction simulating the coseismic slip is applied to a vertical fault causing displacements of the upper surface of a crustal block. We demonstrate the effectof geometrical non-linearity in this problem.Acknowledgement:The Engineering and Physical Sciences Research Council provides the funding for the research project under the contract EP/D03728X/1.

Keywords: deformation, viscosity, power law

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JGS003 **Poster presentation** **208**

Monitoring volcanic activity in Central Andes with INSAR interferometry

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Since the year 2002, we carried out an interferometric survey of the Central Volcanic Zone (CVZ, 14S 28S) using ASAR-ENVISAT data acquired in the framework of to ESA projects (AO-ENVISAT n 857 & Cat-1 n 2899). We have produced more than 400 interferograms on various active or possibly active targets of the CVZ (Sabancaya, Ubinas, Misti, Lascar, Lastarria, etc) and a global interferometric mosaic of the area for the period between the austral winters 2006 and 2007. All interferograms were corrected from topographic, orbital and atmospheric contributions in order to make easier the detection of ground displacements. We have detected several fringe patterns related to volcanic or tectonic activity during the time of our survey. One of the more impressive interferometric signals is a large wavelength (45 x 37 km) elliptical ground inflation localised on the Lastarria Cordon del Azufre volcanic massif at the Chile-Argentina border. Our data show that this ground inflation, first revealed in 2002 by Pritchard and Simons from ERS data spanning the 1996-2000 period and then detected again, from ASAR data, by Froger et al. (2007) for the 2003-2005 periods, still continues during the 2006-2007 period. Thanks to new ASAR images in two different swaths, we were able to improve the displacements characterisation and to provide new constraints on their sources.

Keywords: radar interferometry, andes, volcanic deformation

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JGS003 **Poster presentation** **209**

Toward Broadband Exploration of Tectonic-Magmatic Interactions: Demonstration of Self-Consistent, "All-in-One" Rapid Analysis of GPS Mega-Networks using the Ambizap Algorithm

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In recent years, transients have been detected in GPS networks reflecting rheological responses to the history of stress changes in the so-called "solid Earth" over a broad spatio-temporal spectrum. Although rheological responses can be modeled as linear, independent processes, connections between different spatio-temporal scales are possible due to common forcing factors, such as earthquakes and magmatic events, and due to feedback between such processes and the resulting changes in stress. Transients in geodetic data over different scales have recently suggested a link between deep crustal magmatism [Smith et al., 2004] and the spatio-temporal pattern of strain spanning the extensional plate boundary of the Great Basin, USA [Davis et al., 2006]. As a measurement technique to explore such interactions, geodesy is ideally suited to connect the spectral gulf between seismology and geology. Toward "broadband exploration" of tectonic-magmatic interactions, it is essential to develop a GPS analysis scheme that is self-consistent over all spatio-temporal scales of interest. For this purpose we have developed an "all-in-one" approach to the analysis of GPS mega-networks. This new capability can in principle be used to reduce all the world's geodetic GPS data to a unique solution, with potential temporal resolutions of 0.01-10 years, and spatial resolutions of 1-10,000 km. A major hurdle to GPS network analysis in the past has been the problem that computation time goes as the number of stations to the power 4. This arises from the estimation and resolution of the integer ambiguities in the double-difference carrier phase measurements, more specifically, the "bootstrapping" algorithm. Zumberge et al. [1997] proposed the revolutionary precise point positioning (PPP) technique, which scales linearly with number of stations but only in the case that integer ambiguities are not resolved. Here we adopt an approach that augments PPP with ambiguity resolution, but gives up bootstrapping in favor of including data from as many GPS stations as possible to ensure successful ambiguity resolution. The "ambizap" algorithm has a processing time that scales linearly with the number of stations, and gives statistically the same positioning results (<< 1 mm) than when using the full network approach. Our initial tests show that a 98 station network is resolved on 1 cpu in 7 minutes versus the 22 hours it takes using the current GIPSY-OASIS II method nearly a factor of 200 improvement in speed. The resulting station coordinates agree to 0.8 mm RMS, smaller than the daily repeatability (approx 3 mm for PPP). A block-diagonal covariance is also produced which closely approximates the rigorously formal variances of station and baseline coordinates, suitable for subsequent strain analysis. In addition to reducing processing time, linear schemes readily lend themselves to parallel processor implementation. Thus real processing time can be reduced by several of orders of magnitude for extremely large networks. For example, on our 40 cpu cluster, the above 98 station network can be resolved in ~15 seconds, a factor ~5000 faster than the standard approach. Application of the ambizap algorithm will greatly assist analysis of crustal movement in regions such as the western North America, which have dense overlapping GPS networks. For example, a network solution from one day of the ~1000 station Plate Boundary Observatory can be produced from RINEX files in about 7 minutes on a 40-cpu cluster (most of which is required by initial PPP).

Keywords: gps, ambiguity resolution, transient

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JGS003 **Poster presentation** **210**

Triggering of Great Earthquakes: Seasonal Variation

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It is now well established that even great earthquakes are triggered by relatively small stress changes provided that the stress change increases the Coulomb failure. Stress changes of a few tenths to a few bars have both advanced and inhibited earthquakes.Four centuries of earthquake occurrence data in Northeast Japan allowed a ~36 year lag time of subduction events after on-land earthquakes to be determined (Rydelek and Sacks, 1990). The elastic-viscoelastic model of the crust-lithosphere derived from geodetic observations over about 50 years can explain the time lag. The stress diffusion from the 1940's Nankai trough earthquakes, M ~8, slowly unloaded the normal stress clamping the Nojima fault over a 50 year period, resulting in the 1995 Kobe earthquake, m=6.9 (Pollitz and Sacks, 1997). From the earthquake record spanning about 12 centuries, the 1940's Nankai trough earthquakes were themselves advanced in time, the interval since the previous event of 1854 being clearly the shortest on record. Strain diffusion from the on-land great Nobi earthquake of 1891 explains not only the advance, but also the two year delay between the eastern (Tonankai) and western (Nankaido) events. The failure mechanism was modeled by Rydelek and Sacks (2003). In the above examples, the strain diffusion has created stress changes of a fraction to a few bars at the fault so as to increase the Coulomb failure and modify the occurrence time by a significant amount, i.e. many years on a fault with recurrence interval of more than a century. Here we describe a situation in which strain changes, even though less than a tenth of a bar have governed great earthquake occurrence for more than a thousand years.Continuous GPS observations enable insight into much lower stress triggering of great events. It has long been recognized that most Nankai trough events (since 684), with recurrence intervals of one to two centuries, occur in the winter. A seasonal shortening of the continental plate (Heki, 2004) overlying the subducting Philippine sea plate, causes a reduction of stress on the thrust fault. Even though this stress change is less than 0.1 bar, and the yearly stress loading of the fault may be 0.5 to 1 bar, it seems to be sufficient to influence the failure time.

Keywords: coulomb stress, earthquake triggering, great earthquakes

JGS003 **Poster presentation** **211**

Bay Area Regional Deformation (BARD) network. Constraints on the active seismic systems in the San Francisco Bay Area

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The San Francisco Bay area (SFBA) is one of the most actively deformed areas in California. A large part of the deformation (75 %) between the north American plate and the Pacific plate is accommodated along faults lying in a land stripe of about 50 km width. At least two major events (M_w>6.5) are expected along two major faults: the San Andreas and the Hayward fault. Possible triggering between the two events is not excluded. Since 1994, the Berkeley Seismological Laboratory has been involved in collecting and processing data from the cooperative regional BARD network of permanent GPS receivers (Bay Area Regional Deformation network, reference: Murray et al., 1998).The Berkeley Seismological Laboratory (BSL) currently maintains 30 BARD sites and is in the process of upgrading its infrastructure so that it better responds to the needs of earthquake hazards related research, and in particular the use of GPS data in real-time. Most of the BARD stations operated by BSL are collocated with seismic instruments (broadband seismometers or geophones) or strain-meters. We present here for the first time the BARD GPS sites velocities computed in the ITRF2000 (Altamimi et al, 2002) from the data collected from 1994 to present. The velocity field highlights the deformation across the two main active faults in the SFBA. We have compared our results with the velocity field obtained from previous studies and obtained good agreement. In particular the ITRF2000 and the BAVU (dAlessio et al., 2005) velocities will be discussed. Additionally, we discuss the velocities of sites belonging to the recently installed mini-PBO network which contribute to constraining the extent of the locked section on the northern part of the Hayward fault.

Keywords: gps, seismology

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JGS003 **Poster presentation** **212**

Possible slow slip event on the plate interface induced by the largest aftershock of the 2005 Miyagi-oki earthquake

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We found possible episodic slow slip event on the plate interface between the subducting Pacific plate and the overriding continental plate beneath Northeastern Japan by analyzing GPS time series after the Miyagi-oki Earthquake (M7.2) on 16 August 2005. The source area of the 2005 Miyagi-oki Earthquake overlapped with the southeast portion of the rupture area of the 1978 Miyagi-oki Earthquake (M7.5), which is expected to reoccur in the near future. The largest and second largest aftershocks (M6.6 on 2 December 2005 and M6.1 on 17 December 2006) and post-seismic slip occurred after the main shock. GPS time series after the largest aftershock suggest that another aseismic slip event might start immediately after the largest aftershock at some area north of its hypocenter. Thus, we applied time dependent inversion analysis based on Yagi and Kikuchi (2003) to the GPS time series to estimate the distribution and evolution of aseismic slip on the plate interface. The result shows that a slow slip event occurred around the hypocenter of the second largest aftershock which occurred 15 days after the largest aftershock at a distance of about 40 km to the north. This slow slip event might be induced by seismic motion or static stress change due to the largest aftershock. Stress accumulation by this slow slip event might affect the occurrences of the second largest aftershock and small repeating earthquakes which occurred on January 2006 in the hypocentral region of the second largest aftershock.

Keywords: slow slip event, subduction zone, 2005 miyagi oki earthqyake

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Coseismic and postseismic displacements from the Machaze, Mozambique, earthquake of 23 February 2006 detected by InSAR

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A Mw7.5 (USGS) earthquake occurred on 23 February, 2006 (local time), in the southern part of , Africa. Its epicenter was estimated to be (21.2S, 33.3E) by USGS(2006). Fenton and Bommer (2006) made a reconnaissance survey in the epicentral region and reported the distribution of surface ruptures of up to 2m. Unfortunately they could not survey the total extension of the surface ruptures, since its southern part is located in an area of landmines. The western branch of East African Rift reaches the northern but its southern extension is unclear. There has been a long controversy on the southern extension of the rift, especially in relation to the triple junction in the Indian Ocean. Both USGS and Harvard CMT solutions of this event are of normal fault type with the strike of nearly north-south, which is consistent with an east-west extension. This earthquake occurred close to the southern extension of the rift and is considered to be related to the activity of this rift. Therefore it is important to investigate the fault geometry and characteristics of slip distribution of this event. We tried to detect coseismic and postseismic displacements from this event and collected Envisat SAR images acquired before and after its occurrence. We obtained two interferometric images of coseismic displacement fields by analyzing pairs of scenes taken on November 11, 2003 and May, 7 or June 11, 2004. We detected at least twelve fringes (>30cm LOS displacement) at the southern extension of the presumed surface ruptures. Unfortunately there were no clear fringes in the northern part due to poor coherence. We also obtained an interferometric image of postseismic displacements from the pair of scenes taken on May 7 and June 11, 2006. There is a sharp discontinuity in fringes longer than 50km in the epicentral region, which probably corresponds to the fault trace. We will present models of these displacements and more interferograms for different periods. Fenton, C.H., and J.J. Bommer, The Mw7 Machaze, Mozambique, earthquake of 23 February 2006, Seismological Research Letters, Vol.77, No.4, 426-439, 2006.

Keywords: insar, machaze earthquake, crustal deformation

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The Contemporary Crustal Deformation across Active Faults and Folds of Tien from GPS

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Using The GPS data of inner and outer Tienshan (include Xinjiang of China, Kazakhstan, Kyrgyzstan) that was collected from 382 observation data during 1992~2005, we have calculated the present-day multiple-epoch GPS velocity field and have drawn different velocity profile in different sub-area.Use the simplified faults geometry and movement modle, we have proved that the crustal movement of Tienshan accords with the model of ETOD (elastic theory of dislocation). The tectonic deformation of Tien has the tendency of block movement, and is controlled by boundary fault movement. the velocity vector decreases gradually from the west to the east, the velocity vector in the west Tienshan (72~77E) is (201)mm/a, the middle Tienshan (77~82E) is (121)mm/a, and the east Tienshan (82~92E) is only (41)mm/a. The mean convergence velocity vector in whole Tienshan is 12mm/a.But the crustal shortening in Tienshan is not proportional, it can be divide into a few of parts. The main deformation takes place at the reverse fault and fold zone along both sides of Tienshan Mountain . At the inner of Tienshan, the convergence velocity is nearly zero, and looks like a rigid body. At the same time, the deformation intensity of the whole Tienshan has a good consistency with the seismic activity. The differential movement of lithosphere and asthenosphere caused the Neozoic deformation of Tienshan. The difference on the crustal shortening in west-east direction of Tienshan, is from the pushing action by pamir and the clockwise rotation of Tarim. In the west Tienshan (west to 75E), the convergence is caused by the push of Pamir in NNW direction, and the east to 75E, the differentce of deformation in Tienshan is caused by the clockwise rotation of Tarim.

Keywords: tienshan, gps, tectonic deformation

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Lithospheric rheological structure constrained by eodetic survey in Altai, Xinjiang

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Lithospheric viscosity is the key to understand rock dynamics. Combining precision triangulation in the 1950s and modern GPS to monitor and model the past about 50 years postseismic deformation caused by M8 Fuyun earthquake in 1931 adopting postseimic viscoelastic relaxtion models, the best fit lithospheric viscosities are 1.61019 ~7.91019Pa.s for lower crust and 1.61018 ~6.31019Pa.s for the upper mantle,which are consistent with ones in other regions, for example, North China and Nevada . According to the best fit lithospheric rheological model, the maximal horizontal relactive velocity along the rupture in the past 50 years caused by the postseismic viscoelastic relaxation was about 5 mm/a. This study shows there may be significant surface deformations in curent crust velocities fields caused by M7~8 earthquake several decades ago, which can be monitored by modern GPS .

Keywords: postseismic deformation, viscosity, altai area

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GPS-geodetic monitoring of the South West seismic zone of western Australia: progress after two observational epochs in 2002 and 2006

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The Australian south-west seismic zone (SWSZ) is a northwest-southeast trending belt of intra-plate earthquake activity that occurs in the southwest of Western Australia, bounded by 30.5S to 32.5S and 115.5E to 118E. This is one of the most seismically active areas in . Since the SWSZ lies as close as ~150 km from the ~1.4 million population of the Perth region, it poses a distinct seismic hazard. However, little is currently known about the magnitude and orientation of this deformation, and whether there is any associated ongoing surface expression. It is also not known how this intra-plate activity compares with that observed elsewhere in or on other tectonic plates. Earthquake activity recorded by Geoscience over the past four decades suggests that the SWSZ could be deforming with strain rates between 10-9 /yr and 10-8 /yr, or with displacements between 0.1 mm/yr and 1 mm/yr across the 200km width of the currently active SWSZ. This estimate is derived by applying the Kostrov formula to the current rate of moment release of 3.3x1019 Nm from the nine earthquakes over magnitude 5 that have occurred in the SWSZ between 1968 and 2002. The largest of these was the M6.8 Meckering earthquake of 14 October 1968. Early geodetic studies of the SWSZ that used both terrestrial and Global Positioning System (GPS) techniques were inconclusive, due mainly to the imprecision of the technologies used in relation to the likely small amount of any surface deformation. Therefore, in 2002 a new 48-point campaign GPS network was established across the SWSZ to attempt to detect surface deformation, using ground-level forced-centred monuments. The first two observational epochs were in May 2002 and May 2006. In both surveys, the GPS data were collected continuously at each monitoring point over a 5-7 day observation period. In order to complete the surveys in an economic timeframe, although perhaps undesirable, a combination of Trimble, Ashtech and Leica receivers and antennae were pooled from the participating organisations. Comparison of these two repeat surveys shows that strain rates in the order of 10-9 /yr can, in principle, ultimately be resolved if the deformation across the SWSZ occurs uniformly, but that the four-year time interval between the existing two surveys is not yet adequate to detect deformation with complete confidence given the noise in the estimated coordinates at each epoch. Further repeat surveys after, say, 8 and 12 years should begin to reveal any observable deformation significantly in excess of the observational error.

Keywords: intra plate, seismicity, gps

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Remarkable strain changes associated with the activity of non-volcanic deep low-frequency tremors in the Tokai district, Central Japan -observed with Ishii-type borehole strainmeter installed at 1020M depth

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During the period from July 2005 to February 2007, three short-term slow slip events (SSE) associated with non-volcanic deep low-frequency tremor activity (LFT) in the Tokai district, central Japan were observed with an Ishii-type borehole strainmeter installed at Byobu-san borehole observatory at the depths of 1020m (BYB; Ishii et al, 2003, IUGG2003 JSS01/30A/D-011), that is located to the north of LFT. In the same period, these SSEs were also observed with tiltmeters and strainmeters that are located just above or south of LFT (e.g. Hirose and Obara, 2006; Kobayashi et al, 2006). A strain change of the 10-8 order was observed at BYB in July 2005, persisted for several days, synchronized with LFT in the Aichi prefecture, and can be explained by SSE activity in the Tokai district. The slip corresponds to the moment magnitude of approximately Mw6.0 (e.g. Kobayashi et al, 2006). This SSE model can also explain strain changes observed at other sites. In January 2006, a strain change of the 10-7 order was observed, one order larger than that of other observation sites, persisted for approximately 17 days, and synchronized with whole period of the series of episodes of LFT and SSE in Tokai district at January, 2006 (National Research Institute for Earth Science and Disaster Prevention; NIED, 2006). But the SSE model of whole episodes (NIED, 2006) can not completely explain the observed strain change at BYB. On the other hand, strain changes observed at other sites are synchronized with only LFT in the Aichi pref., persisted for a few days, and can be explained by only SSE model in the Aichi pref. which is a part of SSE model of entire episodes. However, this partial model can not explain the observed strain change at BYB. We are trying to clarify the mechanism of observed strain change in January 2006. In February 2007, presently, a strain change similar to that of July 2005 associated with LFT in the Aichi pref. is now in progress. We will present the details of these strain changes associated with LFT and SSE.

Keywords: ishii type strainmeter, deep low frequency tremors, remarkable strain changes

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Crustal deformation sensed by GPS and reservoir earthquake potential possibility in the three gorges area after the impoundment

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Three Gorges Reservoir will be holding 3.92175m high water level when Three Gorges Project (TGP) will be completed in 2009. Previous researches and experience have shown that such a big project might trigger earthquakes, which are mainly caused by unstable faults attributed to the decrease of rock friction intensity derived from hole pressure diffuseness and water permeation. To detect and prevent this potential disaster, a high spatial resolution crustal deformation monitoring network was jointly established by seismological bureau and the investor of TGP,based on the observations of GPS, precise water level, gravity, laser range, cave strain measurement and subsidence survey. It is the first time to build such a crustal deformation-monitoring network with a high spatial and time resolution for thelarge reservoir in China. In this paper, the data are sensed by 32 GPS sites covered the key area of TGP with average interval of 10-10 mm. The maximum subsidence is located in the segment of the reservoir from Maoping to Xiangxi. The water-loading induced deformation diminishes rapidly with the distance outwards from the reservoir. Meanwhile, the loading deformation was also simulated for each GPS site. On the basis of a high resolution InSAR-derived Digital Elevation Model, a DEM of 1:250000 from National Mapping Bureau and the water depth data of various hydrological sites before the impoundment along the Yangtze River, the water level increment of each point in the interior of TG reservoir and the increasing capability of reservoir were calculated. The comparisons of GPS measurements with modeling results show that their magnitude is consistent in terms of crustal deformation caused by water loading in the reservoir area, which implies that the transient subsidence is attributed to deformation response of elastic crust in a short period. The overall pattern of transient deformation is consistent with the prediction proposed by Farrell, and is attributed to the elastic response of upper lithosphere crust to overlying water reservoir.

Keywords: three gorges, impoundment, deformation

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JGS003 **Poster presentation** **219**

Analysis of anomaly in gravity observation before and after strong earthquakes

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In order to explore the abnormal varieties before the great Kunlun Mountain Mw7.8 earthquake in November 14 2001 and Sumatra Mw9.0 earthquake in December 26 2004, the minutely sampled data are analyzed which covered before and after the earthquakes. Butterworth highpass filtered results and spectrograms show that there are abnormal changes in station Urumqi and Korla at two time spans before the Kunlun Mountain Ms8.1 earthquake, which appeared from November 3 to 5, and from November 11 to 13, respectively. Both abnormities seemed to be something like vibration signal with low frequency, and magnitude of the latter is stronger. But no vibration like these appeared in the other stations. The same signals are recorded at station Korla and Urumqi before Sumatra Mw9.0 earthquake. At the same time, the recording curve of superconducting gravimeter in Wuhan became thicken beginning from the afternoon of December 15 2004.

Keywords: gravity, spectrogram, slow earthquake

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The GRACE Results and Earthquake in China

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The GRACE mission, designed to monitor mass flux on the Earth's surface at monthly intervals with high spatial resolution and long lifetime, was launched successfully in March 2002. Since then there have been a lot of GRACE observational data and products released , including the time-variable global gravity field models with the maximum degree to 120,and 1 month time resolution. The GRACEgravity field model products from April 2002 to noware used to computegravity changes in China. We truncate the GRACEspherical coefficients to degree and order 70 and use the Gaussian spatial average with 800km smoothing radius. Finally, by Combining the GRACE results with earthquake taking place in China, the relationshipbetween earthquake auspice andgravity satellite missionis discussed.

Keywords: grace, earthquake, gravity

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Geo-information technology and artificial intelligence for optimizing the displacements of earthquakes: a case study for syrian active fault zones

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Mohamad Rukieh

The frequent occurrence of earthquakes causing extensive human and property losses has made it crucial to develop an effective data processing strategy for optimising of the displacement produced by these earthquakes. In Syria, the relation between earthquake risk, seismic risk and vulnerability was considered in 2004 by the General Organisation of Remote Sensing to establish the neotectonic map (1:500000) for supporting and investigating the geodynamic activity in the western part of Syria and in Damascus area using geodesical, seismological, tectonical and geological methods. Several selected sites examined in details to study the volcanic activity and few samples were collected to carry out absolute age analysis and paleomagnetic analysis. The results of this study are presented in a geodynamic and seismologic maps that can be used by decision makers as a base for a reliable, scientific and national strategy for mitigation of the effects of future earthquakes in this vulnerable region, and for site selection of vital establishments and infrastructures. However, the volume of data collected for this study is growing rapidly and robotic algorithms that can provide a degree of functionality to efficiently optimise this volume is essential. Therefore, an innovative methodology based on the advanced space and geo-information technologies (GPS, RS, GIS, etc) coupled with dynamic optimization procedures based on artificial intelligence can provide valuable tools for developing of this processing strategy. Developing this strategy requires the neotectonic map with a centralized database which contains all the related information, and a dynamical model based on optimization and simulation procedures and linked with the internet. This strategy will: (1) provide access to a wide range of data collected at investigated region, (2) combine the observational data (geodesical, seismological, tectonical and geological) with innovative data analysis in order to improve forecasting and assessment of the geodynamic activity, (3) contribute deeply for understanding of the structural complexities with strike-slip faulting and tectonic position which will help in clarifying the zones of earthquakes centers, as well as understanding of the associated seismicity, microseismicity and volcanism, and strong ground motion simulation, (4) examine largely unstudied areas along the fault zone and determine if the characteristics and tectonic evolution of constituent terrains and other units are similar to those of rocks in the areas which has been studied in much greater detail, (5) help in identifying of the areas which are most susceptible to natural hazards as the ability to undertake seismic microzonation for large areas is very expensive, (6) describe the spatial variation of seismicity parameters observed in the aftershock activity of the earthquake, and the non-uniformity both in space and time, and how the observed characteristics relate to other aftershock sequences, (7) support to derive high-resolution velocity models from seismic first arrivals picked off raw data and then using these models in a pre-stack Kirchhoff depth migration to directly image subsurface structures, and (8) develop earthquake scenarios for possible earthquakes for each area and undertaking comprehensive studies for active fault activities for the probability of earthquake generation.

Keywords: earthquakeandseismicris, neotectonicmap, geo informationtechnology

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The gravity changes caused by the coupling movement between deformation and density changes in the earths interior

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The internal earth movement is an important problem which international geophysicist, geologist and geodetic scientist always pay attention to. Based on the view that the deformation and the density changes are two most basic forms of movement in the earths interior, this paper theoretically analyzes the characteristic of the coupling movement between the internal deformation and density changes of the earth and put forward the theory of coupling movement theory: the coupling movement between deformation and density changes is the basic form of movement in the earths interior and it meet the continuity equation of the internal earth movement. Under the continuous action of external earth force and material exchange, the internal earth deformation occurs which makes internal earth material adjust and change (density changes). At the same time the internal earth density changes make the internal earths deformation adjust and change. They both mutually couple and act which makes earth continuously change, and form the tectonic motion. This kind of coupling movement between internal earth deformation and density appears as surface deformation and temporal and spatial variable gravity field at the earth surface.Based on this internal earth coupling movement, the strict formula of the temporal and spatial variable gravity field resulting from this movement is deducted from the angle of deformation movement. It is generalized and developed from the study result of Walsh (1975) 、Reilly & Hunt (1976) 、Chen Yuntai (1980) and Li Ruihao(1988) etc. That result can be regarded as boundary value of the coupling movement between medium deformation and density changes of earth (including crust) and is directly related to geodetic data.Thus, we must make use of all kind of geodetic data to synthetically study the information of deformation and gravity field change so as to integrally study the coupling movement between the internal crustal deformation and density changes. This has important theoretic and realistic signification to truly know and understand the crustal movement and promote the development of continent dynamics and earthquake prediction study. If we study the density information from the surface gravity field and ignore the deformation effect or make use of the surface deformation information to study the surface or deep stress or stain and ignore the density change action, it will be not conducive to factual systemic and integral study of crustal movement.

Keywords: gravitychanges, couplingmovement, theearthsinterior

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Absolute Datum Determination of China Earthquake Gravity Network

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Lelin Xing, Hui Li, Rugang Xu, Shaoan Sun

The Institute imported a set of FG5/232 absolute gravimeter and 8 CG5 relative gravimeters in 2006. This paper introduced their technical characters, principles, and then described the experimental observations at Wuhan seismic station, at last several the results about datum of China Earthquake gravity network were displayed.. The results indicated that the set standard deviation is under 210-8ms-2, and 310-8ms-2 for vertical gradient. They can satisfy the requirement of high precision measurement for the earthquake monitoring and the net work controlling.

Keywords: absolutedatum, earthquakegravitynetwork, gravimeter

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Study on the Dynamic Source of the Lijiang Earthquake (Ms 7.1, Feb. 1996) Using of Repeated Gravimetric Data

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Lijiang earthquake was occurred at the Red River fault belt. Southern of the epicenter is the local gravity networks of the Western Yunnan Earthquake Prediction Experiment Area(WYEPEA) in the area of 24-27N , 99-102E. 36. repeated gravimetry campaigns are carried out for 2~3 times per year by Lacoste & Romberg G model gravimeters during 1985 to 1996.This paper gave the gravity changes firstly, and then calculated the plumb line deflection varied with time, thirdly the dislocation revision results for the faults were displayed, at last the seismic activities before and after the earthquake were analyzed. According the results, the comprehensive explanation is that the dynamic source of Lijiang earthquake is mainly caused by the jostle of India plate to the Tibet plate, because the south-east movement of the east part of Tibet plate brings the different slips between the two sides of the Red River fault.

Keywords: lijiang earthquake, dynamic source, repeated gravimetric data

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Background gravity field before second impoundment of three gorges reservoir

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The Three Gorges project is about to be completed and the second impoundment will be carried out. Based on the fine processing the data observed in the gravity network of the in the head area of the reservoir after the first impoundment, this paper analyzes the change character of background gravity field in the head area of reservoir before second impoundment and presents the latent dangerous area where the second impoundment induced earthquake.

Keywords: three gorges reservoir, the second impoundment, the background gravity field

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Conjunct geodetic and geologic analysis of the Apennines active deformation (ITALY)

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It is well known that the Apenninic chain is one of the main seismically active regions in Europe, as it is well depicted by instrumental seismicity and by several seismic historical catalogues, spanning back in time about 2000 yr.. What appears as striking evidence along the Apennines is that the vertical component of movement seems to play an important role on the tectonic processes acting both at local and large scale. On one side, looking at the kinematic of each single seismic source, we may notice that CMT focal plane solutions of medium-large crustal earthquakes suggest a dominant normal faulting style within the Apenninic range, in agreement with recent GPS horizontal strain rate estimates. On the other hand, it is widely reported that regional uplift has to be considered as a first order dynamic mechanism of the main peninsular mountain range of Italy.In order to better understand the active deformation occurring along the Apennines, we decided to apply a multidisciplinary approach, based on a combination of data derived from leveling geodesy, geology, seismology and modeling. In our opinion it appears important to make a new effort involving an intense use of geodetic leveling data to provide a) a quantitative description of the short-term vertical velocity field across the Apennines, to be compared to the few available geological estimates; b) an independent analytical evaluation of the seismic behavior of some Italian faults, activated in the past century, to be compared to the seismological and geological ones. We present large scale vertical movements of the Apennines as evidenced by both geodetic leveling and geologic data together with a brief discussion on the comparison between short- and long-term deformation patterns and on the interplay between high rate of regional uplift and seismic moment release.At the local scale we want to illustrate two intriguing geodetic dataset in central Apennines, where the detected aseismic geodetic deformation has been interpreted as pre-seismic slip in the case of the 1997 Umbria-Marche mainshock (Mw 6.0) and as creeping along the Amatrice fault. Moreover, we show and discuss the evidences for coseismic slip along some of the main 1997-98 Umbria-Marche seismogenic structures obtained from both geodetic leveling and paleoseismologic data. Finally, we present the use of geodetic leveling data to highlight late stage movements of the postseismic relaxation process after the event occurred in 1915 (Mw 6.7) in central Apennines, where the leveling dataset covers the 1950-2000 time interval.

Keywords: leveling, uplift, seismic cycle

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JGS003 **Poster presentation** **227**

The VELISAR initiative: mapping ground velocity in Italian seismogenic areas by InSAR techniques

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In Italy, little is known about the spatial variations of the interseismic deformation along major fault zones.Recent space geodetic studies in extensional tectonic regimes show that strain accumulation is characterised by variable intensities and spatial patterns at the scale of the single active faults, providing in perspective useful data for an improved assessment of the seismic hazard.INGV has started the VELISAR (Ground VELocity in Italian Seismogenic AReas) research initiative, with the scope to produce the high-resolution ground deformation data set necessary to model the seismic cycle in the italian seismogenic areas, using multi-temporal SAR Interferometry techniques.VELISAR will exploit the information content of the archived ERS 1-2 data from 1992 to 2001, and will make use of two advenced processing methodologies for time-series InSAR: the PS (Permanent Scatterers) and SBAS (Small BAseline Subset) techniques.Several thousands of ERS images will be processed; the resulting ground velocities will be validated by means of independent space and ground geodetic data.An important objective of VELISAR is to make available to the scientific community the ground velocity maps, and this is accomplished through a dedicated web site, open also to the general public.We will present the initiative, its scope and the results obtained so far.

Keywords: interseismic deformation, sar interferometry, velisar

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Application of polarimetric SAR Interferometry in measuring the depth of a fault

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Polarimetry is the science of using measurements of the full polarization scattering matrix to infer physical properties of the earth's surface. The scattering matrix is measured by a SAR system by transmitting with two orthogonal polarizations. On transmission, the two orthogonal polarizations are alternated on successive pulses. On reception, the 2 polarizations are received simultaneously, leading to four channels of received data. The new earth observation satellites ENVISAT, ALOS and RADARSAT-II all have synthetic aperture radar (SAR) onboard, which all have partial or fully polarimetric imaging capabilities. The mission shall include a mode of operation that will allow the simultaneous acquisition of the four polarization combinations: HH, HV, VH and VV. This mode shall have a spatial resolution of at least 25m and a continuous swath of at least 50km .Multiple polarizations help to distinguish the physical structure of the scattering surfaces: 1- Vertically polarized waves interact with vertically structured vegetation 2- Horizontally polarized waves have greater penetration to underlying soil 3- cross-polarizations are sensitive to the target volume and may be less sensitive to row effects. Consequently we can obtain the depth of fault with changing the polarization of radar into HH mode.

Keywords: polarimetry, sar, depth of fault

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PBO Borehole Strainmeter Network

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UNAVCO is a non-profit, community-based organization funded by the National Science Foundation to install and operate the geodetic component of EarthScope called the Plate Boundary Observatory (PBO). UNAVCO will install 103 borehole tensor strainmeters/seismometers and 28 borehole tiltmeters These instruments will be used to study the three-dimensional strain field resulting from deformation across the active boundary zone between the Pacific and North American plates in the western United States in hopes of increasing our understanding of the causes and mechanisms associated with earthquakes and volcanic activity. This represents almost a tripling of all installed borehole strainmeters in North America. Since the initial deployment of strainmeters in the early 1980s, borehole strainmeters have contributed valuable data at periods ranging from minutes to weeks with sensitivities two to three orders of magnitude better than continuous GPS at periods of days to weeks. Borehole strainmeters have been used to image earthquakes, slow earthquakes, creep events and volcanic eruptions in the US, Iceland and Japan. A brief history of US BSM program is presented. Initial PBO strainmeter deployments show promising results: imaging two slow slip events in the PNW along with excellent tele-siesmic imaging. Exciting work has been done in the PBO community relating modeled strain from the GPS network to observed strain from the BSM network. PBO also plans the installation of three volcanic arrays at Mt St Helens, Yellowstone and Long Valley.In addition to strainmeters, each borehole contains a three-component geophone and a pore pressure transducer. A subset of the boreholes are also used for heat flow measurements. When completed the PBO borehole strainmeter network will be the largest network of strainmeters installed to date and one of the worlds largest borehole seismic networks. These instruments will bridge the gap between seismology and space-geodetic techniques and represents the first dense, geographically distributed observations in this temporal regime in the US.

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JGS003 **Poster presentation** **230**

Geodesy and petrology agree: variation in shallow magma storage at alaskan volcanoes

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Geodetic data collected at several volcanoes along the Alaska-Aleutian volcanic arc document significant variation in depths of shallow magma storage from volcano to volcano. Okmok caldera in the eastern Aleutians has undergone substantial inflation over the decade since its last eruption, with the inflation source consistently located ~3 km beneath the geometric center of the caldera. Although the rate of inflation has varied substantially over this time, the location of the source has remained constant within <500 meters. Deformation at Westdahl and Akutan volcanoes suggest a source at intermediate depths, 5-7 km, and deeper sources are found for Veniaminof and Augustine. The 2006 eruption of Augustine provided a particularly interesting case, as the pre-eruptive inflation suggested a small, shallow (~1.5 km) inflation source, but the deflation in the eruption showed that most erupted magma came from a much greater depth.Petrologic observations can provide independent constraints on the pressure magmas experienced before ascent and eruption. In the case of Okmok, magma storage pressures inferred for the 1997 eruption suggest that the magma was stored at a similar depth to that inferred from geodesy. Vapor saturation pressures calculated from basaltic melt inclusions from two Holocene caldera-forming indicate two distinct pressure regions: 0.8 0.4 km and 3.7 1.0 km. The latter pressure is consistent with current geodetic observations of inflation depth. Vapor saturation pressures from andesitic Akutan melt inclusions indicate entrapment at 4.1 km, and basaltic melt inclusions from Augustine indicate deeper pressures of entrapment of 14 3.3 km; depths from both volcanoes are consistent with geodetic data. The uniform composition of phenocrysts hosting the melt inclusions from each center suggest entrapment occurred in a single event. The similarity between geodetic and petrologic pressure estimates suggest both techniques are recording the same shallow magma storage conditions.

Keywords: volcano, deformation, pressure

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JGS003 **Poster presentation** **231**

Active deformation of the Panarea hydrothermal system (Aeolian Island, Italy) from GPS measurements

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The Panarea volcano belongs to the Eastern sector of the Aeolian volcanic arc (). On 3 November 2002, a submarine gas eruption started in the shallow area between Lisca Bianca, Bottaro and Lisca Nera islets. Exhalative activity at Panarea was well known since historical times as reported in Mercalli (1883); Romano (1973); Bellia et al. (1986; 1987); Gabbianelli et al. (1990); Italiano and Nuccio (1991); Calanchi et al. (1995) and Anzidei (2000), although gas eruptions like that of Novembr 2002 have not previously been observed in the last century. To provide a geodetic monitoring of the geothermic-hydrothermal area of Panarea volcano, a multidisciplinary program funded by the Italian Dipartimento di Protezione Civile was established. In particular, a local GPS network was designed, set up and measured. We analyze data from GPS measurements, carried out during the time span December 2002 - October 2005, by means of Bernese 5.0 software, and discuss the results. The area is affect by general subsidence and shortening can be interpreted as the response of the surface to the variation of the hydrothermal system reservoir which is progressively reducing its pressure after the gas phreatic eruption. We observed that the main pathways for the upwelling of hydrothermal fluids coincide with the NE-SW and NW-SE tectonic systems. The GPS network is an essential tool for monitoring this island, previously never consider active.

Keywords: aeolian arc, gps, gas eruption

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JGS003 **Poster presentation** **232**

Volcano-tectonic deformation models for Tenerife Island (Canary Islands, Spain)

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The Canarian Archipelago lies 100 km to the west of Africa, and constitute an important reference from the volcanic point of view since there are nearly a dozen of historical eruptions from 1500 to 1971. In 2004, there was reported an increase of the seismic activity with some felt events. This situation demand a permanent volcano surveyance. Among other techniques, continuous and sporadic geodetic GPS observations have been carried out. A geodynamic GPS network has been designed in order to detect the volcano-tectonic activity. This network is composed by seven stations, two of them in continuous register at one Hz, in Tenerife Island , and two reference stations more at La Palma (LPAL EUREF) and Gran Canaria (MASP IGS) islands. To control the occurrence of posible landslides in the area were seismic activity is concentrated, high resolution levelling network has been established. Besides that, a spatial inclinometer with five benchmarks will allow to control in real time the deformation of the Teide stratovolcano.

Keywords: volcano geodesy, gps, deformation models

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JGS003 **Poster presentation** **233**

Volcano deformation models an source location for Deception Island (South Shetland Islands, Antarctica)

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From 1991/1992 to 2002/2003 antarctic campaings, the using of GPS observations in the REGID geodetic network in Deception Island (South Shetland Islands,Antarctica) has allowed to characterize the existing deformation in the island due to its volcanic activity. An extensive radial process together with an uplif from January 1992 until December 1999 was detected. Two important seismic crises took place during this period, in particular, during the 1991/92 and 1998/99 campaings. From 2000 until 2003, it is not noticed considerable displacements, thought the stations seem to converge on a compressive radial process together with a subsidence, reflecting a change in the geodynamical of the island. According to the contour maps that characterize the deformation, two clear alignments are observed: one in the NW-SE direction, from 1991/92 to 1999/2000, and another one in the NE-SW, from 2000 to 2003, coinciding with the principal directions of the tectonic features of the region: the Fracture Hero Zone and Bransfield Rift. On the other hand, the location and geometry of the sources causing the 1992 and 1998 crisis estimated by means of Mogi's Model. They are located approximately 5 km and 1.5-2.5 km depth respectively, both of them in the central part of the island.

Keywords: volcano geodesy, gps, deformation models

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JGS005 **234 - 282**

Symposium
Observations of the Cryosphere from Space (IAG and UCCS Symposium hosted by IAG - merged with JGS004)

Convener : Dr. Isabella Velicogna, Prof. Konrad Steffen, Dr. Mark Drinkwater

Recent advances have been made in the development and implementation of new concepts for cryosphere-dedicated space missions, as well as the development and maturation of methods for retrieving a variety of important geophysical parameters. Both ESA and NASA have dedicated cryospheric sciences missions planned/in orbit. In addition, gravity missions such as CHAMP, GRACE and planned follow-ons and satellite altimeter missions such as ICESat, ENVISAT, JASON-1 are providing unique data on the topography and mass balance of the cryosphere. The purpose of this session is to present the latest results of observations of all aspects of the cryosphere from space. We invite presentations on the use of satellite, airborne and in-situ measurements to study sea-ice and terrestrial ice surfaces. We also invite presentations describing the accuracy and limitations of the different methods.

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JGS005 **Oral Presentation** **234**

Mass budget of the grounded ice in Lambert Glacier-Amery Ice Shelf system

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We present estimates of the mass budgets of the grounded ice in the Lambert Glacier-Amery Ice Shelf system (LAS) consisting of drainages 9, 10 and 11, using a GIS environment to combine a variety of data sets derived from remote sensing and in situ measurements. The grounding line of the LAS defined by Fricker et al. (2002) is updated with InSAR and velocity data with a spacing interval of 400 m. Our findings show the total accumulation of the grounded portion of the LAS is 84.74.2 Gt a−1 while the ice flux across the grounding line into the Amery Ice Shelf is 88.98.9 Gt a−1, which implies the entire grounded drainage basin is approximately in balance. Drainages 9, 10 and 11 are also nearly in balance with mass budgets of -2.52.8 Gt a−1, -2.67.8 Gt a−1 and 0.912.3 Gt a−1, respectively. The region upstream of the Australian Lambert Glacier basin traverse has a net mass budget of 4.46.3 Gt a−1, while the downstream region has -8.99.9 Gt a−1. These results indicate that the glacier drainages in western, central and eastern portions of the LAS, upstream and downstream of the Australian LGB traverse are close to balance or have relatively small imbalances.

Keywords: mass budget, antarctica

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JGS005 **Oral Presentation** **235**

Ground-based surface mass balance patterns from radar in Antarctica as reference for space-borne sensing

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Mapping Antarctica's surface mass balance from space is one of the current challenges for remote sensing techniques. The only feasible method to provide ground-truth observations on the spatio-temporal accumulation field to date is provided by ground-penetrating radar (GPR). We present studies from different areas in Dronning Maud Land, Antarctica, where GPR has been used to map the internal structure in the firn column. The isochronous property of reflectors in the firn, verified by combination with firn cores, was used to determine surface mass balance patterns with a meter resolution along GPR profiles and temporal resolution of decades. The patterns indicate that surface mass balance is much more variable than commonly assumed, varying by several 10% over distances of only a few kilometers. In some areas patterns have been stable over centuries, in others they migrate at velocities of several 10s of meters per year relative to ice flow. These observations have to be considered when trying to deduce variations in surface mass balance from space-borne sensors, such as passive microwave, altimetry, or gravity.

Keywords: surface mass balance, ground penetrating radar, antarctica

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JGS005 **Oral Presentation** **236**

Observed Ku-Band Radar Response to Snow and Terrain Properties

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Kelly Elder, Simon Yueh

The high sensitivity of Ku-band radar response to snow properties has been demonstrated by experimental data, by first- and second- order dense-media radiative transfer (DMRT) models and by direct solution of the Maxwell equations for complex snow packs. One-way penetration depths are typically 4 m at Ku-band, which is sufficient to penetrate most natural dry snow cover. Field measurements at these frequencies have demonstrated a sensitivity of about 4-7 cm SWE per dB, which is sufficient to measure the range of SWE expected for about 90% of global snow cover. Ku-band is considered to be a key frequency for observing snow water equivalent and other terrestrial snow properties from space using radar, and together with X-band is included in the ESA CoRe-H2O spaceflight mission concept recently selected by ESA for further study. Here we report on new airborne Ku-band radar observations of snow collected over a wide range of terrain in the second NASA Cold Land Processes Experiment (CLPX-II) during the 2006-2007 winter season. The Jet Propulsion Laboratorys Ku-band Polarimetric Scatterometer (POLSCAT) was enhanced to enable conical scanning and the acquisition of Ku-band radar imagery. The instrument was flown in three campaigns, each one month apart (December 2006, January 2007, and February 2007), over a 9-km x 90-km study area in north-central Colorado, USA. The study area included large gradients in snowpack properties corresponding to elevation, vegetation, and dominant weather patterns. Multi-polarization Ku-band imagery (HH, VV, HV, and VH) was acquired over the study area on multiple consecutive days in each campaign, with a ground resolution of 100-200 m (depending on surface elevation). Between December 2006 and January 2007, several changes were observed in the snow and terrain characteristics. Significant snow accumulation occurred throughout the study area between the first and second campaigns, with the greatest accumulation in the high-elevation Rabbit Ears Pass area. This area, characterized by moderate to dense coniferous forest cover, also experienced a) a change from extensive intercepted snow in the forest canopy in the first campaign to very little snow in the trees in the second campaign, b) a shift from frozen to thawed soil beneath the snowpack, typical of this area in mid winter as the increasing snowpacks provide greater insulation between the soil and the atmosphere, and c) a transition towards larger, more faceted grains within the snowpack. In the lower elevation North Park and Yampa Valley areas, characterized by sagebrush and culativated grasslands, there was a shift from low vegetation protruding through the snowpack in the first campaign to predominantly snow-covered vegetation in the second. In these lower elevation areas with shallow snowpacks, the underlying soil remained frozen in both campaigns. We observed an increase of 1-3 dB from Dec 2006 to Jan 2007 over the sagebrush/pasture fields in North Park and the Yampa Valley. Radar backscatter over forested areas appeared to decrease from December to January. We speculated that the presence of thaw layers in the snow-ground interface or the excess attenuation effects of snow on backscatter from vegetation under the snow pack may be responsible for this. In forested areas, snow accumulation over tree limbs appears to increase the radar backscatter by about 2 dB. In one part of the study area, wind-driven removal of intercepted snow from the forest canopy over a period of four days resulted in a daily decrease in backscatter that totaled about 2 dB. Other daily changes in radar backscatter were observed, which appeared to be driven by the presence of hoar frost on the snow surface. The sensitivity of various radar polarizations to snow pack appeared similar between the first two campaigns, although the cross-polarized returns seemed to differ between forest and brush/pasture

fields. In this presentation we will elaborate on these results and include the results of the third campaign.

Keywords: snow, ku band, radar

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JGS005 **Oral Presentation** **237**

Ice-sheet mass balance from repeated altimeter surveys: an assessment

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Curt Davis, Earl Frederick, William Krabill, Yonghong Li, Serdar Manizade, Chreston Martin

Satellite radar-altimetry data have been used extensively to estimate the rates of change of surface elevation, and hence mass balance, of the Greenland and Antarctic ice sheets. They provide the longest available altimetry time series over ice sheets, and this is likely to be sustained for many years to come. Indeed, the prime objectives of ESAs upcoming CRYOSAT include the measurement of ice-sheet elevation changes. Since 1991, ice-sheet topography has also been measured by airborne laser altimeters, with extensive repeat surveys over Greenland providing the first evidence for substantial mass loss, particularly on some of the faster-moving outlet glaciers. Since 2003, a laser altimeter aboard NASAs ICESat has provided similar data. Consequently, it is timely to assess the viability of these different techniques for monitoring ice-sheet mass balance. Here, we compare estimates of elevation-change rates derived from different sensors, in order to reveal differences, we shall offer possible explanations of these differences, and we shall discuss potential weaknesses of each approach.

Keywords: ice sheets, mass balance, altimetry

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JGS005 **Oral Presentation** **238**

Glacier Fluctuations in the Nanga Parbat Himalaya, Pakistan

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Himalayan glaciers are thought to be sensitive to climate forcing due to the high altitude and significant debris-cover variation. Remote-sensing based studies in the eastern Himalaya reveal relatively high retreat rates and downwasting for some glaciers. In the western Himalaya, many glaciers do not exhibit significant changes in terminus position, although many exhibit geomorphological conditions presumably resulting from downwasting. Given that glacier sensitivity to climate forcing in the Himalaya is relatively unknown, downwasting patterns have not been well documented, and because glaciers in the western Himalaya may show a different response to global warming, our objective was to assess glacier fluctuations over the Nanga Parbat massif in Pakistan. Specifically, we used multi-temporal satellite imagery and ASTER-derived digital elevation models to assess glacier fluctuations from 1934 to 2004. Our results indicate that small to medium sized glaciers exhibit relatively low retreat rates since 1934, although the Patro Glacier has advanced and several exhibit oscillating terminus positions. Conversely, the large Rupal Glacier on the south side of Nanga Parbat has significantly retreated. This discrepancy can be attributed to the influence of topography on radiative shielding and ablation, and its influence on orographic precipitation and accumulation. Preliminary results on changes in glacier surface elevations from 2000 to 2004 indicate no detectable changes, even though relative high ablation rates have been reported. Collectively, these results suggest that glacier ablation gradients at Nanga Parbat are spatially and temporally complex and strongly controlled by multi-scaled topographic effects. They also reveal that specific glacier mass-balance estimates/conditions should not be extrapolated to represent adjacent glacier conditions or to generate regional estimates.

Keywords: glaciers, remote sensing, himalaya

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JGS005 **Oral Presentation** **239**

Melt, accumulation, and water percolation on the Greenland ice sheet from passive and active satellite microwave data

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Son Nghiem, Russell Huff

The possibility of future sea level rise necessitates a precise knowledge of the mass balance of the large ice sheets in Greenland and Antarctica. Understanding the ice-sheet accumulation and melt characteristics is critical to the assessment of ice sheet mass balance. For Greenland, results from QuikSCAT scatterometer and SSM/I radiometer show a record extensive melt zone in 2002 and 2005. Snow accumulation measured by QuikSCAT reveals an anomalous massive amount with 186 gigaton of ice in just the first quarter of 2005. QuikSCAT snow accumulation is then partitioned into major drainage basins to determine the snow accumulation mass in each basin. The QSCAT snow accumulation algorithm captures an extreme snowfall in mid-April 2003 when half a meter of snow deposited on the southeast side of the ice sheet in a single day. New results from the latest QSCAT data detected peculiar melt in wintertime on the west flank of the ice sheet. The anomalous snow accumulation of 1.6 m/year in January-June 2005 is double the long-term average of 0.8 m/year at NASA-U. This record amount of snow accumulation is the highest observed along the western slope of the ice sheet based on automatic weather station data for the past decade.

Keywords: greeland, melt, accumulation

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JGS005 **Oral Presentation** **240**

Significant Glacier Thinning in the Larsen B Embayment, Antarctica, 2002-2006

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Altimetry data derived from ten ICESat operational periods and two long-range aircraft ATM missions acquired between November 2002 and November 2006 quantify significant elevation changes for a glacier flowing into the now-collapsed section of the Larsen B Ice Shelf. Where ICESats Track 0129 crosses the Crane Glacier, about 12 km from the March 17, 2002 ice edge, little to no elevation change occurred between November 26, 2002 and October 30, 2003 despite an ~11 km retreat in the ice edge location just down fjord; this is apparently due to inland ice moving downstream rapidly to temporarily maintain the floating glacier terminus. However, between Oct. 30, 2003 and March 2, 2004, >70 m of elevation loss occurred at this point, what was a >5 km wide and ~600 m thick glacier became a fjord. The Cranes ice front moved a further ~8 km inland in less than a year and has held a relatively stable position near this point since late 2004 (~65.33S 297.66E). In addition, the combined elevation time series from ICESat and ATM indicates the surface height of the lower Crane Glacier where it was crossed by ICESat Track 0018, about 24 km inland from the March 17, 2002 ice edge, lowered >145 m between November 26, 2002 and October 31, 2006. At this location, an average >40 cm/day elevation loss was observed over ~3 months in late 2004 - early 2005 as the glacier responded to the collapse. Close to 50 km inland, the Crane has shown distinct changes only since mid-2006 with >17 and >13 m elevation losses where Track 0390 crosses the upper Crane tributaries. In contrast to the Crane, the nearby but smaller Melville Glacier that also flows into the Larsen B embayment shows little elevation change as do the more southerly Flask and Leppard Glaciers at locations where the ATM and ICESat data intersect. These latter two glaciers are similar in area and thickness to the Crane (before its dynamic thinning) but are still buttressed by a remnant of the Larsen B Ice Shelf. Bedrock elevations in all cases were derived from available KU/CReSIS radar profiles. The available altimetry data is too limited to resolve seasonal or dynamic variations in elevation change but these results indicate the critical role that ice shelves play in the dynamics of the area's large outlet glaciers. Although the majority of the mass contributions from the Crane may have already occurred and are a small portion of total sea level rise, these elevation time series data further illustrate the critical role of ice shelves to ice sheet mass balance and ongoing sea level rise.

Keywords: laser altimetry, larsen b, crane glacier

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JGS005 **Oral Presentation** **241**

Seasonal and long term ice mass variations from GRACE

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John Wahr

Using measurements of time variable gravity from the Gravity Recovery And Climate Experiment (GRACE) satellites we determine long term and seasonal mass variations of the Antarctic and Greenland ice sheets during the period April 2002-Aug 2006.We use monthly GRACE gravity fields to estimate the linear trends in Greenland and Antarctic ice mass. This represents a new and independent estimate of the polar ice sheet mass balance. Both ice sheets display a large mass imbalance during the analyzed period. The mass of the Antarctic ice sheet decreases significantly from2002 to2006. Most of this mass loss is generated by the West Antarctic Ice Sheet. The Greenland ice sheet displays significant mass loss during the same period with a continuous increase during the period.The ice mass loss is almost entirely due to loss in southern Greenland. We will present results of our analysis for the seasonal and long term variability of ice sheet mass and we will discuss error sources, strengths and weaknesses of this new remote sensing tool.

Keywords: satellite, antarctica, greenland

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JGS005 **Oral Presentation** **242**

Improving glacier surface models using laser scanning and aerial imagery

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Digital elevation models (DEMs) are increasingly becoming invaluable for a variety of monitoring and modelling applications in the cryospheric sciences. In particular, the retrieval of elevation information from overlapping stereo-imagery has important implications for our ability to extend temporal records of ice mass changes beyond the era of modern altimetry measurements. Extraction of elevations from stereo-imagery relies on both image texture and good quality, well distributed georeferenced ground control. In this paper we present a new technique to apply airborne laser scanning (lidar) data as a source of control information for DEMs produced using digital photogrammetry. In order to assign standard errors to extracted ground control points (GCPs), lidar elevation accuracies are examined using both relative (overlap analysis) and absolute (independent GPS check data) methods. We then outline a technique to extract large numbers of GCPs from a raw lidar point cloud and use these to process a series of DEMs of Midtre Lovnbreen, a small (~6 km2) valley glacier in NW Svalbard. GCPs extracted from a 2003 lidar dataset are used to process DEMs using vertical aerial photographs collected simultaneously with the lidar. We examine the effects of control point addition on both DEM accuracy and calculations of glacier volume change and mass balance by comparing our derived models with repeat survey data of the glacier from 2005. We show that the elevation accuracy of lidar data, while degraded over steep slopes, has a root mean square (RMS) residual of 0.14 m when compared to independent check data and may be used to detect elevation changes due to surface melt over a 10 day survey period. Using lidar for ground control has implications for the retrieval of high-quality elevation information from image archives and may be used for imagery such as survey and reconnaissance aerial photography, declassified satellite imagery and combined nadir and backward-looking satellite sensors such as the VNIR band of the advanced spaceborne thermal emission and reflection radiometer (ASTER). This is particularly important given the lack of both spatial and temporal resolution in global records of glacier volume change and mass balance.

Keywords: lidar, gcp, photogrammetric

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JGS005 **Oral Presentation** **243**

Mass balance of the ice sheets surveyed by space altimetry and gravimetry.

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The mass balance of ice caps of Antarctica and Greenland is of major concern as to their dynamical state as well as to sea level change. Satellite radar altimetry has shown to be of great interest to survey ice sheets and in particular their topography, temporal surface height variation. Height is tricky to recover over land since the surface slope induced error affect widely the absolute height measurement much more than the classical atmospheric or orbital errors on ocean surfaces. The difficulty to compare 2 successive measurements made people concentrate on crossover points where at least the 2 measurements must be exactly at the same location and hence receive exactly the same slope/topographic error. However the error budget is in general large over continental surfaces. Here, we applied a method which accounts for both the local errors like the slope induced and the time variation of the radar echoes shape, at each point along track using the long time series. This method has the advantage to open the view on much more data (e.g. about 100 times more over Antarctica, a bit more over Greenland). We applied this new processing to both ERS and ENVISAT, to Antarctica and to Greenland. We show the results in terms of seasonal variations both in amplitude and phase and compare the ENVISAT (2003-2007) period to the ERS2 period (1995-2003). We also computed trends over the 2 periods and show the similarity and differences. Besides, satellite gravimetry (GRACE) is a way to measure time variations of the gravity field thus of the mass changes of the ice caps. We used 10-day GRACE products lately computed by GRGS (07/2002 05/2006) grace data to compute maps of ice caps surface height change comparable to the trends from radar altimetry. The comparison shows some significant agreements and large differences. Mainly, some big structures visible in the altimetric trends show up shifted in space in the gravimetric trends. We decompose the interpretation in terms of snow, ice and crust changes. Using spatial/spectral correlations we investigate the consistency of the 2 datasets. Levels of measurement errors are discussed. We suspect the earth isostatic adjustment to be responsible for the major differences between the 2 types measurements.

Keywords: ice sheet mass balance, altimetry, gravimetry

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JGS005 **Oral Presentation** **244**

Regional trend analysis of satellite-derived snow extent and temperature anomolies

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The extent and variability of seasonal snow cover are important parameters in climate and hydrologic systems due to effects on energy and moisture budgets. Northern Hemisphere snow cover extent, comprising about 98 percent of global seasonal snow cover, is the largest single spatial component of the cryosphere, with a mean maximum extent of 47 million square kilometers (nearly 50 percent of the land surface area). During the past four decades, much important information on Northern Hemisphere snow extent has been provided by the NOAA weekly snow extent charts, derived from visible-band polar orbiting and geo-stationary satellite imagery. Since 1978, satellite passive microwave sensors have provided an independent source for snow monitoring, with the ability to penetrate clouds, provide data during darkness, and the potential to provide an index of snow water equivalent. We see both positive and negative statistically significant trends in snow cover derived from these data sets, depending on region and time of year. We present regional trend analysis of both visible and microwave snow cover data sets, and comparisons with gridded temperature anomalies from the NASA GISS Surface Temperature Analysis data. Efforts are under way to look for attribution of the observed snow cover trends.

Keywords: snow extent, trends, temperature

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JGS005 **Oral Presentation** **245**

Ice sheet mass balance in Enderby Land, East Antarctica, inferred from GRACE, ICESat and in-situ measurements

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Keiko Yamamoto, Takashi Hasegawa, Koichiro Doi, Kazuo Shibuya, Hideaki Motoyama

The ice sheet mass balance in Antarctica attracts special attention because the Antarctic ice sheet holds about 90 % of fresh water in the world and its melting gives serious influences on the global climate changes. It can be estimated by the mass budget method, which calculates the net accumulations minus losses in the region concerned or measuring the elevation change over the time period with satellite and/or air-borne altimetry. However, the mass balance method is far from perfect for evaluating the total mass balance because of limited data coverage and measurement accuracies. Since the launch of GRACE, gravity measurements from space give more direct estimation of large scale mass balance in Antarctica. Actually GRACE revealed the continental scale negative mass trend in Antarctica (e.g., Velicogna and Wahr, 2006). Moreover, it revealed 3 areas with striking interannual mass trend in Antarctica. Among them, the positive mass trend in Enderby Land, East Antarctica, has not been well explained due to the several uncertainties. Since Post Glacial Rebound (PGR) , for instance, also causes large mass trend in Antarctica, we have to distinguish the sources of the mass trend to evaluate the ice sheet mass balance. Therefore we mainly concentrate our discussion on the sources of the regional mass trend in Enderby Land in this study. We compared the GRACE mass trend with a landwater model, Ice Cloud and land Elevation Satellite (ICESat) laser altimeter data [Zwally et al., 2002] and in-situ surface snow accumulation data measured with snow-stakes method by Japanese Antarctic Research Expedition (JARE). We also evaluated PGR models with surface geodetic data such as GPS and precise gravity measurements. Taking all the evidence into account, the main part of the mass trend in Enderby Land can be explained by the snow accumulation.

Keywords: grace, icesat, icesheet

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Fifteen years of suglacial water activity beneath MacAyeal Ice Stream, West Antarctica

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A recent study using ICESat data (2003-2006) has revealed a widespread subglacial water system in West Antarctica, beneath Mercer and Whillans ice streams. As part of that study, active hydrological signals were also found on MacAyeal Ice Stream, which clustered into four regions in the lower ice stream near the grounding line. These regions allfall within the orbital limit of the ERS-1 (1991-2000), ERS-2 (1995-2003)and ENVISAT (2002-present) satellites, which all carry radar altimeters (RA). Here, we use along-track ERS and ENVISAT RA data to examine the history of the hydrologyof the ICESat-identified lakes, and assess whether the lakes are permanent on the 15-year time scale. Measurements of the transient water volumes were improved by using Landsat imagery to correct for parallel, but non-coincident, ICESat surface elevation profiles. We confirm some of our findings with MODIS image differencing from various epochs.

Keywords: icesat, hydrology, lakes

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Mapping of thin sea ice and ice production in the Southern Ocean and Okhotsk Sea

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Most of coastal polynyas are latent heat polynyas, which are formed by the divergent ice motion due to prevailing winds or oceanic currents. Salt rejection due to active sea ice formation there produces dense water, which can be a source of bottom or intermediate water in the world ocean. Antarctic coastal polynyas are responsible for Antarctic Bottom Water (AABW) formation and Okhotsk coastal polynyas are responsible for ventilation of North Pacific Intermediate Water. Because in-situ observation of coastal polynyas is extremely difficult, detection of polynya areas by use of satellite data are very useful way for the investigation of coastal polynyas. In this study, we estimate sea ice production in the coastal polynyas from the satellite microwave data and heat flux calculation, and discuss the spatial distribution of sea ice production and interannual variability of the production. We develop an algorithm that estimates thin ice thickness in coastal polynyas from the SSM/I data, based on the comparison with ice thickness estimation from the AVHRR data. This algorithm uses 37 and 85 GHz brightness temperature data, and can also detect large icebergs and landfast ice. Using thin ice thickness distribution derived from this new algorithm and surface input data from the ECMWF Re-Analysis, heat flux calculation is performed on a daily basis and we estimate sea ice production under the assumption that heat loss in polynyas are assumed to coincide with the ice production, ignoring the effect of oceanic heat flux from below. The highest ice production area in the Southern Ocean is the Ross Ice Shelf Polynya, which is consistent with the production area of AABW with the highest salinity. Along the coast of East Antarctica, high ice production areas of coastal polynyas appear on the west side of peninsulas and glacier tongues, downstream of the Antarctic Coastal Current. It is noted that the second highest ice production area is the Cape Darnley polynya west side of Prydz Bay, suggesting the bottom water formation there. Highest interannual variability in the production is found in the Ross Sea among the Antarctic coastal polynyas. The ice production there has decreased from the1990's to 2000's, which may be a candidate for a recent change of the bottom water there. We also made a mapping of sea ice production in the Okhotsk Sea in a similar way. AMSR-E data is also used for estimation of thin sea ice with higher resolution as well as SSM/I. The mapping reveals that the highest ice production area in the Okhotsk Sea is the northwest shelf polynya, which is considered to be the main formation area of dense shelf water. About 30% of the total ice production over the entire Okhotsk Sea occurs over the northwest shelf within about 120km of the coast.

Keywords: coastal polynya, sea ice production, passive microwave

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JGS005 **Oral Presentation** **248**

Combining ICESat and ENVISAT Altimetry over Sea Ice

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Satellite altimeters on-board NASAs ICESat and ESAs ENVISAT continue to provide valuable data describing the topography of sea ice in the polar oceans. We present techniques which combine satellite laser and radar altimetry for the measurement of important geophysical parameters such as sea ice freeboard and snow thickness. Comparisons between the latest ICESat laser altimetry data and temporally and spatially coincident ENVISAT radar altimetry data allow us to examine retrievals of sea surface topography and sea ice freeboard in the Arctic and Southern Ocean. We discuss the challenges and limitations associated with combining datasets from two alternative altimeters. A major source of error in the conversion of sea ice freeboard to sea ice thickness, is uncertainty in snow depth. Laser altimetric measurements over sea ice include sea ice freeboard and snow depth, while radar altimetry measures sea ice freeboard alone. Therefore by differencing coincident laser and radar altimetric data, the possibility exists to obtain estimates of snow depth on sea ice. We explore the potential of combining satellite laser and radar altimetry for the retrieval of snow depth.

Keywords: cryosphere, satellite altimetry, remote sensing

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JGS005 **Oral Presentation** **249**

A refined GIA filter for GRACE applications

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In the application of GRACE derived time-dependent gravity observations to the problem of inferring the ongoing rates of loss of land ice from Alaska, Greenland and Antarctica, it is first necessary to filter the raw observations to remove the "contamination" due to the continuing influence of the Late Quaternary ice-age. The quality of the required filter may be tested on the basis of its ability to reconcile the continuing influence of Glacial Isostatic Adjustment (GIA) in regions where the only significant influence is due to this cause. The most important region where this test may be performed involves the Canadian sector of the North American continent which was once covered by the vast Laurentide Ice Sheet (LIS), the largest accumulation of land ice that existed in the northern hemisphere at Last Glacial Maximum approximately 21,000 years ago. Initial analyses of the GRACE data set have demonstrated that the ICE-5G(VM2) model of Peltier (2004: Ann. Rev. Earth PLanet. Sci. 32, 111-149) provides a very good first order fit to the observations in this region. There are nevertheless areas in which misfits do exist to the observed GRACE surface mass-rate field, misfits that may be employed to further improve the model. In this paper I will describe the refinements of the ICE-5G surface mas load component of this model that are necessary to improve the quality of the surface mass-rate predictions. The refined model is then employed in a series of forward modeling calculations to infer the ongoing rates of surface mass loss characteristic of each of the previously mentioned regions.

Keywords: grace, isostasy, degionlaciat

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JGS005 **Oral Presentation** **250**

Elevation Changes in Smaller Arctic Ice Caps and Glaciers Detected by ICESat

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Although tasked primarily with monitoring the spatial and temporal changes in the topography of the Greenland and Antarctic ice sheets, the Ice, Cloud and land Elevation Satellite (ICESat) provides a unique platform from which to observe other ice caps and glaciers at high latitudes. Notably smaller than their ice-sheet counterparts, these ice caps and glaciers, nonetheless, may still make significant contributions to sea-level change in the next few decades. Given recent evidence of accelerating climate change in the polar regions, their location makes them potential early warning indicators, perhaps responding more rapidly to temperature changes than the more massive ice sheets. Their location, however, also makes them less accessible, and thus, historically, less well-surveyed. Since its launch in January 2003, ICESat's Geoscience Laser Altimeter System (GLAS) has completed 12 mapping campaigns, accumulating an extensive time series of elevation profiles along reference ground tracks, with increasingly dense spatial coverage to +/- 86 deg latitude. This study examines two regions in the Arctic: Svalbard, Norway, and the Canadian Arctic Archipelago. A repeat-track analysis method is applied to the along-track elevation profiles in both areas, from all of the fully calibrated ICESat campaigns, to obtain estimates of elevation change rates. An important component of this approach is the determination of any cross-track slope from the small, but nonzero, horizontal offsets of the various campaign tracks from the targeted reference track. The results are compared to earlier surveys made using the Airborne Topographic Mapper (ATM). In addition, the cumulative elevation changes are compared to airborne and satellite imagery, at available intervals. Finally, the implications for global sea-level are discussed.

Keywords: icesat, arctic, glacier

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MODIS Fractional Snow Cover Products for Hydrologic Science with Space-Time Consistency

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Melt of seasonal snow cover in mountain ranges of the globe provides the dominant source of water resources to over a billion people. These regions are increasingly experiencing the pressing, coupled implications of climate change, drought, and population/demand increase. We present here validated, enhanced snow cover products using a multiple endmember spectral mixture analysis model that inverts MODIS surface reflectance products (MOD09) for fractional snow cover, plus the grain size and albedo of the fractional snow cover, to more accurately characterize global water resources. The MODIS Snow Covered Area and Grain Size/Albedo (MODSCAG) model specifically provides an accurate estimate of snowcover for regional studies in mountainous areas across the globe but also applicable to polar and grassland regions. The model uses spectral libraries generated with a radiative transfer model for varying grain size snow, adapting the spectral library according to the specific scene solar geometry. MODSCAG improves on extant delivered products in that it gives a physical retrieval of fractional snowcover with < 10% uncertainty in SCA and can serve as the next generation snow cover mapping for VIIRS on NPOESS and the GOES-R Advanced Baseline Imager. To provide hydrologic users with spatially and temporally consistent, physical fields, we must use the daily time series in an intelligent way incorporating persistence and knowledge of sensor and surface geometry to improve the estimate of the measured snow properties for a particular day. We consider two scenarios: one is the forecast mode, whereby we use the past, but not the future, to estimate the snow-covered area and albedo on that day; the other is the retrospective mode, whereby in the summer after the snow is gone we reconstruct the history of the snow properties for that water year. This space-time interpolation presents both scientific and data management challenges. The scientific question is: how do we use our knowledge of viewing geometry, snow accumulation and ablation, along with available ground data, to devise a scheme that is better than generic multidimensional interpolation? The data management involves large three-dimensional objects, identification of erroneous data, and keeping track of the lineage of the way a set of pixel values has been interpreted.

Keywords: snowcover, optical, fractional

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GRACE and ICESAT connections over Greenland and Antarctica

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GRACE gravity data and ICESat elevation measurements from 2003-2007 are compared over the Greenland and Antarctic ice sheets. The results to be presented will make use of tailored GRACE gravity solutions created using the newly reprocessed CSR RL04 data, released in February 2007. These updated CSR GRACE data sets are a significant improvement over previous releases, providing much greater resolution of the time-variable component of the gravity signal. Despite the improvements made in generating the RL04 data release, the solutions are still susceptible to high frequency noise and require that some level of spatial filtering be applied. Since the choice of filter can influence the interpretation of results, various spatial filtering methods will be explored to evaluate their impact on the final surface mass estimates. Spatial filtering and averaging of the high-resolution ICESat altimetry is explored to better characterize the large-scale similarities and differences between the GRACE gravity and ICESat elevation (melt and accumulation) signals. The polar-orbiting twin Gravity Recovery And Climate Experiment (GRACE) satellites provide global coverage of the Earth. Monthly GRACE gravity solutions have been provided since launch in 2002, with periodic upgrades to the mean background gravity field. The time-varying gravity solutions of the new version RL04 data have a spatial resolution of a few 100s of km and may support better than monthly temporal resolution. The Ice, Cloud, and land Elevation Satellite (ICESat) was launched in 2003. ICESat laser altimetry captures elevation measurements at 40 Hz from an orbit of 600 km altitude, 94 inclination, providing dense ~170 m along-track sampling up to 86 latitude. The ICESat mission scenario includes about three 33-day measurement campaigns per year, which have required extensive post-processing of the precision attitude determination to meet the mission requirement of a 1-sigma 1.5 arcsecond pointing error. Nearly all ICESat measurement campaigns are now fully calibrated, which provide the precise geolocation for cm/year elevation change detection. We have computed synchronized GRACE gravity solutions coincident with the ICESat measurement campaigns. Comparison of both products yields correlation between topographic changes observed by ICESat and mass changes observed by GRACE.

Keywords: grace, icesat, climate change

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JGS005 **Oral Presentation** **253**

Combination of Spaceborne, Airborne and Surface Gravity in Support of Arctic Ocean Sea-Ice and MDT Mapping

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Improved knowledge of the gravity field in the Arctic is a key to the utilization of satellite altimetry to determine sea-ice thickness and mean dynamic topography (MDT). In the paper we outline the construction of a new gravity field of the Arctic Ocean region, combining new GRACE and ICESat observations with earlier compilations of airborne, surface, and submarine gravity data from the Arctic Gravity Project. We compare the corresponding geoid model to a mean sea surface (MSS) model derived from ICESat lowest-level filtered laser altimetry and retracked radar altimetry, including consistent estimate of an Arctic Ocean MDT field. Arctic Ocean sea ice freeboard heights (and thus ice thickness) are an integral part of these investigations, and ICESat-derived freeboard heights show a good correlation to multi-year ice distribution as determined from Quikscat. Formal estimates of geoid error and error covariance functions are carried out using least-squares collocation, and investigations are carried out to get quantitative estimates of errors due to tides, MDT and geoid in an operational linear MSS estimator, to be used for the generation of CryoSat freeboard heights. The investigations represent the core of a recently completed ESA study ArcGICE, aimed a.o. at showing the synergy in the combined use of GOCE and CryoSat for enhanced estimation of sea-ice freeboard heights.

Keywords: arctic, geoid, cryosat

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Spatial variability of glacier elevation changes in the Alps obtained from the SRTM DEM

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According to the direct measurements on ten Alpine glaciers, the last 25 years were characterized by nearly continuous negative mass balances with an increasing trend and record values reaching ten-times the long-term mean loss. The related glacier down-wasting is already obvious for a large public as melt protection covers at ski-resorts and slowly collapsing rock walls generated a high media attention. The question, however, remains open as to what degree the small number of directly measured mass balances can be representative for the entire Alps. This question has been a fundamentally important aspect in systematic climate-related glacier monitoring. The comparison of recently obtained digital terrain information over wide areas now enables a closer analysis of corresponding causes and effects.The SRTM3 DEM has been acquired in February 2000 and is available for free at 90 m (3") spatial resolution for most parts of the world. It offers the unique opportunity to assess glacier elevation changes over the entire Alps by subtracting it from an earlier DEM. Such a DEM is available at 25 m spacing for the entire Swiss Alps and parts of Austria from the years around 1985. This study presents glacier-specific elevation changes for more than 1000 glaciers >0.1 km2 in the Swiss Alps using digital glacier outlines from 1973 as a proxy for the 1985 glacier extent and GIS-based automated data processing.Extreme thickness losses (partly exceeding 100 m) result for many flat and/or low lying glacier tongues and general thinning is documented over large parts of most other tongues. While the loss does not primarily seem to depend on geographic location, there is a certain dependence on elevation and a correlation (r=0.5) with glacier size and potential global radiation in summer. An earlier reported bias of the SRTM3 DEM is also visible in our study at elevations > 2800 m, but there is also some evidence that this is not an artefact. Nevertheless, more detailed studies including comparisons with photogrammetrically derived DEMs have to be performed to confirm this. The calculated mean mass change for five mass balance glaciers is much more negative than measured, indicating that the measured values require further calibration. On the other hand, the cumulative overall mass loss is 5 m w.e. less negative, indicating that the measured mean value overestimates glacier thickness loss the Alps.

Keywords: srtm, elevation change, alpine glaciers

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JGS005 **Oral Presentation** **255**

Studies of Ice Sheets and Sea Ice by ICESat Laser Altimetry: Recent Results and Future Missions

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other AGU

Waleed Abdalati

NASAs Ice, Cloud, and Land Elevation Satellite (ICESat), which was designed to operate continuously for 3 to 5 years, has acquired science data during twelve periods of laser operation ranging from 33 to 54 days each. The primary purpose of ICESat has been to acquire time-series of ice-sheet elevation changes to determine the present-day mass balance of the ice sheets, study associations between observed ice changes and polar climate, and improve estimates of both the present and future contributions of the ice sheets to global sea level rise. ICESat data is providing the most accurate elevation maps of Greenland and Antarctic ice sheets and is enabling detailed characterization of topographic features on ice sheet, ice shelves and ice streams. Ice sheet elevation changes derived from nearly 3 years of intermittent data are showing that some significant changes in the rates of mass input and output have occurred since the 1990's. Sea-ice freeboard and estimates of ice thickness are being mapped, showing seasonal and interannual changes in both the Arctic and Southern Oceans. The recent report of the US National Academy of Science on recommendation for future Earth observations, recommended extension of these laser altimeter measurements of ice sheets and sea ice with a ICESat-II follow-on mission. The planning and developments for ICESat-II are for similar but improved laser instrumentation, in particular to provide continuous long-term laser operation.

Keywords: icesat, polar ice, laser altimetry

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JGS005 **Oral Presentation** **256**

Sea ice effects on ocean tides

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It is known that sea ice presence may affect ocean tides both in amplitude and phase. However, only a few studies have been carried out in the past. The recent increasing interest in the polar regions and the arising need for accurate ocean tide models motivated this study which aims at quantifying the change of ocean tides as a function of sea ice concentration. Tide gauge records in the Arctic and Antarctic Oceans were analyzed and eight major tidal constituents were estimated for three months time periods. Time series of tidal constituents were then correlated with sea ice concentration obtained from ice charts and passive microwave data (SSM/I). It was found that sea ice decreases the amplitudes of almost all tidal constituents. A comparison with global and regional tide models reveals that none of the models shows any correlation with sea ice. This is due to the fact that most models assimilate altimetry data only in open water or during the summer months. The sea ice effects are quantified and a correction method is proposed which accounts for sea ice in ocean tide models for selected locations.

Keywords: sea ice, ocean tides, altimetry

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Validation Experiments in the Arctic supporting the CryoSat-2 mission

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The primary goals of CryoSat are to derive improved rate of change thickness estimates of the Earth's land and marine ice fields. Validating such retrievals derived from a phase coherent pulse-width limited polar observing radar altimeter such as SIRAL, the primary payload of CryoSat, is not a simple one. In order to fully understand all the respective error co-variances it is necessary to acquire many different types of in-situ measurements (GPR, neutron probe density profiles, drilled and electromagnetic derived sea-ice thicknesses, for example) in highly inhospitable regions of the cryosphere at key times of the year. In order to correlate retrievals from CryoSat with the in-situ data it was decided early in the CryoSat development that an aircraft borne radar altimeter with similar functionality to SIRAL would provide the necessary link, albeit on the smaller scale, and provide pre-launch incite into expected performances and issues. In 2001 ESA commenced the development of its own prototype radar altimeter that mimics the functionality of SIRAL. Similar to SIRAL, but with subtle functional differences, the airborne SAR/Interferometric Radar Altimeter System (ASIRAS) has now been the centre piece instrument for a number of large scale land and sea ice field campaigns in the Arctic during spring and autumn 2004 and 2006. Additional smaller science/test campaigns have taken place in March 2003 (Svalbard), March 2005 (Bay of Bothnia), March 2006 (Western Greenland) and April 2007 (CryoVEx 2007 in Svalbard). It is a credit to all parties that constitute the CryoSat Validation and Retrieval Team (CVRT) for the coordination, planning, acquisition of in-situ and airborne measurements and the subsequent processing and distributing of its data for analysis. CVRT has a robust infrastructure in place for validating its level 2 products derived from an operational CryoSat-2. This paper describes the different types of measurements acquired, the key science results to date and we stress the importance of the campaigns to date (despite the loss of CryoSat-1 in Oct 2005) and those planned in the run up to a CryoSat-2 launch.

Keywords: cryosat, ice fields, measurements

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Origin of internal radar reflectors at the EPCIA DML drill site - constraints for space-borne P-band radar

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Currently, feasibility studies are in progress to image the large ice sheets with P-band radar from space. In addition to determining ice thickness on continental scales, this technique could also be used to map the internal structure on an ice sheet, and exploit these to improve understanding of ice dynamics and ice-sheet history. Understanding the physical origin of these structures requires in-situ measurements, as provided by ice cores, and ground-based or air-borne radar measurements for reference. We present results on the origin of internal layers, as observed with radio-echo sounding data at the EPICA deep-drilling site in Dronning Maud Land, Antarctica, with a 60 ns and 600 ns long pulse at a frequency of 150 MHz. Most reflectors can be linked to volcanic peaks, as evident from the conductivity profile of the EPICA ice core. However, a particularly strong reflector at larger depth seems to originate from changes in the crystal c-axes, the fabric. It shows a dominant change from a girdle-type to increased single-maximum orientation. Our observations allow not only to determine accurate spatial age-depth distributions of the ice, but also to extrapolate the crystal orientation feature along the reflector, with implications for ice-sheet evolution, e.g. as considered by dynamic modelling. We therefore suggest to consider detection of such reflectors in the design of space-borne systems.

Keywords: radar, internal structure, reflector origin

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Ice topography seen from space with SIRAL 2,The cryosat altimeter

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After the loss of CryoSat in October 2005, due to launcher failure, development of the SAR Interferometer Radar Altimeter -2 (SIRAL-2) commenced in March 2006 in Alcatel Alenia Space following the approved procurement of the CryoSat-2 mission funded by ESA. To improve overall mission reliability SIRAL-2 contains accommodates two radars ed for purposes of cold redundancy whilst sharing the same interferometric antennas on the platform under the responsibility of mission prime contractor ASTRIUM GmbH. The most challenging features driving the design are high instrument stability and tracker robustness. CryoSat-2s mission objectives remain the same as CryoSat which were to measure, via estimates of surface elevation, rates of change of ice thickness on both land and sea very precisely to reduce uncertainties in the knowledge of the trend towards diminishing polar ice cover and thus furthering our understanding of the relationship between ice and global climate. This paper gives a detailed description of the instrument behaviour by means of: the measurement modes for each intended surface type, the methods of on-board tracking for each surface types, the contribution of the instrument in the measurement budget through its calibration modes. Currently all modules of the instrument are in development prior to final integration on the platform in 2008 and an expected CryoSat-2 launch in 2009. The next several months will be dedicated to intensive testing which will give a detailed insight of the instrument performance and capabilities, essential for the success of the mission.

Keywords: ice, topography, siral2

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Comparing summer and winter sea ice concentrations obtained from visual shipborne and satellite data in the Barents and Kara Seas

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Passive microwave imagery is an important source of sea ice extent and sea ice concentration data, providing daily coverage of the polar regions under all sky conditions. Shipborne observations are collected sporadically, but allow us to obtain detailed information about numerous sea ice characteristics. Sea ice parameters are estimated continuously, dividing track of the ship movement onto the zones with homogeneous ice conditions. In this study we compare available visual shipborne and satellite datasets. We use shipborne ice concentration as the basis for comparison. We employ visual shipborne observations obtained onboard research vessels Akademik Fedorov (2000, 2005), Mikhail Somov (2003) in summer and onboard icebreakers Kapitan Nikolaev (1995), Kapitan Dranitsyn (2000), research vessel Mikhail Somov (1996, 1997) in winter. These data are compared to the Special Sensor Microwave/Imager (SSM/I) satellite data for the same periods in the Barents and Kara Seas. The satellite data, derived by the NASA Team algorithm, are archived at the National Snow and Ice Data Center (NSDIC). Statistical analyses are presented for summary results, then separately for summer and winter seasons, for different ice conditions, and finally for total ice concentration including or excluding new ice forms. To investigate errors in different ice conditions, statistics are calculated based on the compactness of the ice pack, according to the three category (0-3, 3-6, 6-10 tenth) of SSM/I total ice concentration. Generally, in more compact ice conditions (6-10 tenth) errors are much lower than in regions with sparse ice (0-3 and 3-6 tenth). In low concentration conditions (0-3 tenth) satellite images underestimate total ice concentration. The maximal error is found in medium concentrations (3-6 tenth), most often coincide with the edge of the ice massive. We estimate influence of such parameters as ice forms, hummocks and ridges concentration, melting stage, snow depth and width of the fractures (obtained from shipborne observations) in order to find a possible source of errors in satellite data.

Keywords: visual, ice, concentration

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JGS005 **Poster presentation** **261**

Glacier change detection through assessment of debris-cover and supra-glacial lakes in the Hindu Kush and Himalaya.

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The glaciers of the Hindu Kush and the Himalaya have all been much larger in Pleistocene to mid-Holocene time. At present many are seen to be severely down-wasting and/or back-wasting, which has increased debris cover and supra-glacial lakes, as well as caused retreat of the lowest points of some white-ice streams in between multiple medial moraines. Probable increases in basal melt water may also be increasing surge frequency of glaciers in some areas. Such changes are highly variable, however, and do not seem to follow any discernable pattern; for example, in various places debris cover and supra-glacial lakes have increased in magnitude and frequency though coalescence, or ice glaciers have converted to rock glaciers, or lightly debris-covered termini have deflated to leave only ground moraine, or have seemingly inflated in shadowed north-facing regions. Data sources to document such change detection include historical maps (German, Austrian, Soviet military, US Department of Defense, Government of Afghanistan, Government of India, Government of Pakistan) of varying degrees of accuracy of cartographic and ground survey and photography, as well as multi-temporal satellite imagery. Historical aerial photographs, local government topographic maps, and hydrological runoff data are generally considered low-level state secrets so that access to such data is commonly problematic for foreign scientists; judicious use of such materials is sometimes possible, however, where adequate technical and political preparation is done. Provision of valuable information gained and training of local personnel in new technologies in remote sensing and GIScience has allowed some access to important data. Separate studies of glaciers in the Koh-i-Baba, Mir Samir, Koh-i-Bandaka, and Keshnikhan Hindu Kush, and the Wakhan Pamir of Afghanistan, are contrasted with the Tirich Mir Hindu Kush, Nanga Parbat Himalaya, Hunza Karakoram, and Baltoro-K2 Karakoram Himalaya of Pakistan. Glaciers in these areas have been instructive of the effects of change, although deconvoluting general regional trends from more global changes is not yet possible. On-going assessments of changes in the ice mass in High Asia through the GLIMS (Global Land Ice Measurements from Space) Southwest Asia Regional Center are important for overall measurement of the stored freshwater resources of a region upon which many tens of millions of people depend.

Keywords: glaciers, hindu kush himalaya, remote sensing

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SPOT5-HRS digital elevation models and their application to the monitoring of glacier elevation changes. A case study in North-West Canada and Alaska.

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Studies of the high latitudes ice bodies (including glaciers, ice caps and Greenland and Antarctic ice sheets) suffers from a poorly-known relief. The Shuttle Radar Topographic Mission (SRTM) provided a nearly comprehensive topography between 56S and 60N but did not reach the polar regions. Radar altimetry, on-board ERS and ENVISAT satellites, permits to survey accurately the low slopes of the central part of the Antarctic and Greenland ice sheets but this technique is less efficient for their steeper margins or on smaller glaciers and ice caps. The SPOT5-HRS (High Resolution Stereoscopic) instrument has the potential to accurately map the polar regions. The sensor acquires pairs of high resolution stereoscopic images which, given the good knowledge of the SPOT5 orbit, can be processed without ground control points (GCP) to generate Digital Elevation Models (DEM) covering up to 120 km by 600 km in a single pass. Mainly unglaciarized regions have been mapped by HRS since 2002 but the acquisition of a massive HRS archive over the polar regions is planned by the French Space Agency (CNES) and Spotimage during the International Polar Year (IPY). To prepare this mission, the accuracy of HRS DEM over ice and snow surfaces has to be evaluated. Here, we process SPOT5-HRS images acquired in May 2004 over South-East Alaska (USA) and northern British Columbia (Canada). Our DEM is generated without GCP by combining tools available from CNES with the OrthoengineSE of PCI-Geomatica software. It is then evaluated on and around the glaciers through comparison with SRTM-DEM and a few ICESAT-GLAS profiles. Despite the important snow cover at this time of the year, the DEM is calculated over 70% of the ground. A good agreement between SRTM and HRS is found both in planimetry and altimetry. When blunders are excluded, over non glaciarized areas, the mean elevation difference and its standard deviation are 5.1 m and 15.7 m, respectively. We also demonstrate the usefulness of sequential topography (SRTM in February 2000 and SPOT5-HRS in May 2004) for the monitoring of glacier elevation changes. We observe in details the elevation changes induced by a surge of one of the tributary of Ferris glacier. Surface lowering of 25 m and rising of nearly 60 m are observed in the 4 years time interval. Thinning rates up to 4 to 5 m/a are experienced at low elevations on Carroll, Muir and Burroughs glacier and confirms the ongoing wastage of glacier in South-East Alaska.

Keywords: alaska, glacier thinning, spot5 glims

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NSIDC DAAC Data Sets and Proposed Services to the IPY Community

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The International Polar Year offers an opportunity to the science community for ground breaking science. The data sets required by the IPY projects described in the submissions list on the IPY website span studies to be conducted by individual scientists to international consortia of programs and across many geophysical disciplines. Satellite data will no doubt play an important role in these proposed studies. The National Snow and Ice Data Center (NSIDC) Distributed Active Archive Center (DAAC) is a repository for snow and ice data products from the US NASA Earth Observing System satellites. These satellites and sensors provide a significant advancement over their predecessors and are providing a wealth of information on snow and ice. The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Aqua and Terra spacecraft and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) on the Aqua spacecraft provide improved visible/infrared and passive microwave imagery and products. The Geoscience Laser Altimeter System (GLAS) on the Ice, Cloud, and land Elevation Satellite (ICESat) is the first satellite-borne laser altimeter and represents an entirely new technology for ice remote sensing. Specifically the NSIDC DAAC archives and distributes data from the MODIS sensors on AQUA and TERRA, the GLAS instrument in ICESat, and the AMSR-E instrument on AQUA. All of these data products will be of interest to some degree to IPY research programs. This paper will describe the data products distributed by the NSIDC DAAC and offer suggestions as to how these data can be acquired by IPY research programs. NSIDCs philosophy is to work with our science clientele in the distribution of data and data products and in the modification of distribution approaches based on user comment. In addition to distribution of data sets and products, NSIDC is involved in several IPY projects. This paper will briefly describe our involvement in the Global Inter-agency IPY Polar Snapshot Year (GIIPSY) and the IPY Data and Information Service (IPY-DIS) efforts, with emphasis on the role NSIDC DAAC data sets play in these projects.

Keywords: satellite data, ipy

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The Italian Radio Echo Sounding investigation in Antarctica and last improvements of the RES system

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Radio Echo Sounding (RES) system is an active remote-sensing instrument that uses the electromagnetic wave penetration into the ice to obtain information on the level of the bedrock, the ice thickness and its inhomogeneties, i.e. the internal layering of glaciers and subglacial lake exploration. In 1995 the INGV developed its own airborne radio echo sounding system which is continuously upgraded. During the 1995, 1997, 1999, 2001 and 2003 Italian Antarctic Expeditions, the RES system has been put on an aircraft flying 1000 feet above the ice surface with two folded dipole antennas mounted beneath the aircraft wings, one for transmission and the other for receiving. The airborne radio sounding system operates at 60 MHz with a pulse width variable between 0.3 s and 1 s. The listing time of is 64 s and consequently the maximum penetration depth (range) in the ice is about 5.3 km. The horizontal sampling rate is 10 trace/s. At a mean speed of the aircraft of about 70 m/s, is equivalent to about 143 traces per kilometre (1 trace every 7 m). Navigation relied upon a GPS receiver on board giving longitude, latitude, altitude and time for each acquired radar trace. In this poster the enhanced RES system developed by INGV is described. This system, with a new carrier signal (phased coded), operates at 150 MHz with a new antennas system (8 folded dipoles) and with the implementation of powerful signal processing techniques. This new RADAR will improve horizontal and vertical resolutions in the ice with a capability to discriminate the internal layers (less than 1m) obtaining the measure of the ice accumulation rate through the knowledge of the depth of the known isochronal horizons. The first test phase of the whole system is planned for the next Italian Antarctic expedition 2007-2008.

Keywords: res system

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Results of the investigation on the Shackleton ice shelf area (Antarctica)

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In this poster we present the interpretation of radio echo sounding (RES) measurements collected during 2003 Italian expedition in Antarctica on the region between Mirny and Casey Stations. Data were acquired by means of an airborne radio echo sounding system (named INGV-IT, see poster The Italian RES investigation in Antarctica: the new radar system by the Italian glacioradar group in the same session) for remote-sensing studies of the polar ice in Antarctica. The aim was to define the morphological characteristics of the Shackleton ice shelf area. Several analysis were made on the RES data set: maps of bedrock morphologies, ice thickness, ice surface and its gradient. The different information coming from the maps were combined to define the characteristics of the area. In particular it was well defined the morphological structure of the main ice drainage of the region corresponding to Northcliffe, Denman and Adams outlet glaciers. The analysis of the ice thickness of the ice shelf also gave important information about actual anchorage line.

Keywords: radio echo sounding, bedrock morphologies, outlet glaciers

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JGS005 **Poster presentation** **266**

The 2006 melt extent and intensity over the Greenland ice sheet from passive microwave observations

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There are many factors that make Greenland important: climatologically as a center of cooling, hydrologically, as a large storage area, and, from a hazard perspective, because it produces large quantities of icebergs, to name a few examples.Differently from dry snow, wet snow has a relatively low albedo at visible and near-infrared spectral bands, absorbing more incoming solar radiation than dry snow. Recent studies also point out that an increased melt can provide a vapor source for cloud formation and enhances glacial sliding by migration of surface meltwater to the ice-bedrock interface.

Keywords: greenland, snowmelt, microwave remote sensing

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JGS005 **Poster presentation** **267**

Potential of dual frequency altimeter signal to survey snow accumulation over Antarctica

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Data from ENVISAT dual frequency radar altimeter are available over about 80% of Antarctica from November 2002 up to now and turn out to be relevant to study the Antarctica ice sheet. Indeed, the 35 days repeated period provides us with large datasets from which information concerning the ice sheet behavior is expected to show up. The altimeter waveforms shape is known to depend on the topography, the surface roughness, micro roughness and snowpack composition (stratification, grains size). The two radar frequency signals depend differently on these geophysical characteristics. It is therefore natural to search a link between the effect of volume echo on the radar waveforms and the accumulation process which builds the snowpack.From the radar altimeter waveforms, we use 8 parameters available in ENVISAT GDR products, namely the height, backscatter, leading edge width and trailing edge slope (H, Bs, LeW, TeS) in both Ku and S bands.We produced maps of these parameters for each ENVISAT 35 days repeated cycle. We find that the parameters show interesting and complementary average patterns. We also investigate the seasonal signals and trends.We conducted an empirical orthogonal function analysis to find some relevant relations between the radar signals and observed (compilations) or modeled (ECMWF/NCEP) accumulation patterns. We find that the additional S band waveform brings very significant information on the snowpack. The radar observations once properly combined prove to be linked with snow accumulation features. This presentation will show the first results associating radar altimeter observations and accumulation features.

Keywords: antarctica, dual frequency, snow accumulation

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Cryosphere Laser Altimetry from Space: An Advanced Measurement Approach Airborne Demonstration

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The Swath Imaging Multi-polarization Photon-counting Lidar (SIMPL) is an airborne prototype in development to demonstrate laser altimetry measurement methods and components that enable efficient, high-resolution, swath mapping of topography and surface properties from space. The main focus of this instrument development, sponsored by the NASA Earth Science and Technology Office Instrument Incubator Program, is to achieve detailed monitoring of ice sheet, sea ice and glacier change from a spacecraft in low Earth orbit. It builds upon the successes and lessons learned from the Geoscience Laser Altimeter System (GLAS) flown aboard NASAs Ice, Cloud and land Elevation Satellite (ICESat) mission. Although currently emphasizing polar-region cryosphere objectives, the SIMPL approach is also applicable in other scientific applications including changes in land topography, forest height and structure, and inland water and snow cover height and extent. Analysis and laboratory testing of the approach documents that accurate (cm-level) ranging is achieved with only ~10s of detected photons by (1) transmitting short (~1 nsec), low-power (1 microJ), high-rep rate (300 kHz) laser pulses, (2) illuminating small footprints (~10 m) thus limiting pulse broadening due to surface relief, (3) precisely timing (0.1 nsec) the detection of single photons per pulse, (4) applying time-space correlation of transmit pulses and receive photons, and (5) accumulating surface return photons from successive pulses. Because of the efficiency of this approach, multiple, adjacent, along-track profiles distributed cross-track can be measured simultaneously, forming an elevation image with 10 m spatial resolution. Measurement of the backscatter energy at 532 nm and 1064 nm with polarization parallel and perpendicular to the laser transmit pulse provides the depolarization ratio of the surface returns. Laboratory measurements we have performed of range-resolved, laser retro-reflection at these two wavelengths documents that the depolarization ratio can be used to differentiate surface types, including water, snow and ice based on differences in their wavelength-dependent scattering properties. A one-beam, breadboard version of SIMPL is planned for airborne testing and validation of the measurement approach in the spring of 2007. In early 2008, a four-beam version of the SIMPL prototype will be completed and tested, and deployed on airborne missions conducted as a part of the International Polar Year.

Keywords: lidar, cryosphere, topography

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Global automated multisensor snow and ice mapping system

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Dan Tarpley

A new global automated snow and ice mapping system has been developed and implemented into operations at NOAA/NESDIS. It generates daily continuous (gap-free) maps of snow and ice distribution at a nominal resolution of 4 km. The system is based on a synergy of satellite observations in the visible/infrared and microwave spectral bands from meteorological polar-orbiting and geostationary satellites. The idea behind combining observations in different spectral bands was to fully utilize both the all-weather monitoring capability inherent to microwave sensors and the high spatial resolution of satellite measurements in the visible and infrared. Currently data from GOES-East and West Imager, MSG SEVIRI, NOAA AVHRR and SSMI/I onboard three DMSP satellites are used. In the algorithm we tried to make maximum use of multiple observations from different satellite platforms. Both spectral signatures and temporal variability of the scene response are utilized to identify snow and ice. Climatological data on the snow cover distribution and the land surface temperature are applied to improve discrimination between snow and clouds in the satellite imagery. In the presentation we will give an overview of the developed algorithm and will analyze the system performance during the last two winter seasons. To assess the accuracy of the product, retrievals are compared to reports from ground stations and to results of NOAA interactive analysis of snow and ice distribution. The project Web page is http://www.orbit.nesdis.noaa.gov/smcd/emb/snow/HTML/multisensor_global_snow_ice.html

Keywords: snow

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JGS005 **Poster presentation** **270**

Space-borne detection of glacial lakes in the Russian Central Caucasus

Dr. Olga Tutubalina

Space-borne detection of glacial lakes is a key tool for prediction of glacial lake outburst floods (GLOFs) near retreating mountain glaciers worldwide. GLOFs threaten downstream populated areas; up-to-date lake locations and characteristics form a key part of regional datasets underlying hazard prediction and risk management. Techniques for glacial lake detection have been suggested for several areas, such as Swiss Alps and Himalayas. This study applies and refines existing techniques for a case study of the Russian Central Caucasus where until recently even the number of glacial lakes was unknown.Space-borne glacial lake detection techniques should fulfil several parameters: there should be frequent reassessment (once every 1-3 years) for the whole region, lakes of critical size should be resolvable in enough detail and reliably mapped using a uniform methodology. These criteria combined are currently only met by medium-resolution multispectral satellite imagery. Of these we assess SPOT XS/XI (20 m), Terra ASTER (15-90 m) and Landsat ETM+ (30 m) for an area of active lake development on the north-east slope of Mt. Elbrus in the Central Caucasus. Detection problems, such as distinguishing lakes from wet glacier ice are illustrated. It is shown that the Normalised Difference Water Index (NDWI), previously applied by other researchers for the Swiss Alps has region-specific and sensor-specific range of values for the study area. We also use our most recent inventory of glacial lakes in the Central Caucasusto check variability of NDWI for other selected lakes. Finally, recommendations are made on the choice of medium- and high-resolution satellite imagery and semi-automated techniques for glacial lake detection in an arbitrary glaciarized mountain area.

Keywords: glacial lakes, remote sensing, detection

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Combining satellite radar interferometry and inverse numerical modeling to infer the rheology of Larsen B before its disintegration

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The disintegration of 3250 square kilometers of Larsen B Ice Shelf in the Antarctic Peninsula within 5 weeks in 2002 provided the opportunity to establish a clear connection between the removal of ice shelves and the acceleration of their ice streams. Radar interferometry observations analyzed by Rignot et al. [2004] revealed that glaciers flowed up to eight times faster after the collapse of Larsen B, while Scambos et al. [2004] detected a lowering of ice stream surfaces by up to 38 m. The significance of these findings is heightened by the fact that neighboring ice streams with intact ice shelves remained largely unchanged. In this work, we use satellite radar interferometric observations of Larsen B obtained in 2000, which provide a near-complete coverage of ice velocity, to infer the spatial distribution of ice rigidity (flow law parameter B) before the disintegration by an inverse control method. Of particular interest is how the presence of rifts affected the distribution of ice rigidity and ice shelf flow patterns compared to the case of a non-rifted ice shelf. We further employ these results to investigate factors that could have contributed to the observed 20% acceleration of ice shelf flow between 1996 and 2000 [Rignot et al., 2004]. This work raises the prospect of using the inferred ice rheology patterns as proxy to predict whether other ice shelves are in the process of collapse, refining forward numerical modeling by the application of parameter B as a distribution rather than a single averaged value, and elucidating the role of fracture in ice shelf processes. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration, Cryospheric Sciences Program.

Keywords: inverse modeling, ice shelves, larsen b

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JGS005 **Poster presentation** **272**

Analysis of combined passive microwave and enhanced-resolution scatterometer sea ice estimates

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Passive microwave sea ice concentration fields provides one of the longest running and most consistent records of changes in sea ice. Scatterometry is a more recently developed data product, but now provides a record of ice conditions over several years. Resolution enhancement techniques applied to scatterometer fields can provide much higher effective resolution (~10 km) than are available from standard scatterometer and passive microwave fields (25-50 km). Here, we combine ice extent fields from enhanced resolution scatterometer fields with passive microwave sea ice fields to create merged fields that provide concentration estimates with a higher resolution ice edge along with data confidence levels that provides unique insights into state of the sea ice for the period 1999-2004.

Keywords: sea ice, passive microwave, scatterometer

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Operational Sea Ice Charts: A New Tool to Evaluate Passive Microwave Estimates of Arctic Sea Ice and Track Interannual Variability

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Harry Stern, Florence Fetterer

Operational sea ice charts produced weekly by the U.S. National Ice Center have been gridded to a 25-km EASE grid and are available for the period 1972-2004. These charts use manual interpretation of satellite imagery and other information to create accurate analyses of Arctic sea ice conditions. Though they employ passive microwave data when other sources are not available, they are a relatively independent estimate of sea ice concentration and extent, particularly after 1995 when use of synthetic aperture radar data became prevalent. Also since 1995, partial ice concentrations were reported in the ice charts, including multi-year, first year, and thin ice categories. Thus, the ice charts provide a unique data set to track trends and to compare with the passive microwave data sets on a hemispheric and regional scale. The results show deficiencies in the passive microwave data particularly near the ice edge and during summer conditions. Such information can provide insights into quantitative errors of the passive microwave estimates and possibilities for improvements.

Keywords: sea ice, passive microwave, operational ice charts

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JGS005 **Poster presentation** **274**

Estimating the snow properties of the Antarctic ice-sheet from the dual frequency altimeter of Envisat

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Monique Dechambre, Frdrique Rmy

Spatial radar altimeters have been widely used over the Antarctic or Greenland ice-caps for mass balance studies. However, the radar signal is sensitive to many properties of the snow that impacts the height measurements. These snow properties can be recovered by a carefull analysis of the altimetric signal.Since the launch of Envisat in 2002, two datasets at two different frequencies are available over the Antarctic ice-cap, at Ku (13.6 GHz) and S band (3.2 GHz). Previous studies on these signals show that the two bands have different interactions with the sensed snow medium. Surface roughness at different scale, snow grain size or stratification have a different effect at these two frequencies. The dual frequency signal provides therefore a unic chance to get to know these snow properties. We propose to achieve this goal through the modelling of the altimetric echo and its inversion.First, we show the prime importance of the small-scale roughness on the radar signal. These observations underline the need to adapt the pre-existing altimetric echo models, in order to fully compare the two Envisat bands. A model is then developped that takes into account the small-scale snow roughness through an IEM method. The sub-surface is then modelled with both an inhomogeneous medium composed of snow grains and dielectric discontinuities at the layer interfaces. We use the model to explain the observed altimetric signal. In particular, we focus on the explanation of its seasonal variations. Based on the modelling, we finally use the dual-frequency dataset to retrieve properties of the snowpack over the Antarctica plateau, and analyse their distributions.

Keywords: antarctica, snow, altimetry

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Effect of firn depth and density variations on ice sheet elevation changes in Antarctica

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IMAU Posc Doc

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Satellite altimetry (radar on ERS-1and ERS-2, laser on IceSAT) is a valuable tool to monitor ice sheet elevation change (dh/dt). Before dh/dt observations can be translated into long-term volume changes, corrections must be made for postglacial rebound (usually < 1 cm per year) and short-term variability in firn densification rate and accumulation. Because dh/dt observations cover a period of about 15 years, annual to decadal anomalies in the firn depth and density can have a significant contribution to ice sheet elevation changes. We calculated this contribution, using 6-hourly output of a regional atmospheric climate model (1980-2004) to drive a time-dependent firn densification model. The results show that a significant part of the observed elevation changes in Antarctica in the period 1995-2003 can be explained by changes in firn depth and density caused by temperature and accumulation variability. An exception is the Amundsen coast of West Antarctica, where glacier thinning clearly exceeds or is even opposed to changes expected from firn modeling. These results are therefore useful to separate long-term (ice dynamical) effects from the short term climatic noise in satellite dh/dt data.

Keywords: antarctica, satellite altimetry, mass balance

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Ice velocity along the transect from Zhongshan station to dome a from static GPS observation, East Antarctica

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E Dongchen, Wang Zemin, Zhou Chunxia

Dome Argus, the highest ice feature in Antarctica, comprising a dome or eminence of just over 4000 m elevation, located near the center of East Antarctica and approximately midway between the head of Lambert Glacier and the South Pole. In the framework of the International Trans-Antarctic Scientific Expedition (ITASE) and Chinese Antarctic glaciological research program, glaciological studies have been conducted along the transect from Zhongshan station to Dome A. The first expedition was carried out to a point 296km. Repeat GPS measurements in 1996-2005 provided ice velocities along the transverse profile from Zhongshan Station to Dome A

Keywords: dome a, ice velocity, gps

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Variations in mass balance and snow and firn densities along a transect in the percolation zone of the Greenland ice sheet

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Changes in ice sheet mass balance are often derived from large spatial scale satellite measurements of elevation change. However, in the percolation zone of ice sheets seasonal changes in snowpack density ensure that large changes in mass can occur with only limited change in surface elevation. Meltwater generated at the surface refreezes at depth in the snowpack/firn causing a redistribution of mass through densification; this densification varies spatially across the percolation zone. In Greenland in 2004 and 2006, snow pit and shallow core density measurements were made to ~3 m depth in the spring, prior to summer melt, and in the autumn following summer melt, percolation and refreezing. Short spatial changes were investigated at 9 sites within 1 km2 at 1 m, 10 m, 100 m, and 1 km intervals from T5 on the EGIG line (1940 m.a.s.l. 690 51N, 470 15W) along two transects, parallel and perpendicular to the EGIG line. Larger spatial scales were investigated at 7 sites along the EGIG line, at ~10 km intervals from T1 to T7 in 2006, and in 2004 at 2 sites located 10 km toward both the ice sheet margin and interior from T5 (T4 and T6 respectively). At each site, we derived average firn density for post melt 2003, 2004 and 2005 snowpacks.For all post melt snowpacks, the average density increased with distance towards the ice sheet margin. For the 2005 post melt snowpack, average density increased by 20% over 57 km (an elevation change from 2050 m to 1680 m) between T7 and T1. The same densification rate was observed for the 2004 post melt snowpack between T6 and T4. A similar trend was observed in 2003 although the densification rate was reduced. Measurements in snowpack density prior to melt reveal no significant change with elevation. Quantification of the magnitude and spatial variability of these densification gradients is essential for more accurate estimates of mass balance change derived from elevation changes measured by satellite radar altimetry.

Keywords: greenland, mass balance, altimetry

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Controls on spatial and temporal variability in the snowpack of a High Arctic ice cap: Devon Island Ice Cap, Nunavut, Canada.

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Temporal and spatial variations in rates of accumulation, surface melting, percolation and refreezing create complex snowpack structure across high Arctic ice caps. Quantifying this variability is a crucial component of efforts to accurately derive mass balance changes from satellite measurements of surface elevation change and a better understanding of the causal processes is important in determining the crucial contribution of melt water retention by refreezing to the surface mass balance of arctic ice masses. Detailed stratigraphic logging of snowpack and ice core structure and density to ~3 m depth was carried out at ~ 1 km intervals along a 48km transect on the Devon Ice Cap, Canada, in spring (pre-melt) and autumn (during/after melt) 2004 and 2006 to characterise snowpack variability seasonally and across the full range of snow facies. Simultaneous meteorological measurements were gathered by 3 AWS and 15 HOBO temperature loggers along the transect. Dye tracing experiments were also conducted from spring to autumn 2006 to identify the locations and depths to which melt water penetrates and refreezes. Spring snow packs show little spatial variability in density and structure across the transect, but by autumn the density of the snowpack increases with proximity to the equilibrium line. This snowpack densification is largely caused by an increase in the percentage of total mass concentrated within ice layers as elevation decreases. Dye tracing reveals that in summer 2006 surface meltwater generated at 1400 m.a.s.l. percolated through the summer 2005 surface and several minor ice layers to a depth of 1.5 m. Above this, meltwater was retained in the 2006 snowpack. Below this, no dye was recovered and a dramatic reduction in the summer snowpack was observed with large-scale runoff generation evident along a perched runoff horizon evident from 1350 m.a.s.l., some 400-500 m elevation above the long-term ELA. Results present a profound but important challenge to ongoing efforts to effectively model snowpack and firn evolution across High Arctic ice caps and highlight the current limitations of satellite radar altimetry as a means of quantifying mass change.

Keywords: glacier, cryosphere, mass balance

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JGS005 **Poster presentation** **279**

Arctic sea ice freeboards and mean dynamic topography in the Arctic Ocean from satellite altimetry

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The ability to map changes in the mean dynamic topography (MDT) in the Arctic and thus the underlying ocean circulation provide insight into the basal melting process of the sea ice, since the changing inflow of Atlantic and Pacific waters is believed to be a major source of currently observed sea ice changes. Recent methods developed to observe sea ice freeboards from altimetry are highly dependent on identification of open water in the ice cover. This knowledge can be used to estimate the present sea surface in the Arctic Ocean, and thus by subtracting a geoid model, an observed MDT is found. In this paper we present the methods for estimation of sea ice freeboards, and MDT in the Arctic from satellite altimetry. We use data from ERS radar altimeter up to 82N and measurements from ICESat laser altimeter covering up to 86N. In the radar data open leads within the sea ice are identified from specular returns of the radar pulses. The return of the laser altimeter pulse does not show the same characteristic specular returns, and instead a lowest-level filtering algorithm is applied to estimate the present sea surface. The sea ice freeboards estimated by these techniques give realistic results, and show qualitatively same features, when compared to QuikSCAT backscatter maps. The surfaces spanned by the open water measurements identified in the freeboard estimates represent the mean sea surface. By using a draping technique a composite mean sea surface based on the ERS and ICESat are found, and subtracted from a geoid model, here using the geoid derived within the Arctic Gravity Project (ArcGP), we obtain for the first time a MDT based on satellite observations. The MDT observed by satellite altimetry maps the main circulation in the Arctic, e.g. the Beaufort Gyre, and the low in the Norwegian-Greenland Sea, and a comparison to existing global and regional oceanographic models of the Arctic MDT show good qualitative agreement.

Keywords: arctic, sea ice, altimetry

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Icesat elevation change detection in Antarctica

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The Ice, Cloud, and land Elevation Satellite (ICESat) has provided elevation measurements of the Earth with unprecedented accuracy. Launched in 2003, ICESats primary mission is to measure elevation change of the major ice sheets with cm/year accuracy. We discuss some of the mission calibration and validation operations that have lead to precise elevation change detection and then exhibit the full changing landscape of Antarctica as detected by ICESat. A critical mission requirement is a 1-sigma pointing knowledge of 1.5 arcseconds, necessary for precise geolocation of the laser footprints on the surface of the Earth. Footprint geolocation, calibration, and validation methods are shown. ICESat laser altimetry captures elevation profiles at 40 Hz from an orbit of 600 km altitude, 94 degrees inclination, providing dense ~170 m along-track sampling up to +/-86 degrees latitude. The ICESat mission scenario includes about three 33-day measurement campaigns per year since launch in 2003, with nearly all campaigns fully calibrated. ICESat data have sub-decimeter accuracy, and across flat smooth surfaces the ICESat measurement precision is shown to be 2-3 cm. We discuss ICESat measurement error sources and the potential for future data enhancements. The changes observed by ICESat across the Antarctic landscape vary widely in scale and spatial extent. Some of the largest features are meter per year changes in the ice streams leading into the Ross embayment (rise in Kamb (C) and fall in Whillans (B)). ICESats small footprint and high resolution reveal details not previously detectable with large-footprint radar altimetry, such as subglacial lakes and volcanoes; several examples of these incredible features are shown, both corroborating other detection methods and making new discoveries. Other example areas highlighted are changes in the West Antarctic outlet glaciers, the Scott Coast feeding into the Ross Sea, the East Antarctic coast near Williamson Glacier, and the New Swabia area near 0 degrees longitude feeding the Larsen and Fimbul ice shelves. In these areas, ICESat detected elevation changes are computed and are compared to ice stream balance and/or measured velocities. We discuss the climate change implications of these areas.

Keywords: icesat, antarctica, climate change

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JGS005 **Poster presentation** **281**

Change of the Greenland ice sheet from GRACE, ICESat and airborne laser

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The GRACE mission gravity field change data provides a direct estimate of mass loss of the Greenland ice sheet. We use in the paper a formal generalized inverse technique on monthly GRACE spherical harmonic solutions to model mass changes of the Greenland ice sheet. We compare available GRACE level-2 solutions from different processing centers, showing a reasonable overall agreement in the trend. Results obtained for the period 2002-6 show values around 120 km3/year, using a simple correction for postglacial rebound based on observed rates of height to gravity change ratios from Scandinavia. Changes are compared to height changes observed from ICESat and airborne lidar campaigns in selected margin areas of the ice sheet, and also compared to mass and height change estimated by a simple glaciological-climatological model and NCEP temperature data.

Keywords: grace, greenland, icesat

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GRACE-Based Estimates of Arctic Freshwater

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Streamflow from Arctic river basins has been increasing in recent decades in response to warming climate. In addition to being a sensitive indicator of global change, Arctic discharge is the most critical component of the freshwater budget of the Arctic Ocean, where increasing freshwater flows may slow rates of North Atlantic Deep Water formation and heat transport by the thermohaline circulation. However, quantifying rates of freshwater discharge from the entire Pan-Arctic drainage has been troublesome using traditional stream gauging methods. Here we use satellite measurements of variations in continental water storage from the GRACE mission to present first estimates of monthly freshwater discharge from the entire Pan-Arctic for the period 2003-2005. Results show that rates of Pan-Arctic discharge for this time period are significantly larger than those suggested by gauge-based estimates, and furthermore, may indicate that discharge rates are accelerating.

Keywords: freshwater discharge, grace, water balance

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