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GGSP: Realisation and Maintenance of the Galileo Terrestrial Reference Frame

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Abstract

The realisation and maintenance of a Galileo Terrestrial Reference Frame (GTRF) is the main function of the Galileo Geodetic Service Provider (GGSP). The GTRF shall be compatible with the latest International Terrestrial Reference Frame (ITRF) within a precision level of 3 cm (2 sigma). The connection to the ITRF is realized and validated by stations of the International GNSS Service (IGS) and by geodetic local ties to stations equipped with other geodetic techniques. It is demonstrated that this GTRF can be maintained by including the Galileo Signal-in-Space data, once Galileo reaches its operational stage.

The GGSP will also provide additional products, such as Earth Rotation Parameters, satellites orbits, clock corrections for satellites and stations, which will be offered to the Galileo user community to have most precise access to the GTRF and will be used to monitor the accuracy of the corresponding Galileo Mission Segment.

The GGSP was built up in time, and for a final demonstration the full system was operated for an interval of 6 months. During that time also microwave data from the two active GIOVE satellites were used.

The GGSP Consortium followed the most up to date IGS standards of weekly processing during seven monthly campaigns (November 2006 to June 2008) and a continuous processing from September 2008 to February 2009 delivering several versions of the GTRF. The latest GTRF solution (GTRF09v01) has an RMS position difference with respect to the ITRF2005 computed over the 71 common stations of 1.1 and 2.9 mm in the horizontal and vertical components, respectively. The RMS velocity differences are 0.3 and 0.6 mm/y, respectively. The GGSP GPS satellite orbits and clock corrections agree with the IGS Final products at a level of 5-11 mm and 0.02-0.03 ns, respectively. The quality of the GIOVE orbits is at a level of 20-30 cm. The Hydrogen-Maser on board of GIOVE-B is nearly one order of magnitude better than the GPS satellite clocks.

1. Introduction

A highly precise and stable Galileo Terrestrial Reference Frame (GTRF) is the basement, upon which all Galileo products and services will rest. Therefore the network of Galileo Sensor Stations (GSS) defining this reference frame is of fundamental importance being the interface between the geodetic reference and all Galileo products.

The realisation of the GTRF is the main function of the Galileo Geodetic Service Provider (GGSP) serving both the Galileo Core System and the Galileo users. The GGSP will enable all users of the Galileo system, including the most demanding ones, to rapidly access the GTRF with the precision required for their specific application. The GGSP responsibility will additionally include the generation of other precise products that are needed to get full and unlimited access to the GTRF. These products, which are generated simultaneously with the GTRF activities, comprise Earth Rotation Parameters (ERP) as well as satellite orbits and clock corrections. Only with such a complete and consistent set of high precision products the GGSP can truly fulfil its prime task of providing a reference frame to the various user communities. This implies that all the related products will be made openly available to the user community. In addition, these high precision products will be extremely valuable for the validation of the operational products generated by the Galileo Ground Mission Segment (GMS).

The GGSP Prototype is being realized by the consortium given in Table 1.

Table 1. GGSP Prototype consortium

Partner		Country	Responsibility
GFZ	Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum, Potsdam	Germany	Coordinator, PF, Orbit/clock combination
AIUB	Astronomical Institute University of Bern, Bern	Switzerland	PF, Validation
ESOC	European Space Operation Centre, Darmstadt	Germany	PF, Interfaces
BKG	Bundesamt für Kartographie and Geodäsie, Frankfurt(Main)	Germany	Validation, Outreach
IGN	Institut Géographique National, Sant-Mandé	France	GTRF generation
NRCan	Natural Resources Canada, Ottawa	Canada	Validation, Outreach
WHU	Wuhan University, Wuhan	China	Special studies, Outreach

(PF: Processing Facility)

2. Aspects of Reference Frame Realisation

2.1 General

The precision the Terrestrial Reference Frame (TRF) has to be realised with and maintained over decades is approaching the mm level in position and the mm per year level in velocity for applications like monitoring of crustal movements and sea level changes. Although the GNSS technique has evolved in the last decade to the most important contributor to the TRF realisation the other space geodesy techniques (in particular Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI)) are of high importance for the International Terrestrial Reference Frame (ITRF) origin and scale definition. Doppler Orbitography Radiopositioning Integrated by Satellite (DORIS) is also an important technique contributing to the ITRF and providing a large number of co-location sites with GNSS (Altamimi et al., 2006). The particular strengths of one observing method can compensate for weaknesses in others if the combination of the various space geodesy techniques is properly constructed, suitable weights are applied and accurate geodetic local ties in co-location sites are available. None of the space geodesy techniques is able to provide all the necessary parameters for the TRF datum definition (origin, scale, and orientation). Co-location sites are the basis of the existence of the ITRF. The SLR technique provides the most precise connection of the reference frame to the Earth centre of mass, a natural TRF origin. VLBI is the only technique able to realise the connection to the inertial frame for a precise monitoring of the Earth rotation (UT1), precession and nutation, which deliver the necessary parameters and models for deriving precise analyses in all satellite geodetic applications. The main role of GNSS is the densification of and the access to the ITRF given the limited number of expensive SLR and VLBI stations. The GNSS network is hence playing a major role in the ITRF construction by connecting SLR and VLBI networks, given the relevance of these two techniques for the ITRF origin and scale (Altamimi and Collilieux, 2008; Ray et al. 2004). The GNSS is also delivering the most accurate and best time-resolved polar motion time series.

The GTRF has to fulfil the following general requirements:

- Accurate TRF for all relevant Galileo operations.
- Long-term stability with high accuracy and reliability.
- Connection to ITRF at the same accuracy level.
- Maintenance of GTRF to the maximum extent independent from other TRF realisations.

The necessity and importance of having GSSs co-located to instruments from other space geodesy techniques is important for an independent maintenance – at least from other GNSS. It is essential that a permanent (e.g. weekly) monitoring of the station behaviour is performed. Moreover the advantage of a continuous analysis is the ability to early detect changes and events. Two examples illustrate some non-linear station motions and their impact in the time series combination. Seasonal signals can be seen for the station Yakutsk (YAKT, Russia), which are in most cases connected to snow accumulation on the antenna (Fig. 1, Jaldehag et al. 1996). Another interesting effect can be seen at the station Albert Head (ALBH, Canada), where the station motion is affected by so-called 'silent' earthquakes (Fig. 2), driven by the convergence of tectonic plates along the Cascadia zone (Dragert et al. 2001).

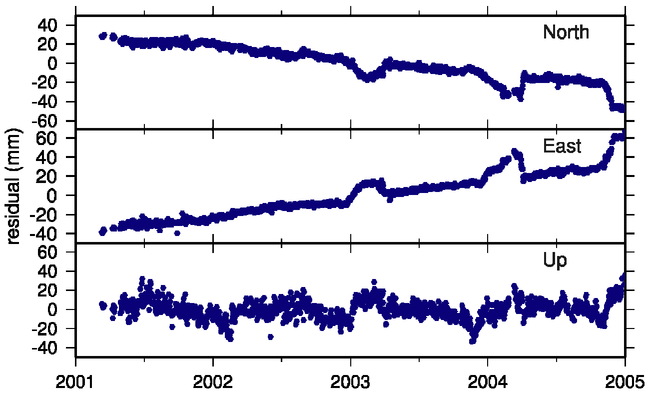

Fig. 1. Position time series of station Yakutsk (Russia) influenced by un-modelled effects like snow accumulation on the antenna

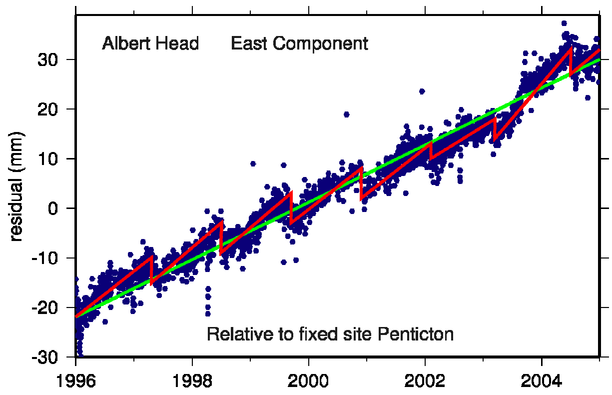

Fig. 2. Position time series of station Albert Head (Canada) affected by 'silent' earthquakes

2.2 Necessity of intra-technique realisation

The International GNSS Service (IGS; Dow et al. 2009) uses its own ITRF realisation, based on GNSS only, but fully consistent with the ITRF in origin, scale, and orientation. The GNSS-only network solution is aligned in positions and velocities to the ITRF using the 14 datum parameters. The reason is that there are still some unresolved coordinate discrepancies between GNSS and other techniques in co-located sites, most probably due to, e.g. dubious geodetic local ties and/or technique-specific (including GNSS antenna) effects. Using ITRF station positions and velocities directly to generate IGS products would introduce distortions and inconsistencies that could not easily be isolated or controlled. Using an IGS realisation does not imply that the GNSS frame is necessarily superior to the ITRF or those of other techniques, just that it is more self-consistent (Ray et al., 2004).

Starting with GPS week 1400 (November 5, 2006), the IGS has switched from relative to absolute model corrections to account for antenna phase centre variations (PCV, Schmid et al. 2007). At the same time, the IGS has adopted the ITRF2005 (Altamimi et al., 2007) to form its specific frame called IGS05, composed of about 100 sites whose ITRF2005 coordinates were corrected to account for relative to absolute PCV differences. In order to preserve the ITRF2005 datum (origin, scale, and orientation) the IGS05 was aligned to the ITRF2005 using a 14-parameter similarity transformation (R. Ferland, Proposed IGS05 Realization, http://igscb.jpl.nasa.gov/mail/igsmail/2006/ msg00170 .html, 2006). In reality, among the 14 parameters, only the scale factor was significant, representing the mean height difference of IGS05 station positions estimated with relative and absolute PCVs.

To get superior quality in all Galileo products, the GTRF realisation should follow the same strategy and should realise a network without any internal distortions and best aligned to the ITRF. This means that in a first step a free-network solution, using all GNSS data, should be generated which is transformed/aligned to the ITRF in a second step using the geodetic minimum constraints approach. The alignment to the ITRF is optimally achieved through the usage of the GNSS/IGS stations of the ITRF.

3. Requirements for GTRF Realisation

From the Galileo project specifications the requirements for the GTRF realisation can be summarized as follows:

- The GTRF shall be defined as a geocentric Cartesian Reference System and shall be compatible with the definition of the ITRF. The relative accuracy (compatibility) of station coordinates in the GTRF and the latest ITRF shall be 3 cm (2 sigma) for the current epoch of the Galileo operational products. Each GSS position shall be defined by three coordinate and three velocity values.
- The GGSP shall update the GTRF in coincidence with updates to the ITRF and otherwise as required in order to maintain the compatibility with the ITRF.

To get an optimal GTRF realisation the selected set of stations should have a good global distribution and should be relatively dense enough to allow for ambiguity resolution. Furthermore, the selected GTRF sites should have a good overlap with existing multi-technique ITRF stations to ensure the reliability and stability of the alignment of the GTRF with the ITRF.

The present realisation and the maintenance will be based on data from GPS and experimental Galileo satellites.

4. Strategy for GTRF Realisation

4.1 GTRF maintenance

GGSP has developed the strategy for maintaining the GTRF during the whole lifetime of the Galileo system. The monitoring shall be continuous and therefore continuous data are needed.

In addition to necessary updates in case of changes in the GSS distribution the reasons to consider regular validations and possible updates in the GTRF comprise un-modelled non-linear station motions and other sources. They can be summarized as follows:

- Changes in local environment and conditions over time.
- Changes in the GSS instrumentation (equipment upgrade, especially the antenna and radome changes).
- Changing 'seasonal' or short periodic effects, which are not yet modelled (atmosphere and groundwater effects, anthropogenic effects, etc.; van Dam et al. 2001, Tregoning et al. 2005).
- Changes resulting from earthquakes, silent earthquakes in position and/or velocity.
- Errors in initial velocities adopted from co-located GNSS solutions or NNR-NUVEL-1A for non-co-located sites.

The maintenance of the GTRF will be based on regular weekly network solutions. Each weekly solution will be compared to the latest version of the GTRF, the solutions of the week before and the accumulated solution including the history of observations. If there are any larger differences detected which exceed the given threshold an alarm is raised and a dedicated analysis is started, which reveals the causes for the detected differences. If requested, a new GTRF is generated, i.e., for some stations new positions and/or new velocities are assigned or a complete new GTRF is released.

4.2 Network

As already outlined, a global free-network adjustment will be applied to get the highest internal network quality. The ITRF alignment will then preserve the full internal consistency of the GTRF. For this purpose a significant number of ITRF stations – co-located or non-co-located to GSSs – have to be part of the GTRF network. To achieve the highest possible quality, additional IGS sites will be included to fill sparse regions for an optimal ambiguity fixing and for a more efficient alignment to the ITRF. Thus we have in total 131 IGS sites. At 25 of these sites we have two active receivers. If data of the "prime" receiver at the site are unavailable the data of the designated "back-up" receiver are used. For the moment data from both receivers will be analysed. Because the GSS are still not available the 13 Galileo Experimental Sensor Stations (GESS) are used instead (Fig. 3), which gives us 144 observation files in total. There are two IGS sites where the observations from one antenna are acquired by two receivers. So the coordinates for 142 sites have to be estimated.

The GTRF stations can therefore be classified into two groups:

- G(E)SS recording GPS and Galileo data using the same antenna but different hardware units steered by the same external clock.
- Additional IGS stations, which should be either IGS reference frame sites or ITRF core stations with co-location of geodetic techniques. From those stations only GPS data are used.

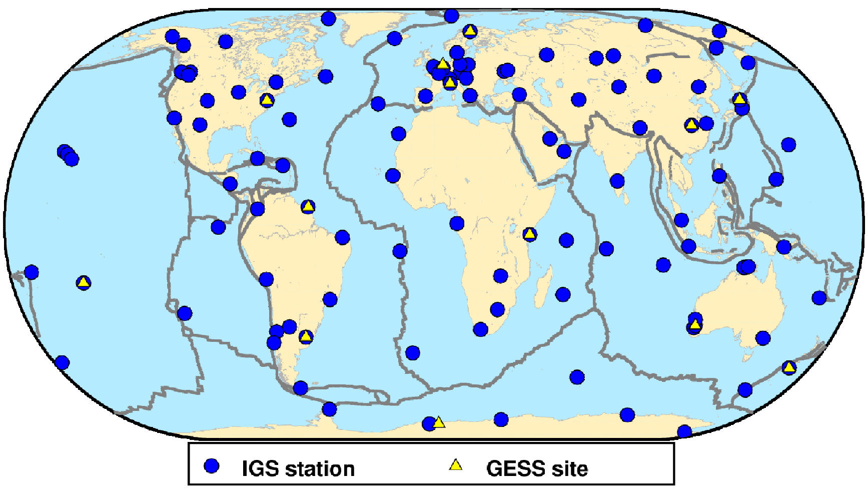

Fig. 3. GTRF station network (February 2009)

4.3 Processing

Three Processing Facilities (PF), using the software packages Bernese GPS Software (AIUB) (Beutler et al., 2007), NAPEOS (ESOC) (Springer, 2009) and EPOS (GFZ) (Gendt et al., 1999), will process data from all stations defining the GTRF. On a weekly basis they generate mean station position solutions (in form of SINEX files, http://www.iers.org/documents/sc/sinex/sinex_v210_proposal.pdf) as well as products for daily satellite orbits, station and satellite clock corrections, and Earth Rotation parameters. All these products are combined to obtain the official GGSP products by the Combination Facilities (CF). The SINEX files yield weekly solutions for validating the GTRF and for generating the accumulated solution for the whole data history. The accumulated solution is the basis for the GTRF. The alignment to the ITRF will be ensured using the minimum constraints approach. This way all GSSs, even those which are not co-located with existing IGS/ITRF stations, will be expressed in the ITRF. For all SINEX combinations the CATREF software (Altamimi et al., 2004) is used.

4.4 Validation

Before releasing or updating any GTRF solution a comprehensive validation is performed at a so-called Validation Facility (VF).

The validation of the requirement ”3 cm (2-sigma) accuracy of GTRF positions with respect to the ITRF” is, however, a complex task. Validation is, therefore, decomposed into a number of sub-tasks including the validation of the quality of individual points to quantify GTRF network deformations, validation of the quality of ITRF attachment points, and validation of adopted velocities. The validation of the GTRF will be performed interactively. Input to the validation procedures are the GTRF positions and velocities as generated by the GGSP, ITRF positions and velocities, site velocities derived from tectonic plate models, measured geodetic local ties between GSS markers and to nearby ITRF/IGS sites, wherever available. Intermediate results such as weekly comparison and combination reports, satellite orbits and clock parameters from the three PFs and from external sources as available serve as additional information for strengthening the findings of the GTRF validation.

As a by-product of the GGSP network solution, vectors between co-located sites (up to hundred meter apart, normally only a few meters) are obtained. Those vectors are used for additional validation with special short baseline solutions (using more precise L1 ambiguity fixed solutions) and with results from geodetic surveys.

5. Results

Between November 2006 and June 2008 seven monthly campaigns were used to generate various versions of the GTRF (see Table 2). Because of the delay of the Galileo In-Orbit-Validation (IOV) with the first four Galileo satellites a so-called fictive IOV has been defined to demonstrate the operability of the GGSP project developments. During 6 months from September 2008 to February 2009 (26 weeks) the GGSP system was operational and has delivered all products within the defined schedules, i.e., daily satellites orbits, clock corrections, ERP, and weekly SINEX files with station coordinate solutions.

Table 2. Versions of GTRF

Version	Released	Data used		Time span
GTRF07v00	Aug 2007	3x4 weeks	(Nov 2006 - Jun 2007)	0.69 y
GTRF07v01	Nov 2007	4x4 weeks	(Nov 2006 - Sep 2007)	0.92 y
GTRF08v01	Aug 2008	7x4 weeks	(Nov 2006 - Jun 2008)	1.69 y
GTRF09v01	Feb 2009	7x4+26 weeks	(Nov 2006 - Feb 2009)	2.34 y

5.1 GTRF

Analysis of time series of station positions is a fundamental tool allowing to assess not only the station behaviour, but also the frame parameters and in particular the physical ones, namely the origin and the scale.

The 54 weekly PF solutions as well as the combined weekly solutions were stacked independently from each other in order to assess their internal consistency in time. The results of the stacked solutions allow recovering the temporal origin and the scale components of each PF with respect to the IGS05 (ITRF2005) frame as illustrated by Fig. 4. From this figure we can see that the three individual solutions agree at the 1 cm level or better in the origin as well as the scale components. After September 2008 we have continuous weekly processing and the results are within the normal scatter between the PFs. This high performance of agreement between the PF solutions is certainly due to the improvement of their analysis strategy and the adherence to common standards and models, in agreement with the IERS Conventions (McCarthy and Petit, 2004), and their updates available at: http://tai.bipm.org/iers/convupdt/convupdt.html.

The results of this stacking procedure also yield weekly weighted RMS (WRMS) values per PF, as a measure of the internal precision (repeatability). Fig. 5 shows the WRMS per PF which range between 1 and 3 mm for the horizontal and between 3 and 7 mm for the vertical component. This figure also shows that the internal precision of the weekly GTRF is even better than any individual PF. From the stacking of the weekly combined GTRF solutions, a GTRF cumulative solution (long-term solution of station positions and velocities) is generated and updated every week. This regular cumulative multi-year solution serves as the basis for the GTRF updates, independent from, but still aligned to the current ITRF solution. Additionally, the cumulative solution will serve for the maintenance of the GTRF over time, taking into account changes that could occur at the stations. From this cumulative solution, time series of position residuals of the individual stations are investigated in order to locate and handle outliers or discontinuities in the time series. In the context of time series analysis, the residuals are station position differences between the cumulative and the weekly solutions.

The Figs. 6 and 7 show position time series for four different GESSs. Fig. 6 shows two examples for typical quality of a position time series. Fig. 7 illustrates the time series of GESS stations where different events occurred. At Noordwijk (GNOR) there was an antenna change on January 17, 2008, which caused a discontinuity in its position time series of about 1.5 and 3.2 cm in the east and up components, respectively. For Mizusawa (GMIZ), the Easter Honshu Earthquake (magnitude 6.9; June 13, 2008) created a discontinuity in its position time series of about 10 cm in the east component.

The quality of the GTRF is also demonstrated by its good agreement for the 71 common stations to the ITRF (Table 3).

Table 3. RMS of station positions between GTRF and ITRF2005 (after Helmert transformation)

No. sta	RMS-Position [mm]			RMS-Velocity [mm/y]		
	East	North	Up	East	North	Up
71	1.1	1.1	2.9	0.3	0.3	0.8

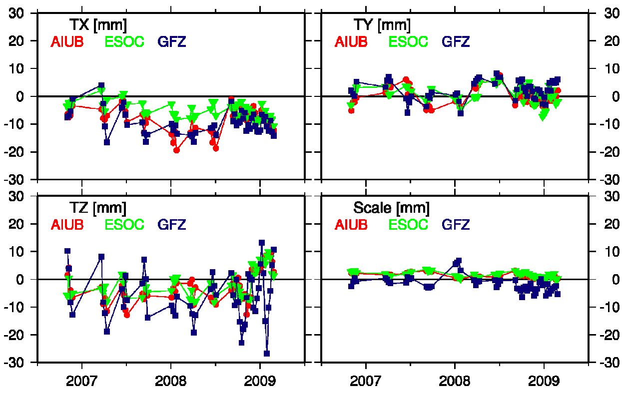

Fig. 4. Translation and scale parameters per PF weekly solutions

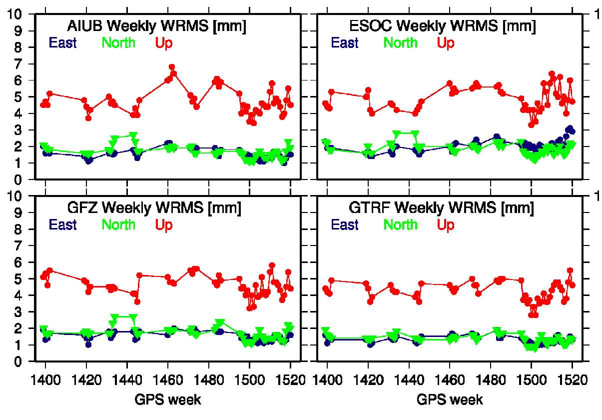

Fig. 5. Internal precision over time of the individual PF solutions as well as the weekly GTRF solutions

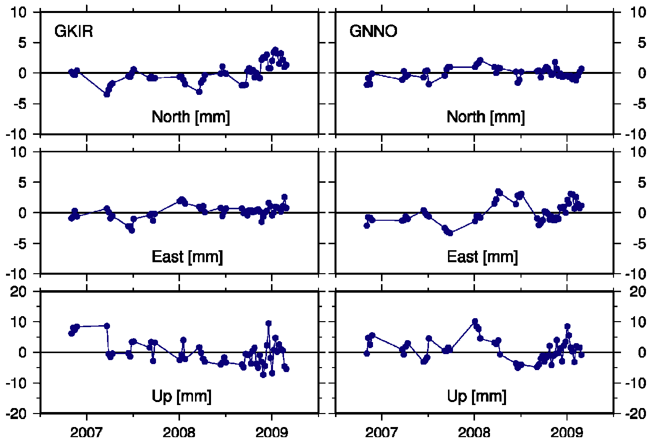

Fig. 6. GKIR (Kiruna, Sweden) and GNNO (New Norcia, Australia) position time series (de-trended)

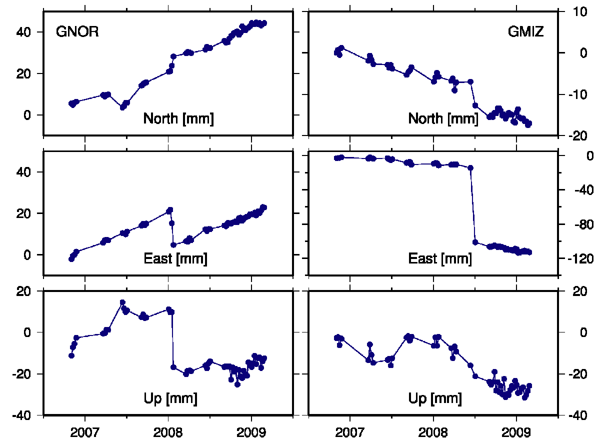

Fig. 7. GNOR (Noordwijk, Netherland) and GMIZ (Mizusawa, Japan) position time series (arbitrary zero line)

5.2 Estimation of station velocities

The cumulative solution obtained by stacking the 54 weekly solutions contains not only station positions, but also station velocities (Fig. 8). The quality and reliability of the estimated velocities depend strongly on the time span of the used observations for each station. At least 2.5 (preferably 3) years of ideally continuous observations are generally needed in order to estimate reliable velocities to minimize the impact of seasonal variations as well as discontinuities frequently found in the time series of station positions. As the 54 weeks cover only 2.34 years (though nearly close to 2.5 years), the generated GTRF09v01 version still includes the GNSS part of the ITRF2005 in order to enhance the station velocity estimates. However, it is informative to compare station velocities obtained from the stacking of the 54 weeks to those generated by the GTRF09v01 computation. Fig. 9 shows the spherical formal errors as derived from the cumulative solution of the 54 weeks and from the GTRF09v01. It can be seen that the station velocities of the cumulative solutions are still less precise than (although almost close to) the GTRF09v01. Their velocity differences for the horizontal components are in most cases rather small (Fig. 10) except for stations with recent events (like Earthquake in Mizusawa). The vertical differences (Fig. 11) are larger mainly because all the seasonal loading effects (atmosphere, groundwater, snow) are not modelled and therefore at least 3 years are needed to get a good mean velocity. Note also that some stations did not observe the full period of the 2.34 years and consequently their velocities may have still larger differences with respect to the GTFR09v01.

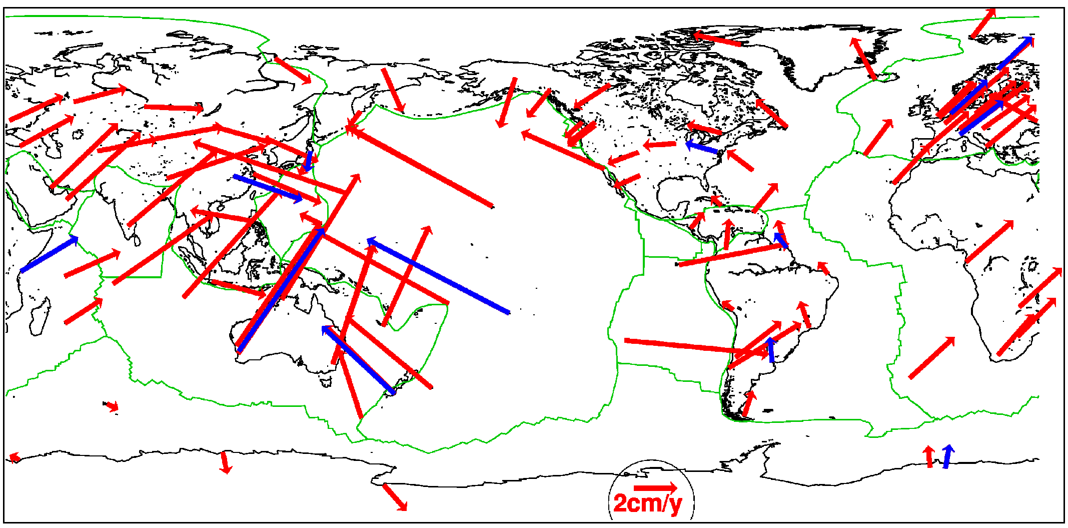

Fig. 8. GTRF09v01 velocity field (GESS are shown in blue; major plate boundaries are shown in green)

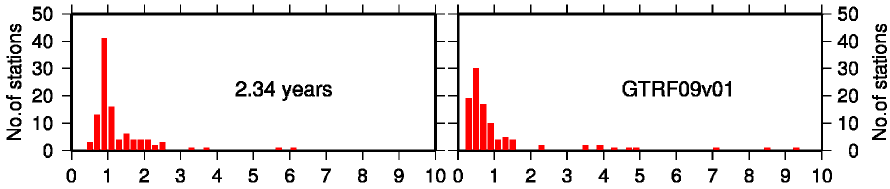

Fig. 9. Spherical formal errors obtained by the stacking of the 54 weeks (left) and as generated from the GTRF09v01 computation (right)

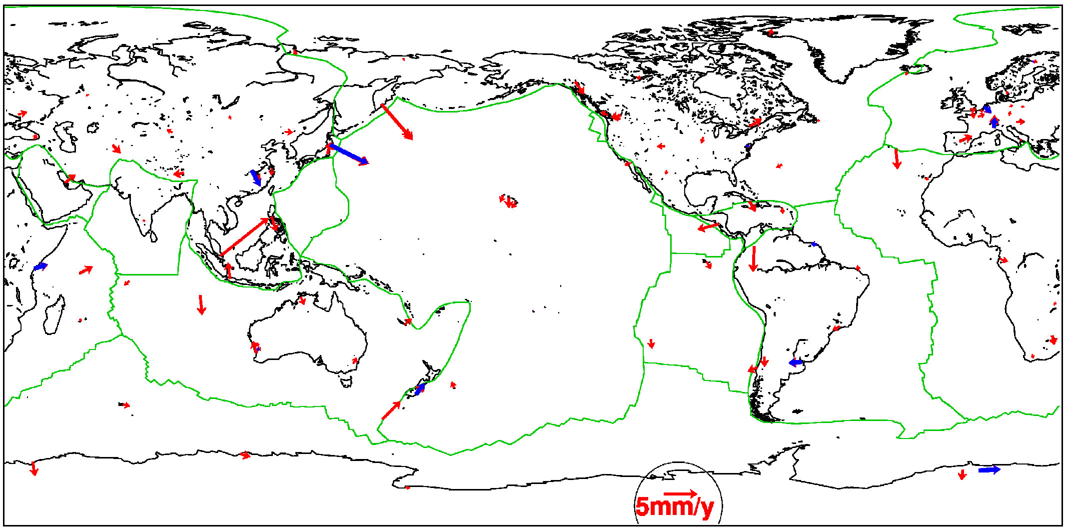

Fig. 10. Horizontal velocity differences between GTRF09v01 velocity field and velocities from 2.34 year solution (GESS are shown in blue; major plate boundaries are shown in green)

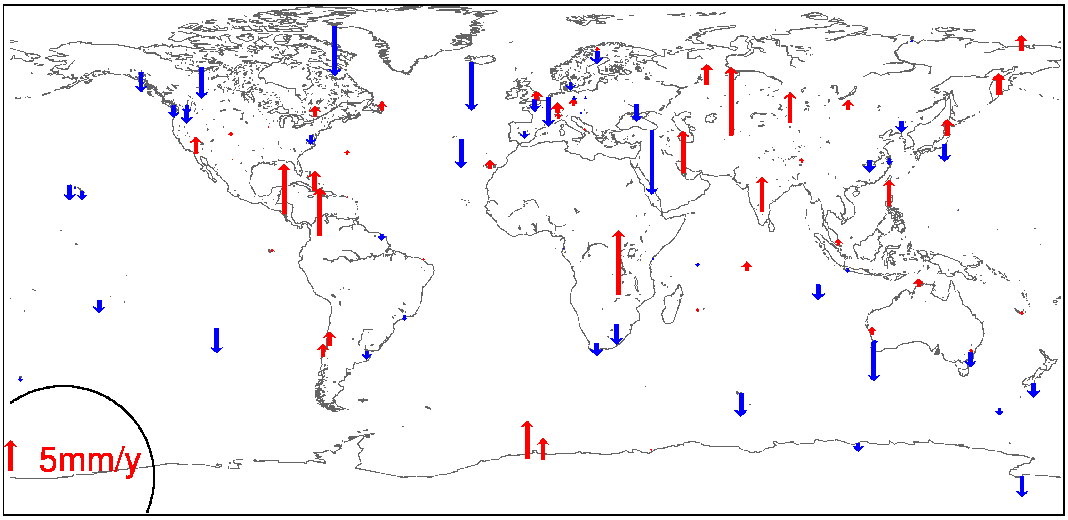

Fig. 11. Vertical velocity differences between GTRF09v01 velocity field and velocities from 2.34 year solution (GESS are shown in blue; major plate boundaries are shown in green)

5.3 Short baseline validation

The short baseline validation, i.e., computing different special solutions for a baseline and compare them to each other and to the solution within the GTRF is an efficient tool for the product assurance. This shall be demonstrated by the following example.

After the change of the antennas - the old was calibrated and the new one not - in Torino and Noordwijk differences in the positions were detected as given in Table 4. Differences in the cm-range were expected because of the missing antenna calibration. However, they should be the same at the two stations, which was only the case for the magnitude of the changes (18.1 mm and 17.9 mm). The deviation between the orientation of the differences indicated that there seemed to be a mis-orientation of one of the antennas. Indeed, such a mis-orientation was later confirmed to be 60 degrees (personnel communication from station manager). This demonstrates the potential of this tool and also the high quality of the GTRF.

Table 4. Antenna change validation (units: mm; horizontal change in N, E, and total 2D effect)

Station	East	North	2D-horizonhal	Up	Comment
Torino	-15.2	-9.9	18.1	21.6	Differences of short baselines
Noordwijk	-16.2	7.7	17.9	23.6	Difference GTRF08v01 to GTRF09v01

5.4 Earth Rotation Parameters (ERP)

The ERPs estimated within the GGSP are also of high quality. The polar motion parameters agree between the PFs as well as between the combined solution and the IGS at the level of 0.05 mas (corresponding to 1.5 mm at the Earth surface) and for the length of the day (LOD) within 0.2 ms (corresponding to about 9 mm at the surface).

5.5 Satellite orbits and clock corrections

The generated satellite orbits and clock corrections from the PFs are combined to GGSP products, too. The contribution from each PF is compared to the combined solution and the combination is validated with the official IGS Final products (Fig. 12, top). The differences between the individual PF orbits and the GGSP combined solutions range from 5 to 15 mm and the combined orbits agree with the official IGS Final orbits, the best orbits available, at a level of 5-11 mm, which is the consistency of the IGS orbits itself. The GGSP clocks (Fig. 12, bottom) agree to the official IGS Final clocks at a level of 0.02-0.03 ns (standard deviation) (0.03 ns corresponds to 1 cm in the light travel time). Using the GGSP orbits and clocks a precise point positioning would result in a scatter of about 1 cm in the station positioning and therefore a user of these products can easily access the GTRF with cm-accuracy.

5.6 GIOVE data analysis

For selected weeks (GPS weeks 1500, 1505, 1510, 1515 spanning the interval from October 15, 2008 to January 24, 2009) the data of the GIOVE satellites (E01, E16) from the 13 active GESS were included into the processing. Due to the very limited number of additional Galileo observations, these products were not significantly different from those obtained with GPS only. The quality of the Galileo orbits, i.e., the differences of the PFs compared to the combined GGSP orbit, is at the level of 10-30 cm (Fig. 13).

The clock estimates for the GIOVE satellites allow also a first quality assessment for the on-board clocks. From Fig. 14, it can be seen that the H-Maser on board of GIOVE-B is nearly one order of magnitude better than the clocks of the GPS satellites (with G32 the best performing clock is shown) and is approaching the mission specifications. The rubidium clock on board of GIOVE-A has also a very good performance. The degradation of the longer wavelength part is caused by the presently not so high quality of the orbits. For comparison the clock result for the H-Maser at GUSN is included. Also in the high frequency part the GIOVE-clocks are better than those of GPS (Fig. 15).

6. Summary

The complete functionality of the GGSP for the maintenance of the GTRF has been demonstrated successfully throughout seven monthly campaigns and the fictive IOV over half a year. The data analysis and the provision of the products were performed according to the schedule (deadlines) defined for the routine permanent GGSP.

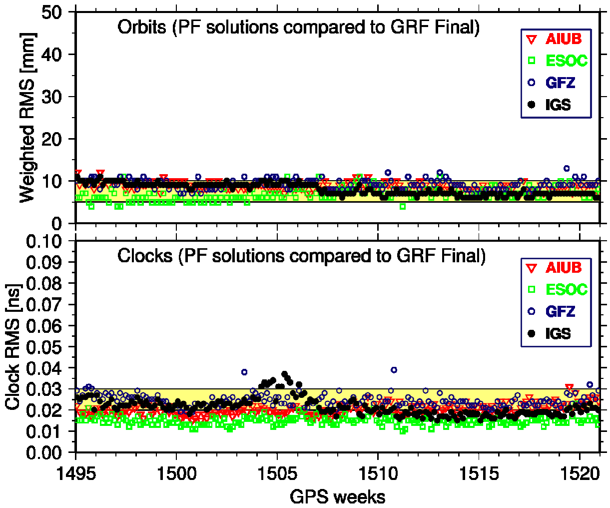

Fig. 12. Comparison of the PF orbits and the IGS Final orbits (IGF) to the combined GGSP product during the fictive IOV (top), same for clocks (10 mm correspond to 0.033 ns; bottom)

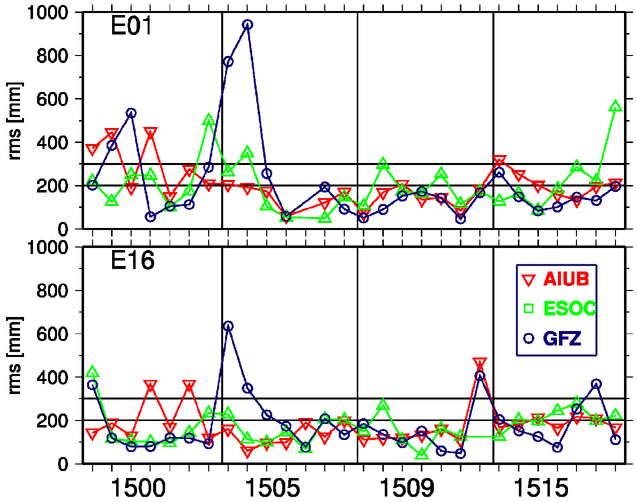

Fig. 13. Differences of the PF's orbits to the combined GGSP orbits for GIOVE-A (E01) and GIOVE-B (E16)

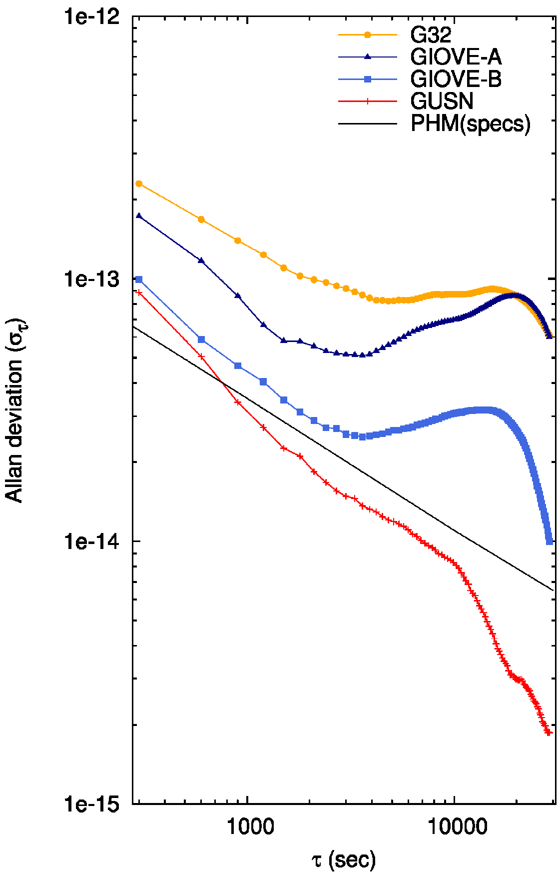

Fig. 14. Allan deviations for GIOVE satellites and its mission specification compared to GPS satellites and ground H-Maser at USNO (GUSN) [ESOC PF results]

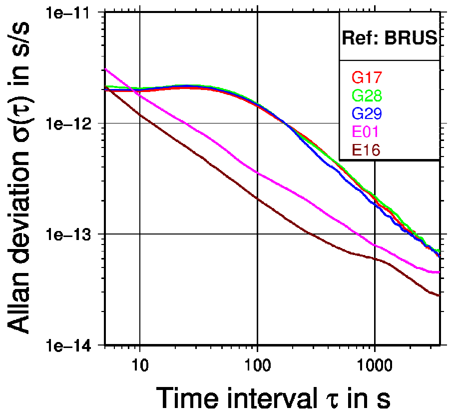

Fig. 15. High frequencies Allan deviations for GIOVE-A (E01) and GIOVE-B (E16) compared to GPS satellites [AIUB PF results]

Using the total 54 weeks of the 7 campaigns and the fictive IOV, a GTRF was generated. The total time span of these 54 weeks is still less than 2.5 years that are necessary to estimate reliable velocities. Therefore the GNSS part of the ITRF2005 at common sites with the GGSP network was included in the computation of the GTRF09v01 to improve the determination of the GTRF station velocities.

Comparisons of the GTRF09v01 to the ITRF2005 demonstrate their full compatibility in terms of frame alignment. In effect the 14 transformation parameters are at the level of 1 mm for positions and less than 1 mm/y for velocities. In addition, WRMS values of these transformations are also given, showing an agreement between these frames at the level of 1-2 mm in horizontal and 2-5 mm in the vertical for station positions and an agreement better than 1 mm/y for station velocities. With these high level results we can conclude that the performance of the implemented prototype with the GESS meets the requirement for the GTRF and its maintenance.

The quality of the additionally generated GGSP products, namely the satellite orbits, clock corrections, and ERPs (polar motion and LOD), is comparable to the quality of the Final IGS products and reaches 1 cm, 0.03 ns, 0.05 mas, 0.2 ms, respectively.

All interfaces and GGSP facilities are in place and run continuously during the demonstration in the fictive IOV.

GGSP contract goals, aimed at having the Prototype up and running were reached:

- The GGSP was successfully developed, on time and within the allocated budget.
- The GGSP is fully functional and could be used for the IOV phase and also for the final operational system.

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