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The Realisation and Validation of the Galileo Terrestrial Reference Frame

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I Background

The Galileo Geodetic Service Provider (GGSP) prototype

- Is a project funded through the sixth Framework Programme for Research and Technological Development of the European Union.
- Started in July 2005 and will be finished in May 2009.
- Is a consortium of seven institutions with the lead by GeoForschungsZentrum Potsdam, Germany.
- Is responsible for the definition, realization, validation and maintenance of the Galileo Terrestrial Reference Frame (GTRF), a special realization of the International Terrestrial Reference Frame (ITRF), maintained by the Galileo system operator.
- Implements a prototype for a permanent service.
- Compiles recommendations for the Galileo Reference Service Provider (GRSP) who will take over the functionality of the GGSP in the operational phase of Galileo.
- Acts as an interface between Galileo and the geodetic community.

II GGSP architecture

The GGSP architecture comprises all external interfaces and internal relations. Figure 1 shows the core facilities of the GGSP prototype:

- The Processing Facilities (PFs) – at AIUB, ESOC, and GFZ – are applying the state-of-the-art approach to estimate satellite orbits, satellite and receiver clock corrections, Earth Rotation Parameters (ERP), and station coordinates.
- The Combination Facility (CF) – at IGN – is responsible for the GTRF realization and for alignment to the International Reference Frame (ITRF).
- The CF – at GFZ – maintains the combination of satellite orbits, satellite and receiver clock corrections, and ERP.
- The Validation Facility (VF) – at AIUB – is applying several tasks to verify the products generated by the PFs and CFs, e.g., by comparison to the IGS final products.
- The VF – at BKG – is analyzing the local ties at co-location sites.

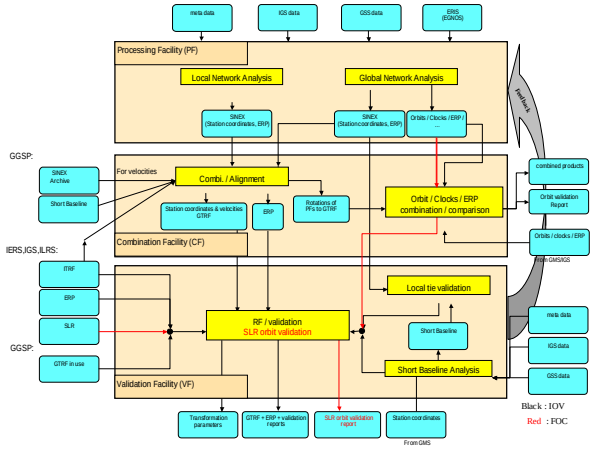

Figure 1: GGSP architecture with internal relations – see section II – and external interfaces – mainly to the IAG services and the Galileo Mission Segment (GMS). Concerning IOV and FOC, see section VI.

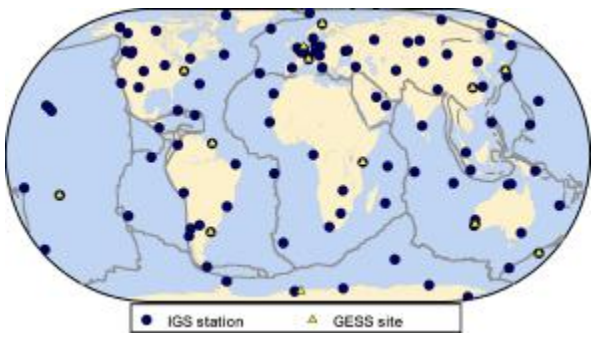

Figure 2: Station distribution used for initial GTRF realization: approximately 100 IGS stations plus 13 Galileo Experimental Sensor Stations

III Initial GTRF realization

- GPS observations were used for the initial GTRF realization;
- Data of approximately 100 IGS stations were used to ensure a homogeneous distribution (see Figure 2);
- Additionally, 13 Galileo Experimental Sensor Stations (GESSs) were included to gain experience with/at co-location Galileo/IGS sites;
- The initial GTRF realization was carried out on a campaign-wise basis;
- Seven campaign (four weeks each) from mid 2006 until mid 2008 were analyzed (see Figure 3).

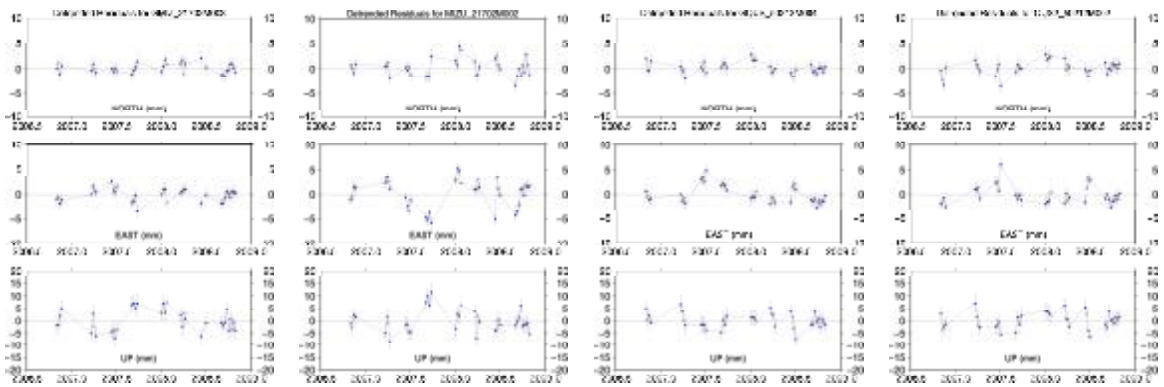

Figure 3: De-trended residual time series at co-location sites Mizusawa (Japan) – stations GMIZ (GESS) and MIZU (IGS) – and Dunedin (New Zealand) – stations GOUS (GESS) and OUS2 (IGS) – for the seven campaigns (see section III) and the beginning of the continuous analysis (see section IV).

IV GGSP maintenance

- Since September 2008 (GPS week 1495) the system is running continuously to demonstrate its operational functionality.
- Continuous analysis, combination and validation are carried out on a weekly basis.
- Purpose is to mimic the procedure of the permanent service.
- As could be expected, the results are fully comparable to the IGS products.

Figure 4: Translation, scale, and rotation of orbits for the three PFs with respect to the GGSP combined solution. For comparison, the IGS final orbit solution is compared to the GGSP solution, too.

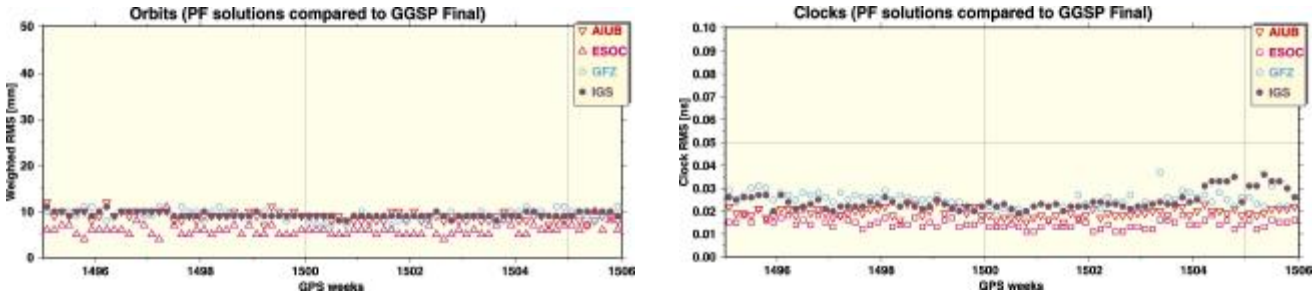

Figure 5: Satellite orbits (left) and clock correction solutions with respect to the GGSP combined solution. For comparison, the IGS final solutions are compared to the GGSP solutions, too.

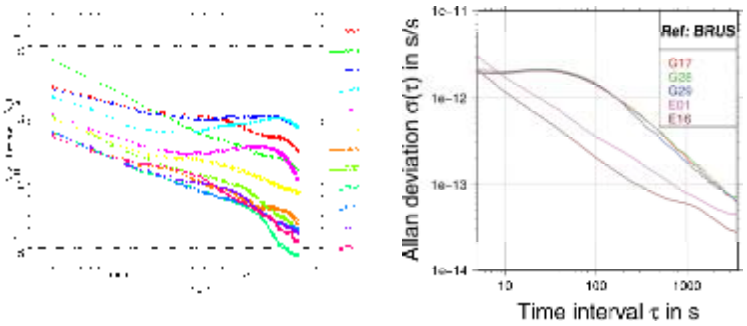

Figure 6: Allan deviation for satellites clocks: GIOVE-A (aka E01), GIOVE-B (aka E16) as well as selected GPS satellites and, for comparison, selected IGS stations equipped with passive hydrogen maser (left, 5 minutes solution). On the right the Allan deviation for selected satellites for a short time interval based on 5 seconds solution.

V GIOVE clock performance

- The GIOVE-B satellite clock performs better in the short-term range than the clocks of the GPS satellites.
- Moreover, the passive hydrogen maser (PHM) on-board GIOVE-B shows a performance comparable to the best ground-based masers, as estimated by the IGS.
- The degradation of the PHM on-board GIOVE-B at time intervals of one hour and longer is probably caused by the combined effects of limited orbit accuracy (due to limited 13 stations ground network) and variations of on-board phase-delay.
- The performance in the very short-term interval of 5 minutes and shorter is very promising for the Galileo system because in contrast to GPS the satellite clock corrections for GIOVE-B can be much better interpolated.

VI Towards the operational GRSP

For the transition phase, i.e., the phase between the end of the GGSP prototype – May 2009 – and the begin of the Galileo In-Orbit-Validation (IOV) – planned for 2010 – the GGSP prototype consortium recommends

- To continue with the GESS monitoring.
- To continue with processing of versioned GTRF realizations.

Moreover, recommendations for the phase between IOV and Galileo Fully Operational Capability (FOC) – planned for 2013 – are:

- To retain the prototype infrastructure which has been proven as reliable and robust.
- To substitute the IGS stations by the Galileo Sensor Stations (GSS) which will be established within the very next years.

Finally, recommendations for the permanent GRSP are:

- To push the inclusion of the GSS into the IGS.
- To force the upgrade of existing IGS stations to full GNSS stations – at least GPS+GLONASS+Galileo+Compass.
- To promote the extension of existing IGS products (orbits, clock corrections, etc.) to full multi-GNSS products with Galileo.
- To develop user-specific products to increase the acceptance of the GRSP.

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