Determination and Maintenance of the Galileo Terrestrial Reference Frame

Mathias Fritsche, GGSP Consortium*, and ESA Project Team*

Background

A highly precise and stable Galileo Terrestrial Reference Frame (GTRF) is a crucial prerequisite for the provision of precise Galileo products and related services. The GTRF determination shall be compatible with the latest International Terrestrial Reference Frame (ITRF) providing the same level of accuracy, long-term stability, and reliability to the maximum extent possible. In particular, the connection to ITRF is realized and validated by stations of the International GNSS Service (IGS). Primary GTRF input data including precise satellite orbit and clocks, ground tracking station coordinates and Earth rotation parameters are provided by the Orbit Validation Facility (OVF). The OVF service is delivered by the GGSP consortium, a group of five European institutes having a strong geodetic background.

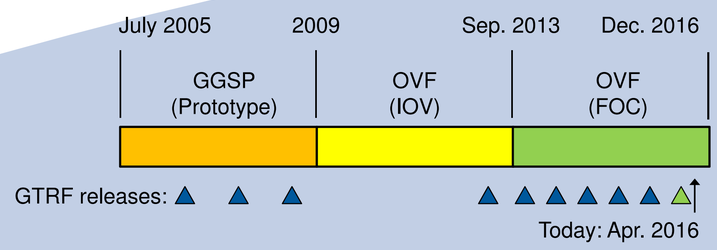

Figure 1 Schedule of Galileo Terrestrial Reference Frame (GTRF) releases. Three realisations have been determined based on early stage activities during the GGSP prototype definition phase. Due to the deployment of new Galileo Sensor Stations, more frequent GTRF updates became necessary during recent years. The latest update GTRF16v01 was released in January 2016.

Galileo Geodetic Service Provider (GGSP) Prototype phase

- Intial campaign-based processing extended to continuous processing since September 2008
- Inclusion of GIOVE-A and GIOVE-B observation data

Orbit Validation Facility – In-orbit Validation (IOV) phase

- OVF activities as part of the *Time and Geodesy Validation Facility*
- Deliverables for GTRF generation and validation products

Orbit Validation Facility – Full Operational Capability (FOC)

- Delivery of daily and weekly products
- Service Level Agreement, i.e. definition of Key Performance Indicators based on accuracy, availability and timeliness

Galileo Terrestrial Reference Frame Determination and Maintenance Results

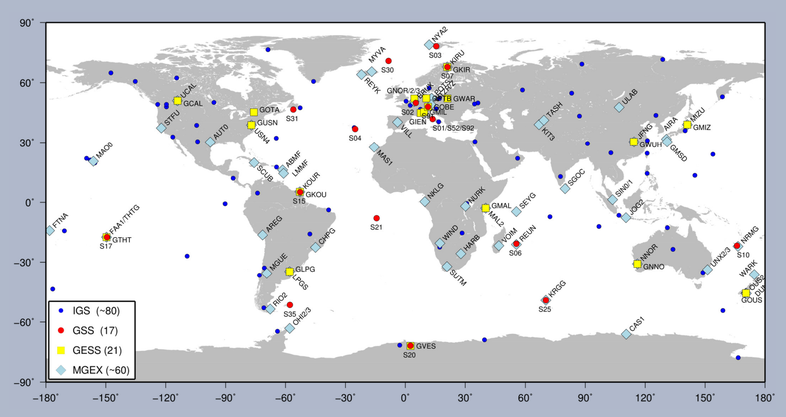

Figure 2 GPS/Galileo tracking network used within OVF processing. Several GESS and MGEX stations are operated by partners of the GGSP consortium.

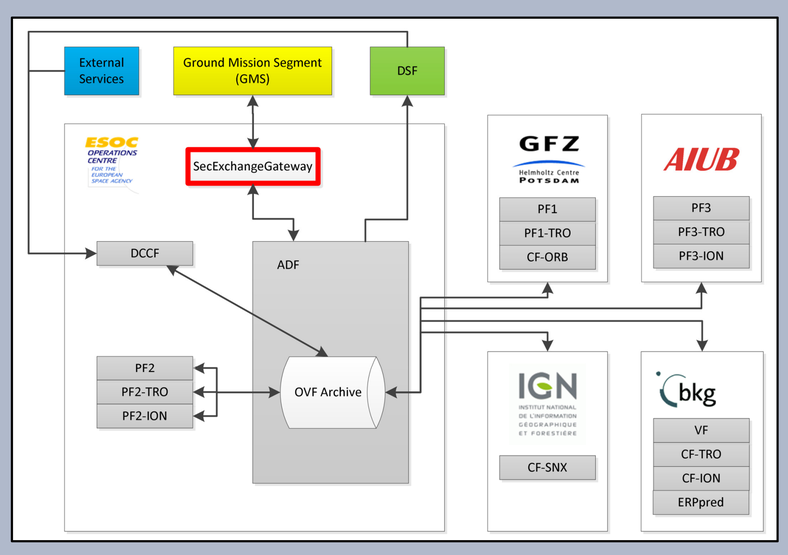

Figure 3 Task distribution within the Orbit Validation Facility (OVF). Activities are shared among different facilities for observation data processing (PF) and product combination (CF).

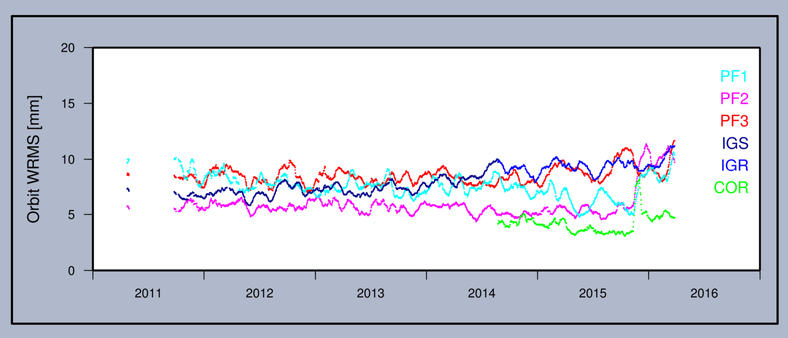

Figure 4 Weighted orbit RMS based on comparison between individual PF orbit solutions and final combined orbits for GPS satellites. Comparison includes IGS final (IGF), IGS rapid (IGR) and OVF internal rapid (COR) solution. Agreement is mostly at a level of 5-10 mm. Differences of the combined orbits w.r.t. IGS products are at the same level.

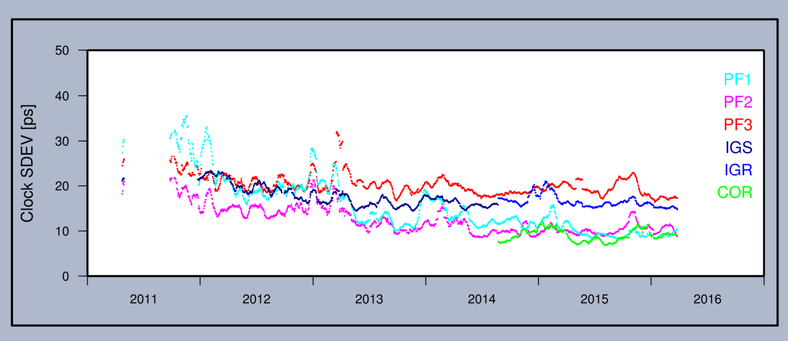

Figure 5 Clock standard deviation (SDEV) based on comparison between individual PF clock solutions and final combined clock solution including satellites and stations. Comparison includes IGS final (IGF), IGS rapid (IGR) and OVF internal rapid (COR) solution. PF clock solutions agree at a level of 15-25 ps. Comparison to IGS products shows similar performance.

Observation Data:

- Currently, the GTRF network comprises 163 stations located in 111 different sites, see Fig 2.
- Observation data from different sources are acquired including: Galileo Sensor Stations (GSS), Galileo Experimental Sensor Stations (GESS), MGEX-tracking network, legacy IGS tracking network

Data Analysis:

- All observation processing and product generation related efforts are shared among the GGSP consortium partners and provided as *Orbit Validation Facility (OVF) service products* to the *Time and Geodesy Validation Facility (TGVF),* a core element of the Galileo infrastucture.
- Fig. 3 provides an overview on the task distribution within the OVF.
- Key elements are:
  - Processing of same GNSS data set with fully independent software packages (PF1, PF2, PF3) in order to ensure robustness of solution. Estimated parameters include: station coordinates, satellite orbits and clocks, tropospheric and ionospheric delay parameters, signal bias parameters
  - Data/products exchange and archiving, interfaces to OVF external entities
  - Combination procedures for: station coordinates (CF-SNX), satellite orbits, clocks and code biases (CF-ORB), troposphere (CF-TRO), ionosphere (CF-ION)
  - Earth rotation parameter (ERP) estimation and prediction
  - Product validation (VF) using external data sources such as operational IGS products
- Provision of combined satellite orbits (Fig. 4) and clocks (Fig. 5) for validation purposes.

GTRF Determination:

- Weekly solutions provided by the three PFs are combined to obtain minimally constrained solutions of weekly GTRF station positions and daily ERP.
- Generation of a precise GTRF long-term solution (station positions and velocities) by accumulating the weekly GTRF combination results.
- Applying minimum constrains, the final GTRF solution is aligned to the latest ITRF realisation, here ITRF2008. 278 weekly solutions covering altogether 9.2 years have been combined for the latest GTRF release GTRF16v01. Fig. 6 illustrates the corresponding velocity field.
- Fig. 7 shows the WRMS in the North, East and Up component as derived from the differences between the weekly GTRF solutions and the long-term solution. On average, the WRMS is 1.5, 1.5 and 4.5 mm, for East, North and Up, respectively.
- Results of Tab. 1 verify that the frame alignment w.r.t. ITRF is obtained at the desired level of consistency, i.e. the 14 transformation parameters between GTRF16v01 and the IGb08 (ITRF2008) are zero. Associated WRMS values for positions are 3.0, 2.5, 4.5 mm, for East, North and Up, respectively. For the velocity components, 0.6, 0.6 and 1.0 mm/y are obtained, respectively.

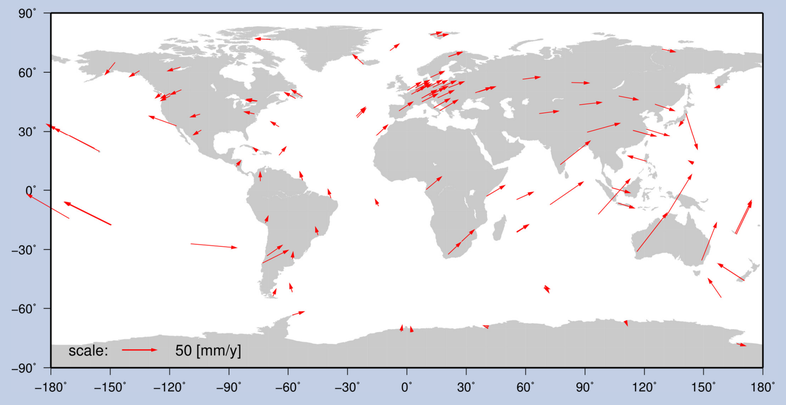

Figure 6 GTRF16v01 velocity field covering a data interval of 9.2 years.

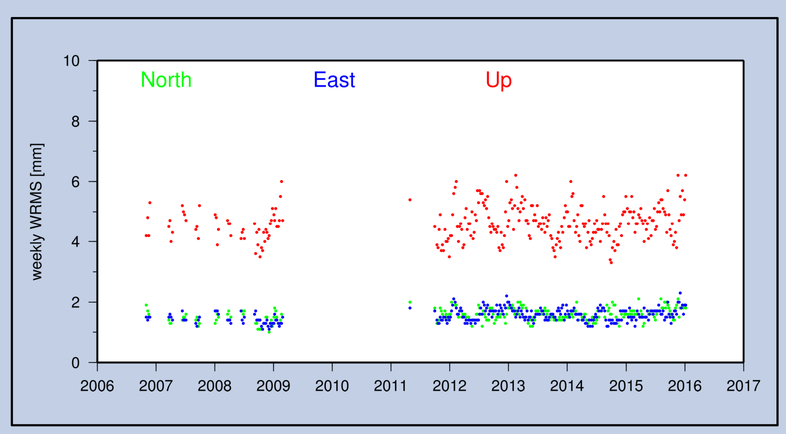

Figure 7 WRMS of the GTRF weekly station coordinate solutions, as a result from the most recent GTRF16v01 analysis.

Table 1 Results from a 14-Parameter similarity transformation between GTRF16v01 and IGb08 (ITRF2008) using 83 selected reference frame stations.

	Tx [mm]	Ty [mm]	Tz [mm]	Scl 10^{-9}	Rx [mas]	Ry [mas]	Rz [mas]
Offsets	0.0	0.0	0.0	0.00	0.000	0.000	0.000
+/-	0.3	0.3	0.3	0.05	0.012	0.012	0.012
Rates	0.0	0.0	0.0	0.00	0.000	0.000	0.000
+/-	0.3	0.3	0.3	0.05	0.012	0.012	0.012

Consortium* and Project Team*

GGSP consortium:

M. Uhlemann, M. Fritsche	Deutsches GeoForschungsZentrum, Potsdam, Germany (GFZ)
R. Dach, E. Orliac, L. Prange	Astronomisches Institut Universität Bern, Bern, Switzerland (AIUB)
J. Dostal, A. Rülke, W. Söhne	Bundesamt für Kartographie und Geodäsie, Frankfurt/Main, Germany (BKG)
W. Enderle, J. Martin, E. Schönemann, T. Springer, R. Zandbergen	ESA / European Space Operations Centre, Darmstadt, Germany (ESOC)
Z. Altamimi, J. Chenal	Institut National de l'Information Géographique et Forestière, Paris, France (IGN)

ESA project team:

S. Binda, F. Gonzales, R. Swinden	ESA / European Space Research and Technology Centre, Noordwijk, Netherlands (ESTEC)

Acknowledgments:

The excellent collaboration with the TGVF Prime Contractors TAS-France team during IOV Phase and GMV team during on-going FOC Phase is very much appreciated.