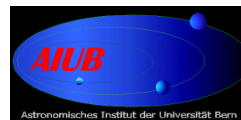


Galileo Terrestrial Reference Frame (GTRF)

Zuheir Altamimi and the GGSP team



Natural Resources
Canada



ICG-4 Meeting, Saint-Petersburg, 14-18 Sept., 2009

- GGSP Consortium
- GGSP Function
- Work performed
- Results
- Conclusion

● "GALILEO Geodetic Service Provider " (GGSP)

Consortium of 7 partners

- ◆ AIUB Astronomical Institute Uni Bern (Switzerland)
- ◆ BKG Bundesamt für Kartogr. und Geodäsie (Germany)
- ◆ ESOC European Space Operations Center (ESA)
- ◆ GFZ **GeoForschungsZentrum Potsdam** **(Germany)**
- ◆ IGN Institut Géographique National (France)
- ◆ WHU Wuhan University (China)
- ◆ NRCan National Resources Canada (Canada)

lead by GFZ.

The GGSP project was managed by the European GNSS Supervisory Authority (GSA) through EU 6FP funds

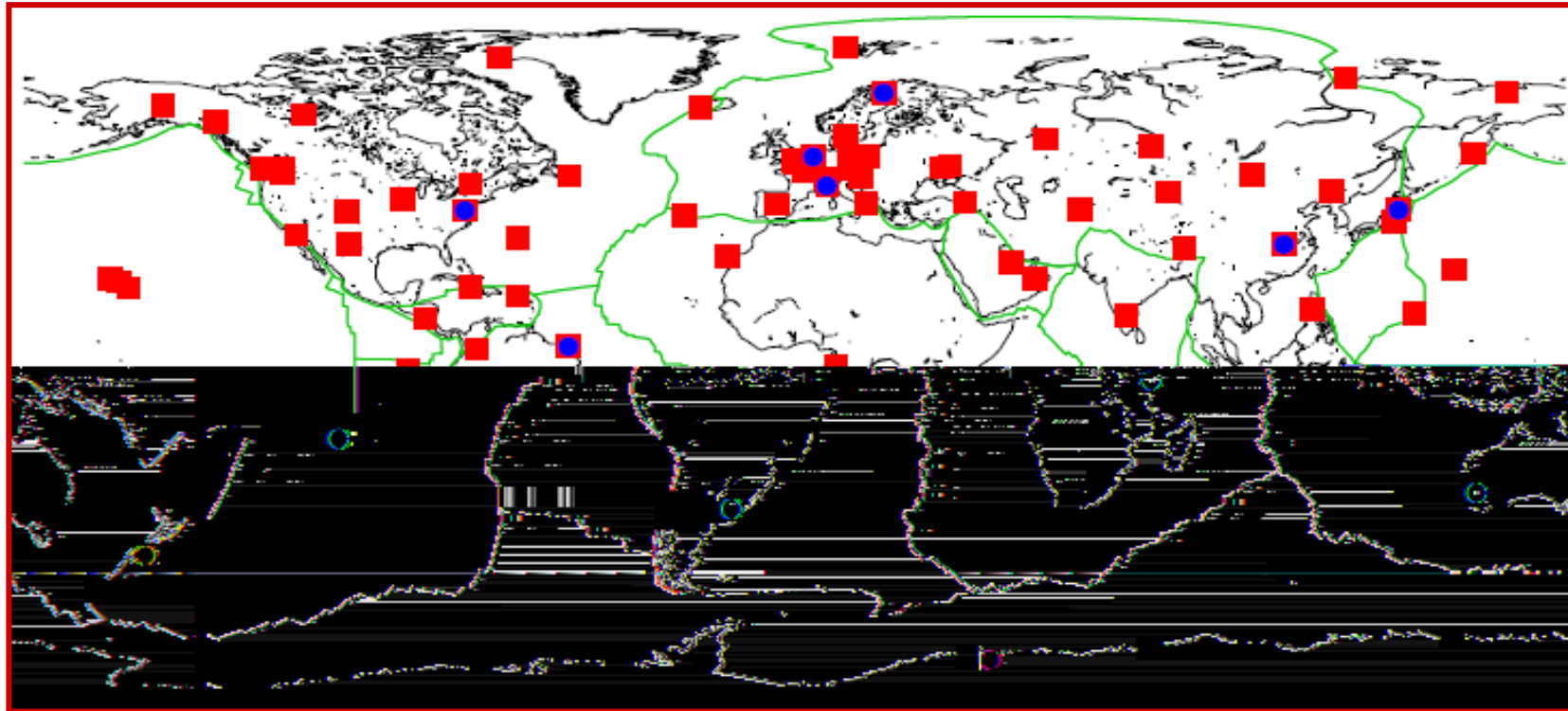
- Realisation and maintenance of a highly precise and stable Galileo Terrestrial Reference Frame (**GTRF**), the basis for all Galileo products and services

Requirement:

- **The GTRF shall be compatible with the International Terrestrial Reference Frame (ITRF) at the precision of 3 cm (2 sigma).**
- **Provide positions and velocities for all Galileo Sensor Stations (GSS)**

Additional GGSP products:

- **Generation of precise products for**
 - ◆ **satellite orbits**
 - ◆ **clocks parameters for satellites and stations**
 - ◆ **Earth Rotation Parameters (ERPs)**
- **Monitoring the quality of products of the Galileo Mission Segment (GMS)**

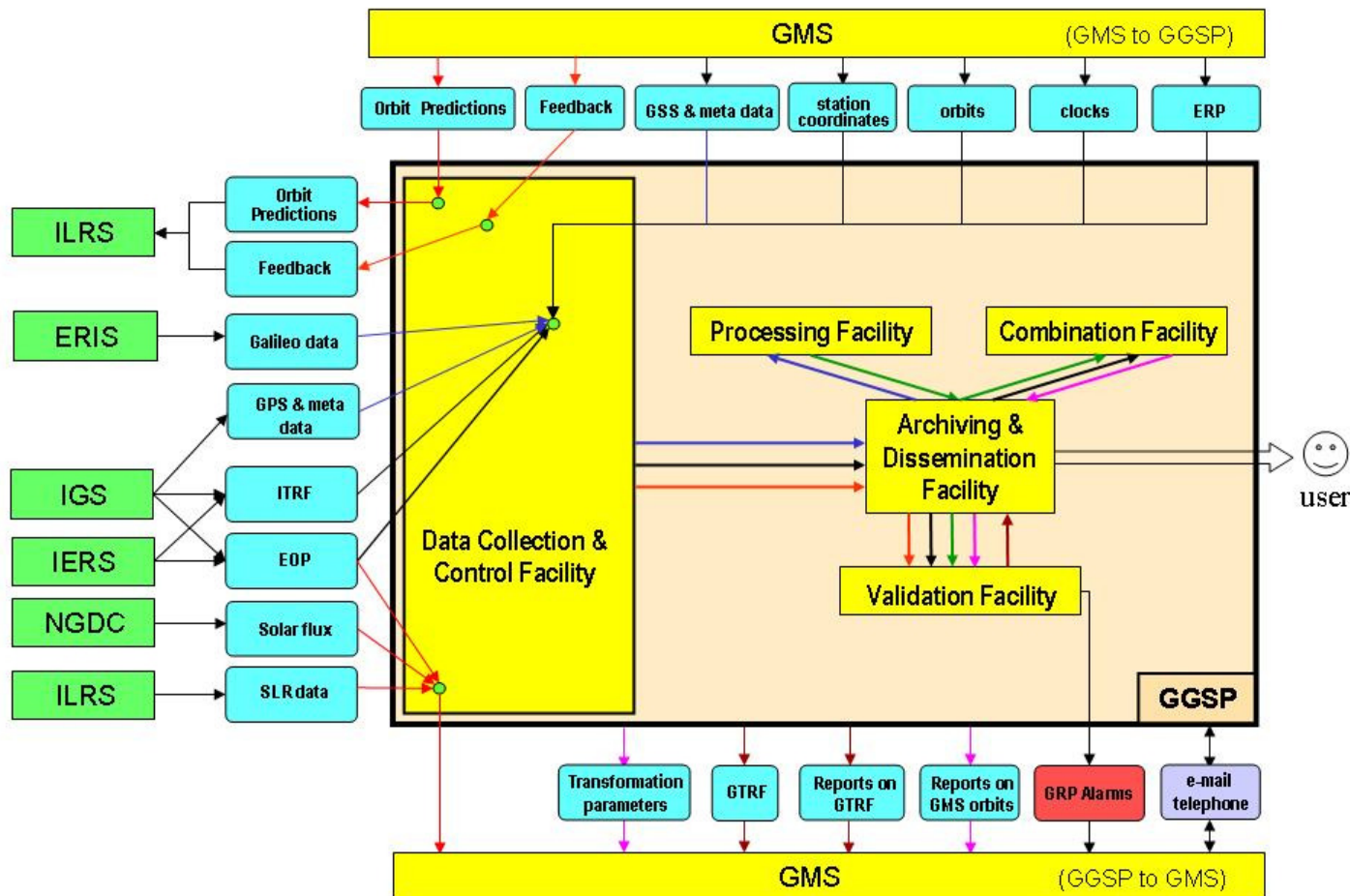


● GESS (13)

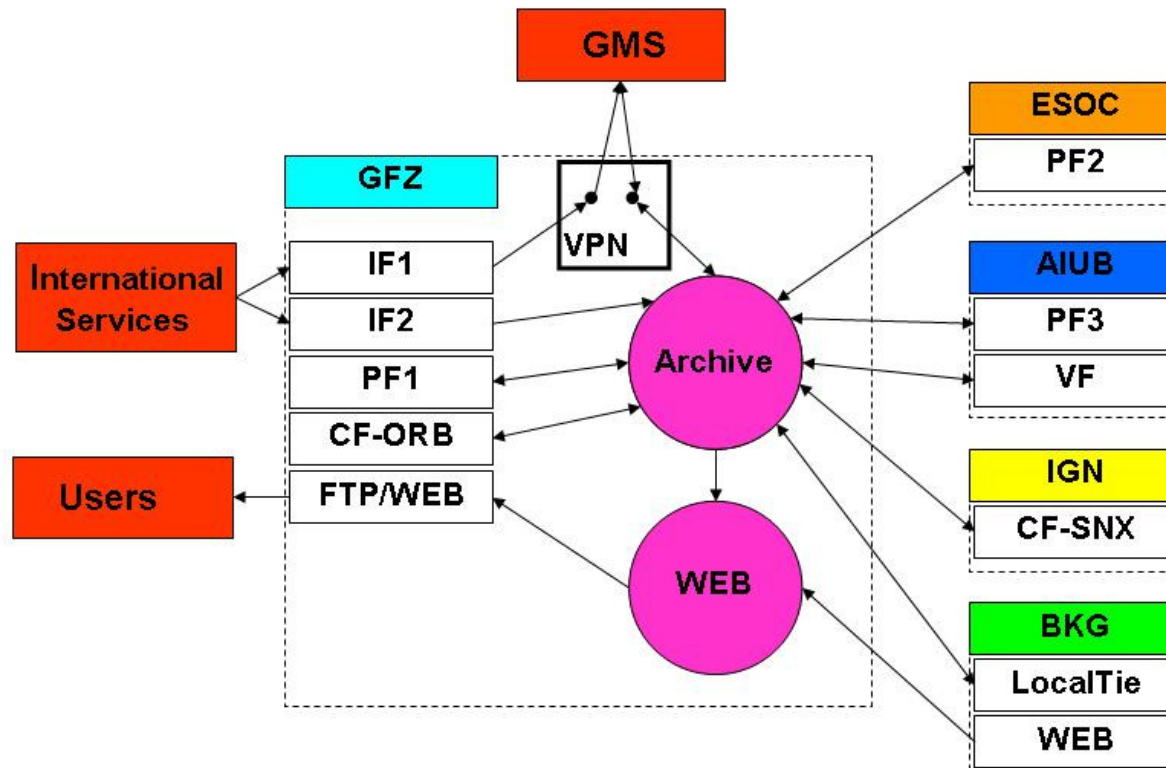
■ IGS station (~120)

- Initial GSS positions & velocities are determined using GPS observations
- Subsequent GTRF versions using GPS & Galileo observations
- Ultimately Galileo Observations only

- Data Collection and Control Facility (DCCF)
- 3 Processing Facilities (PF)
- Combination Facility (CF)
- Validation Facility (VF)
- Archiving and Dissemination Facility (ADF)



- Distributed approach for higher reliability
- 3 PFs to ensure quality and reliability of the products



- IF1 –Interface 1 (external for GMS & to GMS)
- IF2 –Interface 2 (for GGSP internal use)

- **Prototype example using 13 GESS stations:**
 - ◆ 7 campaigns: 4 weeks each 3 months
 - ◆ Fictive IOV: continuous processing during 6 months
 - ◆ Total time span: 2.34 years

- **Weekly solutions (station positions and ERPs) generated by the 3 Processing Facilities (AIUB, ESOC, GFZ)**

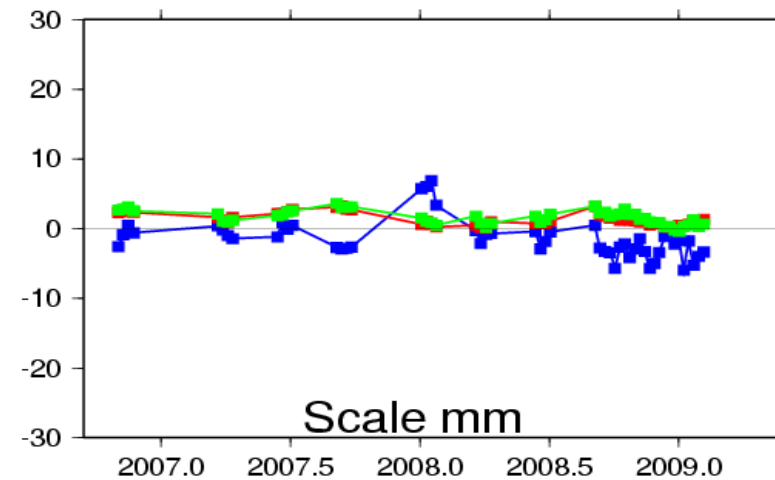
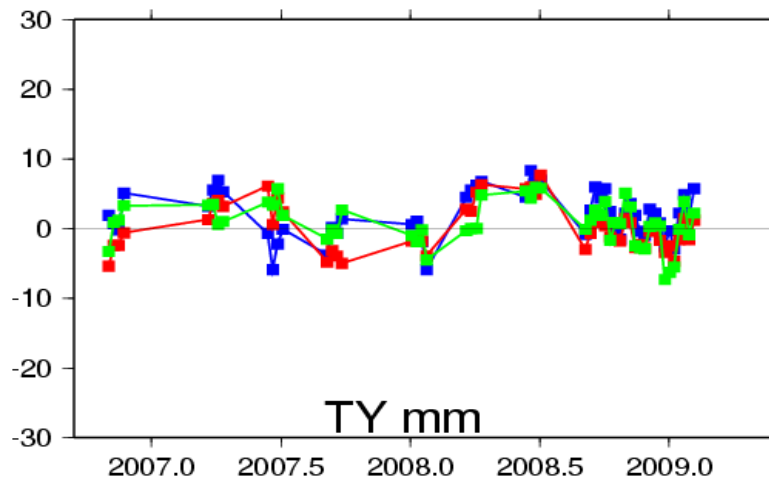
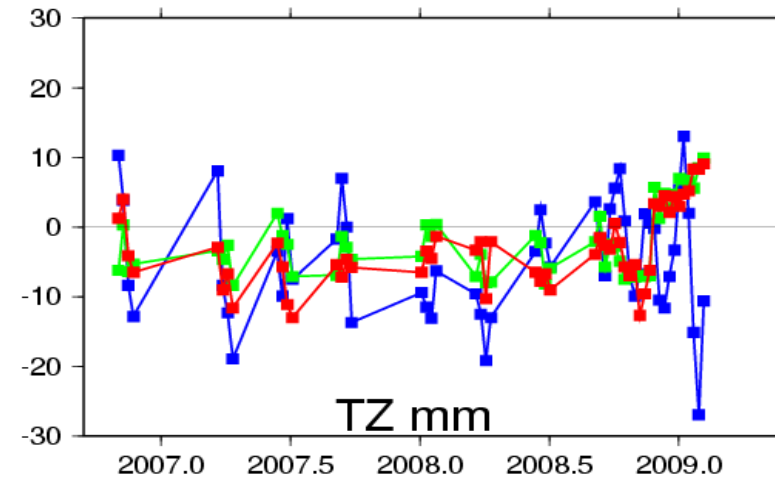
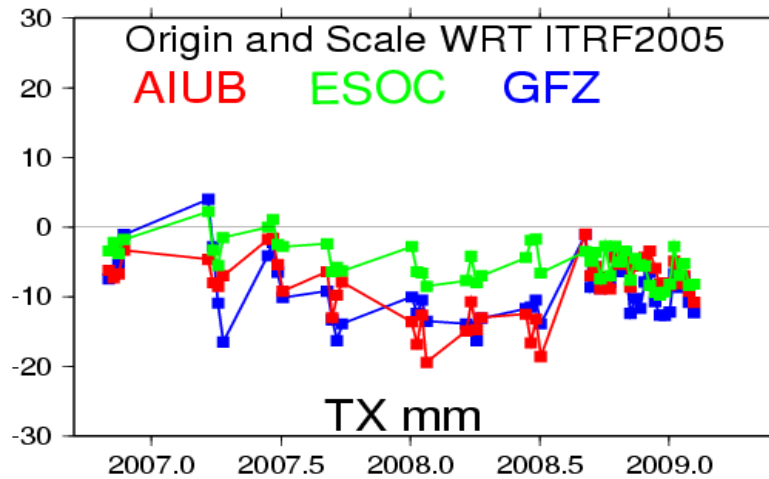
- **Weekly combination of station positions and ERPs**
 - ◆ Detailed analysis with summary report
 - ◆ Combined Solution provided in SINEX (X & ERPs)
 - ◆ Quality assesement
 - ◆ Transformation to ITRF

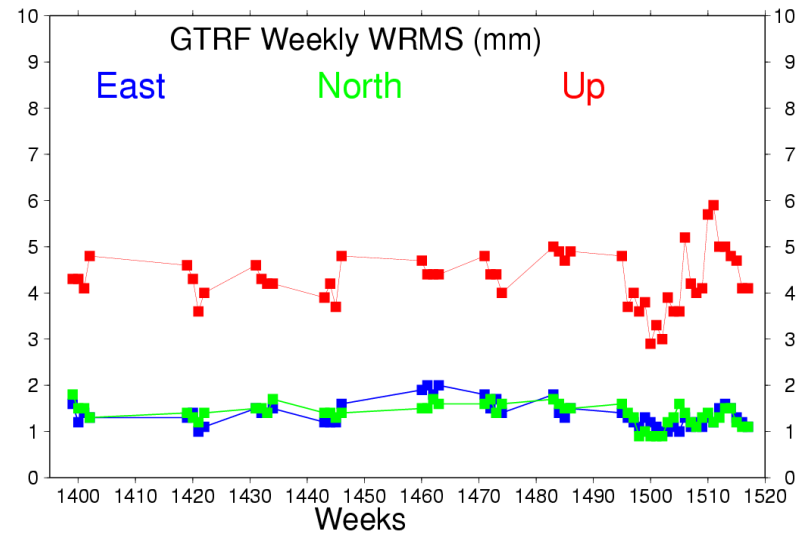
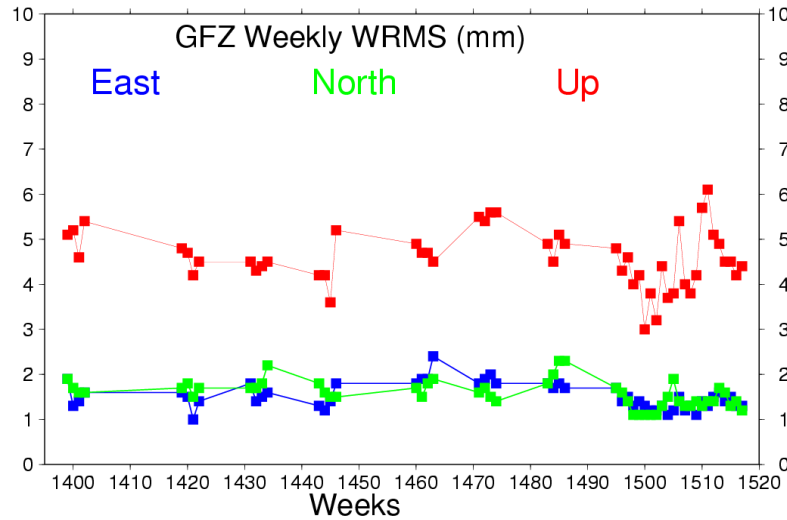
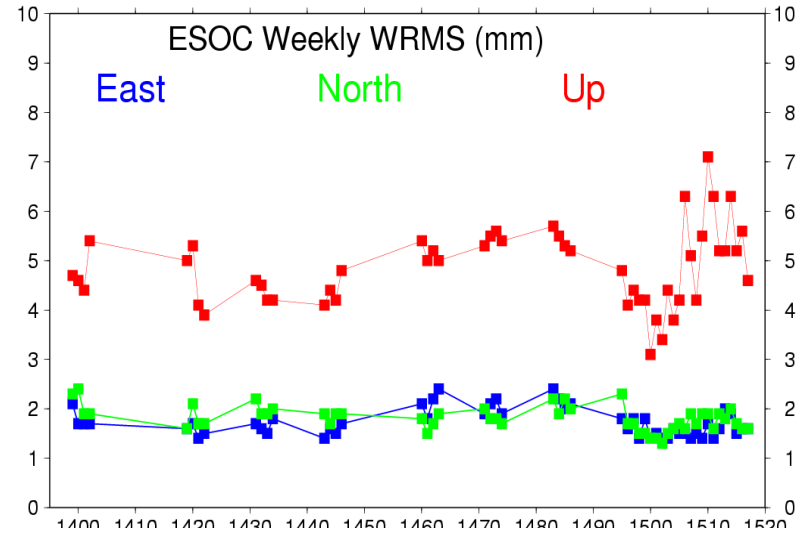
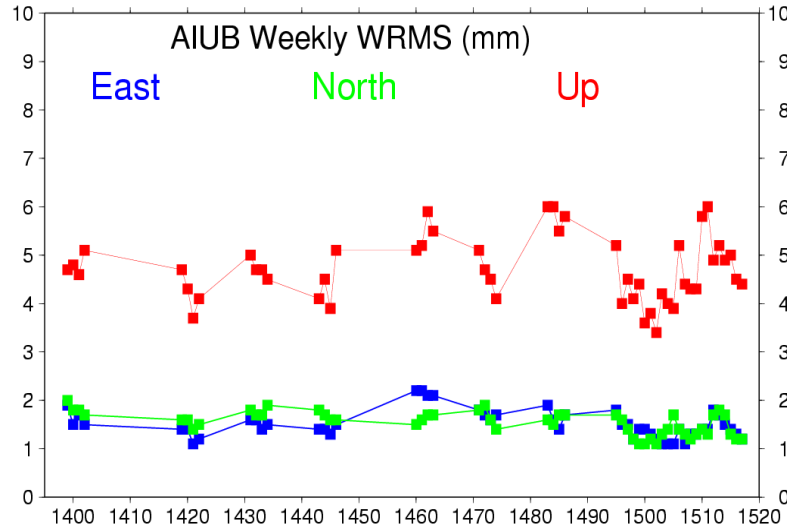
- **Weekly orbit and clock combination**

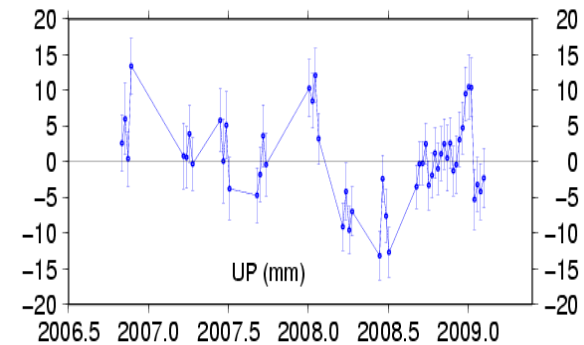
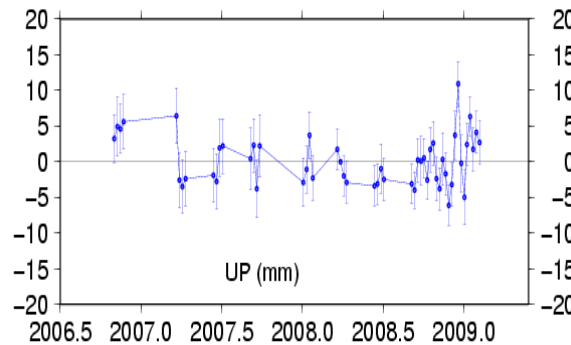
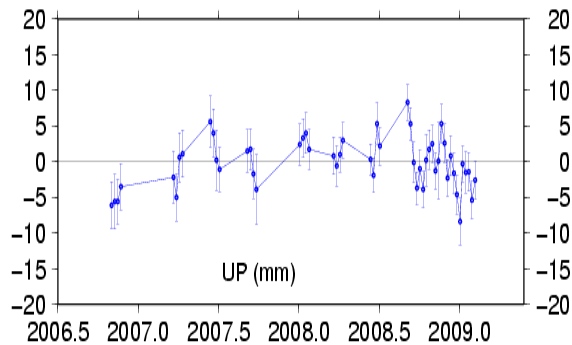
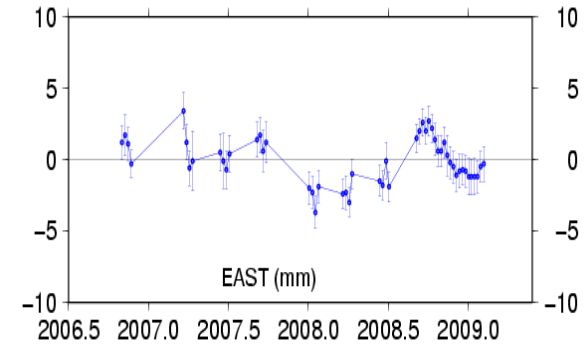
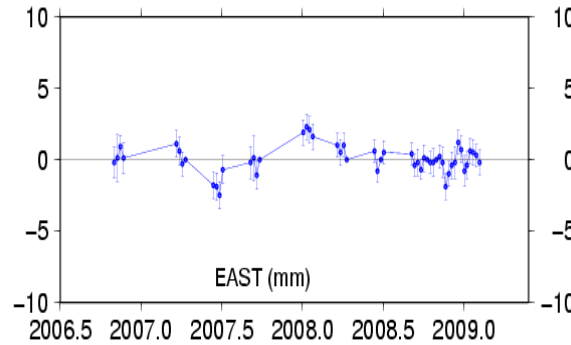
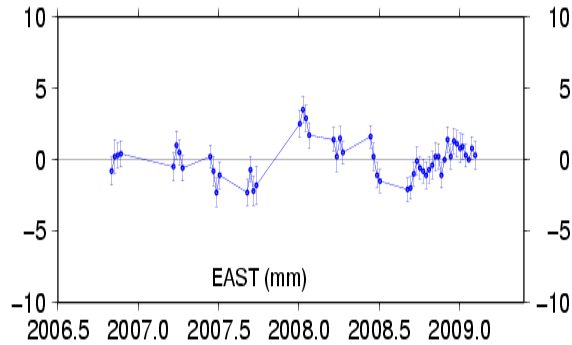
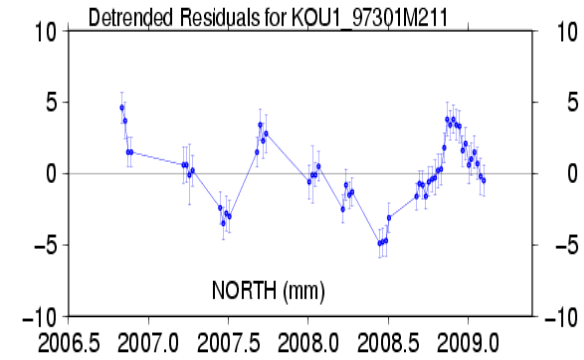
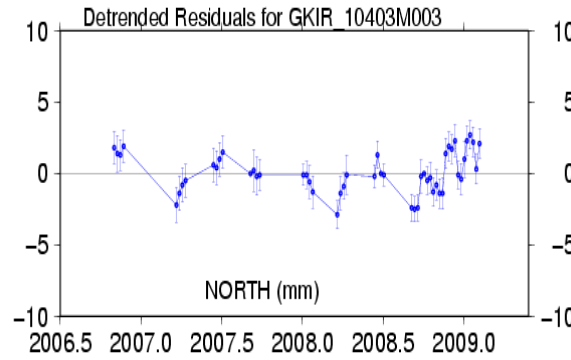
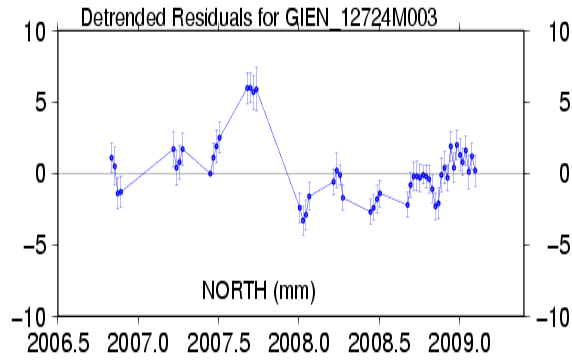
- **Initial GTRF (station positions & velocities) and its updates:**
3 GTRF versions are available so far.

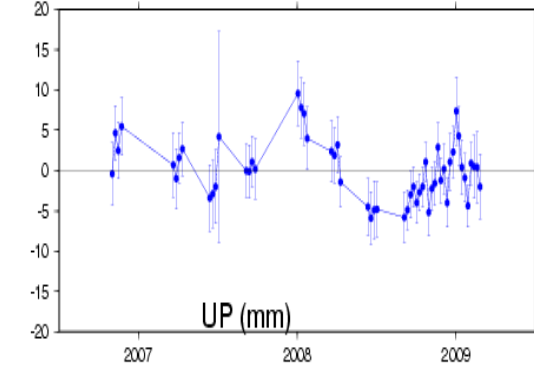
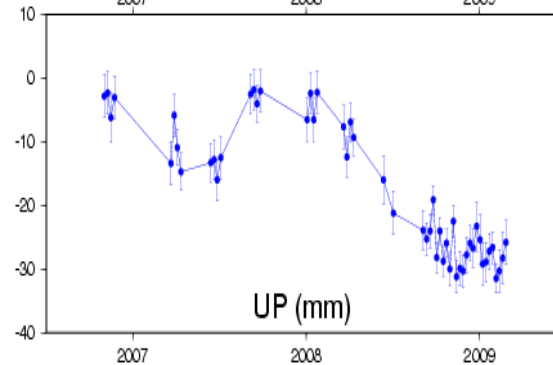
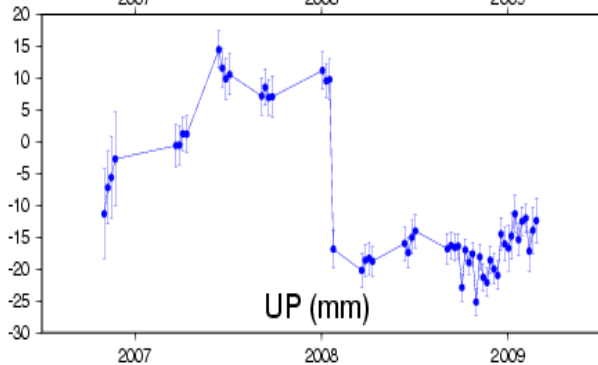
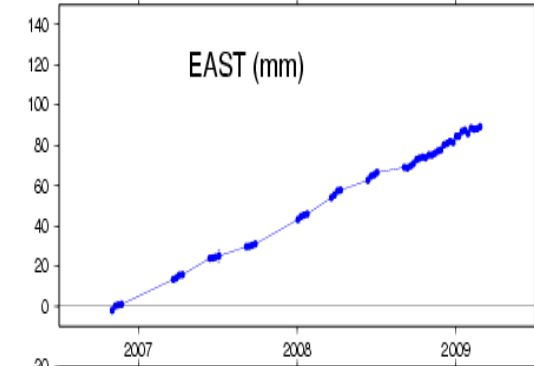
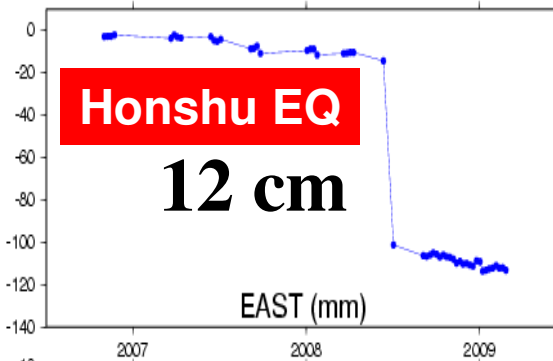
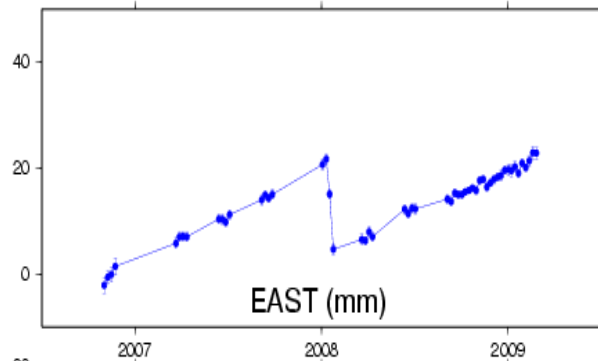
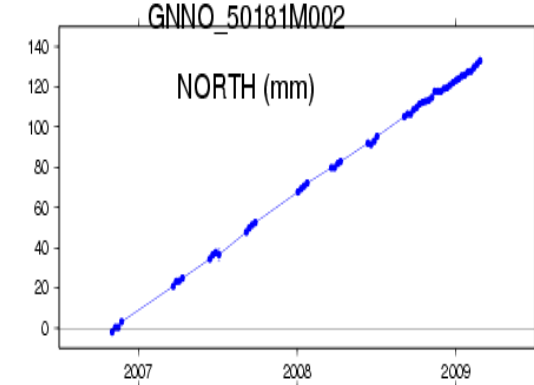
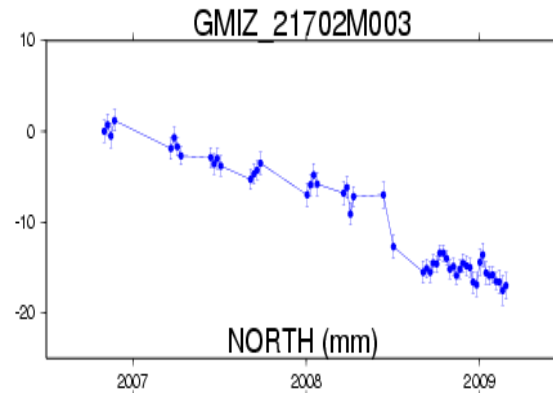
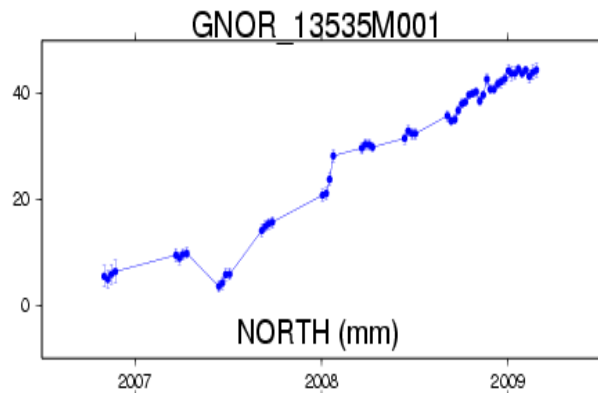
- Use Normal Equations from the 3 PFs
- Adequate for weighing
- Analyse and combine all 3 solutions
- Combined TRF using Minimum Constraints

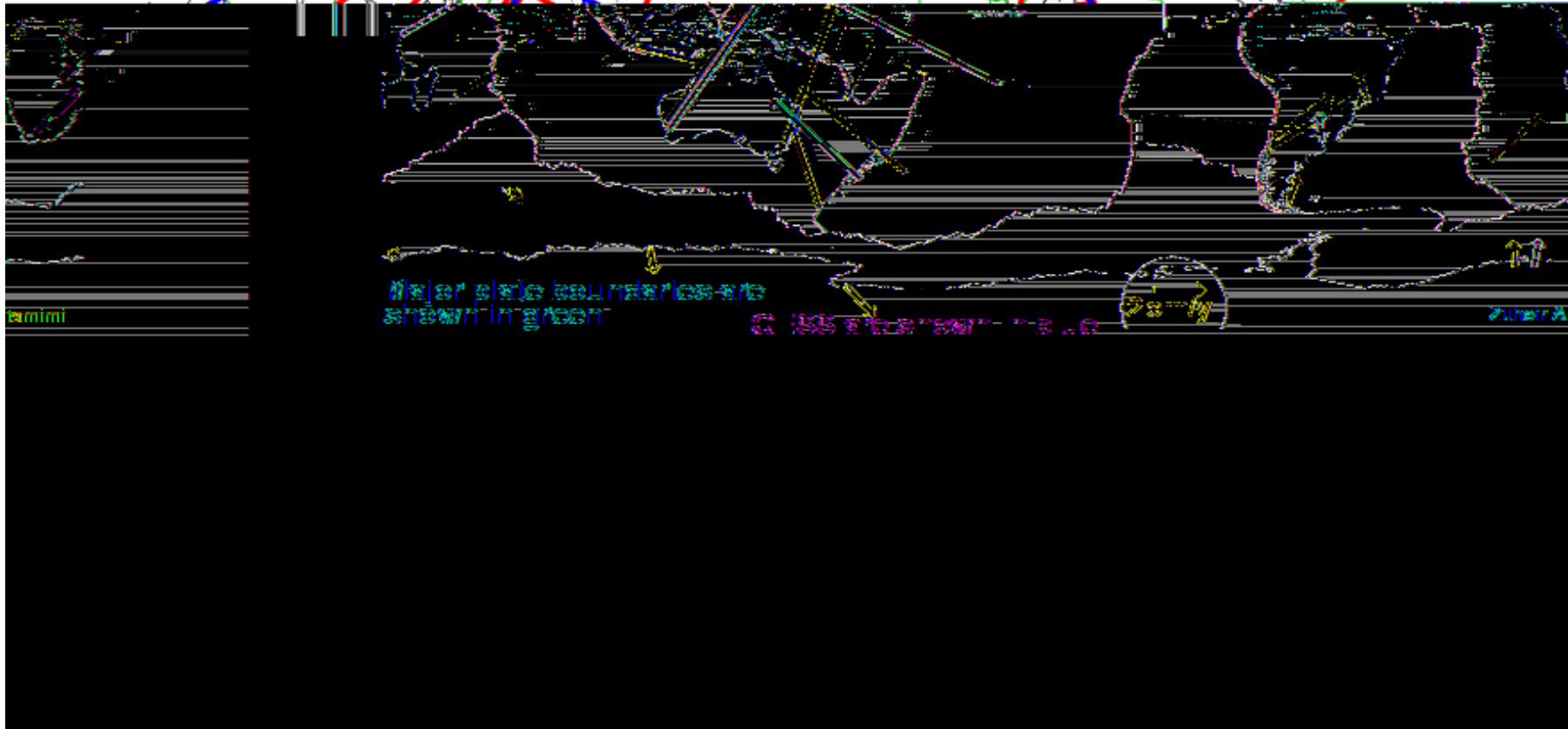
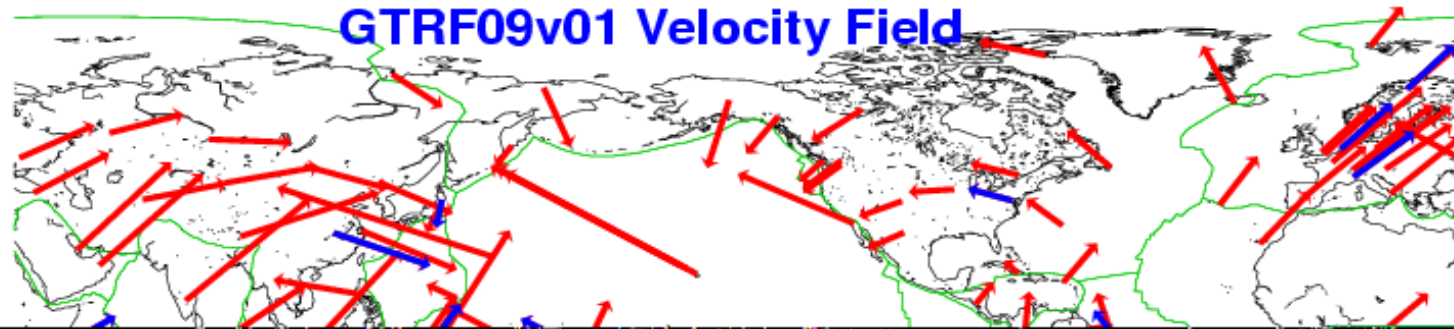
$$\begin{array}{ccc}
 \boxed{X_R = X_c + A\theta} & \xrightarrow{\theta = 0} & \boxed{(A^T A)^{-1} A^T (X_R - X_c) = 0} \\
 \uparrow & & \uparrow \\
 \text{ITRF} & & \text{Combined Solution} \\
 & & \text{(GTRF)}
 \end{array}$$











Transformation parameters

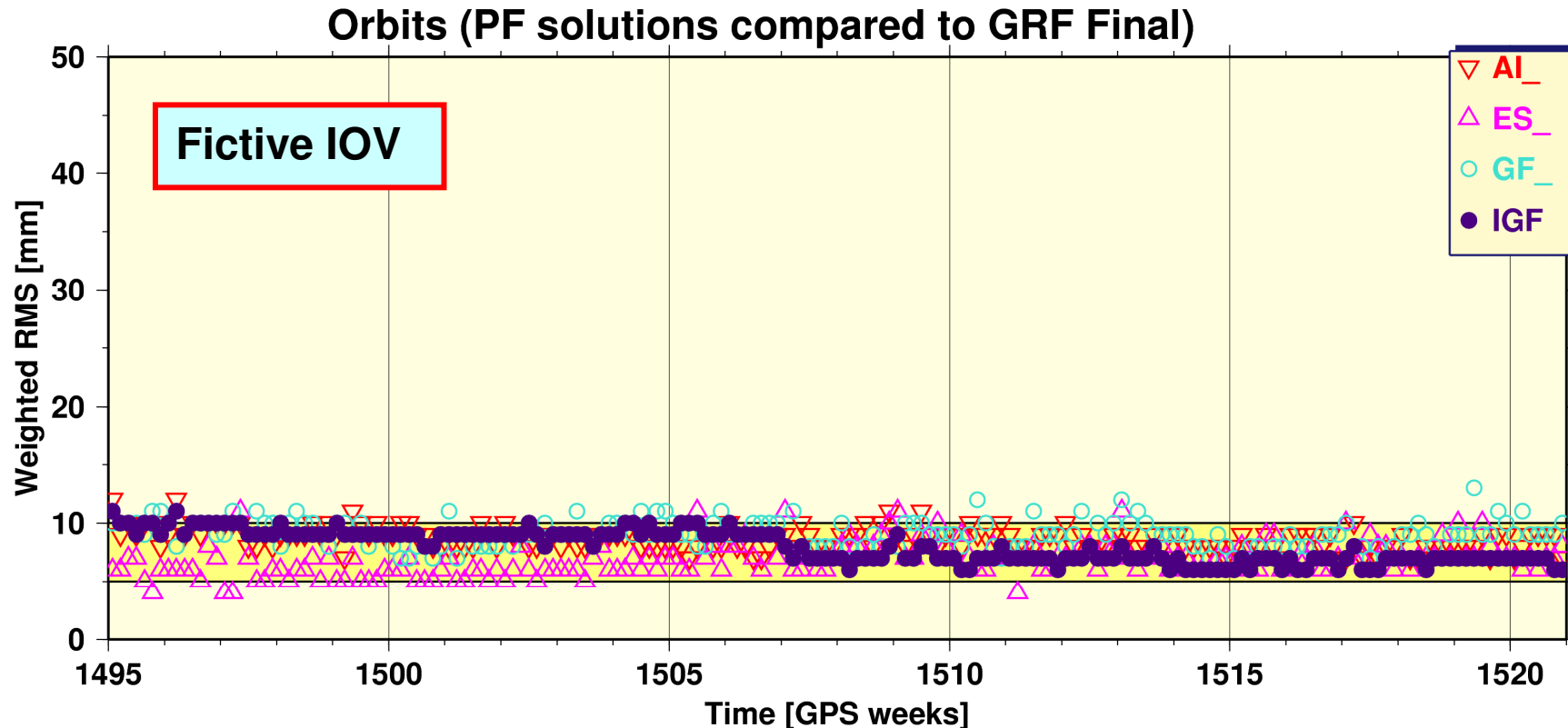
	T1	T2	T3	D	R1	R2	R3	Epoch
	mm	mm	mm	10 ⁻⁹	mas	mas	mas	y
ITRF2005	0.3	-0.3	-0.2	-0.02	-0.003	-0.007	-0.006	7:360
	± 0.2	± 0.2	± 0.2	± 0.03	± 0.007	± 0.008	± 0.008	
Rates	0.0	-0.1	-0.1	0.01	-0.001	-0.002	-0.001	
	± 0.2	± 0.2	± 0.2	± 0.03	± 0.007	± 0.008	± 0.008	

==> Perfect GTRF alignment to the ITRF at the sub-mm level

RMS difference between stations coordinates and velocities

	N	WRMS-Pos.			Epoch	WRMS-Vel.		
		E	N	U		E	N	U
		mm				y	mm/y	
ITRF2005	89	1.0	1.2	2.6	7:360	0.3	0.3	0.6

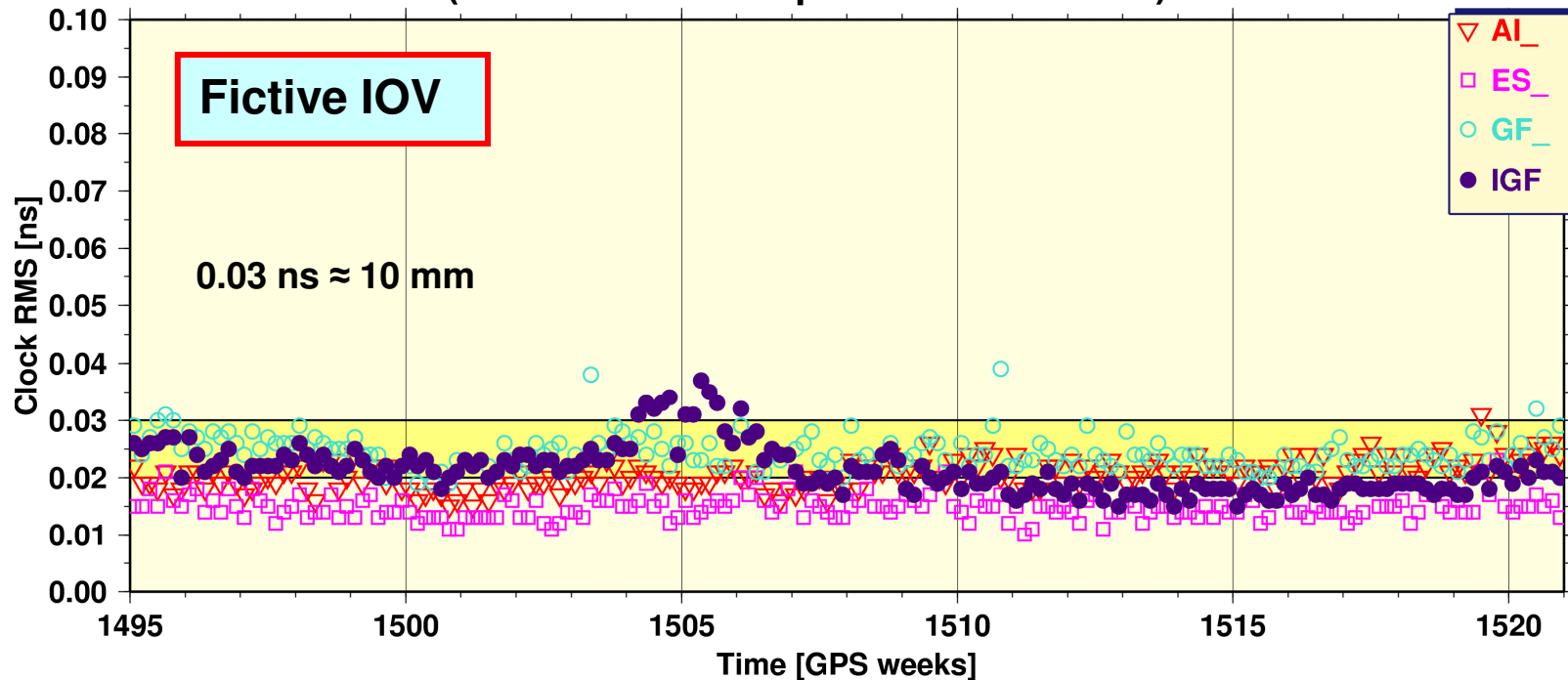
- Orbit comparison (solutions of PFs and IGS Final to combi)
RMS over all satellites compared to GGSP combi



- PFs compare to combined product by 5 to 12 mm
- GRF orbits agree to official IGS Finals at 7 to 10 mm level (precision of IGS itself).

- Clock comparison
RMS over all satellites & stations compared to GGSP combi

Clocks (PF solutions compared to GRF Final)



- GRF clocks agree to official IGS Finals at 0.02 to 0.03 ns level (RMS).
◆ Precise Point Positioning with sub-cm accuracy possible

- **Very good performance of PFs and GTRF combined solutions: repeatability:**
 - ◆ 1-3 mm Horizontal
 - ◆ 4-5 mm Vertical
- **Good agreement between PF solutions in origin and scale**
- **GTRF Maintenance**
 - ◆ **Maintenance as planned**
 - ◆ **Performance meets requirements**
- *Three GTRF versions were released so far*
- *Perfect alignment to the ITRF at the sub-mm level*
- *The GTRF is a key element and will be available for the IOV phase*