European Commission

esa

Views on Interoperability

International Committee on Global Navigation Satellite Systems

Prague, November 10th – 14th 2014

GALILEO EGNOS

Navigation solutions powered by Europe

European Space Agency

INTRODUCTION

- The original purpose of the discussion was to understand **how much similar GNSS providers need to be for a user to benefit from the combined use**
- Interoperability questionnaires have been distributed by most of the service providers
  - **Understanding of users / manufacturers**
  - **Different users = different needs**
  - **The more equal the better?**
  - **What are the outcomes of the questionnaire to be used for? Future services?**

The "*GLONASS DILEMMA*"

INTEROPERABILITY

- **Interoperability** refers to the ability of civil space-based positioning, navigation, and timing services to be used together to provide better capabilities at the user level than would be achieved by relying solely on one service or signal

***NSPD-39: U.S. Space-Based Position, Navigation, and Timing Policy, December 15, 2004**

INTEROPERABILITY

- COMBINED USE OF TWO SYSTEMS FOR BETTER PERFORMANCE AT USER LEVEL
  - Signal-in-Space (frequencies, waveforms, codes, data messages)
    - Signal structure, waveforms, codes and data messages are software: differences cause no problem
    - Different frequencies: Frequency biases degrade accuracy, different front-ends necessary
    - Common centre frequencies needed for inter-operability (combined processing of observations)
    - Coordinate Reference Frame
    - Time Reference Frame

SOME DEFINITIONS

- Reference **System**
  - **Conceptual idea of a reference system including the fundamental theory and standards**
- Reference **Frame**
  - **Realization of a reference system through observations** and
    - a set of station coordinates in case of a reference coordinate system,
    - a single or a set of clocks in case of a time reference system

Moritz, H., I. I. Mueller (1987) Earth Rotation Theory and Observations. The Ungar. Publ. Comp., New York

Kovalevsky, J. et al, eds. (1989) Reference Frames in Astronomy and Geophysics. Astrophysics and Space Library, Vol. 54, D. Reidel, Dordrecht/Boston/London

BASIC REMARKS

- In satellite navigation practice the **Reference Frame** is of importance
- Even if it would be agreed to use the same standards for the coordinate reference system, resp., the way of realization results in differences (of a certain accuracy level) between two satellite systems
- **For the GALILEO Reference System international civilian standards should be adopted**
- For various reasons the realization of the GALILEO coordinate reference frame should be based on stations different from those of GPS
  - Independence of both satellite systems
  - The second satellite navigation system can be used as a backup solution
  - Vulnerability of a satellite navigation system
  - New and better accuracy possible in the realization of a coordinate system

ITRF - INTERN TERR REFERENCE FRAME

- Realization of the International Terrestrial Reference System (ITRS)
- Orientation consistent with BIH System at 1984.0 (Resolutions of IUGG and IAU)
- Established by the Terr Ref Frame Section of the Central Bureau of the International Earth Rotation Service (IERS)
- Implementation of the ITRF based on
  - Set of station coordinates (SSC) and velocities derived from observations of VLBI, LLR, SLR, GPS (since 1991) and DORIS (since 1994)
  - Annual solutions
  - Reduction of the individual SSC´s to a common reference epoch considering their station velocity models (fixed plate motion models or estimated velocity fields
  - Least-squares estimation at reference epoch with seven-parameter transformations of all individual solutions

ITRF – WGS84 – GTRF COORD REF FRAMES

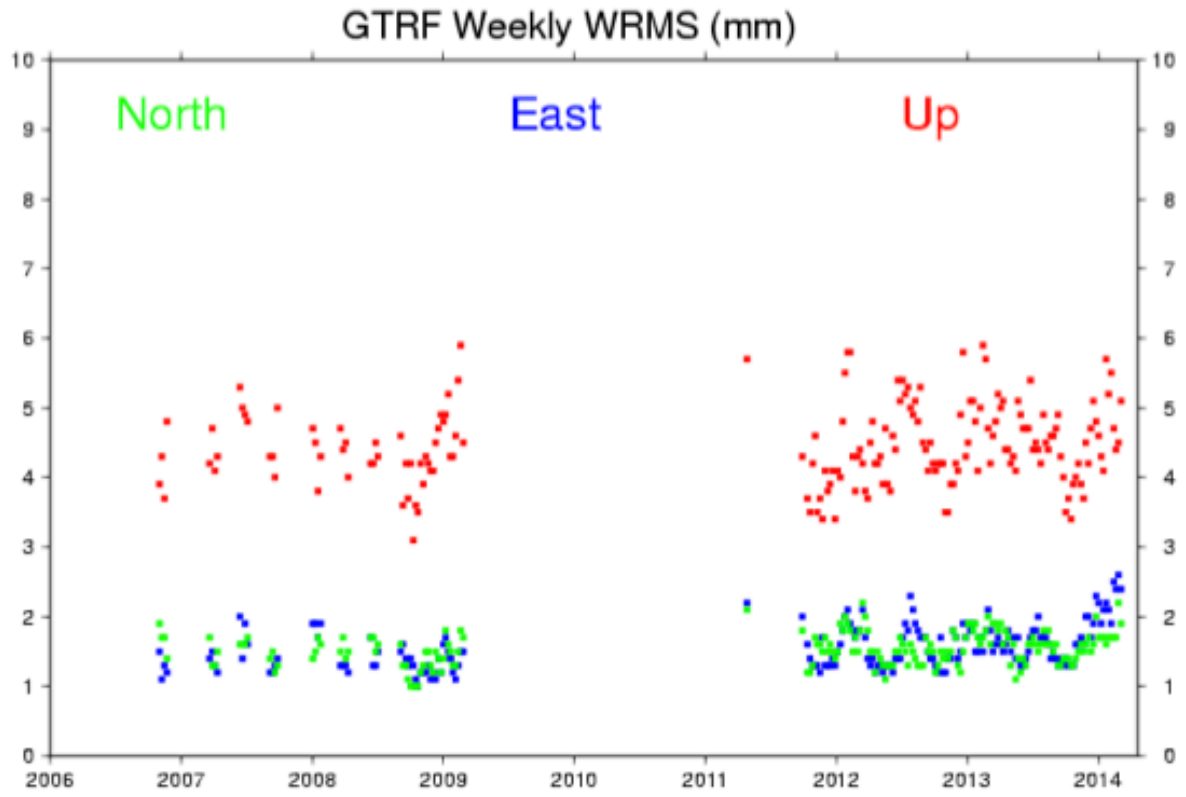
- WGS84 (GPS Coordinate Reference Frame)
  - Realized by the coordinates of the GPS control stations
  - Differences between ITRF96 and WGS84(G1150) < 2-3 cm (GPS was considered in ITRF96)
- Present GALILEO planning for the GALILEO Terrestrial Reference System
  - Realization within < 3 cm (2σ) w.r.t. ITRF

GTRF realization

- Realized by a consortium of Geodetic institutions as the GRSP prototype (OVF)
- Weekly solutions (station positions and ERPs) generated by 3 independent Processing Facilities (PF) (AIUB, GFZ and ESOC)
- Weekly combination of station positions and ERPs
- Weekly orbit and clock combination
- Initial GTRF (station positions & velocities) and its updates:
    - GTRF13v01 – on 18 May 2013
    - GTRF13v02 – on 27 May 2013
    - GTRF14v01 - on 24 April 2014

GTRF realization

- WRMS in the three local components (North, East and Up) for the 182 GTRF weekly solutions used to generate the GTRF14v01.



Comparison of GTRF14v01 to ITRF2008

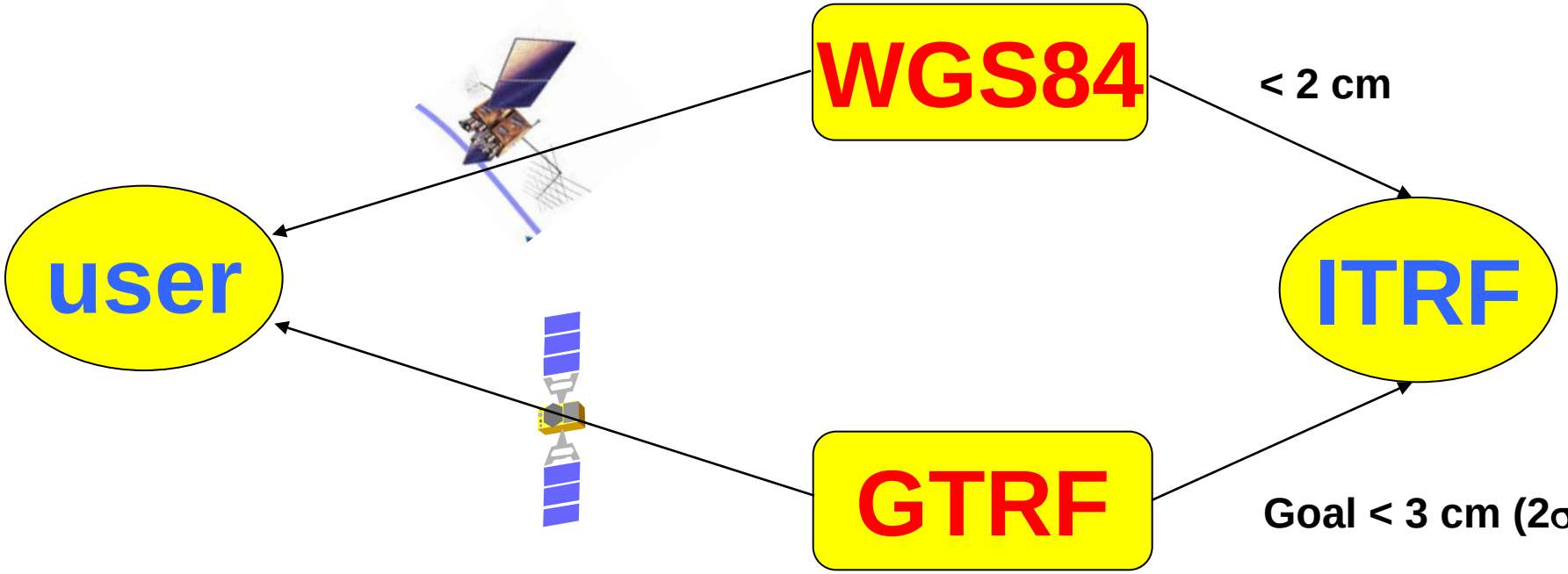
Transformation parameters from GTRF14v01 to IGb08 (ITRF2008)

	T1 mm	T2 mm	T3 mm	D 10-9	R1 mas	R2 mas	R3 mas	Epoch y
	0.0	0.0	0.0	0.00	0.000	0.000	0.000	11:208
+/-	0.3	0.3	0.3	0.04	0.010	0.010	0.010	
Rates	0.0	0.0	0.0	0.00	0.000	0.000	0.000	
+/-	0.3	0.3	0.3	0.04	0.010	0.010	0.010	

RMS differences between GTRF14v01 and IGb08 (ITRF2008) station coordinates and velocities

Station #	RMS-Pos. E mm	RMS-Pos. N mm	RMS-Pos. U mm	Epoch y	RMS-Vel. E mm/y	RMS-Vel. N mm/y	RMS-Vel. U mm/y
91	2.1	1.8	3.7	10:285	0.7	0.7	1.4

ITRF – WGS84 – GTRF
COORD REF FRAMES - CONCLUSIONS



- WGS84 and GALILEO Coordinate Reference Systems are identical within the accuracy of both realizations (compatible)
- Users get access to this realization through the SIS message (satellite coordinates) including additional inaccuracy
- Small remaining discrepancies in the dm level

GST – GALILEO SYSTEM TIME

- GST mod 1 sec will be steered to real-time realization of UTC(k) labs in Europe – through external Galileo Time Service Provider (GTSP)
- GPS time is spec within 1 msec of UTC(USNO) mod whole sec´s Practically kept within ± 25 ns past 8 yrs
- GST is spec within 50 ns (95%) of TAI (International Atomic Time) over 1 yr. Achieved performance during Aug'14: 19.84 ns
- GST – TAI offset: 28 ns (2s) (assuming estimation of TAI six weeks in advance). Achieved performance during Aug'14: 7.90 ns
- User Galileo rcvr is able to predict UTC to 30 ns for 95% of any 24 hrs of operation. Achieved performance during Aug'14: 5.74 ns
- GPS and GST time – like TAI – not adjusted for leap seconds. Achieved performance during Aug'14: 12.83 ns

GST – GALILEO SYSTEM TIME

- GST is steered to UTC mod 1 sec as predicted by European UTC(k) labs - through external Galileo Time Service Provider (GTSP)
- GPS time is spec within 1 msec of UTC(USNO) mod whole sec´s Practically kept within ± 25 ns past 8 yrs
- GST offset to UTC mod 1 sec: Achieved performance during Aug'14: 19.84 ns (95%)
- GST – UTC offset prediction (assuming estimation of UTC six weeks in advance). Achieved performance during Aug'14: 7.90 ns (2s)
- Galileo user receiver UTC reception accuracy, 95% of any 24 hrs of operation. Achieved performance during Aug'14: 5.74 ns
- GPS to GST time offset: Achieved performance during Aug'14: 12.83 ns

TIME INTEROPERABILITY GPS-GALILEO

- Two options:
  - Galileo to GPS Time Offset estimated in GPS-Galileo user equipment at the cost of one SV tracked (fifth satellite)
  - Broadcast of GPS/Galileo Time Offset in each system's navigation message obtained by:
    - Traditional time transfer techniques (Two-way, common view, etc…)
    - Estimation in near real time using combined GPS/Galileo monitor station receivers
- Broadcasting agreed between EC and US
- Goal: 5 ns (1.5 m)

INTEROPERABILITY

Interoperability requires to agree on the minimum set of parameters necessary to provide space-based positioning…

…not more, not less