Standardisation of Geodetic Reference Frames for GNSS based on ITRF

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What is a Terrestrial Reference System (TRS) ?

- Stations positions are neither directly observable nor absolute quantities: they have to be determined with respect to some reference
- TRS: mathematical model for a physical Earth in which point positions are expressed and have small temporal variations due to geophysical effects (plate motion, Earth tides, etc.)
- It is a spatial reference system co-rotating with the Earth in its diurnal motion in space

International Terrestrial Reference System (ITRS): Definition

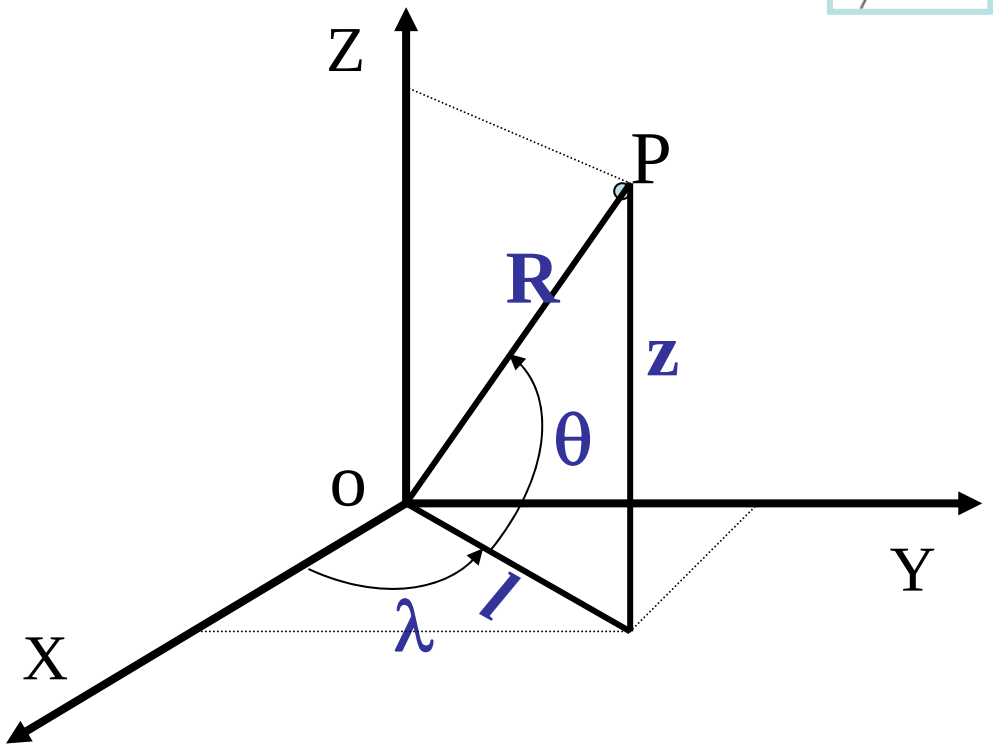
- Origin: Center of mass of the whole Earth, including oceans and atmosphere
- Unit of length: metre SI, consistent with TCG (Geocentric Coordinate Time)
- Orientation: consistent with BIH (Bureau International de l'Heure) orientation at 1984.0.
- Orientation time evolution: ensured by using a No-Net-Rotation-Condition w.r.t. horizontal tectonic motions over the whole Earth

How a TRS is realized ?

- Access to point positions requires measurements (observations) allowing their link to the mathematical object
- TRF: Set of physical points with determined coordinates
- The TRF is a realization of the TRS, making use of Space Geodetic observations
- Each technique and data analysis realizes its own TRS
- Many TRF's exist

Coordinate Systems

- Cartesian: X, Y, Z
- Ellipsoidal: λ, φ, h
- Mapping: E, N, h
- Spherical: R, θ, λ
- Cylindrical: *l*, λ, Z



Crust-based TRF

The instantaneous position of a point on Earth Crust at epoch *t* could be written as :

$$X(t) = X_0 + \dot{X}.(t - t_0) + \sum_i \Delta X_i(t)$$

X_0 : point position at a reference epoch t_0

$\dot{X}$: point linear velocity

$\Delta X_i(t)$: high frequency time variations:

- solid Earth tide
- ocean loading
- atmosphere loading
- geocentre motion

Space Geodesy Techniques

- GNSS (GPS, GLONASS, Galileo, …)
- Very Long Baseline Interferometry (VLBI)
- Lunar Laser Ranging (LLR)
- Satellite Laser Ranging (SLR)
- DORIS

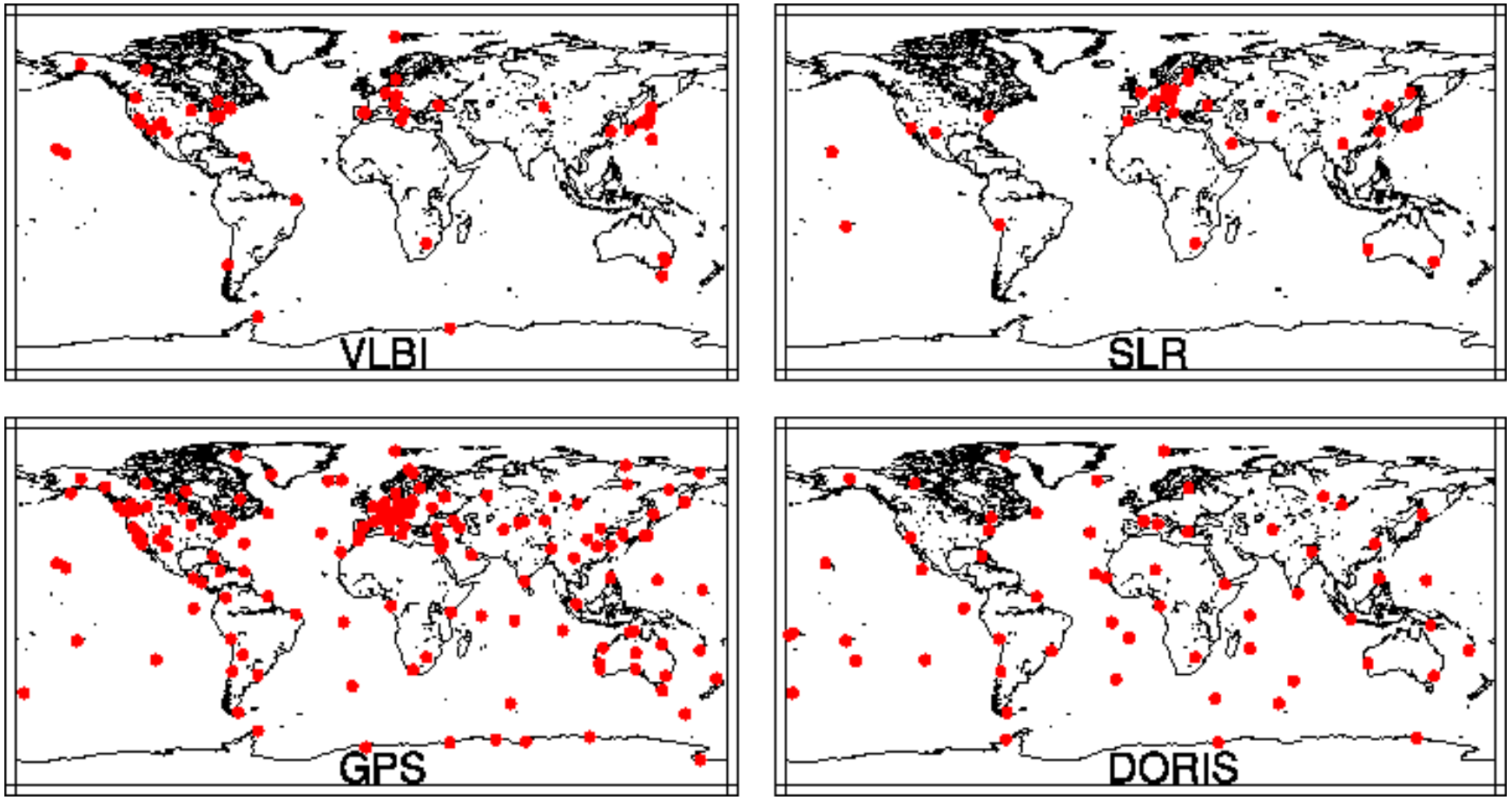
International Association of Geodesy
Associated Space Geodesy Services

- International GNSS Service (IGS) (1994)
- International Laser Ranging Service (ILRS) (1998)
- International VLBI Service (IVS) (1999)
- International DORIS Service (IDS) (2003)

- International Earth Rotation and Reference Systems Service (IERS) (1988)

- http://www.iag-aig.org

Current Space Geodesy Networks (1999.0 onward)



International Earth Rotation and Reference Systems Service (IERS)

Established 1 January 1988 by IAU and IUGG to realize/maintain/provide:

- The International Celestial Reference System (ICRS)
- The International Terrestrial Reference System (ITRS)
- Earth Orientation Parameters (EOP)
- Geophysical data to interpret time/space variations in the ICRF, ITRF & EOP
- Standards, constants and models (“IERS Conventions”)

http://www.iers.org/

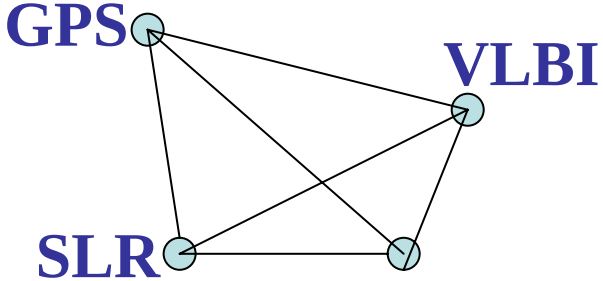
International Terrestrial Reference System (ITRS)

- Realized and maintained by ITRS Product Center of the IERS
- Its realization is called International Terrestrial Reference Frame (ITRF)
- Set of station positions and velocities, estimated by combination of VLBI, LLR, SLR, GPS and DORIS individual TRF solutions
- Based on Co-location sites
- More than 800 stations located on more than 500 sites
- Available: ITRF88, 89,…,2000, latest is ITRF2005

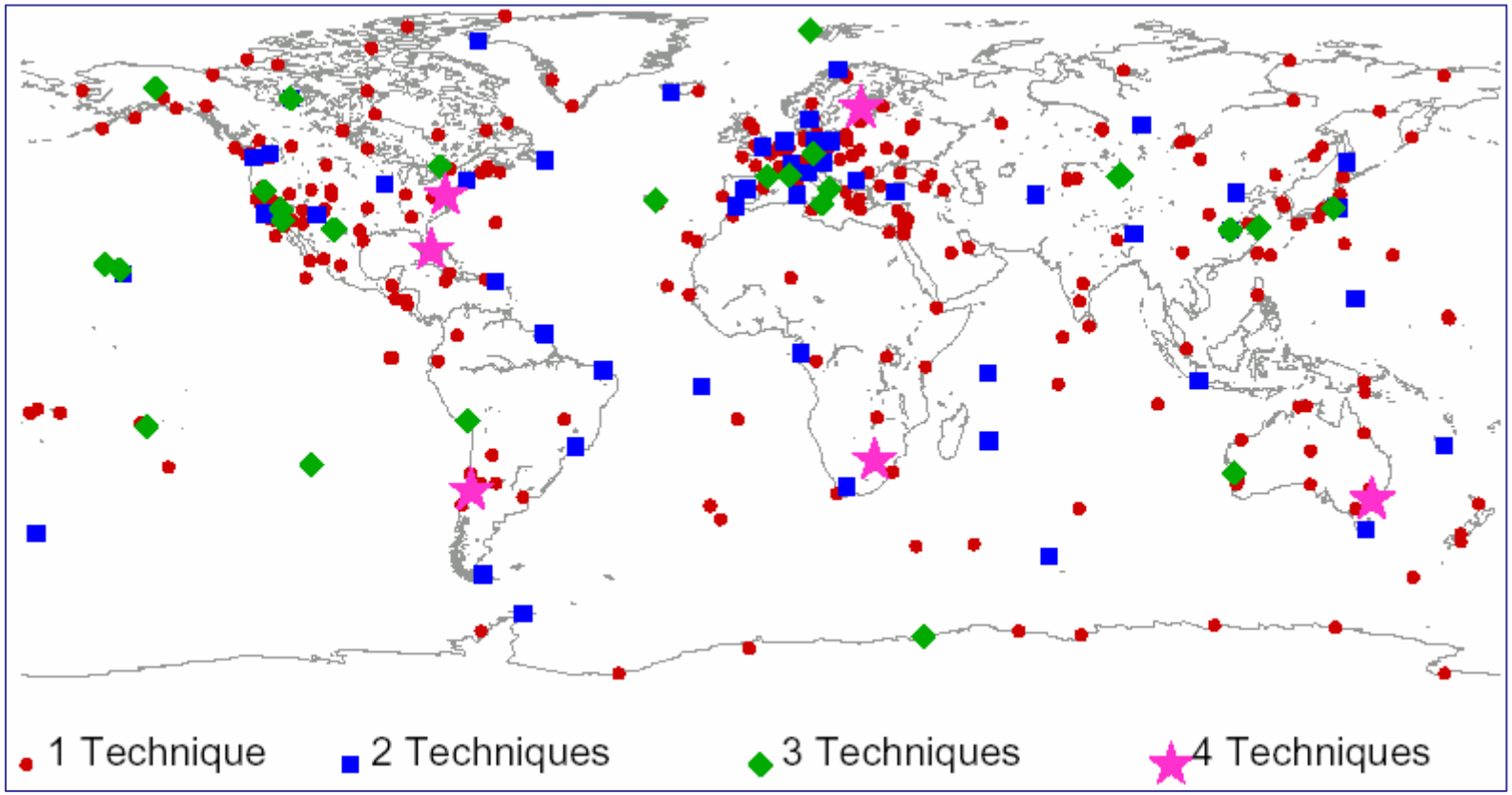
http://www.ensg.ign.fr/ITRF/

Co-location Site

- Site where two or more space geodesy close instruments (hundred metres) are operating
- Precisely surveyed in three dimensions, using classical or GPS geodesy
- Differential coordinates (DX, DY, DZ) are available



ITRF2005 Co-locations



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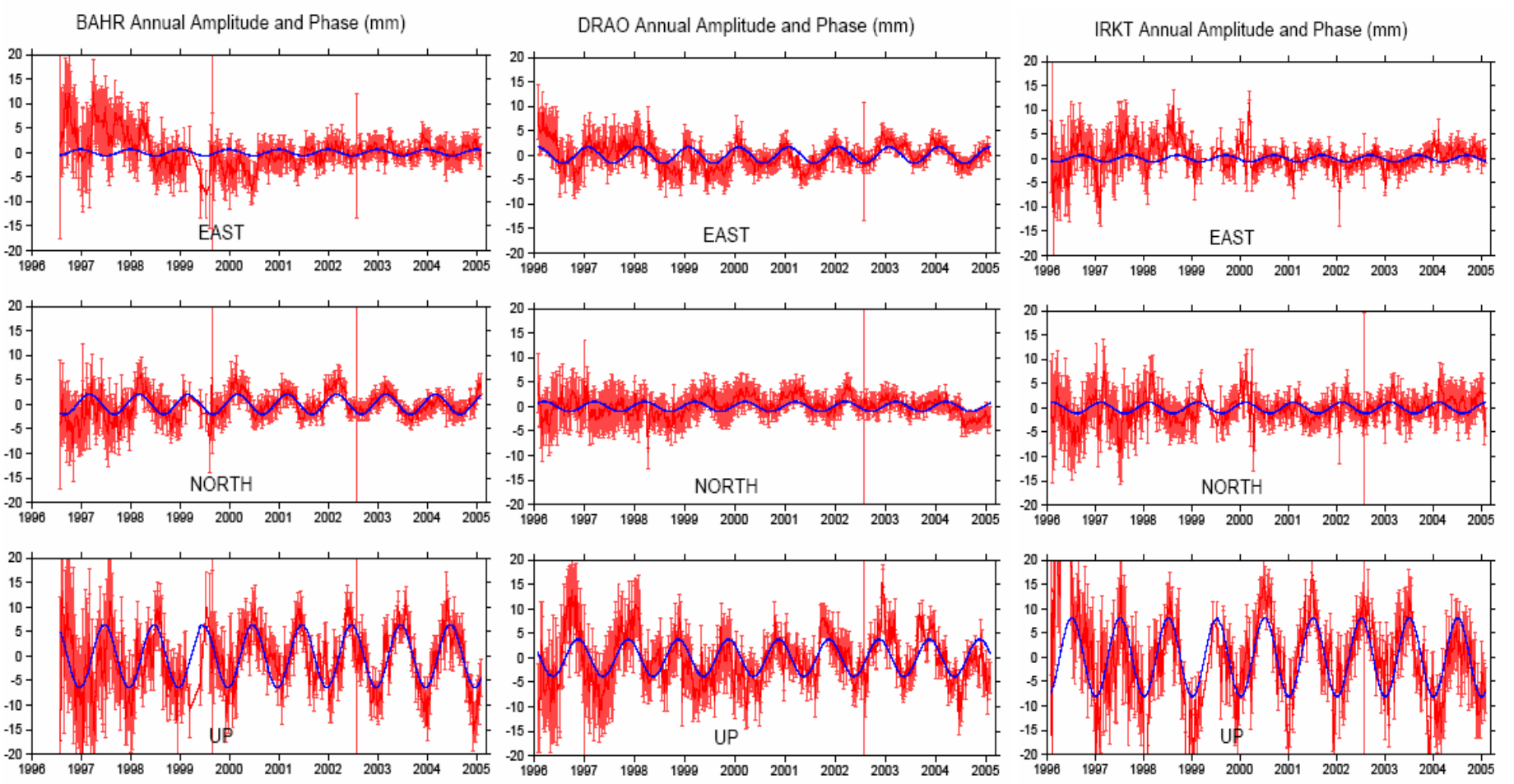
Positioning Performance

WRMS range per technique
(Internal Precision – Repeatability)

Solution	2-D WRMS mm	Up WRMS mm
VLBI	2-3	5-7
SLR	5-10	5-10
GPS	2-3	5-6
DORIS	12-25	10-25

WARNING! These are indicative numbers and are station dependant

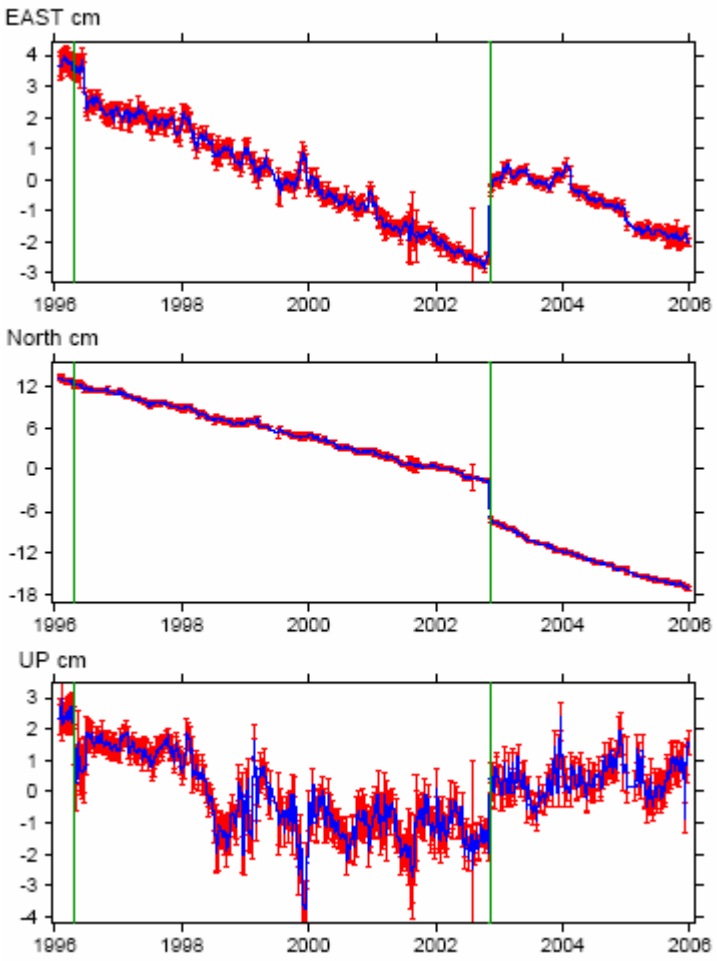
Seasonal Variations GPS/IGS Sites



BAHR **DRAO** **IRKT**

Denaly Earthquake (Alaska)

GPS



Access to ITRS

- Direct use of ITRF coordinates
- Use of IGS Products (Orbits, Clocks): all related to ITRF
- Fixing or constraining some ITRF station coordinates in the analysis of GPS measurements
- Use of transformation formulae

World Geodetic System 84 (WGS 84)

- Collection of models including Earth Gravity model, geoid, transformation formulae and set of coordinates of permanent DoD GPS monitor stations
- WGS 60…66…72…84
- Originally based on TRANSIT satellite Doppler data

WGS 84

- TRS of GPS Broadcast Ephemerides
- Recent WGS 84 realizations based on GPS data:
  - G730 in 1994
  - G873 in 1996
  - G1150 in 2002 (NGA used data from 49 IGS stations, fixed with their ITRF2000 coordinates)
- Now coincides with ITRF at few cm level
- For most applications “WGS 84 = ITRF2000”, but ITRF is better realized (a few mm)

GLONASS Reference Frame PZ-90

- IGS monitors daily the transformation between the GLONASS Broadcast message and ITRF (IGS)
- Variations of metres, day to day
- Improved version PZ-90.02 will be applied to GLONASS starting September 20, 2007. “On switching to the International Terrestrial Reference Frame ITRF2000, PZ-90.02 transformation parameters will contain only origin shift along X, Y, Z by -36 cm, +8 cm, +18 cm respectively” (Announcement of 31.8.2007)

Galileo Terrestrial Reference Frame (GTRF)

- Galileo Geodesy Service Provider (GGSP) Prototype
- GGSP Consortium (GFZ, AIUB, ESOC, BKG, IGN) under contract to GSA:
  - Define, realize and maintain the GTRF
  - GTRF to be compatible with the ITRF
  - Liaison with IERS, IGS, ILRS
- GTRF is a realization of the ITRS
- Similar to IGS/GPS: Galileo Orbits, Clocks will be expressed in GTRF (= ITRF to some mm)

GTRF Implementation

- Initial GSS positions and velocities will be provided using GPS observations
- Subsequent GTRF versions will use GPS & Galileo observations
- Weekly solutions will be performed for the long-term maintenance of the GTRF
  - independent solutions by the 3 Analysis Centres of the GGSP consortium (GFZ, AIUB, ESOC)
  - Analysis of the 3 solutions by IGN:
    - Comparison and quality evaluation
    - Combination and alignment to the ITRF

Reference Frames for Global Navigation Satellite Systems

- GPS Broadcast Message uses WGS-84, which is now well-aligned to ITRF
- GLONASS is adopting a new version of PZ-90 which is becoming closer to the ITRF
- Galileo will use a GTRF which will have cm alignment to ITRF
- Japanese, Indian, Chinese systems …?
- IGS currently monitors routinely the GPS and GLONASS reference frames, others in the future

Concluding Remarks

- IAG Services play a major role in realising the ITRS
- GPS and GLONASS are now using reference frames which are gradually approaching ITRF
- Galileo will enhance the ITRF in the future
- Inter-operability: need for standardisation of GNSS reference frames
- Specifically, all future GNSS's should aim to realise the ITRS at the few cm level or better
- IGS is in a good position to monitor reference frame offsets and stability on routine basis
- Proposal for a WG in ICG, to be discussed in WG-D