



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 ?



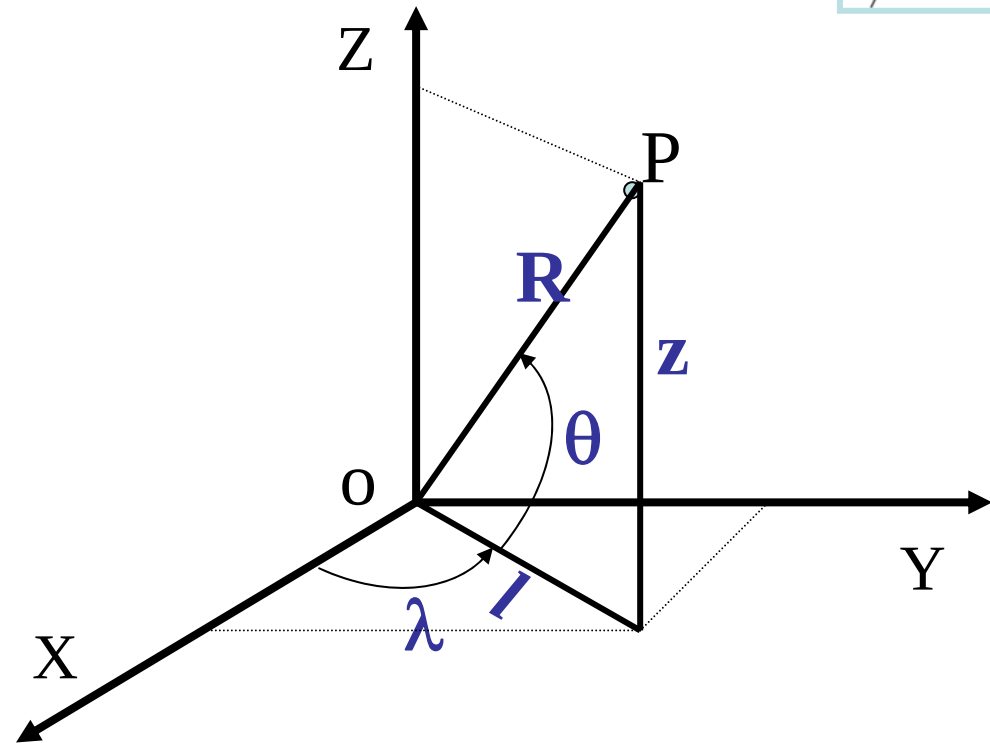
- Access to point positions requires measurements (observations) allowing their link to the mathematical object
- **TRF**: Set of physical points with determined coordinates
- The TRF is a realization of the TRS, making use of Space Geodetic observations
- Each technique and data analysis realizes its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

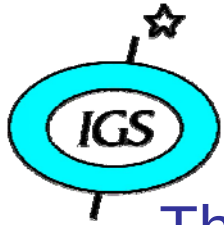


Coordinate Systems



- 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 :

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

- | | | |
|-----------------|---|--|
| X_0 | : | point position at a reference epoch t_0 |
| $\dot{X}$ | : | point linear velocity |
| $\Delta X_i(t)$ | : | high frequency time variations: <ul style="list-style-type: none">- 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



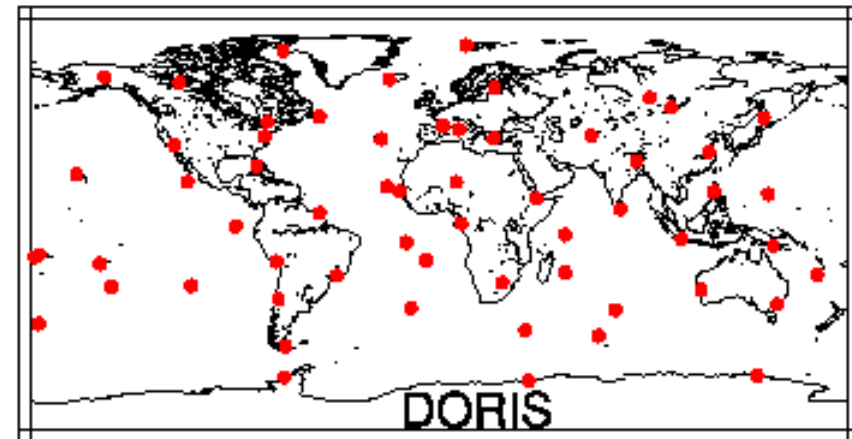
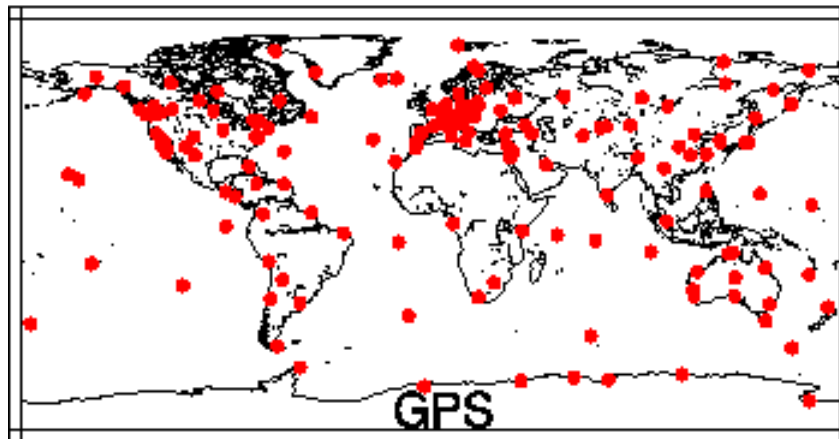
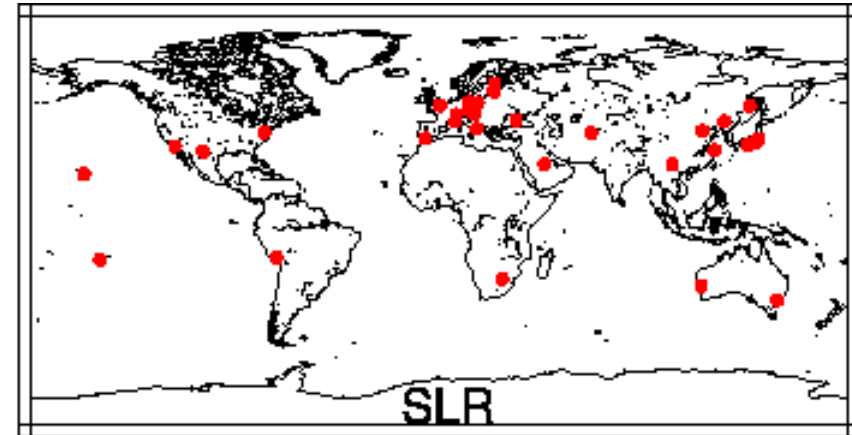
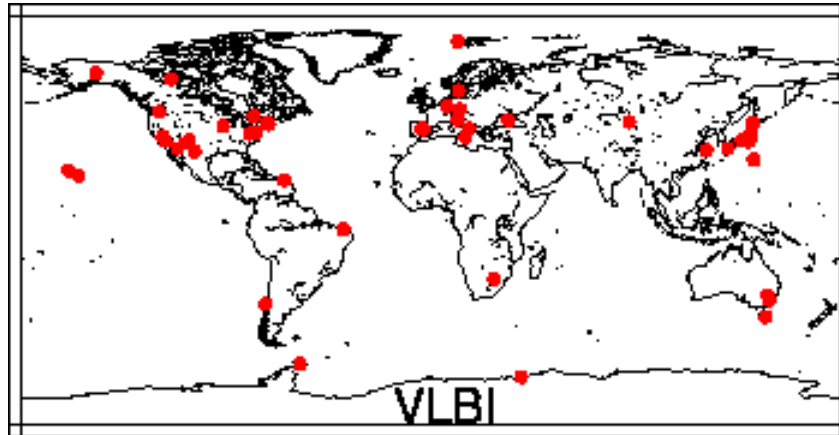
- International GNSS Service (IGS) (1994)
- International Laser Ranging Service (ILRS) (1998)
- International VLBI Service (IVS) (1999)
- International DORIS Service (IDS) (2003)

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

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



Current Space Geodesy Networks (1999.0 onward)



Second Meeting of the ICG
Bangalore, India, 4-7 September 2007



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)



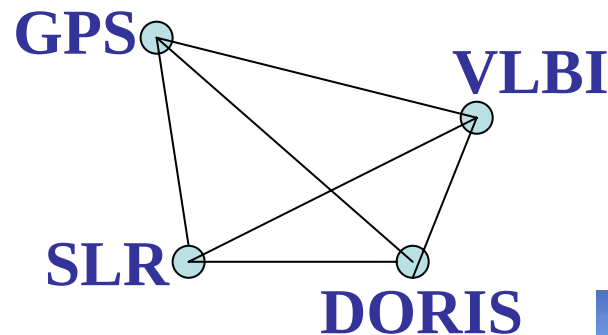
- Realized and maintained by **ITRS Product Center** of the IERS
- Its realization is called International Terrestrial Reference Frame (**ITRF**)
- Set of station positions and velocities, estimated by combination of VLBI, LLR, SLR, GPS and DORIS individual TRF solutions
- **Based on Co-location sites**
- 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

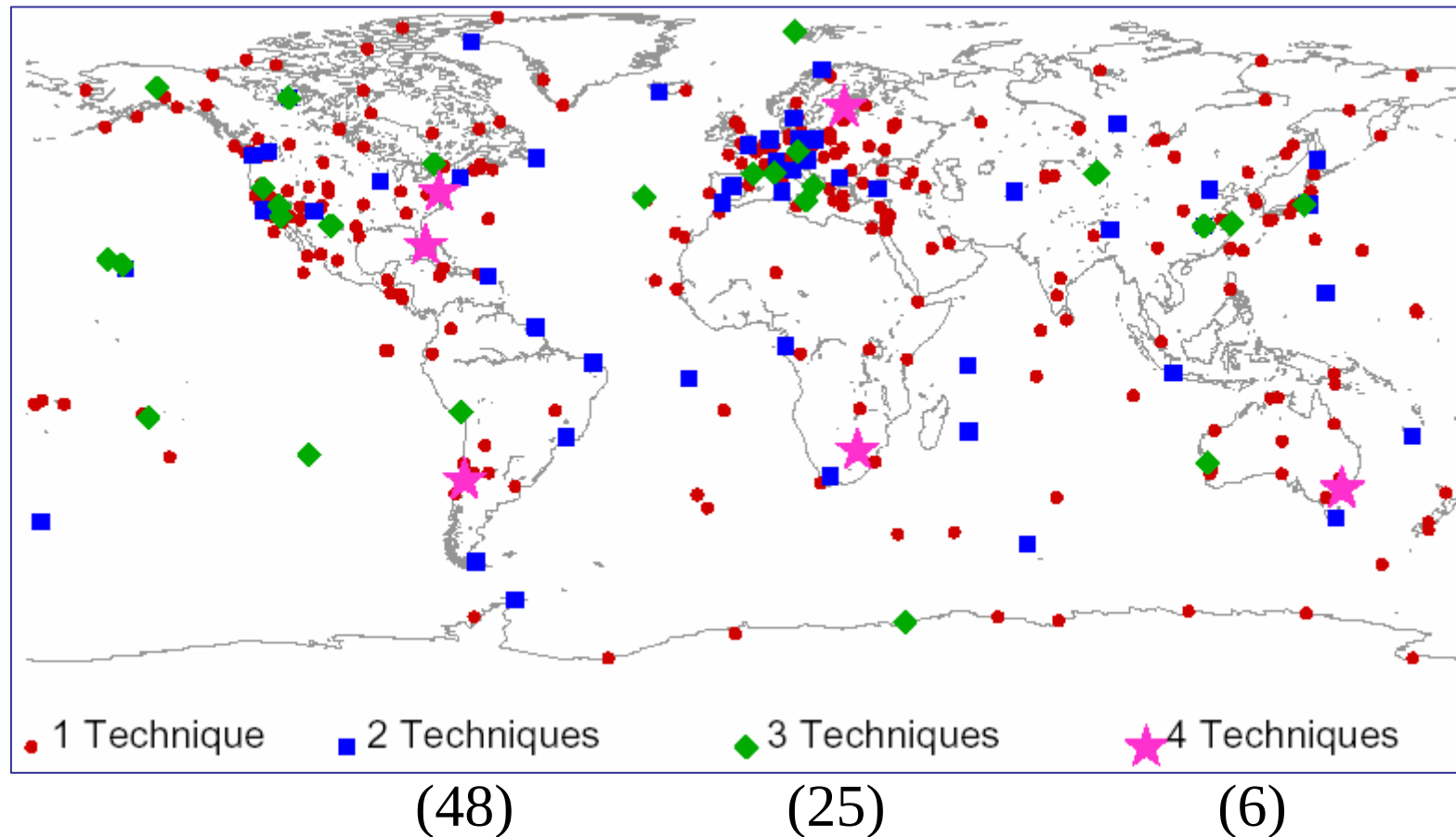
- Site where two or more space geodesy close instruments (hundred metres) are operating
- Precisely surveyed in three dimensions, using classical or GPS geodesy
- Differential coordinates (DX, DY, DZ) are available



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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

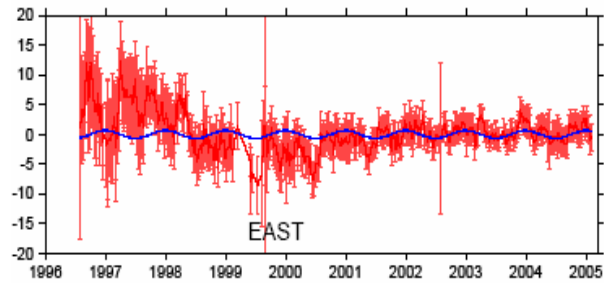
WARNING! These are indicative numbers and are station dependant



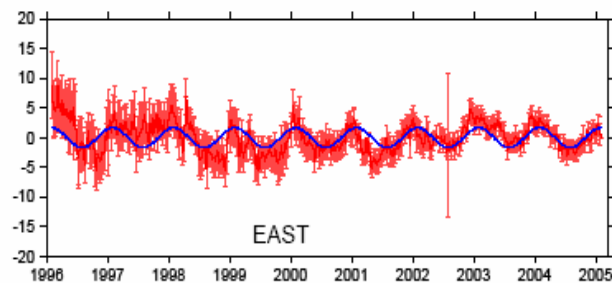
Seasonal Variations GPS/IGS Sites



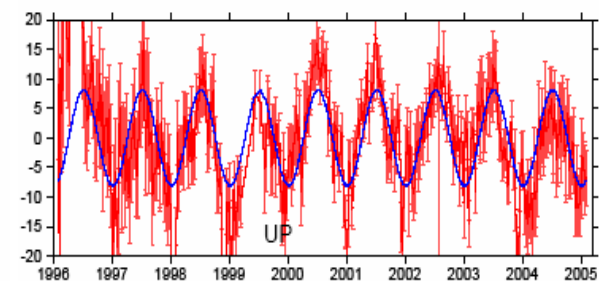
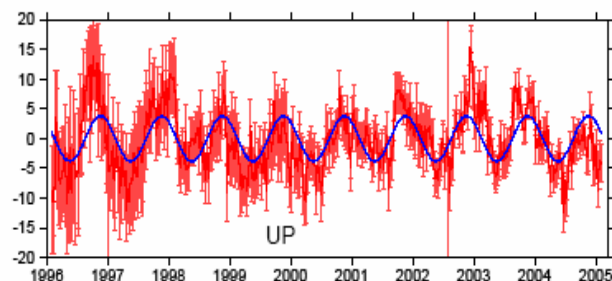
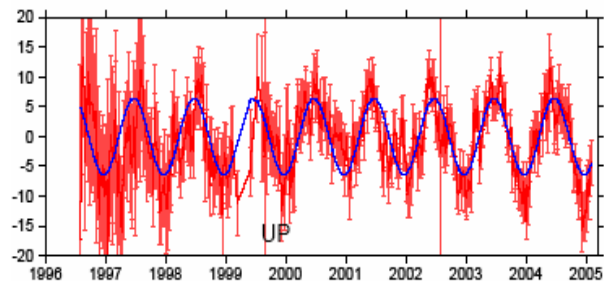
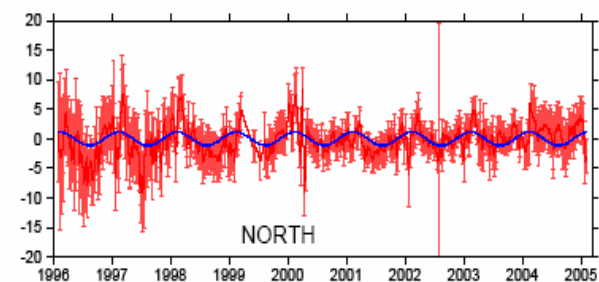
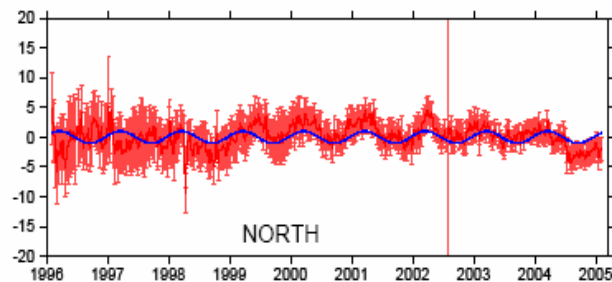
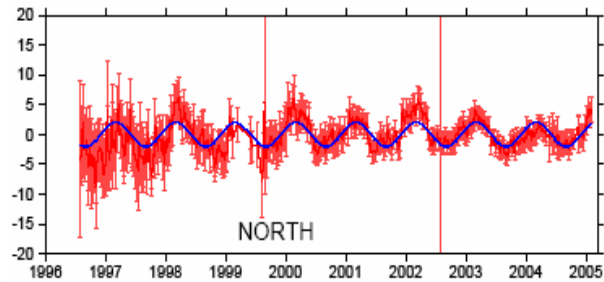
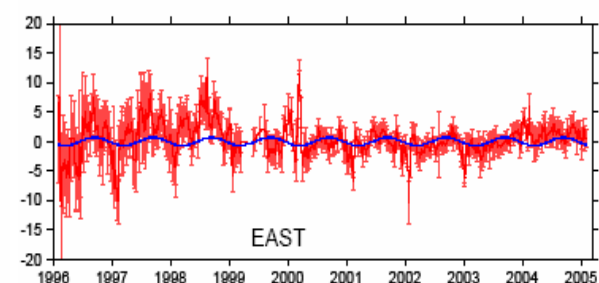
BAHR Annual Amplitude and Phase (mm)



DRAO Annual Amplitude and Phase (mm)



IRKT Annual Amplitude and Phase (mm)



BAHR

DRAO

IRKT

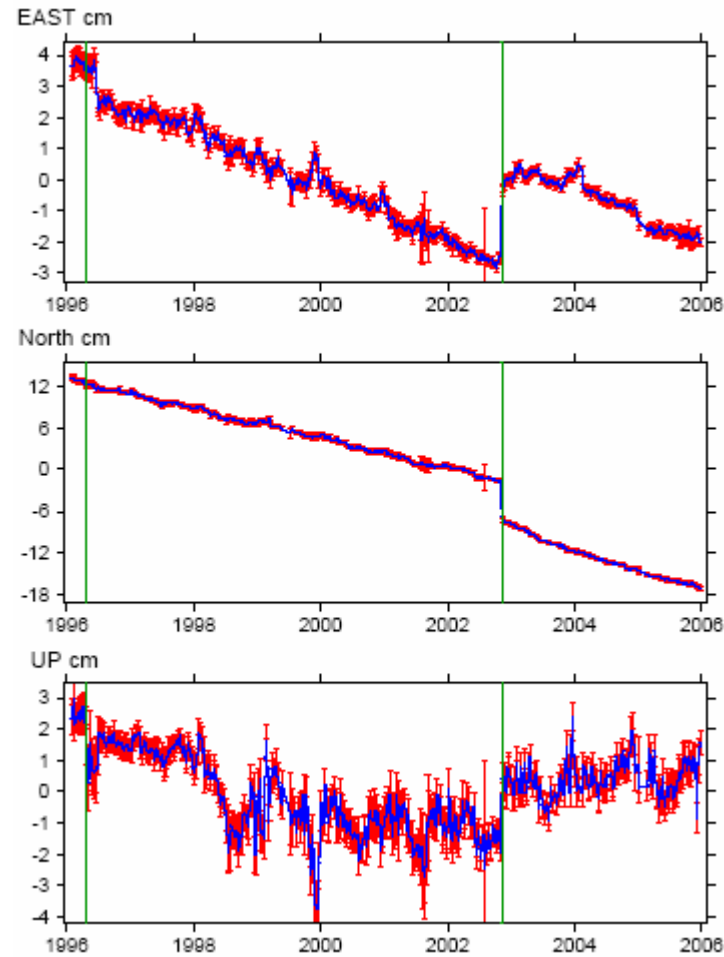
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Denali Earthquake (Alaska)



GPS



**Second Meeting of the ICG
Bangalore, India, 4-7 September 2007**



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**