

# Standardisation of Geodetic Reference Frames for GNSS based on ITRF

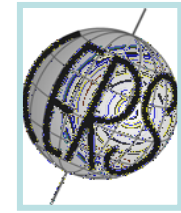
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Chair, IAG Commission 1 (Reference Frames); Head,  
ITRS Product Centre of IERS*



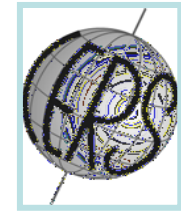
# What is a Terrestrial Reference System (TRS) ?



- 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



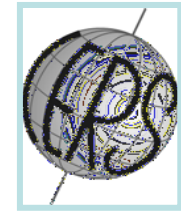
# International Terrestrial Reference System (ITRS): Definition



- **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



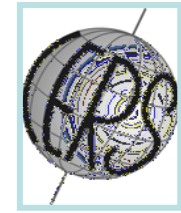
## How a TRS is realized ?



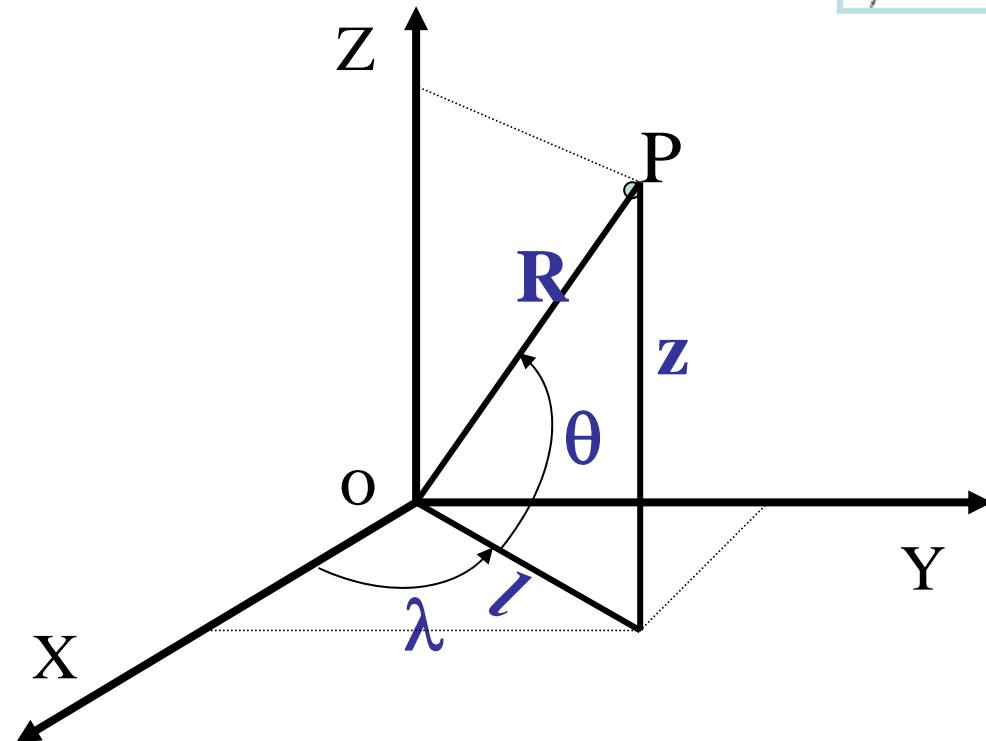
- Access to point positions requires measurements (observations) allowing their link to the mathematical object
- **TRF**: Set of physical points with determined coordinates
- The TRF is a realization of the TRS, making use of Space Geodetic observations
- Each technique and data analysis realizes its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

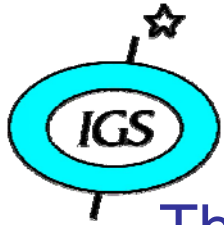


# Coordinate Systems

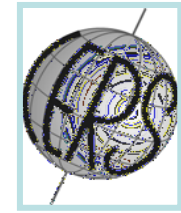


- Cartesian:  $X, Y, Z$
- Ellipsoidal:  $\lambda, \varphi, h$
- Mapping:  $E, N, h$
- Spherical:  $R, \theta, \lambda$
- Cylindrical:  $l, \lambda, Z$





# Crust-based TRF



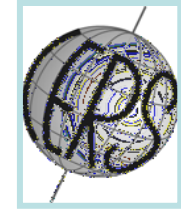
The instantaneous position of a point on Earth Crust at epoch  $t$  could be written as :

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

- $X_0$  : point position at a reference epoch  $t_0$   
 $\dot{X}$  : point linear velocity  
 $\Delta X_i(t)$  : high frequency time variations:  
- solid Earth tide  
- ocean loading  
- atmosphere loading  
- geocentre motion



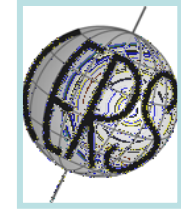
# Space Geodesy Techniques



- 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

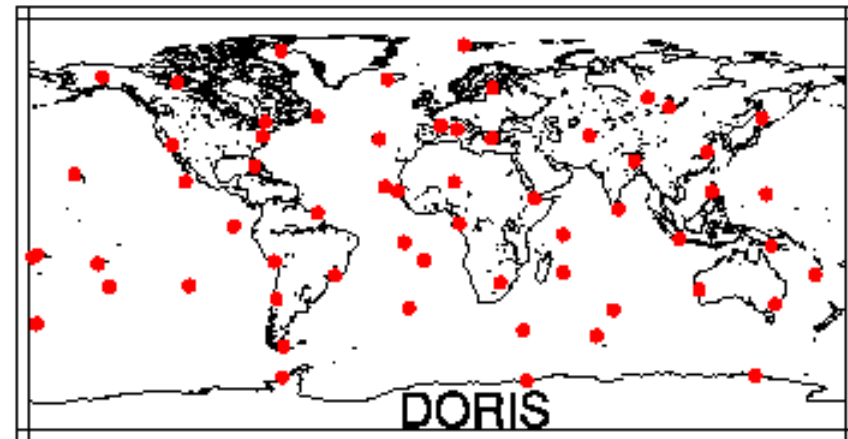
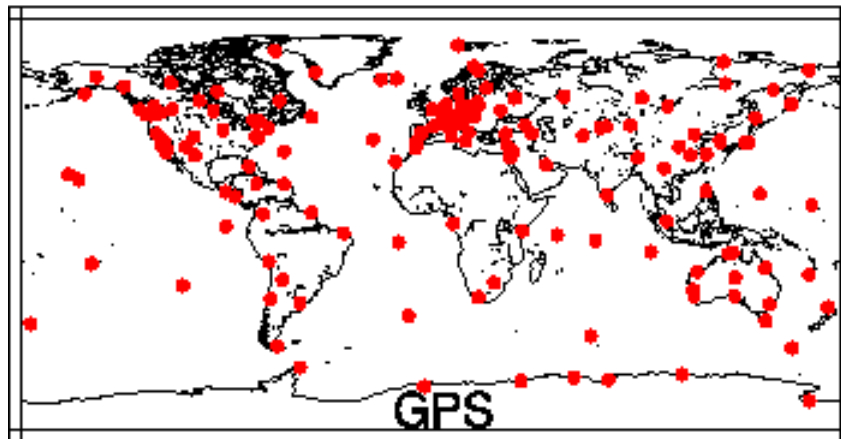
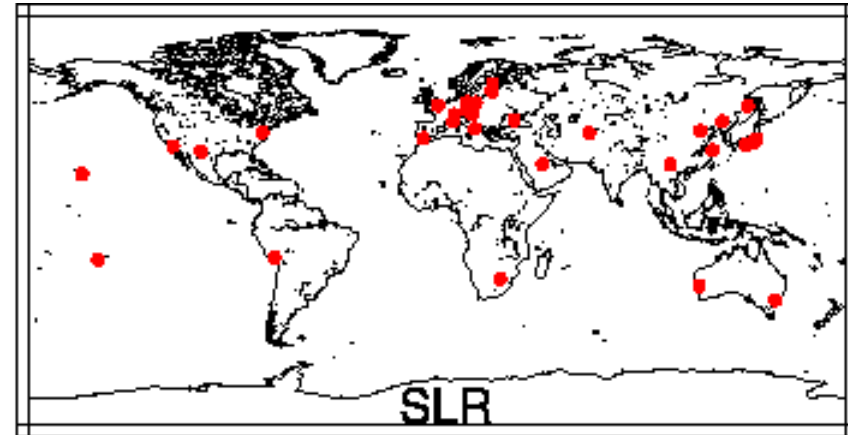
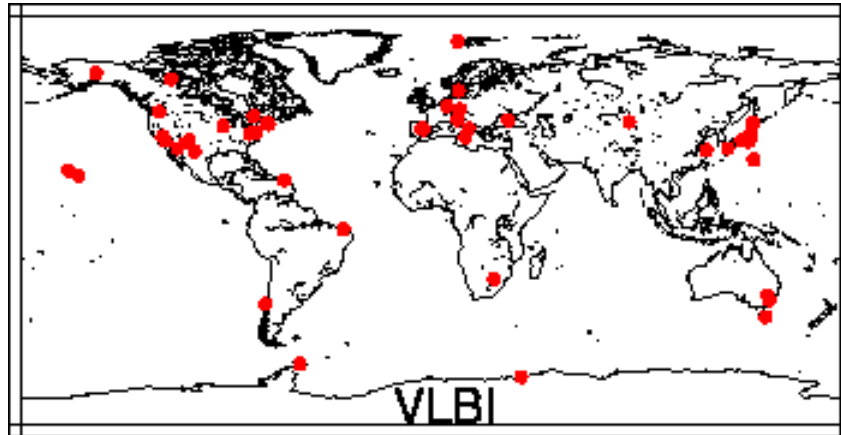
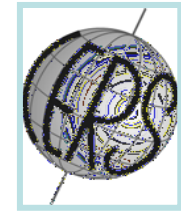


- **International GNSS Service (IGS) (1994)**
- International Laser Ranging Service (**ILRS**) (1998)
- International VLBI Service (**IVS**) (1999)
- International DORIS Service (**IDS**) (2003)
  
- International Earth Rotation and Reference Systems Service (**IERS**) (1988)
  
- <http://www.iag-aig.org>



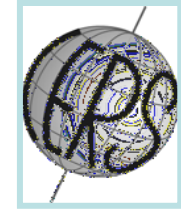


# Current Space Geodesy Networks (1999.0 onward)





# International Earth Rotation and Reference Systems Service (IERS)



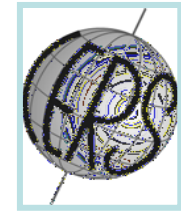
Established 1 January 1988 by IAU and IUGG to realize/maintain/provide:

- 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)

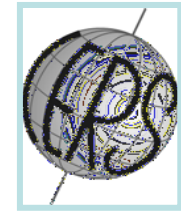


- Realized and maintained by **ITRS Product Center** of the IERS
- Its realization is called International Terrestrial Reference Frame (**ITRF**)
- Set of station positions and velocities, estimated by combination of VLBI, LLR, SLR, GPS and DORIS individual TRF solutions
- **Based on Co-location sites**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

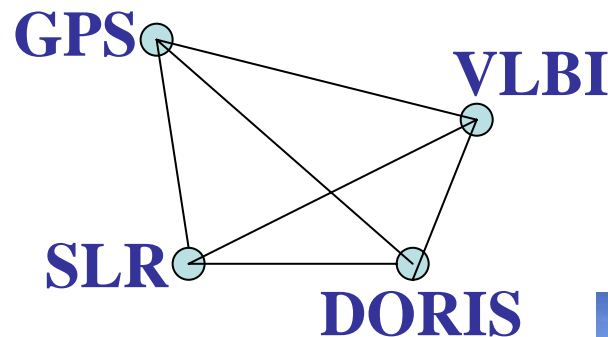
<http://www.ensg.ign.fr/ITRF/>



# Co-location Site



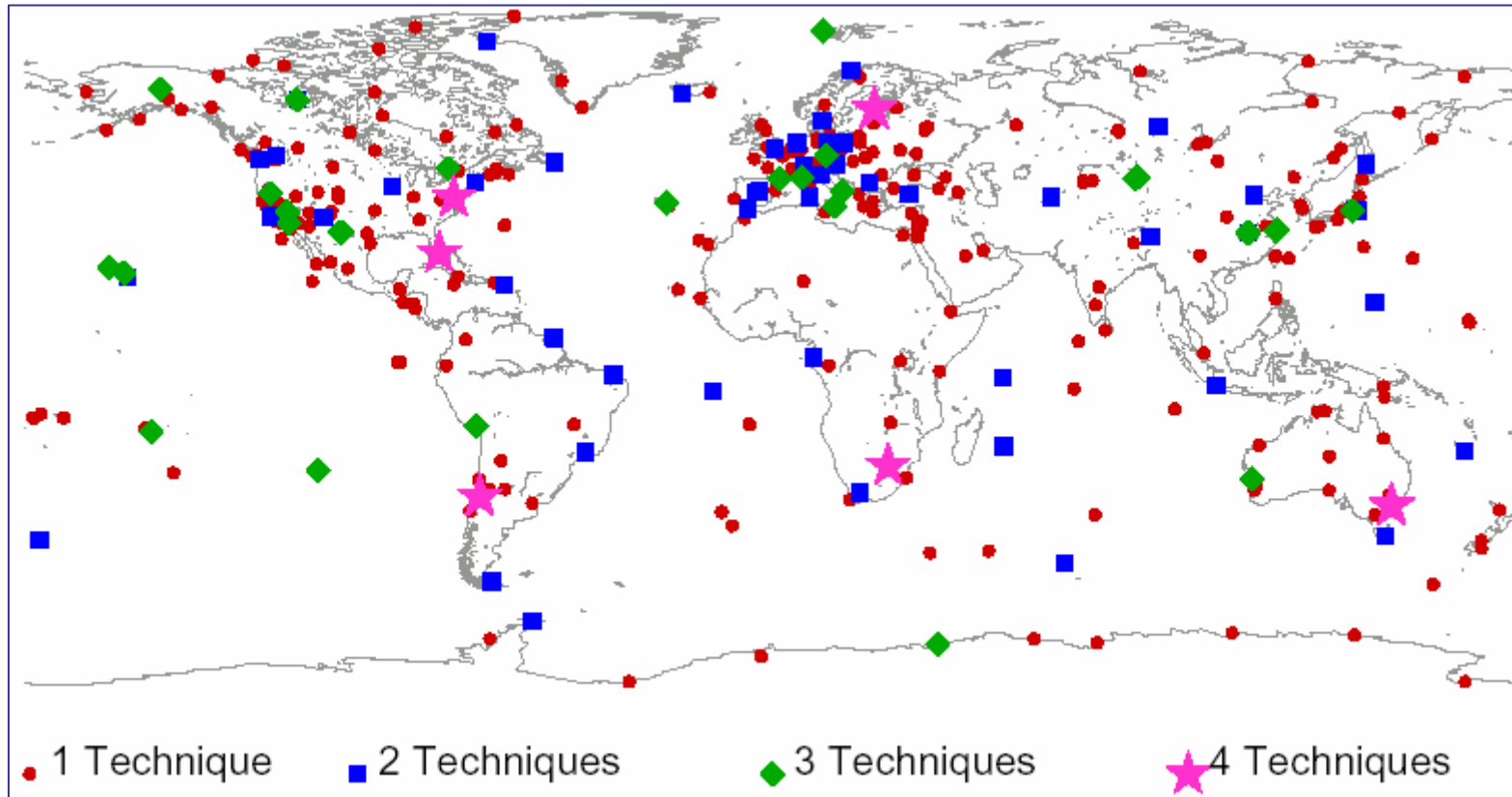
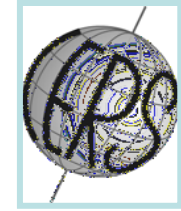
- Site where two or more space geodesy close instruments (hundred metres) are operating
- Precisely surveyed in three dimensions, using classical or GPS geodesy
- Differential coordinates (DX, DY, DZ) are available



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# ITRF2005 Co-locations



● 1 Technique

■ 2 Techniques

◆ 3 Techniques

★ 4 Techniques

(48)

(25)

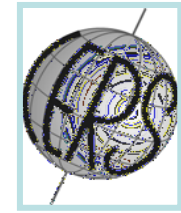
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# Positioning Performance

WRMS range per technique  
(Internal Precision – Repeatability)

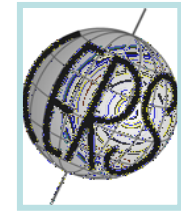


<b>Solution</b>	<b>2-D WRMS mm</b>	<b>Up WRMS mm</b>
<b>VLBI</b>	<b>2-3</b>	<b>5-7</b>
<b>SLR</b>	<b>5-10</b>	<b>5-10</b>
<b>GPS</b>	<b>2-3</b>	<b>5-6</b>
<b>DORIS</b>	<b>12-25</b>	<b>10-25</b>

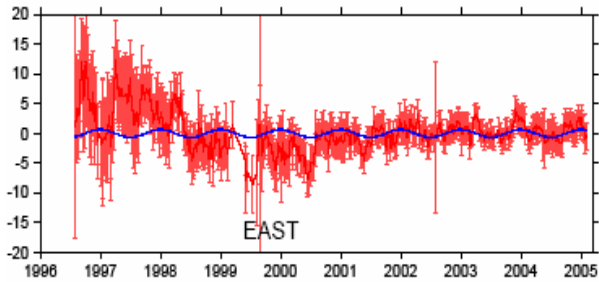
WARNING! These are indicative numbers and are station dependant



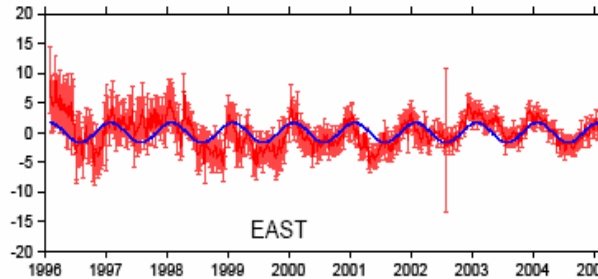
# Seasonal Variations GPS/IGS Sites



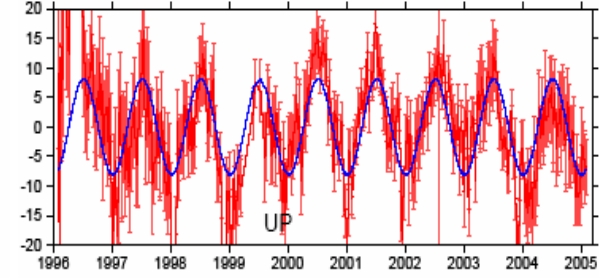
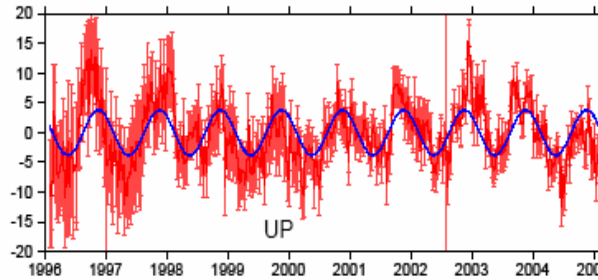
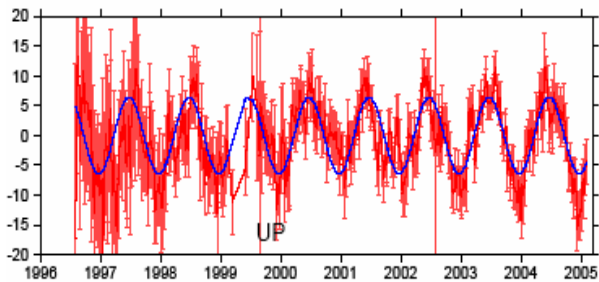
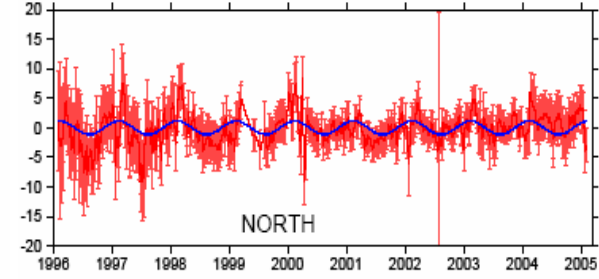
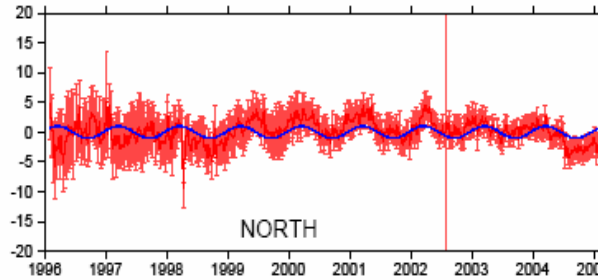
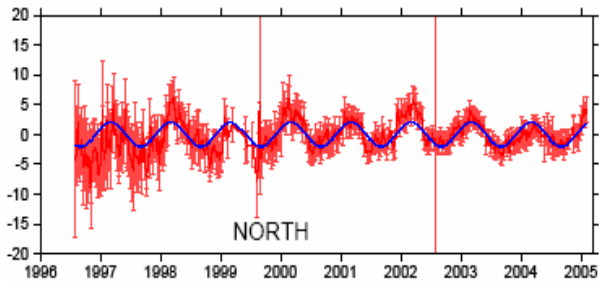
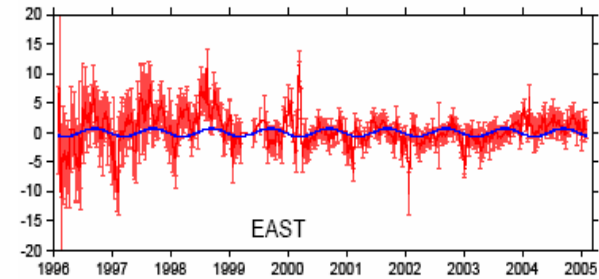
BAHR Annual Amplitude and Phase (mm)



DRAO Annual Amplitude and Phase (mm)



IRKT Annual Amplitude and Phase (mm)



**BAHR**

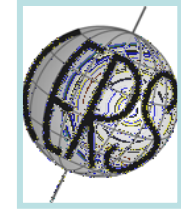
**DRAO**

**IRKT**

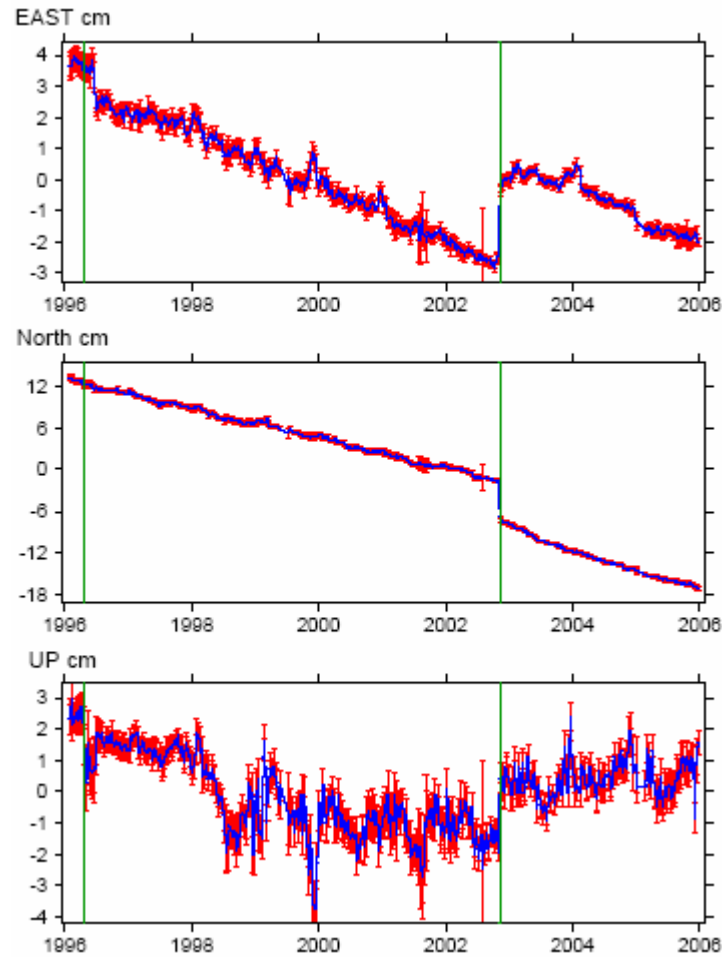
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# Denaly Earthquake (Alaska)

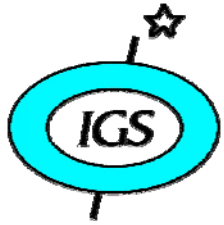


## GPS

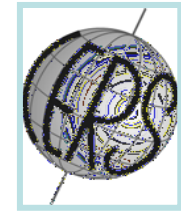


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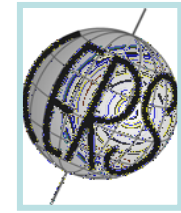
# Access to ITRS



- 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



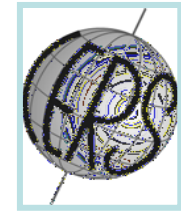
# World Geodetic System 84 (WGS 84)



- 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



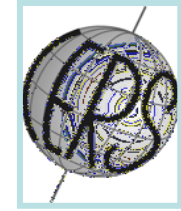
# WGS 84



- 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)



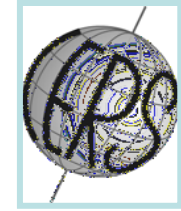
# GLONASS Reference Frame PZ-90



- 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)



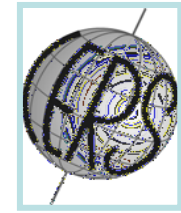
# Galileo Terrestrial Reference Frame (GTRF)



- 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)



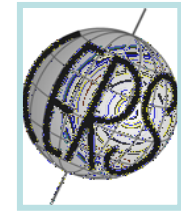
# GTRF Implementation



- 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



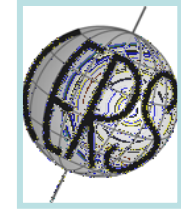
# Reference Frames for Global Navigation Satellite Systems



- 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**