

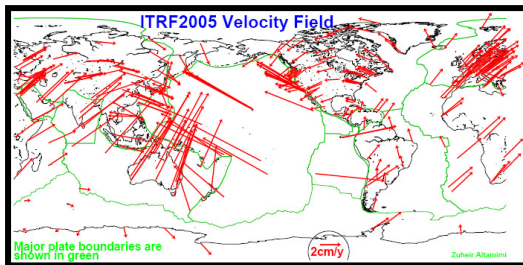
# The International Terrestrial Reference Frame (ITRF)

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International Association of Geodesy **GGOS** ... advancing geodesy ...  
Global Geodetic Observing System

A Constituent Association of the IUGG



Combination of

VLBI

SLR

GNSS

DORIS

# Geodesy

- A fundamental discipline for Earth science applications and satellite navigation
- Is the only science that is capable to realize a truly **global terrestrial reference system**
- The progress accomplished since almost 30 years is due to the international cooperation based on a voluntary contribution for the scientific interest.
- **==> Creation of scientific services**

# Defining a Reference System & Frame:

## Three main conceptual levels :

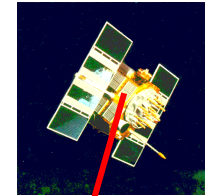
- **Ideal Terrestrial Reference System (TRS):**  
Ideal, mathematical, theoretical system
- **Terrestrial Reference Frame (TRF):**  
Numerical realization of the TRS to which users have access
- **Coordinate System:** cartesian (X,Y,Z), geographic ( $\lambda, \phi, h$ ),  
...
  - The TRF is a materialization of the TRS inheriting the mathematical properties of the TRS
  - As the TRS, the TRF has an **origin, scale & orientation**
  - TRF is constructed using space geodesy observations

# Why a Reference System/Frame is needed?

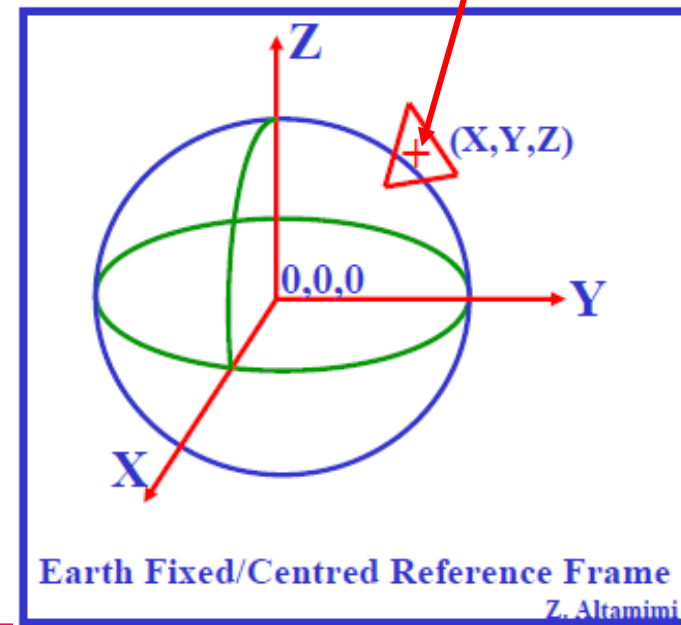
- **Precise Orbit Determination for:**
  - **GNSS: Global Navigation Satellite Systems**
  - **Other satellite missions: Altimetry, Oceanography, Gravity**
- **Earth Sciences Applications**
  - **Tectonic motion and crustal deformation**
  - **Mean sea level variations**
  - **Earth rotation**
  - ...
- **Other applications**
  - **Navigation: Aviation, Terrestrial, Maritime**
  - **National geodetic systems**
  - **Cartography & Positioning**

# What is a Reference Frame?

- **Earth fixed/centred RF: allows determination of station location/position as a function of time**
- **It seems so simple, but ... we have to deal with:**
  - Relativity theory
  - Forces acting on the satellite
  - The atmosphere
  - Earth rotation
  - Solid Earth and ocean tides
  - Tectonic motion
  - ...
- **Station positions and velocities are now determined with mm and mm/yr precision**

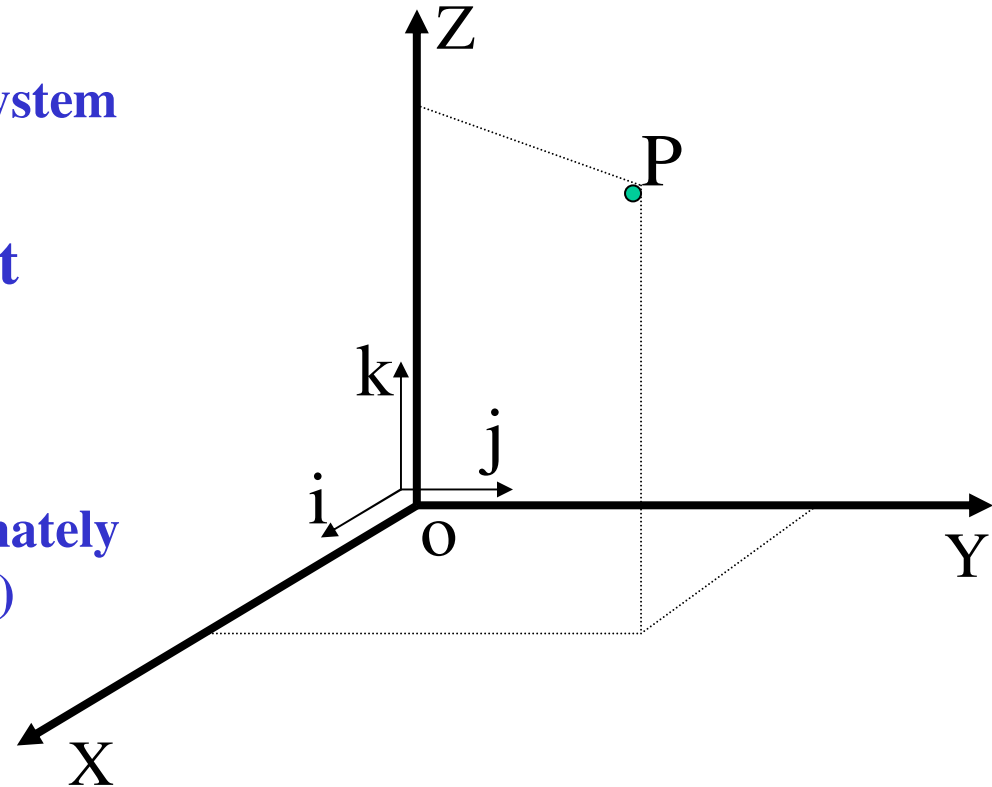


**Origin, Scale & Orientation**



# Terrestrial Reference Frame in the context of space geodesy

- **Origin:**
  - Center of mass of the Earth System
- **Scale (unit of length): SI unit**
- **Orientation:**
  - Equatorial (Z axis is approximately the direction of the Earth pole)



# Space Geodesy Techniques

- **Very Long Baseline Interferometry (VLBI)**
- **Lunar Laser Ranging (LLR)**
- **Satellite Laser Ranging (SLR)**
- **DORIS**
- **GNSS: GPS, GLONASS, GALILEO, COMPASS,**  
...

- 
- **Local tie vectors in co-location sites**

# Complex of Space Geodesy instruments



**SLR/LLR**



**VLBI**



**GPS**

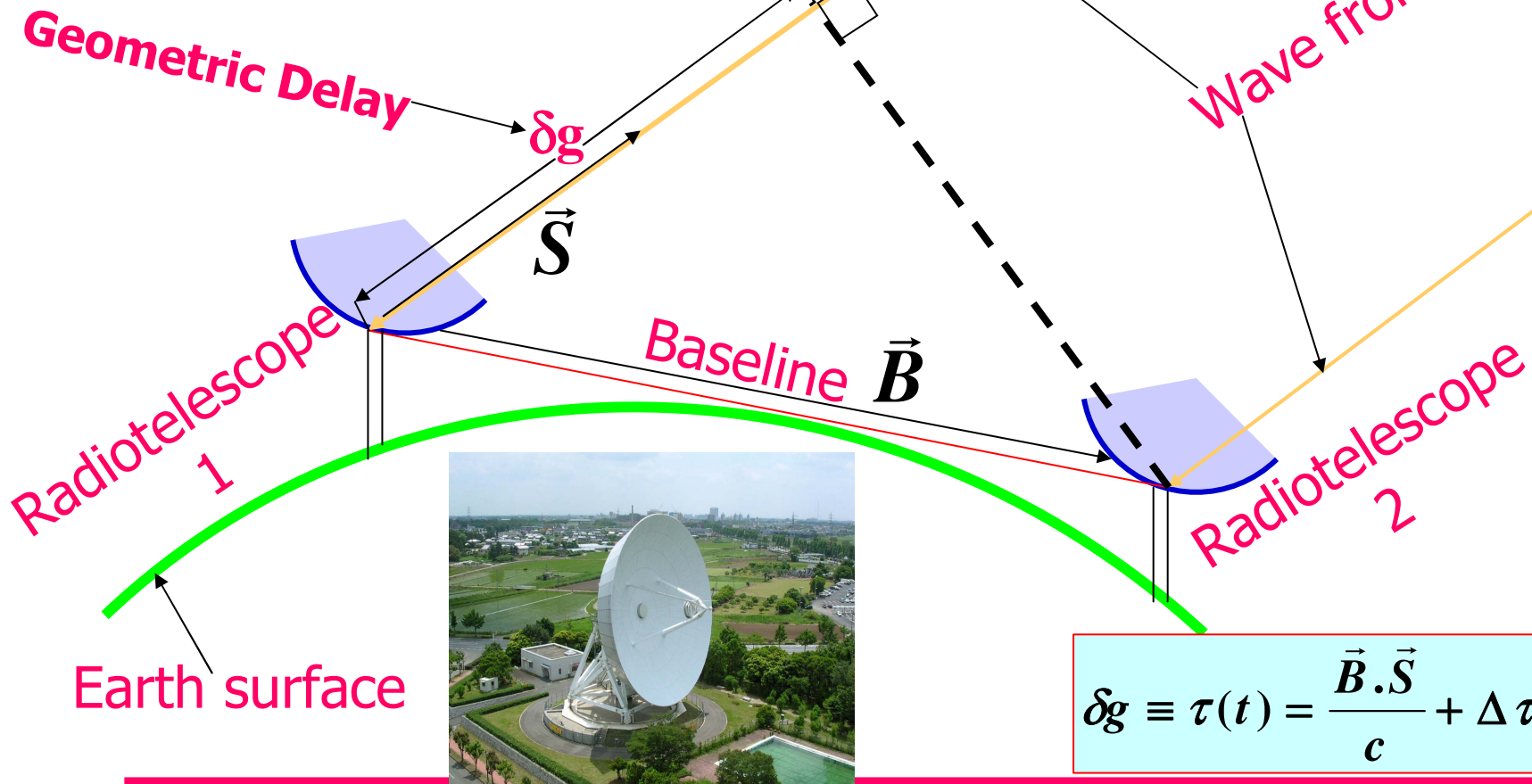


**DORIS**



# Very Long Baseline Interferometry VLBI

*Quasar: quasi-stellar radio source*

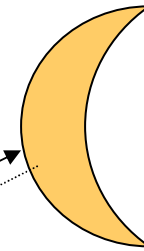


$$\delta g \equiv \tau(t) = \frac{\vec{B} \cdot \vec{S}}{c} + \Delta \tau(t)$$

Lunar  
Satellite

Laser Ranging

LLR  
SLR



Moon

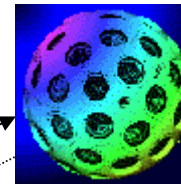
Measuring Time Propagation

LLR Telescope

Passive Satellite

SLR Telescope

Earth



# GNSS



**GNSS Antenna**

Earth



**Satellite**



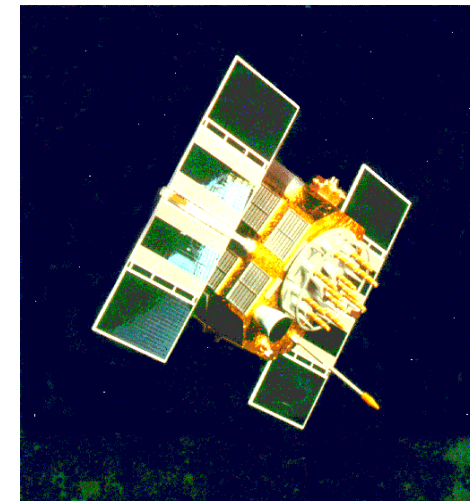
**Satellite Orbit**

**Navigation Message sent by each satellite:**

- Orbit parameters
- Clock corrections

**GNSS Measurements:**

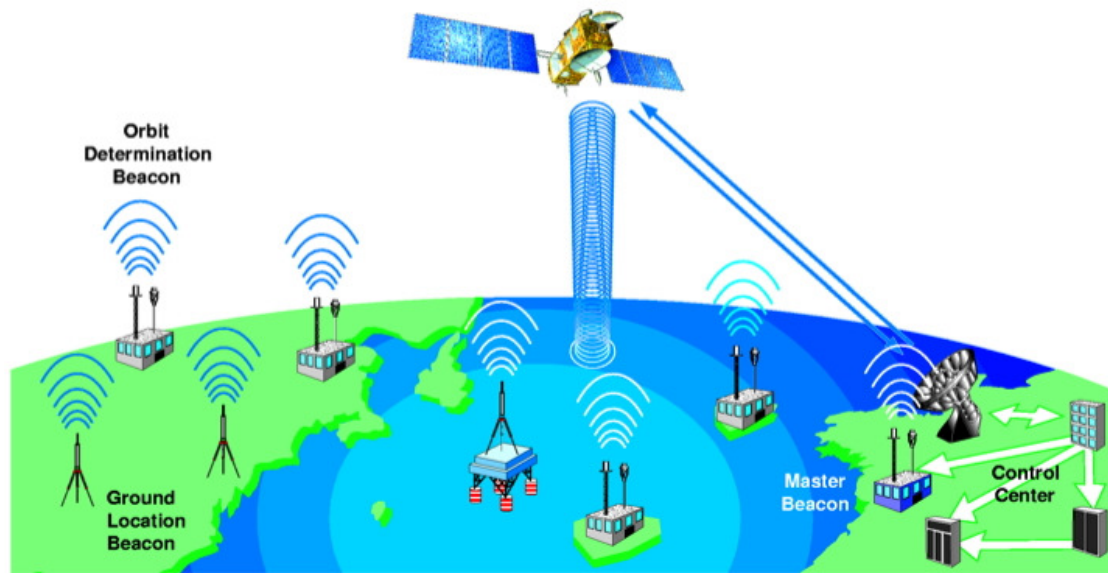
- Pseudorange
- Phase



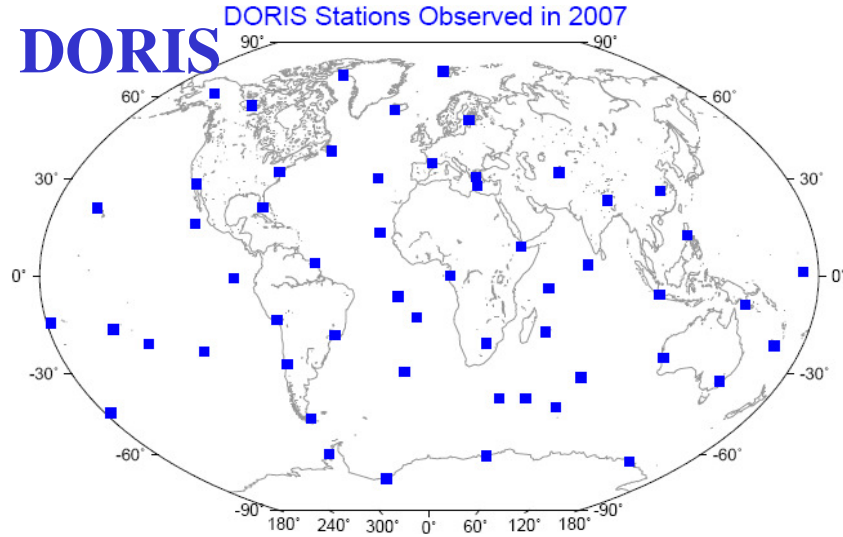
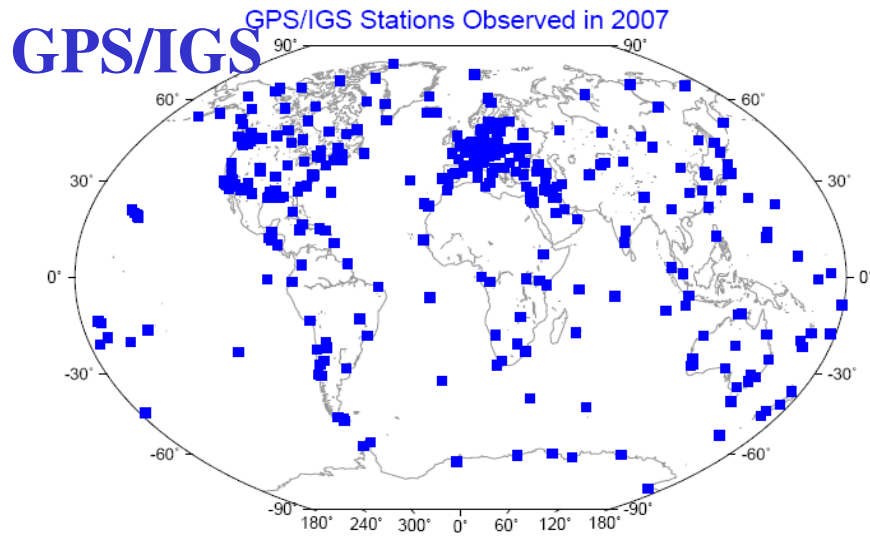
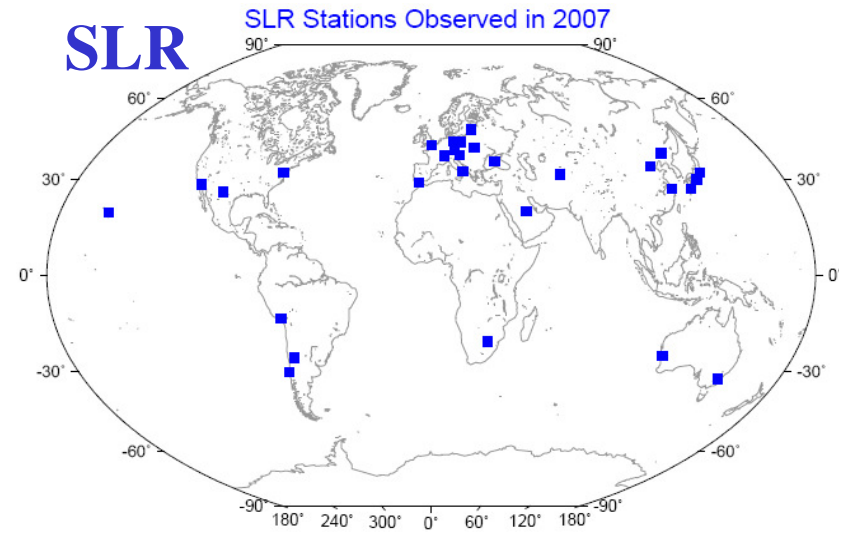
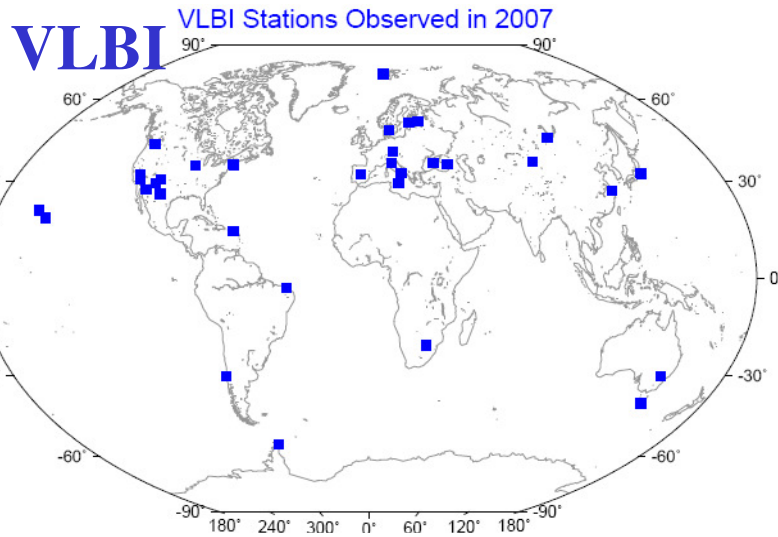
# DORIS

## Doppler Orbitography and Radiopositioning Integrated by Satellite

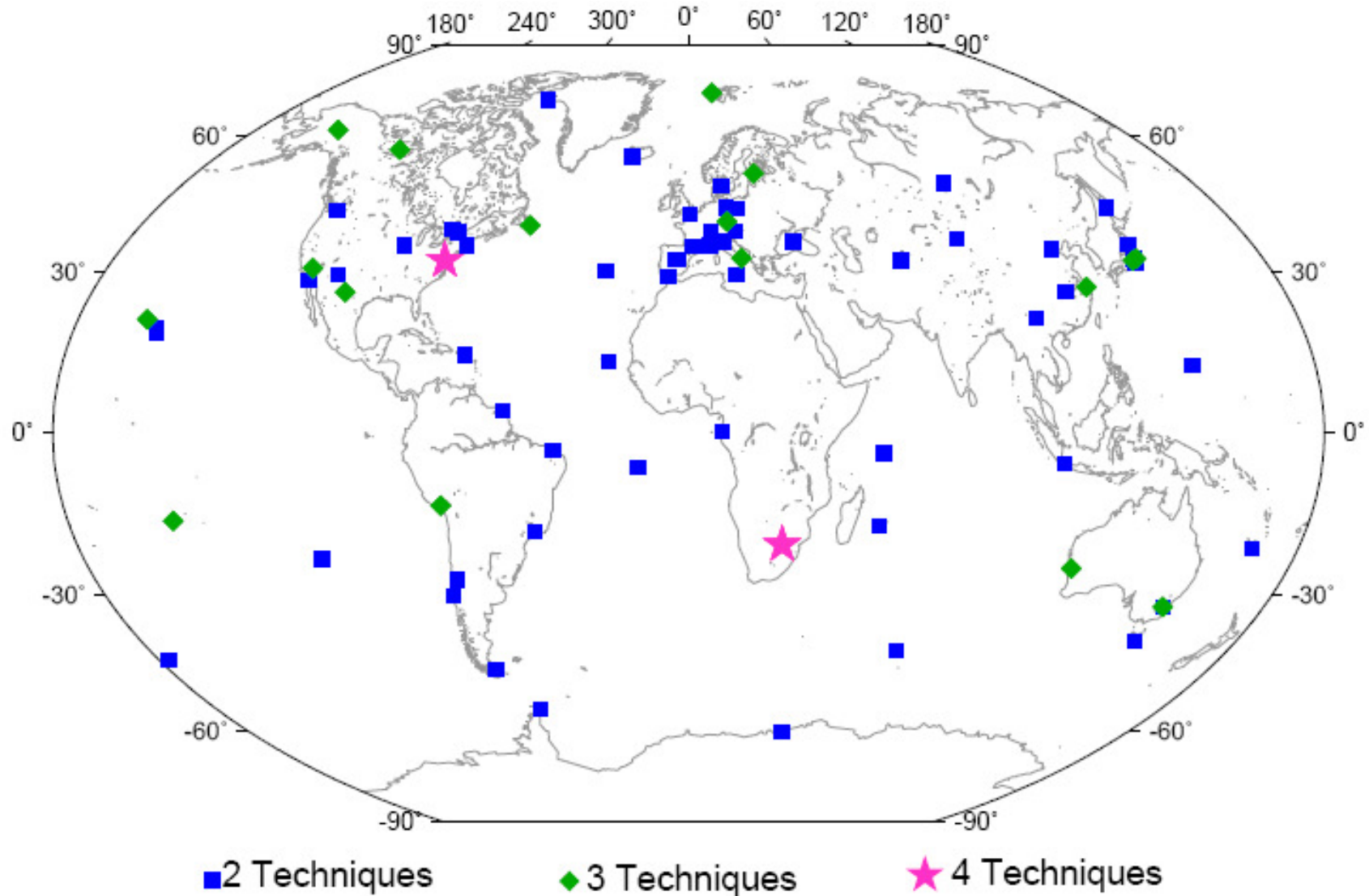
- French Technique developed by CNES and IGN
- Uplink System: on-board receiver measures the doppler shift on the signal emitted by the ground beacon



# Current networks: stations observed in 2007



# Current Co-locations (2007)



# **International Association of Geodesy International Services**

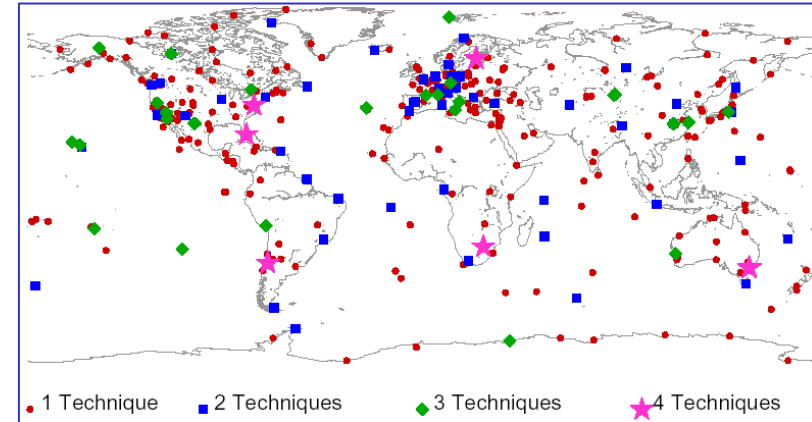
- **International Earth Rotation and Reference Systems Service (IERS) (1988)**
- **Intern. GNSS Service (IGS) (1994)**
- **Intern. Laser Ranging Service (ILRS) (1998)**
- **Intern. VLBI Service (IVS) (1999)**
- **Intern. DORIS Service (IDS) (2003)**

**<http://www.iag-aig.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, SLR, GPS and DORIS individual TRF solutions
- **Based on Co-location sites**

**Adopted by IUGG in 1991 for all Earth Science Applications**



**More than 800 stations located on more than 500 sites**

**Available: ITRF88, 89,...,2000**  
**Latest: ITRF2005**  
**Coming soon : ITRF2008**

<http://itrf.ensg.ign.fr>



# Co-location Site

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

$$DX_{(GPS,VLBI)} = X_{VLBI} - X_{GPS}$$



GPS

VLBI



SLR

DORIS



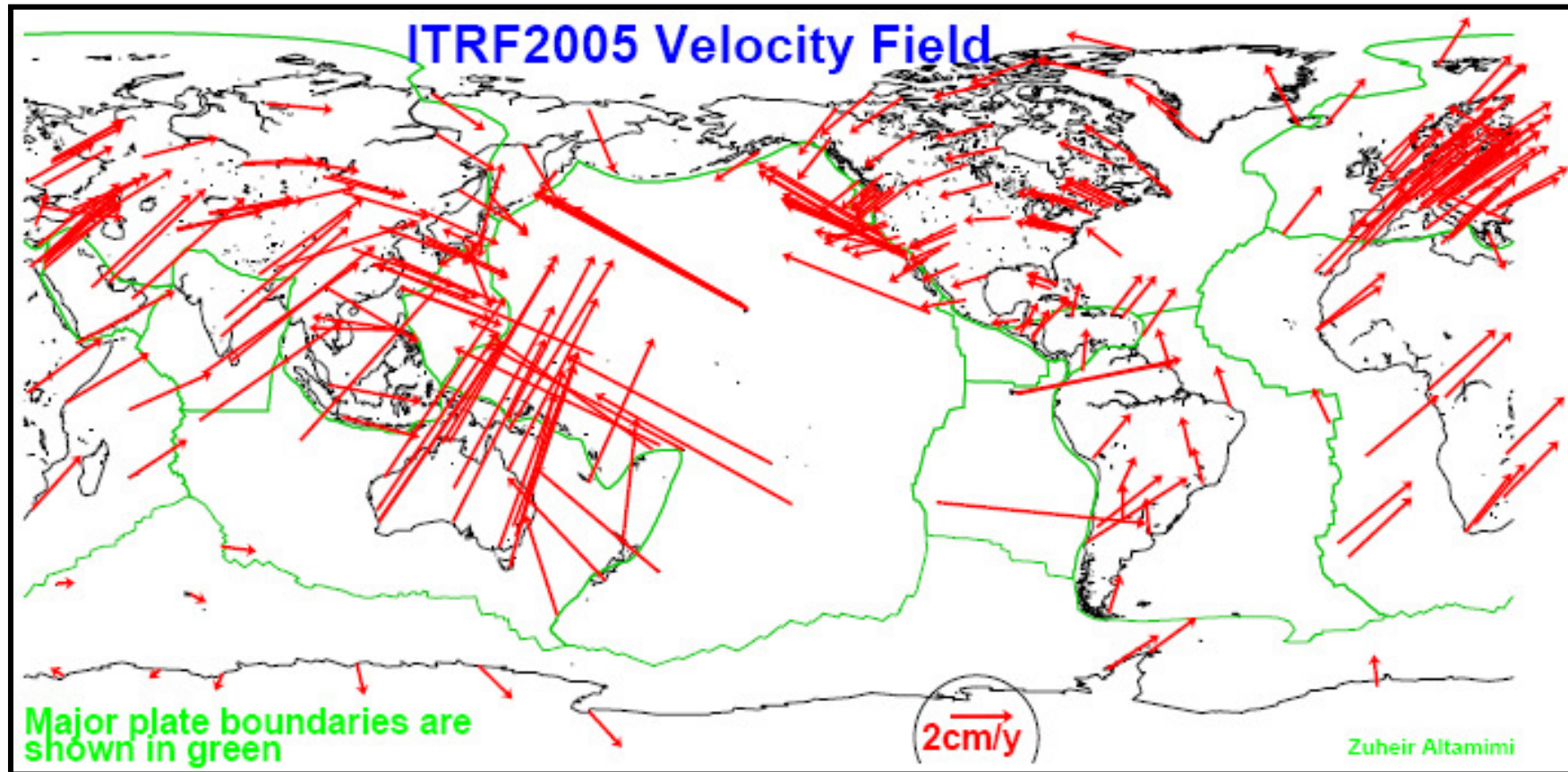
# Strenghts :

## Contribution of Geodetic Techniques to the ITRF

Mix of techniques  
is fundamental to  
realize a frame that  
is stable in origin,  
scale, and with  
sufficient coverage

Technique Signal Source Obs. Type	<b>VLBI</b> Microwave Quasars Time difference	<b>SLR</b> Optical Satellite Two-way absolute range	<b>GPS</b> Microwave Satellites Range change	<b>DORIS</b>
<b>Celestial Frame &amp; UT1</b>	<b>Yes</b>	No	No	No
<b>Polar Motion</b>	<b>Yes</b>	<b>Yes</b>	<b>Yes</b>	Yes
<b>Scale</b>	<b>Yes</b>	<b>Yes</b>	No (but maybe in the future!)	<b>Yes</b>
<b>Geocenter ITRF Origin</b>	No	<b>Yes</b>	Future	<b>Future</b>
<b>Geographic Density</b>	No	No	<b>Yes</b>	<b>Yes</b>
<b>Real-time &amp; ITRF access</b>	Yes	Yes	<b>Yes</b>	Yes
<b>Decadal Stability</b>	<b>Yes</b>	<b>Yes</b>	Yes	Yes

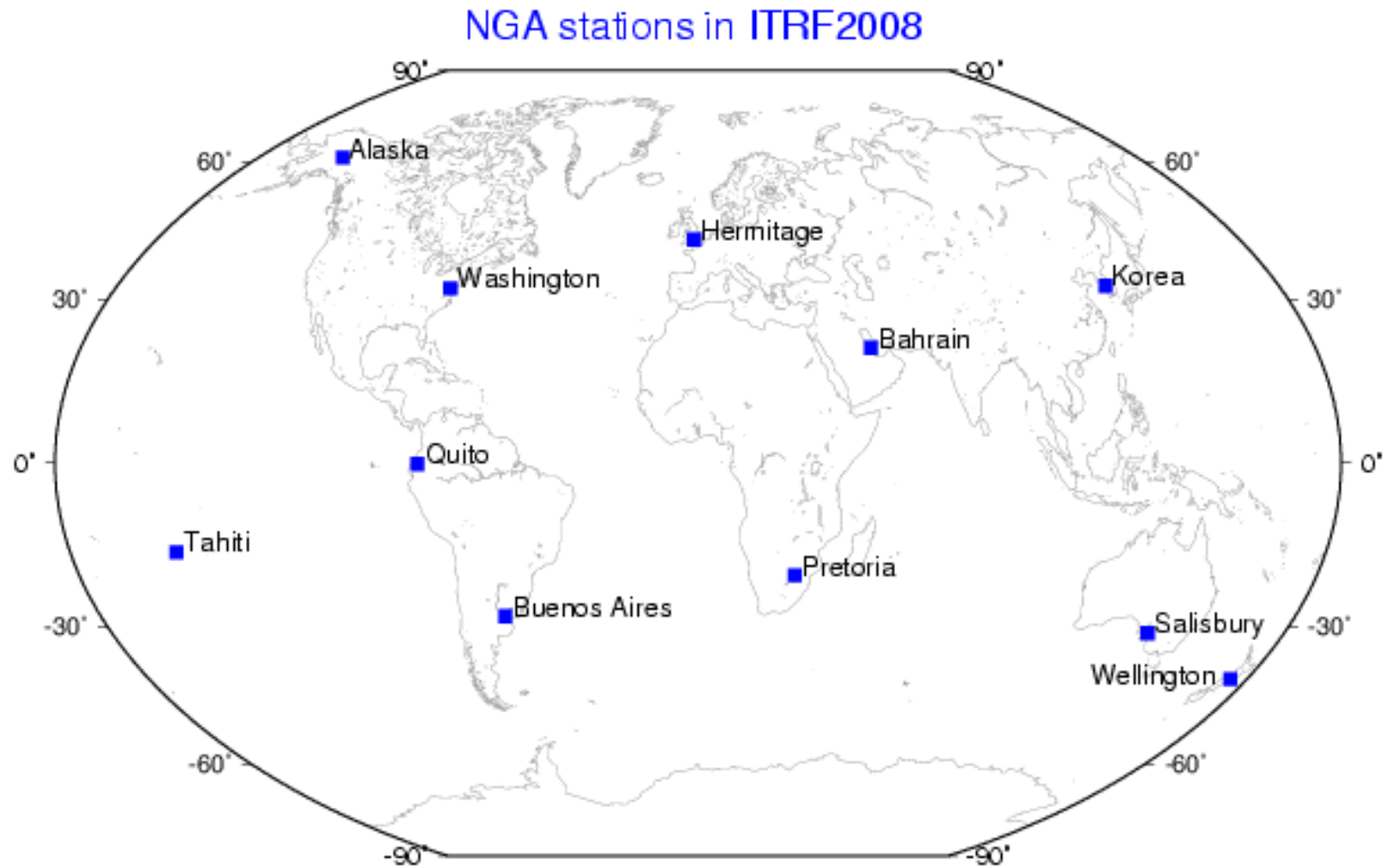
# ITRF2005 Site Velocities with $\sigma < 3\text{mm/y}$



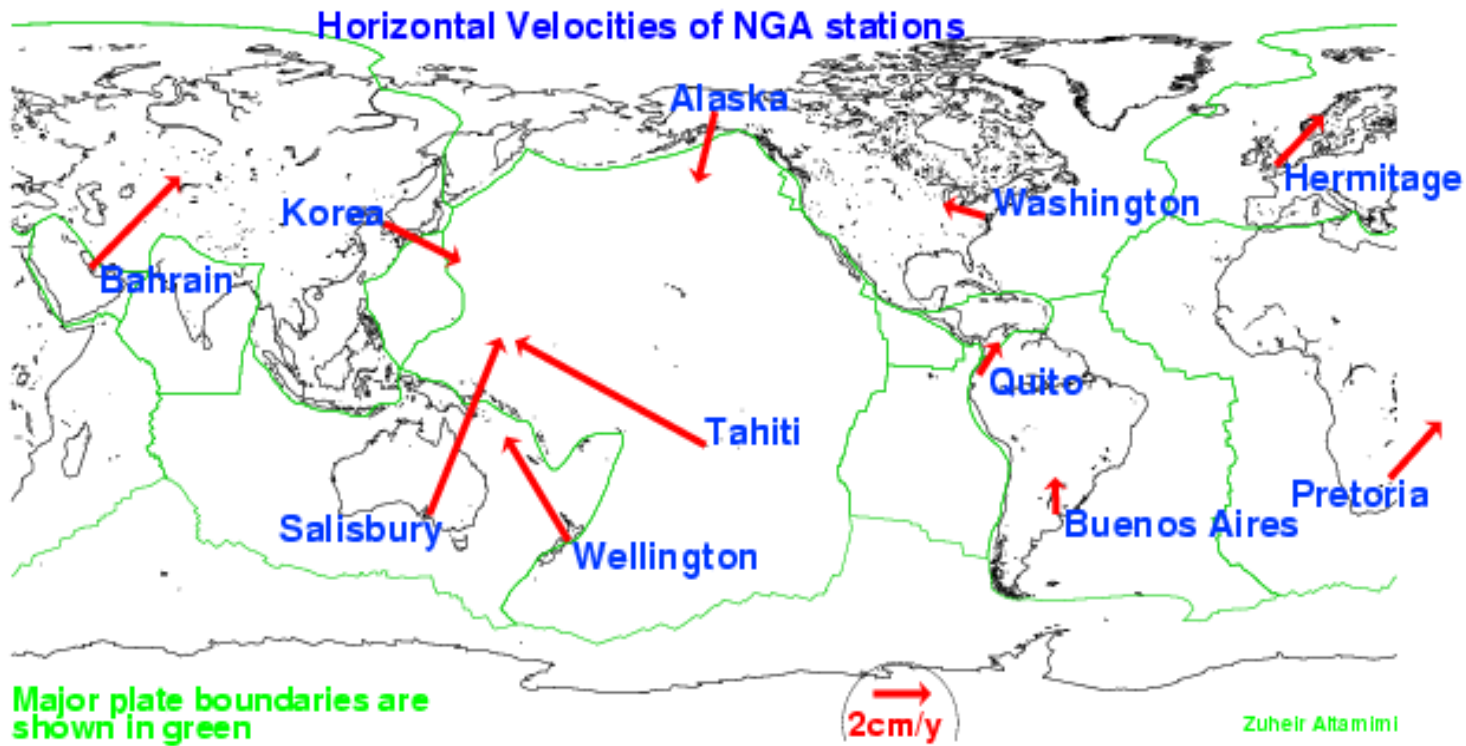
## **GNSS and their associated reference systems**

<b><u>GNSS</u></b>	<b><u>Ref. System/Frame</u></b>
• <b>GPS (broadcast orbits)</b>	<b>WGS84</b>
• <b>GPS (precise IGS orbits)</b>	<b>ITRS/ITRF</b>
• <b>GLONASS</b>	<b>PZ-90</b>
• <b>GALILEO</b>	<b>ITRS/ITRF/GTRF</b>
• <b>COMPASS</b>	<b>CGCS 2000</b>
• <b>QZSS</b>	<b>JGS</b>
• <b>All are ‘aligned’ to the ITRF</b>	
• <b>WGS84 <math>\approx</math> ITRF at the decimeter level</b>	
• <b>GTRF <math>\approx</math> ITRF at the mm level</b>	
• <b><math>\sigma</math>-Position using broadcast ephemerides = 150 cm</b>	

# WGS84 - NGA Stations in ITRF2008



# WGS84 - NGA Stations in ITRF2008



# Access & alignment to ITRF

- **Direct use of ITRF coordinates**
- **Use of IGS Products (Orbits, Clocks): all expressed in ITRF**
- **Use of GGSP/GTRF products (see presentation on GGSP/GTRF)**
  
- **Alternatively: (GTRF experience)**
  - **Process GNSS data together with IGS/ITRF global stations in free mode**
  - **Align to ITRF using minimal constraint approach**

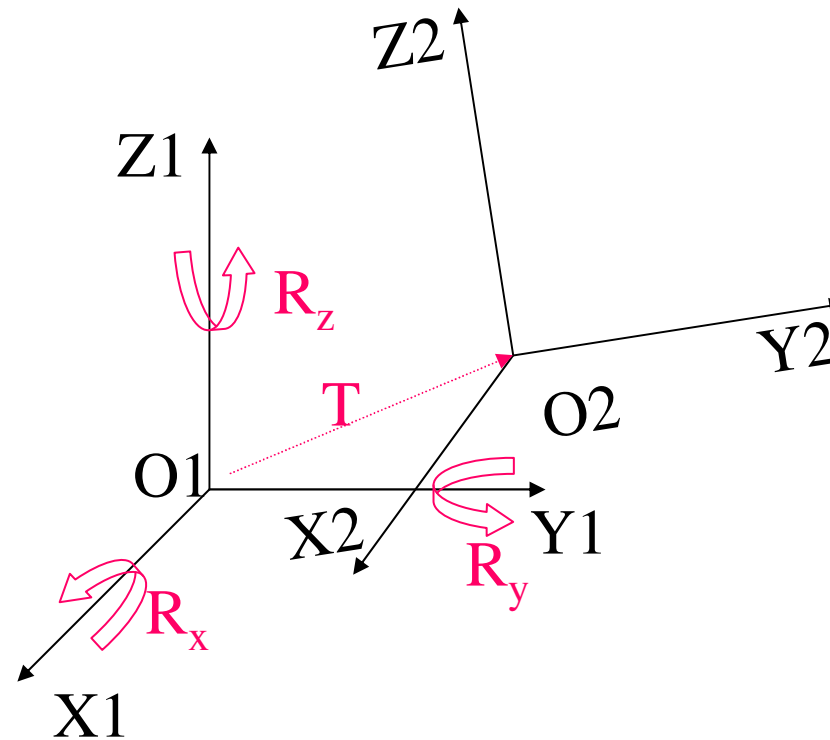
# Conclusion

- **The ITRF**
  - **is the most optimal global RF available today**
  - **gathers the strengths of space geodesy techniques**
  - **more precise and accurate than any individual RF**
- **Using the ITRF as a common GNSS RF will facilitate the interoperability**
- **Well established procedure available to ensure optimal alignment of GNSS RFs to ITRF**
- **To my knowledge: most (if not all) GNSS RFs are already ‘‘aligned’’ to ITRF**
- **GNSS RFs should take into account station velocities**



# Backup slides

# From one RF to another ?



$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_2 = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_1 + \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + \begin{pmatrix} D & -R_z & R_y \\ R_z & D & -R_x \\ -R_y & R_x & D \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_1$$

# How the ITRF is constructed ?

- **Input :**
  - Time series of mean station positions (at weekly or daily sampling) and daily EOPs from the 4 techniques
  - Local ties in co-location sites
- **Output :**
  - Station positions at a reference epoch and linear velocities
  - Earth Orientation Parameters

## Combination model

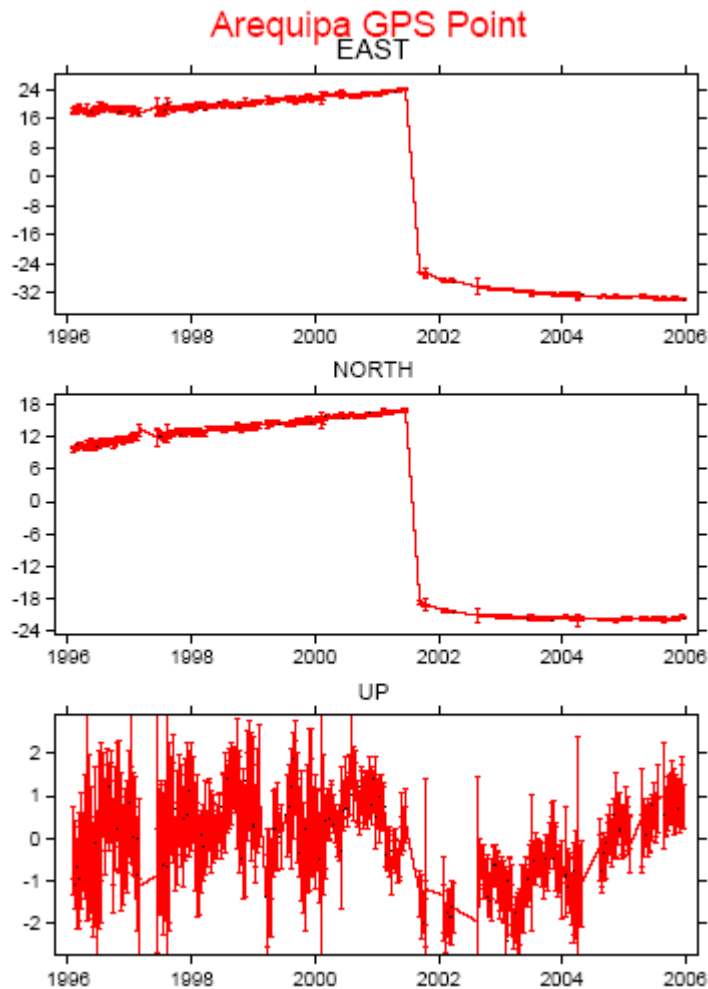
$$\left\{ \begin{array}{l} X_s^i = X_c^i + (t_s^i - t_0) \dot{X}_c^i \\ \quad + T_k + D_k X_c^i + R_k X_c^i \\ \quad + (t_s^i - t_k) \left[ \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \right] \\ \dot{X}_s^i = \dot{X}_c^i + \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \end{array} \right.$$

$$\left\{ \begin{array}{l} x_s^p = x_c^p + R2_k \\ y_s^p = y_c^p + R1_k \\ UT_s = UT_c - \frac{1}{f} R3_k \\ \dot{x}_s^p = \dot{x}_c^p + \dot{R}2_k \\ \dot{y}_s^p = \dot{y}_c^p + \dot{R}1_k \\ LOD_s = LOD_c + \frac{\Lambda_0}{f} \dot{R}3_k \end{array} \right.$$

# Time series of station positions are fundamental for the ITRF construction

## Monitor station behaviour

### Arequipa Earthquake



### Brasilia Seasonal Variations

