The International Terrestrial Reference Frame (ITRF)

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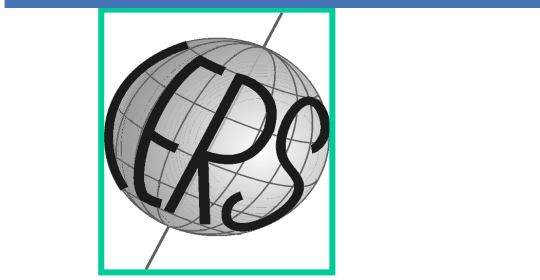
International Association of Geodesy

A Constituent Association of the IUGG

GGOS

... advancing geodesy ...

Global Geodetic Observing System



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 (λ, ϕ, 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**

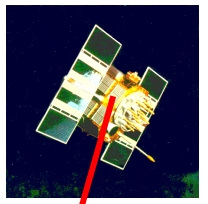
– **TRF is constructed using space geodesy observations**

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?

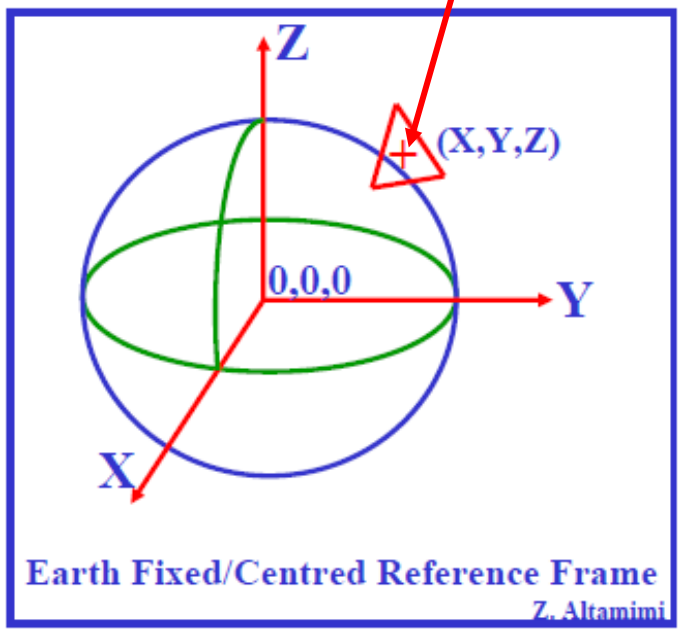
- Earth fixed/centred RF: allows determination of station location/position as a function of time



- 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
  - …

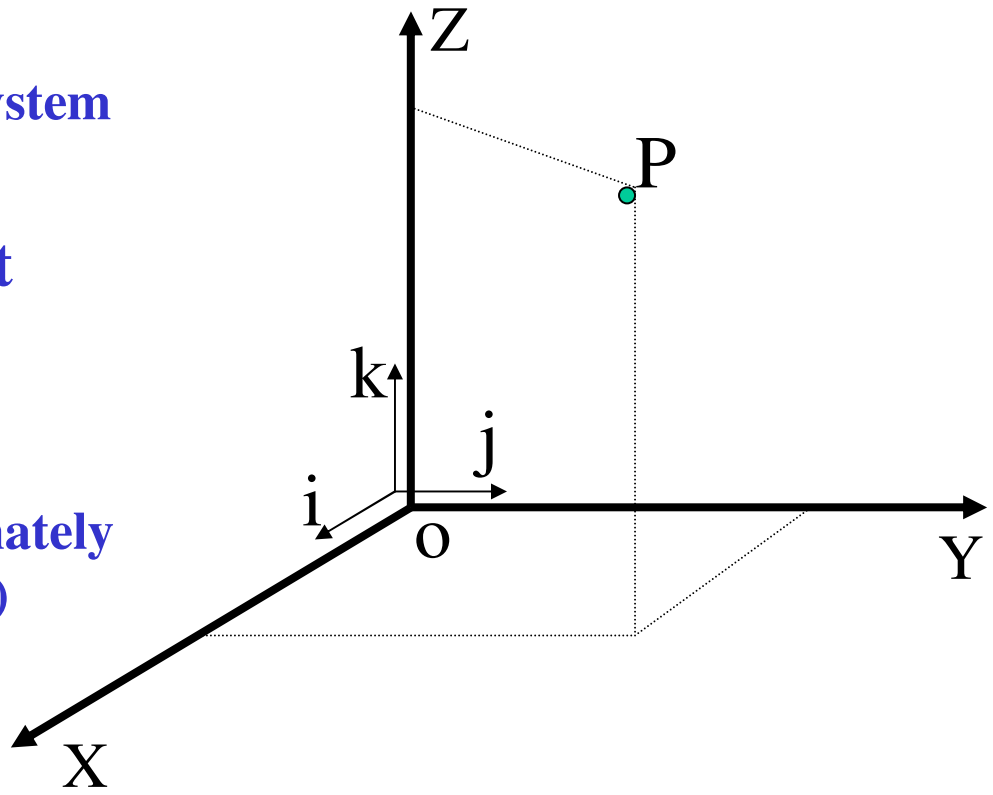
- Station positions and velocities are now determined with mm and mm/yr precision

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

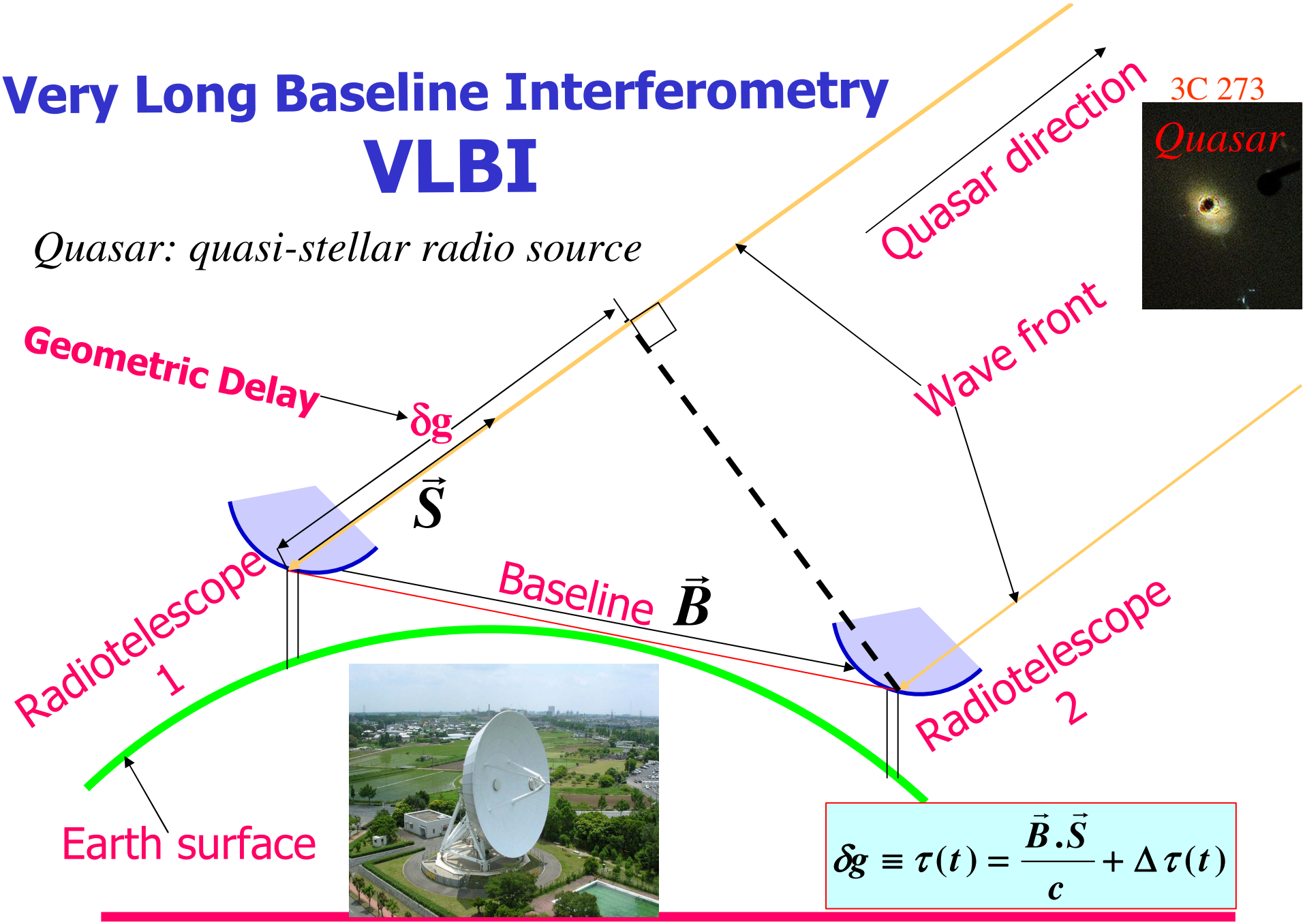
VLBI

GPS

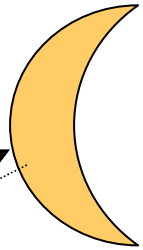
DORIS

Very Long Baseline Interferometry
VLBI

Quasar: quasi-stellar radio source

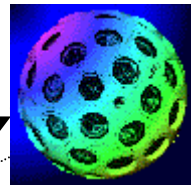


Lunar Satellite } Laser Ranging { LLR SLR



Moon

Measuring Time Propagation



Passive Satellite

LLR Telescope

Earth

SLR Telescope

GNSS

GNSS Antenna

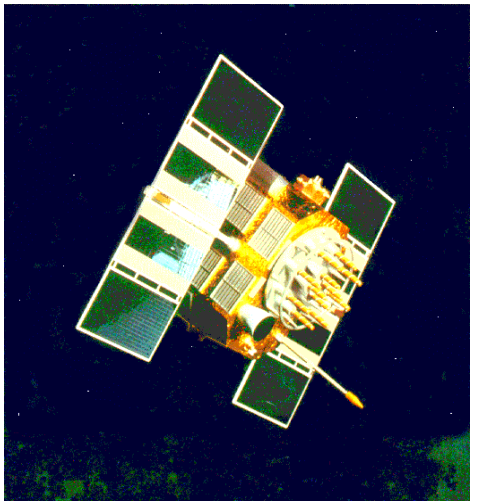
Earth

Satellite

Satellite Orbit

Navigation Message sent by each satellite:
- **Orbit parameters**
- **Clock corrections**

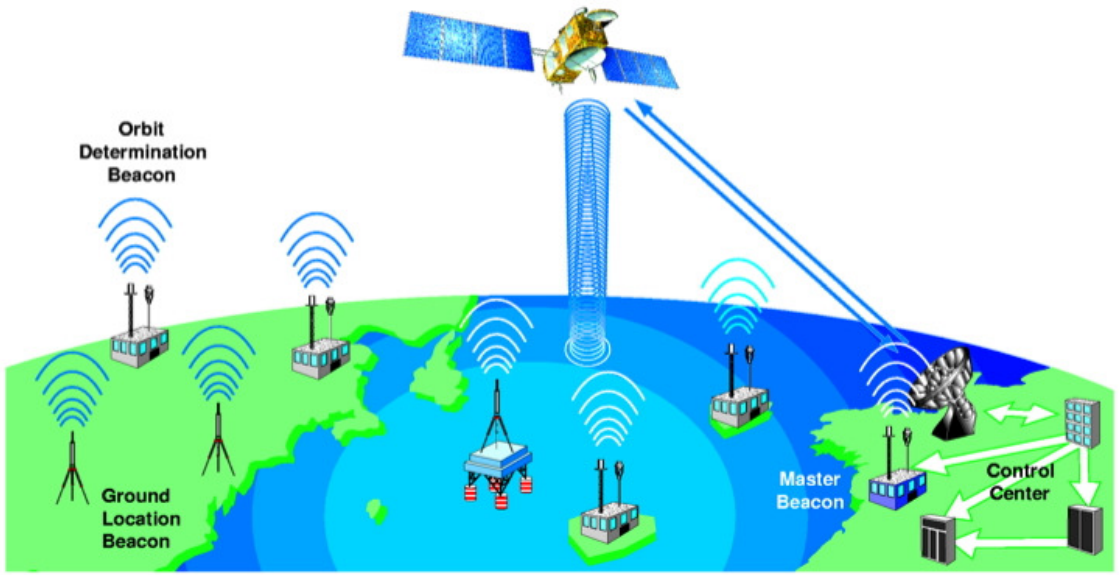
GNSS Measurements:
- **Pseudorange**
- **Phase**



DORIS

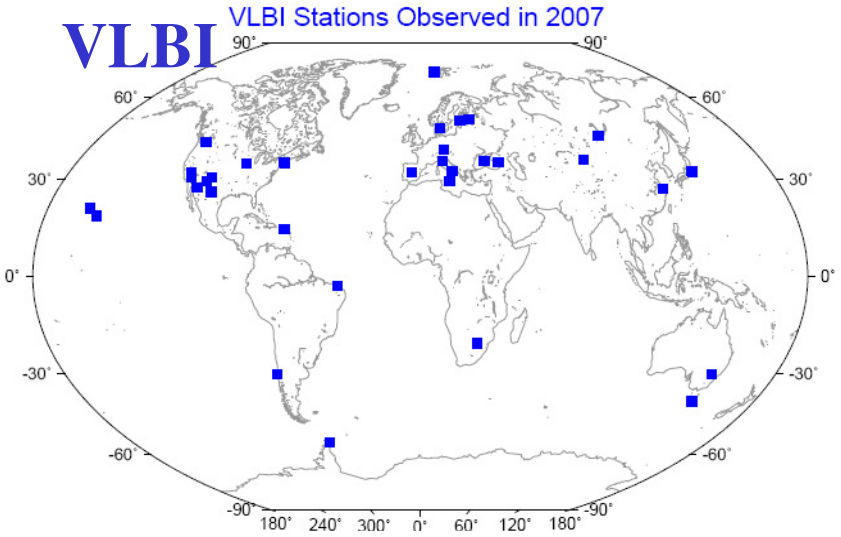
Doppler Orbitography and Radiopositioning Integrated by Satellite

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

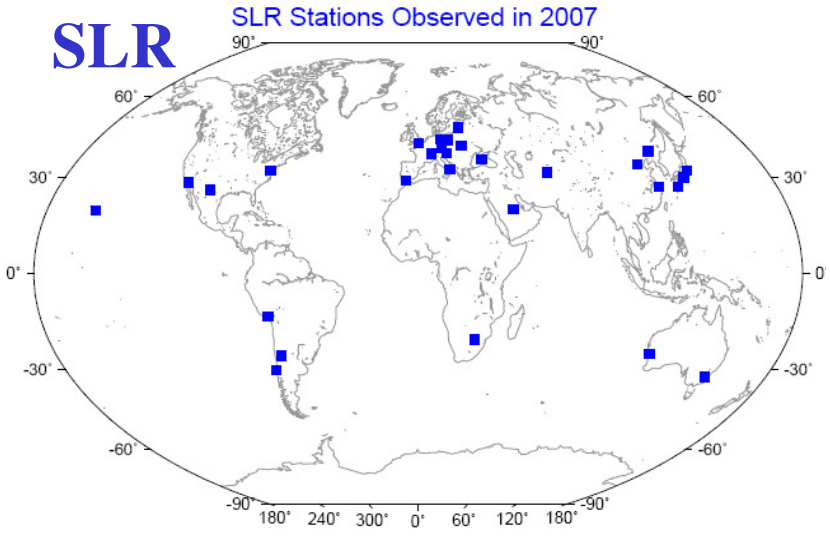


Current networks: stations observed in 2007

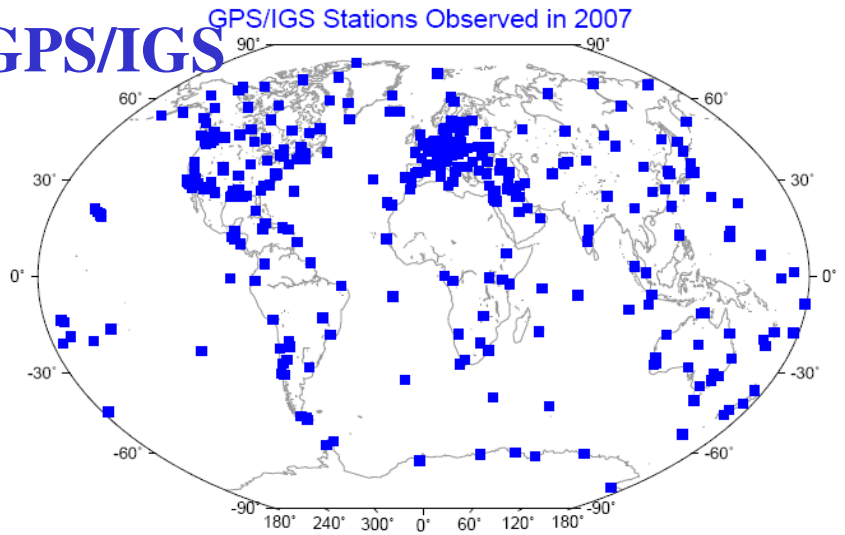
VLBI



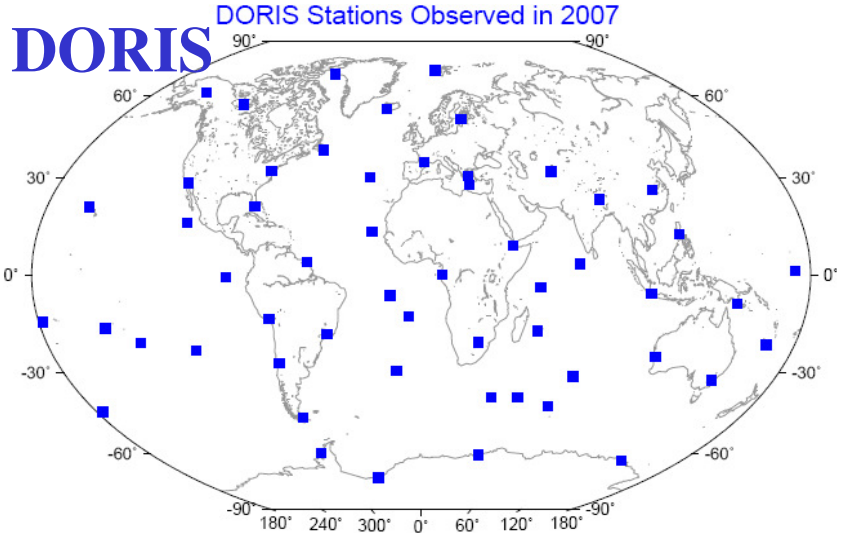
SLR



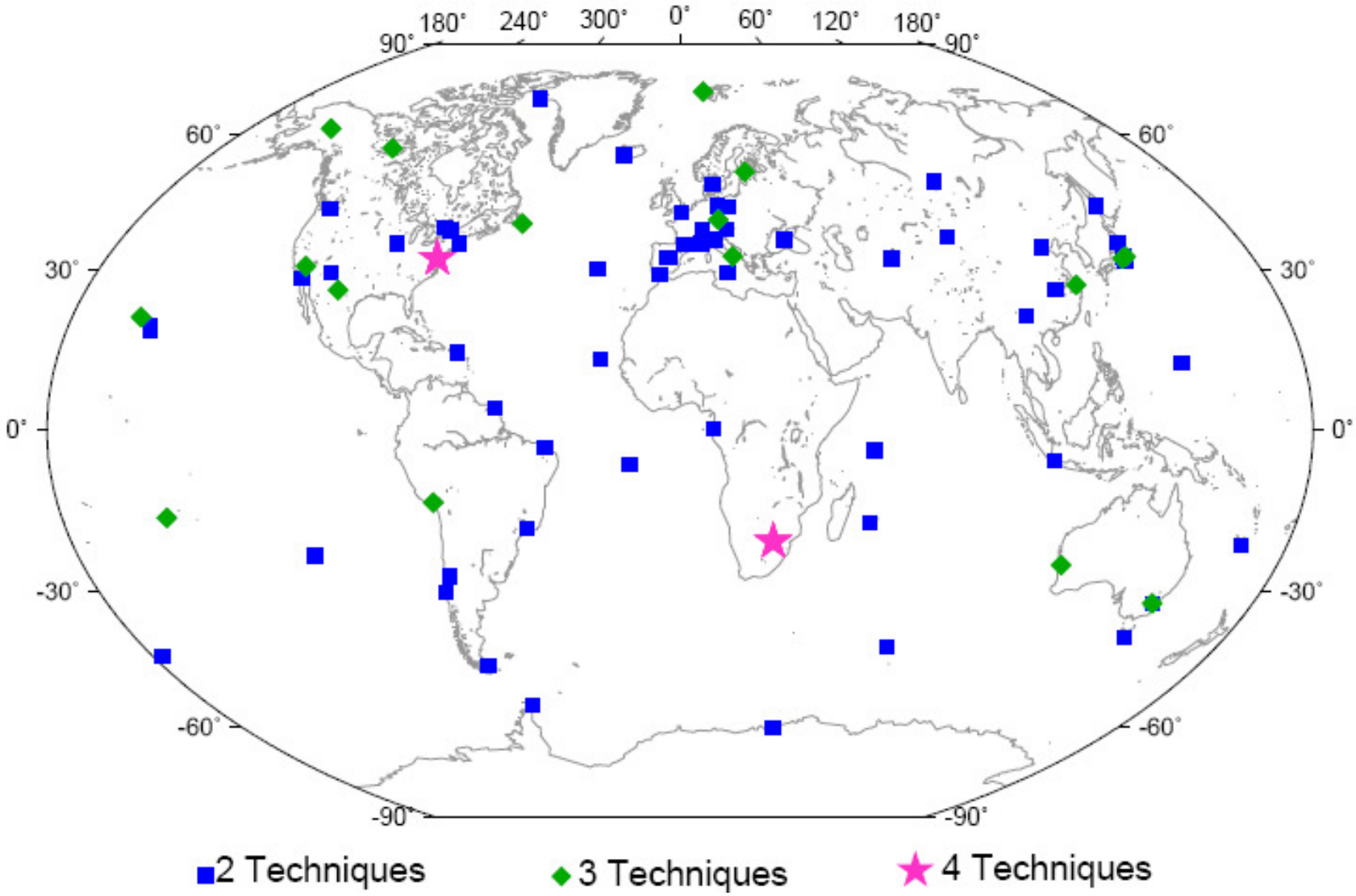
GPS/IGS



DORIS



Current Co-locations (2007)



International Association of Geodesy
International Services

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

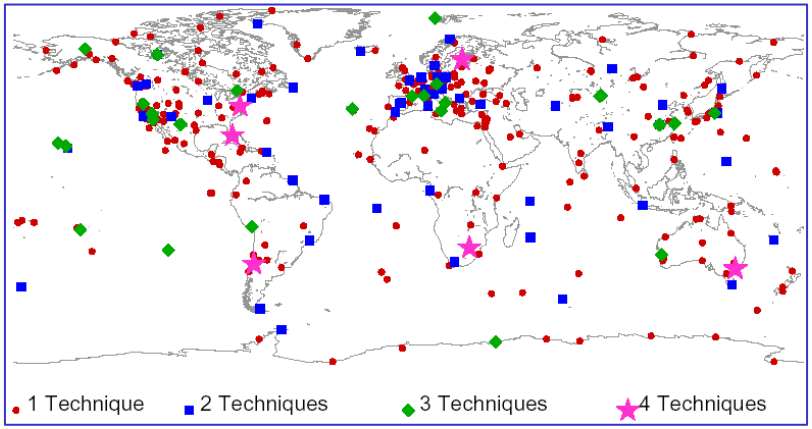
- **Intern. GNSS Service (IGS) (1994)**
- **Intern. Laser Ranging Service (ILRS) (1998)**
- **Intern. VLBI Service (IVS) (1999)**
- **Intern. DORIS Service (IDS) (2003)**

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

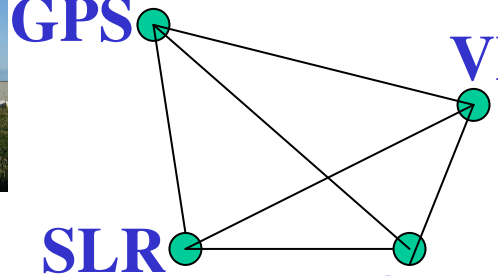
Available: ITRF88, 89,…,2000
Latest: ITRF2005
Coming soon : ITRF2008

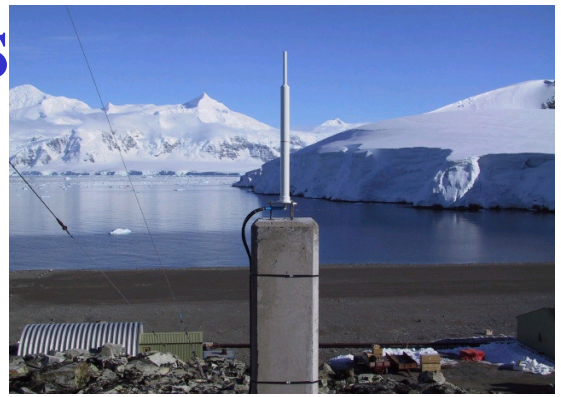
http://itrf.ensg.ign.fr

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

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



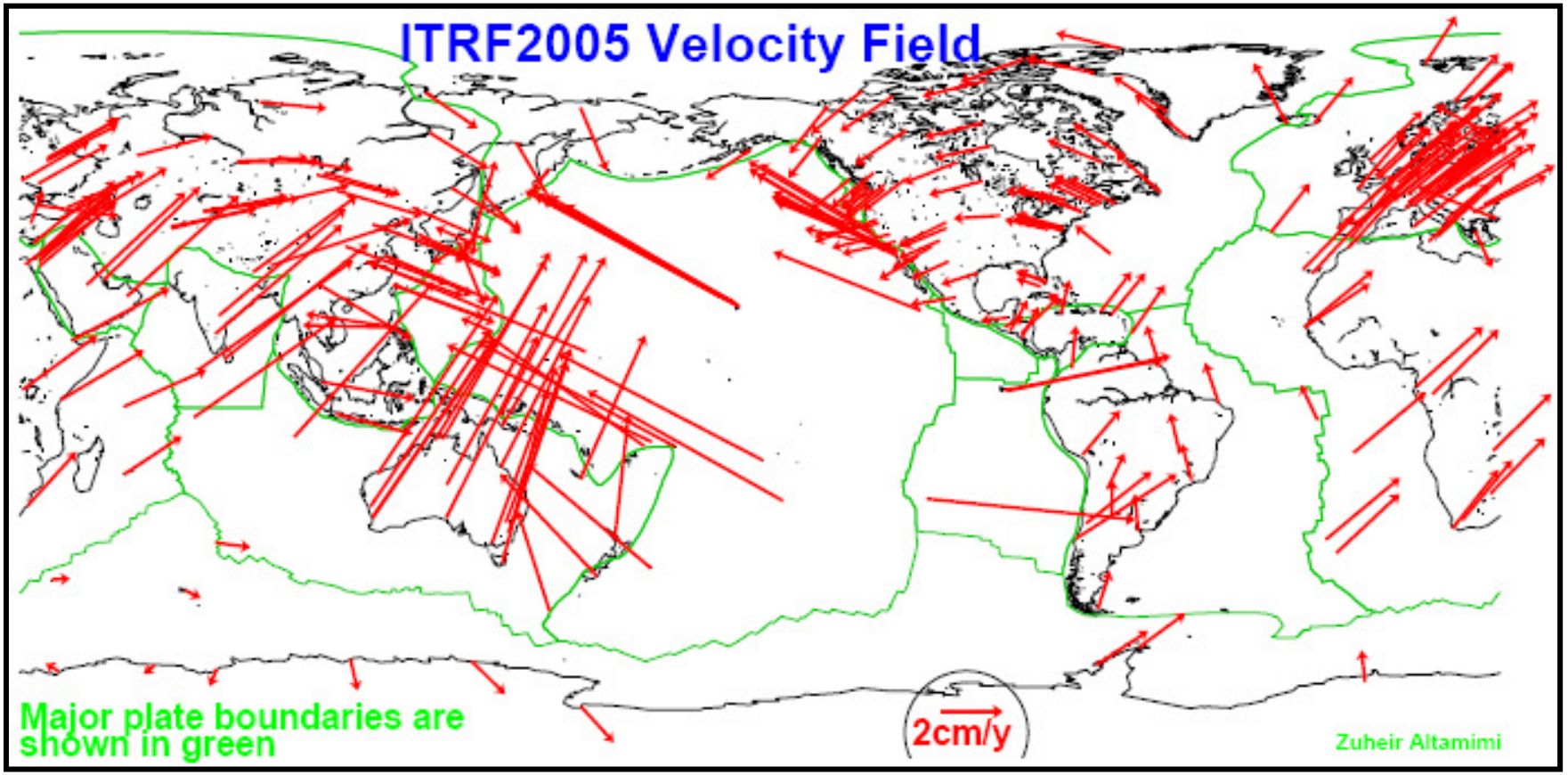


Strenghts :
Contribution of Geodetic Techniques to the ITRF

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

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

ITRF2005 Site Velocities with σ < 3mm/y

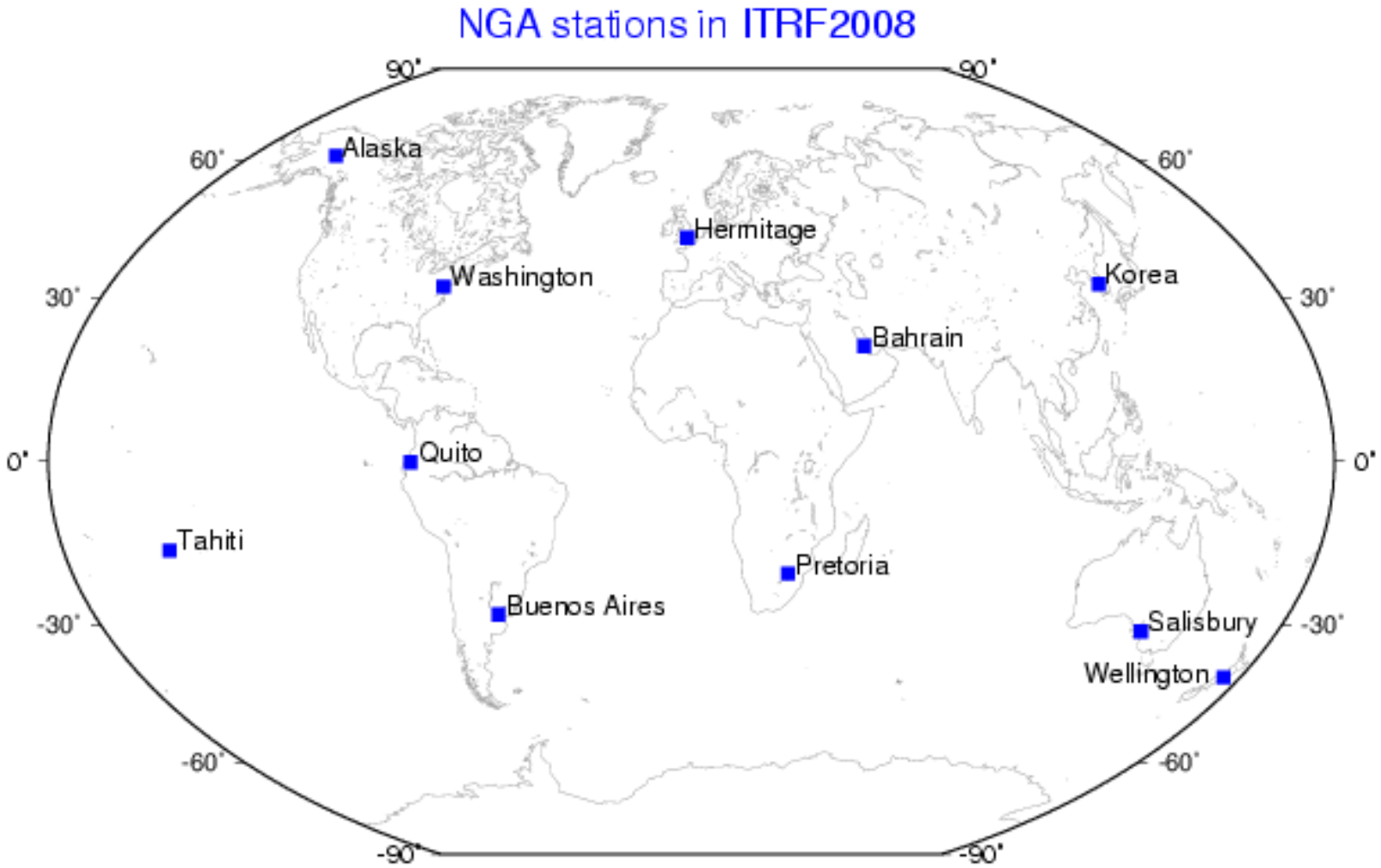


GNSS and their associated reference systems

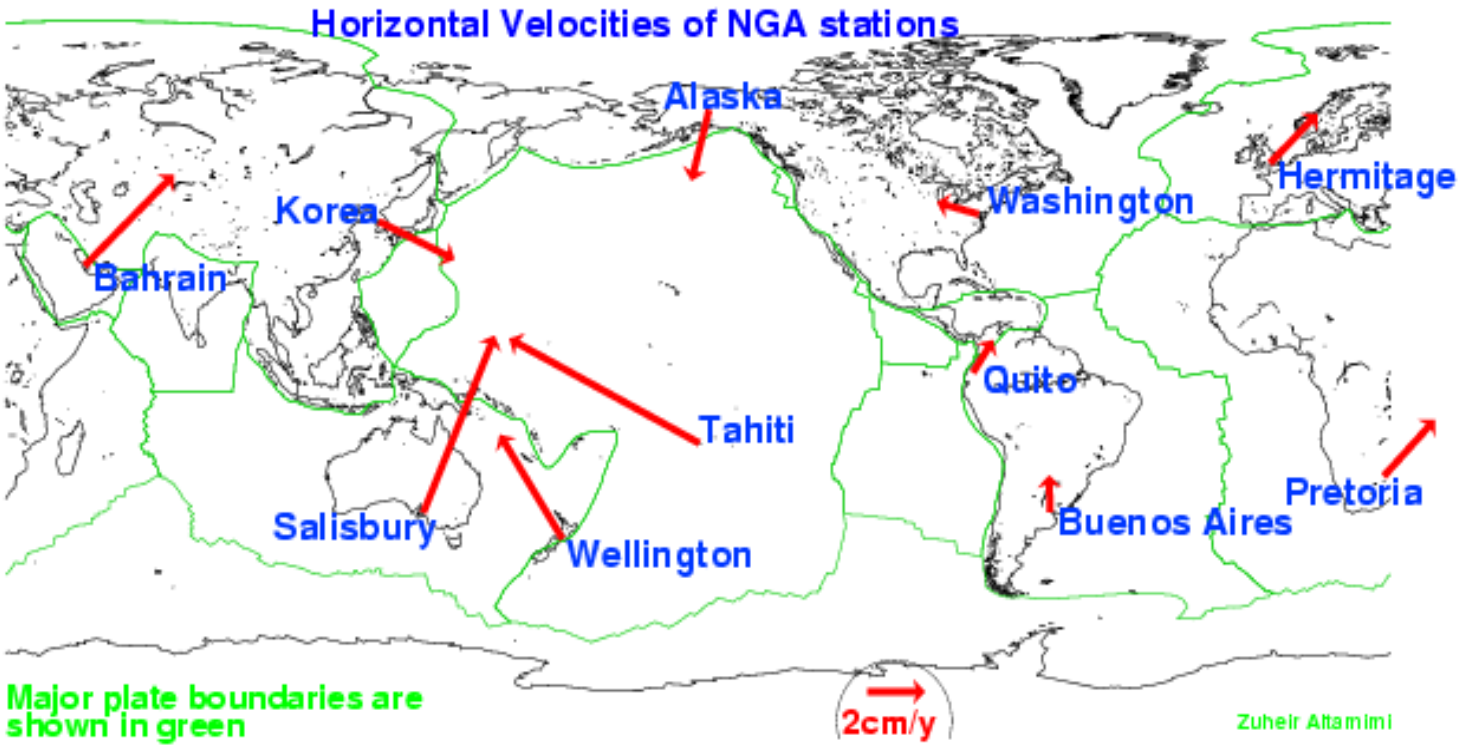
GNSS	Ref. System/Frame
• GPS (broadcast orbits)	WGS84
• GPS (precise IGS orbits)	ITRS/ITRF
• GLONASS	PZ-90
• GALILEO	ITRS/ITRF/GTRF
• COMPASS	CGCS 2000
• QZSS	JGS

- All are ‘’aligned’’ to the ITRF
- WGS84 ≈ ITRF at the decimeter level
- GTRF ≈ ITRF at the mm level
- σ-Position using broadcast ephemerides = 150 cm

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)**

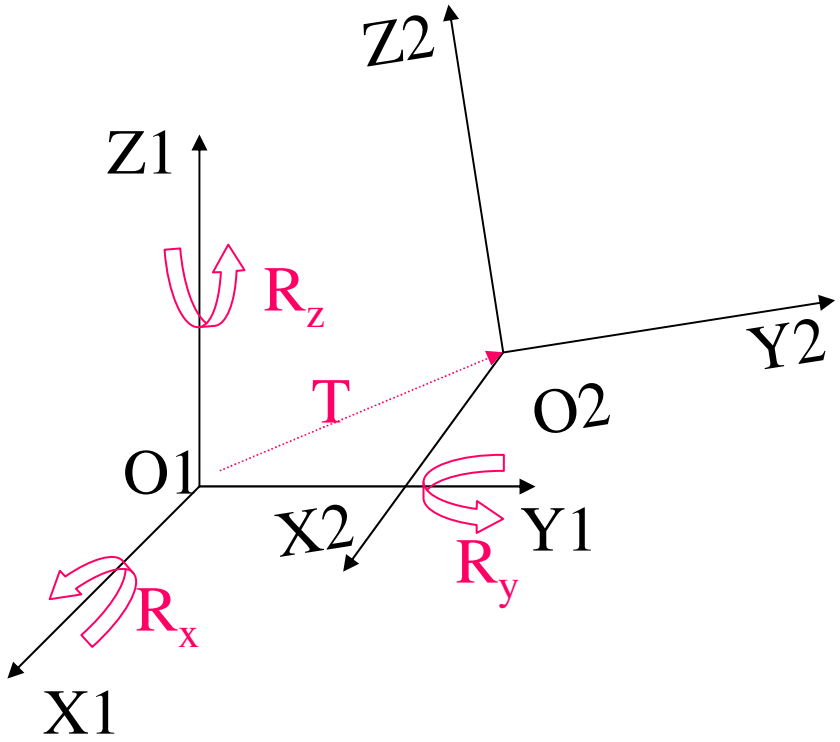
- **Alternatively: (GTRF experience)**
  - **Process GNSS data together with IGS/ITRF global stations in free mode**
  - **Align to ITRF using minimal constraint approach**

Conclusion

- The ITRF
  - is the most optimal global RF available today
  - gathers the strenghs 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

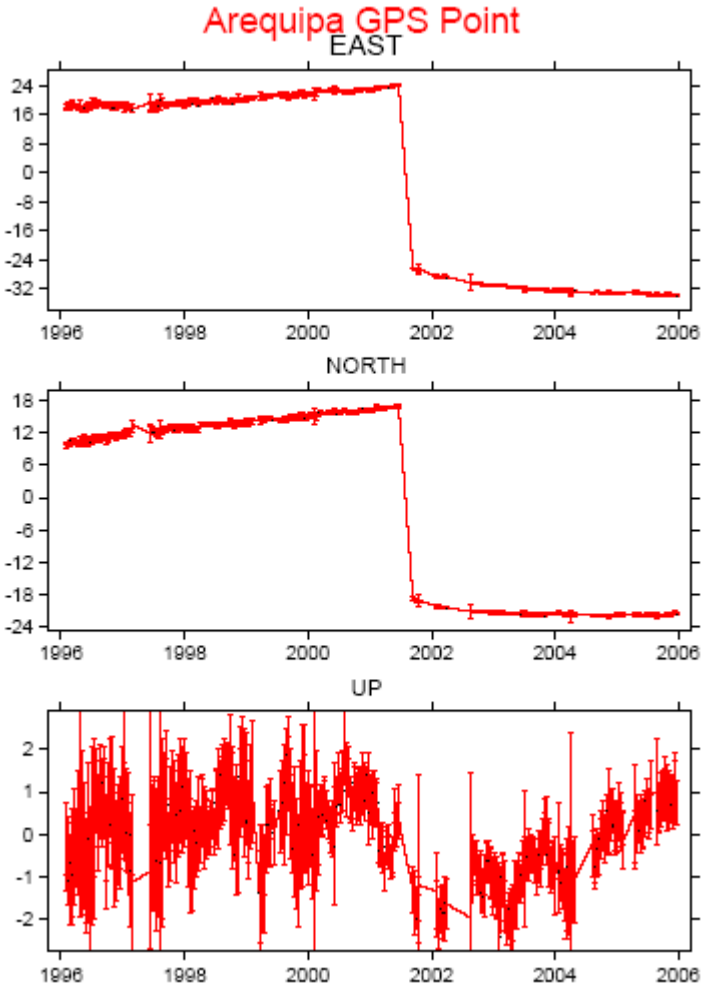
$$\begin{cases} X_s^i &= X_c^i + (t_s^i - t_0)\dot{X}_c^i \\ &+ T_k + D_k X_c^i + R_k X_c^i \\ &+ (t_s^i - t_k)\left[\dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i\right] \\ \dot{X}_s^i &= \dot{X}_c^i + \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \end{cases}$$

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

Time series of station positions are fundamental for the ITRF construction

Monitor station behaviour

Arequipa Earthquake



Brasilia Seasonal Variations