Role and importance of the International Terrestrial Reference Frame (ITRF) for sustainable development

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Outline

- Introduction
- The International Terrestrial Reference Frame (ITRF)
  - current status, results and quality (ITRF2008)
- Access to the ITRF and the IGS role
- GNSS and their associated reference frames
- Some wishes toward GNSS Providers

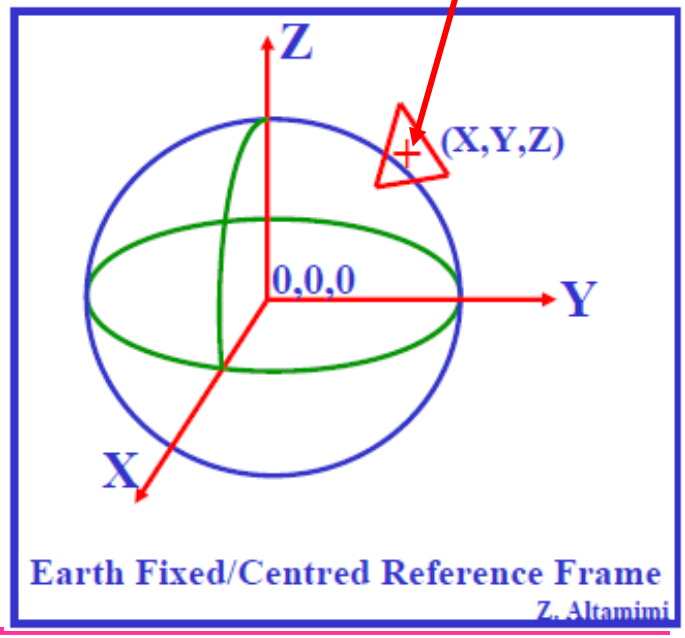
What is a Reference Frame in practice?

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

- **It seems 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



Why is a Reference Frame needed?

- **Precise Orbit Determination for:**
  - **GNSS: Global Navigation Satellite Systems**
  - **Other satellite missions: Altimetry, Oceanography, Gravity**
- **Earth Sciences Applications**
  - **Earth rotation**
  - **Tectonic motion and crustal deformation**
  - **Glacial Isostatic Adjustment (GIA)**
  - **Mean sea level variations**
  - **…**
- **Geo-referencing applications**
  - **Navigation: Aviation, Terrestrial, Ocean**
  - **Surveying**
  - **Positioning**

The International Terrestrial Reference Frame (ITRF)

- Established and maintained by the International Earth Rotation and Reference Systems Service (IERS)
- Numerical realization of the International Terrestrial Reference System (ITRS)
- Adopted by IAG & IUGG in 1991 & 2007 and by CGPM in 2011 for Earth science & timing applications
- Combination of VLBI, SLR, GNSS and DORIS TRFs
- Operated by the ITRS Center, hosted by IGN- France
- Based on co-location sites (see next)
- Updated every 3-5 years: ITRF88,…,2000,2005
- Current Version: ITRF2008

Space Geodesy Techniques Contributing to the ITRF

- Very Long Baseline Interferometry (VLBI)
- Satellite Laser Ranging (SLR)
- DORIS
- GNSS: GPS, GLONASS, (Future: GALILEO, COMPASS, QZSS)

- ITRF Defining Parameters:
  - Origin: CoM of the Earth System: defined by SLR
  - Scale : Consistent with TCG: defined by VLBI & SLR
  - Orientation: Equatorial: Same for all ITRF versions: Currently ensured by mainly GNSS/IGS network
- ITRF Origin & Scale are very critical for science applications, e.g. monitoring of sea level variation
- Science Requirement: ITRF to be stable at 0.1mm/yr level

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Weaknesses of GNSS

- **Imprecise TRF origin (esp in Z) due to mainly orbit mis-modeling errors, e.g. solar radiation pressure**

- **Under-determined TRF scale due to satellite antenna phase center offset (APCO).**
  GNSS TRF scale & APCO are 100% correlated

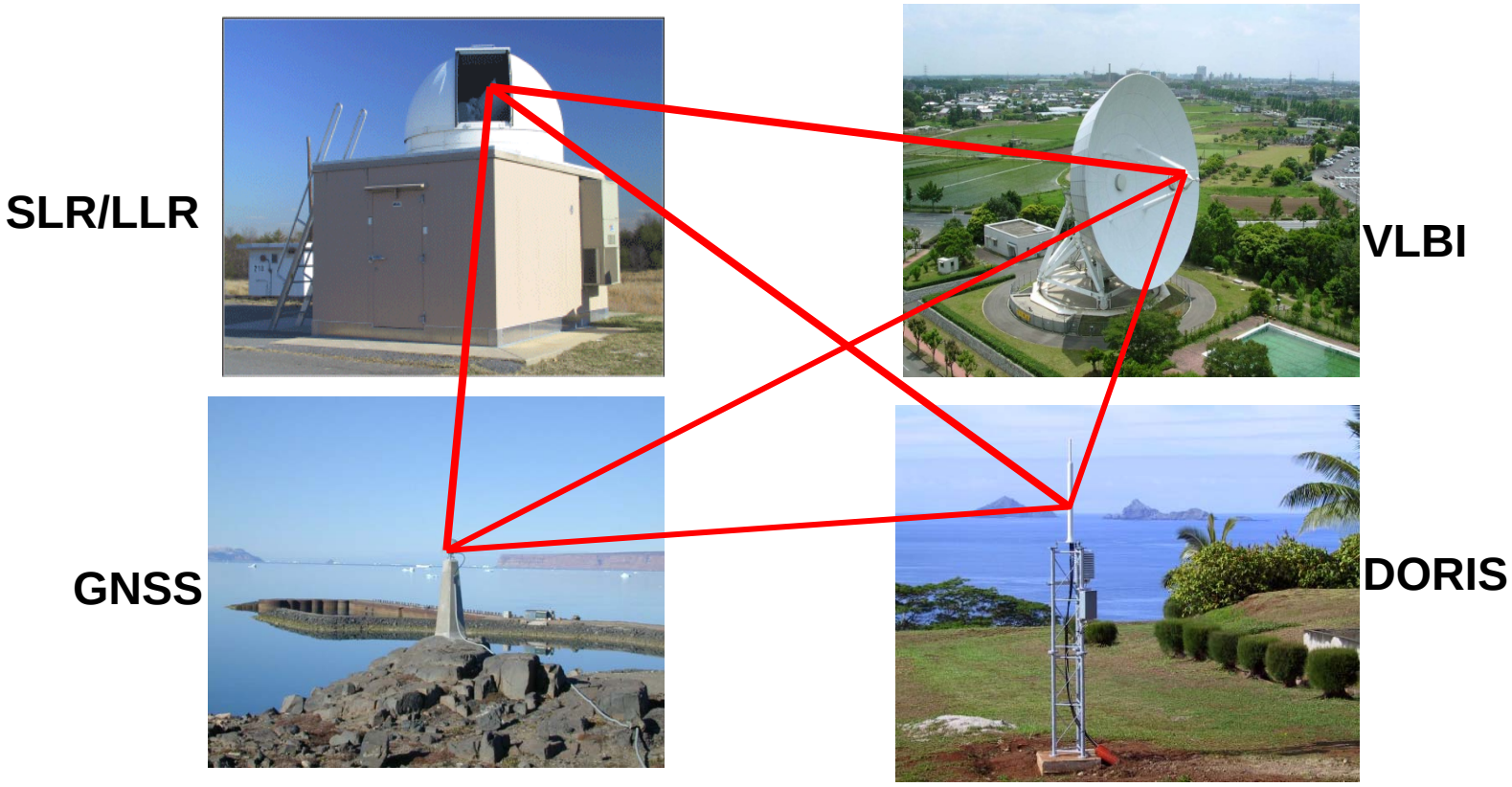
Strengths of GNSS

- GNSS/IGS IS the link between DORIS, SLR and VLBI networks in the ITRF combination
- Geographic density
  - Covering most tectonic plates
  - Allows maintaining the same orientation and its time evolution between successive ITRF solutions
- Most precise and accurate polar motion
- Real, near real time and universal access to ITRF using IGS products

Co-location site

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

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



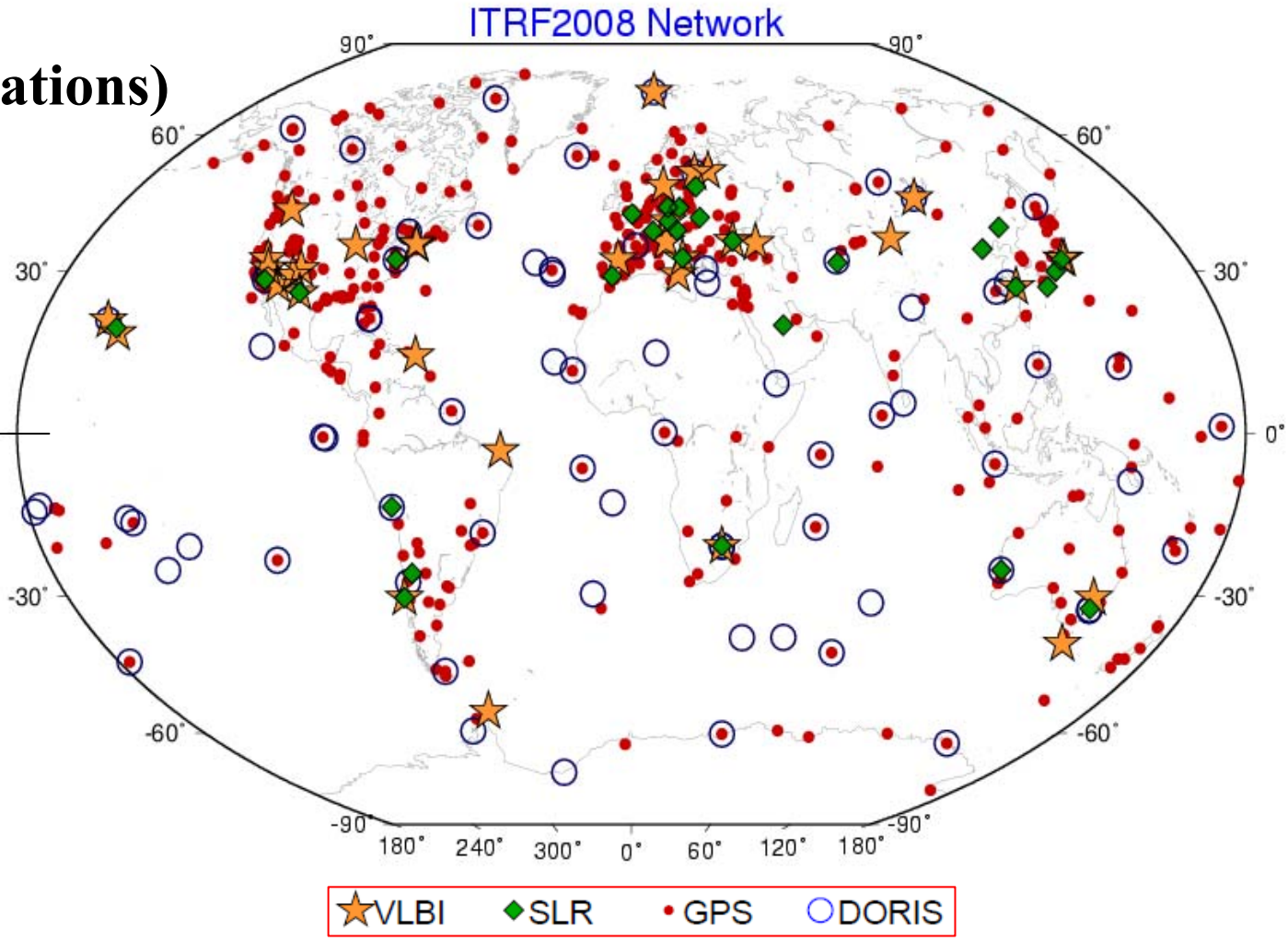
ITRF2008 Network

580 sites (920 stations)

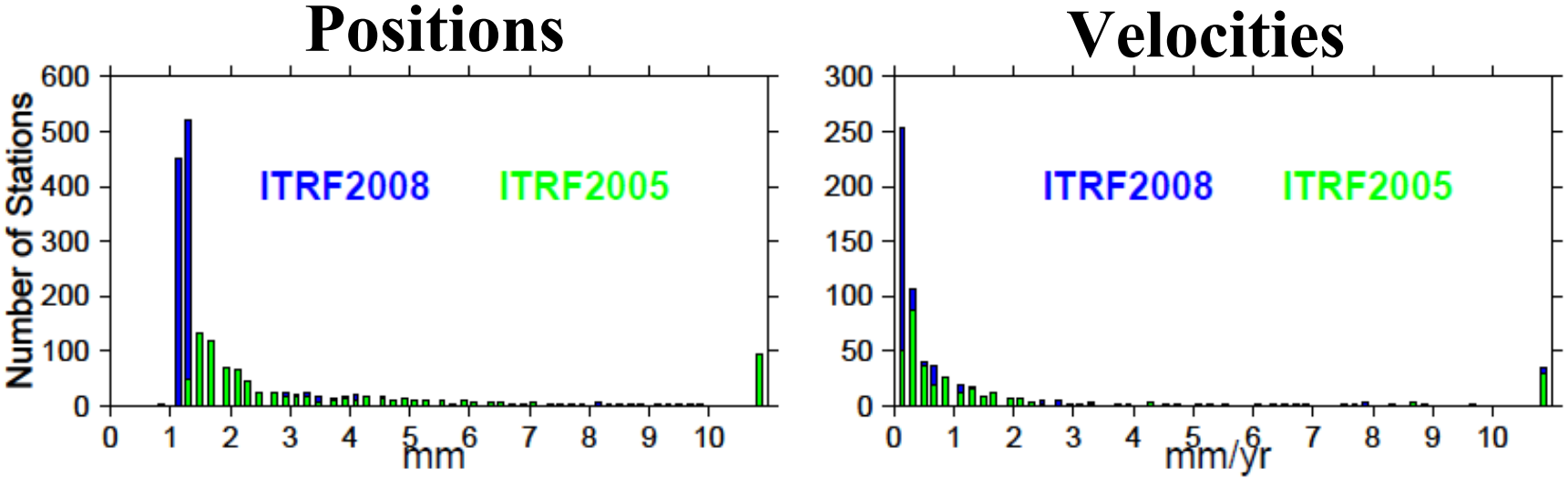
492 GNSS sites

461 Sites North

118 Sites South



ITRF precision (formal errors)

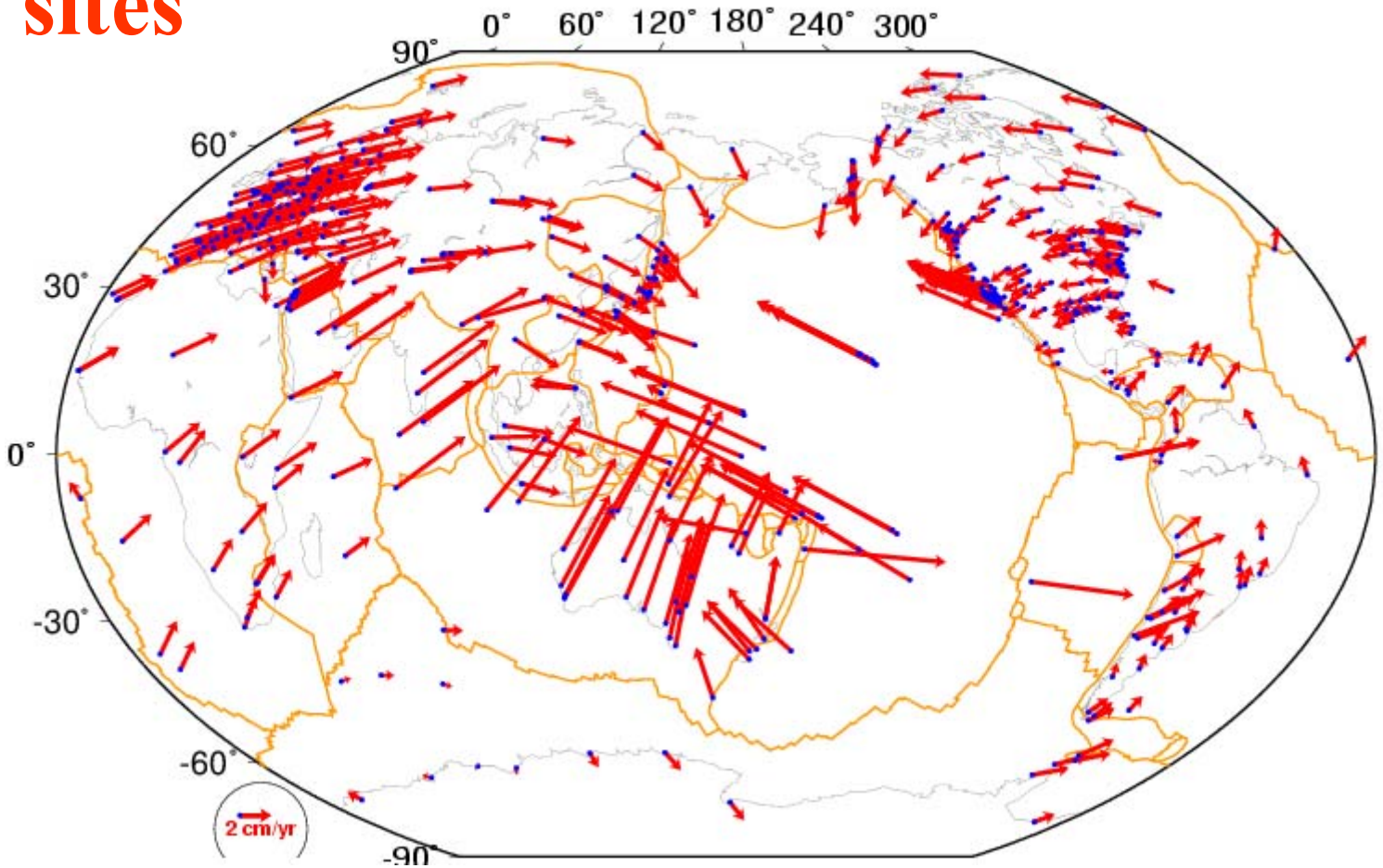


ITRF Accuracy in Origin and Scale ~1 cm (ITRF2008) over its time-span

ALL ITRF2008 Site Velocities:

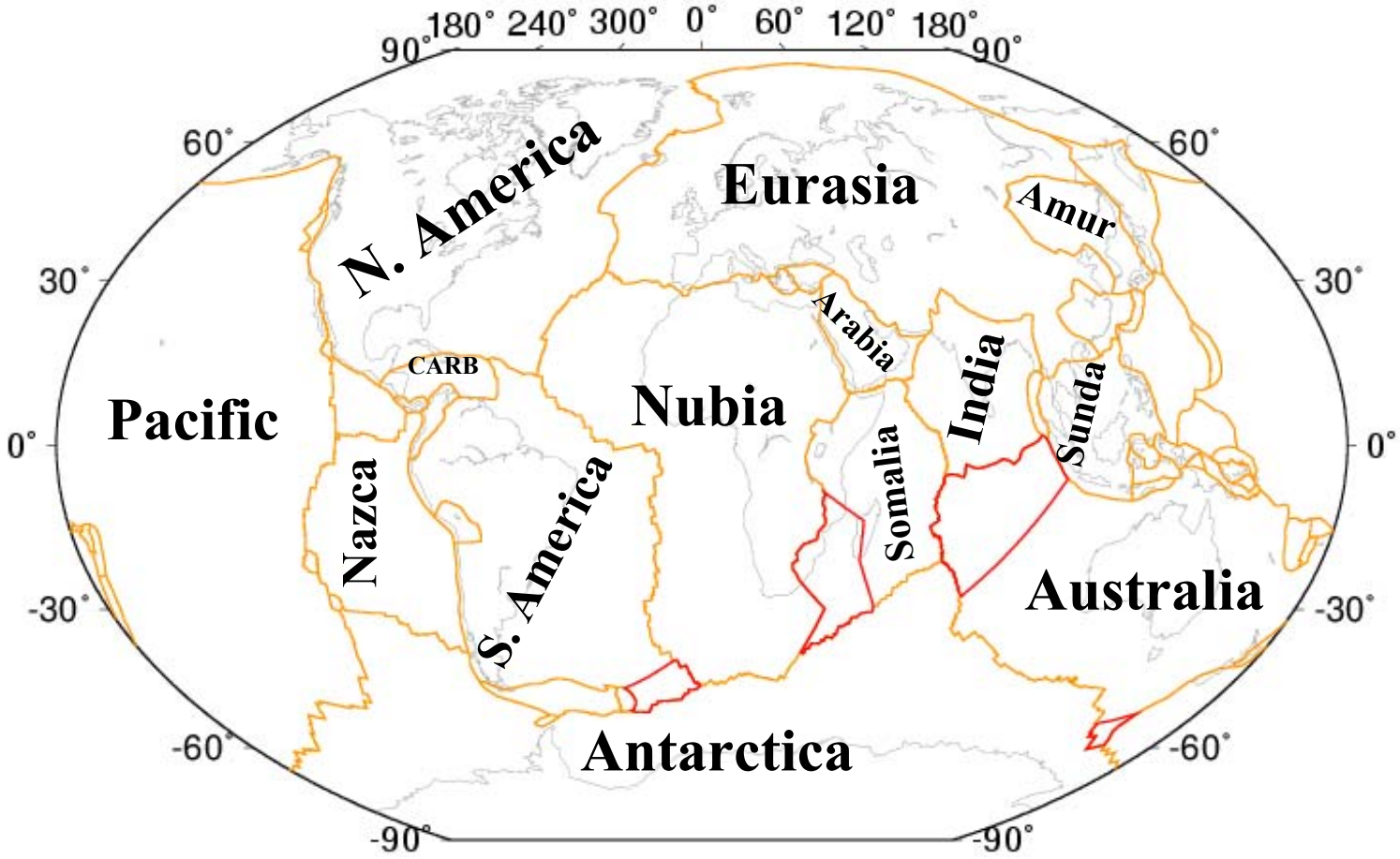
time-span > 3 yrs, (σ ~ 0.1 – 1 mm/yr)

509 sites



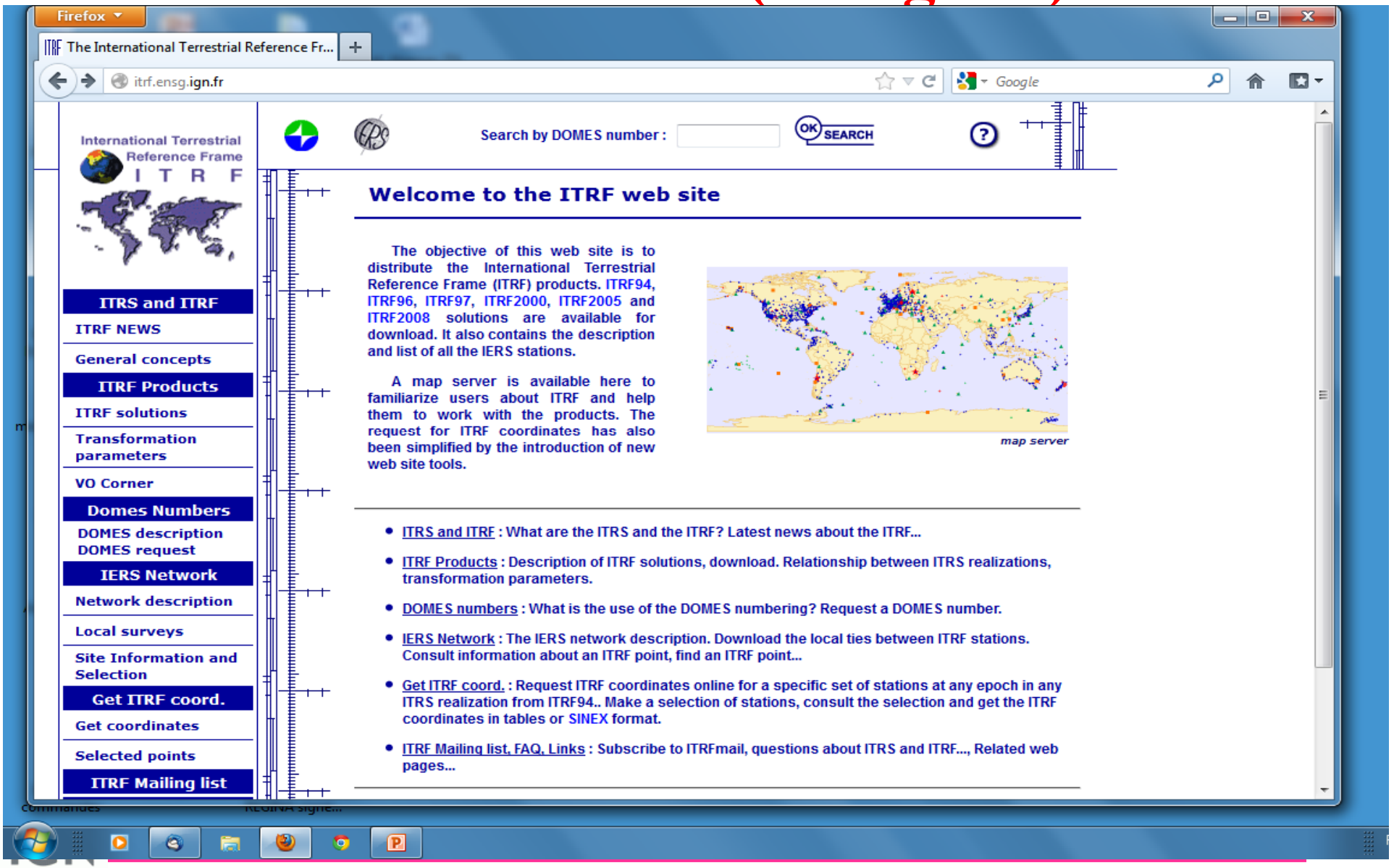
ITRF2008 Plate Motion Model Available for 14 plates

Plate boundaries: Bird (2003) & MORVEL, DeMets et al. (2010)



Altamimi et al., JGR, 2012

ITRF Website (itrf.ign.fr)



Access to the ITRF and the IGS role (1/2)

- **How to express a GNSS network in the ITRF using IGS products (orbit, clocks, ERP: all expressed in the ITRF) ?**
- **Select a reference set of ITRF/IGS stations and collect RINEX data from IGS data centers;**
- **Process your stations together with ITRF/IGS ones:**
- **Fix IGS orbits, clocks and ERPs**
- **Eventually, add minimum constraints conditions in the processing:**

$$X_R = X_c + A\theta \quad \xrightarrow{\theta = 0} \quad (A^T A)^{-1} A^T (X_R - X_c) = 0$$

ITRF Your Solution

Access to the ITRF and the IGS role (2/2)

==> Your solution will be expressed in the ITRFyy consistent with IGS orbits

- Propagate official ITRF station positions at the central epoch (t_c) of the observations:

$$X(t_c) = X(t_0) + \dot{X}(t_c - t_0)$$

- Compare your estimated ITRF station positions to official ITRF values **and check for consistency**:
  - Transformation parameters should be zeros
  - No outliers: residuals smaller than a certain threshold.

Regional & National Reference Systems/Frames

- IAG Commission 1(Reference Frames) ==> Sub-Commission 1.3 (Regional Reference Frames):
  - EUREF/EUROP: ETRS89
  - NAREF/North America: NAD83
  - SIRGAS/South America: SIRGAS
  - AFREF/Africa
  - APREF/Asia & Pacifis
  - SCAR/Antarctica
- Regional Reference Frames: all related to ITRF
- Many countries have redefined their geodetic systems to be compatible/related to ITRF

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

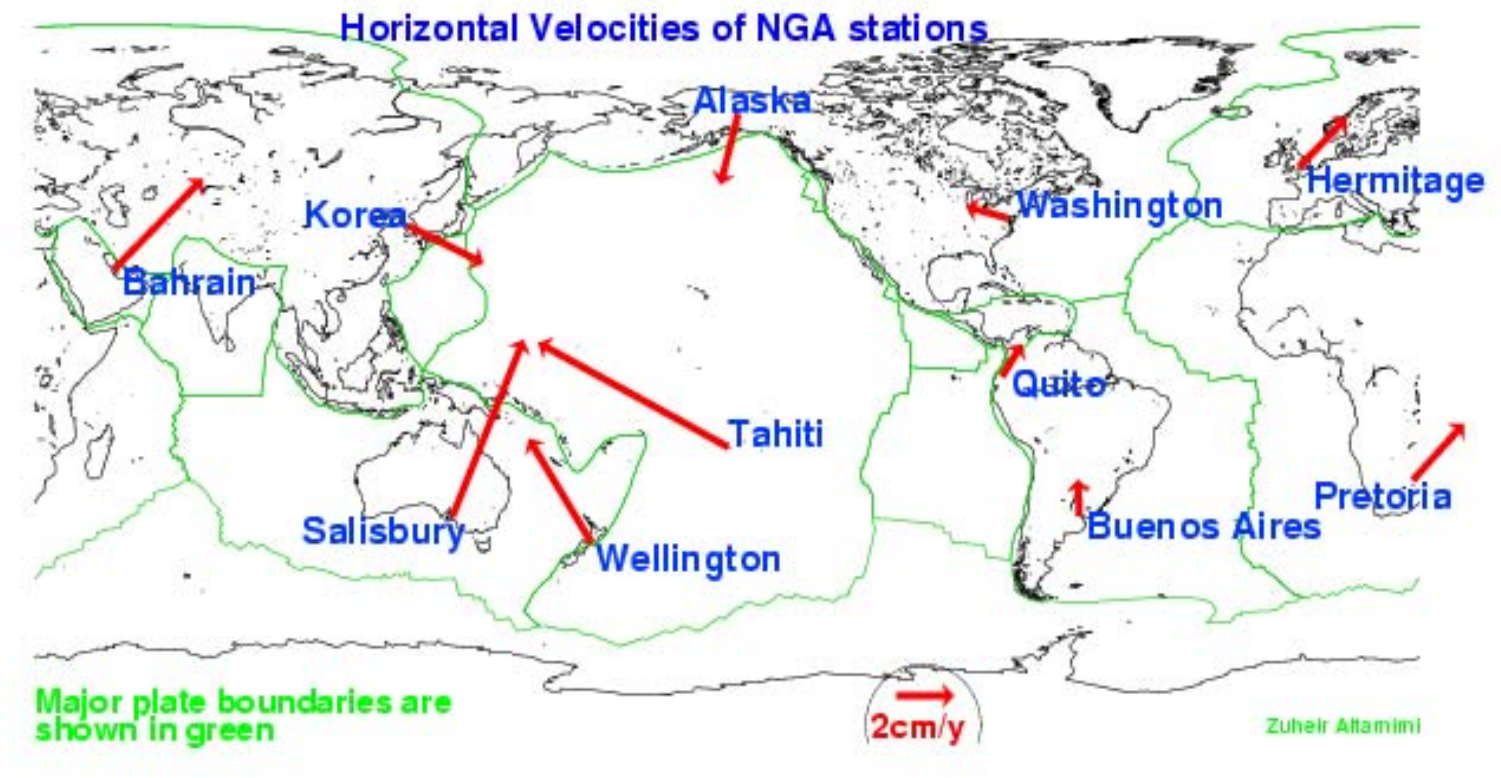
The World Geodetic System 84 (WGS 84)

- **WGS 84 realizations aligned to the ITRF**
  - **G730 in 1994**
  - **G873 in 1997**
  - **G1150 in 2002**
  - **G1674 in 2012 (aligned to ITRF2008)**

- **Coincides with any ITRF at 10 cm level**

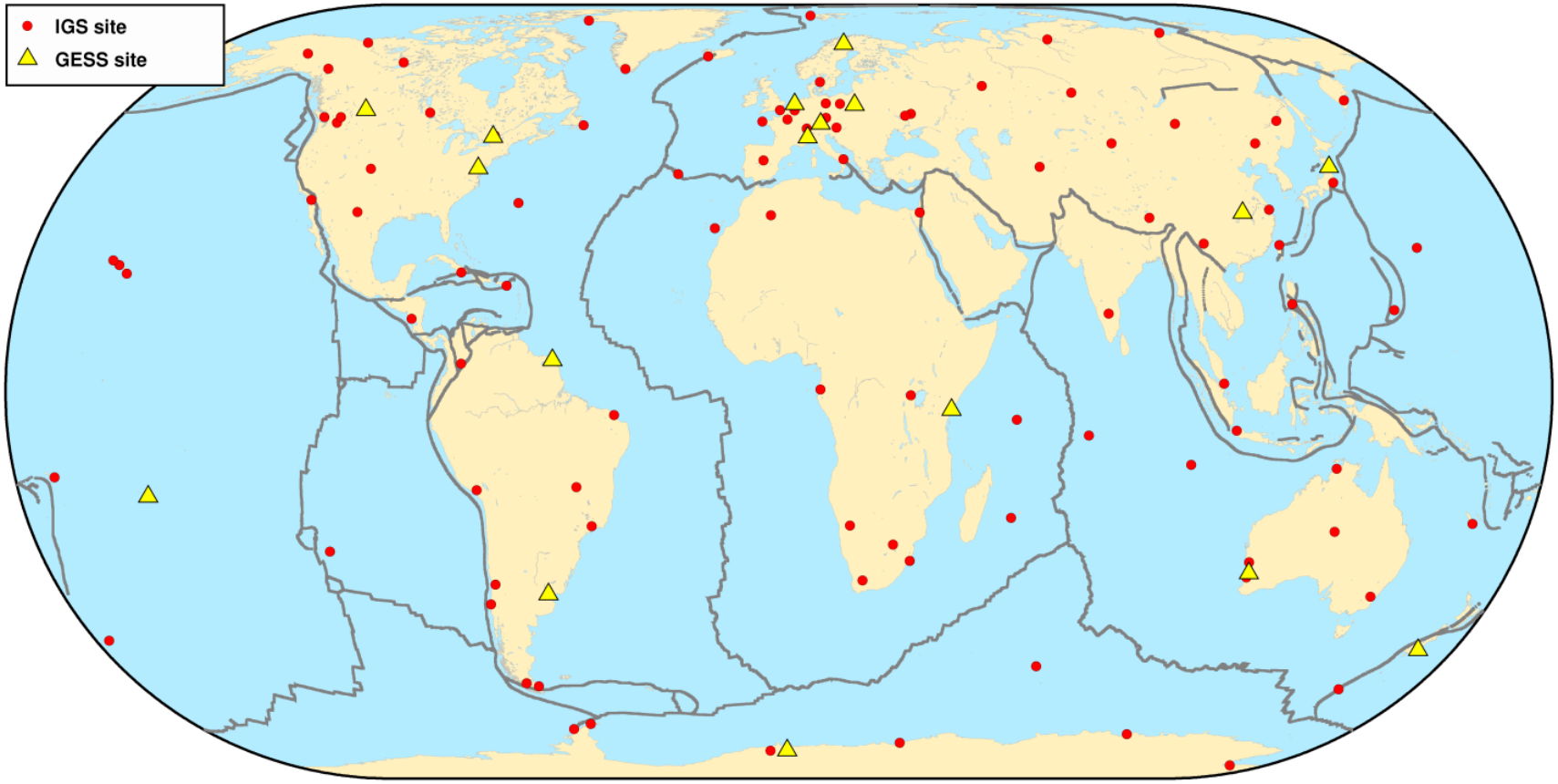
WGS84 - NGA Stations in ITRF2008

NGA: National Geospatial-Intelligence Agency



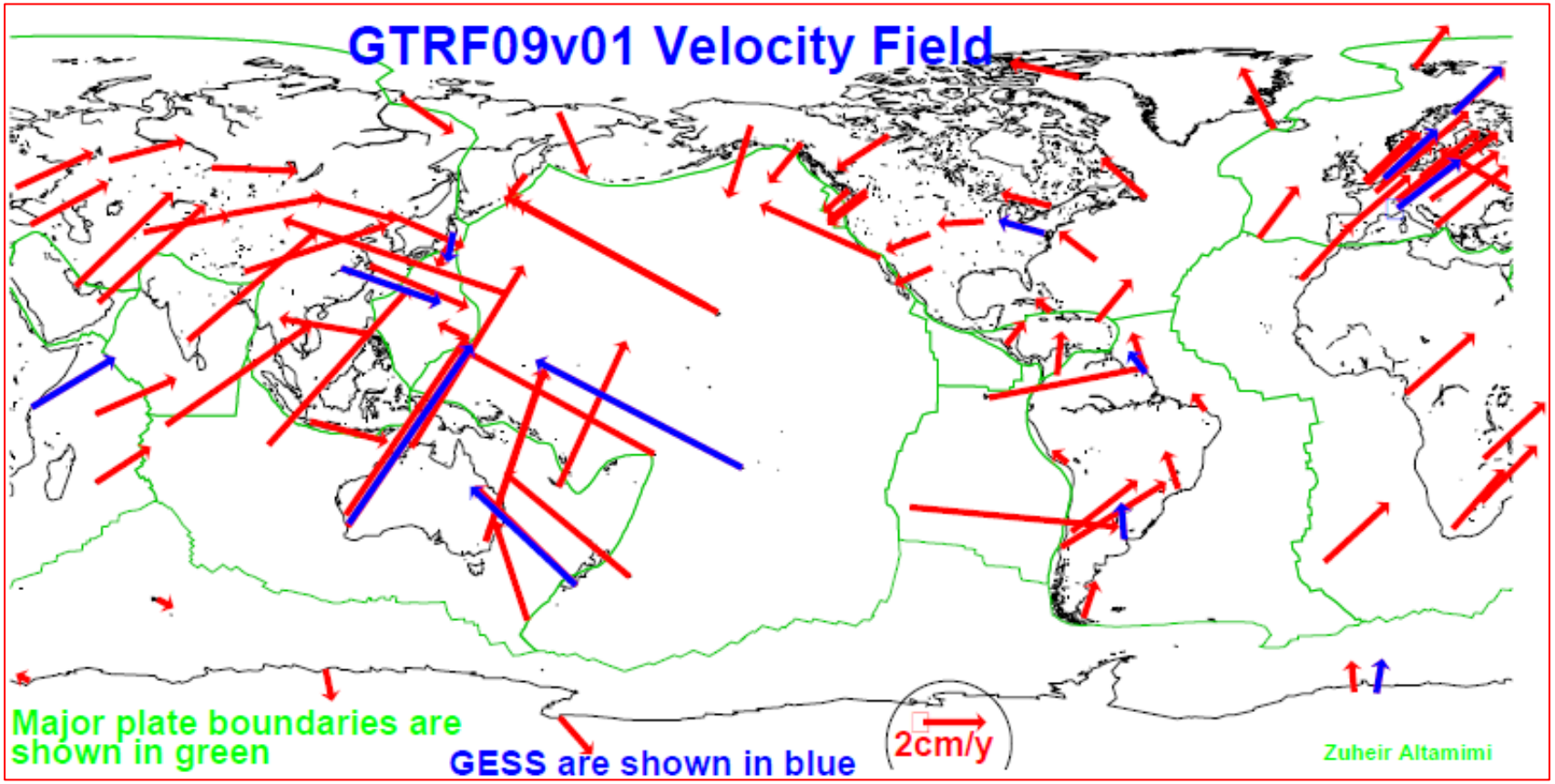
Galileo Terrestrial Reference Frame (GTRF)
Current Network

- Number of stations 127 (19 GESS)



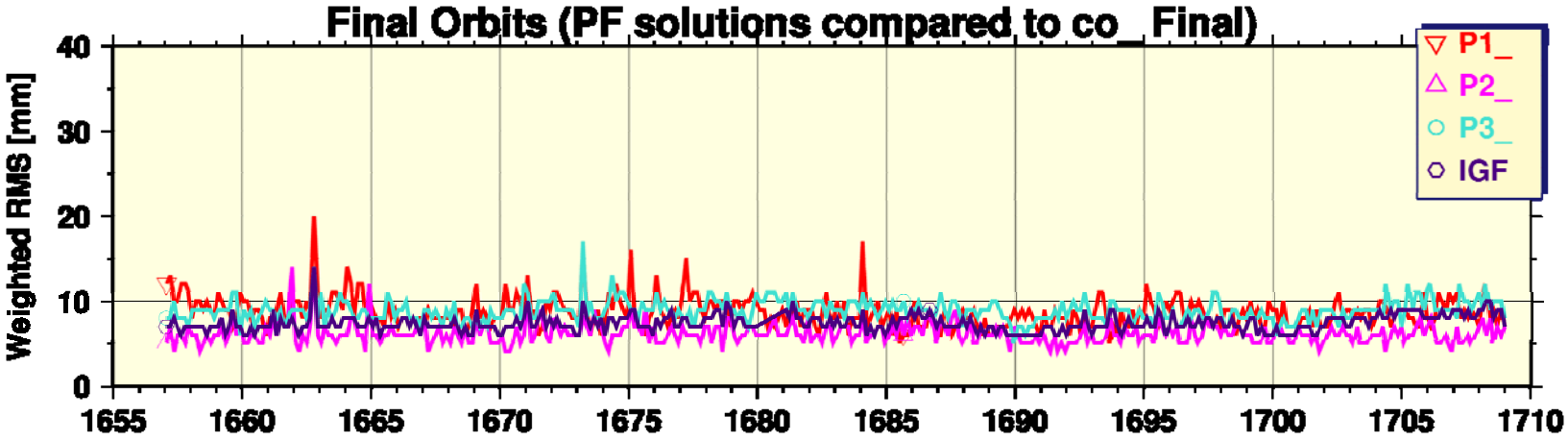
GGSP Consortium (GFZ, ESOC, AIUB, BKG, IGN)

GTRF09v01 horizontal velocities

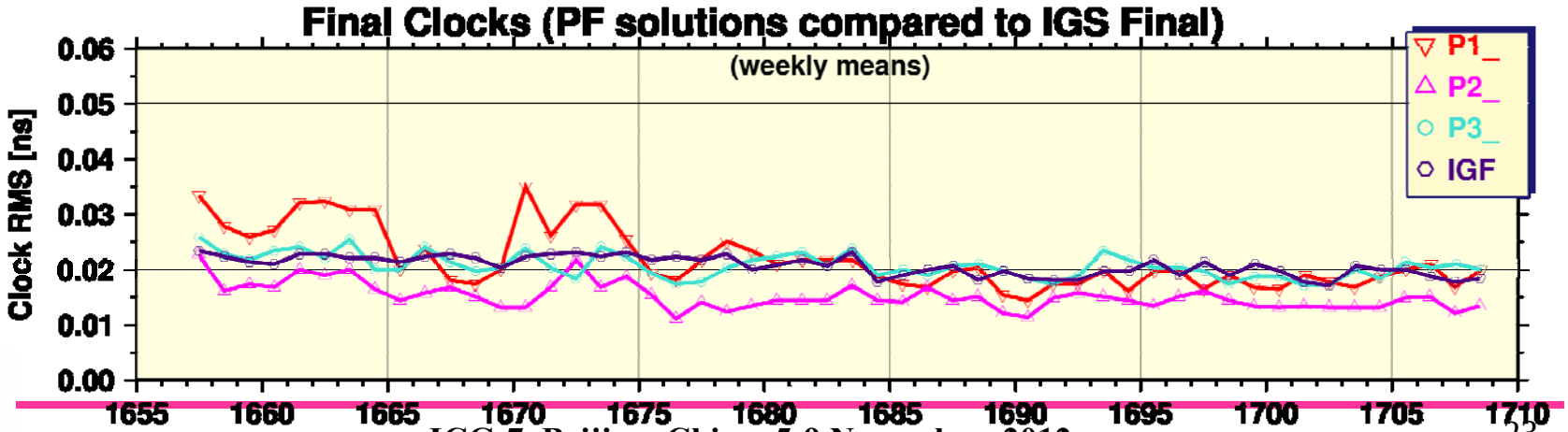


GTRF: Orbit and Clock Combination

- Orbit RMS agreement btw PFs and co_ orbits for GPS satellites is mostly at the level of 5-12 mm
- co_ difference to the IGS Final is in the same order



- agreement for the clocks shows an RMS of about 15 to 25 ps (all biases subtracted)



Conclusion

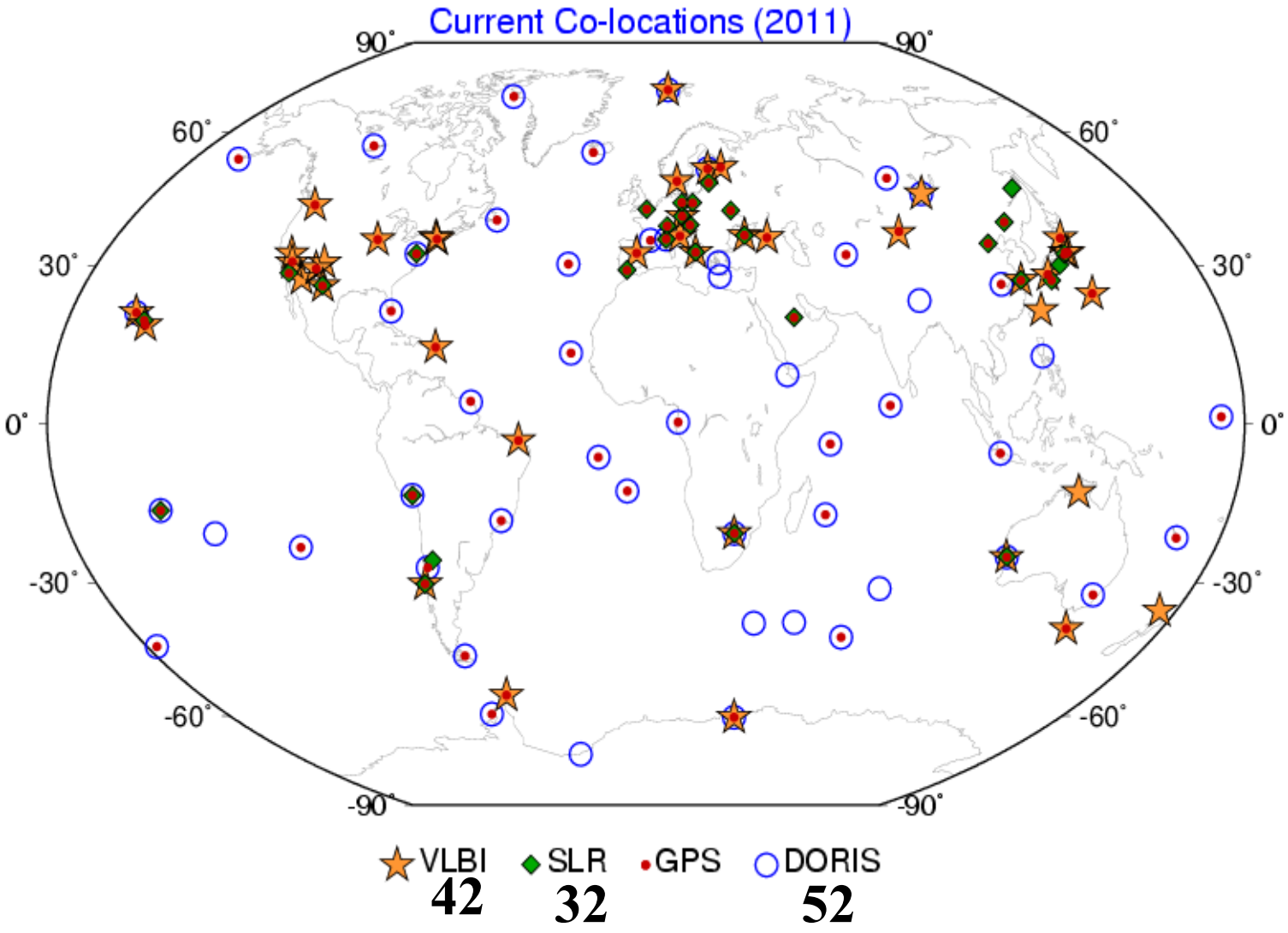
- **The ITRF**
  - **is the most optimal global TRF available today**
  - **gathers the strengths of space geodesy techniques**
  - **is more precise and accurate than any individual RF**
  - **is the achievement of 30 years of international collaboration and investment**
  - **needs to be maintained and improved over time**
- **Using the ITRF as a common standard facilitates the interoperability between the GNSS and regional & national reference frames**
- **There exists a well established procedure to ensure optimal alignment of GNSS and regional RFs to ITRF, using the publicly available IGS products**
- **Improving GNSS contribution to the ITRF is essential**

Geodetic Community Wishes Toward GNSS Providers

- **Satellite antennas should be calibrated before launch**
  ==> Ensure the scale stability of the GNSS Reference Frame
- **Why not add an accelerometer to each GNSS satellite ?**
  ==> Improve the geocenter determination by GNSS
- **Contribute to IGS and ITRF for the benefit of all:**
  –Provide data of subset of GNSS control stations to IGS for inclusion in the ITRF (cf. ICG-6 WG-D Recommendation)
  ==> (1) facilitate GNSS RF alignment to ITRF &
  (2) ensure interoperability between GNSS RFs
  –Contribute to IGS M-GEX Project
  - **Provide antenna offsets and attitude modes**
  - **Provide RINEX navigation data: frequency and signal identifiers**

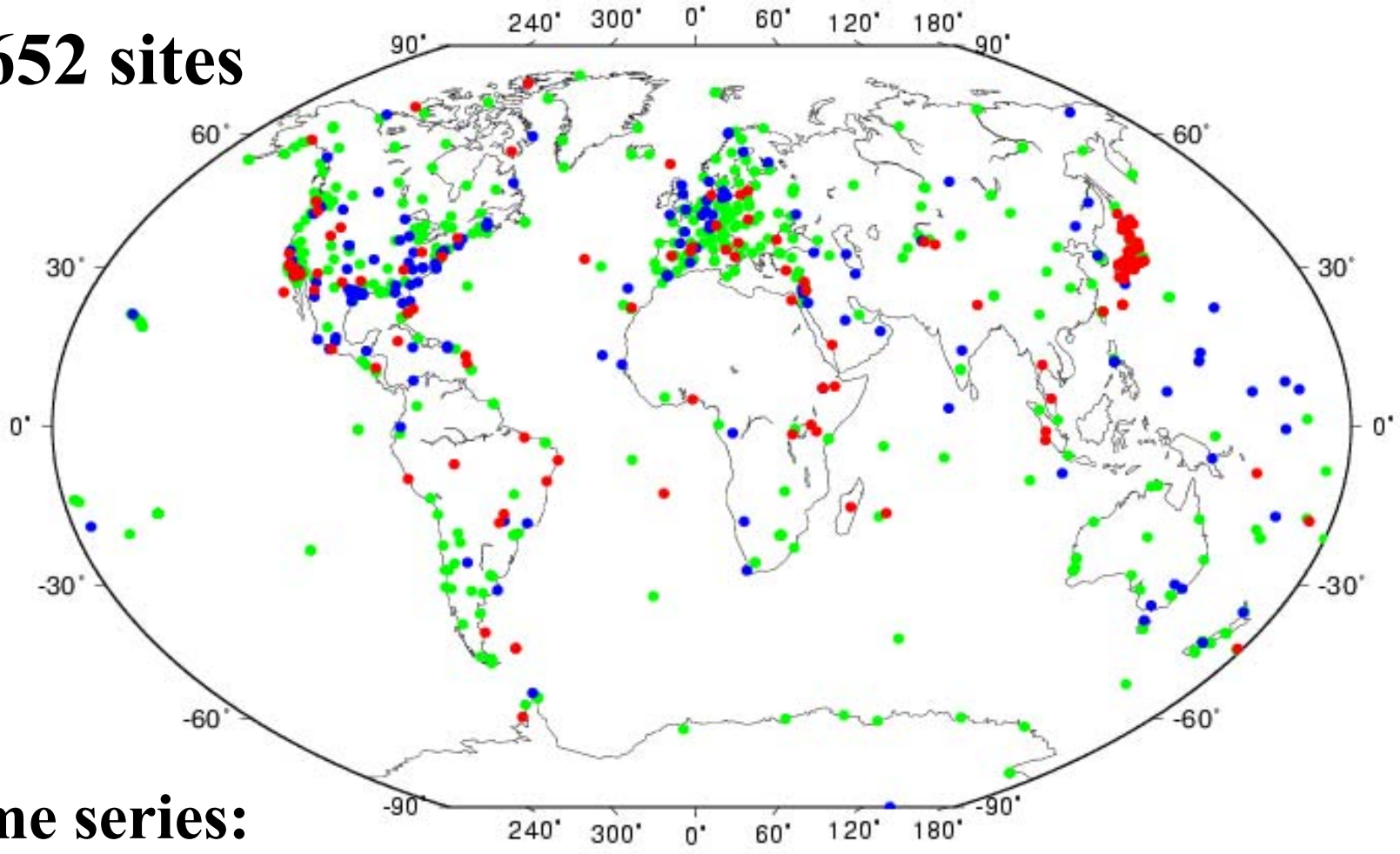
- **backups**

VLBI, SLR, DORIS sites & their co-locations with GPS



Processed IGS/GNSS sites, since 1994

652 sites



Time series:

Red < 5yrs (118), Blue 5-10yrs (138), Green 10-18yrs (396)