

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

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Outline

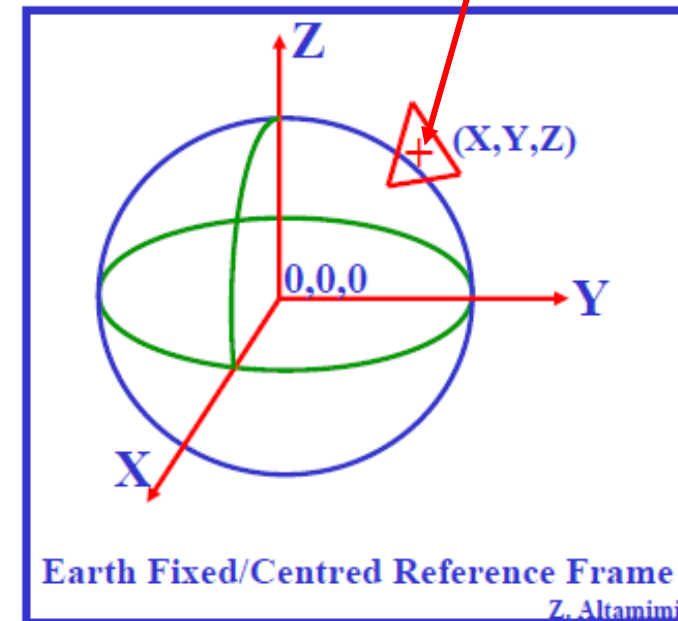
- **Introduction**
- **The International Terrestrial Reference Frame (ITRF)**
 - **current status, results and quality (ITRF2008)**
- **Access to the ITRF and the IGS role**
- **GNSS and their associated reference frames**
- **Some wishes toward GNSS Providers**

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

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

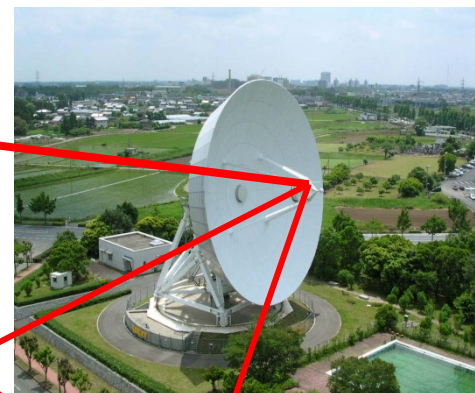
- GNSS/IGS **IS** the link between DORIS, SLR and VLBI networks in the ITRF combination
- Geographic density
 - Covering most tectonic plates
 - Allows maintaining the same orientation and its time evolution between successive ITRF solutions
- Most precise and accurate polar motion
- Real, near real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

$$\mathbf{DX}_{(\text{GPS,VLBI})} = \mathbf{X}_{\text{VLBI}} - \mathbf{X}_{\text{GPS}}$$

SLR/LLR



VLBI

GNSS



DORIS

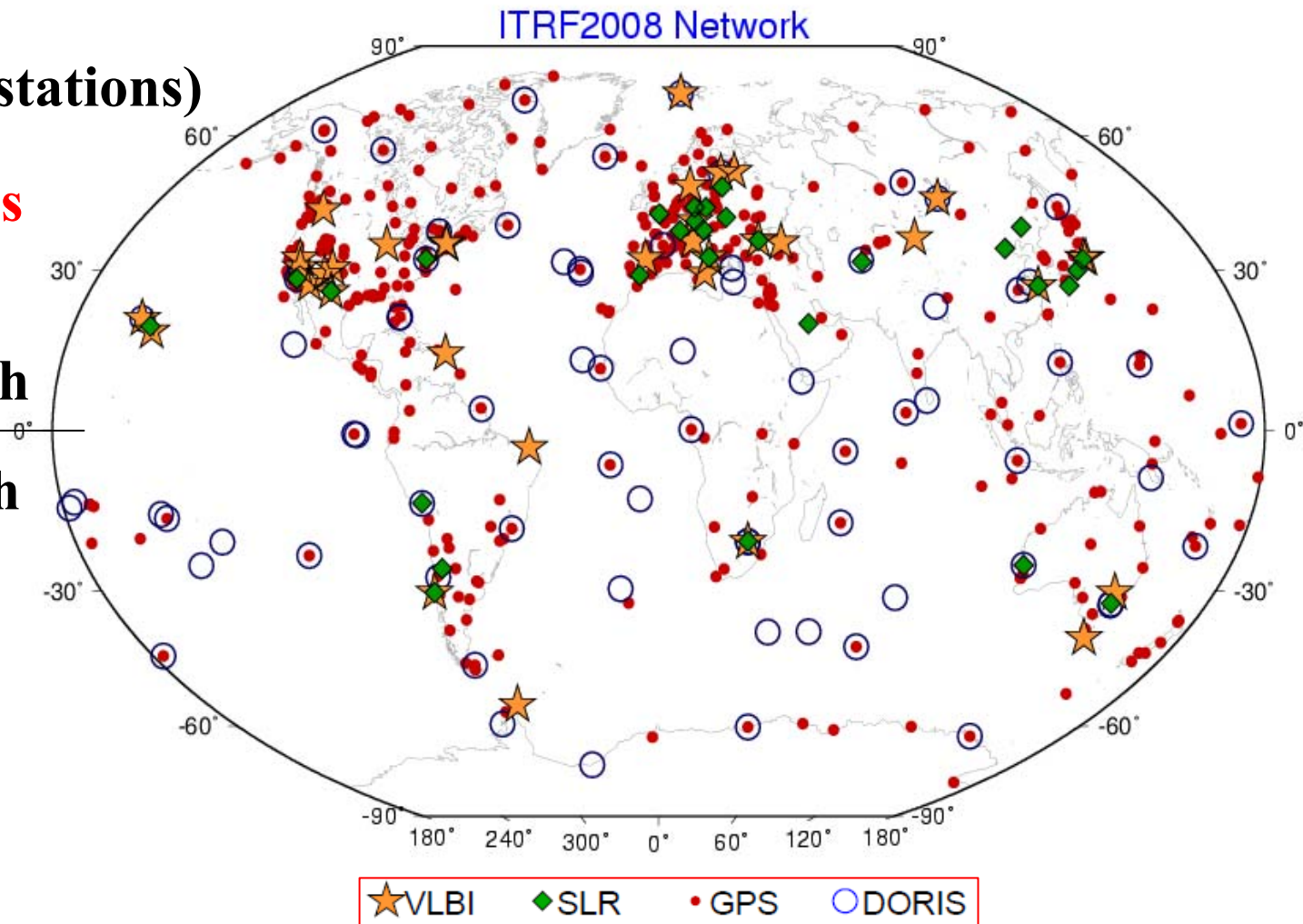
ITRF2008 Network

580 sites (920 stations)

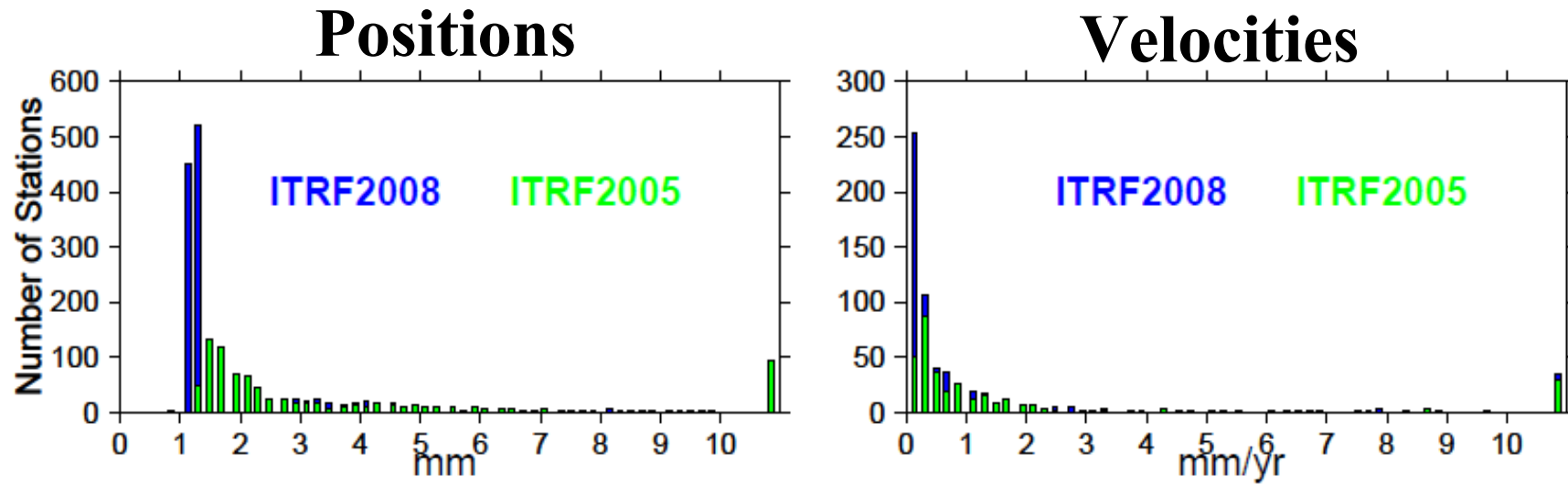
492 GNSS sites

461 Sites North

118 Sites South



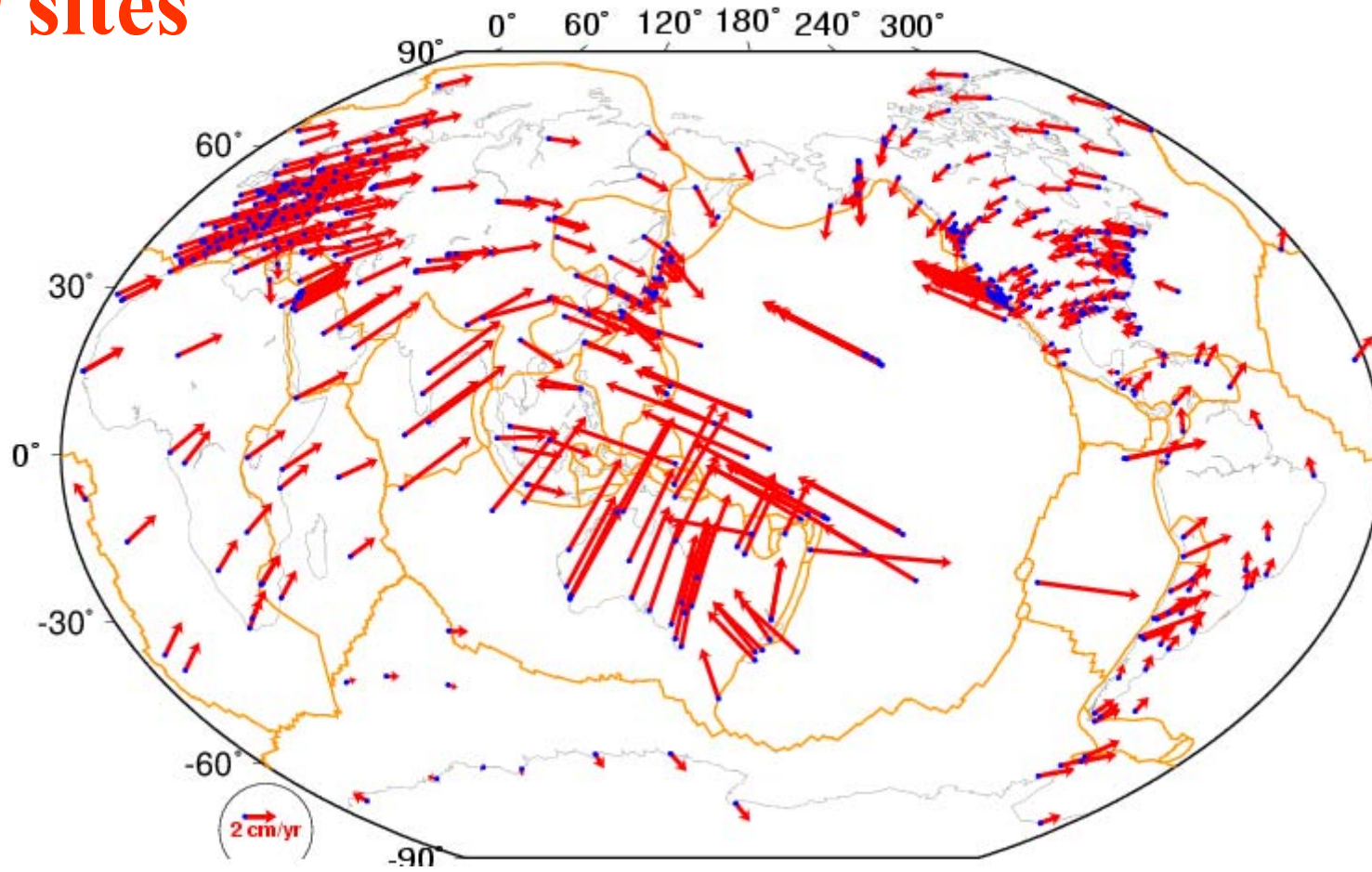
ITRF precision (formal errors)



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

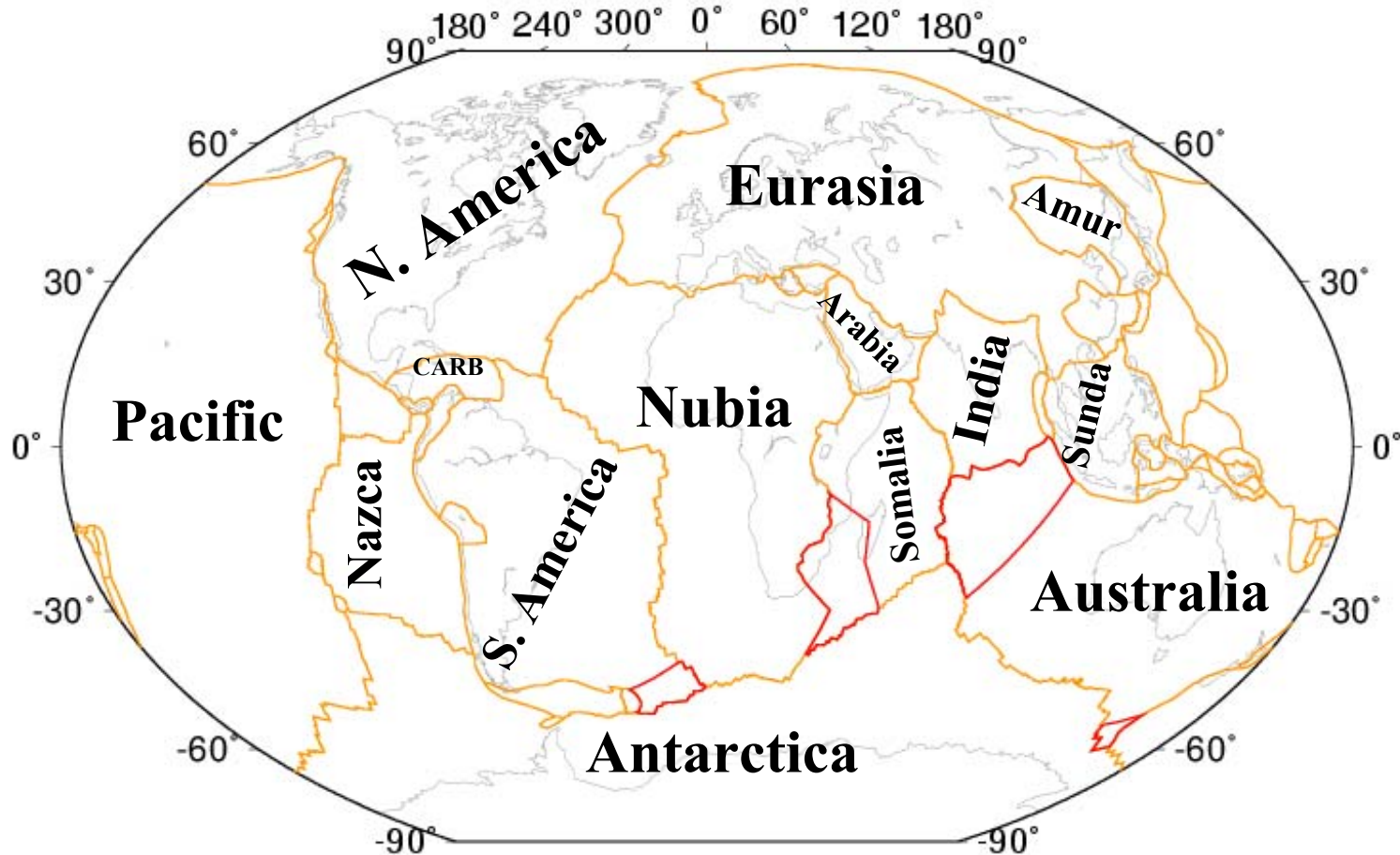
ALL ITRF2008 Site Velocities: time-span > 3 yrs, ($\sigma \sim 0.1 - 1$ mm/yr)

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)

The screenshot shows the ITRF website in a Firefox browser window. The address bar displays "itrf.ensg.ign.fr". The page layout includes a left-hand navigation menu with categories such as "ITRS and ITRF", "ITRF NEWS", "General concepts", "ITRF Products", "ITRF solutions", "Transformation parameters", "VO Corner", "Domes Numbers", "DOMES description", "DOMES request", "IERS Network", "Network description", "Local surveys", "Site Information and Selection", "Get ITRF coord.", "Get coordinates", "Selected points", and "ITRF Mailing list". The main content area is titled "Welcome to the ITRF web site" and contains the following text:

The objective of this web site is to distribute the International Terrestrial Reference Frame (ITRF) products. ITRF94, ITRF96, ITRF97, ITRF2000, ITRF2005 and ITRF2008 solutions are available for download. It also contains the description and list of all the IERS stations.

A map server is available here to familiarize users about ITRF and help them to work with the products. The request for ITRF coordinates has also been simplified by the introduction of new web site tools.

Below the text is a world map labeled "map server" showing the locations of ITRF stations. A search bar at the top right allows users to search by DOMES number.

The bottom of the page features a list of links:

- [ITRS and ITRF](#) : What are the ITRS and the ITRF? Latest news about the ITRF...
- [ITRF Products](#) : Description of ITRF solutions, download. Relationship between ITRS realizations, transformation parameters.
- [DOMES numbers](#) : What is the use of the DOMES numbering? Request a DOMES number.
- [IERS Network](#) : The IERS network description. Download the local ties between ITRF stations. Consult information about an ITRF point, find an ITRF point...
- [Get ITRF coord.](#) : Request ITRF coordinates online for a specific set of stations at any epoch in any ITRS realization from ITRF94.. Make a selection of stations, consult the selection and get the ITRF coordinates in tables or SINEX format.
- [ITRF Mailing list, FAQ, Links](#) : Subscribe to ITRFmail, questions about ITRS and ITRF..., Related web pages...

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:

$$\begin{array}{ccc} \boxed{X_R = X_c + A\theta} & \xrightarrow{\theta = 0} & \boxed{(A^T A)^{-1} A^T (X_R - X_c) = 0} \\ \uparrow & & \uparrow \\ \text{ITRF} & & \text{Your Solution} \end{array}$$

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

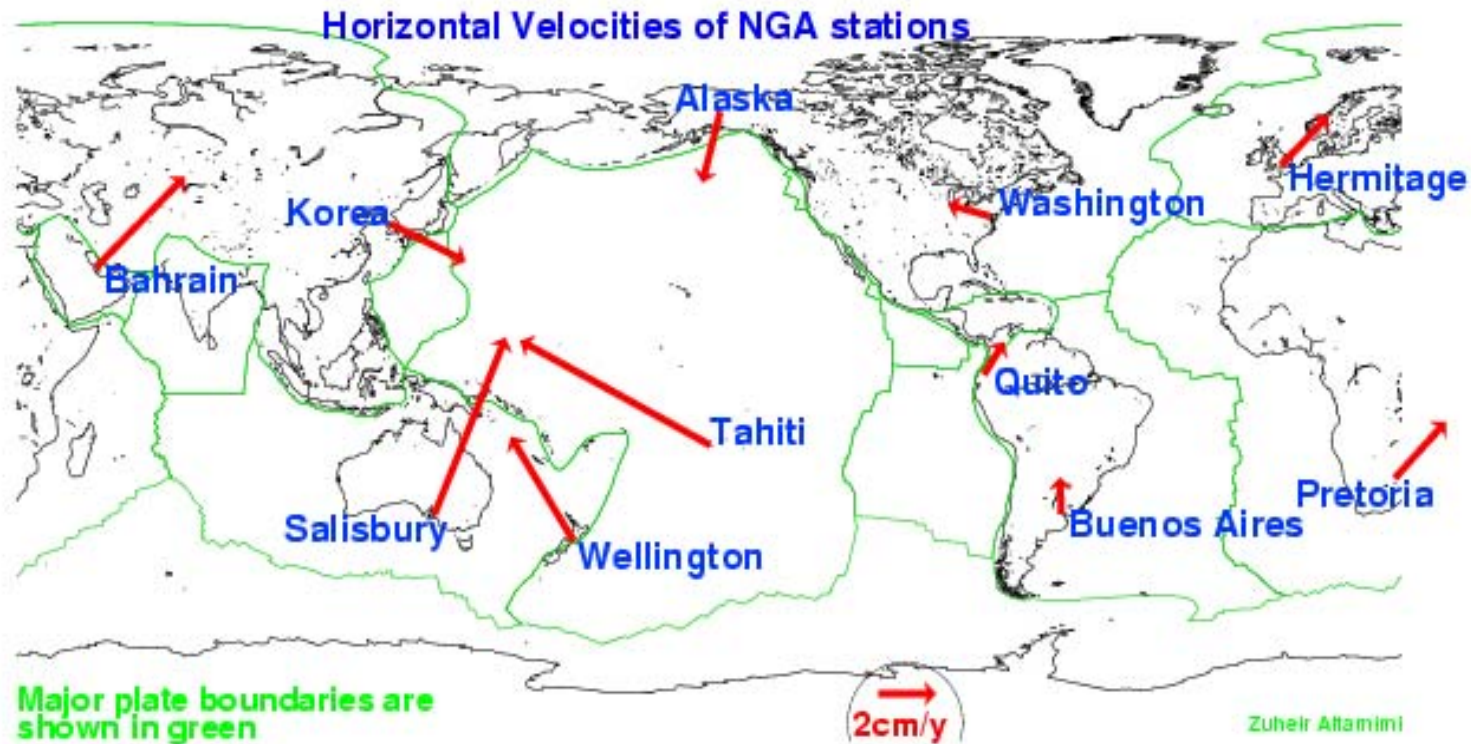
<u>GNSS</u>	<u>Ref. System/Frame</u>
• GPS (broadcast orbits)	WGS84
• GPS (precise IGS orbits)	ITRS/ITRF
• GLONASS	PZ-90
• GALILEO	ITRS/ITRF/GTRF
• COMPASS	CGCS 2000
• QZSS	JGS
• All are “aligned” to the ITRF	
• WGS84 \approx ITRF at the decimeter level	
• GTRF \approx ITRF at the mm level	
• σ-Position 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**

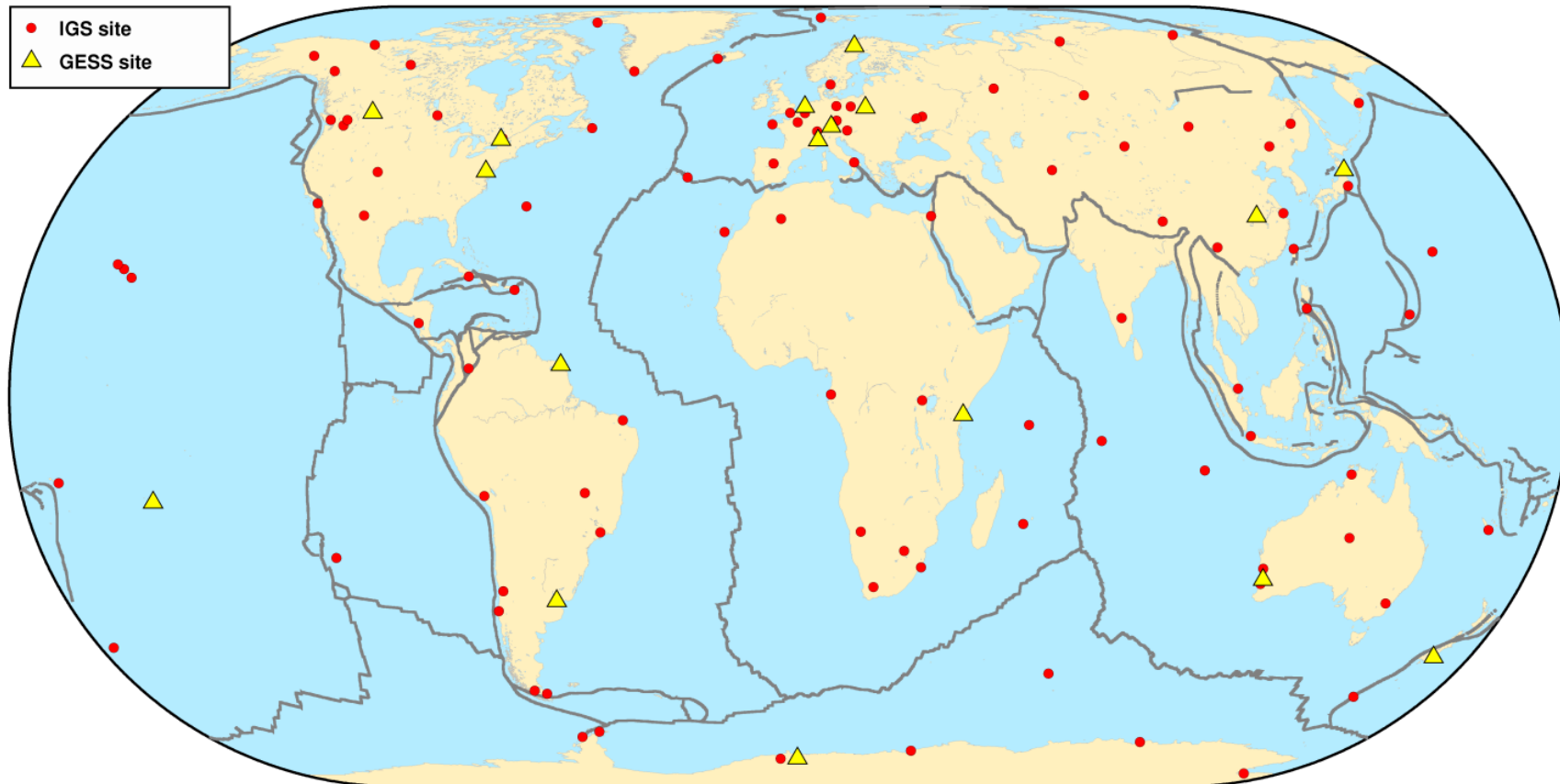
WGS84 - NGA Stations in ITRF2008

NGA: National Geospatial-Intelligence Agency



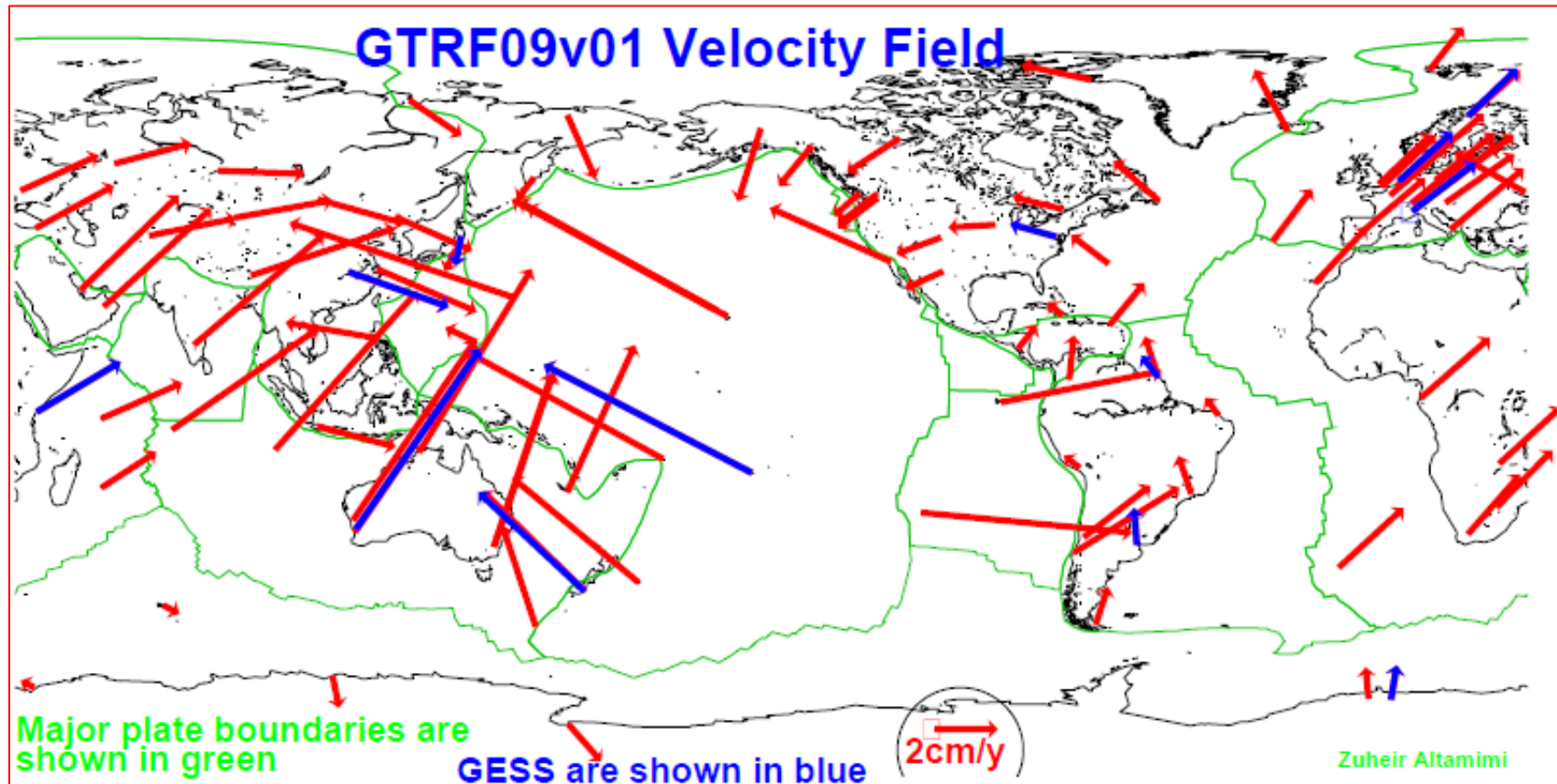
Galileo Terrestrial Reference Frame (GTRF) Current Network

 Number of stations 127 (19 GESS)



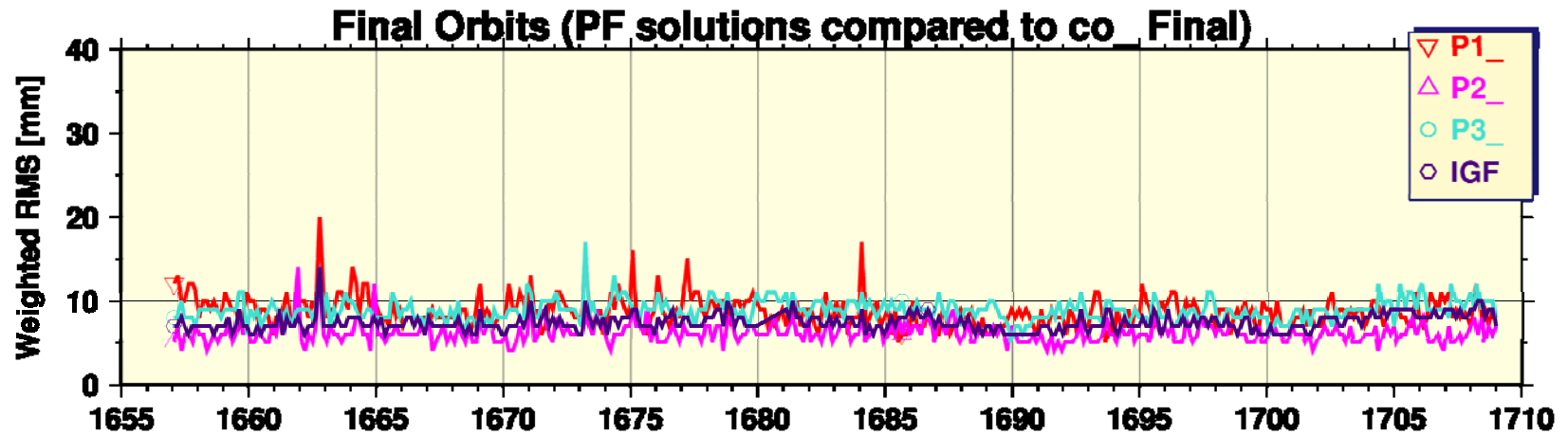
GGSP Consortium (GFZ, ESOC, AIUB, BKG, IGN)

GTRF09v01 horizontal velocities

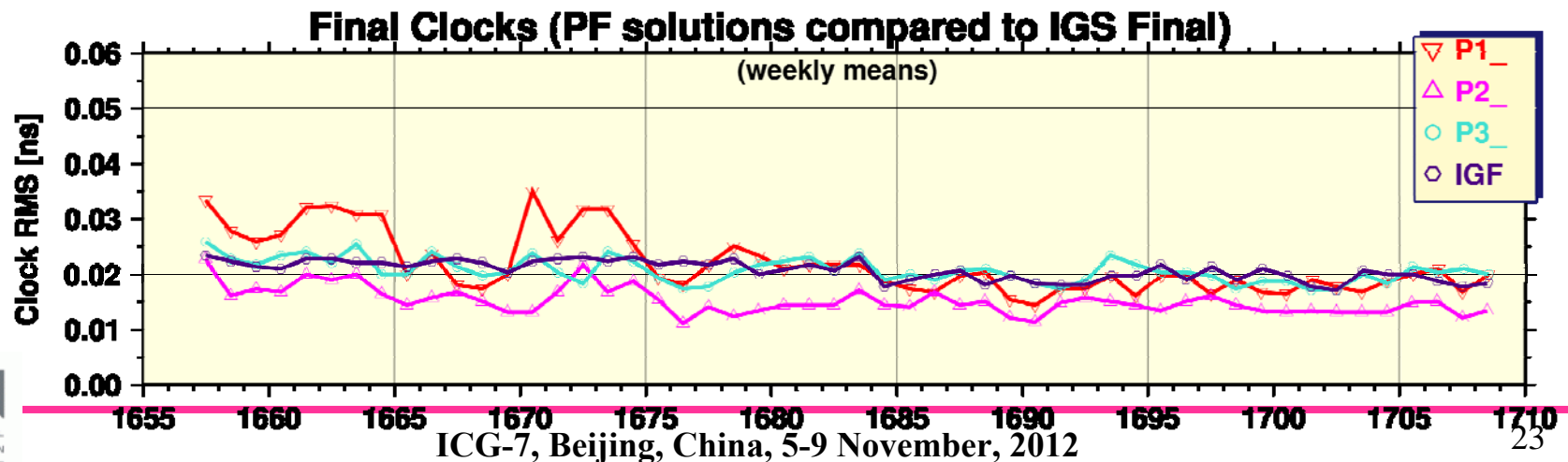


GTRF: Orbit and Clock Combination

- 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

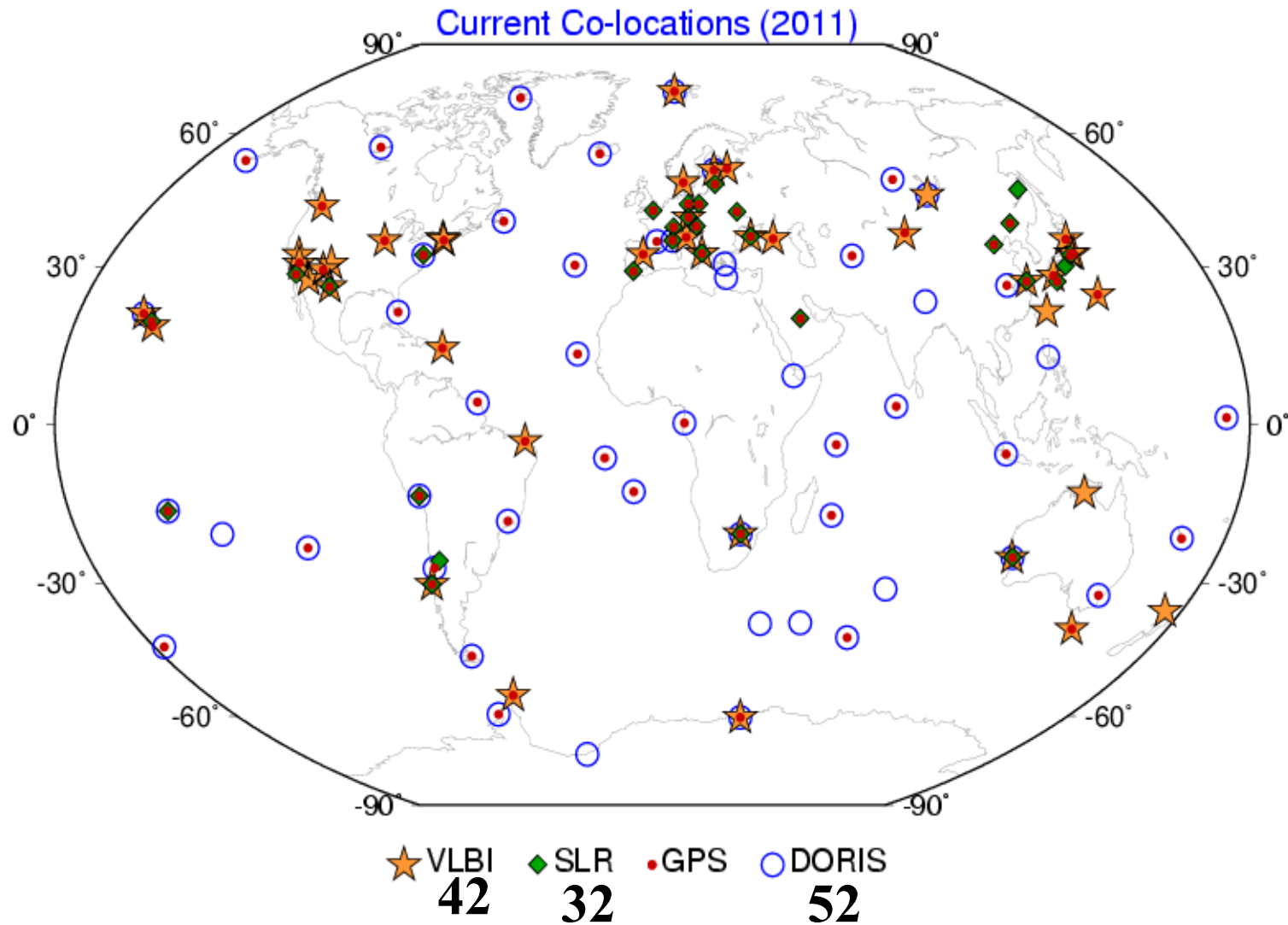
- **The ITRF**
 - is the most optimal global TRF available today
 - gathers the strengths of space geodesy techniques
 - is more precise and accurate than any individual RF
 - is the achievement of 30 years of international collaboration and investment
 - needs to be maintained and improved over time
- 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

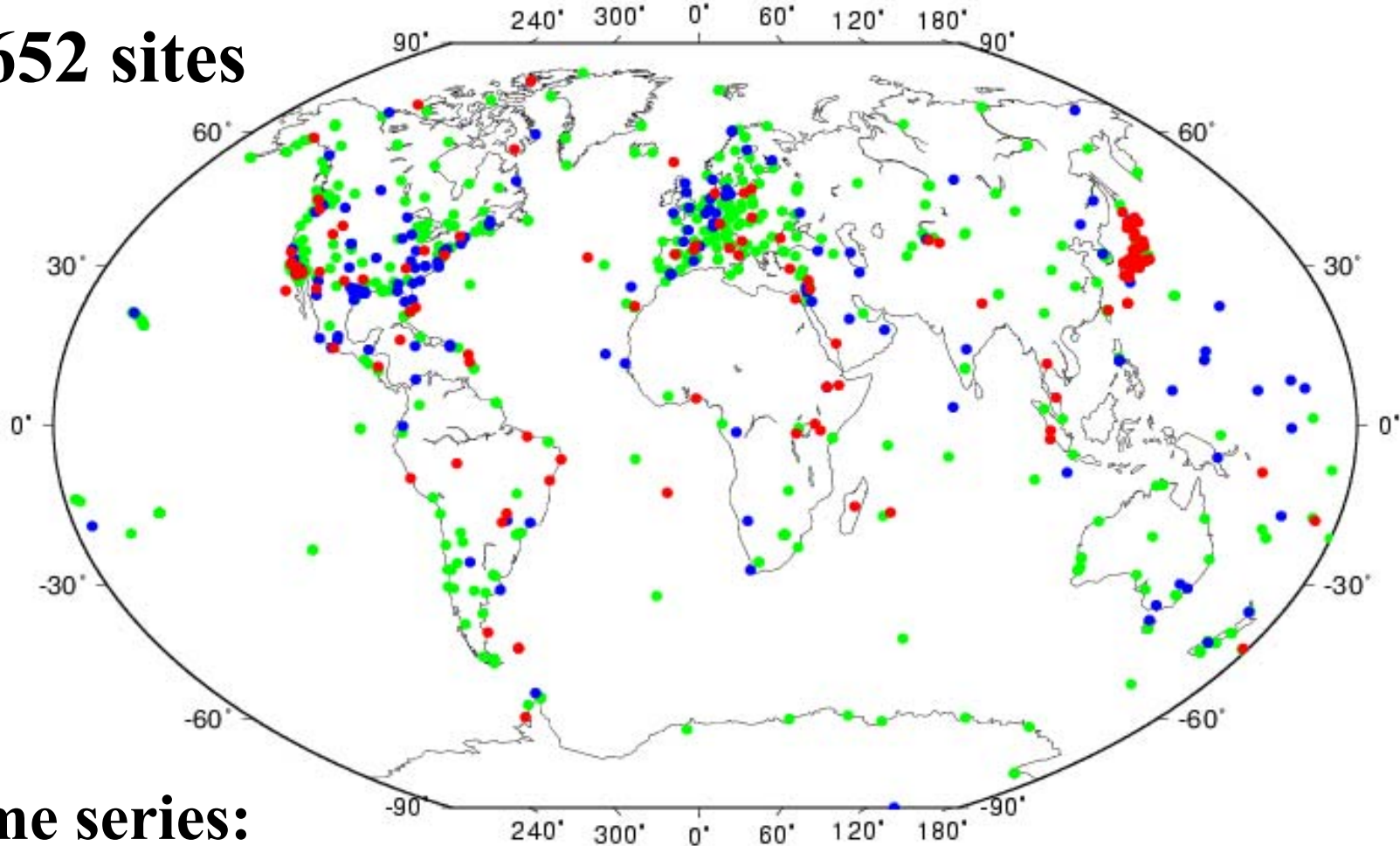
- **backups**

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)