The ITRF
Three decades of research and development, usages and applications

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Outline

- ITRF genesis, continuous development & improvement
- ITRF & science applications
- ITRF2014 and its innovation: modeling of nonlinear station motions : seasonal signals & post-seismic deformation
- Alignment of national, regional & global TRFs to the ITRF using IGS products
- Next steps : preparation for ITRF2020

ITRF: Three decades of research and development

Within the International Earth Rotation and Reference Systems Service (IERS)

The ITRF adventure

- 1985: BTS84: First combined reference frame from space geodesy: (Boucher & Altamimi, 1985):
- 1988: Creation of the IERS ==> ITRF88
- 1992: GPS in the ITRF (ITRF91): 21 sites
- 1994 : Birth of IGS & SINEX format
- 1995: DORIS in the ITRF (ITRF94): 52 Sites
- 1998, 1999, 2003: creation of ILRS, IVS and IDS
- 2000: Reorganization of the IERS ==> ITRS Center, including ITRS CCs (DGFI, followed lately by JPL)
- 1980 – now: 3 generations of combination software packages
- 1995: start of CATREF software
- 13 ITRF versions: ITRF88 up to ITRF2014
- 2016: ITRF2014 published: modelling nonlinear variations
- Up to 2021: Preparation for ITRF2020

ITRF built on Co-location sites

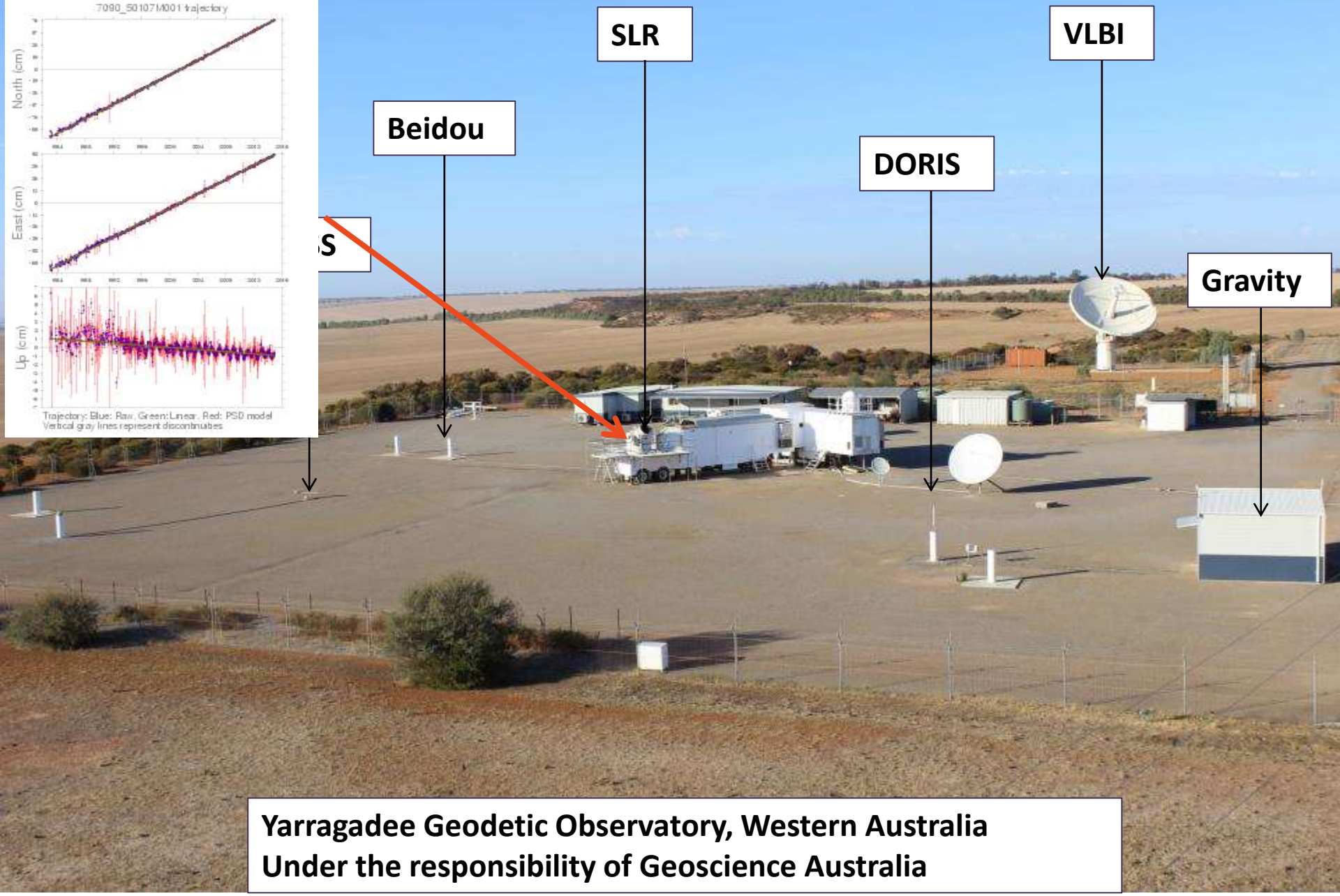
- Site where two or more instruments are operating
- Surveyed in three dimensions, using classical or GPS geodesy

SLR/LLR

VLBI

GNSS

DORIS



Yarragadee Geodetic Observatory, Western Australia
Under the responsibility of Geoscience Australia

Why Multiple Techniques for the ITRF ?

- **VLBI & SLR:**
  - **Fundamental for an accurate definition of the ITRF physical parameters/properties**
  - **SLR determines Earth Center of Mass ==> ITRF origin**
  - **SLR & VLBI define the ITRF scale**
  - **VLBI places the Earth in space ==> Link to the ICRF**
  - **But their ground networks are poorly distributed and in danger of degradation**

- **DORIS: disseminates ITRF in satellite orbit determination**

- **GNSS:**
  - **Ensures the link between SLR, VLBI & DORIS networks**
  - **Is the tool today to access the global ITRF by the regions and nations using IGS products**

ITRF Construction

DORIS
GPS
SLR
VLBI
Time series stacking

Step 1

Long-term Solutions

DORIS
GPS
SLR
VLBI
X V, EOPs

Combination

Step 2

Local ties

Velocity equality

at co-location sites

ITRF
X V, EOPs

ITRF Specifications:
Origin: SLR
Scale: SLR & VLBI
Orientation: Alignment to previous ITRF

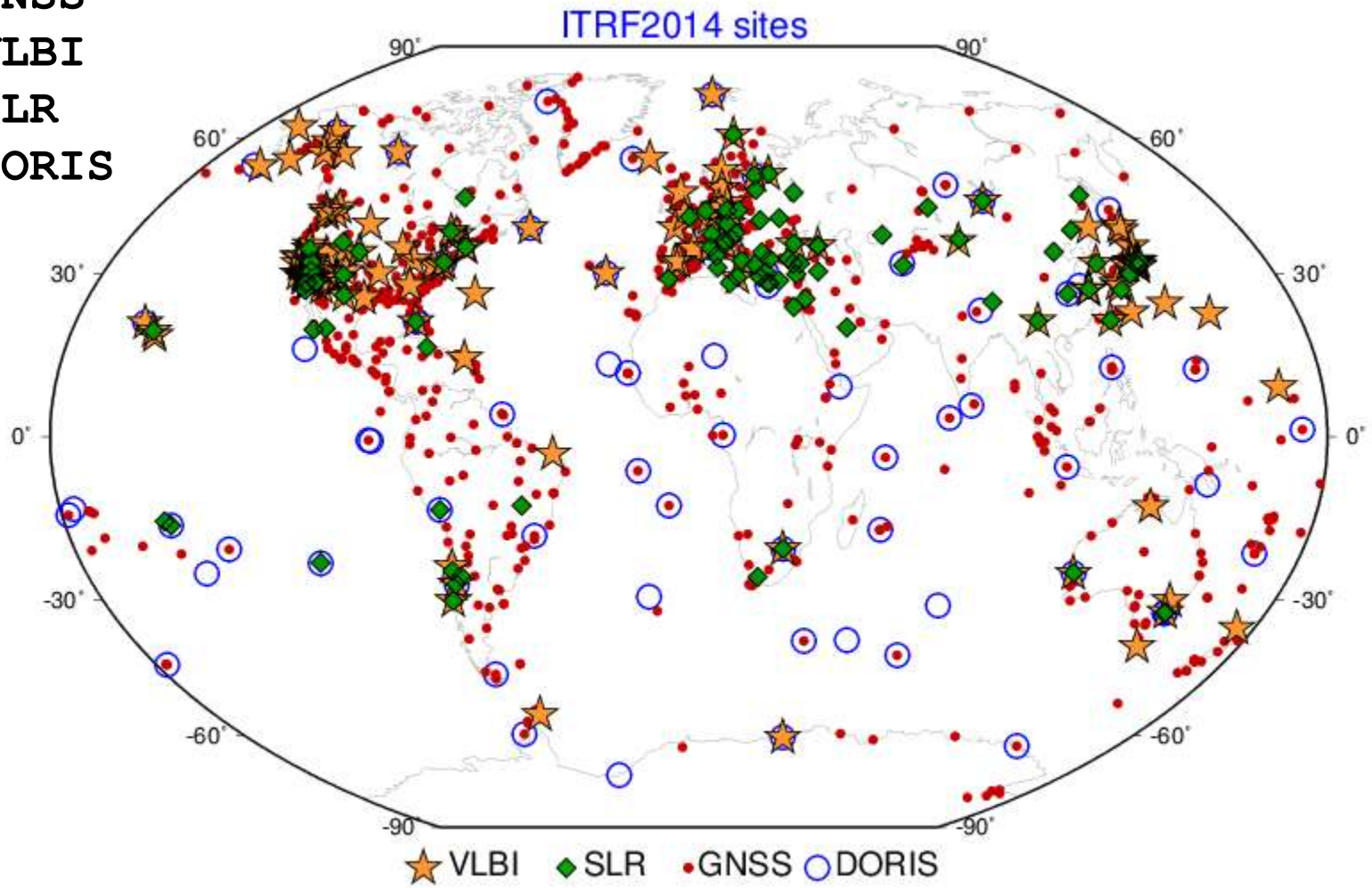
Examples of Technique systematic errors

- DORIS: mis-modelling of the solar radiation pressure ==> inaccurate determination of the geocenter components
- GNSS have multiple weaknesses in recovering the Earth center of mass position and the TRF scale, in the absence of satellite metadata
- SLR range biases have significant impact on the TRF scale
- VLBI signal path variations caused by antenna gravitational deformation ==> impact on the TRF scale

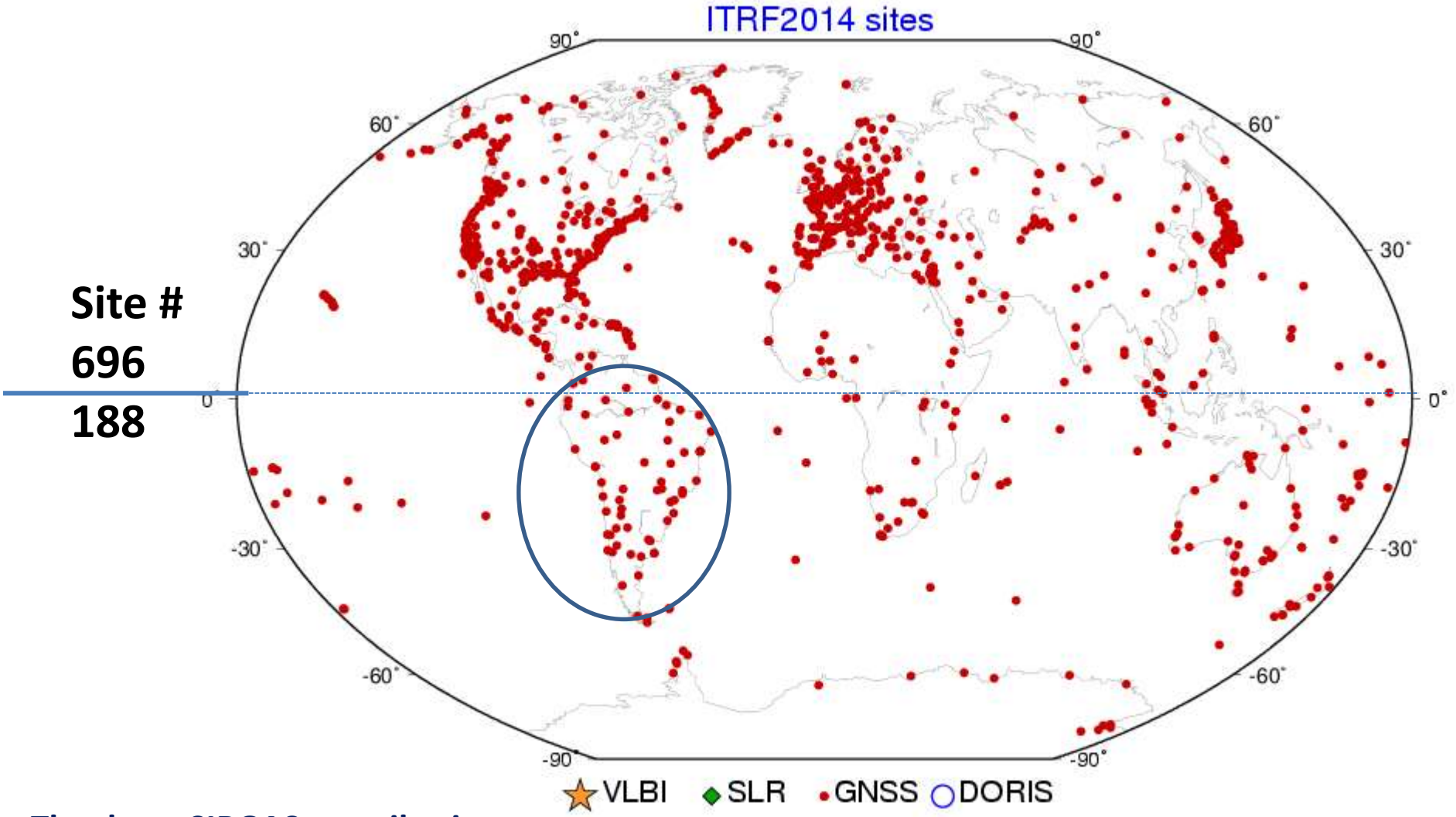
ITRF2014 Sites

Sites per technique:

884 GNSS
124 VLBI
96 SLR
71 DORIS



ITRF2014: GNSS



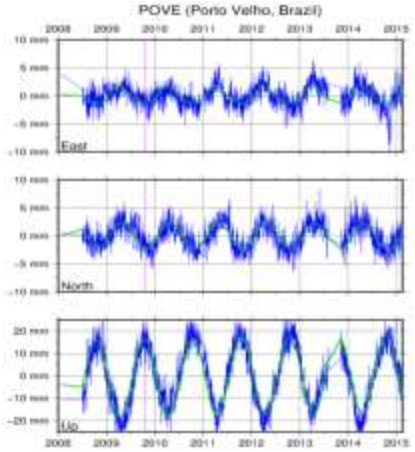
Site #

696

188

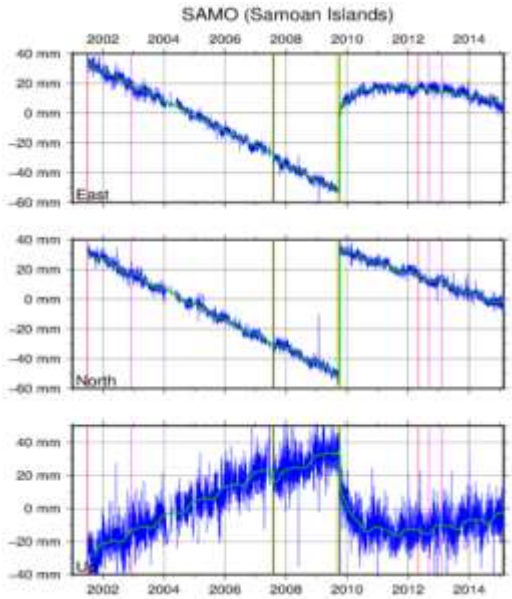
Thanks to SIRGAS contribution

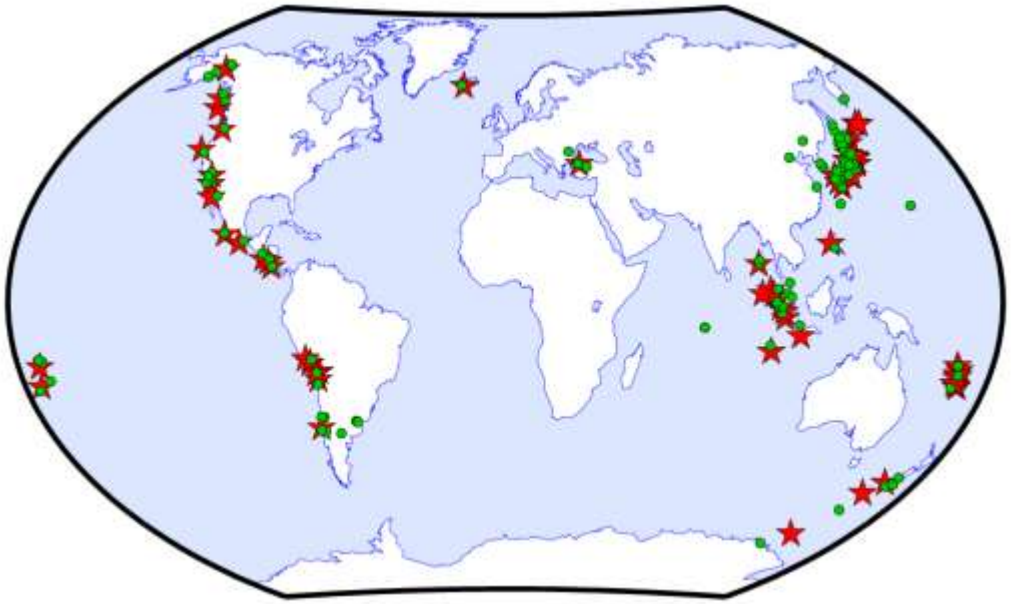
ITRF2014: Modelling nonlinear station motions



- Position time series of all stations exhibit periodic signals

- More than 100 sites are subject to Post-Seismic Deformation due to major earthquakes





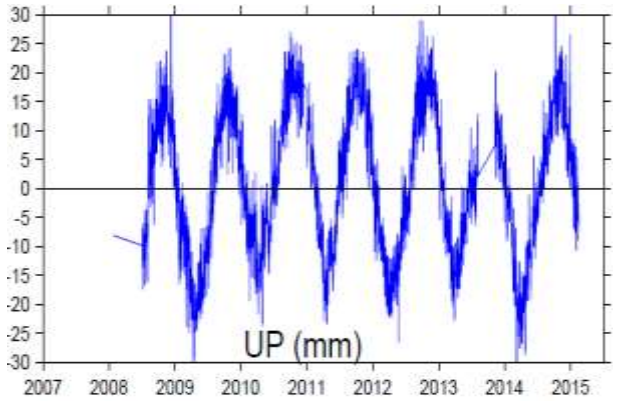
Red Stars: EQ Epicenters (58)

Green circles: ITRF2014 sites (117)

Precisely modeling the above leads to more robust secular frame and site velocities.

Periodic Signals

- **Loading effects:**
  - **Atmosphere**
  - **Terrestrial water (Hydrology)**
  - **Ocean circulation**



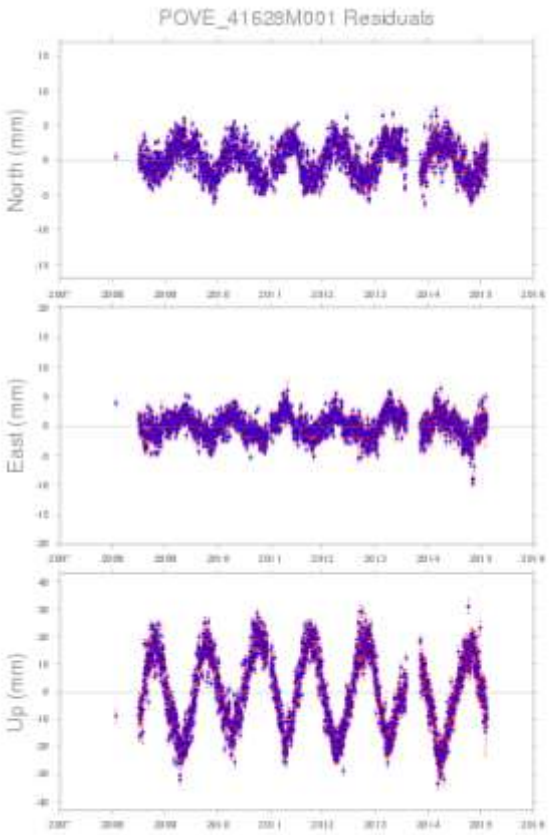
==> Annual, semi-annual, inter-annual, but also short periods (e.g. daily) variations

- **Technique systematic errors, e.g. GPS draconitic year (351.4 days) and its harmonics**

Periodic Signals

Annual & semi-annual terms estimated, using:

$$\Delta X_f = \sum_{i=1}^{n_f} a^i \cos(\omega_i t) + b^i \sin(\omega_i t)$$



ΔX_f **total sum of all frequencies**

n_f **number of frequencies**

$\omega_i = \frac{2\pi}{\tau_i}$

τ_i **period of the ith frequency**

==> 6 parameters per station & per frequency, i.e. a & b along each X, Y, Z axis.

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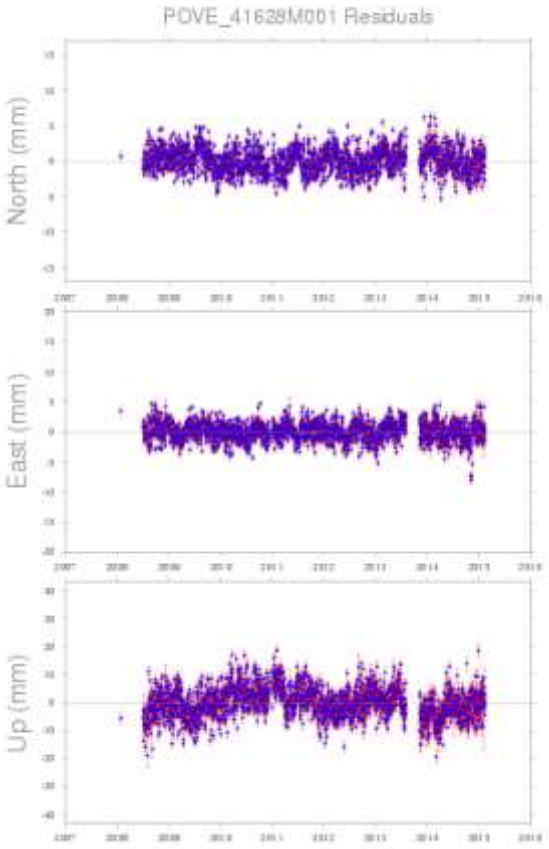

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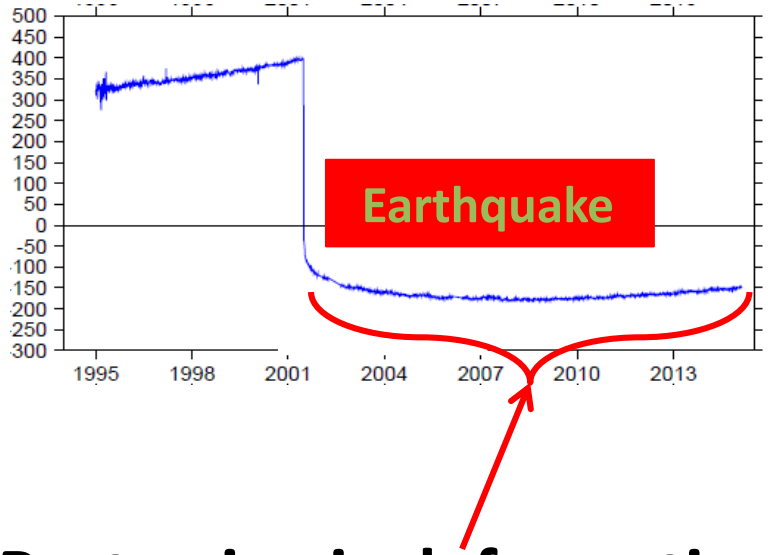
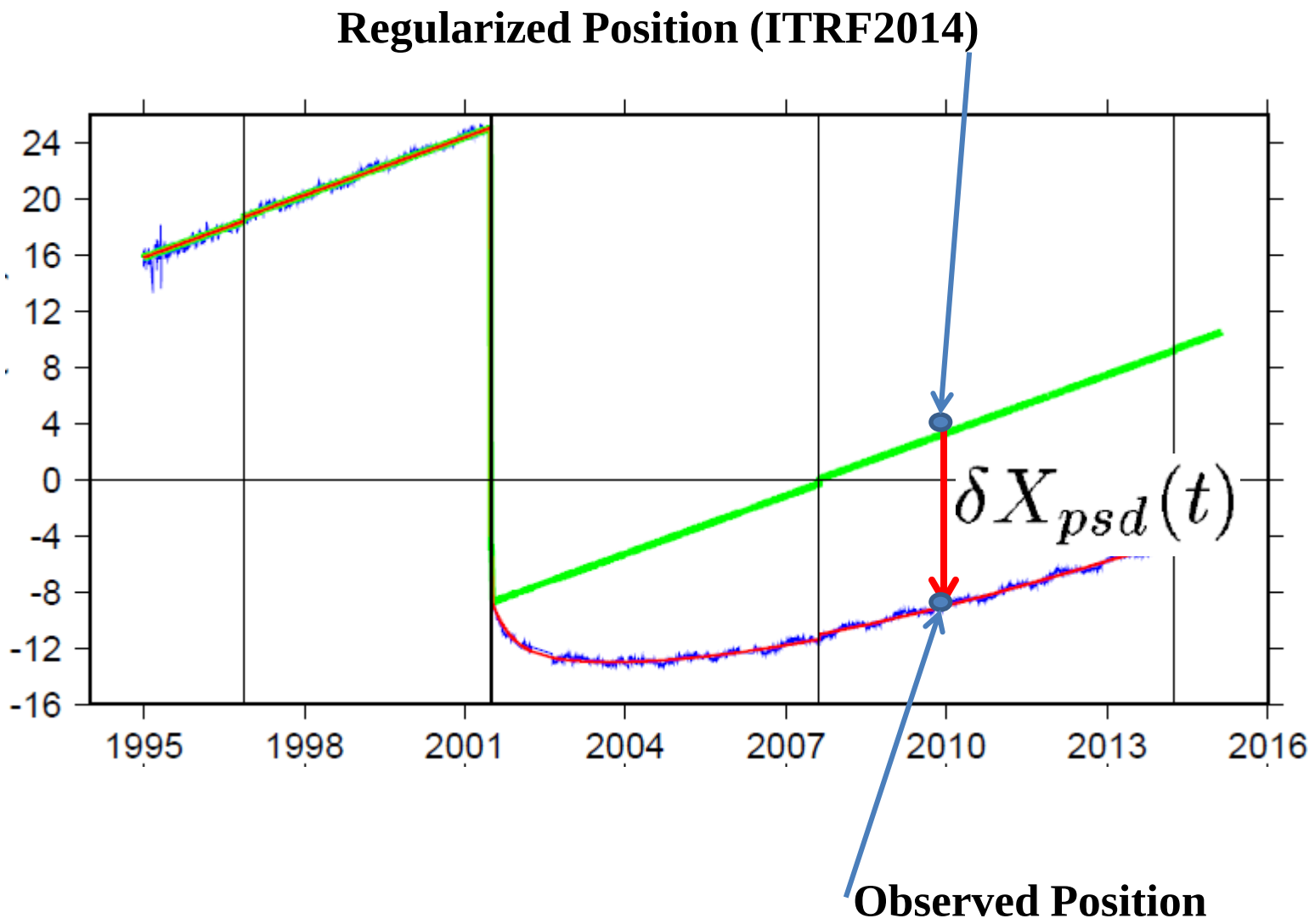
Post-Seismic Deformations

- **Fitting parametric models using GNSS/GPS data**
  - **at major GNSS/GPS Earthquake sites**
  - **Apply these models to the 3 other techniques at Co-location EQ sites**

- **Parametric models:**
  - **Logarithmic**
  - **Exponential**
  - **Log + Exp**
  - **Two Exp**



PSD Correction



How to use ITRF2014 PSD models ?

Regularized Position (ITRF2014)

$$X_{PSD}(t) = X(t_0) + \dot{X}(t - t_0) + \delta X_{PSD}(t)$$

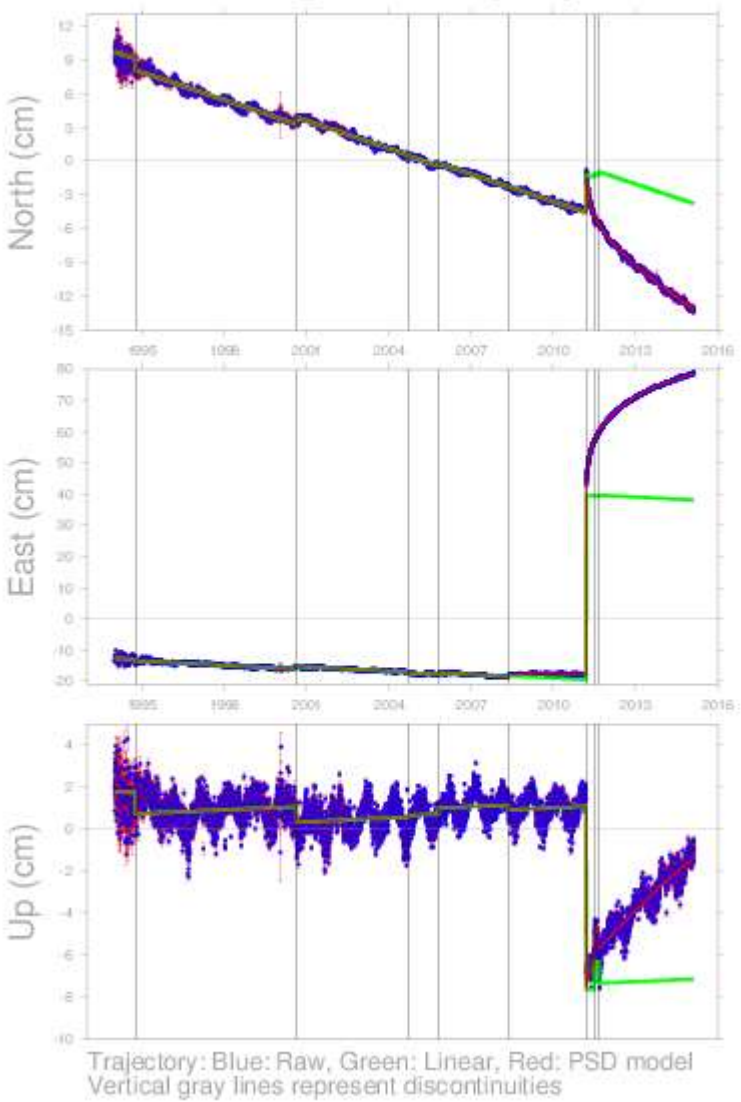
$$\delta L(t) = \sum_{i=1}^{n^l} A_i^l \log(1 + \frac{t - t_i^l}{\tau_i^l}) + \sum_{i=1}^{n^e} A_i^e (1 - \mathrm{e}^{-\frac{t - t_i^e}{\tau_i^e}})$$

Local Frame

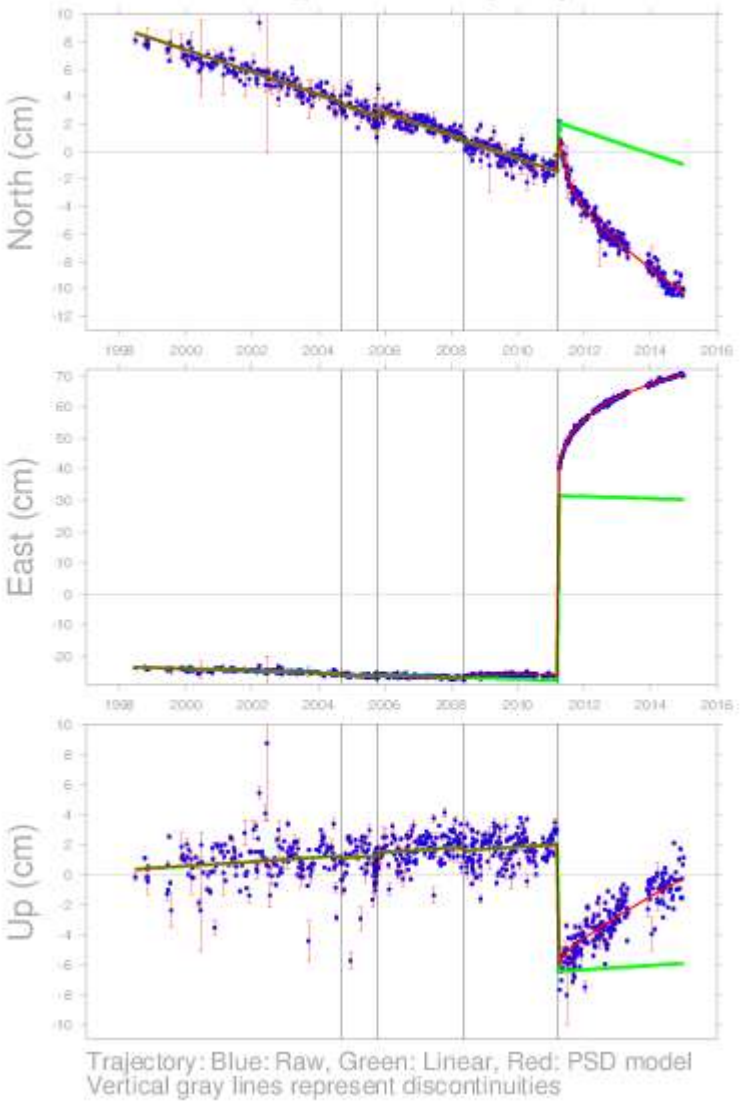
PSD Subroutines available at ITRF2014 Web site:
http://itrf.ign.fr/ITRF_solutions/2014/

Tsukuba (Japan) Trajectory

GPS

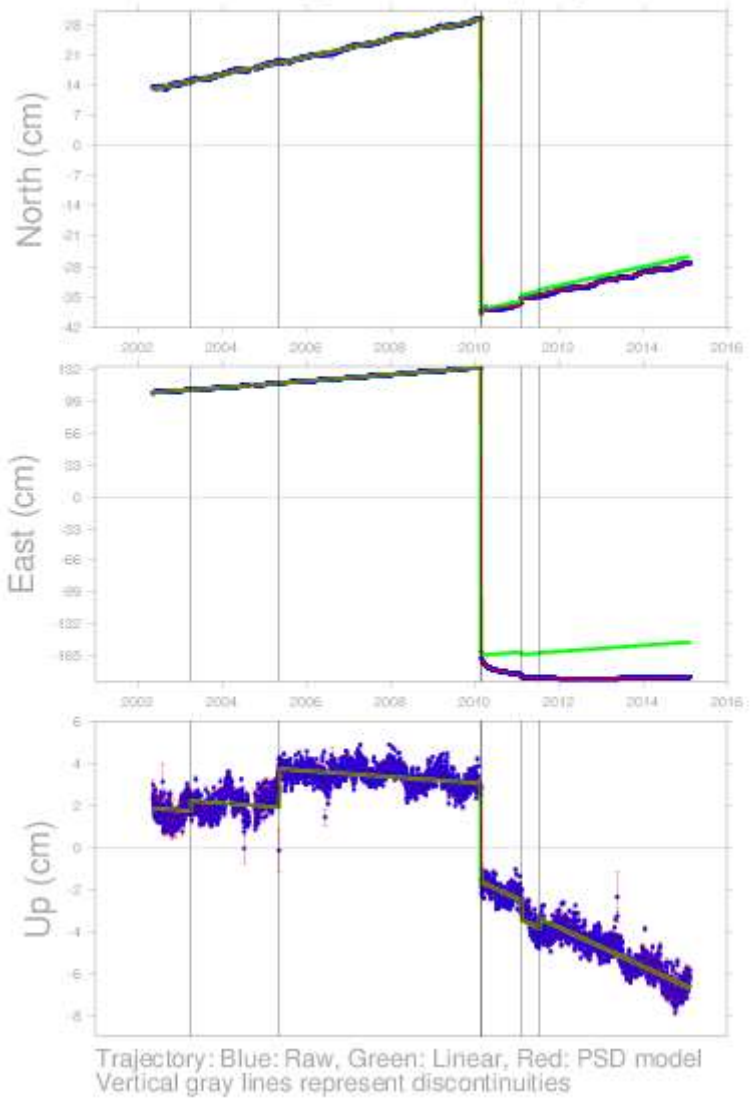


VLBI

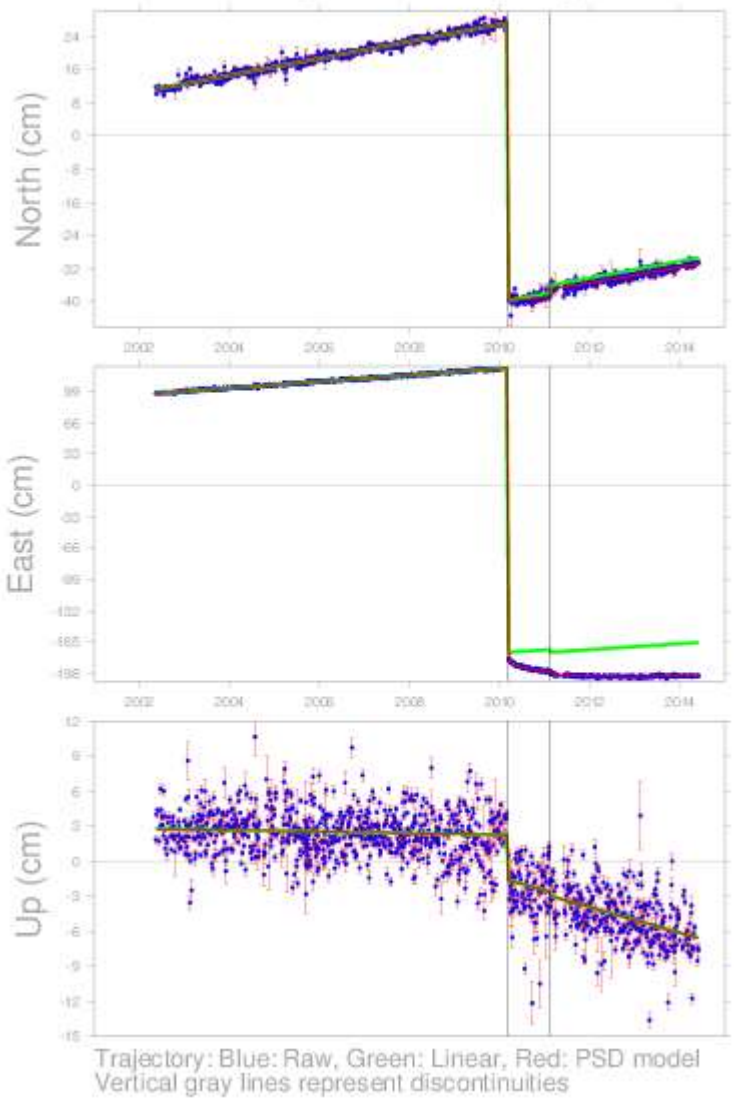


Concepcion (Chile) Trajectory

GPS

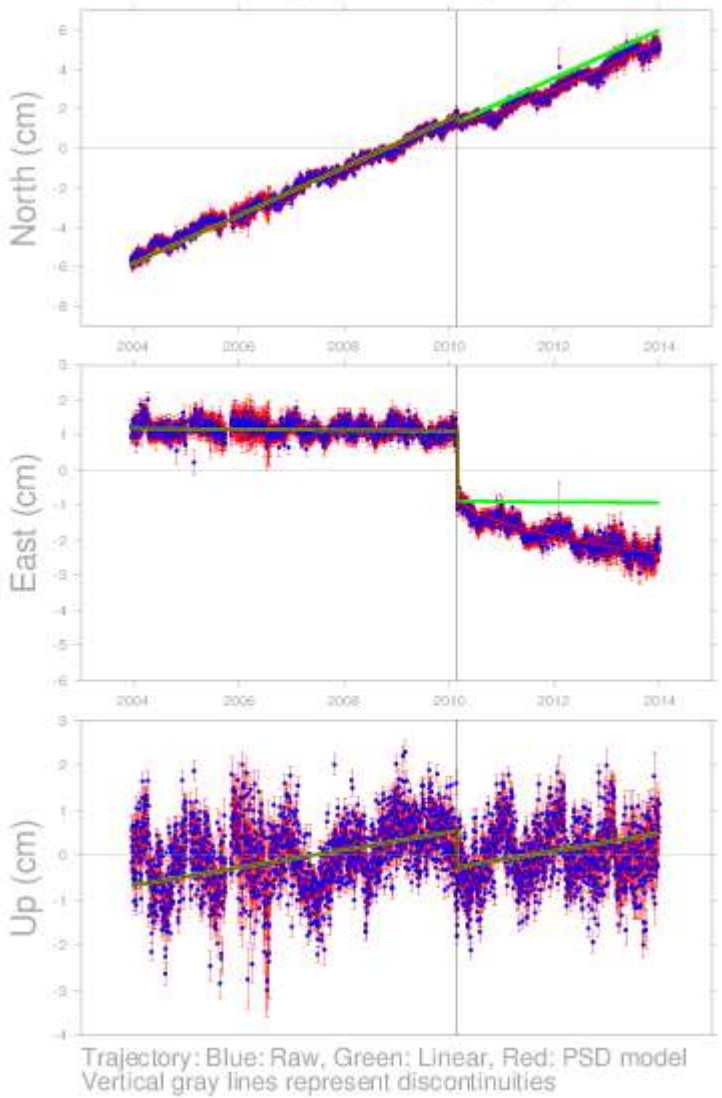


VLBI

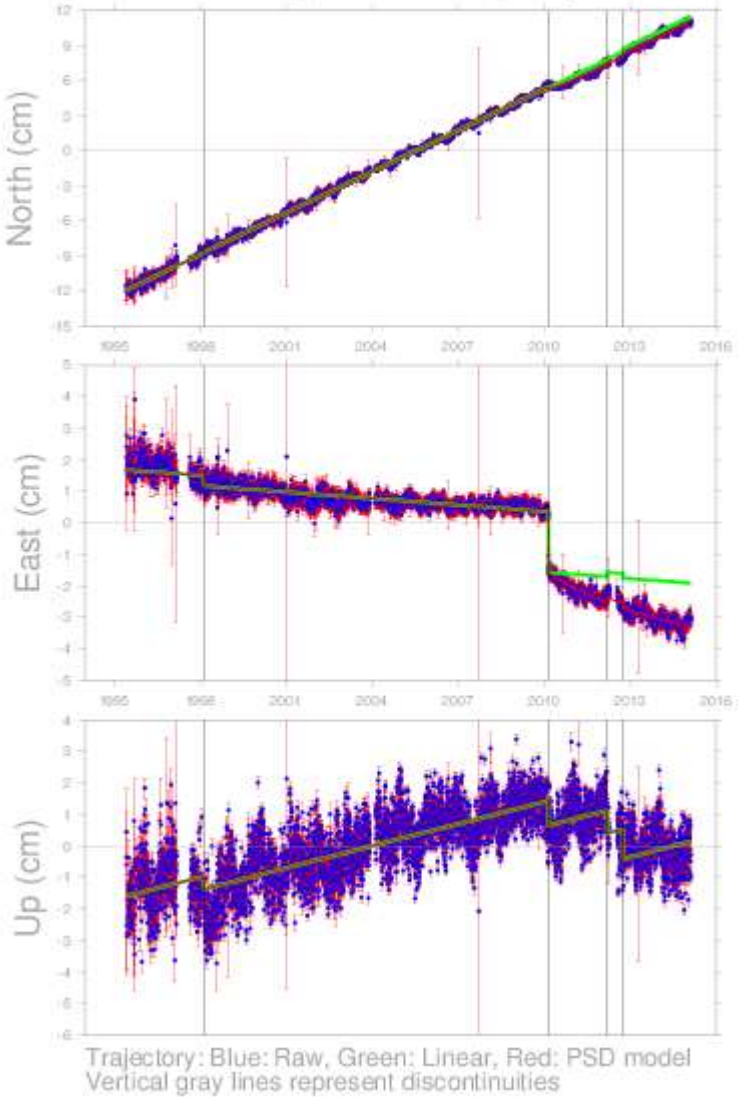


Buenos Aires & La Plata (Argentina) Trajectories

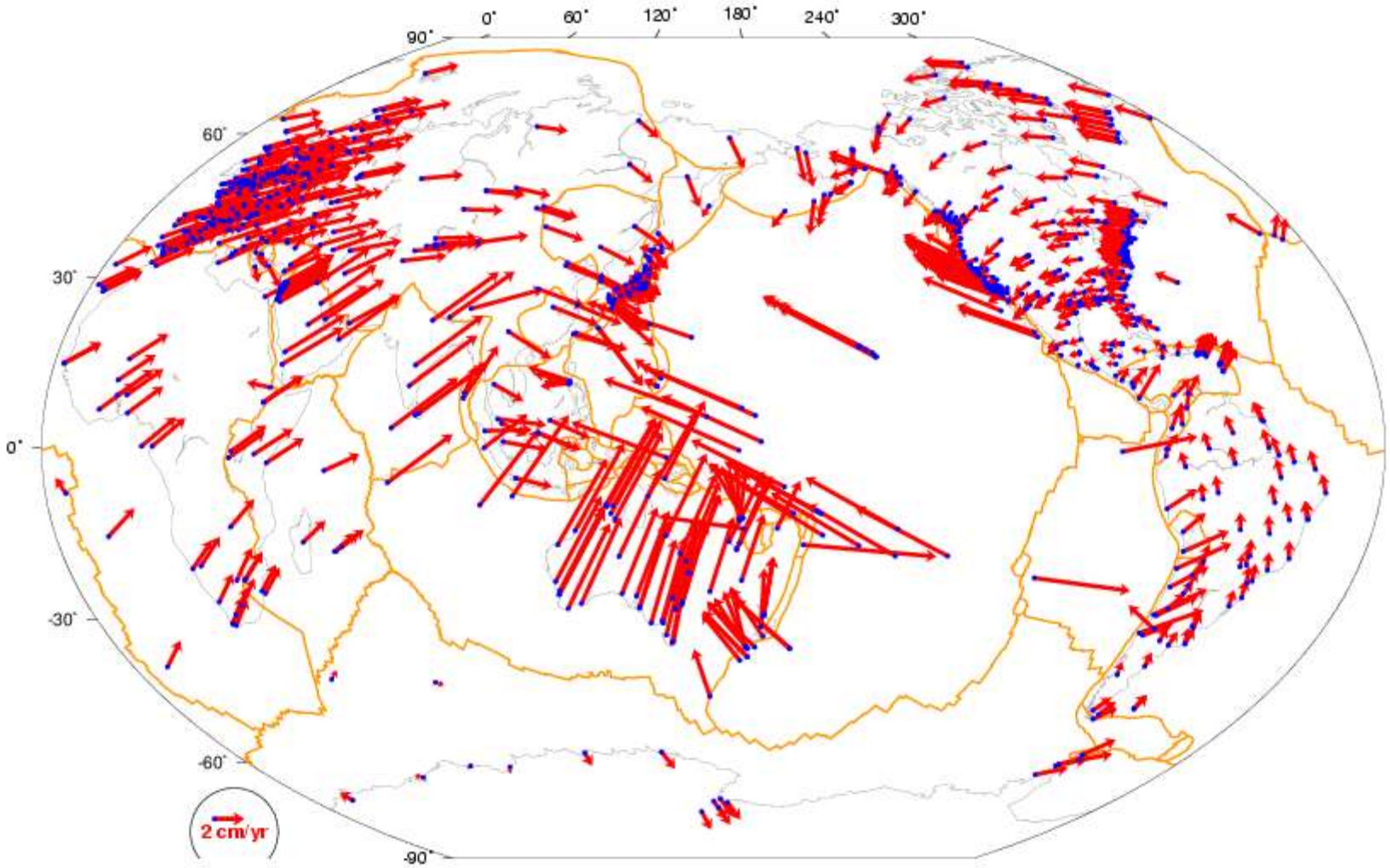
IGM1



LPGS



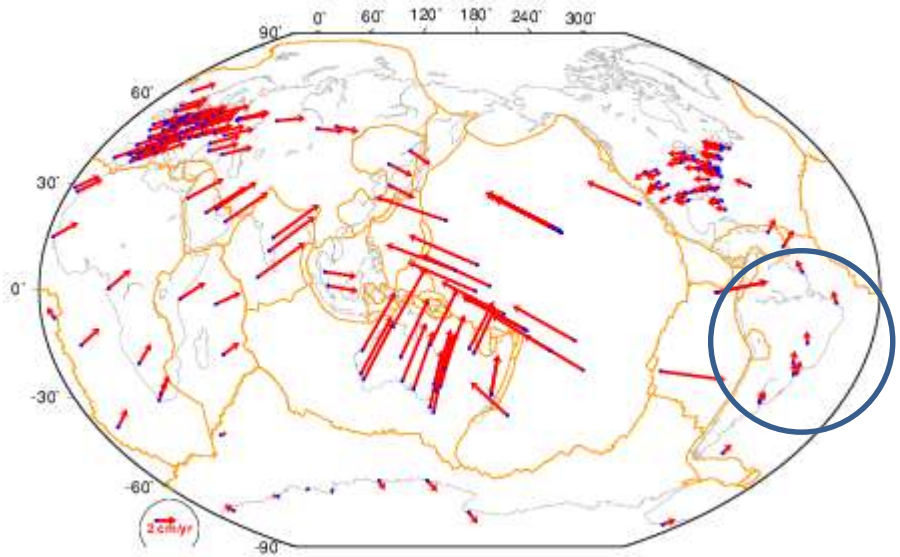
ITRF2014: Horizontal velocity field



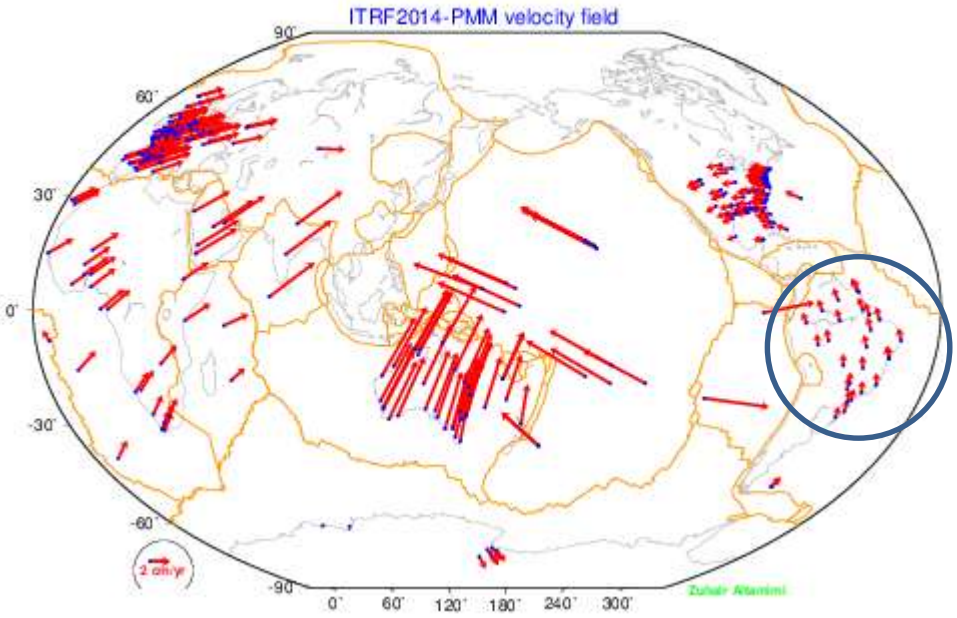
==> ITRF2014 Plate Motion Model

ITRF Plate Motion Models

ITRF2008

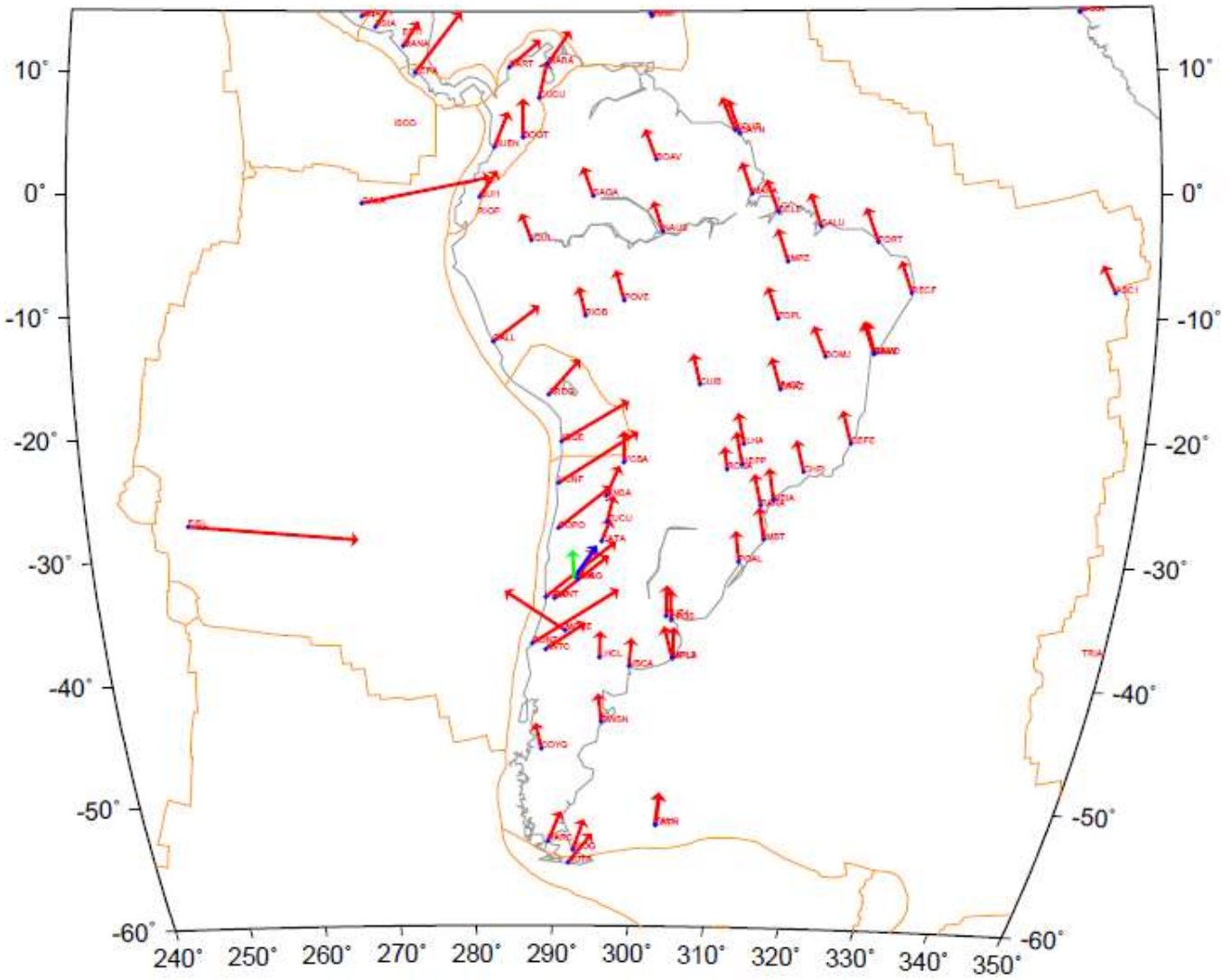


ITRF2014



South America: 3 times more sites in ITRF2014, thanks to SIRGAS contribution

SOAM velocities in ITRF2014

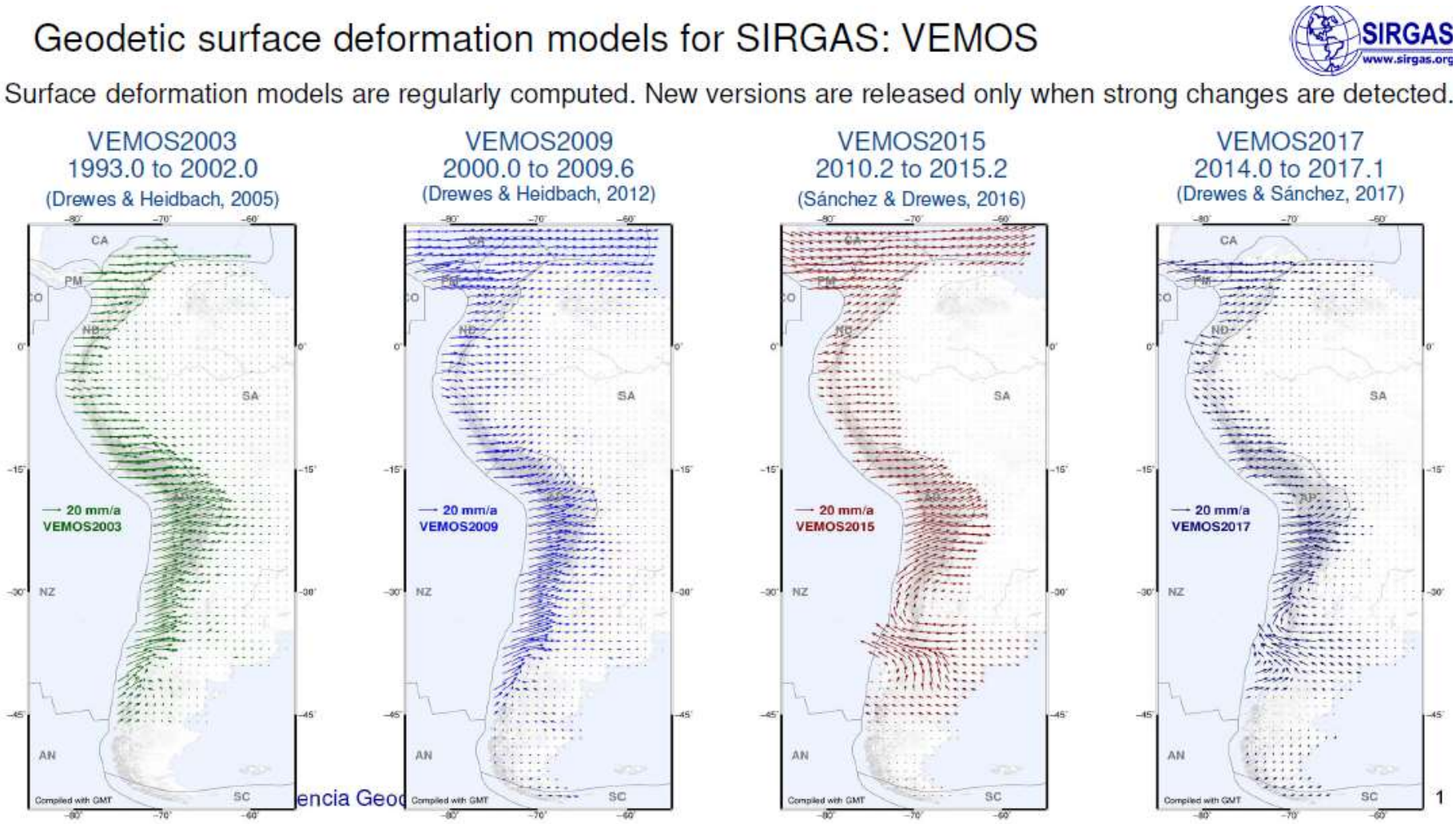


San Juan:

Blue: SLR estimate

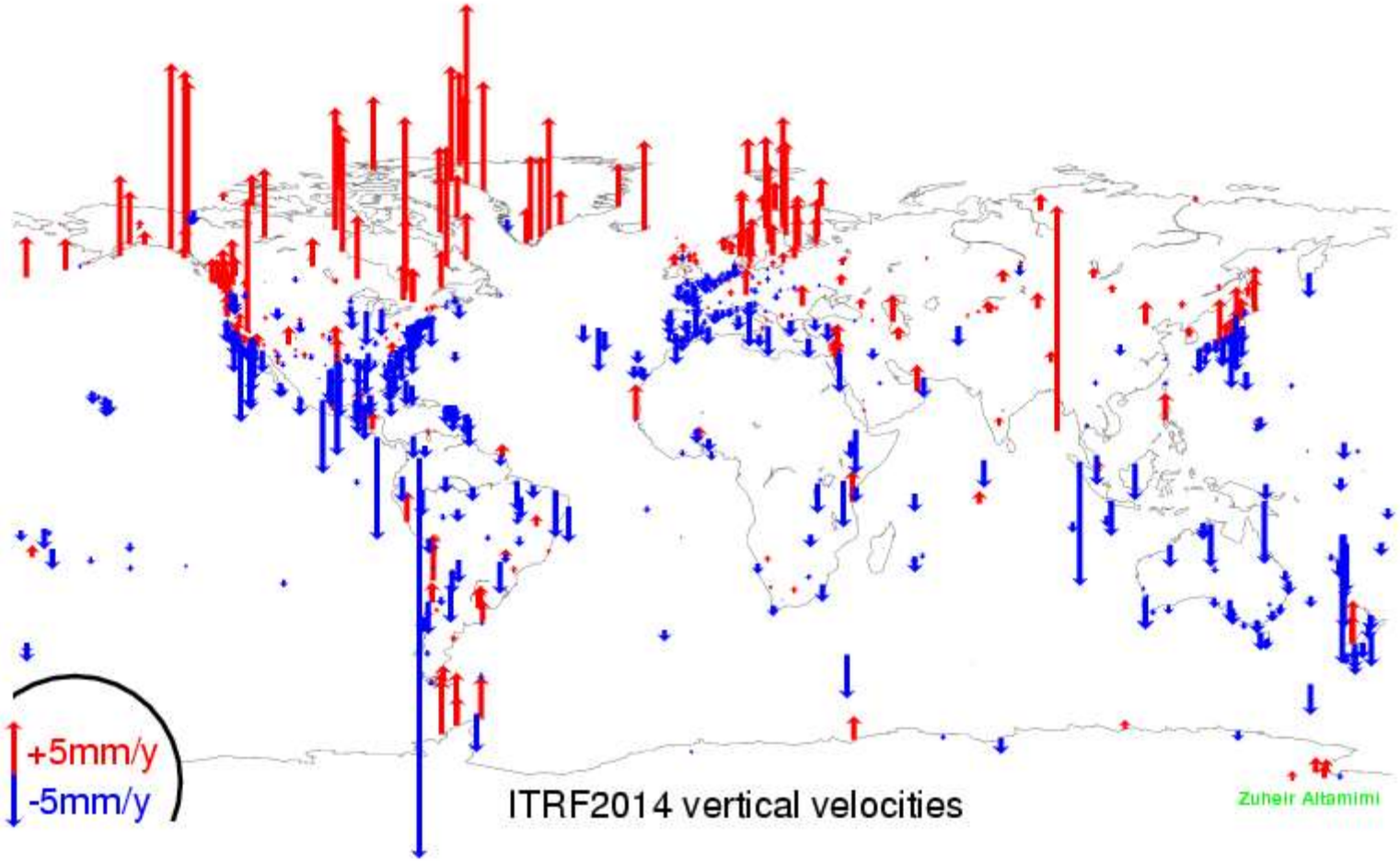
Green: ITRF2014-PMM prediction

Geodetic surface deformation models for SIRGAS: VEMOS (*)

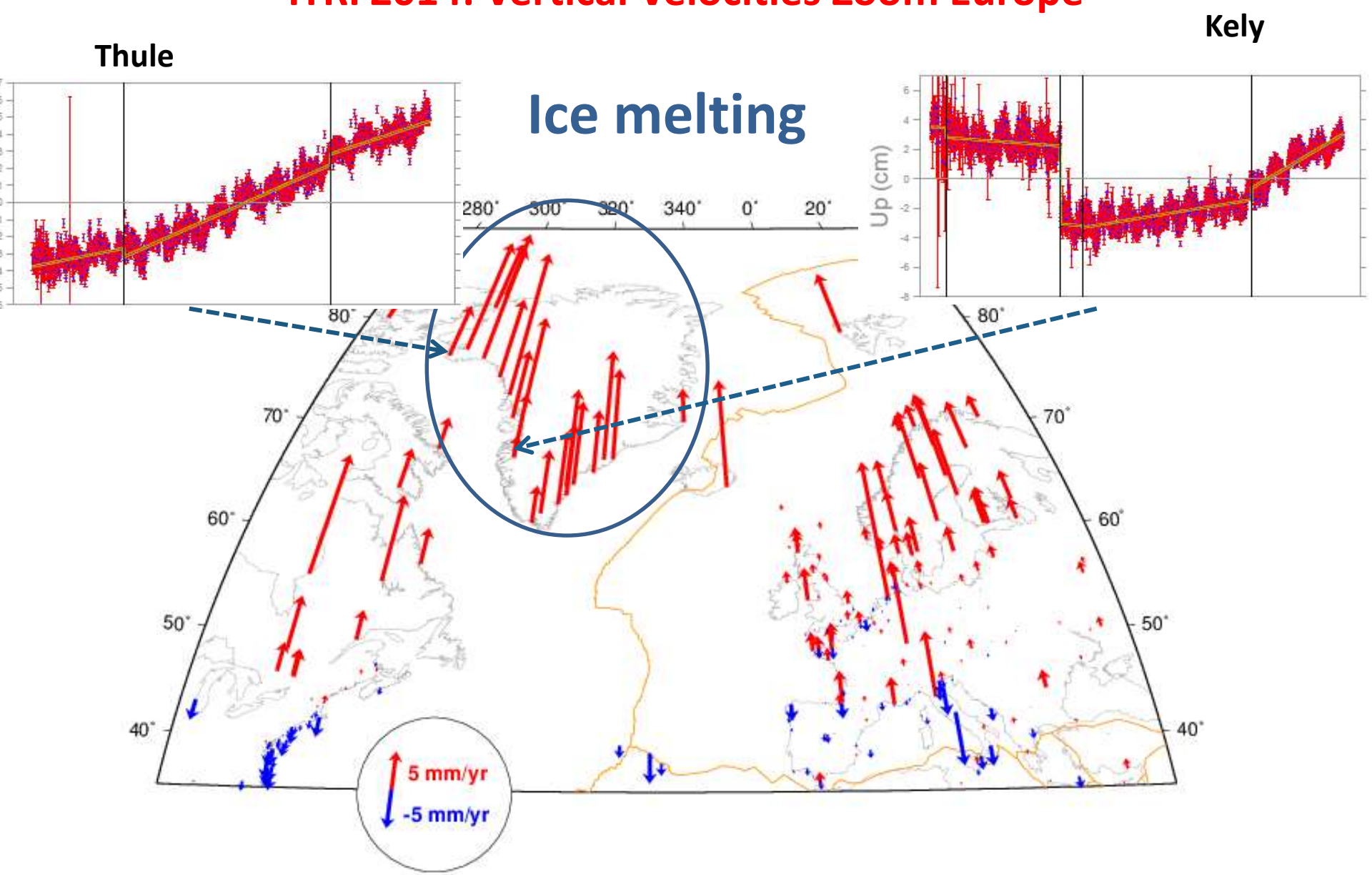


(*) W. Martínez et al., IUGGI 2019

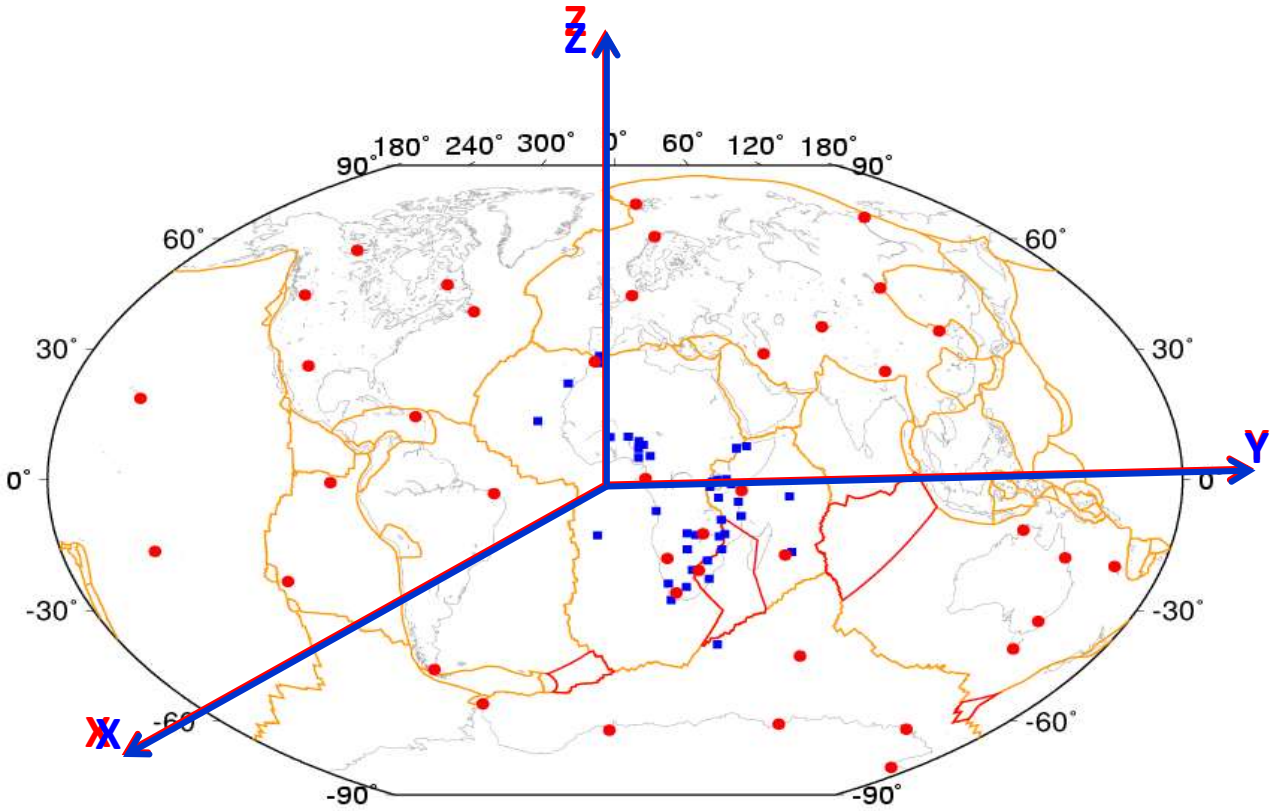
ITRF2014: Vertical velocity field



ITRF2014: Vertical Velocities Zoom Europe



Alignment to the ITRF



Alignment to the ITRF using the IGS products (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, globally distributed, 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

Alignment to the ITRF using the IGS products (2/2)

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

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

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

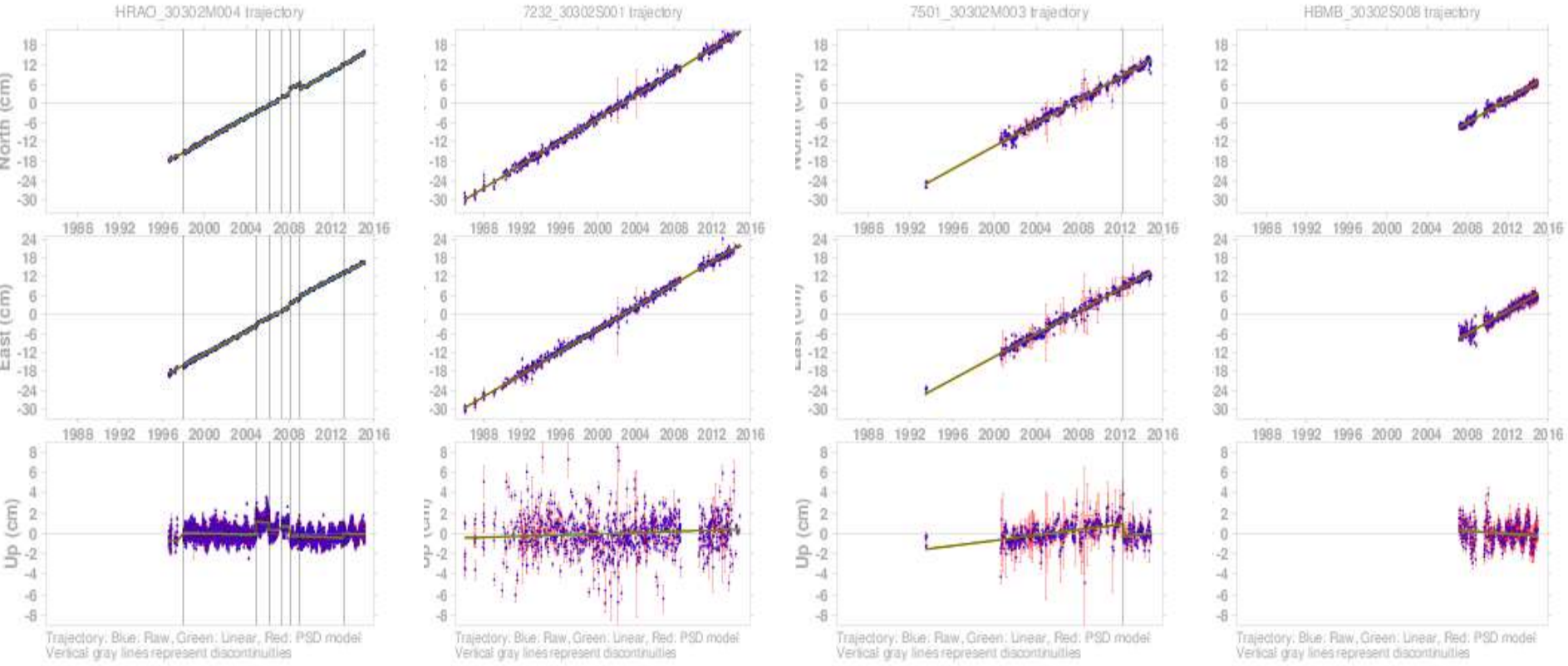
- Compare your estimated ITRF station positions to official ITRF values :
  - Transformation parameters should be zeros
  - No outliers: residuals smaller than a certain threshold

Preparation for ITRF2020 (1/2)

- ITRF2020 ==> Toward improving the ITRF
- At the techniques level: a number of effects and model updates to be considered, e.g.:
  - SLR range biases
  - VLBI antenna deformation
  - DORIS-specific models, e.g. SRP modelling
  - A number of model updates for GNSS
  - All techniques: Improve data processing to reduce the noise level (see illustration next)

Velocities, Periodic signals, Discontinuities and Noise level

GPS **VLBI** **SLR** **DORIS**



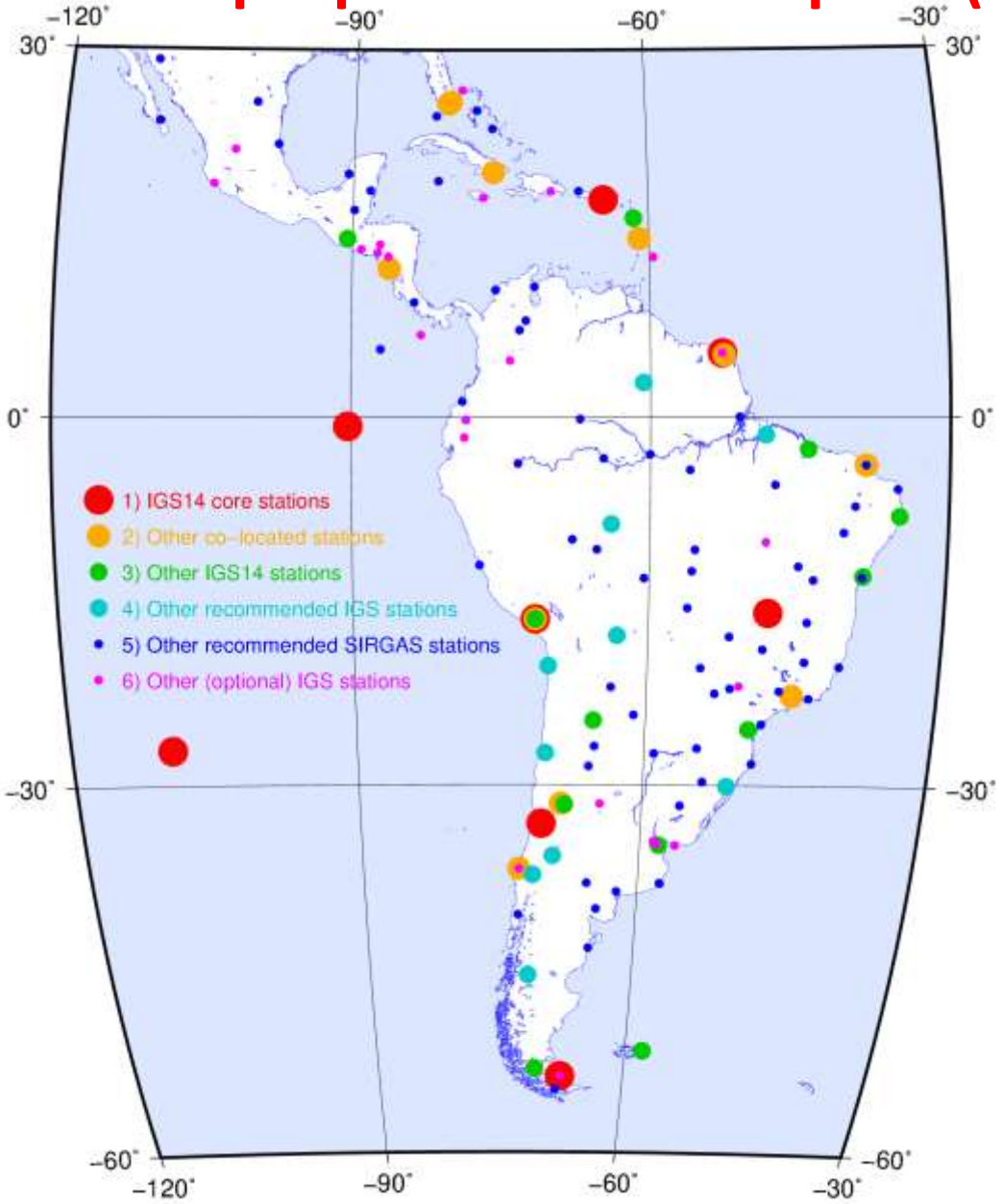
Hartebeesthoek: **at an important co-location site**

Preparation for ITRF2020 (2/2)

- **ITRF2020 ==> Toward improving the ITRF**

- **<u>At the combination level</u>:**
  - **Track down the VLBI & SLR scale discrepancy**
  - **Isolate, understand & handle technique discrepancies in seasonal signals at co-location sites**
  - **Provide annual & semi annual signals for all techniques in the CM frame**
  - **Provide accurate annual and semi-annual geocenter motion models for specific applications, e.g. POD**

SIRGAS stations proposed for IGS repro3 (ITRF2020)



Conclusion

- More than 3 decades of R&D to improve the ITRF

- The most precise/accurate reference frame available today
- Became essential with the increase of GPS/GNSS networks and their science & societal applications

- Accessible everywhere & anywhere thanks to IGS products

- Most of current VLBI and SLR systems are old generation

- Next steps:
  - Need to mitigate technique systematic errors in preparation for ITRF2020
  - Other technical improvements at the combination level
- SIRGAS Contribution to IGS Repro 3 (ITRF2020) is essential.