Reference Frames for science and society and the fundamental contribution of Satellite Laser Ranging to the ITRF

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Key Points

- **Reference Frames for science and societal applications**

- **The UN-GGIM Initiative: a great opportunity for global geodesy**

- **SLR contribution to the ITRF**
  - **SLR current network (Weakness!)**
  - **Center of Mass – ITRF origin (Strength)**
  - **Geocenter Motion (Strength)**
  - **ITRF Scale, together with VLBI (Still work to do)**

- **With some illustrations from ITRF2014 results**

The reference frame & Earth science applications

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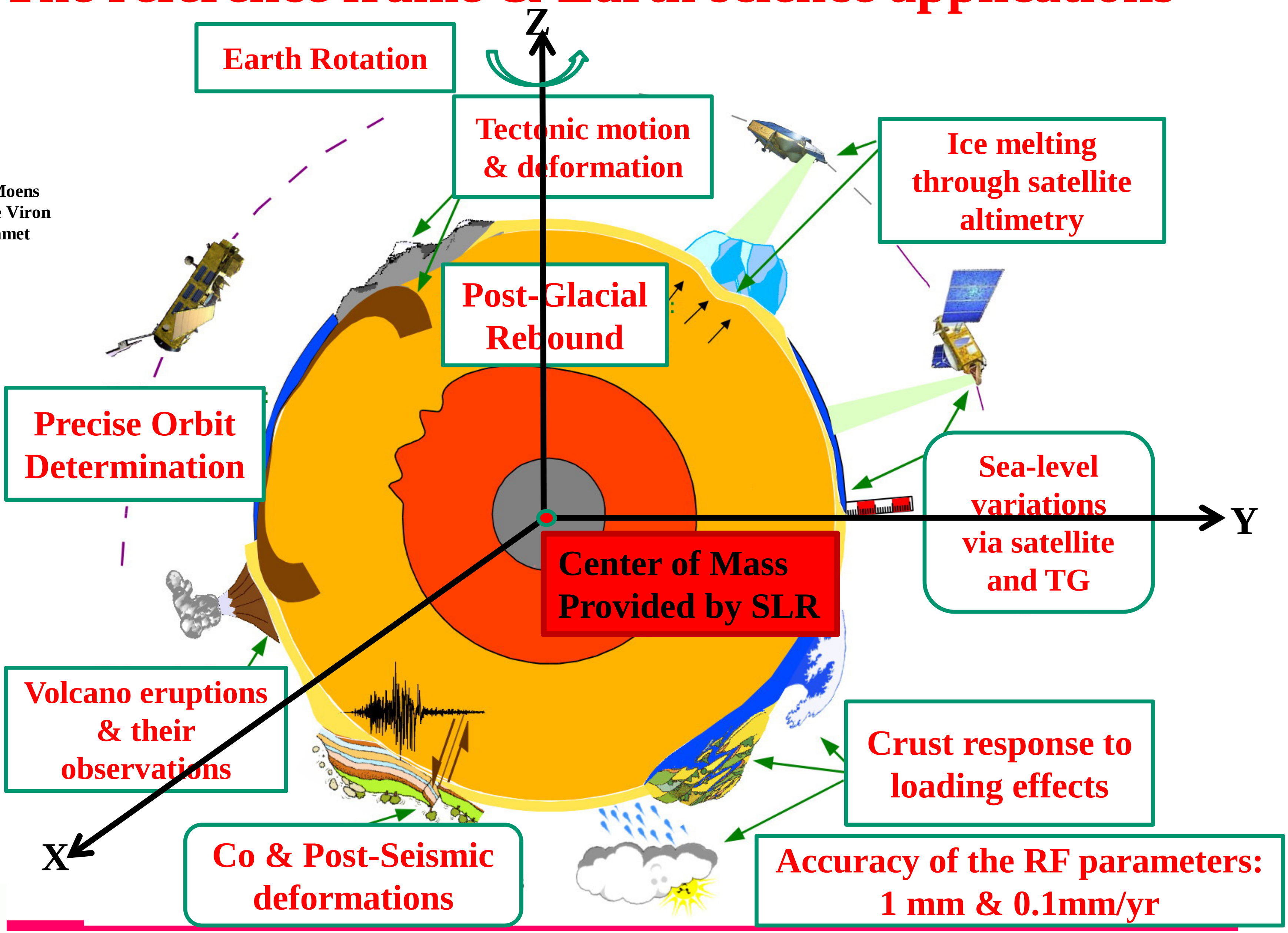

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Reference frames and Societal Applications

- **There are plenty of societal applications, mainly:**
  - **Positioning (location-based) applications** (navigation, surveying, precision agriculture, land & territory management, boundary dispute, cartography, cadaster…)
  - **National & Continental Reference Frames**

- **The UN GA resolution (February 26, 2015) on the:**

Global Geodetic Reference Frame for Sustainable Development

- **UN-GGIM sub-committee on Geodesy**
- **In response to a UN geodetic questionnaire:**

80% of the responding countries use the International Terrestrial Reference Frame (ITRF) to underpin their national coordinate systems

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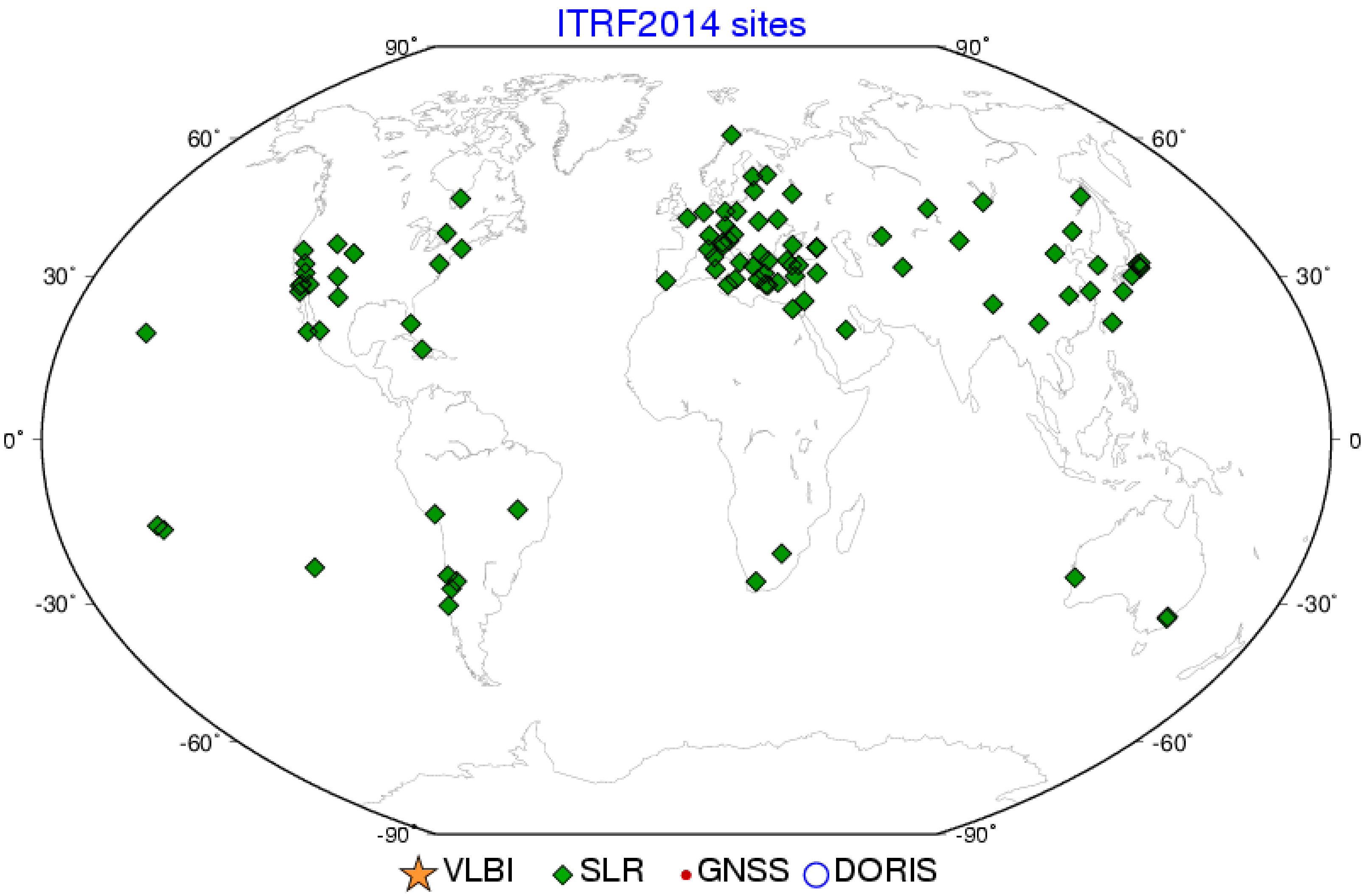
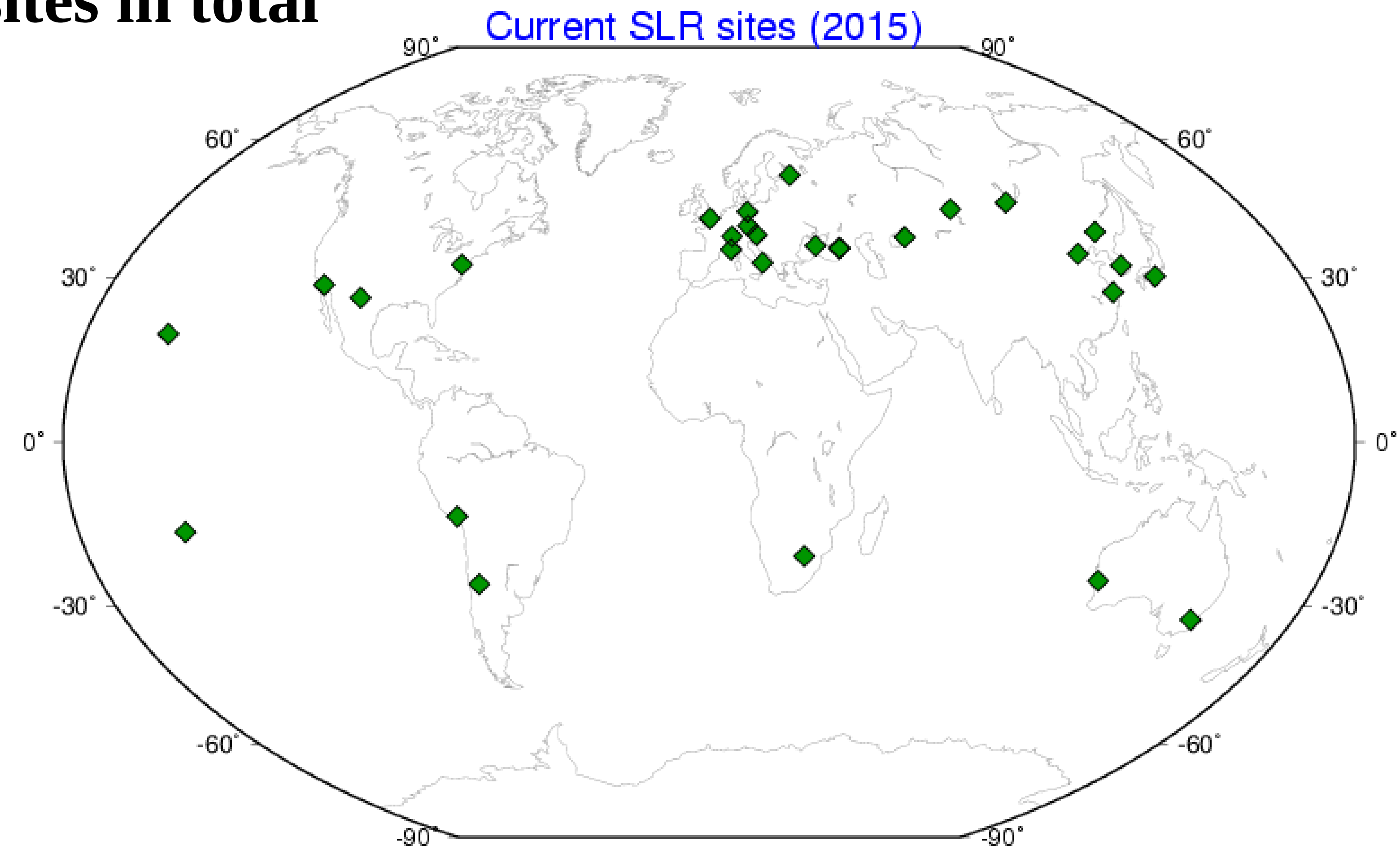
SLR Contribution to the ITRF with some results from ITRF2014

ITRF2014 Network : SLR

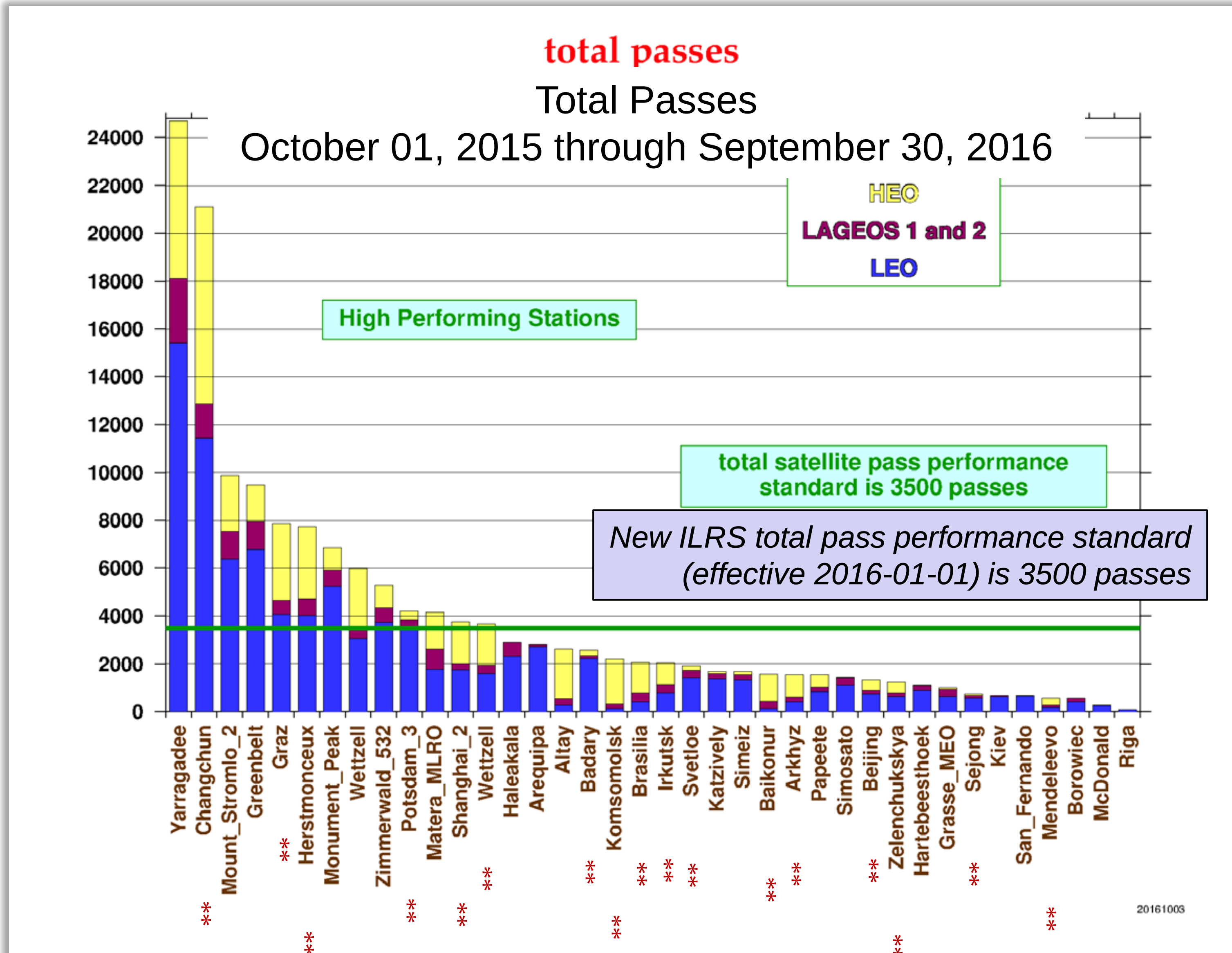


Current SLR network

33 sites in total

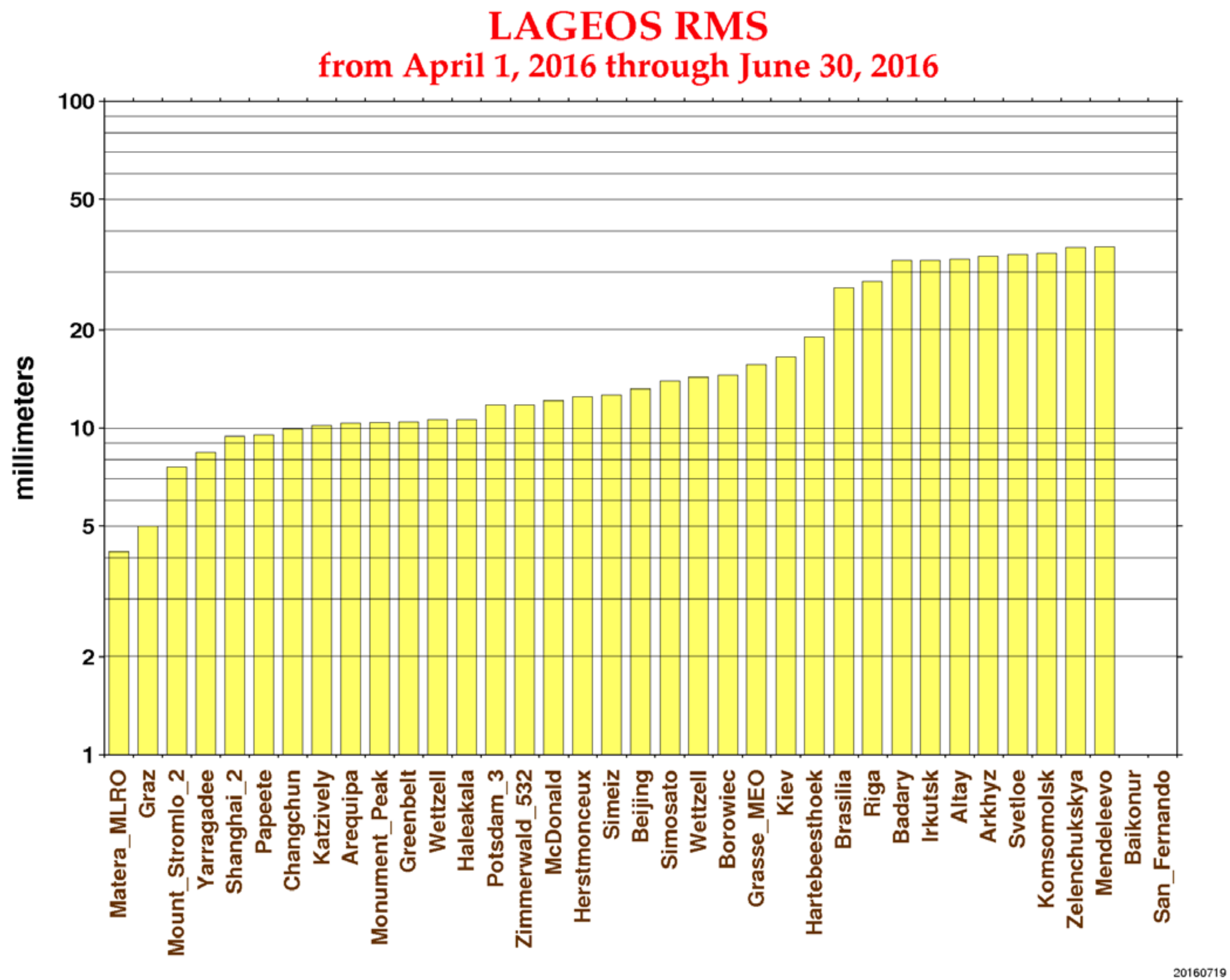


Network performance (1/2)



Courtesy Mike Pearlman

Network performance (2/2)

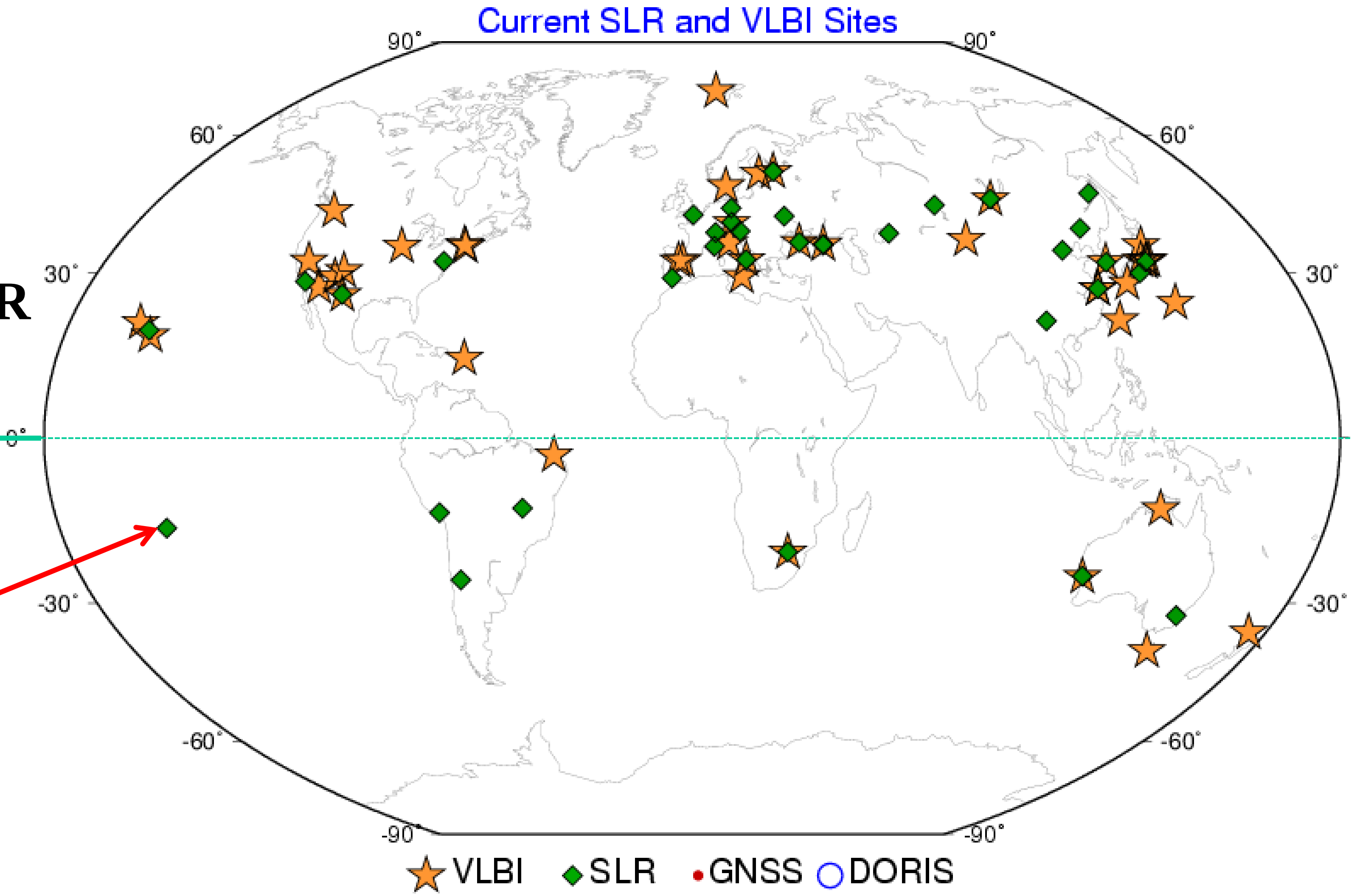


Credit: ILRS Website

VLBI & SLR sites observed in 2015

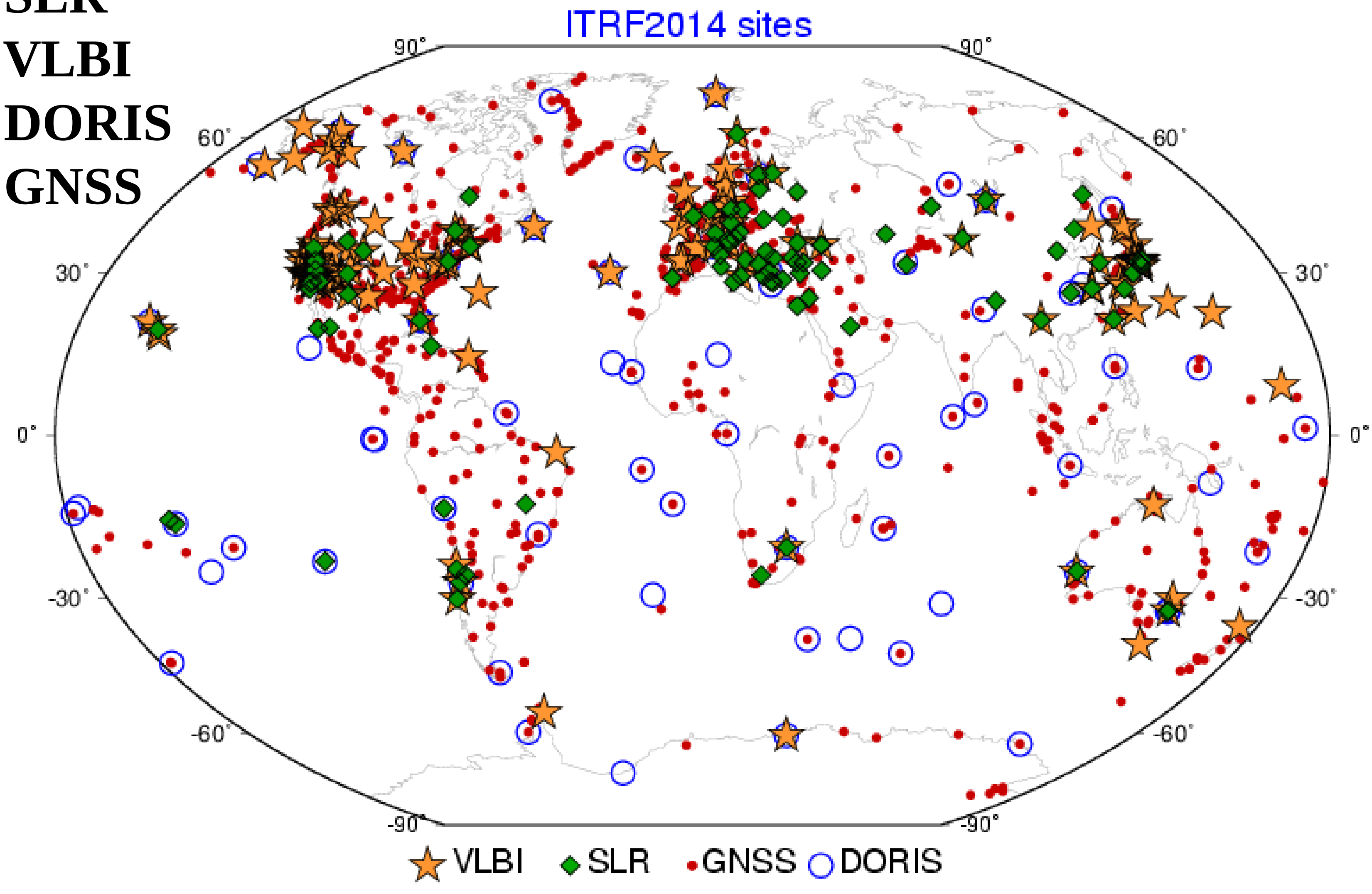
VLBI	SLR
37	28
7	8

Tahiti

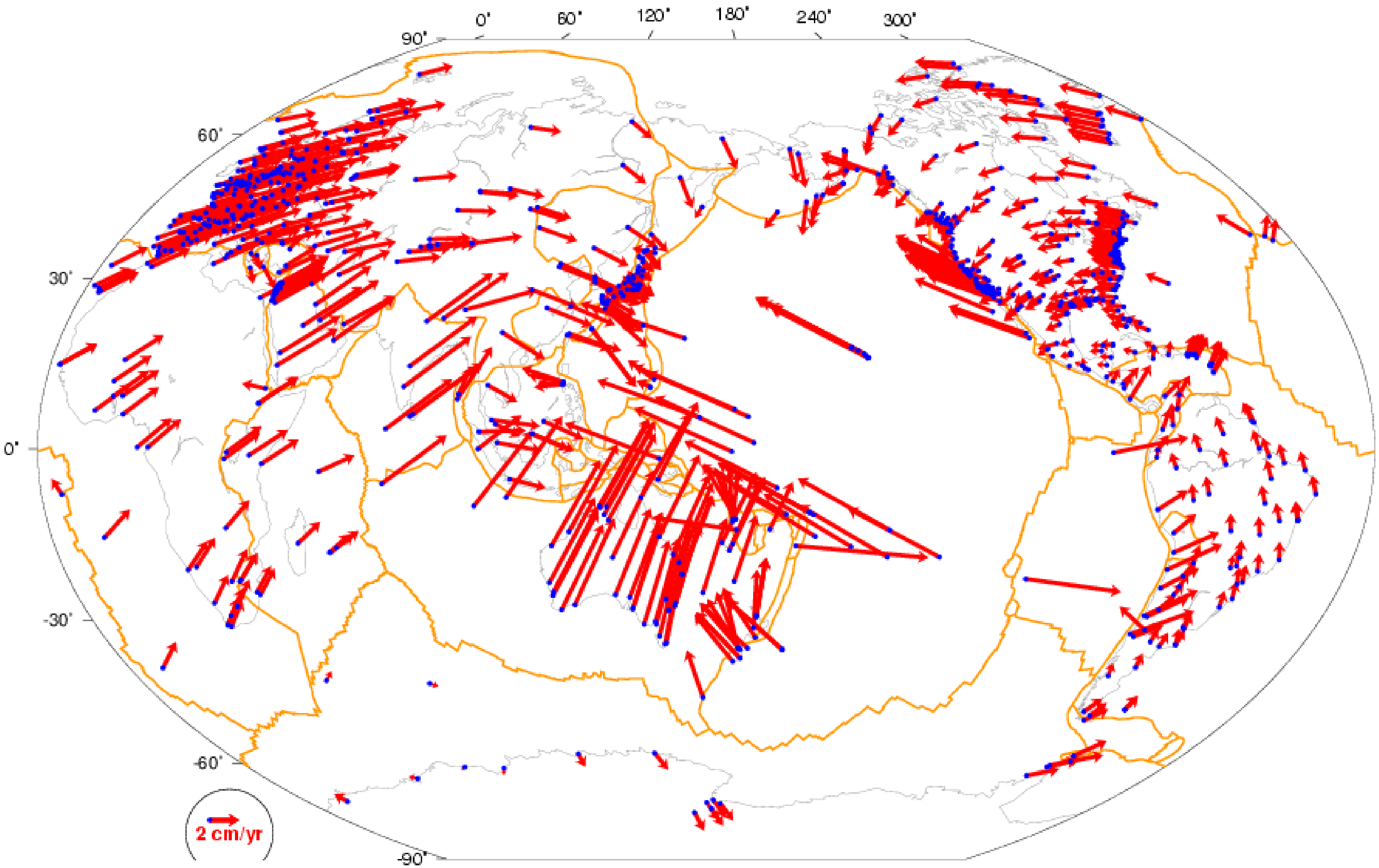


ITRF2014

975 sites in total
96 SLR
124 VLBI
71 DORIS
884 GNSS



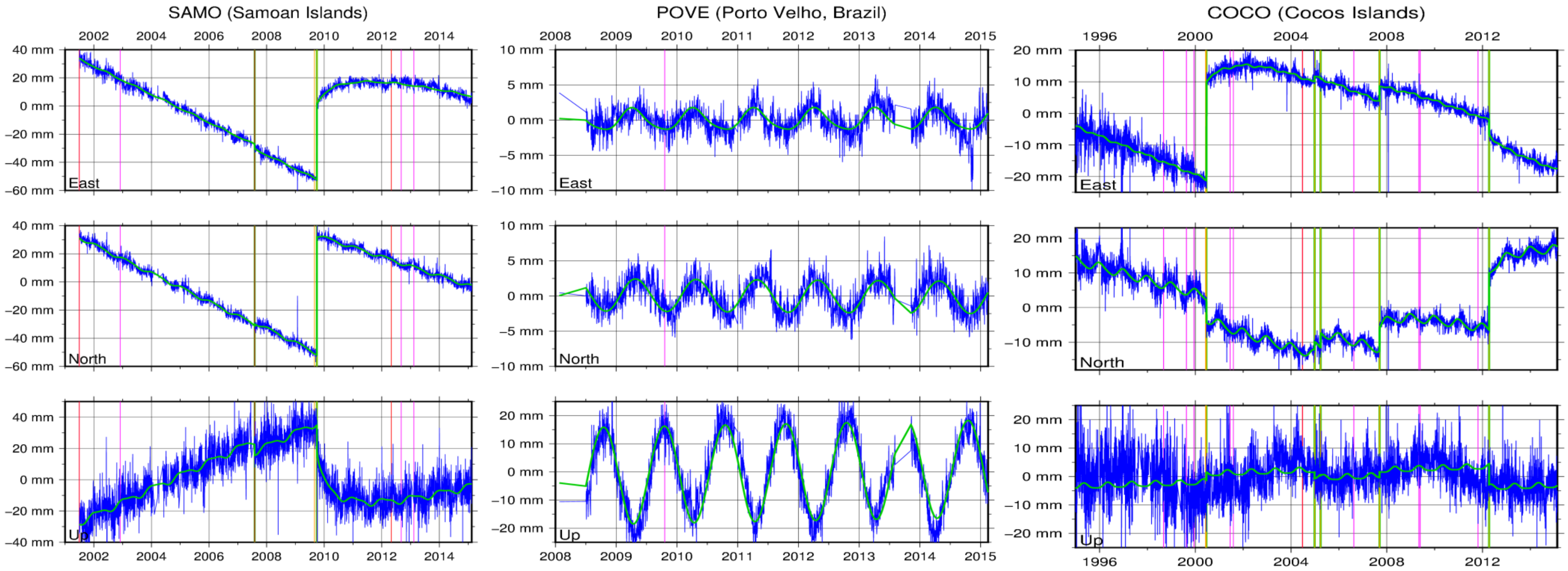
ITRF2014 Horizontal Velocities



It is linear but to do this …

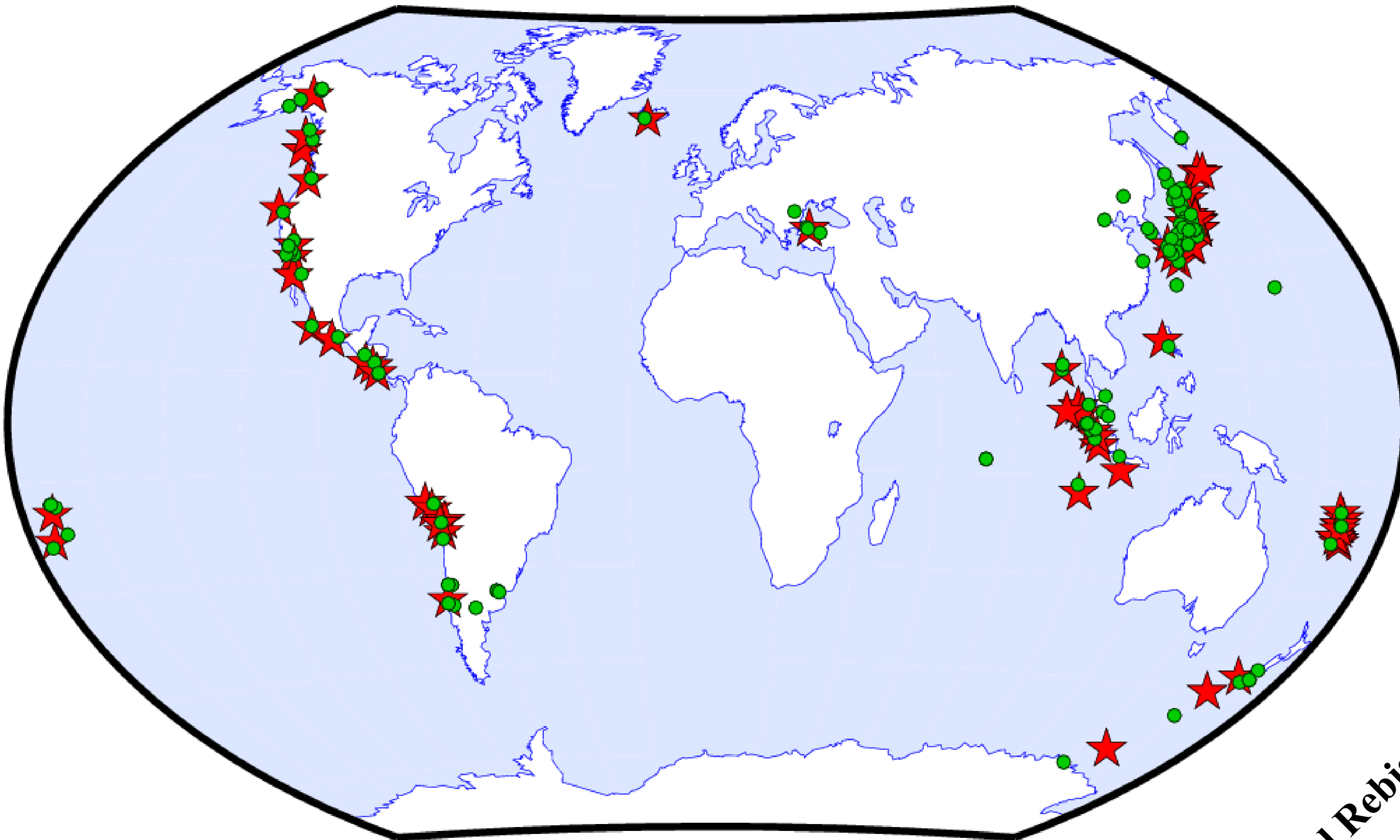
Altamimi et al. 2016, JGR – Solid Earth

Examples of non-linear motions



Co-, Post-Seismic & Periodic Signals

ITRF2014 Sites affected by Post-Seismic Deformation



Red Stars: EQ Epicenters

Green circles: ITRF2014 sites

Artist: Paul Rebischung

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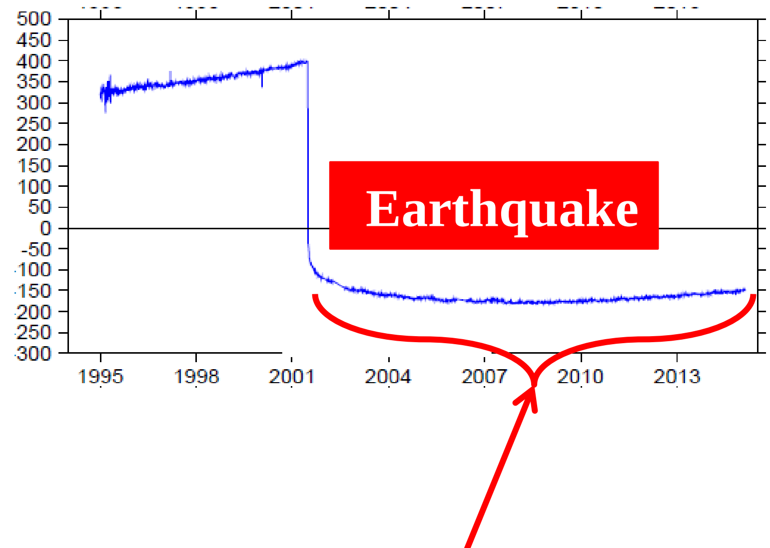
Post-Seismic Deformation (PSD)

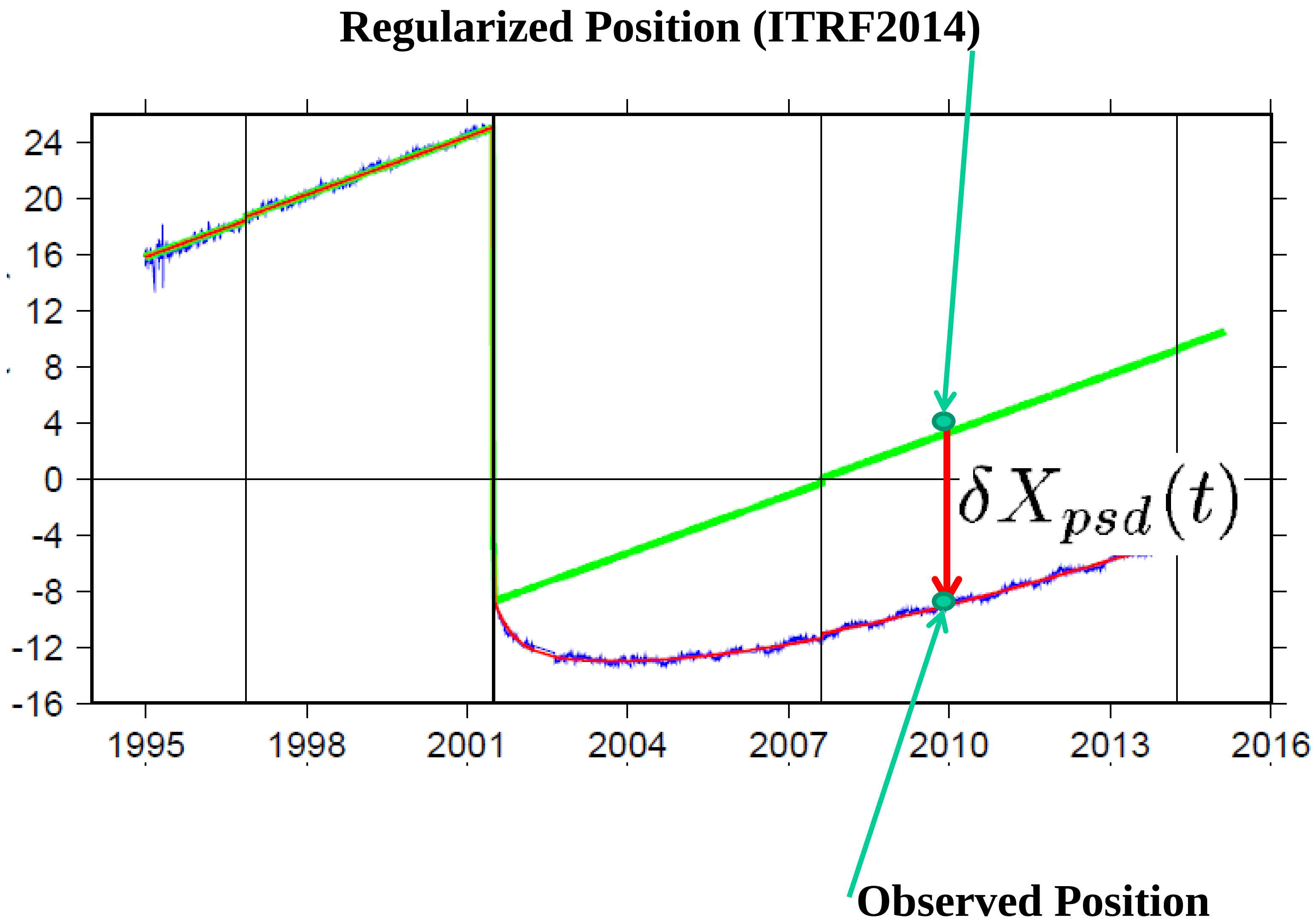
- **Fitting parametric models using GNSS/GPS data**
  - at major GNSS/GPS Earthquake sites
  - apply these models to the 3 other techniques at co-location EQ sites

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



Post-seismic deformation

PSD Correction



How to use ITRF2014 PSD models ?

Regularized Position (ITRF2014)

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

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

Local Frame

PSD Subroutines available at ITRF2014 Web site:

http://itrf.ign.fr/ITRF_solutions/2014/

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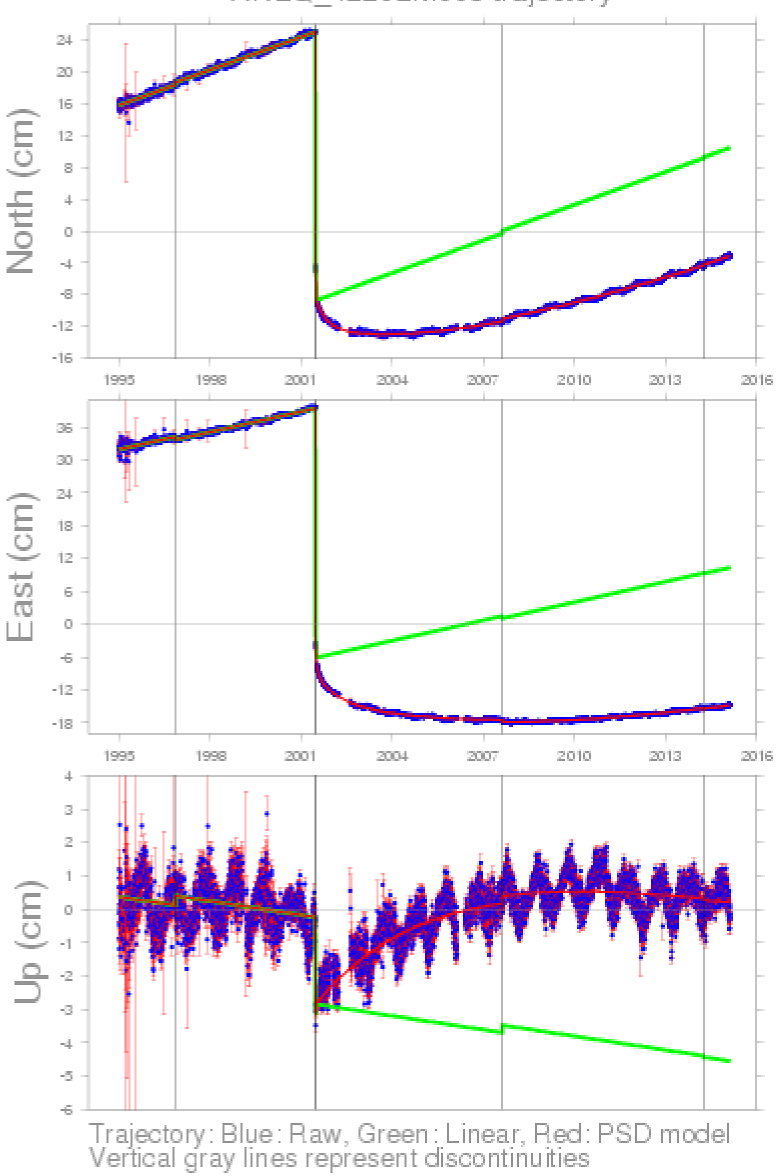
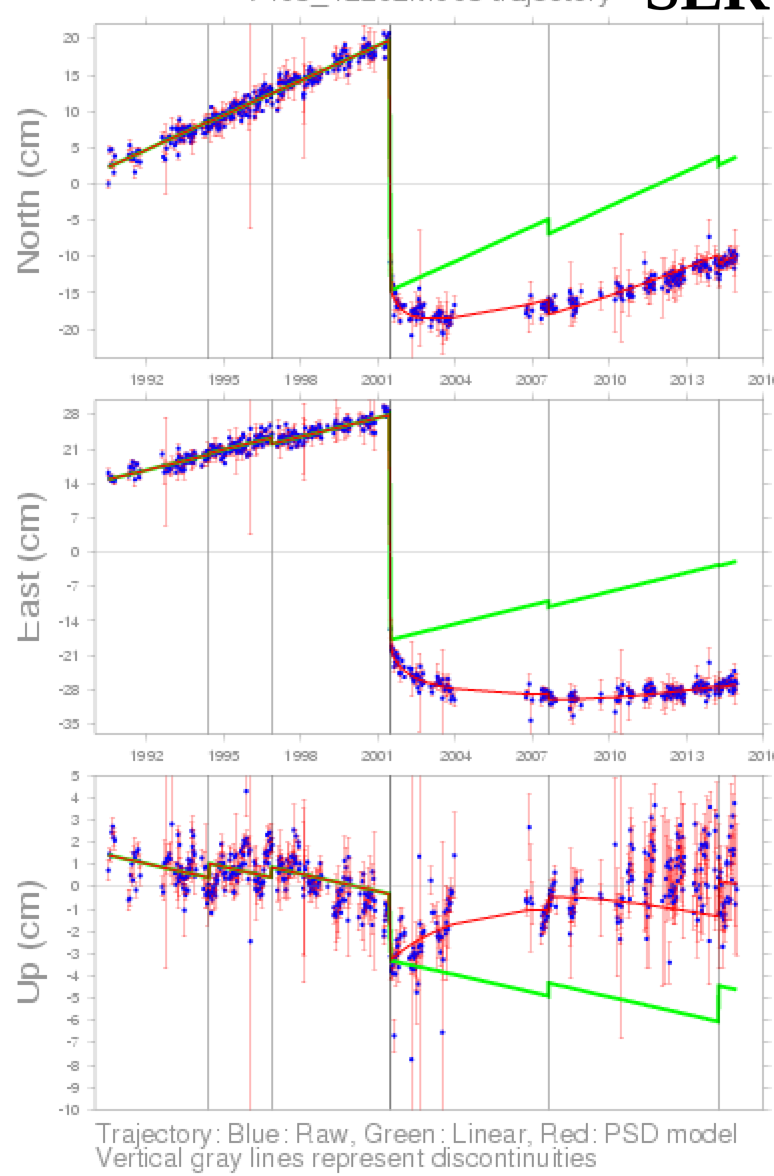
Arequipa: GPS & SLR

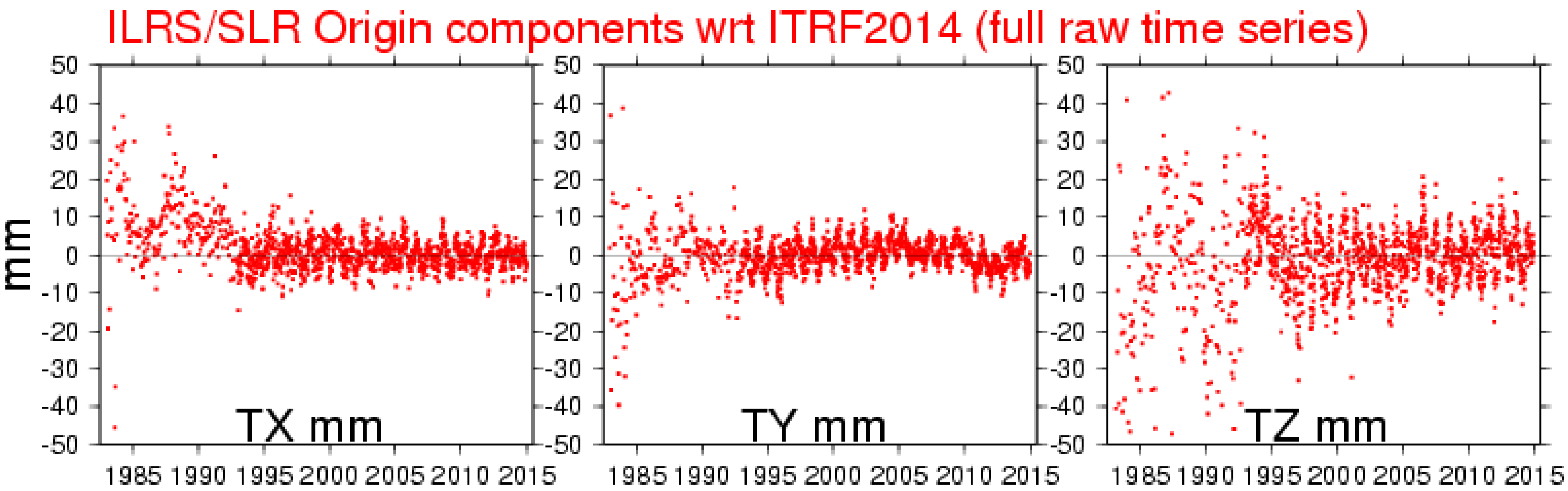
GPS



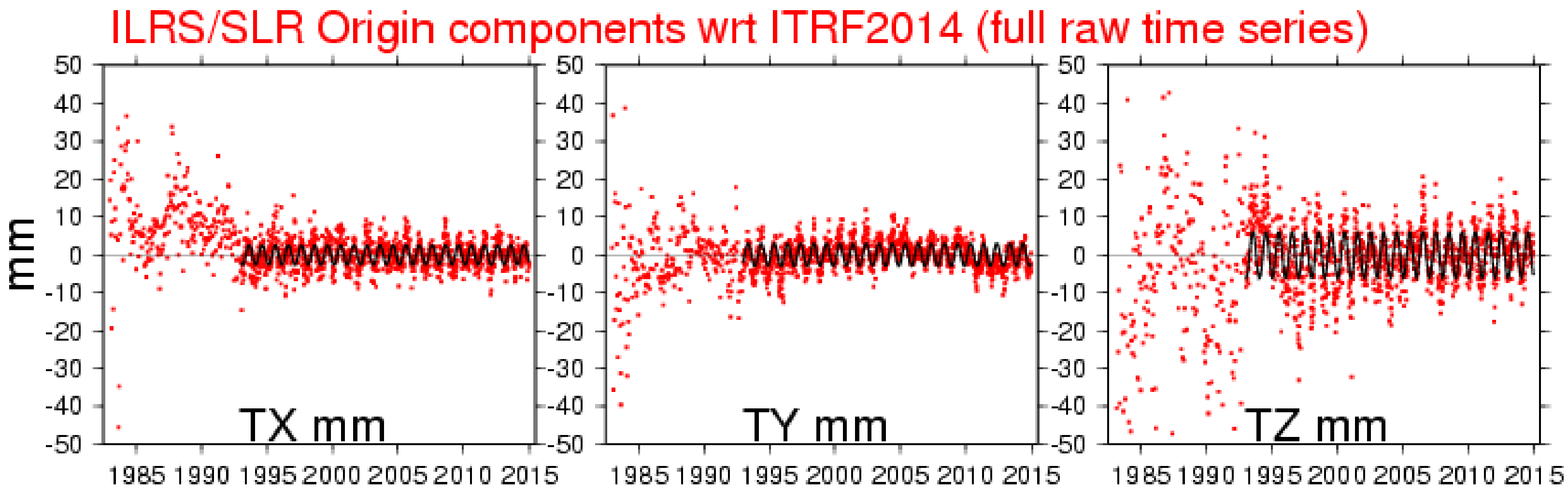
SLR



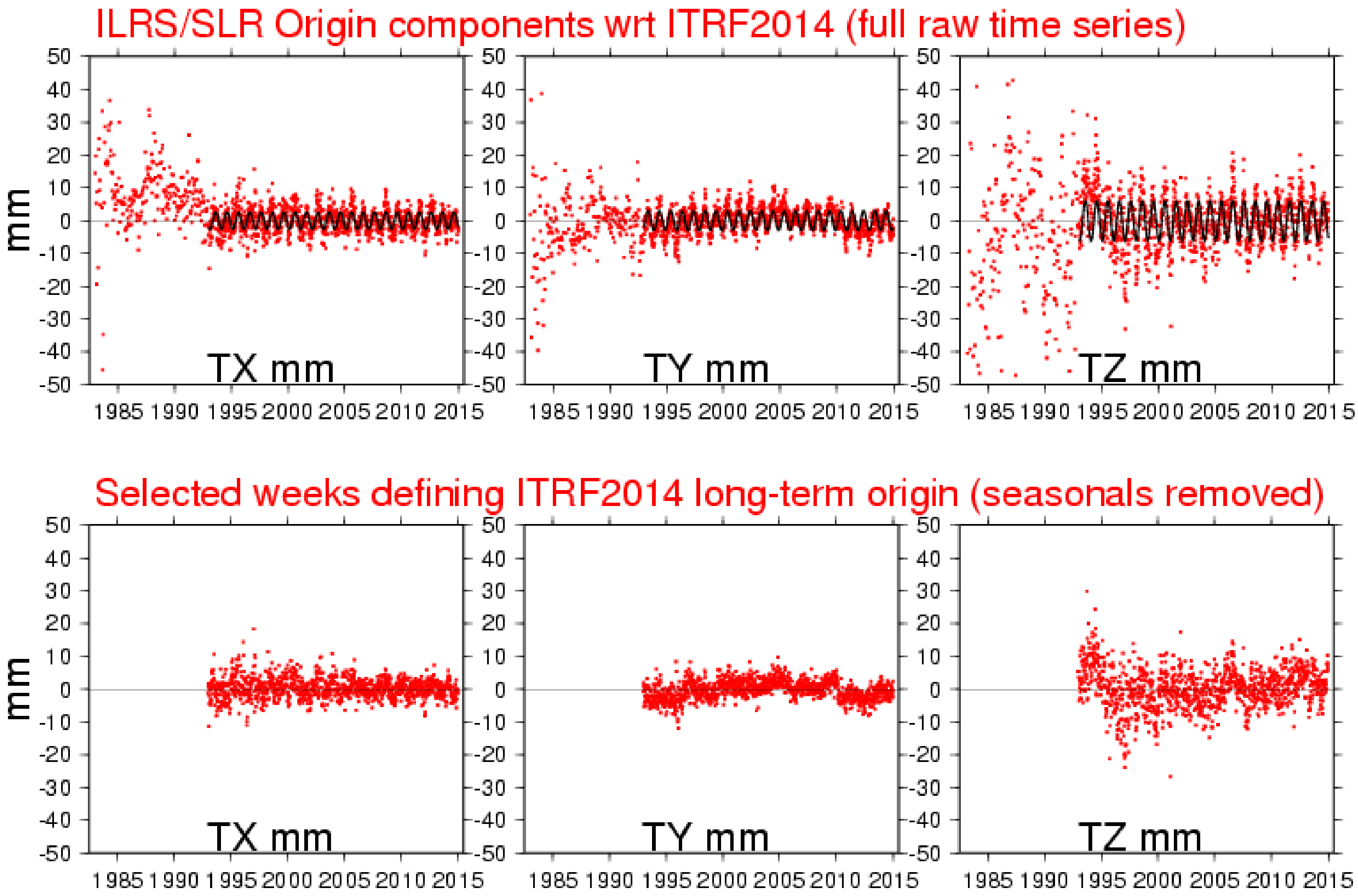
SLR Origin components WRT ITRF2014



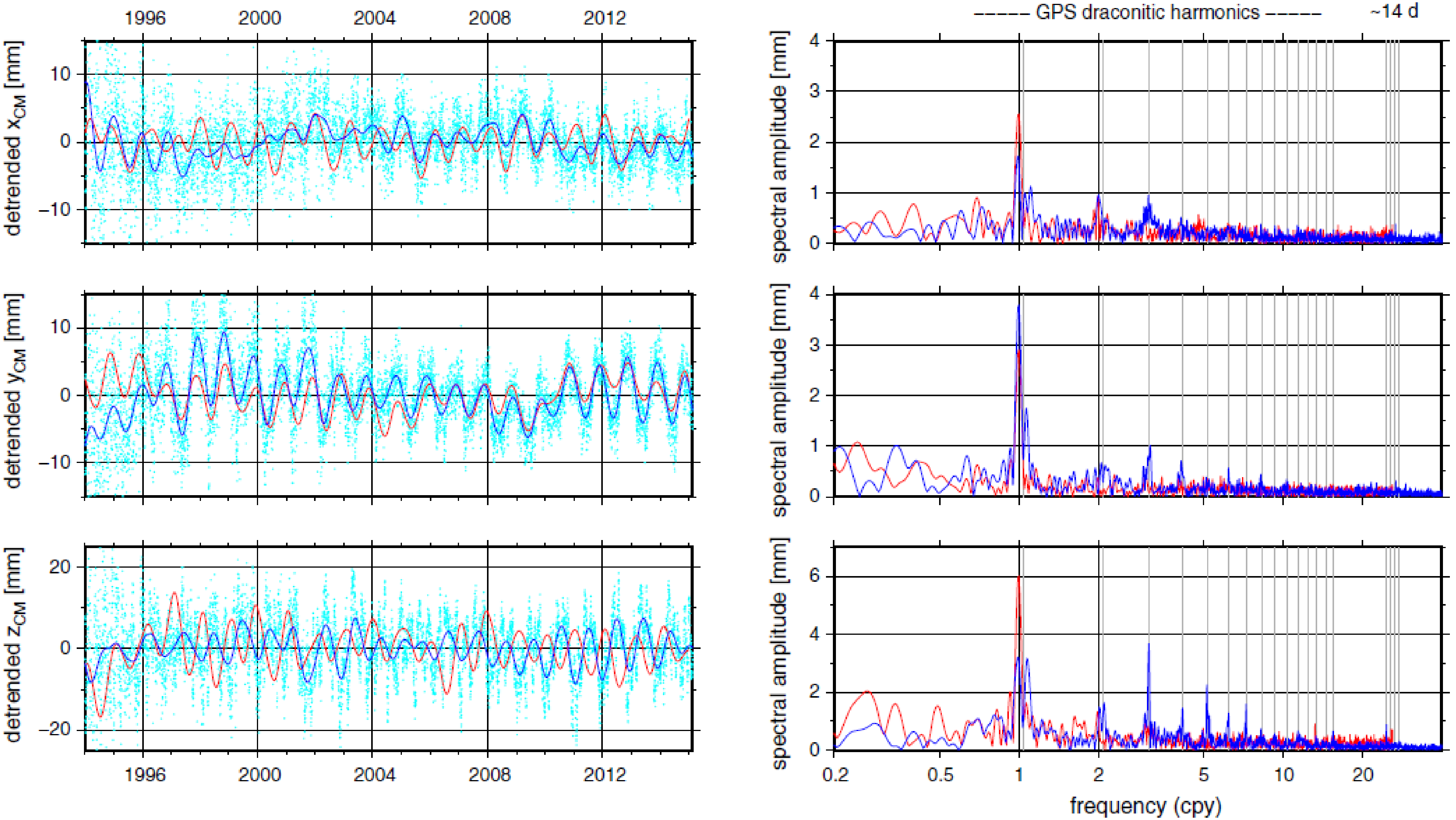
SLR Origin components WRT ITRF2014



SLR Origin components WRT ITRF2014



SLR vs GPS Geocenter motion



Blue & Cyan: GPS

Red: SLR

Rebischung et al., 2015

Annual Geocenter Motion Model

Annual amplitudes & phases fitted to the SLR translation time series

	X		Y		Z	
	A mm	ϕ deg	A mm	ϕ deg	A mm	ϕ deg
ITRF 2014	2.6 ±0.1	226 ±3	2.9 ±0.1	140 ±2	5.7 ±0.2	208 ±2
ITRF 2008	2.6 ±0.1	222 ±3	3.1 ±0.1	135 ±2	5.5 ±0.3	202 ±10

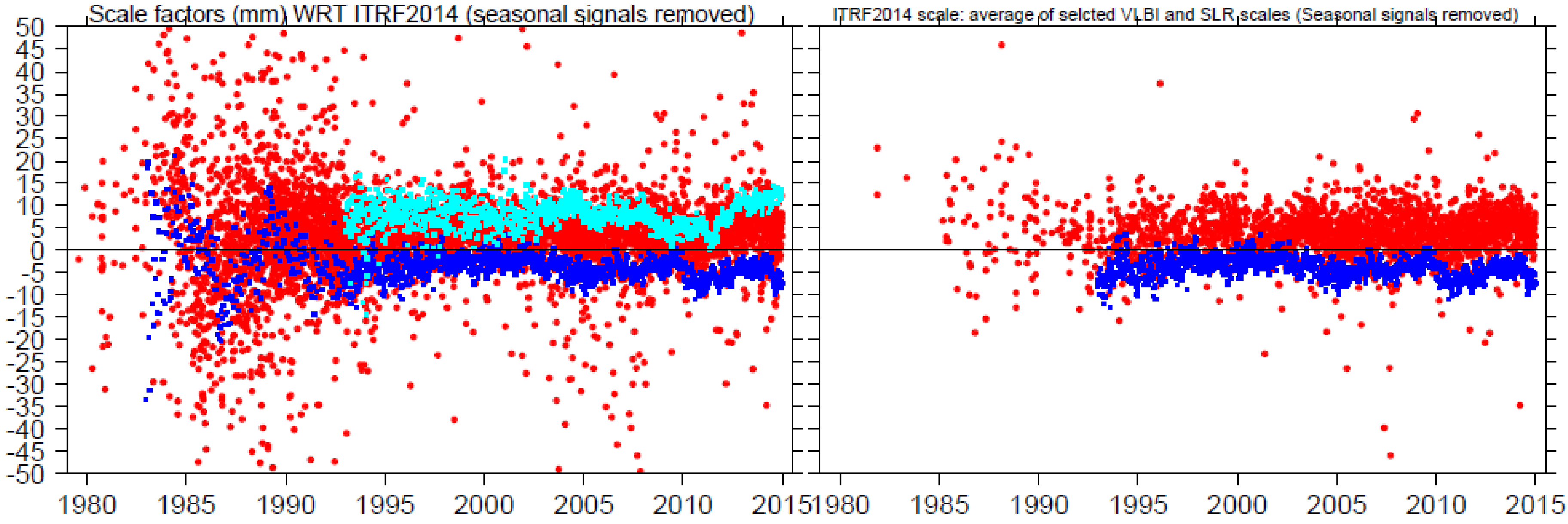
==> Consistency between ITRF2008 and ITRF2014 results

* Phases are off by 180 degrees

DORIS, SLR & VLBI scales wrt ITRF2014

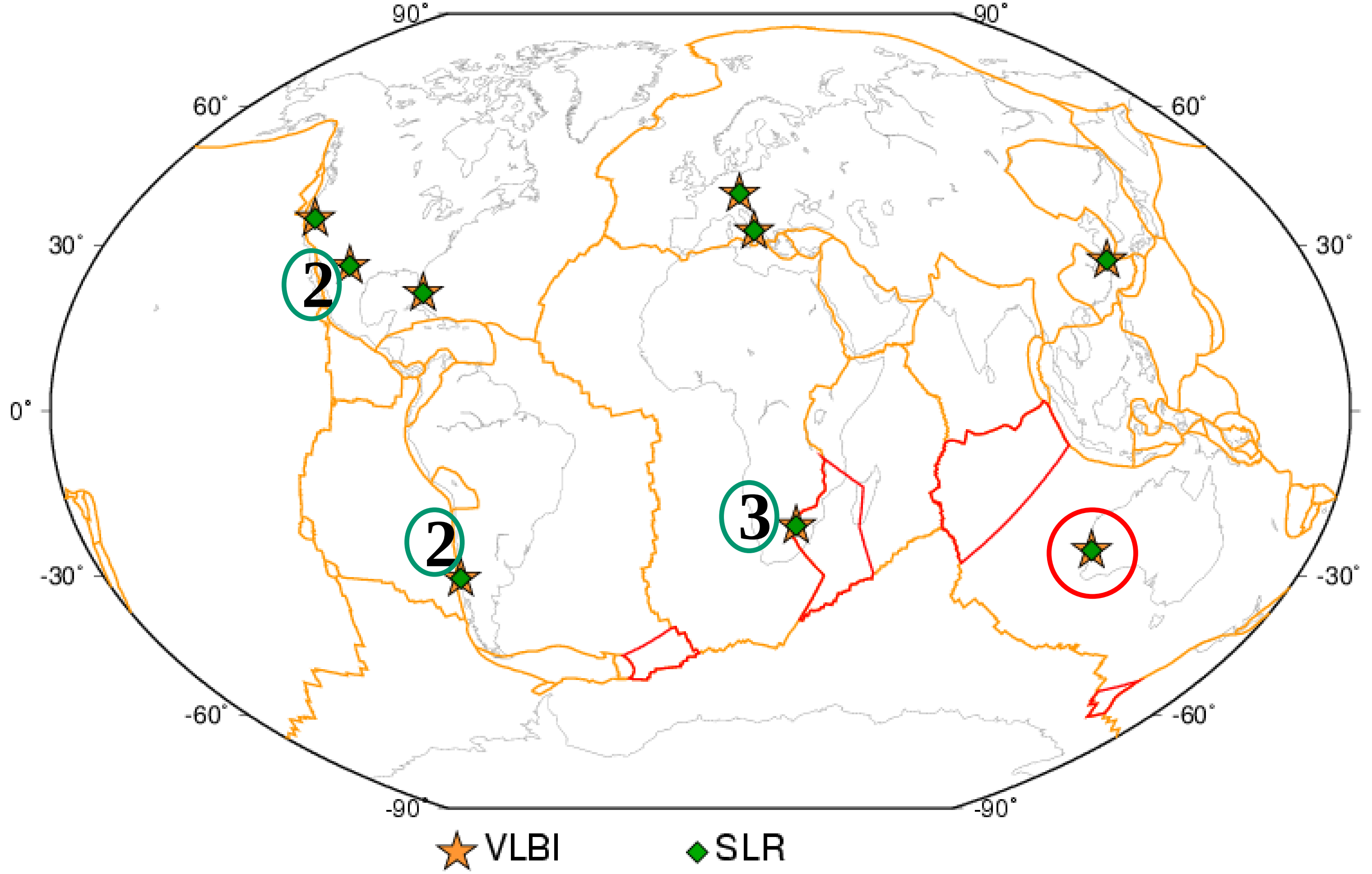
Full time series of scale factors

Scale factors of SLR and VLBI solutions selected to define ITRF2014 scale



DORIS SLR VLBI

ITRF2014 Co-locations
(VLBI & SLR co-locations, NO GNSS)



N : number of tie vectors if > 1

VLBI vs SLR Scale Difference

Solution	Scale at 2010.0 ppb	Comments
ITRF2014	1.37 ± 0.10	All Tie SNX files properly weighted
Rate	0.02 ± 0.02	

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VLBI vs SLR Scale Difference

Solution	Scale at 2010.0 ppb	Comments
ITRF2014	1.37 ± 0.10	All Tie SNX files properly weighted
Rate	0.02 ± 0.02	
VLBI & SLR co-locations, No GPS	1.14 ± 0.29	9 sites (good distribution): 13 LT vectors, properly weighted
Rate	0.02 ± 0.02	

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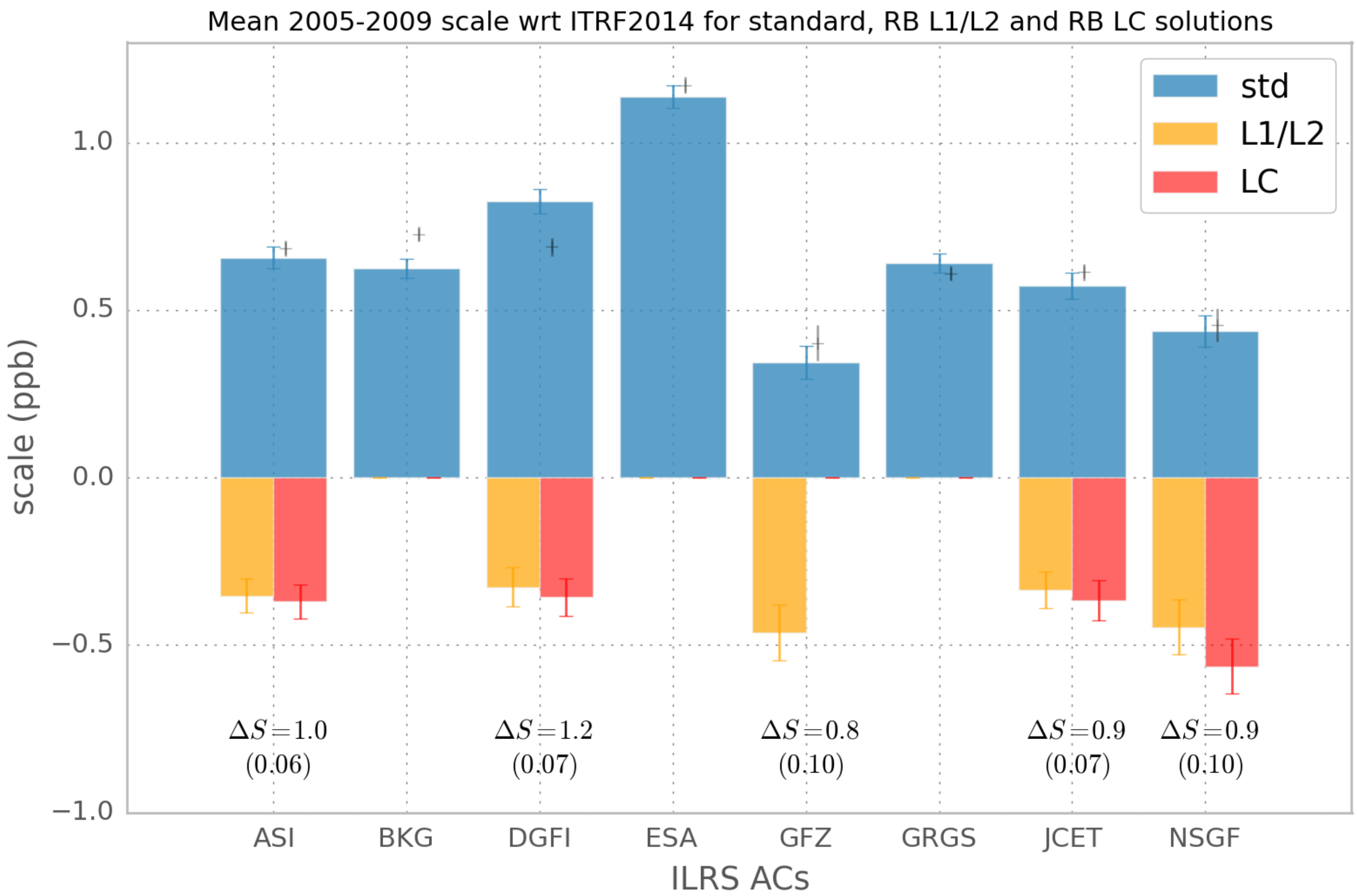
Impact of SLR Range Bias on the Scale



Courtesy Jose Rodriguez

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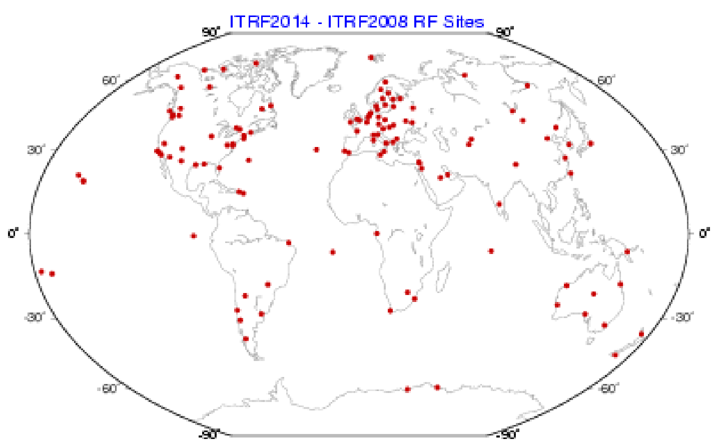
From ITRF2014 to ITRF2008

Using 127 stations

	TX(mm)	TY(mm)	TZ(mm)	Scale (ppb)	Epoch
Offset ±	1.6 ±0.2	1.9 ±0.1	2.4 ±0.1	-0.01 ±0.02	2010.0
Rate ±	0.1 ±0.2	0.0 ±0.1	-0.1 ±0.1	0.03 ±0.02	-



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Conclusions (1/2)

- The Reference Frame (ITRF) underpins science & societal applications : facts & economic benefit

- SLR contribution to the ITRF: Weaknesses & Strengths
  - SLR network and its distribution
  - ITRF origin and geocenter motion (Unique contribution)
  - Annual geocenter motion model consistent with ITRF2014 (& 08) for, e.g. Precise Orbit Determination
  - Origin components between ITRF2014 & ITRF2008 are small (thanks to SLR)
  - Persistent scale offset between VLBI & SLR, but progress is made in range bias estimation by the ILRS

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Conclusions (2/2)

- **UN-GGIM Initiative: A sub-committee on Geodesy**
  - **A great opportunity not to be missed**
  - **Expect to help and facilitate implementing the GGOS initial idea:**

Improving the global geodetic infrastructure