SLR Requirements for the Development of the ITRF

Erricos C. Pavlis and Magdalena Kuzmicz-Cieslak

Joint Center for Earth Systems Technology, UMBC, Baltimore MD, USA

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Background

- Satellite Laser Ranging (SLR) data have been used to derive tracking station coordinates and velocities for the global network for many decades now.
- Since the launch of the BTS, the precursor of the International Terrestrial Reference Frame (ITRF), the SLR contribution has played a unique and fundamental role in the realization of the frame's origin, and shared with VLBI the definition of its scale.
- The ITRF development is based on an inter-technique combination of the geodetic solutions obtained from an intra-technique combination strategy performed at each IAG Technique Centre.
- It is the responsibility of each technique to determine and assess the quality and quantity of data that are required in this process, to ensure the accuracy and stability goal of the model.

The goals set by GGOS

- The ILRS is one of the space geodetic services of the International Association of Geodesy (IAG) and is a member of the IAG's Global Geodetic Observing System (GGOS). The Services, under the umbrella of GGOS, provide the geodetic infrastructure necessary for monitoring global change in the Earth system (Beutler and Rummel, 2012) with very stringent requirements:

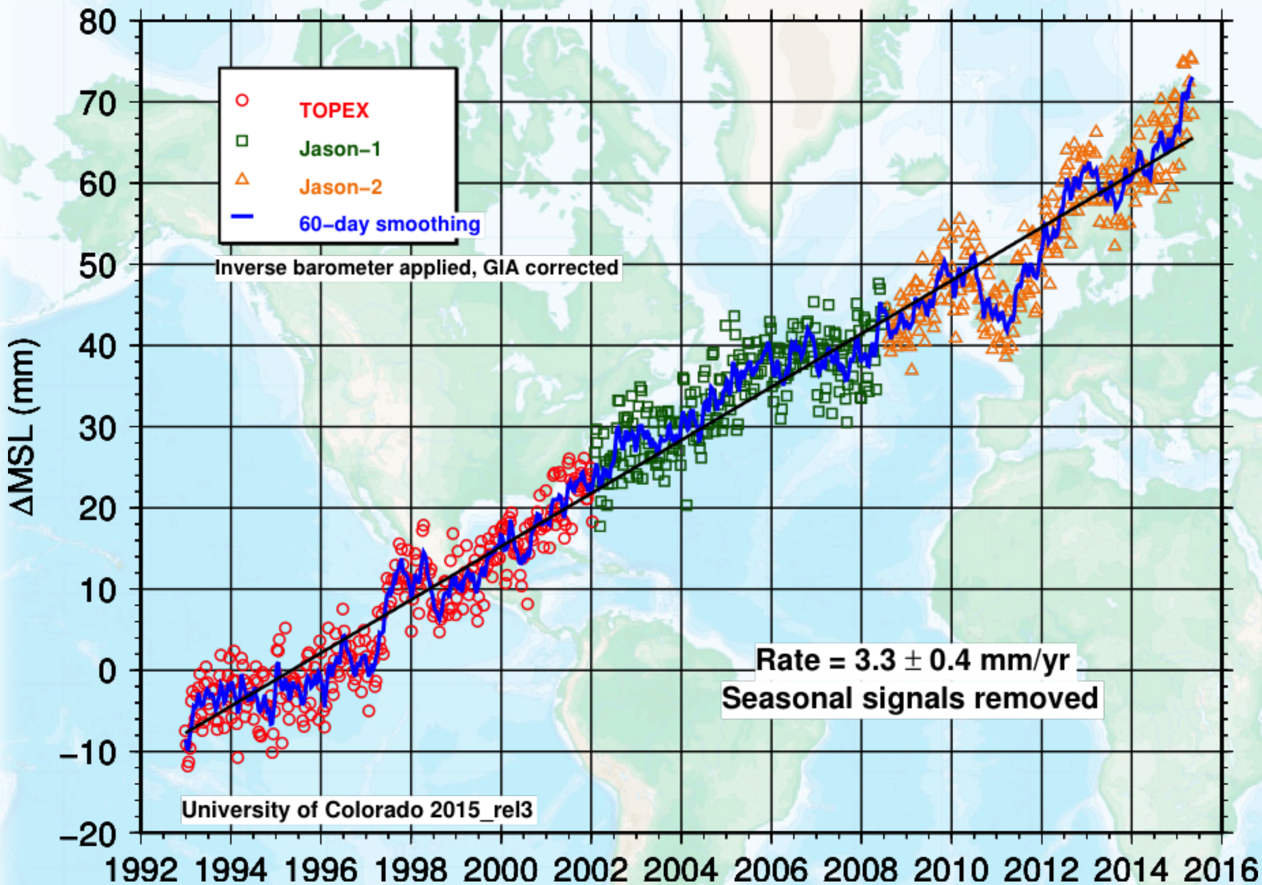
<1 mm in epoch position, and

< 0.1 mm/y in secular change

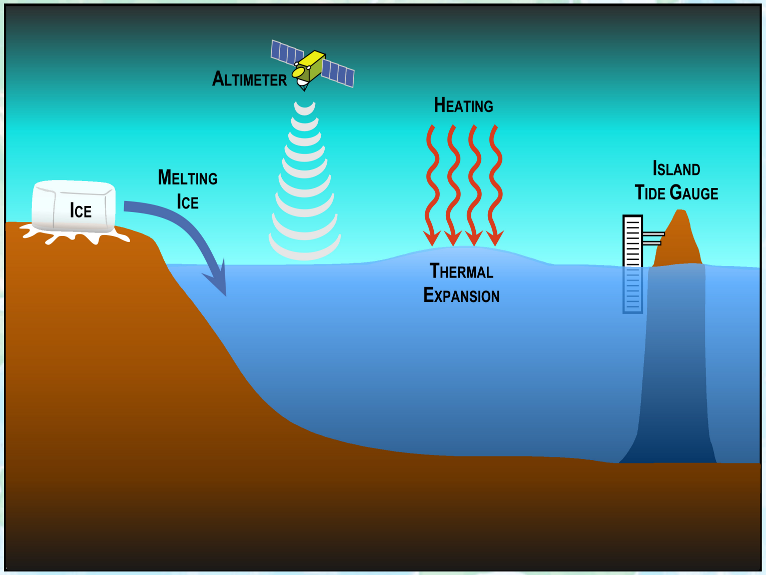
*Current performance: ~ 10 mm and ~ 1 mm/y

- The role of the SLR in supporting the GGOS goals is dual:
  - The main contribution is the establishment of the ITRF itself through the Core network
  - A second, equally important role, is the calibration, scaling and "centering" of the GNSS orbits, since they are the "distributors" of the ITRF to the user community

The phenomena driving these goals

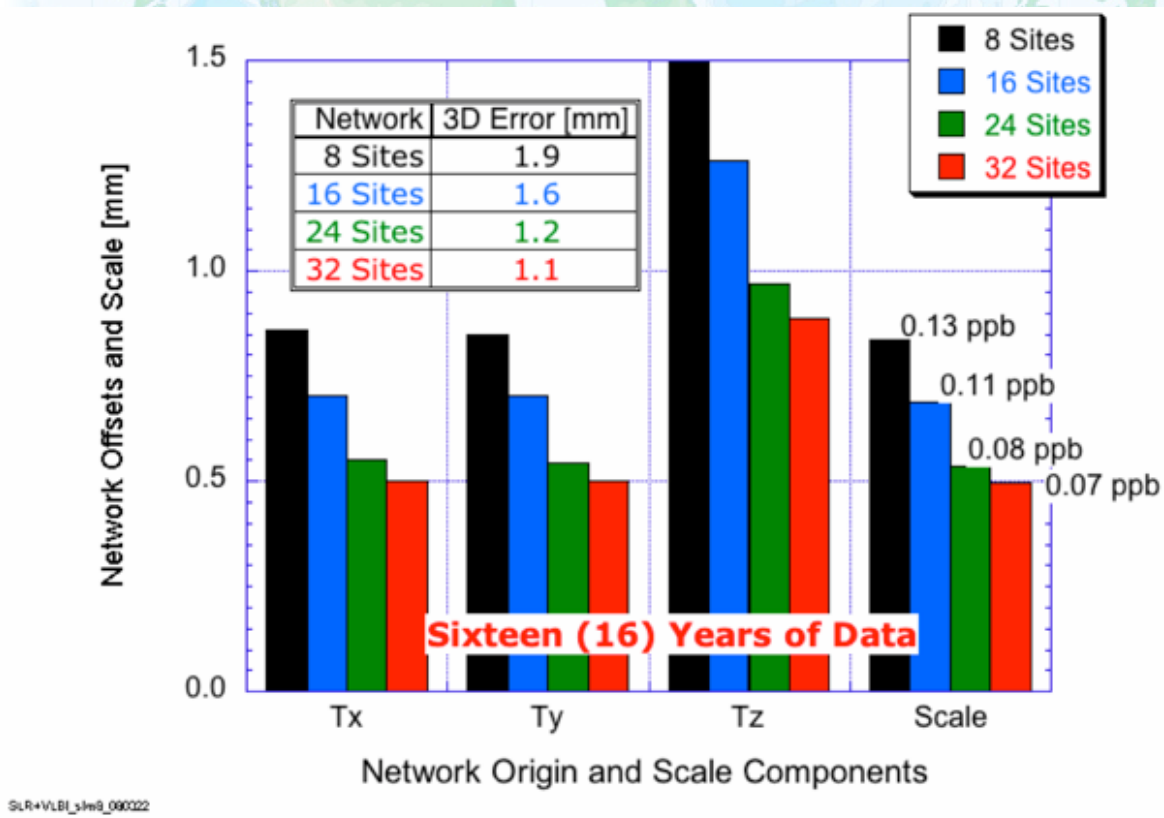


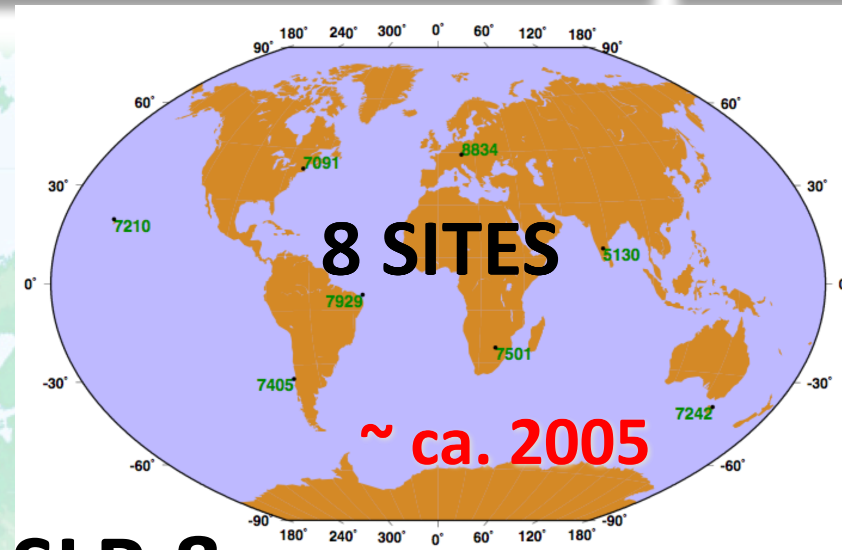
Measurement of sea level change is the primary science driver



What Size Core Network is required?

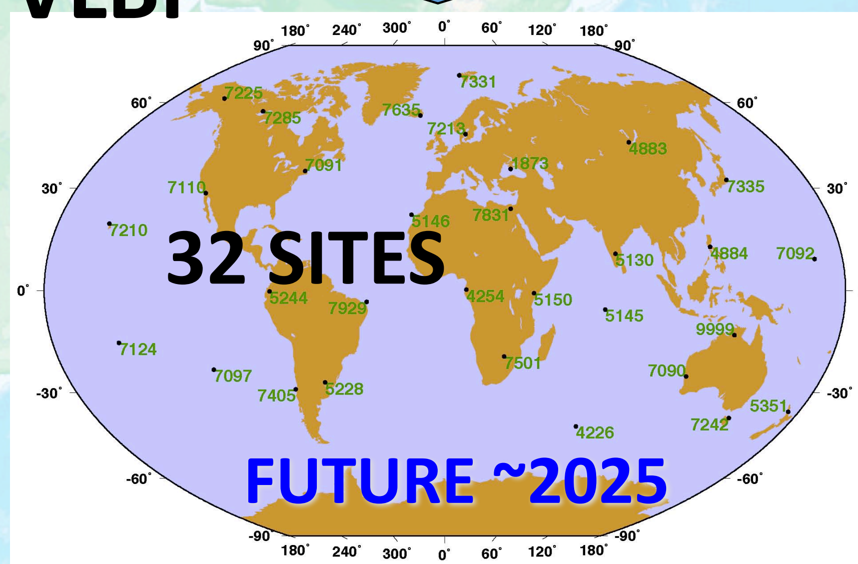
Ten years ago, simulations determined the minimum size of a future network that will deliver the quantity and quality data to support the future requirements of the ITRF accuracy and stability:





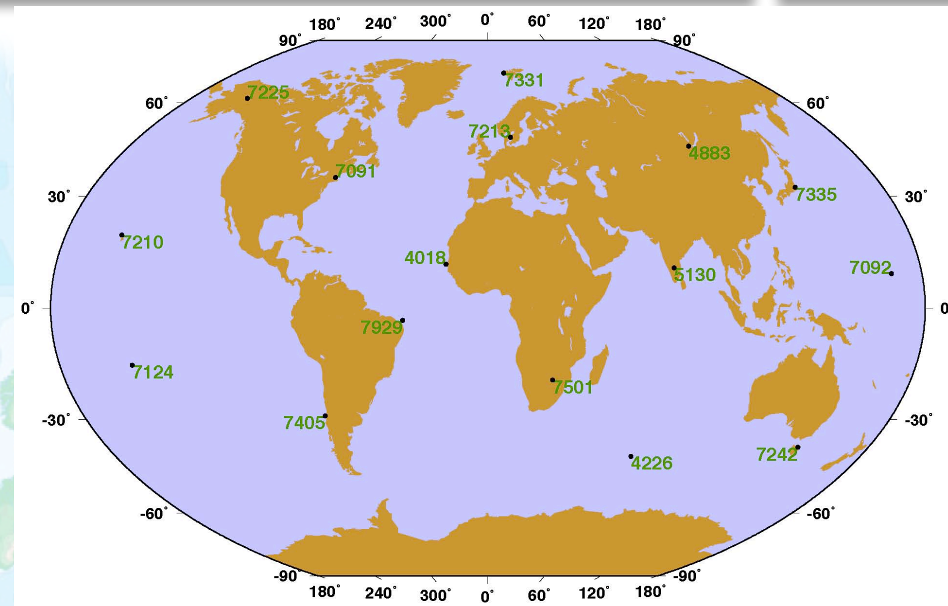
SLR & VLBI

GGOS



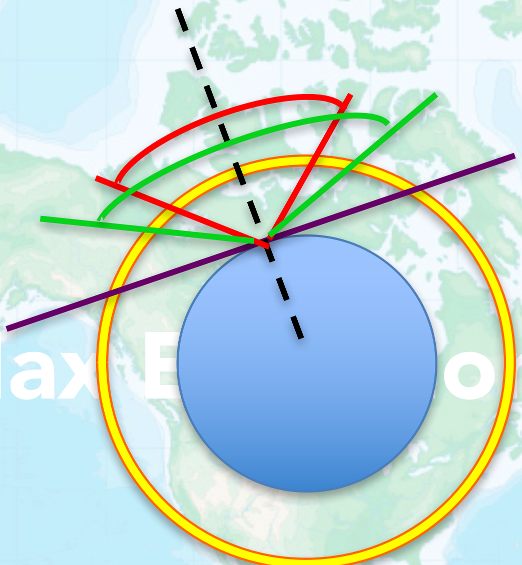
Laser Ranging to GNSS

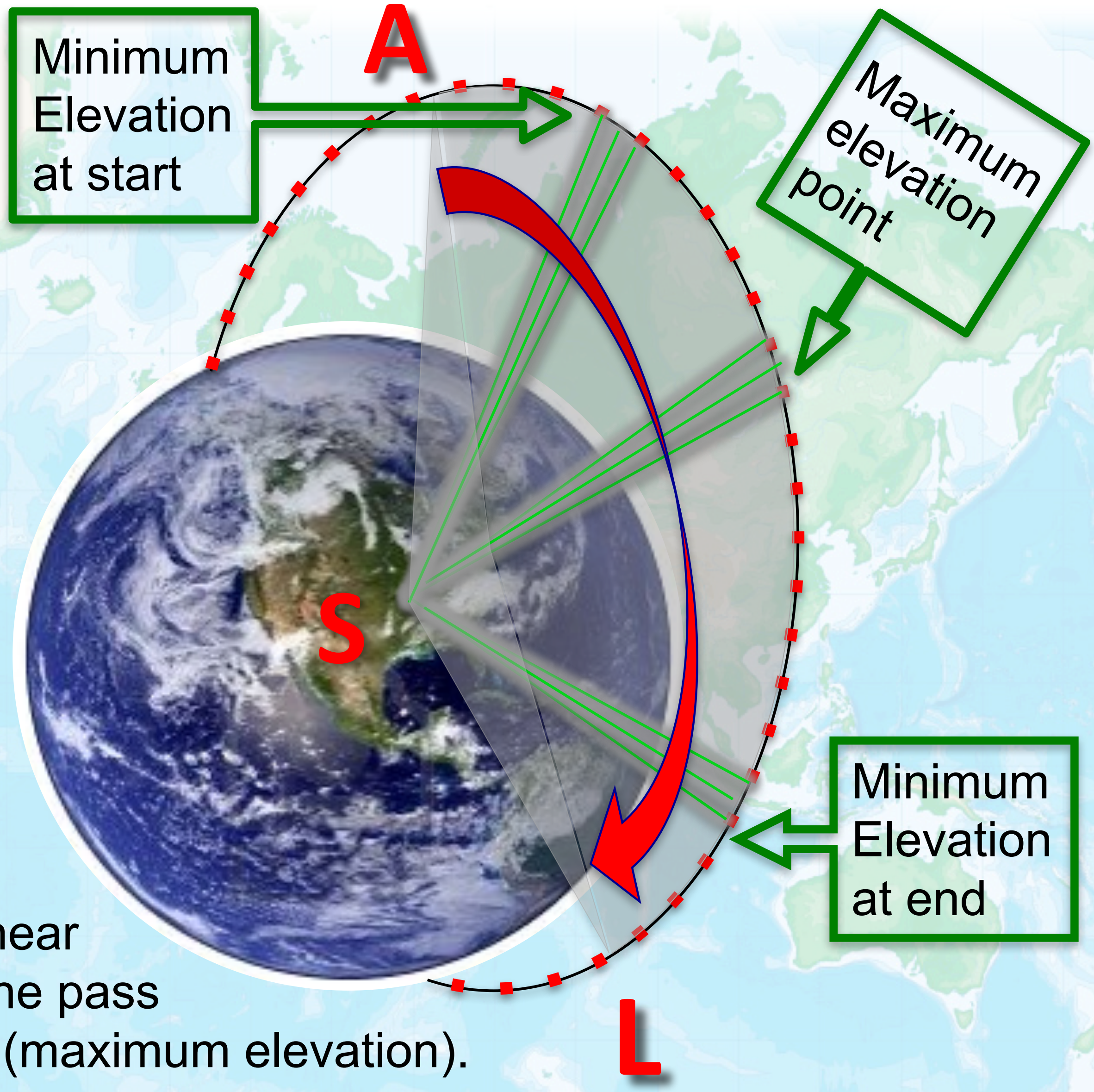
- Tracking a select number (~6) of GNSS spacecraft with SLR over short time periods (of the order of 1 week), allows to center and scale the GNSS orbits with equal accuracy as that obtained from tracking the dedicated SLR targets (LAGEOS 1 & 2).



Attribute	Constellation	8-Site Network	16-Site Network
Scale [ppb]	**26 GNSS s/c**	-0.22 ± **0.5**	-0.08 ± **0.4**
	6 GNSS s/c	0.16 ± **0.6**	0.19 ± **0.7**
Origin 3D [mm]	**26 GNSS s/c**	3.0 ± **2.5**	1.5 ± **1.3**
	6 GNSS s/c	1.6 ± **2.9**	2.3 ± **2.4**

GNSS Tracking Scenarios





A set of simulations evaluated tracking scenarios that are limited to tracking 30% of each pass, distributed in three 10% batches near the minimum elevation region of the pass and the point of closest approach (maximum elevation).

GNSS Tracking Scenarios: Implications

- The definition of the origin is marginally affected by either the loss of low elevation data or the non-continuous tracking of the target

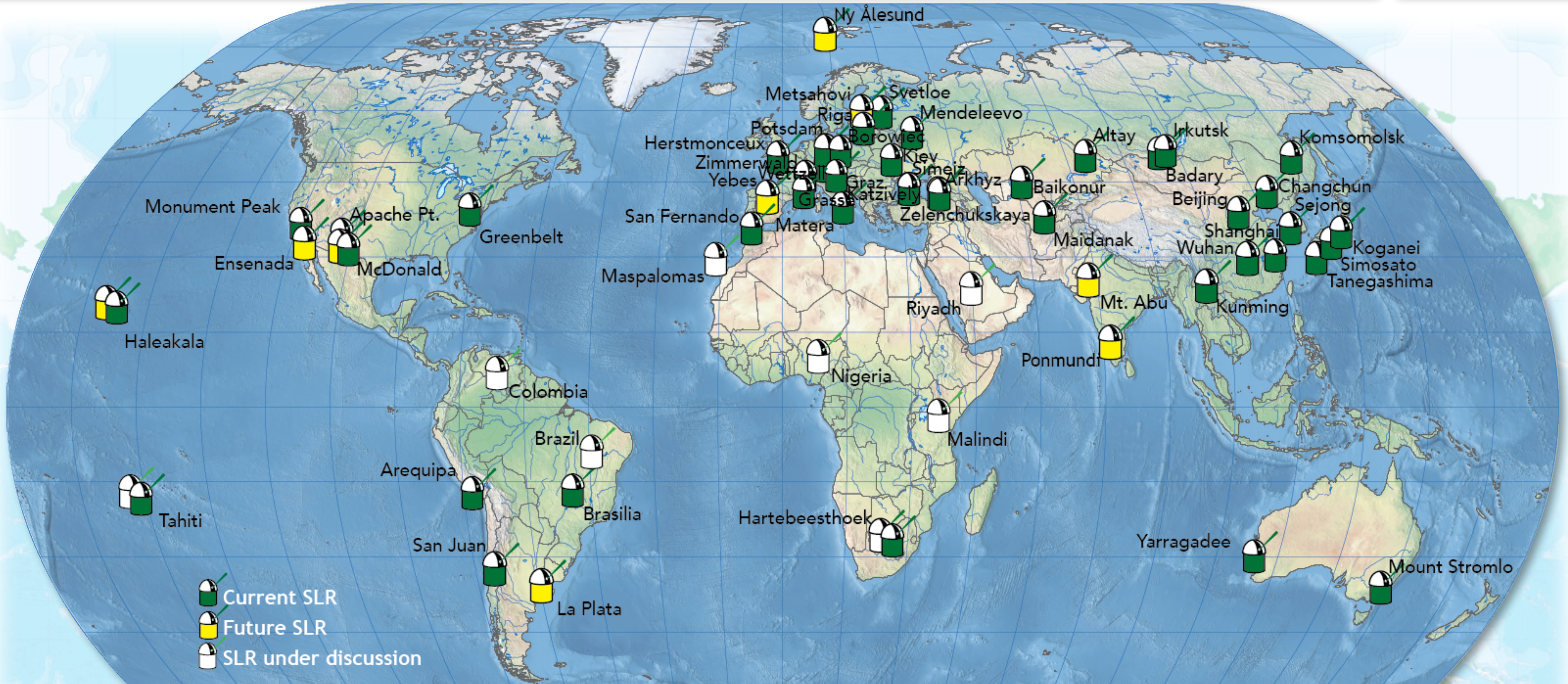
3° vs 10°	All Data Used			30% L-H-L		
[mm]	Xg	Yg	Zg	Xg	Yg	Zg
Points	4	4	4	4	4	4
Mean	0.030	-0.183	-1.349	0.001	-0.039	0.317
Std Deviation	0.085	0.037	0.349	0.106	0.020	0.256

- In all cases the stability of the origin is < 1 mm even though these results are based on only one month

3° vs 20°	All Data Used			30% L-H-L		
[mm]	Xg	Yg	Zg	Xg	Yg	Zg
Points	4	4	4	4	4	4
Mean	-0.287	-0.380	-2.271	-0.235	-0.008	-0.192
Std Deviation	0.077	0.088	0.126	0.046	0.045	0.127

- The definition of the scale on the other hand is affected by the loss of low elevation data and a sequence of simulations we performed where the tracking started/ended at 10°, 20°, 30° and 45° indicated a simple rule of thumb: **for every 10° loss in minimum elevation, we will incur about 2 mm error in the station heights, leading to 0.3 ppb scale error.**

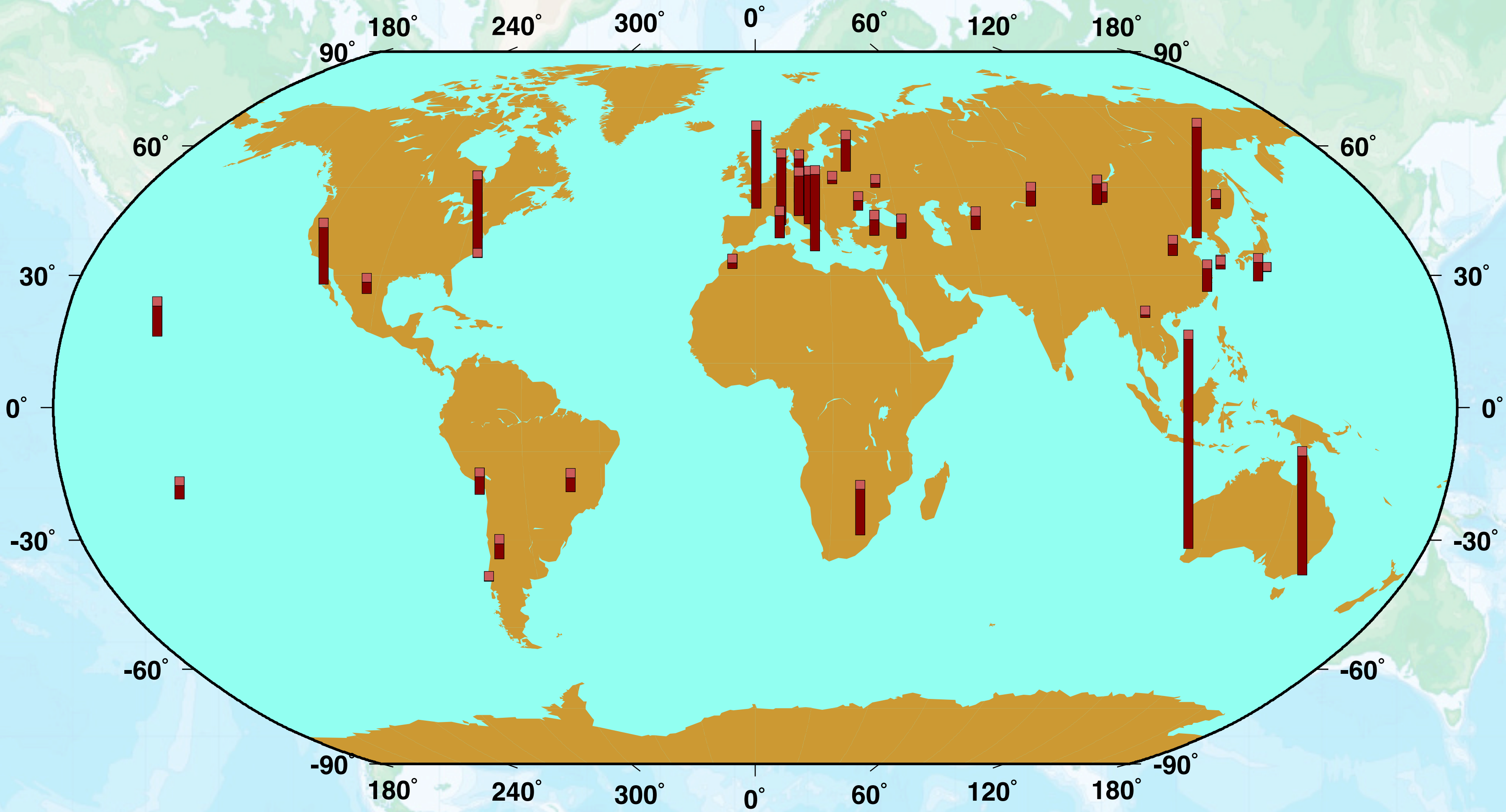
ILRS network: current and planned



- New and upgraded stations in Sejong, Wettzell, Riga, and Borowiec
- BKG AGGO being setup in La Plata Observatory (core site)
- New Russian station operating in Brasilia; new stations underway in Hartebeesthoek and Ensenada; discussion underway on Tahiti
- New NASA and NASA affiliated stations underway at McDonald, Hawaii and Ny Ålesund NMA)
- New stations underway in Metsahovi, India (2), and Yebes
- Some discussions with KACST on resurrection of SALRO
- Upgrades underway in Chinese network: San Juan (Argentina), Wuhan, Shanghai

The network seen via its data yield

- The ILRS-network-provided global satellite laser ranging data for 2014, 2015 and 2016 were distributed by site as shown in this graph:

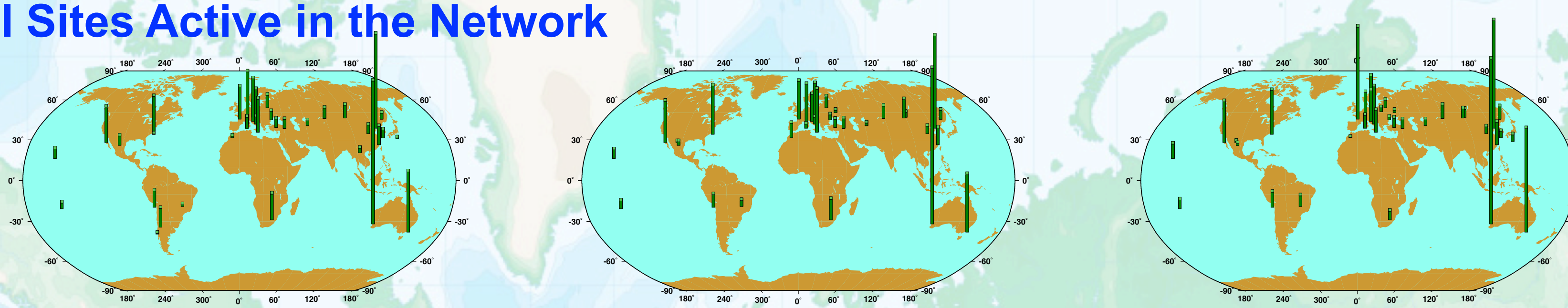


Sub-network solutions vs. the full network

2014 2015 2016

All Sites Active in the Network

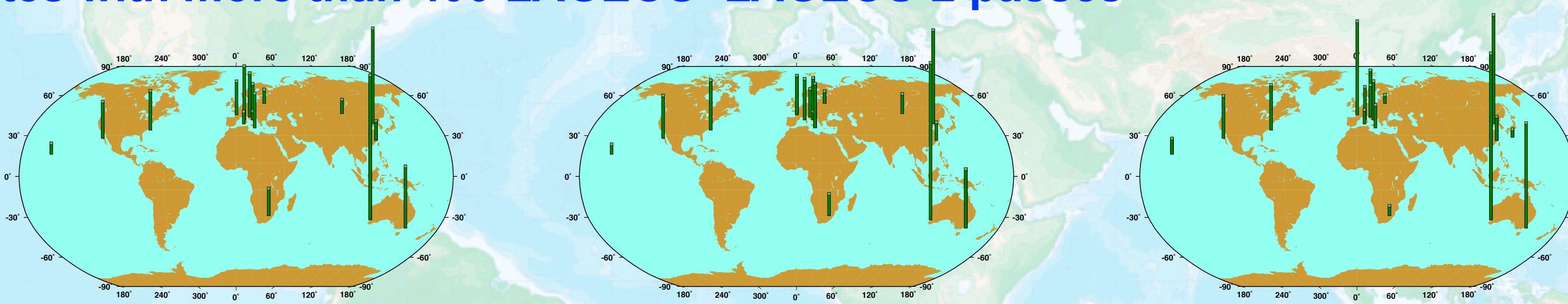
40



A

Sites with more than 400 LAGEOS+LAGEOS-2 passes

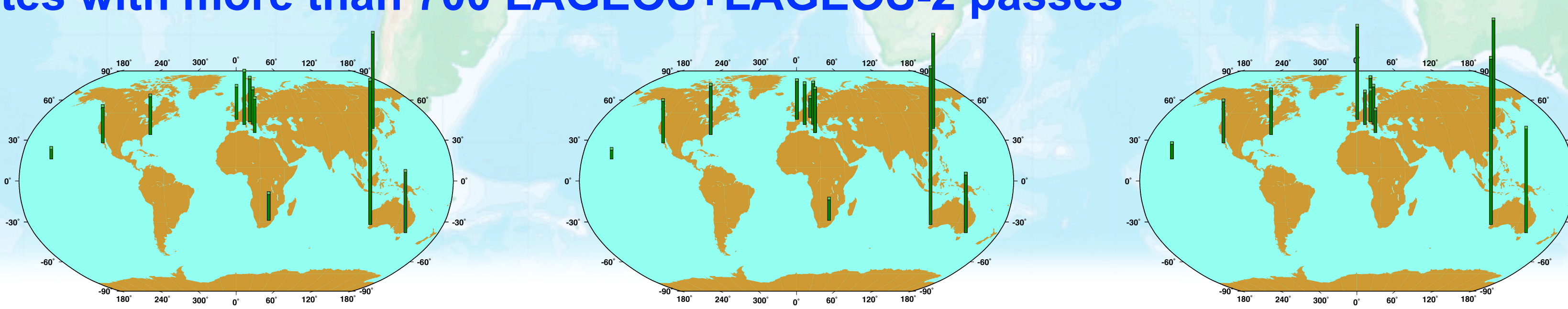
18



B

Sites with more than 700 LAGEOS+LAGEOS-2 passes

12

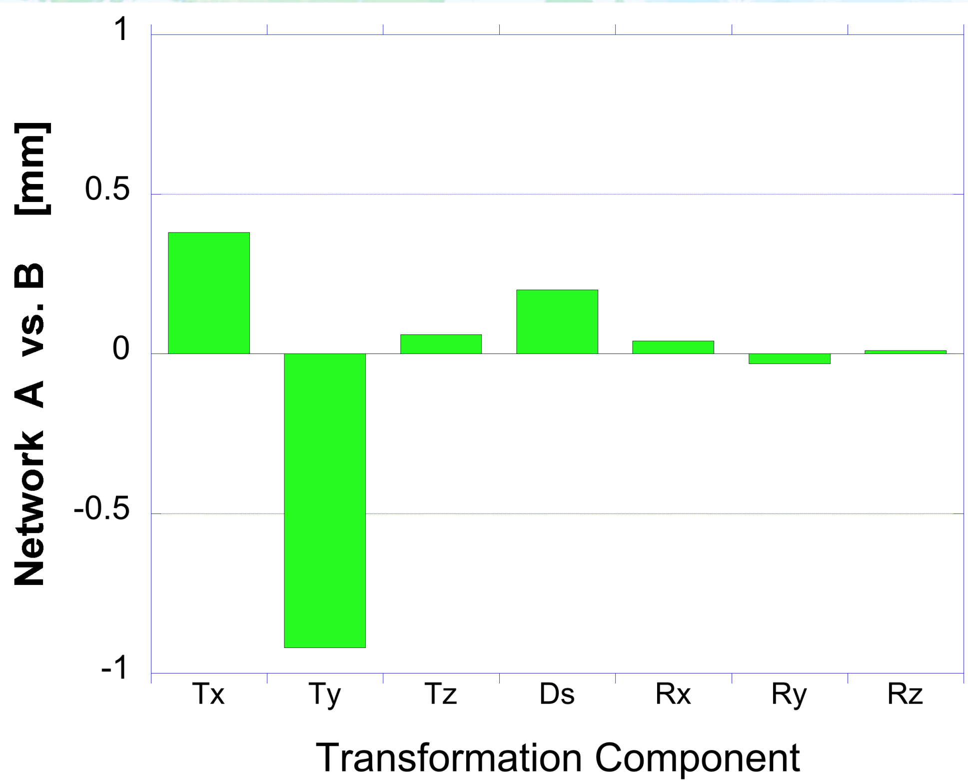


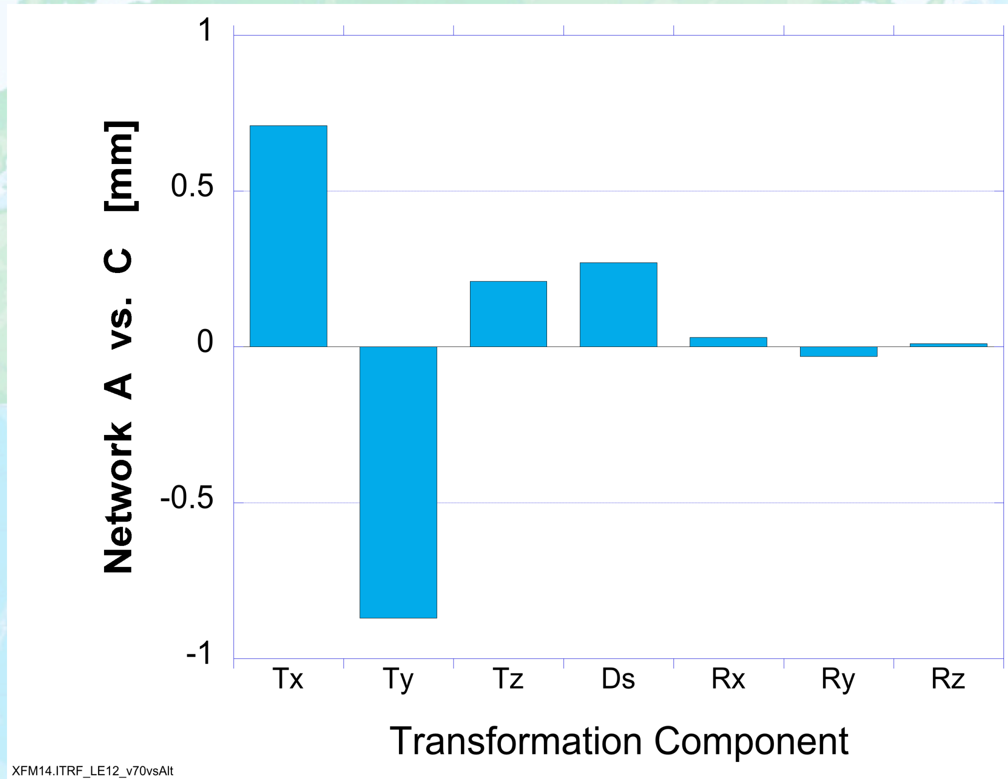
C

Sub-network transformation summary:

Take-away message from these test solutions:

We currently have a TWELVE-site network to depend on, the contribution of the other 28 sites is marginal…





Summary, issues & challenges

- We must meet very stringent accuracy and stability requirements which can only be achieved if we establish a uniform core network of about 32 sites with not only uniform geographical distribution, but **primarily** a **uniform data yield in quantity, quality and continuity**;
- Our task is dual, we must deliver the origin and scale of the TRF, but at the same time, our tracking of the GNSS constellations must ensure they are **calibrated, properly scaled and centered at the TRF origin**;
- We will have numerous additional targets, but we can achieve our goals with the adoption of the **proper concept of operations**;
- We must stop showing nice plots including sites that have not delivered data in decades;
- Above all, take advantage of all of our new and **better targets** to ensure the generation of the **most accurate data** for all of the above tasks.

Backup Slides

LAGEOS Data in ITRF2014: 1993 - 2014