SLR and the Next Generation Global Geodetic Networks

Erricos C. Pavlis & Magdalena Kuźmicz-Cieślak
Joint Center for Earth Systems Technology
University of Maryland, Baltimore County
and NASA Goddard, 698

Motivation

- Space techniques are **indispensable** for the development of the terrestrial reference frame and for geodetic metrology
- The current state-of-the-art does not meet science requirements due to **poor area coverage** and **aging equipment**
- To meet the stringent future requirements (e.g. GGOS), we need to **design a new network** and deploy **modern hardware systems**

Outline

- SLR network
  - Present status
  - Future developments
- SLR contribution to ITRF
  - Accuracy assessment
  - Next generation TRF goals
- Simulations for network optimization
  - SLR & VLBI case studies
  - 8, 16, 24 and 32-site network results
- The next phase
  - Taking advantage of large & fast computer clusters (NASA's Columbia grid) for targeted test cases

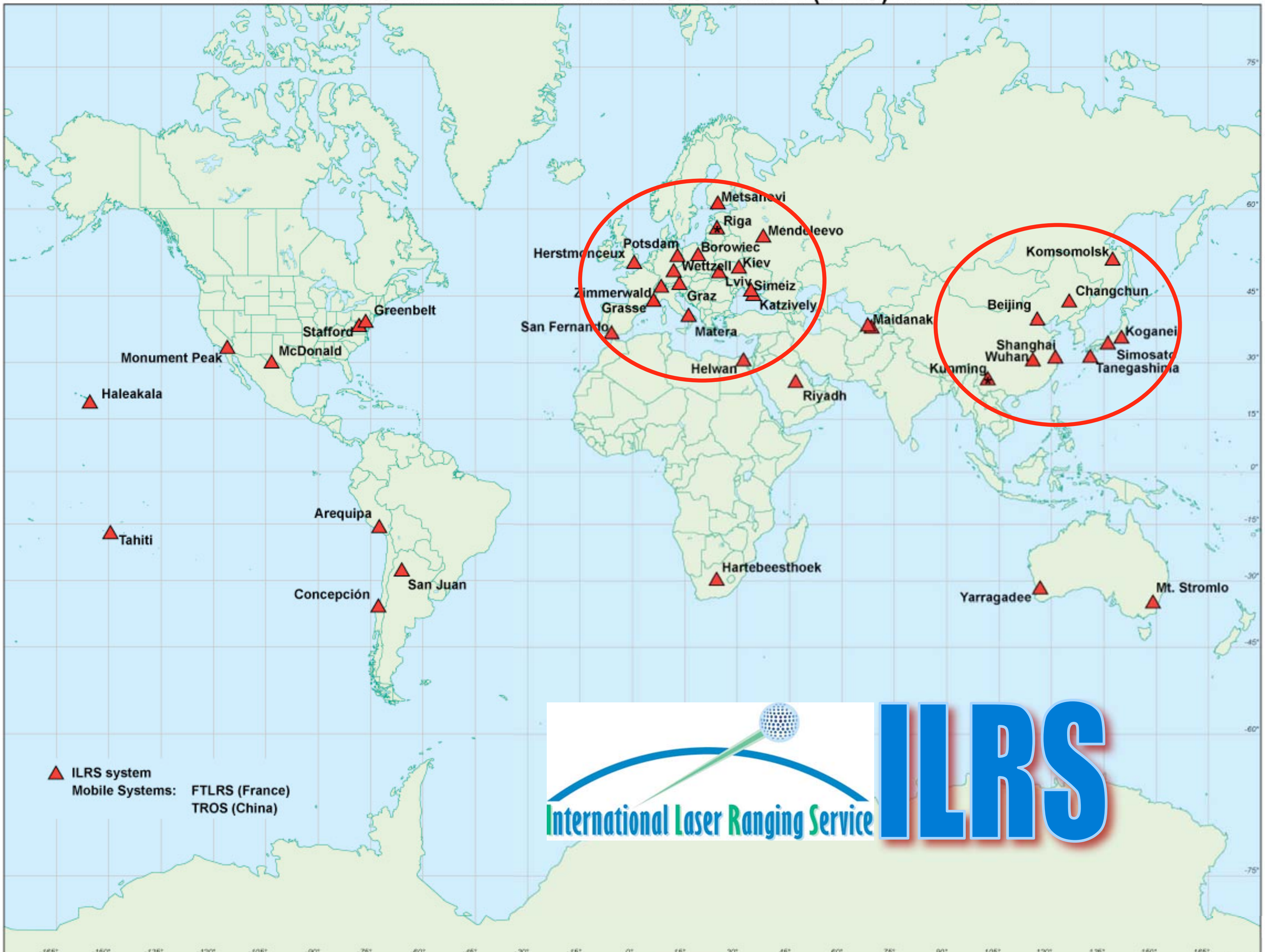
Multiple techniques to solve the puzzle

- High precision geodesy is very challenging
  - **0.1 mm/yr stability required for sea level monitoring**
- Fundamentally different observations with unique capabilities
- Together provide redundancy, cross validation and increased accuracy for TRF
- Strength from improvement of techniques and integration of techniques

Technique Signal Source Obs. Type	**VLBI** Microwave Quasars Time difference	**SLR** Optical Satellite Two-way range	**GPS** Microwave Satellites Carrier phase
Celestial Frame UT1	**Yes**	No	No
Scale	**Yes**	**Yes**	Yes
Geocenter	No	**Yes**	Yes
Geographic Density	No	No	**Yes**
Real-time	No	No	**Yes**
Decadal Stability	**Yes**	**Yes**	Yes

- Fundamental prerequisite: ***Well-distributed, co-located networks with accurate ties***

INTERNATIONAL LASER RANGING SERVICE (ILRS) NETWORK



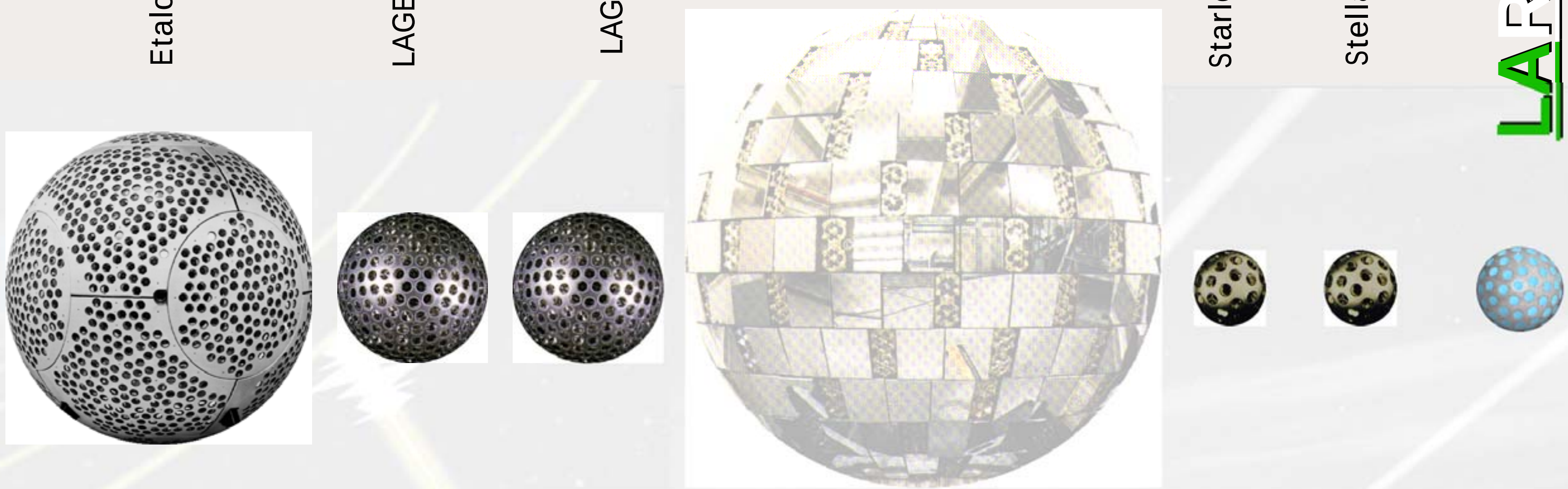
NGSLR Specifications

- Single photon operational regime
- Narrow laser divergence
- Multi-kiloHertz operation (with multiple fires in flight)
- Autonomous, independent operations
- Improved epoch timing
- More stable / better defined pointing and ranging calibrations
- Eye-safe operation, LEO to GNSS
- Predictions and collected data submission via WWW (near real-time)
- Some new applications :
  - kHz scanning of satellite surface (allows for determination of spin-axis and rate);
  - Atmospheric seeing measurements along laser beam;
  - kHz Time Transfer (test using AJISAI and Graz system);
  - kHz LIDAR (under implementation now in Graz);
  - Detection of atmospheric layers, clouds, aircraft vapor trails;
  - …

GGOS http://www.ggos.org

Sample of SLR Satellite Constellation

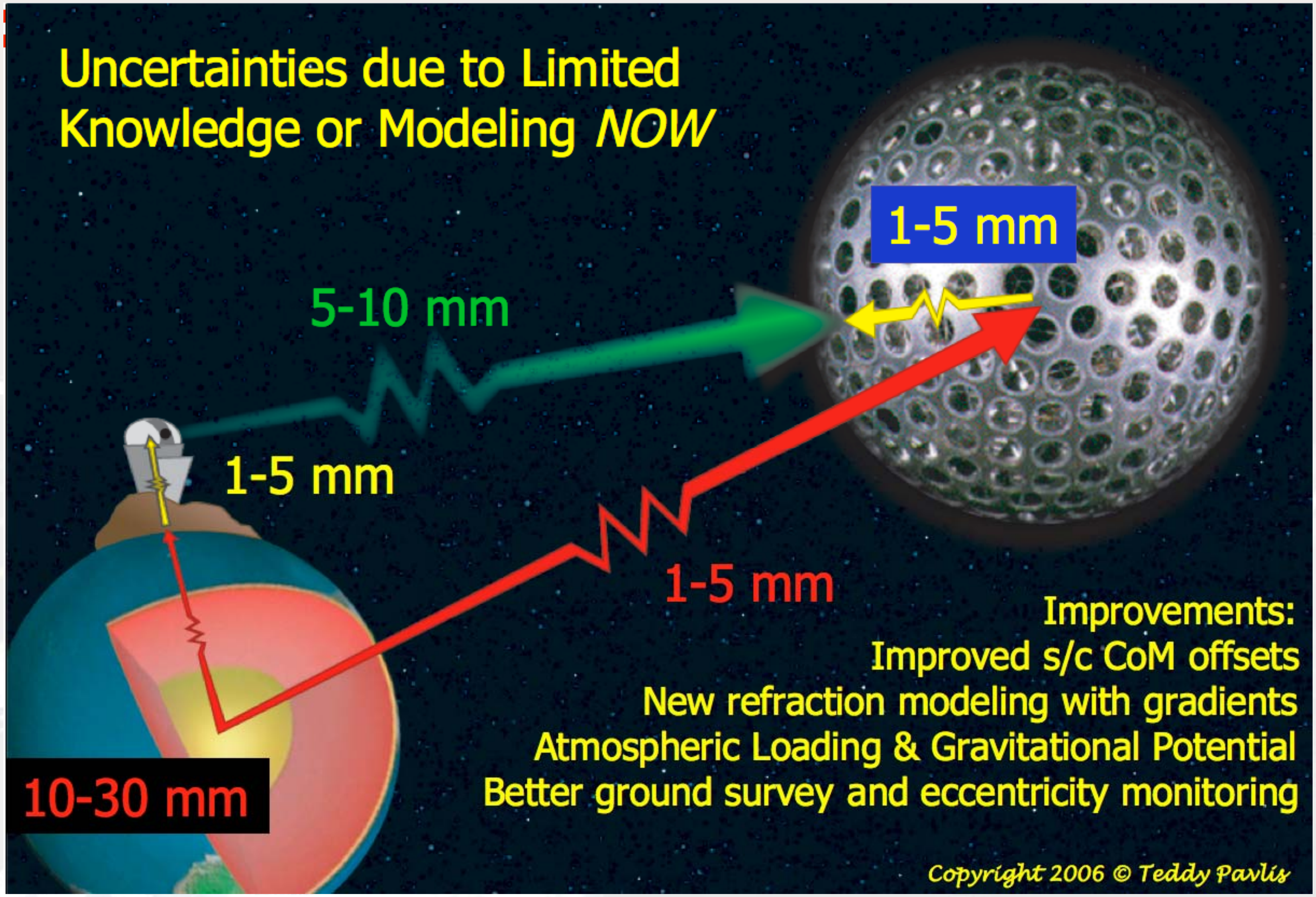
(Geodetic Satellites)



	Etalon-I & -II	LAGEOS-1	LAGEOS-2	Ajisai	Starlette	Stella	LARES
Inclination	64.8°	109.8°	52.6°	50°	50°	98.6°	~70°
Perigee ht. (km)	19,120	5,860	5,620	1,490	810	800	~1500
Diameter (cm)	129.4	60	60	215	24	24	36
Mass (kg)	1415	407	405.4	685	47.3	47.3	400

LARES $_{A/m}$ = 0.36 x LAGEOS

Current SLR Model Status



Design of the Future Network

- SLR and VLBI optimal combination (first step):
  - ✓ Simulate SLR and VLBI data for 2004 from four networks of 8, 16, 24 and 32 sites
  - ✓ Assume system performance of NGSLR and VLBI2010
  - ✓ **Simulation of a 1-year period with SLR and VLBI data (<u>eventually to be extended to ~ 6 years</u>)**
  - – Inclusion of GNSS, DORIS, etc. later, in a future step

Simulation Goal

- **Which network will deliver consistently and reliably:**

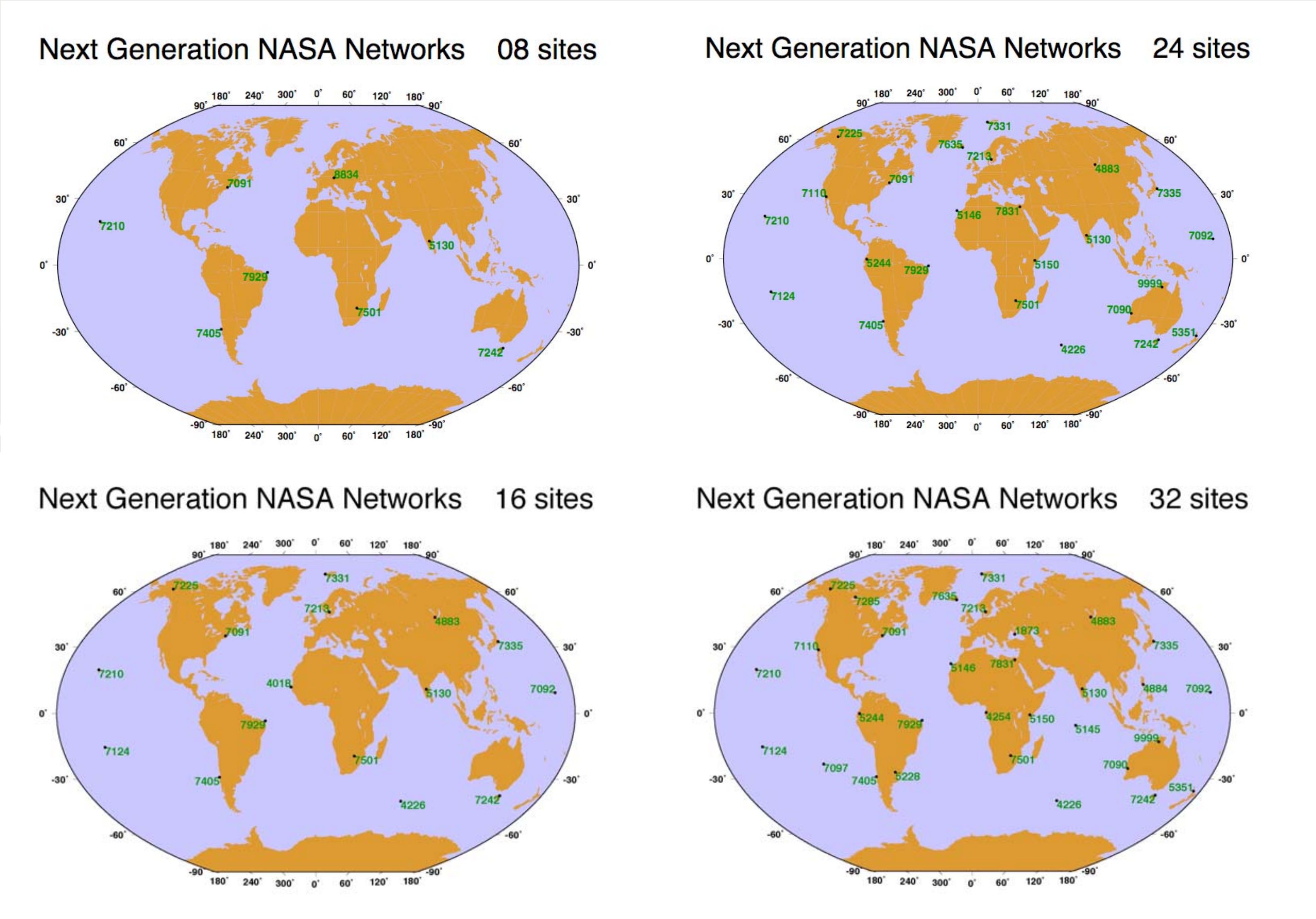
<1 mm epoch position and

< 0.1 mm/y secular change

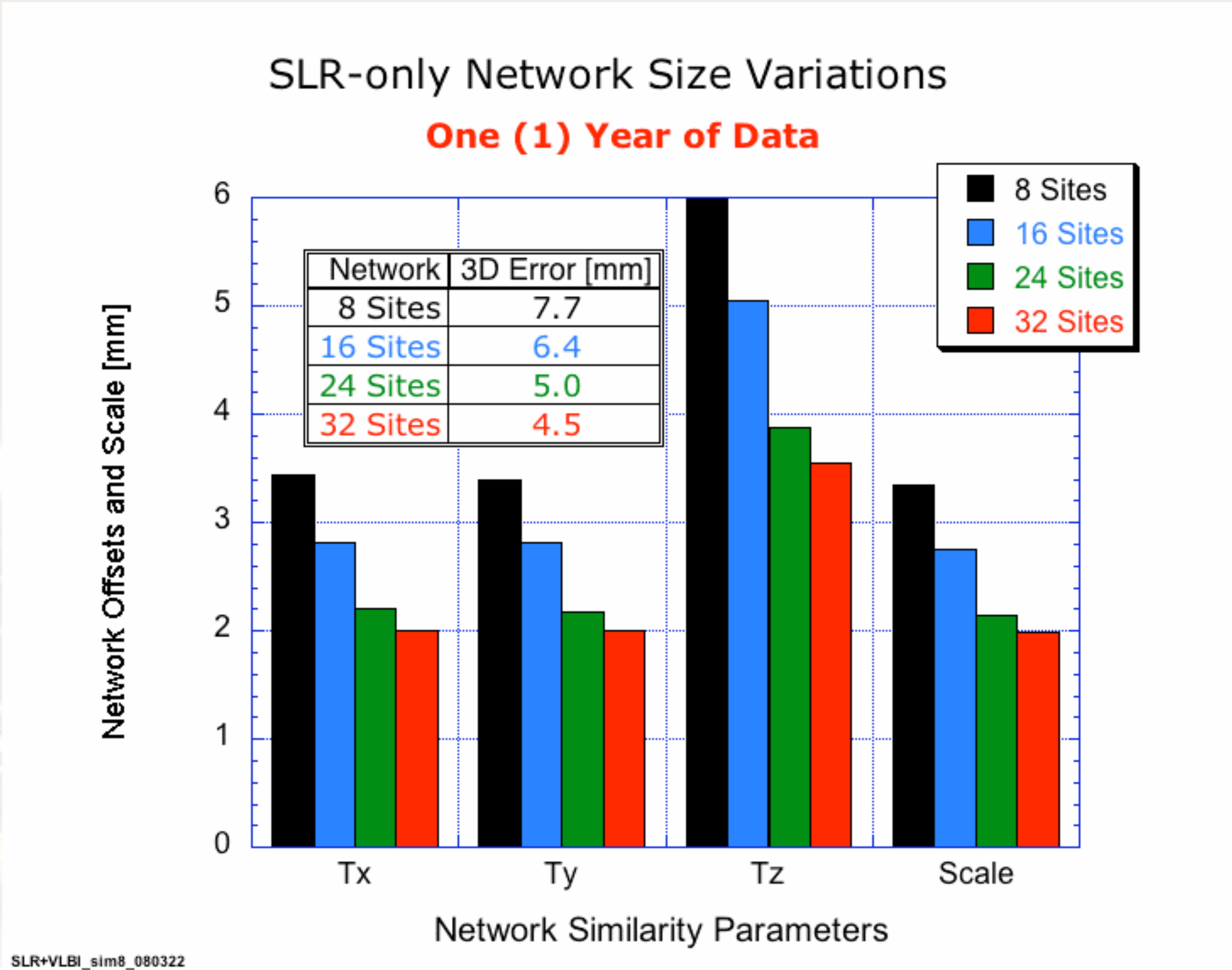
One-year SLR & VLBI Simulation

- Primarily a test to verify the simulation process end-to-end
- Four networks with 8, 16, 24 and 32 sites
- Only site positions and EOP estimated from one year of data
- Scaled error covariance projected on the 7 TRF parameters
- Assuming that errors across years are uncorrelated, we project the one year results to estimate the number of years to reach our accuracy goals

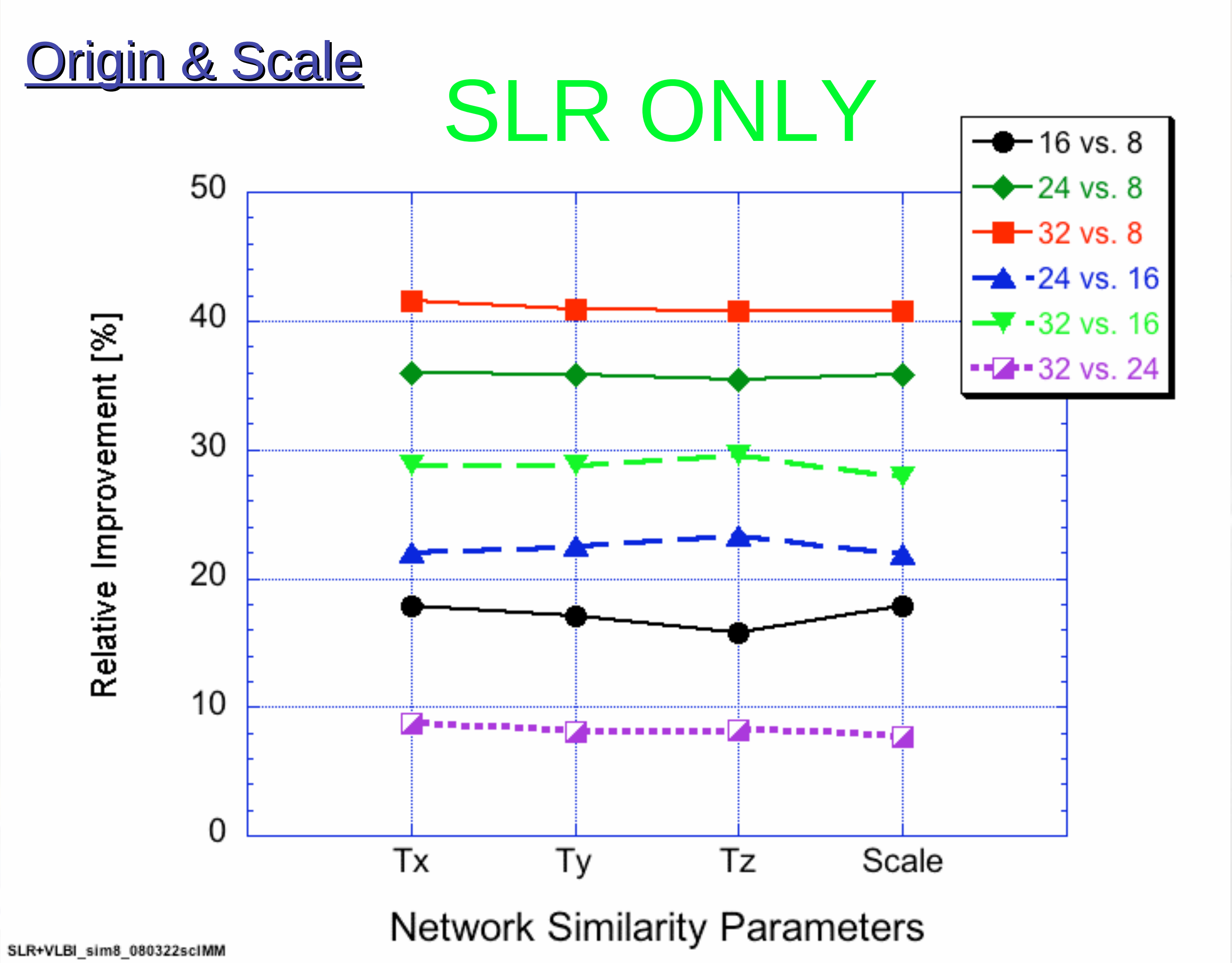
Network variants (8 ⇒ 32)



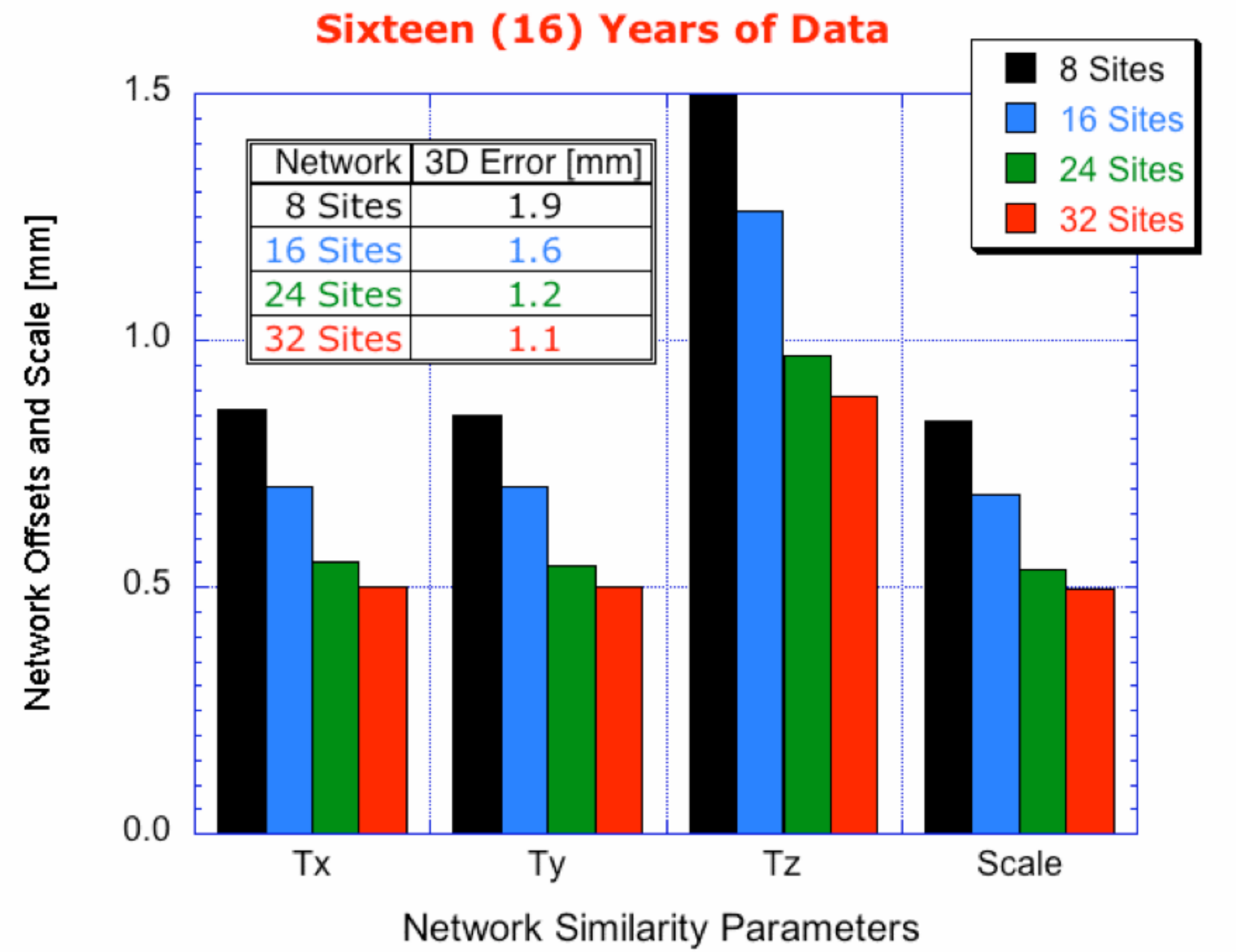
One-year Simulation Results



One-year Simulation Results



4-Networks Results for Origin/Scale



One-year Simulation Results

- The simulation validates the real world experience with 8 sites
- The biggest improvement is seen when going from 8 to 16 sites
- The largest impact of an 8 site addition in the origin is seen when going from 16 to 24 sites (~22%), and the least, from 24 to 32 (~8%)
- Results for a 13 year time span (corresponds to ITRF2005) show a 4- or 5-fold improvement compared to what we estimate for ITRF2005
- A projection for a 16 year time span (*ITRF2008*?) shows that a 32 site network approaches the GGOS goal of accuracy in the origin and scale

Some Simulation Issues:

- We currently work with two techniques only (SLR & VLBI)
- Optimal network size with constrained system performance and background model quality
- Assuming perfect site-ties
- Criterion is "TRF" quality: origin, scale and orientation
- Need to consider temporal variations of the TRF parameters
- Solutions to be repeated with the addition of local tie errors with varied weighting schemes
- We will use the 16 site network to investigate the effect of choosing alternate sites on the results (varying the uniformity of the network)

Summary

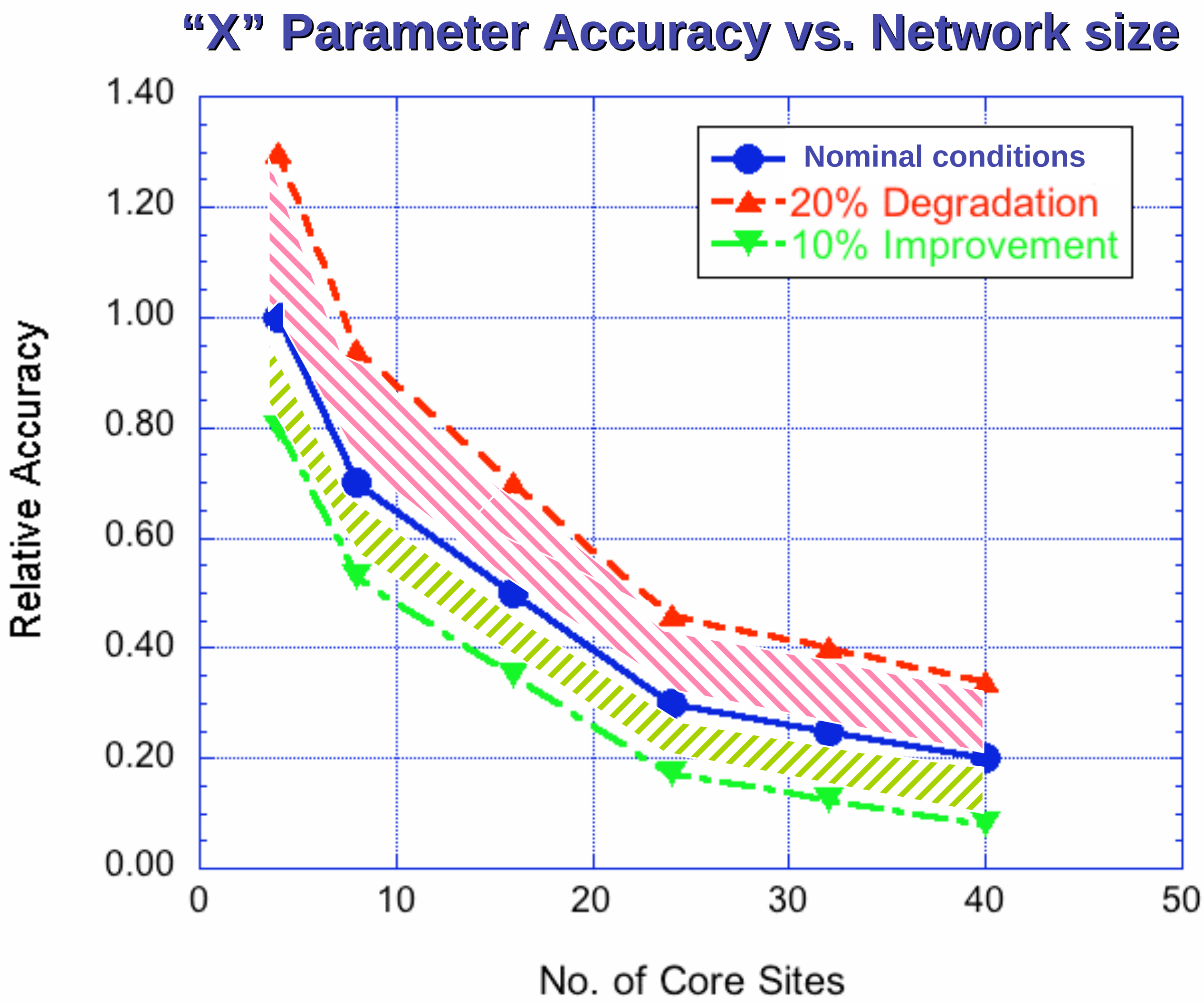
- Origin and scale marginally controlled by a 24 site network; when extended to 32 sites, it approaches GGOS goals (1 mm)
- Orientation seems to be less dependent on the size of the network
- The effect of additional techniques on the quality of the TRF remains to be assessed
- Need to develop scenarios of “degradation” and “improvement” of nominal design parameters

Future Work

- We may have to consider *improvement of our models, analysis techniques and our space segment* (e.g. SLR targets) to improve TRF accuracy while keeping a reasonable network size to reach our goal
- Our simulation process now runs on a faster CPU to allow a quicker turn-around of future cases (Columbia grid cluster)
- As we improve our turn-around time we plan to investigate scenarios with additional parameters varied (more satellites, different orbits, systematic errors, operational modes, etc.)

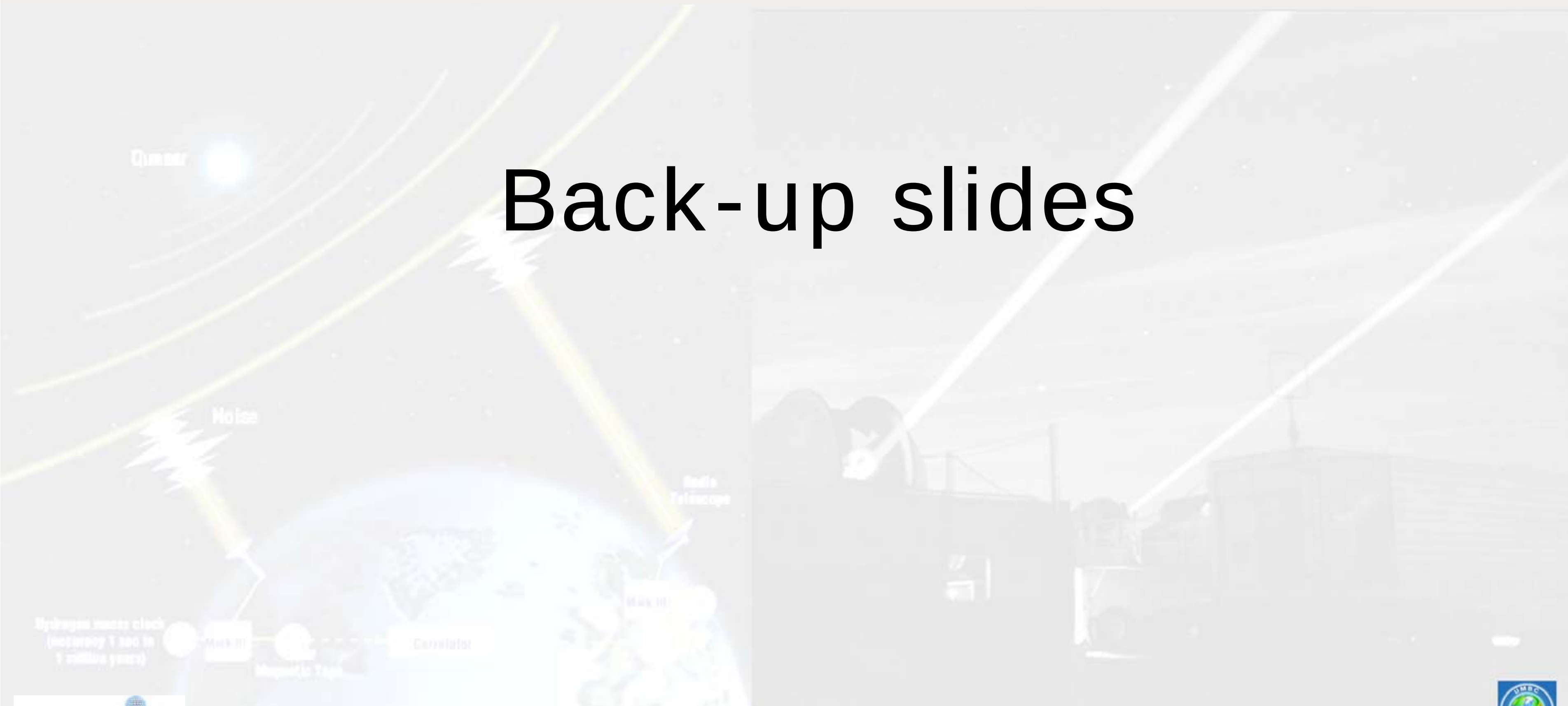
Simulation "end-product"

<1 mm epoch position and < 0.1 mm/y secular variations



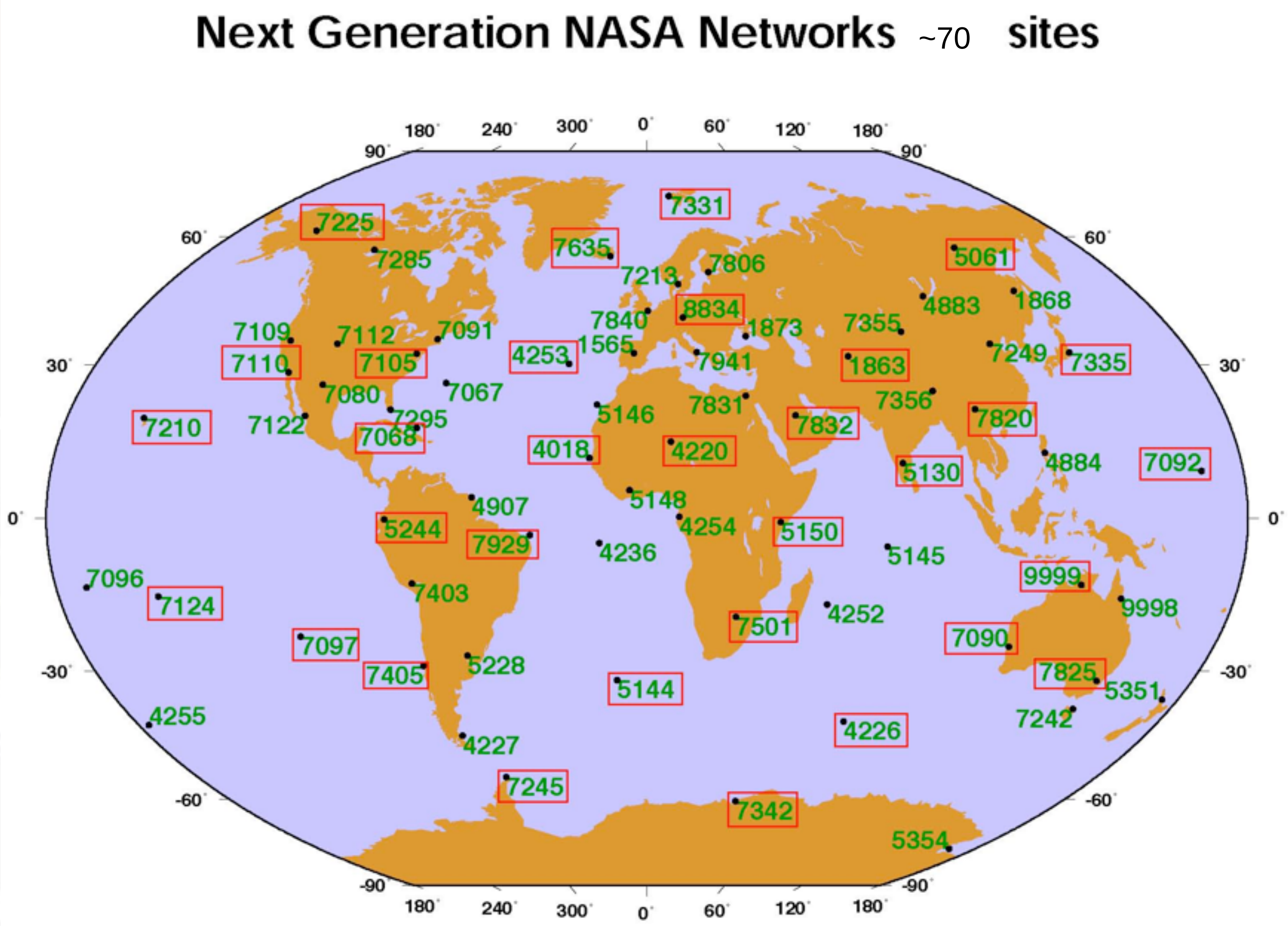
"X": Origin, Scale, EOP, their rates, etc.

Thank you!



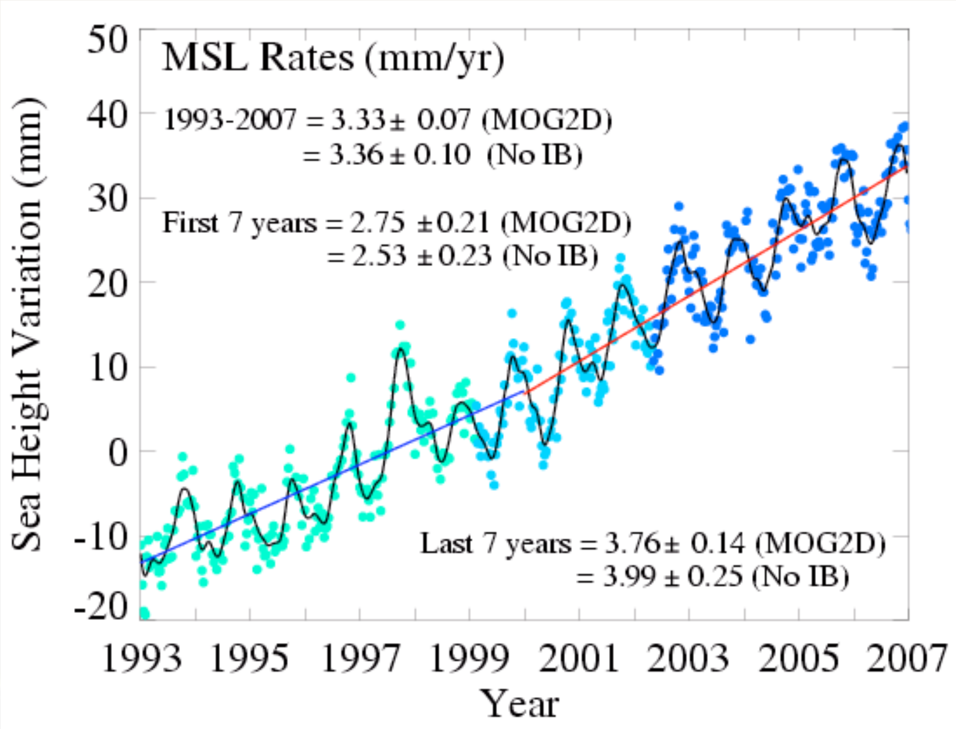
Back-up slides

Maximal Overlapping SLR-VLBI Network [32]



Why 1 mm / 0.1 mm/y?

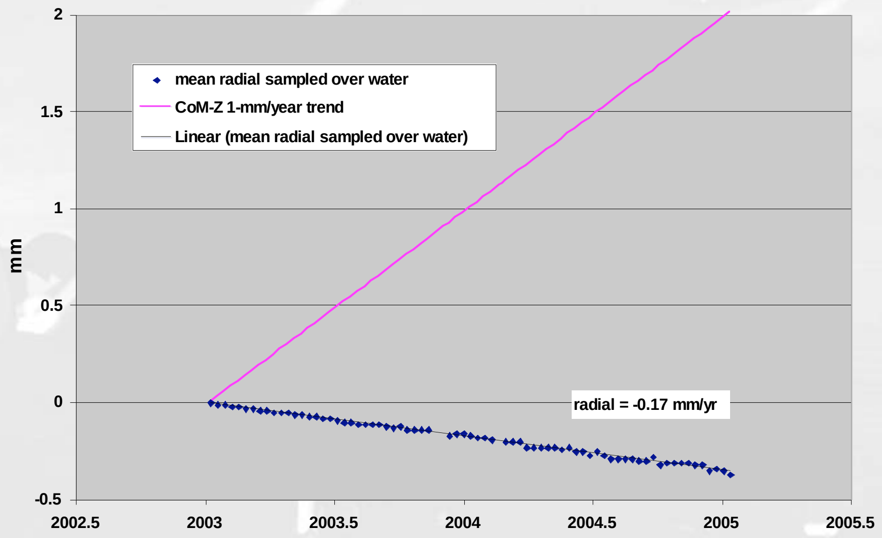
ITRF2005: 3.3 +/- 0.07 mm/yr



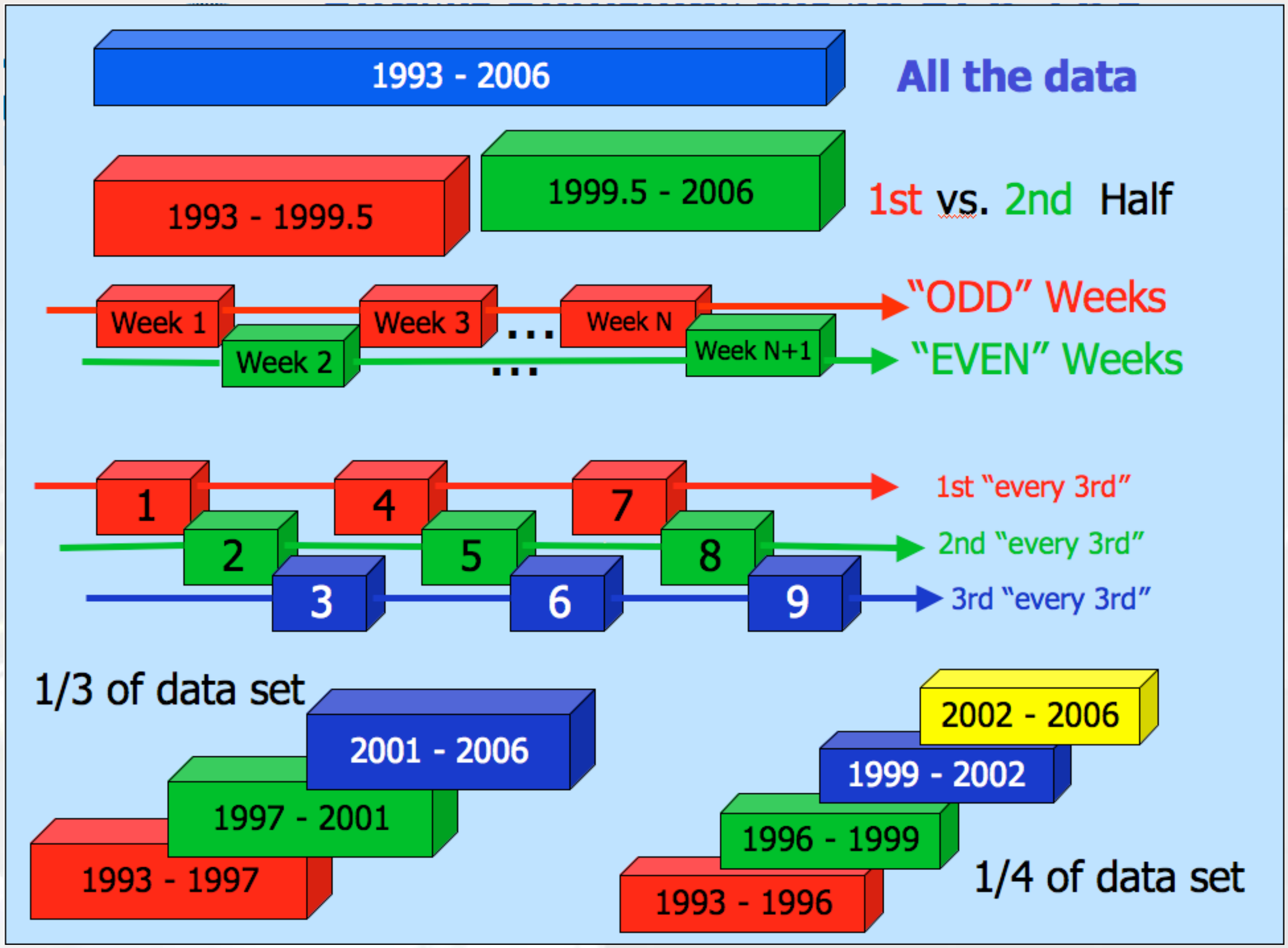
Beckley et al. (2007), *GRL, Fig 4*

For every 1 mm/y Z-trend in the TRF origin, sea-level rates are affected by ~ 0.2 mm/y

Lemoine et al. (2008),
EGU2008-A-11368



Subset Solutions for an SLR TRF



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TRF Subset Solutions Statistics [mm]

Case	ΔX	σ ΔX	ΔY	σ ΔY	ΔZ	σ ΔZ	3D |Δ|	σ 3D Δ
3 **Odd**	-8.37	±10.91	19.25	±10.78	-4.20	±10.32	**21**	**± 17**
4 **Even**	-12.62	± 8.93	5.15	± 8.82	-12.50	± 8.44	**18**	**± 16**
1 **1/2**	-41.20	±35.82	6.26	±35.38	-10.10	±33.86	**43**	**± 61**
2	1.74	± 6.76	8.06	± 6.68	7.28	± 6.39	**11**	**± 11**
15 **1/4**	-60.49	± 23.68	57.43	±23.39	7.48	±22.39	**84**	**± 40**
16	18.65	± 31.40	-57.81	±30.88	-6.19	±29.50	**61**	**± 53**
17	-0.27	± 18.01	-4.74	±17.79	15.72	±17.03	**16**	**± 31**
18	2.07	± 12.29	7.16	±12.18	1.73	±11.60	**8**	**± 21**

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