International Laser Ranging Service

SLR Science Applications and ILRS Analysis Products

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Meeting with E.W. Bergamini/INPE
GSFC, Greenbelt, November 8, 2011

International Laser Ranging Service

SLR Science and Applications

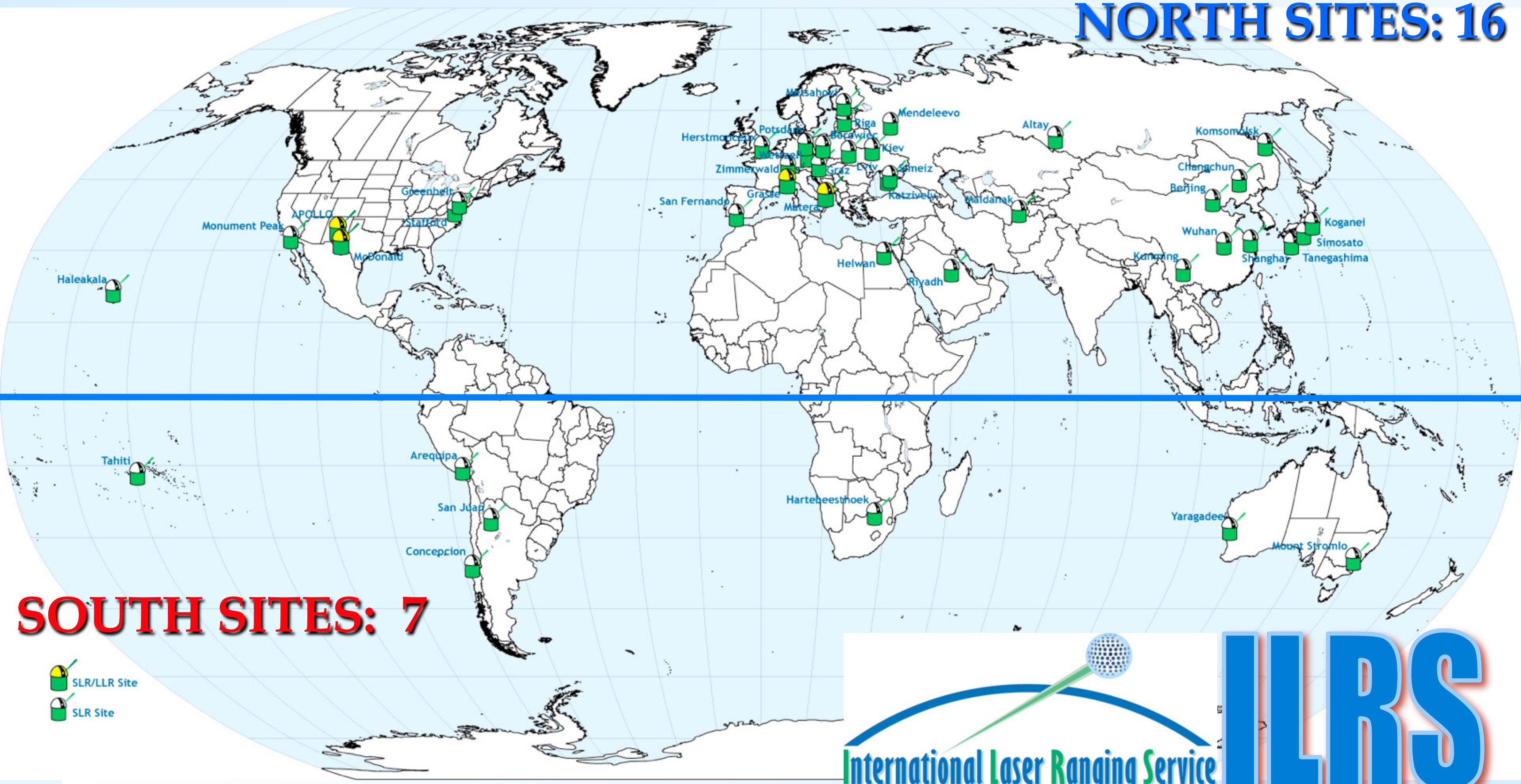
- **Primary Products (Level 1)**
  - Precision Orbit Determination (POD)
  - Time History of Station Positions and Motions & EOP

- **Science Products (Level 2)**
  - Terrestrial Reference Frame (Center of Mass and Scale)
  - Plate Tectonics and Crustal Deformation
  - Static and Time-varying Gravity Field ($C/S_{n,m}$)
  - Earth Orientation Parameters (EOP: Polar Motion, length of day)
  - Orbits and Calibration of Altimetry Missions (Oceans, Ice)
  - Total Earth Mass Distribution
  - Space Science - Tether Dynamics, etc.
  - Relativity Measurements and Lunar Science

- More than 60 Space Missions Supported since 1965
- Four Missions "Rescued" in the Past Decade

The ILRS Network

NORTH SITES: 16

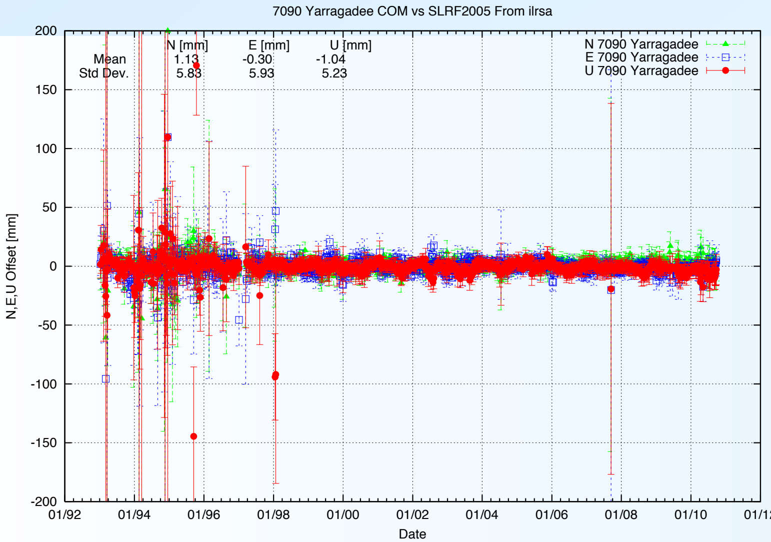


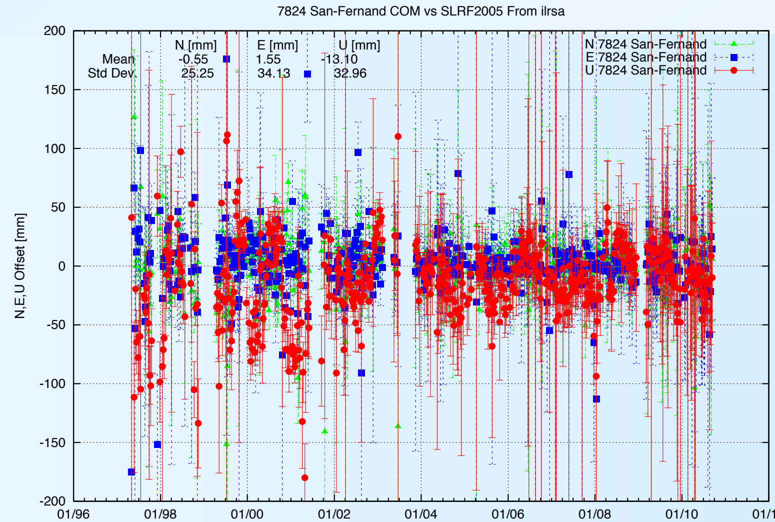
SOUTH SITES: 7

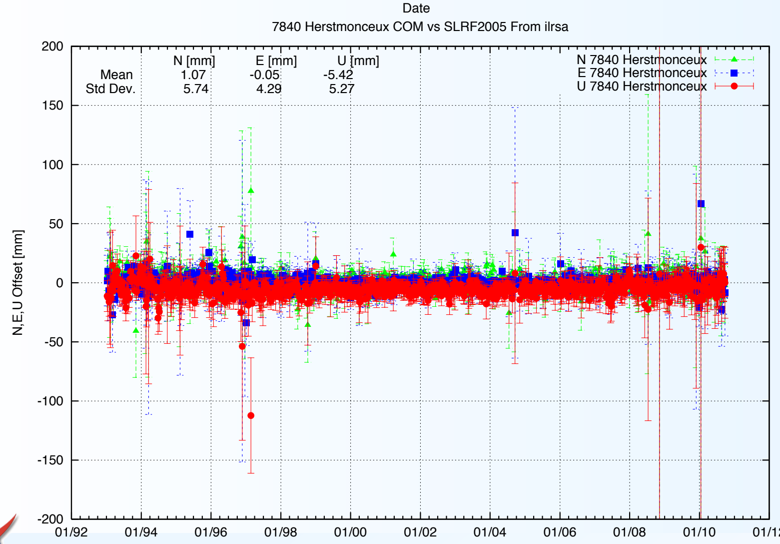
International Laser Ranging Service

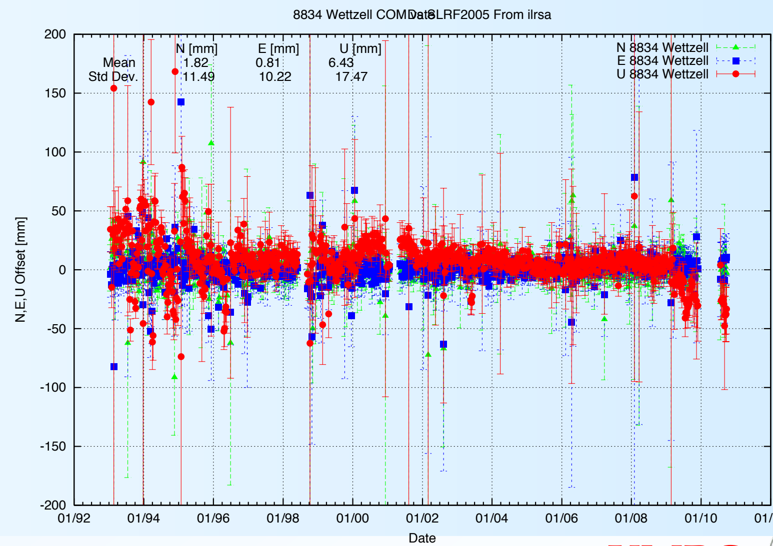
ILRS

Non-uniform System Performance Across Sites & Time

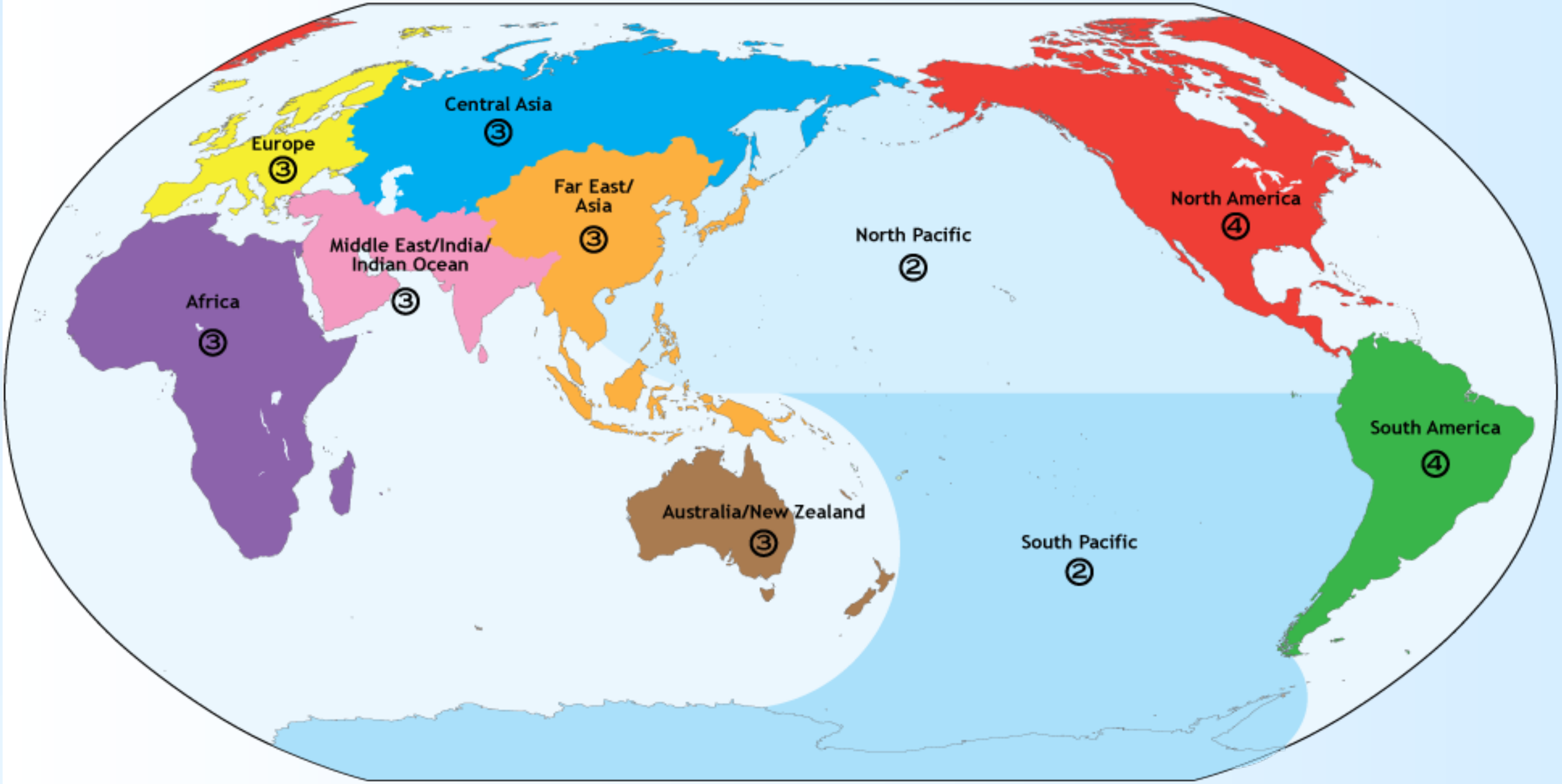




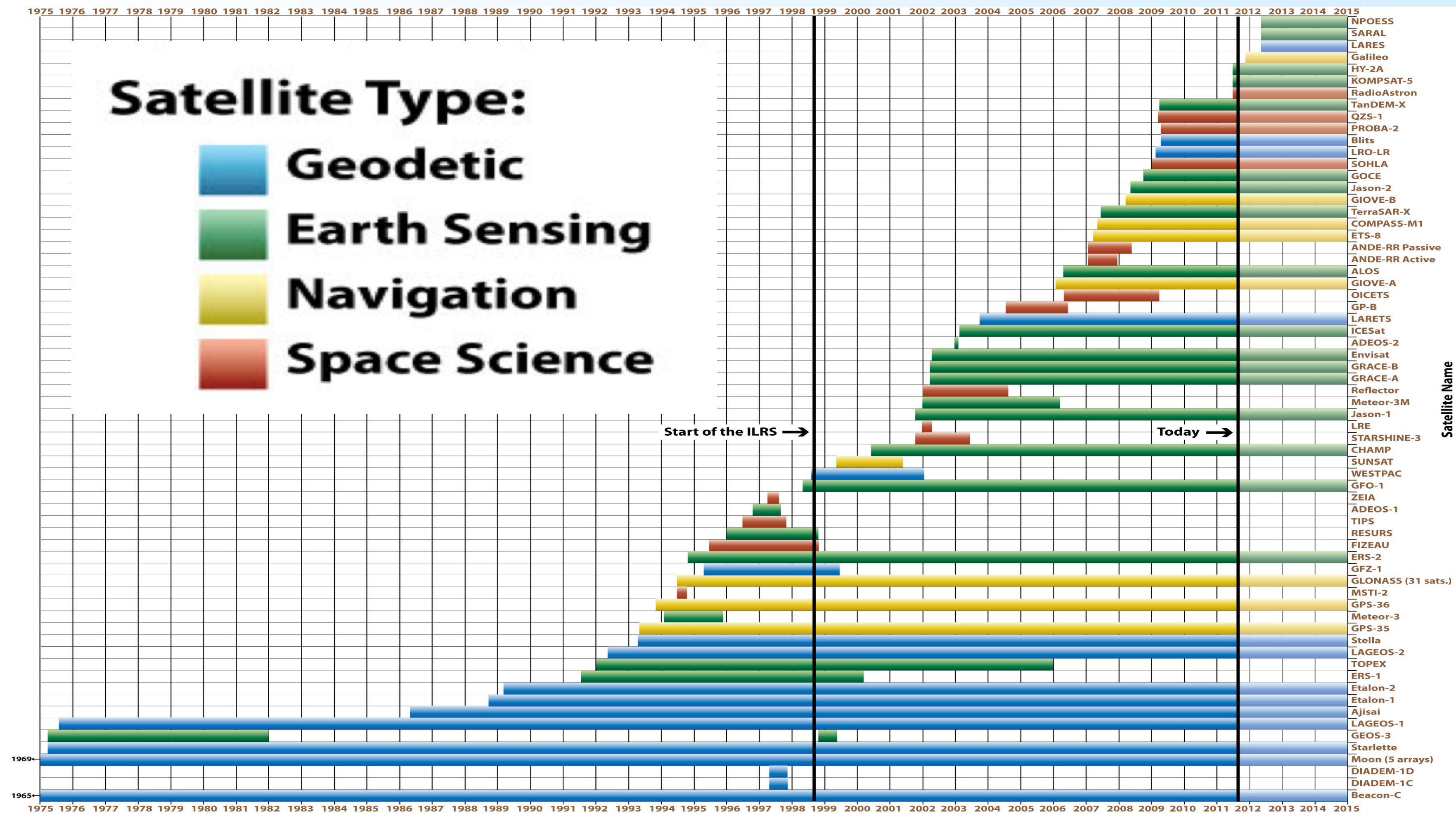




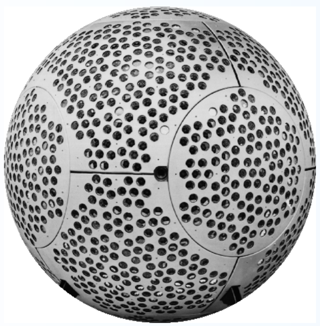
GGOS2020 Core Network



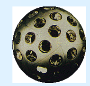
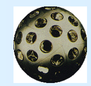
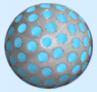
ILRS-Tracked Satellite Missions
(POD Support 3Q2011)



SLR Geodetic Satellite Constellation



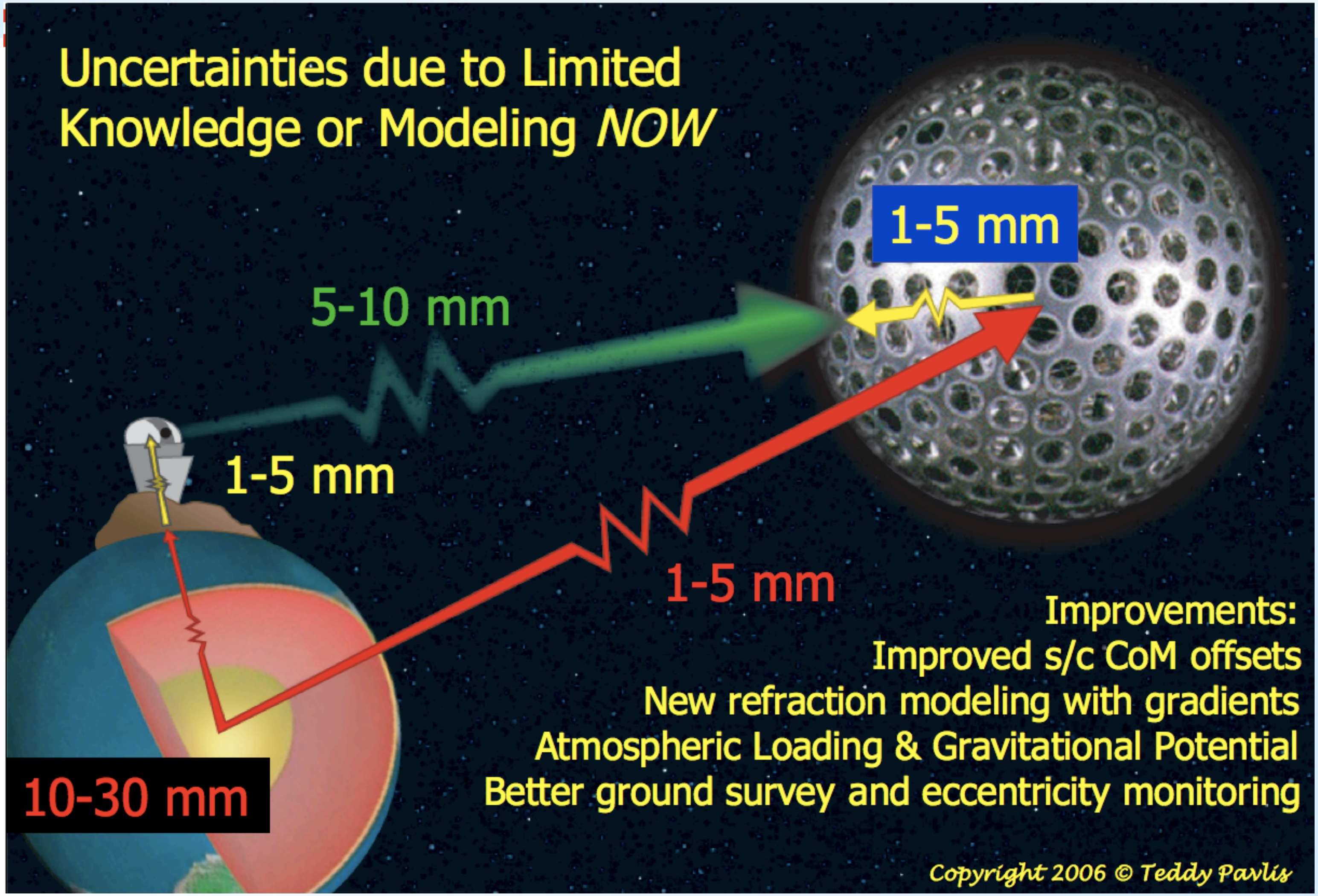


	Etalon-I & -II	LAGEOS-1	LAGEOS-2	Ajisai	Starlette	Stella	LARES
Inclination	64.8°	109.8°	52.6°	50°	50°	98.6°	~70°
Perigee ht. (km)	19,120	5,860	5,620	1,490	810	800	~1500
Diameter (cm)	129.4	60	60	215	24	24	36
Mass (kg)	1415	407	405.4	685	47.3	47.3	~400

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

Current SLR Error Budget

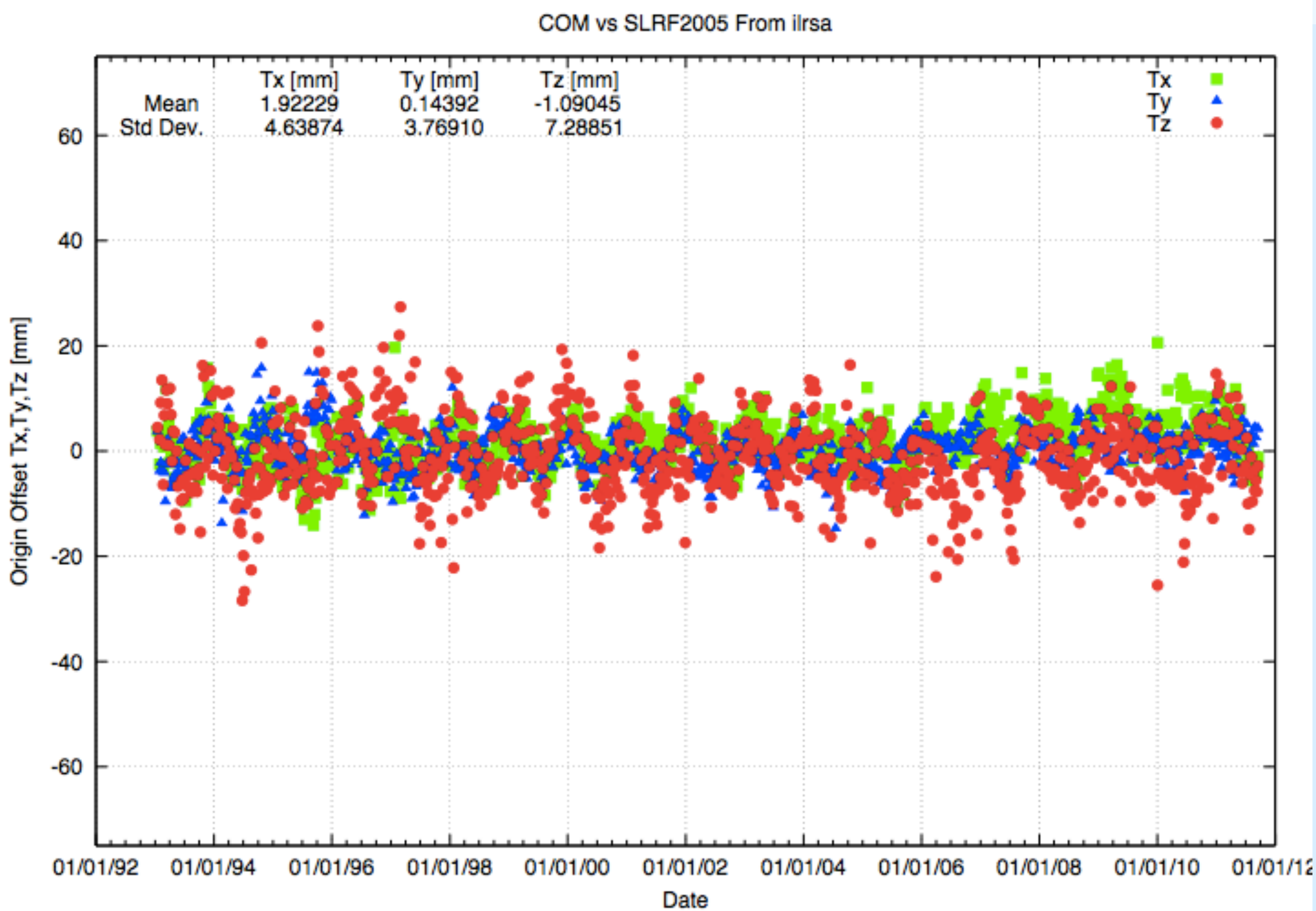


ILRS Analysis Working Group (AWG) Products and Services

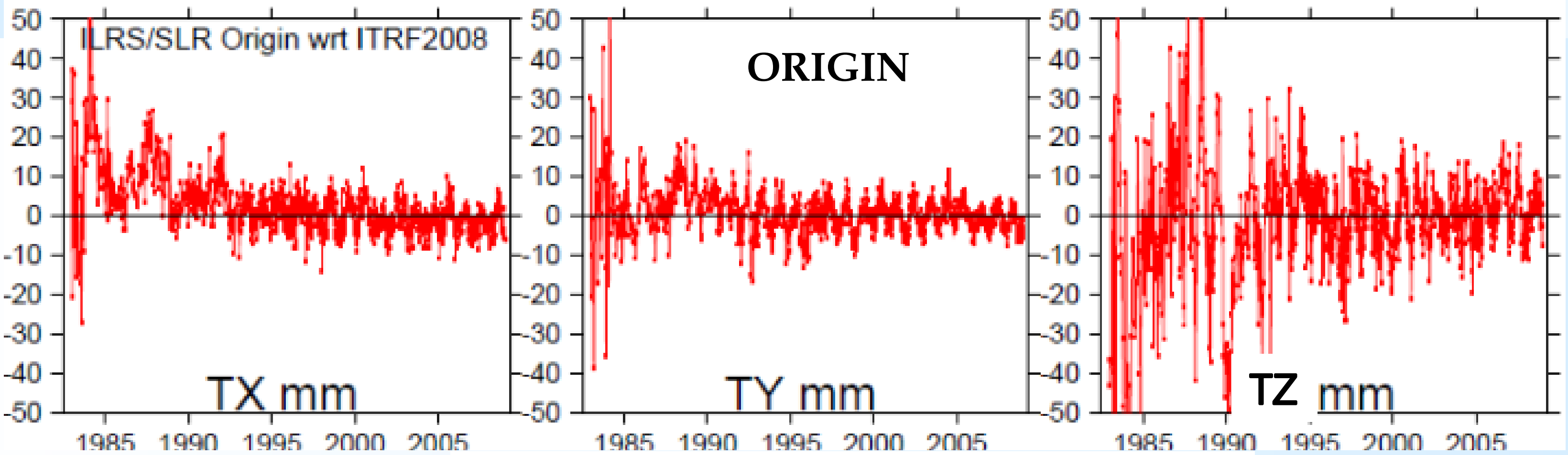
- Nine ACs and two ***CCs***:
  - ***ASI***, BKG, DGFI, ESA, GA, GFZ, GRGS, ***JCET***, and NSGF

- AWG Products and Services:
  - Operational **weekly** & **daily** products routinely delivered
  - ITRF2008-based TRF used internally (SLRF2008)
  - Daily data QC and station feedback
  - Orbit products (SP3C files)
  - Long-wavelength gravity variations (for GGOS)
  - New & returning station validation
  - Validation of new data format (CRD)

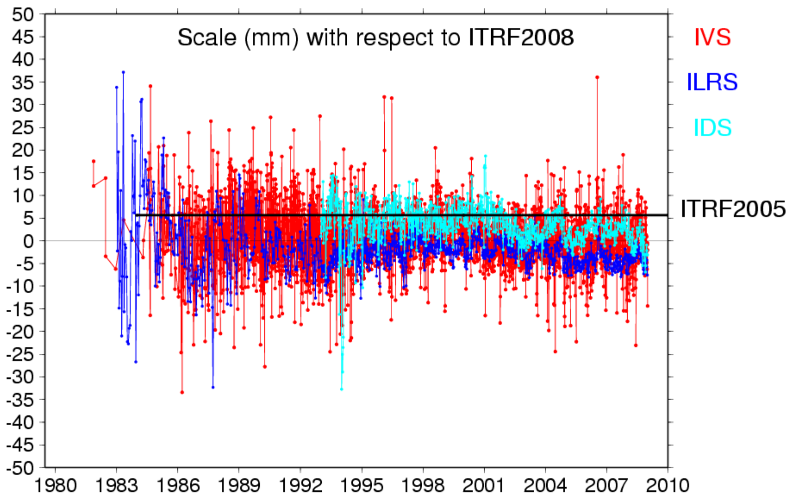
Geocenter Variation from SLR



SLR in ITRF2008

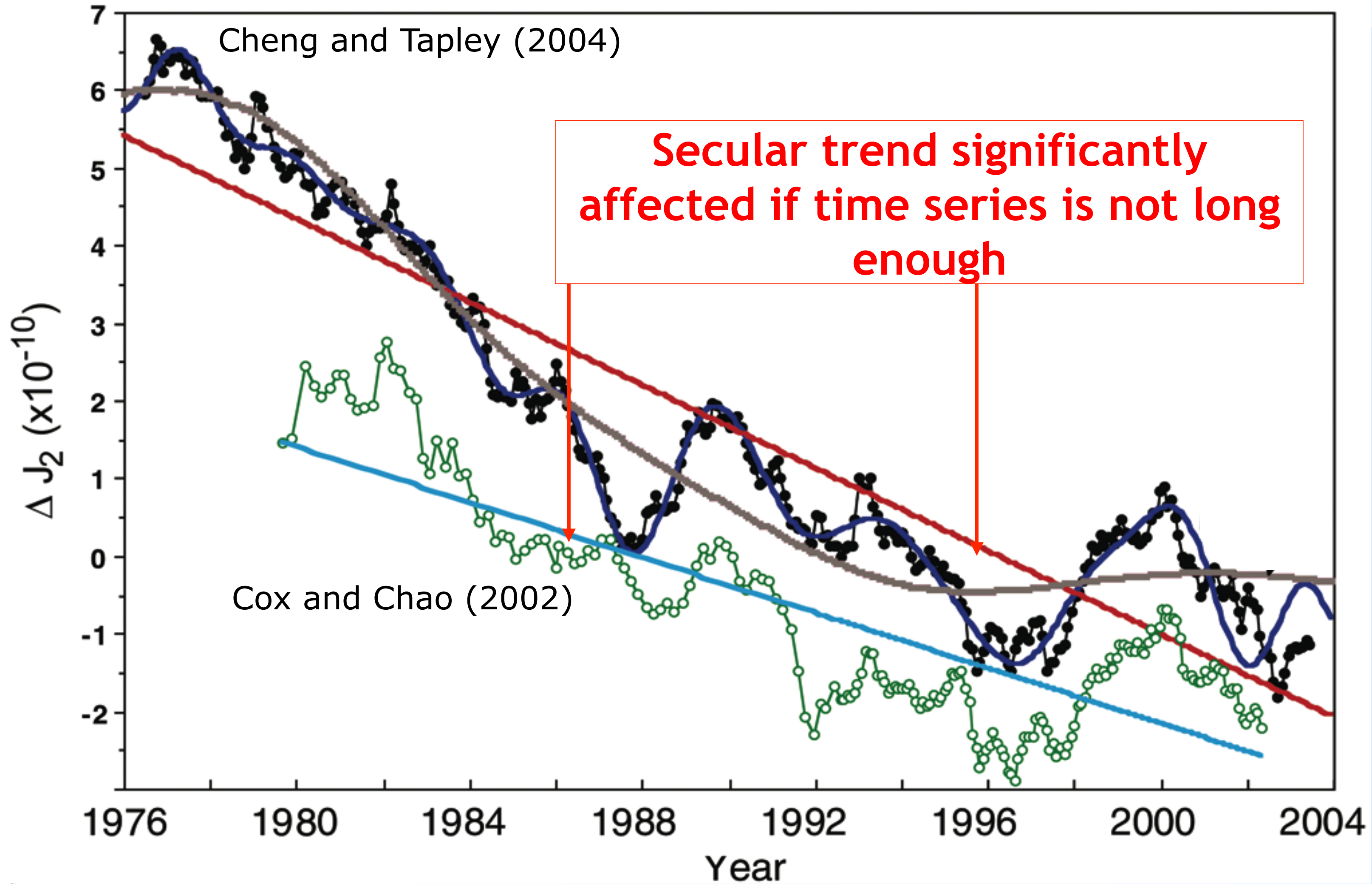


SCALE

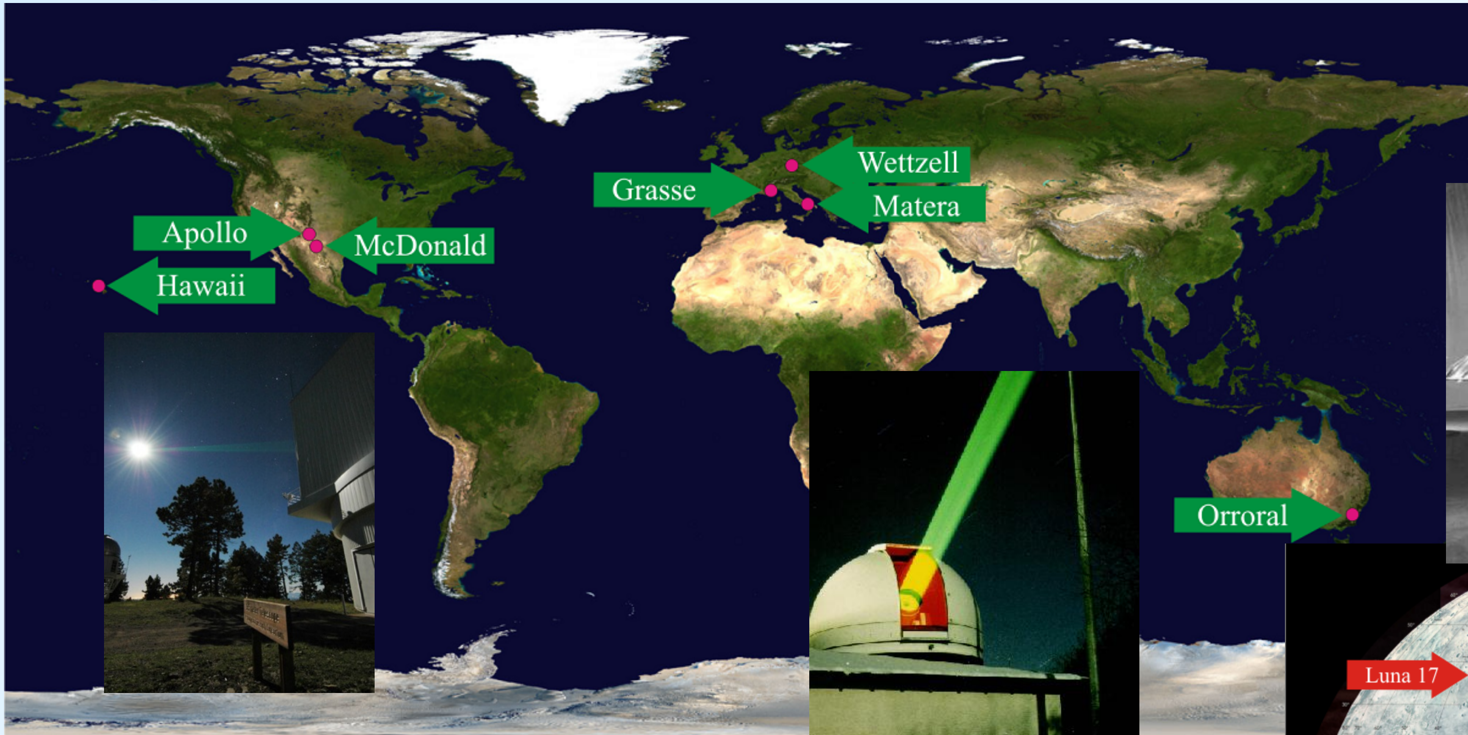


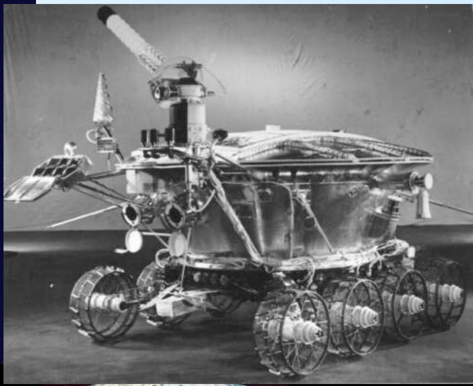
From Zuheir Altamimi, ITRS

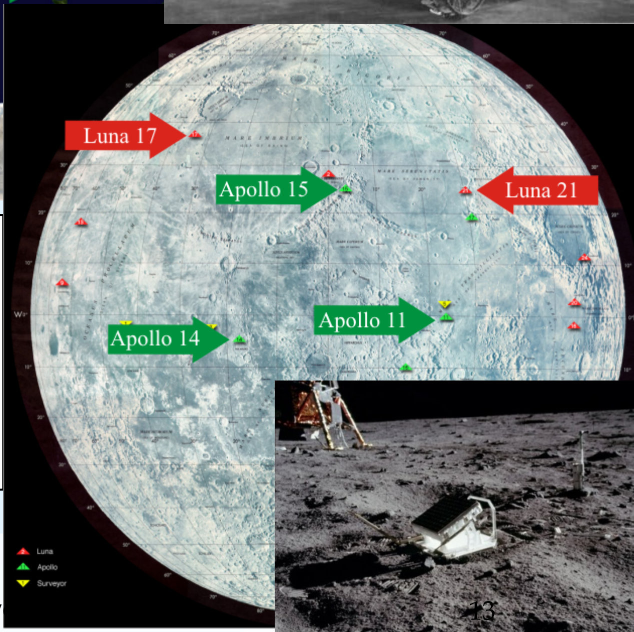
Earth's Oblateness from SLR (seasonal variation removed)



Lunar Laser Ranging (LLR)



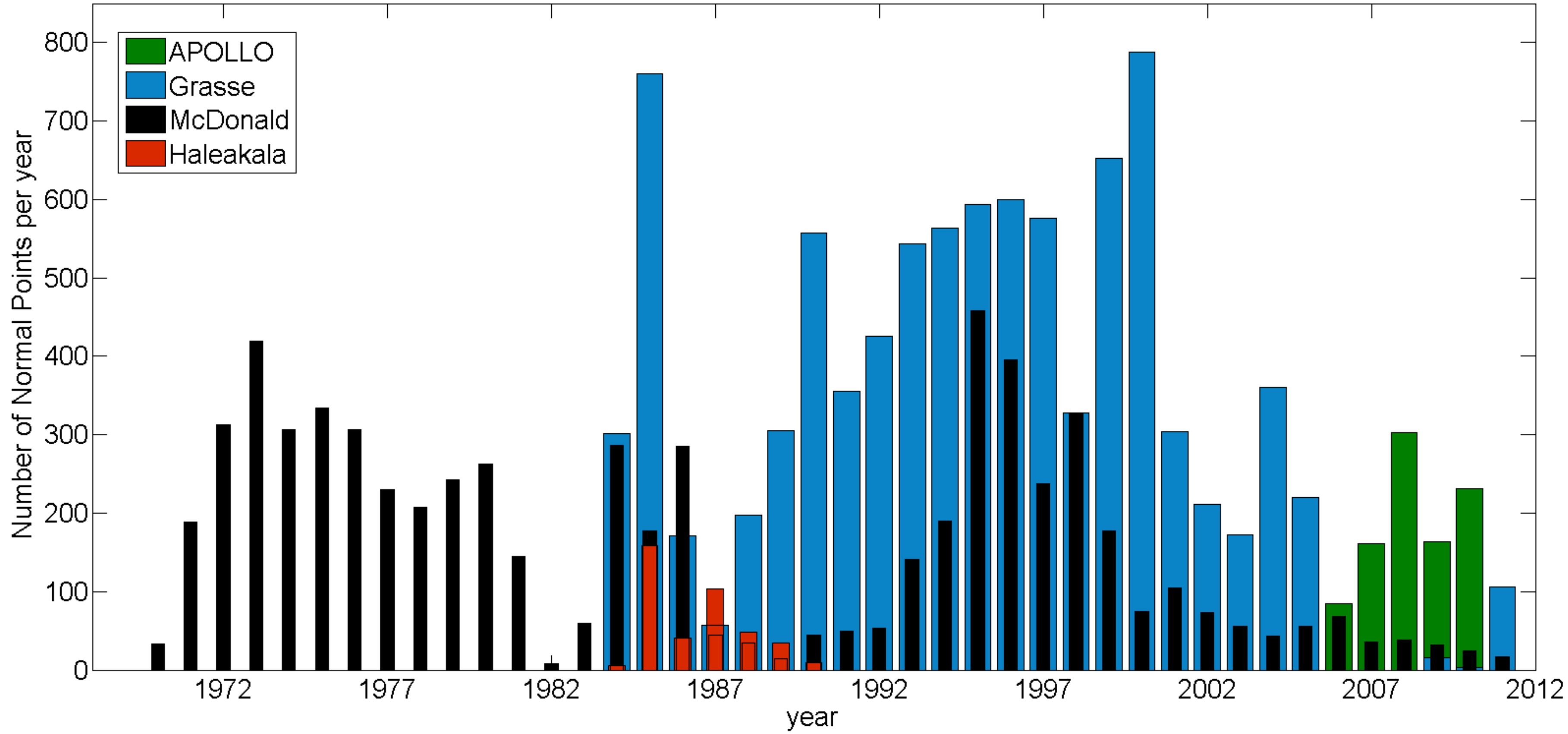




- 42 years of observations
- Post-newtonian model at cm level
- high long-term stability (orbit, reference frames, **Earth orientation**)
- relativity tests

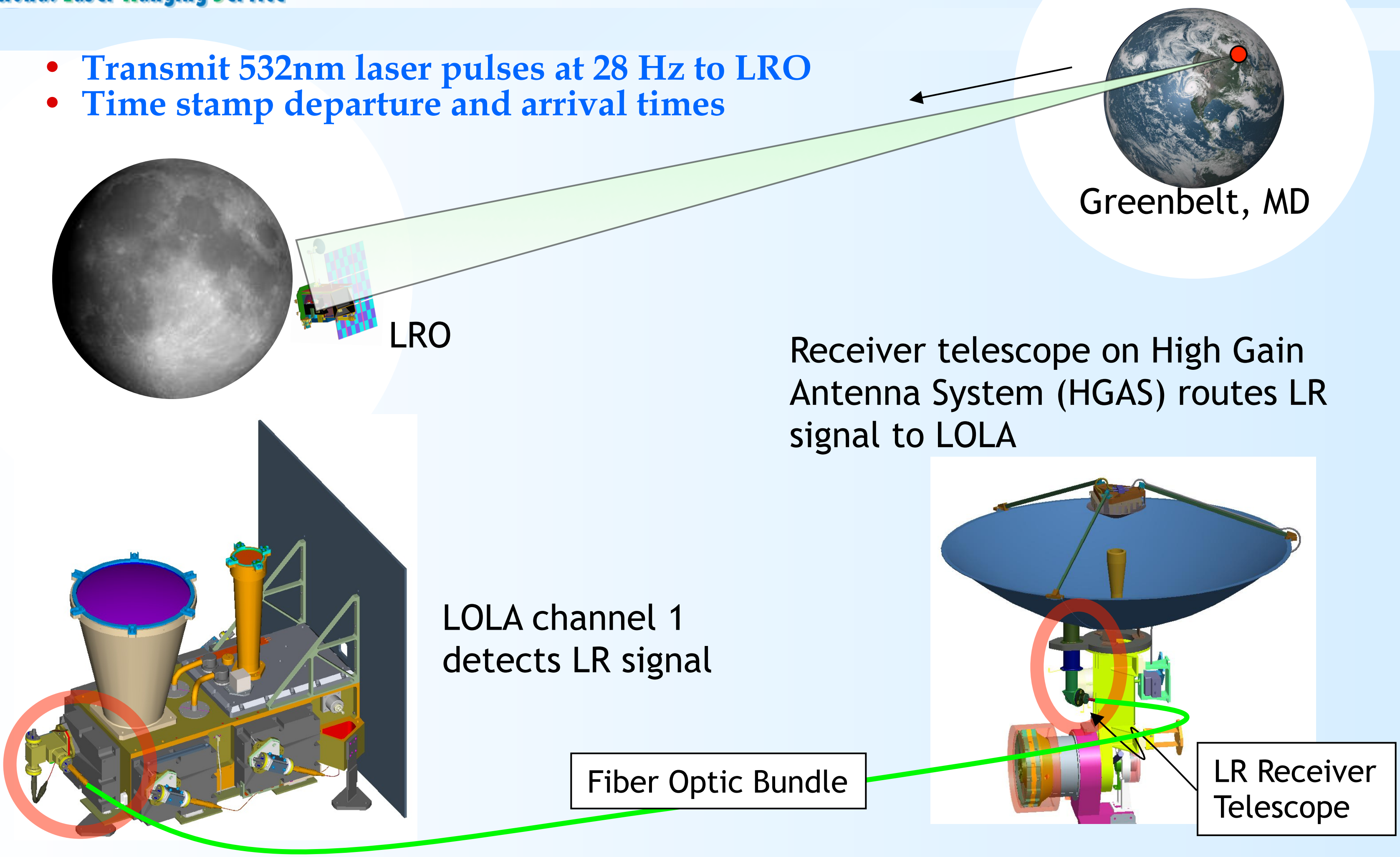
Number of LLR NPs

- **1970 - 2011: ca.17,000 normal points**



LRO Laser Ranging

- Transmit 532nm laser pulses at 28 Hz to LRO
- Time stamp departure and arrival times



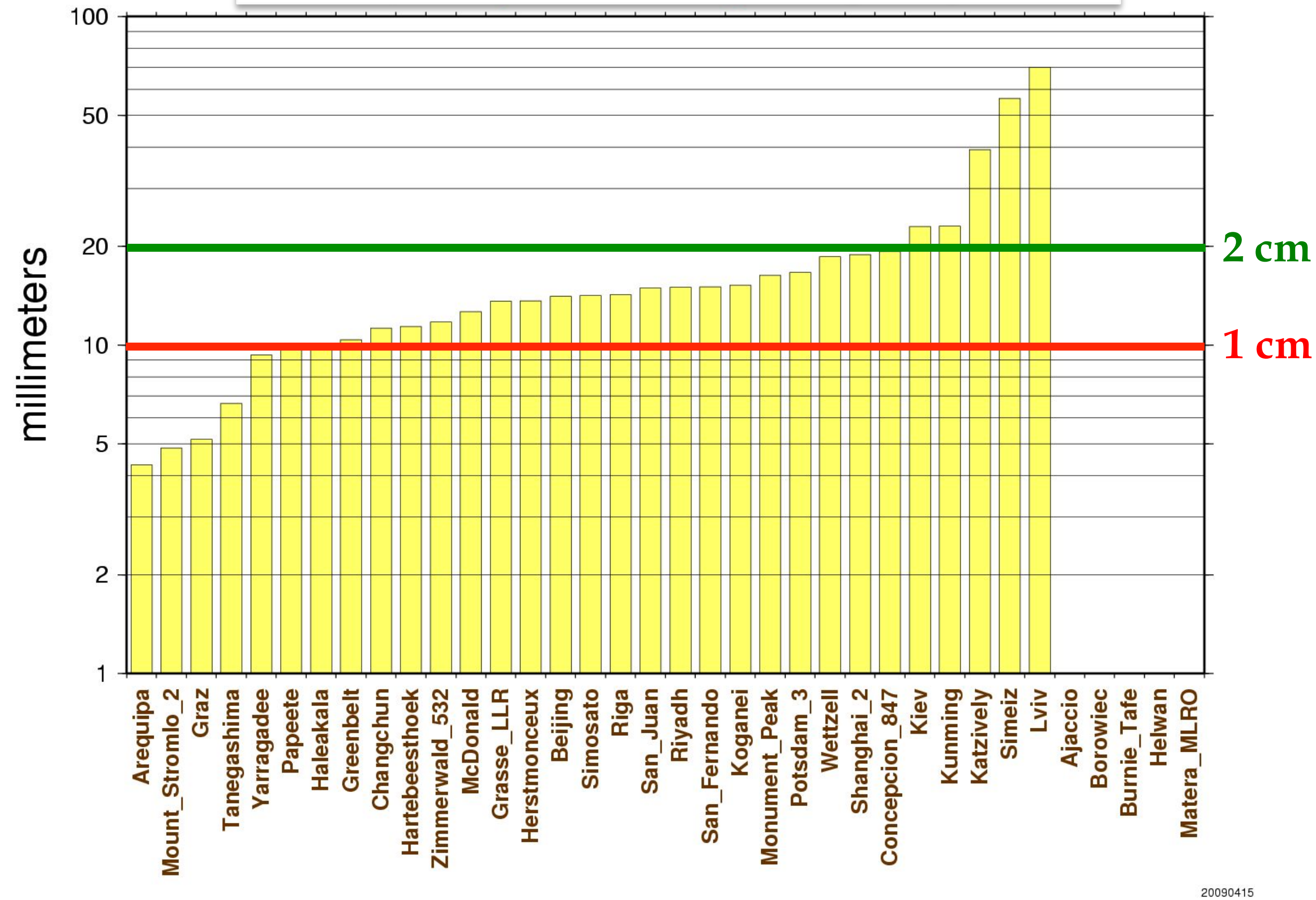
Summary

- SLR is an integral part of the Space Geodetic Networks (Past, Present and Future)
- SLR Products support a large gamut of scientific investigations in many disciplines
- The contribution of SLR to the ITRF is crucial and unique (Origin)
- The new global network will build on the past achievements and extend our capabilities to well beyond what we do today
- We are always looking for new partners!

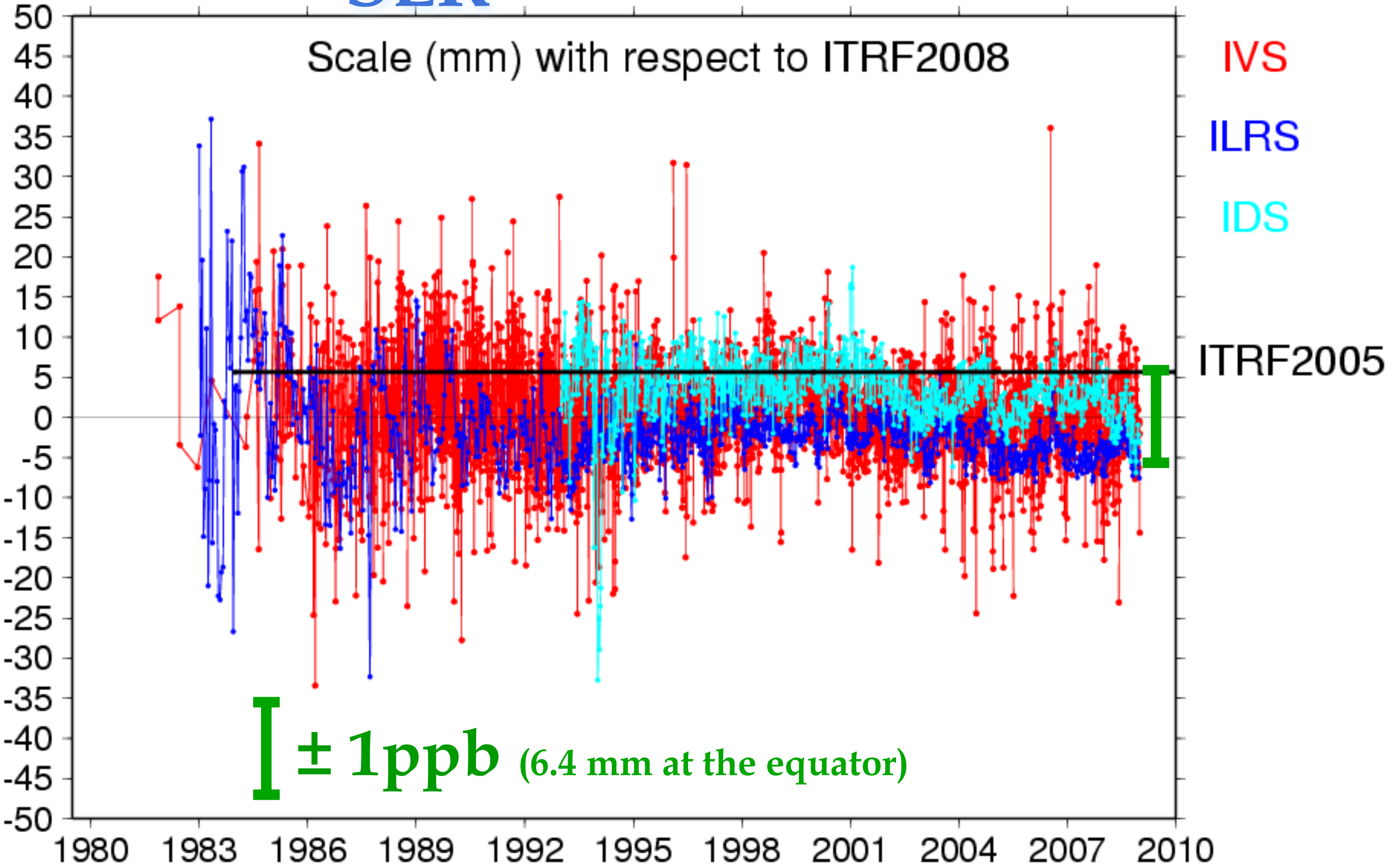
Back-up slides

ILRS-Station Performance

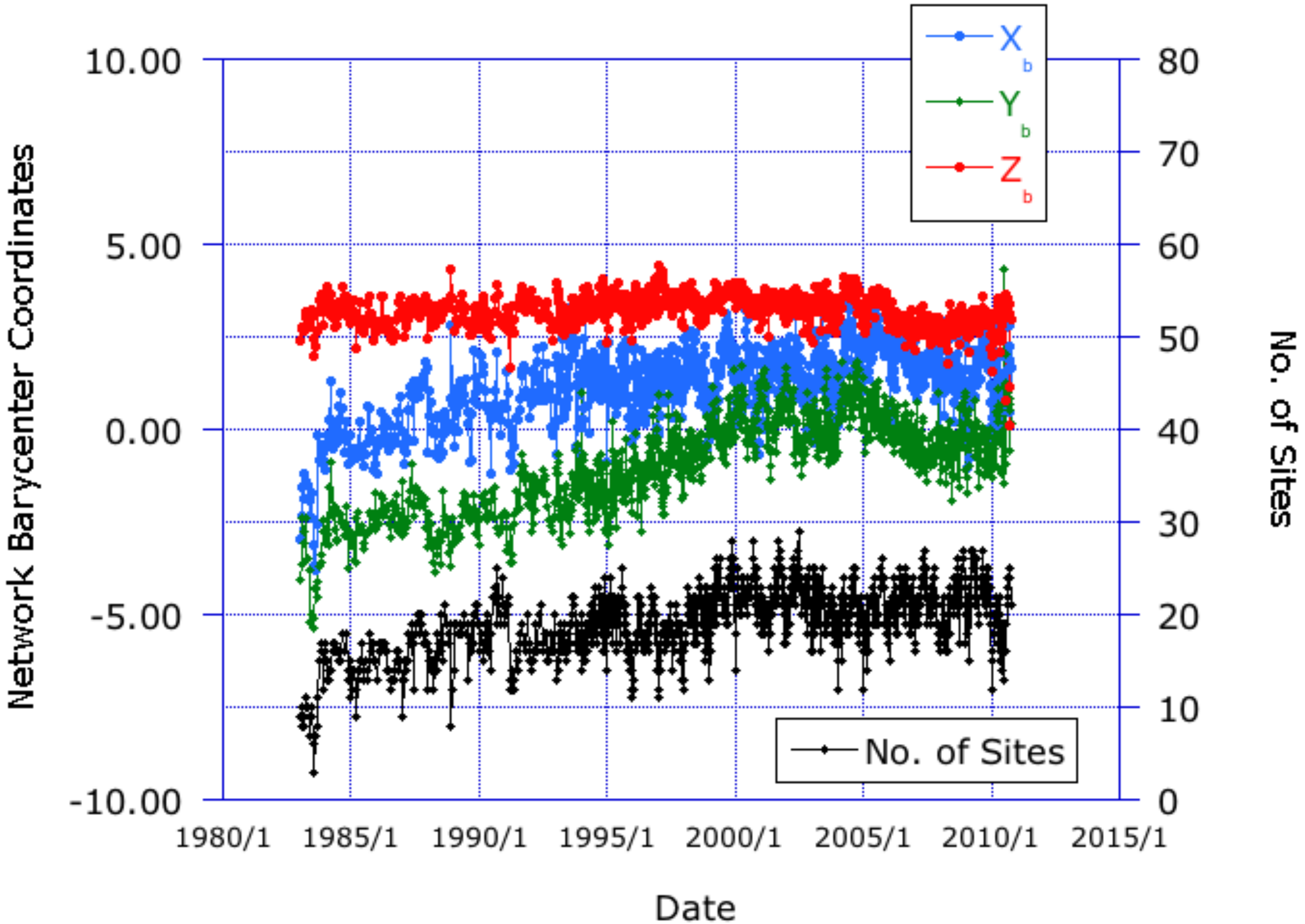
LAGEOS RMS over the past year



ITRF2008 Scale: mean of VLBI and SLR



Non-uniform Network Evolution



The Next Generation SLR Systems

The next generation systems will operate with:

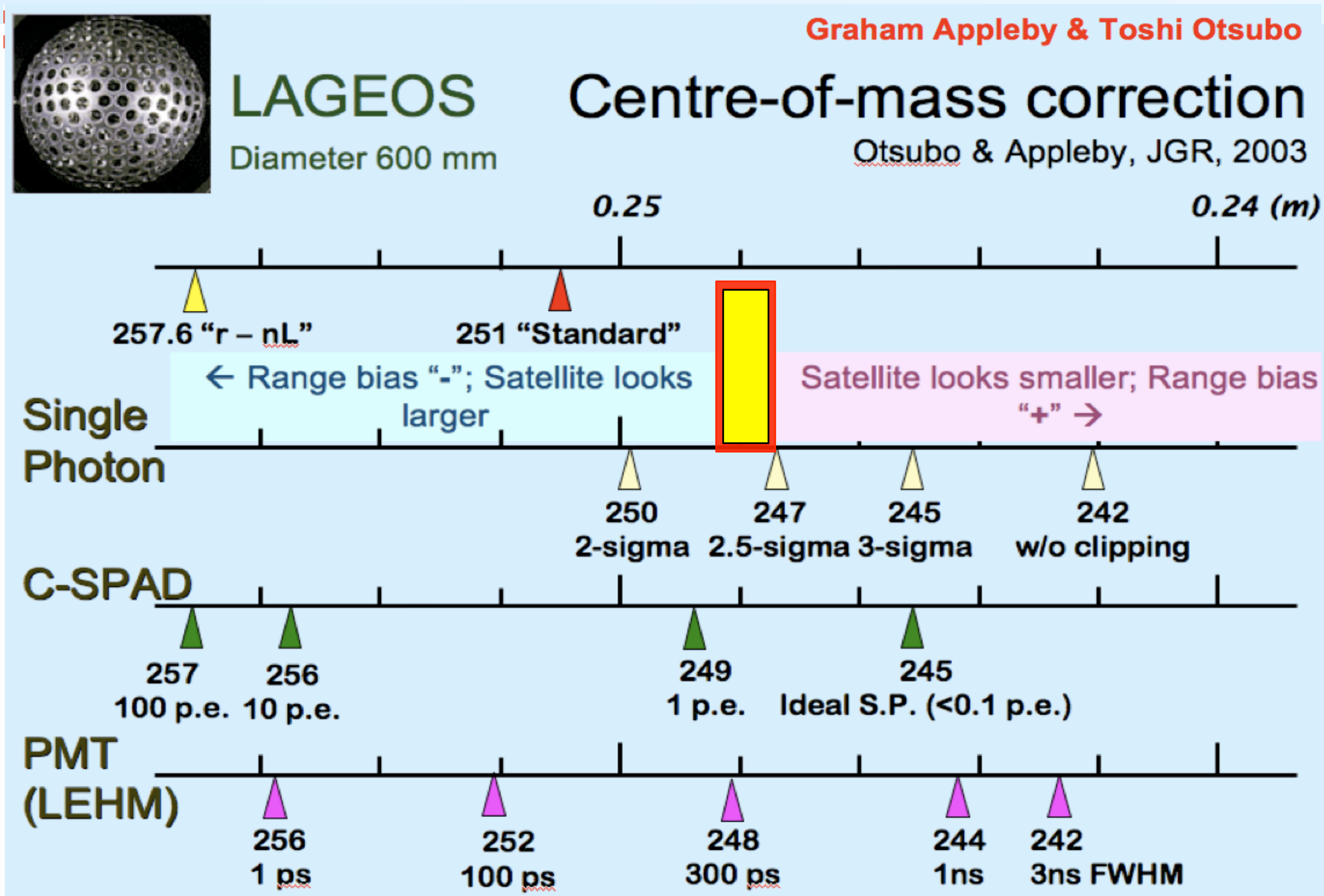
- higher repetition rate (100 Hz to 2 kHz) lasers to improve data yield, improve normal point precision, and pass interleaving;
- photon-counting detectors to reduce the emitted laser energies by orders of magnitude and reduce optical hazards on the ground and at aircraft (some are totally eye-safe);
- multi-stop event timers with few ps resolutions to improve low energy performance in a high solar-noise environment;
- considerably more automation to permit remote and even autonomous operation;

Many systems will operate at single photon levels with

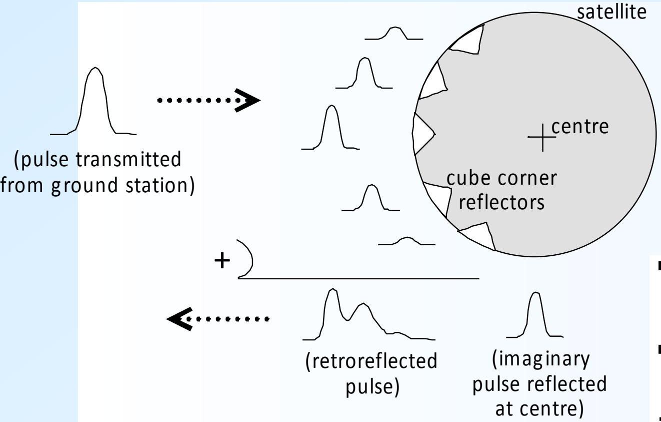
- Single Photon Avalanche Diode (SPAD) detectors or
- MicroChannel Plate PhotoMultiplier Tubes (MCP/PMTs).

Some systems are experimenting with two-wavelength operations to test atmospheric refraction models and/or to provide unambiguous calibration of the atmospheric delay.

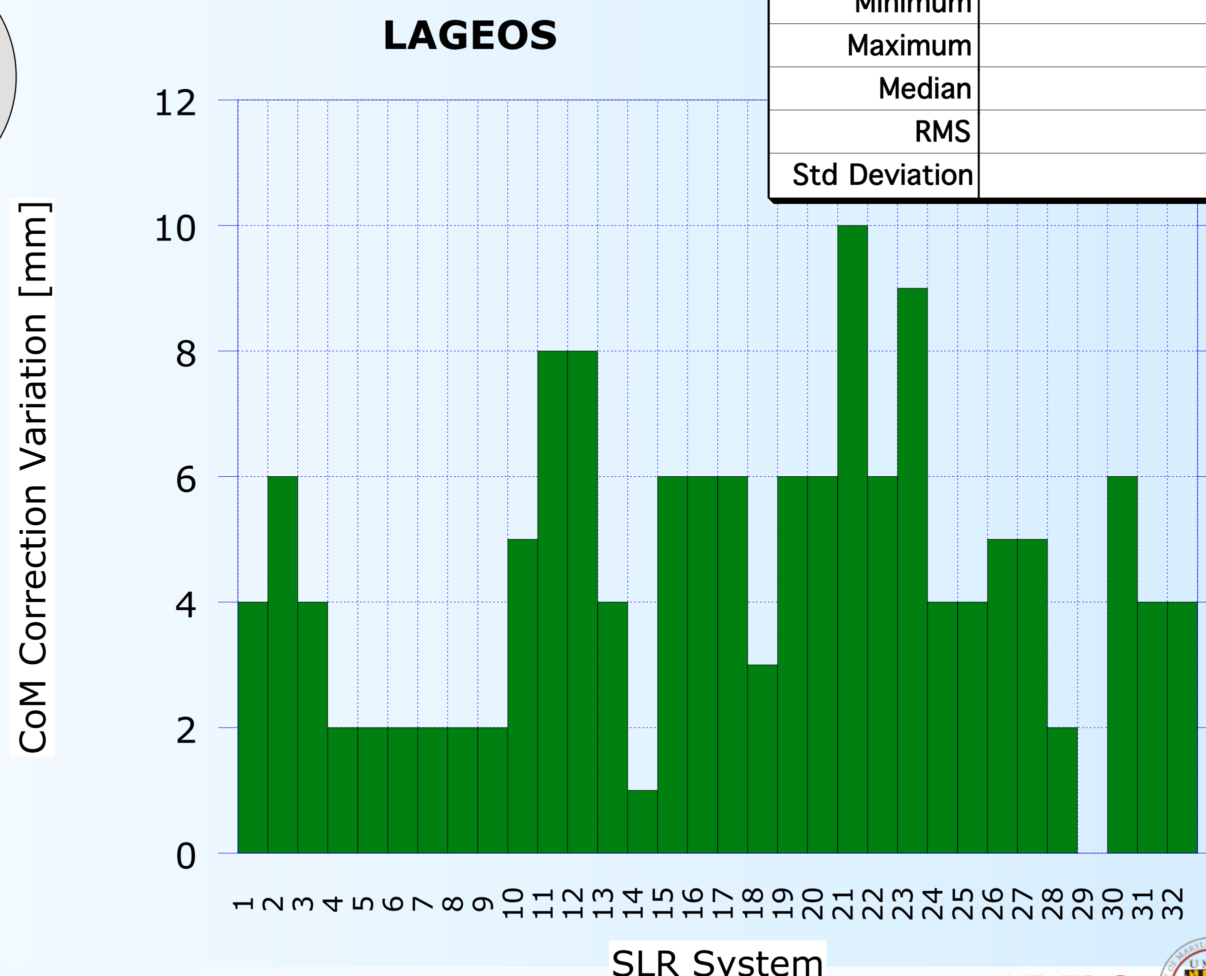
Target signature (CoM)



Target Signature (CoM)



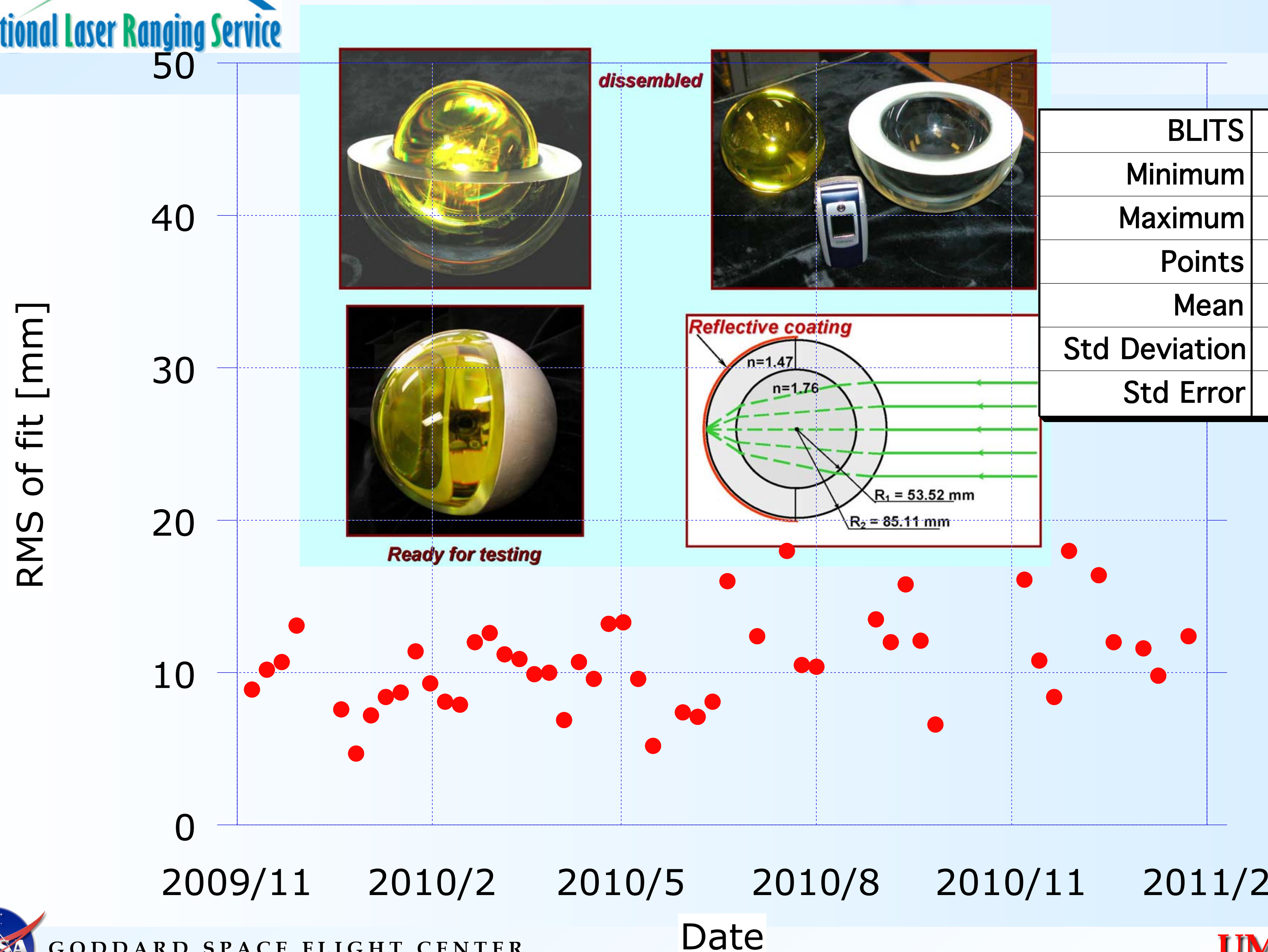
LAGEOS	ΔCoM Range [mm]
Minimum	0
Maximum	10
Median	5
RMS	5
Std Deviation	2



Target signature (CoM)

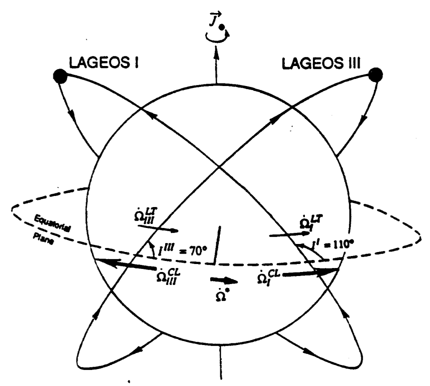
Stn pad ID	Name	Pulse length (ps)	Detector	Regime (single, few, multi)	Editing Level (×σ)	Calib. St. error (mm)	LAGEOS St. error (mm)	LAGEOS CoM range (mm)	LAGEOS CoM ADOPTED (mm)
1873	Simeiz	350	PMT	No CNTL	2.0	60	70	248-244	246
1884	Riga	130	PMT	CNTLD s->m	2.0	10	15	252-248	250
7080	McDonald	200	MCP	CNTLD s->m	3.0	8.5	13	250-248	249
7090	Yaragadee	200	MCP	CNTLD f->m	3.0	4.5	10	250-248	249
7105	Greenbelt	200	MCP	CNTLD f->m	3.0	5	10	250-248	249
7110	Mon. Peak	200	MCP	CNTLD f->m	3.0	5	10	250-248	249
7124	Tahiti	200	MCP	CNTLD f->m	3.0	6	10	250-248	249
7237	Changchung	200	CSPAD	CNTLD s->m	2.5	10	15	250-245	248
7249	Beijing	200	CSPAD	No CNTL, m	2.5	8	15	255-247	251
7355	Urumqui	30	CSPAD	No CNTL	2.5	15	30	255-247	251
7405	Conception	200	CSPAD	CNTLD s	2.5	15	20	246-245	246
7501	Harteb.	200	PMT	CNTLD f->m	3.0	5	10	250-244	247
7806	Metsahovi	50	PMT	?	2.5	15	17	254-248	251
7810	Zimmerwald	300	CSPAD	CNTLD s->f	2.5	20	23	246-244	245
7811	Borowiec	40	PMT	No CNTL f	2.5	16	23	256-250	253
7824	San Fernando	100	CSPAD	No CNTL s->m	2.5	30	25	252-246	249
7825	Stromlo	10	CSPAD	CNTLD s->m	2.5	4	10	257-247	252
7832	Riyadh	100	CSPAD	CNTLD s->m	2.5	10	15	252-246	249
7835	Grasse	50	CSPAD	CNTLD s->m	2.5	6	15	255-246	250
7836	Potsdam	35	PMT	CNTLD s->m	2.5	10	20	256-252	254
7838	Simosato	100	MCP	CNTLD s->m	3.0	20	40	252-248	250
7839	Graz	35	CSPAD	No CNTL m	2.2	3	9	255-250	252
7839	Graz kHz	10	CSPAD	No CNTL s->f	2.2	3	9	255-250?	252
7840	Herstmonceux	100	CSPAD	CNTLD s	3.0	6	15	246-244	245
7840	Hx kHz	10	CSPAD	CNTLD s	-1.5,+2.5	3	9	245	245
7841	Potsdam 3	50	PMT	CNTLD s->f	2.5	10	18	254-248	251
7941	Matera	40	MCP	CNTLD m	3.0	1	5	252-248	250
8834	Wettzell	80	MCP	No CNTL f->m	2.5	10	20	252-248	250

BLITS – Ball Lens In The Space Satellite



BLITS	RMS
Minimum	4.7
Maximum	18.0
Points	48
Mean	10.8
Std Deviation	3.1
Std Error	0.4

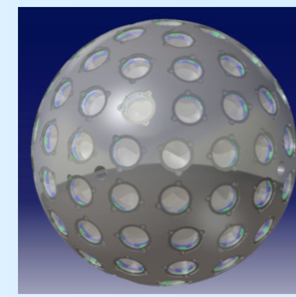
LARES - LAser Relativity & Earth Science Satellite



Object of measurement:

$$\dot{\Omega}^* = \tfrac{1}{2} (\dot{\Omega}^I + \dot{\Omega}^{II})$$

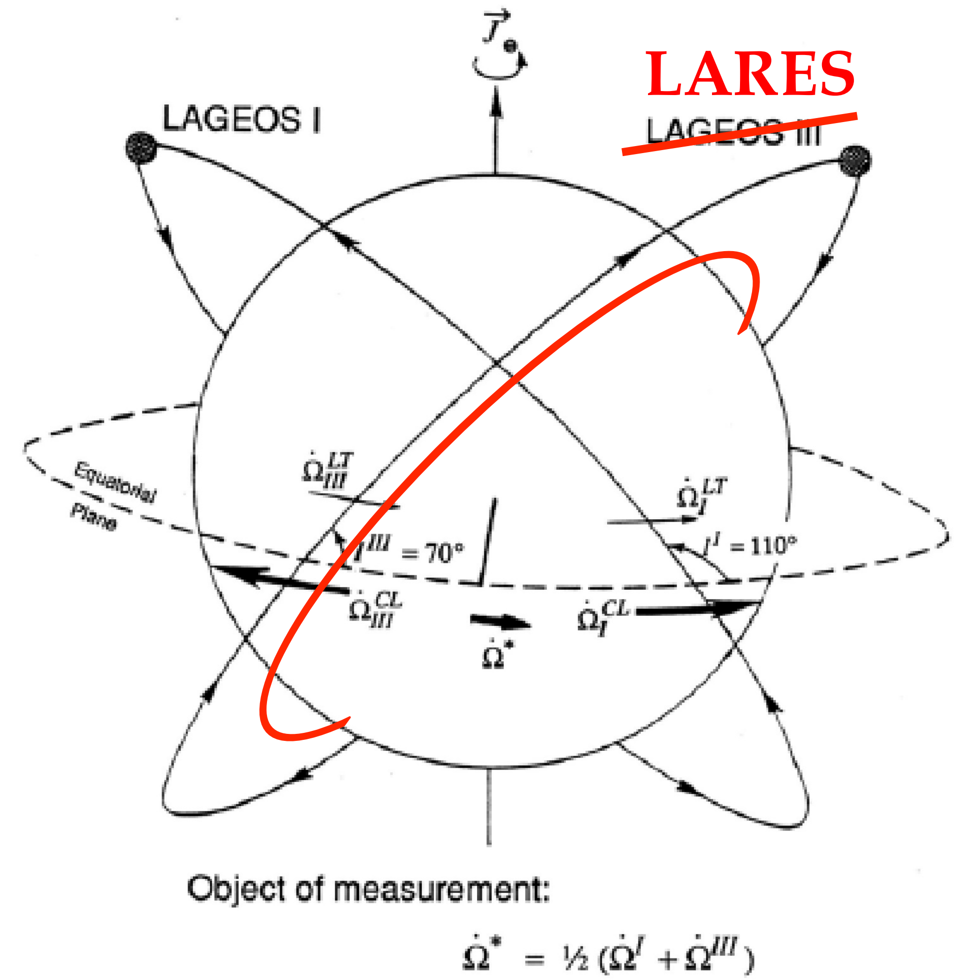
- LARES Parameters:
  - Material — Tungsten alloy (95%)
  - Diameter — ~36 cm
  - Mass — ~420 kg
  - Altitude — 1500 km
  - Inclination — ~70°
  - Eccentricity — Circular orbit
  - CCRs (92) LAGEOS type
  - A/m ratio — 0.36 x LAGEOS



Launch is with ESA's new launcher VEGA, on its inaugural test launch, in late 2011/ early 2012

The LAGEOS III Experiment

The original SLR experiment (LAGEOS III) expected exactly counter-rotating satellites in supplementary inclinations, to cancel classical Newtonian rates and isolate the gravitomagnetic precession. LARES will be based on the same principle.



Space Geodetic Network

Atmospheric Loading (ECMWF)

Difference in the RMS of fit of weekly arcs of LAGEOS SLR for 2001 & 2006 and four Atmospheric loading treatments (one being NO loading)

Variable	Points	Mean	Median	RMS	Std Deviation
ΔRMS v0-NO	52	3.4	2.7	4.45	2.87
ΔRMS v1-NO	104	2.9	2.1	4.31	3.16
ΔRMS v2-NO	52	2.7	1.7	4.09	3.08
ΔRMS v1-v0	52	0.4	0.0	0.92	0.82
ΔRMS v2-v1	52	1.7	1.4	2.58	1.96

"v0": 1970/01 - 2002/08: ECMWF Reanalysis (ERA40), with a spatial resolution of 1.125 degrees

"v1": 2000/12 - 2006/12: ECMWF Operational, with a spatial resolution of about 0.350 degrees

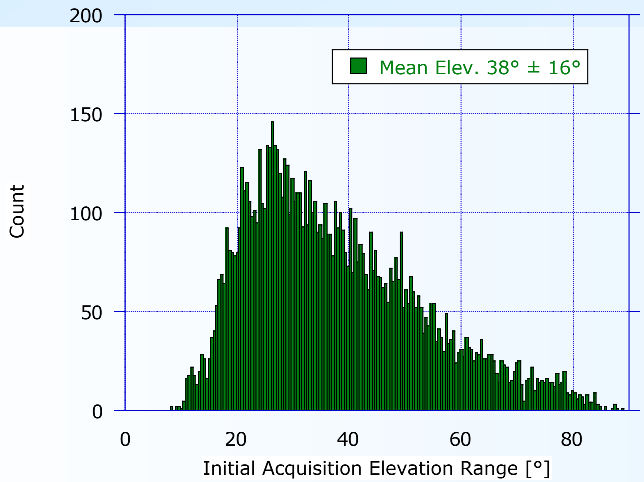
"v2": 2005/10 - now: ECMWF Operational, with a spatial resolution of about 0.250 degrees

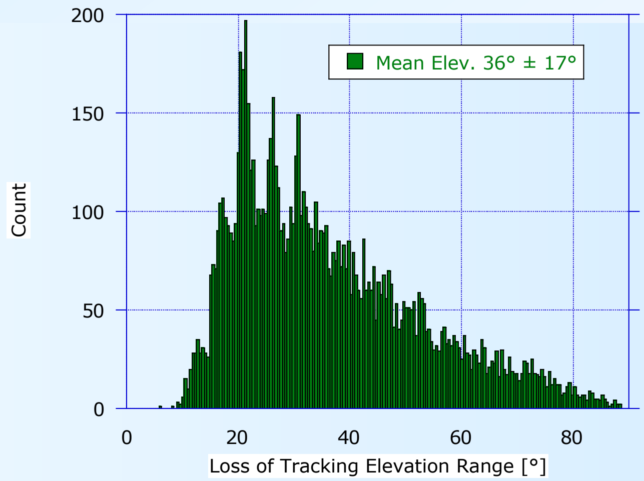
Gradient-corrected SLR Residuals Statistics

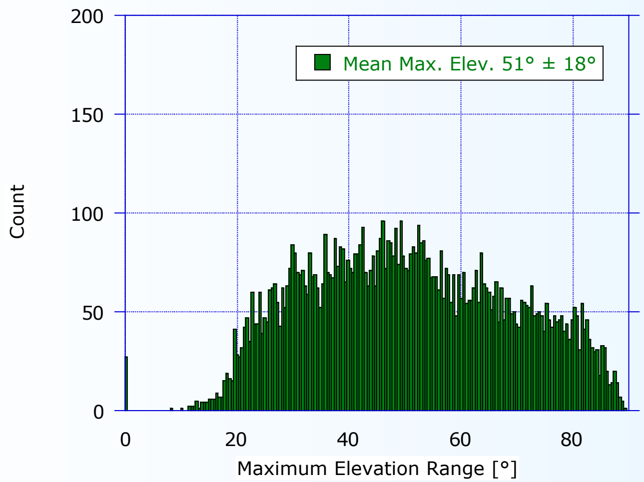
Method	ΔBias (mm)	$\Delta\sigma^2$ (%)
AIRS		
RT_{grad}	0.3 ± 0.3	14.0
RT_{3D}	0.9 ± 1.1	24.8
ECMWF		
RT_{grad}	0.1 ± 0.5	10.8
RT_{3D}	0.6 ± 1.2	22.5

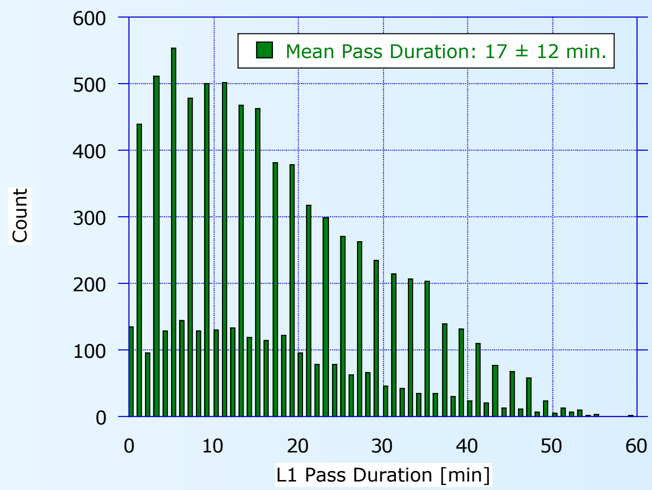
LAGEOS 1 Statistics for 2008

Actual ILRS Data !!!



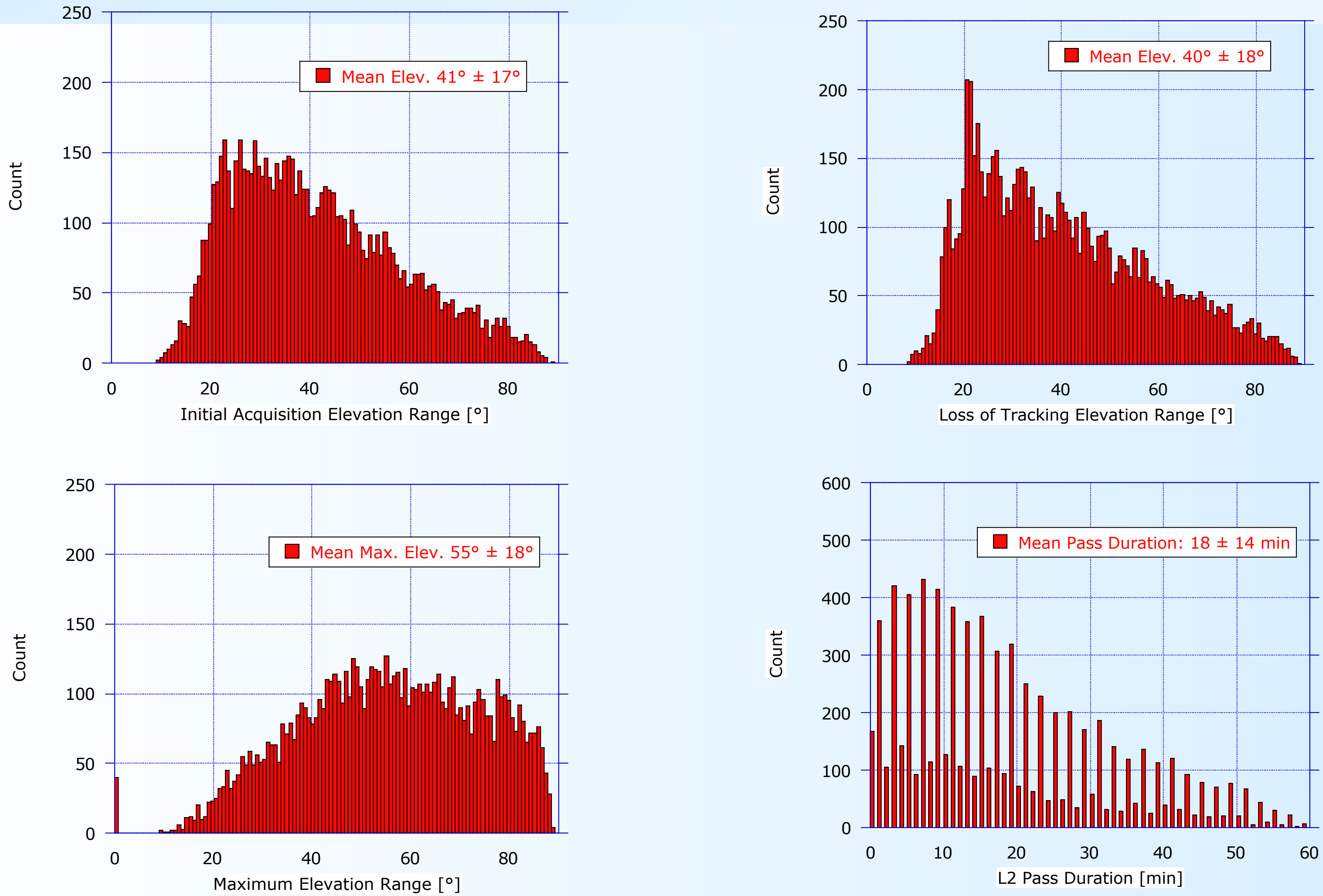






LAGEOS 2 Statistics for 2008

Actual ILRS Data !!!



International Laser Ranging Service

IERS Conventions 2010

- The ILRS AWG complies with the IERS Conventions as they evolve, although our products change at specific instants, usually with a re-analysis of all data, in order to keep our online available products consistent.
- The 2010 Conventions will become our official standard once we release our next re-analysis (sometime in mid-2012).
- http://www.iers.org/nn_11254/IERS/EN/Publications/TechnicalNotes/tn36.html

International Earth Rotation and Reference Systems Service (IERS)
Service International de la Rotation Terrestre et des Systèmes de Référence

IERS Technical Note No. 36

IERS Conventions (2010)

Gérard Petit[1] and Brian Luzum[2] (eds.)

IERS Conventions Centre

[1] Bureau International des Poids et Mesures (BIPM)
[2] US Naval Observatory (USNO)

Verlag des Bundesamts für Kartographie und Geodäsie
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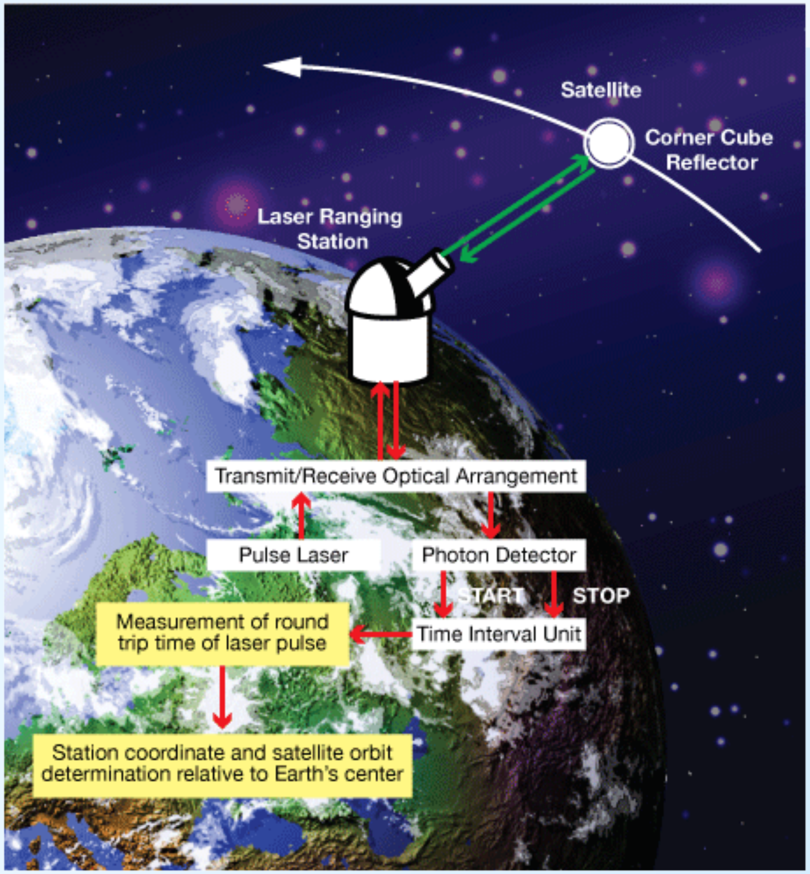
Satellite Laser Ranging - the Technique

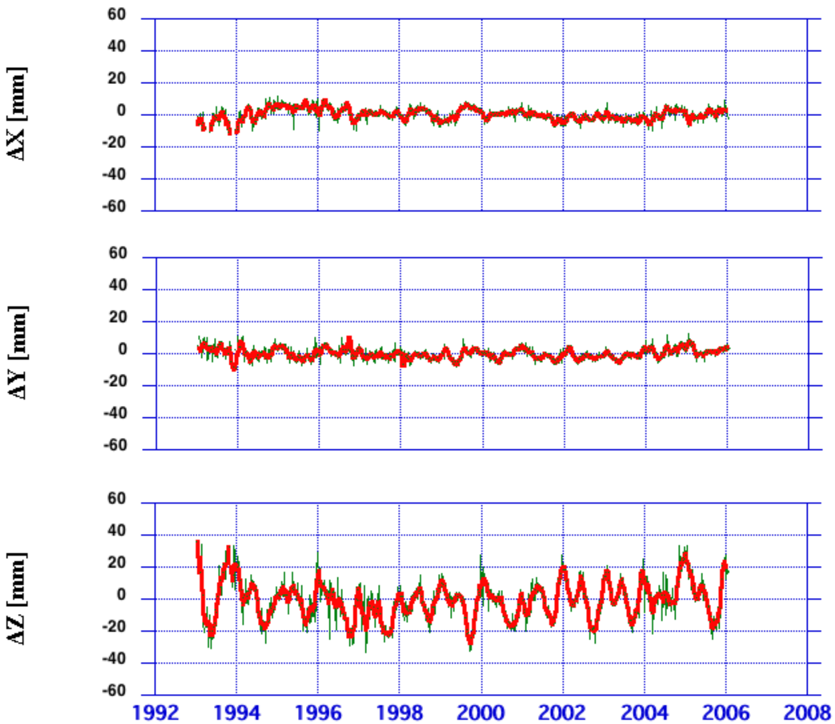
Precise range measurement between an SLR station and a satellite using ultra-short laser pulses.

- Simple range measurement
- Space segment is passive
- Simple refraction model
- Night / Day Operation
- Near real-time global data availability
- Satellite altitudes from <300 km to geosynchronous satellites, and the Moon (Mars also with transponders)



- Unambiguous ~ cm accurate orbits
- Long-term stable geophysical time series

Geocenter Motion



Motion of the ITRF origin w.r.t. the geocenter with secular trends removed

Earth's center of mass relative to the origin of ITRF2000, projected in the equatorial plane. Large excursions have been correlated with recent El Niño events (1996-97 and 2002-03).

- Shown here is the change in the origin of the crust-fixed frame w.r.t. the center of mass due to non tidal mass transport in the atmosphere and hydrosphere.