Contribution of Satellite Laser Ranging to Space Geodesy

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Three Pillars of Satellite Geodesy

Geometry

Determination of geometrical three-dimensional positions and velocities (in global, regional, and local reference frames),

Gravity

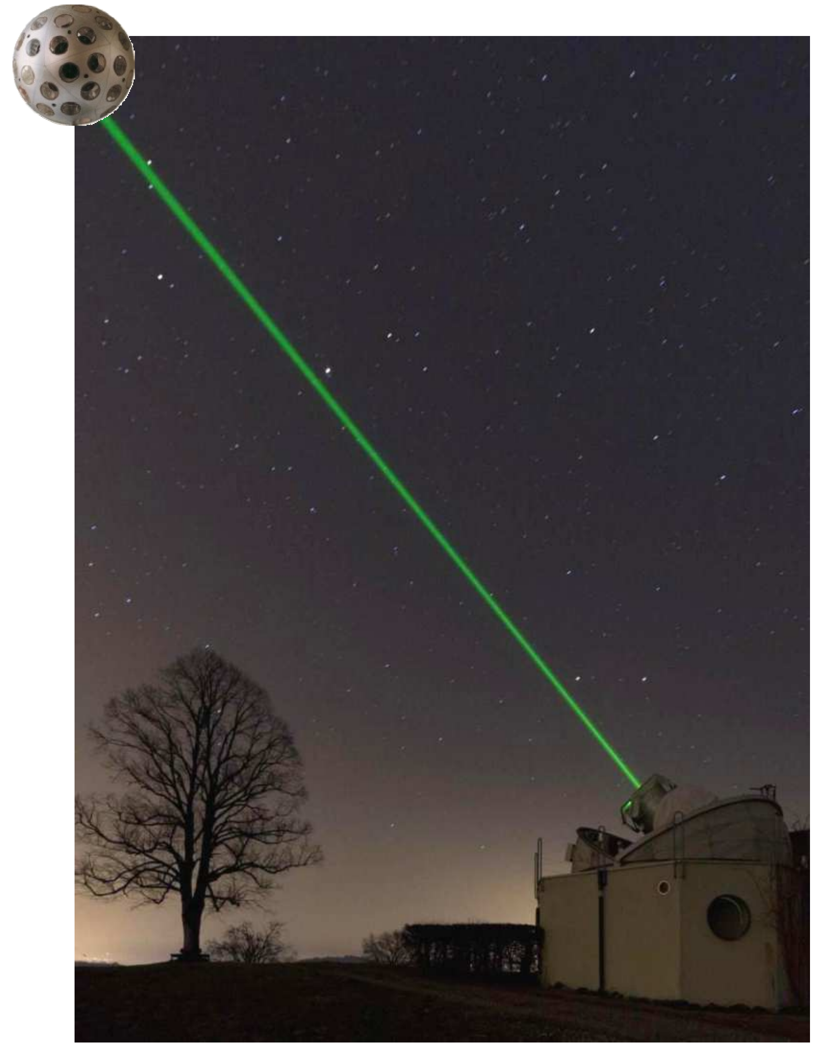
Determination of the Earth's gravity field and its temporal variations,

Rotation

Modeling and observing of geodynamical phenomena (tectonic plates, loading crustal deformations) including the rotation and orientation of the Earth (polar motion, Length-of-day, precession and nutation).

Satellite Laser Ranging (SLR)

- SLR provides very accurate distance measurements (at a few mm-level) between ground stations and satellites.
- SLR geodetic satellites have a minimized area-to-mass ratio. They orbit the Earth at higher altitudes than the satellite gravity missions (e.g., GRACE, GOCE).
- SLR observations are typically used for deriving low-degree gravity field coefficients (degree 2) or zonal harmonics.
- The higher-degree monthly gravity field models can also be well derived from SLR observations using a combination of long and short arcs.

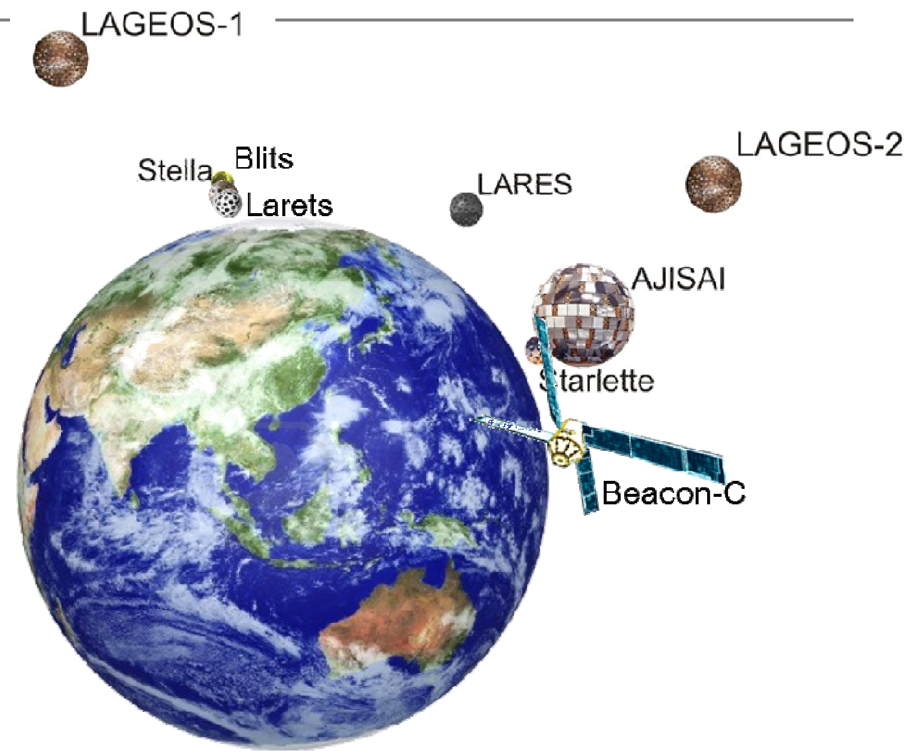


SLR station at Zimmerwald, Switzerland

SLR gravity field solutions in Bernese GNSS Software

		SLR solutions
Estimated parameters		LAGEOS-1/2, Starlette, Stella, AJISAI, LARES, Blits, Larets, Beacon-C
Orbits	**Osculating elements**	a, e, i, Ω, ω, u_0 (LAGEOS: 1 set per 10 days, LEO: 1 set per 1 day)
	Dynamical parameters	LAGEOS-1/2 : S_0, S_S, S_C (1 set per 10 days) Sta/Ste/AJI : C_D, S_C, S_S, W_C, W_S (1 set per day)
	Pseudo-stochastic pulses	LAGEOS-1/2 : no pulses Sta/Ste/AJI : once-per-revolution in along-track only
Earth rotation parameters		X_P, Y_P, UT1-UTC (Piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 30 days
Earth gravity field		Estimated up to d/o 10/10 (1 set per 30 days)
Station coordinates		1 set per 30 days
Other parameters		Range biases for all stations (LEO) and for selected stations (LAGEOS)

Reference: Sośnica, K., Jäggi, A., Thaller, D., Beutler G., Dach, R. (2014). Contribution of Starlette, Stella, and AJISAI to the SLR-derived global reference frame. J Geod 88(8): 789-804, doi: 10.1007/s00190-014-0722-z

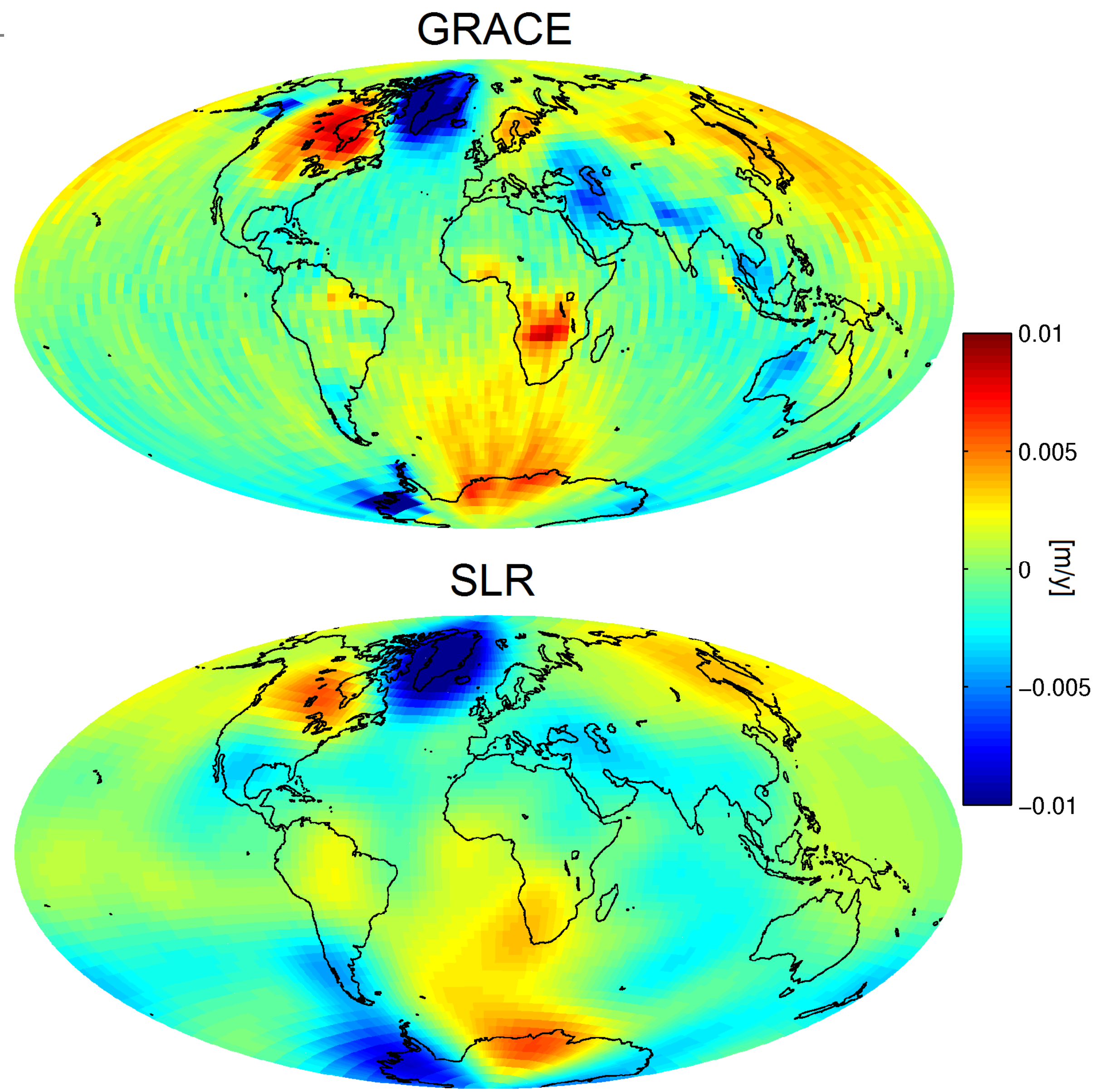


- Up to 9 SLR satellites with different altitudes and different inclinations are used.
- For LAGEOS-1/2: 10-day arcs are generated, for low orbiting satellites: 1-day arcs.
- Different weighting of observations is applied: from 8mm for LAGEOS-1/2 to 50mm for Beacon-C.
- Constraints introduced to regularize the normal equations (on GFC, pulses, EOPs).

Comparison w.r.t. GRACE K-Band

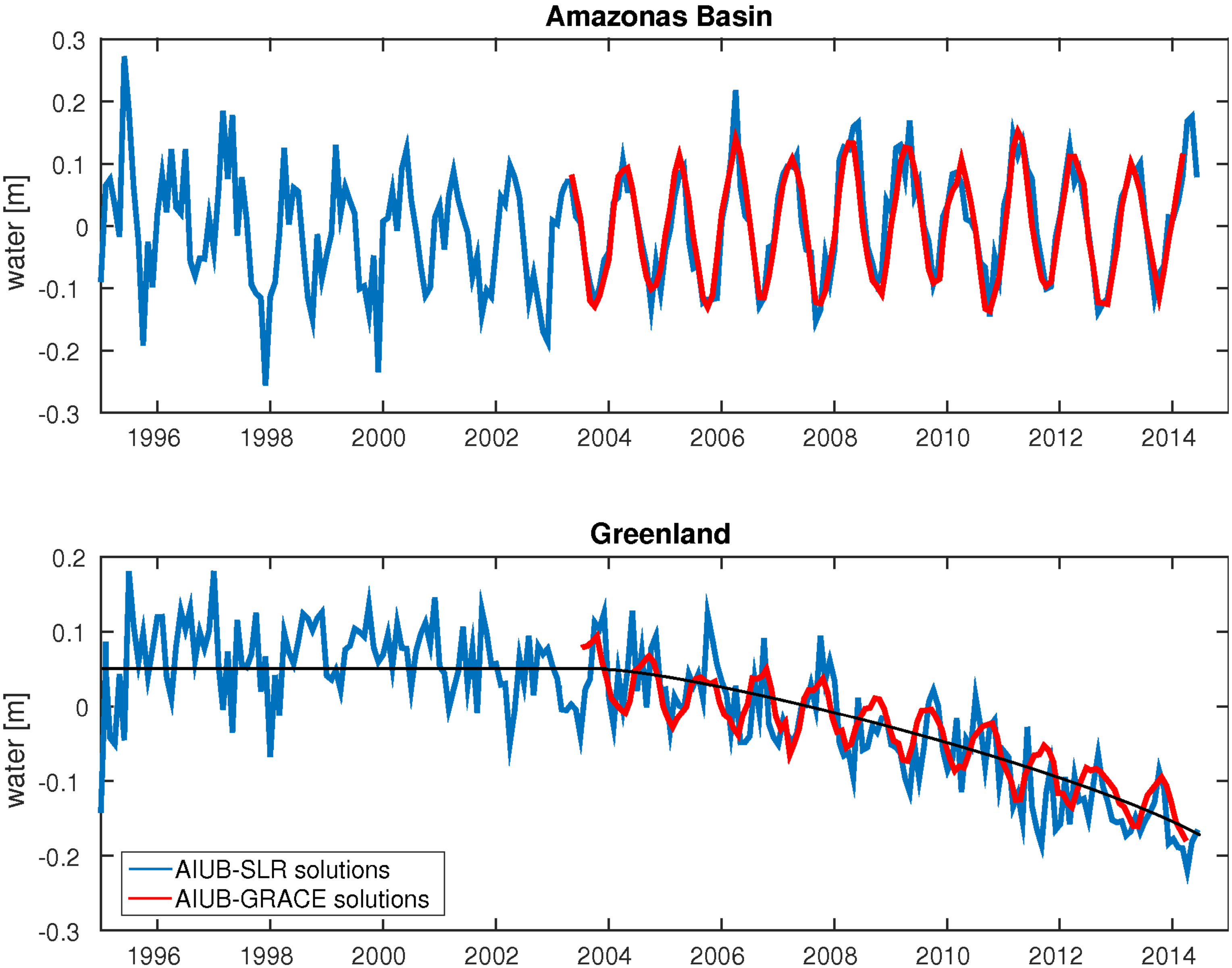
Secular changes of geoid deformations derived from SLR show a very high level of consistency with the GRACE-based results, however, with a lower spatial resolution.

The ice mass loss in Greenland, West Antarctica and Patagonia is well captured in the SLR solutions.



Reference: Sośnica, K., Jäggi, A., Meyer, U., Thaller, D., Beutler G., Arnold, D., Dach, R. (2015). Time variable Earth's gravity field from SLR satellites. **J Geod** (submitted manuscript).

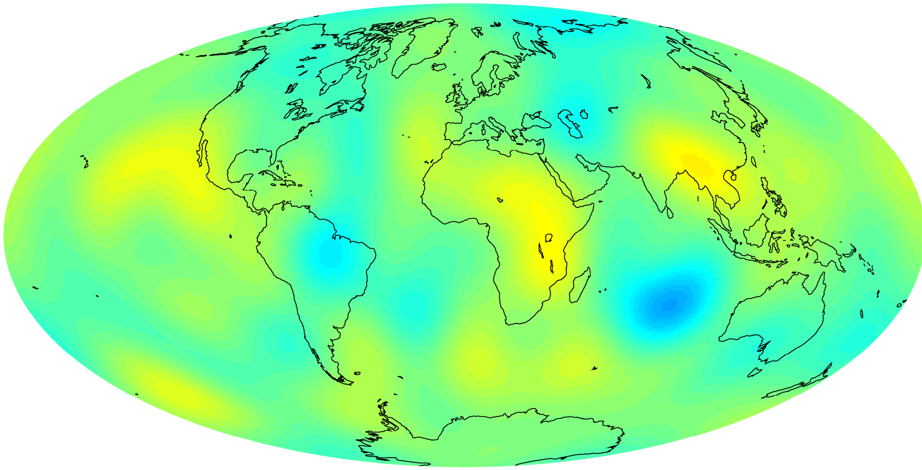
Comparison w.r.t. GRACE K-Band



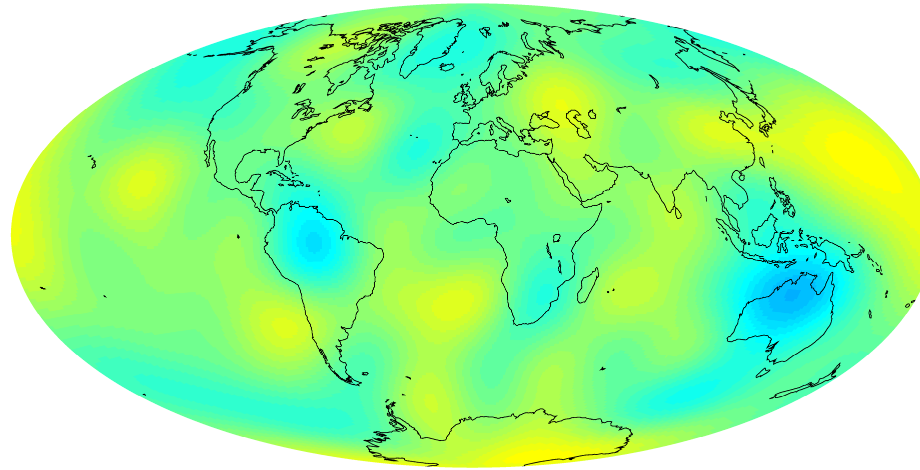
The SLR solutions can recover the largest seasonal and secular variations of the gravity field, which correspond to the large-scale mass transport in the system Earth, e.g., the accelerating ice mass depletion in Greenland.

The amplitudes in the SLR solutions up to d/o 10/10 are typically underestimated due to the limited sensitivity of SLR solutions to coefficients of degree 7-10.

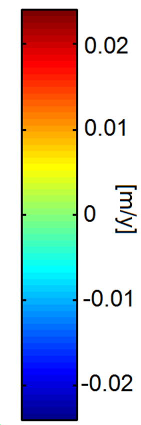
Geoid height changes from SLR

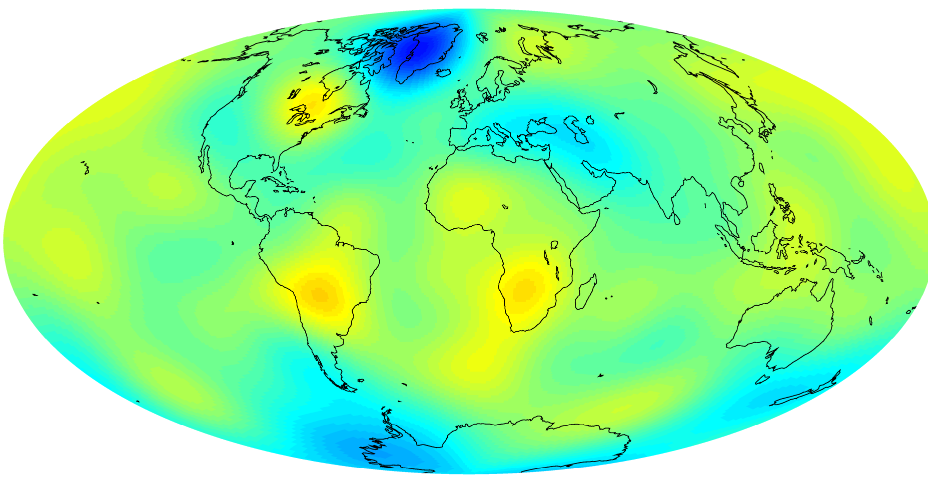


1995–1999

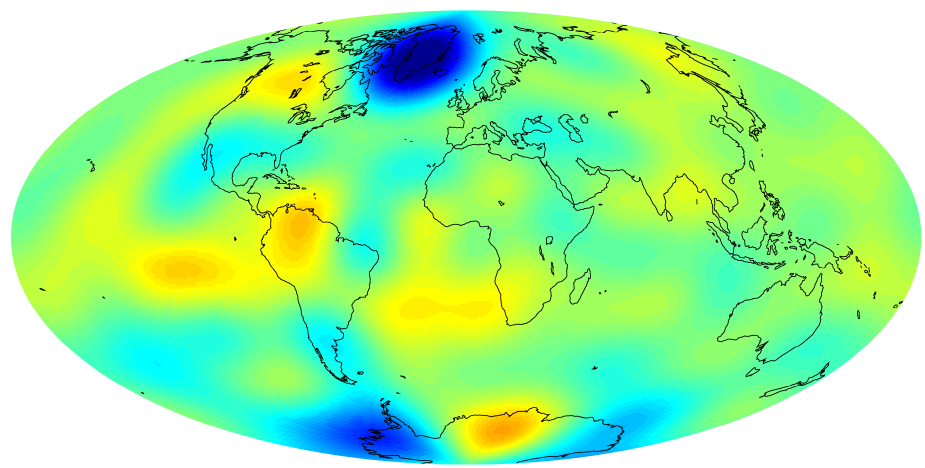


2000–2004



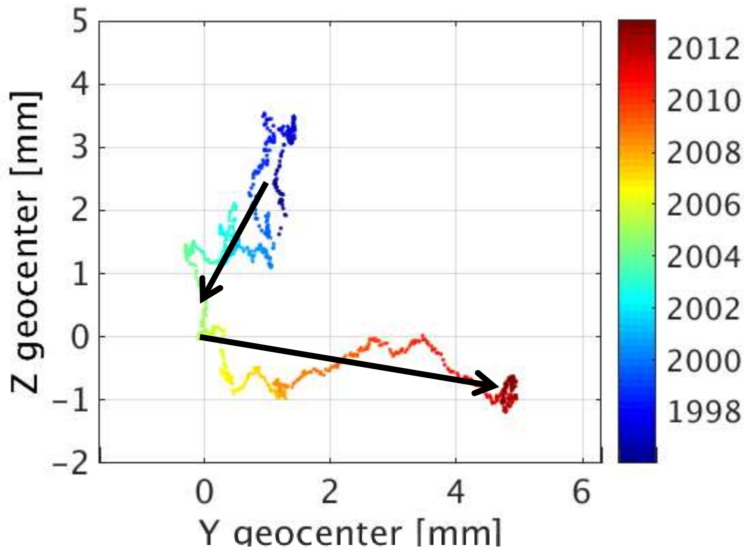


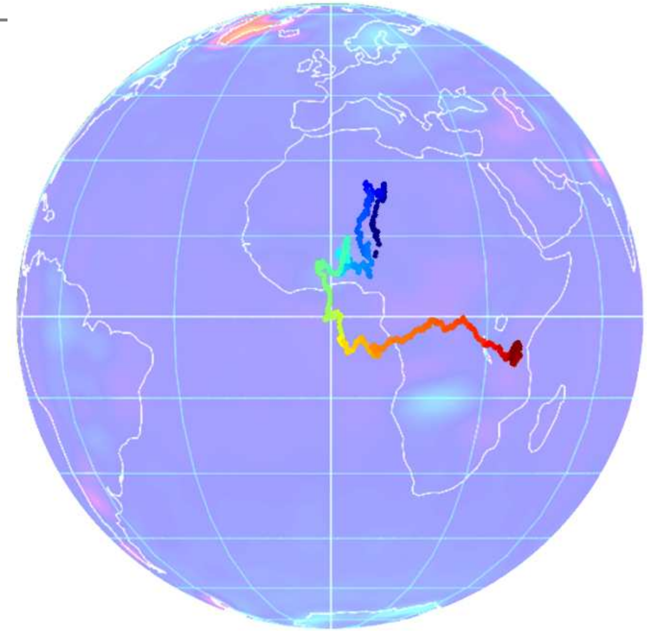
2005–2009

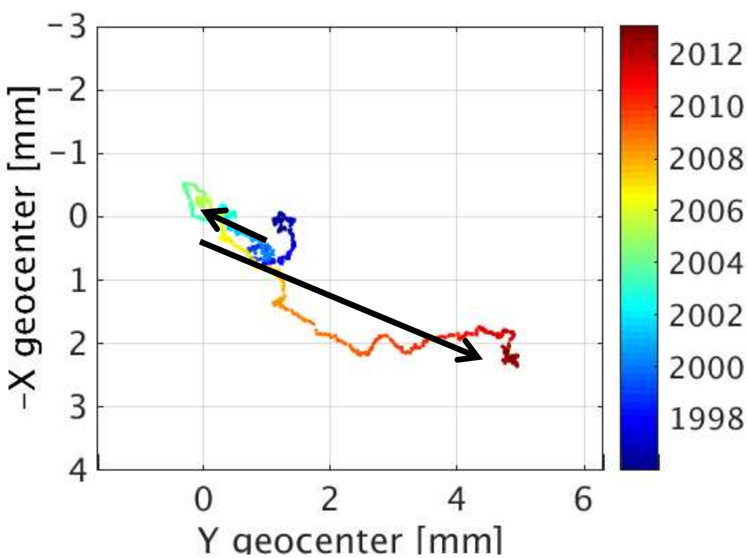


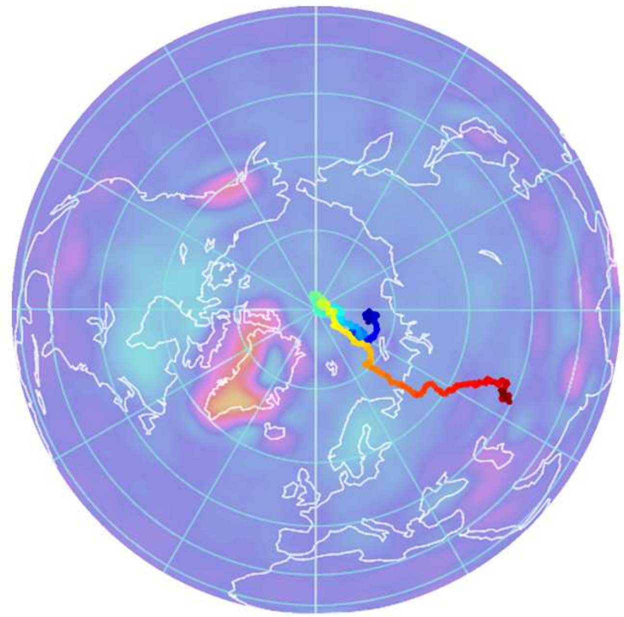
2010–2014

Geocenter coordinates from SLR



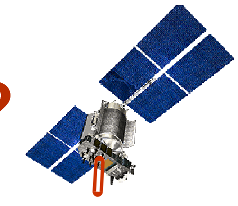






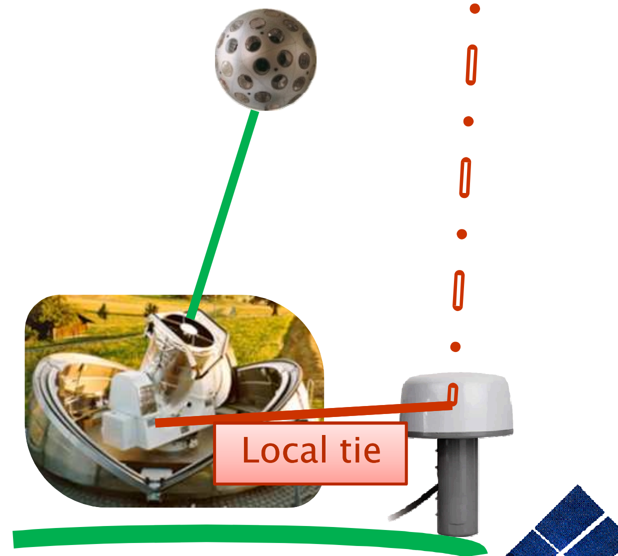
64°E

Why is the SLR tracking of GNSS important?

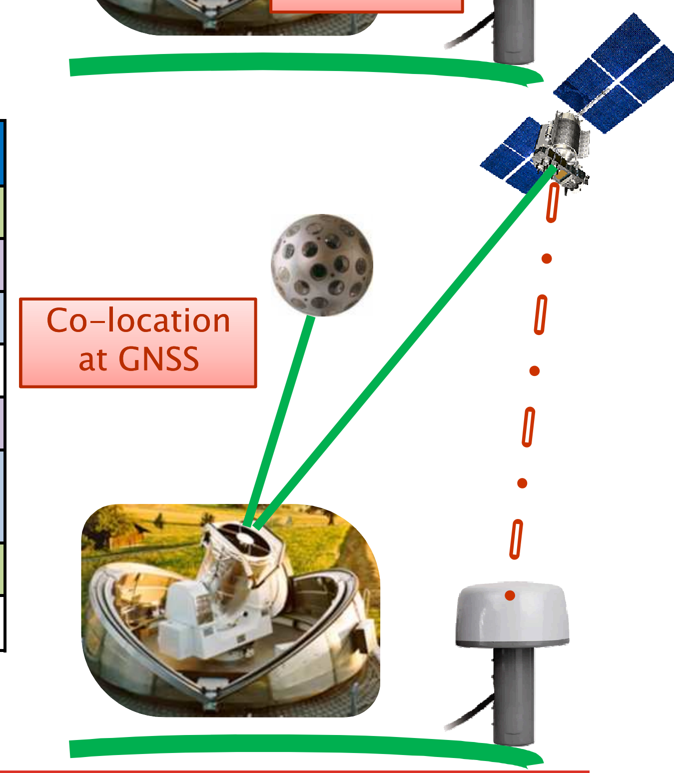


Microwave GNSS	LAGEOS+Etalon
GNSS Station Coordinates	SLR Station Coordinates
-	Geocenter coordinates
GPS and GLONASS orbits	LAGEOS and Etalon orbits
Earth Rotation Parameters (X pole, Y pole, Length-of-Day)	
Phase-code, Inter-system, Inter-frequency Biases	Range Biases (1-3 stations)
APL Scaling Factors	APL Scaling Factors
Troposphere Delays	-

«Classical» co–location on the ground using local ties

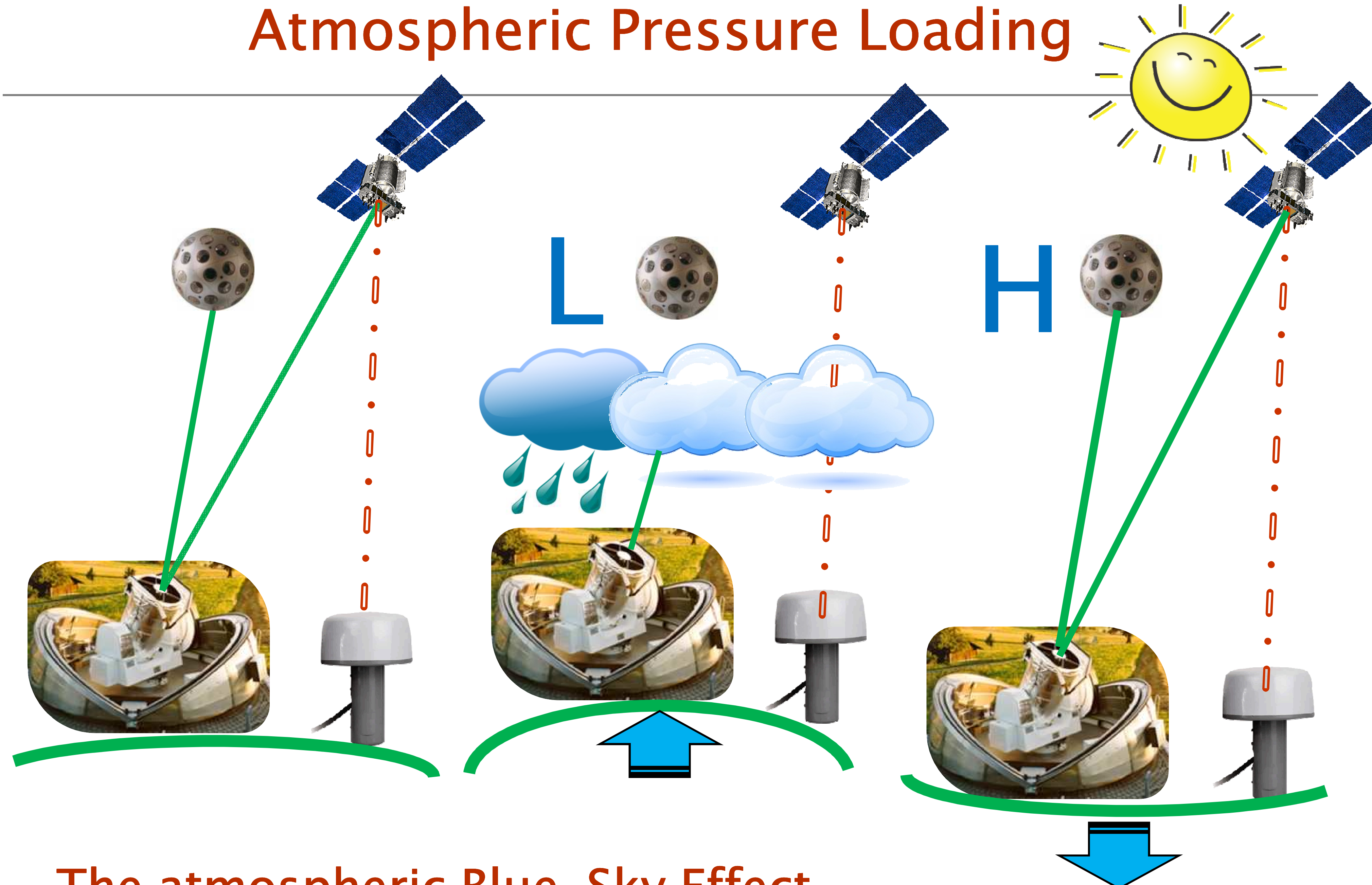


Microwave GNSS	SLR@GNSS	LAGEOS+Etalon
GNSS Station Coordinates	SLR Station Coordinates	
Geocenter Coordinates		
GPS and GLONASS orbits		LAGEOS, Etalon orbits
Antenna Offset	LRA Offset	-
Earth Rotation Parameters (X pole, Y pole, Length-of-Day)		
Phase-code, Inter-system, Inter-frequency Biases	Range biases (all stations)	Range Biases (1-3 stations)
APL Scaling Factors	APL Scaling Factors	
Troposphere Delays	-	



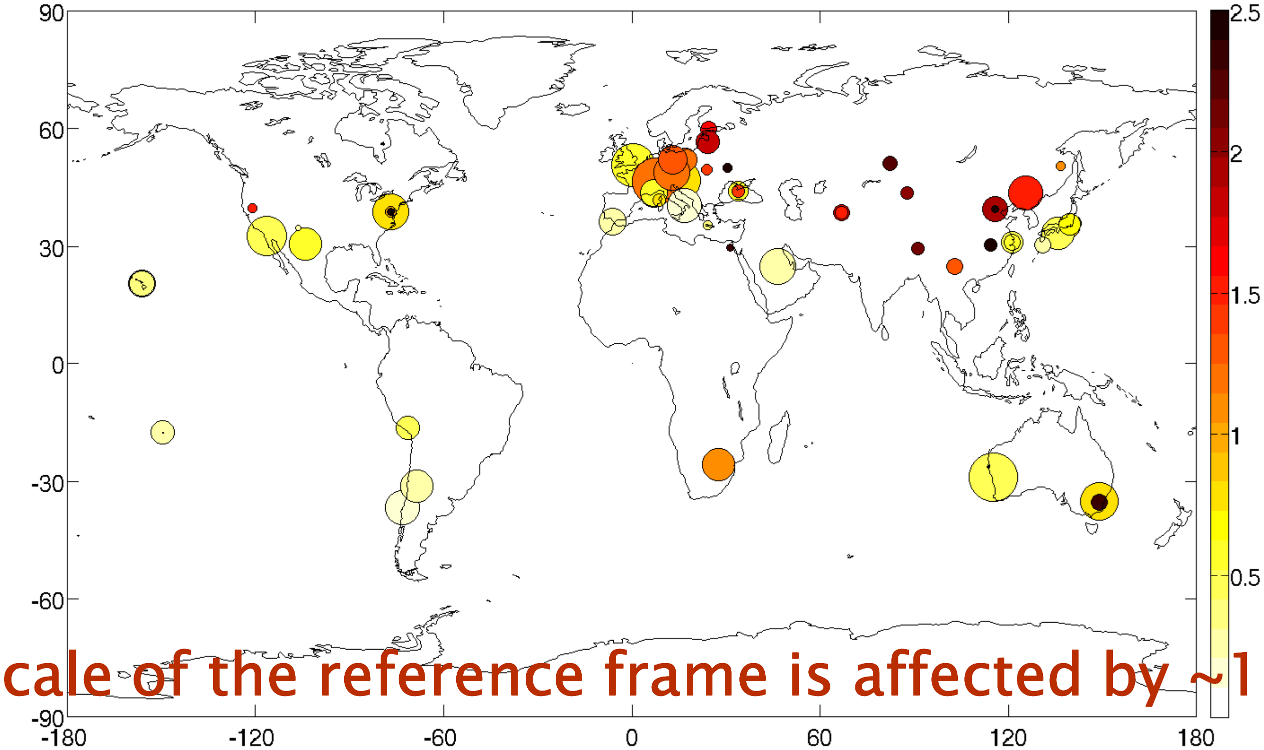
Co–location in space: SLR observations to GNSS are needed

Atmospheric Pressure Loading



The atmospheric Blue-Sky Effect

Atmospheric Pressure Loading– the Blue–Sky Effect

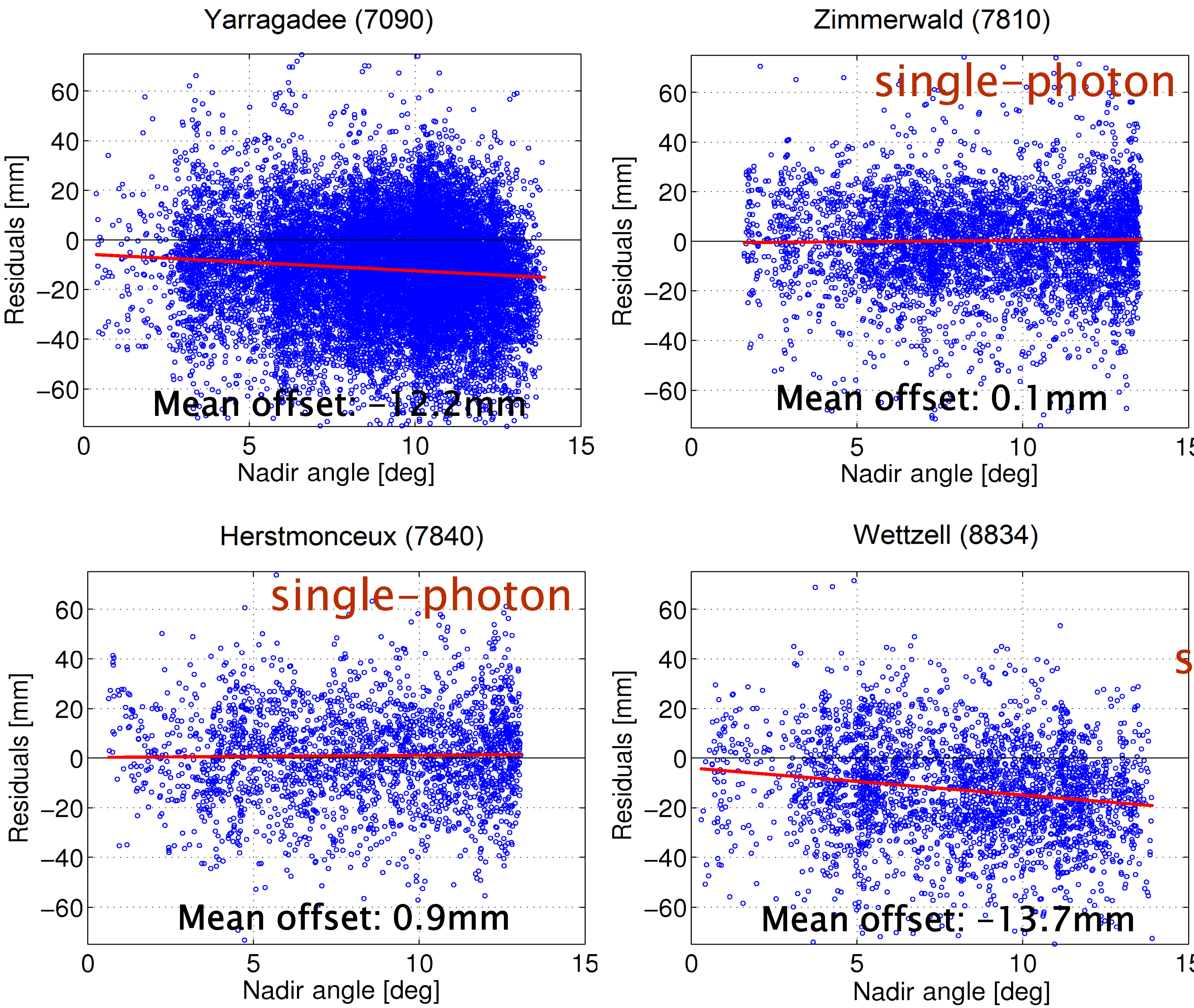


Scale of the reference frame is affected by ~1mm

SLR station	Number of normal points (1999–2010)	Mean impact of Atmospheric Pressure Loading	Blue–Sky effect [mm]
Golosiv, Ukraine	330	6.6	4.4
Wuhan, China	1052	4.9	3.2
Beijing–A, China	189	2.7	2.5
Helwan, Egypt	223	3.2	2.4
Altay, Russia	1776	6.7	2.3

Reference: Sośnica, K., Thaller, D., Dach, R., Jäggi, A., Beutler G. (2013). Impact of loading displacements on SLR-derived parameters and on the consistency between GNSS and SLR results. **J Geod, 87(8): 751–769**, doi: 10.1007/s00190-013-0644-1

Satellite signature effect:
Single photon vs. multi-photon SLR detectors



SLR observation residuals to microwave-derived GLONASS-M orbits with uncoated corner cubes for SLR stations equipped with multi-photon and single-photon detectors.

Differences between the scale in the GNSS and SLR solutions yield ~1mm! (for single-photon stations)

Reference: Sośnica, K., Thaller, D., Dach, R., Steigenberger, P., Beutler, G., Arnold, D., Jäggi, A. (2015). Satellite Laser Ranging to GPS and GLONASS. **J Geod**, submitted manuscript

Summary

1. SLR substantially contributes to the evaluation of the mass transport mechanisms and global variations of the mass balance in terms of the indications of climate change.

2. The consistency between SLR and GNSS solutions is currently mostly limited by two effects, i.e., the Blue-Sky effect, which is related to the atmospheric pressure loading affecting the SLR stations and the weather-dependency of SLR observations, and the satellite signature effect, which is defined as a spread of optical pulse signals due to reflection from multiple reflectors in the laser reflector arrays.

3. The scale agreement between SLR and GNSS solutions is at the level of ~1mm, when using improved solar radiation pressure modeling (the new ECOM), single-photon detectors, and satellites with uncoated corner cube reflectors.

Thank you
for your attention