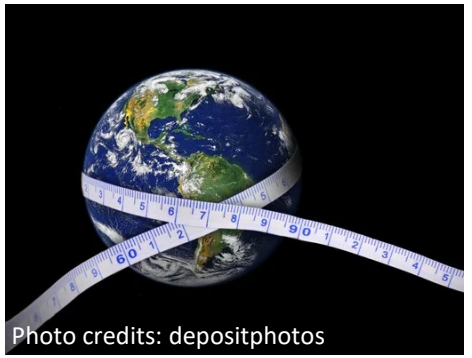
Scientific Potential of the Geodetic Technique of Satellite Laser Ranging

Linda Geisser, Adrian Jäggi, Ulrich Meyer, Daniel Arnold



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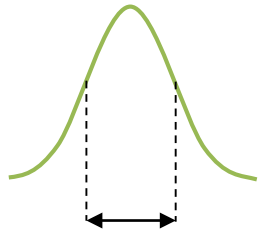
Astronomical Institute, University of Bern AIUB

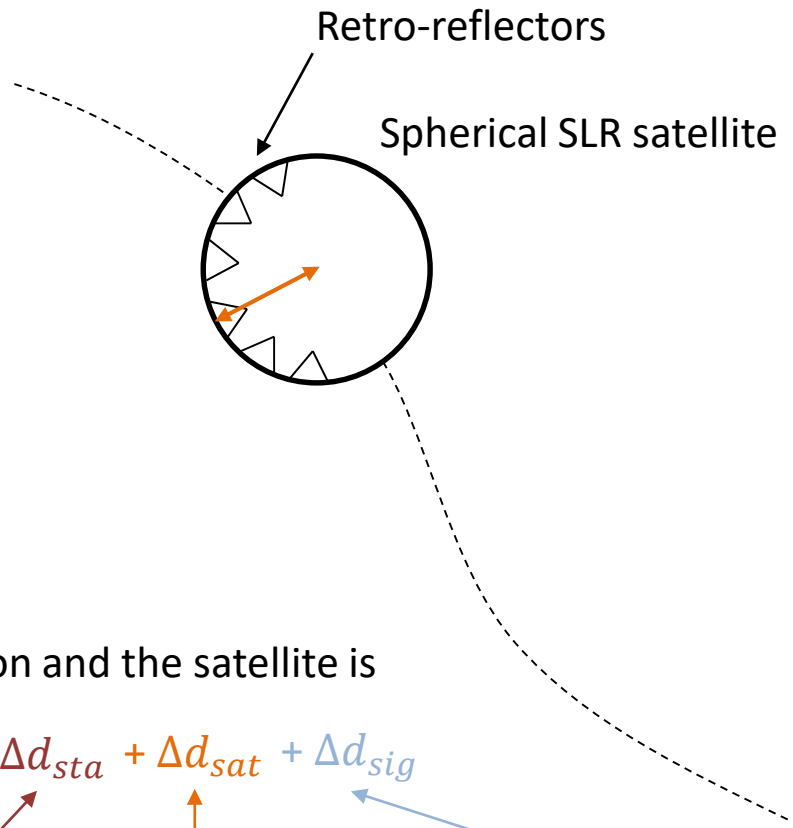
Outline

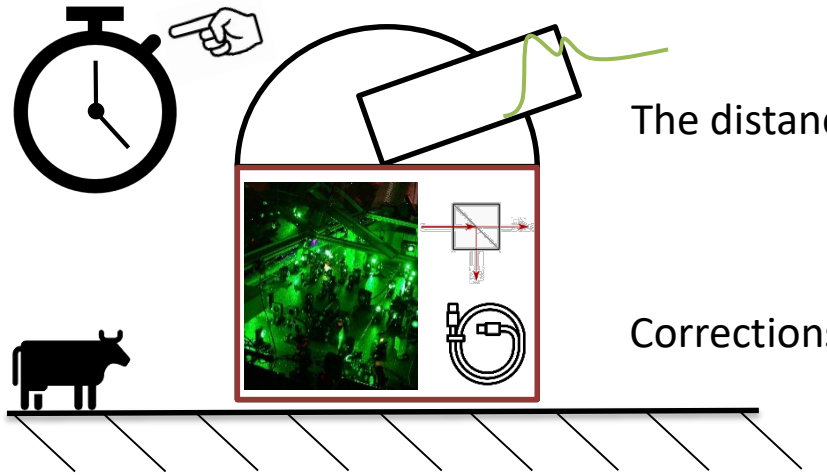
- Introduction on SLR
- Benefits & Challenges of Multi-Satellite SLR Combinations
- Summary & Outlook

Measurement Technique of SLR

1. Emitting ultra-short laser pulses (=> start the timer)
2. Laser pulses travel through the atmosphere
3. Laser pulses are reflected at the satellite
4. Laser pulses are detected (=> stop the timer)
5. Time-of-flight: Δt







The distance between the station and the satellite is

$$d \approx \frac{1}{2} c\Delta t + \Delta d_{sta} + \Delta d_{sat} + \Delta d_{sig}$$

Corrections related to: Station | Satellite | Signal propagation

$\Rightarrow$ Measurement accuracy: few millimeters

Acronyms:
- **SwissOGS:** Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald
- **FWHM:** Full Width at Half Maximum

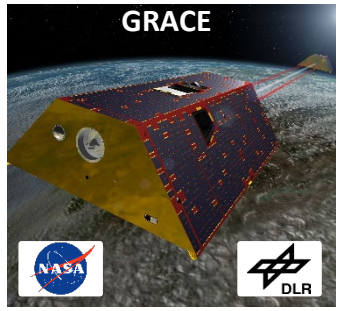
Space and Ground Segements of SLR

- Introduction on SLR
  - Measurement Technique
  - Space & Ground Segments
  - Geodetic Applications
- Multi-Satellite SLR Combinations
- Summary & Outlook

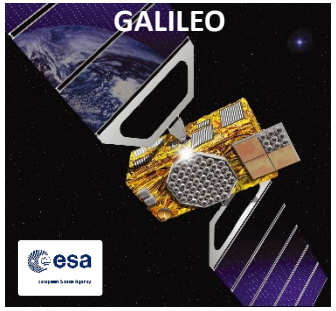
Space segment

Spherical SLR satellites

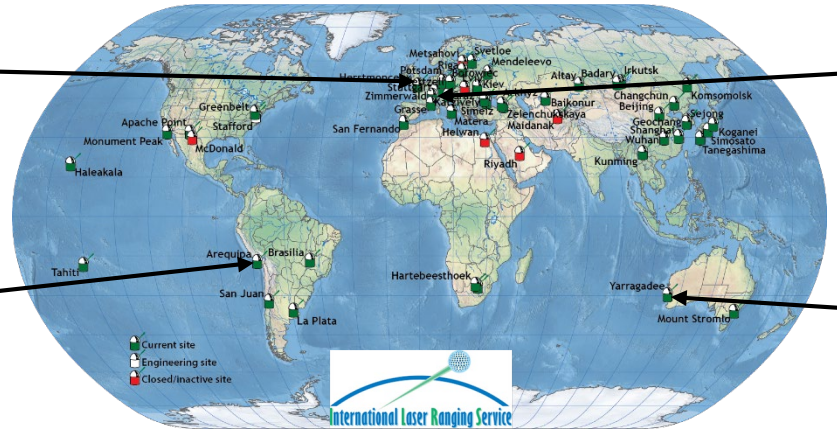
Earth observation satellites

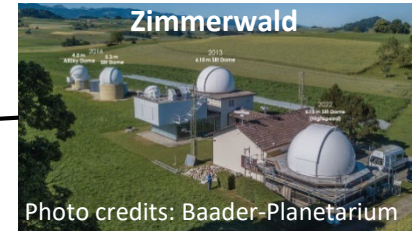


Navigation satellites



Ground segment





References:

[1]: ILRS-website

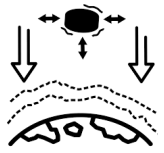
Geodetic Applications of SLR

Determination of

Tectonic plate motion

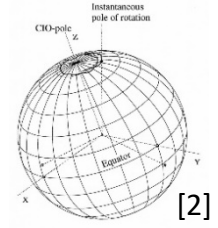
Polar motion and Length of day variations

Geocenter coordinates and global scale (used to realize a terrestrial reference frame)

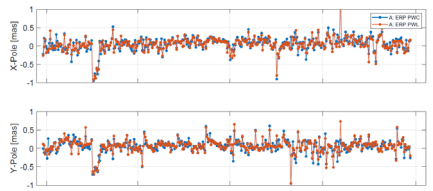


Low-degree gravity field coefficients

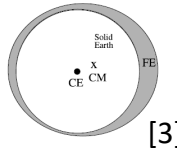
Polar motion



[2]

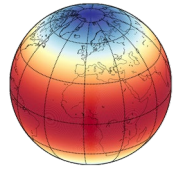


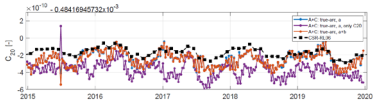
Geocenter coordinates



[3]

Zonal harmonic coefficient C_{20}





References:

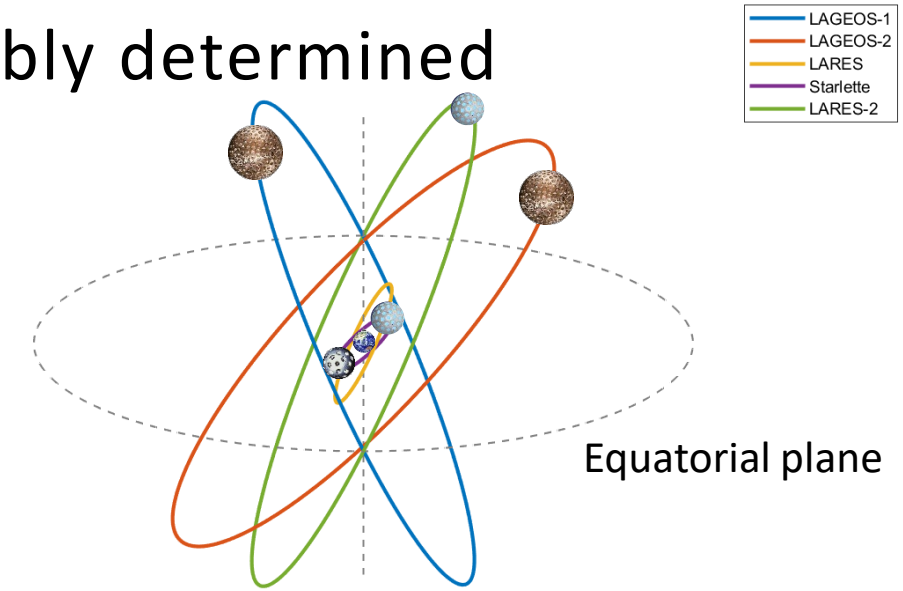
[2]: https://ggos.org/

[3]: Tregoning et al., 2005

Multi-Satellite SLR Combinations

Why focusing on multi-satellite SLR combinations?

- More parameters can be reliably determined
- Decorrelation of parameters



Emerging challenges

- Adaption of the orbit parametrization
- Extension of the parameter space

Subject of this presentation

- Weighting of the satellite specific observations

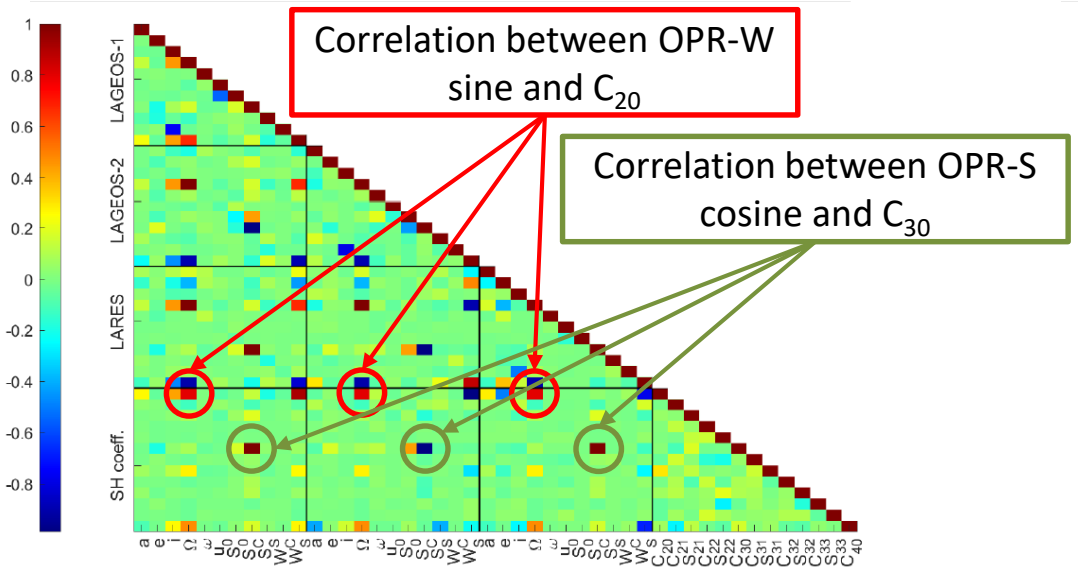
LAGEOS-1/2 & LARES: Parametrization

- Introduction on SLR
- Multi-Satellite SLR Combinations
  - LAGEOS-1/2 & LARES
  - LAGEOS-1/2 & LARES & Stella & Starlette
- Summary & Outlook

Acronyms:
- **S/W:** along-track/cross-track
- **NNR:** No-Net-Rotation
- **NNT:** No-Net-Translation
- **d/o:** degree/order

Parametrization \ Satellites	LAGEOS-1/2	LARES
Osculating elements	$a, e, i, \Omega, \omega, u_0$	
	1 set per 7 days	
Constant and once-per-revolution accelerations	S_0, S_S, S_C, W_S, W_C	
	1 set per 7 days	1 set per 7 days
Pseudo-stochastic pulses	no pulses	in along-track (twice per day)
Earth Rotation Parameters	$X_P, Y_P, UT1 - UTC$	
	piecewise-linear	
Geocenter coordinates		
Station coordinates	1 set per 7 days	
	NNR and NNT	
Range biases	1 set per 7 days for	
	selected stations	all stations
Gravity field coefficients	1 set per 7 days	
	up to d/o ??	

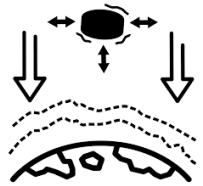
Correlations



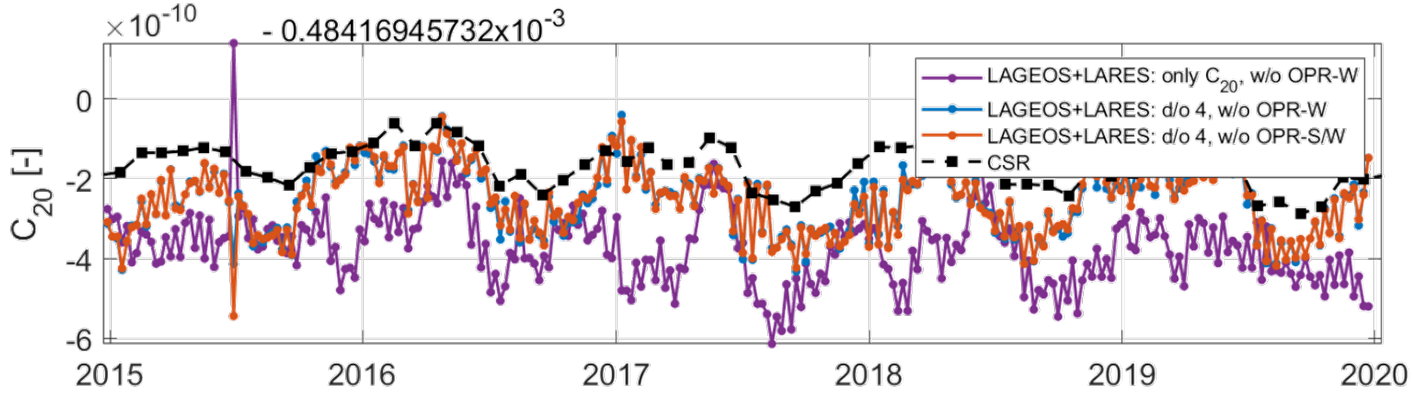
⇒ The lower orbital altitude of LARES increases the sensitivity to the Earth's gravity field.

⇒ New correlations between parameters appear!

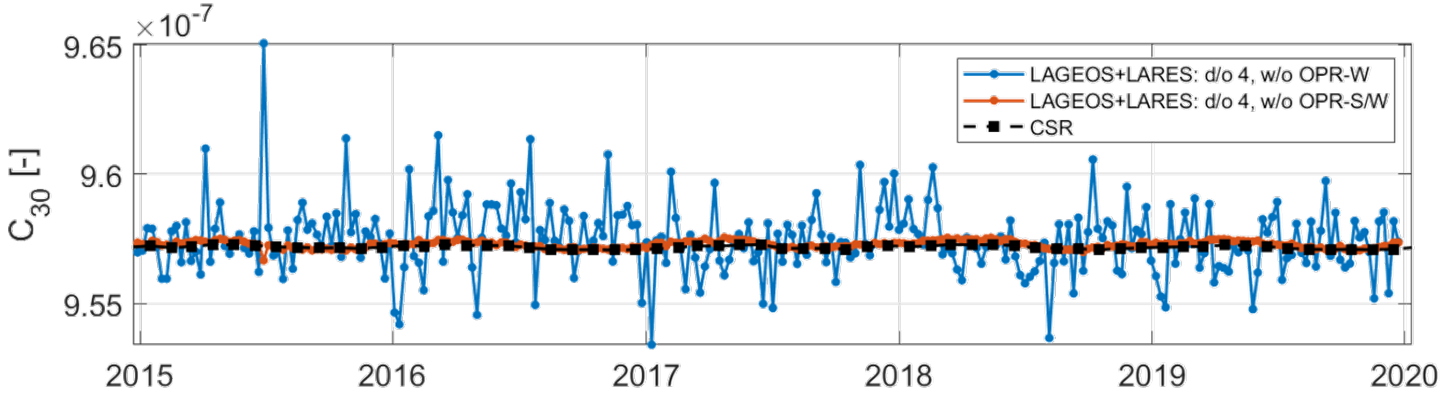
LAGEOS-1/2 & LARES: Gravity Field Coefficients



- Introduction on SLR
- Multi-Satellite SLR Combinations
  - LAGEOS-1/2 & LARES
  - LAGEOS-1/2 & LARES & Stella & Starlette
- Summary & Outlook



⇒ Increased sensitivity to the Earth's gravity field requires an extension of estimated gravity field coefficients!



⇒ Extension of estimated parameters leads to correlations and an adaption of the orbit parametrization!

Acronyms:
- **OPR:** Once-Per-Revolution
- **S/W:** along-track/cross-track

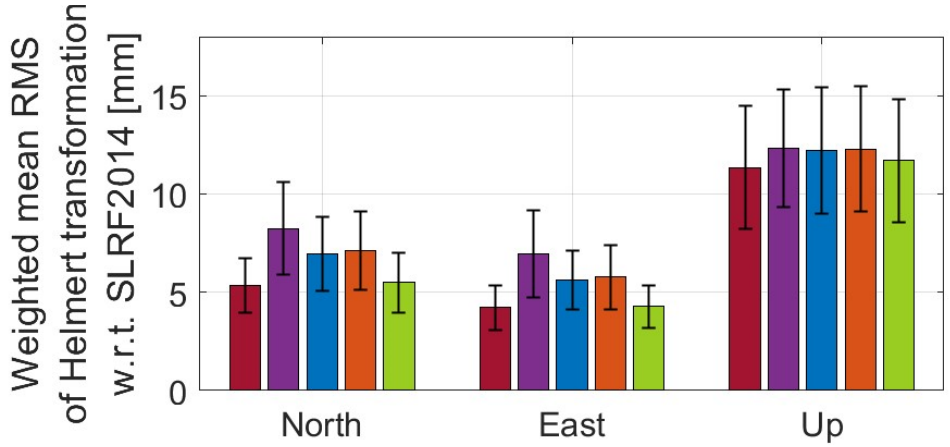
LAGEOS-1/2 & LARES: ERPs and Station Coordinates

Acronyms:
- **OPR:** Once-Per-Revolution
- **S/W:** along-track/cross-track

• Earth Rotation Parameters (ERPs)

	OPR-W	OPR-S	St. pl. (2/day)	SH geop. coeff. (d/o)	X pole [μas]		Y pole [μas]		UT1-UTC [μs]	
					Bias	WRMS	Bias	WRMS	Bias	WRMS
LAGEOS-1/2	✓	✓	-	-	85.6	142.1	31.9	118.1	-1.7	64.3
LAGEOS-1/2 + LARES	×/×	✓/✓	- / -	C20	23.9	217.1	-20.8	177.3	1.9	27.0
LAGEOS-1/2 + LARES	×/×	✓/✓	- / -	4/4	76.0	200.6	10.2	160.3	1.0	25.5
LAGEOS-1/2 + LARES	×/×	✓/×	- / -	4/4	73.1	209.8	14.0	167.2	0.3	25.2
LAGEOS-1/2 + LARES	×/×	✓/×	- /S,W	4/4	60.0	136.9	19.9	125.2	0.4	22.6

• Station coordinates



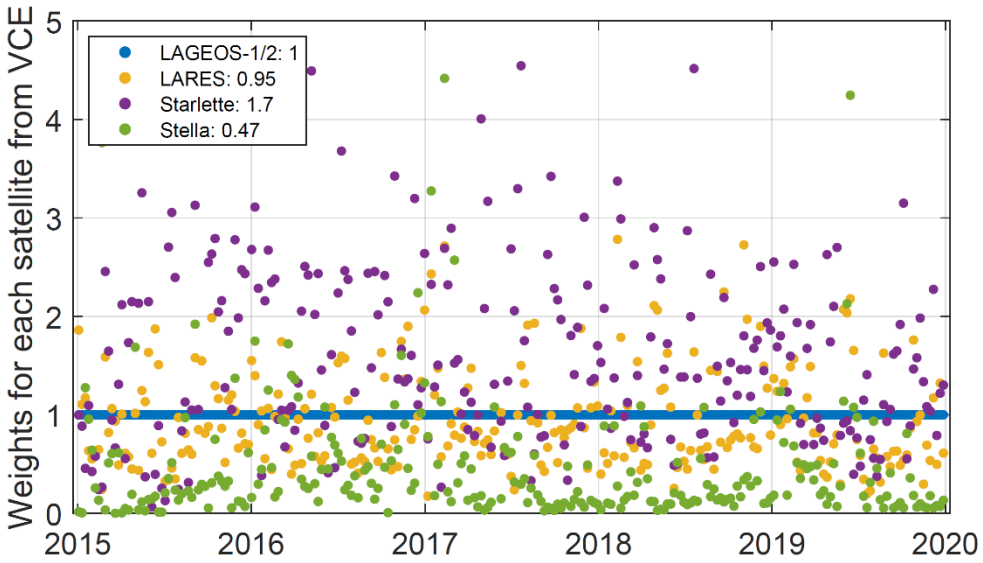
⇒ The removement of OPR-S/W terms degrades the ERPs and station coordinates.

⇒ Background force modeling deficiencies of LARES can be partially absorbed with pseudo-stochastic pulses in S/W.

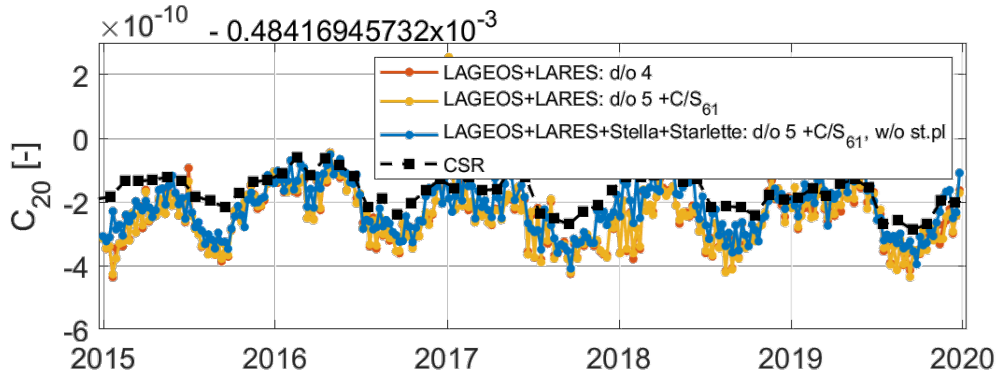
LAGEOS-1/2 & LARES & Stella/Starlette: Parametrization

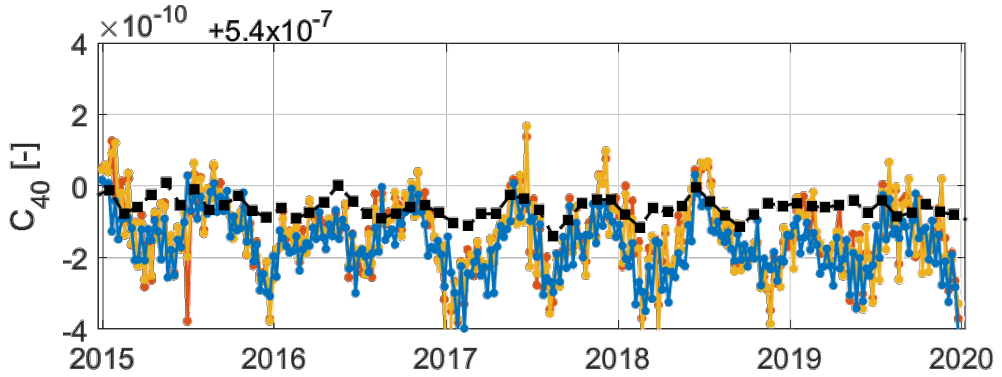
Parametrization \ Satellites	LAGEOS-1/2	LARES	Stella/ Starlette
Osculating elements	$a, e, i, \Omega, \omega, u_0$		
	1 set per 7 days		
Constant and once-per-revolution accelerations	S_0, S_S, S_C	S_0	
	1 set per 7 days		
Pseudo-stochastic pulses	no pulses	in along-track	
		2/day	?/day
Earth Rotation Parameters	$X_P, Y_P, UT1 - UTC$		
	piecewise-linear		
Geocenter coordinates	1 set per 7 days		
	free geocenter		
Station coordinates	1 set per 7 days		
	NNR and NNT		
Range biases	1 set per 7 days for		
	selected stations	all stations	
Gravity field coefficients	1 set per 7 days		
	up to d/o 5 + C_{61} + S_{61}		

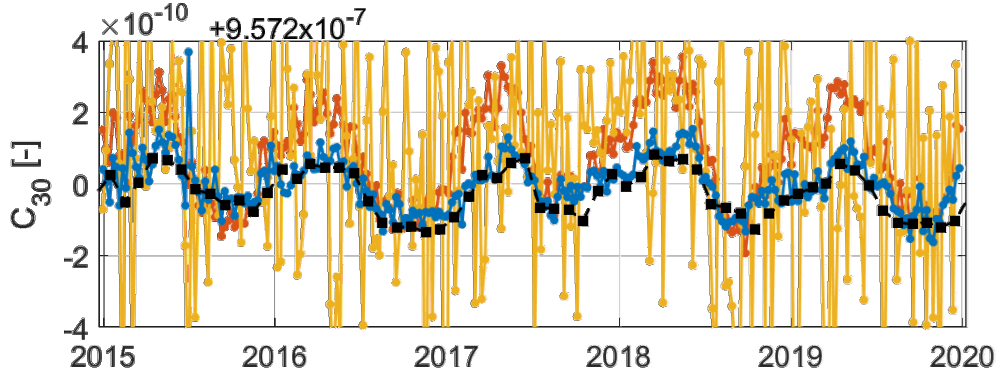
Satellite specific weights are determined by Variance Component Estimation (VCE)

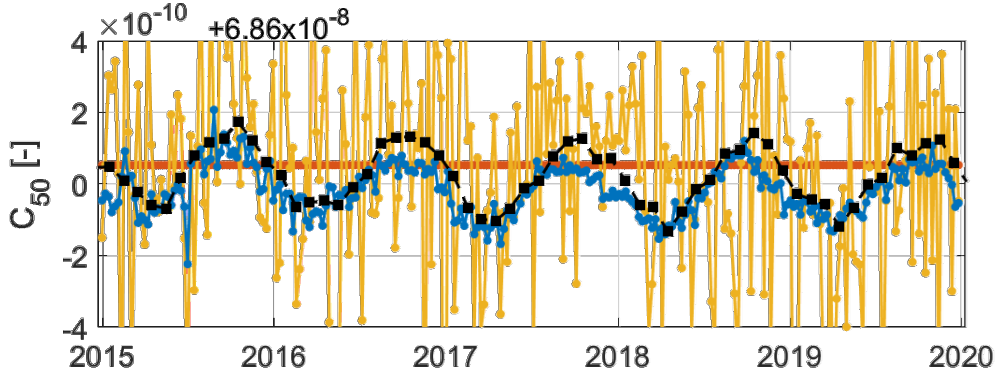


LAGEOS-1/2 & LARES & Stella & Starlette: Gravity Field Coefficients









⇒ Correlation between C_{20} and C_{40} can already be reduced by LAGEOS-1/2 and LARES combination.

⇒ C_{30} and C_{50} can only be decorrelated with the inclusion of Stella and Starlette.

Summary & Outlook

Multi-satellite SLR combinations

- lead to an increased sensitivity to geodetic parameters, e.g., Earth gravity field coefficients.
- allow an extension of the estimated parameter space.
- mitigate correlations between parameters, e.g., C_{20} and C_{40} in a LAGEOS-1/2 and LARES combination.

However, the extension of the estimated parameter space

- may introduce further correlations and will request an adaption in the orbit parametrization.
- must be carefully performed according to the gained sensitivity of each satellite to the corresponding parameter.

Further,

- a contribution analysis can be consulted to perform a reliable extension of the parameter space.
- more satellites, e.g., LARES-2 or Ajisai, can be included.
- the weighting scheme of the satellite combination have to be analyzed, e.g., VCE.

Thank you for your attention!

REFERENCES

[1]: https://ilrs.gsfc.nasa.gov/

[2]: https://ggos.org/

[3]: Tregoning, P., and T. van Dam (2005). Effects of atmospheric pressure loading and seven-parameter transformations on estimates of geocentermotion and station heights from space geodetic observations. *J. Geophys. Res., 110*, B03408. doi:10.1029/2004JB003334.