Multi-satellite SLR solutions including LARES/LARES-2 SLR data

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Outline

- Properties of the satellites and the used data set
- SLR solutions based on LAGEOS-1/2 and LARES with estimating Earth's gravity field coefficients
- Inclusion of LARES-2
- Summary & Outlook

SATELLITE ORBITS AND PROPERTIES

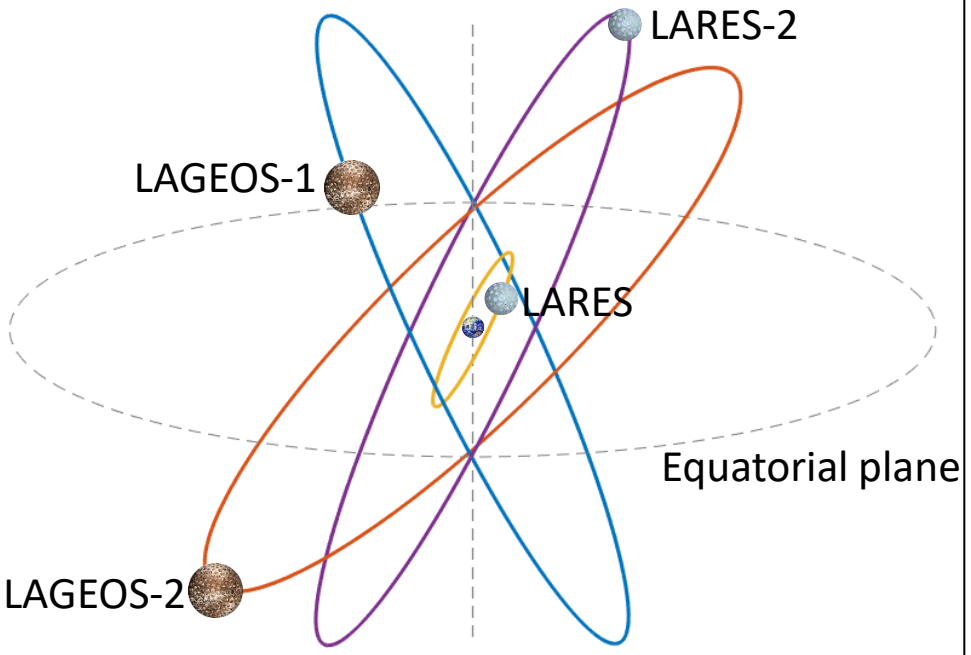
Outline:

- Properties
  - Satellite orbits and properties
  - Data set
- LAGEOS+LARES
- Inclusion of LARES-2
- Summary & Outlook

Sources:

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

- Orbital planes



- Facts

	LAGEOS-1	LAGEOS-2	LARES	LARES-2
Diameter [m]	0.60	0.60	0.36	0.42
Weight [kg]	407.0	405.4	386.6	297.5
Altitude [km]	5860	5620	1450	5899
Inclination [°]	109.8	52.6	69.5	70.2

[1]

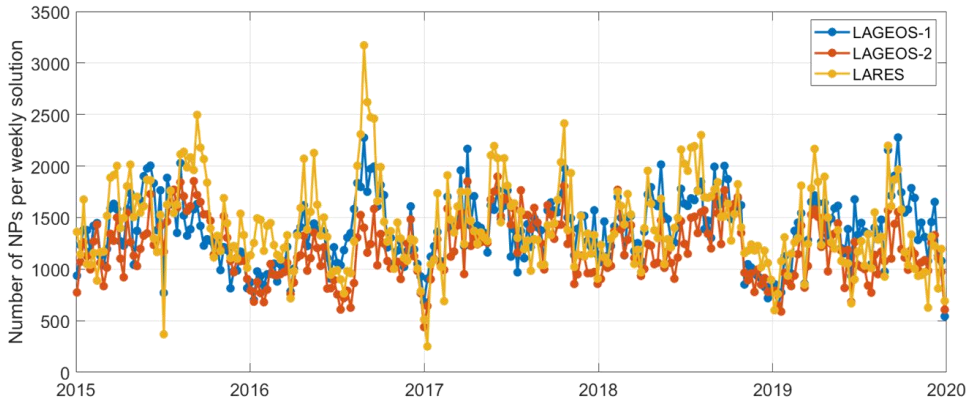
- Launch date:
  - LAGEOS-1: May 4, 1976
  - LAGEOS-2: October 22, 1992
  - LARES: February 13, 2012
  - LARES-2: July 13, 2022

DATA SET

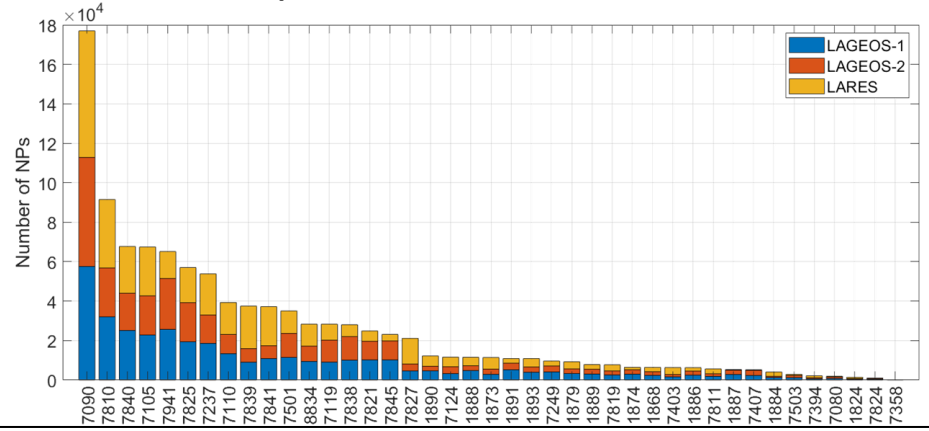
Outline:

- Properties
  - Satellite properties
  - Data set
- LAGEOS+LARES
- Inclusion of LARES-2
- Summary & Outlook

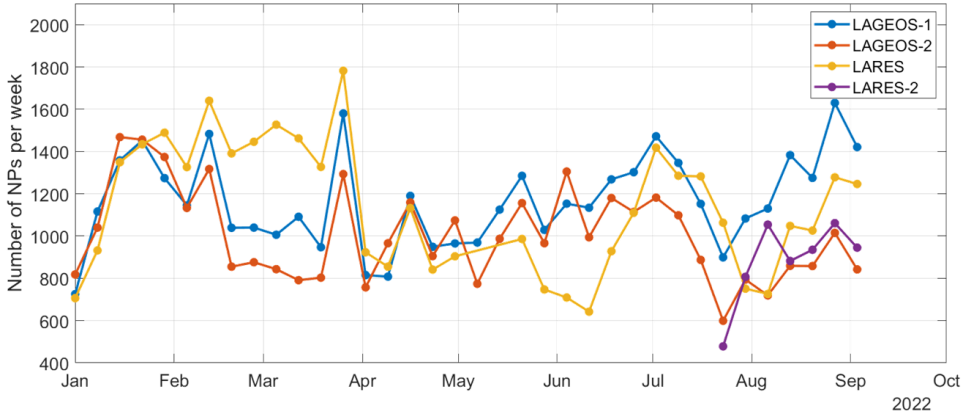
- LAGEOS + LARES: 2015-2020



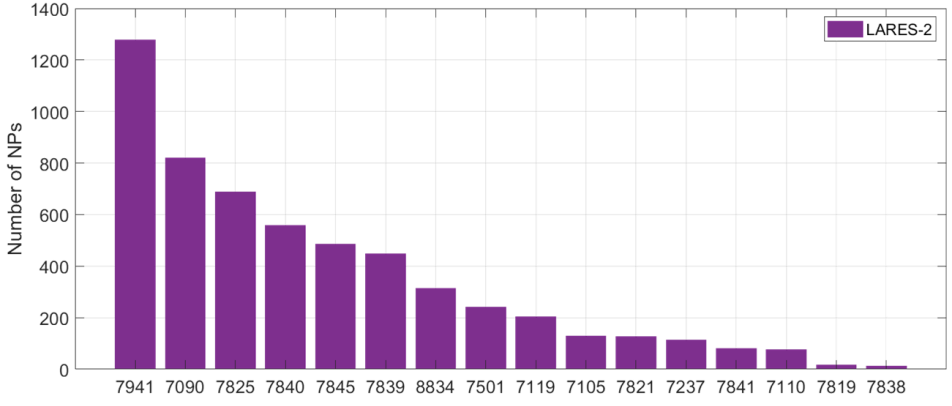
- SLR data per station: 2015-2020



- Inclusion of LARES-2: Jul-Sep 2022



- SLR data for LARES-2 per station

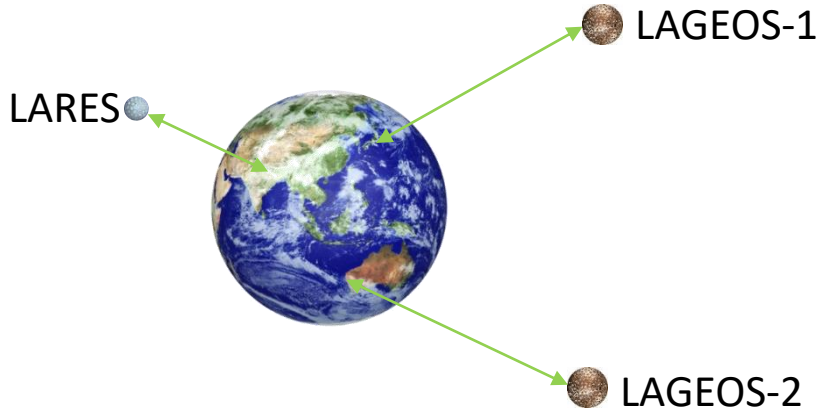


LAGEOS + LARES: PARAMETRIZATION

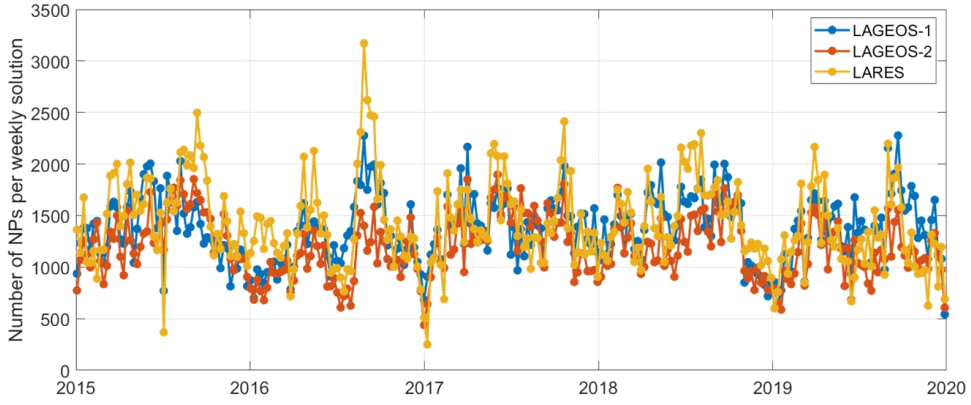
Outline:
- Properties
- LAGEOS+LARES
  - Parametrization
  - Correlations
  - Results
- Inclusion of LARES-2
- Summary & Outlook

Glossary:
- S: along-track
- W: cross-track

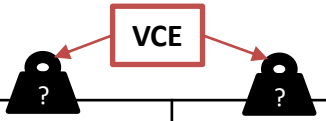
- Satellites



- NP data per satellite



- Parametrization



Parametrization \ Satellites	LAGEOS-1/2	LARES
Osculating elements	$a, e, i, \Omega, \omega, u_0$	
	1 set per 7 days	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	$X_P, Y_P, UT1 - UTC$	
	ise-linear	
Geocenter coordin	er 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 4	

Correlations

LAGEOS + LARES: PARAMETER CORRELATIONS

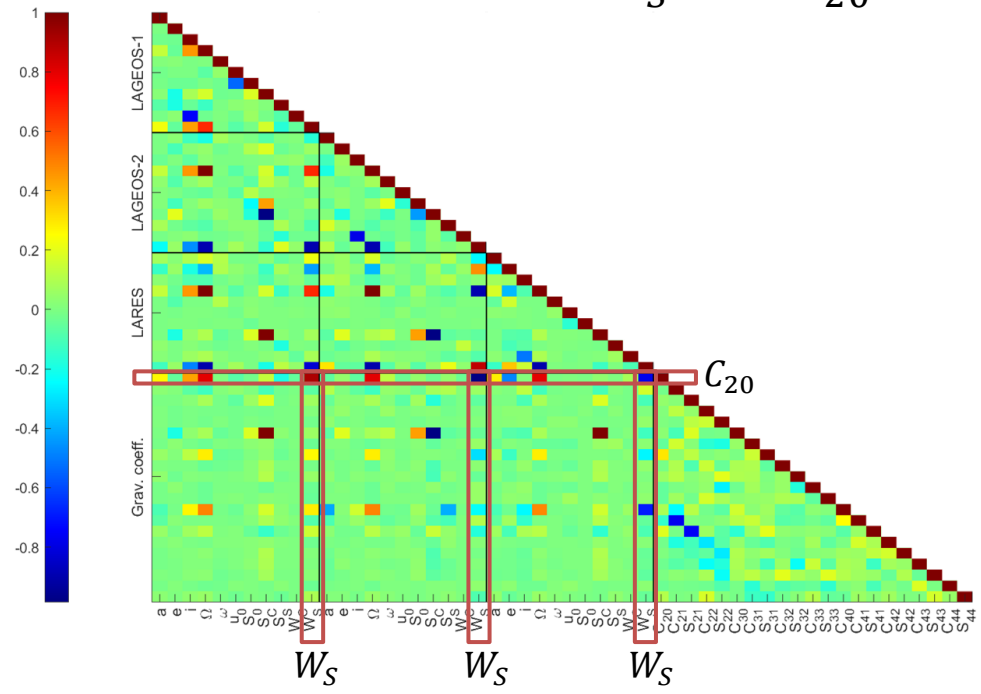
Outline:

- Properties
- LAGEOS+LARES
  - Parametrization
  - Correlations
  - Results
- Inclusion of LARES-2
- Summary & Outlook

Glossary:

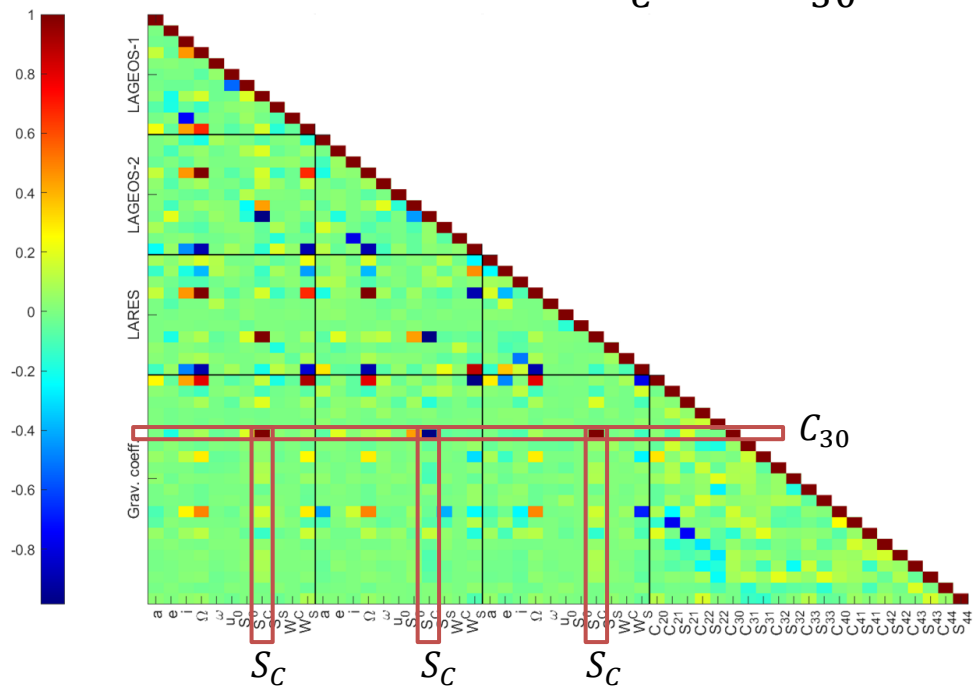
- S: along-track
- W: cross-track

- Correlation between W_S and C_{20}



→ Conclusion: Do not set up W_S in the orbit parametrization of all satellites.

- Correlation between S_C and C_{30}



→ Conclusion: Do not set up S_C only in the orbit parametrization of LARES (LARES is more sensitive to C_{30} because of the lower orbital altitude).

LAGEOS + LARES: RESULTS

Outline:
- Properties
- LAGEOS+LARES
  - Parametrization
  - Correlations
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- Inclusion of LARES-2
- Summary & Outlook

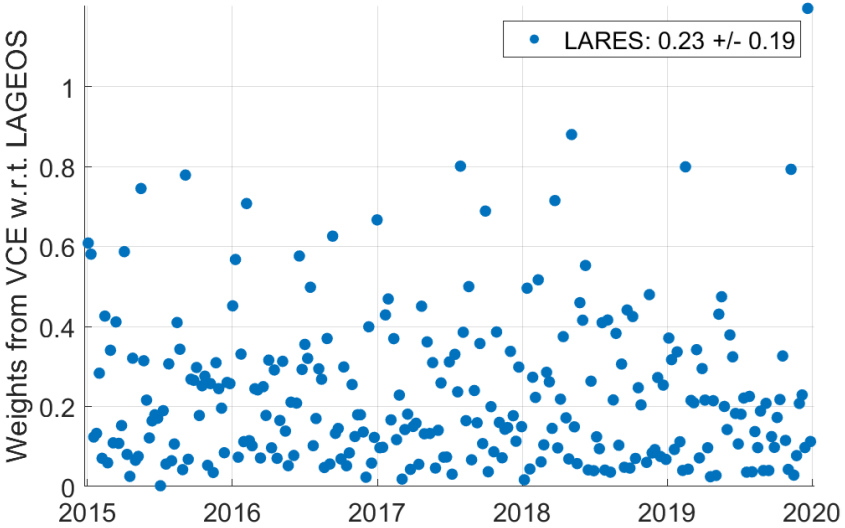
Glossary:
- S: along-track
- W: cross-track

- New parametrization

Parametrization \ Satellites	LAGEOS-1/2	LARES
Osculating elements	$a, e, i, \Omega, \omega, u_0$	
	1 set per 7 days	1 set per 7 days
Constant and once-per-revolution accelerations	S_0, S_S, S_C	S_0
	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	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 4	

[Geisser et al., 2022]

- Weighting of the satellite groups using VCE (LARES vs. LAGEOS)



- Compare
  - Earth Rotation Parameters
  - Station coordinates
  - Earth's gravity field coefficients

LAGEOS + LARES: RESULTS

Outline:

- Properties
- LAGEOS+LARES
  - Parametrization
  - Correlations
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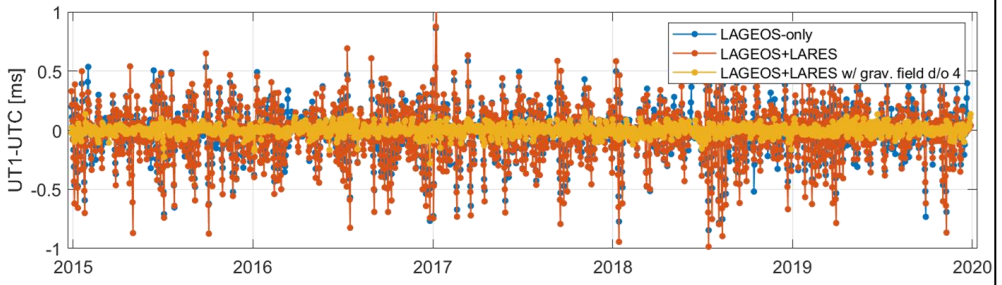
- Summary & Outlook

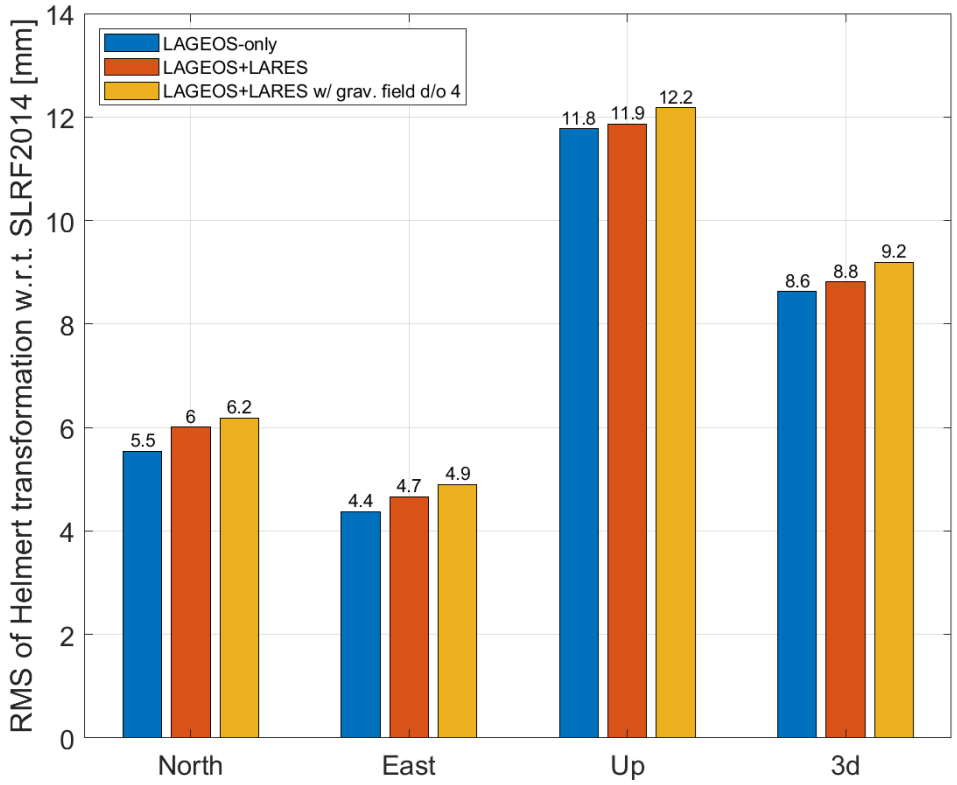
• Earth Rotation Parameters

	Grav. field	X pole [μas]		Y pole [μas]		UT1-UTC [μs]	
		Bias	WRMS	Bias	WRMS	Bias	WRMS
LAGEOS-only	-	85.6	142.1	31.9	118.1	-1.7	64.3
LAGEOS + LARES	-	-12.2	125.0	33.6	122.2	-9.2	76.1
LAGEOS + LARES	d/o 4	63.1	151.3	22.1	140.4	0.9	22.5



→ The main errors in ΔLoD, resp. in UT1-UTC, are caused by the nodal precession due to an offset in C_{20}. [Blossfeld et al., 2014]

• Station coordinates



LAGEOS + LARES: RESULTS

Outline:
- Properties
- LAGEOS+LARES
  - Parametrization
  - Correlations
  - Results
- Inclusion of LARES-2
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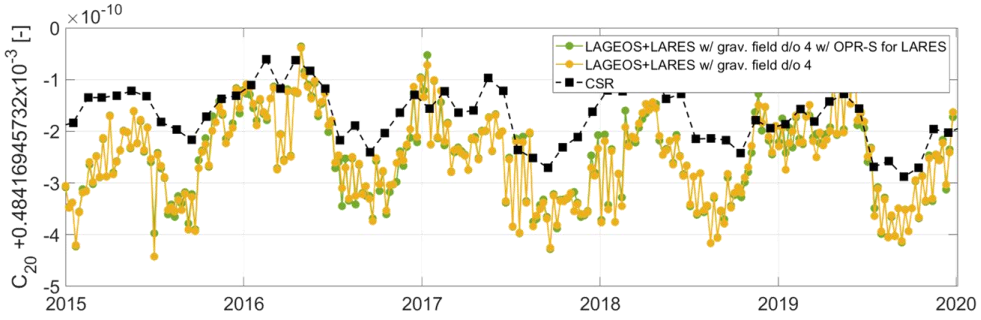
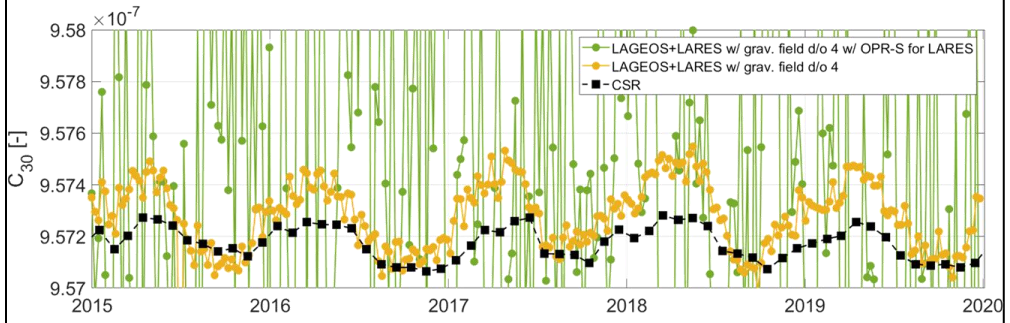
Glossary:
- S: along-track
- W: cross-track

- Earth's gravity field coefficient: C_{20}



→ The estimated C_{20} time series has an offset compared to the CSR reference series.

- Earth's gravity field coefficient: C_{30}



→ The estimated C_{30} time series has a strong annual signal.

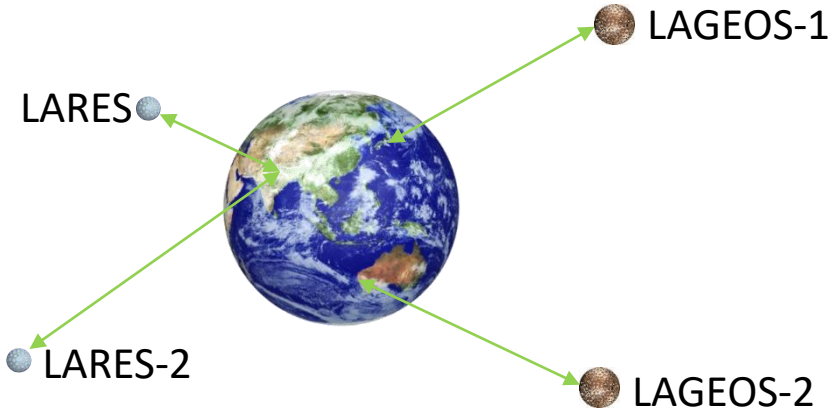
The offset in C_{20} and the strong annual signal in C_{30} can be reduced, if Stella and Starlette are included!

INCLUSION OF LARES-2: PARAMETRIZATION

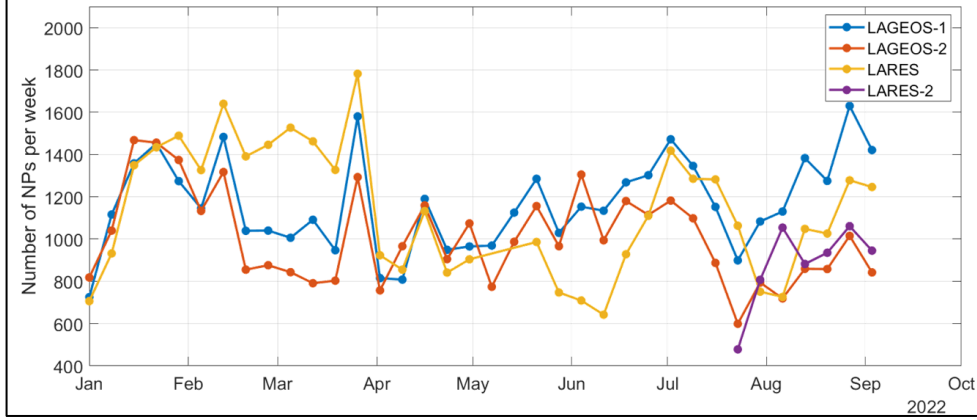
Outline:
- Properties
- LAGEOS+LARES
- Inclusion of LARES-2
  - ➢ Parametrization
  - ➢ First results
- Summary & Outlook

Glossary:
- S: along-track
- W: cross-track

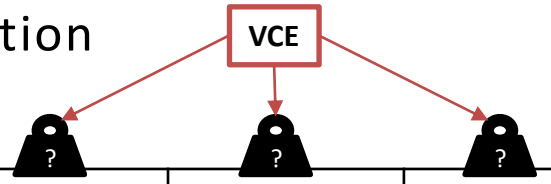
- Satellites



- NP data per satellite in 2022



- Parametrization



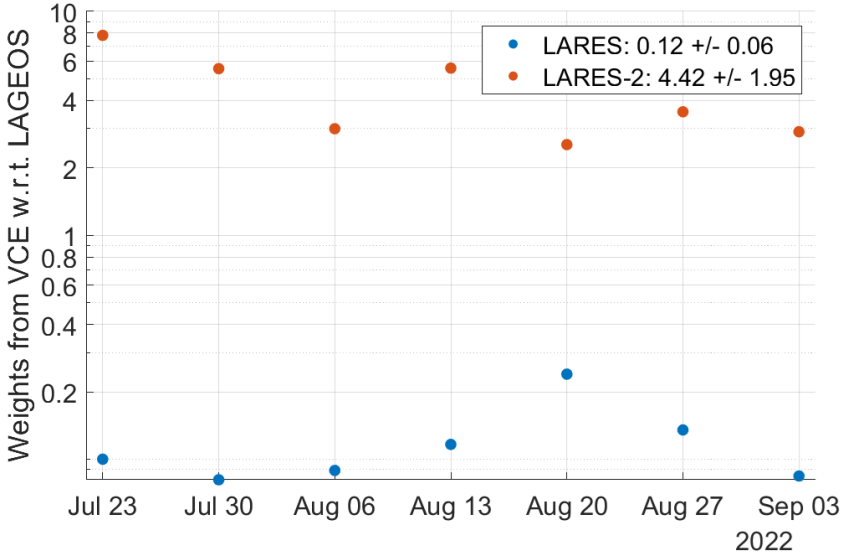
Parametrization \ Satellites	LAGEOS-1/2	LARES	LARES-2
Osculating elements	$a, e, i, \Omega, \omega, u_0$		
	1 set per 7 days		
Constant and once-per-revolution accelerations	S_0, S_S, S_C, W_S, W_C		
	1 set per 7 days		
Pseudo-stochastic pulses	no pulses	in along-track (twice per day)	no pulses
Earth 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	all stations

INCLUSION OF LARES-2: FIRST RESULTS

Outline:

- Properties
- LAGEOS+LARES
- Inclusion of LARES-2
  - Parametrization
  - First results
- Summary & Outlook

- Weighting of the satellite groups using VCE



- Compare
  - Earth Rotation Parameters
  - Station coordinates

- Earth Rotation Parameters

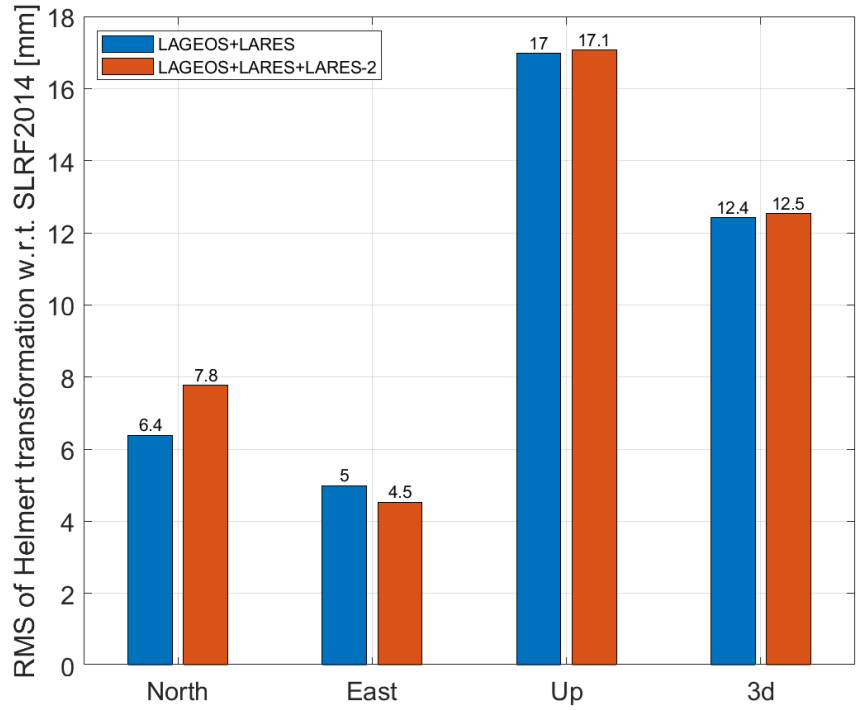
	X pole $[\mu as]$		Y pole $[\mu as]$		UT1-UTC $[\mu s]$	
	Bias	WRMS	Bias	WRMS	Bias	WRMS
LAGEOS+LARES	23.6	108.1	165.0	195.8	-12.2	42.1
LAGEOS+LARES+LARES-2	-19.5	82.7	137.6	178.2	-19.6	81.3

INCLUSION OF LARES-2: FIRST RESULTS

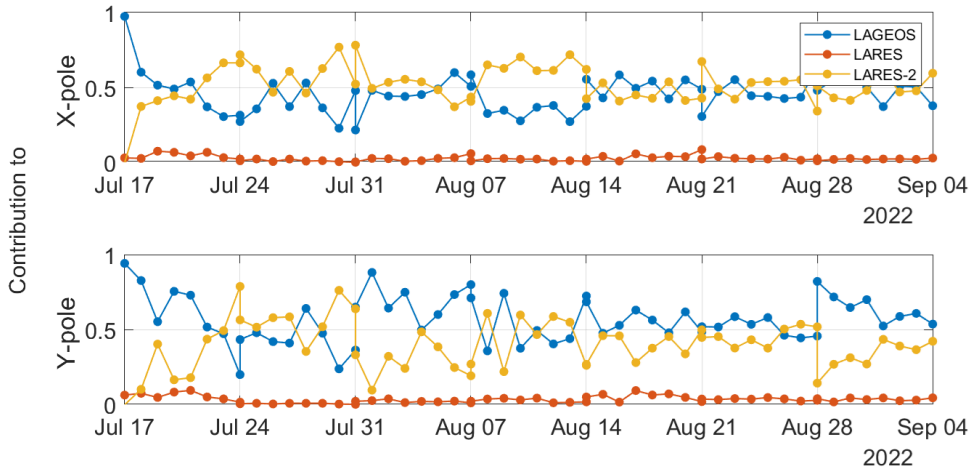
Outline:

- Properties
- LAGEOS+LARES
- Inclusion of LARES-2
  - Parametrization
  - First results
- Summary & Outlook

- Station coordinates



- Contribution analysis

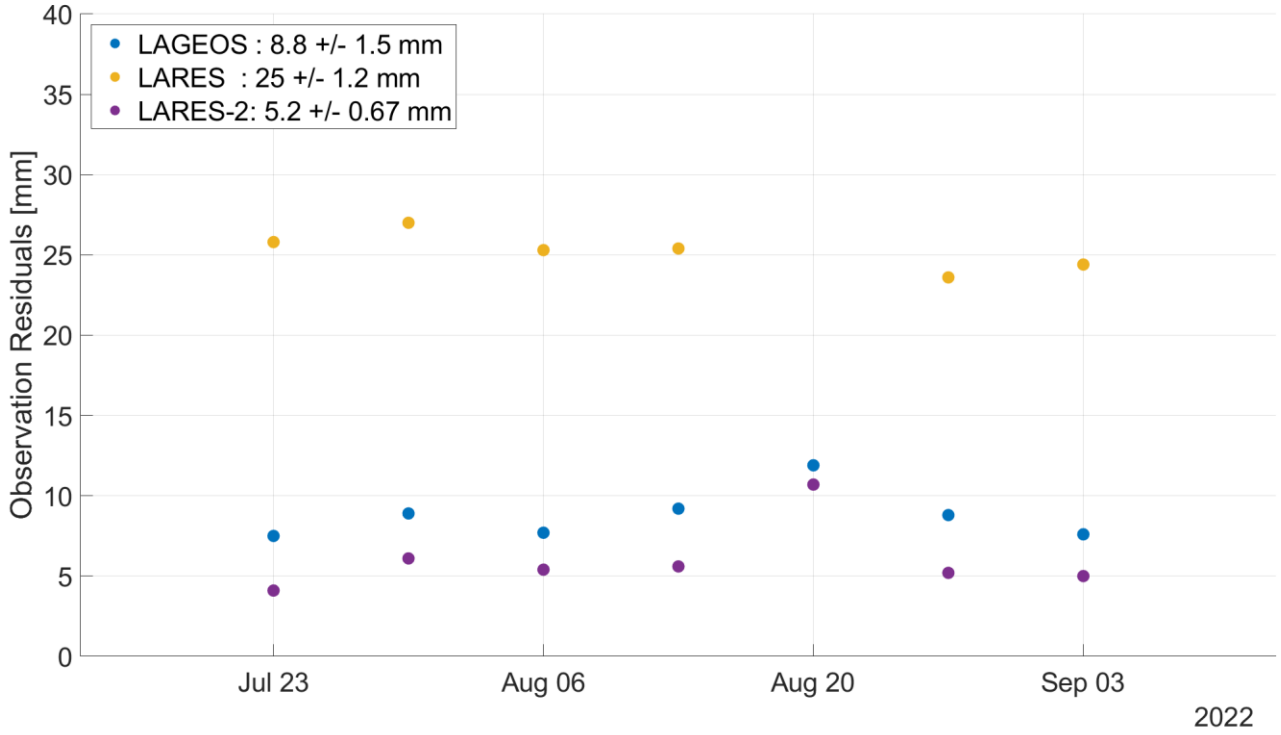


INCLUSION OF LARES-2: FIRST RESULTS

Outline:

- Properties
- LAGEOS+LARES
- Inclusion of LARES-2
  - Parametrization
  - First results
- Summary & Outlook

- Observation residuals



→ LARES-2 observation residuals are 40% smaller than for LAGEOS satellites.

SUMMARY & OUTLOOK

Outline:
- Properties
- LAGEOS+LARES
- Inclusion of LARES-2
- Summary & Outlook

- Summary:
  - Dynamical orbit parameters are correlated with gravity field coefficients. Therefore, the orbit parametrization has to be adapted for a LAGEOS and LARES combination.
  - We successfully included LARES-2 and can confirm the high quality of the observations.
- Outlook:
  - Optimize the orbit parametrization for the low Earth orbiting satellites.
  - Extend the multi-satellite solution with other satellites, e.g., Stella, Starlette or Ajisai.

SUMMARY & OUTLOOK

Outline:

- Initial conditions
- LAGEOS+LARES
- Inclusion of LARES-2
- Summary & Outlook

Thank you for your attention!

REFERENCES

1. https://ilrs.gsfc.nasa.gov
2. M. Bloßfeld, M. Gerstl, U. Hugentobler, D. Angermann, and H. Müller. Systematic effects in LOD from SLR observations (2014). 54(6):1049–1063, a. ISSN 02731177. doi: 10.1016/j.asr.2014.06.009. URL https://linkinghub.elsevier.com/retrieve/pii/S0273117714003512
3. L. Geisser, U. Meyer, D. Arnold, and A. Jäggi (2022). Contribution of LARES SLR data to co-estimated Earth geopotential coefficients. International Association of Geodesy Symposia. (*Accepted*)