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Geoscience Online

Wrocław University of Environmental and Life Sciences

Recent studies on the impact of troposphere delay modeling for Satellite Laser Ranging

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Troposphere delay modeling in SLR solutions

Current model (no tropo parameters are estimated in SLR solutions):

Wet delay: based on water vapor pressure records and the position of an SLR station (latitude, height)

(Mendes and Pavlis, 2004)

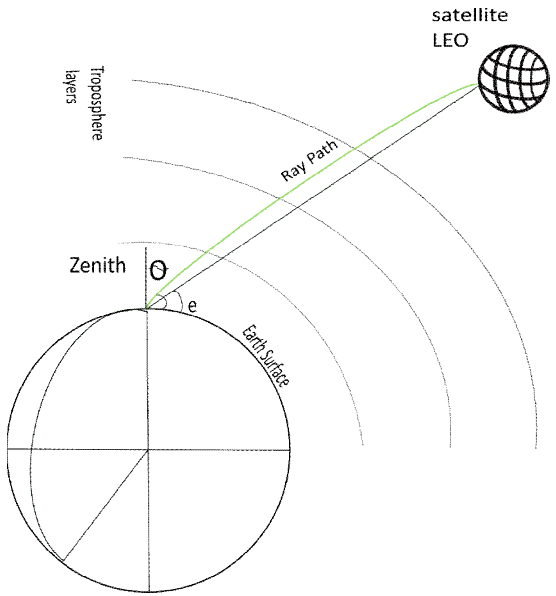
$$d_{atm} = m_{fs}(d_h^z + d_{nh}^z)$$

Common mapping function: based on temperature records and the position of an SLR station (latitude, height)

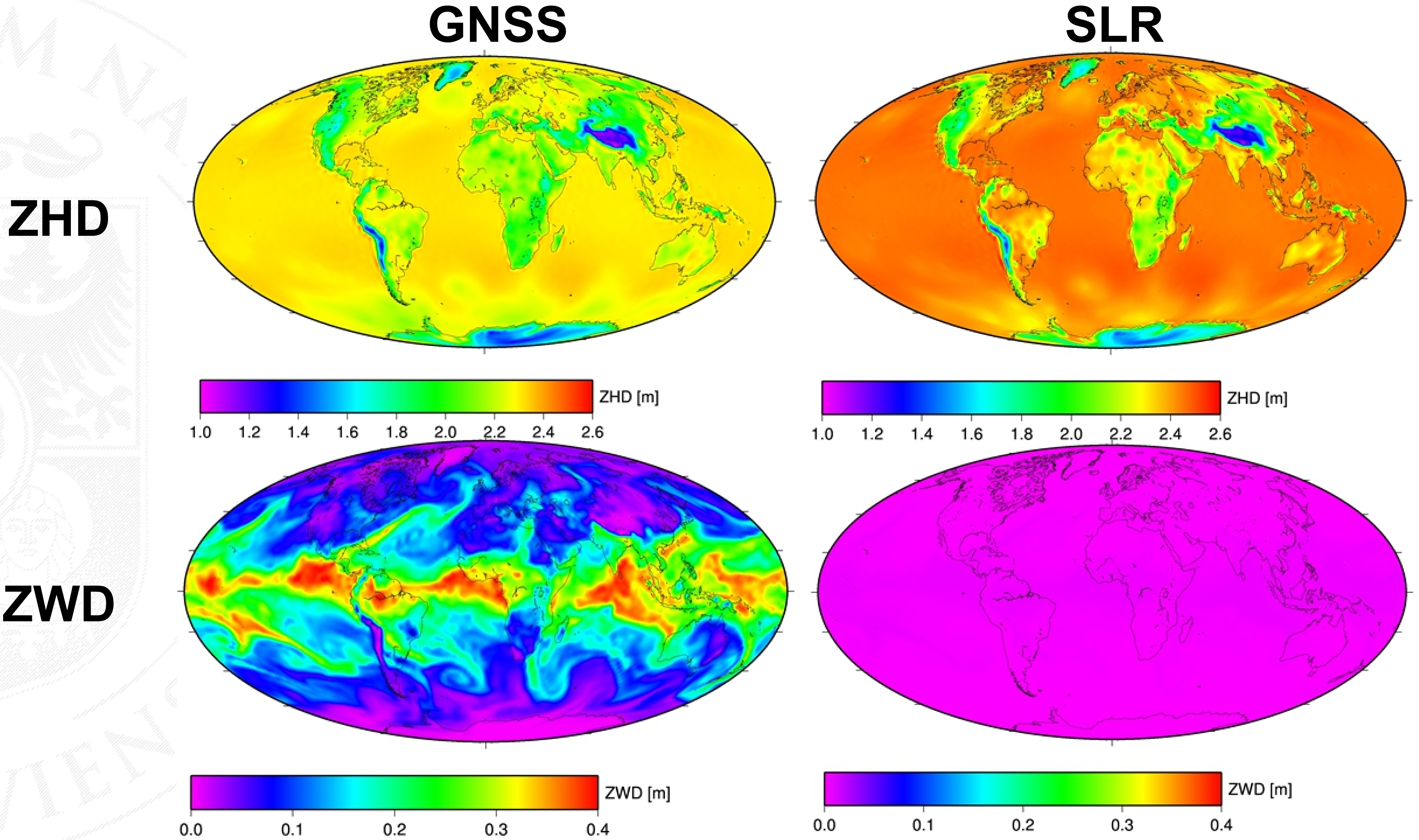
(Mendes et al., 2002)

Hydrostatic delay: based on pressure records and the position of an SLR station (latitude, height)

(Mendes and Pavlis, 2004)



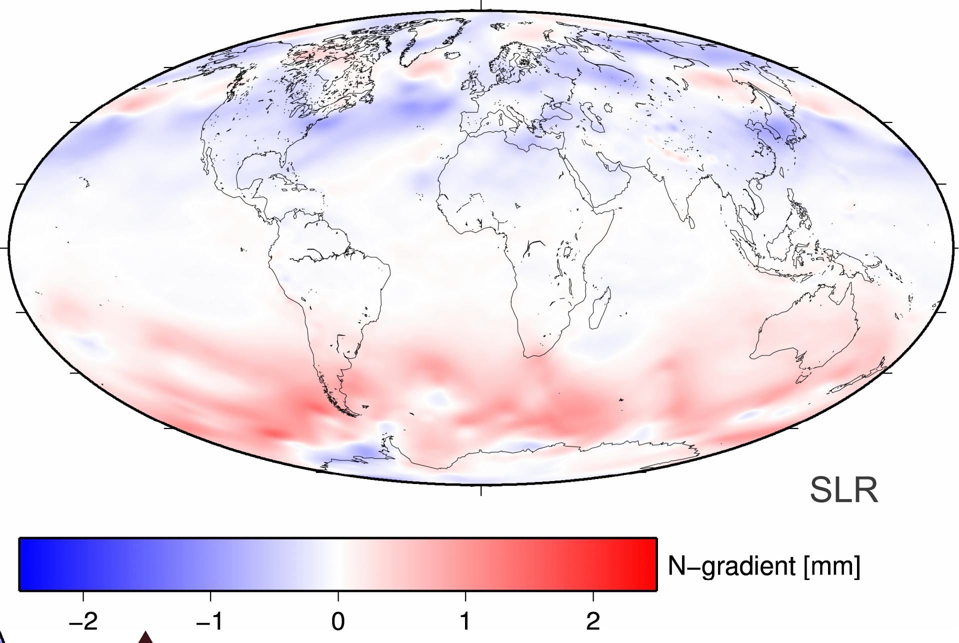
A full symmetricity of the atmosphere over SLR stations is assumed


GNSS
SLR
ZHD
ZWD
ZHD [m]
1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6
ZHD [m]
1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 2.6
ZWD [m]
0.0 0.1 0.2 0.3 0.4
ZWD [m]
0.0 0.1 0.2 0.3 0.4

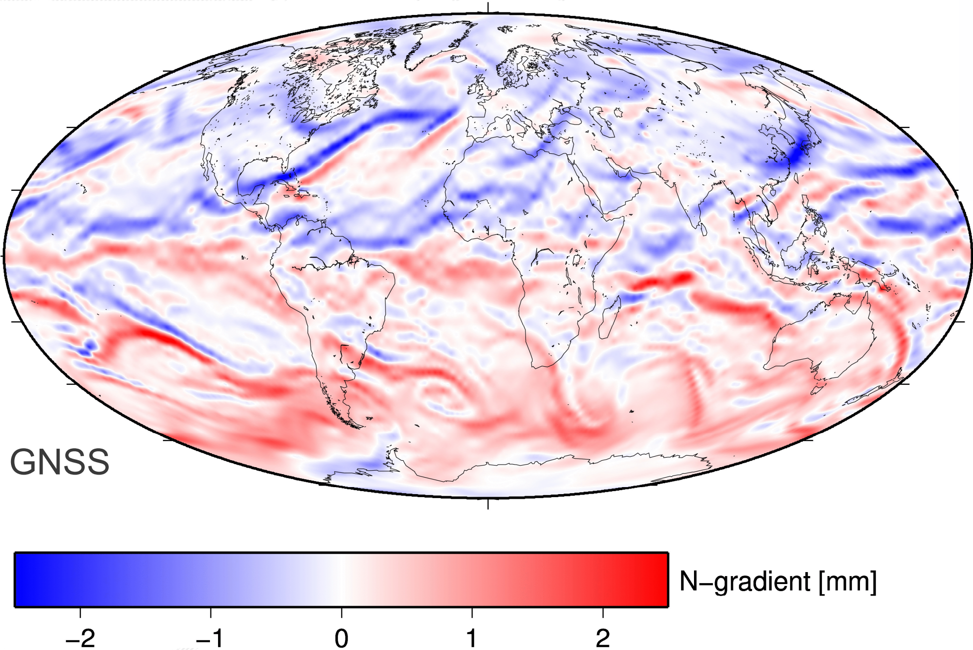
Mapping functions and horizontal gradients dedicated for optical measurements

Comparison of horizontal gradients

- *Time resolution: 6h*
- *Spatial resolution: 0.5x0.5 degree*



North component for SLR (wavelength 530 nm)



North component for GNSS

PMF troposphere delay models

Common mapping function: based on temperature records and the position of an SLR station (latitude, height)

(Mendes et al., 2002)

Hydrostatic delay: based on pressure records and the position of an SLR station (latitude, height)

(MP, Mendes and Pavlis, 2004)

Wet delay: based on water vapor pressure records and the position of an SLR station (latitude, height)

(MP, Mendes and Pavlis, 2004)

$$(1):\ d_{atm} = m_f(d_h + d_w)$$

Potsdam Mapping Function:

$$(2):\ d_{atm} = m_{PMF}(d_h + d_w)$$

O1: Linear horizontal gradients

$$(3):\ d_{atm} = m_{PMF}(d_h + d_w) + m_{CH-H}(G_N \cos A + G_E \sin A)$$

O1+O2: Nonlinear horizontal gradients:

$$(4):\ d_{atm} = m_{PMF}(d_h + d_w) + m_{CH-H}(G_N \cos A + G_E \sin A + G_{NN} \cos^2 A + G_{EE} \sin^2 A + G_{NE} \cos A \sin A)$$

VMF3o troposphere delay model

Separate mapping function:
based on NWM

(Boisits J., et al., 2018)

Hydrostatic mapping function:

$$m(e)_{VMF3oh} = \frac{1 + \frac{a_h}{1 + \frac{b_h}{1 + c_h}}}{sine + \frac{a_h}{sine + \frac{b_h}{sine + c_h}}},$$

Wet mapping function:

$$m(e)_{VMF3ow} = \frac{1 + \frac{a_w}{1 + \frac{b_w}{1 + c_w}}}{sine + \frac{a_w}{sine + \frac{b_w}{sine + c_w}}}$$

Hydrostatic delay:

$$d_{atm\,h} = d_h \cdot m(e)_{VMF3oh} + m_{gh}(G_{Nh} \cdot cosA + G_{Eh} \cdot sinA)$$

Wet delay:

$$d_{atm\,w} = d_w \cdot m(e)_{VMF3ow} + m_{gw}(G_{Nw} \cdot cosA + G_{Ew} \cdot sinA)$$

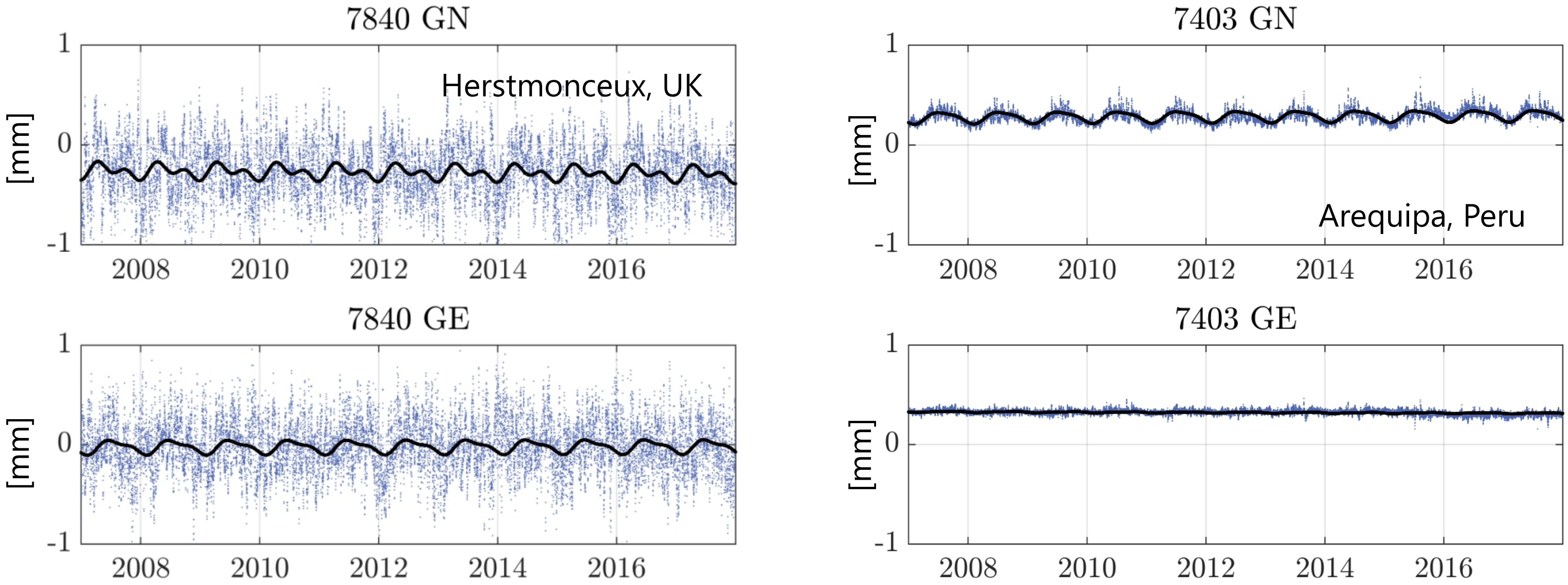
Vienna Mapping Fuction for optical frequencies (VMF3o):

Hydrostatic delay:

Wet delay

$$d_{atm} = (d_{atm\,h} + d_{atm\,w})$$

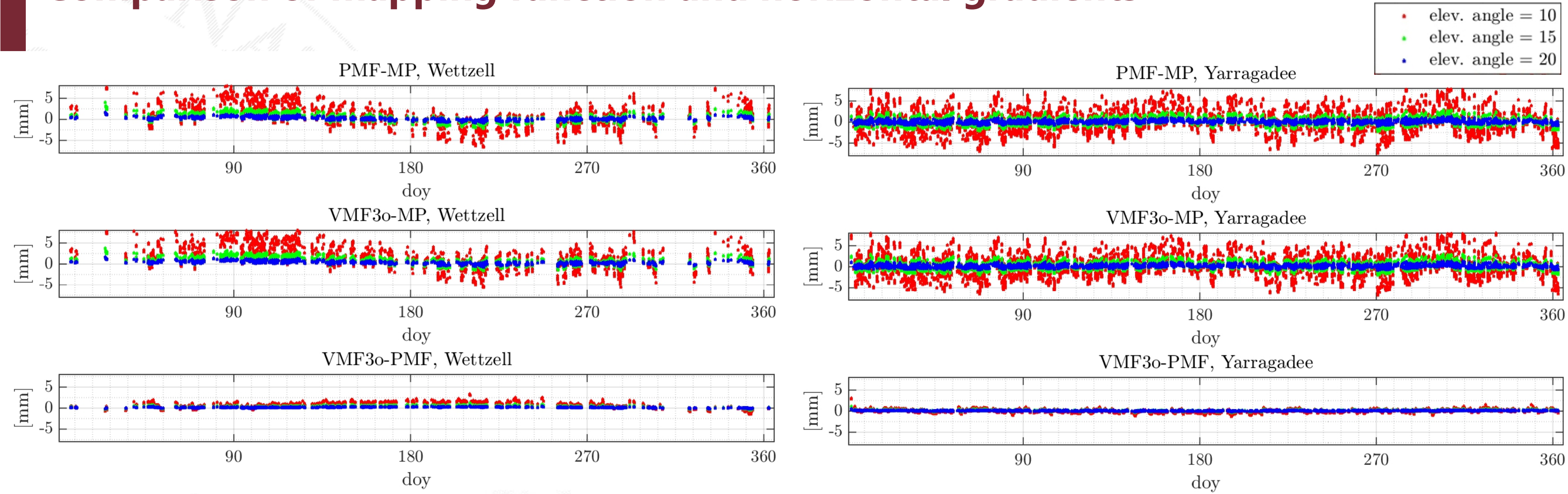
Simple model of gradients for SLR?

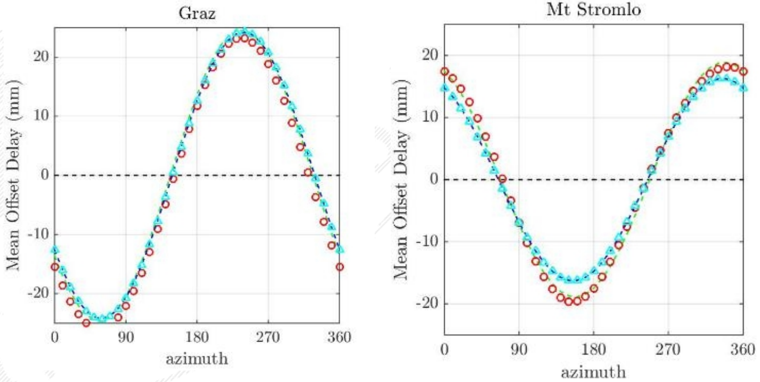


$$f(t) = a_0 + a_1 t + a_{s1} \sin\left(\frac{2\pi}{T}t\right) + a_{c1} cos\left(\frac{2\pi}{T}t\right) + a_{s2} \sin\left(\frac{4\pi}{T}t\right) + a_{c2} cos\left(\frac{4\pi}{T}t\right)$$

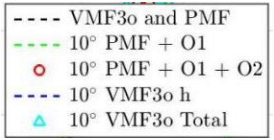
Offset + drift + annual signal + semi-annual signal for each component for each SLR station

Comparison of mapping function and horizontal gradients





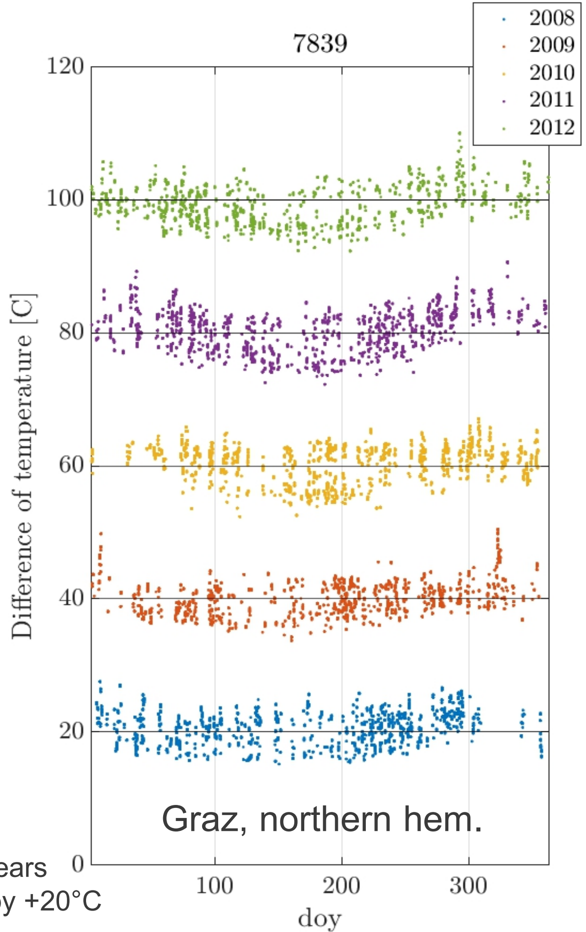
1. Seasonal variations between VMF3o, PMF, & MP
2. Very small systematic differences in the mapping function cause differences in SLR observations of several mm at low elevations
3. Gradients from VMF3o and PMF are very similar

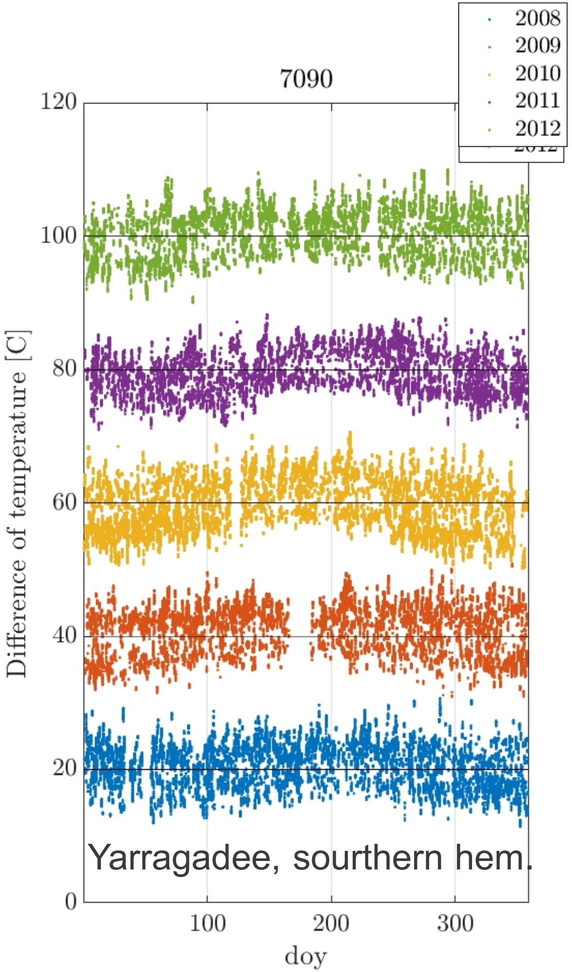


Differences of temperatures (temperature derived from the numerical wheather model and temperature measuered at SLR stations)

A characteristic difference of the temperature for the north and the south hemispheres can be observed (a seasonal variation).

The average value of the temperature difference is at the level of 5 deg [°C]

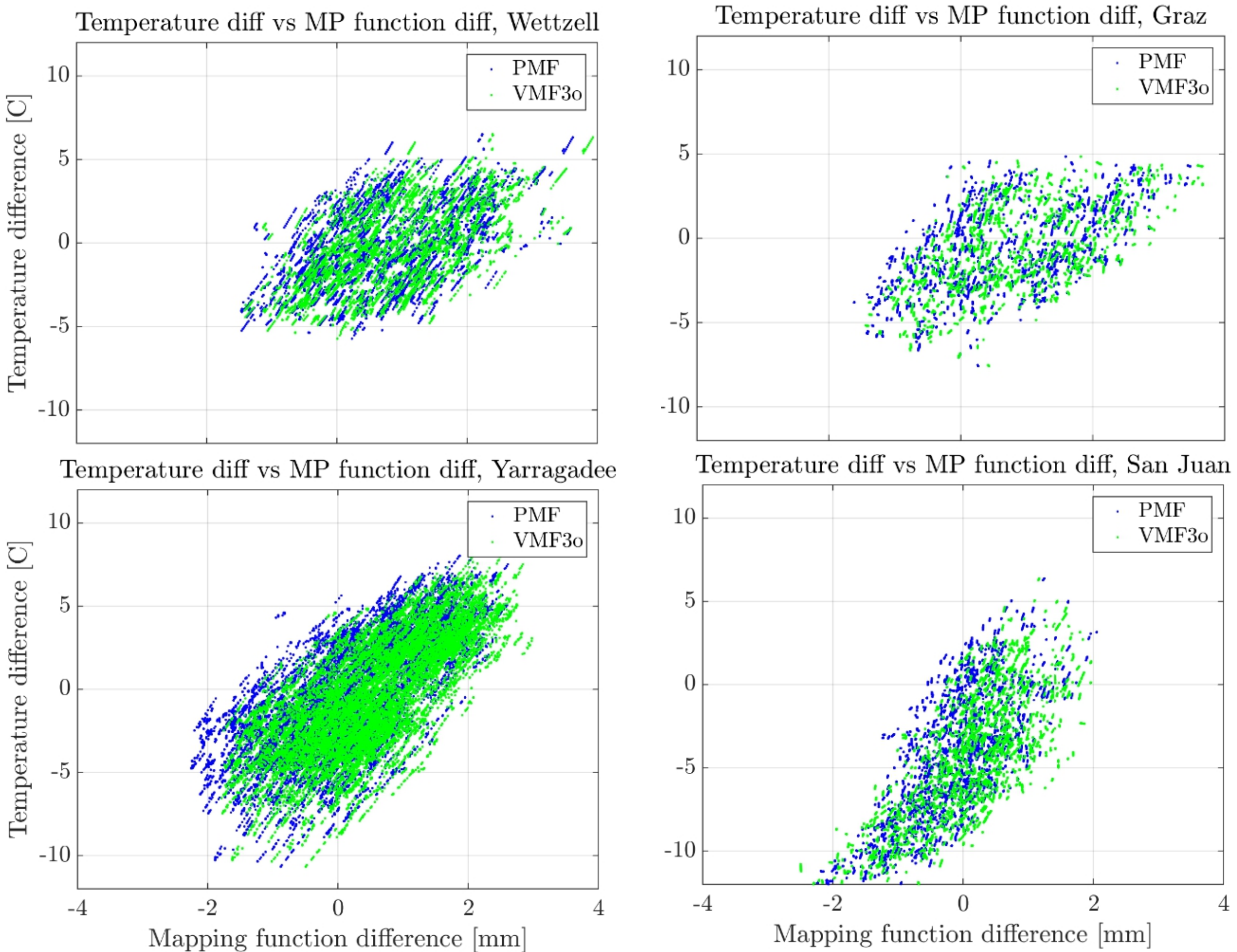




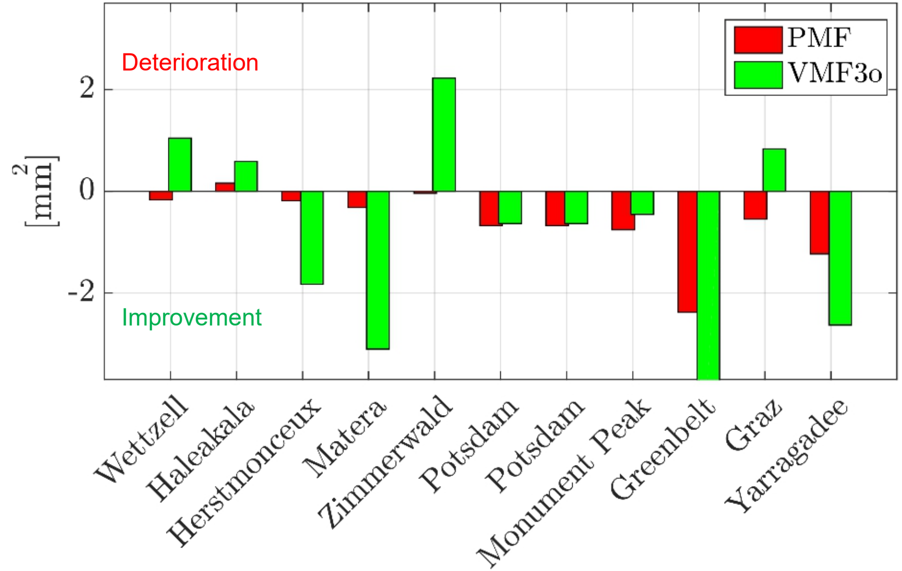
Particular years separated by +20°C

Effect of the difference of the site temperature and the numerical weather model temperature

	Correlation coefficient	
Station	PMF	VMF3o
7080	0.58	0.58
7090	0.66	0.69
7105	0.72	0.73
7119	0.76	0.76
7124	0.73	0.69
7249	0.69	0.72
7358	-0.32	-0.26
7405	0.73	0.76
7406	0.73	0.75
7501	0.93	0.94
7810	0.17	0.31
7820	0.27	0.36
7821	-0.37	-0.34
7824	0.36	0.39
7825	0.62	0.63
7832	0.67	0.66
7839	0.58	0.61
7840	0.28	0.32
7841	0.35	0.38
7845	0.75	0.63
7848	0.82	0.82
7941	0.49	0.53
8834	0.5	0.55



SLR observation residuals to SENTINEL 3a



Average elevation angle of observations: 27° degrees

Analyzed period 2017.0 – 2018.0

Differences the of observations residuals with respect to standard FCULa mapping function

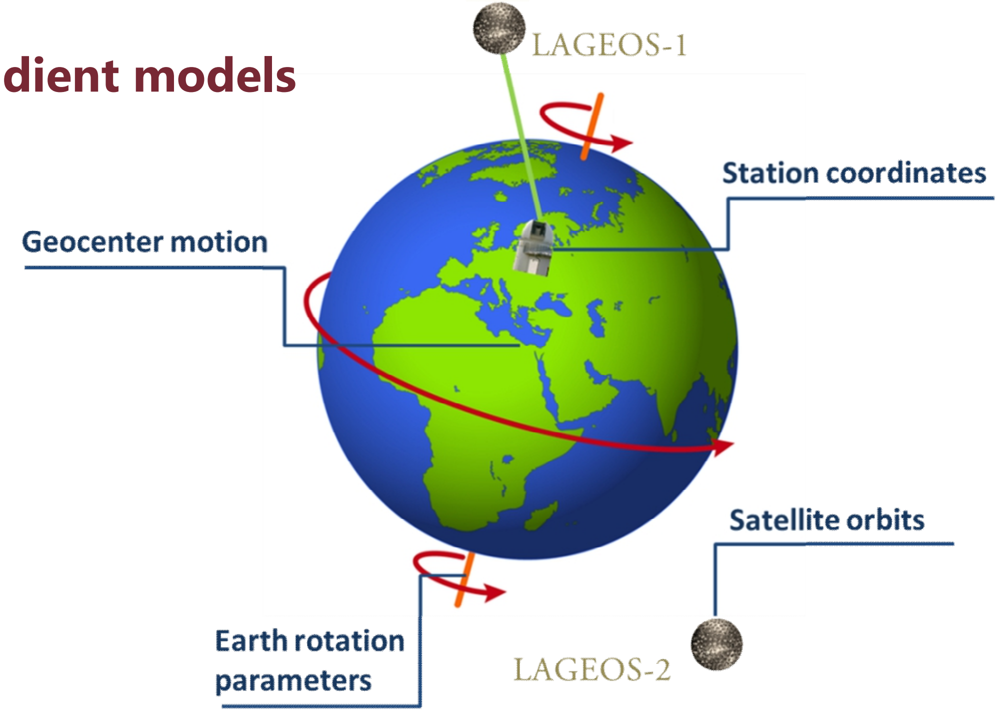
The total improvement of variance for analyzed stations is at the level of 6.8 [mm^2] for PMF, and 11.5 [mm^2] for VMF3o mapping function

SLR solutions for the validation of gradient models

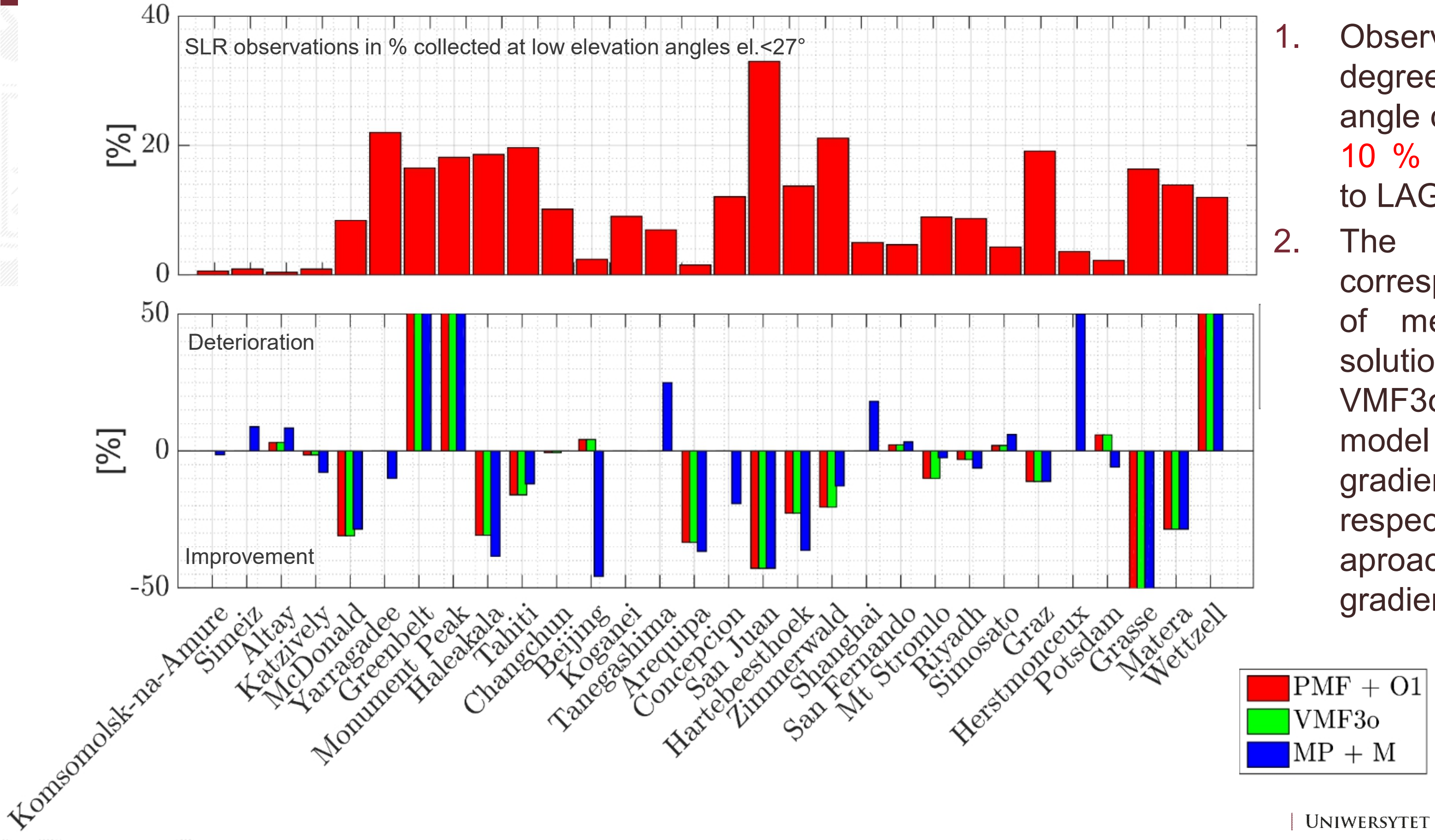
Estimated parameters:

- Station coordinates (7-day)
- Orbit parameters:

  6 Keplerian + 5 empirical (7-day)
- Geocenter coordinates (7-day)
- Range biases for selected stations (1-3 per week)
- X-pole, Y-pole (8 par per 7-day)
- UT1-UTC (8 par per 7-day, 1 parameter fixed)



Observation SLR residuals – impact from including gradients

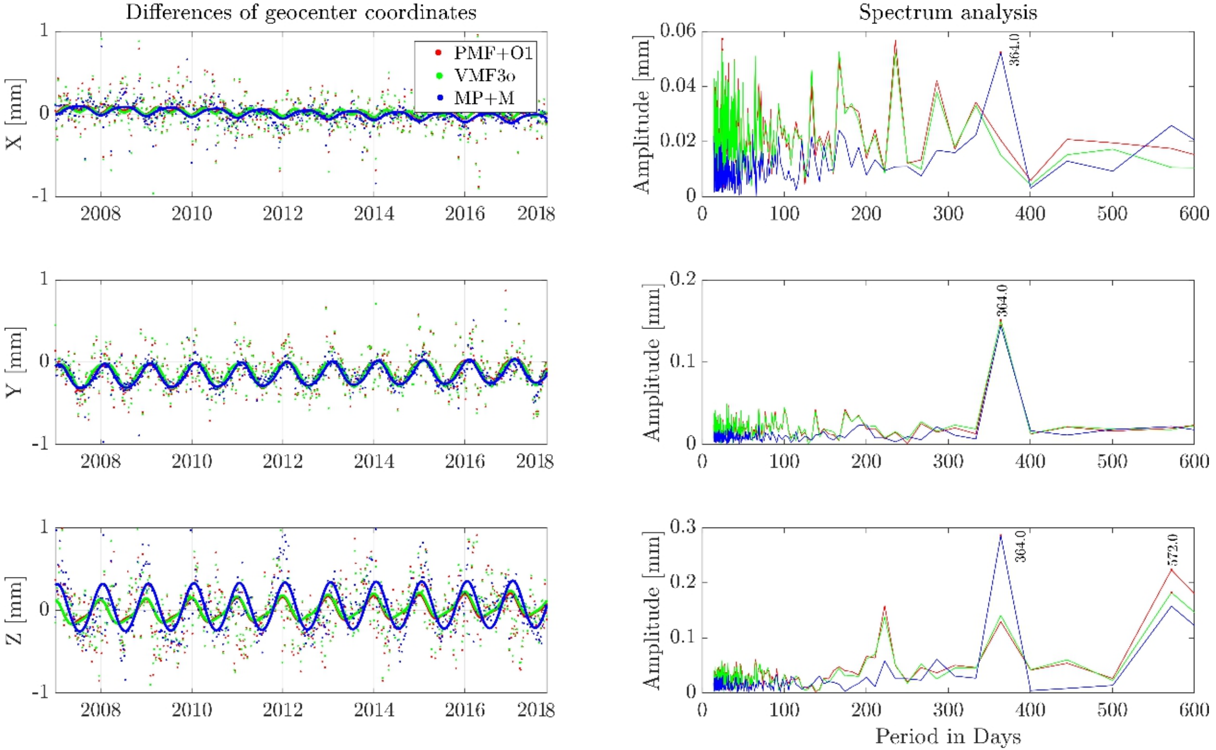


1. Observations below 27 degrees of the elevation angle constitute on average 10 % of SLR observations to LAGEOS-1/2
2. The negative values correspond to a reduction of median residuals for solutions based on PMF, VMF3o or MP + simple model of horizontal gradients model with respect to the standard aproach (MP with no gradients).

Geocenter coordinates

Mean offset at the level of 0.12 mm for Y component for solutions with horizontal Gradients.

Occurrence of periodic components At the level of 0.16 mm for Y and Z Component.



	Mean values of geocenter coordinates [mm]					
	X [mm]		Y [mm]		Z [mm]	
	mean	σ	mean	σ	mean	σ
VMF3o	-0.039	0.004	-0.010	0.003	-0.007	0.008
PMF+O1	0.039	0.006	-0.122	0.009	-0.006	0.017
MP+M	0.035	0.013	-0.126	0.009	-0.038	0.017

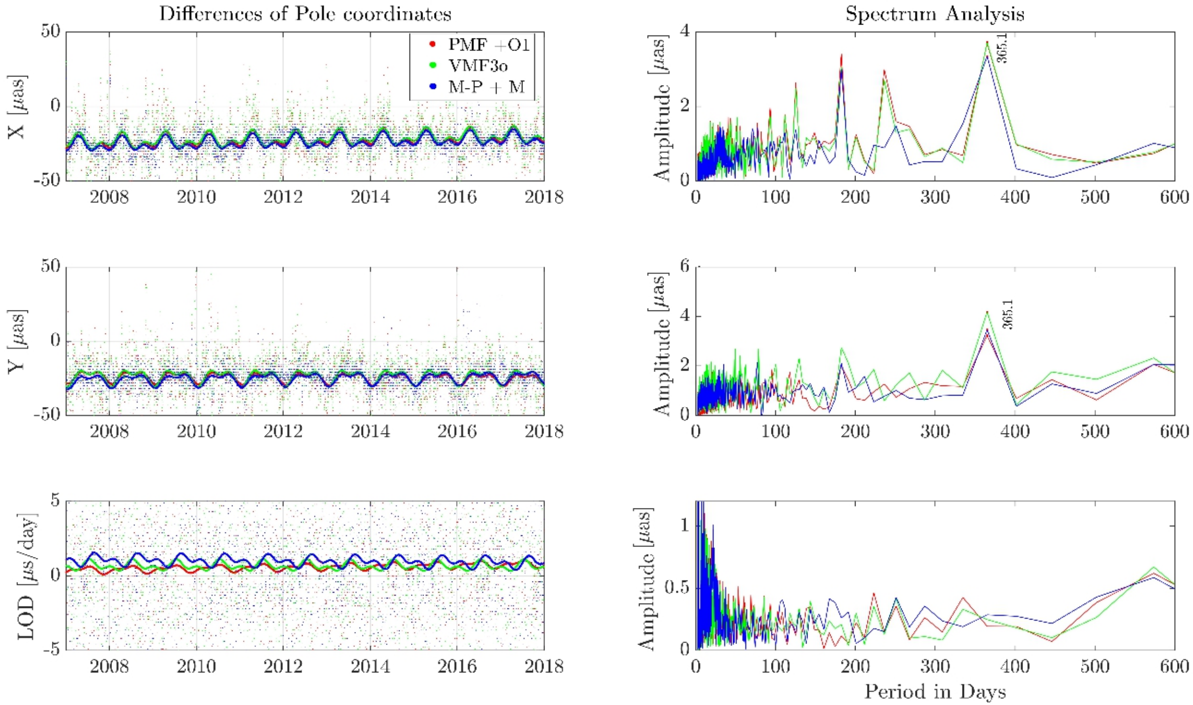
Pole coordinates

Improvement of mean offset value

At the level of 20 µas for X component

Improvement of mean offset between combined solution C04 and SLR at the level of 24 µas for Y component

30 µas = 1 mm on the Earth surface



	X-POLE (µas)		Y-POLE (µas)		LOD (µs/day)		Number of epochs
	mean	σ	mean	σ	mean	σ	
Standard sol.	22	7.5	38	7.6	-77	5.2	574
PMF + O1	2	7.5	14	7.6	-77	5.2	574
VMF3o	10	7.5	12	7.6	-76	5.2	574
M-P + M	7	7.5	11	7.6	-75	5.2	574

Conclusions

1. Modeling troposphere delay with horizontal gradients in SLR solutions improves observation residuals, especially for low elevation angles.

2. SLR solutions become more consistent with the IERS-14-C04 combined series when considering gradients which means that SLR solutions become more consistent with other techniques of space geodesy.

3. A simple model of horizontal gradinates for SLR consisting of the offset, drift, annual and semi-annual signals captures most of the systematic effects (85-95%) in the Earth rotation parameters caused by the horizontal gradients w.r.t. numerical weather models.

4. Differences between site temperatures and temperatures from numerical weather models were detected. These may affect the mapping fuction coefficients.

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Thank you

Literature:

More on troposphere delay in SLR solutions:

Drożdżewski M., Sośnica K., Zus F., Balidakis K. (2019)
Troposphere delay modeling with horizontal gradients for satellite laser ranging
Journal of Geodesy, Vol. 93 No. 10, Berlin Heidelberg, Germany 2019, pp. 1853-1866
DOI: 10.1007/s00190-019-01287-1
URL: https://link.springer.com/article/10.1007/s00190-019-01287-1

Drożdżewski M., Sośnica K. (2018)
Satellite laser ranging as a tool for the recovery of tropospheric gradients
Atmospheric Research, Vol. 212 No. , 2018, pp. 33-42
DOI: 10.1016/j.atmosres.2018.04.028
URL: https://www.sciencedirect.com/science/article/pii/S0169809517313108