Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Extension of the SLR tracking network and its potential for the realization of Terrestrial Reference Frames

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with contribution of Peter König

Technische Universität München
Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)

21st International Workshop on Laser Ranging
Canberra, Australia, 2018-11-05

GGOS Goals

GGOS aims at an accuracy equivalent of

- < 1 mm for positions
- < 0.1 mm/a for velocities

- SLR can be seen as one of the key techniques helping to achieve these ambitious goals

Integration by GGOS

IERS/ IGFS	Geodetic and geophysical target parameters	VLBI	SLR	GNSS	DORIS	LLR	Altimetry	CHAMP, GRACE, GOCE, …
ICRF	Quasar coordinates	X						
	Satellite orbit parameters		X	X	X		X	
	Lunar orbit parameters					X		
EOP	Nutation	X	(X)	(X)	(X)	X		
	Polar motion	X	X	X	X	X	X	
	UT1-UTC	X		(X)	(X)			
	Length of day	X	X	X	X	X		X
ITRF	Station coordinates / velocities	X	X	X	X	X	(X)	X
Gravity field, phys. heights	Center of Mass / Stokes coefficients of degree 2		X				(X)	X
	Earth's gravity field (Stokes coefficients with degree > 2)		X	(X)	(X)			X
	Sea level (e.g., SSH)						X	
Atm.	Thermosphere (density)	X	X	X	X		X	X
	Ionosphere (TEC)	X		X	X		X	X

SLR is the unique measurement technique which allows for an accurate and consistent estimation of TRF, EOP and Stokes coefficients!

+ others (e.g., SAR, terr./air-borne gravimetry)

Courtesy: M. Bloßfeld

The SLR network effect

- SLR is the unique technique that allows to determine the geocenter with very high accuracy and contributes to the realization of the scale of a conventional reference frame (Bloßfeld, 2015)
- Previous studies have shown the effect of the SLR station distribution on the translation time series (Collilieux et al., 2009)

➢ How is the effect of a **changing SLR network geometry** on the origin and scale of a weekly epoch reference frame?

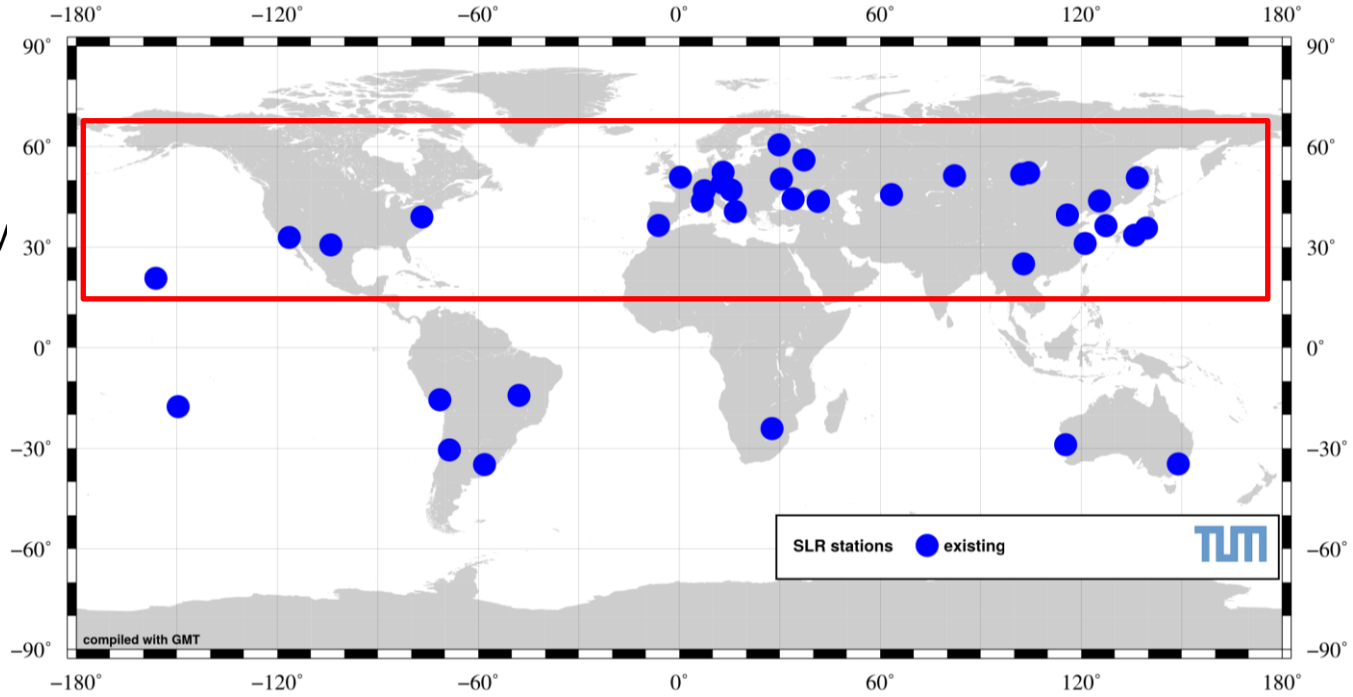
  ➢ New sites have been constructed or are in construction (AGGO La Plata, Ny Ålesund, …)

  ➢ Within the framework of GGOS, several other SLR telescopes are being considered

➢ **Simulation studies** can help to tailor the **SLR network of the future**!

Current situation

- Inhomogeneous station distribution
- The network is mainly concentrated on the northern hemisphere (31 out of 39 active stations between 2014 and 2015)



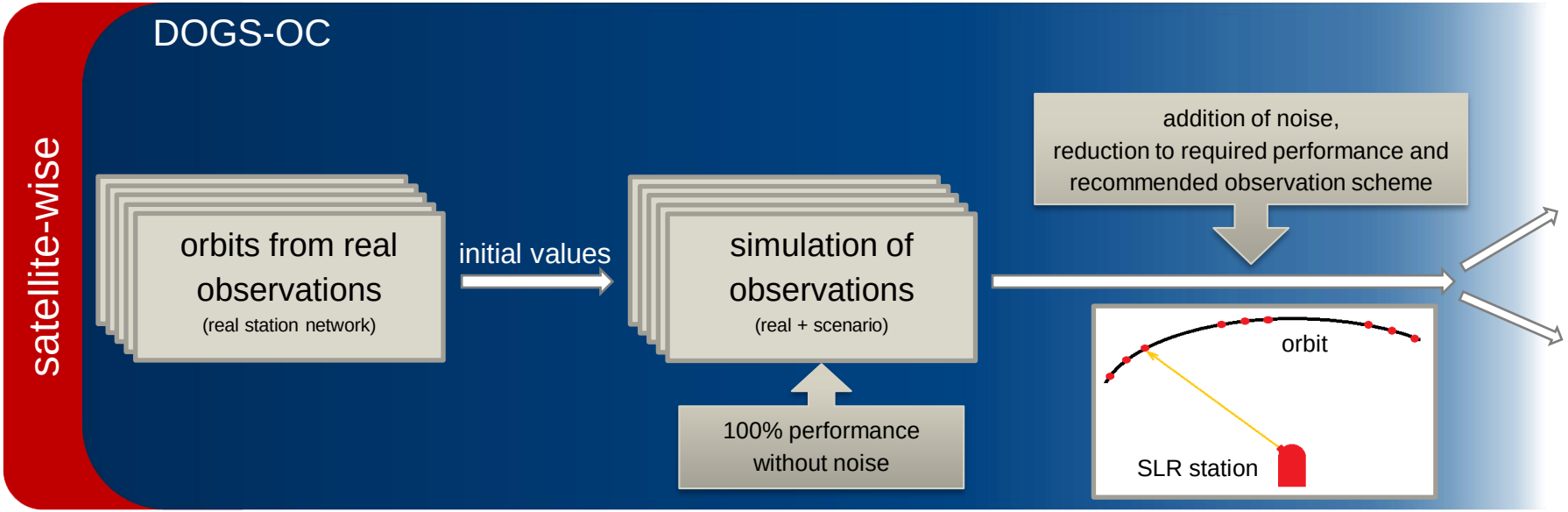
SLR simulation: processing workflow (1)

DOGS = DGFI Orbit and Geodetic parameter estimation Software

-OC = Orbit Computation

-CS = Combination and Solution

All solutions based on a 5-satellite setup including LARES (future ILRS setup)

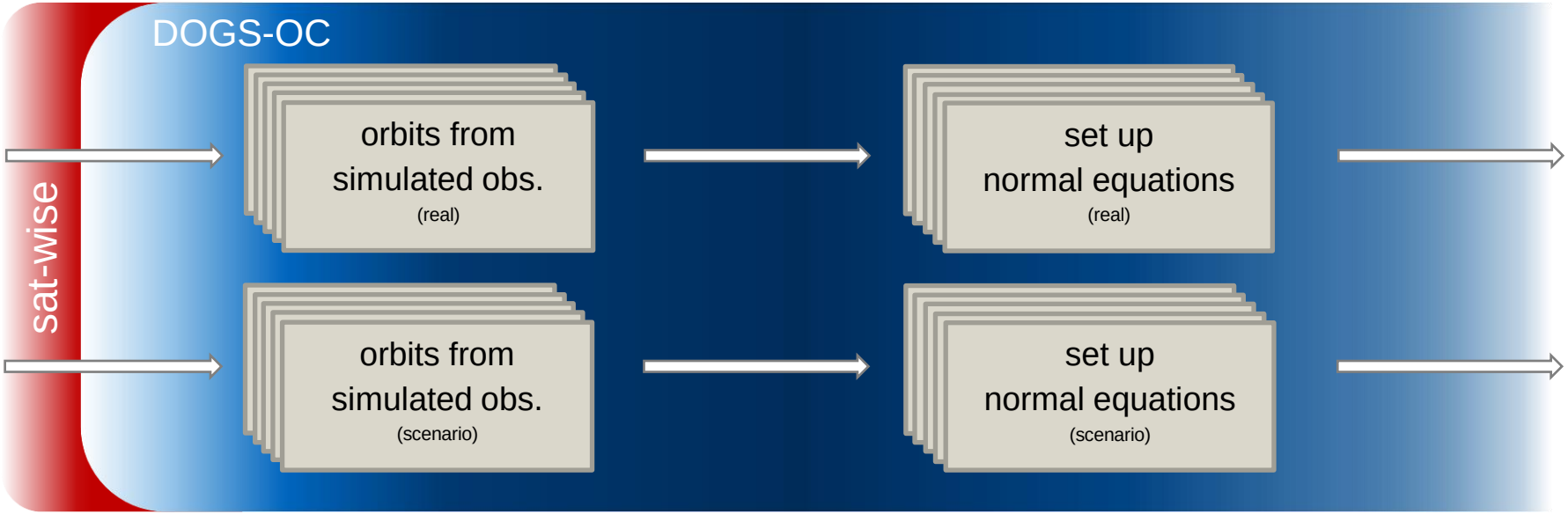


SLR simulation: processing workflow (2)

DOGS = DGFI Orbit and Geodetic parameter estimation Software

-OC = Orbit Computation

-CS = Combination and Solution

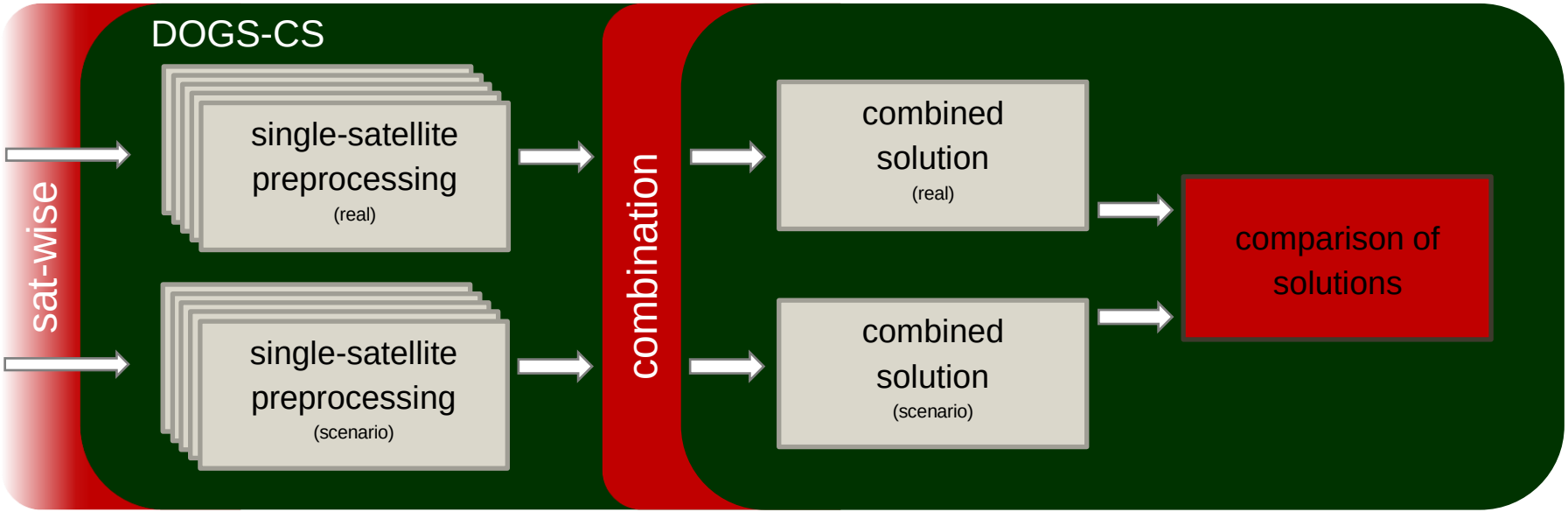


SLR simulation: processing workflow (3)

DOGS = DGFI Orbit and Geodetic parameter estimation Software

-OC = Orbit Computation

-CS = Combination and Solution



Realization of the measurement error

range measurement — geometrical distance — modelled systematic errors

$$\rho + \epsilon = \|\boldsymbol{r}_{\mathrm{sat}}(t_M + \delta t) - \boldsymbol{r}_{\mathrm{sta}}(t_M + \delta t)\| + e_{\mathrm{syst,modelled}}$$

Realization of the **measurement error** within the simulation

$$\epsilon = e_{\mathrm{syst,unmodelled}} + e_{\mathrm{err}}$$

All **remaining errors** assumed as **white noise** σ_{sim}:

$$\sigma_{\mathrm{sim}} = \sqrt{\sigma_{\mathrm{sta}}^2 + \sigma_{\mathrm{other}}^2}$$

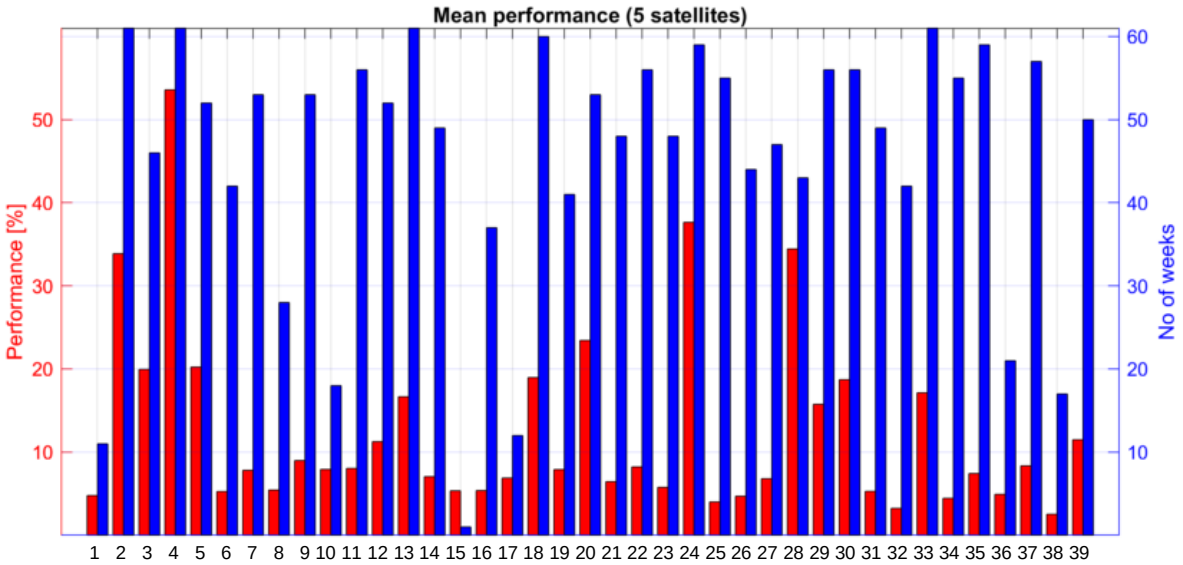
normal point accuracy ≤ 1 mm

remaining errors, noise

Unmodelled systematic errors represented through **variation of models**:

- Gravity field: EIGEN-6S ⇨ GGM05S
- Ocean tides, ocean loading: EOT11a ⇨ FES2004

Realization of the performance



Current station performances within the network: 4 … 54 % (average: 13 %)

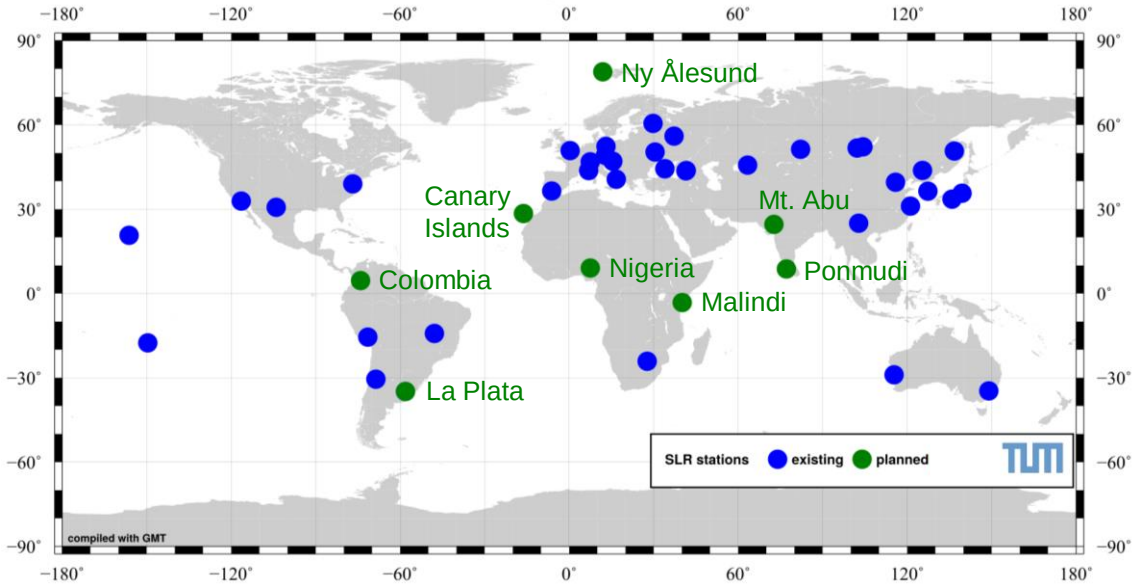
red: performance = $\frac{\text{no. of passes observed}}{\text{no. of possible passes}}$ (omitting longer periods of inactivity > 1 GPS week)

blue: number of weeks with observations (a station has only been simulated within weeks it has actually observed)

Impact of geometry

Scenario 1

- Simulation of the existing network
- Real performances between 4 % and 54 %
- **Adding eight stations** with performances assumed between 15 % and 20 %



Results

Improvement w.r.t. reference solution (simulated real network with real station performances)

Effect of	Helmert parameters (reference: SLRF2008)					EOP (ref.: IERS 08 C04)		
	WRMS				RMS of residuals	WRMS		
	t_x	t_y	t_z	M		x_{Pol}	y_{Pol}	LoD
Geometry (+ 8 Stations)	18 %	20 %	24 %	20 %	6 %	4 %	5 %	2 %

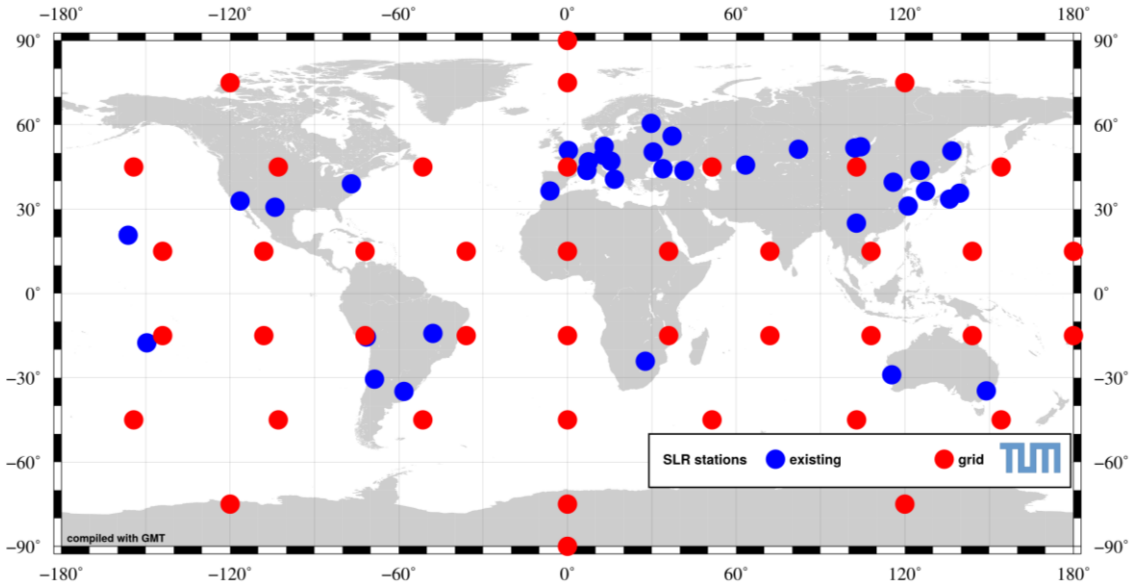
- Adding eight stations to the existing network will lead to a **significant improvement of the estimated datum parameters** (~20 % WRMS reduction in translations and scale)

- The scatter of the realized origin of the TRF will be reduced for epoch-wise solutions
- The impact on the EOP is smaller but still significant
- Details: Kehm et al. (2017)

Where to put the next station?

Scenario 2

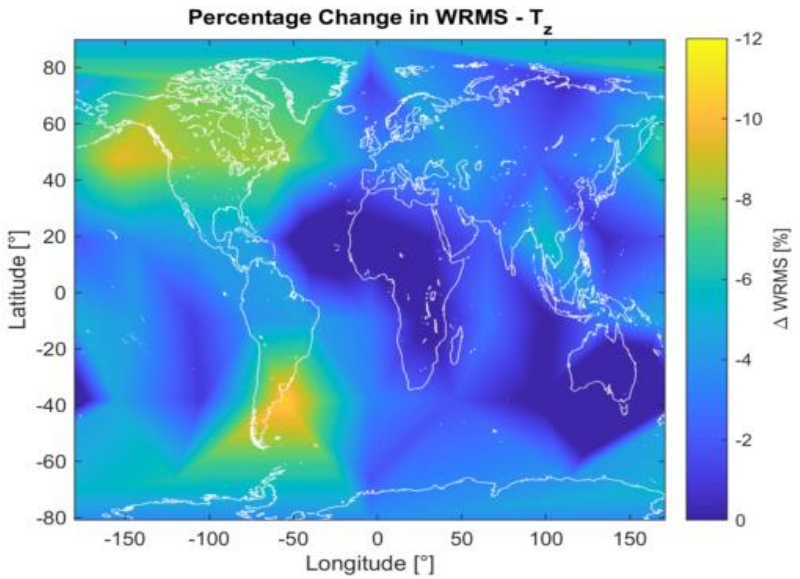
- Simulation of the existing network
- Real performances between 4 % and 54 %
- Adding one of 42 **equal-area distributed stations** with performance of 20 %



Here: **systematic model errors omitted** ⇨ investigation focuses purely on the **geometry** (including the distribution of observations *over space and time*)

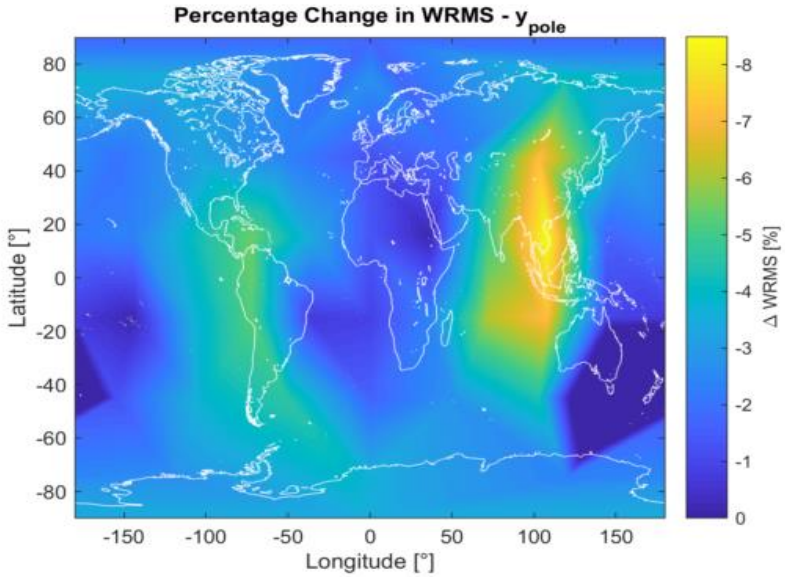
Helmert parameters

- Results refer to the pure impact of the distribution of the observations over space and time
- Only small improvement in t_x and t_y components due to neglection of systematic model errors
- Large impact on t_z
- The improvement of t_z, the scale and the RMS of the residuals of the Helmert transformation show a similar pattern
- Stations in Northern America, the Eastern Pacific, South America and the Indian Ocean region result in a significant benefit



Earth Orientation Parameters

- x_{pole} and y_{pole} can be improved significantly (especially y_{pole} benefits from stations in the East Asian region)
- LOD has a smaller potential for improvement, presumably due to the fact that the East-West distribution of the stations is better than the North-South distribution



Summary

- Extending the existing SLR network for a more homogeneous station distribution helps improve all geodetic parameters
- Under realistic error assumptions, we could show that an SLR network extended by eight stations can significantly improve the datum realization (~20 % in TRF, ~ 5 % in EOP)
- A purely geometric approach omitting systematic errors in a-priori models confirms the assumption that the network at the southern hemisphere needs to be extended

So far, an improvement of the performances of the existing network has not been taken into account.

➢ Presentation by Kehm et al. tomorrow, Session 4, 14:15 hrs

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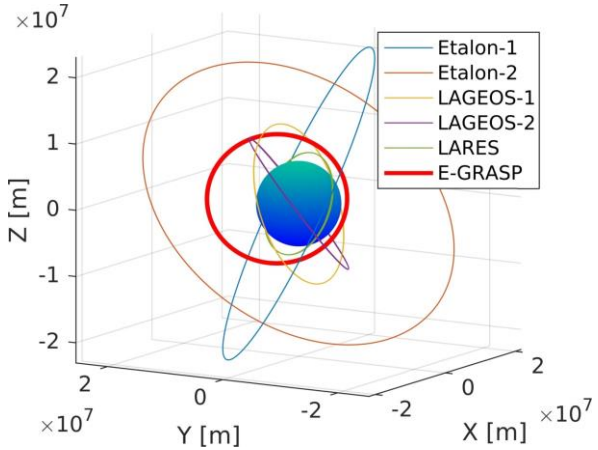
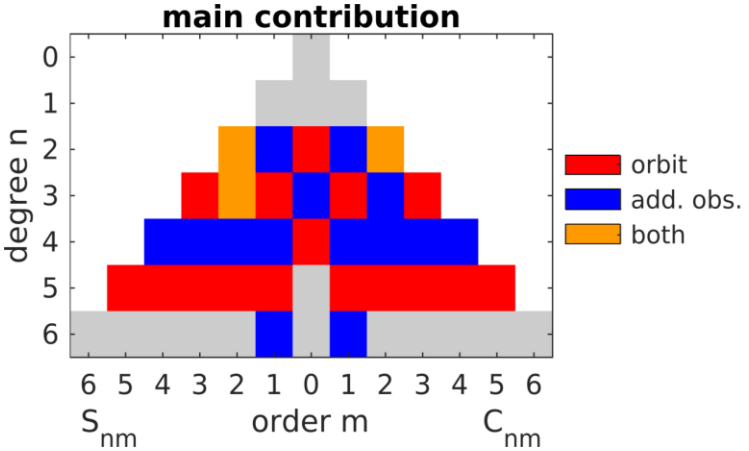
Backup slides

Simulation of SLR observations to an additional orbit





- Benefit of an **additional, highly elliptic orbit** on the solved Stokes coefficients compared to an increased amount of observations to a 5-satellite constellation?

➢ An additional orbit significantly improves the coefficients $C_{2,0}$ and $C_{4,0}$ (Earth's flattening) as well as several tesseral and sectorial coefficients of degrees 3 and 5

Backup – Skyplot