Station-dependent satellite laser ranging measurement corrections for TOPEX/Poseidon

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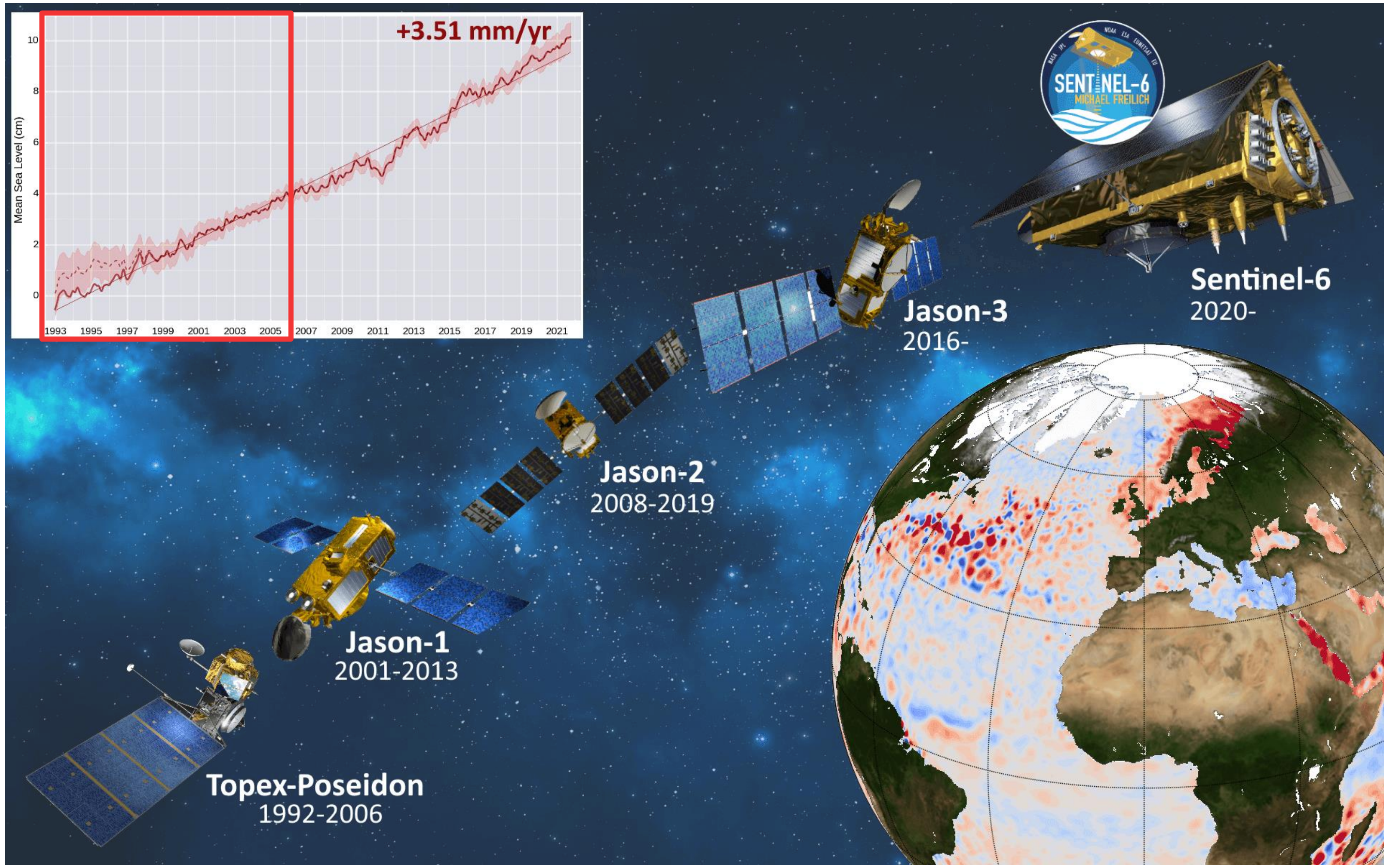
Motivation (1)

- TOPEX/Poseidon (T/P) was one of the first major altimetry missions.
- It was operational between August 1992 and January 2006, and it is the predecessor mission of the Jason and Sentinel-6 series.
- T/P is an important reference mission for continuous global and regional sea level monitoring since 1992.

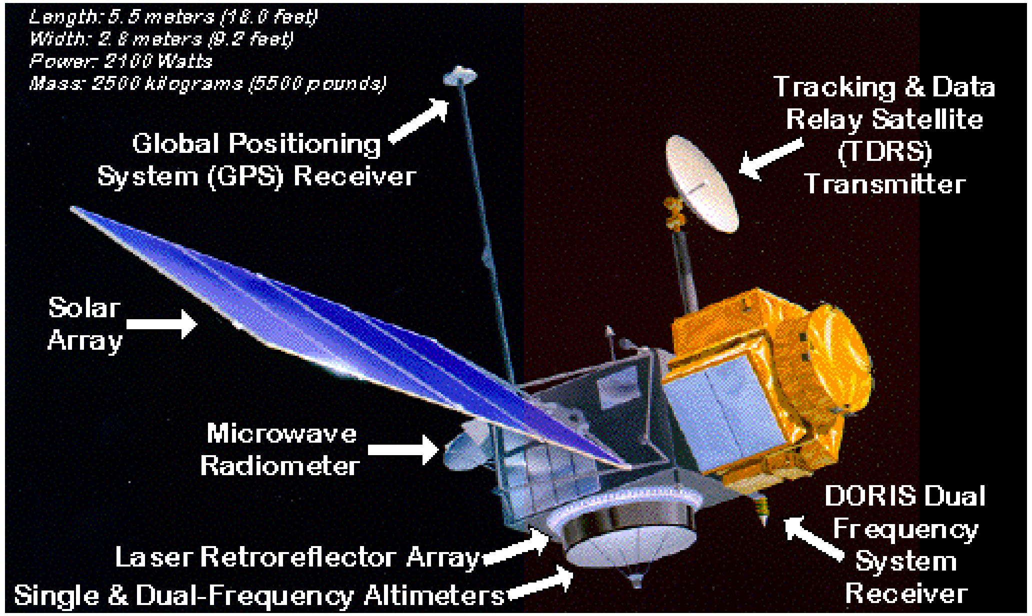


Source: odatis-ocean.fr

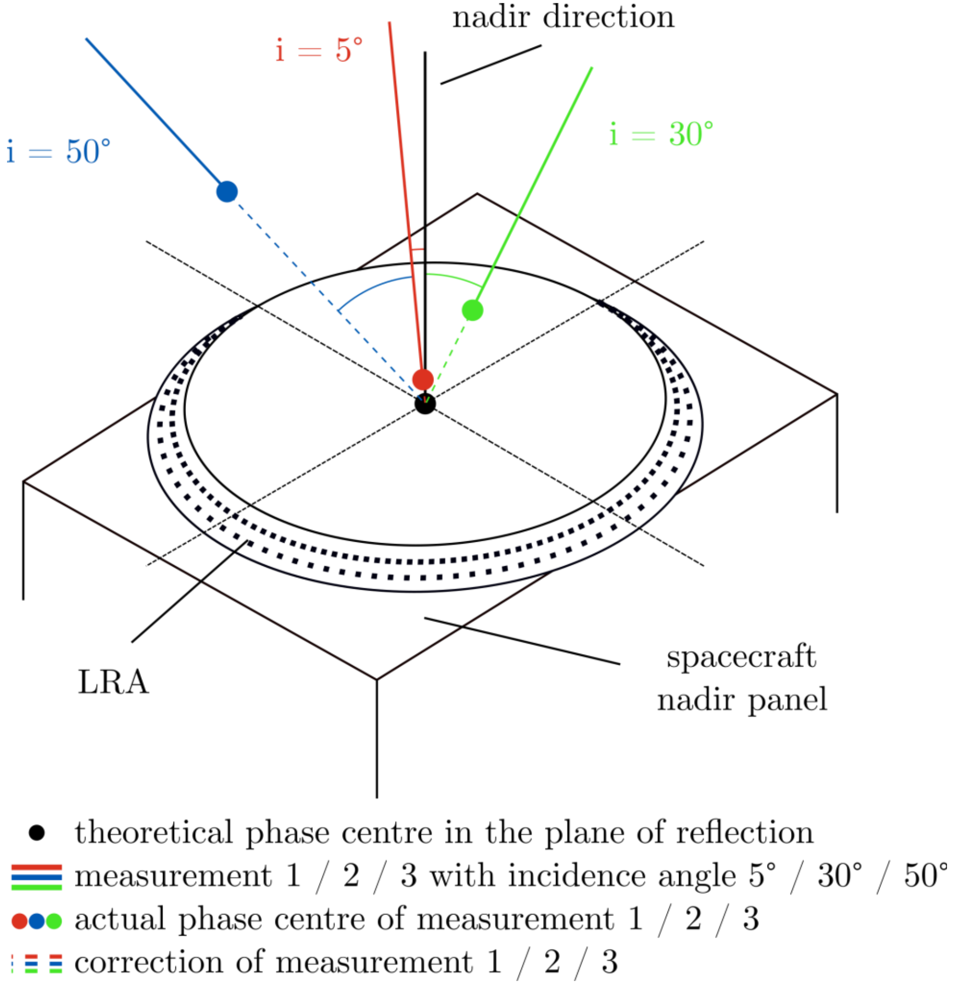
Motivation (2)

Tracking payload of TOPEX/Poseidon

- GPS receiver and DORIS receiver
- Laser Retroreflector Array (LRA) for SLR range measurements
  - Not ideally designed
  - Diameter ca. 160 cm (Schwartz, 1990)
  - Dimensions cause large phase centre variations
  - LRA correction tables by NASA not publicly available



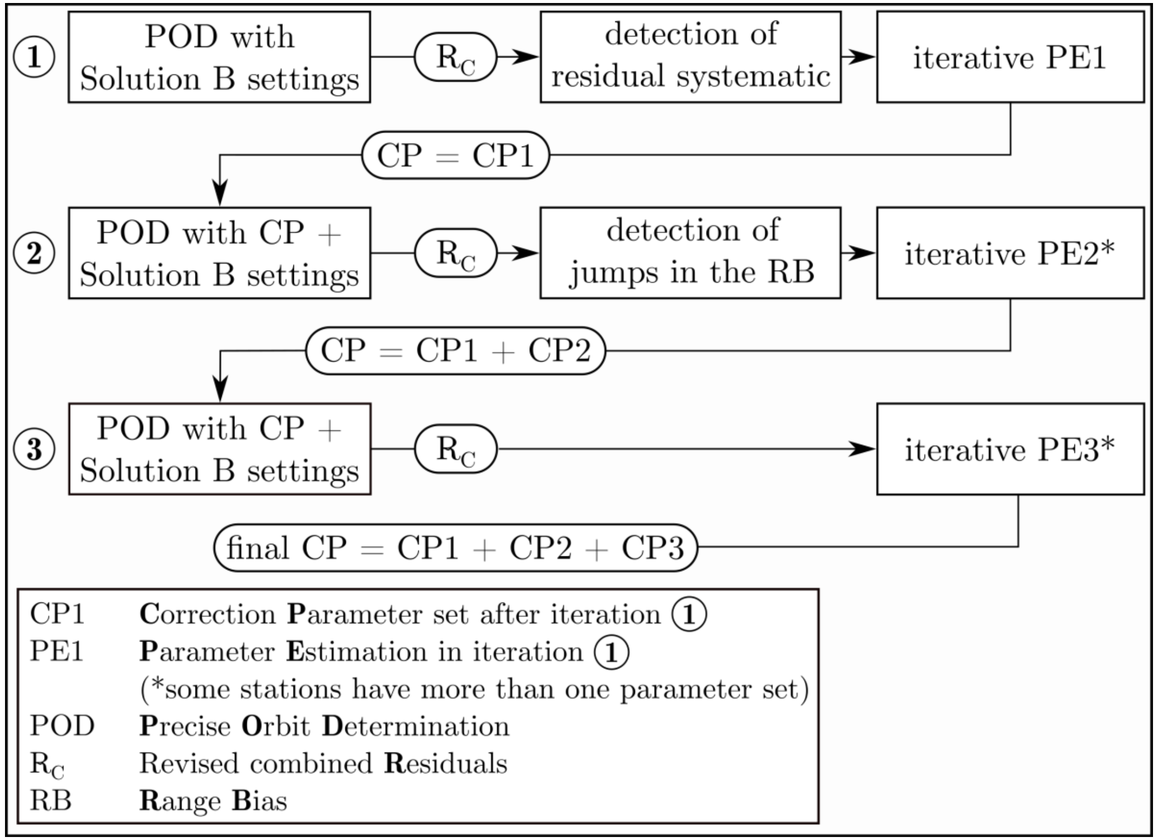
Source: ilrs.gsfc.nasa.gov



Estimation of the T/P SLR measurement correction function

Workflow to determine the correction parameters

- Computation of an uncorrected orbit solution.
- Inspection of the residual behaviour.
- Iterative process (①,②,③) of estimating and enhancing the system-dependent correction function parameters.



Source: Zeitlhöfler et al., 2022

Estimation of the T/P SLR measurement correction function

Generation of revised combined SLR residuals

$$\boxed{\text{SLR residual} = \text{observed SLR range} - \text{computed SLR range}}$$

$$\boxed{\text{combined residual} = \text{SLR residual} + \text{pass range bias}}$$

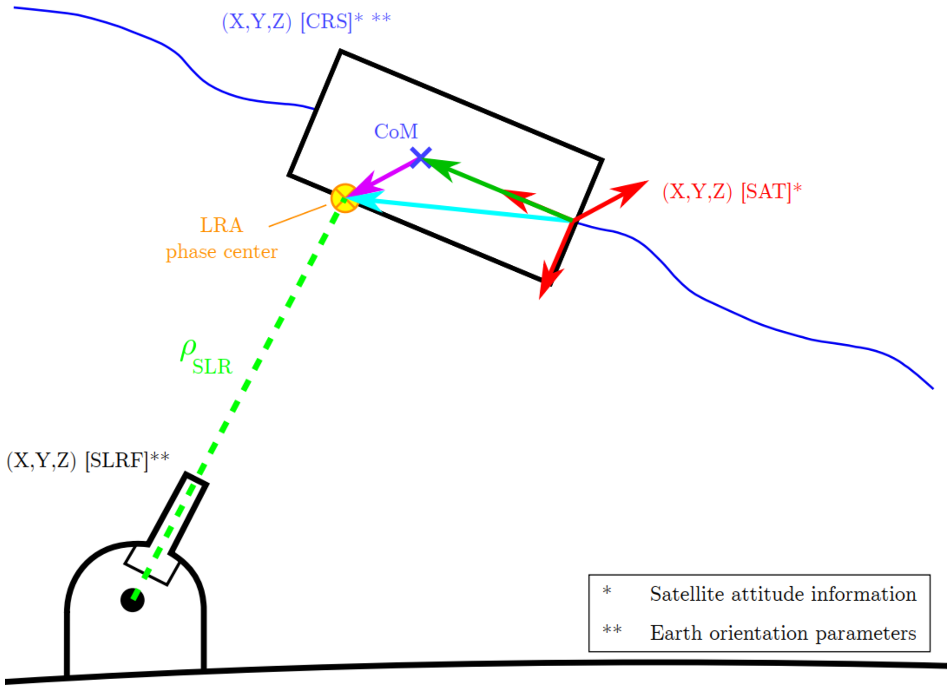
The pass range bias is estimated within the orbit computation per station and per pass.

The combined residuals are used to stabilize the uncorrected orbit and for a successful convergence of the orbit using the SLR measurement correction function.

Note: At the determination of combined residuals, no albedo scaling factor and no empirical accelerations are estimated to prevent the absorption of any LRA related effects.

After the removal of outliers, revised SLR residuals $\tilde{R}_C$ are obtained.

Schematic principle of the SLR technique



Source: Zeitlhöfler, 2019

Estimation of the T/P SLR measurement correction function

Functional model of the measurement correction

The general functional model of the correction function is:

$$\boxed{\tilde{R}_C = C_O + [G_0 \cos a + G_{90} \sin a] \sin i + X_1 \sin i + X_2 \sin^2 i + X_3 \sin^3 i}$$

with:

- a Observation azimuth [rad]
- i Observation incidence [rad]
- $\tilde{R}_C$ Revised combined SLR residual [cm]
- C_O Correction offset [cm]
- G_0 Correction in the 0° azimuth direction in the LRA frame [cm]
- G_{90} Correction in the 90° azimuth direction in the LRA frame [cm]
- X_1 Linear term of the incidence angle [cm]
- X_2 Quadratic term of the incidence angle [cm]
- X_3 Cubic term of the incidence angle [cm]

parameter set

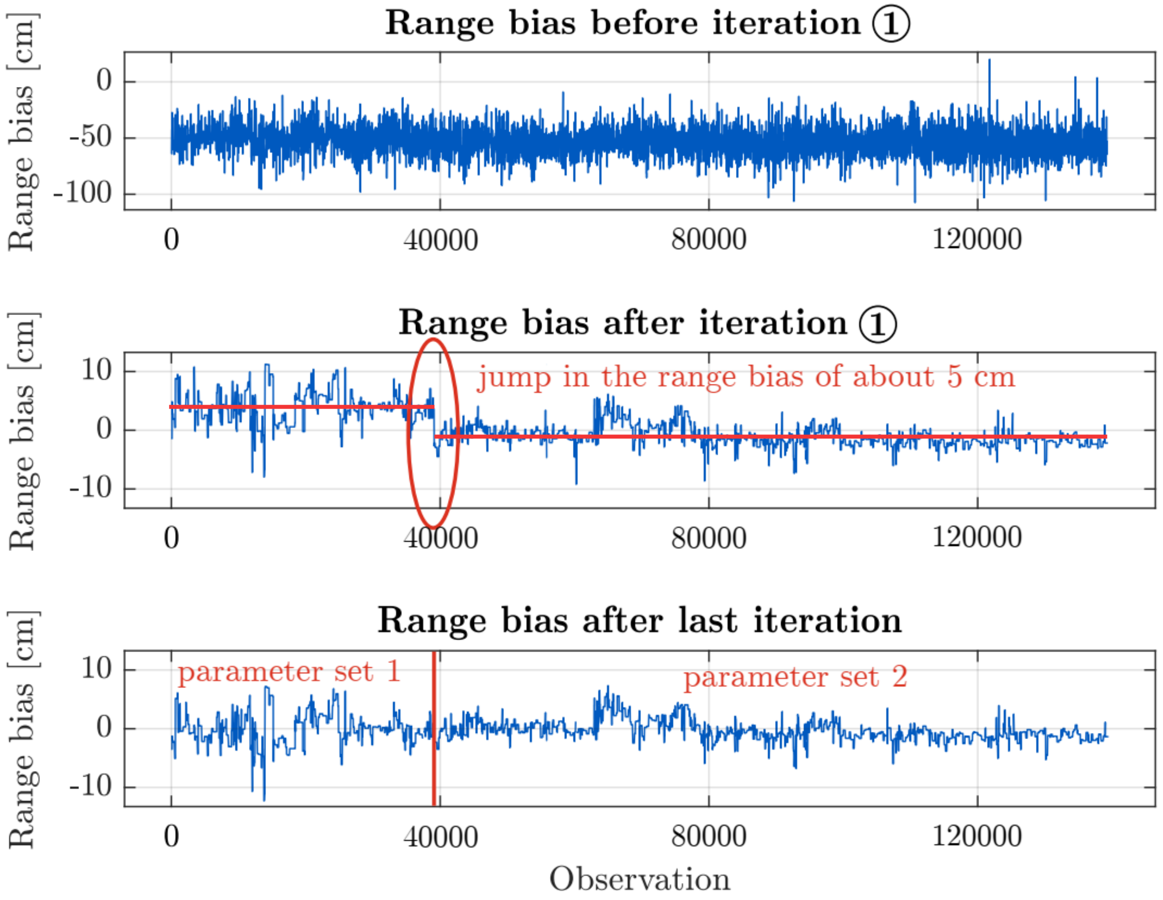
An individual set of six parameters $(C_O, G_0, G_{90}, X_1, X_2, X_3)$ is estimated for each SLR system that tracked TOPEX/Poseidon.

Estimation of the T/P SLR measurement correction function

Detection of jumps in the range bias time series

Estimated parameters for the station **Wettzell (88341001)**:

- Two periods of different SLR residual behaviour detected.
- A set of six correction parameters for each interval optimally corrects the station residuals.

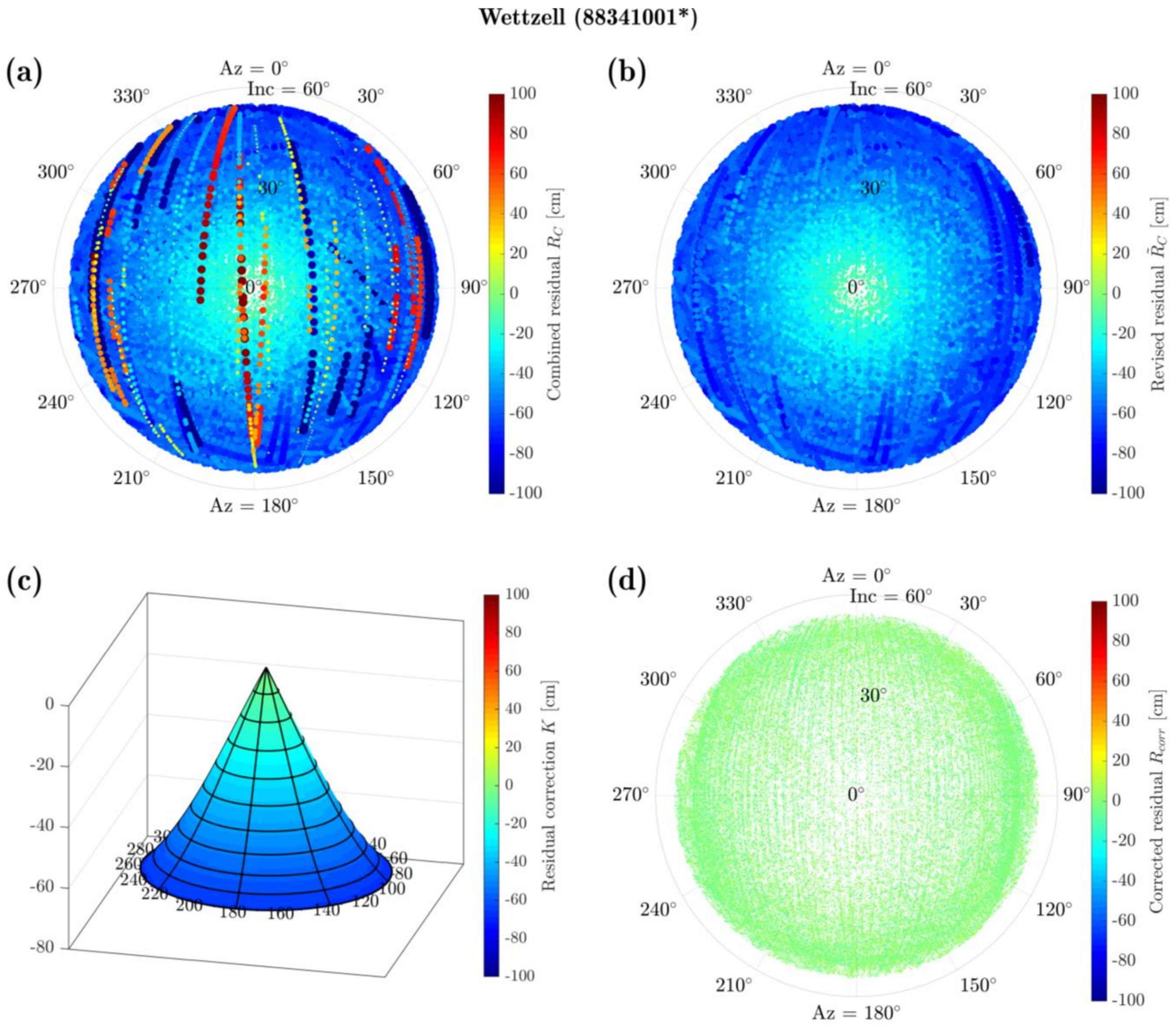


Source: Zeitlhöfler et al., 2022

Results (1)

Residuals of station Wettzell

a) Combined residuals (residual + range bias)
b) Revised residuals
c) SLR measurement correction function
d) Corrected residuals

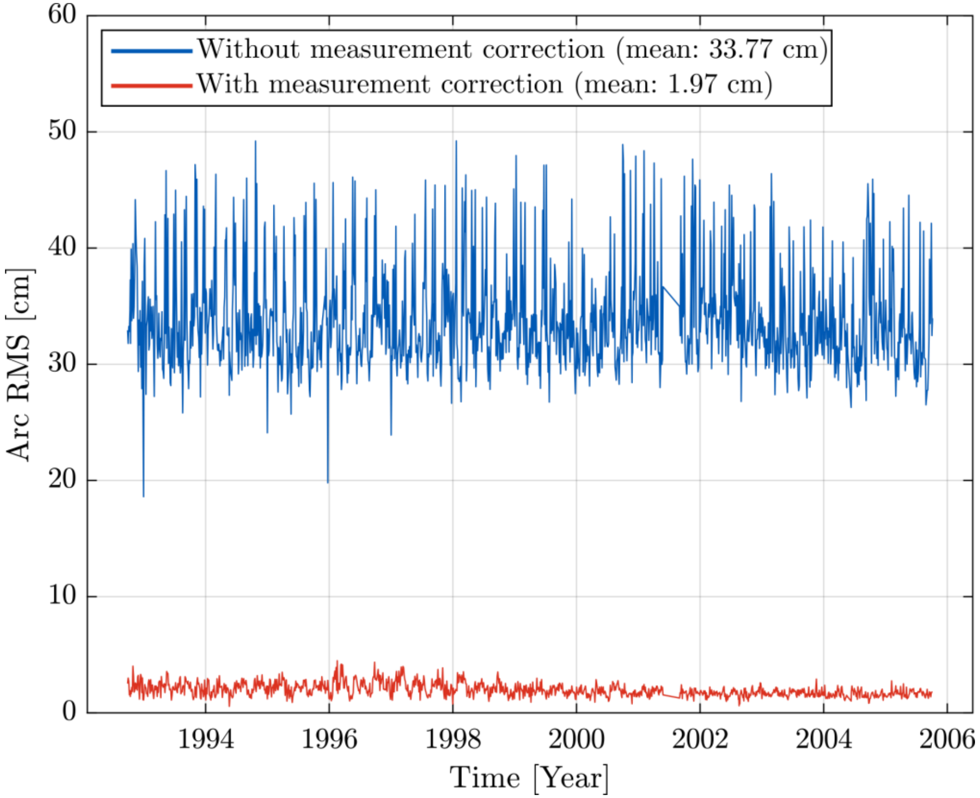


Source: Zeitlhöfler et al., 2022

Results (2)

Left: Applying the correction function to the SLR observations improves the mean orbit arc RMS fit of SLR observations from 33.77 cm to 1.97 cm. This is a reduction by about 94 %.

Right: A comparison with an external GFZ SLR+DORIS solution shows good agreement. All offsets in the uncorrected DGFI-TUM solution are resolved to some millimetres. Unit: centimetre.



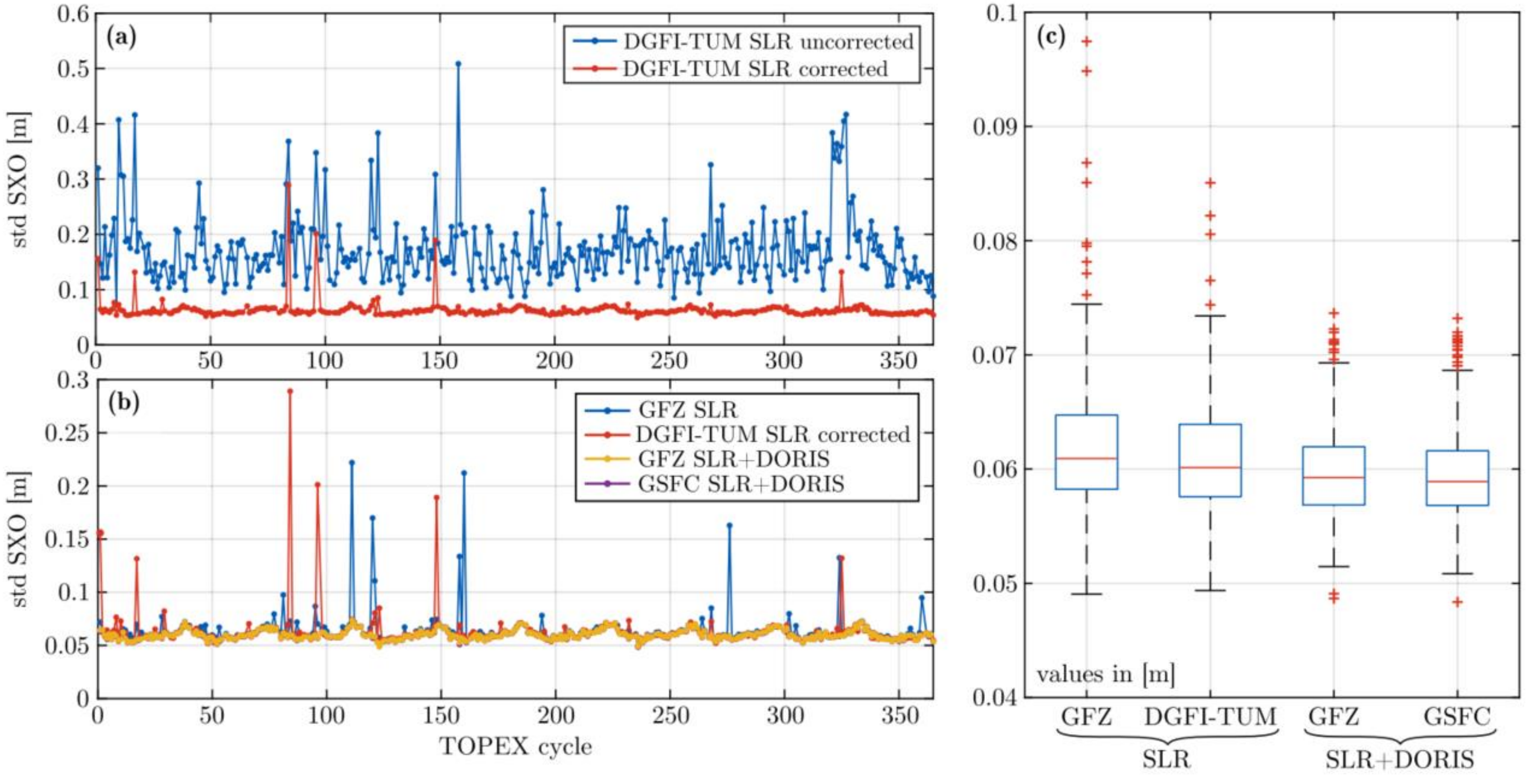
Reference solution	GFZ SLR+DORIS			GFZ SLR
	DGFI-TUM uncorrected	DGFI-TUM corrected	GFZ SLR	DGFI-TUM corrected
Mean radial	−12.11	−0.04	0.00	−0.04
Mean transverse	−9.01	−0.10	0.12	−0.22
Mean normal	−2.69	−0.18	−0.02	−0.15
Std. dev. radial	17.91	1.06	0.58	1.18
Std. dev. transverse	41.84	4.15	3.40	5.25
Std. dev. normal	27.36	2.93	0.98	3.08

Source: Zeitlhöfler et al., 2022

Results (3)

Validation of the correction function

- A single-satellite altimetry crossover (SXO) analysis confirms the enhanced quality of the corrected DGFI-TUM orbit.
- The corrected solution is of similar quality with respect to the combined SLR+DORIS solutions.



Source: Zeitlhöfler et al., 2022

Conclusion and Outlook

- The not ideally designed TOPEX/Poseidon LRA causes large phase centre variations that clearly limit the orbit accuracy.
- Precise orbit determination with a high orbit accuracy is achieved by improving the SLR observations using a station-dependent correction function.
- Applying the correction function resolves the LRA phase centre variation and other satellite and system-dependent effects and reduces the entire mission arc-wise RMS fit of SLR observations by ca. 94 % from 37 cm to 1.97 cm.
- The improved DGFI-TUM orbit shows good agreement to external solutions.
- If you are interested in the topic, please have a look at our paper published in Advances in Space Research. The paper contains the SLR correction parameters for stations that tracked TOPEX/Poseidon which allows the implementation in your POD software.

Zeitlhöfler J., et al. (2022). Station-dependent satellite laser ranging measurement corrections for TOPEX/Poseidon

References

- Schwartz J.A. (1990). Pulse spreading and range correction analysis for satellite laser ranging. Applied Optics 29(25), https://doi.org/10.1364/AO.29.003597
- Zeitlhöfler J. (2019). Nominal and observation-based attitude realization for precise orbit determination of the Jason satellites. Master’s thesis, Technische Universität München, Munich, Germany
- Zeitlhöfler J., Bloßfeld M., Rudenko S., Dettmering D., Seitz F. (2022). Station-dependent satellite laser ranging measurement corrections for TOPEX/Poseidon, Advances in Space Research, https://doi.org/10.1016/j.asr.2022.09.002

Thank you very much for your attention!

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