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First results on combined orbit determination using SLR and DORIS

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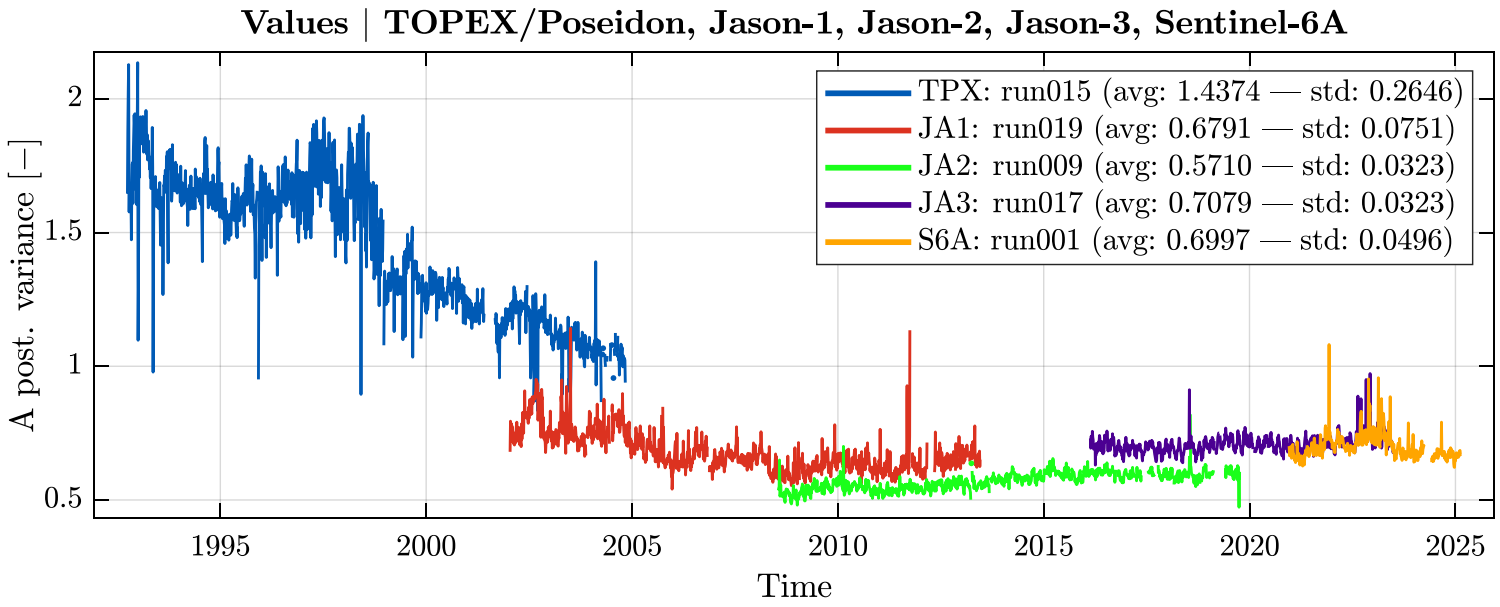
Status of POD of non-spherical satellites at DGFI-TUM

- SLR-only and DORIS-only precise orbit determination for TPX, JA1, JA2, JA3, S6A, S3A, S3B

- Systematic errors:
  - SLR: 1 cm (indications of slightly too optimistic for TPX and pessimistic for other satellites [cf. plot below])
  - DORIS: 0.4 mm/s (indications of slightly too pessimistic)

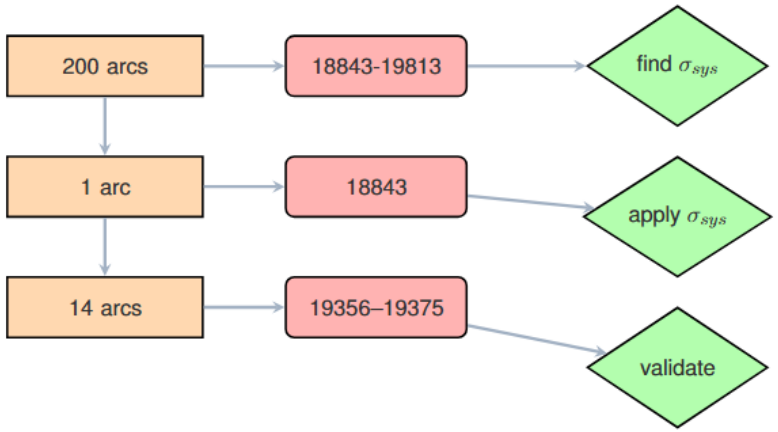


Combined orbit POD of Jason-3 using SLR and DORIS observations

- Literature review on approaches for weighting strategies regarding both space-geodetic techniques (extraction):
  - POE-F standards: 15 cm (SLR) 1.5 mm/s (DORIS)
  - Kong et al., 2017: 15 cm (SLR) 0.2 mm/s (DORIS)

- Relevant parameter in DOGS-OC: technique-specific systematic error σ_{sys}

- Overview of the experiments to determine the technique-specific weighting of SLR and DORIS:
  1) 200 arcs (3.5 days) for analysing the technique-specific behaviour of σ_{sys}
  2) 1 arc (3.5 days) with different weighting strategies for comparisons of the resulting arc w.r.t. a reference solution
  3) 14 arcs (3 days, extraction of middle day) for validation of the chosen combination of σ_{sys} values



Weighting strategies for combined orbits – external orbits

External solutions

- Reference orbits:

Solution	Institute	Techniques	Reference
(1) jplpoe	JPL	GPS	JPL, 2020 Desai et al., 2020
(2) POE-F	CNES	DORIS+GPS	CDDIS, 2020

- Reference differences: POE-F minus jplpoe

➢ Selection of background models according to POE-F standards (CNES, 2018)
➢ DGFI solutions are validated to reference orbit (1) with the aim to minimise the orbit differences
➢ Orbit differences between both reference orbits serve as indication for the quality of the DGFI-TUM orbit solutions

Weighting strategies for combined orbits – parameter setups

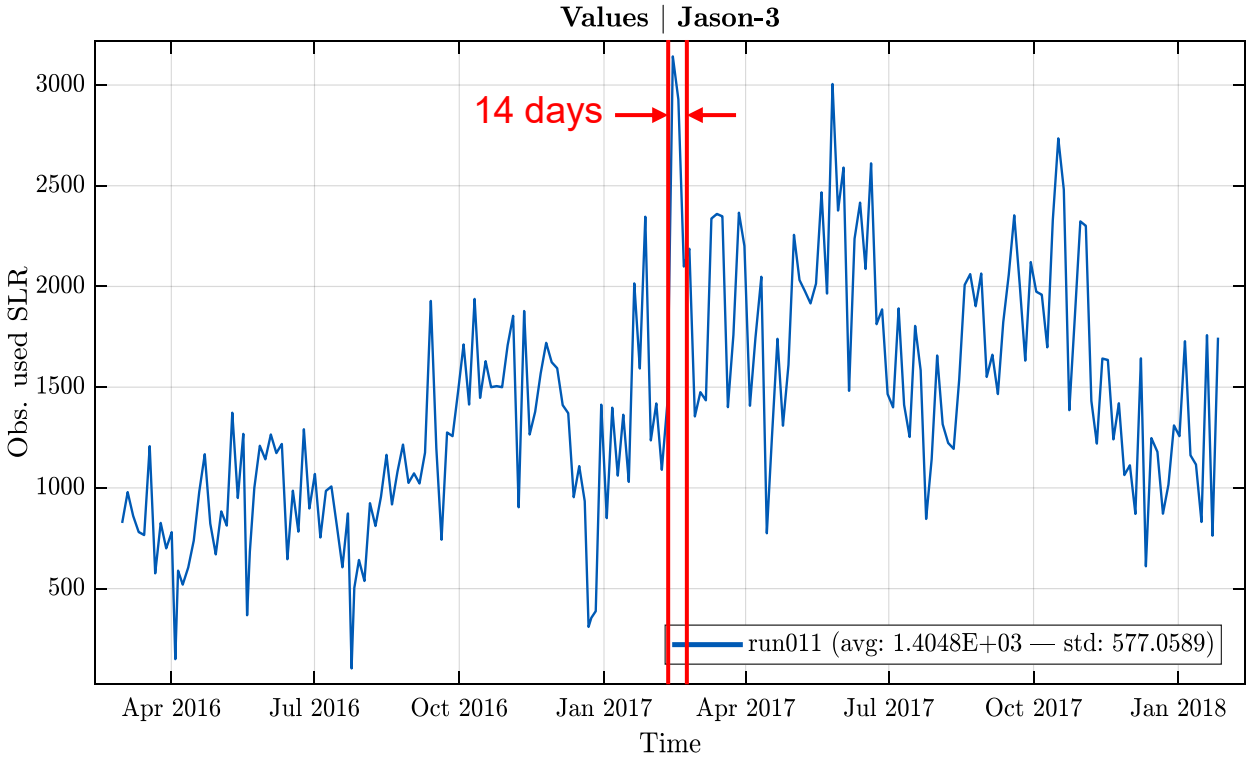
Parameter setup for tight- and loose-constrained scenarios

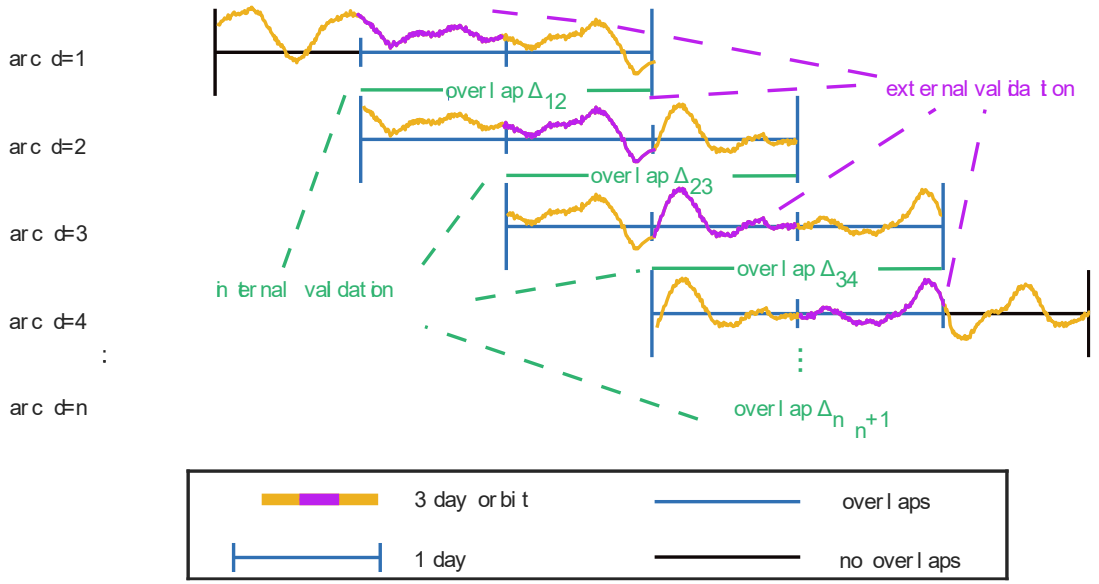
- Parametrisation of the solutions based on tight (tc) and loose (lc) constrained POD parameters
- Biases applied:
  - Frequency bias: per pass
  - Frequency drift: per station
  - Scale of tropospheric refraction: per pass
  - Range bias: per pass (tc and lc1 applied; lc2 estimated)
  - Time tag: not estimated; for Jason-3 for DORIS system: order of 1-2 µs (Lemoine et al., 2018)

Parameter	tc setup	lc setup 1	lc setup 2
Solar radiation pressure scale factor (SRP SF)	0.01	0.01	0.01
Earth radiation pressure scale factor (ERP SF)	0.01	0.01	0.01
Atmospheric drag scale factor (ATM SF)	0.03	1.0	1.0
Emp. acceleration periodic 1/rev (sine, cosine)	0.01 (N)	2.0 (N)	2.0 (NT)
Emp. acceleration polygon (12 h)	0.01 (N)	1.0 (N)	1.0 (NT)

Validation of weighting strategies

- Selection of period with good coverage of SLR observations
- Time span: GPS weeks 1936 and 1937 (2017-02-12 – 2017-02-25)
- Generation of consecutive 3-day arcs starting one day apart
- Extraction of the second day per arc for external validation





External validation – orbit differences

External validation – orbit differences

- Statistics of orbit differences between the reference solution and the other involved solutions for the directions radial (R), transverse (T), and normal (N)

Reference solution (jplpoe) minus …	**Standard deviation [cm]**			**Average [cm]**			**Median [cm]**		
	R	T	N	R	T	N	R	T	N
… POE-F	0.45	0.79	0.72	0.15	0.12	-0.04	0.13	0.10	-0.01
… DGFI DOR+SLR	0.73	2.36	1.17	0.15	0.82	0.12	0.14	0.94	0.10
… DGFI DOR (0.2 mm/s)	0.74	2.45	1.57	0.15	0.80	0.13	0.14	0.92	0.10
… DGFI SLR (5 cm)	0.83	2.79	1.24	0.16	0.66	0.10	0.15	0.71	0.09

- ➢ Best agreement between the jplpoe and POE-F solutions in all directions (**blue**)
- ➢ Improvement in the scattering (std. dev.) of the combined DGFI solution in all components compared to the DGFI single-technique solutions (**red**)
- ➢ Slight degradation of the average and median values in the combined DGFI solution in the transverse direction (**green**)

Internal validation – physical and statistical parameters

Comparison of POD parameters of the different DGFI solutions:

Parameter	DGFI SLR+DOR		SLR		DORIS	
	Avg.	Std. dev.	Avg.	Std. dev.	Avg.	Std. dev.
SRP SF [-]	1.0060	0.0024	1.0040	0.0018	1.0059	0.0021
ERP SF [-]	0.9781	0.0041	0.9766	0.0012	0.9777	0.0037
ATM SF [-]	0.6357	0.5346	0.7097	0.2662	0.6531	0.5100
EA T C [nm/s²]	-0.8187	0.3292	-0.7035	0.2509	-0.7925	0.2938
EA T S [nm/s²]	0.2729	0.4567	0.4299	0.1815	0.3262	0.4115
EA N C [nm/s²]	0.9375	0.2372	0.8157	0.1750	0.9152	0.3240
EA N S [nm/s²]	-0.9147	0.4528	-0.8380	0.4500	-0.8500	0.4493
EA T P [nm/s²]	-0.0044	0.1908	0.0092	0.0377	0.0020	0.1772
EA N P [nm/s²]	-0.0086	0.0066	-0.0021	0.0021	-0.0056	0.0056
A post. var. fac. [-]	2.7284	0.0670	0.0820	0.0204	2.8736	0.0397

References

- CNES (2018) POD configuration POE-F [Technical report]. https://ids-doris.org/documents/BC/data/POD_configuration_POEF.pdf
- Desai SD, Bertiger W, Haines B, Sibois A (2020) Evaluation of the Use of High Rate Tracking Data for Jason-3 GPS-based Precise Orbit Determination. https://ostst.aviso.altimetry.fr/fileadmin/user_upload/tx_ausyclsseminar/files/Desaietal_GPSP_POD_2020OSTST.pdf
- JPL (2020) Jet Propulsion Laboratory [data set]. https://sideshow.jpl.nasa.gov/pub/usrs/jason3/jplgpspoe/
- Kong Q, Guo J, Sun Y. *et al.* (2017) Centimeter-level precise orbit determination for the HY-2A satellite using DORIS and SLR tracking data. *Acta Geophys.* **65**, 1–12. https://doi.org/10.1007/s11600-016-0001-x
- Lemoine FG, Zelensky NP, Belli A, Couhert A, Moreaux G, Saunier J, Ferrage P (2018) The Synergy of Satellite Laser Ranging (SLR) and DORIS as Space Geodesy Techniques [Presentation at 21st International Workshop on Laser Ranging, Canberra, Australia]. https://ids-doris.org/documents/report/publications/IWLR2018-SynergySLR-DORIS-Lemoine.pdf
- NASA (2020) NASA Crustal Dynamics Data Information System (CDDIS). https://cddis.nasa.gov/archive/doris/products/orbits/ssa/ja3/

Conclusions and outlook

- First results of analyses of combined orbit determination based on SLR and DORIS
- Choice of 5 cm for SLR and 0.2 mm/s for DORIS and loose-constrained settings provide best agreement with jplpoe solution
- Enhanced orbit quality of combined solution compared to the single-technique solutions
- Sophisticated analysis of numerous target, statistical and orbit parameters

Next steps:

- Processing of complete JA-3 mission with settings found
- Investigations whether system standard deviations found for Jason-3 also apply for other missions
- Analysis of correlations in the estimated parameters depending on the weighting strategies

Thank you very much for your attention!

External validation – single-and multi-technique POD