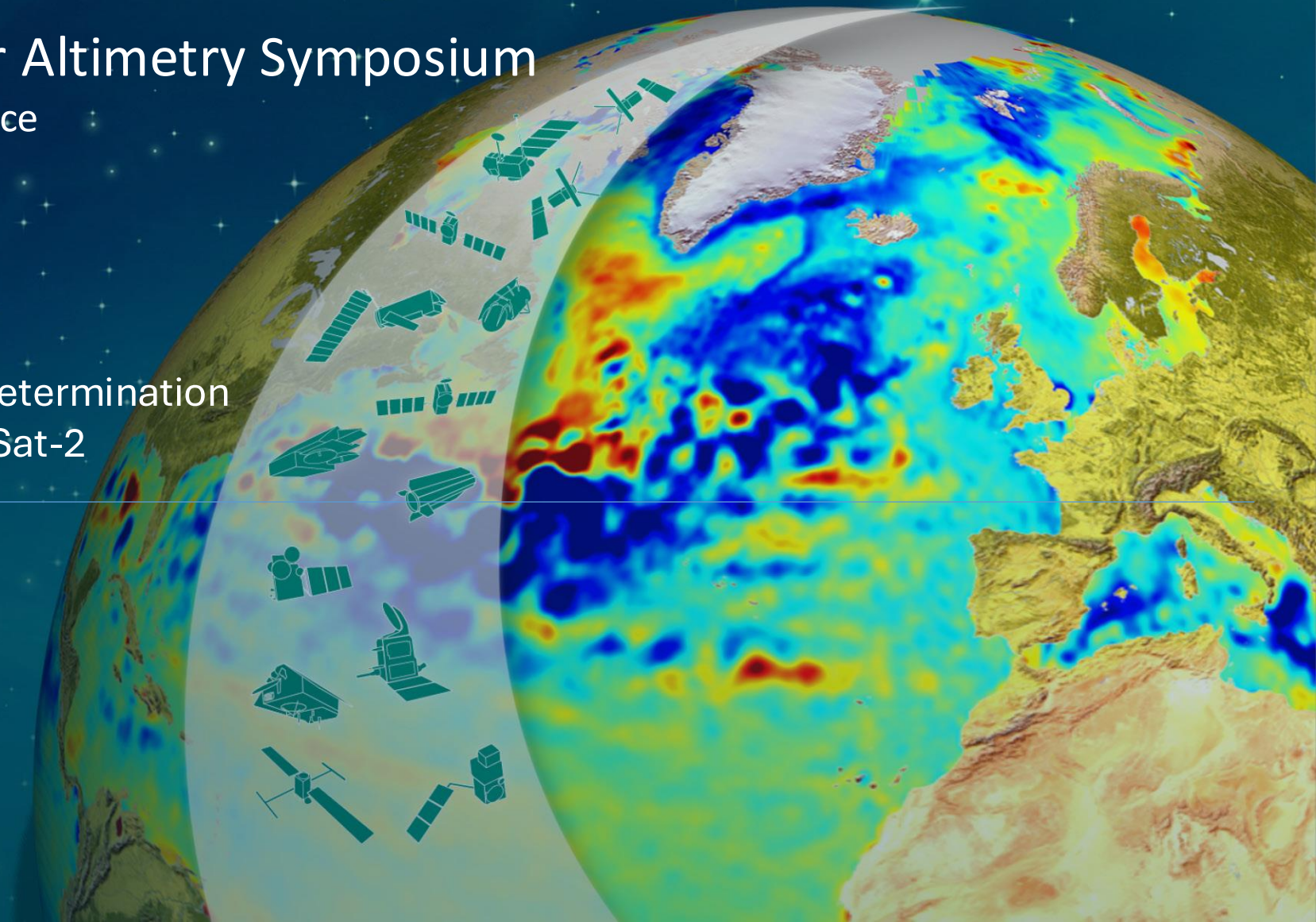
30 Years of Progress in Radar Altimetry Symposium

2-7 September 2024 | Montpellier, France



Improvements in the Precise Orbit Determination using DORIS and laser data for CryoSat-2

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Outline of this talk

- Model set-up and data that is used
- Mapping of observation Residuals
- Time variable gravity, AOD1B and from GRACE/GRACE-FO
- Ocean tide modelling affecting the runs
- Empirical parameters, what do we see in two solar cycles
- External orbit comparison
- Crossover difference analysis, altimeter behavior
- Conclusions

POD setup models and data

- Coordinates
  - Transition to DPOD2020 for all DORIS beacons and SLR stations
  - DPOD2020 version 2.3 : as of 20240711 (new)
  - SLRF2020 version 230322 (new)
- Ocean loading by station/beacon
  - Chalmers ocean loading calculator based op FES2014 or later
- For Doppler IDS format 2.2 ten second data is used
  - Doppler beacon frequency offset estimated by pass
  - Tropospheric zenith delay parameters estimated by pass
- Earth rotation parameters from IERS EOP 2020 C04
- Initial state vector from DIODE navigator orbits
- DORIS stations weights, determined by screening the data residuals (new)

Input to the modelling process

- Gravity models, static part is EIGEN-6S4-V2 at reference 1-jan-2016
- Solar radiation pressure modelling, scaling constant estimated once, CNES model
- Drag modelling, MSIS reference model, 3 hourly patches with constraints
- Ocean tides in POD: nominal via GOT 4.7 setup, alternative models (new)
- Atmospheric and Oceanic part TVG : AOD1B sampled at 3 hourly model outputs
- Terrestrial water storage:
  - Two combination model, relies on EOF compression and interpolation
  - GRACE and GRACE-FO are combined either with a Fourier or a Polynomial method (NEW)
- Empirical accelerations modelling, 6 hourly, piecewise modelling.
- For this all the GEODYN software of the NASA/GSFC is used

TVG modelling from GRACE and GRACE-FO

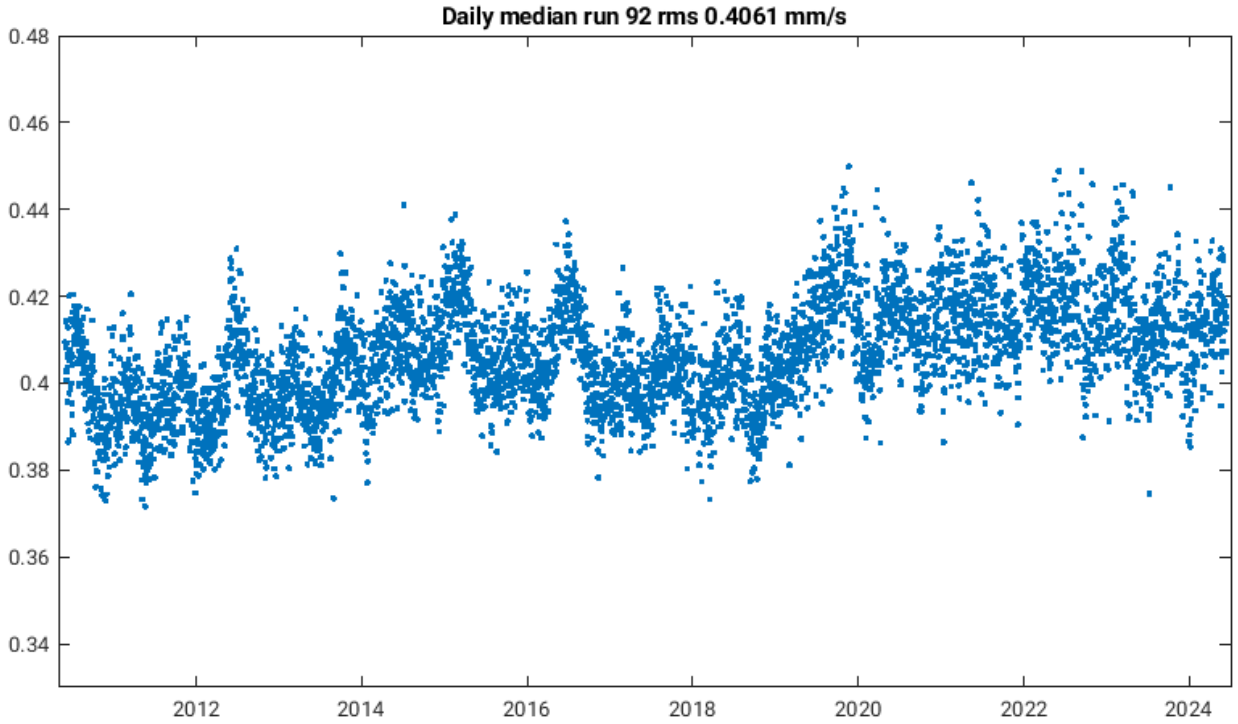
- AOD1B is always used for each arc, (except a test run)
  - Without doubts residuals both for DORIS and SLR benefit from this
- Data gap in GRACE is from 23-5-2017 to 15–6-2018
- GRACE-FO: 15-6-2018 to 19-7-2018; 31-10-2018 to 1-5-2024
- EOF compression and editing before we produce monthly grids
- Strategies to merge the TVG from GRACE GRACE-FO in POD
  - Polynomial approximation locally with patch functions (TVG-P in our paper)
  - Fourier approximation locally with patch functions (TVG-F in our paper)

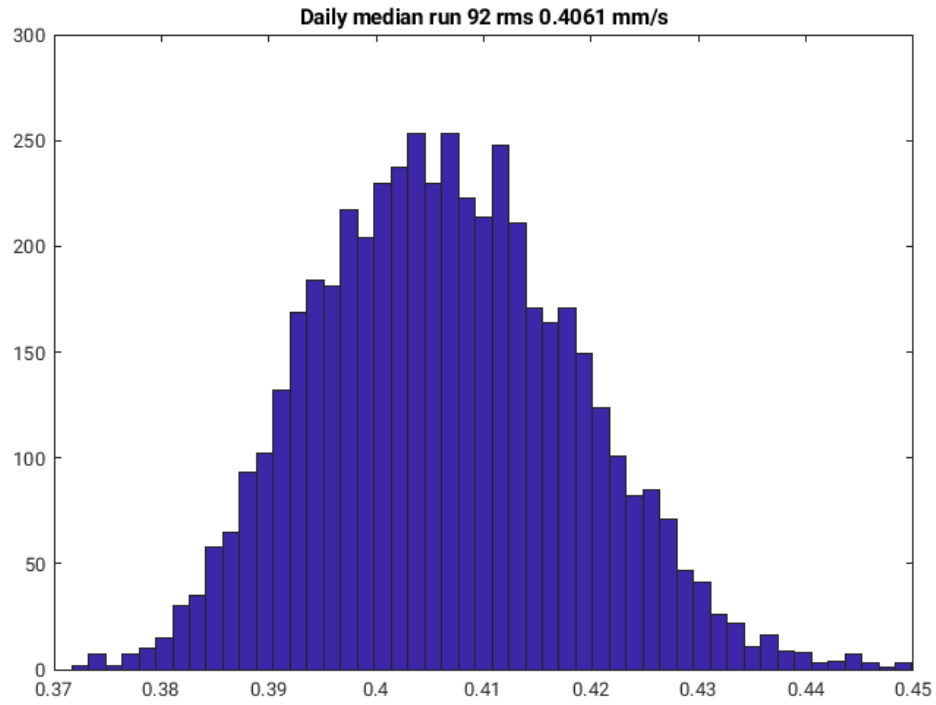
Run tables to analyze the POD performance

Run	AOD1B	TVG	Ocean tide	Doris (mm/s)	SLR (cm)	Comment
88	No	No	GOT4.7 (20x20)	0.4070	1.03	Reference
89	Yes	No	GOT4.7 (20x20)	0.4067	1.01	AOD1B helps
90	Yes	Polynomial	GOT4.7 (20x20)	0.4068	1.02	TVG makes it worse
91	Yes	Fourier	EGM96 (lmax<15)	0.4103	1.22	Worst
92	Yes	Fourier	GOT4.7 (20x20)	0.4061	0.91	Best but cheaper
93	Yes	Fourier	GOT4.10 (50x50)	0.4060	0.91	Best but expensive

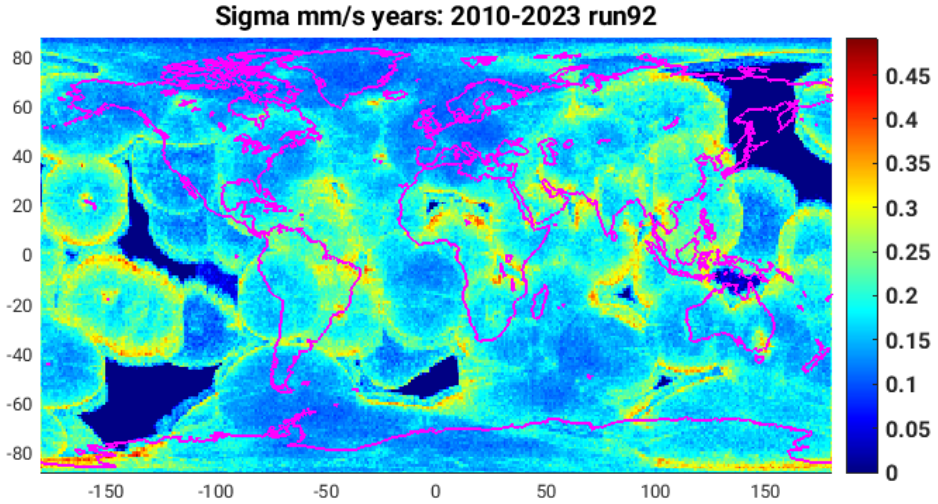
All runs from 2010.42 to 2024.45, median (daily) DORIS and SLR fits, ocean tide model and TVG and AOD1B all affect the quality of the fits, GOT4.10 50x50 is marginally better than GOT 4.7 20x20

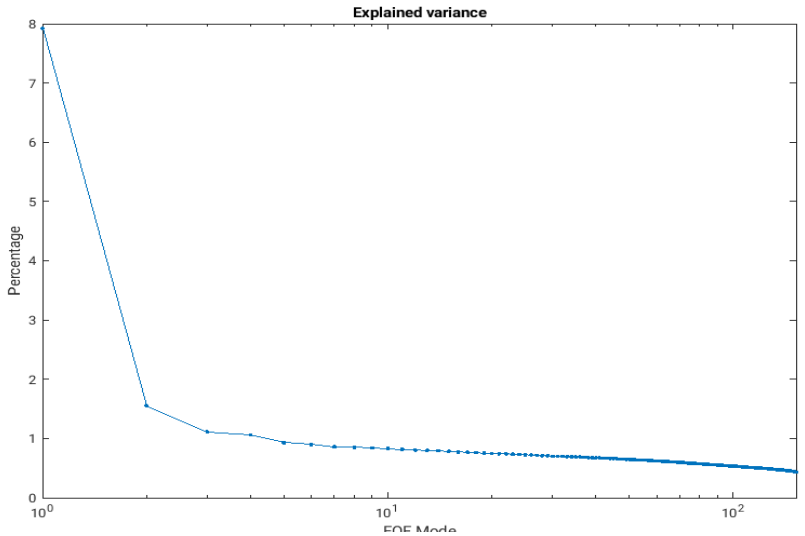
Doppler residuals over 15 years, run 92

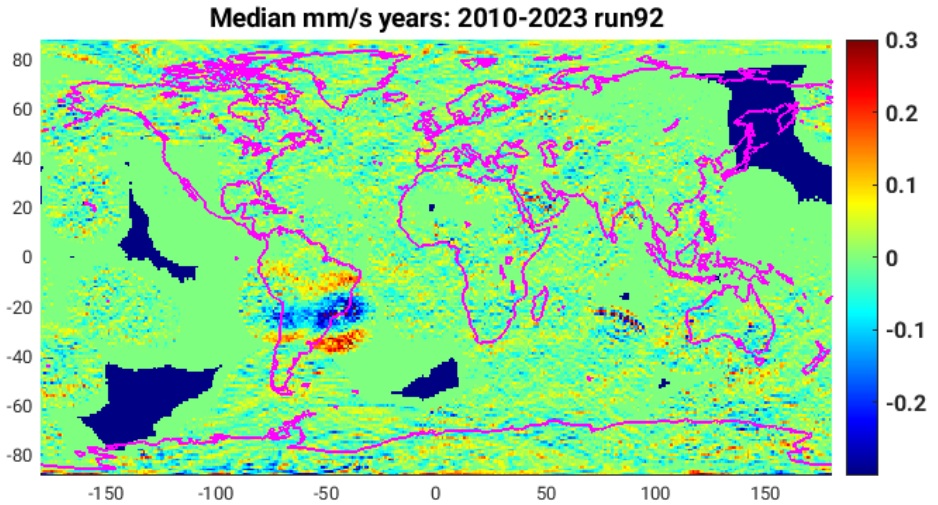




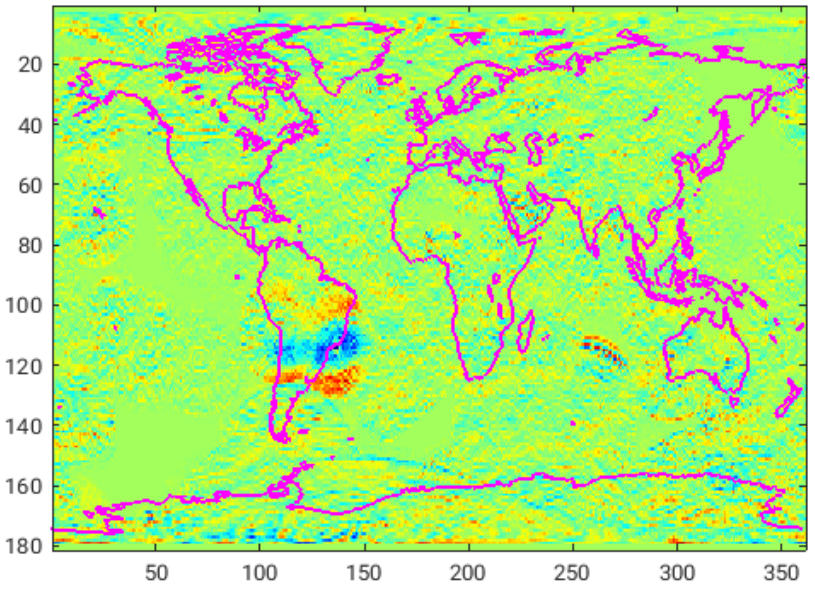
Empirical Orthogonal Functions



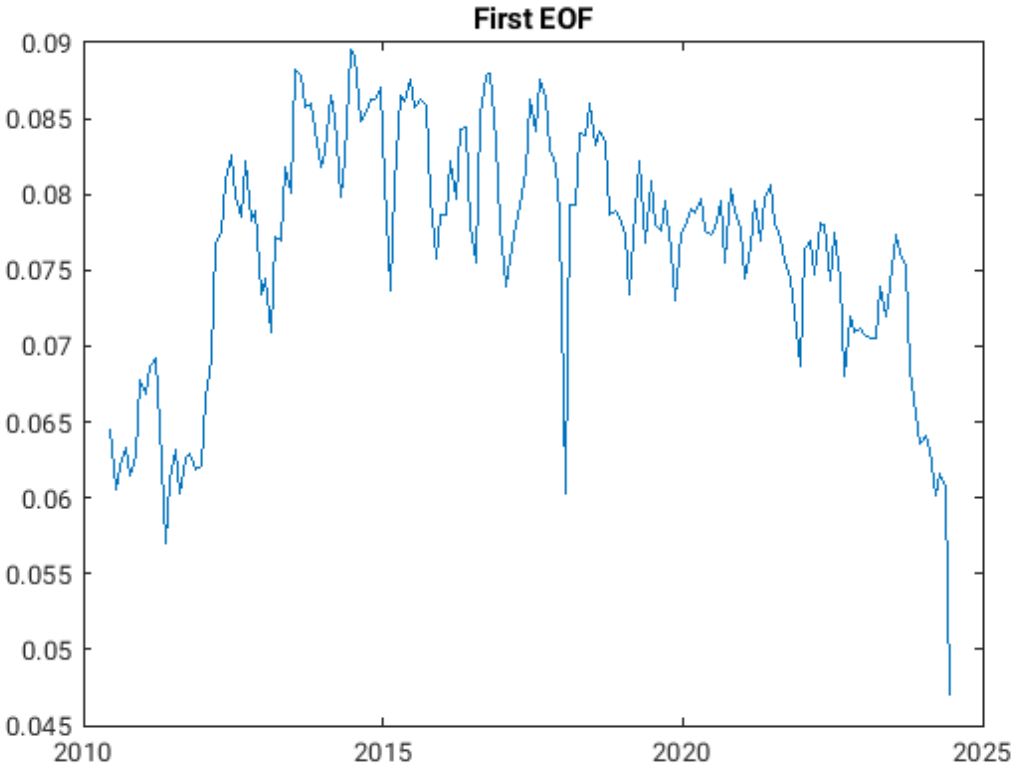


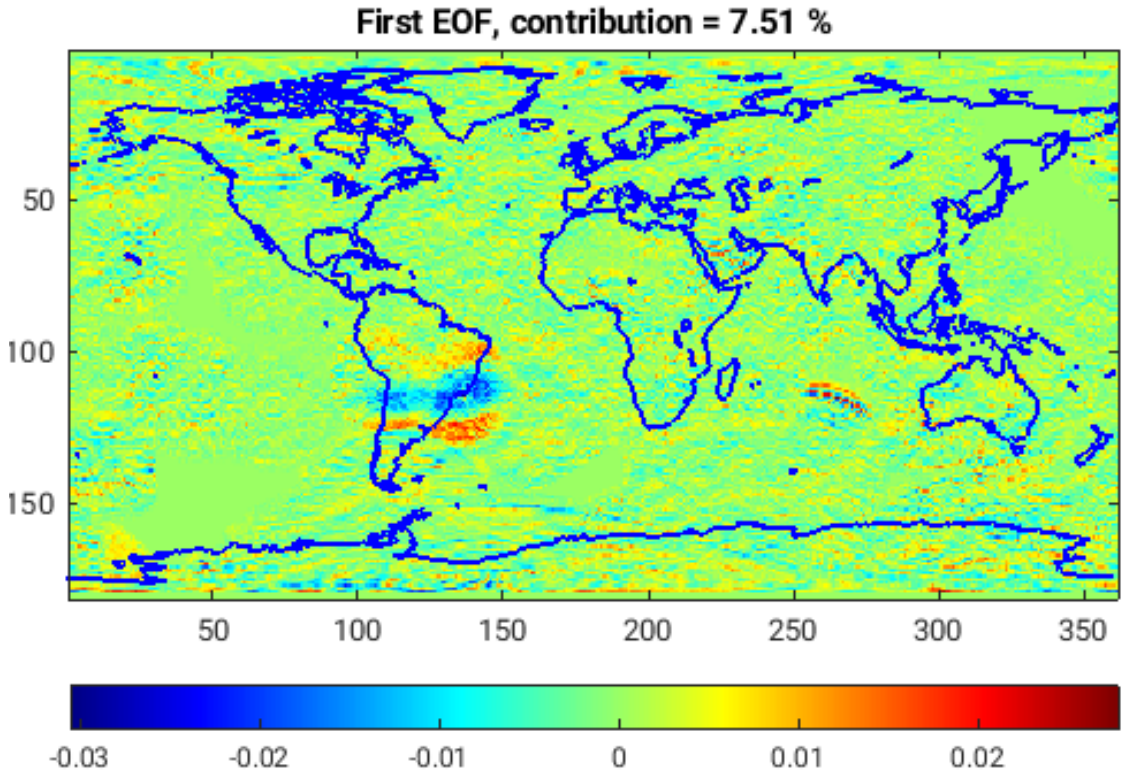


Median first 8 EOFs percentage=14.21

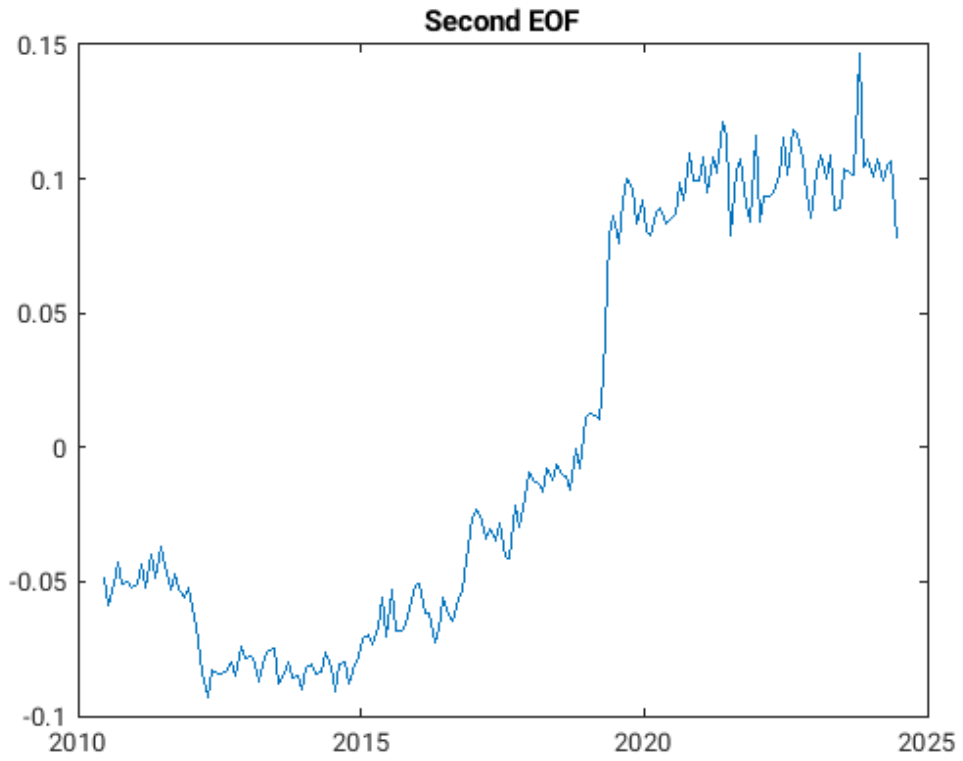


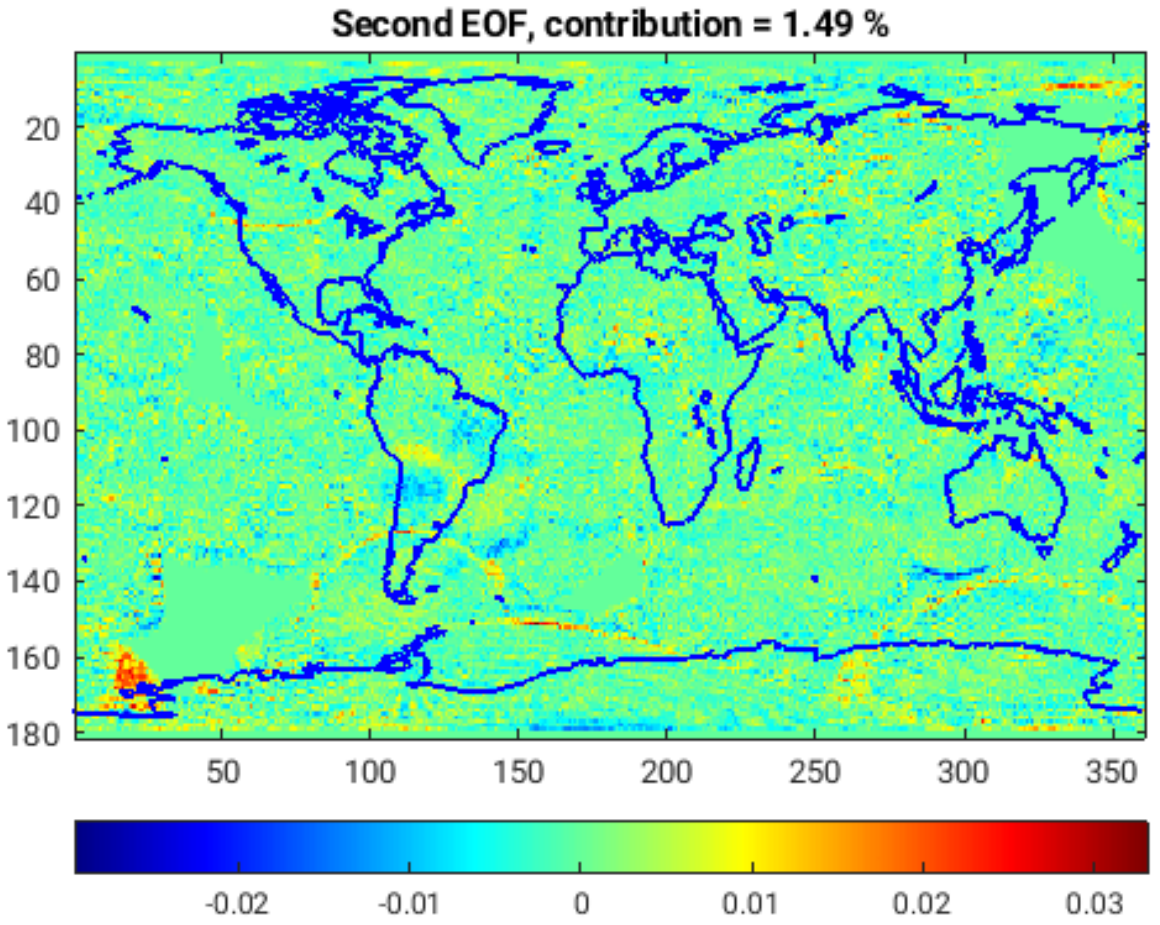
EOF mode 1


First EOF
0.09
0.085
0.08
0.075
0.07
0.065
0.06
0.055
0.05
0.045
2010
2015
2020
2025

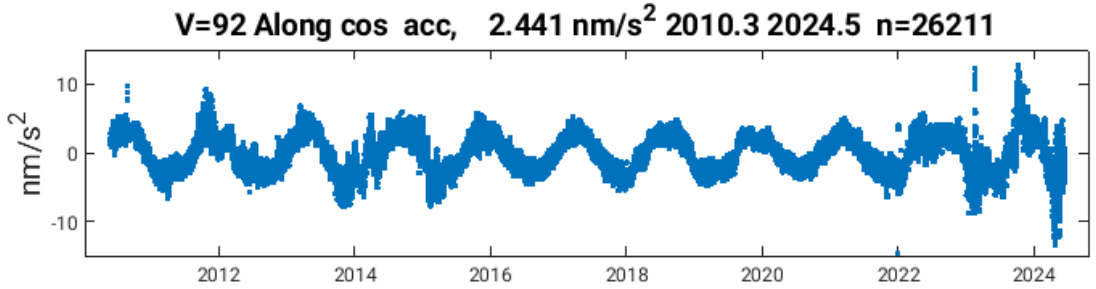

First EOF, contribution = 7.51 %
50
100
150
50
100
150
200
250
300
350
-0.03
-0.02
-0.01
0
0.01
0.02

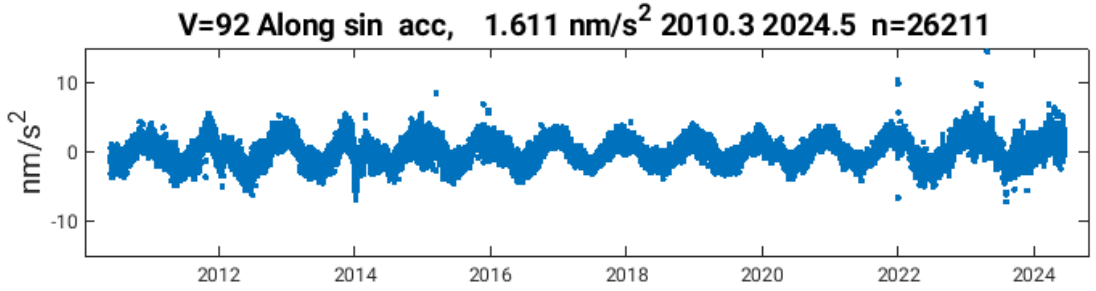
EOF mode 2

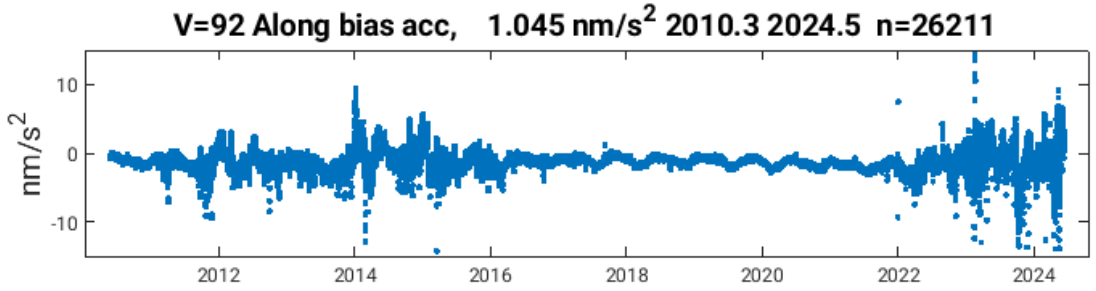

Second EOF
0.15
0.1
0.05
0
-0.05
-0.1
2010
2015
2020
2025


Second EOF, contribution = 1.49 %
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350
-0.02
-0.01
0
0.01
0.02
0.03

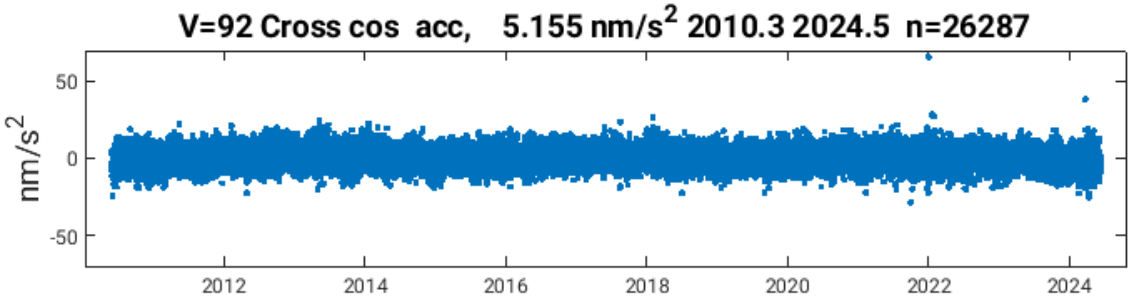
Along track

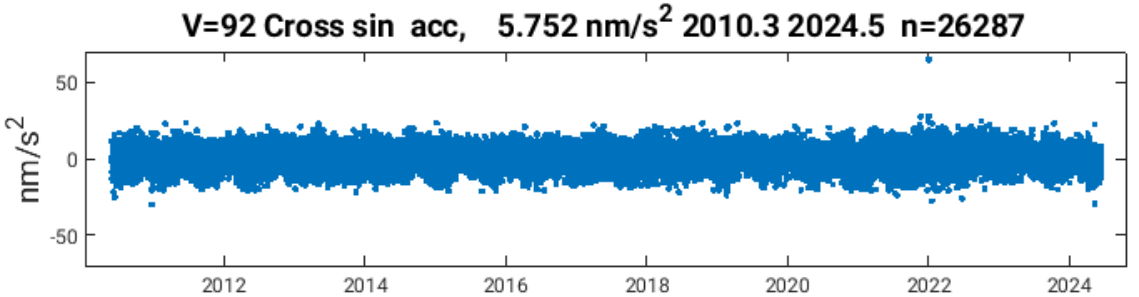


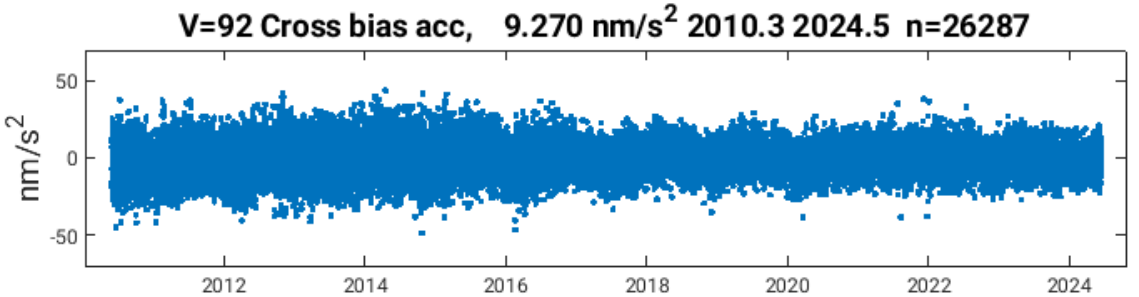




Cross-track



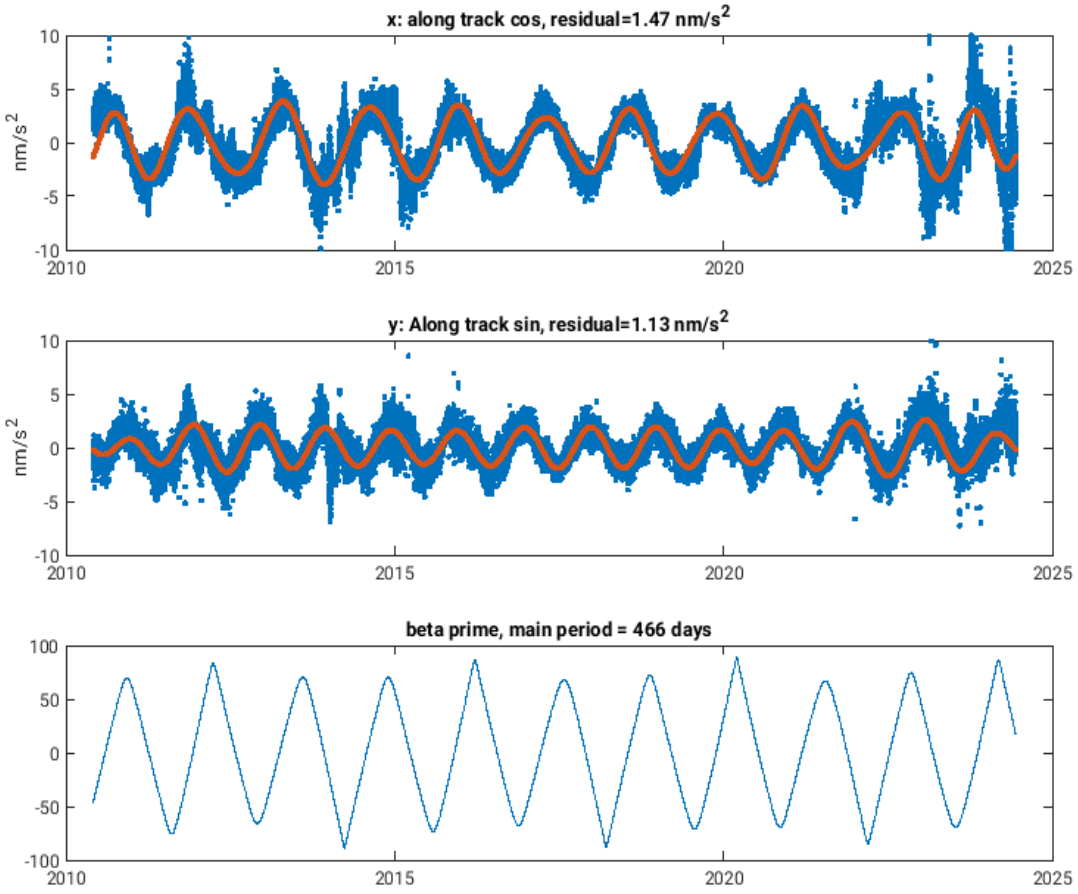


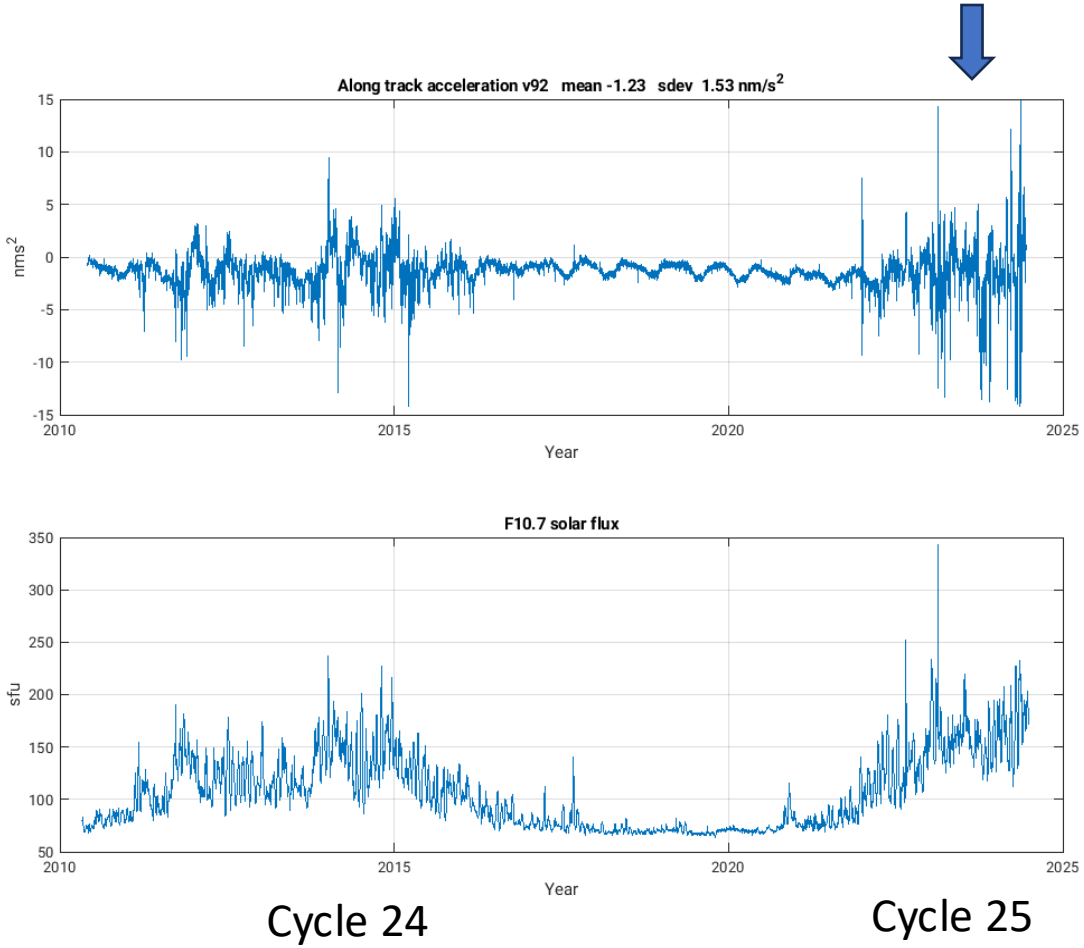


Note that we go from Solar cycle 24 via the doldrums to cycle 25, and it affects to along track bias

Along track empirical acceleration

RCS update Nov 2023





Cycle 24

Cycle 25

Suggests SRP model improvement

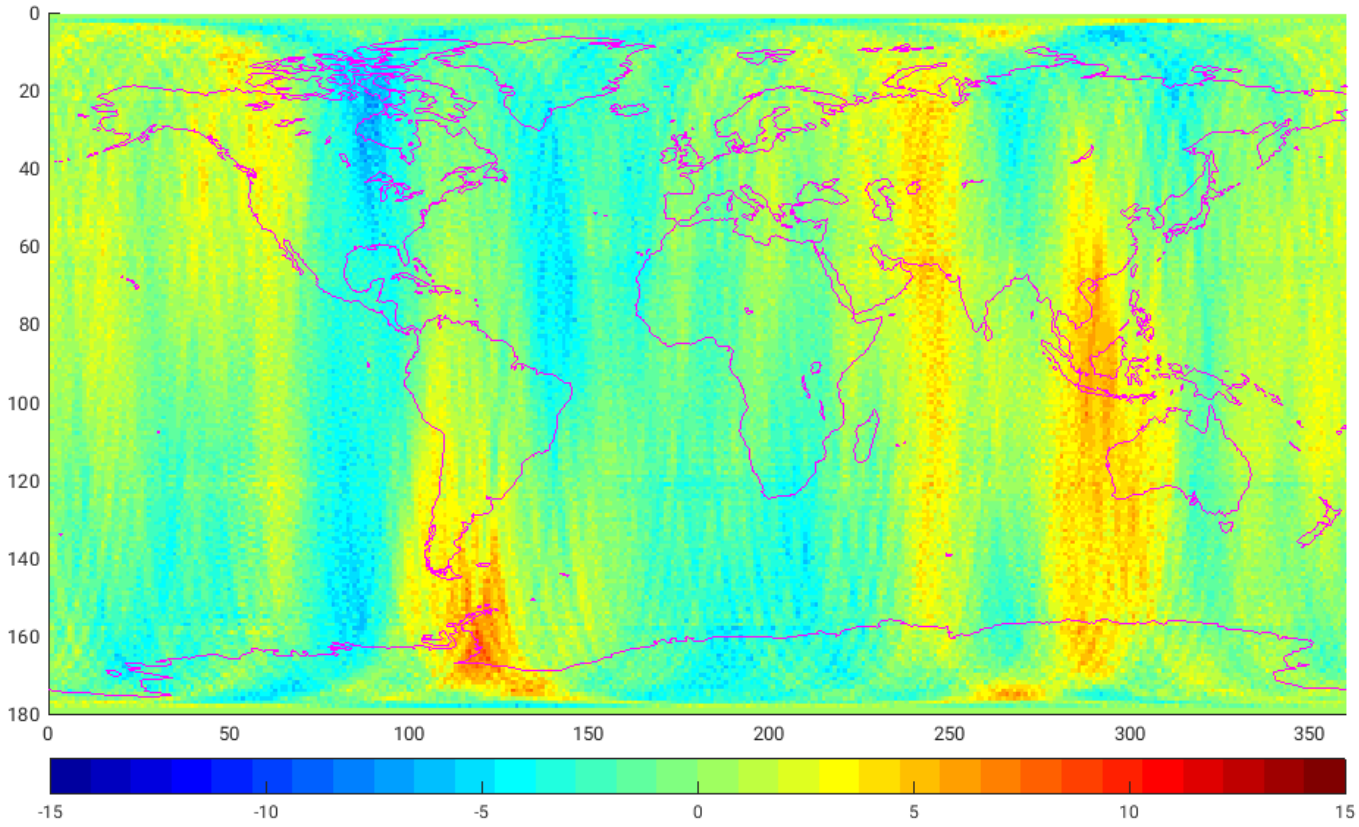
Suggests thermospheric density issue

Empirical accelerations

Run	Ca	Sa	Ba	Cc	Sc	Bc	Power	Comment
88	2.607	1.590	1.003	5.351	6.677	9.612	13.26	Reference
89	2.494	1.577	0.991	5.278	6.313	9.528	12.97	Only AOD1B
90	2.438	1.602	0.991	5.624	6.392	9.689	13.26	Polynomial TVG
91	2.571	1.786	1.006	5.837	6.568	9.894	13.64	EGM96 tides
92	2.441	1.611	1.045	5.155	5.752	9.270	12.45	Best so far
93	2.524	1.591	0.998	5.221	6.037	9.262	12.62	GOT4.10 tides

Reported values are in nms^{-2} for all computed components

Geographic average Jun-2010 till Jul-2024

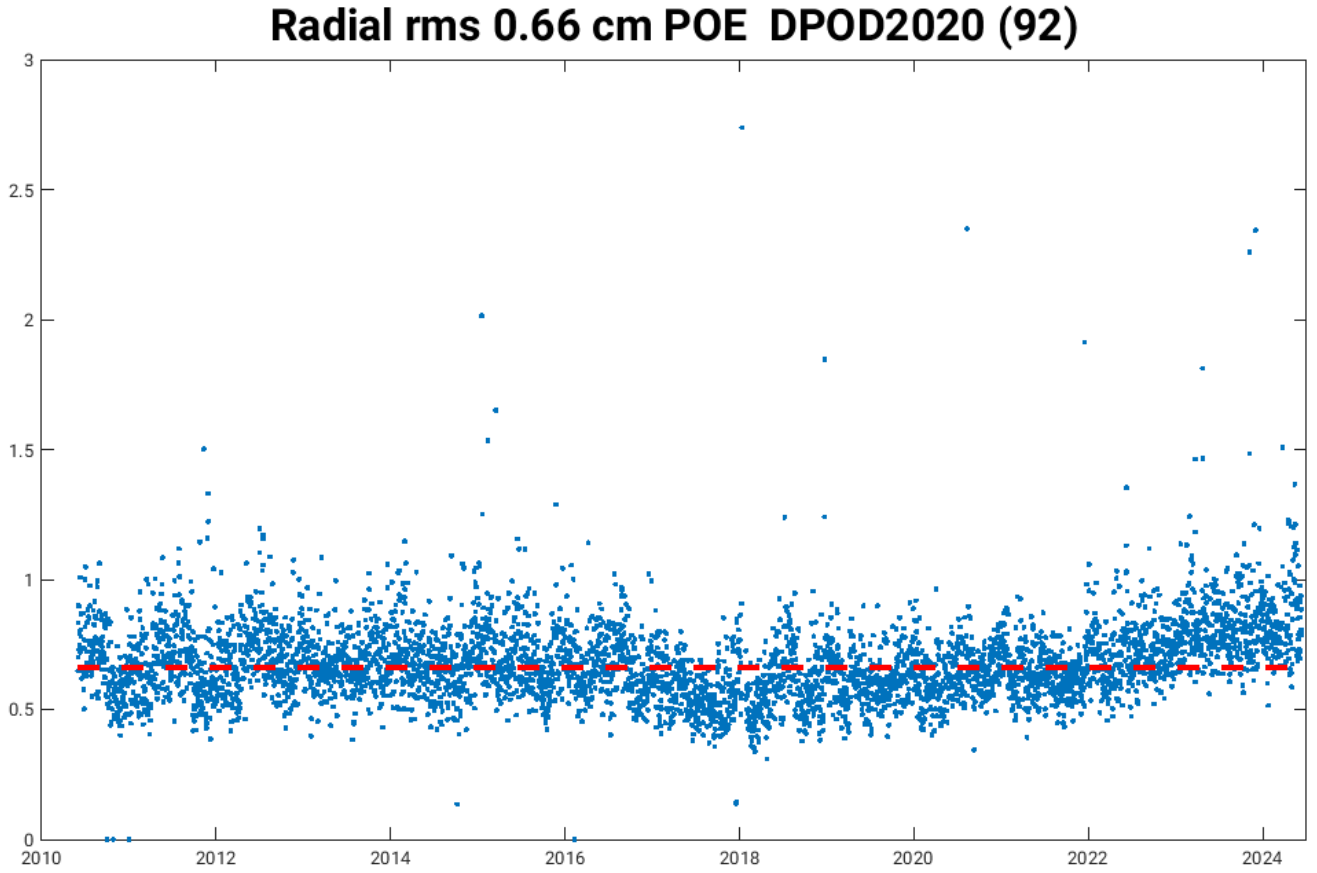


Units: mm

Radial differences (cm)

Run	POE	MOE	NAV
88	0.75	0.87	3.34
89	0.69	0.89	3.34
90	0.70	0.89	3.39
91	1.19	1.32	3.30
92	0.66	0.86	3.40
93	0.70	0.82	3.36

Run 92 compared to POE orbit

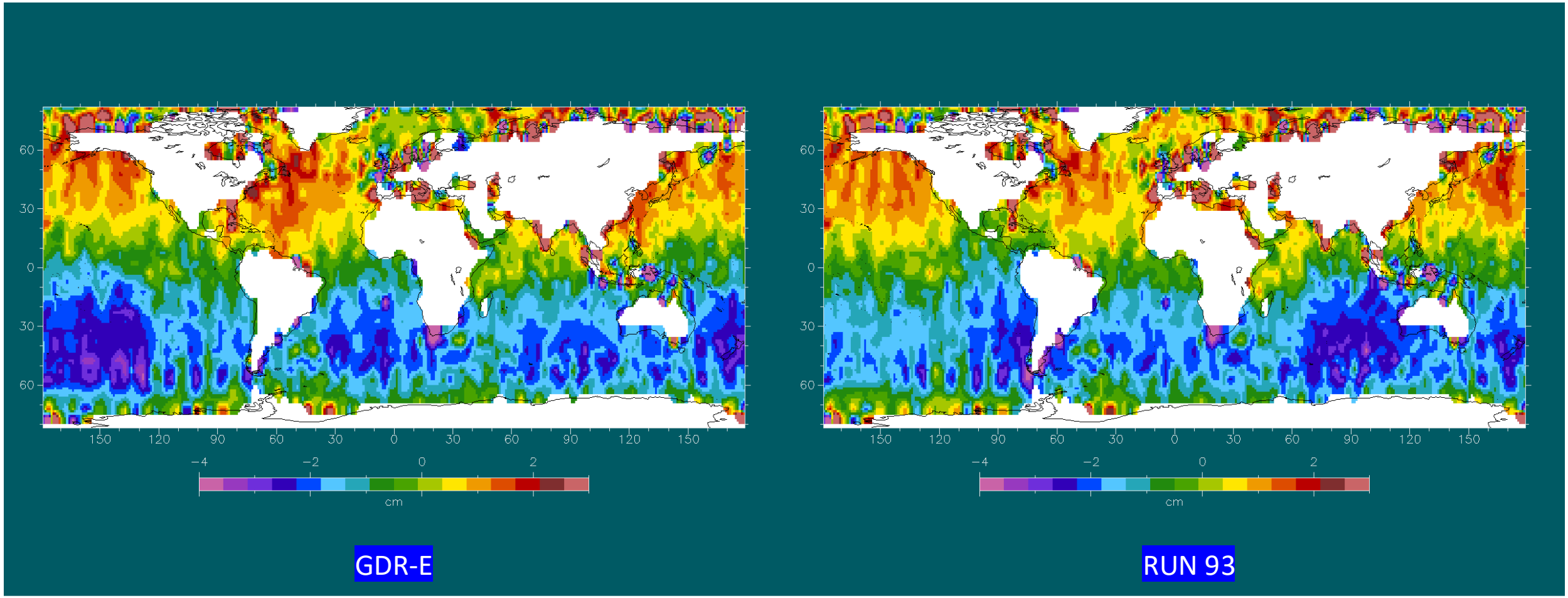


Crossover comparisons

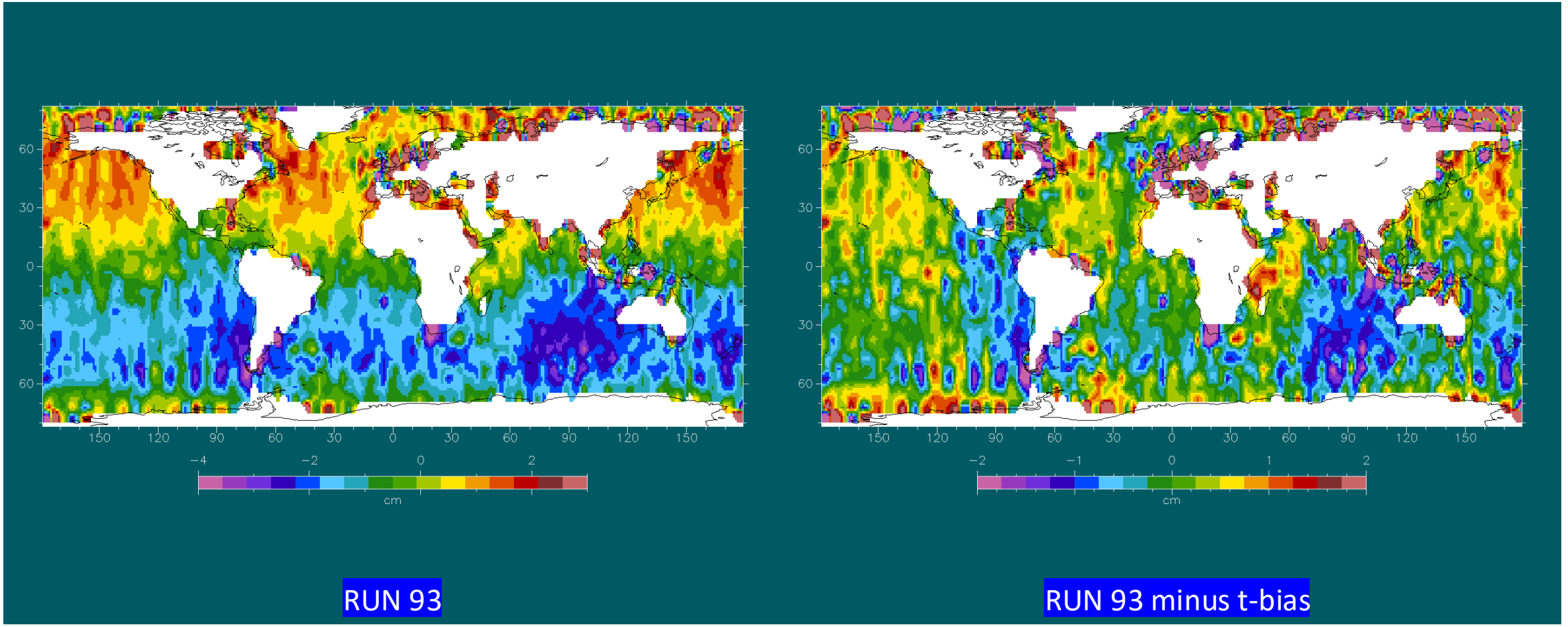
Run type	# xovers	Mean	RMS	sigma		Comment
REF	761390	-0.78	5.81	5.75		GDR-E on RADS
88	750633	-0.85	5.87	5.80		No AOD1B, No TVG, GOT4.7
89	750537	-0.84	5.85	5.79		No TVG, GOT4.7
90	750510	-0.66	5.81	5.77		TVG Polynomial, GOT4.7
91	751283	-0.66	6.01	5.97		TVG Fourier, EGM96 tides
92	753649	-0.66	5.79	5.76		TVG Fourier, GOT4.7
93	754431	-0.68	5.81	5.77		TVG Fourier, GOT4.10
93*	754008	-0.02	5.65	5.65		= run 93, time bias removed

All in cm, editing is applied, for run 93* an altimeter timing bias of 0.29 msec was removed
Max time difference at crossover is 13.5 days, monthly batches are used

“GDR-E” versus “RUN 93” crossover differences



Run 93, effect of 0.29 msec altimeter time tag bias



RUN 93

RUN 93 minus t-bias

Summary

- DPOD 2020 implementation for IDS and SLRF 2020 for SLR. New CRD V2 format on SLR data that includes site calibration data.
- Novel technique for evaluating Doppler residuals.
- CryoSat-2 POD depends for a part on TVG modelling, need to bridge the 2017-2018.5 GRACE to GRACE-FO transition gap,
- Ocean/Atmosphere is a separate activity, AOD1B always available, 3 hourly steps
- Cryosphere/Hydrology/Ocean effect comes from GRACE/GRACE-FO, there is a modest improvement
- AOD1B: do include it since it clearly shows an improvement
- Update the ocean tide model from EGM96 to GOT4.7 20x20, (GOT4.10 50x50 test) The latter is rather expensive, and it does not really help.
- Radial difference to POE orbit is 6.6 mm in the most optimistic comparison
- Along track bias accelerations become noisier in cycle 25, related to 10.7 solar flux index
- RCS update in Nov 2023 does not change the empirical accelerations (it is already obscured by cycle 25)

References

- Schrama EJO and Visser PNAM (2024) Choices for Temporal Gravity field modeling for Precision Orbit Determination of CryoSat-2, Advances in Space Research, Volume 73, Issue 1, Pages 31-41, doi: 10.1016/j.asr.2023.11.034
- Naeije M, Di Bella Alessandro, Geminale T, Visser P (2023) CryoSat Long-Term Ocean Data Analysis and Validation: Final Words on GOP Baseline-C, Remote Sensing 15(22) 5420 doi: 10.3390/rs15225420