Improvements in the Precision Orbit Determination strategy for CryoSat-2

Ernst Schrama, Pieter Visser
Delft University of Technology, The Netherlands
e.j.o.schrama@tudelft.nl

TU Delft

Content

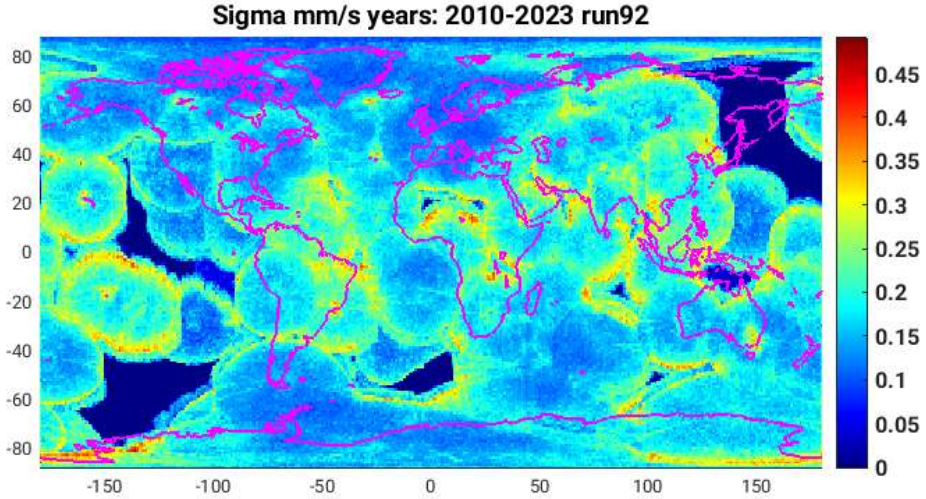
- Input to the modelling
- Mapping of observation Residuals
- Time variable gravity, AOD1B and from GRACE/GRACE-FO
- Empirical parameters
- External orbit comparison
- Crossover difference analysis
- Conclusions

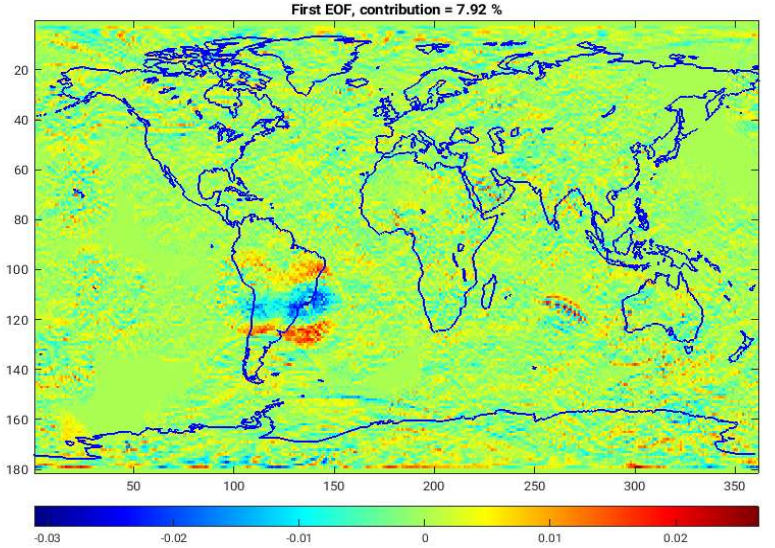
Input to the modelling process

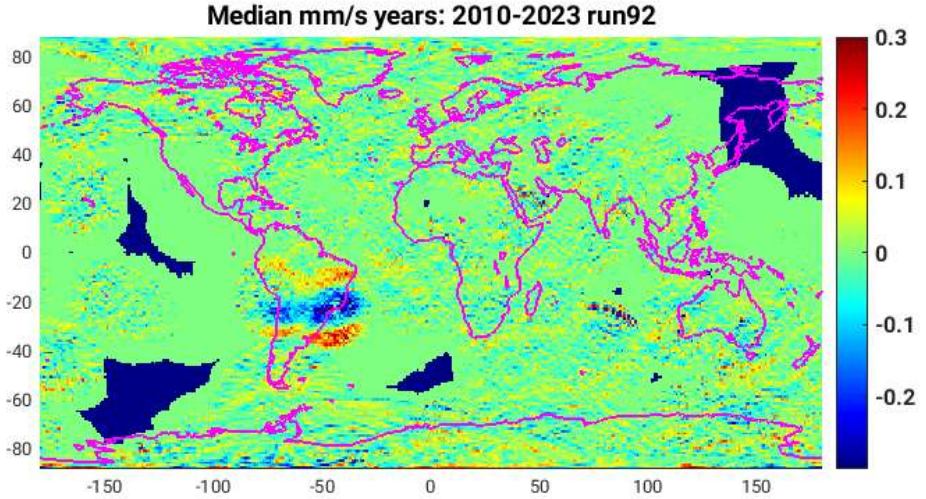
- Coordinates
  - Transition to ITRF2020 for all DORIS beacons and SLR stations (status earlier 2023)
  - Several beacons are not in ITRF2020 (ROZC SJVC SVBV FUUC NOXC) (status earlier 2023)
  - We have switched to DPOD2020 (yet to do HROC MAVC and SCSC) (new)
  - Also SLRF 2020 is already implemented including eccentricity updates (new)
- Ocean loading by station/beacon
  - Chalmers ocean loading calculator based on FES2014
- 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 (new)
- Initial state vector from DIODE navigator orbits
- DORIS stations weights, determined by data residual screening (new)

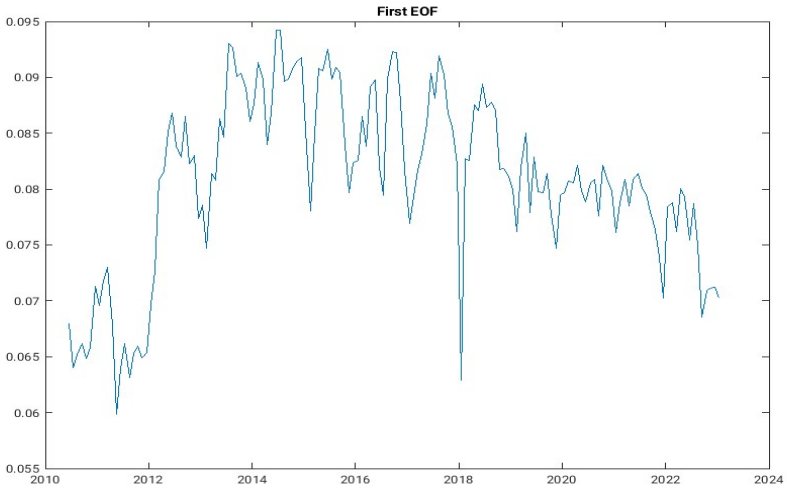
Input to the modelling process

- Gravity model, static part is EIGEN-6S4-V2 at reference 1-jan-2016 (new)
- Solar radiation pressure modelling, scaling constant estimates once, CNES model
- Drag modelling, MSIS reference model, 3 hourly patches with constraints
- Ocean tides affecting the orbit: GOT 4.7 setup + extra radiational lines (bug fix)
- Atmospheric and Oceanic part TVG : AOD1B is the 3 hourly model outputs (new)
- Terrestrial water storage: two model choices GRACE and GRACE-FO (new)
- Empirical accelerations modelling, 6 hourly, piecewise modelling.


Sigma mm/s years: 2010-2023 run92
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0


First EOF, contribution = 7.92 %
20
40
60
80
100
120
140
160
180
50
100
150
200
250
300
350
-0.03
-0.02
-0.01
0
0.01
0.02


Median mm/s years: 2010-2023 run92
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
0.3
0.2
0.1
0
-0.1
-0.2


First EOF
0.095
0.09
0.085
0.08
0.075
0.07
0.065
0.06
0.055
2010
2012
2014
2016
2018
2020
2022
2024

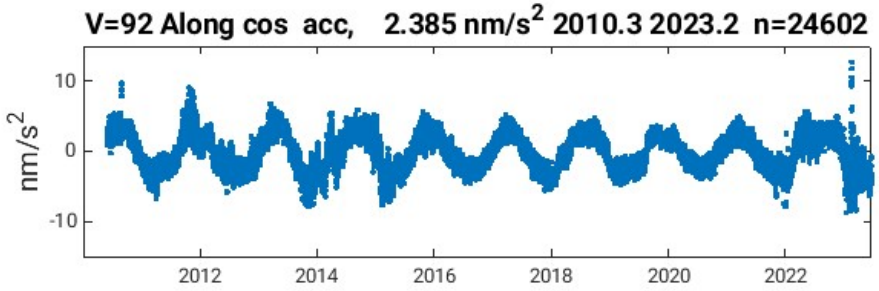
TVG modelling from GRACE and GRACE-FO

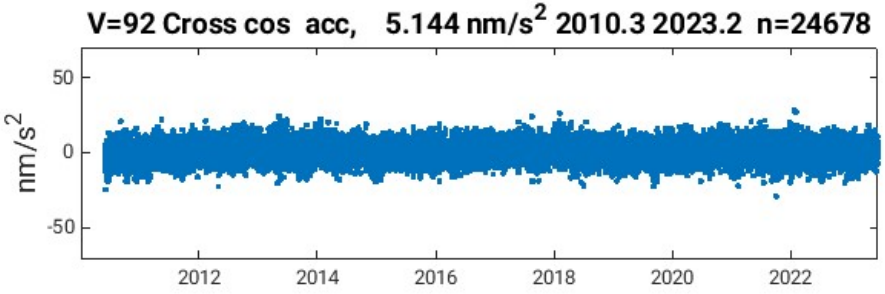
- AOD1B is always used for each arc, (except a test run)
- Without doubts residuals both for DORIS and SLR benefit from this
- Data gap in GRACE is from 23-5-2017 to 15–6-2018
- GRACE-FO: 15-6-18 -> 19-7-18; 31-10-18 -> 31-12-21
- Two strategies to merge the TVG from GRACE GRACE-FO in POD
  - EOF compression and editing
  - Polynomial approximation locally with patch functions (TVG-P)
  - Fourier approximation locally with patch functions (TVG-F)
  - (Caveat emptor: Not everyone agrees with me to demonstrate GRACE GRACE-FO continuity)

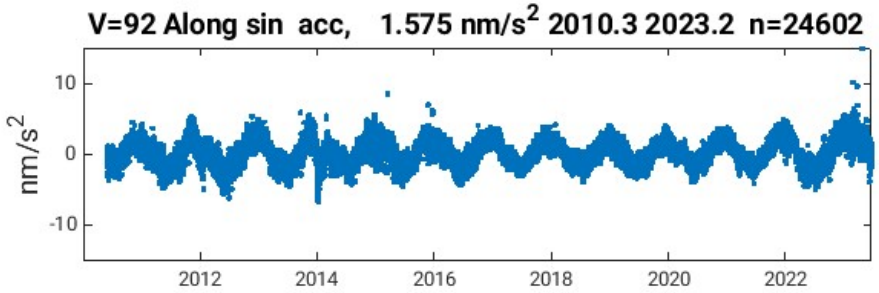
Five runs to analyze the POD performance

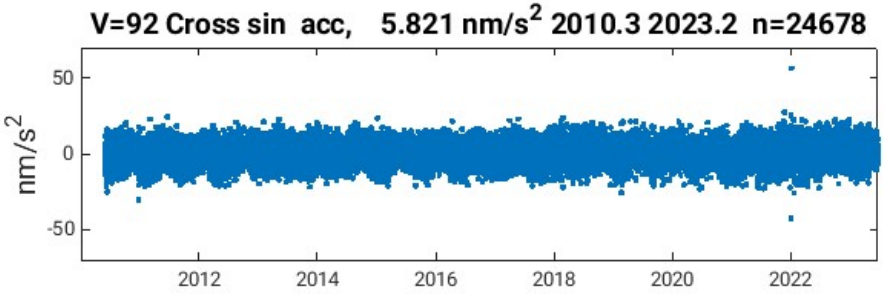
Run	AOD1B	TVG	Tides	Comment
TVG-0	N	N	GOT4.7	No time variable gravity
TVG-A	Y	N	GOT4.7	Only atmosphere and ocean effect
TVG-P	Y	Y	GOT4.7	TVG via polynomial patch model
TVG-F	Y	Y	GOT4.7	TVG via Fourier patch model
TVG-F2	Y	Y	EGM96	TVG via Fourier patch model

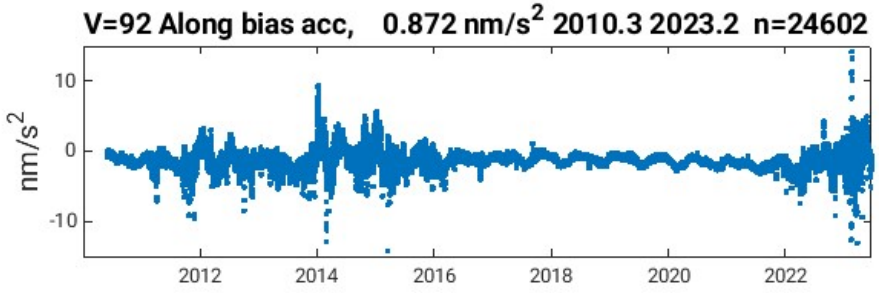
Run	Mean cm	Median cm	Mean mm/s	Median mm/s
TVG-0	1.101	1.036	0.4068	0.4062
TVG-A	1.084	1.014	0.4066	0.4060
TVG-P	1.102	1.033	0.4066	0.4061
TVG-F	1.087	1.020	0.4064	0.4060
TVG-F2	1.280	1.235	0.4100	0.4096

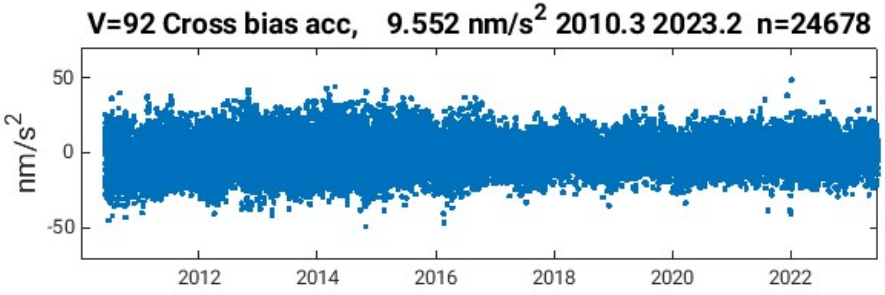

V=92 Along cos acc, 2.385 nm/s2 2010.3 2023.2 n=24602
nm/s2
10
0
-10
2012
2014
2016
2018
2020
2022

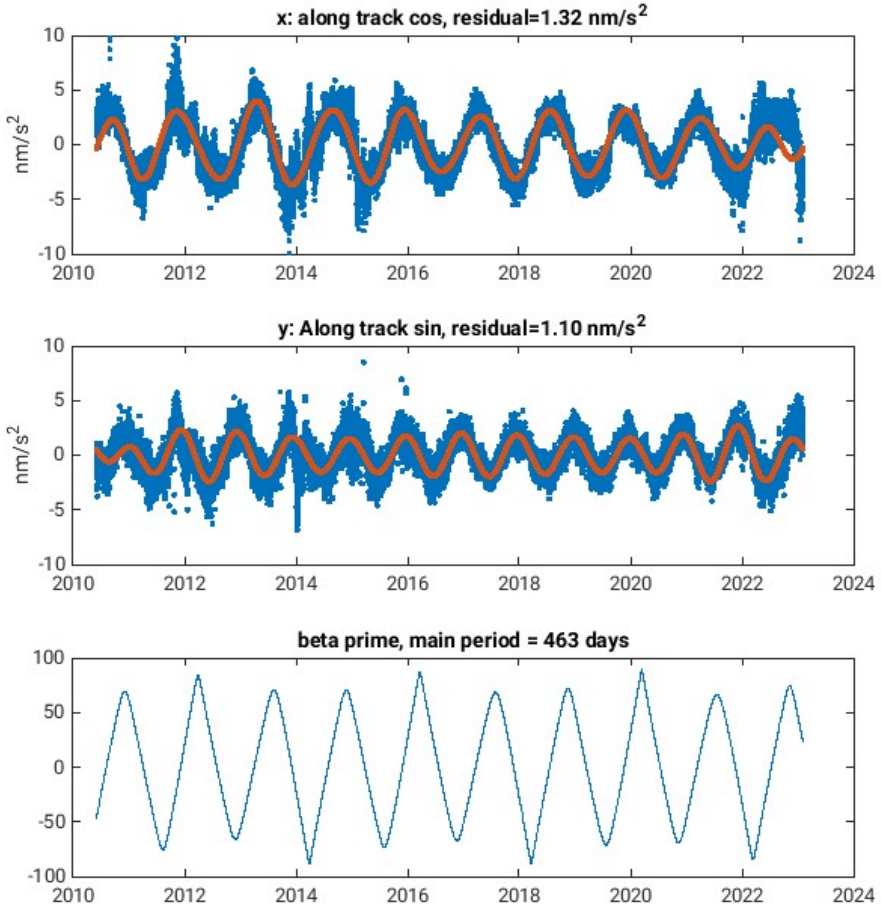

V=92 Cross cos acc, 5.144 nm/s2 2010.3 2023.2 n=24678
nm/s2
50
0
-50
2012
2014
2016
2018
2020
2022

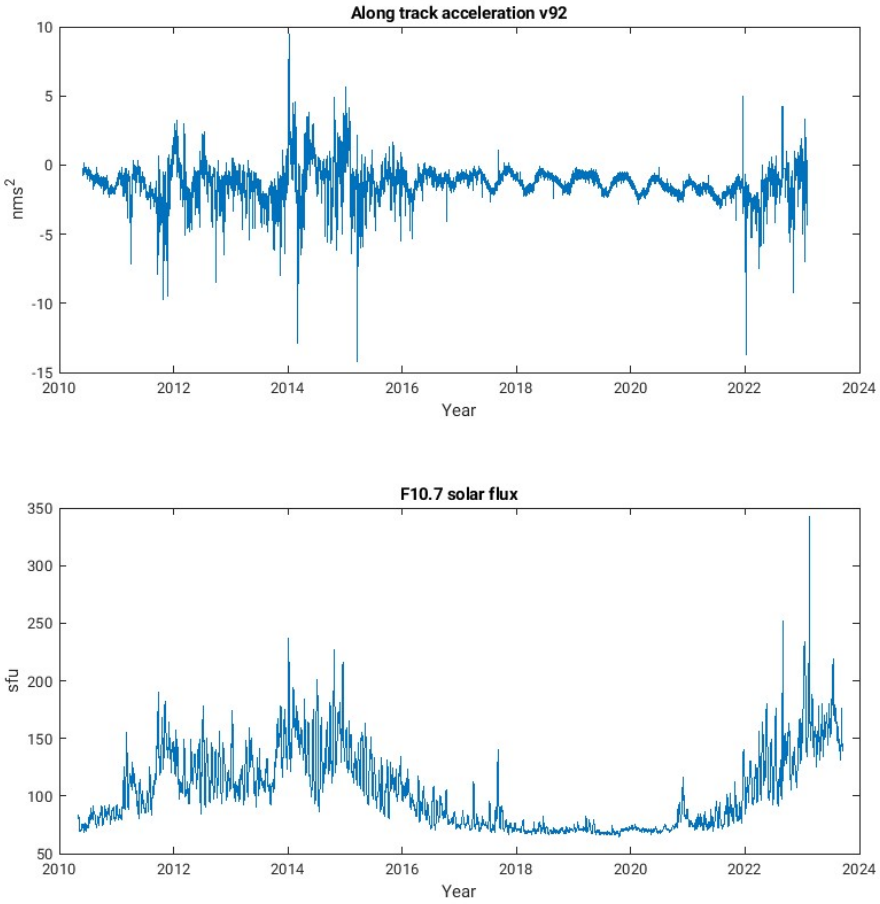

V=92 Along sin acc, 1.575 nm/s2 2010.3 2023.2 n=24602
nm/s2
10
0
-10
2012
2014
2016
2018
2020
2022


V=92 Cross sin acc, 5.821 nm/s2 2010.3 2023.2 n=24678
nm/s2
50
0
-50
2012
2014
2016
2018
2020
2022


V=92 Along bias acc, 0.872 nm/s2 2010.3 2023.2 n=24602
nm/s2
10
0
-10
2012
2014
2016
2018
2020
2022


V=92 Cross bias acc, 9.552 nm/s2 2010.3 2023.2 n=24678
nm/s2
50
0
-50
2012
2014
2016
2018
2020
2022





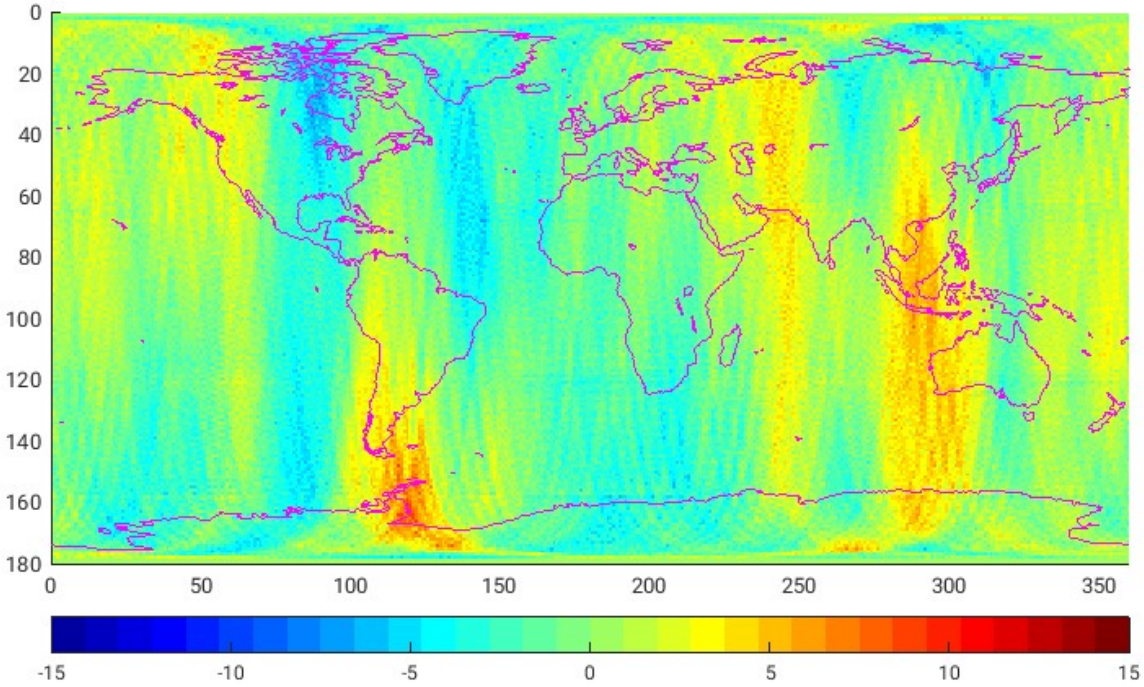
Suggests SRP model improvement

Suggests thermospheric density issue

Empirical accelerations

Run	A_c	A_s	A_b	C_c	C_s	C_b	Along	Cross	Total
TVG-0	2.53	1.57	0.86	5.32	6.47	9.81	3.09	12.90	13.27
TVG-A	2.42	1.55	0.85	6.03	6.96	10.71	3.00	14.13	14.44
TVG-P	2.37	1.58	0.85	5.39	6.15	9.77	2.98	12.74	13.08
TVG-F	2.36	1.56	0.85	5.14	5.82	9.56	2.95	12.32	12.67
TVG-F2	2.52	1.77	0.87	5.80	6.58	10.12	3.20	13.39	13.77

Geographic average over 2010 - 2023



Units: mm

Radial differences

Run	NAV	MOE	POE
TVG-0	3.29	0.86	0.73
TVG-A	3.28	0.88	0.68
TVG-P	3.34	0.89	0.69
TVG-F	3.33	0.86	0.65
TVG-F2	3.25	1.31	1.18

Units: cm

Crossover difference for all solutions

Solution	M	R	S	$M^\star$	$R^\star$	$S^\star$
REF	-0.79	6.82	6.78	-0.77	5.78	5.72
TVG-0	-0.84	6.87	6.81	-0.83	5.83	5.77
TVG-A	-0.83	6.86	6.81	-0.82	5.82	5.76
TVG-P	-0.68	6.83	6.80	-0.66	5.78	5.75
TVG-F	-0.69	6.82	6.79	-0.66	5.77	5.73
TVG-F2	-0.69	6.98	6.94	-0.66	5.98	5.95

Timing bias issue on the altimeter (Naeije et al 2023)

Summary

- ITRF 2020 implementation, for SLR and IDS, also affects the EOPs, New CRD V2 format on SLR data that includes calibration data.
- DORIS residuals in the South Atlantic Anomaly region appear to be correlated with the solar cycle.
- 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, currently in 3 hourly steps
- Cryosphere/Hydrology/Ocean effect comes from GRACE/GRACE-FO, there is a modest improvement
- AOD1B: yes include it always since it clearly shows an improvement
- Biggest surprise was to update our tide model set-up
- Open actions: SRP scaling and drag modelling, ITRF maintenance

Two recently published articles

- Schrama EJO and Visser PNAM (2023) Choices for Temporal Gravity field modeling for Precision Orbit Determination of CryoSat-2, accepted for publication in AISR 24-Nov-2023
- 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