Status of DORIS Processing at GSFC

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Summary of Recent SINEX Submissions Post ITRF2020

Series	Description	Comment
gscwd52	gscwd51 + Sentinel-3B starting 180610	Deliveries Started 2021-10-18
gscwd53	gscwd52 + downweight SAA stations on HY2A by 3X; Remove Arequipa, Kourou, Cacheoira, Santiago, San Juan from HY-2A normal equation before combination. (Recommended after last IDS WS 2022)	Deliveries started 2023-04-25
gscwd54	gscwd53 + replace GOCO05s/SLR+DORIS 4x4 solutions with **CNES_GRGS.RL05MF_COMBINED_GRACE_SLR_DORIS** gravity model, and resubmit SINEX files from 20160101 for the preparation of the ITRF2020 extension.	Deliveries started 2023-11-08. (Delivered from 2016-DOY003 to 2023-DOY365) by February 4, 2024.
gscwd55	gscwd54 + Sentinel-6A	Delivered 2021-2023 on 2024-0306 to 2024-0319.
gscwd58	gscwd55 + dpod2020 + Jason-3 downweighted w.r.t S6A + MSIS2 atmosphere density model + apply nutation corrections.	Internal series for now
gscwd59	Gscwd58 + replace DORIS/V2 normal eq. with DORIS/RINEX normal equations	Internal series for now

Summary of POD Results: RMS of fit for gscwd58/59

*(*preliminary results: DORIS V2 vs. RINEX)*

Satellite	First Arc	Last Arc	No of Arcs	Avg. No SLR obs	Avg. No DORIS obs	Avg. SLR fit (cm)	Avg DORIS fit * (WRMS, mm/s)
Cryosat-2 (V2)	210103	240424	242	764	53,111	0.727	0.3806
Cryosat-2 (Rinex)	210103	240411	238	770	54,698	0.733	0.3850
Saral (V2)	210103	240414	176	865	79,237	0.698	0.3589
Saral (Rinex)	210103	240331	176	867	81,232	0.705	0.3597
HY2A (V2)	140105	200906	397	615	81,558	0.919	0.3524
HY2A (Rinex)	140105	200906	397	614	84,793	0.922	0.3546
Jason-2 (V2)	160103	190908	172	2460	121,362	0.694	0.3346
Jason-2 (Rinex)	160103	190908	172	2458	126,035	0.687	0.3346

* All arcs use elevation-dependent weighting; For simplicity DORIS WRMS is rescaled by 1/0.7 to report aggregate results by satellite.

Summary of POD Results: RMS of fit for gscwd59

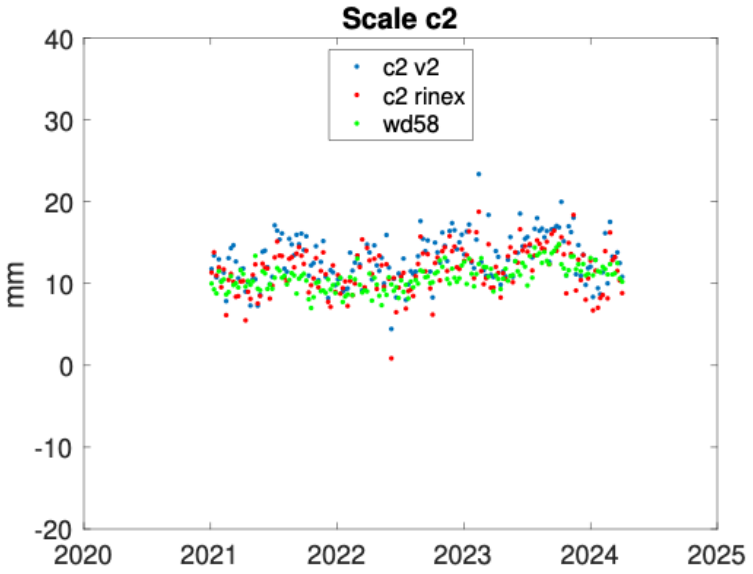
*(*preliminary results)*

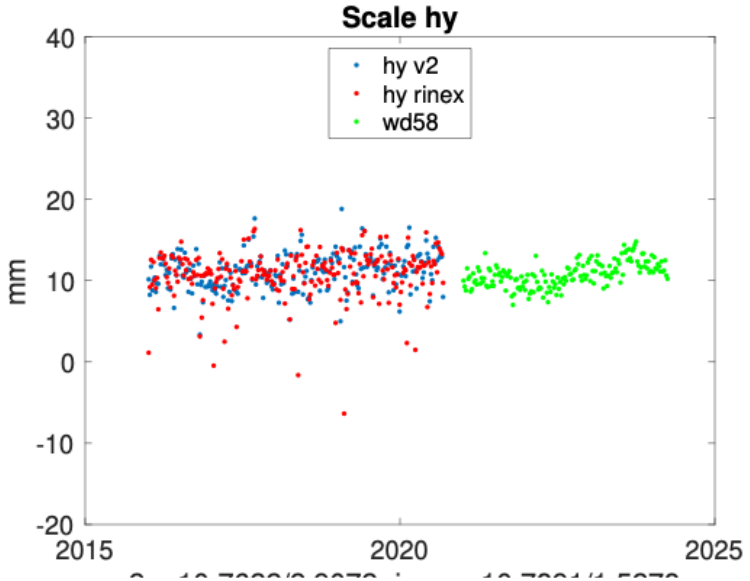
Satellite	First Arc	Last Arc	No of Arcs	Avg. No SLR obs	Avg. No DORIS obs	Avg. SLR fit (cm)	Avg DORIS fit * (WRMS, mm/s)
Cryosat-2 (Rinex)	160103	240411	551	921	61,358	0.713	0.3797
HY-2A (Rinex)	140105	200906	397	614	84,793	0.922	0.3546
Jason-2 (Rinex)	130106	190908	337	2906	129,931	0.777	0.3324
Jason-3	160223	240421	477	2519	132,160	0.690	0.3611
Saral (Rinex)	160103	201227	442	1037	85,609	0.719	0.3581
Sentinel-3A	160302	240424	527	865	75,042	0.622	0.3710
Sentinel-3B	180606	240425	396	790	71,137	0.654	0.3837
Sentinel-6A	210103	240421	200	1922	123,516	0.690	0.3556

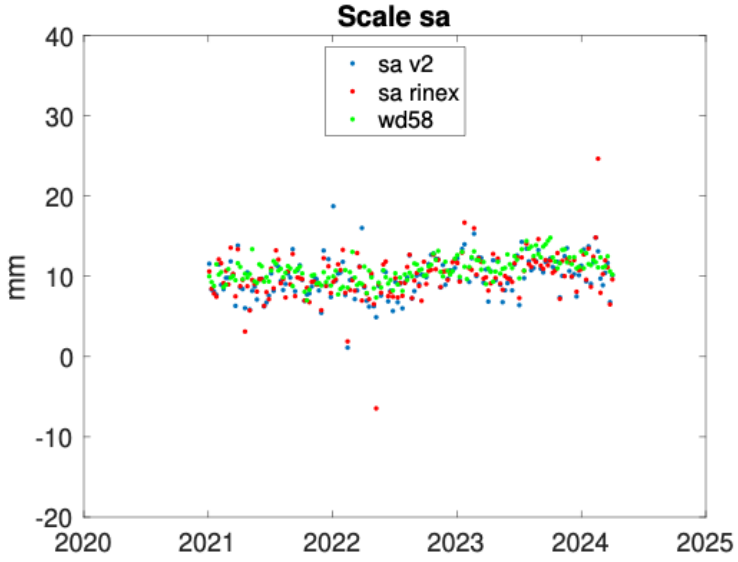
* All arcs use elevation-dependent weighting; For simplicity DORIS WRMS is rescaled by 1/0.7 to report aggregate results by satellite.

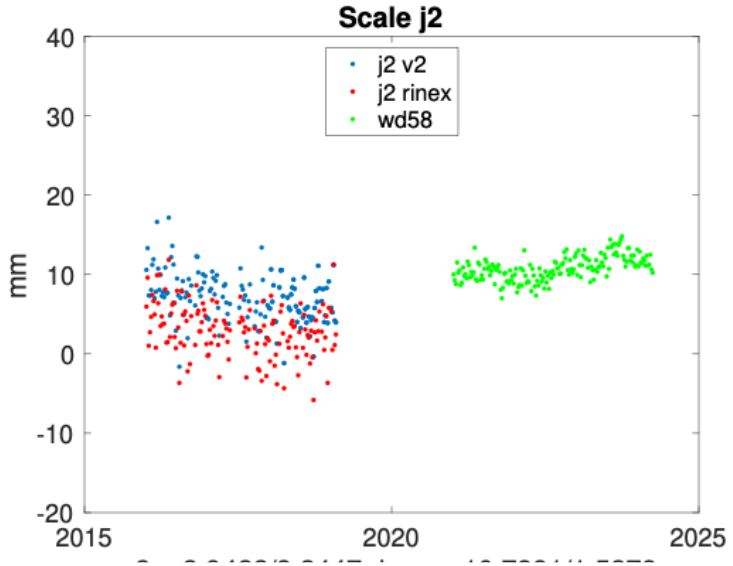
Comparison of Single-Satellite SINEX solutions

(WRMS of DORIS/V2 vs DORIS/RINEX)







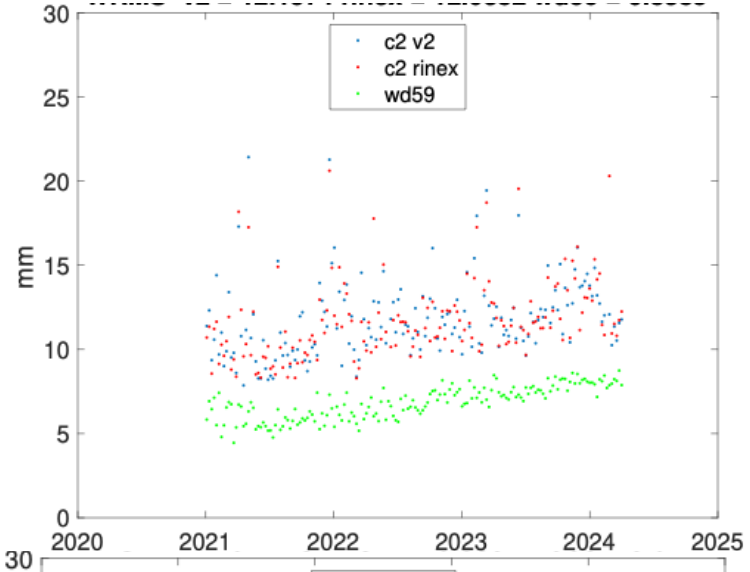


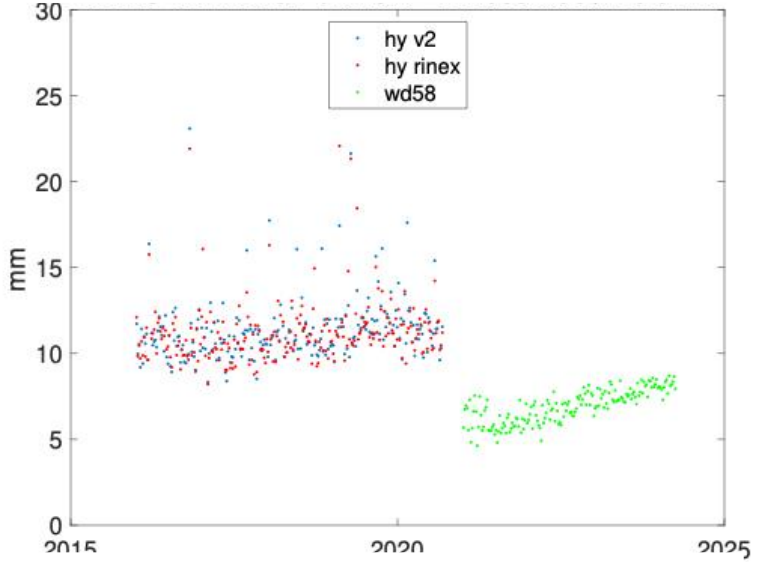
Data set	Helmert Scale mean & σ (mm)
Cryosat/V2	12.99 ± 2.87
Cryosat/Rinex	11.64 ± 2.71
HY2A/V2	11.21 ± 2.37
HY2A/Rinex	10.76 ± 2.91
Saral/V2	9.92 ± 2.37
Saral/Rinex	10.01 ± 2.76
Jason-2/V2	7.12 ± 3.11
Jason-2/Rinex	2.94 ± 3.24

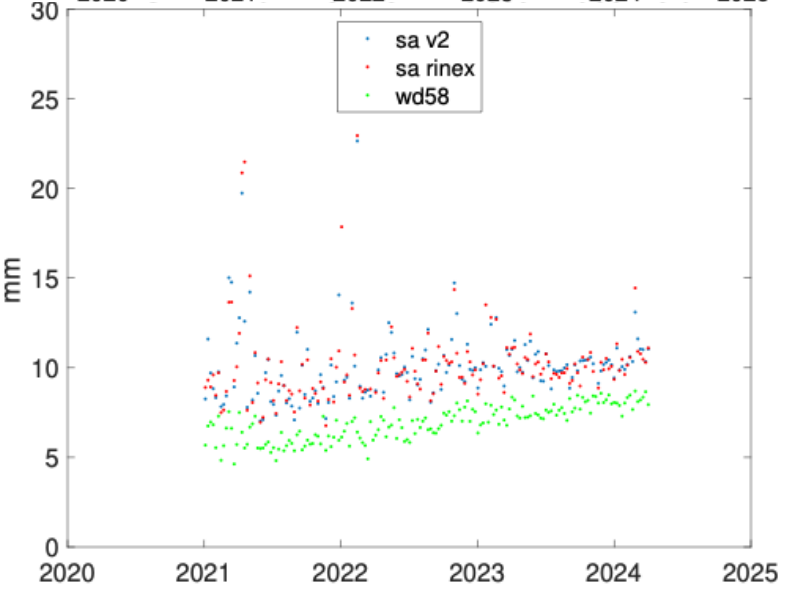
DORIS/RINEX Helmert-derived scale (w.r.t. DPOdD2020) statistically indistinguishable to the DORIS/V2 Helmert-derived scale, except for Jason-2. ➔Need to check Jason-2 modelling.

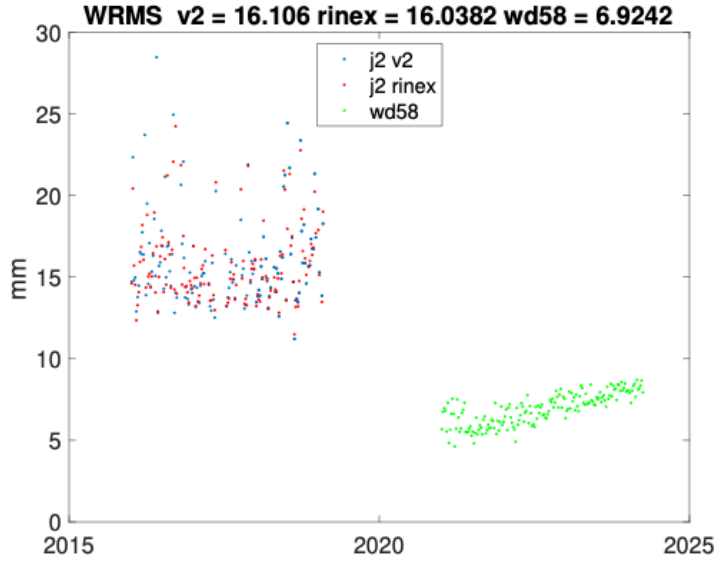
Comparison of Single-Satellite SINEX solutions

(WRMS of DORIS/V2 vs DORIS/RINEX)





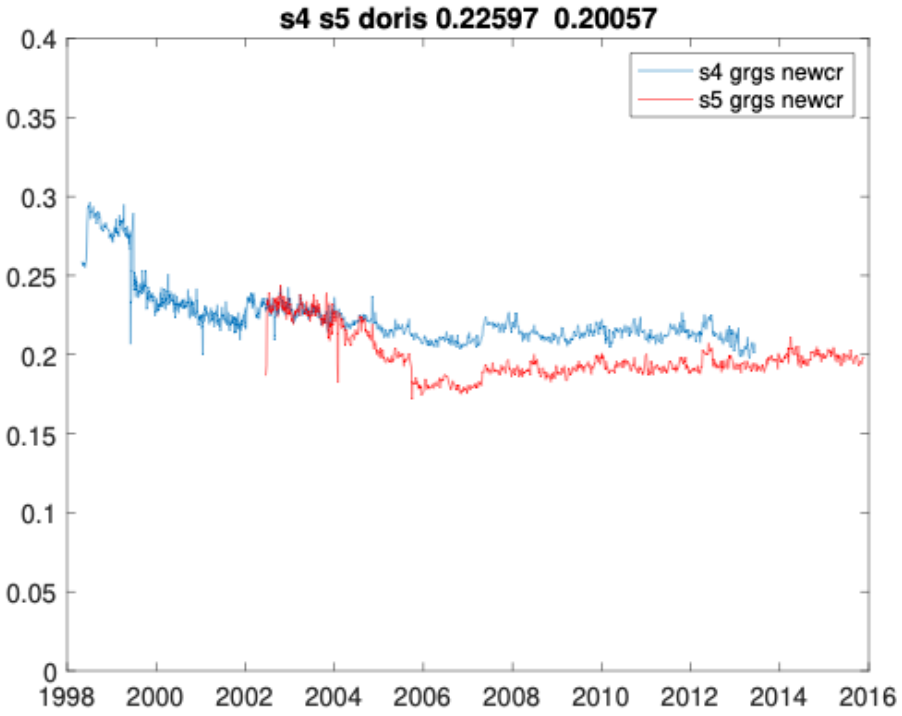




Data set	WRMS (mm)
Cryosat/V2	12.16
Cryosat/Rinex	12.04
HY2A/V2	11.33
HY2A/Rinex	11.20
Saral/V2	10.42
Saral/Rinex	10.84
Jason-2/V2	16.11
Jason-2/Rinex	16.04

RINEX improves WRMS w.r.t. DORIS/V2 except for Saral due to a few outlier arcs that need more work..

Reprocessing of SPOT-4/SPOT5 (1)



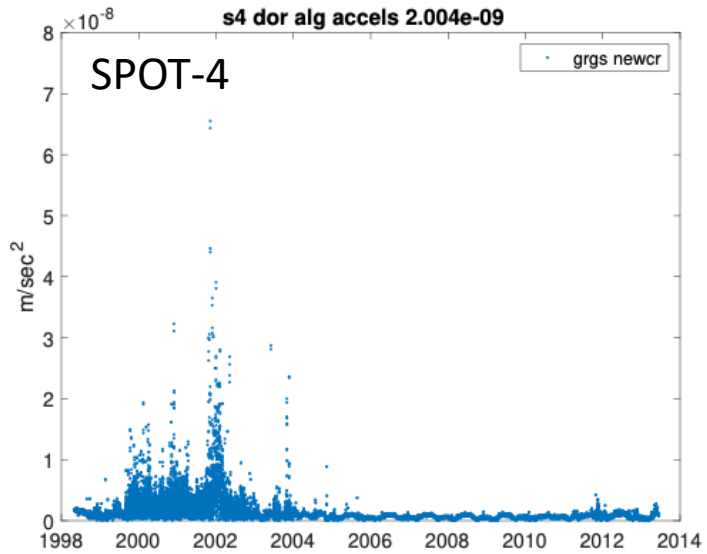
We re-estimated the Average Cr's for SPOT-4 & SPOT-5 with the new processing (DPOD2020 & using MSIS2). Due to the correlation of atmospheric drag and solar radiation pressure for the sun-synchronous orbits, we estimated the Cr's in yearly or multi-year batches. The Cr's are w.r.t to the GSFC micromodel we have previously determined.

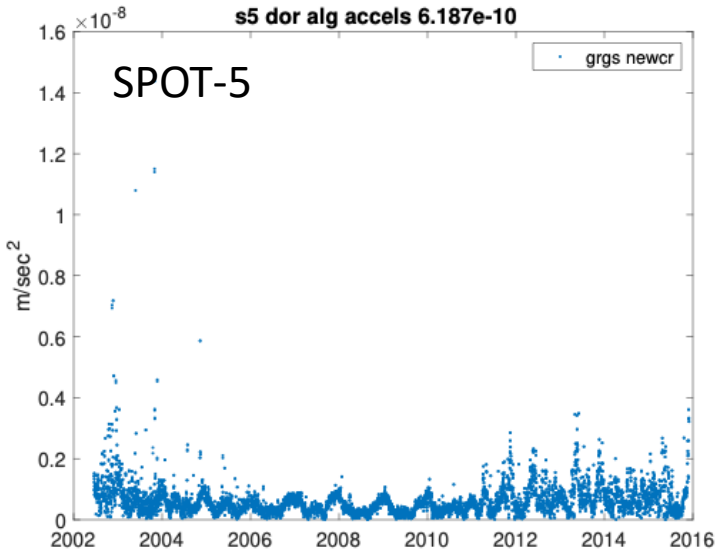
Time Span	SPOT-4 Cr
1998–1999	0.996176
2000–2003	0.995886
2004–2009	0.986294
2010–2013	0.983282

Time Span	SPOT-5 Cr
2002	1.002028
2003	0.999218
2004	0.995959
2005–2009	0.991031
2010–2014	0.994660
2015	0.998106

For SPOT-5 we use the SAA-corrected DORIS data (2006 & later) and apply the solar array pitch biases from the CNES documentation.

Reprocessing of SPOT-4/SPOT5 (2)



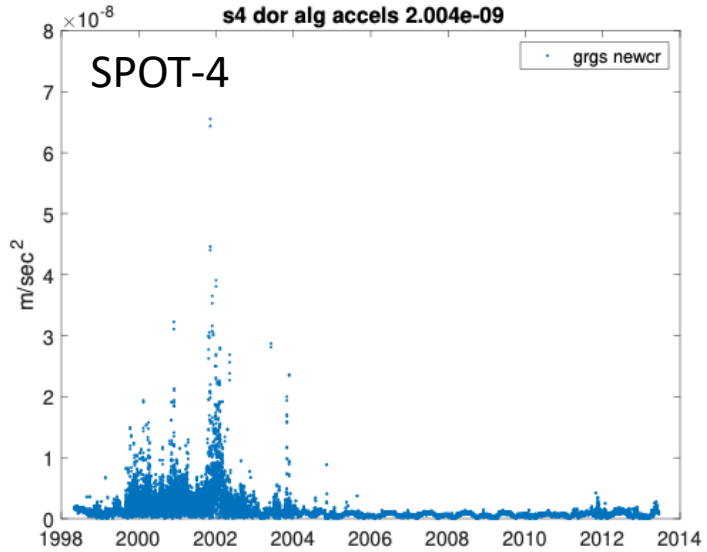


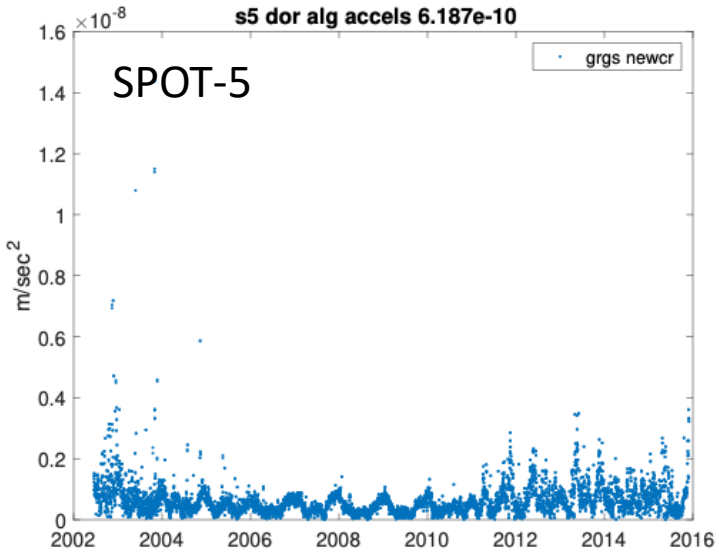
Compare OPR amplitudes 2005–2009 (solar minimum) to measure macromodel performance. (SPOT-4)

Satellite	Cr	N	Along-track Daily Accel (nm/s^2)	Cross-track Daily Accel (nm/s^2)
SPOT-4 (avg)	Cr=1	1802	0.946	3.234
SPOT-4 (RMS)	Cr=1	1802	1.096	3.745
SPOT-4 (avg)	Tuned	1802	0.575	3.379
SPOT-4 (RMS)	Tuned	1802	0.692	3.891

For SPOT-4, a tuned Cr (a small change) reduces amplitude of along-track accelerations by about 39% (on average).

Reprocessing of SPOT-4/SPOT5 (2)





Compare OPR amplitudes 2005–2009 (solar minimum) to measure macromodel performance. (SPOT-5)

Satellite	Cr	N	Along-track Daily Accel (nm/s^2)	Cross-track Daily Accel (nm/s^2)
SPOT-5 (avg)	Cr=1	1781	0.603	1.083
SPOT-5 (RMS)	Cr=1	1781	0.721	1.333
SPOT-5 (avg)	Tuned	1781	0.415	1.056
SPOT-5 (RMS)	Tuned	1781	0.530	1.321

For SPOT-5, a tuned Cr (a small change) reduces amplitude of along-track accelerations by about 31% (on average).

Reprocessing of SPOT-4/SPOT5 (2)

1. **MSIS2** (Mass Spectrometer & Incoherent Scatter). Emmert et al. (2021), *Earth & Space Sci.,* doi: 10.1029/2020EA001321.
2. **DTM2020** (Drag Temperature Model 2020). Bruinsma & Boniface, 2021, *J. Space Wea. Space Clim.,* doi: 10.1051/swsc/2021032.
3. **MSIS86**. Hedin, 1987, JGR-Space-Physics, doi: 10.1029/JA092iA05p04649.

GEODYN *a prior*i before implementation of newer models.

Compare OPR amplitudes 2005–2009 (solar minimum) to measure density model performance

Satellite	model	N	Along-track Daily Accel (nm/s^2)	Cross-track Daily Accel (nm/s^2)
SPOT-5 (avg)	MSIS2	1781	0.603	1.083
SPOT-5 (avg)	DTM2020	1781	0.602	1.086
SPOT-5 (avg)	MSIS86	1781	0.604	1.085

Compare OPR amplitudes 2002–2003 (solar maximum) to measure density model performance

Satellite	model	N	Along-track Daily Accel (nm/s^2)	Cross-track Daily Accel (nm/s^2)
SPOT-5 (avg)	MSIS2	637	0.684	1.770
SPOT-5 (avg)	DTM2020	637	0.670	1.772
SPOT-5 (avg)	MSIS86	637	0.973	1.762

Update on Sentinel-6A POD: Gravity modelling (1)

Some Gravity Model Choices for DORIS Satellite POD

Solutions	Description	Orbits
GRGS_RL04	GRACE + GOCE + SLR solution (1993 to ~2017).	POE-F
GSFC_nominal	GOCO05s + 4x4 model from 1993 – 2020 DORIS+SLR TVG series.	gsfc std2006
GRGS_RL05	GRACE + GRACE-FO + GOCE + SLR+ DORIS solution (1993 to 2022)	POE-G & New gsfc orbits
COST-G FSM	GRACE-FO-based combination solution, annual + linear terms; updated quarterly. Starts in 2018. Latency several months.	New gsfc orbits (S6A)
Loomis et al. SLR (5x5 + C_{61}/S_{61})	Weekly TVG solution from SLR geodetic satellites. Contributes to GRACE (FO) Technical Note 14. About 2 month latency.	New gsfc orbits (S6A)

We have three requirements:
(1) We need a consistent geophysical model, if possible, over the entire time span.
(2) We would prefer a Time-Variable-Gravity (TVG) model that is dynamically updated.
(3) The model should be available in time for the needs of operational processing.

Update on Sentinel-6A POD: Gravity modelling (2)

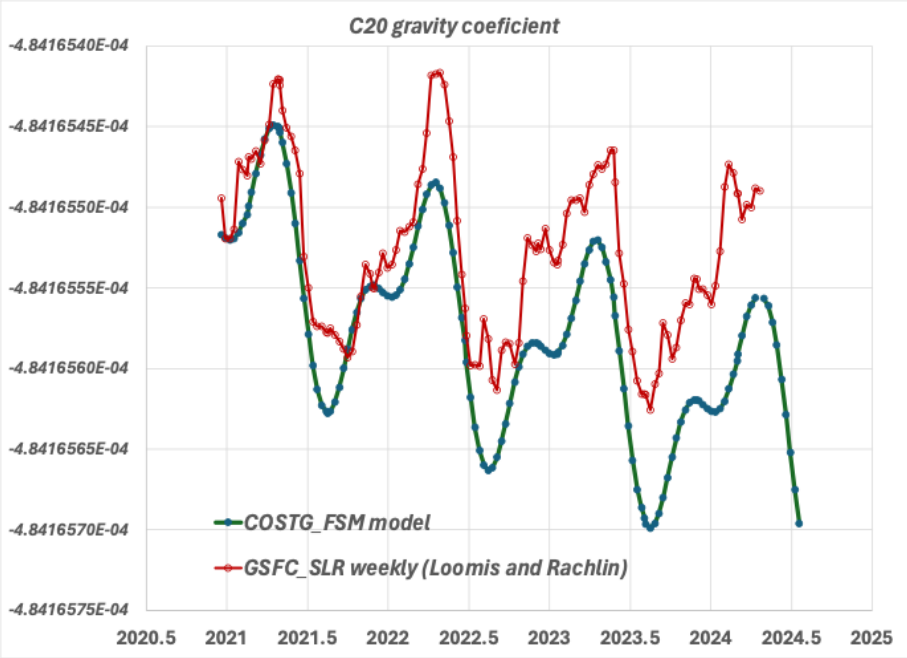
Issues:

(1) GRGS_RL05 is a good model for the historical reprocessing, as its application shows a consistent improvement over its data interval (1993 – 2022*). [Two exceptions: (1) TP, Oct. 1992 – Dec 1992; (2) early 1993, anomalous solution].*

(2) The COSTG-FSM could be a good choice for a model that is dynamically updated, however,

(3) The Earth system continues to evolve in a non-linear way (e.g. Antarctica appears to have gained mass in 2022-2023; C20 evolves differently then the rate term from the COSTG-FSM model would suggest).

(4) So what do we do for operational POD?



Update on Sentinel-6A POD: Gravity modelling (3)

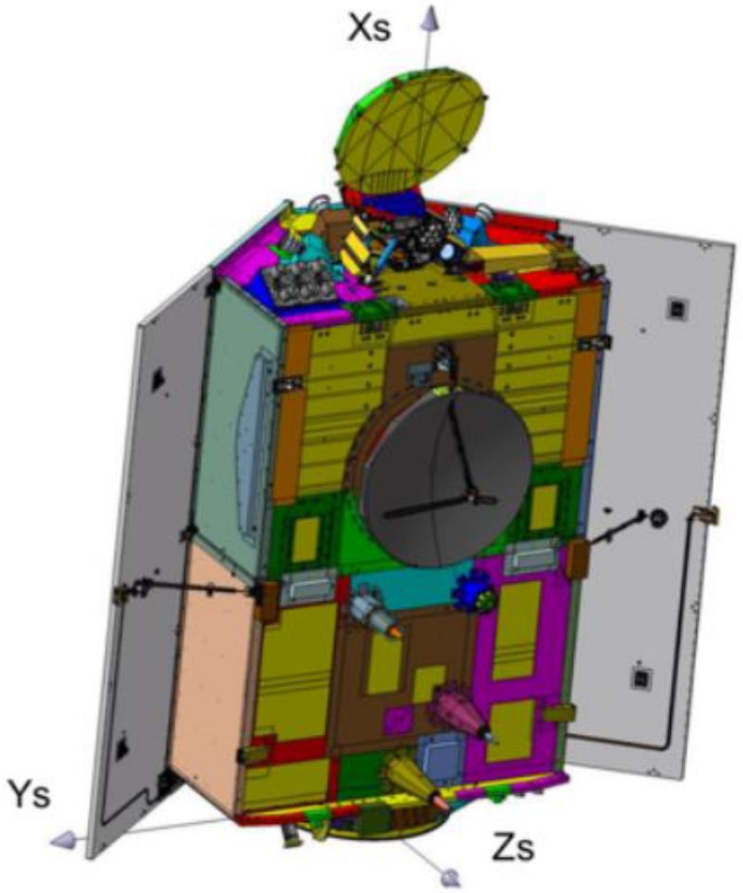
Tests

So we tested a number of static+ time-variable models on Sentinel-6A POD, where we filled in a dynamically updated SLR solution with the latest COSTG-FSM model.

Gravity test summary statistics with Jason3 SLR+DORIS POD (180101 – 240225)

Test (2018.0 – 2024.2, xover to 2023.6)	DORIS RMS residuals (mm/s)	SLR RMS residuals (mm)	Crossover RMS residuals (cm)
Std2300 (slrf2020 + dpod2020)	0.4081	5.92	5.174
Std2300 + grgs_rl05	0.4080	6.02	5.164
Std2300 + costg_fsm	0.4157	5.95	5.165
Std2300 + costg_fsm_slrc20c30	0.4157	5.95	5.164
Std2300 + costg_fsm_slr2x2+c30	0.4157	5.90	5.164
Std2300. + costg_fsm_slr4x4	0.4157	6.02	5.172

Update on Sentinel-6A POD: Macromodel (1)



CNES 6-panel (only optical properties used)

				// Optical properties			// Infrared properties		
// Surf(m²)	// Normal in sat ref frame			// spec	// diff	// abs	// spec	// diff	// abs
3.600	-1.	0.	0.	0.4500	0.1200	0.4300	0.1800	0.0400	0.7800
3.370	1.	0.	0.	0.4590	0.5410	0.0000	0.1920	0.8080	0.0000
8.660	0.	-0.6157	-0.7880	0.0000	0.3370	0.6630	0.0000	0.6150	0.3850
8.660	0.	0.6157	-0.7880	0.0000	0.3370	0.6630	0.0000	0.6150	0.3850
2.990	0.	0.	-1.	0.4550	0.5110	0.0340	0.1140	0.6270	0.2590
15.350	0.	0.	1.	0.3420	0.6300	0.0280	0.0660	0.7240	0.2100

Conrad 12-panel

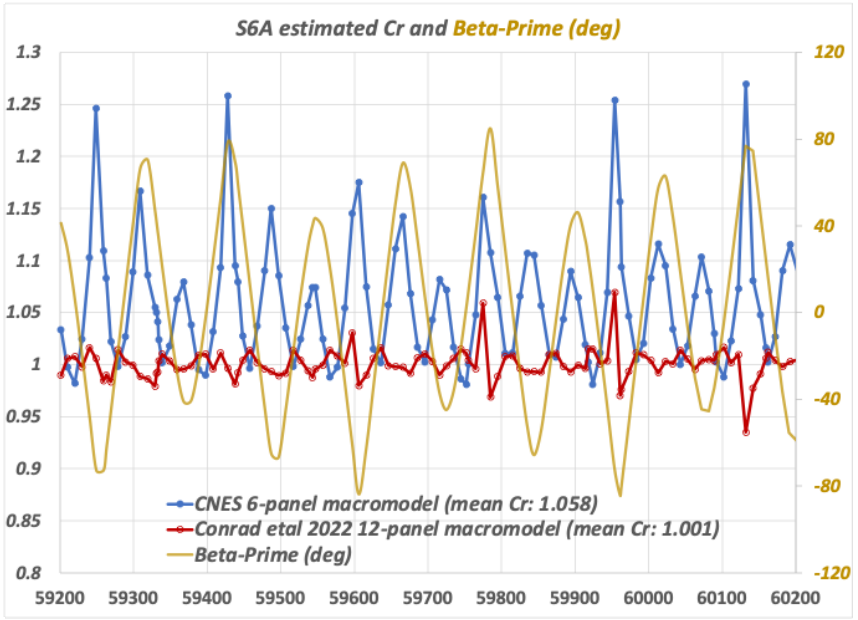
Surface	Surface normal [x,y,z]	Area (m^2)	Diffusivity	Specularity
Body +X	[1.000, 0.000, 0.000]	4.149	0.041	0.349
Body -X	[−1.000, 0.000, 0.000]	3.941	0.042	0.546
Body +Y	[0.000, 1.000, 0.000]	1.329	0.040	0.506
Body -Y	[0.000, −1.000, 0.000]	1.329	0.040	0.506
Body +Z	[0.000, 0.000, 1.000]	11.830	0.016	0.571
Body -Z	[0.000, 0.000, −1.000]	2.072	0.030	0.660
Left SP	[0.000, −0.616, −0.788]	8.65	0.316	0.139
Right SP	[0.000, 0.616, −0.788]	8.65	0.316	0.139
AMR-C (top)	[0.469, 0.000, −0.883]	0.92	0.080	0.000
AMR-C (bottom)	[0.000, 0.000, 1.000]	0.8123	0.563	0.188
Left SP (bottom)	[0.000, −0.616, 0.788]	3.760	0.164	0.013
Right SP (bottom)	[0.000, 0.616, 0.788]	3.760	0.164	0.013

Conrad, Alex et al. (2023), *J. Geodesy*, Table 2, https://doi.org/10.1007/s00190-023-01718-0.

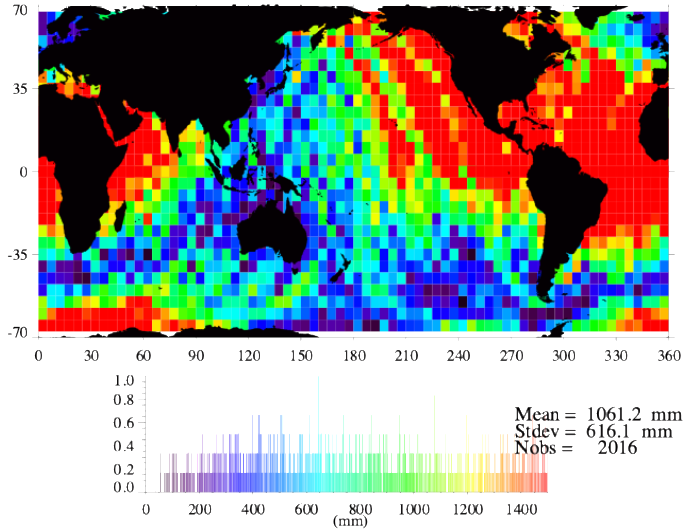
Update on Sentinel-6A POD: Macromodel (2)

(1) Sentinel-6A is uniquely sensitive to radiation-pressure perturbations (large nadir surface areas, and elements that cause self-shadowing).
(2) Fully Dynamic orbits for Sentinel-6A will be highly sensitive to SRP-model error, especially at 59 days, especially if using the six-panel model from the CNES documentation. [*If IR properties used, maybe effect would not be so severe*].
→ **Recommend adoption of Conrad et al. (2023) macromodel for IDS AC.**

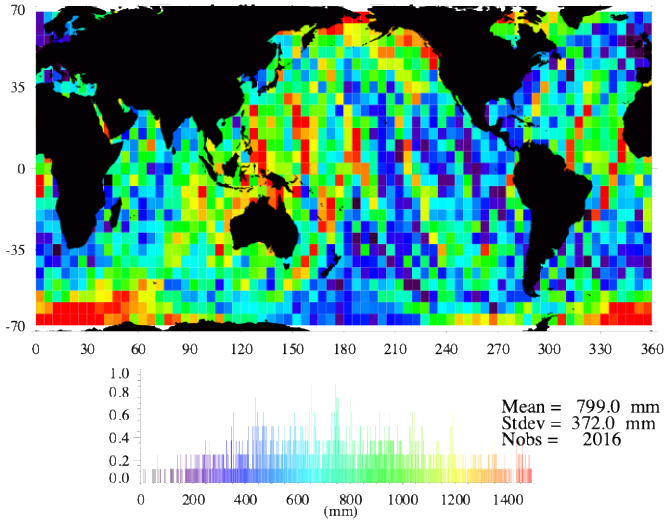
Cr variations dramatically reduced



***A priori* 6-panel SRP model**



***Conrad* 12-panel SRP model**



Amplitude of Orbit differences w.r.t. JPL red-dynamic orbits at 59-days are much reduced.

Conclusions

- We have tested replacement of the DORIS/V2 processing with the DORIS/RINEX processing. Unlike an earlier test (for ITRF2020 preparation), now on 3 of 4 satellites, the derived scales are indistinguishable.
- We have re-processed and retuned the Cr's for SPOT-4 & SPOT-5 satellites. Our goal is to produce a complete series (1993 – 2021) using DORIS/RINEX data only when available, DPOD2020, the grgs_rl05 field, and MSIS2, hopefully by the end of 2024.
- The tests on the SPOT-5 orbits with different contemporary density models show little change in performance. We do confirm that the new models (DTM2020, MSIS2) have a better response than the legacy model we had used previously (MSIS86) over high solar activity periods. More testing necessary.

Recommendations

- The grgs_rl05 field (derived from data from 1993-2022) needs to be updated for the current POD processing (2023-2024). We recommend this model be updated if possible, or that AC's consider adopting COSTG-FSM model for the operational processing possibly augmented with replacement of SLR-derived low degree terms for 2022 and later.
- For Sentinel-6A, IDS AC's should consider the new Conrad et al. (2023) macromodel, especially if they rely more on dynamic orbit determination and do not use the IR macromodel coefficients to reduce the magnitude of the 59-day SRP-related error signals in the S6A orbits.
- More work is still necessary to improve S6A radiation-pressure model.