AWG2024: Status of DORIS Processing at GSFC

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Virtual IDS Analysis Working Group Meeting

Cyberspace

June 4, 2024

GSC Accomplishments since the IDSAWG 2023 (*Saint Mandé, France*)

1.	Delivery of two SINEX series for ITRF2020 extension: wd55 (based on grgs_rl05 gravity model), and wd56 (including Sentinel-6A).
2.	Implementation the new DPOD2020 a priori & SLRF2020. (**dpod2020_015**)
3.	Test DTM2020 & MSIS2 atmosphere models.
4.	Test adding of nutation corrections to operational processing.
5.	Process RINEX data for Cryosat-2, Saral (2016-2024) using new standards.
6.	Operational change: Switch processing to Linux cluster after RAID disk failure on older server.

Other recent changes:

(1) Use Conrad et al. (2023) Macromodel for Sentinel-6A

(2) Change to cd/hr (with time-correlated constraint) for 800 km satellites for 2021-2024. (Many more shorter arcs).

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.
gscwd56	gscwd55 + dpod2020 as a priori; Jason-3 downweighted w.r.t. Sentinel-6A.	Delivered 2021-2023 on 2024-0306
gscwd57	gscwd56 + use MSIS2 atmosphere density model.	Internal series for now
gscwd58	gscwd57 + apply nutation corrections.	Internal series for now

Candidate new atmosphere density models for GEODYN

MSIS2.0

Earth and Space Science

RESEARCH ARTICLE
10.1029/2020EA001321

Key Points:

- A major, reformulated upgrade to NRLMSISE-00 is presented using extensive new data sets from the ground to ~100 km altitude
- Vertical structure of the atmosphere is now self-consistently coupled; O density now extends down to 50 km
- New model is warmer in upper troposphere, cooler in stratosphere and mesosphere; thermospheric N_2 and O densities are lower

Supporting Information:

- Supporting Information S1
- Data Set 1
- Data Set 2
- Data Set 3
- Data Set 4
- Data Set 5
- Data Set 6
- Data Set 7
- Data Set 8

Correspondence to:

NRLMSIS 2.0: A Whole-Atmosphere Empirical Model of Temperature and Neutral Species Densities

J. T. Emmert[1], D. P. Drob[1], J. M. Picone[2], D. E. Siskind[1], M. Jones Jr.[1], M. G. Mlynczak[3], P. F. Bernath[4,5], X. Chu[6,7], E. Doornbos[8], B. Funke[9], L. P. Goncharenko[10], M. E. Hervig[11], M. J. Schwartz[12], P. E. Sheese[13], F. Vargas[14], B. P. Williams[15], and T. Yuan[16]

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Abstract NRLMSIS® 2.0 is an empirical atmospheric model that extends from the ground to the exobase and describes the average observed behavior of temperature, eight species densities, and mass density via a parametric analytic formulation. The model inputs are location, day of year, time of

DTM2020

J. Space Weather Space Clim. 2021, **11**, 47

https://doi.org/10.1051/swsc/2021032

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www.swsc-journal.org

RESEARCH ARTICLE — OPEN ACCESS

The operational and research DTM-2020 thermosphere models

Sean Bruinsma* and Claude Boniface

OMP/GET-CNES, Space Geodesy Office, 14 avenue E. Belin, 31401 Toulouse cedex 4, France

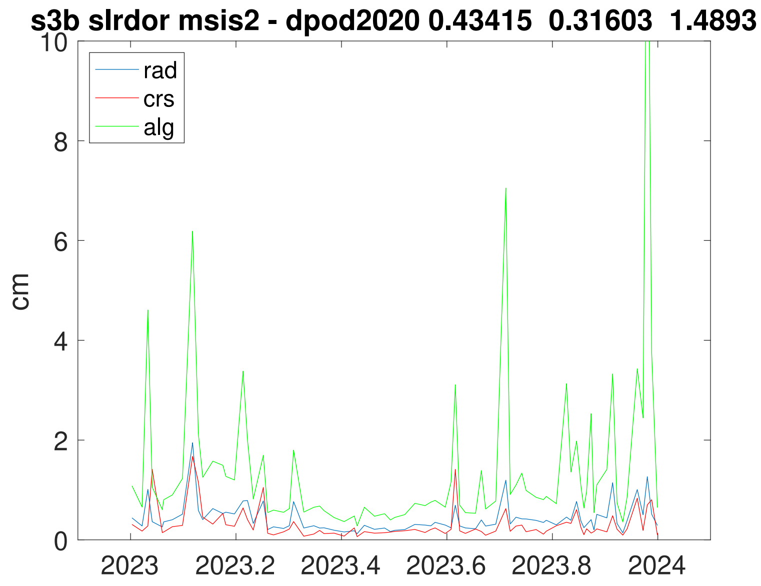
Received 11 June 2021 / Accepted 23 August 2021

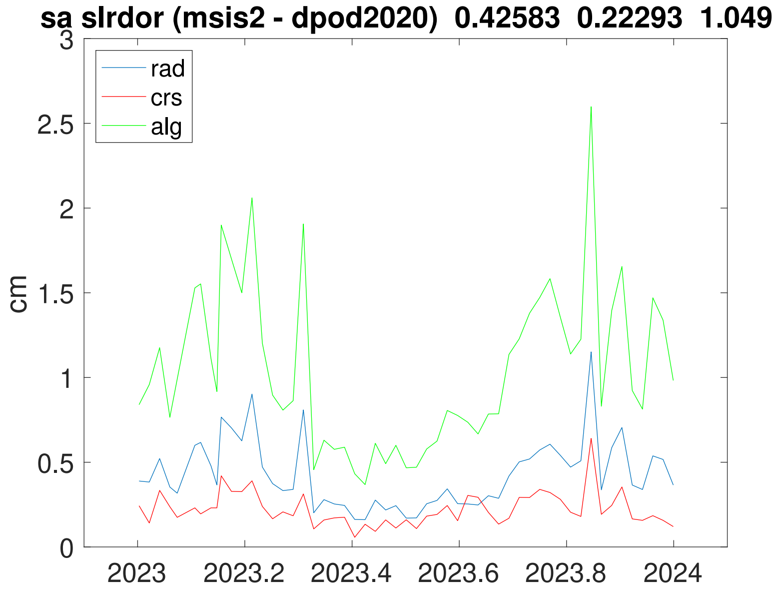
Abstract – *Aims*: The semi-empirical Drag Temperature Models (DTM) predict the Earth's thermosphere's temperature, density, and composition, especially for orbit computation purposes. Two new models were developed in the framework of the H2020 Space Weather Atmosphere Models and Indices (SWAMI) project. The operational model is driven by the trusted and established F10.7 and *Kp* indices for solar and geomagnetic activity. The so-called research model is more accurate, but it uses the indices F30

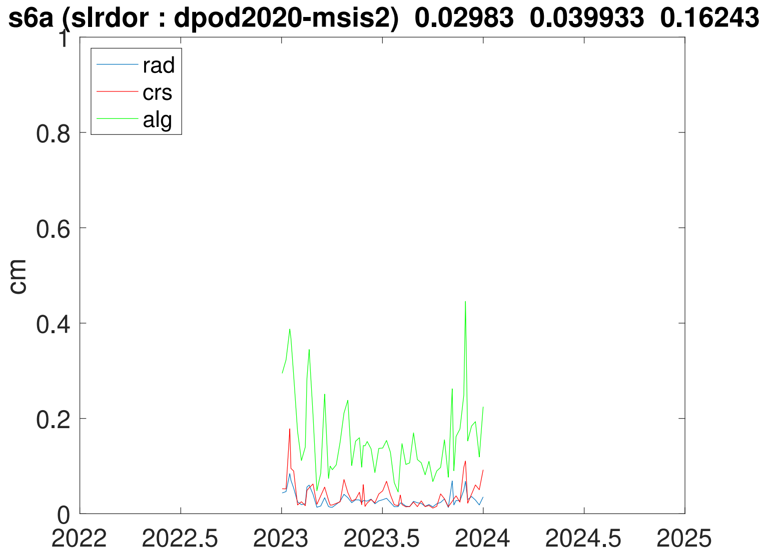
New semi-empirical Density models.

1. DTM2020: (*Drag Temperature Model 2020*). Model backbone based on GOCE, CHAMP, and Swarm A densities, processed by TU Delft, and Stella processed at CNES/GRGS.
2. MSIS 2.0 (Mass Spectrometer and Incoherent Scatter): (Emmert et a., 2021). "MSIS2.0 assimilates extensive new measurements of temperature in the mesosphere, stratosphere & troposphere and atomic oxygen and atomic hydrogen measurements in the mesosphere …" Successor to previous MSIS models. Bulk of measurements upon which model based are < 110 km, + orbit data at 400-575 km (Table 1, Emmert et al., 2021)

Evaluation of MSIS2: Orbit differences vs. prior POD model (MSIS86) (I) (*for arcs in 2023*)





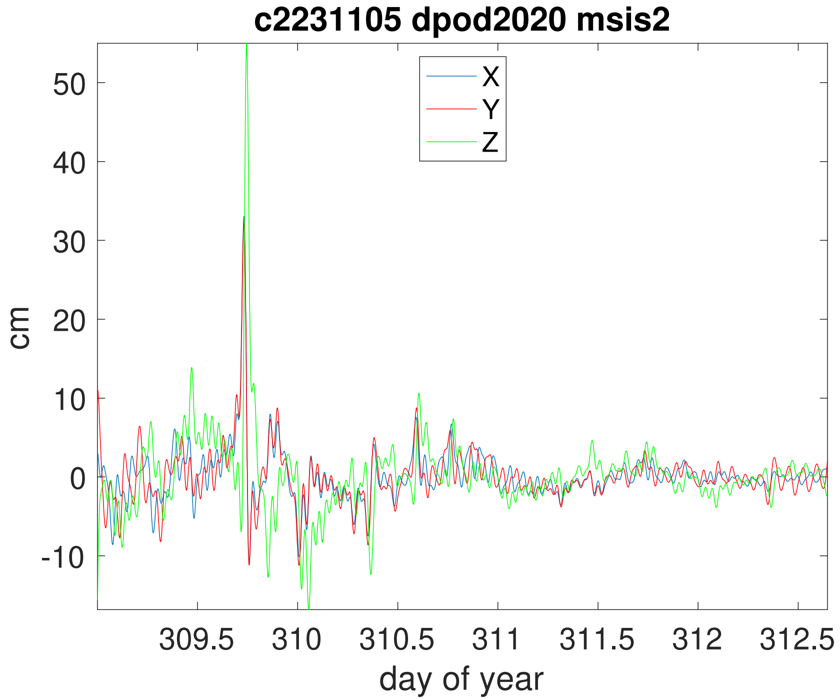


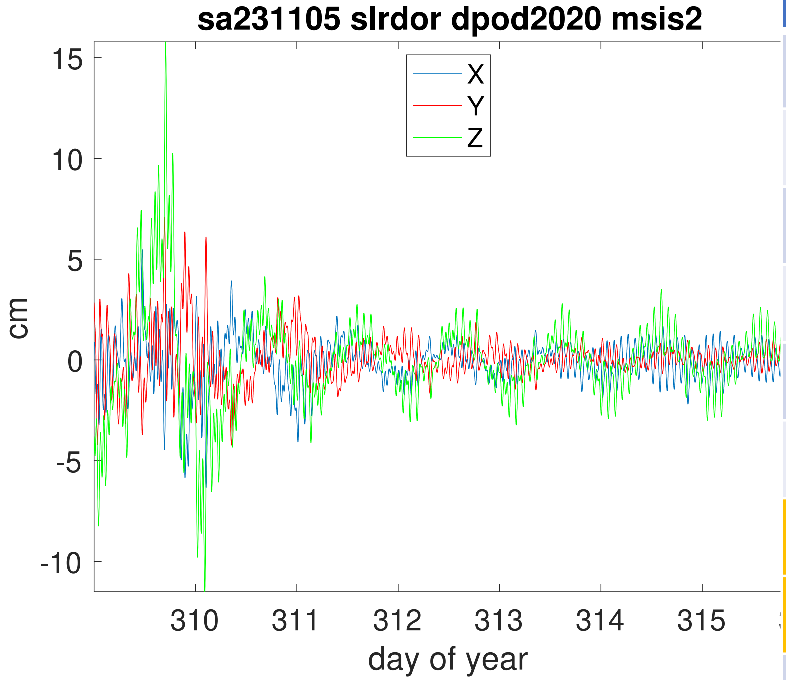
Sentinel-3B:
Avg RMS:
Radial: 0.43 cm;
Cross-track: 0.31 cm;
Along-track: 1.49 cm.

Saral:
Avg RMS:
Radial: 0.43 cm;
Cross-track: 0.22 cm;
Along-track: 1.05 cm.

Sentinel-6A:
Avg RMS:
Radial: 0.30 mm;
Cross-track: 0.40 mm;
Along-track: 1.62 mm.

Evaluation of MSIS2: Orbit differences vs. prior POD model (MSIS86) (II) (*for 231105 arc*)





YYMMDD, DOY	Magnetic Flux Kp	Solar Flux, F10.7
231030	2,66	138.8
231031	2.00	147.0
231101, 305	2.20	158.3
231102, 306	1.66	157.3
231103, 397	0.33	155.4
231104, 308	2.66	154.4
231105, 309	5.49	15**4.5**
231106, 310	4.53	145.4
231107, 311	3.33	144.5
231108, 312	3.00	145.6
231109, 313	2.45	138.5

Evidence of Effect of increase in magnetic flux(Kp) seen in orbit differences?

<u>Cryosat2 RMS of fit, 231105 arc:</u>

1.266 cm (dpod2020) vs 1.249 cm (MSIS2).

<u>Saral RMS of fit, 231105 arc:</u>

0.863 cm (dpod2020) vs. 0.706 cm (MSIS2)

OPR Acceleration amplitudes – Lower altitude DORIS satellites (1)

Cryosat-2 (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1134	2.293	2.157
wd56 dpod2020	1126	2.284	2.082
wd57 MSIS2	1126	2.524	2.090
wd58 nutate	1126	2.524	2.090

Saral (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1085	2.100	0.966
wd56 dpod2020	1085	2.103	0.898
wd57 MSIS2	1085	2.244	0.890
wd58 nutate	1085	2.244	0.893

Sentinel-3A (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1148	0.543	1.328
wd56 dpod2020	1145	0.540	1.274
wd57 MSIS2	1145	1.227	1.262
wd58 nutate	1145	1.227	1.262

Sentinel-3B (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1148	0.939	1.420
wd56 dpod2020	1145	0.944	1.357
wd57 MSIS2	1145	1.681	1.345
wd58 nutate	1145	1.681	1.344

Impact of MSIS2 on OPR’s (along-track) - (I)

Cryosat-2 (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1134	2.293	2.157
wd56 dpod2020	1126	2.284	2.082
wd57 MSIS2	1126	2.524	2.090
wd58 nutate	1126	2.524	2.090

Saral (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1085	2.100	0.966
wd56 dpod2020	1085	2.103	0.898
wd57 MSIS2	1085	2.244	0.890
wd58 nutate	1085	2.244	0.893

Sentinel-3A (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1148	0.543	1.328
wd56 dpod2020	1145	0.540	1.274
wd57 MSIS2	1145	1.227	1.262
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Sentinel-3B (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1148	0.939	1.420
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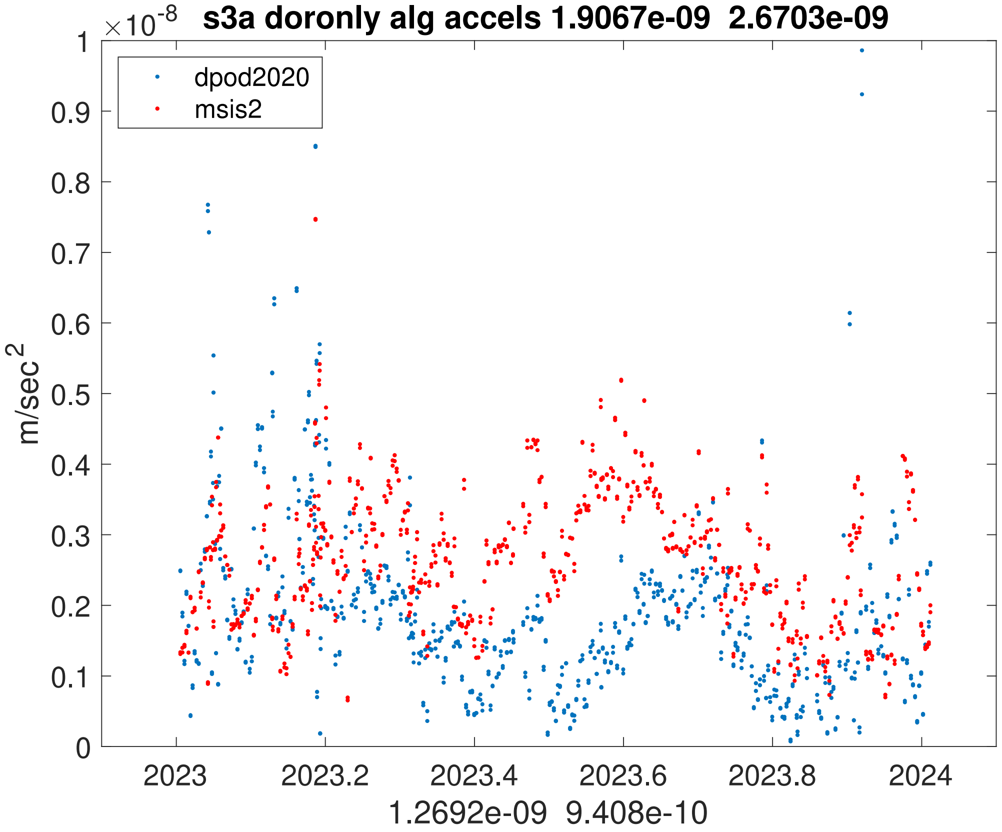
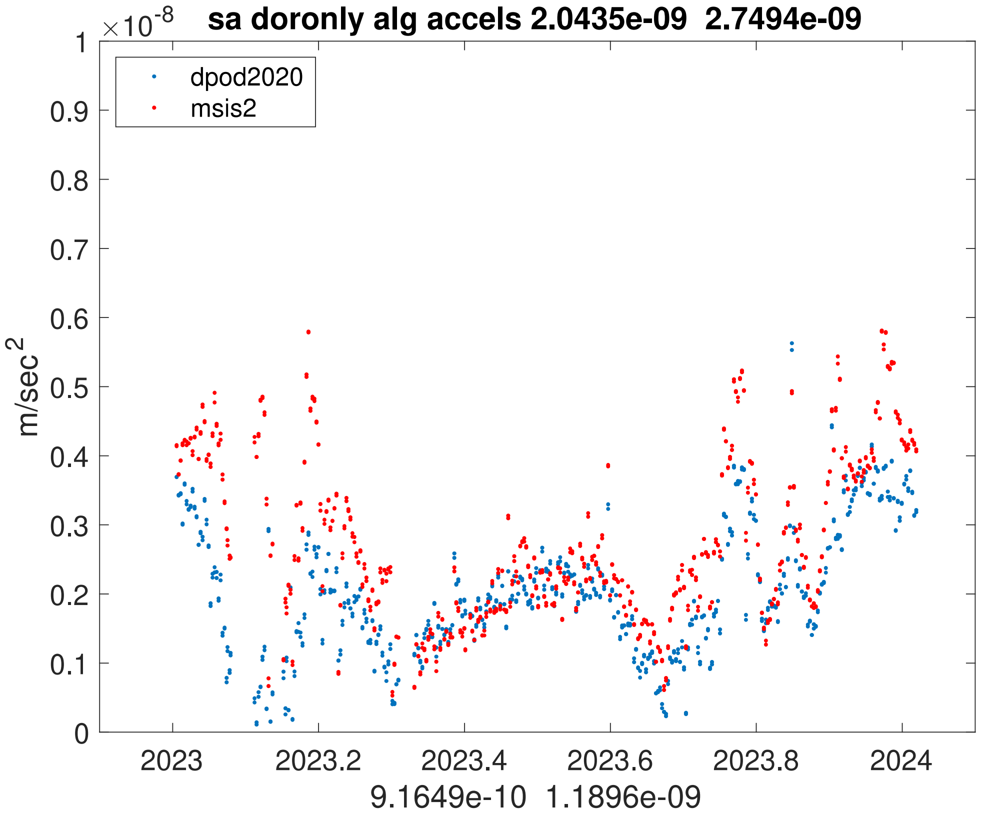
wd57 MSIS2	1145	1.681	1.345
wd58 nutate	1145	1.681	1.344

Impact of MSIS2 on OPR's (along-track) - (II)

Sentinel-3A: Along-track OPR amplitudes: *a priori vs. MSIS2*



Saral: Along-track OPR amplitudes: *a priori vs. MSIS2*



OPR Acceleration amplitudes – S3A vs. S3B

Sentinel-3A (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1148	0.543	1.328
wd56 dpod2020	1145	0.540	1.274
wd57 MSIS2	1145	1.227	1.262
wd58 nutate	1145	1.227	1.262

Sentinel-3B (2021—2023)

Series	Nacc	Along-track (nm/s^2)	Cross-track (nm/s^2)
wd55 dpod2014	1148	0.939	1.420
wd56 dpod2020	1145	0.944	1.357
wd57 MSIS2	1145	1.681	1.345
wd58 nutate	1145	1.681	1.344

Test of Nutation “Corrections” (I)

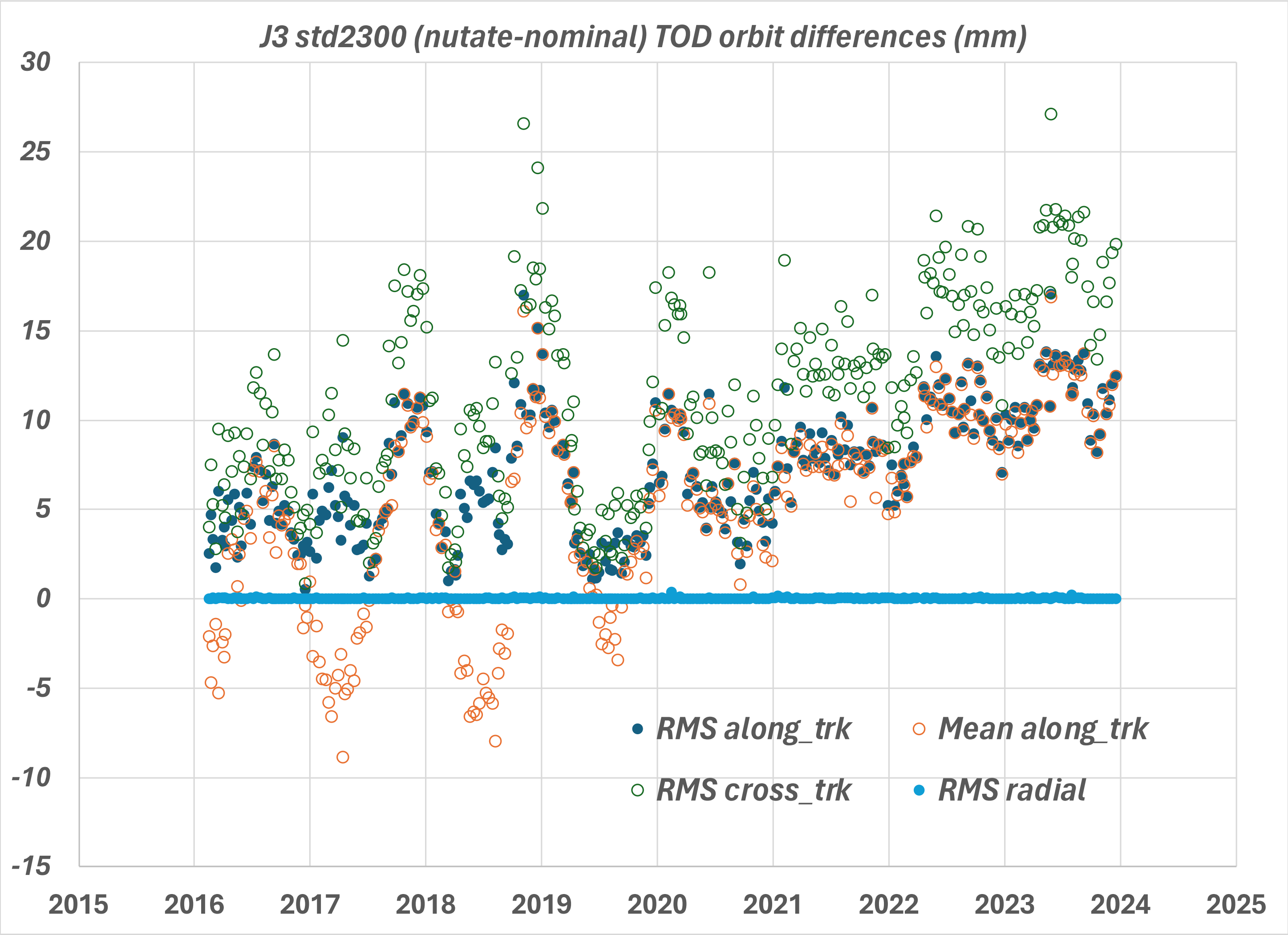
1. Nutation corrections to the IAU2000 nutation model are supplied by the IERS, and part of the data distributed by the IERS. In the space geodesy era, they would be determined by VLBI. Parameters are “dX” and ”dY”.

Time				Pole									UT					Nutation								
MJD	Year	Month	Day	T	x	sigma_x	y	sigma_y	x_rate	sigma_x_rate	y_rate	sigma_y_rate	T	UT1-UTC	sigma_UT1-UTC	LOD	sigma_LOD	T	dPsi	sigma_dPsi	dEpsilon	sigma_dEpsilon	dX	sigma_dX	dY	sigma_dY
-	-	-	-	-	[arcsec]	[arcsec]	[arcsec]	[arcsec]	[]	[]	[]	[]	-	[sec]	[sec]	[sec]	[sec]	-	[]	[]	[]	[]	[arcsec]	[arcsec]	[arcsec]	[arcsec]
T=Type: r=rapid - f=final - p=predictions																										
37665	1962	01	01	-	-0.012700	0.030000	0.213000	0.030000	---	---	---	---	-	0.0326338	0.0020000	0.0017230	0.0014000	-	---	---	---	---	0.000000	0.004774	0.000000	0.002000
37666	1962	01	02	-	-0.015900	0.030000	0.214100	0.030000	---	---	---	---	-	0.0320547	0.0020000	0.0016690	0.0014000	-	---	---	---	---	0.000000	0.004774	0.000000	0.002000
37667	1962	01	03	-	-0.019000	0.030000	0.215200	0.030000	---	---	---	---	-	0.0315526	0.0020000	0.0015820	0.0014000	-	---	---	---	---	0.000000	0.004774	0.000000	0.002000
37668	1962	01	04	-	-0.021999	0.030000	0.216301	0.030000	---	---	---	---	-	0.0311435	0.0020000	0.0014960	0.0014000	-	---	---	---	---	0.000000	0.004774	0.000000	0.002000

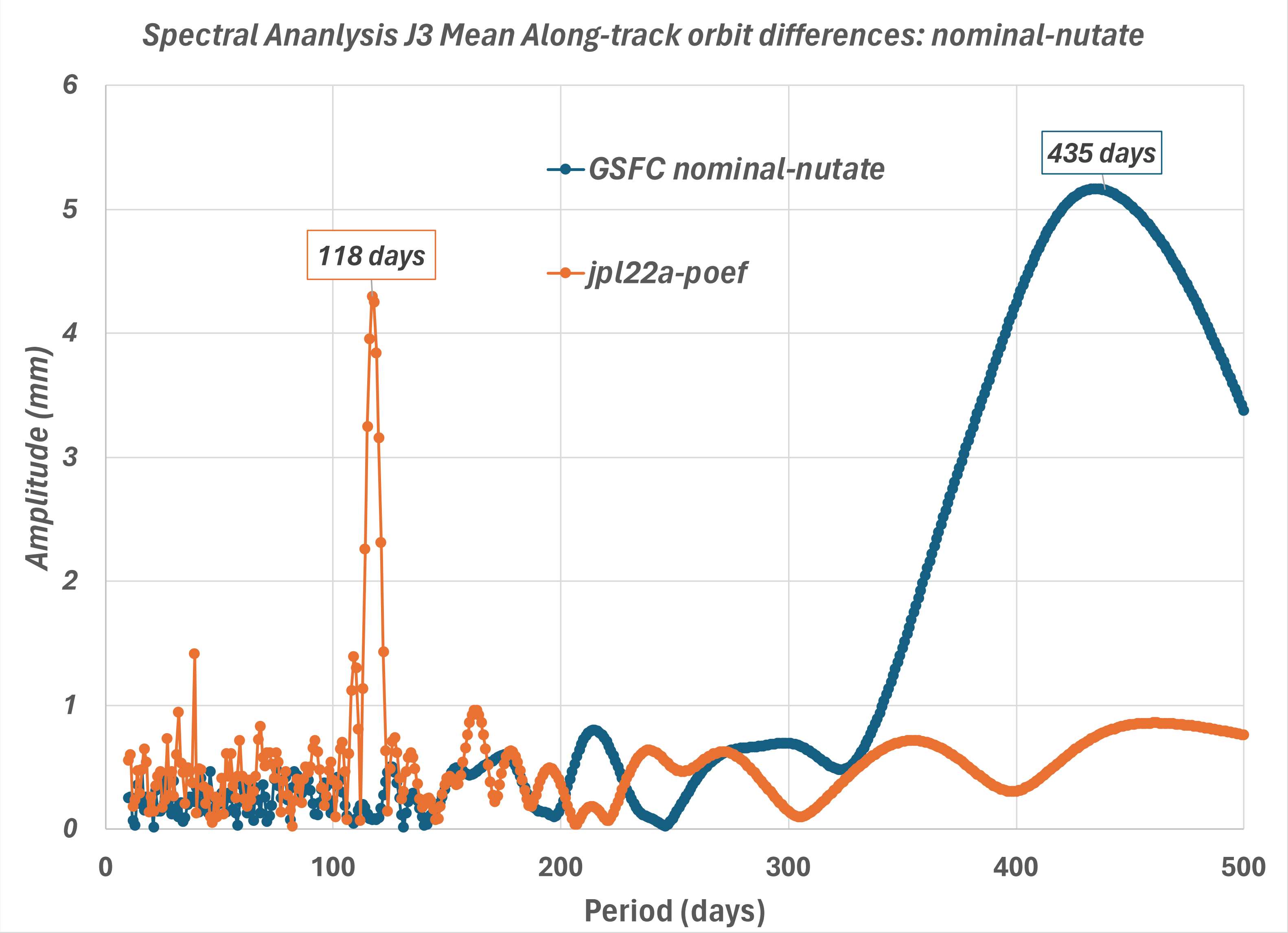
https://datacenter.iers.org/data/html/eopc04_14_IAU2000.62-now.html

2. Nutation corrections to the IAU2000 nutation model are supplied by the IERS, and part of the data distributed by the IERS. In the space geodesy era, they would be determined by VLBI. Parameters are “dX” and ”dY”.
3. Amplitude is up to ~255 μas with the principal effect at the Chandler wobble period (~435 days).
4. Hypothesis: Not including these corrections mean mapping from inertial coordinates to body-fixed coordinates will be incorrect (incorrect positioning of spacecraft and stations) but may be compensated by EOP estatimation – and the error would enter the bias and/or periodic term in differences with IERS C04.

Test of Nutation “Corrections” (II): Jason-3 orbit differences



Test of Nutation “Corrections” (III): Jason-3 orbit differences: spectral analysis



Test of Nutation "Corrections" (IV): Average Jason-3 orbit differences (mm): (cycles 1-226; 160317–220408)

Orbits differenced	Radial	Cross-track	Along-tack	Total 3-D
nominal-nutate	0.03	9.74	6.12	11.51
jpl22a-nominal	5.41	17.85	22.97	29.79
jpl22a-nutate	5.41	19.46	25.48	32.78
poef-nominal	5.89	18.98	24.02	31.52
poef-nutate	5.89	20.85	26.40	34.52
jpl22a-poef	3.97	8.93	10.17	14.38

RMS of fit by satellite – Lower altitude DORIS satellites (1)

Cryosat-2 (2021—2023)

Series	Narcs	DORIS nobs	DORIS WRMS (mm/s)	SLR nobs	SLR WRMS (cm)
wd55 dpod2014	218	53622	0.2669	776	0.763
wd56 dpod2020	218	53296	0.2666	777	0.714
wd57 MSIS2	218	53293	0.2666	777	0.715
wd58 nutate	218	53293	0.2666	777	0.715

Sentinel-3A (2021—2023)

Series	Narcs	DORIS nobs	DORIS WRMS (mm/s)	SLR nobs	SLR WRMS (cm)
wd55 dpod2014	203	69745	0.2619	785	0.720
wd56 dpod2020	218	69875	0.2614	786	0.695
wd57 MSIS2	218	69875	0.2614	786	0.698
wd58 nutate	218	69875	0.2614	786	0.698

Saral (2021—2023)

Series	Narcs	DORIS nobs	DORIS WRMS (mm/s)	SLR nobs	SLR WRMS (cm)
wd55 dpod2014	161	78714	0.2522	853	0.719
wd56 dpod2020	161	79191	0.2513	866	0.692
wd57 MSIS2	161	79187	0.2512	866	0.700
wd58 nutate	161	79187	0.2512	866	0.698

DORIS RMS of fit is modulated by elevation-dependent weighting, so we report the WRMS.

RMS of fit by satellite – Higher altitude DORIS satellites (2)

Jason-3 (2021—2023)

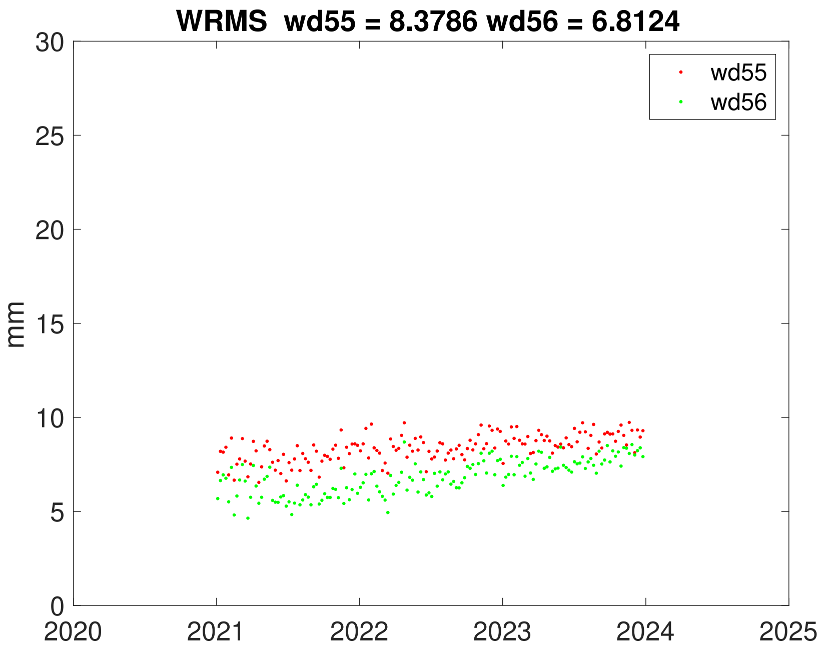
Series	Narcs	DORIS nobs	DORIS WRMS (mm/s)	SLR nobs	SLR WRMS (cm)	Avg. Cr	Cr, Std Dev.
wd55 dpod2014	180	129093	**0.2533**	2052	**0.716**	0.9804	0.00923
wd56 dpod2020	180	127630	**0.2526**	2103	**0.716**	0.9804	0.00921
wd57 MSIS2	180	127628	**0.2526**	2103	**0.719**	0.9816	0.00888
wd58 nutate	180	127628	**0.2526**	2103	**0.719**	0.9816	0.00888

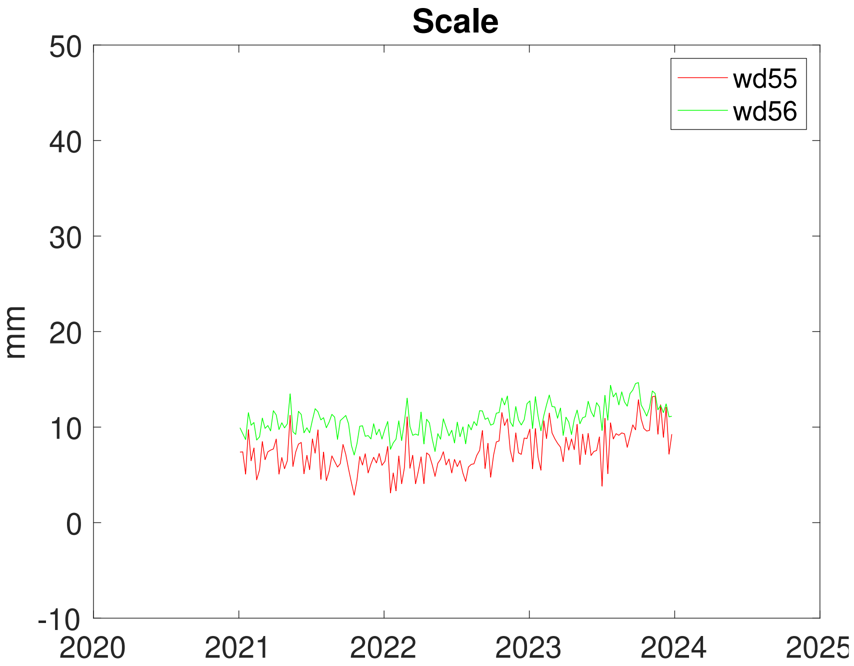
Sentinel-6A (2021—2023)

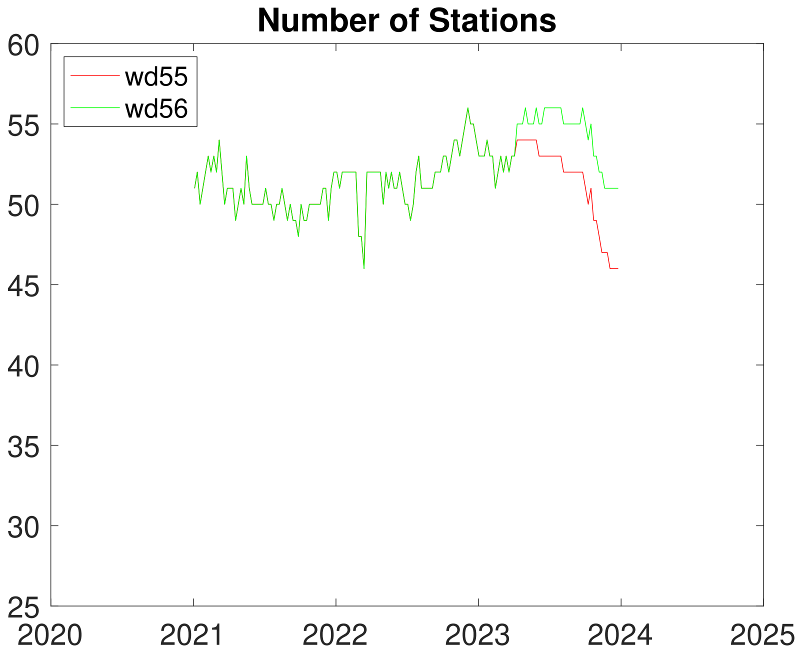
Series	Narcs	DORIS nobs	DORIS WRMS (mm/s)	SLR nobs	SLR WRMS (cm)	Avg. Cr	Cr, Std Dev.
wd55 dpod2014	180	135581	**0.2502**	1819	**0.718**	1.0004	0.0126
wd56 dpod2020	180	124457	**0.2490**	1897	0.676	1.0003	0.0134
wd57 MSIS2	180	124457	**0.2490**	1897	**0.674**	1.0015	0.0128
wd58 nutate	180	124457	**0.2490**	1897	**0.674**	1.0014	0.0127

DORIS RMS of fit is modulated by elevation-dependent weighting, so we report the WRMS.

Results with wd56
(*dpod2020 as a priori*)







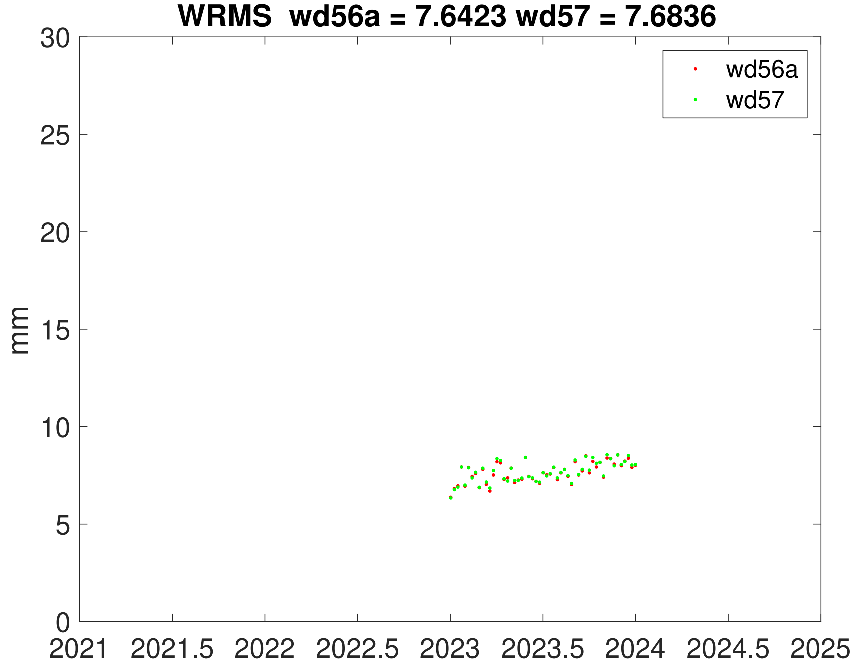
WRMS: dpod2014 (wd55) vs.
dpod2020 (wd56)

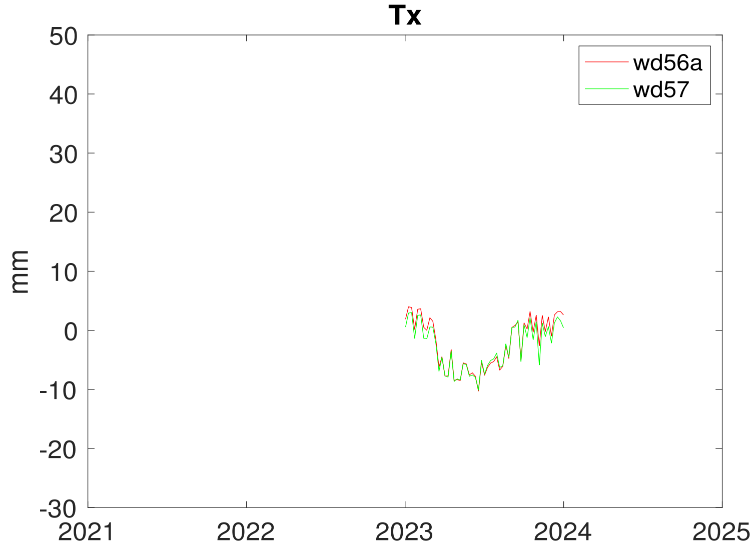
Scale Fit wd55 (2021-23):
$7.48 \pm 2.11 +$
$(1.196 \pm 0.028)(t-t_0)$

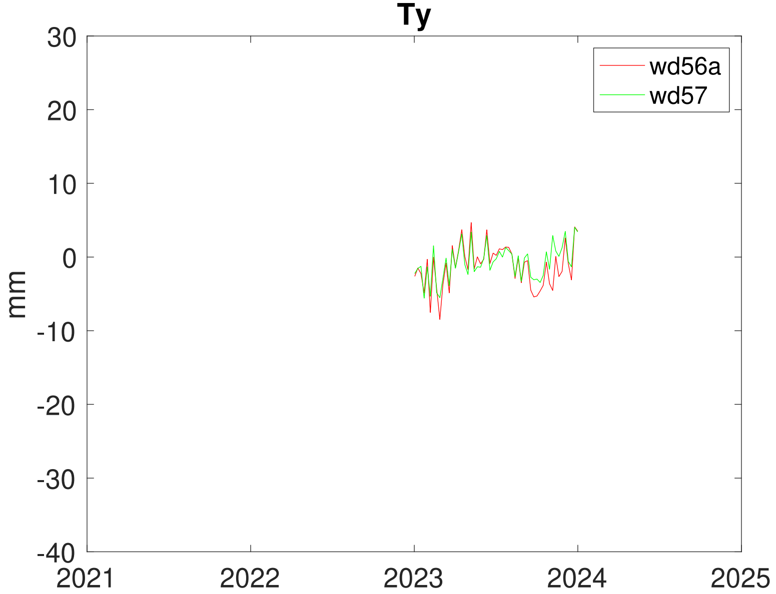
Scale Fit wd56 (2021-23):
$10.78 \pm 1.56 +$
$(0.962 \pm 0.015)(t-t_0)$

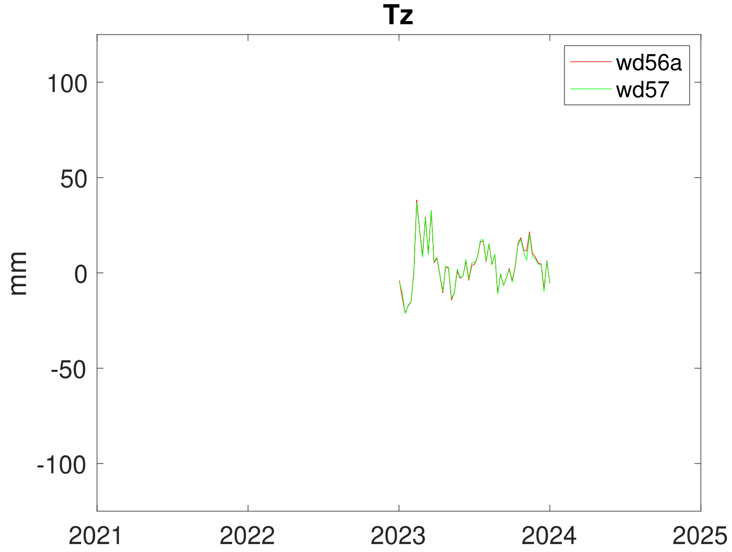
Dpod2020 allows to bring in more DORIS stations starting in 2023.

Results with wd57
(*Test with MSIS2, 2023-only*)









WRMS:
dpod2020 (wd56): 7.64 mm
vs.
+msis2 (wd57): 7.68 mm

MSIS2 has a small or negligible impact on the Helmert parameters:
- Maybe Ty has less scatter.

Summary of POD Results: RMS of fit for gscwd58

*(*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 (V2)	210103	240325	235	772	53,174	0.728	0.3806
Cryosat-2 (Rinex)	210103	240325	235	773	54,770	0.735	0.3850
Cryosat-2 (Rinex)	160103	201227	313	1036	66,422	0.697	0.3756
Jason-3	160223	240412	473	2532	133,144	0.683	0.3604
Saral (V2)	210103	240331	174	866	79,281	0.700	0.3590
Saral (Rinex)	210103	240331	174	869	81,270	0.716	0.3607
Saral (Rinex)	160103	201227	266	1150	85,609	0.733	0.3571
Sentinel-3A	160302	240403	523	865	75,042	0.635	0.3709
Sentinel-3B	180606	240407	391	793	71,378	0.659	0.3837
Sentinel-6A	210103	240407	197	1914	123,253	0.687	0.3556

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

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.
gscwd56	gscwd55 + dpod2020 as a priori; Jason-3 downweighted w.r.t. Sentinel-6A.	Delivered 2021-2023 on 2024-0306
gscwd57	gscwd56 + use MSIS2 atmosphere density model.	Internal series for now
gscwd58	gscwd57 + apply nutation corrections.	Internal series for now

Summary

- **For the GSC DORIS contribution to the ITRF2020-extension, we have submitted two contributions, wd54 and wd55. We have also submitted wd56 (based on dpod2020) to the IDS Data Centers.**
- **Our contribution for the series used in the IDS combination for the ITRF2020-extension included:**

(a) downweighting of SAA stations in POD, and removal of 5 SAA stations in the HY-2A contribution to the combination.

(b) consistent use of the grgs-rl05 gravity model.

(c.) Inclusion of Sentinel-6a (2021-2023) using the Conrad et al. (2023) micromodel.

- We are evaluating other improvements: inclusion of the MSIS2 atmosphere density model, and correct application of the nutation corrections.
- The next priority will be inclusion of newer satellites, and integration of their attitude model into GEODYN.
- Once computer resources become available, we will reprocess the older data with DPOD2020 and the new standards.