GSC Analysis Center Update

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Summary of Modelling updates for ITRF2020 (1)

	ITRF2014	ITRF2020
Gravity Modeling	GOCO2s + SLR+DORIS solutions to 5x5	New background gravity model: GOCO05s: (a) annual and secular terms for post 2003. (b) adapted model for pre 2003.0 (no secular terms).
AOD product	ECMWF-derived 6hr (Univ. of Strasbourg, JP Boy)	RL06 3hrly atmosphere-ocean dealiasing product (provided by GFZ for GRACE FO)
Troposphere	Saastamoinen. GMF. GPT for a priori met. data	VMF1
Atmosphere density	MSIS86	no change
TSI	1367.2 W/m^2	1360.8 W/m^2 (Koop & Lean, 2011)
Nonconservative Force Models	**Updated by satellite. See next slides.**	
Satellite Attitude	Internal attitude law; • Body quaternions for Jason-1 & Jason-2 & some TOPEX arcs.	Internal attitude laws; • Body & solar array quaternions for Jason 1,2,3 satellites. • Body quaternations for some TOPEX arcs.

Summary of Modelling updates for ITRF2020 (2)

	ITRF2014	ITRF2020
Ground Antenna Phase Law	Applied.	Updated for Alcatel antennae (2017).
HF EOP	IERS 2010	IERS 2017
Pole model	IERS 2010	Linear mean pole (IERS, 2017)
Hy2A offset	--	Updated per IDS AWG recommendations.
SPOT-5 radial offset	Not adjusted.	Adjusted per week (reduced from weekly NEQ) to resolve SPOT-5 induced perturbations in DORIS scale.
Geocenter	--	~~Annual model. (Ries, 2013)~~
Station coordinates	DPOD2008	DPOD2014 (latest version Nov. 2020).

Summary of Processing updates for ITRF2020

	ITRF2014	ITRF2020
GEODYN Versions	1410. (2014 version)	1906 & 2002 (2019 & 2020 versions)
pass-by-pass bias estimation	shortcut. akin to arc reduction by iteration.	Explicitly part of normal matrix for batch solution (1)
Editing of Data	--	All data completely re-editted.
Data arc length, 1999 – 2003 for 800 km satellites	Default of 7 days, except for maneuvers or data gaps	Default of 3.5 days, except of maneuvers or data gaps; Arc lengths as short as 1-2 days in very high solar flux periods.
Elevation cutoff	10°	7°
Elevation-dep. weighting	none.	Applied for all elevation angles.
A priori Data sigma (GEODYN)	0.2 mm/s	0.125 mm/s ($\geq$ 2003.0).
Data Editing	3.5 – 4.0 x RMS	Use Huber weighting; Edit data whose max elevation is $\leq 13°$.

(1) The specification of biases is now explicit (MBIAS), rather than "implicit". In the previous "implicit" processing (EBIAS) it was possible that data at the start & end of passes were deleted because the implicit definition of the time span of the biases did not always include all the data. In addition, badly determined troposphere and range-rate parameters (*e.g. < 5 observations*) were included when they should have been deleted.
This would have been invisible to us in most instances, but probably means that a small percentage of data was systematically deleted for every satellite, or conversely in the second case, data were included that weakened the satellite solution.

Summary of Recent SINEX Submissions for ITRF2020

Series	Description	Comment
gscwd35	First test series produced for ITRF2020. Included many of the improvements included in the + first slides.	DORISREPORT 4992 (23-Mar-2020); DORISREPORT 5069 (30-Jun-2020)
gscwd36	gscwd35 + apply HFEOP model.	
gscwd37	gscwd35 + adjust radial offset on SPOT-5	IDSCC Email April 15, 2020.
gscwd38	gscwd35 + adjust radial offset on all SPOT satellites.	internal
gscwd39	gscwd35 + apply 3.5 day arcs for SPOT-2,-4,-5, & Envisat (instead of 7-day arcs), 1999-2003.	internal
gscwd40	gscwd35 + apply radial offset on SPOT-5, HFEOP, 3.5 day arcs (cf. gscwd39) + elevation-dependent weighting on all satellites.	DORISREPORT 5096 (04-Aug-2020)
gscwd41	gscwd40 + use DORIS/RINEX data for Jason-2 with Jason-2-T2L2-derived USO correction	IDSCC Email Dec. 8, 2020.
gscwd48	gscwd40 + (1)Fix problem with Tz & Scale in 2012 by eliminating SYPB at observation level (April 4 – July 1, 2012, Bad data period not previously accounted for); (2) Fix data editing on SPOT-4, and apply modified Cr = 0.988.	Submitted April 2, 2021.

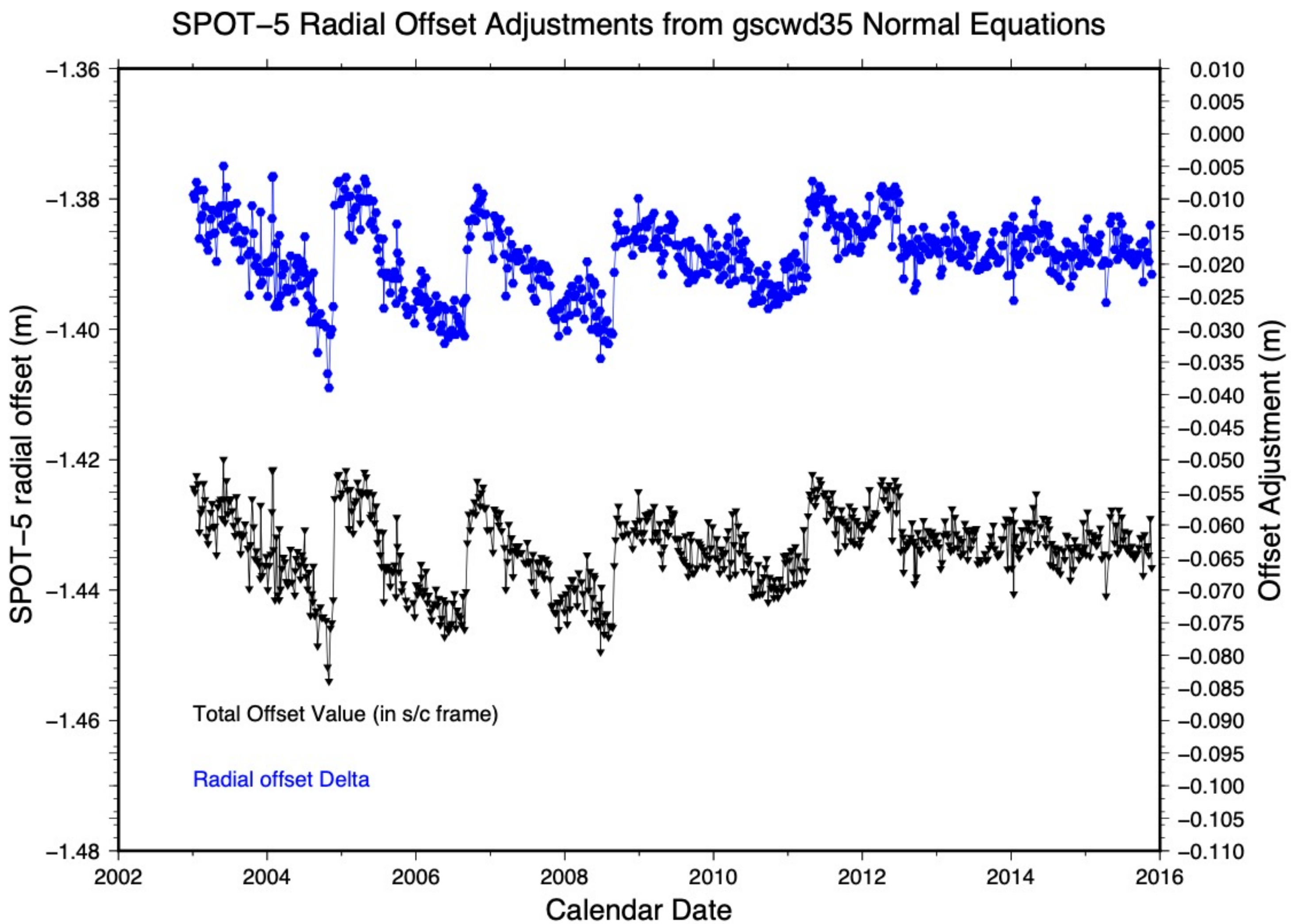
Summary of Recent SINEX Submissions for ITRF2020

Series	Description	Comment
gscwd50	with adj radial z-offsets for Jason-1, adj radial z offsets for SPOT-2 after 2007/11/13, no SPOT-4 after 2013-01-11, start Envisat on 2004/11/07 with Jason-1	Implemented at request of IDSCC
gscwd51	gscwd50 + Add Sentinel-3A + Use NewCr's for SPOT-2 & SPOT-5, + a priori Macromodel for Jason-3 (per NPZ)	Final Deliveries to IDS Data Centers on Sept 28, 2021

Post ITRF2020

Series	Description	Comment
gscwd52	gscwd51 + Sentinel-3B starting 180610	Deliveries Started 2021-10-18 to NASA CDDIS. Current operational series.

SPOT-5 Radial (Z) Offset Adjustments



We adjust the SPOT-5 radial or Z offset, because of the perturbations on the DORIS (combined) scale.

SPOT-2 New Cr Impact

Macromodel derived from Gitton & Kneib (1990)

A priori Cr = 1.00 (gscwd50 and earlier)
New Cr = 0.98544 (gscwd51 & later)

- Adjusted over all of data, excluding years with high drag (1999-2002).

Weighted RMS of fit (1228 arcs)

A priori Cr (1.00) = 0.3730 mm/s.
Adjusted Cr. = 0.3730 mm/s.

Summary of Empirical Accelerations for SPOT-2
(9576 Values from 1993-1998; 2003-2009)

Cr Value	Along-Track Accel Amplitude (nm/s^2)		Cross-Track Accel Amplitude (nm/s^2)	
	Average	RMS	Average	RMS
1.00000	**1.529**	**2.610**	**3.0531**	**5.766**
0.98544	**1.094**	**2.348**	**3.1690**	5.841

SPOT-5 New Cr Impact

Macromodel derived from Lemoine et al. (2016)

A priori Cr = 1.00 (gscwd50 and earlier)
New Cr's (gscwd51 & later)

2002 – 2003:	0.9978
2004 – 2005:	0.9910
2006 – 2007:	0.9895
2008:	0.9902
2009 – 2015:	0.9901

Weighted RMS of fit, 2002-2003 (171 arcs)
A priori Cr (1.00) = 0.3837 mm/s.
Adjusted Cr. = 0.3734 mm/s.

Weighted RMS of fit, 2004-2015 (688 arcs)
A priori Cr (1.00) = 0.4080 mm/s.
Adjusted Cr. = 0.4059 mm/s.

Summary of Empirical Accelerations for SPOT-5
(8594 Values from 2004-2015)

Cr Value	Along-Track Accel Amplitude (nm/s^2)		Cross-Track Accel Amplitude (nm/s^2)	
	Average	RMS	Average	RMS
1.00000	**1.0433**	1.1192	**1.1573**	1.4463
New values	**0.8549**	1.4230	**1.0841**	1.4570

Summary of POD Results (2016 – 2020): RMS of fit

(new satellite data for ITRF2020)

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	150104	201227	378	1022	64330	1.134	0.3977
HY-2A	150104	200906	336	623	83104	1.116	0.3801
Jason-2	150104	190908	227	2687	127916	0.883	0.3819
Jason-3 (new)	160223	201227	274	2828	138082	0.871	0.4043
Sentinel-3A (α)	160508	201231	282	990	76517	0.741	0.3869
Sentinel-3B (β)	180606	201227	163	849	76590	0.752	0.4015

(α) No SLR data for Sentinel-3A from 2016-0306 to week of 2016-0508. Sentinel-3A still included in SINEX solution gscwd51 starting on 160302.
(β) Sentinel-3B not included in the ITRF2020 submission, but is now part of the operational series, gscwd52.

Summary of POD Results (2016 – 2020): Empirical Accelerations

(new satellite data for ITRF2020)

Satellite	First Arc	Last Arc	No of Values	Along-track Accelerations (nm/s^2)		Cross-track Accelerations (nm/s^2)	
				Average	RMS	Average	RMS
Cryosat-2	150104	201227	2200	2.535	5.863	3.449	5.364
HY-2A	150104	200906	2095	0.484	0.626	2.331	2.881
Jason-2 (α)	150104	190908	1410	0.597	0.855	2.359	2.768
Jason-3 (new) (α)	160223	201227	1723	0.638	0.777	1.700	2.121
Sentinel-3A	160508	201231	1726	0.522	0.614	1.135	1.465
Sentinel-3B (β)	180606	201227	948	0.854	0.990	1.342	1.657
Sentinel-3A (γ)	180603	201231	956	0.485	0.577	1.115	1.467

(α) For Jason-2 & Jason-3 Cr's were adjusted per arc in a separate POD step and then held fixed.
(β) Sentinel-3B was not included in ITRF2020, but is now part of the operational series, gscwd52.
(γ) Selecting Sentinel-3A arcs that are coincident with Sentinel-3B for comparison.

SAA Strategy for DORIS Satellites (GSC)

Satellite		SAA stations reduced (eliminated from combination)
SPOT-5	Use SAA-corrected data (2006-2015)	N
Jason-1	Use SAA-corrected data (2004-2008)	Y
Jason-2	Use DORIS V2 data	N
Jason-3	Use DORIS/RINEX data	Y
Sentinel-3A	Use DORIS/RINEX data	N
Sentinel-3B	Use DORIS/RINEX data	N

SAA Stations for Jason-1:

ASDB, ASEB; HELA, HELB; CACB, CADB; SANA, SANB SAOB; AREA, AREB, ARFB; KRUA, KRUB, KRVB, KRWB; LIBA, LIBB, LICB; GALA; EASA, EASB; SALB; TRIA, TRIB, TRJB.

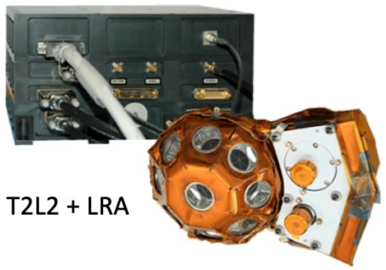
SAA Stations are down-weighted by 3x in orbit determination from 0.125 mm/s to 0.400 mm/s.

SAA Stations for Jason-3:

RIPB; ASEB; ARFB; CADB; KRWB, KRVB; LICB; LAOB; TRIB, TRJB; HELB, HEMB; SCRB, SCRC; SAPC, SAQC, SARC, SJUC.

SAA Stations are down-weighted by 3x in orbit determination from 0.125 mm/s to 0.400 mm/s.

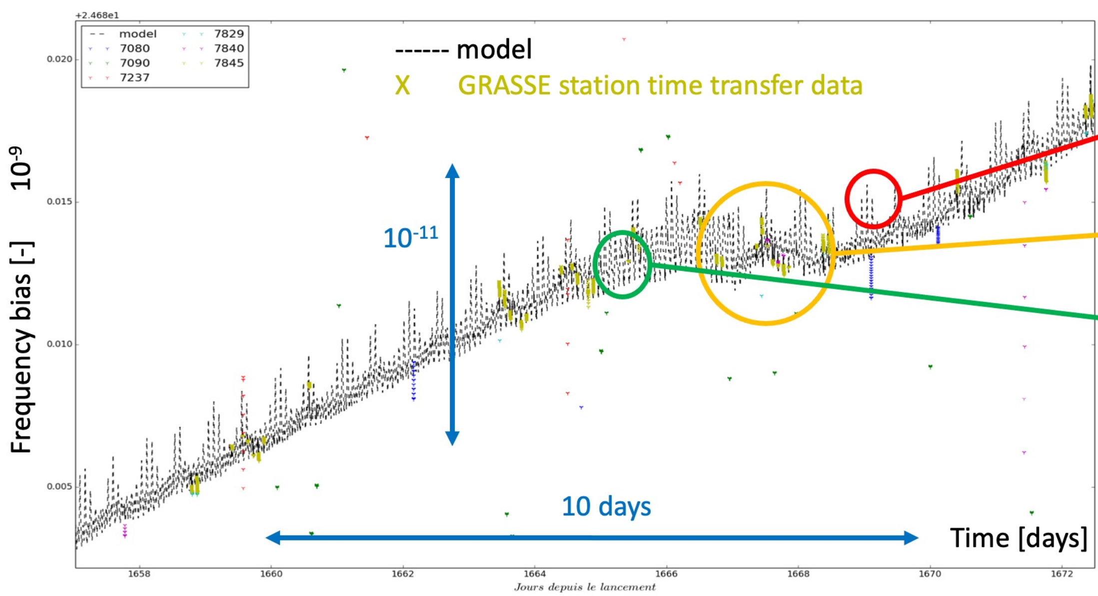
Jason-2 DORIS USO Modelling from T2L2 (1)



T2L2 + LRA

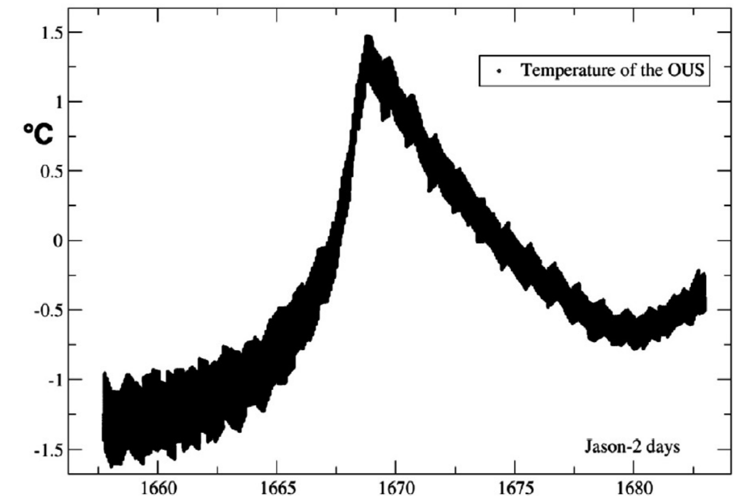
T2L2 :
- Designed for remote clocks synchronization, on-ground and on-board

Time Transfer :
- Determine Time Bias in laser stations (ILRS)
- Read the frequency bias of the USO (Ultra Stable Oscillator)

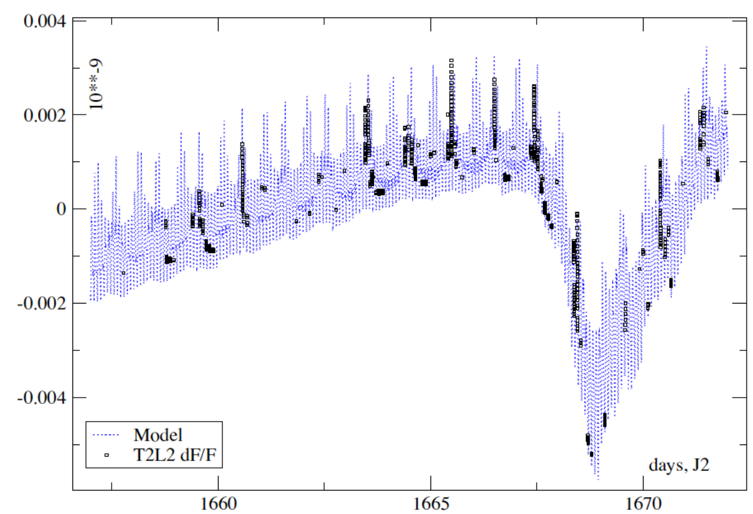


- Radiation + temperature + aging
- Precision around 5-7 x 10^{-13}
- Accuracy 10^{-12}

Belli et al., (2016), Adv. Space Res. "Temperature, radiation and aging analysis of the DORIS Ultra Stable Oscillator by means of the Time Transfer by Laser Link experiment on Jason-2", ***Adv. Space Res., 58(12),*** **2589-2600, doi: 10.1016/j.asr.2015.11.025**



Jason-2 USO Temperature variations in Jan. 2013.



Jason-2 USO Model variations in Jan. 2013.

Jason-2 DORIS USO Test with gscwd41 (vs. gscwd40)

1. So we created a SINEX series (gscwd41) that switched in the Jason-2-corrected data (2008-2016) and tried two different ways to handle the Jason-2 data for 2017-2019: (a) no correction for SAA stations; (b) with correction (reduction) for SAA stations.

2. From Evaluation by IDS CC (email Dec 08, 2020).

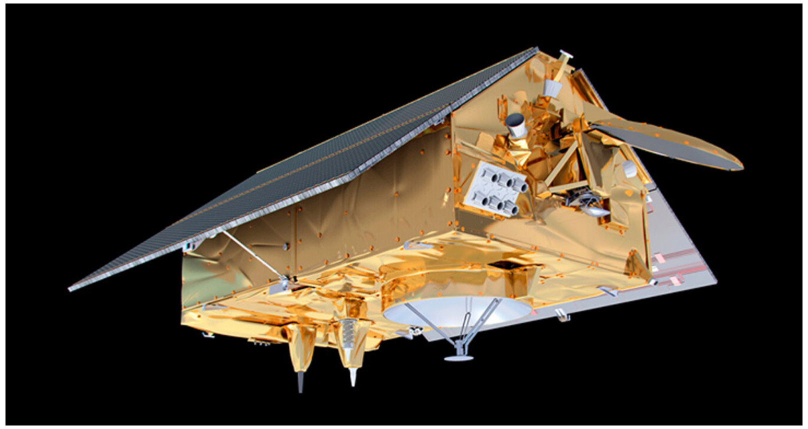
(a) Better centering of Tx, Ty, Tz; Slight degradation of std. dev;
(b) Similar performance in positioning as measured by WRMS (E-N-U).
(c) DORIS-GNSS Tie Discrepancies at SAA sites: Improvement with gscwd41 by 5 mm in mean and std. dev.
(d) Problems: discontinuities in station height in 2008, ARFB, ASEB, CADB HEMB (both solutions); for ARFB, ASEB, CADB, and possibly LAOB for gscwd41 in 2017.

Belli et al., (2021), Adv. Space Res. "Impact of Jason-2/T2L2 Ultra-Stable-Oscillator Frequency Model on DORIS stations coordinates and Earth Orientation Parameters", ***Adv. Space Res., 67(3),* 2589-2600, doi: 10.1016/j.asr.2020.11.034.**

Unit: mm	GSC 40	GSC 41
RMS	49.97	45.07
Median	50.72	39.69
Mean	46.92	42.00
STD	18.12	17.24

DORIS-GNSS Tie Discrepancies at SAA sites (from IDS CC, Dec. 08, 2020)

Sentinel-6A POD Tests with macromodels (1)



CNES (from DORIS Satellite Models pdf)

16.3 MACROMODEL

The optical and infrared properties of the macro-model and the plate surfaces are given below.

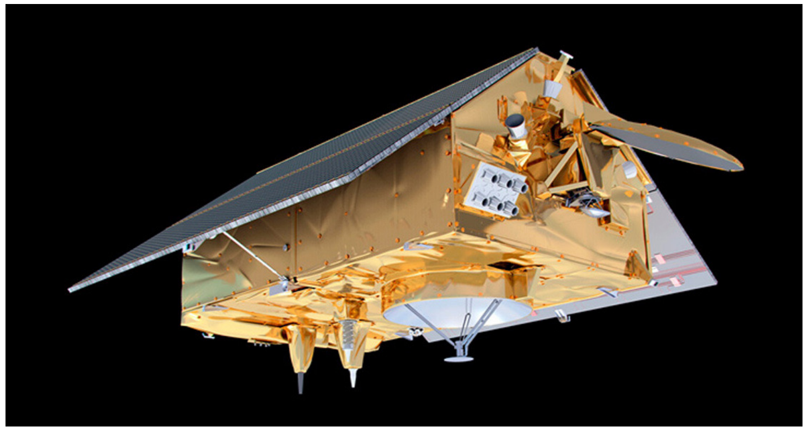
```
                                                   // Optical properties          //  Infrared properties
// Surf(m²)// Normal in sat ref frame // spec  //  diff  //   abs   //  spec  // diff   //   abs
 3.600      -1.     0.        0.        0.4500   0.1200   0.4300   0.1800   0.0400   0.7800
 3.370       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
```

ESA, Cullen (from Montenbruck etal 2021)

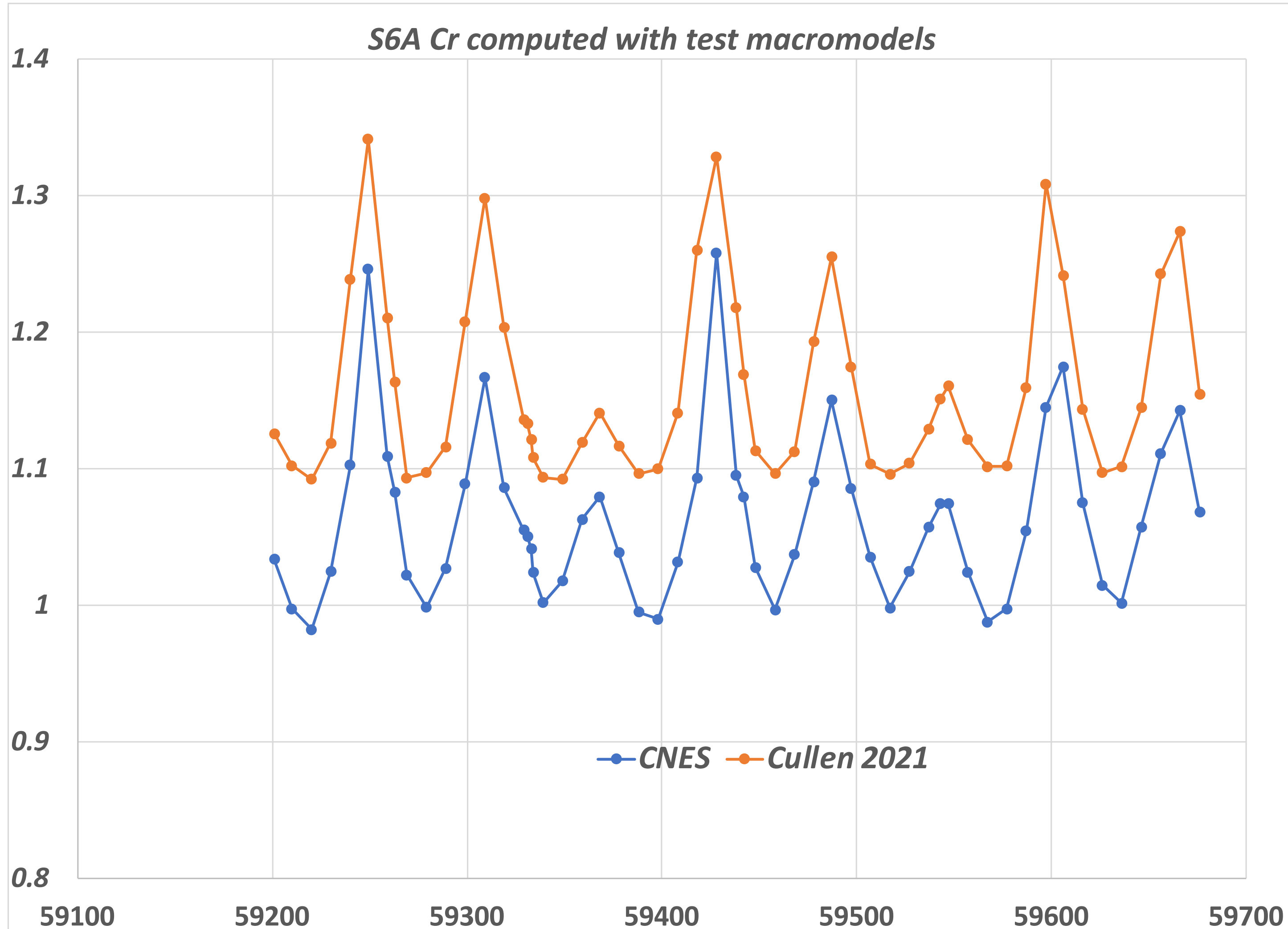
Table 5 Sentinel-6A macro-model. Adapted from Cullen (2021)

Element	Surface normal	Area [m^2]	α_{VIS}	δ_{VIS}	ρ_{VIS}	α_{IR}	δ_{IR}	ρ_{IR}
Body +*X* (front)	(+1.000, +0.000, +0.000)	3.5	0.47	0.04	0.49	0.76	0.04	0.20
Body −*X* (back)	(−1.000, +0.000, +0.000)	3.5	0.43	0.12	0.45	0.78	0.04	0.18
Body +*Z* (bottom)	(+0.000, +0.000, +1.000)	15.5	0.57	0.08	0.35	0.77	0.12	0.11
Body −*Z* (top)	(+0.000, +0.000, −1.000)	2.0	0.35	0.03	0.62	0.77	0.01	0.22
Solar panel (starboard)	(+0.000, +0.616, −0.788)	8.9	0.86	0.14	0.00	0.80	0.20	0.00
Solar panel (portside)	(+0.000, −0.616, −0.788)	8.9	0.86	0.14	0.00	0.80	0.20	0.00
Body +*Y* (bottom structures)	(+0.000, +1.000, +0.000)	1.0	0.43	0.14	0.43	0.75	0.12	0.13
Body −*Y* (bottom structures)	(+0.000, −1.000, +0.000)	1.0	0.43	0.14	0.43	0.75	0.12	0.13

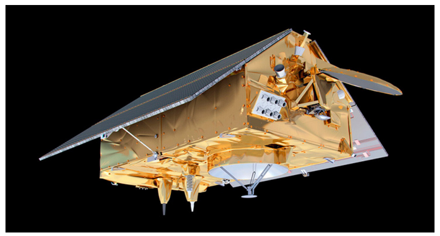
Sentinel-6A POD Tests with macromodels (2)



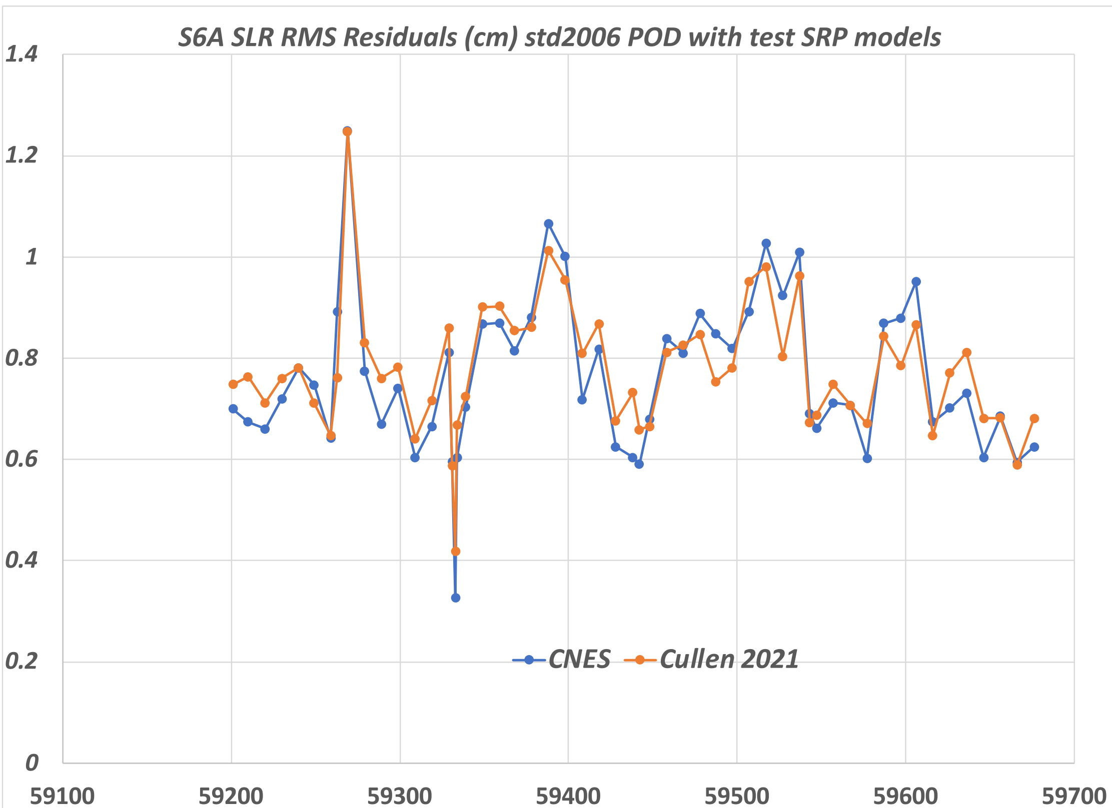
S6A pre-estimated Cr with SLR+DORIS

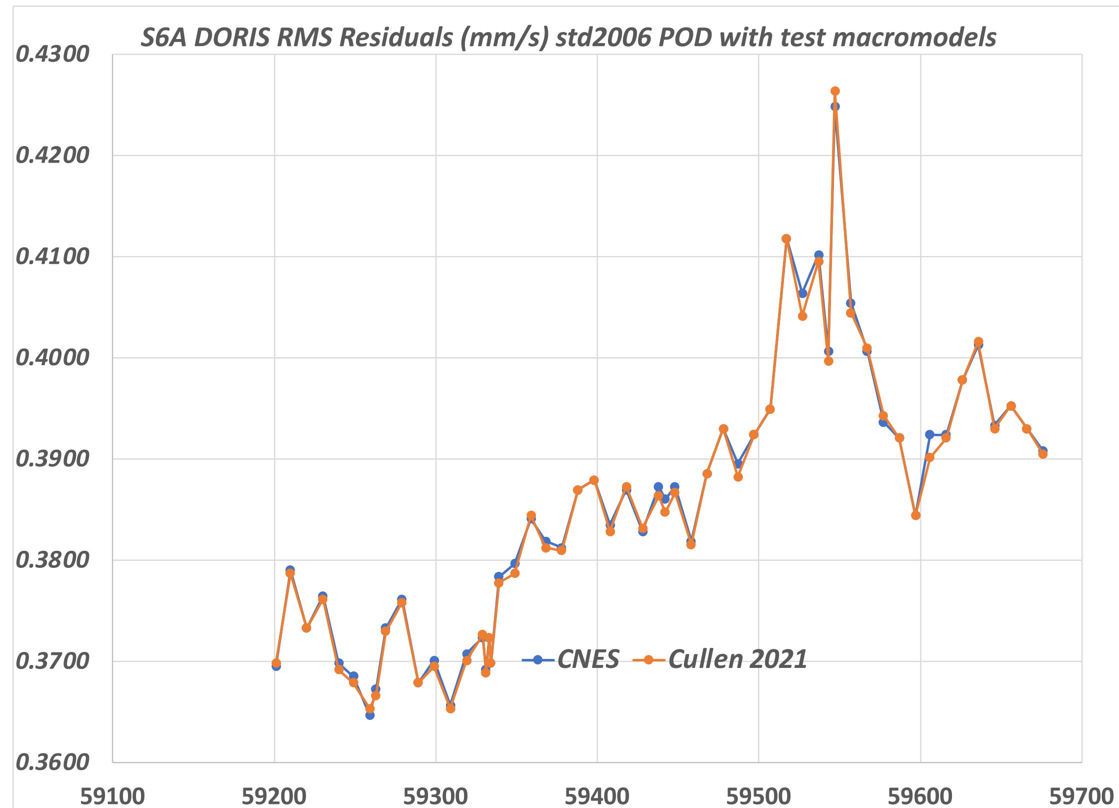


Sentinel-6A POD Tests with macromodels (3)

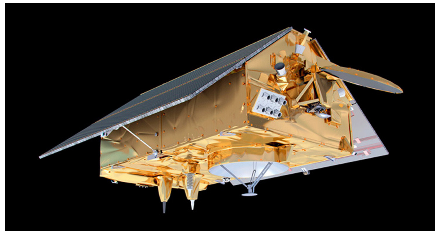


(POD with applied Cr held fixed, and adjusting empirical accelerations, usingDPOD2014.

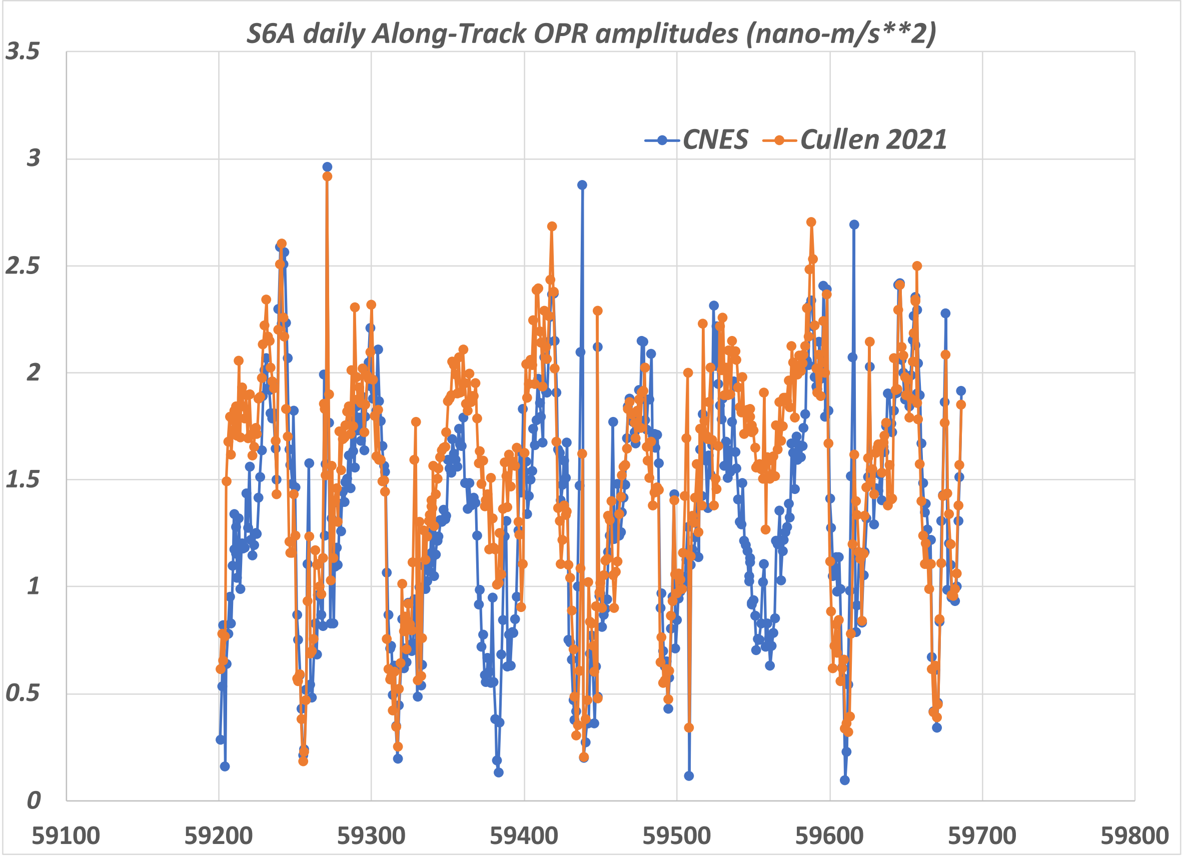


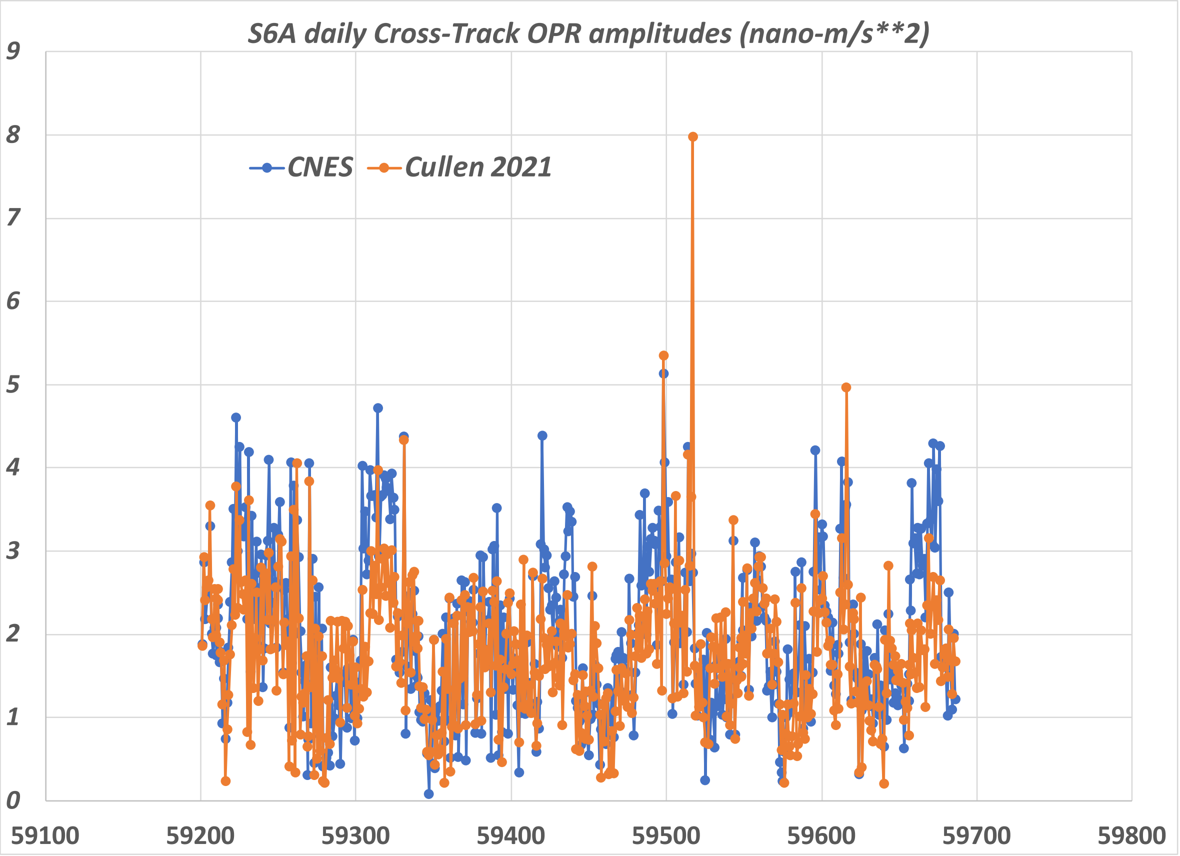


Sentinel-6A POD Tests with macromodels (4)

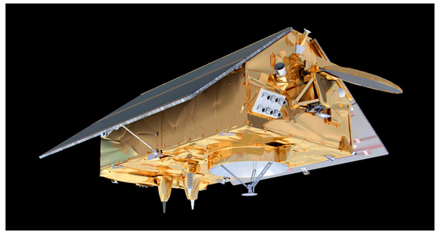


(Empirical Accelerations).





Sentinel-6A POD Tests with macromodels (5)



Test	DORIS RMS residuals (mm/s)	SLR RMS residuals (cm)	Along-trk OPR accel (nano-m/s**2)	Cross-trk OPR accel (nano-m/s**2)
Est. Cr CNES	0.6573	9.372	----	----
Est. Cr Cullen	0.7085	10.033	----	----
std2006 CNES	0.3854	0.761	1.44	2.23
std2006 Cullen	0.3851	0.774	1.60	1.96

Orbit difference RMS (mm) std2006-Test	Radial	Cross-trk	Along-trk
GSFC (Cullen) – GSFC (CNES)	3.1	7.3	21.2
GSFC (Cullen) – CNES/POEF	6.7	18.7	24.0
GSFC (Cnes) – CNES/POEF	6.7	18.1	26.9

Summary: Outstanding Issues after ITRF2020

- Switch to a new "modern" version of GEODYN?

- **CRYOSAT-2**: Residual problems; Higher accelerations, also Tz signal in GSC single-satellite solutions shown by IDS CC.

- **JASON-2: T2L2 model.** How to integrate into processing, and assure consistency?

- **New satellites:**
  HY-2D: How to introduce attitude model into GEODYN?
  Sentinel-6A: Macromodel approach not adequate to model nonconservative forces.

- **Implement GNSS Clock models for routine DORIS processing on new satellites:**
  (Sentinel-3A, Sentinel-3B, Sentinel-6A).
  → Might be a good to have a **working group or Pilot Project** with groups who routinely produce clock products, and make them available, and others who can test them.

- **Implementation of ITRF2020 & Creation of a DPOD2020? How & when will AC's decide to do this?**