

GSFC std2006: An updated set of altimeter satellite orbits for TOPEX, the Jason satellites and Sentinel-6A

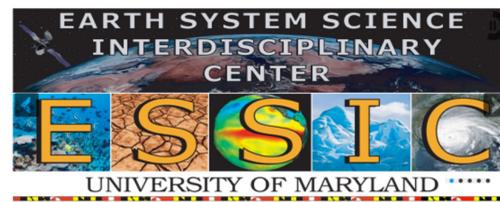
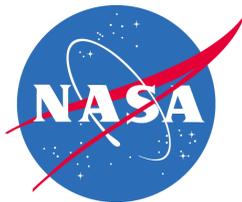
**F.G. Lemoine¹, N.P. Zelensky², B.D. Beckley³,
X. Yang³, D.D. Rowlands¹, D. S. Chinn³, G. Moreaux⁴**

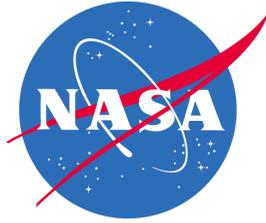
(1) NASA GSFC, Greenbelt, Maryland, USA

(2) ESSIC, University of Maryland, College Park, Maryland, U.S.A.

(3) KBR Inc., Greenbelt, Maryland, USA

(4) CLS, Toulouse, FRANCE





New orbits for TOPEX, Jason 1-3 & S6A

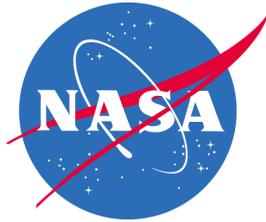


Summary:

Orbits based on updated standards and a complete reprocessing were delivered to the NASA MeaSURES (**Integrated Multi-Mission Ocean Altimeter Data for Climate Research (MEaSURES-SSH, <https://podaac.jpl.nasa.gov/MEaSURES-SSH>)**) for TOPEX, Jasons1-3 & Sentinel-6A, and will be archived at the IDS datacenters once a doi is made available.

We are analyzing improvements to the current set of orbits, (1) using the newly released ITRF2020 realization, and the DORIS extension (DPOD2020), (2) testing application of non-tidal mass loading for all the orbits, (3) by updating the background geopotential models.

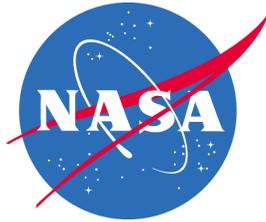
Comparisons of std2006 to independent orbits (CNES/POEF, JPL/Reduced-dynamic orbits) for Jason-3) show RMS radial orbit agreement of 5-7 mm for Sentinel-6A & Jason-3.



GSFC POD Strategy for current orbits



model	std2006
gravity	GSFC 5x5 model (tvg0075) + GOCO05s
atmosphere gravity	GFZ 90X90 3-hr from ECMWF (cf. GRACE FO, RL06)
Geocenter	Annual model (ITRF2014)
mean pole	IERS2014 (linear mean pole)
integration step size	15 seconds
Solar Rad. Pressure	new TSI, tuned SA+, X-, tuned Cr/arc
DORIS Coordinates	DPOD2014 Version 5.5 (August 2021)
DORIS SAA Stations	J1, J3, S6A, downweighted by 3X
elev. cutoff (DORIS)	10 deg.
DORIS data weighting	elevation-dependent (J2, J3, S6A)
SLR Coordinates	SLRF2014 (v200428).
SLR Data Handling	SLRF2014 with T2L2-derived corrections.
LRA phase center	constant + elevation correction.
SLR Data Handling	gsfc2020 (from ILRS, 06-16-2020)
OPR parameters	per 24-hr (along + cross-track)



GSFC POD Strategy for current orbits: Updates

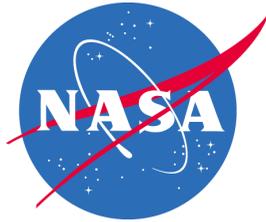


model	std2006
gravity	GSFC 5x5 model (tv90075) + GOCO05s
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**DPOD2020,
Test version.
(built on ITRF2020)**

ITRF2020

*SLRF2020
not yet available,
but promised soon*

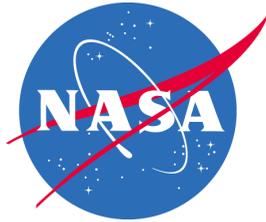


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**Fprward model
Non-tidal mass loading
in science orbits**
<https://massloading.gsfc.nasa.gov/>



GSFC POD Strategy for current orbits

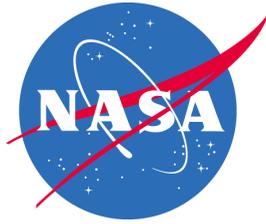


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gravity	GSFC 5x5 model (tv0075) + GOCO05s
atmosphere gravity	GFZ 90X90 3-hr from ECMWF (cf. GRACE FO, RL06)
Geocenter	Annual model (ITRF2014)
mean pole	IERS2014 (linear mean pole)
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Test updated geopotential models: GOCO06s +

- 1. Monthly models (GRACE, GRFO, Swarm) with TN-14 SLR, C_{20} & C_{30}**
- 2. COSTG monthly models and FSM (fitted signal models).**



Evaluation of ITRF2020/DPOD2020

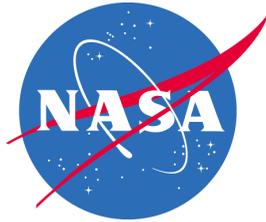


SLR Complement	No of. stations	No. of station solutions	Position Epoch	PSD applied	Date released
SLRF2014 (v200428)	469	523	2010	yes (itrf2014)	2020/04/28
ITRF2020	421	473	2015	yes	2022/04/15

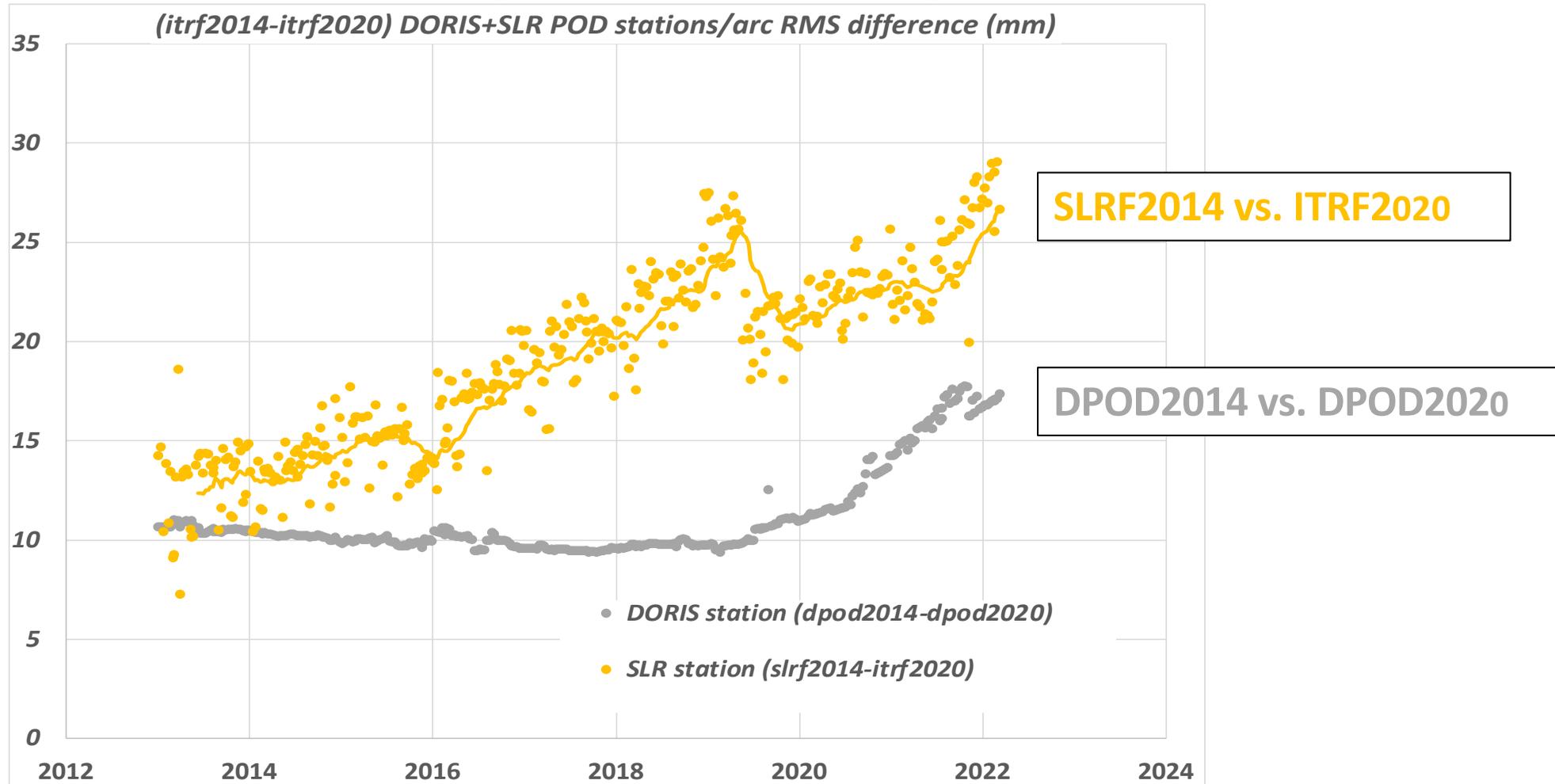
DORIS Complement	No of. stations	No. of station solutions	Position Epoch	PSD applied	Date released
DPOD2014_05p5	214	342	2000	no	2021/11/17
ITRF2020	201	287	2015	yes	2022/04/15
DPOD2020_01	209	355	2000	no	2022/06/26

Compare DPOD2014_05p5 to DPOD2020_01 complements for 4-character station completeness:

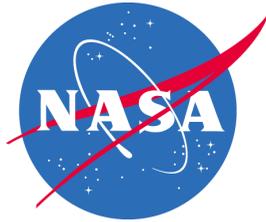
- **six stations missing from DPOD2020_0** : KRUA, RICA, ARLA, SOCA, TROA, HVOA (all heavily down-weighted in POD)
- **one station not found in DPOD2014_05p5**: SJVC (tracking from 2022/06/08, previously SJUC)



SLR & DORIS station position differences, per data arc (itrf2014 – itrf2020)



ITRF2020 will have the most impact in the period where itrf2014 was in extrapolation (after ~2015).



Jason-3 Summary of SLR+DORIS POD statistics using the GSFC, CNES, and JPL orbits

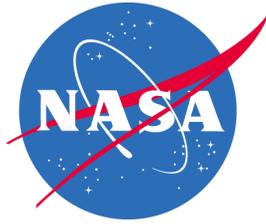


(Dates of Comparison: 2016.1 – 2022.3)

J3 Satellite Orbit	POD test complements	DORIS Stations	SLR Stations	DORIS RMS (mm/s)	SLR RMS (mm)
std2006 (slr+doris)	dpod2014	79	40	0.3942	6.94
	dpod2020	79	40	0.3941	6.31



**ITRF2020/DPOD2020 improves
POD Performance for Jason-3.**



Sentinel-6A Summary of SLR+DORIS POD statistics using the GSFC, CNES, and JPL orbits

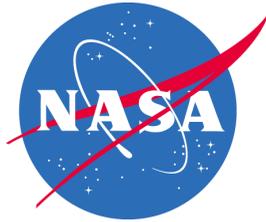


(Dates of Comparison: 2020.9 – 2022.3)

S6A Satellite Orbit	POD test complements	DORIS Stations	SLR Stations	DORIS RMS (mm/s)	SLR RMS (mm)
std2006 (slr+doris)	dpod2014	60	26	0.3853	7.63
	dpod2020	60	26	0.3848	7.28



ITRF2020/DPOD2020 improves POD Performance for Sentinel-6A.



Jason-2 Summary of SLR+DORIS POD statistics

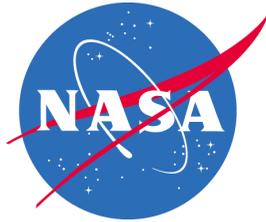


(Dates of Comparison: 2008.5 – 2016.7)

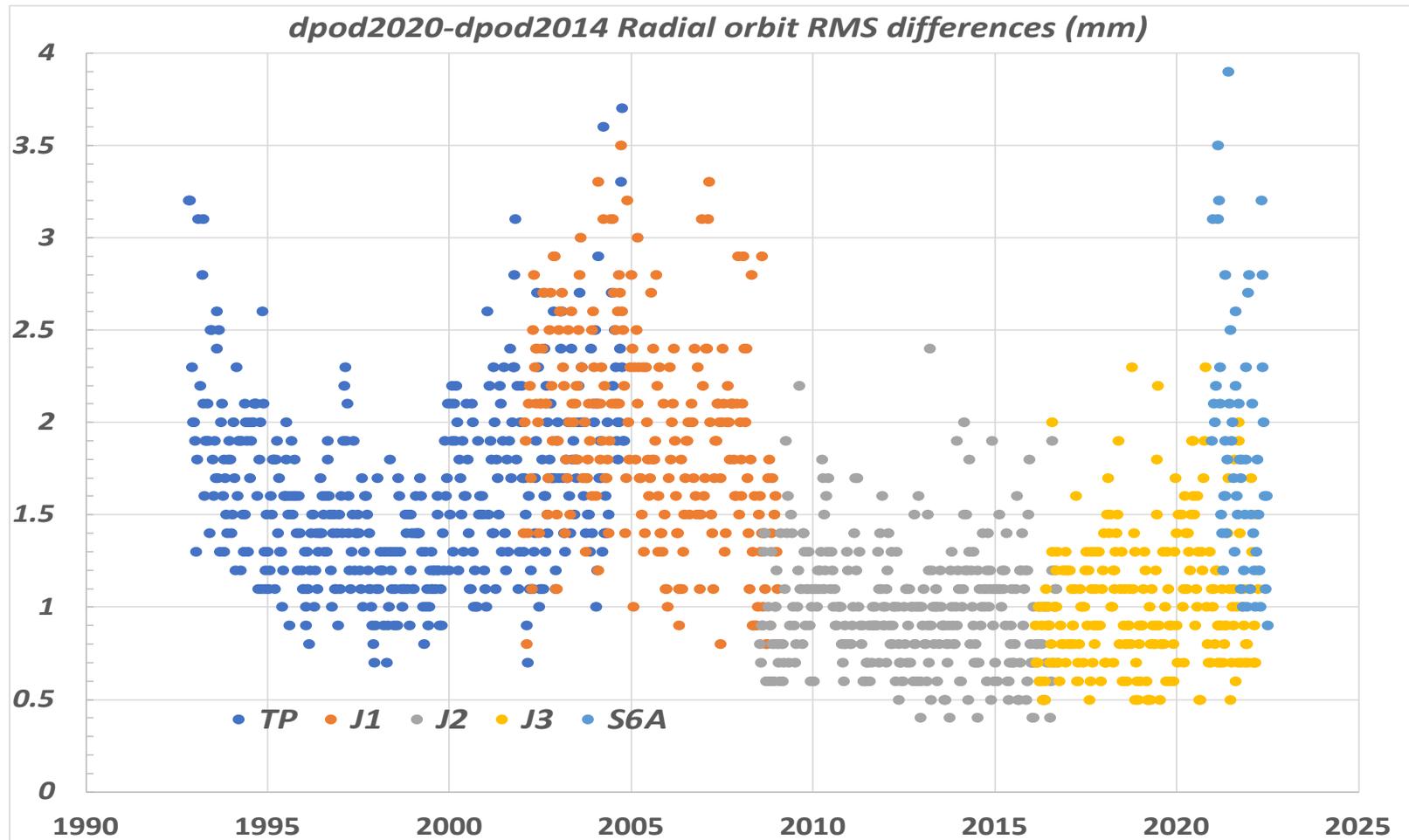
J2 Satellite Orbit	POD test complements	DORIS Stations	SLR Stations	DORIS RMS (mm/s)	SLR RMS (mm)
std2006 DORIS V2	dpod2014	97	47	0.3927	7.29
	dpod2020	97	47	0.3930	7.41
std2006 DORIS/ RINEX + T2L2	dpod2014	100	47	0.3799	7.17
	dpod2020	100	47	0.3801	7.27



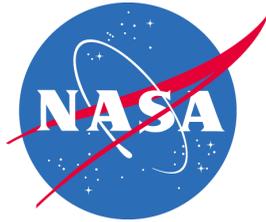
1. ITRF2020/DPOD2020 degrades POD Performance for Jason-2.
2. DORIS/RINEX with T2L2 corrections for Jason-2 USO is superior.



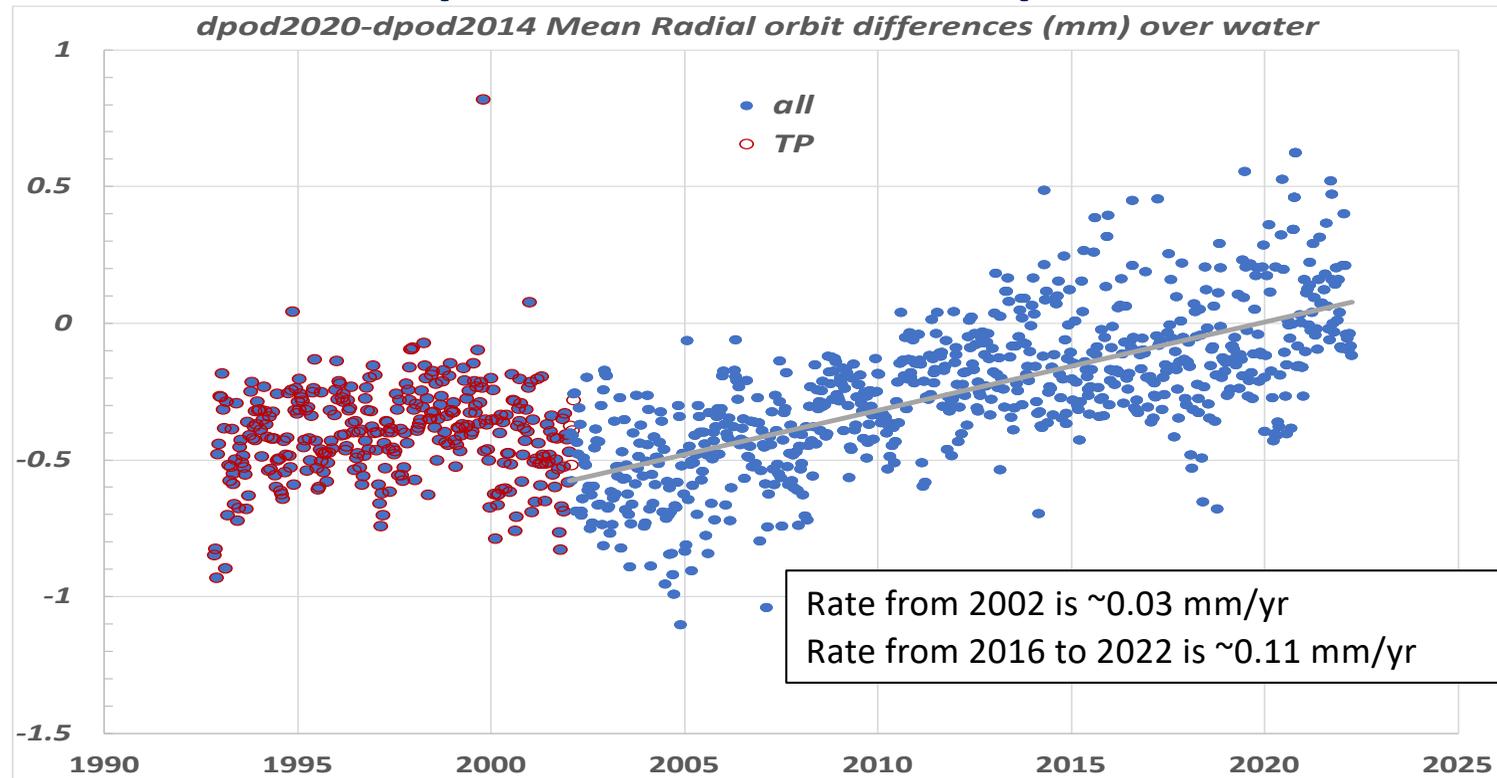
Radial orbit differences from dpod2020/itrf2020 w.r.t. dpod2014/slrf2014



**RMS Radial Orbit Differences of ITRF2020 orbits
w.r.t. current orbits are 1-3 mm per cycle.**

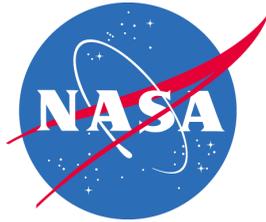


Radial orbit difference rate over the oceans based on the orbit difference $dpod2020/itrf2020 - dpod2014/slr2014$



*Global MSL long-term stability requirement (> 10 years) = 0.3 mm/yr
(from instrumental and geophysical sources).
The results above suggest the new ITRF realisations will not significantly change the MSL rate.*

Ablain et al., (2015), Ocean Sci., 11, 67-82, doi:10.5194/os-11-67-2015)

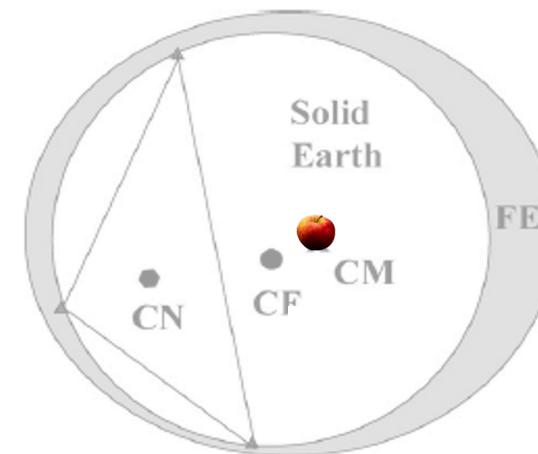


Mass loading test configuration

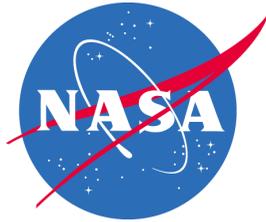


Non-tidal mpload components		
Data from https://massloading.gsfc.nasa.gov		
Component	Model	Description
Atmosphere	GEOS-FPIT	Model resolution: $0.50^\circ \times 0.625^\circ \times 72$ layers \times 3 hours. Latency 6–15 hours. Available since 2000.0101
Hydrology	GEOS-FPIT	
non-tidal Ocean	OMCT05	Ocean Model for Circulation and Tides (OMCT): (Thomas, 2002; Dobslaw & Thomas, 2007)

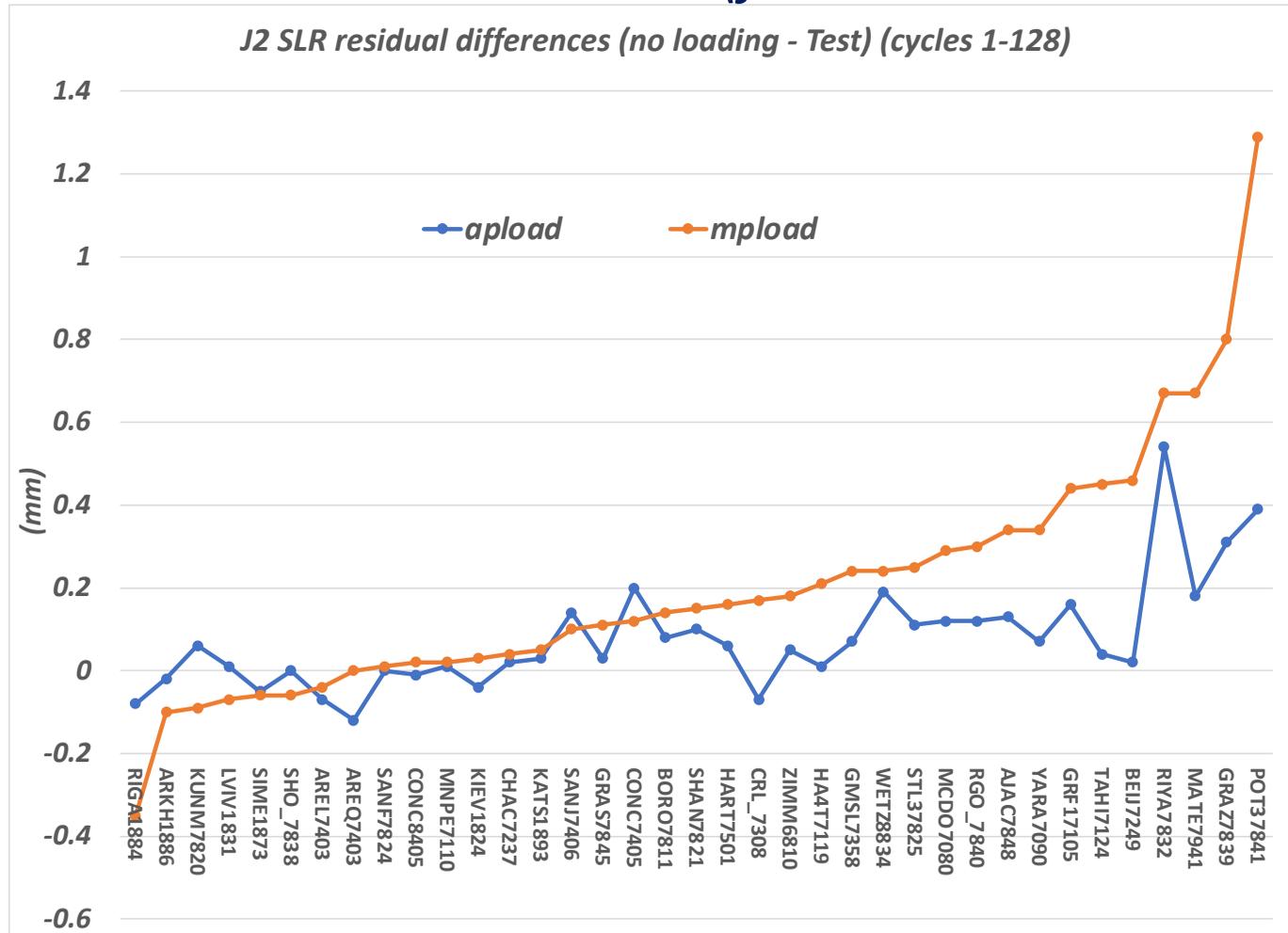
Geocenter (CM) motion test models	
itrf2014	Annual
itrf2020	Annual + Semi-annual



From Wu et al., 2012

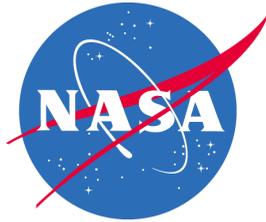


Applying full mass loading model improves station positioning (from tests with Jason-2 SLR data)



J2 Test cycles 1-128	SLR RMS (mm)
noCm	7.37
itrf2014 CM	7.29
itrf2020 CM	7.33
apload	7.25
mpload	7.04

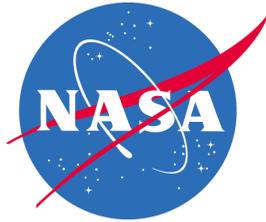
Application of full mass loading superior to using only atmospheric loading



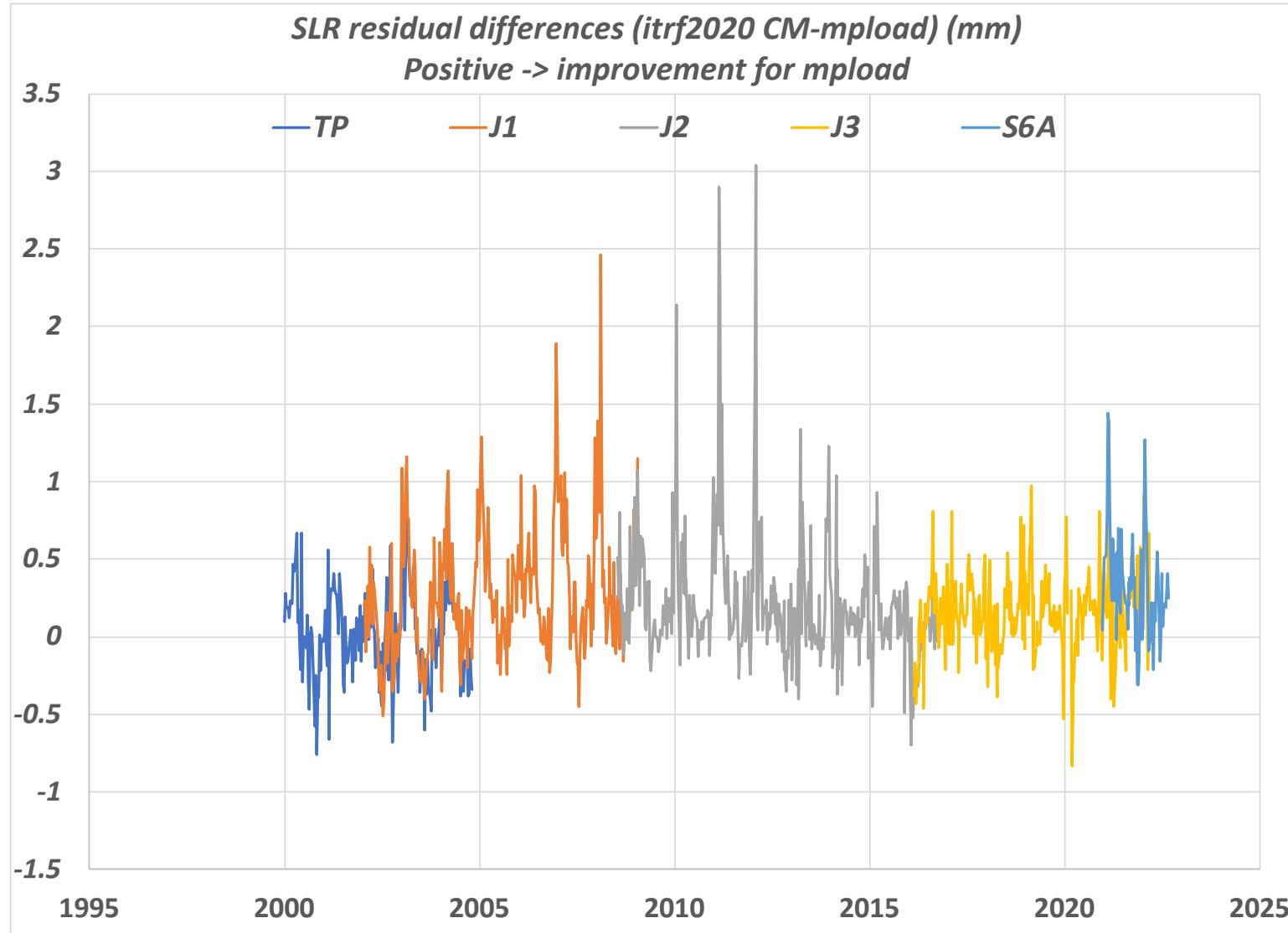
SLR RMS Residuals for Geocenter & Mass Loading Tests



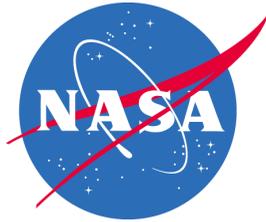
Satellite	No CM model; No mpload	Use ITRF2014 CM	Use ITRF2020 CM	No CM model. Use mpload
	SLR (mm)	SLR (mm)	SLR (mm)	SLR (mm)
TOPEX/Poseidon	15.36	15.35	15.34	15.32
Jason-1	9.01	8.96	8.98	8.70
Jason-2	7.33	7.27	7.30	7.09
Jason-3	6.39	6.31	6.35	6.20
Sentinel-6A	7.31	7.18	7.25	6.93



Improvement in RMS SLR Residuals from Use of Nontidal Mass Loading (w.r.t. using ITRF2020 geocenter model)

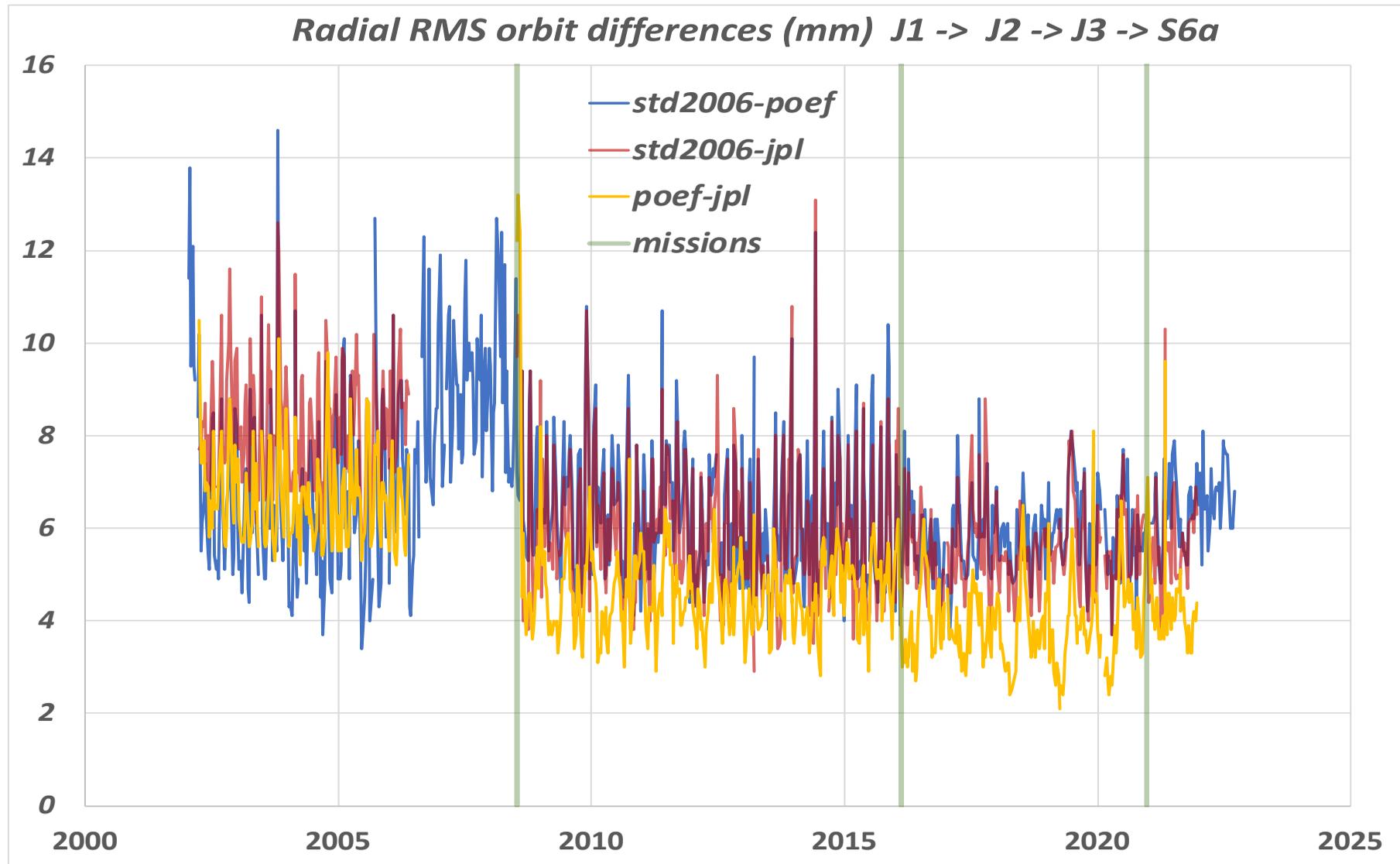


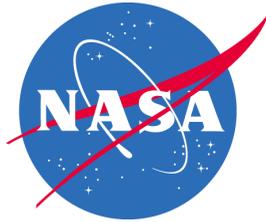
Application of mass loading systematically improves SLR residuals



Orbit performance summary: std2006 (slrf2014/dpod2014)

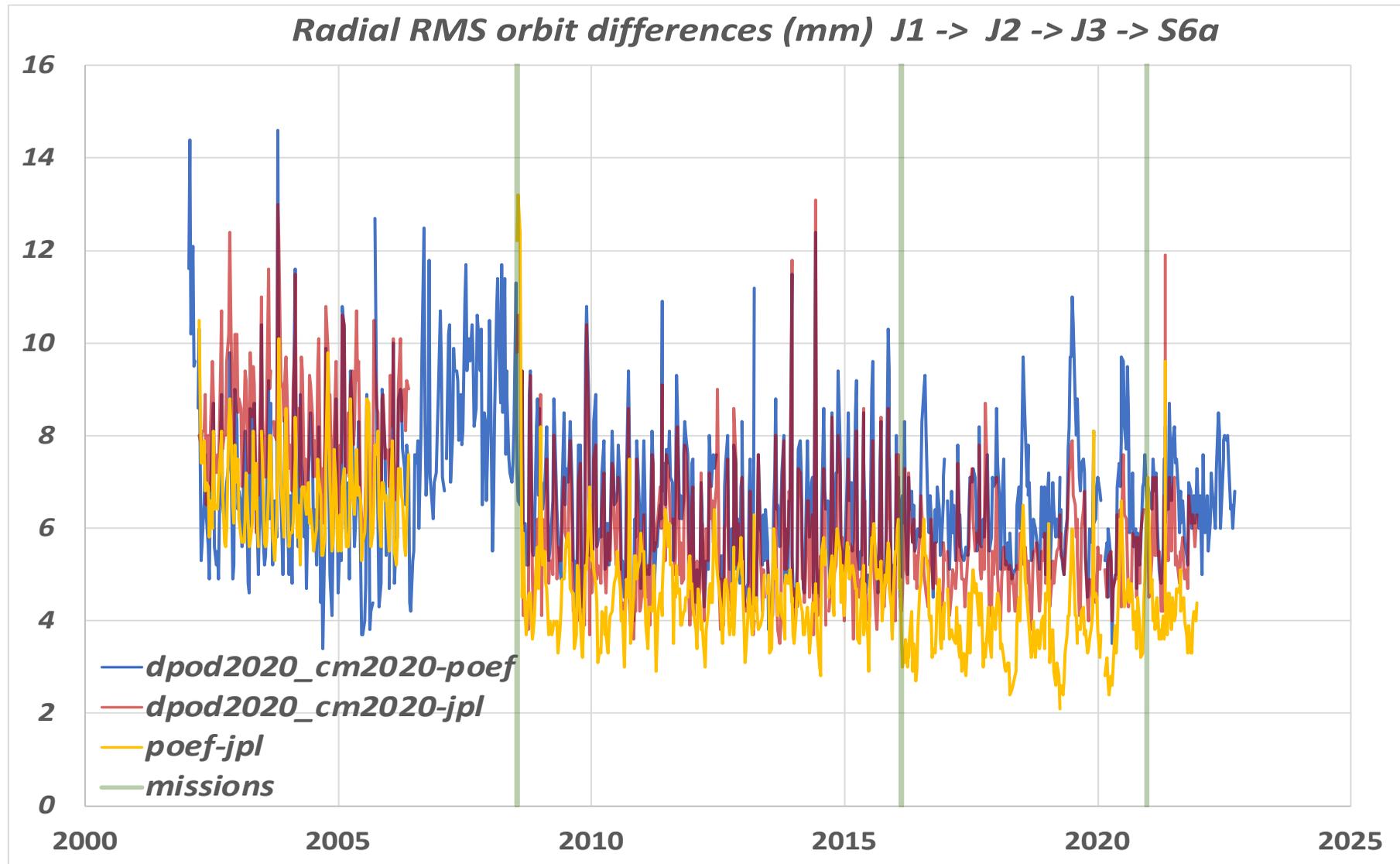
(comparison with CNES/POEF & JPL/gps-only RD orbits)

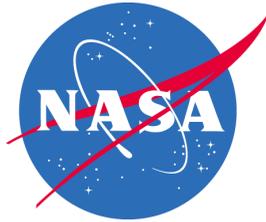




Orbit performance summary: dpod2020_cm2020 (itrf2020/dpod2020)

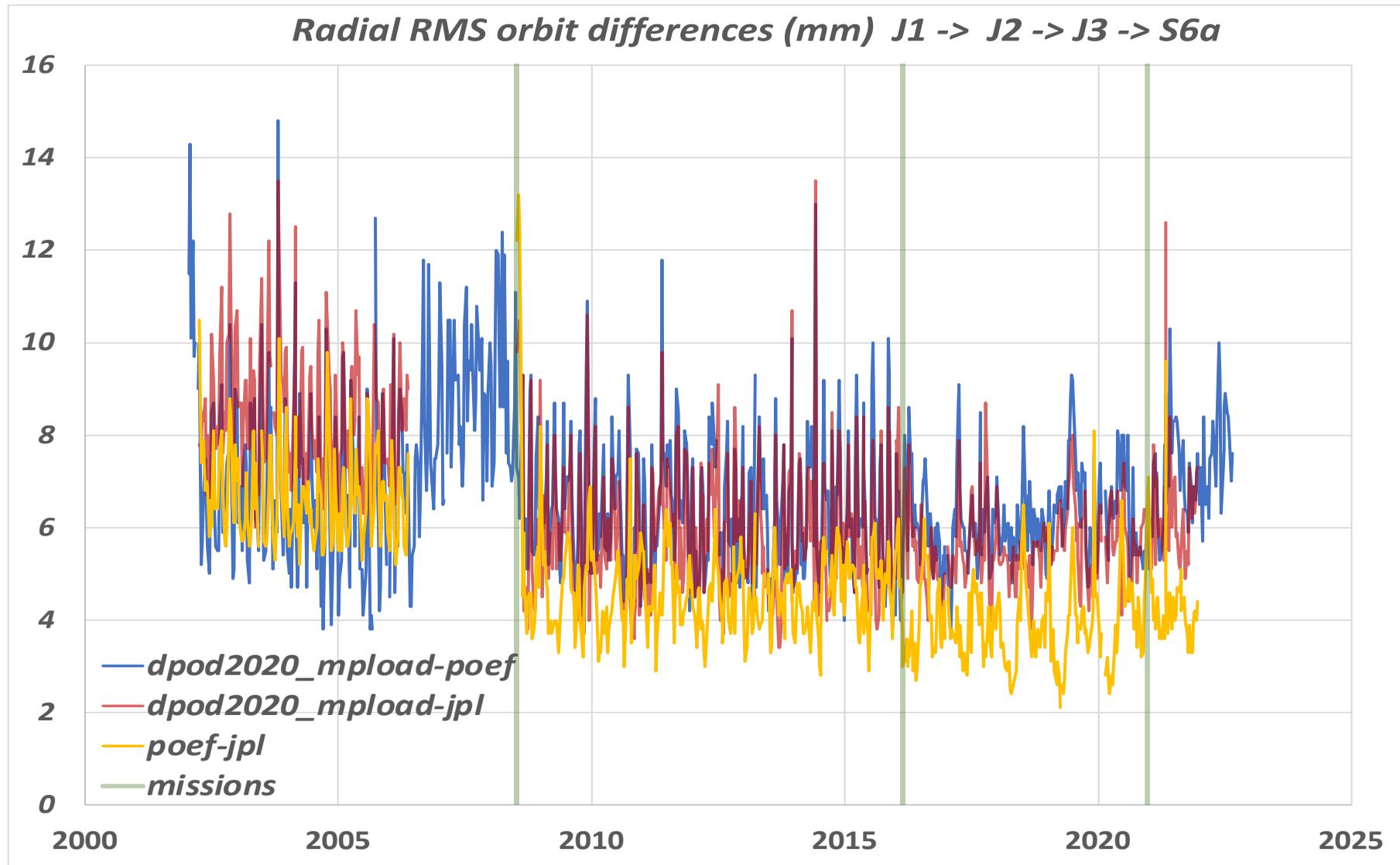
(comparison with CNES/POEF & JPL/gps-only RD orbits)

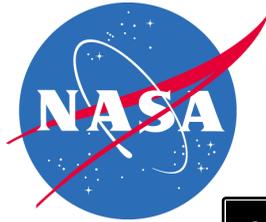




Orbit performance summary: `dpod2020_mpload (itrf2020/dpod2020)`

(comparison with CNES/POEF & JPL/gps-only RD orbits)





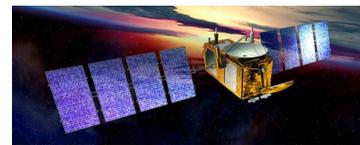
Summary

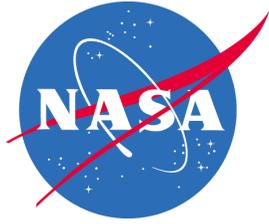


- (1) Current set of std2006 orbits agrees well with external JPL & CNES/POEF orbits: avg. radial RMS: 8-12 mm (J1); 6-8 mm (J2); 5-7 mm (J3 & S6A).
- (2) Compared to SLRF2014, ITRF2020 SLR residuals overall only show improvement after 2014. ITRF2020 includes fewer SLR stations. These results do not apply the ITRF2020 SLR Data Handling File, which has not yet been publically made available.
- (3) Radial orbit differences (ITRF2014 – ITRF2020) are small: 1-3 mm RMS per cycle.
- (4) The impact on GMSL of ITRF2020 vs. ITRF2014 is ~ 0.10 mm/yr (2016-2022).
- (5) Application of full mass loading (atmosphere, hydrology, non-tidal ocean), better centers the orbits, and improves SLR data residuals.

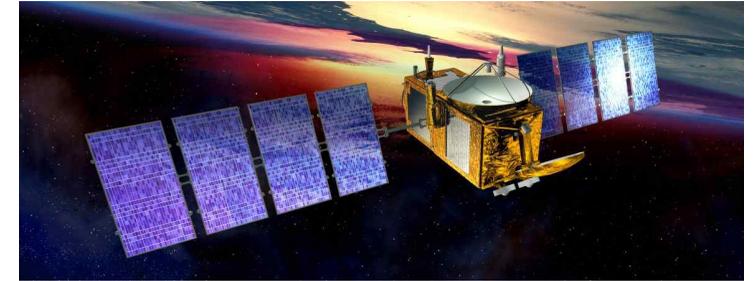
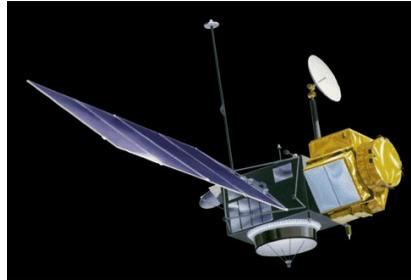
Future work:

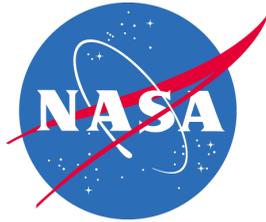
- (1) Distribute std2006 orbits.
- (2) Perform more tests on applying full modelling of mass loading (*atmosphere, hydrology non-tidal ocean*).
- (3) Repeat ITRF2020 tests when other realizations are available (DTRF2020, JTRF2020), and using the ITRF2020 SLR Data Handling File as a guide for proper handling of SLR biases to apply or adjust.
- (4) Continue work on updating geopotential models (static & time-variable)
- (5) Work with POD team to improve non-conservative force modelling on Sentinel-6a.





Backups





Jason-2 Summary of SLR+DORIS POD statistics using the GSFC, CNES, and JPL orbits

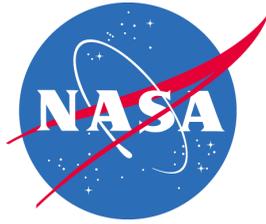


(Dates of Comparison: 2008.5 – 2016.7)

J2 Satellite Orbit	POD test complements	DORIS Stations	SLR Stations	DORIS RMS (mm/s)	SLR RMS (mm)
std2006 DORIS V2	dpod2014	97	47	0.3927	7.29
	dpod2020	97	47	0.3930	7.41
std2006 DORIS/ RINEX + T2L2	dpod2014	100	47	0.3799	7.17
	dpod2020	100	47	0.3801	7.27



poef and jpl18a orbits used as external ephemerides. When we use these external orbits as a reference, but process them with GEODYN, but apply either slrf2014/dpod2014 or itr2020/dpod2020 in the measurement model.



Jason-3 Summary of SLR+DORIS POD statistics using the GSFC, CNES, and JPL orbits

(Dates of Comparison: 2016.1 – 2022.3)



J3 Satellite Orbit	POD test complements	DORIS Stations	SLR Stations	DORIS RMS (mm/s)	SLR RMS (mm)
std2006 (slr+doris)	dpod2014	79	40	0.3942	6.94
	dpod2020	79	40	0.3941	6.31
poef (gps+doris)	dpod2014	79	40	0.3942	9.84
	dpod2020	79	40	0.3941	9.31
jpl22a (gps)	dpod2014	79	40	0.3948	9.47
	dpod2020	79	40	0.3947	8.90



poef and jpl22a orbits used as external ephemerides. When we use these external orbits as a reference, but process them with GEODYN, but apply either slrf2014/dpod2014 or itr2020/dpod2020 in the measurement model.

ITRF2020/DPOD2020 improves POD Performance for Jason-3.