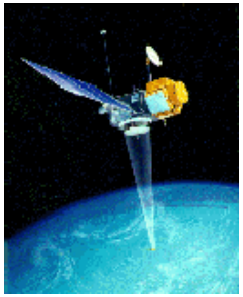
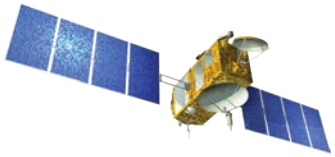



Status of Precise Orbit Determination for Altimeter Satellites at GSFC

F.G. Lemoine[1], N.P. Zelensky[2], D.S. Chinn[2], B.D. Beckley[2], D.E.Pavlis[2]

(1) NASA GSFC, Greenbelt, Maryland, USA

(2) SGT Inc., Greenbelt, Maryland, USA

Introduction:

From the previous OSTST (2015):
The outstanding issues pertained to:
(1) Evaluation of ITRF2014 reference frame.
(2) Demonstration of ability to process Jason-3 RINEX/DORIS data.
(3) How to continue to reduce signatures of force & measurement model errors that surface in the inter-comparisons.
Accomplishments in the past year:
(1) Evaluated the newly-released reference frame realizations (ITRF2014/IGN & JTRF2014) as well as prototype DPOD2014 (DORIS-only) realization.
(2) Evaluated POD tracking on Jason-3.
(3) Contributed to the Jason-2/Jason-3 inter-comparisons.
In addition we have implemented specific improvements:
(1) Tuned offsets and SRP model for Jason-3
(2) Observing an SAA-effect in the DORIS residuals, downweight the SAA stations for J3.
(3) Estimated a (preliminary) geocenter model from L1/L2 for satellite altimetry includes atmospheric loading. → NPZ presentation.
(4) Delivered orbits (Jason-2 & Jason-3).

TP, J1, J2, J3 Orbits Delivered

All the orbits are available via anonymous FTP, and are in the standard POE format (**version, std1504**)

TOPEX/Poseidon: **std1504, cycles 1-481 (ITRF2008)**
Jason-1: **std1504, cycles 1-259** (**ITRF2008**)
Jason-2: **std1504, cycles 1-300a** (**ITRF2008** & **ITRF2014**)
cycles 281-300a (**ITRF2014-reduced-dynamic**)
Jason-3: **std1504, cycles 1-22** (**ITRF2008** & **ITRF2014**) ,
cycles 1-22 (**ITRF2014-reduced-dynamic**)

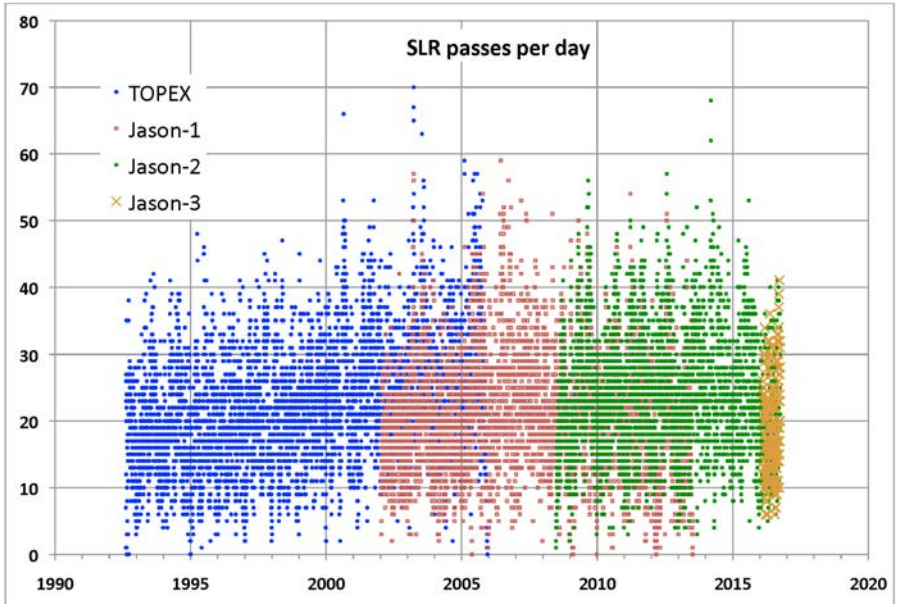
ftp://cddis.gsfc.nasa.gov/pub/misc/test/JasonOrbits/gsfc/tp-orbits/
ftp://cddis.gsfc.nasa.gov/pub/misc/test/JasonOrbits/gsfc/j1-orbits/
ftp://cddis.gsfc.nasa.gov/pub/misc/test/JasonOrbits/gsfc/j2-orbits/
ftp://cddis.gsfc.nasa.gov/pub/misc/test/JasonOrbits/gsfc/j2-orbits/itrf2014/
ftp://cddis.gsfc.nasa.gov/pub/misc/test/JasonOrbits/gsfc/j3-orbits/
ftp://cddis.gsfc.nasa.gov/pub/misc/test/JasonOrbits/gsfc/j3-orbits/itrf2014

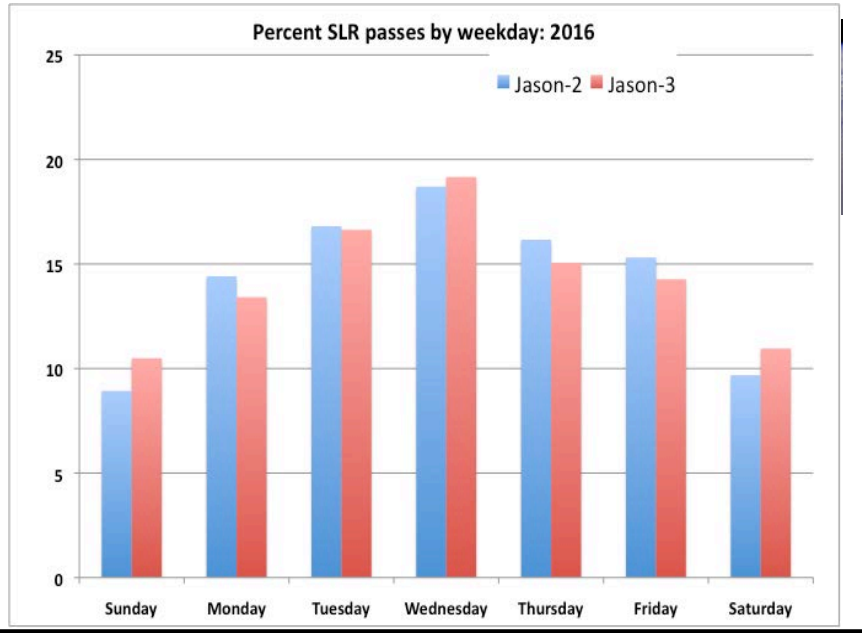
GSFC POE Description

GSFC SLR + DORIS orbits	Description
std1504	**ITRF2008: GDR-E comparable. New TVG modeling & modeling of solar array deviations from nominal. (SLR+DORIS dynamic)**
red1504	**ITRF2008; : GDR-E comparable. (SLR+DORIS, reduced-dynamic).**
std1504_itrf2014	**ITRF2014:** (No other changes)
red1504_itrf2014	**ITRF2014:** (No other changes)

General Model Summary (std1504)

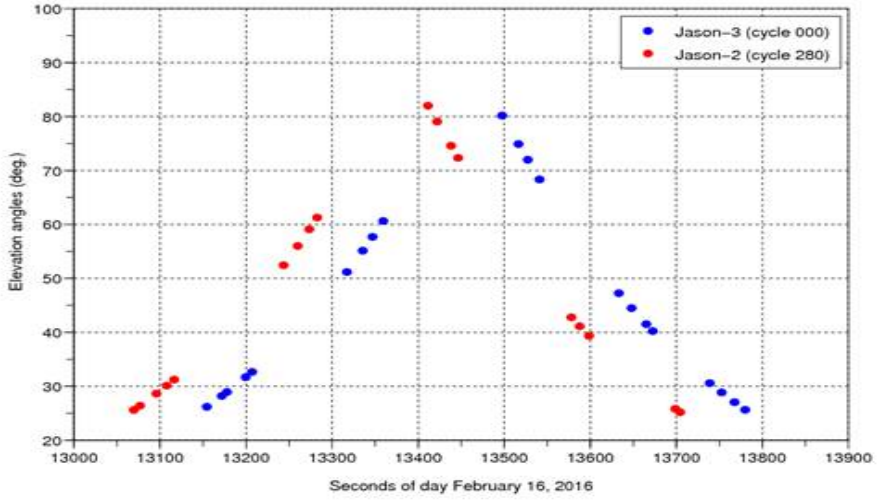
Model Summary	std1504 (new: OSTST-2015)
Station coordinates	**ITRF2008 (**SLRF2008, DPOD2008v15**)**
Geocenter motion	annual model (Ries, 2013)
Dynamic tides	GOT4.10 (50x50)
Ocean loading	GOT4.10
J2 & J3 Cr	Previously tuned for Jason-2. **Tuned for Jason-3**
Solar array orientation	**Quaternions (Jason-1,2,3)**
DORIS Troposphere	VMF1
J1/J2/J3 OPR	12-hr
Pole Model	IERS2010
Static gravity	GOCO2S (> L=5)
TVG	Harmonic piecewise fit to 5x5 weekly solutions



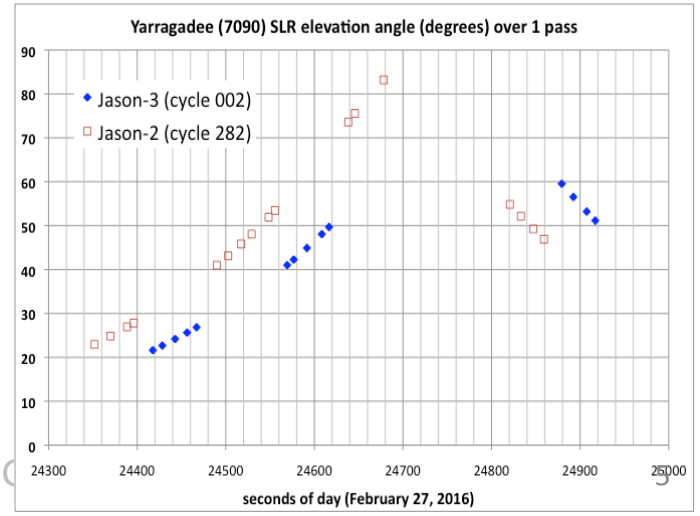


SLR Tracking for J2, J3 (2016) similar to that provided for earlier missions; Amount of data was similar for both satellites due to interleaving during the satellite passes.

Herstmonceux (UK), #7840



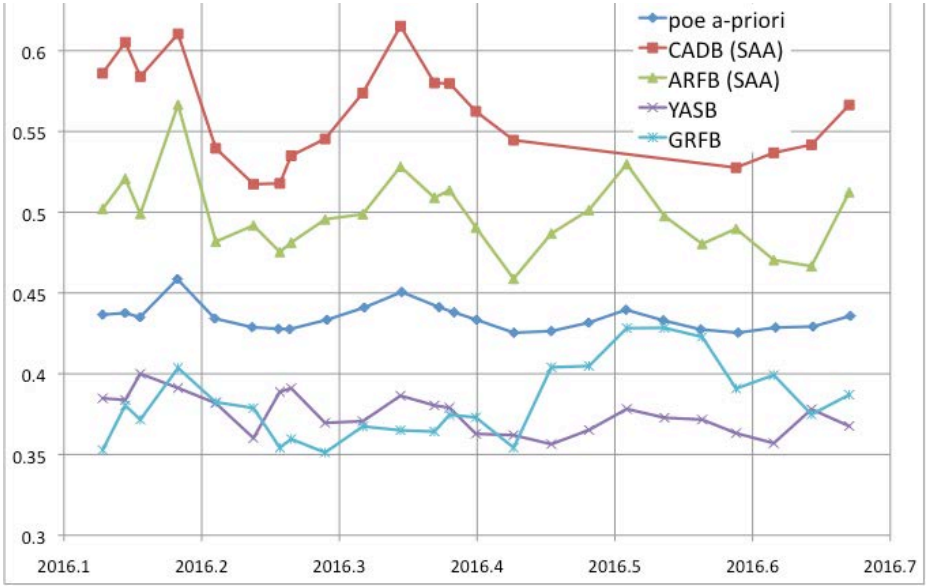
Yarragadee (Australia), #7090

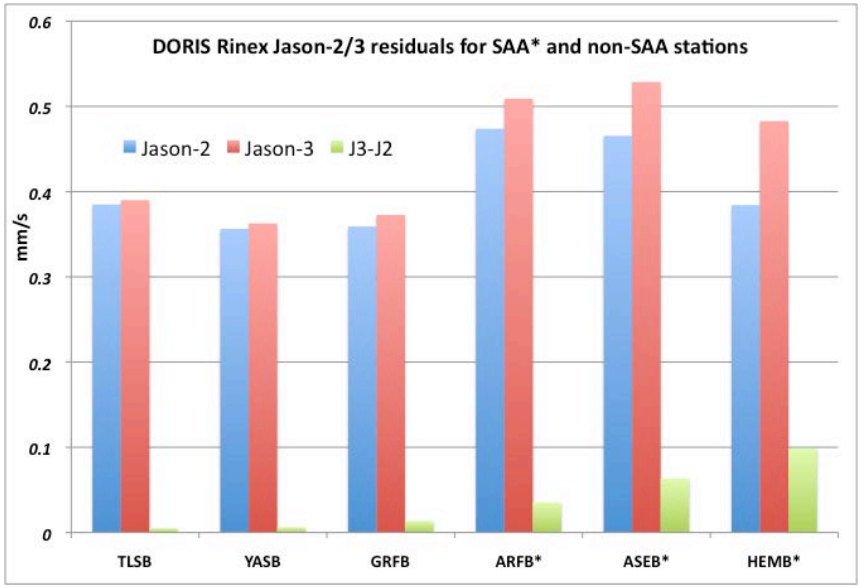


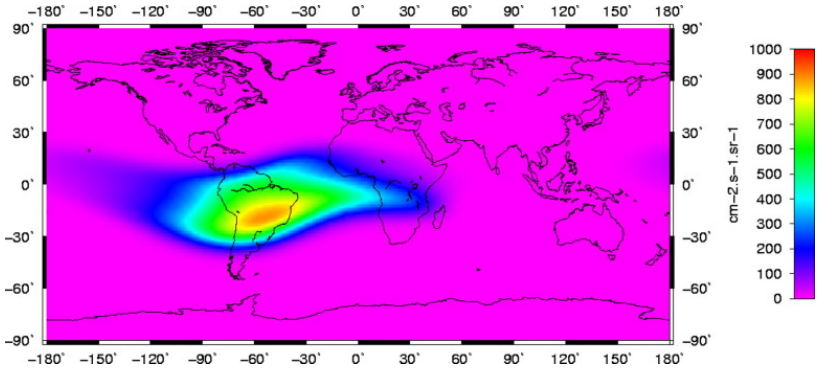
tellites at C

Jason-3 DORIS Status (I)

Jason-3 DORIS RMS of fit (select stations)







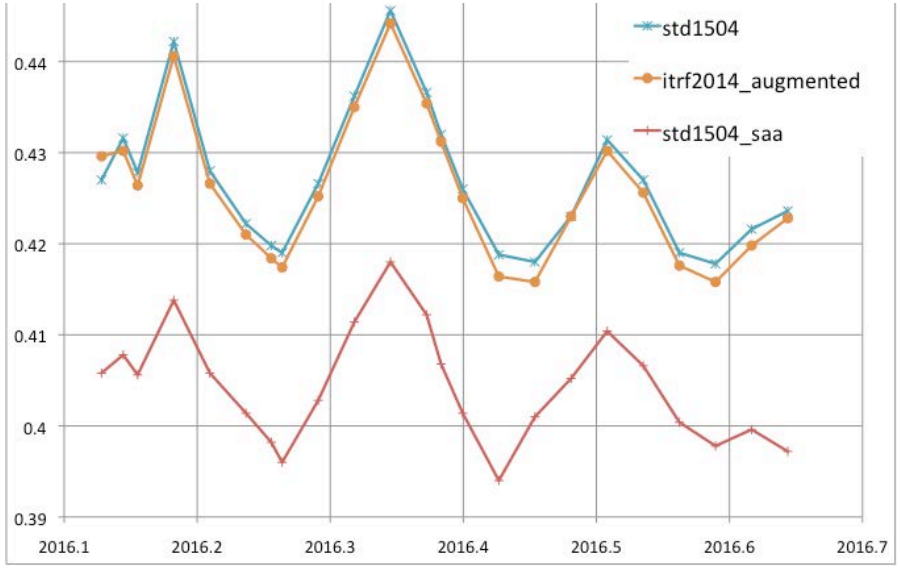
Jason-3 DORIS RMS of fit increases by 10-20% (*compared to Jason-2*) for stations in vicinity of the "SAA (*South Atlantic Anomaly*)".

Jason-2 CARMEN 85MeV Integrated Proton Flux Map (2009-2011)
(*Fig. 11, Capdeville et al., Adv. Space Res., 2016*)

Jason-3 DORIS Status (II)

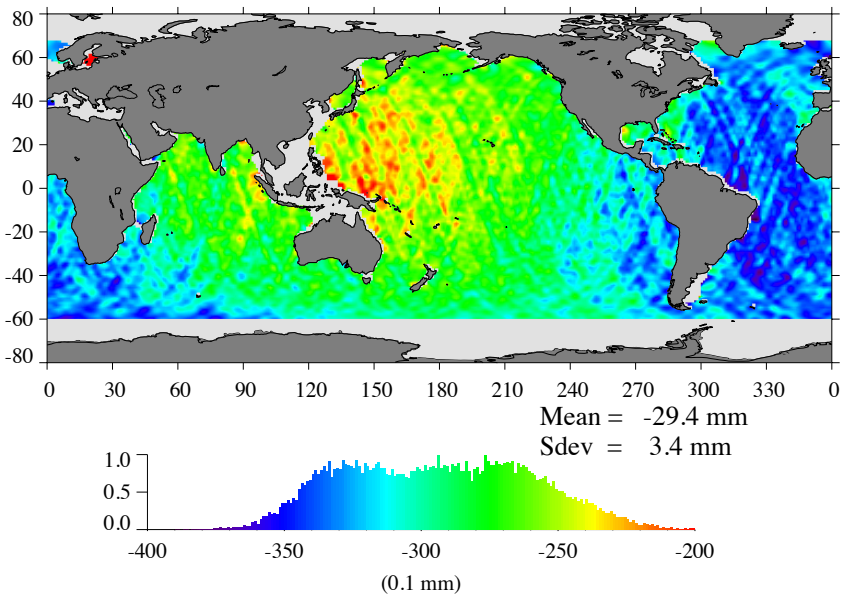
SAA stations: downweight by ~3X compared to non-SAA stations (Intercalibration period: ARFB, ASEB, CADB, HEMB, KRWB, LICB, SAPC)

Jason-3 DORIS RMS of fit without & with downweighting for SAA stations

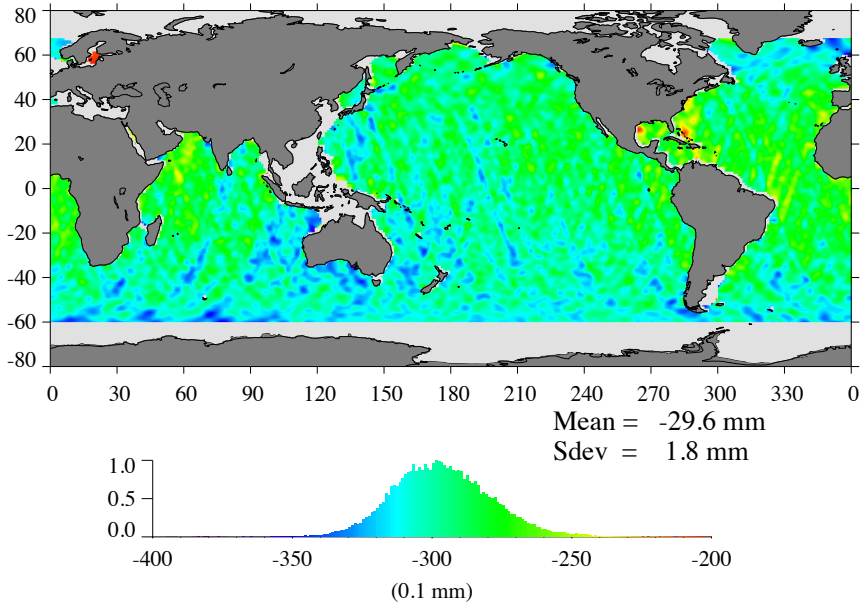


Jason3-Jason2 SSH differences over intercalibration period for SLR+DORIS orbits (ITRF2008)

Jason-3 DORIS SAA stations: No downweighting



Jason-3 DORIS SAA stations: with 3X downweighting



Std. Deviation of SSH differences is reduced from 3.4 mm to 1.8 mm; Obvious geographic signature in SSH differences is removed.

Jason-3 SLR & DORIS Offset Tuning

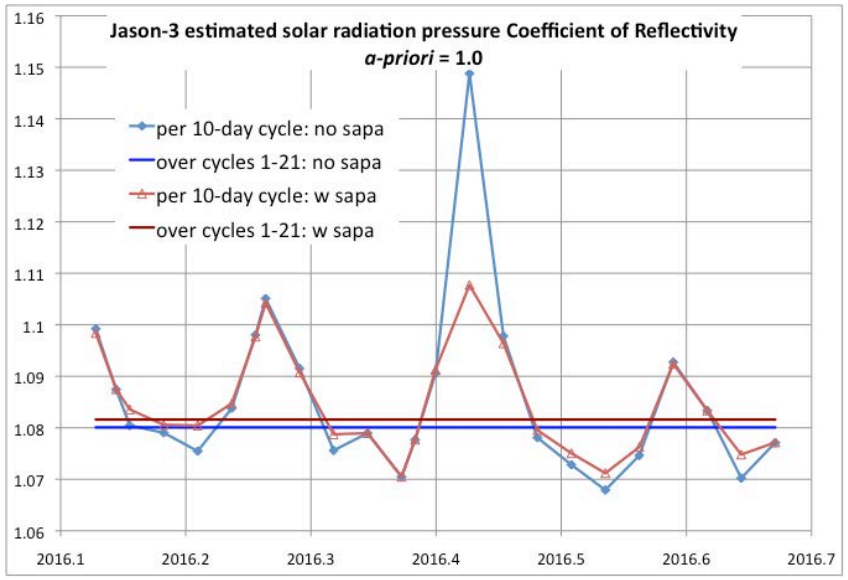
- cycles 1-21 SLR+DORIS (160217 – 160913)
- SLR/DORIS X/Z antenna offsets (m)

Offset (m)	a-priori	correction to a-priori	sigma	final value applied
SLR X	1.194	0.0064	0.00153	1.200
SLR Z	0.6838	0.00183	0.00076	0.6856
DORIS X	2.4128	-0.0017	0.00226	2.4111
DORIS Z	0.9305	0.00343	0.00208	0.9339

Total adjustment is approx. +6 mm & +2 mm in (X,Z) for SLR and approx. -2 mm, & +3 mm in (X,Z) for DORIS

Jason-3 Macromodel Tuning

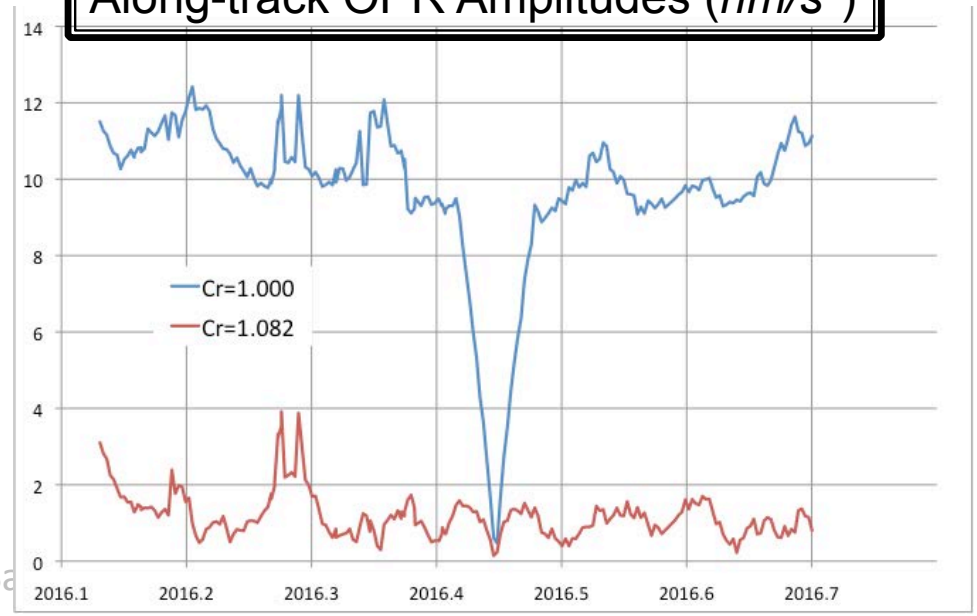
Jason-3:
Macromodel Tuning (C_r) without & with solar array quaternions



We adopt a mean Cr = 1.082 from an average determined over Jason-3 cycles 1-21.

The along-track OPR amplitudes are reduced from ~10 *nm/s²* to ~1.5 *nm/s²*.

Jason-3:
Along-track OPR Amplitudes (*nm/s²*)



Lemoine et al., 2016; Status of POD for Altimeter Sa

Station complement (Reference Frame), SLR+DORIS POD test sets

SLR Test	Description / Number stations
slrf2008	SLRF2008 (v150928) / 169
itrf2014_ augmented	ITRF2014 (IGN) / 139 + missing stations from SLRF2008 rotated to ITRF2014 (14 parameter transformation)

DORIS Test	Description / Number stations
dpod2008	DPOD2008_v15 / 187 (v14 + 9 new sites)
itrf2014_ augmented	ITRF2014 (IGN) / 160 + missing stations from DPOD2008 rotated to ITRF2014 (14 parameter transformation)
DPOD2014.v02	DORIS-only cumulative solution (see OSTST POD splinter poster, Moreaux et al., 2016)

itrf2008 for the std1504 orbits = slrf2008 + dpod2008

Jason-2 GSFC std1504-based orbit performance 080712-160831 (cycles 1-300a)

Test SLR+DORIS orbits	DORIS points	SLR points	DORIS RMS (mm/s)	SLR RMS (cm)	Xover ¶ RMS (cm)
std1504 (ITRF2008)	162513	4109	0.3810	0.877	5.325
std1504_rx (DORIS Pandor Rinex)	171739	4210	0.4113	0.901	5.322
itrf2014_augmented	162394	4211	0.3798	0.824	5.321
dpod2014	160545	4203	0.3654	0.803	5.321

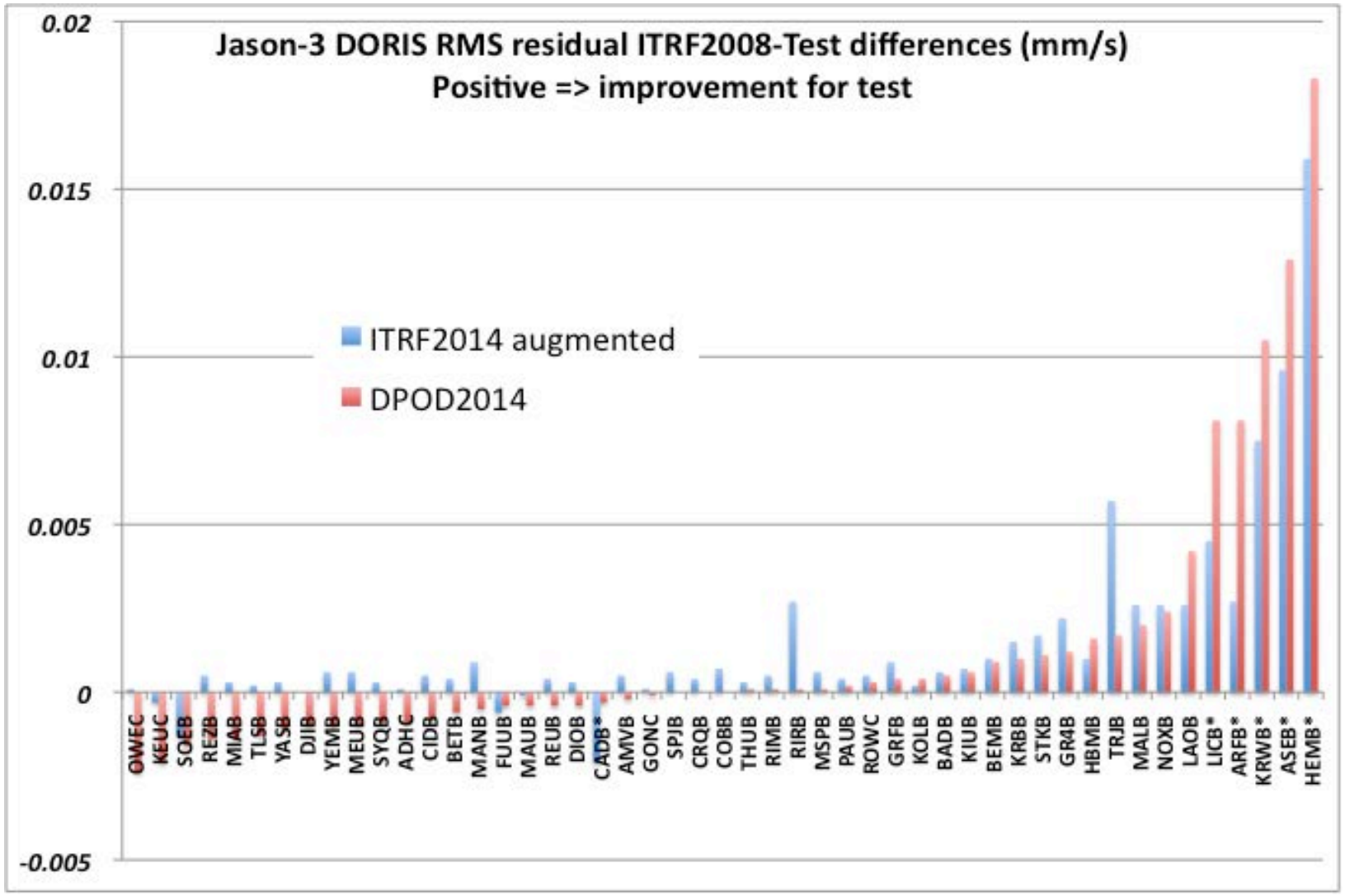
¶ (Xover RMS computed from cycles 1-257 only)

Jason-3 GSFC std1504-based orbit performance 160217-160922 (cycles 1-22)

Test SLR+DORIS orbits	DORIS points	SLR points	DORIS RMS (mm/s)	SLR RMS (cm)	Xover * RMS (cm)
std1504 (ITRF2008)	148846	2257	0.4264	0.921	5.316
std1504_saa **	148839	2257	0.4034	0.938	5.327
itrf2014_aug_saa	152461	2256	0.4030	0.863	5.325
dpod2014_saa	142621	2256	0.4015	0.840	5.321
reddyn_itrf2014_aug_saa	152766	2259	0.4010	1.069	5.297

* independent altimeter GDRT data cycles 1-19
** SAA DORIS stations down-weighted

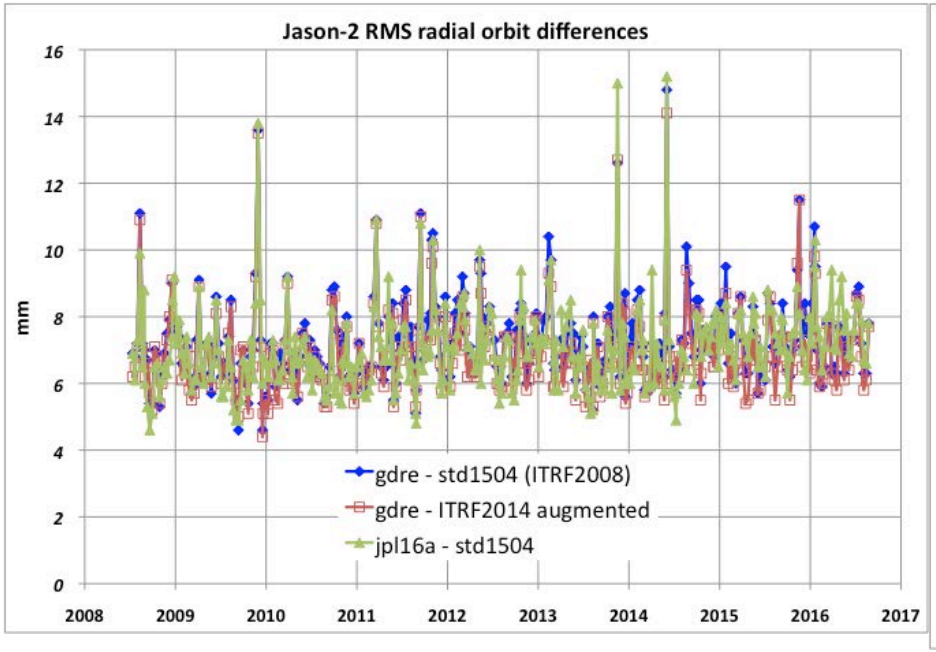
Jason-3 DORIS residuals (160217 – 160922)



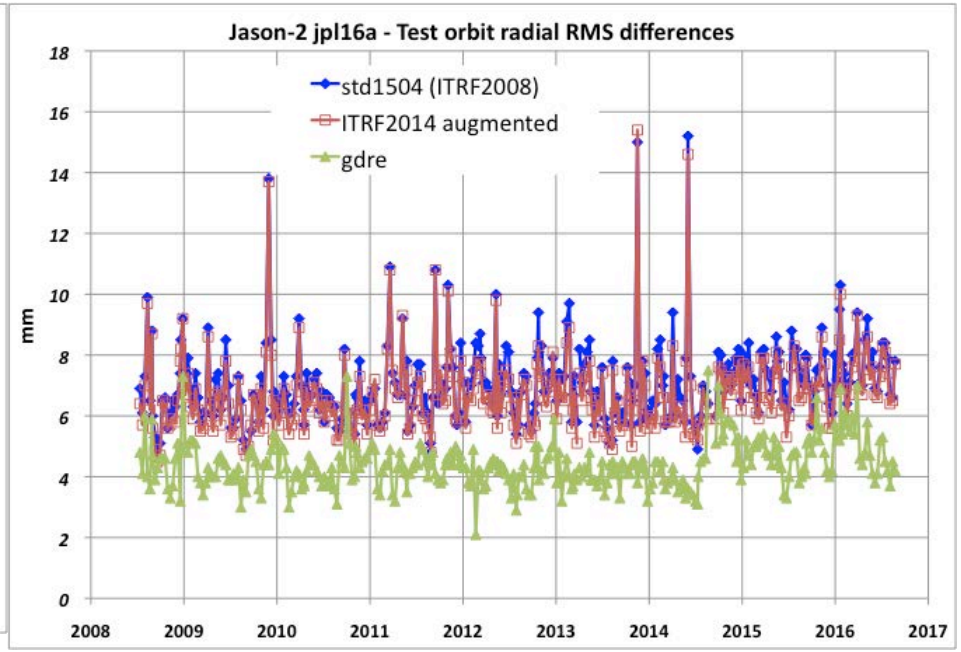
Lemoine et al., 2016; Status of POD for Altimeter Satellites at GSFC, OSTST, Nov. 2, 2016.

Jason-2:
Radial Orbit Differences

Jason-2 GSFC orbits vs. CNES/GDRE & JPL16a



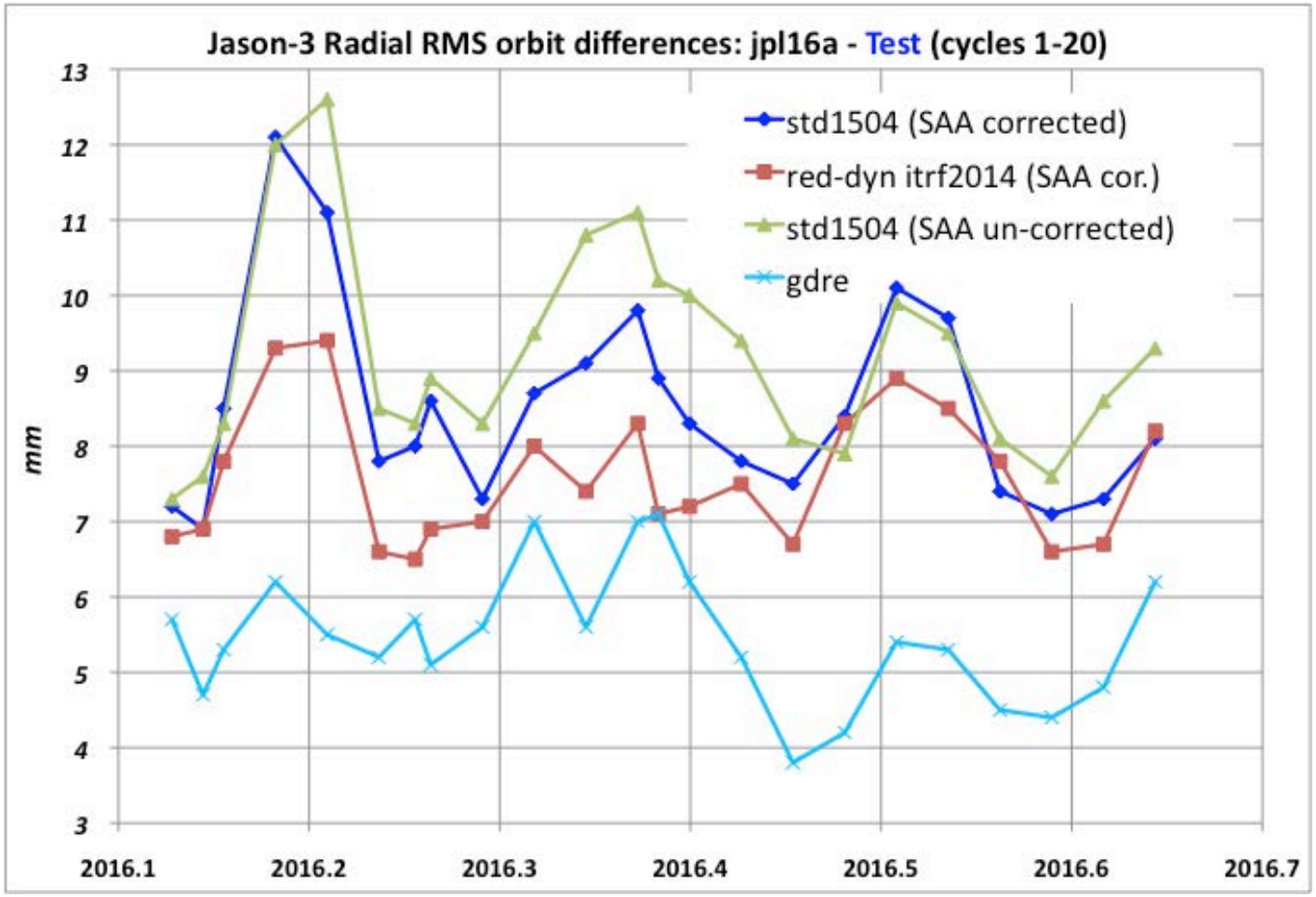
Jason-2 JPL16a orbits vs. CNES/GDRE & GSFC orbits



Lemoine et al., 2016; Status of POD for Altimeter Satellites at GSFC, OSTST, Nov. 2, 2016.

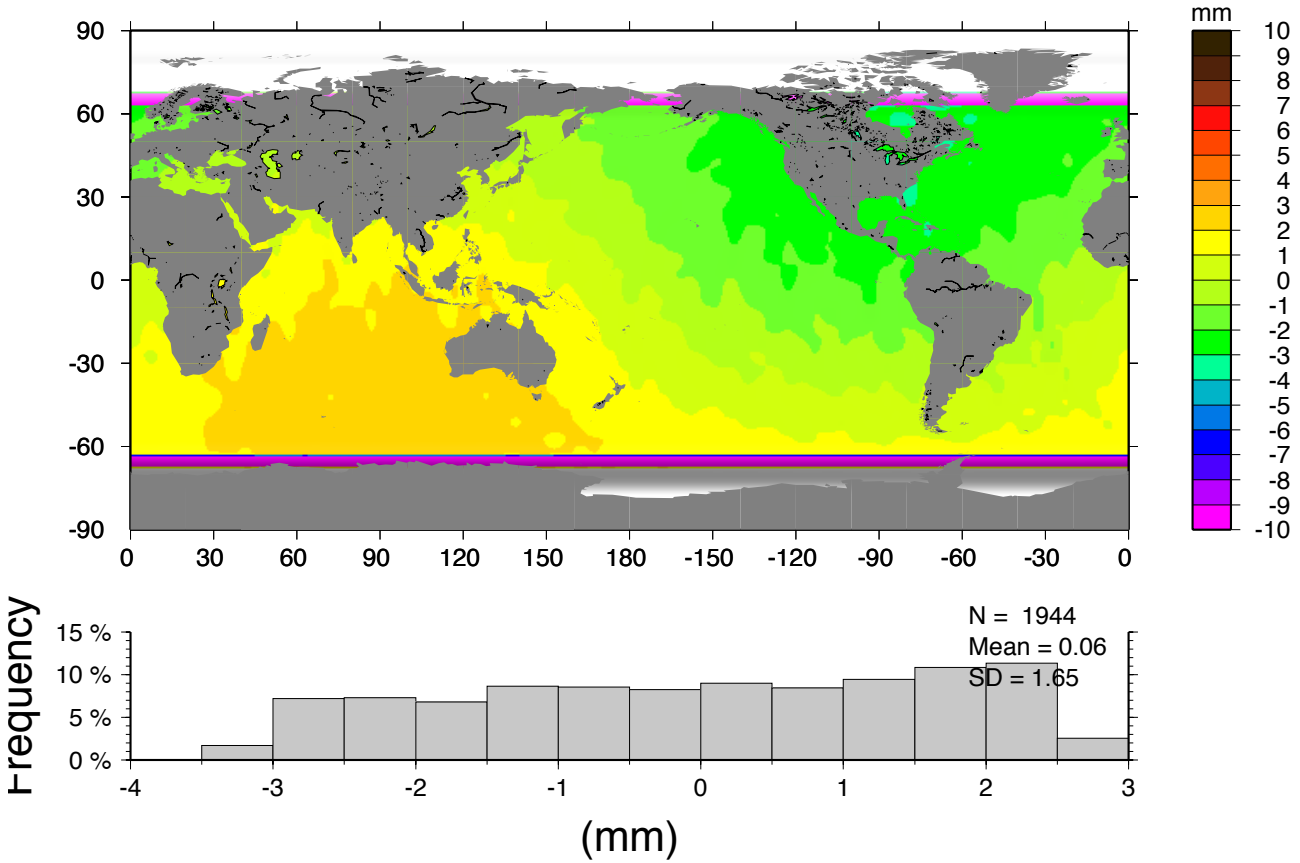
Jason-3:
Radial Orbit Differences

Jason-3 JPL16a orbits vs. CNES/GDRE & GSFC orbits



Lemoine et al., 2016; Status of POD for Altimeter Satellites at GSFC, OSTST, Nov. 2, 2016.

Jason-3: radial orbit differences ITRF2008 vs. ITRF2014 (cycles 1-22)

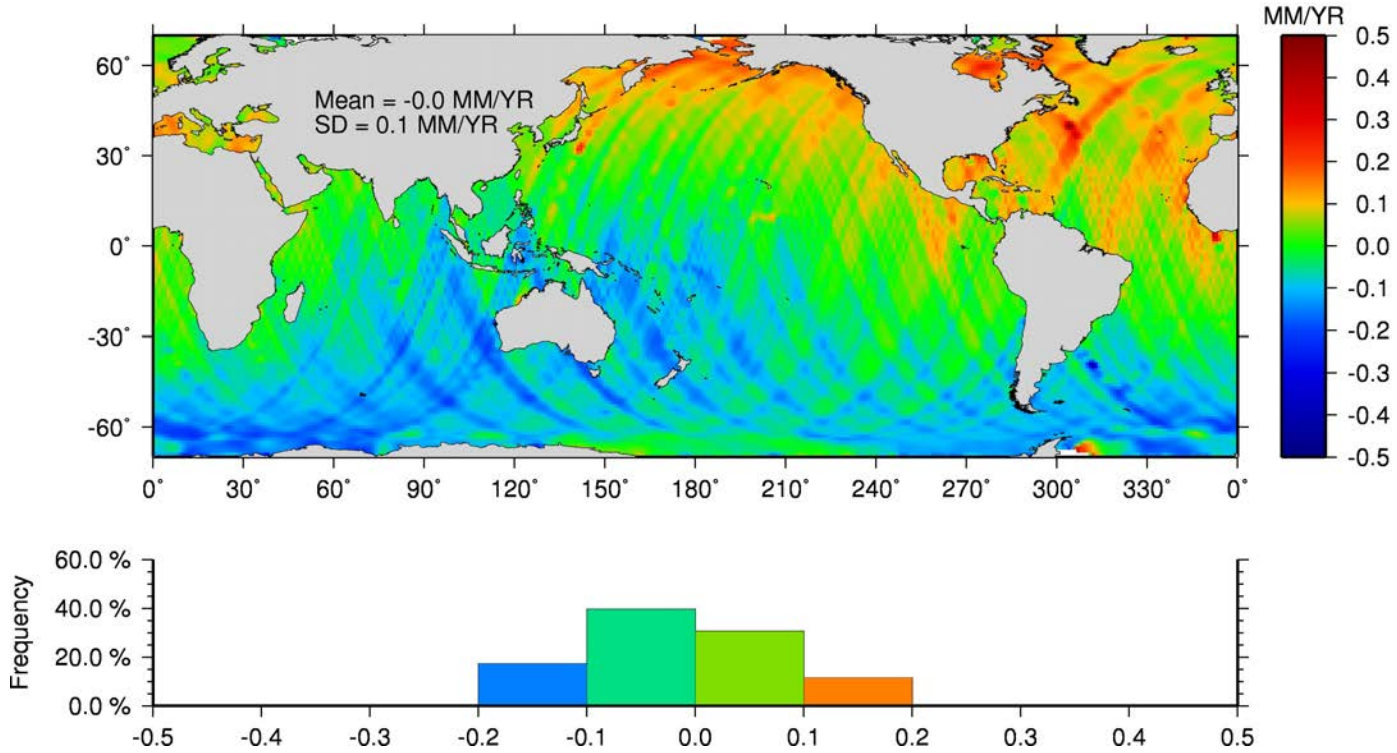


Jason-3 orbit evaluation using external ephemeris 160217-160823 (cycles 1-19)

Test Orbit	DORIS RMS (mm/s)	SLR RMS (cm)	Xover * RMS (cm)	Comment
GSFC std1504_saa (SLR +DORIS)	0.4425	1.022	5.327	Dynamic: ITRF2008
GSFC itrf2014_aug_saa	0.4426	1.074	5.325	Dynamic: ITRF2014
GSFC reddyn_itrf2014_aug_saa	0.4424	1.237	5.297	Reduced-dynamic
CNES gdre (GPS+DORIS)	0.4426	1.269	5.261	
JPL jpl16a (GPS)	0.4433	1.116	5.252	

Impact of New ITRF on Regional Sea Level Trends

Data Source: MEaSUREs merged product v3.2: ITRF2014-ITRF2008



Regional sea level trends over the time period of Jason-2 show a zonal bias and peak differences of ± 0.2 mm/yr at the higher latitudes

Lemoine et al., 2016; Status of POD for Altimeter Satellites at GSFC, OSTST, Nov. 2, 2016.

Summary

(1) The new ITRF2014 realization shows improvements for Jason-2 & Jason-3; the DORIS-only cumulative solution "DPOD2014" looks promising.

(2) The Jason-3 orbits have achieved radial RMS accuracy ≤ 1 cm, based on tests with external orbits (7-8 mm agreement!).

(3) Jason3-Jason2 SSH differences show no signature of orbit error!

(4) Over Jason-2, change in MSL, (ITRF2014-ITRF2008) = ± 0.2 mm/yr

(5) We have tuned the Jason-3 tracking point offsets & Cr for macromodel:

<u>Future work & concerns</u>.

(1) Update of geocenter model using *a priori* atmospheric loading, and introduction of APLOAD into new time series of orbits.

(2) Continue work to improve non-conservative (radiation pressure) modelling by working with Univ. College London, U.K. (*M. Ziebart, S. Bhattarai*).

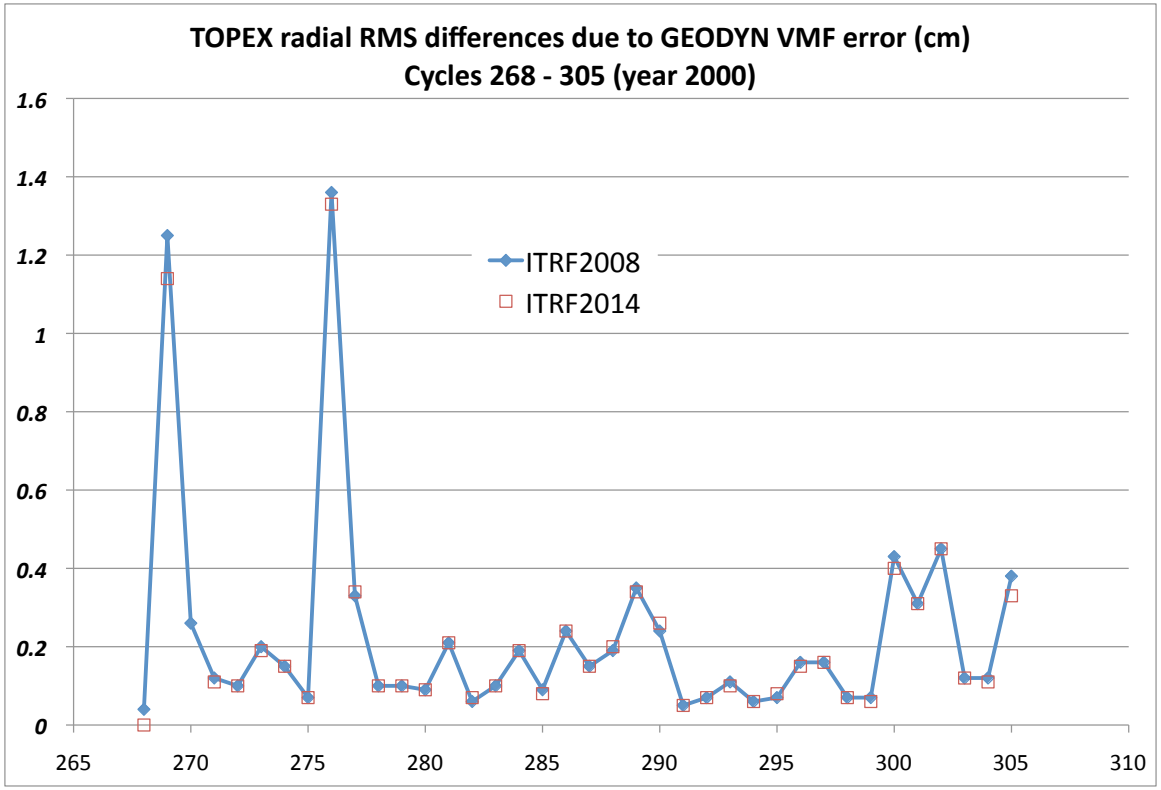
*****(3) Since the Jason-3/USO exhibits sensitivity to the SAA, we will need mitigation strategies and a "SAA-correction" model. Should operation of T2L2 (Jason-2) be continued to supply a precise reference for this model derivation?**

****(4) Update of pole model by IERS. The IERS2010 model is drifting away from reality. This could impact POD, and may "baked" into the new ITRF2014 in terms of artificial position and velocity errors (*see King & Watson, GJI, 2014, Fig. 2*)**

Backups

Pole model slide

Lemoine et al., 2016; Status of POD for Altimeter Satellites at GSFC, OSTST, Nov. 2, 2016.



The original TP orbits for the year 2000 (TP cycles 268-305) were affected by an error in the implementation of the Vienna Mapping Function1, used to compute troposphere refraction for the DORIS data. The corrected orbits were redelivered to the NASA CDDIS. The effect is < 2mm radial RMS for most cycles, except cycles 269 & 276, where sparser SLR tracking meant the error was more consequential.

tvg5x5 time series description

- **20 SLR+DORIS satellites, mostly 7-day arcs (1993-2014).**
(Lageos1, Lageos2, Starlette, Stella, Ajisai, TOPEX, Jason-1, Jason-2 SPOT-2, SPOT-3, SPOT4, Envisat, Larets, Cryosat-2, Blits, Westpac, Lares, Etalon-1, Etalon-2)
- **Subset solution analysis to converge on adopted weights.**
- **Smoothed with a moving window over several solution periods.**
- **Used for ITRF2013 @ NASA GSFC for IDS submission.**
- **Solution compares well with independent solutions to 4x4; Order 1 terms (C_{31}/S_{31}, C_{41}/S_{41}) not so well determined.**

stk5x5 description

Harmonic fit to tvg5x5 time series by time period.
1992.0 to 2003.0; 2003.0 to 2007.0; 2007.0 to 2014.0