Improved orbit time series for the Jason 2 & Jason-3 missions using SLR/DORIS data

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Introduction:

Accomplishments in the past year:

(1) Adopted a new (preliminary) set of orbit standards, for the Jason-2 & Jason-3 orbits; std1808a (*discussed in detail in this presentation*).

➔ THE NEW SLR/DORIS DYNAMIC ORBITS show 2-3 mm improvement in RADIAL ORBIT ERROR.

(2) Conducted a study to assess improving knowledge of the SLR/DORIS phase centers, and of the geocenter (→ *see Presentation by Nikita Zelensky in this session*).

(3) Contributed to development of DPOD2014, DORIS extension to ITRF2014 for Precise Orbit Determination. ("*DPOD2014: A new DORIS extension of ITRF2014 for precise orbit determination*", ***Moreaux et al., 2018, Adv. Space Res., 2018, doi:10.1016/j.asr.2018.08.043*)

(4) With Alexandre Belli (*NPP@ NASA GSFC*), evaluated using improved USO model on Jason-2, applied using DORIS RINEX data (*presented preliminary results at COSPAR2018, in Pasadena, California*).

NEW J2, J3 Orbits Delivered

Orbits were delivered to the POD Team, and are available upon request.

Jason-2: **std1808a cycles 1-303** (**GOCO05S, ITRF2014, IERS2014 mean pole**)
Jason-3: **std1808a**, **cycles 1-87** (**GOCO05S, ITRF2014, IERS2014 mean pole**)

ITRF2014-based orbits are delivered to MEASURES for Sea Level ESDR Product.
(std1504_dpod2014: (**GOCO02S + TVG5x5, ITRF2014, IERS2010 mean pole**)

New means of orbit delivery needs to be arranged, other than CDDIS.

GSFC POE Description (changes)

Models	*dpod2014v04*	*std1808a*
GEODYN version	1612	1802
gravity	GOCO02S +5x5 GSFC	GOCO05S
atmospheric gravity	ECMWF 50x50, 6-hour	GFZ 90X90 3-hour
mean pole	IERS2010	IERS2014 (linear)
integration step size	30 s	15 s
SRP	old TSI, Cr=0.945	new TSI, tuned SA+, X-, tuned Cr/arc
DPOD2014	Version 0.4	Version 2.0
LRA phase center	constant correction	constant + elevation correction
SLR bias template	gsfc2014 (ILRS_Data_Handling_File_2010.snx)	gsfc2018 (ILRS_Data_Handling_File_2018-05-04.snx)
estimate C31/S31 per arc	yes	no

GSFC POE Description (unchanged)

Models	***Std1504_dpod2014* and *std1808a***
Geocenter motion	**annual model (Ries, 2013)**
Dynamic tides	**GOT4.10c (50x50)**
Ocean loading	**GOT4.10c**
Solar array orientation	**Quaternions (Jason-2 & 3)**
DORIS Troposphere	**VMF1**
J2/J3 OPR	**per 12-hrs**
DORIS SAA stations	**Downweight by 3X (Jason-3 only).** **(ARFB,ASEB, CADB, EASB, HEMB, KRWB, LIBB, SAQC, SAOB, SCRB)**

Evaluate GOCO5s

GOCO05S: 280x280 static + Time-Variable, 100x100 linear+annual terms, determined with data from GRACE, GOCE, and 7-LEO-GPS and 6-SLR satellites (2003-2014).

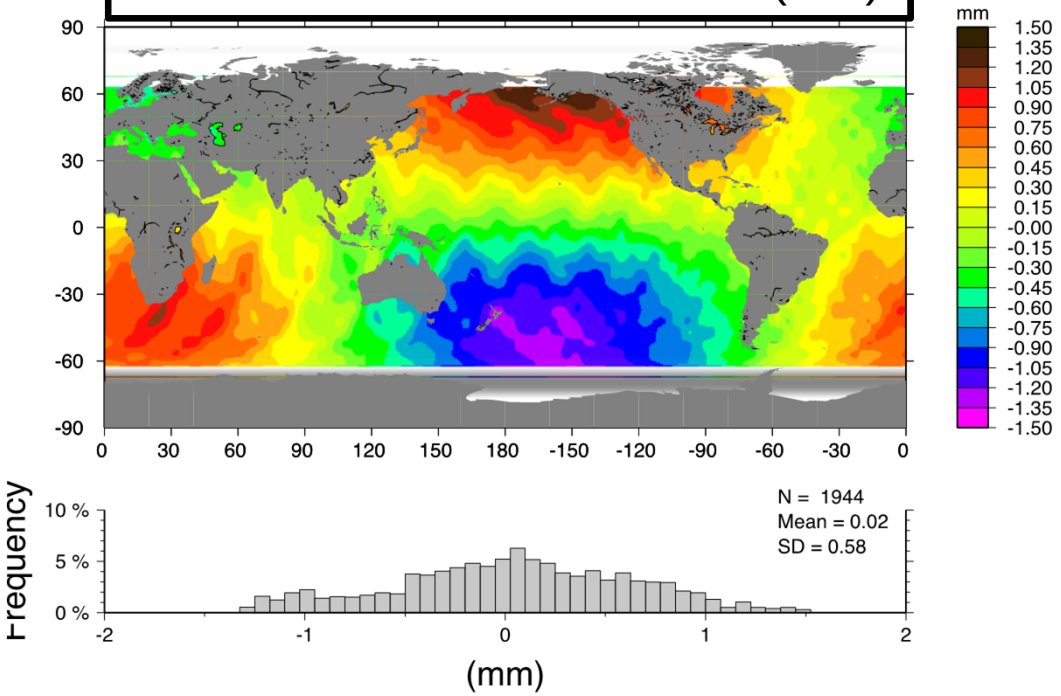
GOCO02S:
180x180 static. No Time-Variable component; TVG from GSFC 5X5 fits to SLR/DORIS weekly solutions (2003-2014) GSFC 5x5 linear+annual+semi-annual, + 20X20 GRACE-derived annual).

GOCO2S standard was "Cut and Paste".
GOC05S model is dynamically consistent, and easier to apply.

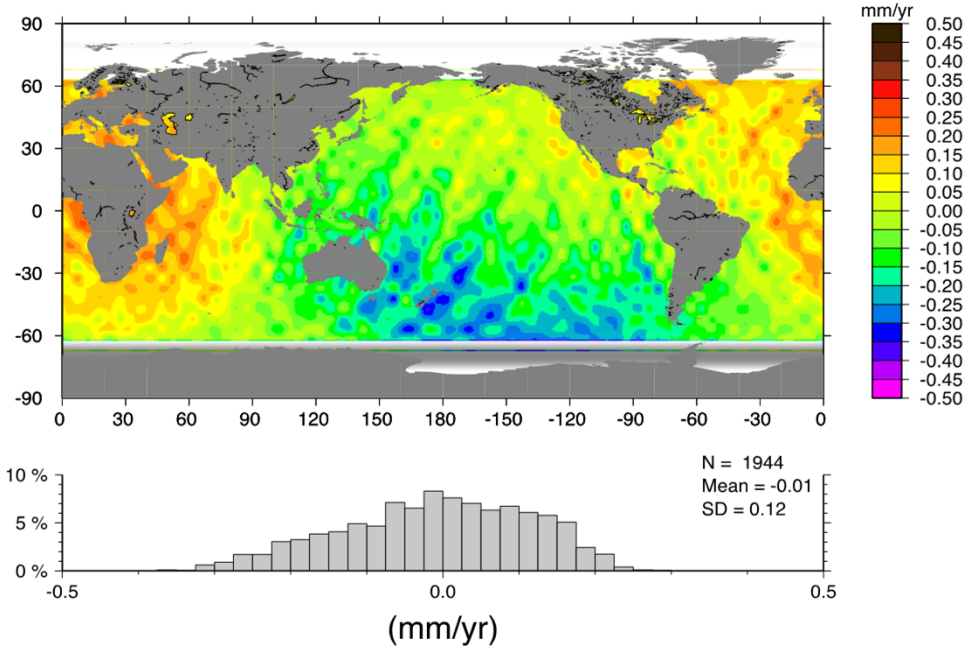
Jason-2 POD tests (2008-2017)	GOCO02s + TVG-etc.	GOCO05s	Comment
SLR (cm)	0.889	0.861	
DORIS (mm/s)	0.3766	0.3764	Larger improvements > 2014.
XOVER (cm)	5.428	5.418	Suggests 3 mm reduction in radial orbit error.
Radial orbit diffs. w. GDRE	7.1 mm	6.5 mm	GOCO05s vs. GOCO02s orbit diffs. Increase from ~3 mm (2008) to ~4.5 -5.0 mm (2017)
Radial orbit diffs. w. JPL17	7.0 mm	6.4 mm	

Mean Pole Model: IERS2010 vs. ITRF2014 SLR+DORIS POD Tests (Jason-3 Test span: 160217 - 180629)

Mean Radial Orbit Differences (mm)



Mean Radial Orbit Difference Rates (mm/y)



iers2010_mp – itrf2014_mp		
Orbit difference RMS (mm)		
radial	**cross-track**	**along-track**
1.4	13.1	8.9

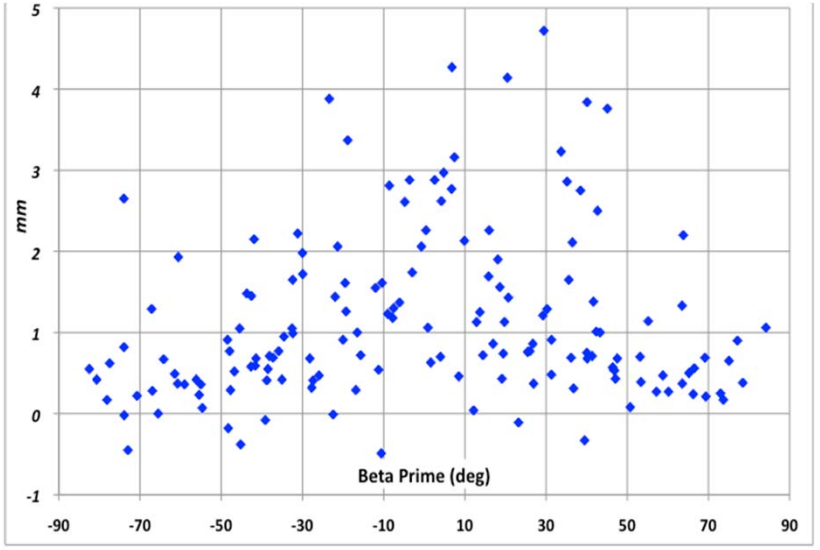
Test Name	Description	DORIS RMS (mm/s)	SLR RMS (cm)
iers2010_mp	IERS2010 mean pole GEODYN 1612	0.3841	0.977
itrf2014_mp	ITRF2014 mean pole GEODYN 1802	0.3839	0.937

SRP model evaluation (Jason-2) - I

Features	old SRP	new SRP
TSI (Total Solar Irradiance)	1367.0 W/m^2	1360.45 W/m^2
Macromodel	*A priori*	tune specular reflectivity of SA+, X- panels
C_R	0.945	separate estimate per arc
Integration step	30 s	15 s

Jason-2 Avg. RMS of SLR/DORIS Residuals (Cycles 1-128)		
SRP model	DORIS (mm/s)	SLR (cm)
old SRP	0.3719	0.879
new SRP	0.3715	0.766

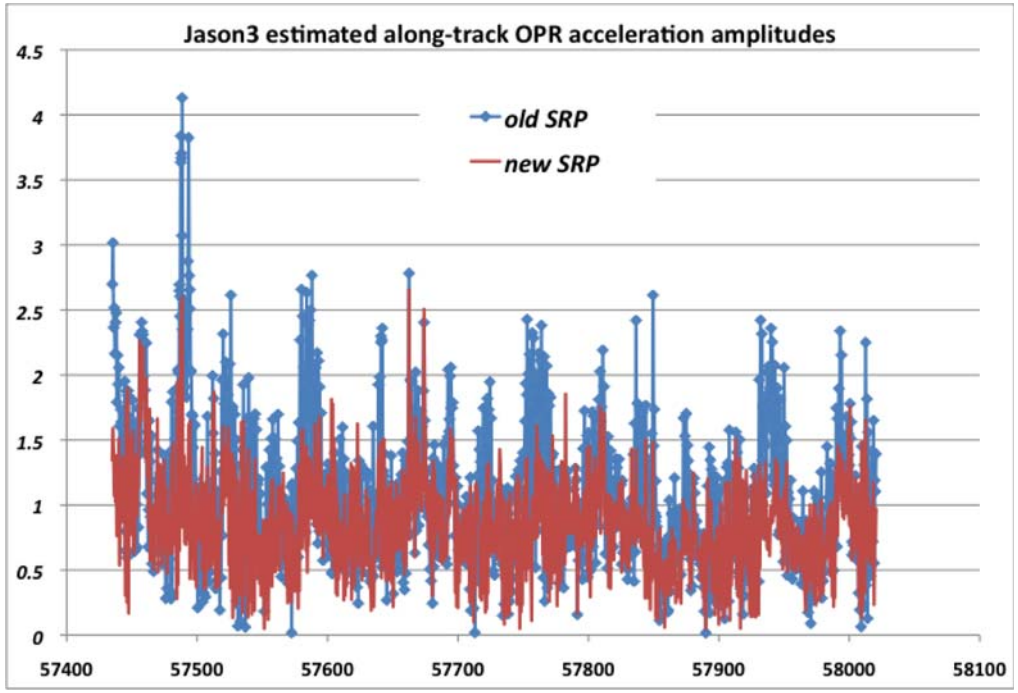
Jason-2 RMS SLR Residuals Difference (Old SRP – New SRP) vs. Beta Prime



1. SLR & DORIS RMS of fit improves even with use of 12-hr OPRs.
2. Improvement of SLR residuals largest at low beta prime: 3-4 mm

SRP model evaluation (Jason-3) - II

Jason-3 Avg. RMS of SLR/DORIS Residuals (cycles 1-81)		
Residuals	**DORIS (mm/s)**	**SLR (cm)**
old SRP	0.3883	0.944
new SRP	0.3841	0.910

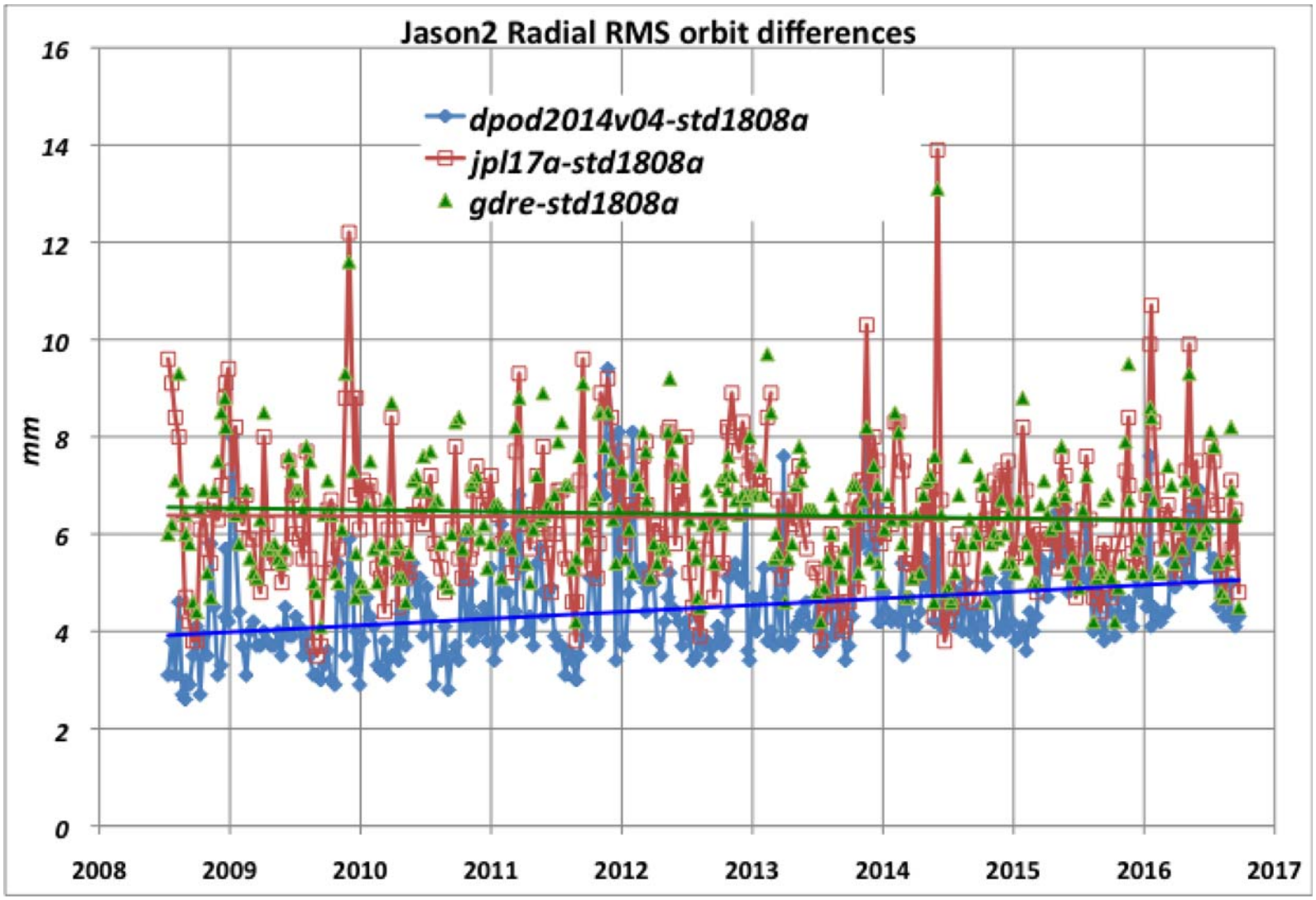


Jason-3 OPR Estimates (nm/s^2), cycles 1-59		
Along-track	**Median**	**RMS**
old SRP	0.98	1.23
new SRP	0.84	0.94
Cross-track	**Median**	**RMS**
old SRP	3.87	4.62
new SRP	3.80	4.59

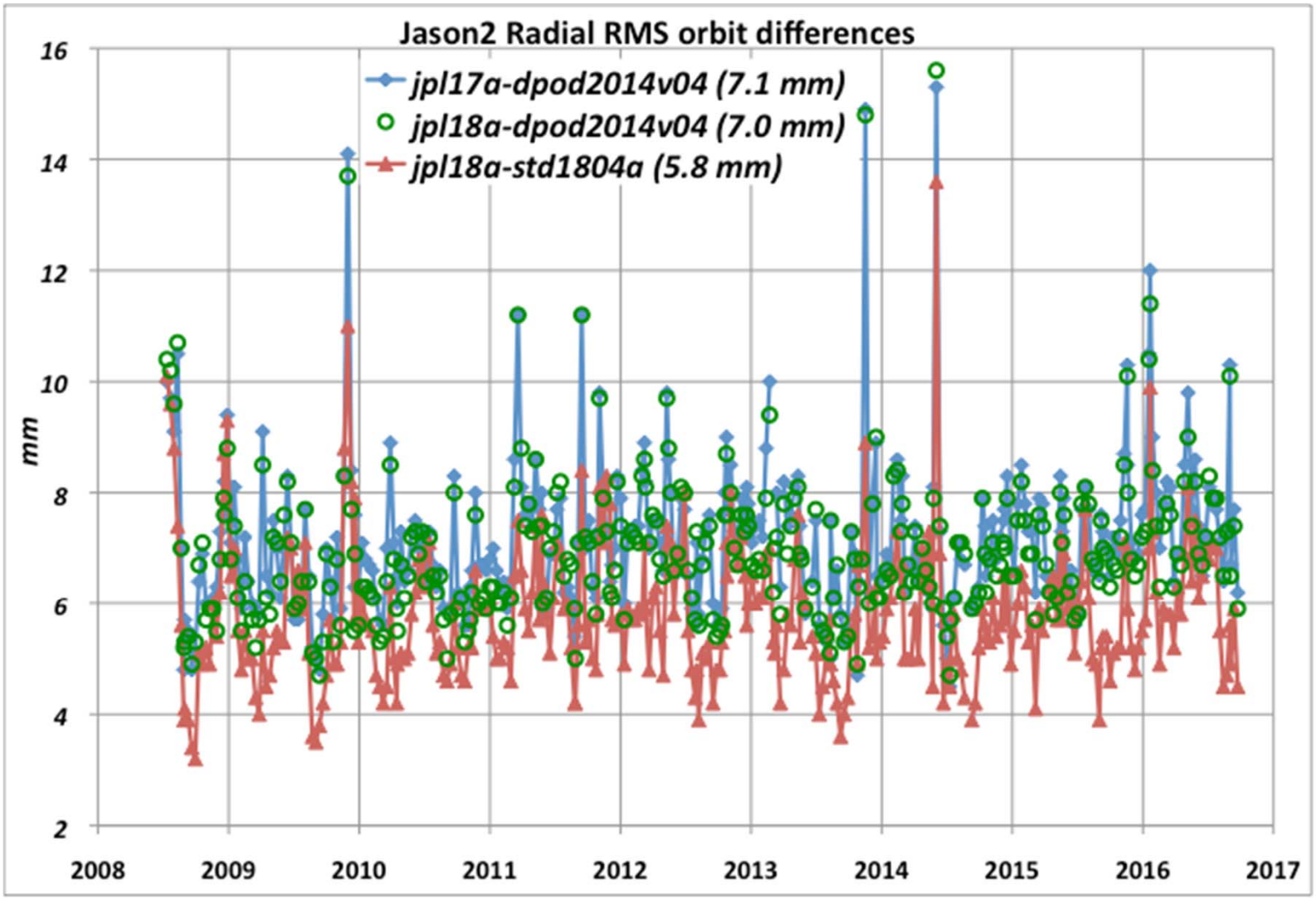
1. New SRP model reduces Jason-3 SLR & DORIS Residuals, even with 12-hr OPR's.
2. Like with Jason-2, along-track residual OPR's are reduced, but cross-track OPR's are largely unchanged.

Next:
Jason-2 & Jason-3 Orbit comparisons

Jason-2 RMS Radial Orbit Differences



Jason-2 RMS Radial Orbit Differences



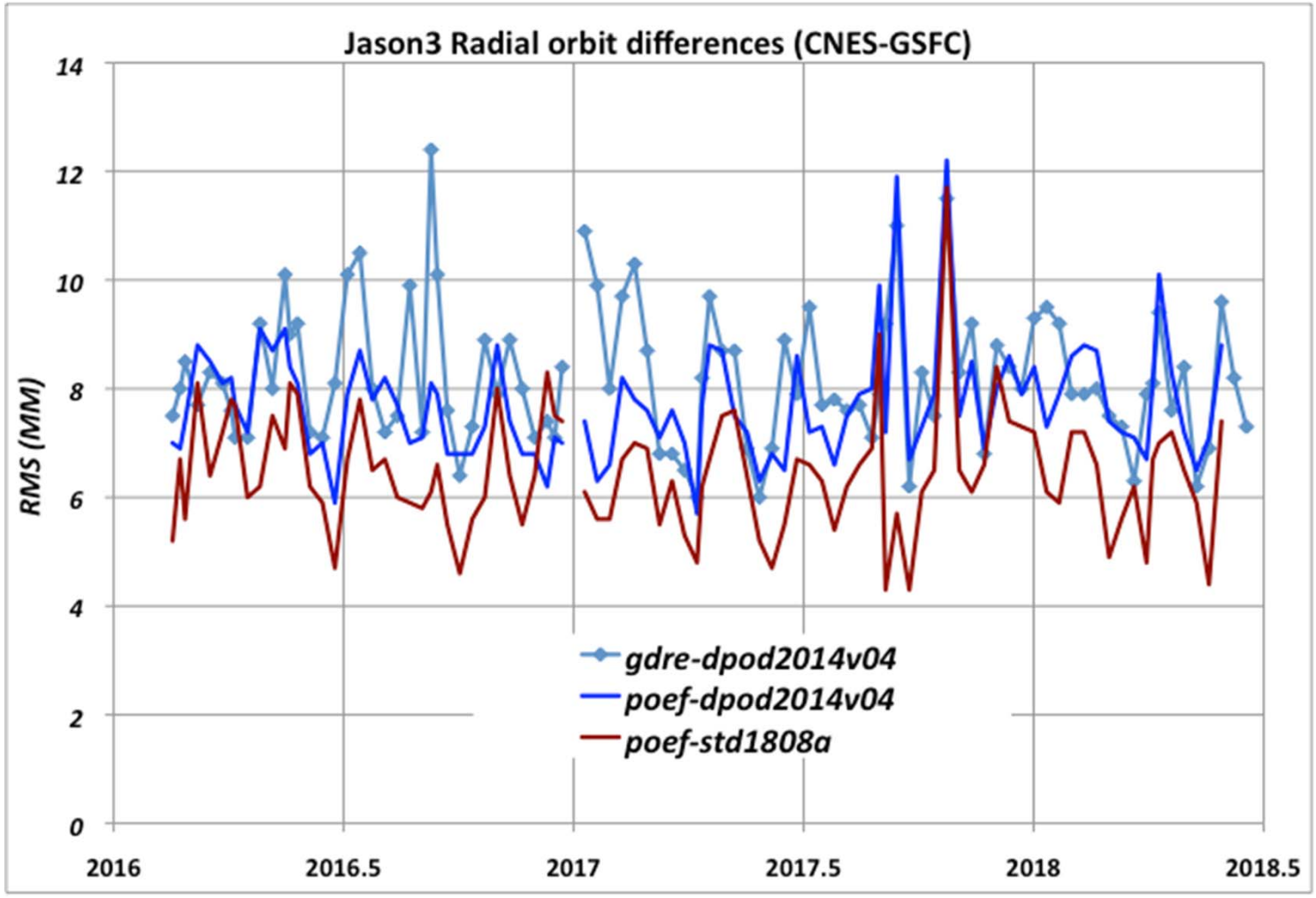
Jason-2 RMS Radial Orbit Differences

Jason-2 RMS orbit differences (mm)			
Difference	**radial**	**cross-trk**	**along-trk**
dpod2014v04-std1808a	4.5	11.2	15.8
jpl17a - dpod2014v04	7.2	22.0	27.9
jpl17a - std1808a	6.4	19.2	24.5
gdre - dpod2014v04	7.2	20.9	27.5
gdre - std1808a	6.4	18.2	24.5

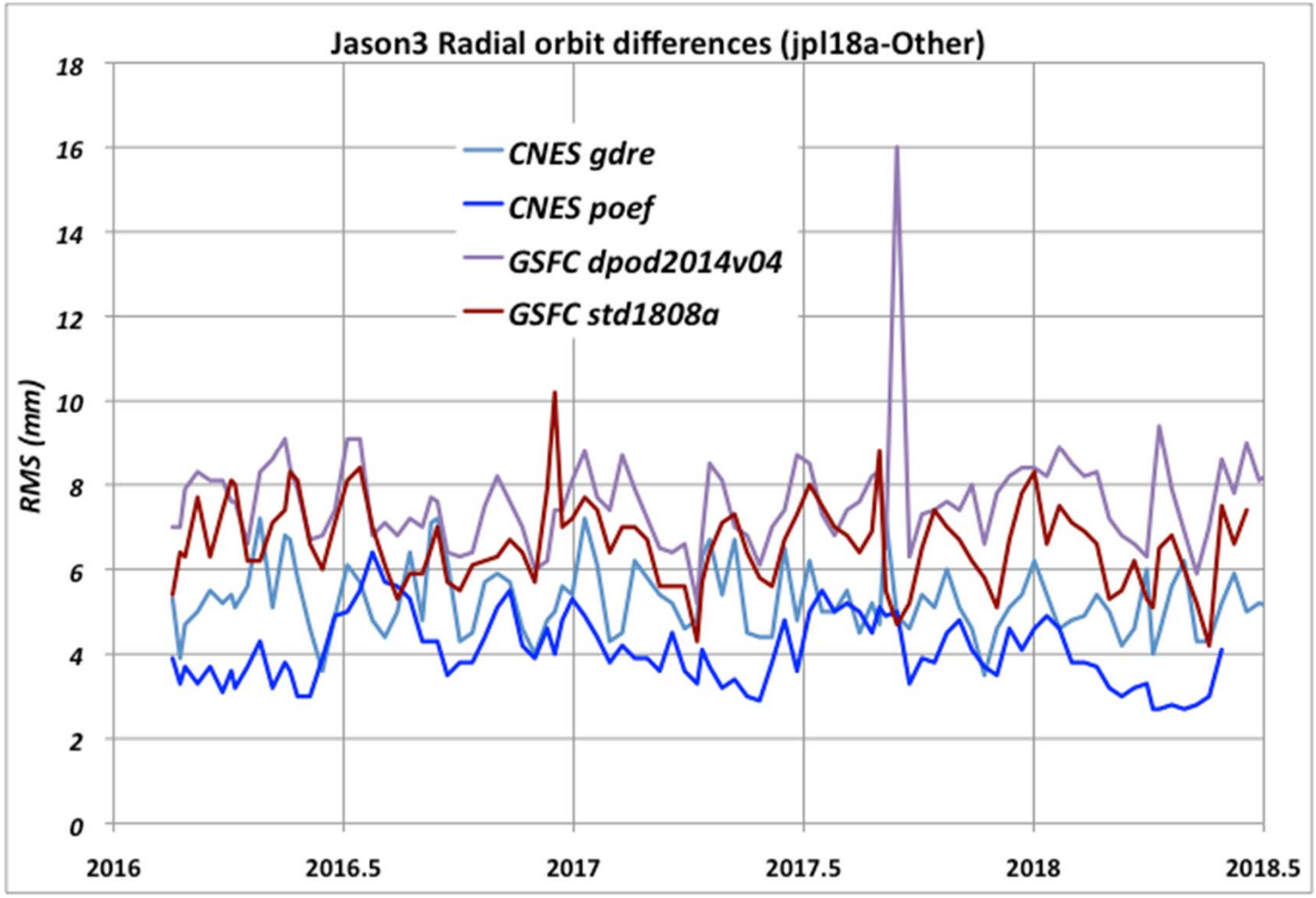
Jason-2 SLR, DORIS, and Altimeter Crossover Avg. RMS of Fit from GEODYN "External Ephemeris" comparisons.

Jason-2 external ephemeris residual comparison cycles 1-303 (080712 – 161002)			
J2 orbit cycles 1-303	**DORIS (mm/s)**	**SLR (cm)**	**Xover (cm)**
dpod2014v04 (gsfc, 2017)	**0.3829**	**1.021**	**5.312**
std1808a (gsfc, 2018)	**0.3895**	**1.150**	**5.285**
jpl17a	**0.3834**	**1.149**	**5.243**
jpl18a	**0.3895**	**1.216**	**5.220**
gdre	**0.3826**	**1.202**	**5.237**

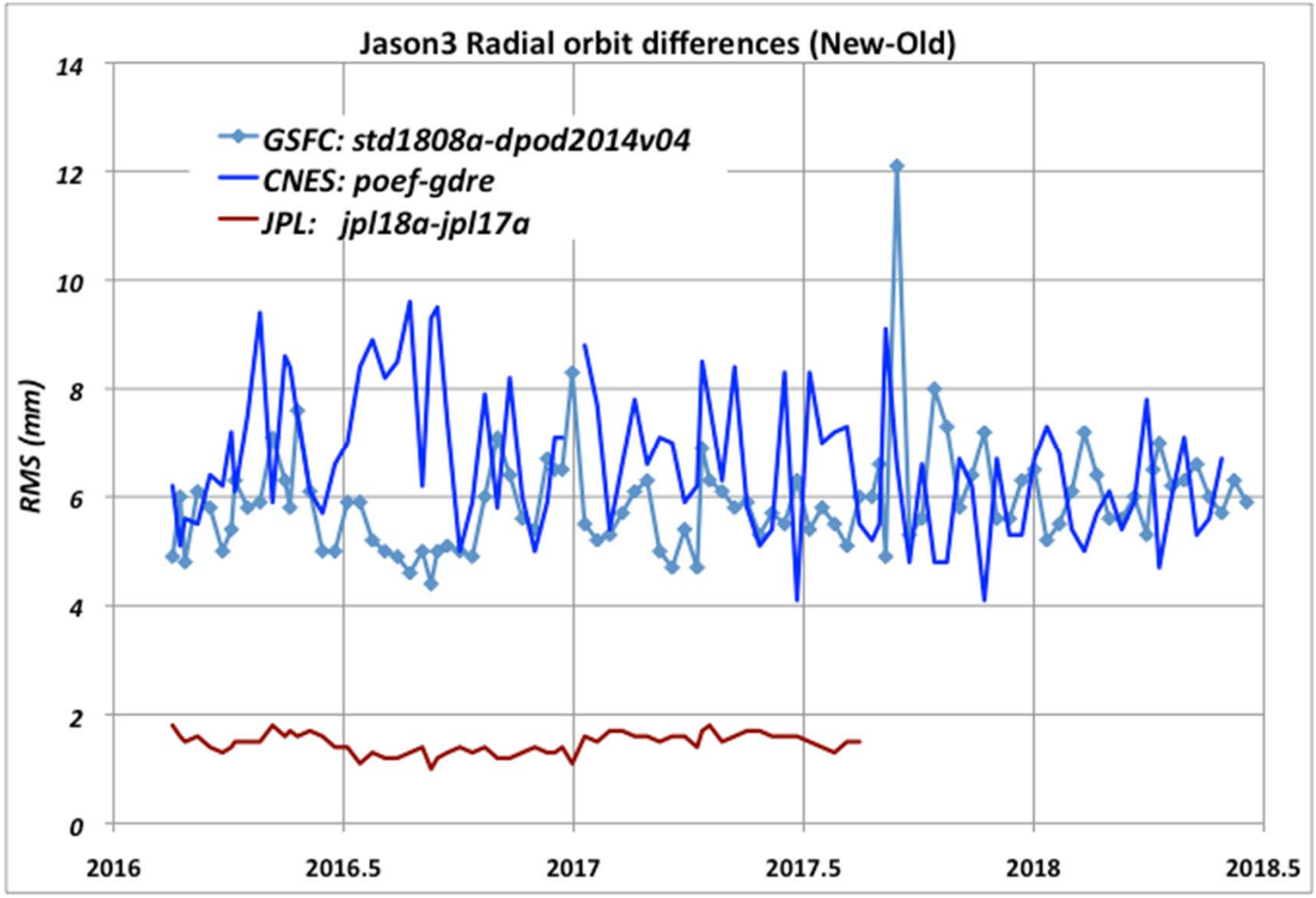
Jason-3 RMS Radial Orbit Differences



Jason-3 RMS Radial Orbit Differences (all orbits vs. jpl18a)



Jason-3 RMS Radial Orbit Differences (each center's orbit with its predecessor)

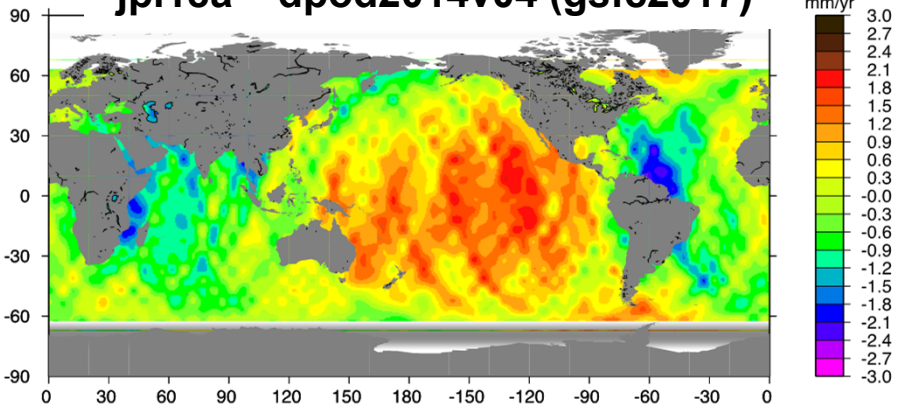


Jason-3 SLR, DORIS, and Altimeter Crossover Avg. RMS of Fit from GEODYN "External Ephemeris" comparisons.

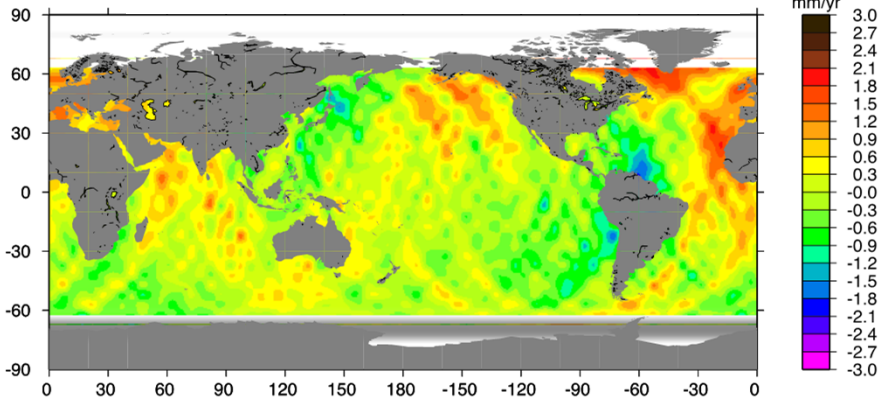
Jason3 residuals summary using external ephemeris cycles 1-85			
Orbit	**DORIS (mm/s)**	**SLR (cm)**	**Xover (cm)**
GSFC, dpod2014v04	0.4151	0.985	5.262
GSFC, std1808a	0.4151	1.205	5.247
CNES, gdre	0.4151	1.258	5.196
CNES, poef	0.4147	1.118	5.220
JPL, jpl18a	0.4153	1.067	5.196

Jason3 radial orbit difference rates (mm/yr)
(160217 – 180818; 92 cycles)

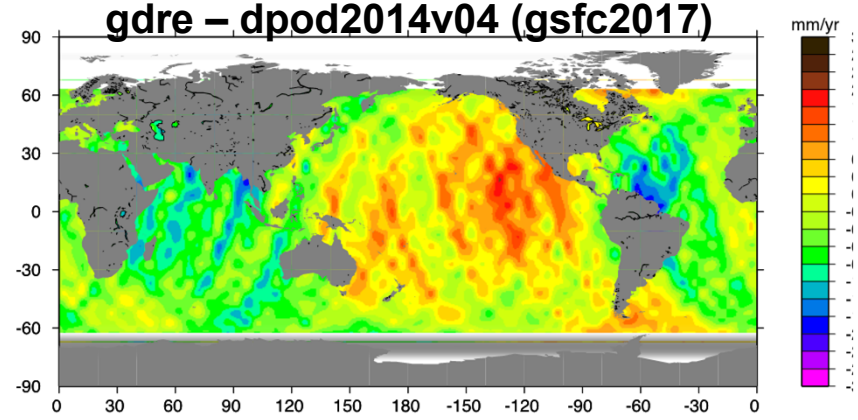
jpl18a – dpod2014v04 (gsfc2017)



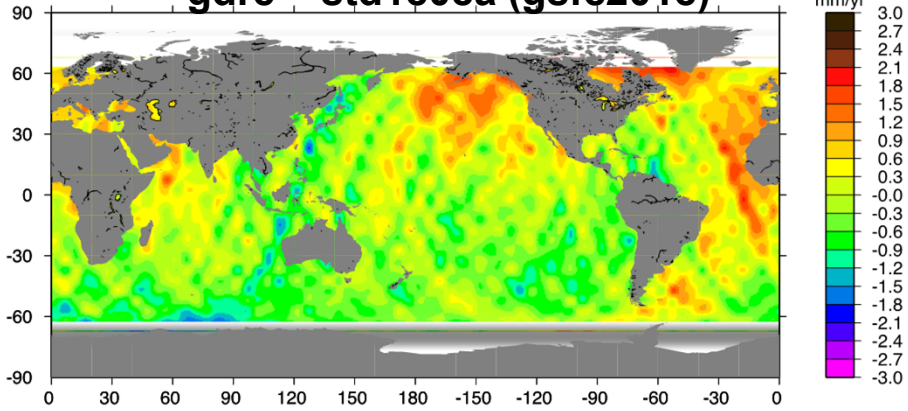
jpl18a – std1808a (gsfc2018)



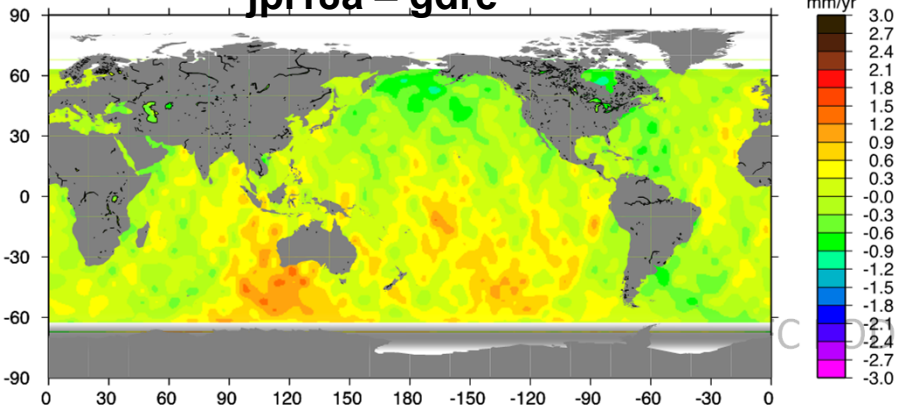
gdre – dpod2014v04 (gsfc2017)



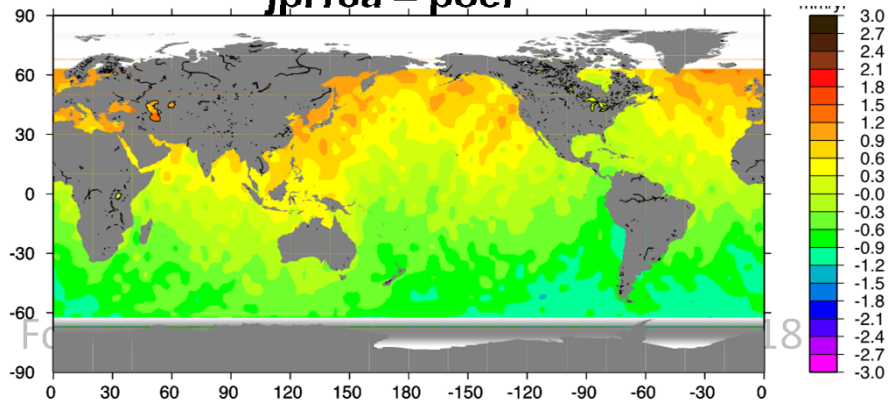
gdre – std1808a (gsfc2018)



jpl18a – gdre



jpl18a – poef



Summary

(1) We have produced a new series of SLR+DORIS "dynamic" orbits based on a newer GRACE+GOCE-based gravity model, more detailed modelling of Time-variable gravity, application of the IERS2014 linear mean pole, improved SRP modeling and other changes (std1808a).
(2) The new orbit series is improvement over the previous series (dpod2014) presented to the 2017 OSTST.
(3) The ensemble of orbit tests and comparisons (GSFC, JPL, CNES) allow us to assert that the radial orbit error on Jason-2, Jason-3 is now at the level of ~8 mm RMS.

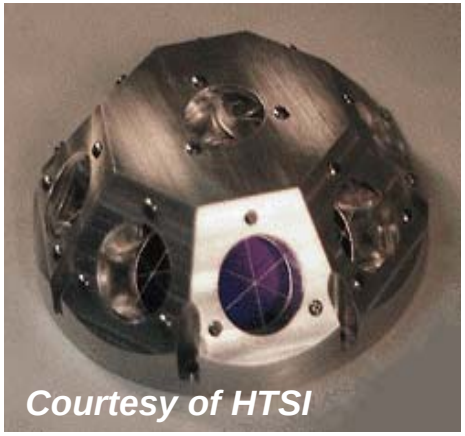
Future work & concerns.

(1) Characterize and mitigate systematic errors in the tracking data that affect POD; DORIS USO (Jason-2, Jason-3); SLR ranging and timing biases. Introduce these corrections into POD. (work of Alexandre Belli at NASA GSFC).
(2) Modify low degree coefficients of GOCO05s, especially for period after 2014. Define a strategy for pre-2003.
(3) Continue to investigate cause of large radial orbit rate differences between different sets of orbits.

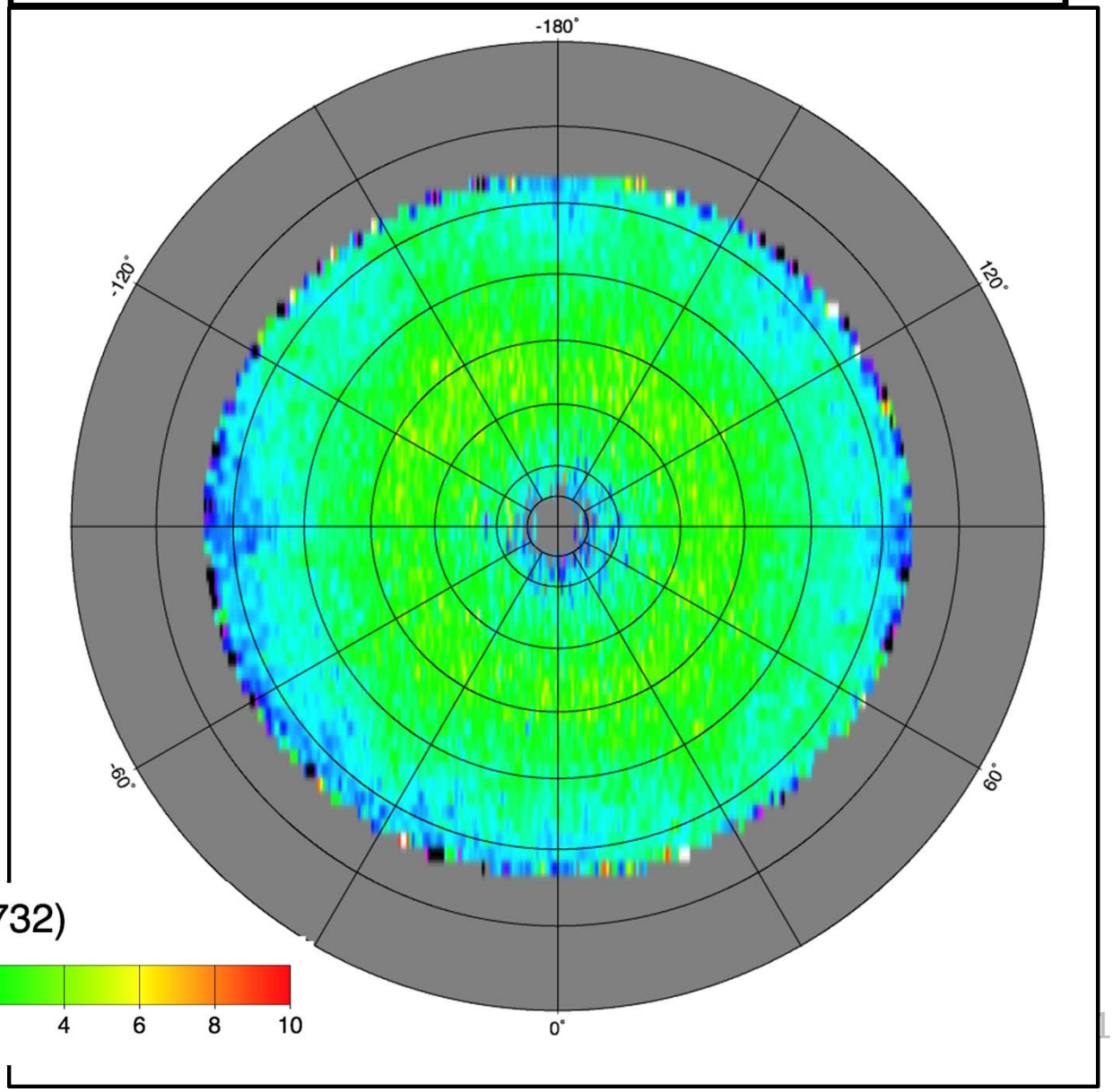
Backups

Development of new LRA correction for Jason-2 & Jason-3 (I)

Jason-2 LRA

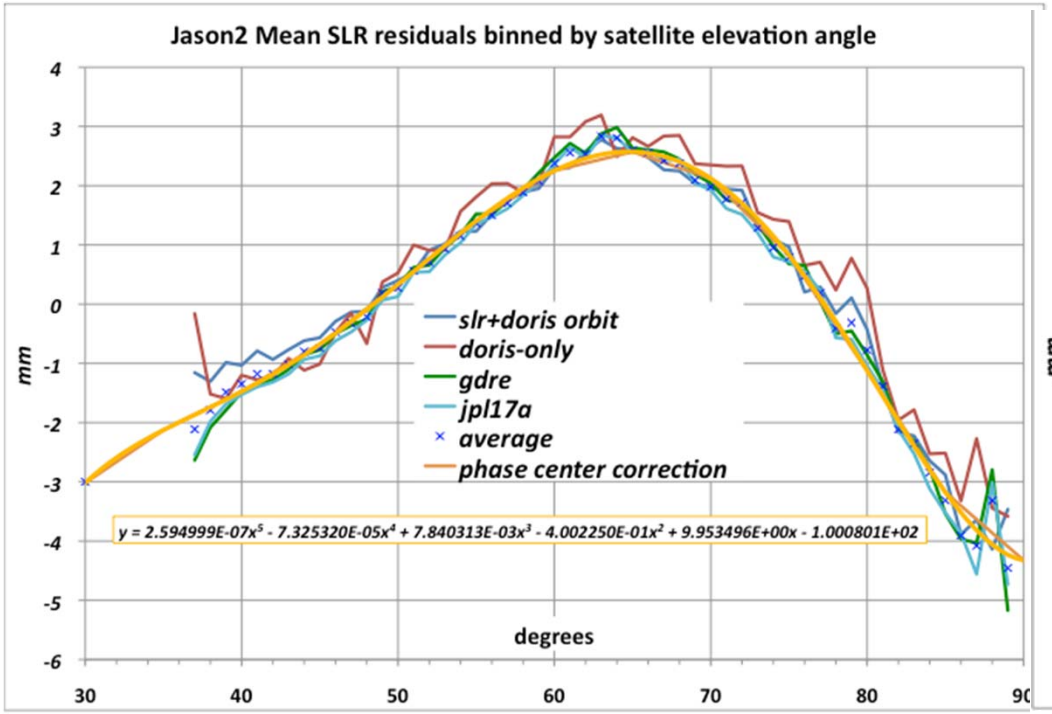


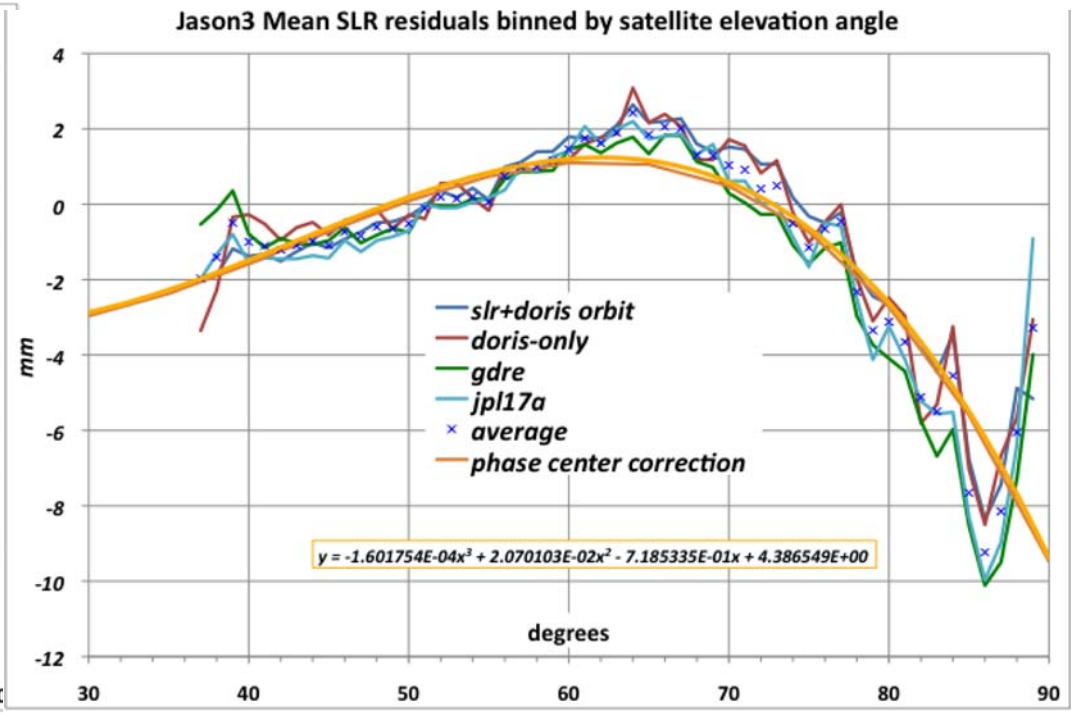
SLR Residuals to jpl17 orbits in 1° x 1° bins, Jason-2 cycles 1-303 for elevations 35-90°.



Development of new LRA correction for Jason-2 & Jason-3 (I)

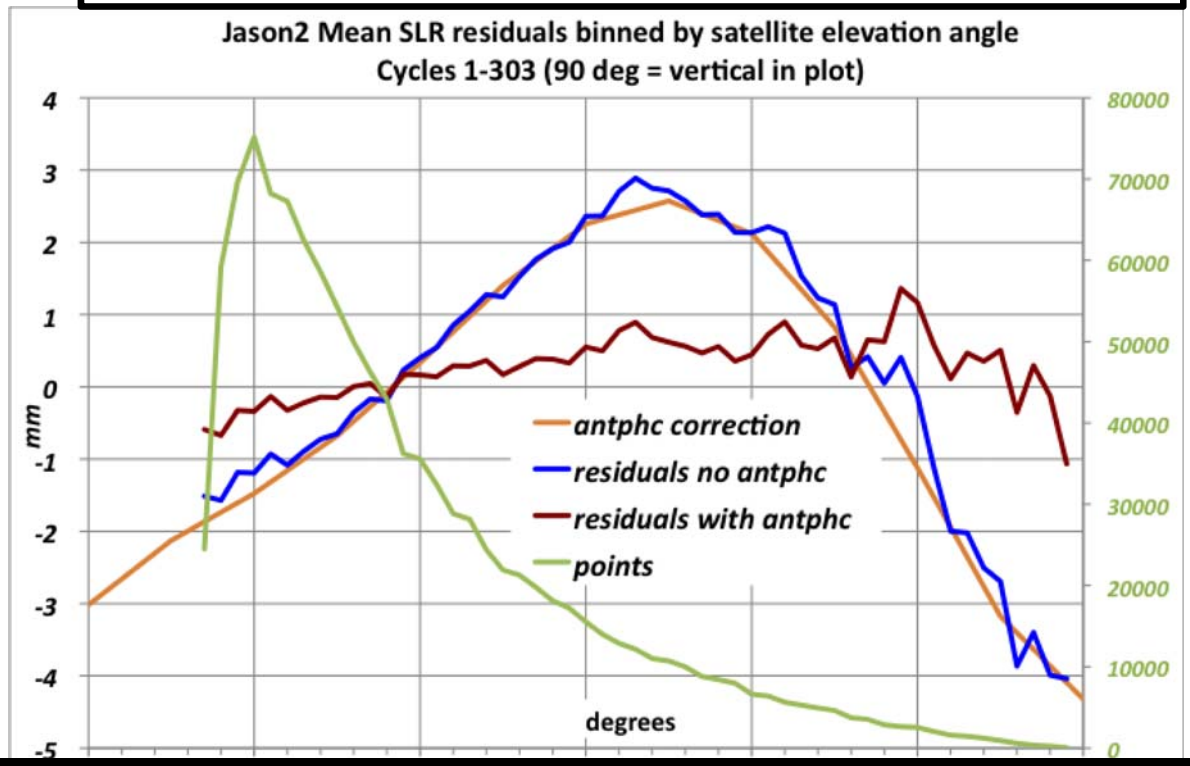
Jason-2 & Jason-3 LRA elevation angle correction (antphc) computed from polynomial fit to average of binned Mean SLR residuals.





Development of new LRA correction for Jason-2 & Jason-3 (II)

Jason-2 LRA elevation angle correction brings mean residuals closer to zero.

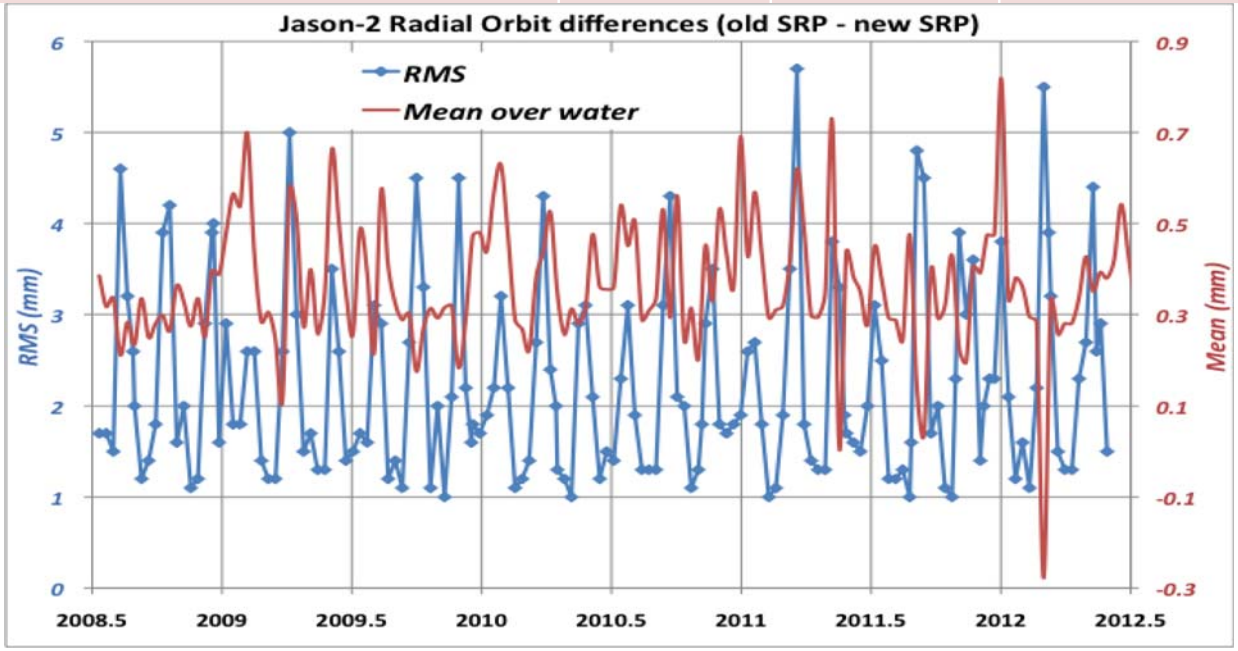


satellite	LRA Corr.	DORIS RMS (mm/s)	SLR Mean (mm)	SLR RMS (mm)
Jason2 cy. 1-40	old	0.3677	-0.23	7.03
	new	0.3677	-0.19	6.93
Jason3 cy. 1-87	old	0.3882	-0.52	10.13
	new	0.3842*	-0.40	10.08

1. Little change in the RMS of fit because the centroid in number of SLR observations is at low elevation.
2. Use of the SLR LRA correction allows SLR to make a better assessment of radial orbit error using high-elevation data for all types of orbits.

SRP model evaluation (Jason-2) - III

Jason-2 RMS orbit differences (mm), avg. (Cycles 1-128)			
Difference	**radial**	**cross-trk**	**along-trk**
old SRP - new SRP	2.2	3.1	9.0
jpl17a - old SRP	**6.9**	**20.7**	**26.7**
jpl17a - new SRP	**6.3**	**20.5**	**24.1**
gdre - old SRP	**7.1**	**19.6**	**27.3**
gdre - new SRP	**6.6**	**19.3**	**24.6**



1. **Radial orbit difference reduction of ~0.5 to 0.6 mm with respect to external orbits.**