Calibration and Validation of the Precise Orbits for OSTM – Extending the TOPEX, Jason-1 and Jason-2 Climate Data Record for MSL Studies

F.G. Lemoine[1], N.P. Zelensky[2], D.D. Rowlands[1], S.B. Luthcke[1], T.A. Pennington[2] , D.S. Chinn[2] , BD. Beckley[2] , M. Ziebart [3] , A. Sibthorpe[3] , P. Willis[4] , V. Luceri[5]

[1] NASA Goddard Space Flight Center, Greenbelt MD, 20771 USA   [2] SGT Inc , Greenbelt, MD , USA   [3] University College, London, UK   [4] Institut De Physique Du Globe De Paris, France   [5] E-GEOS S.P.A, Italy

ABSTRACT

The quality and the precision of the satellite orbit is a critical component of the OSTM mission and provides the central reference frame for the altimeter data. The analysis of OSTM altimeter data and data from TOPEX/Poseidon and Jason-1 requires that the orbits for all three missions be in a consistent reference frame, and calculated with the best possible standards to minimize error and maximize the data return from the 15+ year time series, particularly with respect to the application of measuring global sea level change. We discuss the (1) the validation of the tracking systems on OSTM by processing data from all available tracking systems on the spacecraft (SLR, DORIS, GPS and altimeter crossovers); (2) the production of a consistent set of orbits for TOPEX/Poseidon Jason-1 and the OSTM using updated orbit and geophysical model standards. The quality of the dynamic models and the tracking systems are also assessed.

Extending the TOPEX, Jason-1, Jason-2 accurate and consistent orbit time series

Both MSL studies and Calibration/Validation require consistent orbits across Missions

Figure 1 shows systematic TP orbit error on the GDR caused by progressive degradation of the CSR95 SLR/DORIS station complements following 1996 (cycles 150-359). Figure 2 illustrates the need for consistent and accurate orbits for inter-mission calibration.

Figure 1. GSFC – GDR TP Radial Orbits

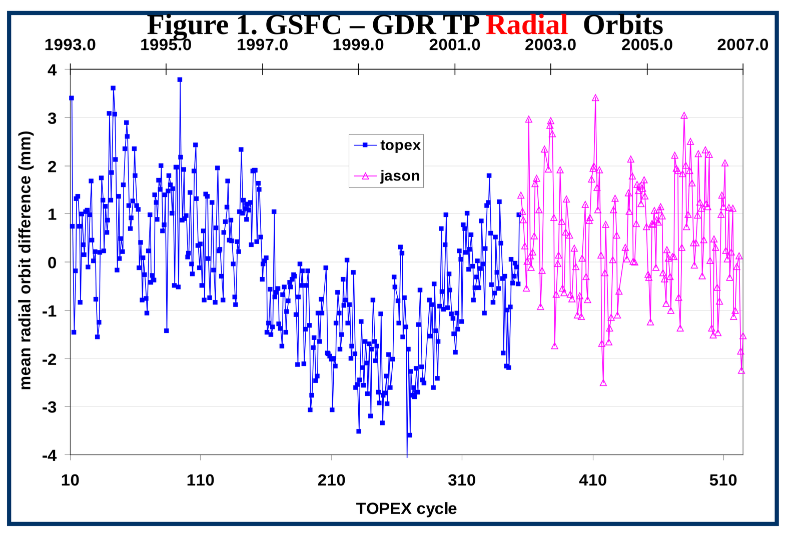
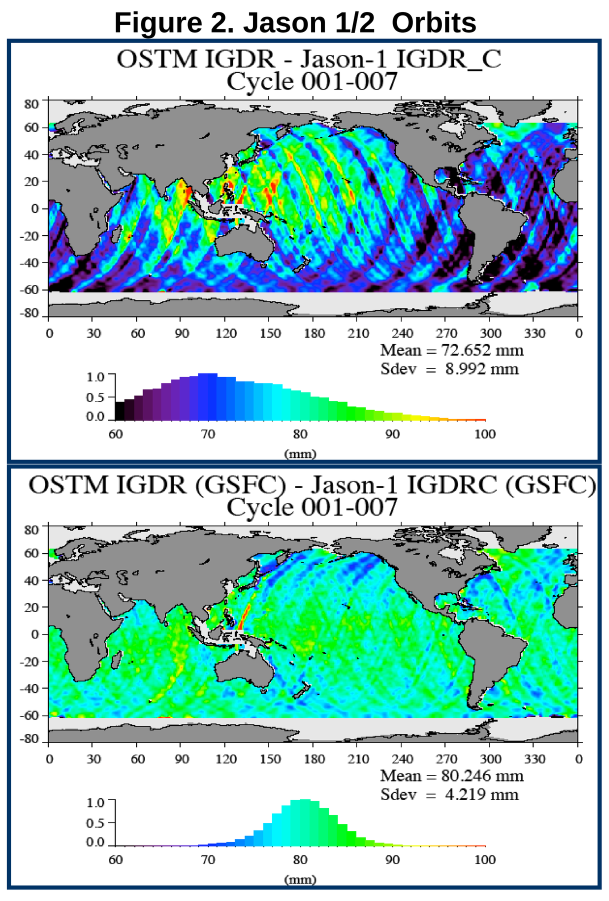


Figure 2. Jason 1/2 Orbits



Sources of Systematic Orbit Error

Error sources include drift in the reference frame (Figure 5), SLR station-dependent range biases and error in station velocity (Figure 6), possible trends in the CoM station displacement Z-component (Figure 7), satellite surface radiation modeling (Figure 8), and observed trends in atmospheric gravity (Figure 9), which if not modeled may cause systematic orbit error directly or affect the realization of the next ITRF.

Figure 5. TP (ITRF2005-GDR) orbit error due to TRF Z-drift directly affects MSL

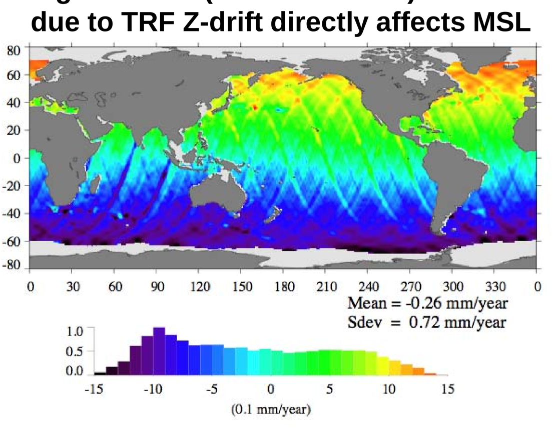


Figure 7. Wu CoM series and effect on Jason-1 SLR/DORIS orbit

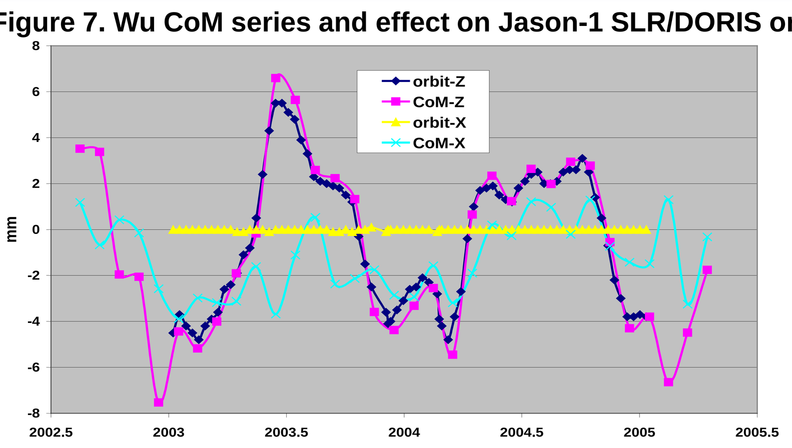


Figure 6. Evidence of SLR station bias / position error, the LPOD2005 solution, and affect on the Jason-1 orbit.

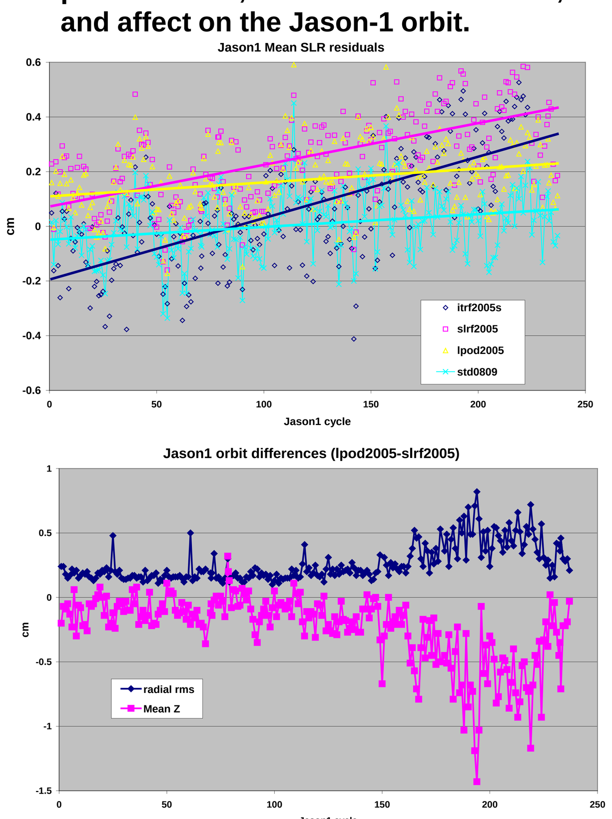


Figure 8. Jason-1 120-day radial orbit difference amplitude (mm)

SLR/DORIS: (Cr=1) - (Cr=0.914)

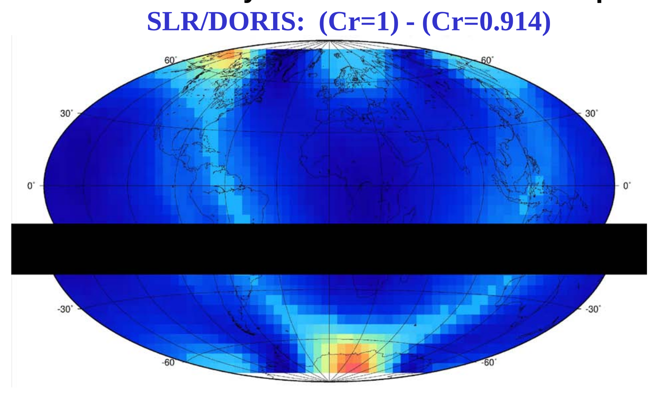
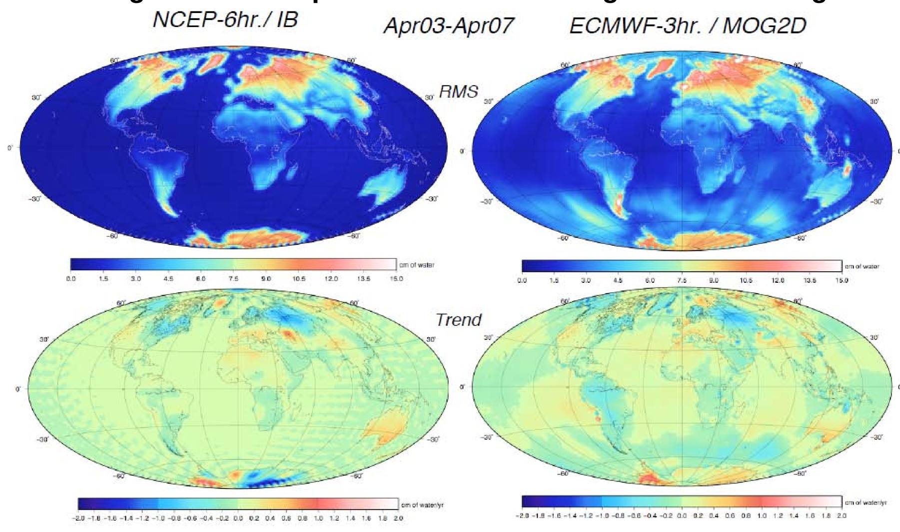


Figure 9. Atmosphere and ocean background modeling



NEW POD STANDARDS DEVELOPED AND TESTED FOR OSTM

Tests using the latest POD models show progressive improvement of the Jason-1 orbit (Table 1). The culmination of these tests has led to the definition of the latest GSFC POD standards (Table 2), which are consistent with the GDRC. Application of the new standards result in a superior orbit series for both TP (Table 3) and Jason-1 (Figure 3). Difference with the previous nominal_2007 series show 6-mm geographically correlated peaks due to differences in the GGM02C/EIGEN_GL04S1 gravity fields (Figure 4).

Table 1. New POD Standards progressive testing

test name	Jason-1 SLR/DORIS residual summary cycles 1-21	doris rms (mm/s)	slr (cm) mean	slr (cm) rms	xover rms (cm)	include new standard
nominal 2007	itrf2005(s)_merged (itrf2000) slr/doris, got0.0 selected oloads ggm02c, annual 20x20 3-yr grace model, ncep-6hr, got0.0 tides, pre-launch panel & C_R=1, lra (-4.9 cm)	**0.3976**	**-0.073**	**1.519**	**5.730**	**----**
trf2005	as nominal + slrf2005/dpod2005 & complete got4.7 oloads	**0.3979**	**0.086**	**1.508**	**5.732**	**yes**
lra phase map(cnes)	as trf2005 + LRA phase map from pre-launch measured 3-points; (with range correction=-5mm)	**.3979**	**0.057**	**1.501**	**5.734**	**no?**
eigen_gl04s	as trf2005 + switch to eigen gl04s	**0.3979**	**0.081**	**1.479**	**5.728**	**yes**
tidal_eop	as eigen_gl04s + tidal eop	**0.3978**	**0.076**	**1.435**	**5.724**	**yes**
tidal_com	as tidal_eop + tidal CoM (got4.7)	**0.3978**	**0.073**	**1.428**	**5.724**	**yes**
tvg_4yr	as tidal_com + switch to grace annual 20x20 4-yr model	**0.3979**	**0.075**	**1.428**	**5.724**	**yes**
ecmwf-6hr	as tvg_4yr + switch to ecmwf-6hr	**0.3979**	**0.075**	**1.428**	**5.724**	**yes**
cnes_panel	ecmwf-6hr +latest CNES macromodel	**0.3979**	**0.056**	**1.411**	**5.738**	**no**
got4.7	as ecmwf-6hr + got4.7 20x20 tides	**0.3979**	**0.076**	**1.427**	**5.724**	**yes**
cr_panel	as got4.7 + panel macromodel; tune Cr=0.929	**0.3978**	**0.074**	**1.409**	**5.727**	**yes**
optide	as cr_panel + ocean pole tide	**0.3978**	**0.069**	**1.404**	**5.727**	**yes**
lpod2005	as optide + lpod2005 (version 10)	**0.3978**	**0.120**	**1.333**	**5.725**	**yes**
std0809	as lpod2005 + lra phase map estimated using 2-years SLR data	**0.3978**	**-0.041**	**1.324**	**5.725**	**yes**

Table 3. Evaluation of new TOPEX std0809 orbits

TOPEX SLR/DORIS Orbits Cycles 1-364	DORIS RMS (mm/s)	SLR RMS (cm)	SLR mean (cm)	Altimeter Crossover RMS (cm)
GDR	*0.5348*	*2.210*	*0.323*	---
ITRF2005 SLR-rescaled (Nominal 2007)	*0.5111*	*1.828*	*0.347*	---
LPOD2005 (Std0809)	*0.5110*	*1.824*	*0.415*	---
Subset Analysis: 21 TOPEX Cycles (344-364)				
ITRF2005 SLR-rescaled (Nominal 2007)	*0.4682*	*1.553*	*0.198*	*5.526*
LPOD2005 (Std0809)	*0.4677*	*1.544*	*0.255*	*5.521*

Figure 3. Jason1 RMS SLR residuals

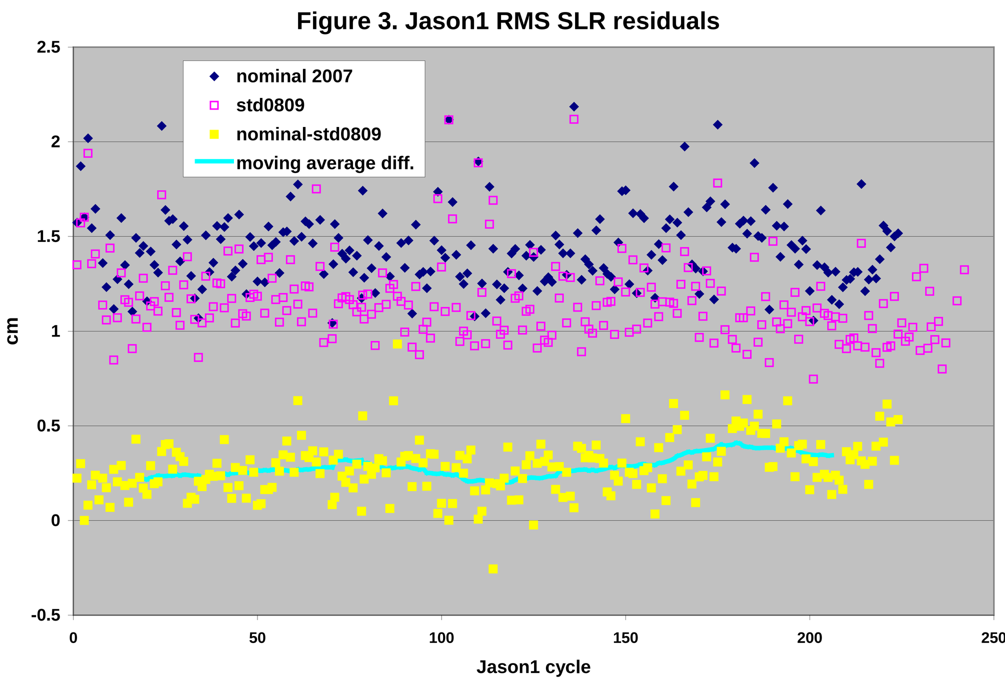


Figure 4. Jason-1 std0809-nominal_2007 radial differences cycles 1-21

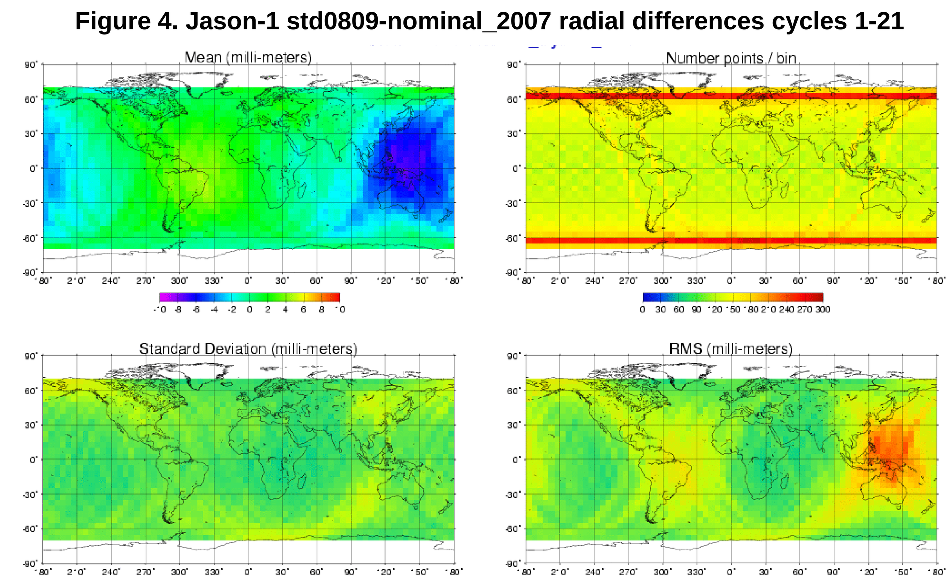


Table 2. GSFC POD Model Standards; October 2008

Reference frame and displacement of reference points			
SLR	**SLRF2005 + LPOD2005 (version 10)**		
DORIS	**DPOD2005**		
Earth tide	**IERS2003**		
Ocean loading	**GOT4.7, All stations**		
Tidal CoM &EOP	**GOT4.7; VLBI high frequency terms**		
EOP	**IERS Bulletin A daily (consistent with ITRF2005)**		
Precession / Nutation	**IAU2000**		
Gravity			
Static	**EIGEN-GL04S**		
Time varying	**Linear C20-dot, C21-dot, S21-dot (IERS2003) + 20x20 annual terms from GRACE**		
Atmospheric	**ECMWF, 50x50@6hrs**		
Tides	**GOT4.7 20x020 (ocean); IERS2003 (Earth)**		
Satellite Surface Forces and attitude			
Albedo /IR	**Knocke-Ries-Tapley (1988)**		
Atmospheric drag	**MSIS86**		
Radiation pressure	**TOPEX**	**Jason-1**	**Jason-2**
	tuned 8-panel	**pre-launch 8-panel**	**Jason-1 model**
Radiation scale coeff.	**C_R = 1.0**	**C_R = 0.929**	**C_R = 0.916**
Attitude	**Nominal Yaw; quaternions off-nominal**	**Nominal Yaw**	**Quaternions**
Tracking data and parameterization			
Tracking data	**SLR/DORIS (Jason1 DORIS corrected for SAA¶) ¶ (J.M. Lemoine and H. Capdeville, 2006, J. Geodesy)**		
Parameterization	**Drag/8 hrs + opr along & cross-track /24 hrs + DORIS time bias /arc; 10-day arc dynamic solution**		
Antenna reference	**TOPEX**	**Jason-1**	**Jason-2**
SLR	**LRA model**	**tuned offset, phase map**	**tuned offset**
DORIS	**pre-launch**	**pre-launch**	**tuned offset**

POE ORBIT AVAILABILITY

We have placed an accurate and consistent set of our latest GSFC SLR/DORIS dynamic replacement orbits for OSTM (Jason-2), Jason-1, and TOPEX on our anonymous ftp site:

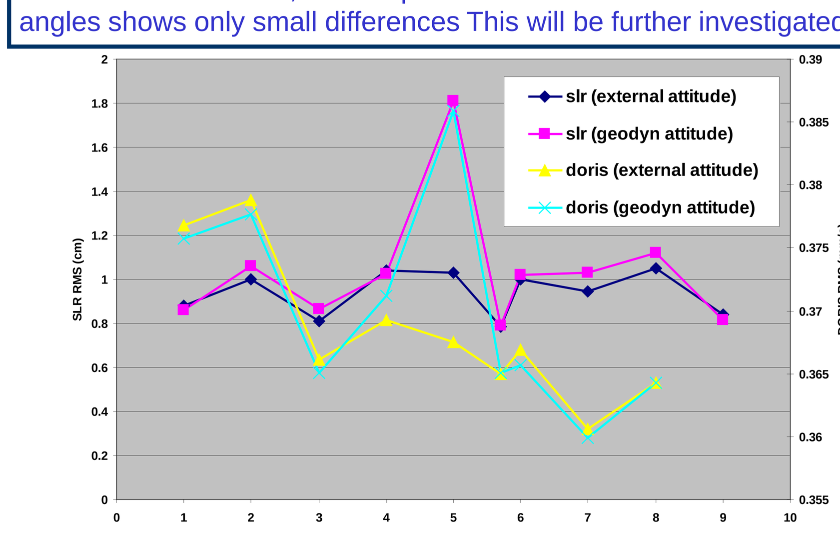
dirac.gsfc.nasa.gov
pub/earth/repro-jason/ostm/
gsfc_ja2_poe_std0809.$cycle.Z   Jason-2 $cycle=001-007
pub/earth/repro-jason/swt08/
gsfc_poe_std0809.$cycle.Z   Jason-1 $cycle=001-246
pub/earth/repro-topex/swt08/
gsfc_poe_std0809.$cycle.Z   TOPEX $cycle=001-443

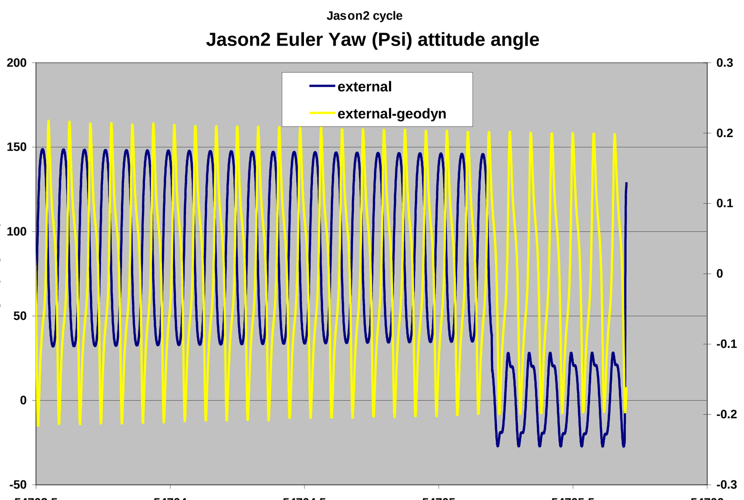
These orbits are not the GSFC final product.

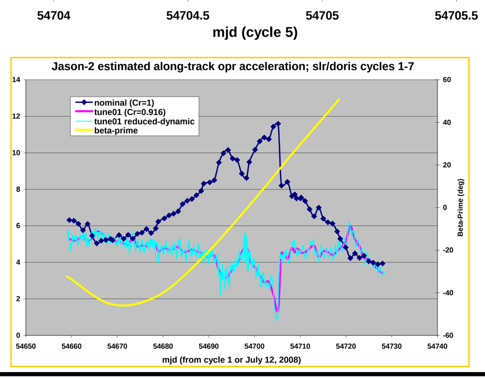
Jason-2

Application of External Attitude Data (quaternions) improves orbit performance

SLR/DORIS residuals show improvement with use of external attitude information. However, a comparison of the external/internal Euler angles shows only small differences This will be further investigated.







Tuning the C_R, LRA and DORIS antenna offsets

Cycles 1-7 SLR/DORIS data were used to tune the C_R, LRA and DORIS antenna offsets as shown below. The new C_R significantly reduces the amplitudes of the estimated 1 cpr accelerations. Surprisingly the DORIS offset adjusts 13.5 cm in Z. Using the new offset, both the DORIS and SLR residuals improve, including the independent SLR-residuals to a DORIS-only orbit. More cycles are needed to confirm the new offset estimate.

Jason-2 Estimated Solar Radiation Pressure Coefficient (C_R)
SLR/DORIS cycles 1-7; Jason-1 panel cards (external attitude, std0809 models)

	a-priori	estimated increment	standard deviation	new value
C_R	1.00000	-0.08394	0.01660	0.916

Jason-2 Center of Mass (m) cycles 1-7	x	y	z
	0.9772	0.0001	0.0011

Jason-2 Estimated Laser Retro-reflector Array Offset
SLR/DORIS cycles 1-7; -4.9 cm range correction (external attitude; std0809 models)

LRA offset (m)	a-priori	estimated increment	standard deviation	new value
X	1.194	-0.00619	0.00179	1.188
Y	0.598	-0.00097	0.00172	0.597
Z	0.6838	0.00084	0.00179	0.6846

Jason-2 Estimated DORIS Antenna Phase Offset
SLR/DORIS cycles 1-7; (external attitude; std0809 models)

DORIS antenna offset (m)	a-priori	estimated increment	standard deviation	new value
X	1.194	-0.00191	0.00254	1.192
Y	-0.598	0.00626	0.00237	-0.592
Z	1.022	0.13498	0.00254	1.157

Jason2 Model Tuning Evaluation residual summary cycles 1-7 external attitude; std0809 models	doris rms (mm/s)	doris time bias (μs)	slr (cm) mean	slr (cm) rms	xover (cm)
slr/doris					
nominal (std0809)	**0.3689**	**-2.35**	**-0.089**	**1.191**	**5.534**
ld_cr: as nom+ Cr=0.916	**0.3681**	**-2.34**	**-0.059**	**1.150**	**5.542**
lra01: as ld_cr +est. lra offset	**0.3681**	**-2.41**	**-0.033**	**1.137**	**5.545**
dor01: as ld_cr + est. doris antenna offs.	**0.3610**	**-2.19**	**-0.044**	**1.121**	**5.545**
tune01: as ld_cr + est. lra/doris ant. offs	**0.3610**	**-2.24**	**-0.020**	**1.102**	**5.550**
slr-only					
nominal	----	----	**-0.043**	**0.936**	**5.725**
slr_cr: as nom+ Cr=0.916	----	----	**-0.001**	**0.886**	**5.705**
lra01: as slr_cr +est lra offset	----	----	**0.015**	**0.863**	**5.701**
doris-only					
nominal	**0.3689**	----	**-0.4**	**3.6**	**5.571**
dor_cr: as nom+ Cr=0.916	**0.3677**		**-0.5**	**3.5**	**5.576**
dor01: as dor_cr + est. doris antenna offs.	**0.3608**	----	**-0.1**	**2.7**	**5.581**

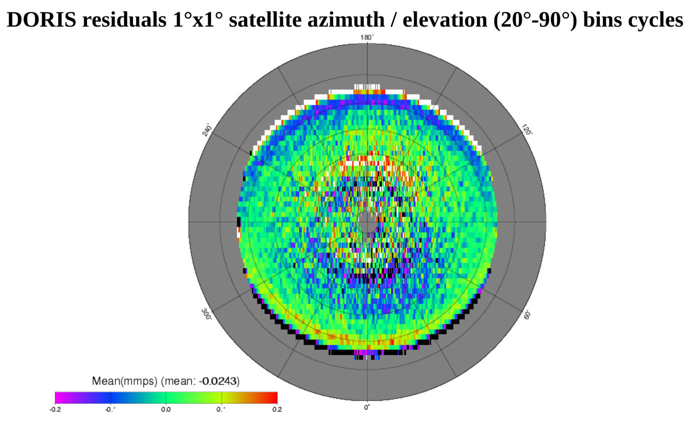
Jason-2 orbit difference summary cycles 1-7: model tuning

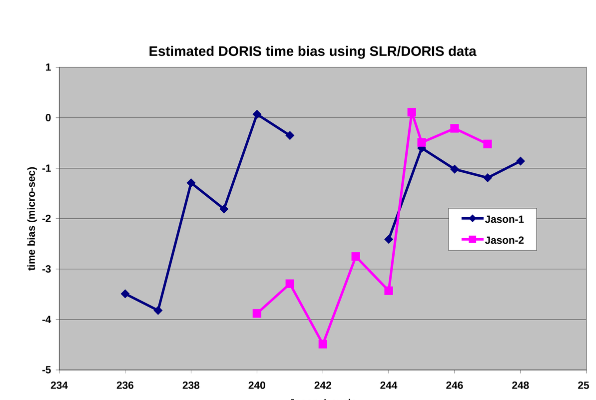
Difference = (none-test)	RMS (cm) radial	RMS (cm) cross track	RMS (cm) along track	Mean (cm) X	Mean (cm) Y	Mean (cm) Z	Mean (cm) radial
new doris offset; slr+doris orbit	0.07	0.60	0.23	0.00	0.01	0.00	0.00
new doris offset; doris orbit	0.10	3.21	0.59	-0.01	0.00	0.02	-0.01
new Cr; slr+doris orbit	0.24	0.74	0.48	0.03	-0.09	0.03	0.04
combined; slr+doris orbit	0.28	1.09	0.62	0.02	-0.09	0.05	0.04

DORIS

The latest advance in DORIS receiver technology promises significant benefit for Jason-2 POD. The strength of this dataset dominates the dynamic solutions and significantly improves orbit accuracy in the reduced-dynamic. The residual plot below suggests a tuned phase map can benefit DORIS data processing.

DORIS residuals 1°x1° satellite azimuth / elevation (20°-90°) bins cycles 1-7





ORBIT EVALUATION

Orbits from JPL, CNES, and GSFC are directly compared and evaluated by computing DORIS, SLR, and Altimeter Crossover residuals. DORIS appears to drive POD when present.

Jason2 orbit evaluation cycles 1-6	doris rms (mm/s)	slr (cm) mean	slr (cm) rms	xover rms (cm)
jpl_gpsr_rlse08a (gps-only)	**0.3831**	**0.083**	**1.404**	**5.505**
cnes_ldg_gdrcp_v00 (**gps**,slr,doris)	**0.3827**	**-0.163**	**1.518**	**5.544**
cnes_ldg_gdrcp_v01 (gps,**slr,doris**)	**0.3825**	**-0.060**	**1.147**	**5.544**
gsfc slr+doris_tune01 dynamic	**0.3827**	**-0.043**	**1.222**	**5.551**
gsfc slr+doris_tune01 reduced-dynamic	**0.3820**	**-0.113**	**1.209**	**5.484**

Jason-2 orbit difference summary cycles 1-7

GSFC / CNES orbits	RMS (cm) radial	RMS (cm) cross track	RMS (cm) along track	Mean (cm) X	Mean (cm) Y	Mean (cm) Z	Mean (cm) radial
test - cnes_ldg_gdrcp_v00 (**gps**,slr,doris)							
slr-only	1.76	2.47	7.49	0.18	-0.14	-1.34	0.10
doris-only	1.23	6.08	3.75	0.18	-0.19	-0.36	0.10
slr+doris	1.22	2.94	3.49	0.07	0.07	-0.44	0.10
slr+dor_tune01_dynamic	1.27	1.59	3.51	0.08	0.17	-0.64	0.06
slr+dor_tune01_reduced-dyn	1.00	1.61	3.09	0.06	0.06	-0.47	0.06
test - cnes_ldg_gdrcp_v01 (gps,**slr,doris**)							
slr+dor_tune01_reduced-dyn	0.86	1.66	3.03	-0.02	-0.1	0.21	0.06
cnes_ldg_gdrcp_v00	0.77	0.51	2.03	-0.07	-0.16	0.68	0.00
test - jpl_gpsr_rlse08a (gps-only)							
slr+dor_tune01_reduced-dyn	0.95	1.89	3.08	-0.34	0.40	-0.25	0.04
cnes_ldg_gdrcp_v01	1.10	1.39	2.81	-0.31	0.52	-0.54	-0.02
cnes_ldg_gdrcp_v00	1.11	1.31	2.98	-0.37	0.36	0.19	-0.03

Conclusions & Future Work

- We have delivered a consistent time series of our latest and most accurate SLR/DORIS orbits for TP, Jason-1, and OSTM.
- We will investigate use of GPS data for OSTM POD, and refine OSTM model tuning.
- Future analysis, as well as model and solution strategy improvements will be made in order to further reduce the orbit uncertainties. The success, in large part, will depend on the continued diligence and cooperation of the OSTM POD Team members: CNES, NASA GSFC, JPL, UT CSR.

Contact Information:
Frank Lemoine
NASA / GSFC Code 698
Phone: 301-614-6109
email: Frank.G.Lemoine@nasa.gov

Acknowledgements: We acknowledge the International Laser Ranging Service (ILRS) for their support of Jason-1 & Jason-2, especially during the calibration phase; The new LPOD (SLR) solutions were developed by John Ries (UT/CSR); The DPOD2005 (DORIS) solutions are from P. Willis et al. (2008).

OSTST 2008
SB.5-043
Nice., France