Towards a Seamless Transition from TOPEX/Poseidon to Jason-1

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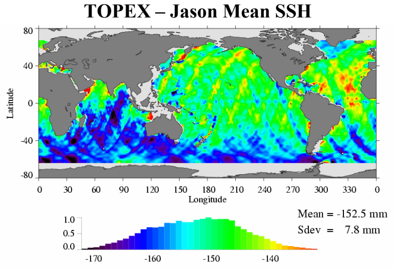
Abstract

The Jason-1 verification phase has proven to be a unique and successful calibration experiment to quantify the agreement with its predecessor TOPEX/POSEIDON. Although both missions have met prescribed error budgets, comparison of the mean and time varying sea surface height profiles from near simultaneous observations derived from the missions' Geophysical Data Records exhibit significant basin scale differences. Several suspected sources causing this disagreement are identified and improved upon, including (a) replacement of TOPEX and Jason project POE with enhanced orbits computed at GSFC within a consistent ITRF2000 terrestrial reference frame, (b) application of waveform retracking corrections to TOPEX significant wave height and sea surface heights, (c) resultant improved efficacy of the TOPEX sea state bias estimation from the value added sea surface height, and (d) estimation of Jason-1 sea state bias employing dual TOPEX/Jason crossover and collinear sea surface height residuals unique to the validation mission. The resultant mean sea surface height comparison shows improved agreement at better than 60 percent level of variance reduction with a standard deviation less then 0.5 cm.

TOPEX – Jason Mean SSH



TOPEX minus Jason mean SSH profile during validation phase (Jason cycles 1 through 21). Jason height profiles are derived from project GDR employing non-parametric sea state bias (SSB) correction. TOPEX height profiles are derived from NASA Ocean Altimeter Pathfinder data set based on project MGDR_B employing updated parametric SSB (Chambers, et al., 2003). Color scale is exactly +/- 2 cm about mean relative bias.

Summary of TOPEX GDR (NASA) orbit (TOPEX cycles 344-364) versus GSFC replacement orbit.	RMS residuals		
	DORIS (mm/s)	SLR (cm)	Crossover (cm)
GDR (NASA)	0.467	2.522	5.618
Replacement GSFC reduced dynamic SLR+DORIS, ITRF2000	0.465	1.979	5.545

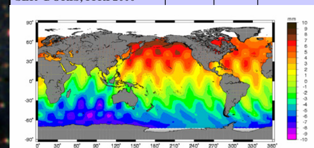


Figure 2.a Mean radial orbit differences of TOPEX GDR (NASA) – GSFC reduced dynamic replacement orbit.

Summary of Jason-1 GDR Orbit (Jason cycles 1-21) versus GSFC replacement orbit.	RMS residuals		
	DORIS (mm/s)	SLR (cm)	Crossover (cm)
GDR	0.408	2.697	5.950
Replacement GSFC reduced dynamic SLR+DORIS (cycles 1-7) GPS+SLR (cycles 8-21)	0.408	1.542	5.694

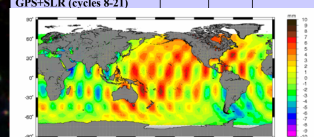


Figure 2.b Mean radial orbit differences of Jason-1 GDR – GSFC GPS based replacement orbit.

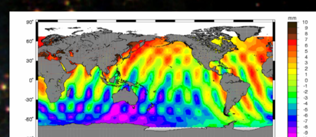


Figure 2. Radial orbit differences averaged over 5° x 5° bins, for Jason cycles 1-21, show TOPEX and Jason geographically correlated GDR orbit error in figures 2.a and 2.b respectively. Figure 2.c is the difference between figures 2.a and 2.b, and illustrates the inconsistency between the TOPEX and Jason GDR datasets due to GDR orbit error. Figures 2.d and 2.e shows the improved TOPEX/Jason SSH agreement after the sequential application of GSFC TOPEX reduced dynamic orbits, and Jason GPS based orbits (Luthcke, et al., 2003).

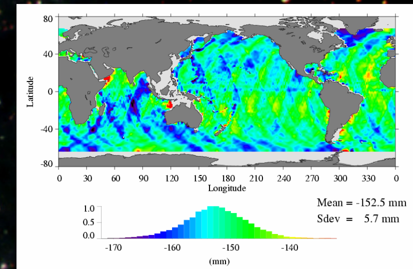


Figure 2.d TOPEX mean SSH (with GSFC reduced dynamic orbits) – Jason mean SSH (with GDR orbits).

For details on GSFC enhanced orbits see Luthcke, S.B., N.P. Zelensky, D.D. Rowlands, F.G. Lemoine and T.A. Williams, "The 1-centimeter Orbit: Jason-1 Precision Orbit Determination Using GPS, SLR, DORIS and Altimeter data," *Marine Geodesy*, Special Issue on Jason-1 Calibration/Validation, Part 1, Vol. 26, No. 3-4, 2003.

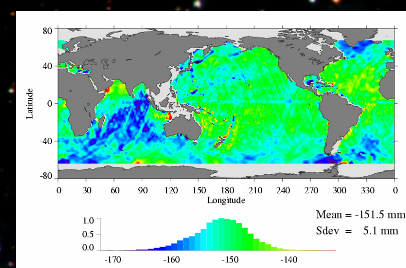
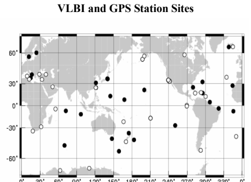


Figure 2.e) TOPEX mean SSH (with GSFC reduced dynamic orbits) minus Jason mean SSH (with GSFC GPS orbits).

Monitoring the Jason-1 Microwave Radiometer with GPS and VLBI Wet Zenith Path Delays

VLBI and GPS Station Sites

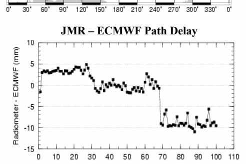


Jason-1 JMR is monitored using coincident wet zenith delay estimates from VLBI and GPS geodetic sites near altimeter ground tracks. The solid circles are older GPS sites, and the open circles are for sites that began observing after 1997. Two offsets have been observed centered about cycles 30 and 69.

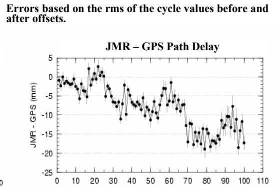
	JMR - ECMWF	JMR - GPS
cycle 30	-3.6 +- 0.2 mm	-5.4 +- 0.7 mm
cycle 69	-8.7 +- 0.4 mm	-7.7 +- 0.8 mm

Errors based on the rms of the cycle values before and after offsets.

JMR – ECMWF Path Delay

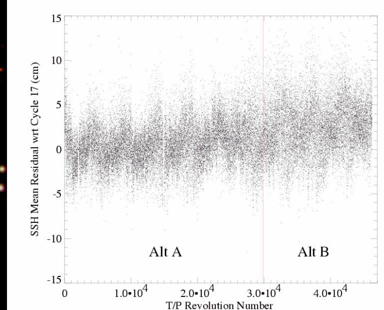


JMR – GPS Path Delay



For more details on JMR monitoring see D. Macmillan, B. Beckley, P. Fang, *"Monitoring the TOPEX and Jason-1 Microwave Radiometers with GPS and VLBI Wet Zenith Path Delays"*, *Marine Geodesy, Special Issue on Jason-1 Calibration/Validation, Part 3, (in press).*

Retracking TOPEX, and the Sea State Bias



Time series of mean T/P (MGDR_B) sea surface height residuals per revolution with respect to TOPEX cycle 17 shows a less pronounced annual signal after transition to Alt-B. This may be due in part because TOPEX Alt-A instrument corrections were checked and adjusted to retracking, while TOPEX Alt-B did not undergo the same retracking scrutiny. In order to be certain that there are no remaining sea state bias (SSB) effects in the TOPEX data we apply the retracking corrections from the JPL GDR Compatibility Product (GCP) and the reduced dynamic orbits to a full year of TOPEX data spanning cycles 328 – 364. From this augmented 1 year data set we compute a revised estimate of the SSB based on the same parametric form in the project MGDR_B (Gaspar, et al., 1994), the so called BM4 model:

$$SSB = SWH\,[a_1 + a_2{*}SWH + a_3{*}U + a_4{*}U^2] \qquad (1)$$

where U is the wind speed derived from the Gourrion et al. (2000) algorithm to remain consistent with the Jason project GDR, and SWH is the re-estimated Ku band significant wave height from retracking.

For the sake of consistency, we have replaced the Jason project non-parametric SSB with a parametric BM4 estimate. In an effort to minimize some of the error sources traditionally inherent in an altimetry-based empirical estimate, we take advantage of the coincident Jason/TOPEX collinear data during the validation period. A primary concern when deriving the dependence of SSB with respect to SWH and wind speed via SSH residual minimization is the resultant removal of some of the oceanographic signal, thus the reluctant rationale to employ the more limited crossover data set (constrained within each cycle) with an average time difference of 3-4 days to the more data rich collinear residuals with 10 day differences. From Gaspar, 1994 these differences directly yields,

$$\Delta SSH = \Delta SSB + \Delta\eta + \varepsilon \qquad (2)$$

where η is the dynamic topography, and ε the altimetric measurement error from instrument independent environmental and geophysical corrections.

If however we assume that the current value added TOPEX data set can provide a good approximation of the global time-variant dynamic topography via collinear residuals, and since the georeferenced Jason/TOPEX sea surface height observations are nearly temporally coincident, equation 2 becomes

$$\Delta SSH_{Jason} = \Delta SSB + \Delta SSH'_{TOPEX} \qquad (3)$$

Where $\Delta SSH'_{TOPEX}$ is the TOPEX SSH residual with the revised SSB estimate based on the one year of TOPEX with GCP retracking corrections and reduced dynamic orbits applied.

This procedure also benefits from the complete cancellation of all instrument independent environmental and geophysical corrections, and does not restrict the computation of the collinear SSH residuals to adjacent cycles since the expected goal is

$$[SSH_N - SSH_{N\,+/-\,\Delta N}]_{Jason} = [SSH_N - SSH_{N\,+/-\,\Delta N}]_{TOPEX}$$

where N = cycle number

The total number of SSH residuals made available in the SSB estimate is then increased to N*(N-1)/2. This significant increase of observations then provides flexibility to examine SSB estimates through analysis of ascending and descending passes and/or quadrants separately.

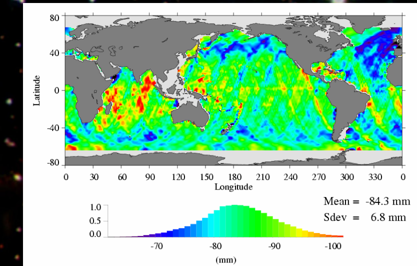


Figure 4.a) TOPEX (with GCP retracking corrections applied) minus Jason mean SSH. Sea state bias corrections and replacement orbits are NOT applied.

Figure 4 Geographical distribution and magnitude of mean SSH profile signatures previously obscured by orbit errors are highly correlated with mean JPL – CNES Jason retracking range correction differences shown in figure 4.c at right.

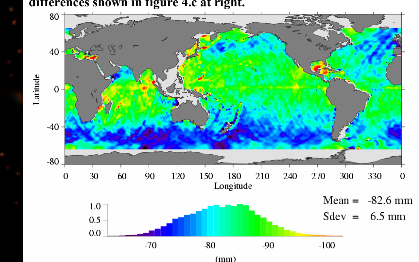


Figure 4.b) Same as figure 4.a but with replacement orbits applied.

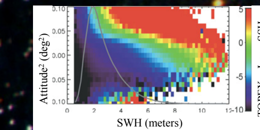


Figure 3. TOPEX (retracked with GSFC reduced dynamic orbits applied) minus Jason (with GSFC GPS-based orbits applied) mean SSH differences binned with respect to significant wave height and attitude. Trends in the height residuals with both attitude and SWH (stronger with respect to attitude) resemble residual signatures from mean JPL – CNES Jason retracking correction differences. The histogram (gray line) is the normalized distribution of global SWH for Jason cycles 1 – 21.

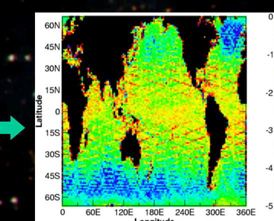


Figure 4.c) Mean differences of JPL minus CNES derived retracking corrections for Jason-1.

Stability of Relative Bias Estimate

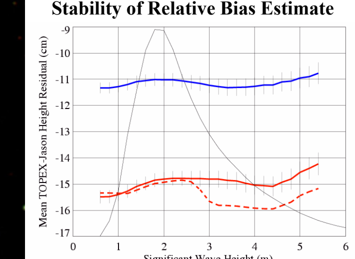


Figure 5 Mean TOPEX minus Jason SSH residuals are binned with respect to significant wave height to examine stability of the global bias estimate. The dashed red curve represents the height residuals shown in figure 1 derived from standard user GDR products. The solid red line represents the height residuals from TOPEX retracked heights with reduced dynamic orbits minus the Jason GDR product. The blue line represents the height residuals from TOPEX retracked heights with reduced dynamic orbits minus Jason with GSFC GPS-based orbits and parametric sea state bias estimate. Error bars are one standard deviation of height residuals within each 20 cm SWH bin. The histogram is the normalized distribution of global SWH for Jason cycles 1 – 21.

TOPEX – Jason Mean Sea Surface Height

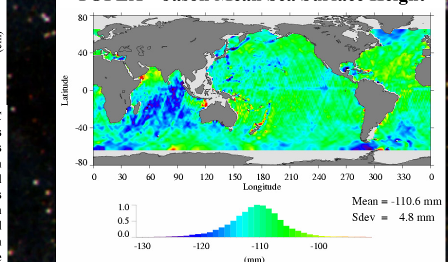
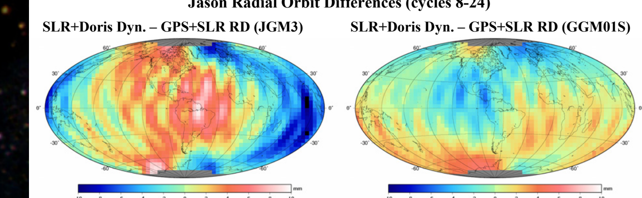


Figure 6. TOPEX minus Jason mean SSH profiles as shown in figure 1 after adding value through application of Jason GPS-based orbits, TOPEX reduced dynamic orbits, TOPEX retracking, and revised parametric sea state bias solutions. Nearly all of the residual orbit error trackiness has been eliminated with the application of improved precision orbit ephemeredes (POE) to both Jason-1 and TOPEX. The reduced dynamic POE solution for TOPEX in particular contributes to a significant reduction in the geographically correlated error as seen by the reduction in the Indian and North Atlantic asymmetry. Clearly the geographically correlated orbit errors have not been entirely eliminated, though further improvements are anticipated with orbits based on future GRACE gravity models (Tapley et al., 2004). The significant reduction in the residual height anomaly throughout the southern oceans can be primarily attributed to the application of TOPEX reduced dynamic orbits within the ITRF2000 reference frame, and to a lesser extent to the application of TOPEX GCP retracking corrections and the subsequent revised SSB estimate. A small residual signal along the equator is evident due to the remaining range rate noise in the retracking corrections applied to TOPEX.

Reducing the Geographically Correlated Gravity Error

Jason Radial Orbit Differences (cycles 8-24)

SLR+Doris Dyn. – GPS+SLR RD (JGM3) SLR+Doris Dyn. – GPS+SLR RD (GGM01S)



Both figures are made solely from Jason orbits. The figure on the left is Jason GPS+SLR reduced dynamic orbits minus SLR+DORIS dynamic orbits. This figure clearly shows the geographically correlated JGM3 gravity error mostly remaining in the SLR+DORIS dynamic orbits. The figure on the right is the same difference, but now using the preliminary GRACE GGM01S field. The most striking improvement is the reduction in the Indian Ocean. This shows that we can expect similar improvement in the remaining geographically correlated errors in the Jason/TP comparisons when we do these comparisons with Jason and T/P orbits determined from a GRACE geopotential.