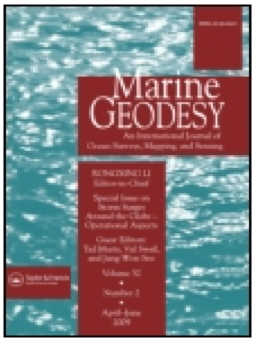

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Retracking of Jason-1 Data

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We present the results of retracking 18 cycles (15 from the Jason-TOPEX collinear period) of Jason-1 data. We used the retracking method of Rodriguez which simultaneously solves for all relevant waveform parameters using a 26 Gaussian model of the altimeter point target response. We find significant differences from the Jason-1 Project retracking in the key parameters of range and significant wave height (SWH) in the second version of the Project SGDRs. The differences from the Jason-1 data have a strong dependence on off-nadir angle and some dependence on SWH. The dependence of range on SWH is what is called sea state bias. The retracking technique also estimates surface skewness. For Jason-1 with its very clean waveforms we make the first direct estimates of the skewness effect on altimeter data. We believe that the differences found here and thus in overall sea surface height are the result of the standard project processing using a single Gaussian approximation to the Point Target Response (PTR) and not solving simultaneously for off nadir angle. We believe that the relatively large sea state bias errors estimated empirically for Jason-1 during the cal/val phase result from sensitivity of quantities, particularly SWH, in project GDRs to off nadir angle. The TOPEX-Jason-1 bias can be determined only when a full retracking of Jason-1 is done for the collinear period.

Keywords altimeter waveform, retracking, sea state bias

During the Jason-1 calibration period a relatively large, additional 1–2% of significant wave height (SWH) sea state bias (SSB) effect—apparent variation of range or sea surface height (SSH) with SWH—was noted in the Jason-1 data (Zanife et al. 2003). The source of this effect was not clear, and several groups produced empirical fits to bring the data into alignment with TOPEX data for the period ("collinear") when the satellites were closely spaced along the same ground track. Here, we present results that indicate that the apparent SSB effect results from particular features in the retracking and instrument corrections of the Jason-1 GDR data. The main difference is that we find a relatively large variation of parameters with off-nadir angle (called "attitude" here). This result presumably arises from our simultaneous solution for attitude with other parameters during retracking, which is not done in producing Jason-1 GDRs.

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The Jason-1 Cal/Val effort also made clear that TOPEX Alt-B is not calibrated as well as Alt-A, with Alt-B exhibiting a larger SSB (Chambers et al. 2003). This is mainly because TOPEX Alt-A instrument corrections were adjusted to retracking over part of the parameter range, while Alt-B had no adjustment to retracking. It is also likely that the waveform "leakages" are somewhat different between Alt-A and Alt-B, so that the exact variations of Alt-B with SWH, attitude, and range rate (because of the leakages) are different than Alt-A. Thus, in order to have highly accurate TOPEX data to compare to Jason-1, it is necessary to use the TOPEX GDR Correction Product (GCP) with retracking (Callahan 2002). Those data were produced with software nearly identical to that used here with appropriate parameters for TOPEX Alt-B.

Retracking Method

In order to understand retracking, it is necessary to recall some of the details of pulse limited altimetry as described in Chelton et al. (2001). The altimeter determines the range and SWH by "tracking" the midpoint and estimating the slope respectively of the leading edge of the return waveform. A schematic waveform is shown in Figure 1 (taken from Amarouche et al. 2004; Figure 3).

The waveform is represented by the Brown model (Brown 1977), in which the return signal is a convolution of the instrument point target response (PTR), the flat surface response (FSR), and the probability density function of the sea surface height. The PTR is well approximated by

$$\mathrm{PTR(t)} = (\sin(\mathrm{Bt})/(\mathrm{Bt}))^2, \tag{1}$$

where B is the altimeter signal band width, 320 MHz for Jason-1 (same as TOPEX).

The flat surface response is a complicated function that incorporates the geometry of the observation. The key point is that it involves the square of the attitude and the antenna beam width (BW). After several simplifications appropriate to the spaceborne altimeter

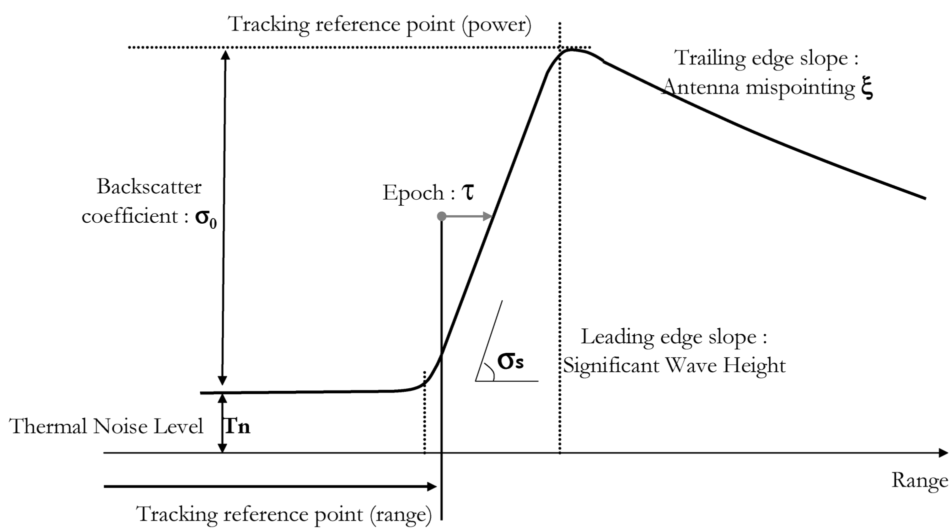


FIGURE 1 Schematic of altimeter waveform with a range error of τ. The slope of the rising leading edge is related to the significant wave height. (Taken from Amarouche et al. 2004, Figure 3).

case, notation from Amarouche et al. (2004) is used to allow easy comparison:

$$\mathrm{FSR(t)} = \mathrm{A} \exp(-\delta \mathrm{t}) \mathrm{I}_0(\beta \mathrm{t}^{1/2})\, \mathrm{U(t)}, \tag{2}$$

where A is a scale factor, I_0 is the modified Bessel function of the second kind, U(t) is the unit step function, and

$\beta = (4/\gamma)\ (\mathrm{c/h})^{1/2} \sin(2\ \xi)$, ξ being the off nadir angle,
$\delta = (4\ \mathrm{c/h}\ \gamma) \cos(2\ \xi)$;
$\gamma = (\sin^2 \mathrm{BW}/2)/(2 \ln 2)$, BW being the altimeter antenna full 3 dB beam width, and
$\mathrm{h} = \mathrm{H}\ (1 + \mathrm{H/R})$, H being the altimeter altitude and R the radius of the Earth.

I_0 is usually expanded to second order to get adequate accuracy for the off nadir angles encountered in measurements of interest.

The probability density function of the sea surface height (PDFh) is assumed to be mainly Gaussian with higher order moments such as skewness,

$$\begin{aligned}\mathrm{PDFh(t)} = {} & (4/(\mathrm{sqrt}(2\pi)\mathrm{SWH}))\exp(-0.5(4\mathrm{ct}/\mathrm{SWH})^2)^* \\ & (1 + (\lambda/6)((4\mathrm{ct}/\mathrm{SWH})^3 - 3(4\mathrm{ct}/\mathrm{SWH}))),\end{aligned} \tag{3}$$

where λ is the surface height skewness and the surface height standard deviation is given by SWH/4.

The instrumental tracking is subject to errors that depend on the details of the signal processing interacting with the signal itself, particularly the SWH and the off nadir angle. The instrumental errors can be corrected in two basic ways: (1) correction tables or polynomials developed from simulations of the altimeter; and (2) retracking—fitting of the full waveform model—of the waveforms sent down in telemetry.

TOPEX uses polynomials parameterized by SWH and attitude (pointing angle/sea state correction) that are applied directly to the instrument tracker values. Jason-1 uses tabular corrections parameterized by SWH and signal-to-noise ratio (SNR) (Thibaut 2004) that are applied to retracking which uses a simplified waveform model (Amarouche et al. 2004).

For retracking, one needs a model of the altimeter PTR, the antenna beam width, and any adjustments to the telemetered waveform samples. We have examined one month of Jason-1 calibration data and found results entirely consistent with Thibaut (2004). The PTR is well determined by onboard calibration data. The Jason-1 PTR is very close to the theoretical $(\sin(\mathrm{Bt})/(\mathrm{Bt}))^2$, so that is used in the retracking. The relative gains for the waveform samples are also determined by onboard calibration data. The gains of the waveform samples vary about $\pm 2\%$ over the 128 samples. The results appear to be quite stable so an average over one month of data was used. In standard Jason-1 processing daily averages are used. We note that this may introduce some very small variations into Project GDRs that are not necessary given the long term stability of the system.

The retracking method developed and employed by Rodriguez and collaborators (Rodriguez 1988; Rodriguez and Chapman 1989; Rodriguez and Martin 1994) over many years of the TOPEX mission has been applied to 18 cycles of Jason-1 data including cycles 1–15 from the TOPEX-Jason-1 collinear period. The key features of this method are: (1) fitting for a full set of parameters: range (also called epoch), SWH, amplitude, attitude, and skewness; and (2) use of 26 Gaussians to represent the PTR, which greatly speeds computation by allowing analytical calculation of derivatives.

The Gaussian representation of the PTR is produced by successively fitting Gaussians to the highest peak in the PTR or its residual from the previous fit. For Jason-1, 26 Gaussians of three fixed widths with adjustable center locations and amplitudes were fit by hand leaving no peak value greater than 4.0E-3 (-24 dB, original peak value = 1).

For processing, we used Jason-1 SGDRs (version 2) which provide GDR values, waveforms, and some intermediate results. A solution is obtained from data for each frame (1 sec) with one SWH, skewness, and attitude (off-nadir angle squared as that is the natural parameter in the waveform model), while a range is estimated for each individual (20/frame) waveform. Skewness is not estimated if SWH <1.0 m. The range estimate is the correction to the tracker range; the tracker is nominally positioned at sample 44 of the 128 waveform samples (31 of the 104 samples in the SGDR data). The solution is a least squares fit via singular value decomposition (SVD) to the differences between model waveforms based on tracker values and the observed waveforms. The SVD provides robust estimates that are needed with the relatively noisy individual waveforms. Because of the speed provided by the Gaussian PTR method, data processing takes approximately 2–3 minutes per pass on a typical workstation.

Processing Flow Details

For each record, fitting as described above is done separately for Ku and C band:

1. The waveform samples are scaled by the relative gains of the waveform samples to account for system response.
2. The noise for the observed waveform (WF) is estimated using specified samples, scaled, and subtracted. The resulting waveform is normalized by a scale factor.
3. Initial, linearizing values of the waveform parameters are taken from tracker values or from the previous retracking step if it was good and there is not a gap.
4. A model WF is calculated from the linearizing parameters.
5. The model WF is subtracted from the observed waveforms.
6. The derivatives of the parameters to be estimated are calculated from the model parameters for each Gaussian component of the PTR as indicated in #4 above.
7. The derivatives and WF residuals are passed to the SVD solver that returns the estimated parameters.
8. The 20/frame range corrections are compressed to 1/frame using the same compression algorithm that is used in GDR processing for this purpose. The 1/frame value is used in the comparisons here.

Additional Retracking Tests

We have investigated the effects of changing the number of Gaussians used to represent the PTR and of changing the antenna beam width (BW). Figure 2 shows a histogram of the difference between the range correction for the PTR representation with 26 Gaussians and with 1 Gaussian for Jason cycle 14 pass 129 which included an "ABCal" maneuver (off nadir pointing in a cross to check the attitude estimates from the satellite against that from retracking). Figure 3 shows the difference in SWH for the same case. We have done similar tests with TOPEX retracking on much larger data sets and find nearly identical results.

Figure 2 shows that the range change peaks at 4 mm but has a relatively long tail. The range change is not a strong function of SWH or attitude (not shown). Figure 3 shows an SWH difference of approximately 0.4 m for the 1 Gaussian and 0.1 m for the 26 Gaussian cases from Jason-1 GDR value. The fact that a 1 Gaussian PTR produces a bias in SWH is well known. The bias and the basic variation of SWH with SWH itself for the 1 Gaussian

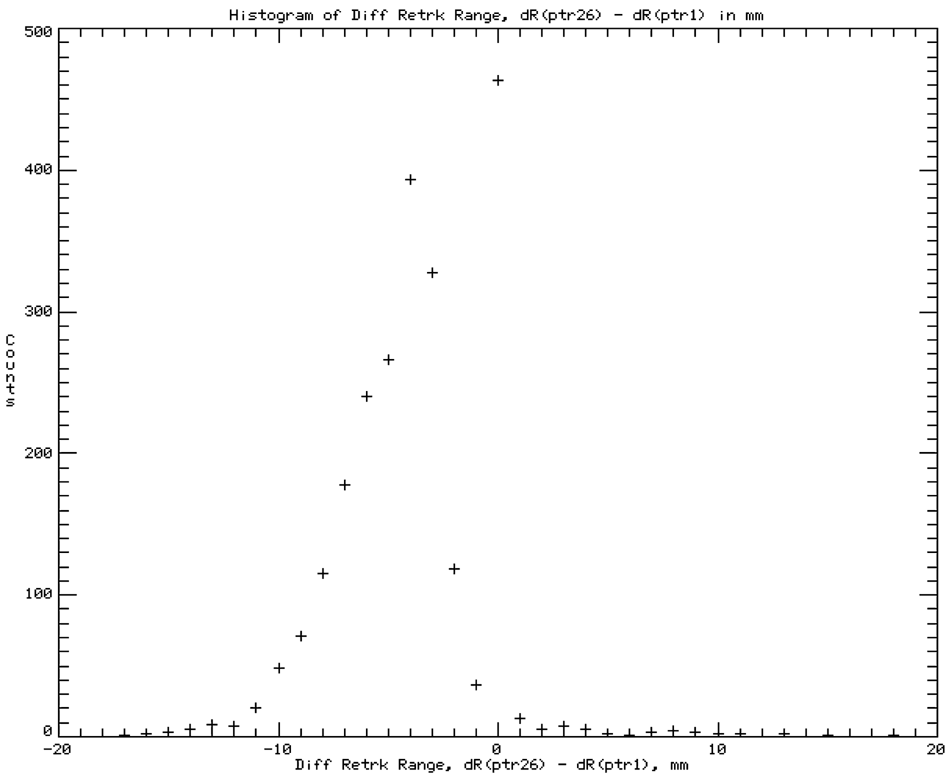


FIGURE 2 Histogram of the difference between the range correction for the PTR representation with 26 Gaussians and with 1 Gaussian in millimeters for Jason cycle 14 pass 129 that included an "ABCal" maneuver. The spike at 0 is from points that do not retrack in either case.

case are corrected in Project processing with lookup tables (Thibaut 2004; Amarouche et al. 2004); the correction to SWH is $\sim$ 0.2—0.25 m for typical SWH.

Figure 4 shows the estimated attitude using what we believed to be the nominal beam width of 1.30 deg and the differences in estimated attitude between using the BW of 1.30 deg and 1.34 deg and 1.40 deg. We have since been informed that the nominal BW is 1.28 deg. We did tests with this BW and found changes consistent with those shown. The figure shows the attitude excursions during an attitude bias calibration (ABCal) maneuver. The differences (both offset by -0.1 in plot) show that a larger BW will produce more negative attitudes as well as larger estimates of attitude excursions. The latter is because more attitude change is needed with a larger BW to produce a given change in the waveform. The excursions of the retrieved attitude for the ABCal are not quite as large as the designed maneuver, suggesting that a slightly larger BW should be considered. On the other hand, more negative typical attitudes are not desirable as the distribution shown in Figures 6b and 7 already has a large negative tail. For a spacecraft with well-controlled attitude, one would expect the estimated attitude to be near zero with some spread from noise and some positive values, as any off nadir pointing will cause a drop in the tail of the waveform and thus a positive attitude estimate. Using too large a BW will result in relatively more negative estimated attitudes as fall off in the observed waveform tail will be interpreted as only small off nadir pointing. Another consideration is that measurements on TOPEX (Callahan and Haub 1995) indicated that the TOPEX on-orbit BW was larger than the nominal. Since the difference between a

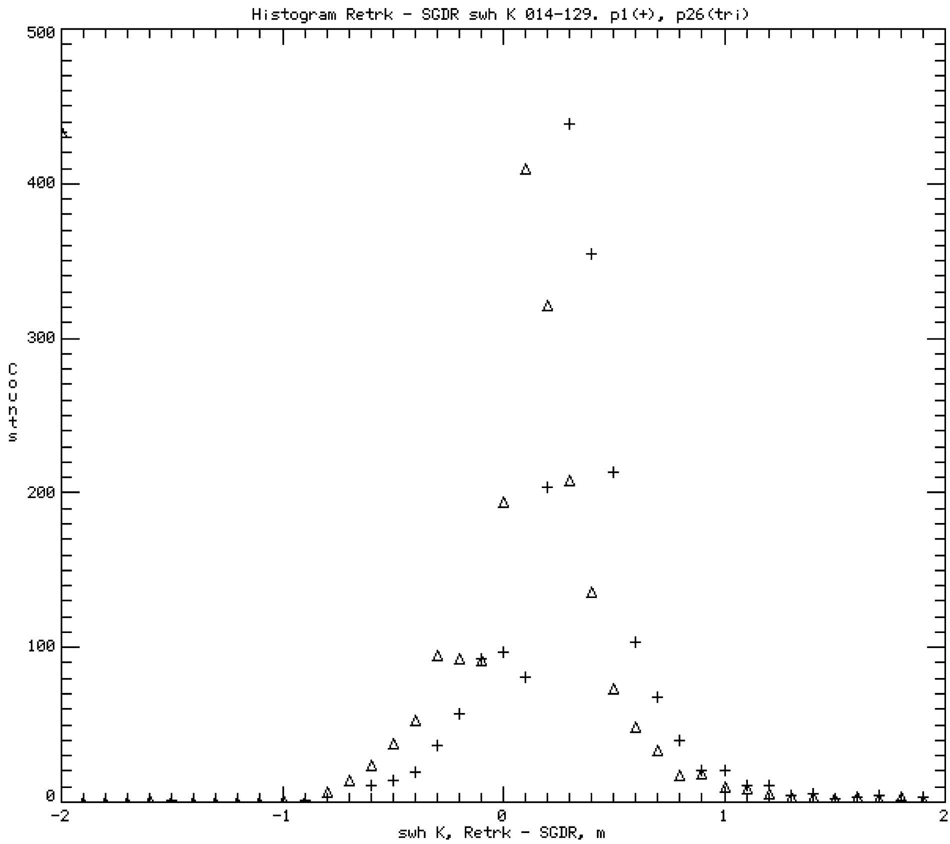


FIGURE 3 Histograms of difference between the retracked SWH for the PTR representation with 26 Gaussians (triangle) and with 1 Gaussian (+) and the Jason GDR SWH for Jason cycle 14 pass 129 that included an "ABCal" maneuver. The difference is small for the 26 Gaussian case because SWH on the GDR is corrected for the Project 1 Gaussian retracking.

BW of 1.28 and 1.30 deg will be a bias of about 0.01 deg^2 and relative variations of less than 0.01 deg^2 in the estimated attitude, we believe that the current results would not be substantially altered by using a BW of 1.28 deg in our retracking.

Retracking Results

Range

For 1 Hz data our retracked range correction is compared to the quantity

$$\begin{aligned}\text{CNES\_Retrack\_Corr} = -\ &(\text{ku\_range} + \text{Avg(ku\_range\_20 Hz)} \\ &- \text{Avg(ku\_tracker20 Hz)} + \text{instrument\_model\_corrku}) \quad (4)\end{aligned}$$

from values on the Jason-1 SGDRs, where ku_range is the fully corrected 1 Hz range including tracker, CNES retracking, instrument model correction, and several 1 per frame instrument corrections given by

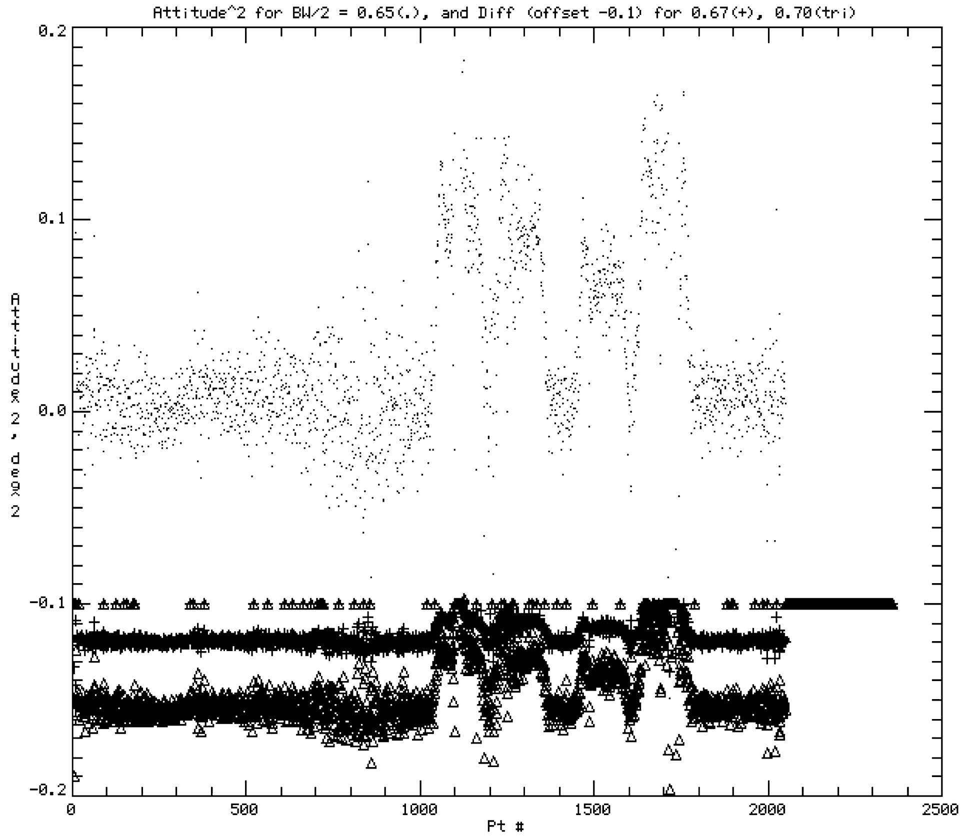


FIGURE 4 The JPL Retrack Attitude^2 with a BW of 1.30 deg for Jason cycle 14 pass 129 that included an "ABCal" maneuver is shown as dots. The difference between the Attidue^2 for the beam width of 1.30 deg and ones with 1.34 deg (+) and 1.40 deg (Δ) (BW_trial – BW_1.30 -0.1, i.e., the differences are offset) in deg^2 are shown below the attitude profile. The difference for the larger BW has a larger bias and larger excursions.

sum_range_corrections = USO_corr_range + path_delay_corr_ku + Dopp_corr_range;
ku_range_20 Hz are the 20 Hz differences from ku_range within a 1-sec frame;
ku_tracker20 Hz are the 20 Hz altimeter tracker values which are also fully corrected as is the ku_range (Vincent et al. 2004);
instrument_model_corr_ku is a correction computed to correct for differences between the modeled system response (tracker + retracking) and the model inputs (SWH, Attitude, range, SNR, etc.); and
Avg indicates taking the average over the frame.

CNES_Retrack_Corr defined in Eq. (4) contains the Jason-1 retracking and its associated instrument model correction. We believe that this is the proper quantity to compare to our full retracking.

Figure 5 shows an overall comparison of our retracked range to CNES_Retrack_Corr. There is very high correlation between the two retracking results; however, there are systematic differences at the level of several centimeters, particularly in the region where most of the data occur as indicated by the dashed red curve. Figure 6 shows the difference between our retracked range and CNES_Retrack_Corr plotted against (a) SWH and (b) Attitude^2 from the SGDR. The dashed curves show the distribution of data to indicate what part of

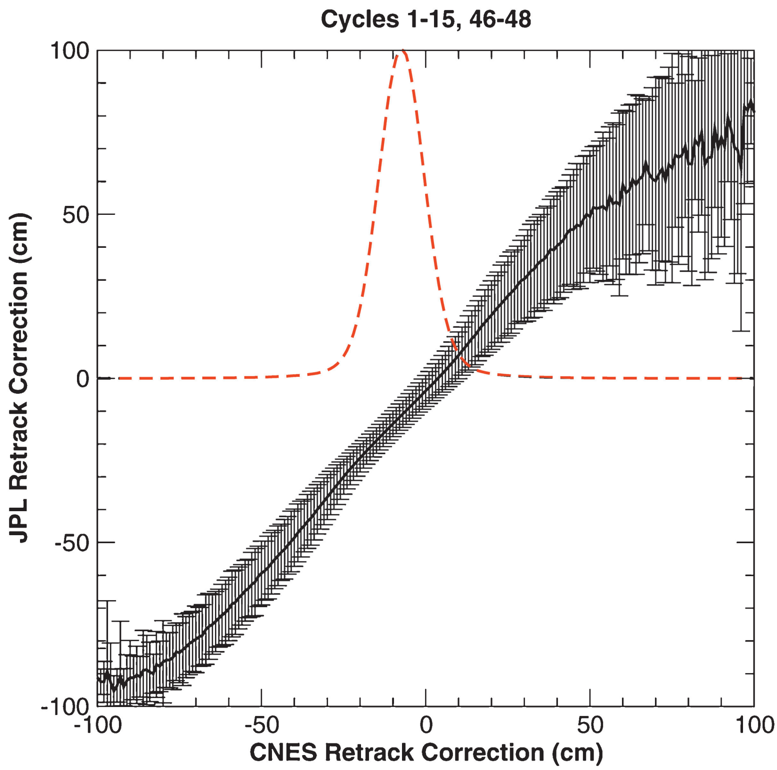
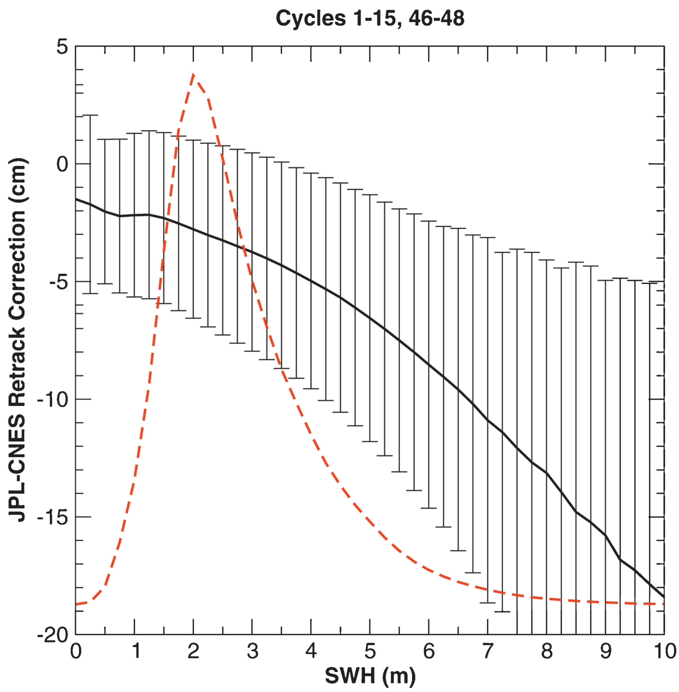


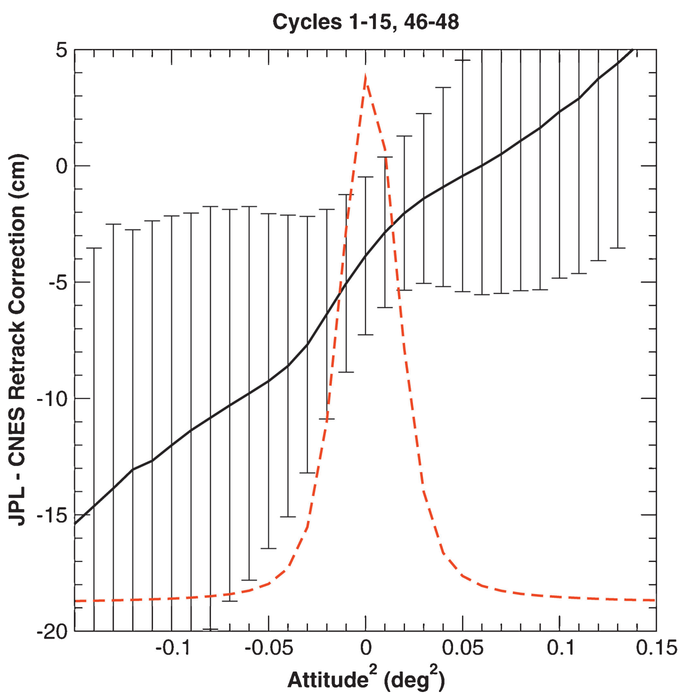
FIGURE 5 Comparison of retracked ranges. The central line shows the mean of JPL Retrack correction as an function of the CNES_Retrack_Corr (Eq. 4). The bars show one standard deviation. The red dashed line shows the relative distribution of the data.

the difference is of main interest. One sees that over typical SWH of 1–6 m the difference goes from about -2 to -7 cm. The attitude plot shows a somewhat different picture. While the typical span of attitude is rather small (-0.04 to $+0.05$ deg^2, i.e., off nadir angles of approximately 0 to 0.2 deg, see Figure 7), the range difference varies rapidly from about -9 to -2 cm. The meaning of negative attitude is that the tail of the waveform does not fall off as quickly as would be expected for the beam width. The relatively large number of negative attitudes found (dashed distribution curve) suggests that the beam width should be narrowed slightly to give a faster fall off of the model of the tail as discussed above. Figure 7 shows the distribution of data for Jason cycles 9–12 plotted in the two dimensional SWH-Attitude^2 (our retracked attitude) coordinates. The main data area is shown in red, while there are $>\sim$ 1000 counts per bin (0.2 m in SWH, 0.01 deg^2 in attitude) between attitudes of about -0.04 deg^2 to 0.05 deg^2 for SWH around 2 m. Later displays of differences are shown for an attitude range of $+/-0.10$ deg^2 in attitude to concentrate attention in the main data region.

Figure 8a is a two dimensional display of the retracking difference in SWH-Attitude^2 coordinates. The data-rich region spans approximately -8 to 0 cm, but calibration to the centimeter level is required. Figure 8b is a geographic display of the differences. The effect of the global variation of average SWH (see Figure 10) can be seen. Below we show that there is little variation of attitude with SWH, and we have checked that, as one would expect, there is not a systematic geographic variation of attitude. So there is probably little attitude effect causing the difference, even though that is the stronger variation in the retracking results.



(a)



(b)

FIGURE 6 The difference between JPL retracked range and CNES_Retrack_Corr (Eq. 4) plotted against (a) SWH and (b) Attitude.[2] The bars show the distribution of data about the mean line. The dashed red curve shows the distribution of data.

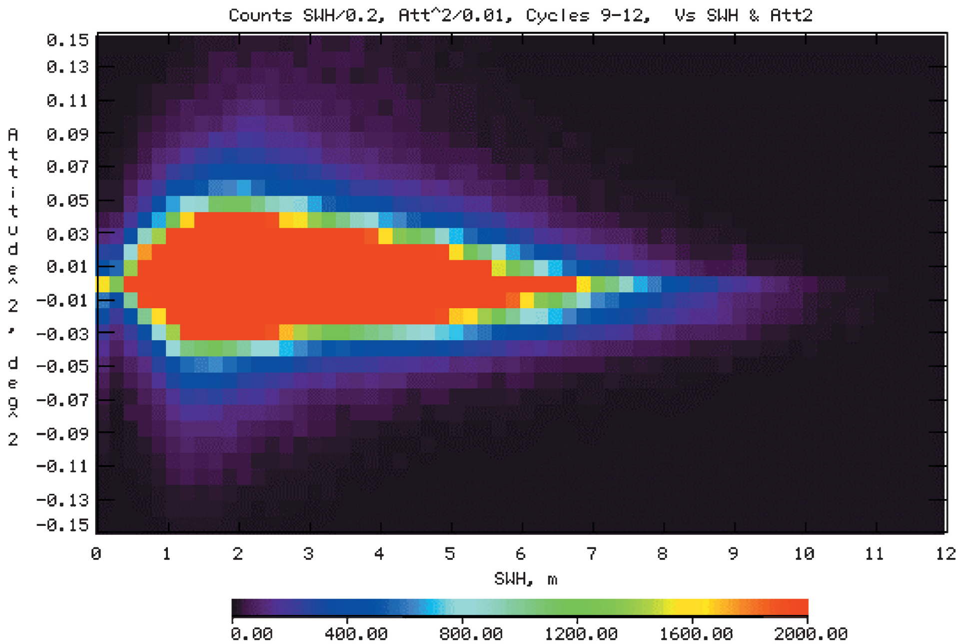


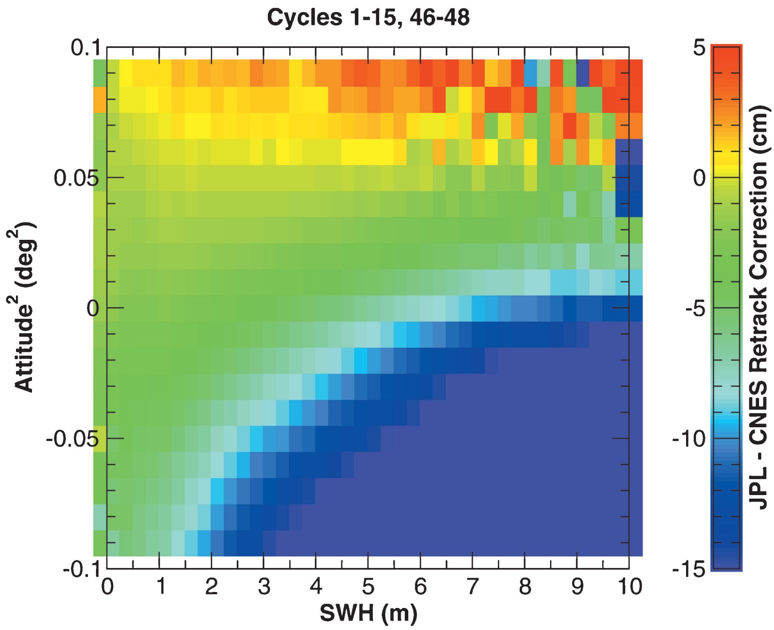
FIGURE 7 The distribution of counts in SWH and Attitude^2 coordinates using JPL Retrack SWH and Attitude.^{2} SWH bins are 0.2 m; Attitude^2 bins are 0.01 deg^2.

We believe that the strong variation of range with attitude results from not fitting this quantity directly in the project processing (Amarouche et al. 2004). The attitude is introduced by a linear fit to the tail of the waveform but is not further adjusted. Since we are interested in centimeter corrections to range (less than 0.1 of a waveform sample span) and approximately 0.1 m corrections to SWH, it should not be surprising that not allowing the attitude parameter to vary in fitting the waveform model to the rather noisy 20 Hz waveforms results in differences. It should be noted that the Jason-1 correction tables do not address this problem as the second variable (besides SWH) is SNR (Thibaut 2004) which has only weak dependence on attitude and will not help the negative attitude data. Thibaut (2004) does not discuss varying attitude in the waveform model while developing the instrument model correction tables.

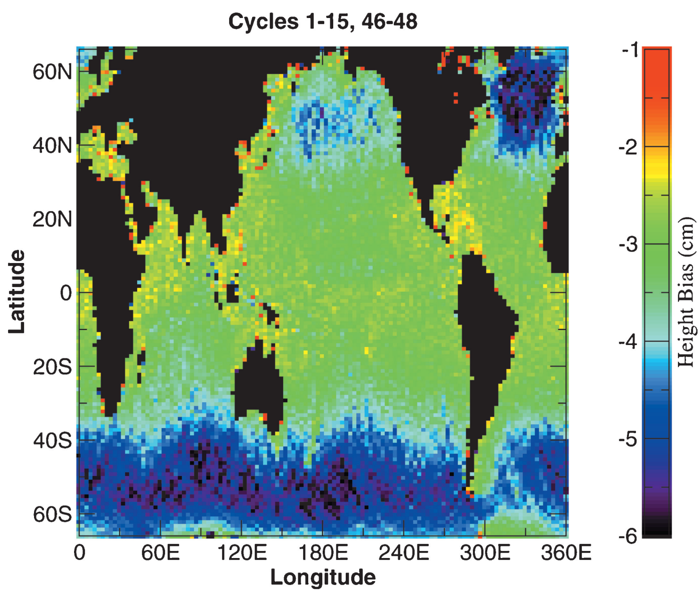
Significant Wave Height

Figure 9 shows the difference between our retracked SWH and that in the Jason-1 SGDRs plotted in (a) SWH-Attitude^2 coordinates, and as (b) a global map for Jason cycles 9–12. Over the main data region, there is a variation from about +0.3 to −0.1 m with somewhat larger positive errors at large SWH. Figure 9b shows that the attitude variations in SWH do average out in the global distribution (again no geographic variation of attitude), so that the differences are all positive and strongly correlated with average SWH (Figure 10).

Errors in SWH can also cause errors in the range when incorrect SWH values are used in the instrument model look up tables. However, this is a relatively small effect—a few tenths of a meter error in SWH causing errors in both instrument correction and EMB/SSB of 1–2 cm. However, we believe that the strong variation of SWH with attitude is the main contributor to the large apparent SSB found for Jason-1 (see Summary).

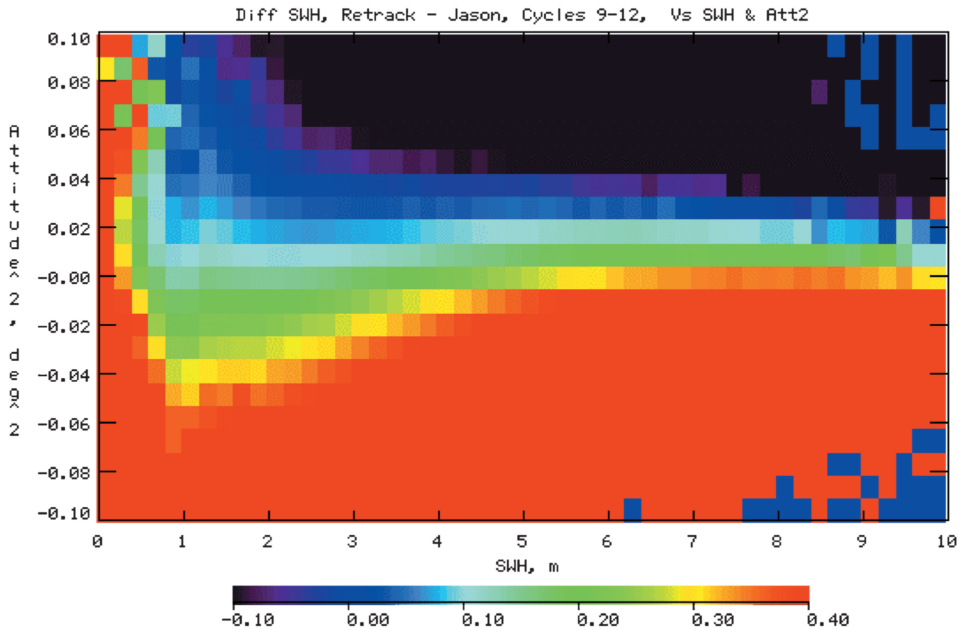


(a)

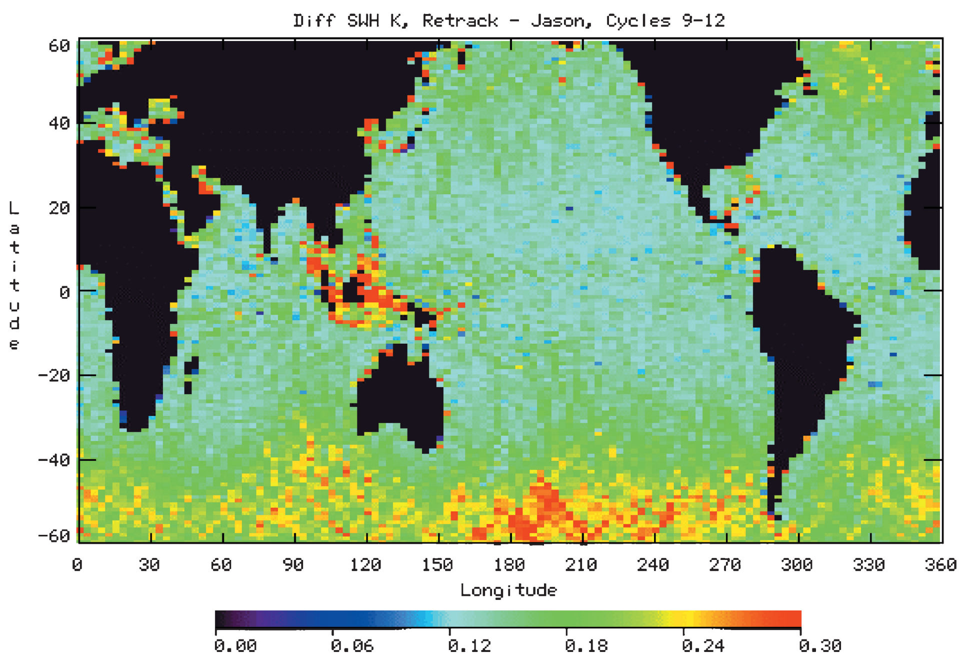


(b)

FIGURE 8 (a) The difference between JPL retracked range and CNES_Retrack_Corr (Eq. 4) plotted in SWH-Attitude^2 coordinates. There is very little data in the purple area in the lower right. (b) The difference between JPL retracked range and CNES_Retrack_Corr (Eq. 4) plotted geographically. Compare to global map of SWH in Figure 10.



(a)



(b)

FIGURE 9 The difference between our retracked SWH and Jason-1 SGDR SWH for Jason cycles 9–12 plotted in (a) SWH- Attitude^2 coordinates, (b) latitude-longitude. Compare the global distribution in 9(b) to the global map of retracked SWH in Figure 10.

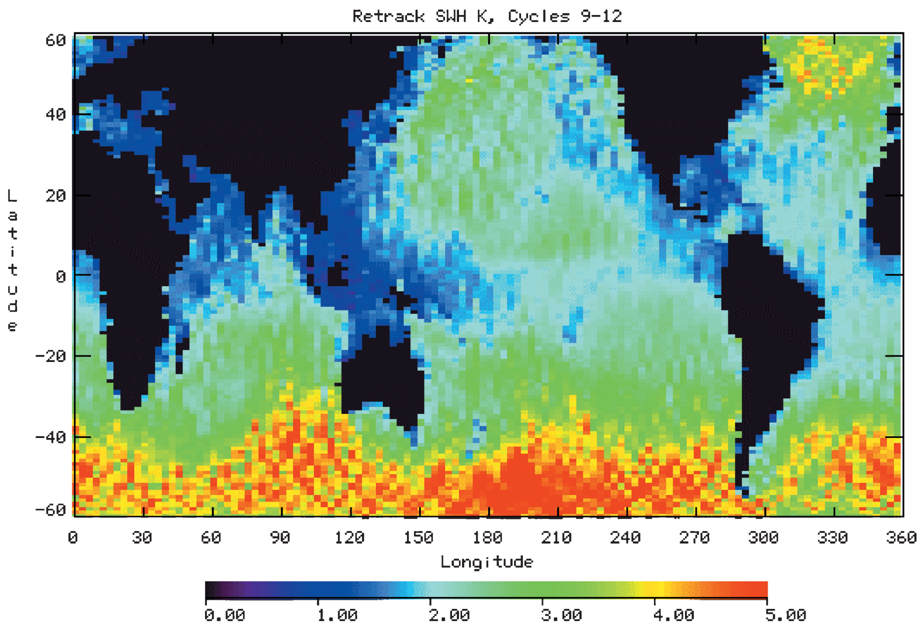


FIGURE 10 Global average of Retracked SWH for Jason cycles 9–12.

Attitude

Figure 11 shows the difference between our retracked attitude and that in the Jason-1 SGDRs for Jason cycles 9–12 plotted in the same coordinates. Over the main data region ($>\sim 1000$ points per bin) of -0.04 to $+0.05$ deg^2, there is a variation from about -0.02 to $+0.03$ deg^2, relatively independent of SWH (variation $<\sim 0.01$ deg^2) but strongly dependent on attitude

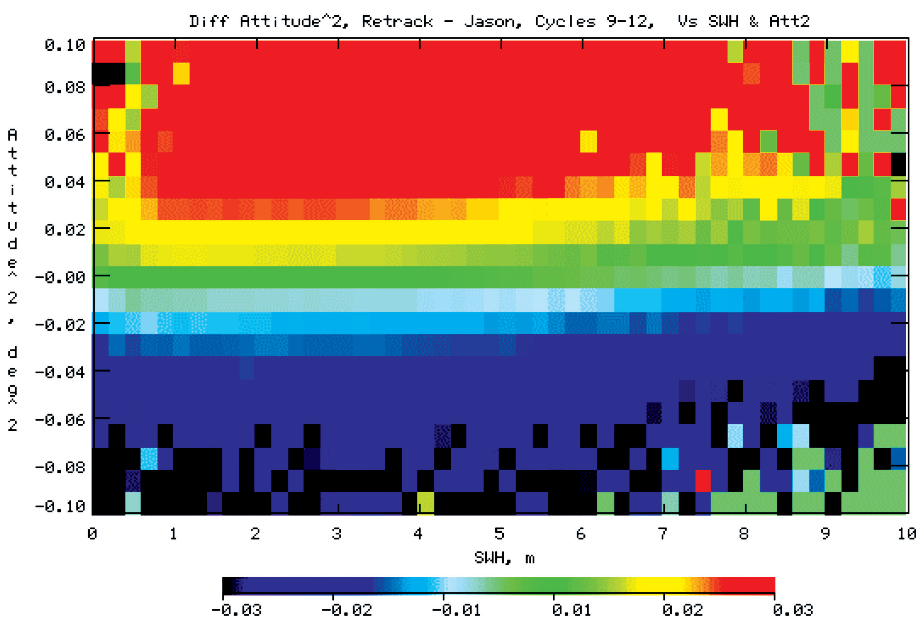


FIGURE 11 The difference between JPL retracked attitude and that in the Jason-1 SGDRs in JPL-Retracked SWH-Attitude^2 coordinates for Jason cycles 9–12. Note that there is very little variation with SWH but that the attitude difference is nearly as large as the value.

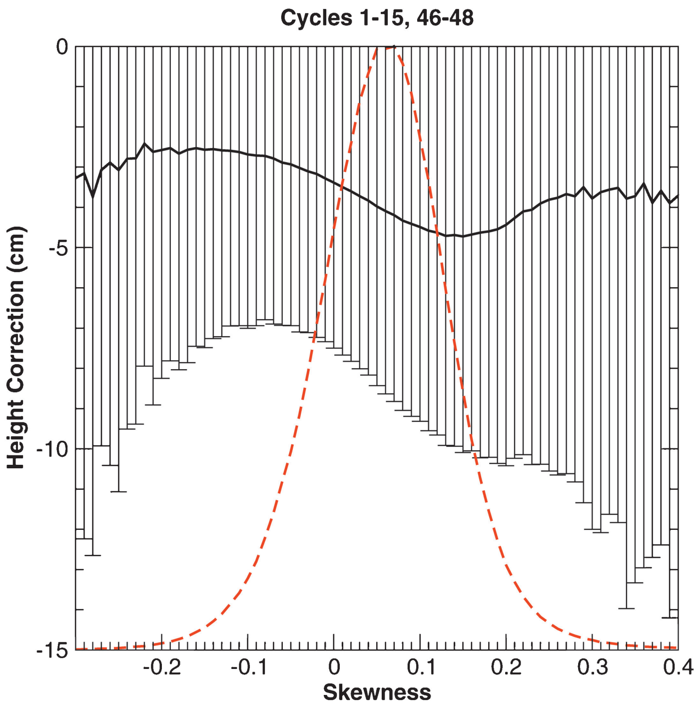


FIGURE 12 The difference between our retracked range and CNES_Retrack_Corr (Eq. 4) plotted against our estimated skewness averaged over 31 seconds. The dashed curve shows the distribution of skewness values. The overall mean is approximately 0.06.

itself. While the variation may seem small, it is comparable to the range of typical values. This is another indication that the results in the project GDRs are very sensitive to attitude estimation and possible variations. A difference in attitude bias of $\sim$0.01 deg^2 is shown in Amarouche et al. (2004) between current Project processing (MLE3) and an improved model that solves for attitude (MLE4).

Skewness

Figure 12 shows the difference between our retracked range and CNES_Retrack_Corr plotted against the retracked skewness. The dashed curve in Figure 9 shows a histogram of the retracked skewness. As it is a higher order parameter and mainly determined by a few samples at the beginning of the rising edge of the waveform near the noise level, the measurement is noisy and has been averaged over 31 seconds. The average value is about 0.06. The Jason-1 correction tables were generated with an assumed skewness of 0; TOPEX correction tables were generated for an assumed skewness of 0.1.

Figure 13 shows the difference between our retracked range and CNES_Retrack_Corr plotted against the retracked skewness multiplied by SWH. The dashed line shows the expected skewness range error of $-\lambda$SWH/24 (Srokosz 1986; Rodriguez 1988). While we have discussed several other causes of the difference in retracked range, the skewness correction could account for some (1–2 cm) of the difference. This is the first direct observation of this effect.

Figure 14 shows a global average of skewness for Jason cycles 9–12. The values range from near zero to 0.1. The larger values are strongly correlated with higher average SWH

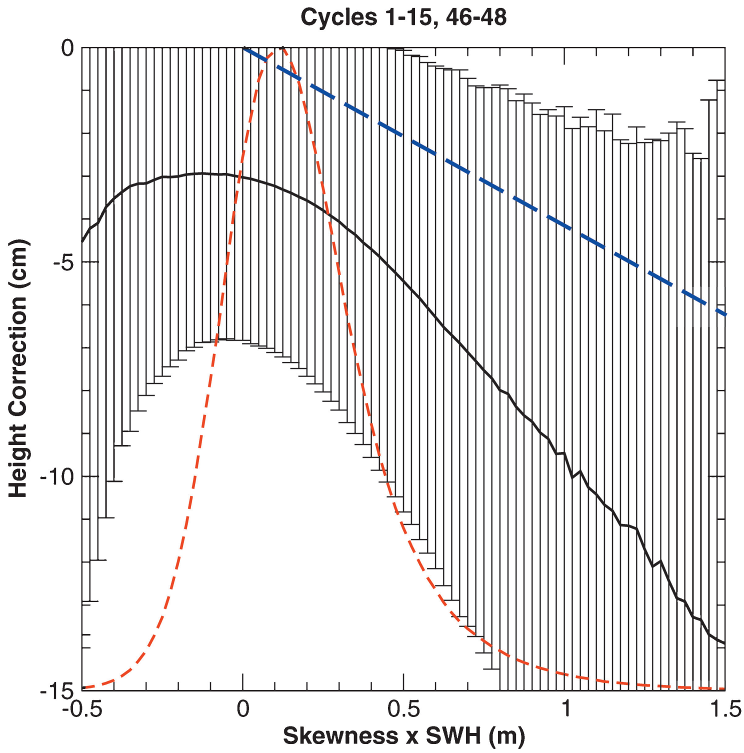


FIGURE 13 The difference between our retracked range and CNES_Retrack_Corr (Eq. 4) plotted against our estimated skewness * SWH. The light dashed red curve shows the distribution of skewness values. The heavy dashed blue line shows the expected skewness range bias.

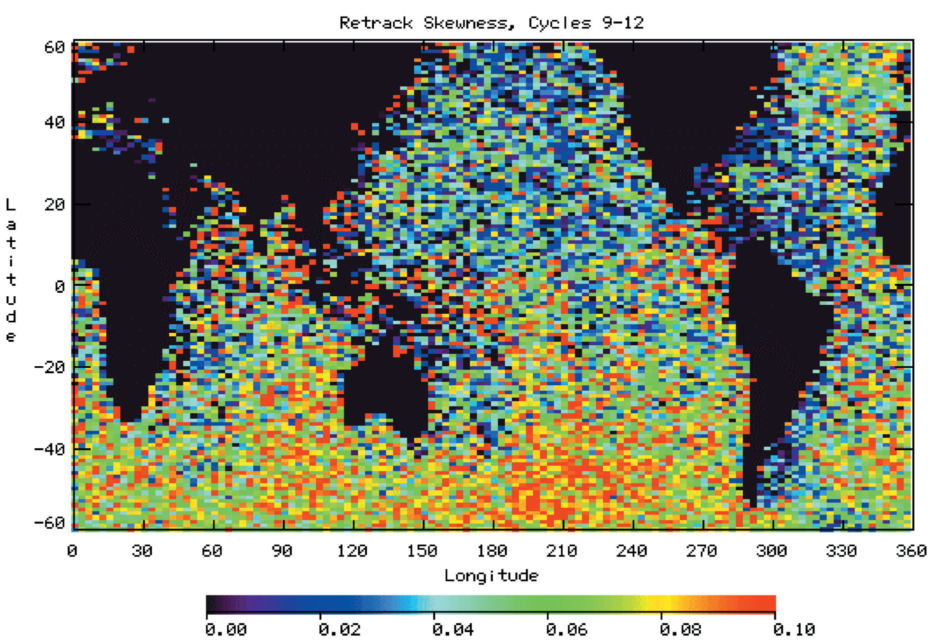


FIGURE 14 Global map of our retracked skewness for Jason cycles 9–12. Compare to global map of SWH in Figure 10.

shown in Figure 10. Given the geographic and seasonal variation of SWH this indicates that regional or time dependent errors could be introduced into the sea surface height if a fixed value of skewness is used in the processing. CNES has found similar values for skewness; however, they find a very different geographic and SWH dependence (Private communication from P. Vincent, 2004). Confirmation of the skewness and its effects must await full understanding of the issues in retracking Jason-1 data.

Summary and Conclusions

We have shown significant differences between the values of range, SWH, and attitude on the Jason-1 SGDRs and results from our retracking with a more complete model. The difference in attitude estimation has been addressed in Amarouche et al. (2004). We believe that the differences found here are the result of the standard project processing using a single Gaussian approximation to the PTR, not including attitude in the simultaneous fit to the waveform, and parameterization of the postretracking instrument correction tables in terms of SNR rather than off nadir angle as the second variable in addition to SWH (Thibaut 2004). The differences found here are more than a factor of 2 larger than any of the Project supplied corrections when considered in SWH-Attitude coordinates. The effect of varying the antenna beam width (1.28 deg instead of 1.30 deg used here) in the retracking should be further explored to ensure that the distribution of retrieved attitudes is consistent with the known behavior of the spacecraft. We do not believe that a small change in beam width will significantly change these results.

Comparison to Beckley et al. (this volume) shows that the difference between TOPEX and Jason-1 sea surface heights (SSH) is almost identical to the difference found here between the Jason-1 retracking value and our retracking results. This comparison between SSH and retracking can be made simply during the collinear period because environmental effects, in particular the physical electromagnetic bias (EMB) which cannot usually be separated from instrumental SSB, are common to the two altimeter measurements of SSH, and thus the difference between them, leaving only the fundamental measurements of range and orbit altitude with errors that are unique to the two systems.

The magnitude of the differences in Figure 8 is similar to the SSB corrections that were inferred during the cal/val period. We believe that the relatively large sea state bias errors estimated empirically for Jason-1 during the cal/val phase probably resulted from sensitivity of the SWH in project GDRs to attitude. This results in unrealistic SWH differences when solving for the sea state bias from differenced data. As is well known, estimating SSB from differences (crossover or along track) is quite sensitive to any kind of error, as most of the data lie in a narrow range of parameter space. So differences are small compared to the range needed for the correction. If the SWH differences are mainly due to random differences in attitude caused by the way in which it is introduced from a separate fit in project processing, then the relation of the SWH differences to the sea surface height differences will not be meaningful.

We presented the first clear demonstration of the skewness effect in altimeter measurements. The result shows clear global patterns and could lead to sea surface height errors of 1–2 centimeters over the range of interest. Retracking would be the most straightforward way to eliminate this error. However, care would be needed because of the relatively noisy skewness measurement.

The Jason-1 waveforms have no leakages or distortions and appear to be quite stable. Relatively simple tests of retracking can be used to revise the model parameters. Retracking TOPEX and Jason-1 data with the same software with appropriate and consistent models will allow comparing the data in all wind/wave regimes and precisely determining the

TOPEX-Jason-1 bias to allow a highly consistent ongoing estimate of sea surface height for climate change studies. It is strongly recommended that a detailed comparison of retracking methods and parameters be carried. This work can also lead to an estimate of the physical electromagnetic bias (EMB) effect as distinguished from altimeter effects that give a total SSB.

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