CONSISTENCY OF WIND AND WAVE DATA FROM PAST AND PRESENT ALTIMETRIC MISSIONS

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The altimeters on board ERS-1 (1991 - 1996), ERS-2 (1995 -), TOPEX (1992 -) and GEOSAT Follow-On (1998 -) provided almost continuous wind speed and significant wave height measurements over more than a 10 year long time period. The launches of JASON-1 and ENVISAT lead to the unprecedented opportunity to get five satellite altimeters, flying together.

Here we present long term validation of altimeter significant wave height and wind speed using global statistical analysis and cross validation of altimeter measurements at same time and location. Long term results are given for ERS-1, ERS-2, TOPEX and GFO, over time period from 1991 to beginning of 2002. For SWH, corrections deduced from independent comparisons between buoys and altimeters are then applied to the data. The TOPEX side-A drift is estimated and removed using TOPEX ERS-2 colocated measurements. Proposed corrections are then tested over the whole colocated data set for TOPEX, ERS-2 amd GEOSAT FO. For wind speed, long term statistics show large differences between the altimeters, resulting from backscatter coefficient differences. Data from JASON-1 are colocated with ERS-2 and GFO. Results are given for SWH and sigma0, for JASON cycles 8 to 12.

LONG TERM COMPARISONS

Simple SWH, wind speed and sigma0 statistics are computed over successive 10-day time periods, for the global ocean limited by the 66° North - 66° South latitude range of the TOPEX orbit ground track. Data are selected according to the various quality flags given in the products.

On average over 10 days the number of altimeter measurements (1 s along track samples) is about 420000 for ERS-1 and ERS-2, 490000 for TOPEX and 480000 for GFO. The 10-day sequences for which the number of data is less than 300000 are discarded. POSEIDON data are not analyzed in this long term statistics because the altimeter is operating only during one tenth of the time.

CROSSING-POINT COMPARISONS

The colocation procedure consists in selecting the measurements of the two satellites when within a one hour time window at ground track crossing points. To smooth the wave variability within this time window, the measurements are further averaged along track, 50 km each side of the crossing point.

DATA

ERS-1 and ERS-2 : ESA Ocean Product (OPR) processed and distributed by CERSAT

TOPEX : AVISO Merged-GDR

GEOSAT Follow-On : (MOE) NOAA IGDR provided by J. Lillibridge on ftp://gfo:cal_val!@eagle.grdl.noaa.gov/igdr

JASON-1 : IGDR calval data

SIGNIFICANT WAVE HEIGHT

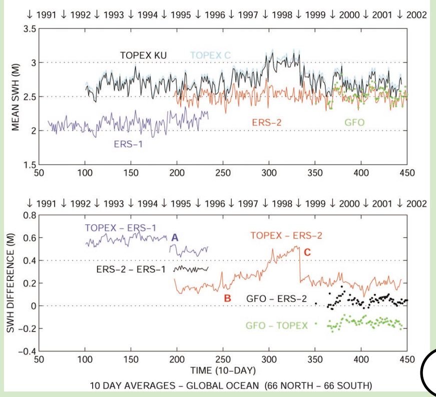

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Figure 1 : time series of 10-day, global ocean, mean values of SWH measured by ERS-1, ERS-2, TOPEX and GFO (top graph). Significant differences (bottom graph) exist between the altimeter SWH estimates. A mean bias of 0.6 m is observed between ERS-1 and TOPEX. The level change occuring in March 1995 (A on the graph) corresponds to a processing software change for ERS-2 compatibility (note that a large part of ERS-1 data before March 1995 has been re-processed recently with the ERS-2 processing, and will be validated soon). The bias between ERS-2 and TOPEX is about 0.2 m in 1995 and 1996. It then increases, after February 1997 (B on the graph), up to 0.5 m on February 1999 (C), due to TOPEX side-A drift. TOPEX spare side-B was then switch on, on February 1999, with the consequence of a sharp 30 cm change in SWH estimate (C). TOPEX Ku-band and C-band estimates are close together. GFO estimates are in agreement with ERS-2, and are biased low (about 20 cm) relative to TOPEX.

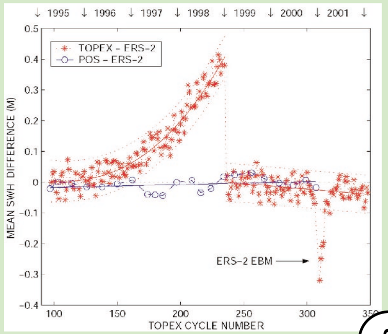

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Figure 2: mean values of SWH differences between TOPEX/POSEIDON and ERS-2 altimeter co-located measurements, as a function of TOPEX cycle number. The corrections estimated from the buoy comparisons have been applied.

To correct the TOPEX SWH drift, a third order polynomial is fitted to the colocated data mean difference (continuous red line) and used to establish the correction (1) as a function of the TOPEX cycle number *cy*, for cycle number 98 to 235. In first approximation this correction was estimated on the mean values of differences, because the SWH drift is not significantly depending on SWH level as indicated when investigating for three SWH bins: 0-2 m, 2-4 m and 4-6 m (not show here). After cycle number 235 TOPEX was corrected using the linear regression obtained over cyle numbers 236 to 348, as (2). This relation was obtained discarding the time period corresponding the extrem values observed for cycles 310 to 313, associated to ERS-2 gyro problems during the altimeter Extra Back-up Mode phase from 2001/2/5 to 2001/3/23.

(1) $SWH_{COR} = SWH + \delta$

with:

$$\delta = \sum_{i=1}^{3} a_i (98^i - cy^i) \ for\ 235 \ge cy \ge 98$$

and

$$a_1 = -1.6\ 10^{-3};\ a_2 = -2.2424\ 10^{-6};\ a_3 = 5.9830\ 10^{-8}$$

(2) $SWH_{COR} = SWH + \delta \quad for\ \ cy \ge 236$

with:

$$\delta = 3.5385\ 10^{-4} \times cy - 0.0832$$

SWH CORRECTIONS

Independent buoy altimeter comparisons were performed (D.Cotton) and some linear corrections proposed, based on orthogonal distance principal component analysis. The ERS-1 correction is based partly on buoy and and partly on TOPEX comparisons. These corrections can be applied to the SWH altimeter data.

For ERS-1:

-data before March 1995: $SWH_{ERS1cor} = 1.19\ SWH + 0.19$

-data after March 1995:

$$SWH_{ERS1cor} = -0.0035(SWH)^3 + 0.0558(SWH)^2 + 0.8684\,SWH + 0.4610 \text{ if } SWH \le 2.5m$$

$$SWH_{ERS1cor} = 1.1276\,SWH + 0.1069 \text{ if } SWH > 2.5m$$

For ERS-2: $SWH_{ERS2cor} = 1.0627\,SWH + 0.0454$

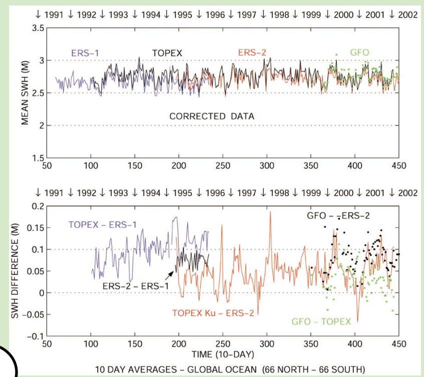
For TOPEX:

TOPEX side-A, before cycle 236 (estimated before the beginning of the drift i.e. TOPEX cycle number 128 (March 5 1996): $SWH_{TOPEXcor} = 1.0658\ SWH - 0.0888$

TOPEX side-B, from cycle 236: $SWH_{TOPEXcor} = 1.0376\ SWH - 0.0674$

For GEOSAT FO: $SWH_{GFOcor} = 1.0633\ SWH - 0.0808$

Figure 3: as figure 1, but buoy corrections and TOPEX drift removal have been applied to the measurements. There are still some trends and biases on differences, but the amplitudes are largely reduced, to about 15-20 cm range. Note that 10-day sampling variability has also an effect on differences.



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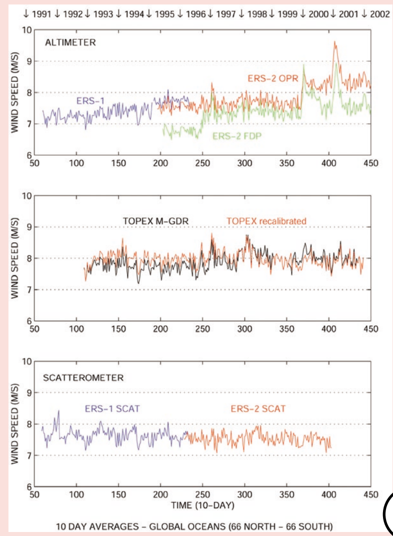
WIND SPEED AND SIGMA0

Figure 9: 10-day global ocean (66 N - 66 S) averages of wind speed measurements of ERS altimeters (top), TOPEX altimeter (middle) and ERS scatterometers (bottom). There are large differences among the sensors. ERS-1 exhibits a 0.8 m/s drift between 1991 and 1996, due to sigma0 drift (not shown here). ERS-2 OPR wind speed is stable and in good agreement with ERS scatterometers, till January 2000, when a sigma0 drop occurs (see figure 10). A jump is also observed in the beginning of 2001, corresponding to gyro problems and to ERS-2 Extra-Backup mode. For TOPEX M-GDR (middle, black curve) there is some difference in the wind speed level before and after 1997. This difference decreases when computing the wind speed (red curve) with a corrected sigma0, using the calibration tables provided by G. Hayne and D.Hancock (draft, March 2002).

Figure 10: time series of 10-day global ocean (66° N - 66° S) averages of backscatter coefficients (top) show the sigma naught differences between ERS-2, TOPEX and GFO. The two periods (A and B), before and after the ERS-2 sigma0 jump are analysed (discarding the ERS-2 EBM period), showing a sigma0 decrease about 0.25 db. Note that 0.63 dB has been subtracted from the TOPEX sigma0 M-GDR, as done for using the operational wind speed algorithm.



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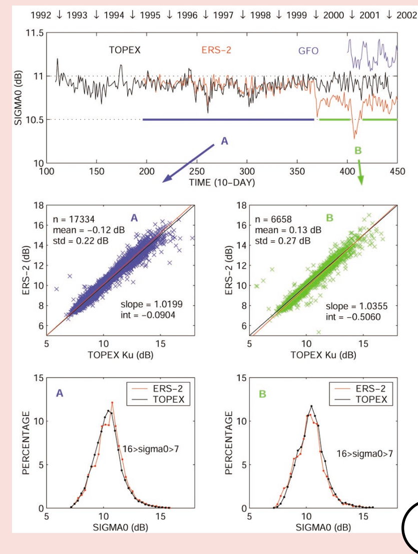

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Figures 4, 5 and 6 show scatterplots and histograms, comparing colocated SWH measurements from ERS-2 and GFO (left), ERS-2 and TOPEX (middle), GFO and TOPEX (right). For each panel results are given for raw data (i.e. as obtained from CD-ROMS or FTP) and for corrected data, using buoy correction relations, and TOPEX drift removal. Number of data (n), mean and standard deviations of the differences (x-y), correlation coefficients, slope and intercept of orthogonal distance regression are given for each pair of altimeters.

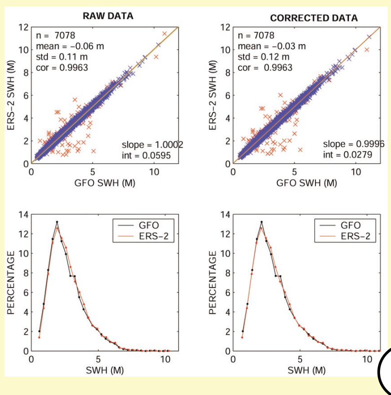

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Figure 4: GFO and ERS-2 SWH are in a good agreement. Red symbols on the scatterplots are for data with differences larger than 3 times the standard deviation of differences. These data are discarded for statistics. Raw and corrected data are almost in same agreement,

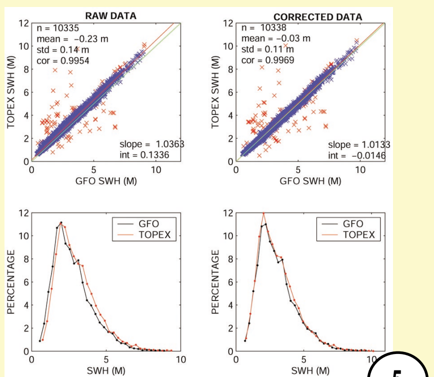

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Figure 5: for TOPEX ERS-2 comparison, data corrections improve the agreement between the two data set. The mean bias is reduced from 0.20 m to about 0, and the standard deviation from 0.17 m to 0.1

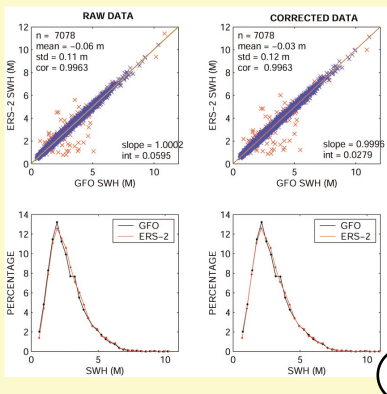

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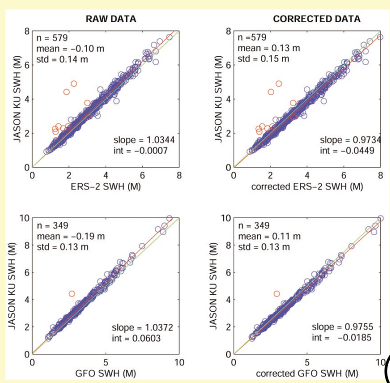
Figure 6: for TOPEX GFO comparison, data corrections improve also the agreement between the two data set. The mean bias is reduced from -0.23 m to -0.03 m, and the standard deviation from 0.14 m to 0.11 m.

COMPARISON OF JASON SWH WITH ERS-2 & GFO COLOCATED DATA



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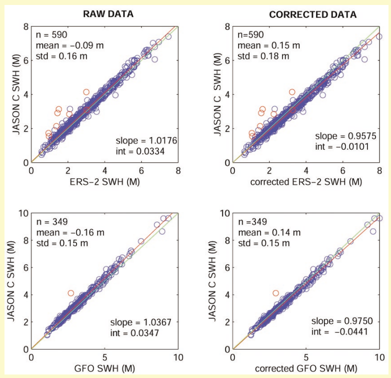

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Figure 7: comparison of JASON Ku band SWH with ERS-2 (top) and GFO (bottom) colocated data shows mean differences of -10 cm relative to ERS-2 and -19 cm relative to GFO, for the raw data (left). When ERS-2 and GFO are corrected (right), the means of differences change to 13 cm and 11 cm, and the regression lines show that JASON Ku SWH is slightly underestimated relative to ERS-2 and to GFO, and could be corrected as: SWHcor = 1.0273 SWH + 0.0461 (relative to ERS-2) or SWHcor = 1.0251 SWH + 0.0190 (relative to GFO). These two relations differ by less than 5 cm over 1 m 8 m SWH range. Red points on the graphs correspond to discarded data for which SWH standard deviation over 100 km is larger than 2 m.

Figure 8: as for Ku band the JASON C band SWH seems to be slightly underestimated, and could be corrected as SWHcor = 1.0444 SWH + 0.0105 (relative to ERS-2) or SWHcor = 1.0256 SWH + 0.0452 (relative to GFO). Difference between these two relations is larger than for Ku band: about from -1 cm to 11 cm over 1 m to 8 m SWH range . Note also that the observed standard deviations are larger than for Ku band.

COMPARISON OF JASON, ERS-2 & GFO SIGMA0

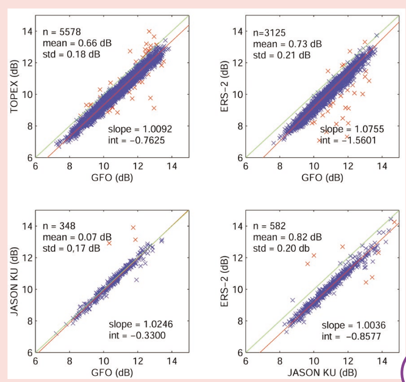

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Figure 11: sigma0 comparisons, at crossing points, over time period B. The two graphs on the left show a standard deviation about 0.18 dB for GFO - JASON and GFO - TOPEX, and that JASON Ku is underestimated about 0.07 dB relative to GFO and 0.04 dB relative to TOPEX when the 0.63 dB is not substracted from the M-GDR. Right graphs show that ERS-2 is low relative to JASON and GFO. A high slope of 1.07 is observed between GFO and ERS-2.