MERGED ALTIMETER WAVE HEIGHT DATA BASE. AN UPDATE

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ABSTRACT

The Ifremer Laboratoire d'Océanographie Spatiale (LOS) performed, for a long time, an independent monitoring of the quality of significant wave height (SWH), backscatter coefficient and wind speed measurements from the various altimeter missions. A merged and calibrated altimeter wave height data base has been setup and is regularly updated (ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/). Main recent improvements of the data base are presented. A summary of the accuracy of SWH measurements from past altimeters is given. Then validation results for SWH data from two recent altimeter missions are shown. First, the Cryosat-2 IGDR wave height provided by the NOAA Laboratory for Satellite Altimetry were validated for both Low Rate Mode (LRM) and Pseudo-LRM data. These data were then implemented in the merged data base. Second, preliminary results of validation of the SARAL AltiKa, launched in February 2013, are given, showing a very high accuracy of the AltiKa SWH measurement.

1. INTRODUCTION

From ERS-1 to SARAL, ten altimeter missions were operated over the last 22 years, providing continuous significant wave height (SWH) data over this time period. Global coverage and long time period of altimeter measurements are interesting in many wave study domains, like wave climate, wave modeling, extreme wave events analysis... This global data set is characterized by a large diversity resulting from the various satellites, sensors, Space Agencies, products, formats and accuracies. There was therefore a strong need for setting up an homogeneous data base, including calibrated SWH data. This is illustrated in the classical updated Fig. 1, showing long-term monthly mean values of SWH over the globe for the altimeter Geophysical Data Records (GDR) issued from the various space agencies (data where limited between extreme latitudes of 66° S and 66°N). Large SWH differences are observed between the various altimeters, particularly for the oldest altimeters (ERS-1, ERS-2 and TOPEX). Most recent missions seem to provide more consistent data (Envisat, Jason-1, Jason-2, Cryosat-2). To improve the data consistency among the various altimeters, several validation and calibration exercises were conducted [1-5]. The Ifremer Laboratoire d'Océanographie Spatiale (LOS) performed, for a long time, an independent monitoring of the quality of SWH, backscatter coefficient (sigma0) and wind speed measurements from the various altimeter missions. SWH are validated and calibrated using buoy and cross-altimeter collocation comparisons. Data outliers are discarded using some native GDR quality flags, outliers filtering and test of the 1 Hz SWH root mean square (rms) measurement level, relative to SWH. A merged and calibrated altimeter wave height data base has been setup and is regularly updated (ftp://ftp.ifremer.fr/ifremer/cersat/products/swath/altimeters/waves/). Data are provided on daily data files, merging the various altimeters, in a common format. Note that the data base is relative to GDR products, and not to near real-time or OGDR products.

In recent years this effort was confirmed in collaborating to the ESA GlobWave project (http://www.globwave.org). The objective of the original GlobWave project (2009-2013) was to improve the uptake of model and satellite-derived wind-wave and swell data by the scientific, operational and commercial user community. Altimeter products provided by GlobWave consist of individual pass data files for each altimeter, including the parameters present in the original GDR files, with a complementary synthetic quality flag, estimated from the various quality flags in the GDR product. Corrected SWH values, mainly based on LOS input, are also provided. Main differences between GlobWave and LOS product is that only valid SWH, and corresponding sigma0 and wind speed values, together with the corrected ones appear in the LOS data, and quality tests are different. This should be harmonized in the future.

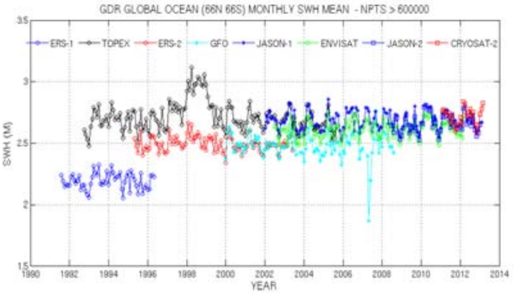

Figure 1. Global Ocean altimeter monthly mean SWH

The paper gives some information on the status of the updated data base, concerning SWH accuracy. Global results of SWH validation are given for the oldest

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altimeters in section 2. The accuracy of the more recent NOAA ocean product of Cryosat-2 is analyzed in section 3, and first results of validation of the SARAL AltiKa, launched in February 2013, are given in section 4.

2. PAST ALTIMETER SWH ACCURACY

SWH measurement accuracy is summarized in Fig. 2, for ERS-1, ERS-2, TOPEX, GEOSAT Follow One, Jason-1, Jason-2 and Envisat. These results were obtained from long-term comparisons with buoy data, using collocation methods developed previously [1]. Results are detailed and updated in [5]. Buoy data are issued from the US NDBC, UK, Irish, Spanish and French buoy networks.

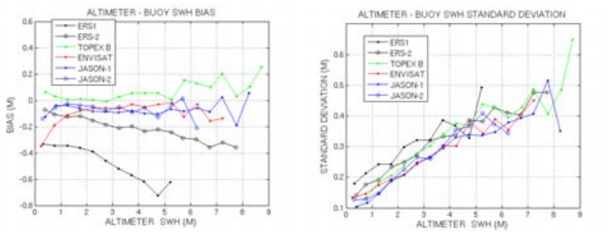

Figure 2. Altimeter and wave buoy SWH comparisons. Biases (left) and standard deviations of differences(right)

Fig. 2, left,shows the altimeter SWH biases as a function of SWH. Largest biases are observed for oldest missions. ERS-1 has a negative bias increasing from 30 cm at low SWH to 70 cm at higher SWH. The ERS-1 validation range is limited to SHW less than 5.5 m (no significant results over this value, because a poor collocated data number). The bias is less for ERS-2 than for ERS-1. Jason1 and Jason-2 exhibit a relative low bias (less than about 10 cm), as for Envisat for SWH larger than 2 m. At low SWH Envisat exhibits an increasing, non linear, negative bias.

Standard deviations of differences (Fig. 2 right) are lowest for Jason-1, Jason-2 and Envisat (less than 10% of SWH), and highest for ERS-1 and ERS-2.

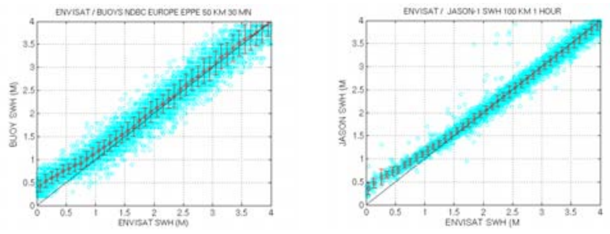

Figure 3. Envisat SWH comparison with buoy (left) and Jason-1 (right) measurements. Zoom over 0-4m SWH range

Fig. 3 left shows the non-linear Envisat SWH bias behavior relative to buoy data. This bias is confirmed when comparing with Jason-1 data (Fig. 3 right).

When comparing with buoy data, plots as in Fig. 3 are used to estimate the corrections to be applied, considering the buoy measurements as sea truth, and fitting linear inertial regression (for Jason1, Jason-2, GFO, and ERS-2) or polynomial expressions (ERS-1, Envisat). These fitted relationship are then used to correct the GDR SWH, for each altimeter. Details of the validations and of the proposed corrections can be found in [5].

3. CRYOSAT-2 SWH VALIDATION

Though dedicated to ice study and monitoring, Cryosat-2 [6] is operating over the global ocean, and ocean products, providing sea surface height, SWH and sigma0, are produced by various agencies (ESA, CNES, NOAA). Here the NOAA product provided by NOAA Laboratory for Satellite Altimetry (ftp://ibis.grdl.noaa.gov/pub/cs2igdr/) is used. It includes the Low Resolution Mode (LRM) data, corresponding to conventional pulse limited altimetry over ocean, and a Pseudo LRM data reconstructed from the ice dedicated SAR mode data. Comparisons at crossing points with Jason-1 and Jason-2, over 2 years, and with Envisat, over 1 year, were performed.

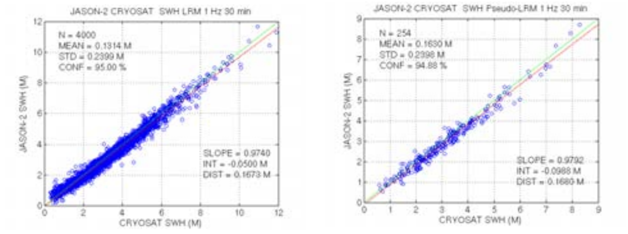

Figure 4. Cryosat-2 SWH comparison with Jason-2, for LRM (left) and Pseudo-LRM (right) data

Fig. 4 left shows the Jason-2 SWH comparisons for LRM data. The agreement between the two altimeter measurements is good, with a mean bias of 13 cm, and standard deviation of 24 cm, with a non linear negative bias at low SWH . Note that the Jason-2 SWH used in this comparison are not corrected. Pseudo LRM data results (right) can be considered as almost similar to the LRM ones, though the number of data is much less than for LRM, the SAR mode being operated over a restricted number of selected ocean areas.

The Cryosat-2 non linear bias at low SWH is confirmed in Fig. 5 right, when comparing with the corrected GDRs from Jason-1, Jason-2 and Envisat, with a good consistency among the three altimeter curves. Furthermore the validity of the proposed non-linear correction for Envisat SWH at low sea state is confirmed by the improvement of the consistency of the results when the three altimeters are corrected (left). Merging the comparison data set from the 3 altimeters is used to estimate a preliminary correction for Cryosat-2 SWH. Details on the Cryosat-2 validation is available in [7].

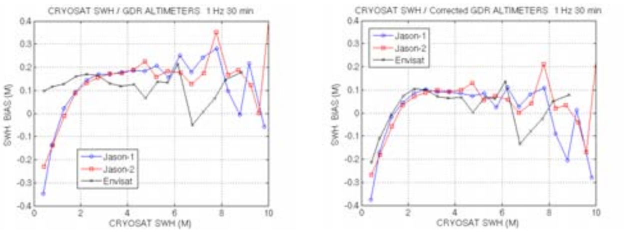

Figure 5. Cryosat-2 SWH bias relative to the GDR (left) and to the corrected GDR (right) of Jason-1, Jason-2 and Envisat

This correction was tested using the 3-year Cryosat-2 NDBC buoy collocated data set recently produced by CERSAT. Improvement of the SWH accuracy at low SWH is shown in Fig. 6 comparing Cryosat-2 and buoy SWH for raw data (left) and corrected data (right). Note that raw Cryosat-2 data exhibit negative values of SWH (previously discarded in the above comparison with other altimeters). This is due to the fact that SWH is estimated as the root square of the difference between two quantities, and in the wave form processing, at low SWH, this difference may be negative due to the noise, and in this case the SWH is set as negative. Obviously the proposed correction is efficient for correcting these negative values, but this could be investigated further.

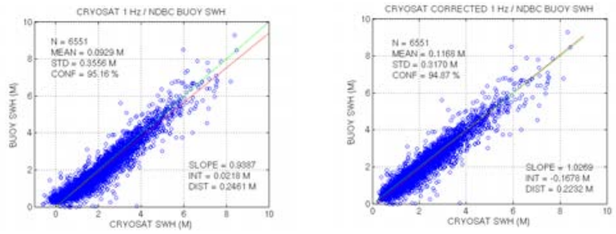

Figure 6. Cryosat-2 SWH comparison with NDBC buoys for raw (left) and corrected (right) data

4. SARAL ALTIKA SWH VALIDATION

The CNES AltiKa altimeter on the Indian Space Research Organization (ISRO) SARAL satellite was launched on February 25, 2013. The first IGDR were available for the validation Principal Investigator teams on March 14, 2013. AltiKa [8] is operating at Ka-band (35 GHz), a higher frequency than for other altimeters using Ku-band (14 GHz) with complementary C-band (5 GHz) or S-band (3 GHz) frequency. At Ka-band, measurements are less affected by ionosphere, and have better vertical and spatial resolutions, but are more sensitive to clouds and rain.

SWH validation was performed over the time period March 12 to August 24, 2013, using Jason-2, Cryosat-2 and NDBC buoy comparisons. Fig. 7 left shows the comparison with Jason-2 (corrected GDRs), for collocated 1 Hz data cells within a 30 minute time window. The bias is about 2 cm (negative), the standard deviation of differences is 20 cm, and the inertial regression line is close to the perfect line. Increasing the time window to 1 hour, and averaging altimeter data over 50 km along track (Fig. 7, right) reduce the bias to 1 cm and the standard deviation to 10 cm, which is a very good result.

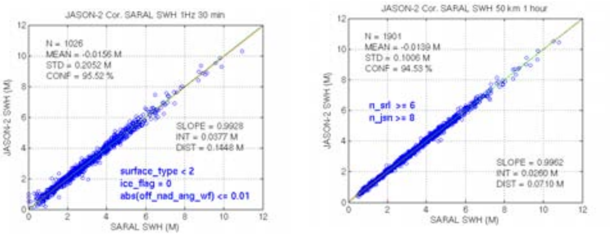

Figure 7. SARAL SWH comparison with Jason-2 corrected GDR for 1 Hz, 30 mn (left) and 50 KM averaged, 1 hour (right) collocated data

Preliminary results of comparisons with NDBC buoy measurements are shown in Fig. 8 for 1 Hz data cells within 50 km and 30 mn of the buoy (left), and for 50 km along track SARAL average (right). The agreement is good, and results are almost similar for 1 Hz and 50 km averaged data, indicating a rather high quality of the 1 Hz SARAL SWH measurement.

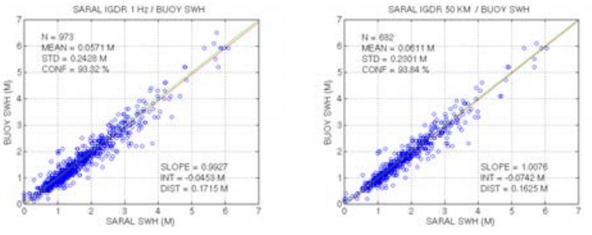

Figure 8. SARAL SWH comparison with NDBC buoys for 1 Hz, 30 mn (left) and 50 KM averaged (right) collocated data

Summary of validation is given in Tab. 1, for the bias, the standard deviation of differences, and the slope difference relative to the unit slope (in percent) and the intercept of the inertial regression line. The second column numbers are the results when the Jason-1, Jason-2 or Cryosat-2 SWH are corrected. Applying the corrections reduces significantly the biases, the standard deviation relative to Cryosat-2, and the slope differences relative to unity. When data are corrected, the results obtained relative to the 3 altimeters are very good and very consistent, validating also, in some sense, the previously proposed corrections for the 3 altimeters.

Table 1. Comparison of SARAL SWH with Jason-1, Jason-2, Cryosat and NDBC buoy data: number of data, bias, standard deviation of differences, slope and intercept of the inertial regression line. Second column when the 3 altimeters are corrected

	N	Bias (cm)	Std (cm)	(Slope -1) x100	Int. (cm)
Jason-1	732	8 0	21 21	-1.7 0.3	2 1
Jason-2	1026	6 -2	21 21	-2.2 -0.7	1 4
CryoSat-2	787	-7 3	27 23	3.9 0.3	-5 2
Buoys	973	6	24	-0.7	5

Preliminary investigation on the impact of clouds and rain on SARAL SWH measurements was performed. Fig. 9 shows an example of SWH measurement along SARAL and Jason-2 collocated tracks, with less than 7mn in measurement times at the crossing point. Large SWH spikes are observed on SARAL, when Jason-2 exhibits much less SWH variations.

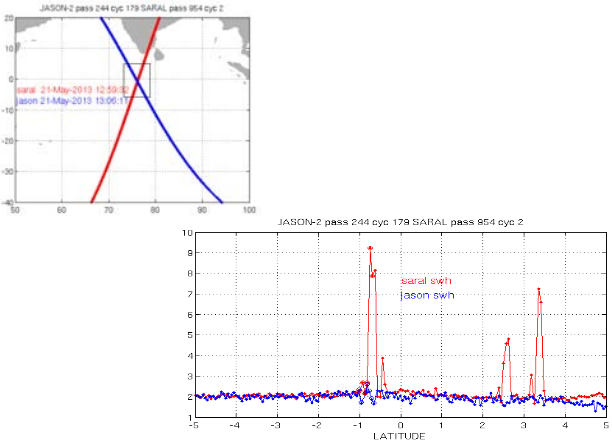

Figure 9. SARAL (red) and Jason-2 (blue) SWH measurements along collocated tracks

These SWH spikes are associated with strong SARAL sigma0 attenuations (Fig. 10 top), and high 1 Hz SARAL SWH rms values (Fig. 10 bottom). This last parameter was used to flag the SARAL SWH erroneous spikes. Fig. 11 shows the distribution of the logarithm of SWH rms values for a narrow (10 cm) SWH bin at 5 m SWH, over the 35-day cycle number 1. Though the distribution is not Gaussian, an upper threshold value was estimated in adding two times the standard deviation to the mean value of the logarithm of the SWH rms. This is performed for each SWH bin, providing an upper limit for SWH rms as a function of SWH values, in order to eliminate associated erroneous SWH spikes.

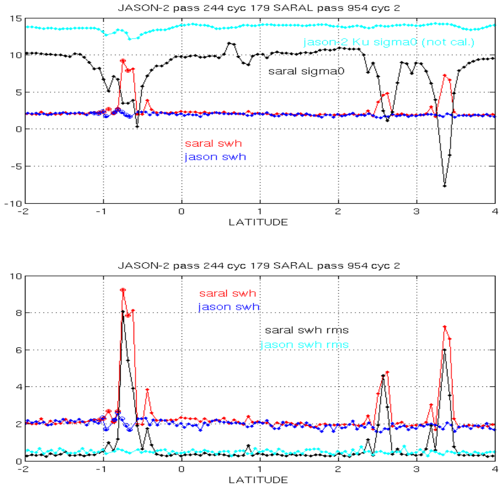

Figure 10. SARAL (red) and Jason-2 (blue) SWH, with sigma0 (top) and SWH rms (bottom) measurements along collocated tracks

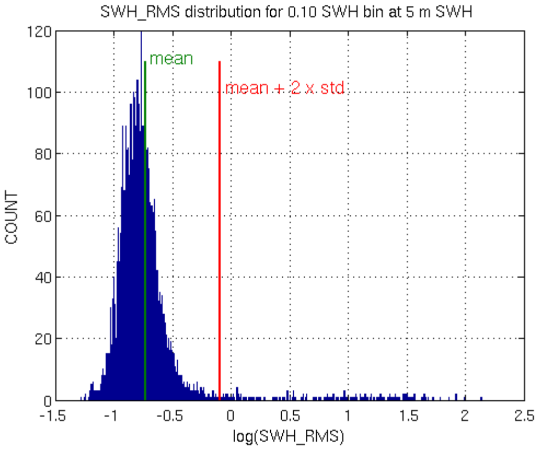

Figure 11. Histogram of the logarithm of SWH rms values for a narrow (10 cm) SARAL SWH bin at 5 m SWH, over the 35-day cycle number 1

Such SWH rms thresholds were already estimated and used for other altimeters (Cryosat-2, Envisat, Jason-1 and Jason-2) to eliminate SWH spikes, often occurring in case of sigma0 blooms for these altimeters. Results obtained for the various altimeters are compared in Fig. 12, indicating various behavior among the altimeters, and showing that the lowest threshold is observed for SARAL AltiKa. Note that, in practice, over 8 m SWH a constant threshold value is used.

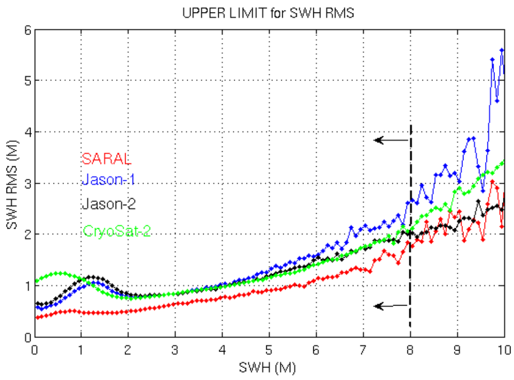

Figure 12. Comparison of the estimated SWH rms thresholds for Jason-1 (blue), Jason-2 (black), Cryosat (green) and SARAL (red)

5. SUMMARY AND CONCLUDING REMARKS

After corrections and quality checking, an homogeneous altimeter SWH data base can be set up, as illustrated in Fig. 13, which is the same as Fig. 1, when the various altimeter SWH are corrected: results are in much better agreement, remaining differences being associated mainly with geographical sampling differences.

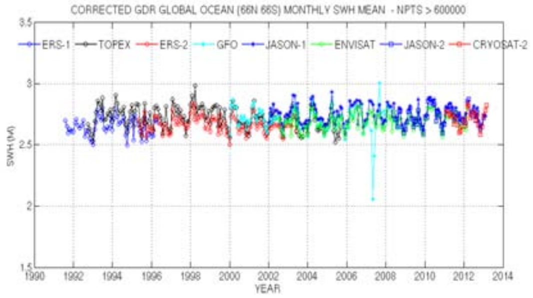

Figure 13. As Fig. 1, for corrected data

The oldest altimeters need larger corrections. For ERS-1 and ERS-2 a global reprocessing is going on within the ESA REprocessing of Altimeter Products for ERs (REAPER) project, and the reprocessed SWH data will have to be validated. One can still rise the question about a reprocessing of the TOPEX mission. The Envisat and Cryosat-2 corrections are non-linear at low SWH, and this could be improved in the waveform processing in a future reprocessing. Jason-1 and Jason-2 need only small and linear SWH corrections. Preliminary validation results indicate that the 1 Hz SARAL SWH measurement is of high accuracy. AltiKa data will be soon integrated in the SWH data base. For all altimeters a specific test is needed to eliminate SWH spikes induced by sigma0 blooms, and / or rain contamination. In the present data base the test is performed using a SWH rms threshold, depending on SWH level.

6. REFERENCES

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