VALIDATION OF THE UPDATED ENVISAT ASAR OCEAN SURFACE WAVE SPECTRA WITH BUOY AND ALTIMETER DATA

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1. INTRODUCTION

Ocean surface wave forecasting is an important tool for aiding various marine activities. The state of art wave forecast is based on an ocean surface wave spectral model. Developing and validating wave spectral models result in a direct demand for global ocean surface wave spectral observation. Traditional buoy observations can not meet this demand alone because of their limited space coverage and restriction on directional information. Remote sensing instruments, like altimeter and synthetic aperture radar, have greatly enhanced the possibility to achieve global monitoring of the ocean surface wave condition.

The advanced synthetic aperture radar (ASAR) on board the ESA Envisat satellite is a good example of global ocean surface wave spectral observation (ESA 2002). However, assessment of this valuable data set is not straightforward, due to a lack of other independent ocean wave spectral observations. The radar altimeter (RA2) on board the same satellite measures ocean wave height at the same time as the ASAR but at a different location about 200 km distant. A small number of moored buoys produce 1-D ocean wave spectra operationally but few ASAR spectra fall on the buoy positions in a given time period. An indirect comparison method by pairing the three independent observations with wave model spectra is proposed by Li and Holt (2009) to bridge the spatial and temporary gaps among these observations and gain an objective validation of the ASAR wave spectra. The study covered 20 months from July 2004 to February 2006 and revealed that the Envisat ASAR ocean surface wave spectra are generally in good agreement with the other two observations though some spurious long waves are present in the ASAR spectra.

The Envisat ASAR fast delivery ocean surface wave spectral data have undergone an important upgrade in late October 2007 (Johnsen and Collard 2006) and preliminary study has shown that the updated spectra have removed the spurious long waves in the old ASAR spectra, leading to enhanced agreement of the ASAR and spectral buoy data in the long wave range. In addition, the updated ASAR spectra have tidied up short wave noises beyond the azimuthal cutoff. This paper presents a validation study of the updated Envisat ASAR wave spectra for 14 months, 11/2007 to 12/2008, using the same indirect comparison technique as Li and Holt (2009).

Integrated parameters are often used for comparisons of ocean wave spectra and the most widely used parameters include the significant wave height (SWH), mean wave direction, and mean wave period. As the ASAR could not resolve the wind sea of wavelength shorter than the azimuthal cutoff (~ 200 m) along the satellite track, the SWH integration over the ASAR spectra may not be complete. Mean directions and periods derived from the ASAR spectra are then unreliable. A parameter equivalent to the widely used SWH but integrated over a finite spectral sub-range, and hence the name, sub-range wave height (SRWH), is used to show the spectral performance of these observations. The SRWH between the frequency ranges from f_1 to f_2 is defined as

$$H_s(f_1, f_2) = 4\left(\int_{f_1}^{f_2} df \int_0^{2\pi} E(f,\theta) d\theta\right)^{1/2} \qquad (1)$$

where $E(f, \theta)$ is the 2-D ocean wave energy spectrum and θ represents the direction. SWH is equal to SRWH when integrated over the whole frequency range, that is, $H_s(0, \infty)$, or simply H_s. Four sub-ranges bounded at exactly $T = \infty$, 16, 10, 5, 0 s or frequency $f = 0.0$, 0.0625, 0.1, 0.2, ∞ Hz are used here. The 4-bin SRWH provides a practical solution to tackle the varied spectral resolutions among the different observations and wave models.

2. COMPARISON OF OBSERVATIONS

The Envisat ASAR wave spectra used here are the fast delivery level-2 (ASA_WVW_2P) product from ESA. Each ASAR 2-D spectrum is derived from a wave mode 5 km by 5 km synthesized image of the ocean surface and can be considered as an average of the same area. Sampling interval along the satellite track is about one image every 100 km. Each ASAR spectrum is collocated with a model spectrum at the nearest time step (30 min) and space grid (~ 60 km). The study covers 14 months from November 2007 to December 2008 after the later October 2007 ASAR data reprocessing algorithm update.

The ESA Envisat RA2 altimeter ocean SWH data (RA2_WWV_2P product Ku band) for the same time period are also used in this comparison study. The RA2 SWH data are in a resolution of about 7 km, much higher than the model resolution (~ 60 km) so each RA2 SWH is paired with an interpolated model SWH. It allows filtering of spurious RA2 data, especially near coastlines. Both the

ASAR and RA2 measurements become erroneously large near coastlines where the radar echo is contaminated by land surface. To remove these spurious large values, any observed SWH value larger than the model value by 5.0 m is removed from the selection. The large difference threshold 5.0 m is chosen so that it would not exclude possible real high waves underestimated by the model.

Directional wave energy spectra from moored buoys are retrieved from the NDBC web site. Three buoys are selected for the old ASAR data assessment by Li and Holt (2009). Due to page limits, this study will only use the buoy near Cape San Martin (SM, buoy ID 46028 at 35.75° N 121.89° W) on the west coast of California. The SM buoy is in a mixed wave environment within reach of both the North Pacific swell and local wind sea. The buoy data on the web site have already gone through quality control and are used directly without further filtering. Each buoy wave spectrum is an average of 20 minute measurements and represents a space average of roughly 6-24 km for a wave group speed of 5-20 m s^{-1}.

For comparison with the buoy data, collocated model and satellite data are restricted within a 10º (latitude and longitude) box near the buoy site. The SM buoy site is about 3º away from the box centre along each side to minimize land surface within the box. The observed SWHs from the three independent observations and the RA2 wind speed within the box area are plotted against collocated model values respectively and packed into Fig.1. The top-left panel in Fig.1 is a scatter plot of the model and SM buoy SWHs from 11/2007 to 12/2008, total 8943 pairs. Each pair of model and buoy SWHs are plotted as a grey '+' symbol in the diagram with its *x*-coordinate equal to the buoy SWH and *y*-coordinate to the model SWH. The contours indicate the relative data density in percentage within a box of $1/50^{th}$ of the plot range in both directions. The contour values are 0.25, 0.5, 1.0, and 2.5%, respectively. The centre of the large cross sign marks the mean values and the cross height and width indicate the standard deviations (SDs) of the two data sets, respectively. The mean value of the model SWHs (2.405 m) at the buoy site is higher than the average of the buoy SWHs (2.373 m). The model and buoy SDs are 0.692 m and 0.993 m, respectively. The standard deviation of the difference (SDD) between the model and buoy SWHs is 0.571 m. The correlation coefficient for the model and buoy data is 0.828.

The lower-left panel in Fig.1 compares the model SWHs with the RA2 altimeter Ku band data within the same 10º box at the SM buoy site during the 14 months as the buoy plot. A total of 22797 pairs of data are selected. The model mean SWH (2.624 m) is also higher than the altimeter mean (2.535 m). The SDs of the model and RA2 SWHs are 0.747 and 1.018 m, respectively. The SDD of the model and RA2 SWHs is 0.657 m and the correlation coefficient 0.765. Comparing this panel with the top-left buoy one, it is evident that the RA2 SWHs are close to the buoy values with comparable mean (2.535 vs 2.373 m) and SD (1.018 vs 0.993 m) values. It also reveals that the wave model has slightly overestimated ocean swell.

The top-right panel in Fig.1 is the scatter plot of model SWHs against ASAR level 2 SWHs within the same 10º box at the SM buoy site and the same 14 months time interval as the RA2 and buoy plots. There are 1072 pairs of data in this selection. Both the mean SWH (2.713 vs 2.641 m) and SD (0.740 m vs 1.095 m) are similar to those in the RA2 and buoy comparison. The ASAR vs the model SDD (1.004 m) and correlation (0.456) are also acceptable. These results indicate that the updated ASAR 2D wave spectra are in good agreement with the buoy and altimeter observations. The ASAR data prior to the late October 2007 update had larger SD values and poorer correlation in comparison with buoy and altimeter data (cf. Fig.5, 8 and 11 in Li and Holt 2009).

The lower-right panel in Fig.1 is a scatter plot of the model wind speeds against the measured wind speeds from the Envisat RA2 data. The wind speed pairs correspond to the SWH pairs used in the lower-left panel and they share the same total number (22797). The model wind is quite close to the observed one. Their mean wind speed (6.337 vs 6.681 m s^{-1}) and SDs (2.903 vs 2.954 m s^{-1}) are in good agreement and the correlation is as high as 0.848.

As Envisat RA2 measures only the significant wave height, the 4-bin SRWH comparison is carried out for ASAR and buoy data only in Fig.2. The four panels in the left column of Fig.2 show scatter plots of the 4-bin SRWHs integrated from the model and the SM buoy wave spectra. The collocated data are exactly the same as used in Fig.1 with a total of 8943 pairs. The sub-ranges or bins are indicated by the wave periods, T > 16 s, 16-10 s, 10-5 s, and T < 5 s, respectively. The first two bins (T >16 s and 16-10 s) may be considered representing primarily long-distance swell while the last two bins (10-5 s and T < 5 s) the locally-generated wind sea. At the SM buoy site both wind sea and swell are expected and the wave spectra from both the model and buoy show a balanced distribution of energy over the 4 sub-ranges.

The 4-bin break down of the ASAR wave energy near the SM buoy site is shown by the four panels in the right column of Fig.2. The SRWHs are evaluated from the same collocated wave spectra as used in the ASAR-model SWHs scatter plot in Fig.1. As illustrated in the 16 – 10 s bin, the ASAR spectra contain more long-period swell energy (SRWH mean 2.039 m) than the model (1.656 m) and the SM buoy spectra (1.383 m). The ASAR spectra in the first bin (T > 16 s) show much improved agreement with model and buoy values in comparison with the ASAR spectra prior to the 2007 update. In the wind sea frequency range or the 10-5 s and T < 5 s bins, the ASAR data have clearly less wave energy than the model and buoy spectra. These are expected results because the ASAR instrument could not resolve high frequency wave spectra and hence miss part of the wind sea.

3. SUMMARY AND CONCLUSIONS

The updated EAS Envisat ASAR fast-delivery level-2 ocean surface wave spectra are compared with other independent ocean wave measurements for 14 months from 11/2007 to 12/2008. The Met Office global wave spectral model is used to bridge the gaps among the ASAR observations with the other two independent ocean surface wave data, measured by the altimeter RA2 on board the same ESA Envisat satellite and by the spectral buoy near Cape San Martin (buoy ID 46028) on the west coast of California. Direct comparison of these observations is impractical due to the spatial and temporal differences between these observations. Indirect comparison of these observations is achieved by inter-comparison of their differences from the wave model. A parameter equivalent to the widely used SWH but integrated over a finite spectral sub-range, and hence called sub-range wave height (SRWH), is used to show the spectral performance of these observations. This indirect comparison reveals that the updated ASAR 2-D wave spectra have improved and are in better agreement with the other two independent observations than the old ASAR wave spectra prior to the late October 2007 update. The improved long wave part or swell of the Envisat ASAR wave spectra is comparable with the buoy and model spectra. However, ASAR spectra have less wave energy in the wind sea than the buoy and model spectra due to its technical restrictions. So the Envisat ASAR wave data are good guides to 2-D swell spectra on the global scale. It also revealed the usefulness of the SRWH parameter to illustrate the spectral characteristics of ocean wave energy especially for partial spectra like the ASAR ones. The SRWH parameter is much economical for operational use than the 1-D or full 2-D spectra.

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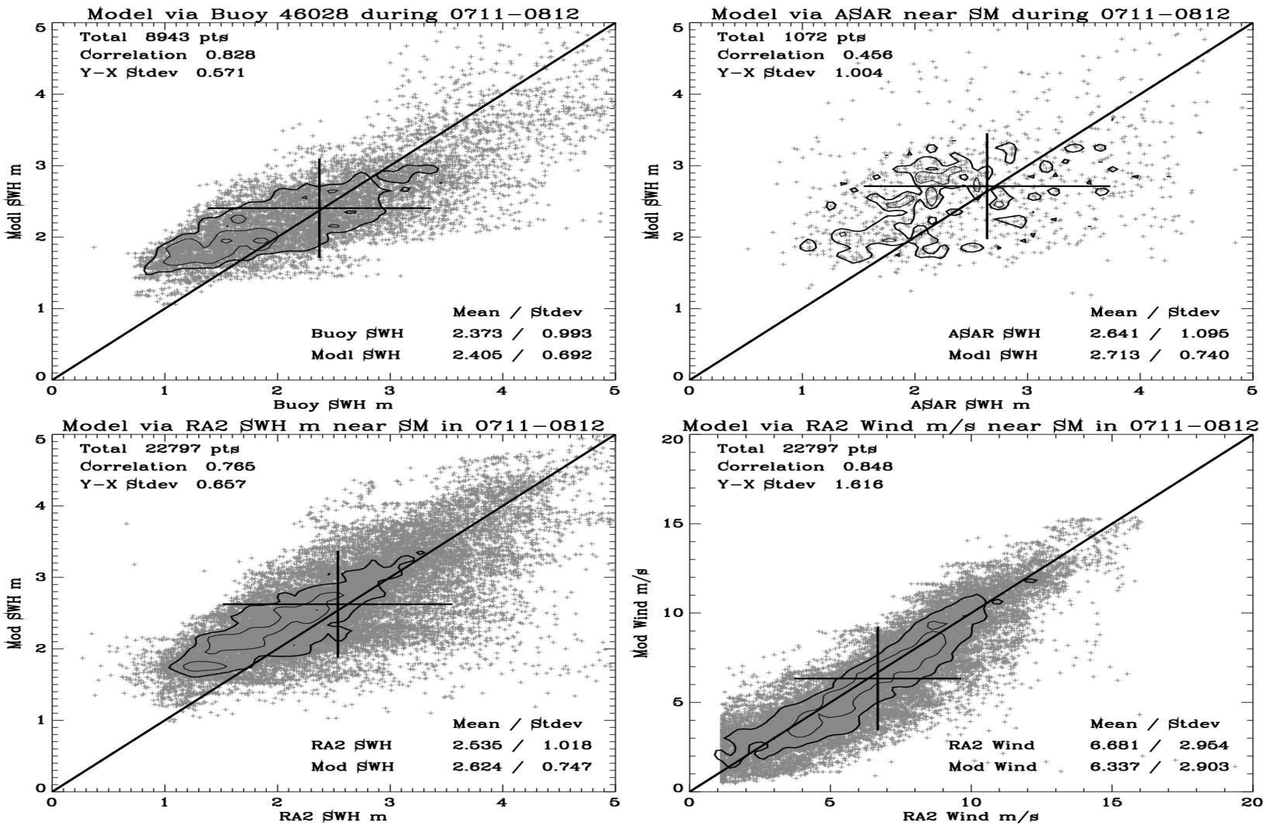

Fig.1. Comparison of model SWHs with the SM buoy (ID 46028) and Envisat ASAR and RA2 measurements near the SM buoy site from November 2007 to December 2008.

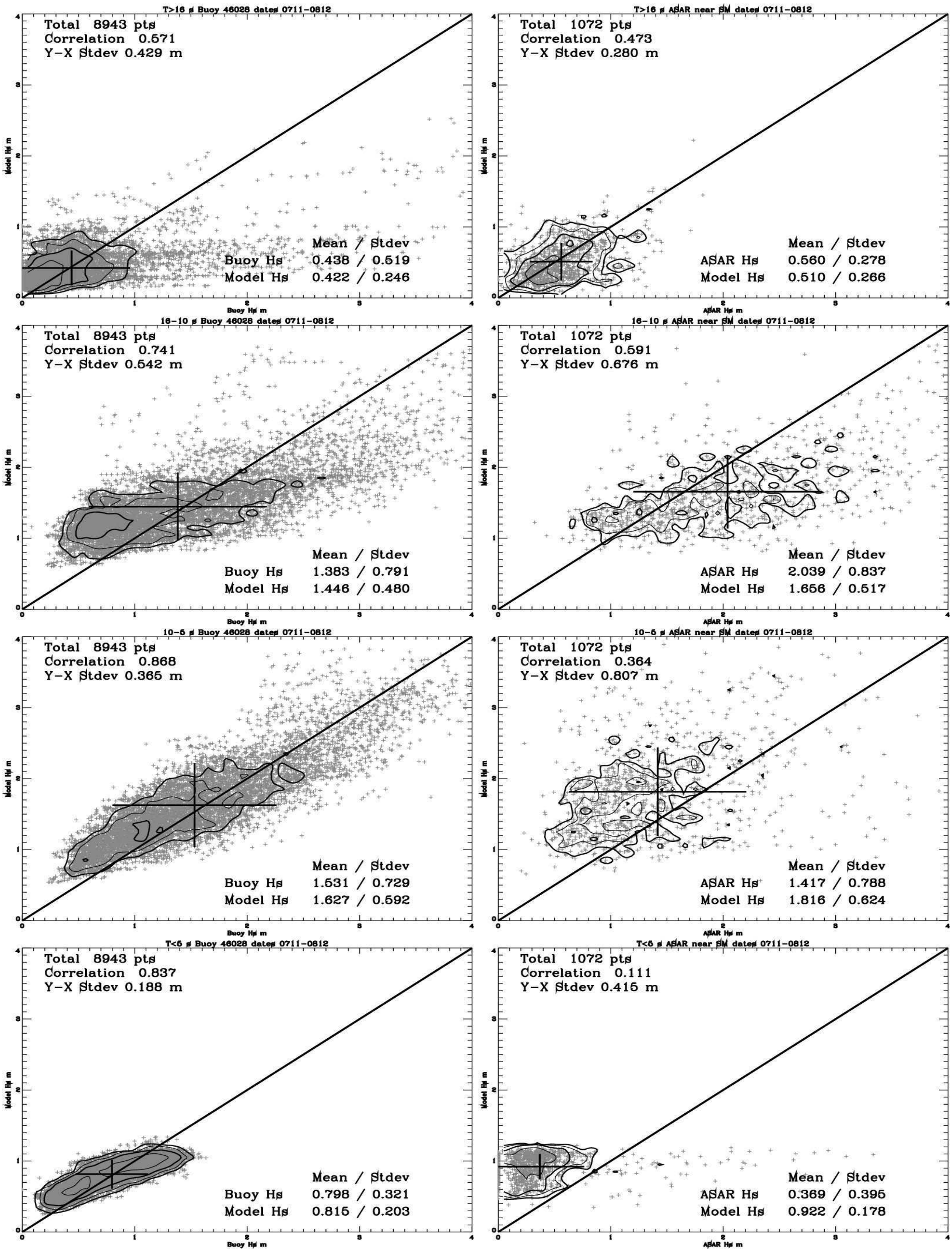

Fig.2. Indirect comparison of SM buoy (ID 46028) and ASAR SRWH via model spectra. The 4 sub-ranges are indicated by wave periods, T > 16 s, 16-10 s, 10-5 s, and T < 5 s, respectively.