GLOBAL VALIDATION AND ASSIMILATION OF ENVISAT ASAR WAVE MODE SPECTRA

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ABSTRACT

ENVISAT Fast Delivery ASAR Wave Mode products are routinely received, monitored and validated at ECMWF. ASAR Wave Mode Level 1b (ASA_WVS_1P) product is inverted using the MPIM scheme to obtain the ocean wave spectra. This product agrees well with the wave model counterpart in terms of all used integrated parameters. On the other hand, ASAR Wave Mode Level 2 Ocean Wave Spectrum (ASA_WVW_2P) product agrees well with the wave model in terms of swell significant wave height and mean period. The agreement is not so good for any other parameters describing the spectral shape. The PF-ASAR Version 3.07 has a positive impact on the quality of the inverted spectra but no impact on Level 2 product. The impact of wave model changes on 9 March 2004 (unresolved bathymetry) and 5 April 2005 (improved dissipation term) is generally positive. Assimilation experiments with assimilation of ASAR Wave Mode Level 1b showed minor positive impact on wave analysis and forecast. This product has been assimilated operationally at ECMWF since 1 February 2006.

1. INTRODUCTION

ENVISAT Fast Delivery ASAR Wave Mode, both Level 1b and Level 2, products are routinely monitored and validated at the European Centre for Medium-Range Weather Forecasts (ECMWF). ECMWF runs operationally a global wave model called ECWAM [1]. Model wave spectra are used for the validation of ASAR products. Level 1b product is the reference product upon which basic quality control is done. Data processing is similar to the procedure used for ERS-2 SAR processing (c.f. [2]). Here is a summary of this procedure.

The stream of ASAR product is split over 6-hour time windows centred at the main synoptic times to coincide with the model output times. The data contents of each time window is pre-processed to generate a collocation list to be used for the SAR-inversion. This includes pre-processing quality control to reject any spectrum with obvious anomalies and/or inconsistencies. The nearest wave model spectra are extracted and used as the first guess to invert the ASAR product. The Max-Planck Institut für Meteorologie (MPIM) scheme (c.f. [3]), which is an iterative method based on the forward closed integral transformation, is used for the inversion. During and after the inversion further quality checks are done. The iterations stop when there is a convergence (within a given tolerance) or until the iteration procedure is unstable. The final value of the cost function and the stability of the procedure define the quality of the final inverted spectrum.

Any Level 2 product is accepted only if the corresponding Level 1b product passes the quality control. Further quality checks are performed over accepted Level 2 products to ensure their consistency. Each quality controlled product is then collocated with the closest wave model spectrum. It should be noted that most of the comparisons (scatter plots and time series derived from those plots) between Level 2 product and the wave model are carried out within the spectral range resolvable by ASAR. Therefore, the part of the spectrum with wavelengths higher than the azimuthal cut-off length (as provided by the ASAR Level 2 product) is considered. This is different from the comparisons between ASAR Level 1b product and the wave model where the whole spectrum is considered. Therefore, one needs to be careful in drawing conclusions when comparing both products.

Validation of wave spectra with large number (100's) of degrees of freedom is not a straightforward task. Therefore, the validation is usually done in terms of a limited number of integrated parameters. Significant wave height (SWH), mean wave period (MWP) and wave spectral peakedness factor of Goda (WPF) are among the most commonly used. These parameters can be defined as:

1. Significant wave height (SWH), H_s, is defined as:

$$H_s = 4.0\sqrt{m_0} \tag{1}$$

where m_0 is the "zeroth" moment of the wave spectrum. In general, the "*n*-th." moment of the spectrum, m_n, is defined as:

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$$m_n = \int d\theta \int df \; f^n F(f,\theta) \tag{2}$$

where F is the wave spectrum in frequency, f, - direction, θ, space. The first integration is done over all directions while the second is usually carried out from frequency 0 to ∞. However, for the verification of Level 2 product, the frequency integration is limited up to the frequency corresponding to the azimuthal cut-off wavelength.

2. The mean wave period (MWP) based on the "-1 th." moment (m_{-1}), T_{-1}, is defined as:

$$T_{-1} = m_{-1} / m_0 \tag{3}$$

where m_0 and m_{-1} are respectively the "zeroth" and the "-1 th." moments of the spectrum defined in Eq. 2.

3. The wave spectral peakedness factor of Goda, (WPF), Q_p, is defined as:

$$Q_p = 2 m_0^{-2} \int d\theta \int df \; f \, F^2(f,\theta) \tag{4}$$

2. VALIDATION OF ASAR WAVE MODE LEVEL 1B PRODUCT

SWH is the most commonly used parameter for typical validation of ocean wave products. Fig. 1 shows a density scatter plot for globally collocated SWH pairs of inverted ASAR Wave Mode Level 1b and the analysis ECWAM wave model for the period from 11 April to 31 August 2005. It is clear that the agreement between the ASAR and the model is quite good with ASAR slightly underestimating wave heights (by about 8 cm). The global scatter index (defined as the ratio between the standard deviation of difference and the mean of the observations) is about 13.5%. Scatter plots of mean wave period show even better agreement between the ASAR product and the wave model (not shown) with virtually no bias (about 0.1 s) and very small scatter index (about 6%). On the other hand, the same can not be said about parameters describing the spectral shape such as Q_p. Fig. 2 shows the globally collocated Q_p pairs of inverted ASAR Level 1b and the ECWAM analysis for the same period. Although, there is a good agreement for most of the pairs with peakedness values less than about 1.5, the agreement does not hold anymore for higher values with a clear split into two families. The scatter index is rather high (~50%) while the correlation is rather low (~0.49).

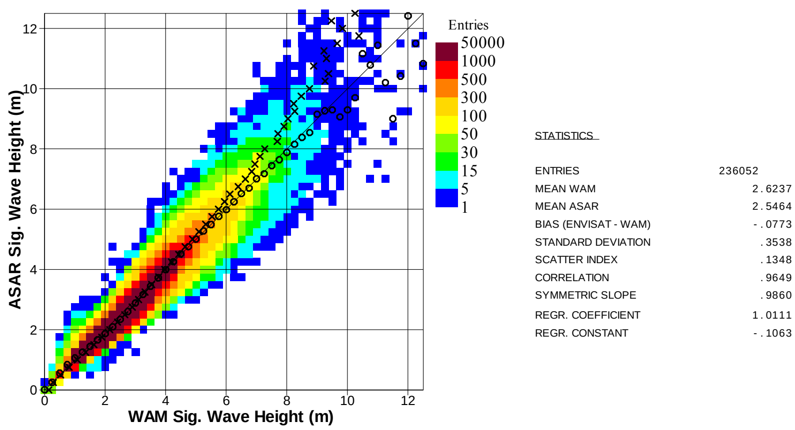

Fig. 1. Global comparison between inverted ASAR Level 1b and ECMWF model significant wave height during the period from 11 April to 31 August 2005.

The time series of bias between inverted ASAR Level 1b and ECWAM mean wave period is shown in Fig. 3 while the scatter index time series is shown in Fig. 4. The two abrupt changes in the wave period bias can not be missed in Fig. 3. The first is associated with the ASAR processing chain PF-ASAR Version 3.07 on 4 May 2004 and the second is associated with a wave model change involving a new wave dissipation term on 5 April 2005. PF-ASAR Version 3.07 corrected a problem with the code that applies the elevation antenna pattern correction. Although this correction appears to increase the scatter index of the mean wave period (as well as other integrated parameters), it definitely had a positive impact. After that date, the inversion process produced higher quality inverted spectra as can be seen in Fig. 5.

It is quite clear that the amount of excellent quality inversion (with cost < 0.1) started to dominate the inversion output. The MPIM inversion method returns a spectrum contaminated with the first-guess model spectrum if it is interrupted due to unstable iterations. As Fig. 5 shows, there were a large portion of unstable iterations before the change resulting in a comparison of model spectrum against a spectrum very close itself for those unstable iterations. The model change on 5 April 2005 resulted in slightly better agreement between the inverted ASAR product and the wave model as can be seen in Figs. 3 and 4 for wave period as well as for some of the other parameters (not shown).

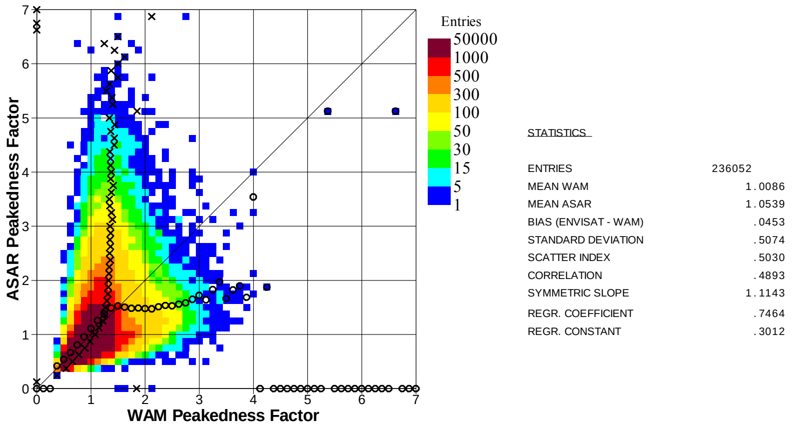

Fig. 2. Global comparison between inverted ASAR Level 1b and ECMWF model wave spectral peakedness factor of Goda during the period from 11 April to 31 August 2005.

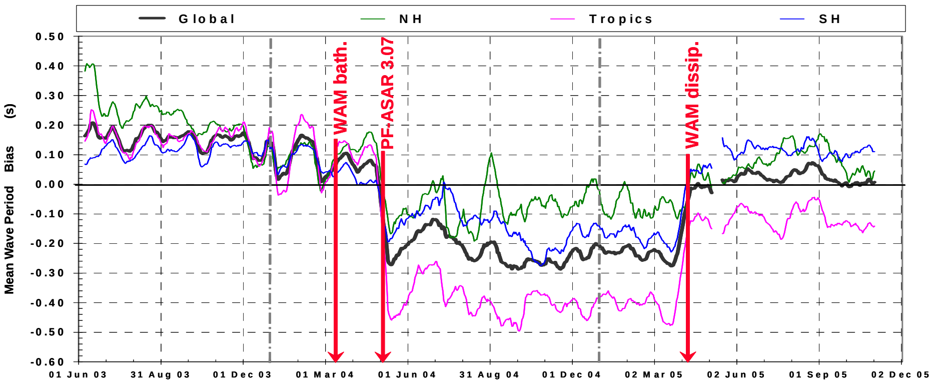

Fig. 3. Time series of mean wave period bias between ASAR Level 1b inverted product and wave model.

3. VALIDATION OF ASAR WAVE MODE LEVEL 2 PRODUCT

It is stressed that the integrated parameters used here for the various comparisons are computed for the part of the spectrum which is resolvable by the ASAR instrument. This means that wave components with wavelengths longer than the azimuthal cut-off wavelength reported in the ASAR Wave Mode Level 2 (ASA_WVW_2P) product are used. The term swell is used for those parameters to reflect this fact.

Fig. 6 shows a density scatter plot for globally collocated swell SWH pairs of ASAR Wave Mode Level 2 and the wave model for the period from 11 April to 31 August 2005. The agreement between the ASAR and the model is quite good for the bulk of the data. However, there are quite a number of outliers. The agreement becomes even worse when other parameters are used. For example, the globally collocated swell wave peakedness factor pairs of ASAR Wave Mode Level 2 and the wave model for the same period are shown in Fig. 7. One can clearly notice the poor agreement between the ASAR and the model. The ASAR mean value is about twice the model mean value. It indicates that the ASAR spectra have too narrow peaks compared to the model. Furthermore, the standard deviation of the difference is comparable with the ASAR mean value and larger than the model mean value (scatter index much higher than 100%). More importantly, there is not any correlation between both quantities.

The scatter index time series of swell wave height (Fig.8) shows that the model changes reduce the disagreement. This However, there is no abrupt or unusual change in the various statistics. The implementation of the PF-ASAR Version 3.07 had no impact on the statistics since the bug only affected Wave Mode Level 1b processing.

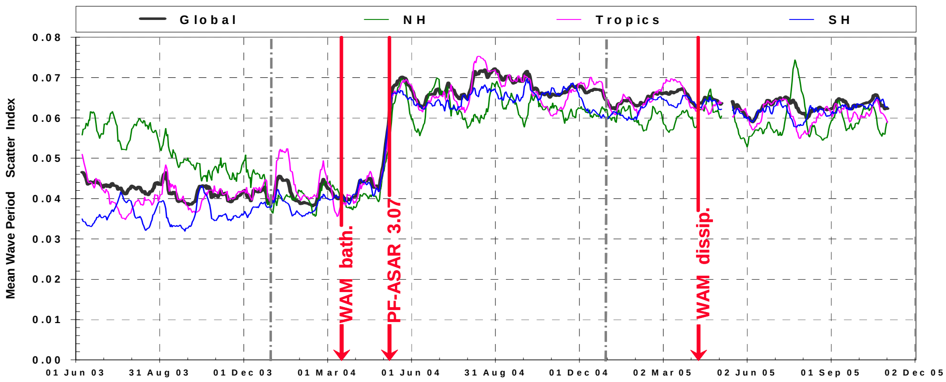

Fig. 4. Time series of mean wave period scatter index between ASAR Level 1b inverted product and wave model.

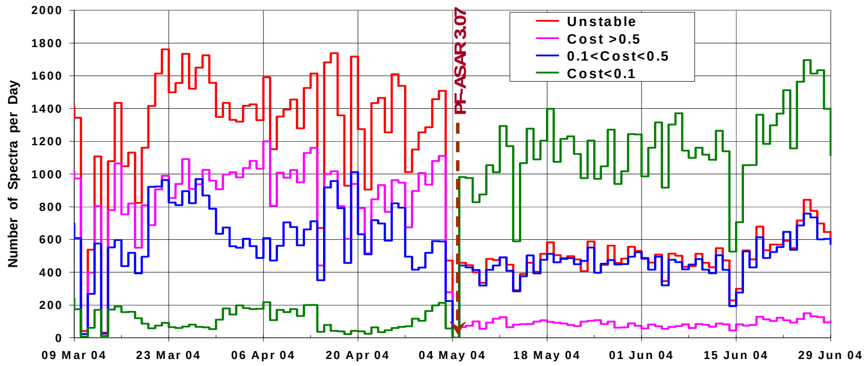

Fig. 5. Time series of the daily results of the inversion of ASAR Level 1b.

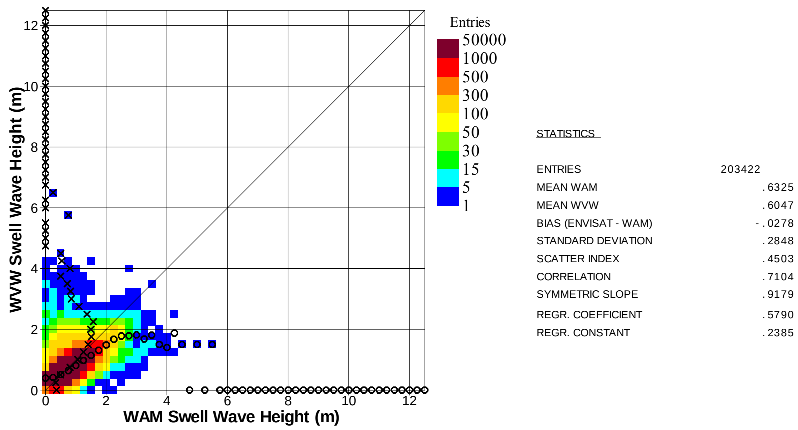

Fig. 6. Global comparison between ASAR Level 2 and ECMWF model swell significant wave height during the period from 11 April to 31 August 2005.

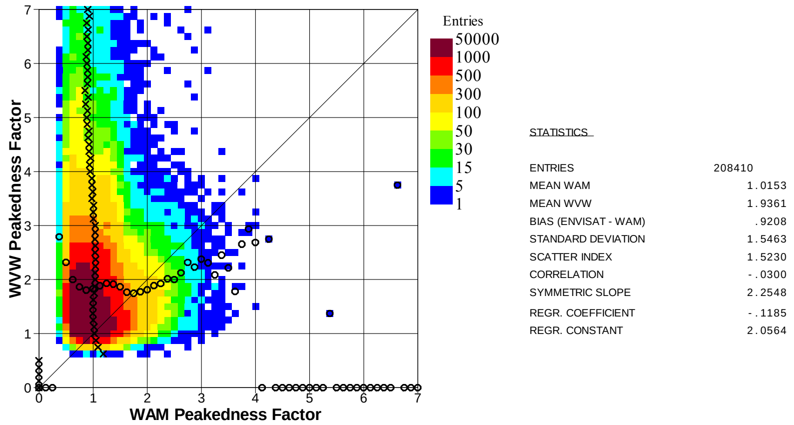

Fig. 7. Global comparison between ASAR Level 2 and ECMWF model swell wave spectral peakedness factor of Goda during the period from 11 April to 31 August 2005.

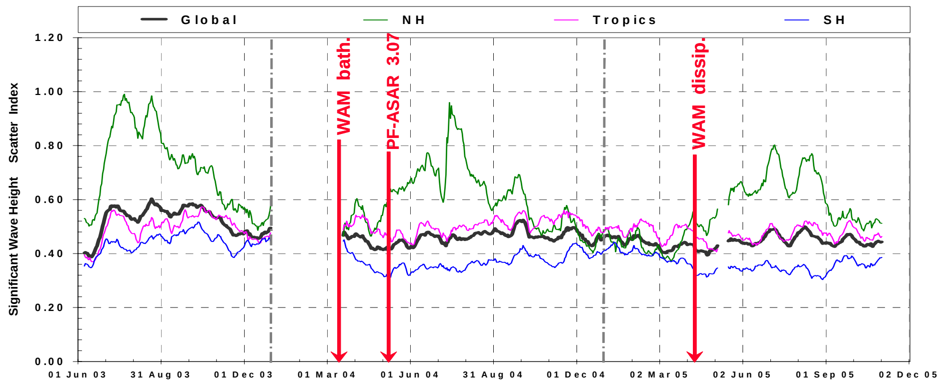

Fig. 8. Time series of swell significant wave height scatter index between ASAR Level 2 product and wave model.

4. ASSIMILATION OF ASAR WAVE MODE LEVEL 1B PRODUCT

In general, assimilation of SAR observations is not straightforward due to three main difficulties:

1. As SAR observation is based on frozen imaging, it is not possible to decide about the direction of propagation causing a 180° directional ambiguity. However, the imagette cross-spectra are utilised to resolve this ambiguity in ENVISAT ASAR wave mode product.
2. SAR spectra suffer from nonlinear distortion induced by motion effects.
3. SAR can detect only long waves with wavelengths larger than 100 m or so. This restriction is more severe for wave components propagating along the flight direction causing the cut-off values (known as azimuthal cut-off wavelengths) to be in the order of few hundred meters.

SAR inversion schemes, e.g. [3], solve the first two difficulties. The resolved part of SAR spectrum (i.e. with wavelengths above the azimuthal cut-off value) can be assimilated.

Although a full wave spectrum (within the azimuthal cut-off) is available from SAR observations, the implemented assimilation procedure is based on the assimilation of wave systems as derived from a partitioning scheme. The full spectrum is divided into several systems using the principle of the inverted catchment area (e.g. [4]). The different wave systems are characterised by their total energy, mean frequency and mean propagation direction. These integrated parameters are assimilated using a simple Optimum Interpolation (OI) scheme following a cross assignment procedure to correlate the observed systems with the modelled first-guess (FG) ones. The analysis (AN) integrated parameters obtained from the OI scheme are used to construct the AN spectra by resizing and reshaping the FG spectra.

Several numerical experiments were carried out to assess the impact of ASAR Wave Mode Level 1b assimilation. Fig. 9 shows the mean impact over the whole month of April 2005 compared to the in-situ buoy wave spectra (c.f. [5]). In general the impact is positive although rather limited (compared to altimeter assimilation for example; e.g. [6]).

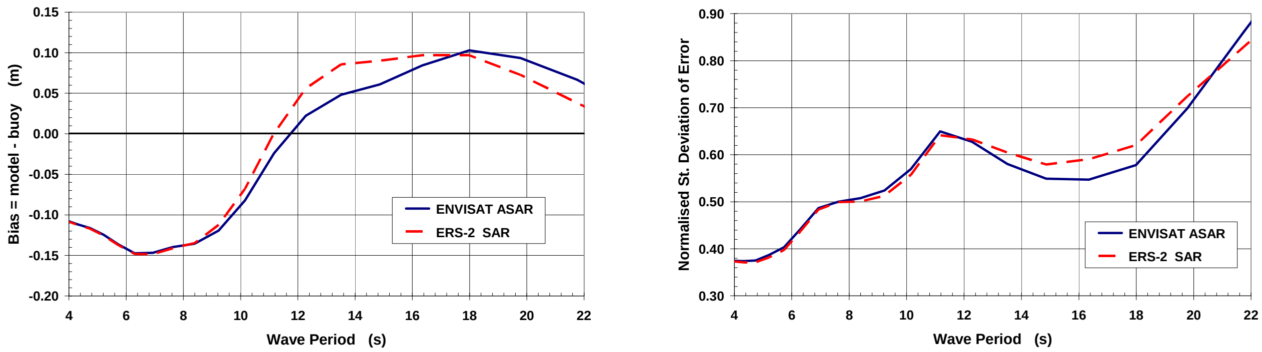

Fig. 9. ASAR assimilation impact on wave spectrum according to buoy data around Hawaii in terms of equivalent 2-s significant wave height (1-30 April 2005)

5. CONCLUSIONS

The inverted ASAR Wave Mode Level 1b product agrees well with wave model of ECMWF. PF-ASAR Ver. 3.07 (4 May 2004) has positive impact on the product and thus on the inversion process. The impact of model change of unresolved bathymetry (9 March 2004) is not clear possibly due to the PF-ASAR bug before May 2004. The model change of improved dissipation (5 April 2005) has positive impact.

The bulk of ASAR Wave Mode Level 2 product agrees well with the wave model in terms of swell significant wave height and mean wave period. However, the spectral shapes do not agree. PF-ASAR Ver. 3.07 has no clear impact on the agreement. Positive impact after March-May 2004 may be due to model change of unresolved bathymetry. Model change of improved dissipation (April 2005) has positive impact on the agreement.

Assimilation experiments with ASAR Wave Mode Level 1b showed minor positive impact on wave analysis and forecast. As a consequence, this product has been assimilated operationally at ECMWF since 1 February 2006.

ACKNOWLEDGMENTS

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