# EVALUATION OF ENVISAT ASAR WAVE MODE RETRIEVAL ALGORITHMS FOR SEA-STATE FORECASTING AND WAVE CLIMATE ASSESSMENT


**F.J. Melger**

*ARGOSS, P.O. Box 61, 8335 ZH Vollenhove, the Netherlands, Email: info@argoss.nl*



## ABSTRACT/RESUME

The Envisat mission will offer new ocean wave products from its ASAR Synthetic Aperture Radar: an imagette cross-spectrum derived from two consecutive looks (level 1b) and an ocean wave spectrum product (level 2), developed for ESA by NORUT IT and IFREMER. The wave validation team evaluates these data products and compares the level 2 product to wave spectra retrieved with alternative processing methods. Three aspects were investigated:

- The potential benefits of the level 1b product over the earlier ERS SAR wave mode spectra.
- The quality of the level 2 ocean wave retrieval algorithm.
- The performance of the Envisat ASAR wave mode products.

First two aspects were carried out before the launch on “simulated” ASAR wave mode data, obtained by re-processing of ERS-2 SAR. The comparison of level 1b with ERS SAR was based on the SPRA scheme of ARGOSS. Reference data were data from a wave forecasting model.

Based on the simulated data set it was found that:

- Using the ASAR level 1b product can reduce the error in wave height by at least 10-15%.
- The level 2 product and the forecasted wave spectra match rather well over a wide range of ocean wavelengths, and also overall wave heights and periods agree closely to the reference data. The outcomes underline the importance of providing guidance for the use of the level 2 product, as wind-sea outside the linearly mapped wave number region is not included and adding this information is left to the user. If this is not done, overall parameters like the significant wave height will lose their validity at high wind sea conditions.
- The inversion scheme relies on the assumption that the azimuthal bandwidth and the mapping relations derived from a wind sea estimate are closely related. Moreover it assumes that the short wave energy can be parameterised. For certain ocean wave spectra (high sea states, short period swell) these approximations might result in a deterioration of the performance of the level 2 product.
- The 180-degree ambiguity is solved very well with the ASAR cross spectra.

Although the number of Envisat acquisitions was limited, some interesting results were found already:

- Initial problems with the wave mode products are solved already.
- The retrieved wind speed and the normalised inverse wave age (together they define the energy contribution of the wind-sea) do correlate and the applicability of both parameters to estimate the wind sea energy is questionable.
- For current data set the phase velocity of the wind sea peak is approximately constant.


## 1. INTRODUCTION

ENVISAT is equipped with an advanced version of the Synthetic Aperture Radar (SAR) that was flown on the ERS-1 and ERS-2 missions. Like the SAR on the two ERS missions, the ENVISAT ASAR will feature a so-called wave mode, a global mode in which the SAR will acquire small images (imagettes) along its track. However, the image power spectrum product of ERS will be replaced in the ENVISAT mission by the complex ASAR image cross-spectrum, known as the WVS_1P or level 1b product. The cross-spectrum is based on two sub-images separated in time. Engen and Johnson [1] [2] first described the advantages of processing SAR data to complex cross-spectra, rather than to power spectra.

- The speckle in the two sub-images used to determine the cross-spectrum is un-correlated, which means that speckle in the cross-spectrum of the sub-images is strongly suppressed.
- The conventional power spectrum is symmetrical, resulting in a 180-degrees ambiguity in the propagation direction of the ocean wave components retrieved from the power spectrum. The phase of the cross-spectrum, however, is shifted in accordance with the propagation of the wave crests between the first and second sub-image. Hence the 180-degree ambiguity can in principle be resolved from the cross-spectrum.


*Proc. of Envisat Validation Workshop, Frascati, Italy, 9 – 13 December 2002 (ESA SP-531, August 2003)*

General purpose is to demonstrate the quality of the Envisat ASAR wave mode products for sea-state forecasting and wave climate assessment. Processing of SAR data to complex cross spectra is new and although the theoretical advantages of this new processing method are known, there is no practical experience. The method used to retrieve ocean wave spectra from ASAR spectra for the level 2 product is not completely new but the merits and weaknesses of this method are not completely known yet. Because Envisat ASAR wave mode products differ from ERS SAR wave mode products mainly in the processing and not in the raw data, ERS2 SAR SLC imagettes were reprocessed to simulate the new products. Results with this simulated dataset are reported by Melger [4].

Due to initial problems with the quality of real Envisat data, only, a very limited dataset was prepared by NORUT, IFREMER and ESRIN for evaluation purposes. In totally, only 5 tracks of level 1b and 1 track of level 2 data could be used for a first evaluation. From this set, 248 level 1b and 140 level 2 acquisitions could be collocated with data from the ECMWF WAM model. The geographical locations are given in fig. 1.

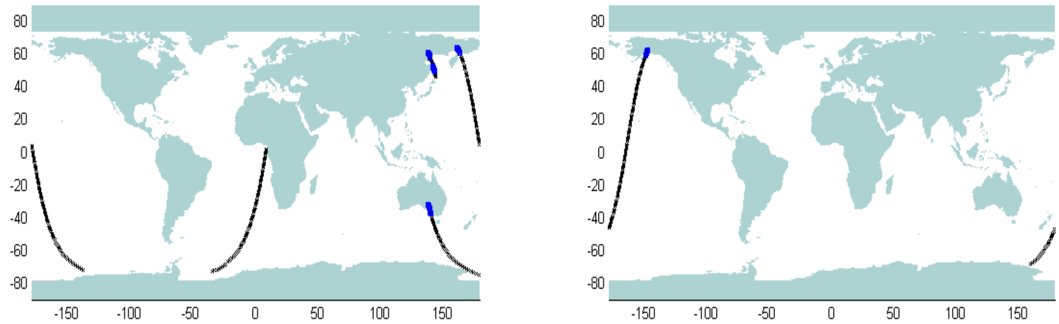


Fig. 1 Locations of the Envisat level 1b (left) and level 2 (right) dataset. The blue records were marked as land.

## 2. FIRST EXPERIENCES WITH THE ENVISAT WAVE MODE PRODUCTS

The quality of the level 1b product can not be directly examined. The relation between the ocean wave surface and the ASAR observation is very well understood but because of the non- linearity's difficult to invert. Inversion is necessary before ASAR spectra can be compared to ocean wave spectra. The ocean wave spectra were retrieved from the level 1b ASAR complex cross spectra by ARGOSS with the SPRA scheme [3]. The wind vector from the WAM model is used together with the ASAR spectrum to make a parametric estimate of the wind sea peak of the spectrum, and the remaining energy is inverted through a linearised model to generate an estimate of the swell. Fig. 2 shows that the wave height retrieved from the ASAR level 1 product agrees reasonable very well with the WAM model.

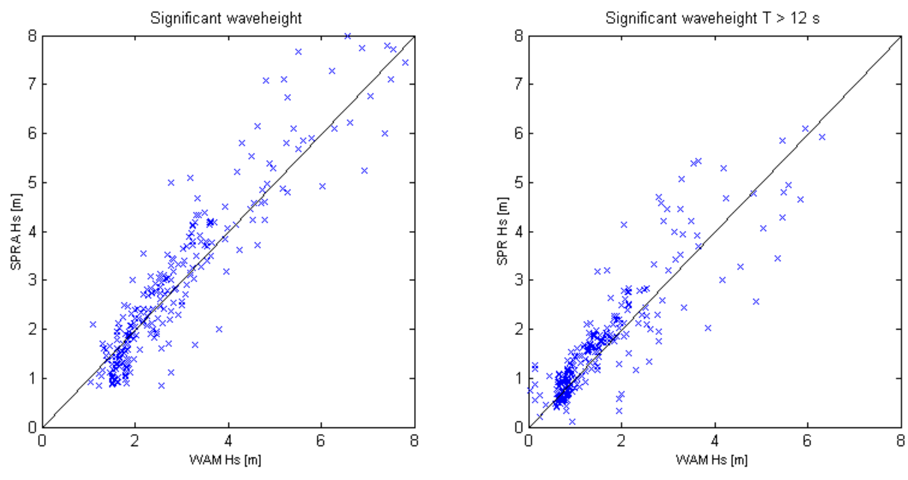


Fig. 2 Significant wave height (left) and wave height of waves with wave period longer than 12 seconds (right) retrieved from the ASAR level 1 product (SPRA scheme) versus WAM significant wave height.

It is remarkable that the reduction of wave energy, which would be expected to occur because of azimuthal smearing, is not visible in the results. One possible explanation is that the contribution of swell energy with short wave periods is relative low. Furthermore, the scatter looks a little bit high, at least higher than found by Melger [4] for the pre-launch simulated dataset. It is not entirely sure whether this scatter should be attributed to the spectra retrieved from the level 1b product, or to the WAM model predictions.

## 3. COMPARISON OF THE LEVEL 2 PRODUCT TO WAVE MODEL SPECTRA

Instead of comparing 2 dimensional wave spectra from the level 2 product and the WAM model only overall parameters are compared. The available samples are different from the samples used to examine the level 1b product (fig. 1). From the 140 available samples the confidence swell flag was set for 80 records: the signal to noise ratio was too low to solve the wave propagation ambiguity.

Fig. 3 shows that the retrieved wind speed agrees well with the WAM model. The level 2 wind speed of records with WAM wind speeds less than 4m/s were close to zero (red circles). The scatter might be attributed to the WAM model but this data set is far too limited for conclusions.

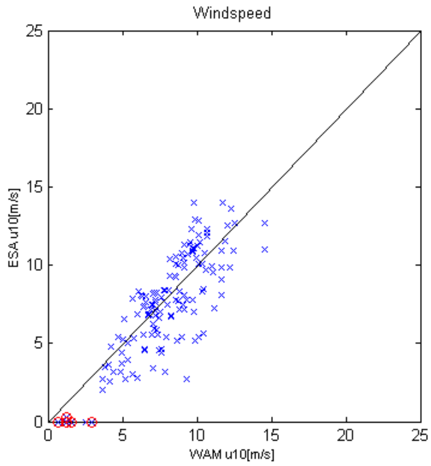


Fig. 3 Level 2 (ESA) wind speed against ECMWF (WAM) wind speed.

Fig. 4 shows that apart from a few obvious errors, the wave height from the ASAR level 2 scheme agree very well with the WAM model. The retrieved wind speed of the marked records was approximately zero. The wave energy for waves with periods longer than 12 seconds seems to be slightly higher in comparison to WAM. Normally the azimuthal smearing reduces the ability of ASAR to detect wave energy at wave numbers outside the azimuthal bandwidth. Based on this one might expect that this would result in overall wave heights being somewhat underestimated. Because no real underestimation of level 2 significant wave height was found in this data set, it is likely that the long wave energy is somewhat overestimated.

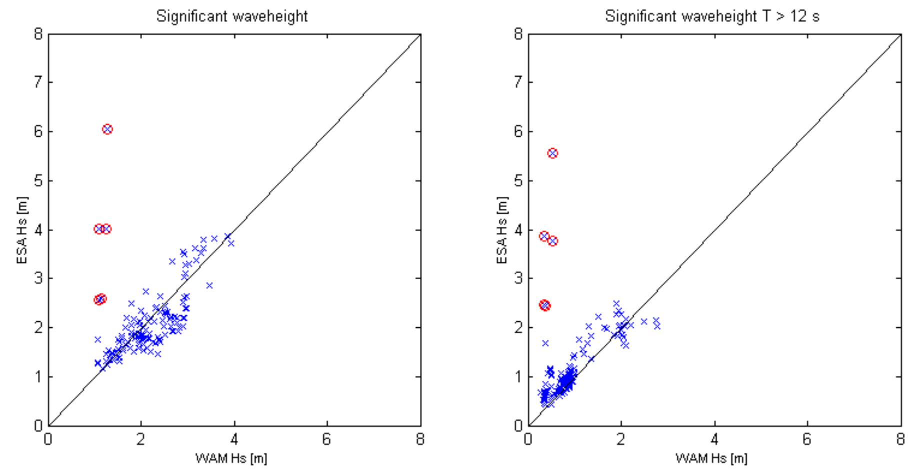


Fig. 4 Significant wave height (left) and wave height of waves with wave period longer than 12 seconds (right) retrieved from the ASAR level 2 product versus WAM significant wave height.

The saturation of wave height as in the pre-launch dataset [4] does not show up in this dataset. Perhaps the inversion algorithm has been changed since the pre-launch phase, but it is not unlikely that the current sample dataset does not include records were saturation occurs. To illustrate this we have estimated the energy of the wind waves, and added it to the level 2 wave energy. The estimation was based on the retrieved wind speed and normalised inverse wave age as given in the level 2 product. The results are given in fig. 5.

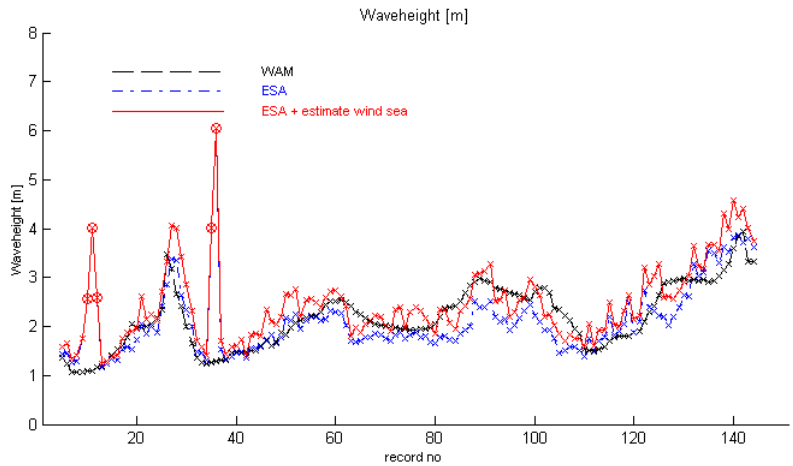


Fig. 5 Level 2 (blue dashed dotted), Level 2 plus estimate of wind sea contribution (red solid) and WAM (blue dashed) significant wave height as function of succeeding locations.

From fig. 5 it is clear that the long wave energy (swell) dominates in all acquisitions, even in case of high wind speeds. Without reliable in-situ measurements (buoys) it is impossible to decide whether the relatively low wind sea energy found is correct. However, we do have an indication that the retrieved wind sea height is not reliable. Given the wind speed, the wind-sea height is determined by the inverse wave age (the ratio of wind speed and phase velocity of the peak). The inverse wave age (fig. 7) appears to be almost perfectly correlated with the wind speed (fig. 6).

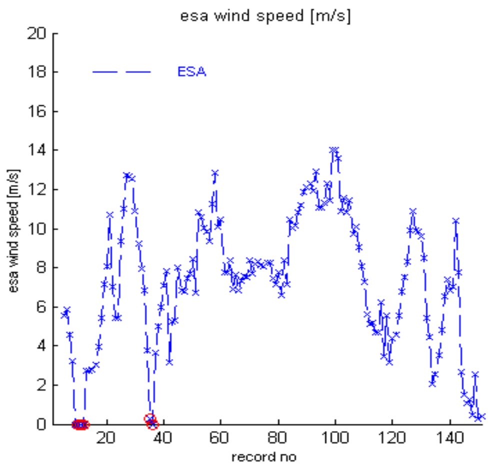


Fig. 6 Level 2 (CMOD) wind speed

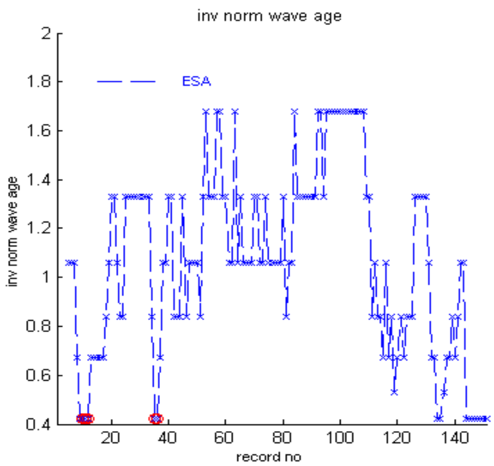


Fig. 7 Level 2 normalized inverse wave age.

The correlation coefficient is 0.9. The result of this correlation is that the phase velocity of the wind sea peak (fig. 8) is almost uniform over the available data set. The overall result is that the retrieval has been computed with effectively the same quasi-linear mapping over almost the entire data set. It is highly unlikely that the peak phase velocity is really constant, so

- the retrieved wave age is not reliable and therefore cannot be used to estimate a wind-sea spectrum to be merged with the retrieved level 2 spectrum
- the wave age estimate is probably compensating for model deficiencies.

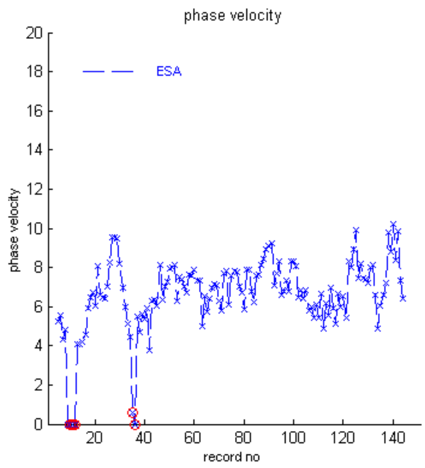


Fig. 8 Phase velocity derived from wind speed and inverse wave age as function of succeeding locations.

As spectra in the available data set can almost all inverted reasonably well using the same quasi-linear mapping, the range of conditions present in the data set must be rather narrow. This underlines the need for a much larger and more representative data set for a proper validation of the product.

## 4. REFERENCES


1. Engen G. and Johnson H., *SAR image cross spectra from ERS single look complex data*, NORUT information technology, December 3 1995.
2. Engen G. and Johnson H., *SAR ocean wave inversion using image cross spectra*, IEEE transactions on geoscience and remote sensing, VOL 33 NO4, July 1995.
3. Mastenbroek C. and De Valk C., *A semi-parametric algorithm to retrieve ocean wave spectra from SAR*, J. Geophysical Research, VOL. 105, NO. C2, February 15 2000.
4. Melger F., *Validation of ASAR wave mode retrieval algorithms for sea-state forecasting and wave climate assessment*, ESA, European Space Agency, November 2001.