

# ENVISAT ASAR WAVE MODE PRODUCTS - QUALITY ASSESSMENT AND ALGORITHM UPGRADE

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## ABSTRACT

Global calibration, validation and long-term quality assessment of the ASAR WM products have been conducted on a monthly basis since January 2003, using collocated WAM model as provided by ECMWF as well as available buoy data. The monitoring of the geophysical calibration constant indicates a slow decrease in the instrument gain of about 1dB in the period June 2003 to September 2005. The ground segment processing has been updated with the new value of the calibration constant.

The geophysical validation consist of systematic regional and seasonal comparisons with collocated wave parameters of the WAM model. Although the agreement is good on a global basis for the swell part of the wave spectra, significant deviation is observed for the mean wave period (RMS=1.7sec, BIAS=1.0sec) and significant waveheight (RMS=0.6m, Bias=0.3m), for waves within the SAR resolution domain. The deviation is mostly due to an imperfect detrending of the images as well as the use of improper modulation transfer function (MTF) at low wavenumbers.

The outcome of the geophysical validation process has resulted in an upgraded algorithm for the ASAR WWV (Level2) product. The upgrade consists of both refinements and new developments such as: - improved azimuth cut off estimation, - a new spectral detrending procedure, - modification of MTF at low wavenumbers, - improved propagation ambiguity removal. Validation of the upgraded processing shows a significant improvement in the geophysical quality of the Level2 product as well the number of products passing the quality control. The latter is of importance for the assimilation of Level2 products into NWP models.

The new Level2 algorithm is currently used for the reprocessing the whole Envisat ASAR WM archive at IFREMER.

## 1. INTRODUCTION

The ENVISAT ASAR Wave Mode (WV) products offer the unique ability to provide continuous global directional information on wave field for various uses such as input to numerical weather prediction models (NWP) as well as ocean wave climate tools. Wave mode products correspond to small measurements called wave cells which are approximately 5 km along-track by (up to) 10 km in across-track., acquired at 100 km intervals. The cells may have alternating positions in the same swath or be in alternating swaths. The data used in this study are acquired in the standard configuration which is swath 2 (incidence angle of 22.7°) and VV polarization. The Wave Mode provides three different products: - the WVI product, which is the single-look complex imagette including the image cross spectra, - the WVS product, which is only the image cross spectra, - and the WWV product, which is the SAR ocean wave spectra. Although the validation and algorithm upgrade are done for both the WVS and the WWV product, we will in this paper only discuss the results of the WWV product upgrade.

## 2. ALGORITHM UPGRADE

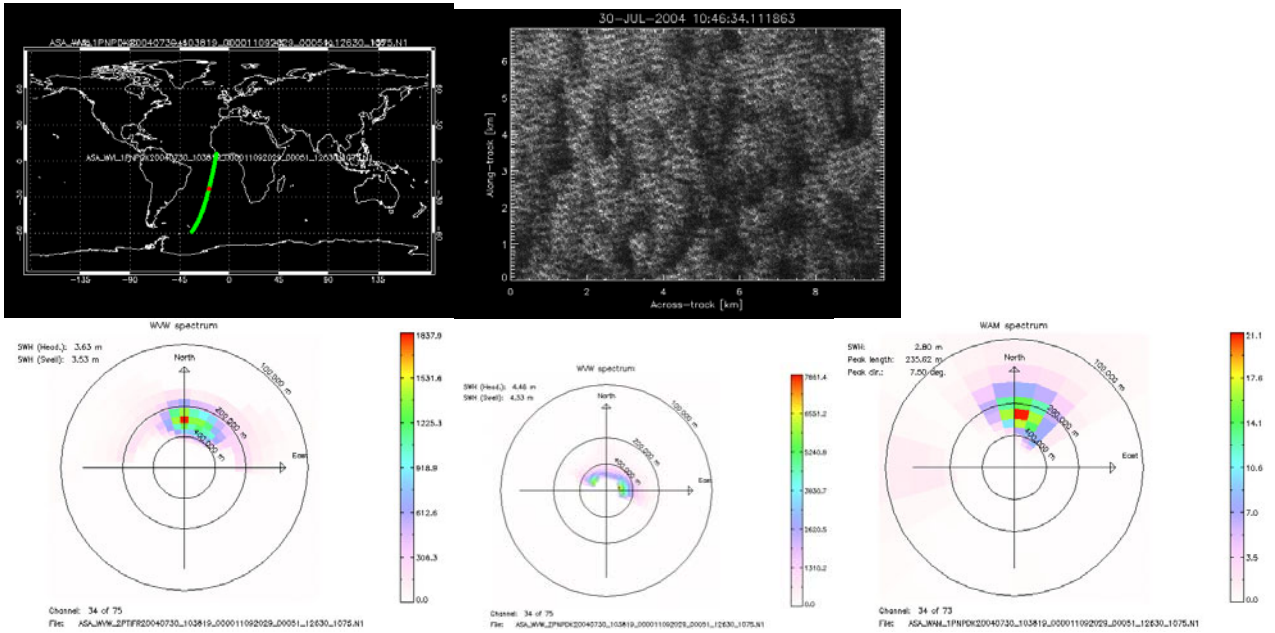
Based on the systematic long term validation of the WWV product [1], [2], an upgrade of the Level 2 algorithm was developed and implemented at IFREMER/CERSAT. The major problems observed in the first version of the Level 2 algorithm are related to; - large number of non-physical spectra, - overestimation of mean period of swell, - overestimation of Hs, especially at low sea-state, - ambiguity in swell propagation direction at low SNR, - azimuth cut-off value

The solutions were found by; - detrending in spectral domain, - modification of the modulation transfer function at low wavenumbers, - improved SNR measure, and new ambiguity flag, - a new azimuth cut-off estimator.

The large number of non-physical spectra were related to improper detrending of the imagette. An additional non wave feature removal is applied in the Fourier domain of the image cross spectra by removing spectral contributions that are maximum at the cutoff frequencies (800m) and decreasing monotonically to higher wavenumbers. Example of improvements of the final wave spectra are shown in the Figure 1.

The ambiguity removal in the Level 2 processing is based on generating a symmetric and a anti-symmetric wave spectra by applying the modulation transfer function (MTF) on the real and imaginary parts of the cross-spectra, respectively. Then only those wave component in the symmetric spectrum with values above certain positive value in the anti-symmetric spectra are kept. However, it has turned out that the imaginary part of the cross-spectra has often a low SNR, which in combination with the MTF may produce ambiguities in the wave direction retrievals. We thus recommend to apply on the imaginary part of the cross-spectra a modified MTF that is thresholded to avoid noise amplification at low frequencies and a weighting function based on the ambiguous inverted wave spectrum. This improvement in ambiguity removal has a strong impact when several wave systems are present at the ocean surface since the imaginary part of the longer wave system might have an SNR lower than the some surrounding low frequencies or noise contribution. Additionally a new parameter (*ambiFac* instead of *signal-to-noise*) is used to assess the confidence flag of the swell inversion. The *ambiFac* is also stored in the spare field of the *OCEAN WAVE SPECTRA MDS* of the new Level 2 product.

It has further been observed that the actual SAR MTF tends to overestimate the swell at low wavenumbers. This has the double impact of reducing the relative importance of rather developed wind seas (in the range 100-200m) and overestimating the wavelength of swell systems. This artefact is due to the assumption that all spectral components of the wave spectrum are free propagating waves. This assumption is no longer valid for wavenumber lower than the spectral peak which are not propagating waves but effects of wave groupiness (limited number of waves within a group equivalent to a peak broadening in the spectral domain). We thus suggest to apply on wavenumber lower than the peak for each single direction the same transfer function as for the peak wavenumber.



**Figure 1: upper left) imagette location. upper right) imagette backscatter. lower left) inverted wave spectrum (new version) . lower mid) inverted wave spectrum (old version). lower right) collocated wave model spectrum**

### 3. VALIDATION RESULTS

The validation consist of intercomparison of wave spectral parameters derived from the various sources (ASAR, NDBC buoys, WAM), followed by an estimation of RMS error and bias. The wave spectral parameters of particular interest is the wave period,  $T_p$ , the significant waveheight,  $H_s$ , and the wave direction,  $\Phi_p$ , which are derived from the two-dimensional wave spectra as described in the following. The ASAR Wave Mode Level 2 spectra are given on log-polar grid in wavenumber and direction domain,  $F(k, \phi)$  [3]. Note that the ASAR spectrum is in general not the total ocean wave spectrum, but only the wave spectrum within the SAR imaging domain. The size of this domain is again dependent on the azimuth cut-off which again is dependent on the sea state. The frequency-,  $F(f)$  and directional spectra,  $\psi(\phi)$  are then derived from the Level 2 spectra,  $F(k, \phi)$  according to the formulas:

$$(1) \quad F(f) = \int F(k, \varphi) k \cdot dk df \cdot d\varphi$$

$$(2) \quad \psi(\varphi) = \int F(k, \varphi) dk$$

$$(3) \quad \phi(f) = \tan^{-1} \left( \frac{\int F(k, \varphi) \sin \varphi d\varphi}{\int F(k, \varphi) \cos \varphi d\varphi} \right)$$

where  $dkdf = 4\pi\sqrt{k/g}$ . The significant waveheights,  $H_s, H_s^{12}$  mean periods,  $T_p, T_p^{12}$ , and mean wave direction,  $\Phi$  are then computed as:

$$(4) \quad H_s = 4 \sqrt{\int_{f_{\min}}^{f_{\max}} F(f) df}, \quad H_s^{12} = 4 \sqrt{\int_{f_{\min}}^{1/12} F(f) df}$$

$$(5) \quad T_p = \frac{\int_{f_{\min}}^{f_{\max}} F(f) f^{-1} df}{\int_{f_{\min}}^{f_{\max}} F(f) df}, \quad T_p^{12} = \frac{\int_{f_{\min}}^{1/12} F(f) f^{-1} df}{\int_{f_{\min}}^{1/12} F(f) df}$$

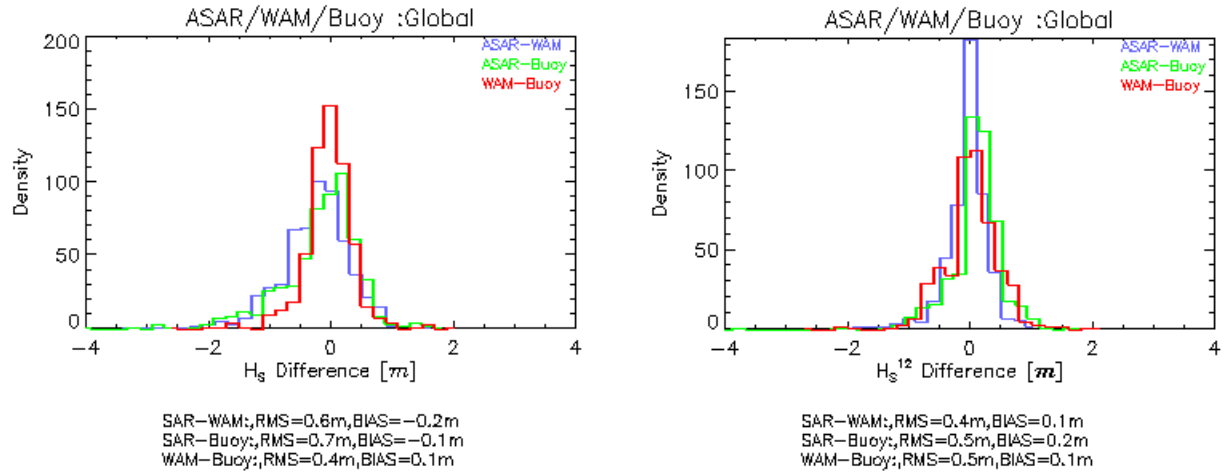
$$(6) \quad \Phi = \tan^{-1} \left( \frac{\int_{f_{\min}}^{f_{\max}} F(f) \sin(\phi(f)) df}{\int_{f_{\min}}^{f_{\max}} F(f) \cos(\phi(f)) df} \right)$$

where  $f_{\min}, f_{\max}$  are the lowest and highest frequencies in the spectrum to be computed over. Similar parameters can be derived from the co-located WAM and buoy spectra. Spectral peak period,  $T_{peak}$  and direction,  $\Phi_{peak}$ , given as the peak of  $F(f)$  and  $\psi(\varphi)$ , respectively, are also computed and compared. The wave directions are always clockwise from north towards the direction the waves propagate.

The  $H_s^{12}$  and  $T_p^{12}$  are computed for waves with period longer than 12 sec, which in most cases are longer than the azimuth cut-off period.

### Significant Waveheight:

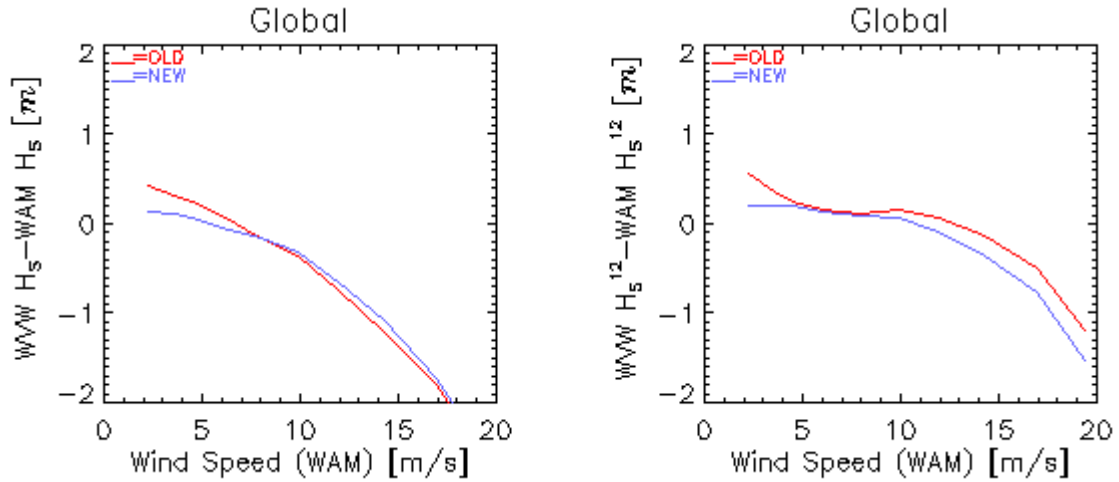
Comparison of the ASAR significant waveheight of the old (first version) WWV product with the WAM spectra, showed RMS error and bias 0.6m and 0.3m, globally for  $H_s^{12}$ . The bias in  $H_s^{12}$  showed also strong geographical dependency, 0.2m in the Central and West-Pacific and 0.7m in the East-Atlantic US coast [1]. The deviations in significant waveheight also show a clear dependency with wind speed, even for  $H_s^{12}$  at low wind speeds. The results of the significant waveheight analysis of the new processing is shown in Figure 2.



**Figure 2: Comparison of significant waveheight from ASAR WM, WAM and buoy for May, September, and December 2004. The ASAR WM data are processed with the upgraded Level 2 processor at IFREMER.**

Figure 2 shows that the bias in  $H_s^{12}$ , with the new Level 2 processing, is reduced to only 0.1m as compared to WAM. We also see that the RMS and bias compared to the buoy are comparable with the corresponding values for the WAM. The geographical dependency in the  $H_s^{12}$  bias is also significantly reduced, now 0.0m in the Pacific and 0.2m in the East-Atlantic US Coast.

In Figure 3 we show the improvements in the  $H_s$  and  $H_s^{12}$  bias as function of wind speed for the new Level 2 processing.

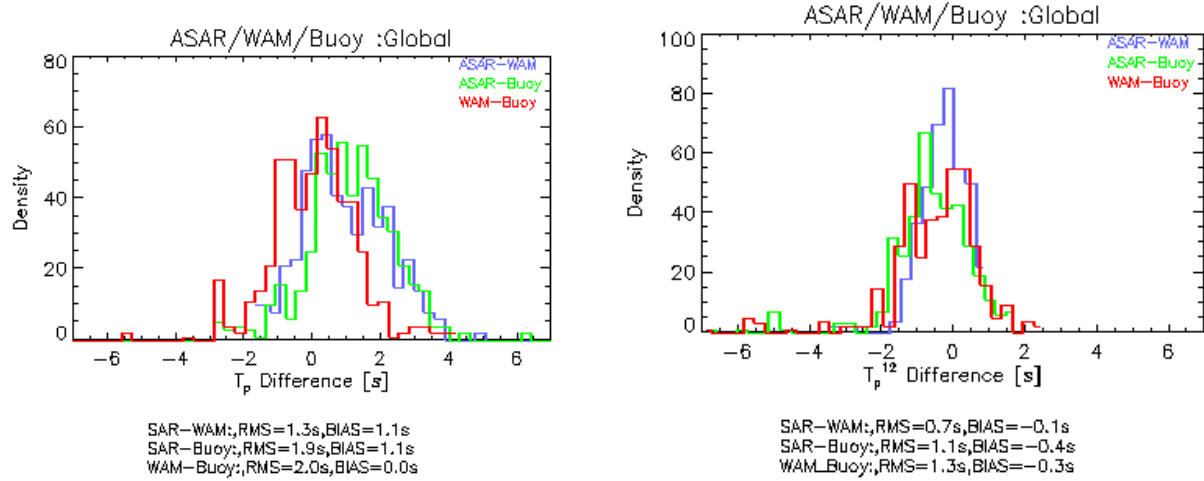


**Figure 3: Mean difference in  $H_s$  and  $H_s^{12}$  between ASAR and WAM as function of wind speed, for the old Level 2 processing (red ) and the new Level 2 processing (blue).**

Figure 3 shows that the wind speed dependency in the significant waveheight bias at low wind speed is reduced significantly, and for the swell part almost no dependency is observed for wind speeds below 10m/s. For higher wind speeds, a dependency on wind speed is expected even for the swell since then the azimuth cut-off will be in the swell domain.

## Mean Wave Period:

Comparison of the ASAR mean wave period from old version of the WVW product with the WAM spectra, showed RMS error and bias of 1.7s and 1.0s for  $T_p^{12}$ , globally. The bias in  $T_p^{12}$  showed also strong geographical dependency, 0.7s in the Pacific and 2.6s in the East-Atlantic US coast. The result of the mean period analysis is shown in Figure 4.

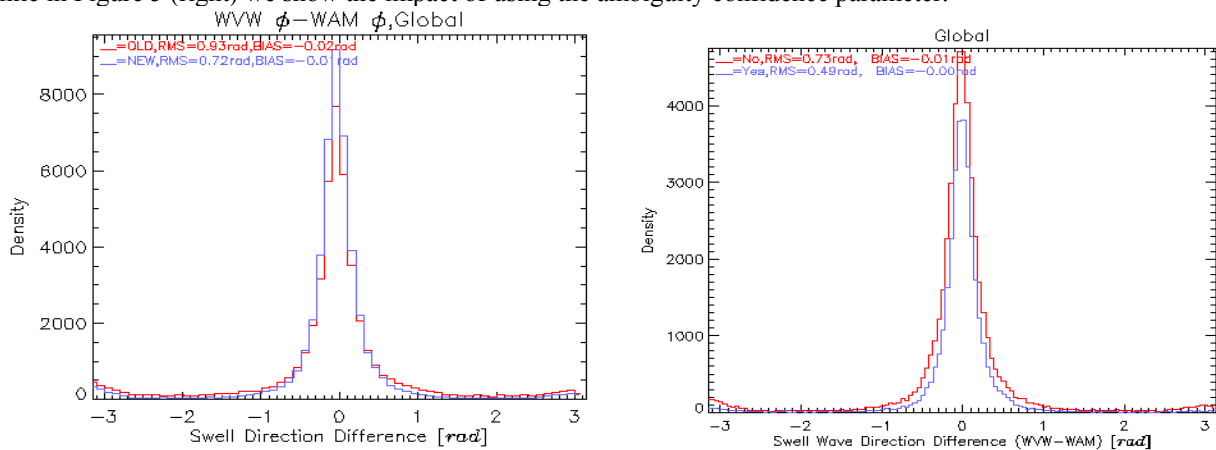


**Figure 4: Comparison of mean wave period from ASAR WM, WAM and buoy for May, September, and December 2004. The ASAR WM data are processed with the upgraded Level 2 processor at IFREMER.**

Figure 4 shows that the bias in Level 2  $T_p^{12}$ , with the new processing, is reduced to -0.1s as compared to WAM. We also see that the Level 2 bias (-0.4s) and RMS error (1.1s) compared to the buoys are comparable with the corresponding values for the WAM (-0.3s and 1.3s).

## Wave Direction:

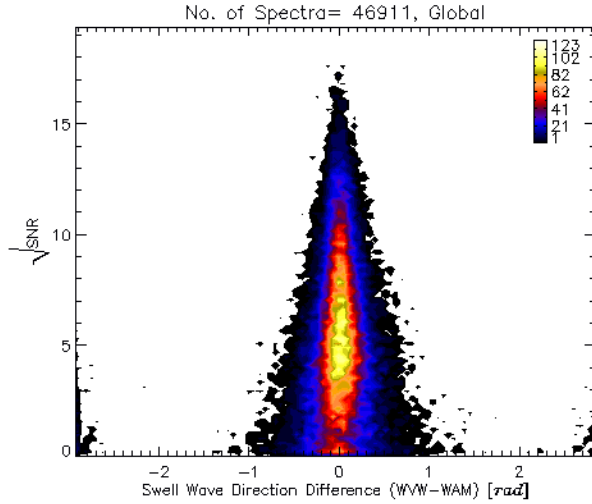
Comparison of the ASAR wave direction from old version of the WVW product with the WAM spectra, showed RMS error of around 0.9 rad and a bias of 0.02 rad. Unfortunately, the directional informations from buoys are so far limited, so the comparison is only done against WAM data. A partitioning of the spectra was done and the swell direction of WAM and ASAR Level 2 was done. A new parameter describing the confidence of the propagation ambiguity removal was introduced and tested in the following. In Figure 5 (left) we show the results of the comparison of swell direction, while in Figure 5 (right) we show the impact of using the ambiguity confidence parameter.



**Figure 5: Left: Histogram of swell propagation direction difference between ASAR and WAM for the old Level 2 processing (red ) and the new Level 2 processing (blue). Right: Histogram of swell direction difference between ASAR and WAM with no ambiguity flag (red ) and with ambiguity flag set (blue).**

Figure 5 (left) shows that swell propagation direction RMS difference between ASAR and WAM is reduced from 0.93 rad to 0.72 rad with the new processing. We also see a reduction of the corresponding bias from  $-0.02$  rad to  $-0.01$  rad. In Figure 5 (right) we see that by using the ambiguity flag of the new Level 2 processing, we further reduce the RMS and bias in swell propagation direction difference to 0.49 rad and 0.00 rad, respectively.

The ambiguity parameter used in Figure 5 (right) is stored in the new Level2 product header. In Figure 6 it is plotted against the swell wave direction difference between Level 2 and WAM. Figure 6 is then used to define the threshold to filter out the ambiguity SAR spectra.



**Figure 6: Ambiguity (SNR) as function of swell wave direction difference between Level 2 and WAM spectra.**

Figure 6 shows that swell wave direction difference between Level 2 and WAM spectra increases with decreasing SNR, and that a threshold can be established to filter out ambiguity data. For the analysis shown in Figure 5 (right) we used the threshold  $\sqrt{\text{SNR}} = 3$ , i.e. disregarding all data with values below this threshold.

#### 4. CONCLUSIONS

We conclude that the upgrade of the ASAR WM Level 2 processing has significantly improved the product quality. Less RMS deviation and bias between Level 2 and WAM or buoy wave spectra parameters are observed. More WM data gives meaningful wave spectra, and an improved flagging of ambiguity data is achieved

#### 5. REFERENCES

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