ENHANCING ENVISAT ASAR WSM SEGMENTS TO DETECT OIL SPILLS IN THE FRAMEWORK OF THE "20 YEARS OF OIL ROUTES" PROJECT

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ABSTRACT

A project is under way to retrieve the routes of oil tankers from the spills they release across the world seas. This project called "20 years of oil routes" requires the processing a large amount of ERS SAR and Envisat ASAR data acquired from 1991.

A huge bibliography demonstrates that the automatic detection of oil slicks is not an easy task. Many factors are influencing the readability of the images and many black bodies that often are not oils may be improperly detected. This paper presents a rigorous way to pre-process the Envisat ASAR radar segments acquired in the wide swath mode (WSM). Three models of radar backscattering over oceans (CMOD4, CMOD5 and CMOD5.N) are compared to the mean of the cross-sections.

The best model CMOS5 is used to normalize the column distribution to a predefined mean m_0 and a predefined standard deviation σ_0 (see fig. 1).

The ScanSAR mode WSM may produce visible boundaries between the 5 sub-swaths. Analysing precisely the statistics around the supposed locations of the 4 junctions enables to detect and correct a possible discontinuity (see fig. 5).

1. INTRODUCTION

1.1. The ESA / VisioTerra project

VisioTerra is a French company specialized in "*Scientific consulting for Earth Observation*". Two of its main activities are the development of software and the production of spacemaps using its own software.

One project is ongoing with the European Space Agency (ESA) to retrieve the maritime routes of tankers from the oil spills seen in the Radar images acquired from more than 20 years. A huge quantity of scenes observed by the ERS/SAR and Envisat/ASAR instruments are being processed. In particular, the Wide Swath Mode (WSM) of Envisat/ASAR is very suitable to monitor oil spills because of its spatial resolution (around 150 metres), the width of its swaths (400 km) and the undefined length of its products that may match up to thousands of kilometres.

1.2. The defects of the WSM images

The detection of oil spills and its distinction from other "black bodies" over the ocean, require the best pre-processing of data. In particular, one should homogenise the brightness and contrast across the whole image in whatever column: near range like far range.

User should have the possibility to set a mean m_0 and a standard deviation σ_0 for the whole image.

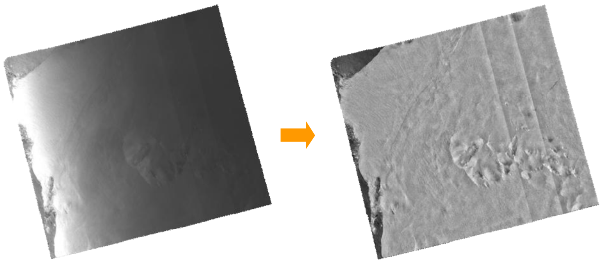

Figure 1. ASAR WSM scene before (left) and after homogenisation to m_0, σ_0 (right).

An other defect is more visible after a strong contrast enhancement: the limits between the five (5) sub-swaths of the ScanSAR acquisition mode of WSM. For example the limits between the sub-swaths S3/S4 and S4/S5 are particularly visible in the right part of the homogenised image in fig. 1.

2. COLUMN EQUALIZATION

The column equalization to a user-defined mean m_0 and standard deviation σ_0 requires to:

- compute the statistics per column of the level 1B product (before reprojection),
- look for the C-band model (CMOD) fitting the best with the observed data,
- apply this CMOD to force the desired mean and standard deviation column per column.

2.1. Observed statistics per column

Before any projection, the level 1B Envisat ASAR WSM product has columns matching the distance to the NADIR with almost the same incidence angle for all the pixels of a same column.

The “observed mean” $m_r(j)$ and standard deviation $\sigma_r(j)$ are computed for each column j according to the following equations:

$$m_r(j) = \frac{1}{\sum_{i=0}^{M-1}\delta(i,j)} . \sum_{i=0}^{M-1}\delta(i,j)\times r(i,j) \qquad (1)$$

$$\sigma_r(j) = \sqrt{\frac{1}{\sum_{i=0}^{M-1}\delta(i,j)} . \sum_{i=0}^{M-1}\delta(i,j)\times r^2(i,j) - \left(m_r(j)\right)^2} \qquad (2)$$

Where:

- M is the number of lines in the image,
- $m_r(j)$ is the mean of the digital numbers (DNs) of the “sea pixels” along the column j,
- $\sigma_r(j)$ is the standard deviation of the DNs of the “sea pixels” along the column j,
- δi,j) is a sea / land indicator (=1 if the pixel is in majority in the sea and =0 otherwise),
- r(i,j) is the digital number (DN) of the pixel (i,j).

Plotting the column means and standard deviations shows the Radar cross sections (RCS). The amplitude of the plot is depending on the azimuth and modulus of the wind over the ocean.

Figure 2 here below show for example one level 1B ASAR WSM product before any projection (left) and the plot of the observed means and standard deviations for various ASAR WSM products.

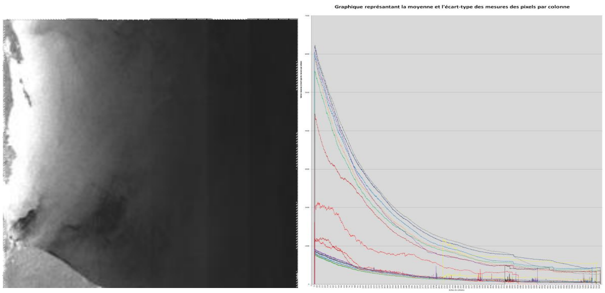

Figure 2. Level 1B Envisat ASAR WSM scene (left) and the observed means and standard deviations per columns for various ASAR WSM products (right).

2.2. From DN to the Radar Backscattering

In that follows the Radar backscattering coefficient usually called “*sigma nought*” is called $\overline{M}$ in order not to confuse it with the σ_0 of the user-defined standard deviation.

This Radar backscattering coefficient is computed from the observed mean of the column applying the following equation:

$$\overline{M}(j) = \frac{\left(\overline{m_r}(j)\right)^2}{K} \times \sin(\overline{\theta}(j)) \qquad (3)$$

Where:

- M(j) is the Radar backscattering coefficient observed at column j,
- $(m_r(j))^2$ is the intensity of the average of the observed pixel values (DNs) at column j,
- K is the “Absolute gain Calibration Factor” found in metadata of the product,
- θ(j) is the mean of the incidence angle θ(i,j) found for each pixel (i,j) of the column j.

2.3. CMOD of the NRCS

The normalised radar cross-sections (NRCS) computed from the observed data may be modelised by functions of the wind speed V, the wind direction ϕ with regard to the radar beam, and the incidence angle θ.

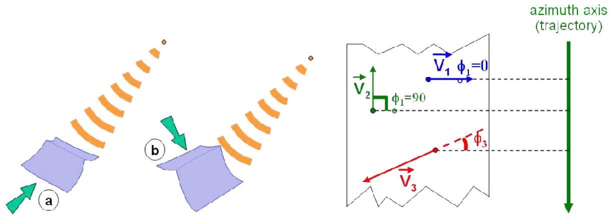

Figure 3. Angle ϕ between the wind direction and the direction of the radar beam.

Three CMOD functions have been tested: -CMOD4 [1], -CMOD5 [2], and –CMOD5.N [3]. The full equations are given in their relative references. Only the first equation of CMOD4 and CMOD5 are given here below.

$$\dot{M}_{CMOD4}(V,\phi,\theta) = b_0\left(1 + b_1\cos\phi + b_3\tanh b_2\cos 2\phi\right)^{1.6} \qquad (4)$$

$$\dot{M}_{CMOD5}(V,\phi,\theta) = b_0\left(1 + b_1\cos\phi + b_2\cos 2\phi\right)^{1.6} \qquad (5)$$

Equations of CMOD5 and CMOD5.N are the same but only the coefficients differ.

Making vary the wind speed V and the wind direction ϕ, we look for each one of the three models the couple (V_0,ϕ_0) for which the difference between the observed sigma nought M(j) and the modelised one $M_{CMODx}(j)$ is the smaller one.

The mean of the linear correlations between M(j) and $M_{CMODx}(j)$ has been computed for 54 scenes Envisat ASAR WSM. As shown in the table here below, the correlations are very high for the three models. A very small advantage has been noted for CMOD5.

Model	CMOD4	CMOD5	CMOD5.N
Mean correlation	0.930 725	0.949 304	0.947 753

2.4. Homogenisation of the column statistics

Let m_0 and σ_0 be the mean and standard deviation user wants to set as local statistics across the whole image, the columns may linearly stretched using the CMOD5 model registered for the couple (V_0,ϕ_0) using the following formula:

$$r'(i,j) = \frac{\sigma_0}{\sigma_{CMOD5}(V_0,\phi_0,j)} \times r(i,j) + \left[\overline{m}_0 - \frac{\sigma_0}{\sigma_{CMOD5}(V_0,\phi_0,j)} \times \overline{M_{CMOD5}(V_0,\phi_0,j)} \right] \quad (6)$$

Where:

- $r(i,j)$ is the pixel value in input,
- $r'(i,j)$ is the pixel value in output,
- $M_{CMOD5}(V_0,\phi_0,j)$ is the backscatter value of the model CMOD5 for a wind speed V_0 and a wind direction ϕ_0 at column j,
- $\sigma_{CMOD5}(V_0,\phi_0,j)$ is the standard deviation deriving from the model CMOD5 for a wind speed V_0 and a wind direction ϕ_0 at column j given by the formula:

$$\sigma_{CMOD5}(V_0,\phi_0,j) = \alpha \times \overline{M}_{CMOD5}(V_0,\phi_0,j) \quad (7)$$

Where:

- α is the linear regression factor linking the observed mean and the observed standard deviation,

$$\sigma(j) \approx \alpha \times \overline{m}(j) \quad (8)$$

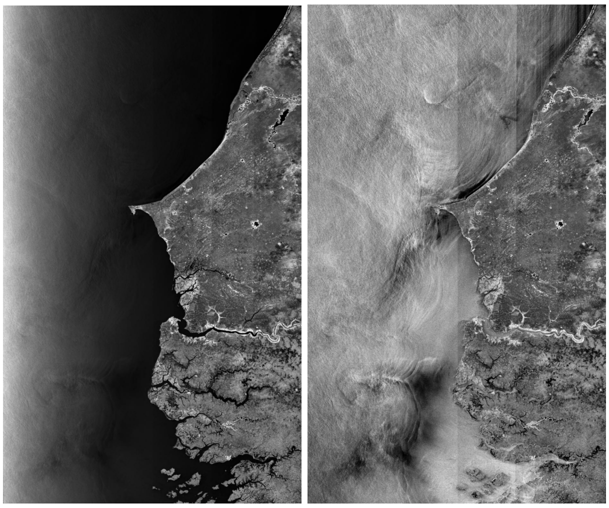

Figure 4. ASAR WSM scene before (left) and after homogenisation to m_0, σ_0 (right).

3. C0RRECTION OF SUB-SWATH JUNCTIONS

3.1. Observed defect

As shown in fig. 5, one may observe the junctions between the five (5) sub-swaths in the level 1B raw image and much more again in the stretched images with a desired high standard deviation σ_0.

In particular, the observed mean per column of the two junctions of the far range columns (junctions j3 and j4) show a greater discontinuity zooming in the radar cross sections.

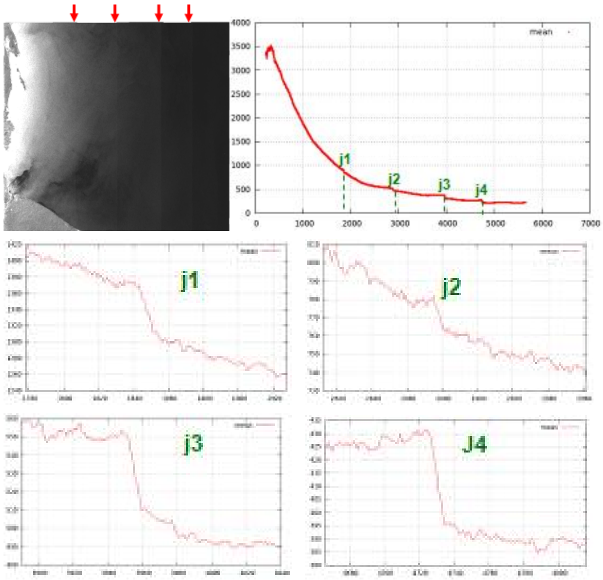

Figure 5. Location of the junctions between sub-swaths and zoom on the cross-section profiles.

3.2. CMOD5 centring and reduction

Dividing the mean of the backscattering coefficient M(j) (see eq. 3) by the best fit mode $M_{CMOD5}(V_0,\phi_0,j)$, one obtain a "centred-reduced radar cross-section" that clearly show the sub-swath discontinuities (see fig. 6).

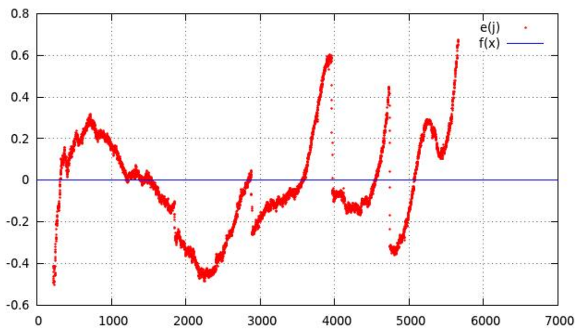

Figure 6. "Centred-reduced radar cross-section".

To automatically retrieve the location of the inter-swath junctions (that are not always exactly at the same location) and to assess the magnitude of these discontinuities, one computes a gradient of the smoothed centred-reduced cross-section (see fig.7).

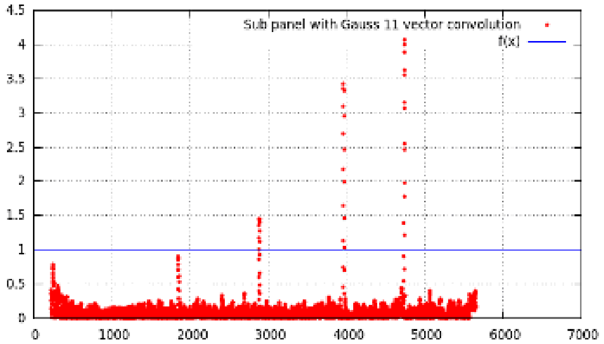

Figure 7. First derivative of the smoothed "centred-reduced radar cross-section".

Two semi-linear models are applied to the left and to the right of each junction to linearly adjust the values on the junction while leaving unchanged the column located at the centre of the sub-swath. Equation 9 here below illustrates for example the correction applied around the first junction j1.

$$c_1(j) = \begin{cases} e(j) - \dfrac{e(j_1') - e(j_1'')}{2} \times \dfrac{j}{j_1'} & \text{if} \quad 0 \le j \le j_1' \\ \dfrac{e(j_1') + e(j_1'')}{2} & \text{if} \quad j_1' < j \le j'' \\ e(j) + \dfrac{e(j_1') - e(j_1'')}{2} \times \dfrac{j - \frac{j_1 + j_2}{2}}{j_1'' - \frac{j_1 + j_2}{2}} & \text{if} \quad j_1'' < j \le \dfrac{j_1 + j_2}{2} \end{cases} \qquad (9)$$

Applying the semi-linear models leads to remove the discontinuities around the junctions of the sub-swaths in the cross-sections (fig. 8) and in the images (fig. 9).

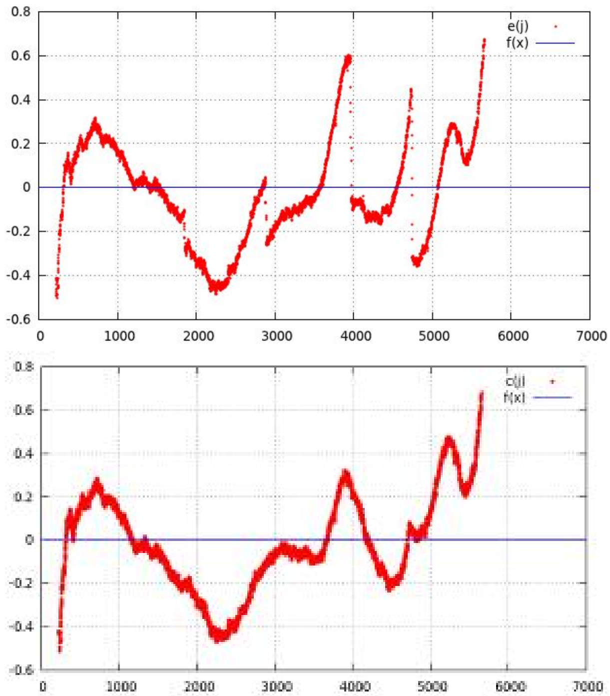

Figure 8. "Centred-reduced radar cross-section" before and after the corrections around the 4 junctions.

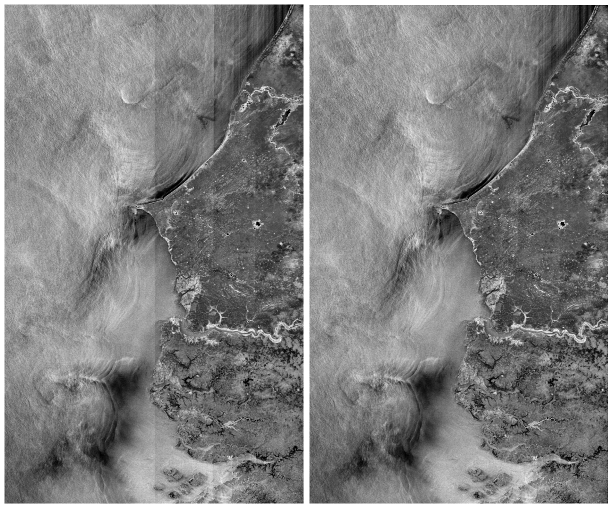

Figure 9. ASAR WSM scene before (left) and after the semi-linear correction around the sub-swath junctions (right).

REFERENCES

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