CYCLONE TRACKING WITH ERS-2 SCATTEROMETER: ALGORITHM PERFORMANCES AND POST-PROCESSED DATA EXAMPLES

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ABSTRACT

Every year, Tropical Cyclones (TC) produce important damages on a high number of countries: the floods caused for the heavy rain, strong winds and bad sea conditions are producing human and economic losses. Satellite data can help the scientific comunity to study these events. In particular the processing of the backscattering measurements acquired over the ocean is giving important information on the wind field at sea level. The knowledge of the TC wind field structure can help the scientific community to better understand and better forecast these events. To meet the needs of the scientific community, the Product Control Service (PCS) at ESRIN has developed a post-processing procedure for the fast delivery (FD) products processed from the data acquired with the C-band Scatterometer (Scat) flown onboard the ERS satellites. The major skills of this post-processing are: the detection of a TC, the quality improvement of the retrieved wind field and the availability on a web in near "real-time"of a report about this TC and the corresponding reprocessed Scat FD products.
The paper describes the techniques adopted to detect the TC and to improve the Scat wind field. It also presents statistic results about the detection skill of the method.

INTRODUCTION

The ERS Scatterometer is a three antennae radar working at C-band. This frequency is very sensitive to the sea surface roughness which could be related with the wind field by using an appropriate model. The returned echoes are stored onboard the satellite and downloaded to the ground station every orbit (roughly every 100 minutes). The processors installed at each ground station retrieve the backscattering coefficients (three sigma naught for three different azimuth angles) from the echoes with a resolution of 50x50 kilometers and sample on a grid of 25x25 kilometers. In addition, by using a wind retrieval algorithm based on the CMOD-4 empirical model [1] and an ambiguity removal algorithm, the wind vectors (speed and direction) are computed from each sigma naught triplet. Within three hours from sensing, backscattering coefficients and wind field estimations are provided to the international meteorological and oceanographic organizations via the World Meteorological Organization network called GTS. The European Centre for Medium-Range Weather Forecasts (ECMWF) has proven that the assimilation of Scat data into meteorological models can improve the forecast and the estimation of the TC's position [2].

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Figure 1: Red points (nodes) are used to calculate the vorticity of the green node.

However, wind information given in the FD product acquired over TC's are showing two major problems. The first one is that the retrieved wind speed is highly underestimated for high wind speed like in TC's. The second one is linked to the wind direction; the ambiguity removal algorithm has difficulties to choose the correct one when the wind structure is too complex. These two problems are linked to the calibration of the CMOD-4, which was not tuned for high wind speed (as we have in the TC), and with the performance of the ambiguity removal algorithm used at present in the ground processing.
In this paper it is described a procedure used within the ESRIN PCS to detect the TC from Scat FD data and to upgrade the wind field. In the conclusion it is given a description of the report information available on the web.

THE DETECTION OF A TC

Dishtwal et al. in [5] estimate the TC centre using the methodology of high density Scat winds. They assume that there is a circular symmetry (high vorticity) in the inner core of the cyclone in the intense stage. As the speed contours are not perfect circles, the centre is found by using a minimisation approach. The method presented here uses the sigma naught properties acquired over TC's to detect the centre of the cyclone. This is an advantage because the measurements are directly linked with a geophysical phenomena (sea roughness) rather than being the results of a geophysical model function inversion. The flow chart of the algorithm used to detect a TC is shown in Figure 2.

The Vortex Integral

The first step is the detection of the TC using the criteria of the high vorticity of a node. The vorticity of one node is calculated using the following formula:

$$I_{vort} = \frac{\sum_{j=1}^{n-2}[(V_J(n-1,j) - V_J(0,j)] + \sum_{i=1}^{n-2}[(V_I(i,n-1) - V_I(i,0)]}{\sum_{i=1}^{n-2}[V(i,0) - V(i,n-1)] + \sum_{j=1}^{n-2}[V(0,j) - V(n-1,j)]}$$

with

$$V_I(i,j) = V(i,j)\cos(\phi_M(i,j) - \phi(i,j))$$
$$V_J(i,j) = V(i,j)\sin(\phi_M(i,j) - \phi(i,j))$$

V is the wind speed

ϕ is the wind direction wrt North

ϕ_M is the mid beam look angle

n is the dimension of the window

Figure 1 shows the nodes used (red points) in the case of n = 7. For the nodes at near and far range of the swath, the full set is reconstructed by substituting the missing points by the ones situated in the opposite part of the set, as in a mirror image of the existing points, adding 180 degrees to the initial direction. This addition is performed in order to have a reconstructed set with a consistent flow of the wind with respect to the original set. The criteria for selecting a product is based on the absolute value of the node vorticity (within that product). If it is higher than 0.75, this product is selected. If the vorticity is not high but the wind speed is greater than 19.7 m/s for a given node, this product is also selected.

The Centre estimation of a TC.

Once a product is selected, the second step is the estimation of the TC centre. The centre estimation procedure uses the properties of the fore and aft antennae signals as described in [3]. The method uses a linear fit for two perpendicular lines where the difference of sigma nought fore and aft is zero. The lines are tilted 10 degrees with respect to the satellite swath and they should cross the eye of the cyclone. If the distance between the high vorticity node (Vc) and the

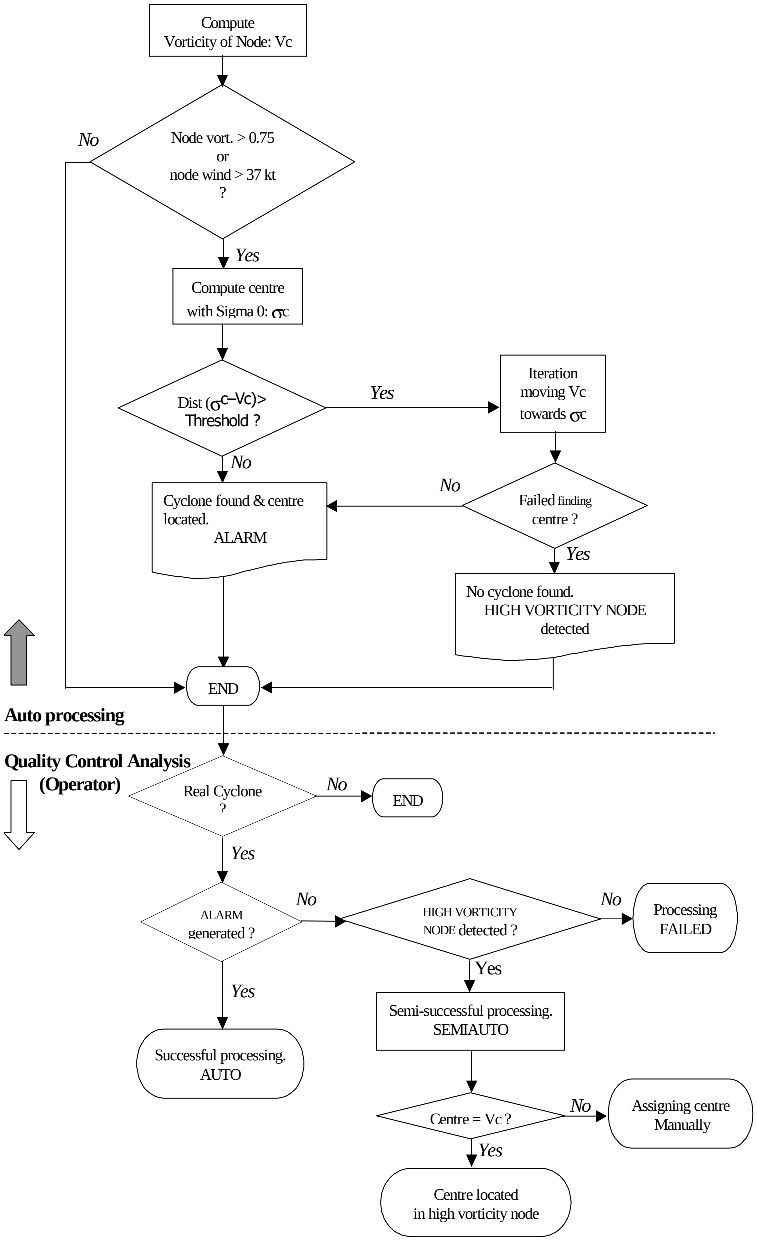

Figure 2: Flow chart of the overall processing

cross point (σc) defined by the intersection of the two line fits is greater than roughly 300 kms, the event is rejected (No cyclone found). If that is not the case, the procedure searches for the TC centre moving the Vc towards the σc. This action is repeated until the distance between the two points is less than 50 kms (the scat data resolution). The centre of the TC is the σc if the number of iteration is greater or equal than two and the Vc if the contrary.

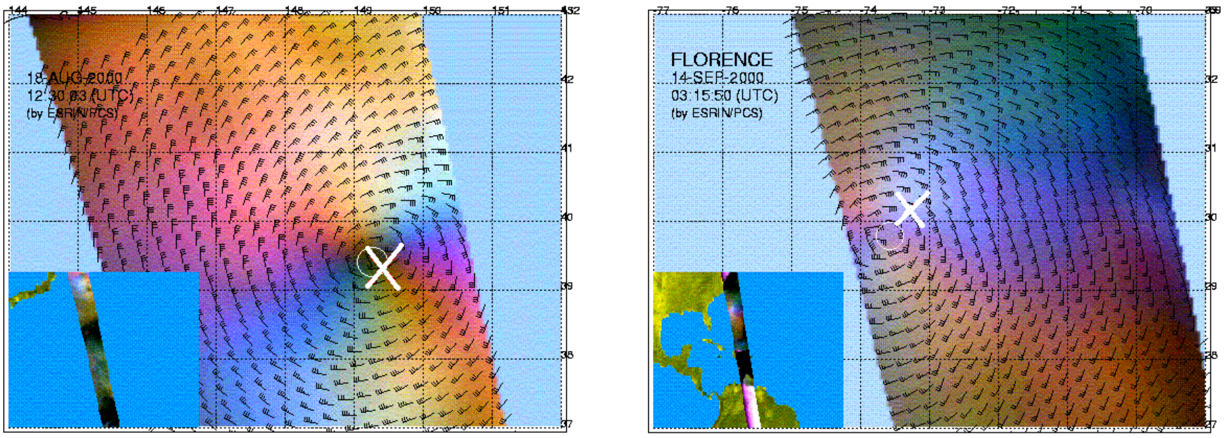

Figure 3: EWINIAR and FLORENCE centre position (white cross) by meteorological warning centres.

Every output of the software passes a Quality Control Analysis in order to check whether the procedure has worked successfully or not.
In Figure 3 a white cross is superimposed where the meteorological analysis localise the cyclone centre. If it is located within the white circle, that centre position is considered in agreement with the Scat centre, as in the first case of the figure (EWINIAR). In the case of TC FLORENCE (right image of Figure 3) the Scat data give the opportunity to have a more precise localisation of TC centre with respect to the meteorological warning.

Statistics on TC Algorithm Performance

To assess the performance of the algorithm, some statistics have been computed over the period 18th May 1999 to 6th August 2000 (Figure 4).
It is considered that the algorithm has fully worked (AUTO) when a cyclone has been found with centre location and maximum wind speed as direct outputs of the processing. If a high vorticity node is found but the algorithm is not able to locate the centre using the characteristics of sigma 0, the processing has partially worked (SEMIAUTO). It fails when a cyclone is completely ignored by the overall algorithm. The algorithm detects almost the 75% of the cyclone events hit by the scatterometer. On average, we have 2 events detected per day, but in most of the cases these are structures associated to high or low-pressure air zones. It is also possible that a poor ambiguity removal performance had generated a non-real circulation of the wind which was not rejected by the processing.

THE REFINED WIND FIELD

The Wind Direction Correction

At this stage, we compare the wind direction in the FD data with a theoretical model for a TC. A new ambiguity removal procedure is performed taking into account that the wind blows with an anticlockwise turn for the Northern Hemisphere or clockwise turn for Southern Hemisphere. Given a centre, the theoretical direction of the wind for a node is the tangent in that node to a circumference centred in the TC centre and rotated 10 degrees inwards. If the difference between the wind in FD data and the theoretical model is greater than 60 degrees, a new direction is searched among the four solutions of the wind retrieval function. Selected the direction, it will have the minimum difference with respect to the theoretical one. If this minimum difference is less than 60 degrees, the new direction is chosen; if not, no change is done.

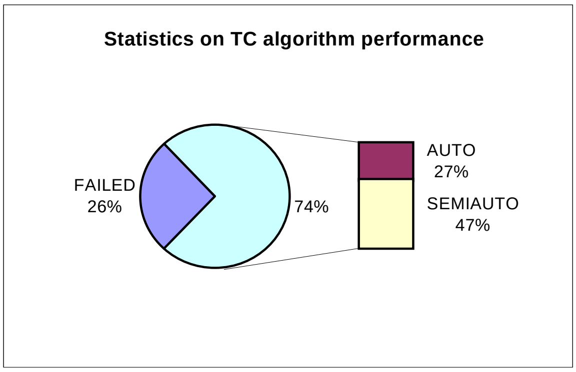

Figure 4: Statistics on TC algorithm performances

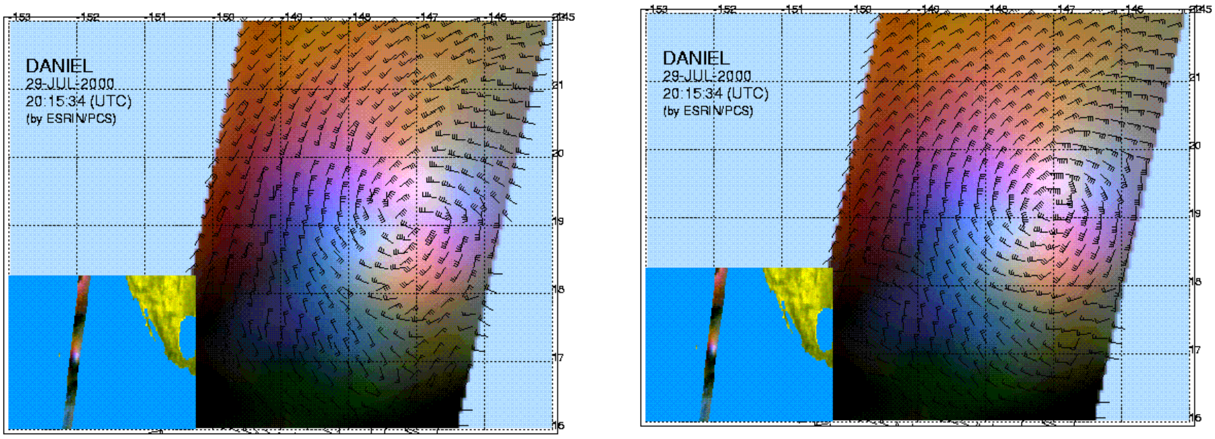

Figure 5: Wind field of DANIEL using operational ambiguity removal (left) and PCS reprocessing (right).

Two examples of the backscattering image before and after the re-processing of wind field are shown in Figures 5 and 6 in the case of TC ROSITA and DANIEL respectively. The improvement in the consistency of the wind turn is evident. Using the re-processed data, the PCS generates a structure of the cyclone. Figure 7 shows the results in the case of the cyclone ROSITA.

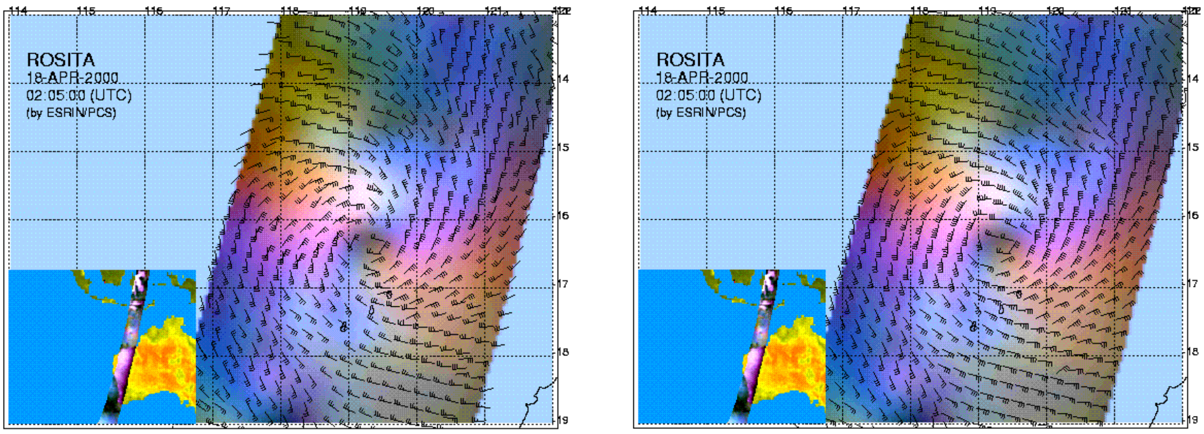

Figure 6: Wind field of ROSITA using operational ambiguity removal (left) and PCS reprocessing (right).

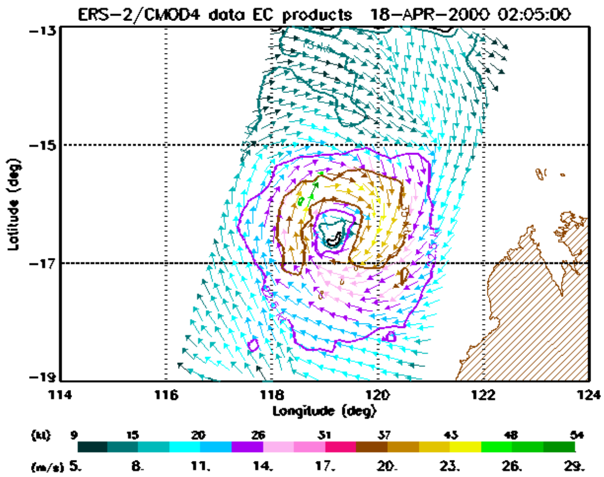

Figure 7: Structure of ROSITA

The Wind Speed Correction

A model that takes into account the slight calibration of CMOD-4 for high wind speeds and the error related to the resolution of the instrument is used to correct the wind speeds. The method is fully explained in [4]. Winds higher than 15 m/s are corrected with a result of a more realistic pattern of wind field structure and speeds. In Figure 8 we have plotted the maximum Scat winds compared with maximum wind speed reported by TC warnings. The temporal window for the collocation was $\pm$1 hour. It is clear that the corrected Scat values are in a better agreement that the Fast Delivery (FD) product speeds.

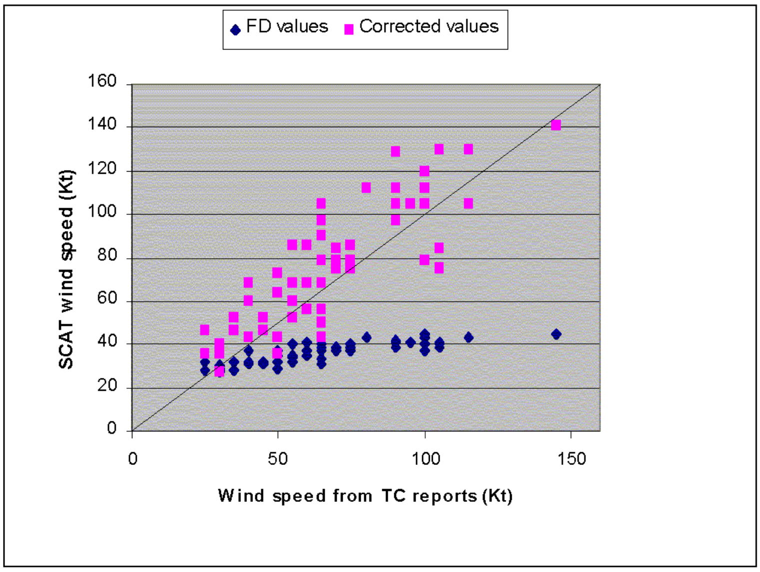

Figure 8: Comparison of TC warning report speeds with Scat wind speeds.

CONCLUSION

The Product Control Service (PCS) at ESRIN has developed a post-processing for the ERS Scat data acquired over a TC in order to improve the quality of both wind field and TC centre position. Moreover, the PCS gives to the scientific community a "near" real- time report for each TC event sensed by ERS Scat with the following contents:

- A backscattering image of the TC with the superposition of wind field. The backscattering image is obtained by the modulation of the three colour components (Red, Green and Blue) with the signals coming from the three scat antennae after a spatial re-sampling and normalisation with an empirical model of the sea backscattering to avoid the effect of the incidence angle.

- A table with the centre position and the maximum wind speed of the TC.

- A 2 dimensional plot with the structure of the TC (Figure 7, ROSITA structure).

- The FD data with the re-processed wind field.

- An ASCII file with the geolocated wind field data.

The whole processing is able to detect a TC in a 74% of the cases. On average, the number of alarms generated per day is two.

It is important to underline the unique source of information to generate this report. All the information given in the report is retrieved using only the Scat data within few hours from sensing. The full reports concerning the last TC events as well as the Scat data are available from the web site http:// pcswww.esrin.esa.it.

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