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ASCAT coastal AWDP prototype

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1 Introduction

Local wind fields, such as land-sea breezes and katabatic wind flows strongly affect the weather and microclimate in coastal regions. They determine to a large extent the advection and dispersion of pollutants in the atmosphere and coastal waters (by generation of local wind driven currents). Since most of the world's population lives in coastal areas, most activity at sea occurs in the coastal region (traffic, off-shore, tourism, wind parks), and most pollutants are released into the environment near coasts, the study of these local winds is also of great relevance for environmental purposes. As such, near-shore sea-surface wind field information can be important in a number of applications, such as in semi-enclosed seas, straits, along marginal ice zones and in coastal regions.

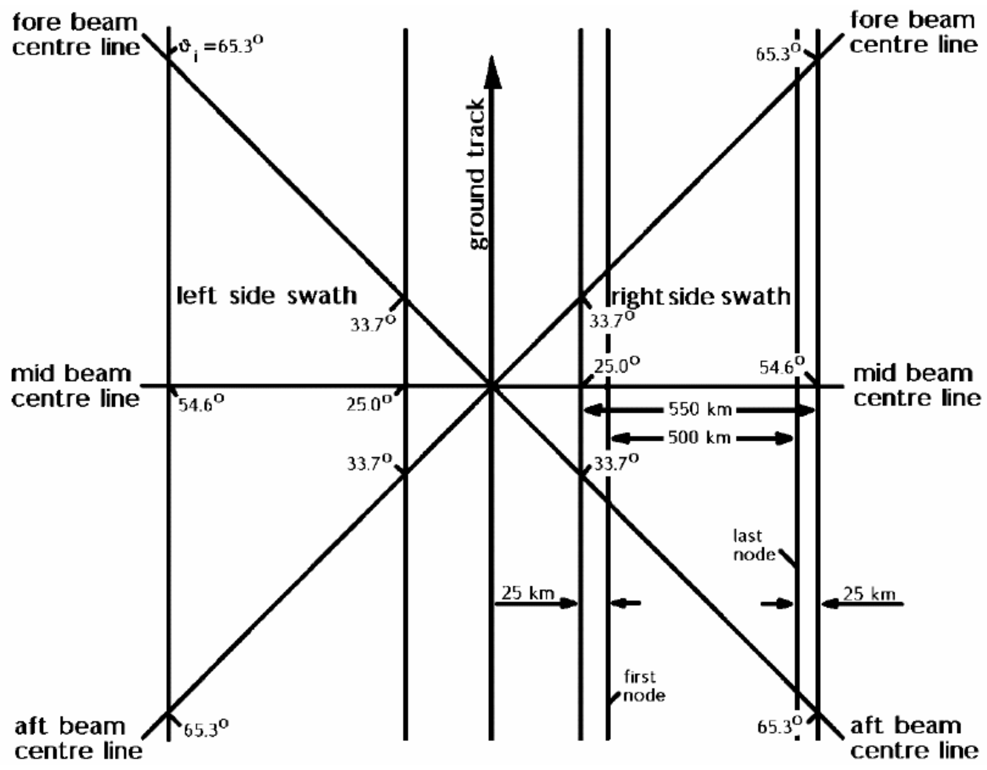

Figure 1. ASCAT swath geometry (Figure II.4 of *ESA-EUMETSAT, 2004*).

The Advanced Scatterometer (ASCAT) instrument is a real aperture vertically polarised C-band radar with high radiometric accuracy and stability. Its main aim is to provide high-resolution sea-surface wind vector observations at a global scale. It has two sets of three fixed fan beam antennas, each set pointing at either side of the sub-satellite track (see Figure 1).

The ASCAT scatterometer level 2 (L2) product includes direct estimates of the global sea surface wind vector field with a nominal spatial sampling of 25 km and an accuracy of 3 m/s (in wind vector). However, since backscatter measurements (σ^0) of up to 70 km away from each wind vector cell (WVC) center are used in the spatial averaging (see cosine weighting function in Figure 2), WVC's within the first 50-75 km off the coast will be flagged because of land/ice contamination. Therefore, it is worthwhile to investigate whether more advanced methods of near-coastal spatial averaging may result in more good-quality ASCAT winds near the coast.

In contrast with the ERS scatterometer processing, ASCAT includes a radar backscatter full resolution (FR) product, i.e., the level 1b (L1b) FR. The product contains the individual radar

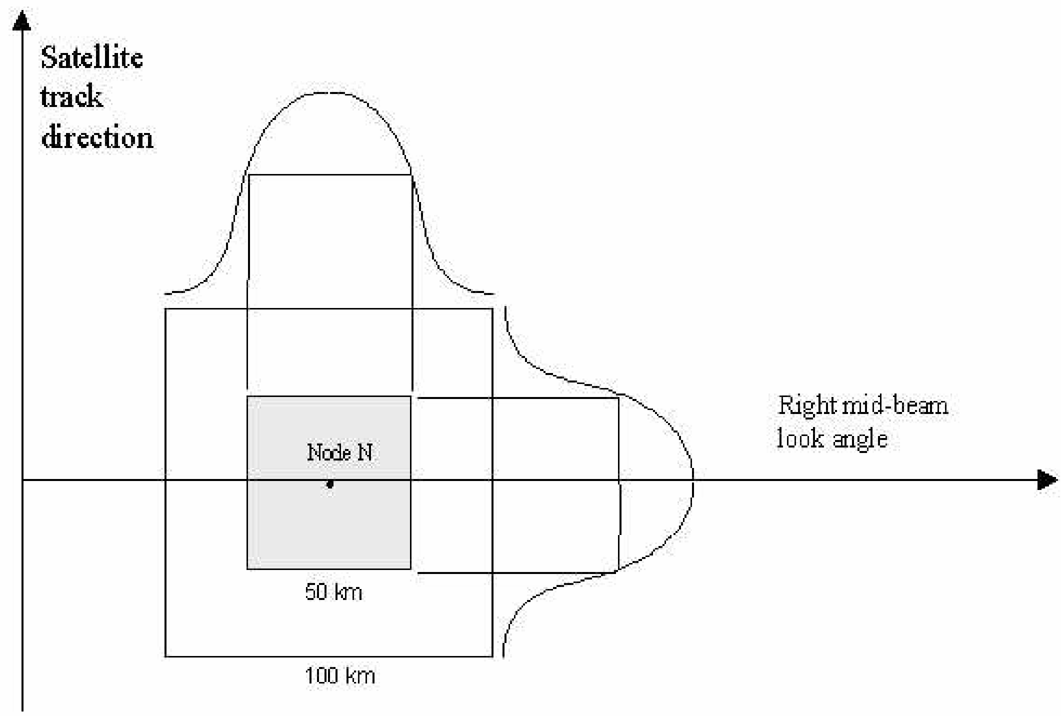

Figure 2. Ground geometry of the spatial smoothing for σ^0 values corresponding to the right mid beam for a given WVC (node) N, for the 50-km resolution product (Figure 4a of *EUMETSAT, 2004*).

backscatter values, 256 values along each antenna beam, localised on the surface of the Earth. In such product the data are organised per position along the antenna beam and not per WVC in the swath. The sampling of individual backscatter values along-beam is of approximately 2 km for mid beams and 3 km for side beams. The FR backscatter values along every antenna beam represent footprints of about 10 km x 20 km of various shapes and orientations (see *EUMETSAT, 2004*).

We propose to use L1b FR product and investigate replacing the Hamming filter (i.e., cosine weighting function in Figure 2) by an alternative averaging appropriate for the coastal area to produce 25-km winds, e.g., a simple 25 by 25-km box (i.e., constant weighting function) averaging like that used for SeaWinds. The objective is, in contrast to the 25-km level 2 product, to provide sea-surface wind information down to 17.5 km off the coastline.

The ASCAT level 2 product also includes a high-resolution 12.5-km sampled research wind product, which will flag wind data within the first 25-37.5 km off the coast. Within the NWP SAF Continuous Development and Operations Phase (CDOP) plans, a 12.5 km resolution scatterometer coastal product (up to 12.5 km off the coast) should be ready by 2011. The development of the 25-km coastal ASCAT Wind Data Processor (AWDP) prototype proposed here will be a good starting point for this future high resolution product. Moreover, the development may result in a much earlier implementation of coastal winds in the 25-km product.

2 Noise filter

As seen in Figure 2, the Hamming filter uses backscatter information from neighbouring WVCs in the averaging. This in turn will lead to some correlation between the retrieved winds from neighbouring cells. On the other hand, one can perform box averaging only with the backscatter information inside each WVC and therefore avoid wind correlation. The box averaging however produces noisier triplets than the Hamming filter (less backscatter measurements are used in the former averaging), and therefore potentially noisier retrieved winds. *Portabella and Stoffelen* (2004) show that there are effective ways to reduce the noise and maintain the geophysical information from relatively noisy backscatter measurements.

Due to the non-linear relationship between the backscatter measurements and the wind and to the measurement errors, scatterometer wind inversion does not lead to a unique solution but rather to a set of few ambiguous solutions at each WVC location (e.g., see *Stoffelen, 1998*, and *Portabella, 2002*). A spatial filter, which uses additional background information (generally NWP output) in combination with spatial filter functions, can be applied to remove the ambiguity such as the median filter (*Stiles et al., 2002*). The median filter forces spatial wind direction or wind vector continuity while near-surface wind fields are better described generally by divergent and rotational wind structures. Meteorologically consistent analyses are performed by variational analysis type of filter that use spatial filtering structures consistent with the general errors in the background information (see *Stoffelen et al., 2000*). In particular, a variational analysis ambiguity removal (AR) filter, such as 2D-Var (see *Vogelzang, 2007*, and *Verhoef et al., 2008*), is able to keep most of the meteorological information and, at the same time, remove most of the noise (see *Portabella and Stoffelen, 2004*). Figure 3 shows a meteorological case where the scatterometer retrieved wind field is produced with two different AR procedures: a median filter (Figure 3a) and 2D-Var (Figure 3b). The latter shows smoother (see bottom left part of the plot) and more meteorologically consistent (see cold front air flow in the middle left part of the plot realistically depicted by Figure 3b) winds than the former.

The ASCAT wind data processor (AWDP), which includes 2D-Var AR processing, is used here to build the ASCAT 25-km coastal wind processing prototype.

We anticipate that in order to get as close as possible to the coastline some (25 km x 25 km) WVCs may contain a small number of backscatter measurements. In order to reduce the signal-to-noise in the averaged backscatter (at least to 0.05), we may allow some backscatter measurements from neighbouring WVCs in the box averaging and therefore some correlation in the resulting wind field. In this work we do not seek for a non-correlated wind product but rather for a useful and extended coastal wind product.

a) b)

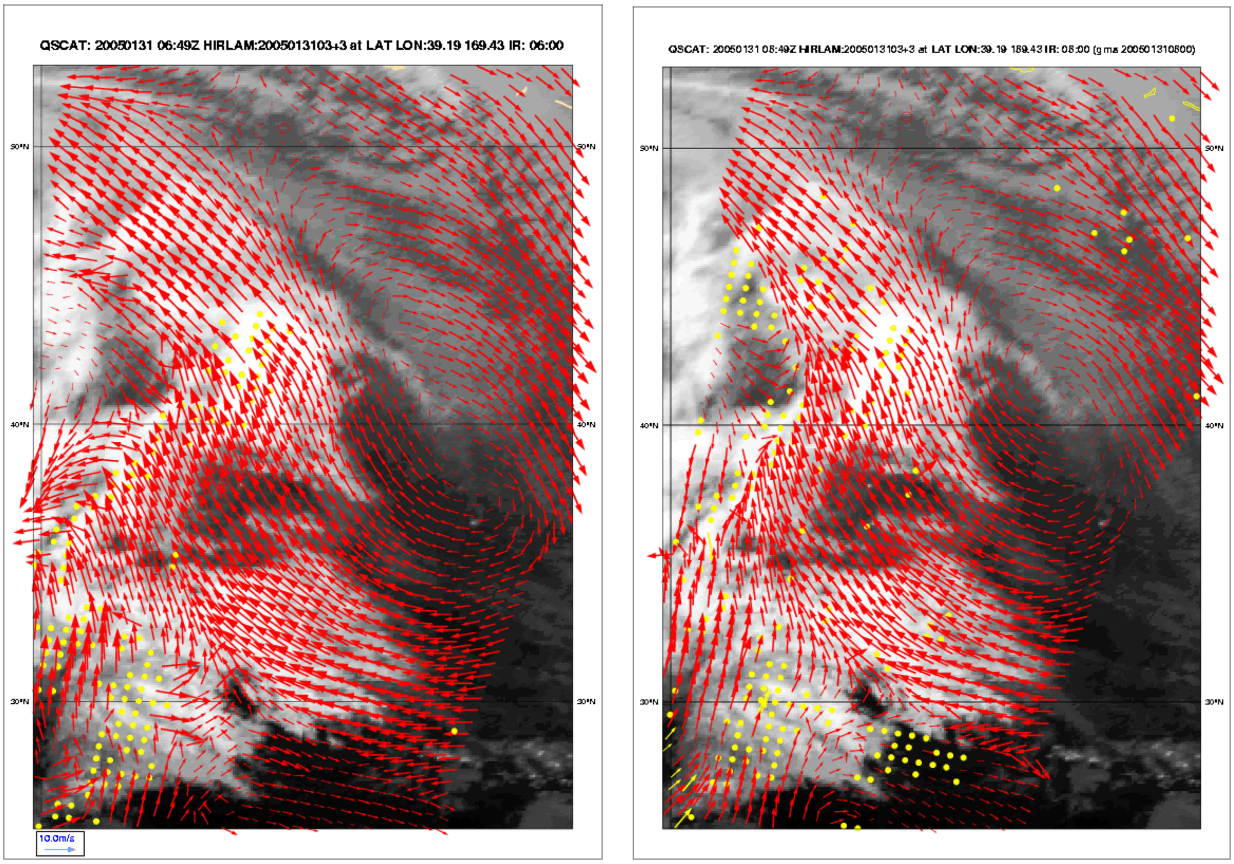

Figure 3. SeaWinds scatterometer retrieved wind field using (a) a median filter AR and (b) the 2D-Var AR as part of the NWP SAF SeaWinds Data Processor (SDP).

3 AWDP extension

The FR product does not contain WVCs and thus we need to define them. The simplest way to build and test the FR product is to synchronize it with the normal AWDP processing where the WVC definition is established and may be used as WVCs for the FR product.

In order to achieve this, AWDP reads in a 25-km ASCAT nominal product and the FR product of the corresponding orbit. For each WVC, the FR product is searched for backscatter data having a latitude/longitude location closer than 20 km to the latitude/longitude location of the nominal WVC. The nominal product data in the WVC for σ^0, incidence angle, azimuth angle (of fore, mid and aft beams), and latitude/longitude are replaced by the mean values as calculated from the FR measurements. Only those FR measurements that are not over land contribute to the average values, those which are considered to be land contaminated are rejected. This means that the latitude/longitude coordinates of WVCs close to the coast will be shifted in a direction away from the shore.

For the computation of the land contamination of a FR measurement, a land-sea mask from the ECMWF operational model containing 400 grid points between equator and pole is used, i.e., at about 25-km spacing. A measurement land fraction is calculated using all land-sea mask grid points closer than 20 km from the measurement location. Every grid point found yields a land fraction (between 0 and 1). The land fraction of the measurement is calculated as the average of the grid land fractions, where each grid land fraction has a weight of $1/r^2$, r being the distance between the FR measurement and the model grid point.

The noise values of fore, mid and aft beams in the nominal WVC is replaced by a value calculated as the square root of the variance in all contributing FR σ^0s divided by σ^0. This Kp value is divided by 5, see the next section for more details on the Kp computations.

Now that the backscatter and latitude/longitude data in the nominal 25-km WVC are replaced by averaged FR data, the rest of the wind processing is done in the same way as for the nominal pre-operational ASCAT 25-km wind product.

4 Noise estimation

An accurate estimation of the measurement noise is very important for the scatterometer wind retrieval process, notably for quality control (see *Portabella and Stoffelen, 2001*) and 2D-Var AR (see *Portabella and Stoffelen, 2004*). The AWDP, which has been adapted for processing L1b FR data, uses the instrument noise (Kp) values available from the averaged L1b products, i.e., the 12.5-km and the 25-km. The Kp of the averaged measurement is estimated as the standard noise within the averaging area defined by the Hamming window (*EUMETSAT, 2005*):

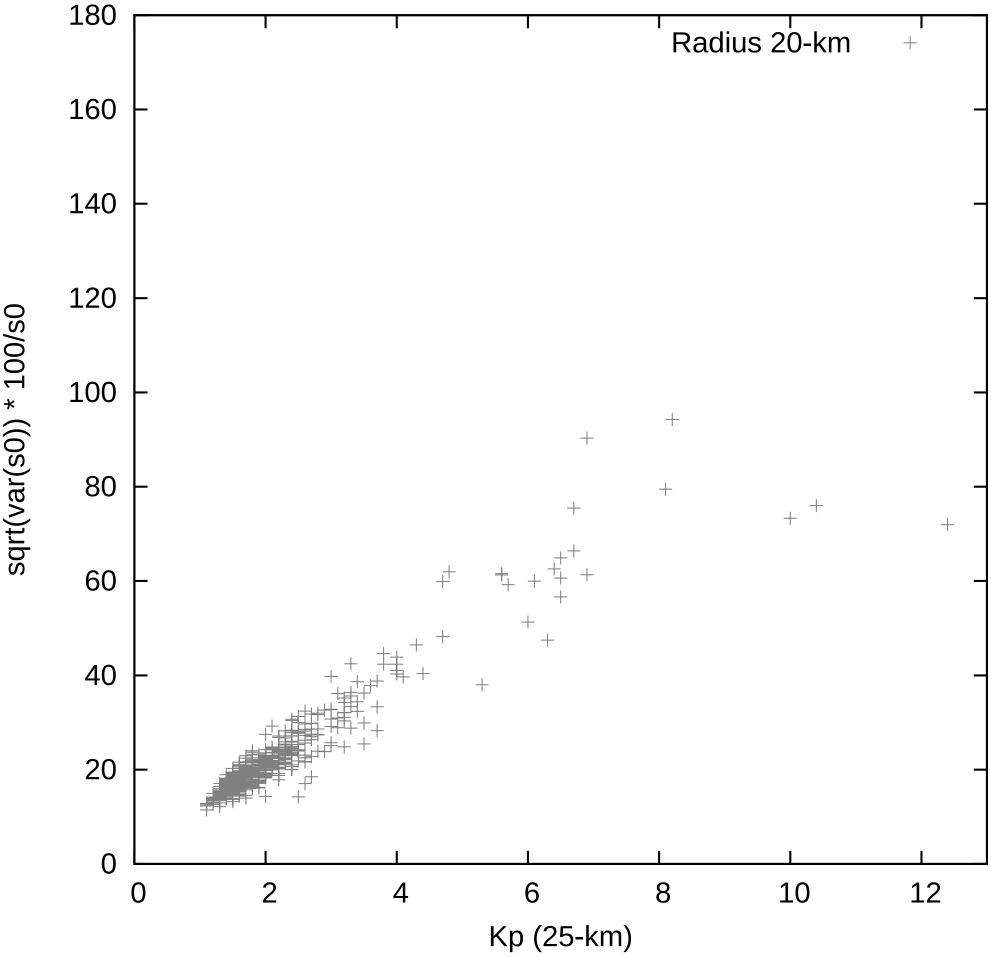

Figure 4. “Trial” Kp over a 20-km radius versus the L1b 25-km Kp

$$Kp = \frac{\sqrt{\mathrm{var}(\sigma^o_{WVC})}}{\sigma^o_{WVC}} \quad (1)$$

where σ^o_{WVC} corresponds to the spatially-weighted averaged (according to Hamming window) FR backscatter measurements and $\mathrm{var}(\sigma^o_{WVC})$ to its variance. In Equation 1, the measurement correlation due to the previous on-board along-track and across-track average is additionally taken into account (see more details in *EUMETSAT, 2005*). To estimate the coastal Kp, we therefore need to estimate the coastal σ^o_{WVC} and its variance within a pre-defined coastal WVC. The σ^o_{WVC} is derived with a simple box averaging (all FR measurements within the WVC have equal weight). However, to compute its variance according to EUMETSAT's algorithm, the information on the measurement noise correlation is required. Because of EUMETSAT's focus on the ASCAT 3-transponder calibration, we did not receive this information yet. In the meantime, we present a simple approach to roughly estimate the local coastal Kp values.

We define the coastal WVC as the area within a 20-km radius from the L1b 25-km WVC centre, and compute the "trial" Kp using all FR measurements within the coastal WVC and assuming no FR measurement noise correlation in Equation 1. The 20-km radius dish (spatial resolution of 28 km) is thus convolved with the radar footprints (resolution 25 km) inside it, which makes the expected spatial resolution of this product about 38 km. Therefore, more Kp noise is expected as compared to the regular 25-km product which is at 50-km resolution by a factor of 1.3.

Figure 4 shows the "trial" Kp versus the L1b 25-km Kp. It is clear that the "trial" Kp is highly correlated with the L1b 25-km Kp. However, they differ approximately by a factor of 10. The difference drops to a factor of 5 if the "trial" Kp is compared to the L1b 12.5-km Kp (not shown). Taking into account that an area of 20-km radius corresponds to a resolution of about 38 km, which is roughly 1.5 times the resolution of the 12.5-km product (see *EUMETSAT, 2004*), we would expect similarity between the EUMETSAT product Kps and Kp obtained with the simple approach (we expect small measurement noise correlation). However, to remain compatible with the EUMETSAT Kp estimates we compute the Kp as:

$$Kp_{coastal} = Kp_{trial} / 5 \quad (2)$$

to estimate the Kp for the averaged L1b backscatter values in AWDP.

5 Prototype validation

In order to test the validity of the simple approach to compute Kp (see Section 3) and the adaptations of AWDP for coastal processing, ASCAT orbit 3739 is processed with both the 25-km nominal and coastal AWDP data streams. Tables 1 and 2 show the wind speed bias and the root mean square (RMS) of the wind vector difference between ASCAT and the European Centre for Medium-Range Weather Forecasts (ECMWF) model output, for the 25-km nominal wind product and the coastal wind product, respectively. The scores correspond to the WVCs that passed quality control (QC), including the land flagged WVCs. Note that the land flag is set when the σ^{o}_{WVC} "footprint" contains any land fraction below 0.02. The "footprint" radius for land screening is taken as 80 km for the nominal wind product and as 20 km for the coastal wind product. In the coastal product, a land-sea mask from the ECMWF operational model containing 400 grid points between equator and pole is used, i.e., at about 25-km spacing. WVCs with a land fraction above 0.02 are quality controlled by AWDP and therefore not accounted for in the wind scores presented here (for more detailed information see *Verhoef and Stoffelen, 2007*).

As expected, the number of data N in Table 2 is larger than that of Table 1, indicating that more wind information, i.e, closer to the coast, is provided in the coastal product as compared to the nominal product, since a smaller averaging area is used to compute the land fraction. The overall statistics show marginal bias for both products and a slightly larger RMS value for the coastal product (see first column in Tables 1 and 2). Similar results are obtained when looking at the scores for no land flagged WVCs (see second column of Tables 1 and 2). As such, the slightly larger RMS value of the coastal product may be due to its larger wind variability as compared to

Table 1 Wind statistics for the ASCAT L2 nominal wind product against ECMWF winds.

	All processed WVCs	Not land flagged WVCs	Land flagged WVCs
N	44385	42897	1488
BIAS (m/s)	-0.05	-0.06	0.36
RMS (m/s)	2.20	2.19	2.53

Table 2 Wind statistics for the ASCAT Coastal wind product against ECMWF winds.

	All processed WVCs	Not land flagged WVCs	Land flagged WVCs
N	45994	43979	2015
BIAS (m/s)	-0.05	-0.07	0.51
RMS (m/s)	2.31	2.25	3.37

the nominal L2 product, i.e., the coastal product has a resolution of 29 km whereas that of the nominal L2 product is 50 km.

The larger wind score differences between the nominal and the coastal products correspond to the land flagged WVCs (see third column in Tables 1 and 2). The number of such WVCs is 35% larger for the coastal product than for the nominal product, which clearly indicates that the coastal product gets substantially closer to the coast as compared to the nominal product. Both the bias and the RMS values are substantially larger in the coastal product, indicating an increasing discrepancy between ASCAT and ECMWF winds for decreasing distances to the coast. This may be due to either a substantial land contamination of the σ^o_{WVC} footprint that leads to low quality ASCAT retrieved winds, or an increase in true wind variability at coastal areas which is not well resolved by the low resolution (100-200-km scales) ECMWF model winds, or a combination of both. To clarify this point, we look at the consistency of the retrieved wind fields.

a) b)

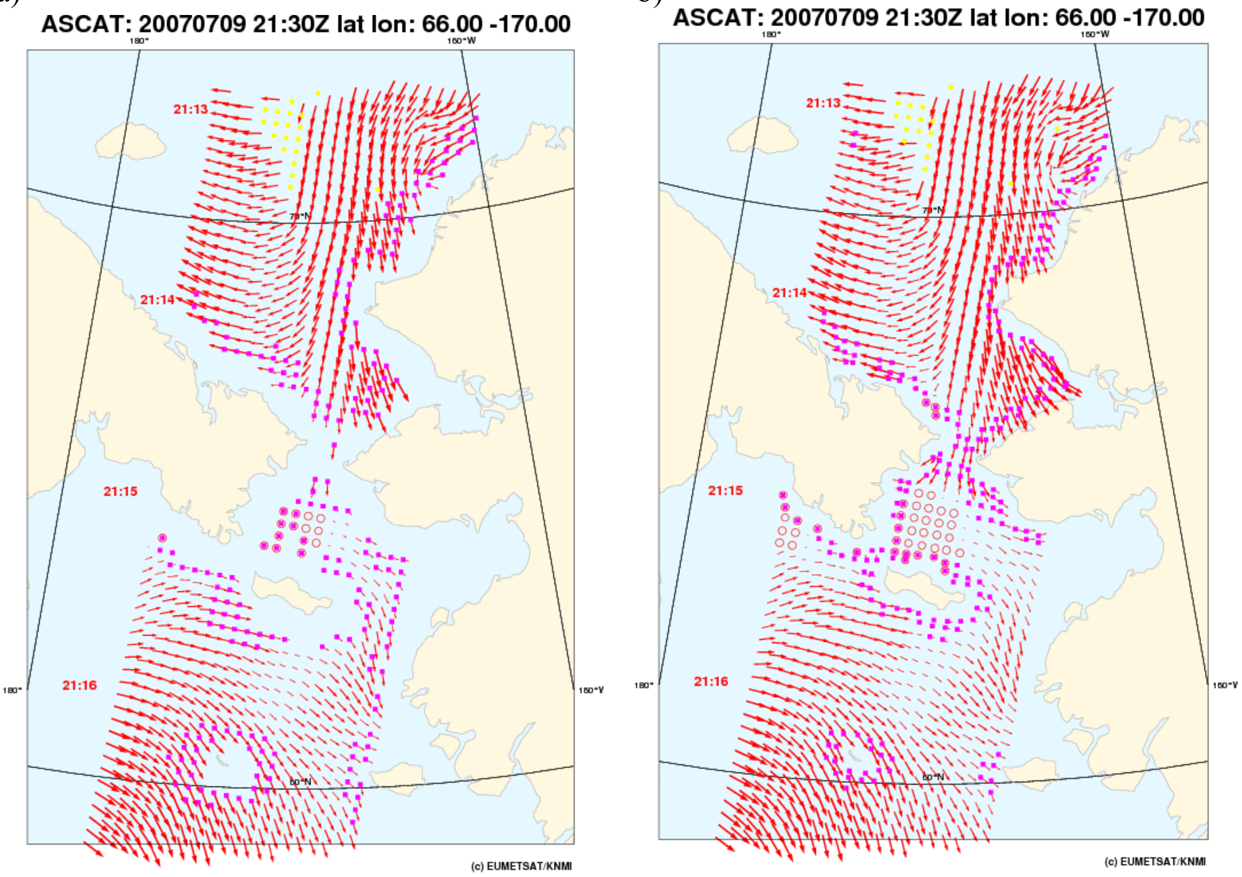

Figure 5. ASCAT L2 wind field (a) and ASCAT coastal wind field (b). The circles represent winds below 0.5 m/s. The purple squares correspond to WVCs where the land flag is set.

Figure 5 shows an ASCAT retrieved wind field over the Bering Strait on July 9, 2007 at 21:30 UTC (orbit 3739) using the nominal (a) and the coastal (b) processing streams. It is clear that the coastal product provides wind information at much shorter distances to the coast than the nominal product. Whereas in Figure 5a, wind information is not available within the first 50-75 km off the coast, in Figure 5b this distance is reduced to 20-25 km. Figure 5b also shows a spatially consistent coastal wind field and therefore no clear evidence of land contamination.

From these preliminary results it is therefore concluded that the simple box averaging approach implemented here leads to the production of higher-resolution spatially-consistent winds closer to the coast as compared to the nominal L2 product.

6 Summary and Recommendations

6.1 Summary

AWDP has been adapted to process L1b FR backscatter measurements and produce ASCAT winds closer to the coast as compared to the ASCAT L2 25-km operational wind product.

In this preliminary work, the 25-km grid from the ASCAT nominal product is used as reference and the coastal WVC is defined as a box average of all backscatter FR measurements located within a 20-km radius of a 25-km WVC grid point. A simple approach to estimate the (coastal) σ^o_{WVC} Kp, in which the FR measurements used in the averaging are assumed uncorrelated, is followed. The estimated coastal Kp is highly correlated to the L1b 12.5-km Kp, which accounts for measurement correlation and is of comparable resolution (25-35 km) to the coastal product. However, the local backscatter variance SD as computed by the simple method appears a factor 5 different from the EUMETSAT L1b Kp's. This would imply a rather large spatial noise correlation.

Preliminary results show that the coastal product is of comparable quality to that of the ASCAT L2 25-km product. Moreover, the former contains wind information much closer to the coast (20-25 km off the coast) as compared to the latter (50-75 km off the coast). Discrepancies between ASCAT and ECMWF winds increase as the distance to the coast decreases. Although land contamination may decrease the quality of the retrieved winds, these are found spatially consistent and therefore of acceptable quality.

6.2 Recommendations

The ASCAT L2 nominal wind product has been recently declared pre-operational. A new AWDP version will be soon released with improved QC, inversion, and 2D-Var AR. Moreover, an improved calibration of L1b data, based on the external 3-transponder calibration performed by EUMETSAT is now being tested at KNMI for ASCAT L2 production. Future coastal product development will include the mentioned improvements.

In the near future, EUMETSAT will provide KNMI with the measurement noise correlation information, which will lead to a more precise estimation of the coastal Kp. Moreover, this information will enable testing alternative WVC definitions which may be more suitable than the 20-km radius definition used here for coastal wind production.

An ECMWF high-resolution land-sea mask is used in AWDP. Alternative higher resolution land-sea masks will be tested in the future. Sea ice flagging is more complex and is currently taken up by the OSI SAF (*Verspeek, 2006*). Once the OSI SAF ice screening becomes operational, it will be assessed for wind production close to marginal ice zones.

Finally, high resolution wind data sources, which are able to resolve ASCAT wind variability, are certainly appropriate for validation purposes. As such, besides ECMWF winds, high-resolution model output, such as the one provided by the High Resolution Limited Area Model (HIRLAM), and moored buoy winds will be used to validate the ASCAT coastal wind product in the NWP SAF CDOP.

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