Advancements in Scatterometer Wind Processing

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ABSTRACT

The EUMETSAT Advanced Scatterometer ASCAT on MetOp-A was launched on 19 October 2006 as the third wind scatterometer currently in space joining up with the ESA ERS-2 and the NASA SeaWinds scatterometers. Scatterometers measure the radar backscatter from wind generated cm-size gravity-capillary waves and provide high-resolution wind vector fields over the sea. Wind speed and wind direction are provided with high quality and uniquely define the mesoscale wind vector field at the sea surface. The all-weather ERS scatterometer observations have proven important for the forecasting of dynamical and severe weather. Oceanographic applications have been initiated using winds from SeaWinds on QuikScat, since scatterometers provide unique forcing information on the ocean eddy scale. Together, ERS-2, ASCAT and SeaWinds provide good coverage over the oceans and are now used routinely in marine and weather forecasting. In this paper we show progress in high resolution processing and its verification, in providing gridded winds with mesoscale detail, and in processing closer to the coast with improved geophysical interpretation.

1. INTRODUCTION

The all-weather capability of a scatterometer provides unique wind field products of the most intense and often cloud-covered wind phenomena (for example, see figure 1). As such, it has been demonstrated that scatterometer winds are useful in the prediction of tropical cyclones, e.g., Isaksen and Stoffelen (2000), and extra-tropical cyclones (Stoffelen and Beukering, 1997). At the moment the EUMETSAT ASCAT, ESA ERS-2 and the NASA SeaWinds scatterometer on QuikScat provide a selection of regional real-time and global near-real time data streams. In addition, in 2008 ISRO will launch an Indian Ku-band. As such, continuity of both services is likely provided to the operational meteorological community for another period of 15 years.

In Europe, scatterometer product development is organised through the EUMETSAT Satellite Application Facilities, SAF, at KNMI. Available scatterometer data products and wind retrieval software are summarised at http://www.knmi.nl/scatterometer). The SAFs attempt to improve the spatial filtering properties of the wind retrieval by using prior information on the expected meteorological balance, e.g., favouring rotational structures in high-latitude regions. Moreover, we use solutions in all wind directions, but weighted by their inherent probability. The 2D-VAR method has the advanced filtering properties for maintaining small-scale meteorological information in SeaWinds, while reducing noise. This is tested by comparing the spatial covariance structures of the KNMI products, with those of the NOAA SeaWinds product, and, for reference, those of NWP models and buoys. The methodology leads towards a high-resolution scatterometer wind product. Based on these principles KNMI plans in the next phase of the SAFs to develop a 12.5-km ASCAT scatterometer wind product in the coastal zone.

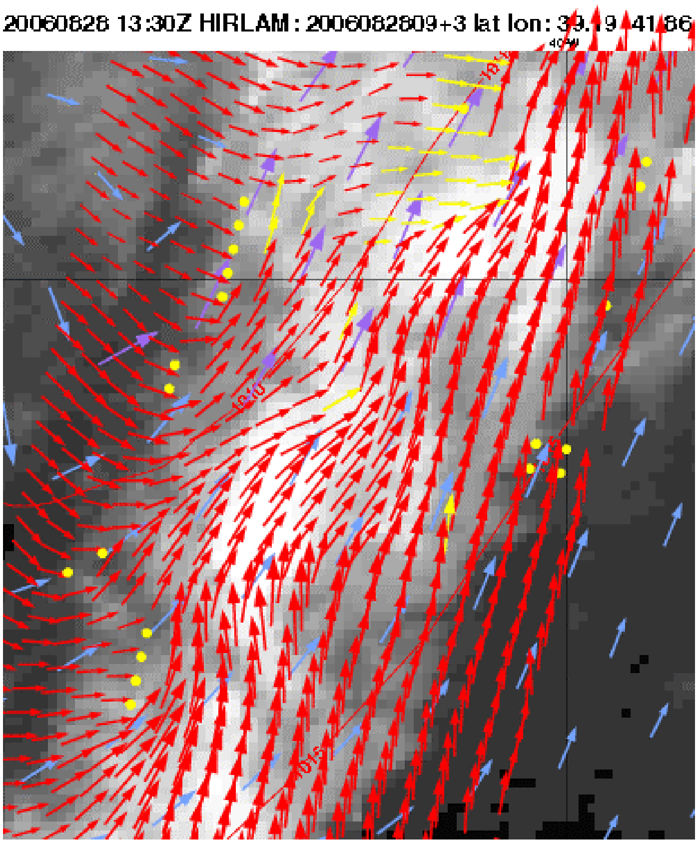

Figure 1. ERS-2 scatterometer winds (red) on 28 August 2006 13:00 Z showing a train of atmospheric waves in the North Atlantic at 25W and 40N. Yellow arrows and dots are quality-flagged ERS-2 scatterometer cells. The blue and purple arrows depict simultaneous background Numerical Weather Prediction, NWP, model winds (KNMI HiRLAM) that generally do not resolve such weather phenomena. The METEOSAT Infra-Red background image is consistent with the scatterometer surface winds. (from www.knmi.nl/scatterometer) © EUMETSAT. The missed Rossby train resulted in a bust NWP forecast the next day in the Netherlands and England.

In Figure 2 an overview of the scatterometer wind processing package is given. Scatterometer sea surface wind research and development lies at the basis of wind product innovation:

- Input product consistency checks, quality control, rain (for SeaWinds) and ice (for ERS) screening;
- Simultaneous processing of multiple ERS-2 ground station acquisitions in order to
    - provide unique processing at all wind vector cells (WVC), i.e., avoid duplicates;
    - complete backscatter triplets by combining acquisitions of all available ground stations at each WVC;
- Spatial averaging methodologies to reduce noise and enhance quality of SeaWinds products;Inversion: computation of optimal wind solutions and associated probabilities from measurement information;
- Determination of information content; definition of observation operator; ambiguity removal (spatial filter to determine a unique wind vector field);
- Processors for real-time and archive scatterometer wind and stress products;
- Active monitoring and quality assurance methodologies (of instrument and processing); and
- Web site (visualisation) and product distribution;

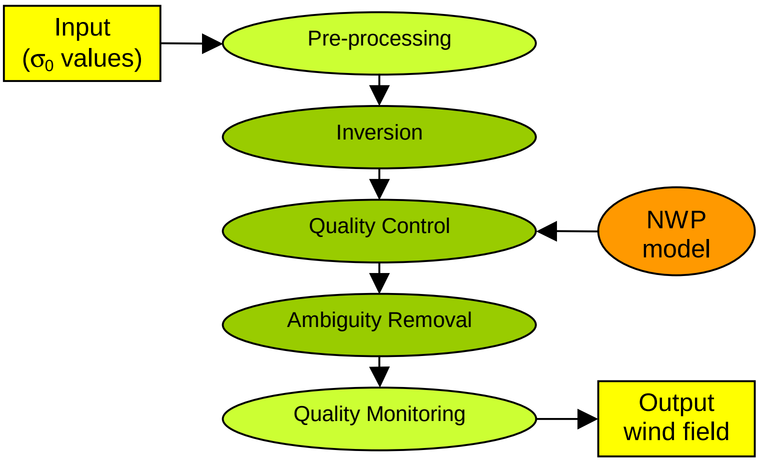

Figure 2. Overview of scatterometer wind processing from the basic backscatter.

Product enhancement and the preparation of wind production and user services for ASCAT on MetOp are the main goals of this R&D. KNMI currently processes global OSI SAF QuikScat 100-km and 25-km products, a global pre-operational ASCAT OSI SAF 25-km wind product, and a North Atlantic ERS-2 25-km product in quasi real-time through the EUMETSAT Advanced Retransmission Service (EARS). Moreover, at http://www.knmi.nl/scatterometer links to the visual presentation of these products are provided, both in vector and flag presentation. Global maps of wind speed are provided over the last 22 hours, segregated in ascending and descending orbit tracks. By mouse clicks on these maps more detailed regional plots become available (as in figure 1). The link also provides documentation, papers, and software products.

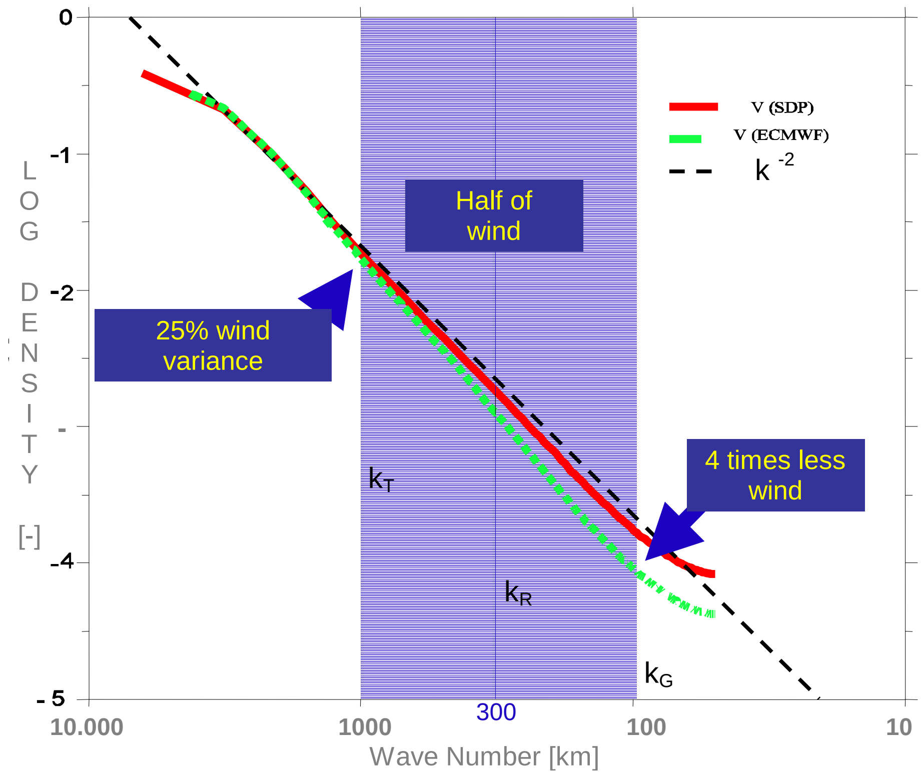

Figure 3. Comparison of the logarithmic along-track wind component variance spectrum versus wave number of the KNMI SeaWinds 25-km product, the ECMWF background winds and a climatological spectrum. The annotations refer to the ratio of ECMWF and SeaWinds variances, showing a spatial deficit in the ECMWF model.

2. PRODUCT VERIFICATION

At the 8th IWW KNMI provided evidence of the reduction of noise properties in the SeaWinds products as produced at KNMI. The standard Ocean and Sea Ice, OSI, SAF 100-km QuikScat product has been developed for NWP assimilation and it is verified to compare better with independent ECMWF NWP winds than the NOAA DIRTH product and the OSI SAF 25-km product and is thus indeed suitable for NWP assimilation (Portabella, 2002). From Figure 3 we estimate that the ECMWF winds miss 1,2 m/s variance w.r.t. the scatterometer product. At higher resolutions more random wind noise is expected from SeaWinds. Noise reduction is beneficial and further progress is being made by implementing the so-called Multiple Solution Scheme (MSS) as presented at the 7th IWW. The improvement is brought by using wind vector probability information in combination with the 2D-VAR background constraints on rotation and divergence (Portabella and Stoffelen, 2003). We further note that the improved verification of MSS is mainly due to the reduction of occasional erratic noise; coherent mesoscale structures remain present and become more visible due to the noise reduction.

Based on this experience a 25-km MSS SeaWinds product has been developed and is now operated operationally at KNMI (see www.knmi.nl/scatterometer). Figure 4 shows an example of the product in the tropical region. Scatterometer products thus provide wind variance on scales not well analysed by NWP models (see e.g. Figure 4). It of interest to verify the scatterometer provided wind variance with buoy data.

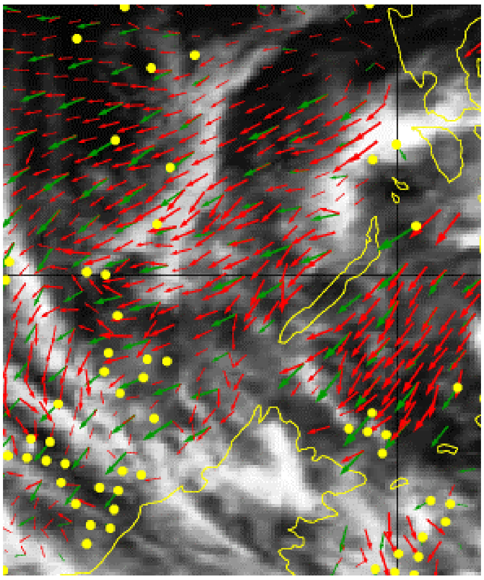

Figure 4. QuikScat 25-km (red) wind product generated at KNMI on top of the background ECMWF winds (green) used in 2D-VAR. GOES IR cloud imagery is provided underneath for reference.

Table 1. Buoy verification of the Ocean and Sea Ice SAF 25-km ASCAT, SeaWinds 25-km and SeaWinds 100-km product. Both tropical and extratropical moored buoys are used for one month of data.

ASCAT 25		SeaWinds 25		SeaWinds 100	
SD u [m/s]	SD v [m/s]	SD u [m/s]	SD v [m/s]	SD u [m/s]	SD v [m/s]
1.76	1.79	1.84	1.83	2.19	2.00

Buoy verification statistics of the Ocean and Sea Ice SAF 25-km ASCAT, SeaWinds 25-km and SeaWinds 100-km product are provided in Table 1. Both tropical and extratropical moored buoys are used for one month of data. It is interesting to note that the ASCAT 25-km product compares best to ECMWF as it compares best of all products to the buoys as well, providing evidence of the superior quality of the ASCAT scatterometer winds. The ASCAT 25-km winds are effectively at 50 km resolution and it is interesting to note that the SeaWinds 25 km product, while supposedly at higher resolution and containing more mesoscale wind detail, also must contain more wind error than ASCAT in order to provide worse buoy verification. Finally we note that the ECMWF model verification with the buoys is very similar to the SeaWinds 100-km product, as may be expected from the above-presented analysis (not shown here). Scatterometer data thus indeed capture mesoscale detail not resolved by NWP model analyses and forecast fields, but that verifies with buoy merasurements.

3. INCREASED SPATIAL RESOLUTION WIND FIELDS

In section two we noted that the spatial deficit of the ECMWF model in terms of RMS wind variance amounts to an estimated 1.2 m/s globally with respect to the scales resolved by scatterometers (Figure 3). Scatterometer winds are routinely provided to the ECMWF analyses, as are other resolving wind measurement systems over the ocean, such as drifting and moored buoy and ship data. Moreover, passive radiometers do resolve wind scales in the ECMWF model spatial deficit regime indicated by Figure 3. One may therefore expect that much of this resolved mesoscale variability will be added to the ECMWF analysis.

However, this is not the case as illustrated in Figure 5, which shows the mean RMS 10m wind analysis increment for an arbitrary day which appears modest with respect to the noted spatial deficit. In terms of wind variance, i.e., the squared RMS values, the analysis increments represent about 0.3 m^2/s^2 or less than 25% of the noted spatial deficit. Moreover, the changes do not only appear on the mesoscale, but also on much larger scales. The mesoscale scatterometer information thus remains largely unexploited, as does the mesoscale information provided by the other wind finding systems.

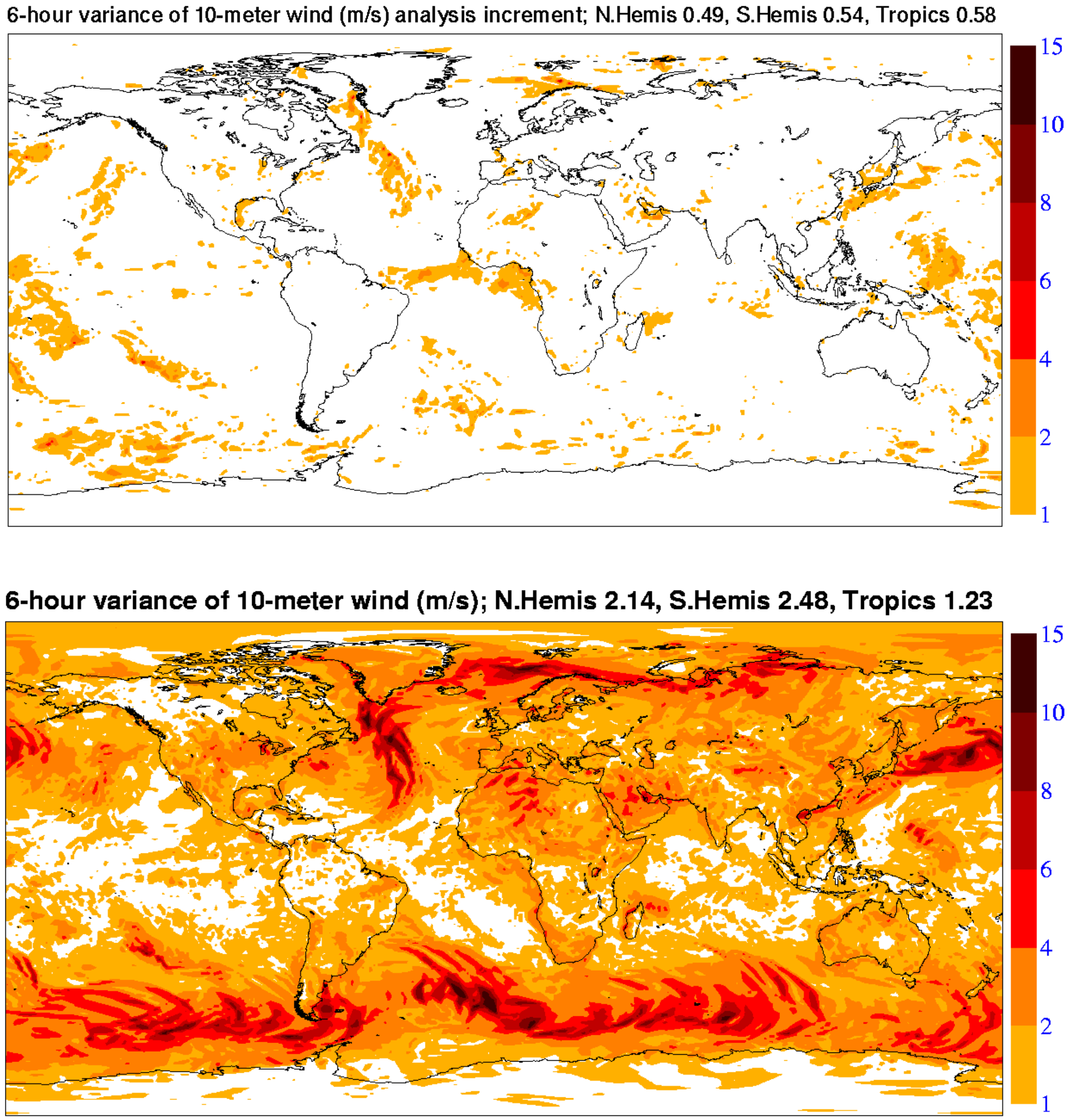

Figure 5. Mean RMS analysis increments of the ECMWF 4D-VAR analysis system (top), and the mean RMS 6-hourly change in the ECMWF model over the same day (bottom) for the 10-m wind vector.

We note that the objective of NWP data assimilation is NWP forecasting. Adding uncertain mesoscale information to the NWP analyses, only near the surface and not in the upper air, may be detrimental for NWP. NWP analyses thus extract mainly the larger scales (low pass filter). Other applications, such as ocean forcing, and wave or surge modeling may need inputs on scales not provided by NWP analyses.

In the context of the European Global Monitoring and Environmental Services, GMES, Marine Core Services, MCS, the MyOcean consortium proposed, among many other services, a mesoscale gridded wind product. A main question is how often such mesoscale gridded wind product should be provided. Currently, ocean models, and also many surge and wave models are forced by 6-hourly or 3-hourly fields. One may wonder how such temporal frequency match the spatial scales of interest. Figure 5 (bottom) shows the mean RMS temporal change over 6 hours in terms of the 10-m wind vector over the same day as shown in the top plot.

We note that in the storm track regions the temporal wind change over 6 hours in terms of vector variance is much larger than the noted spatial benefit, i.e., 3 to 4 times larger. So, if one would keep the wind field fixed over 6 hours, then one would make an average RMS error in the ocean wind forcing that is much larger than the error due to the lack of mesoscale detail. We suggest that forcing by the smooth ECMWF 10-m wind fields may be carried out reasonably well by using cubic time-interpolated 3-hourly fields. Clearly, using 6-hourly wind forcing without interpolation causes serious additional error on top of the errors caused by the spatial deficit.

It is clear that ocean forcing is dominated by transient or temporal effects. An important question thus emerges, whether eddy-scale ocean forcing can be provided at the hourly scale ? We show in section 2 that MSS and 2D-VAR provide scatterometer analyses on the mesoscale that well verify with buoy wind measurements. Another question is whether the 2DVAR increments may be advected in time? Evidence from mesoscale analyses and simple evolution models, e.g., shallow water models, show that mesoscale details may be beneficial for the verification scores up to several hours. Anyway, these questions will be addressed in more detail in MyOcean. For the MyOcean wind services, a product will be investigated providing hourly mesoscale winds.

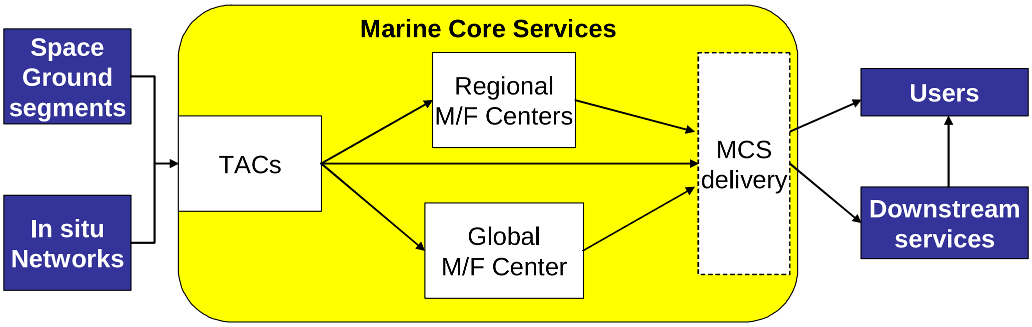

Figure 6. The mesoscale wind services will be part of the MyOcean Thematic Assembly Centres, TACs, as depicted here.

Figure 6 shows how the MyOcean wind services are embedded in the MCS. Besides wind, the Thematic Assembly Centres, TACs, will provide in situ, SST, Sea Ice, Oil Spill and Ocean Colour gridded products for the general user and the Marine Forecasting (M/F) centres.

4. COASTAL SCATTEROMETER PRODUCTS

Another new development for the ASCAT scatterometer will be in the development of a coastal product. Figure 7 depicts the spatial ASCAT processing. The projected scatterometer fan beams of approximate 20 km width are along the long axis cut into pieces of approximate 10 km length. The remaining footprints thus have typical dimensions of 10 by 20 km with a main orientation across the beam, as represented by the elliptical shapes in figure 7. Currently, these backscatter measurements are collected over a hamming window extending over 100 km (50 km spatial resolution). It may be clear that near the coast land contamination will be probable due to the extent of the hamming filter, since land or coastal returns are generally high relative to the ocean returns. In the context of the NWP SAF visiting scientist scheme, KNMI build a prototype ASCAT wind processor based on a box-average spatial averaging scheme. In a box average much closer distances to the coast may be achieved than with the Hamming window. The next step will be in the tuning and verification of the coastal processor with NWP and buoy data.

5. OUTLOOK

Scatterometers provide accurate and spatially consistent near-surface wind information (Stoffelen, 2008). Hardware permitting, there will be a continuous series of scatterometers with at times ideal coverage of the ocean surface wind for the first two decades of this century. EUMETSAT provides user services in collaboration with KNMI, where these are now being set up and freely available at http://www.knmi.nl/scatterometer for the ASCAT, QuikScat and ERS-2 scatterometers. Near-real time FTP products or software can be obtained after registration. Moreover, a visiting scientist scheme is funded in order to support the development programme and the use of the KNMI services. The authors will provide more information on request.

The OSI SAF ASCAT product proves to be of unprecedented quality as compared to other scatterometer products. ASCAT winds for the northern hemisphere ascending tracks are being made available within 30 minutes through the EARS programme. KNMI developed a spatial filtering method that fully exploits the information obtained by scatterometer wind retrieval, called MSS (Portabella and Stoffelen, 2003), and which is meteorologically balanced through the application of a 2D Variational Ambiguitity Removal, 2DVAR, scheme. Given the beneficial working of MSS, an increase in the resolution of the QuikScat wind products is verified against buoy observations.

Improvements in geophysical modeling are being persued and a change of the SAF product definition to 10-m equivalent neutral winds is being made (Portabella and Stoffelen, 2008). Moreover, KNMI participates in the NOAA hurricane hunter air campaign to provide ASCAT underflights with the IWRAP instrument. Prototypes on higher resolution ASCAT winds (12.5 km) and for winds nearer to the coast exist. Moreover, the SAFs provides a wind product independent of the SeaWinds input, such that user applications may be transparent to the forthcoming updated NOAA stream.

KNMI is involved in the GMES MCS MyOcean consortium with the ambition to provide, together with IFREMER, gridded mesoscale wind forcing with an hourly frequency. The ISRO SCAT at 12 LST nicely complements SeaWinds at 6 LST and ASCAT at 9:30 LST, and will be a very useful complement for providing temporally-resolved eddy-scale ocean winds. Global NRT backscatter (L2A) products would be greatly appreciated from ISRO to aid in a timely exploitation of the instrument and its data.

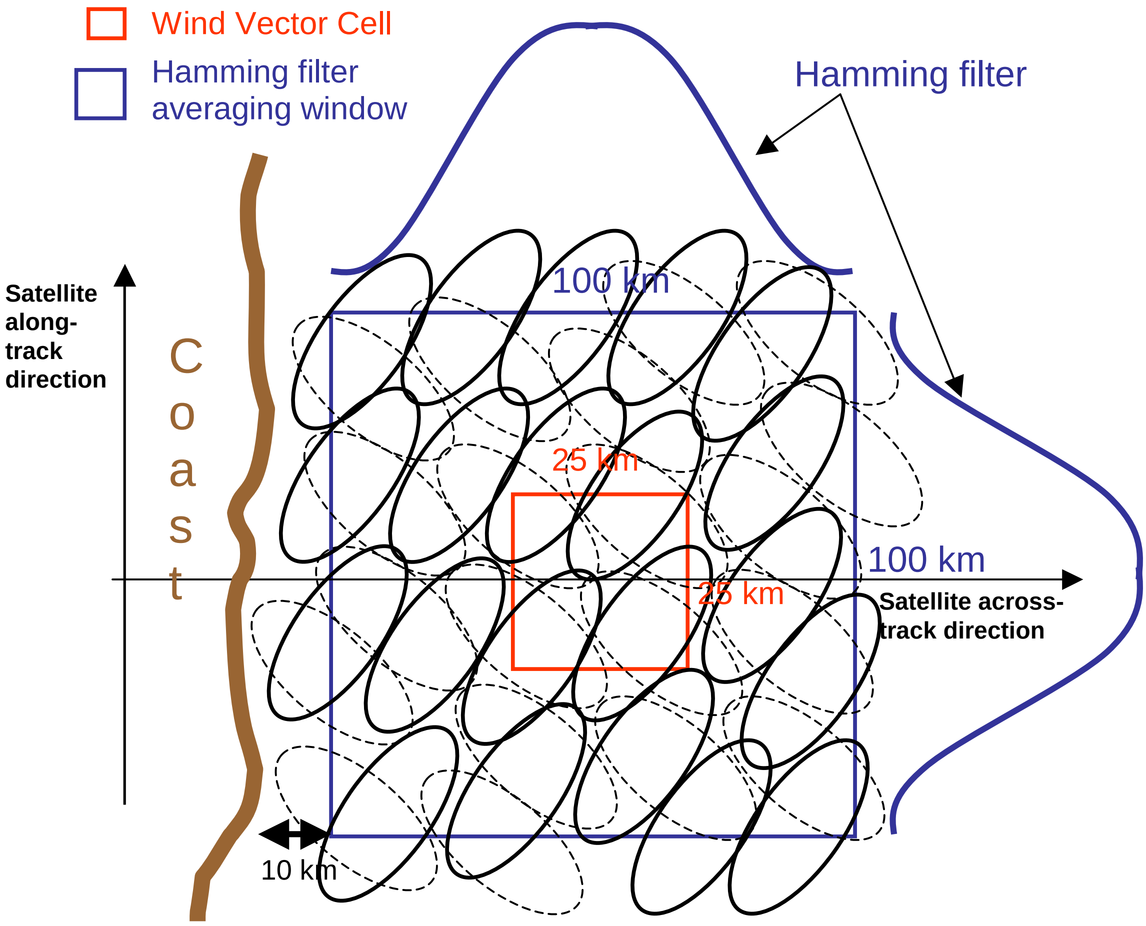

Figure 7. Depiction of the application of a Hamming filter in the ASCAT backscatter processing.

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