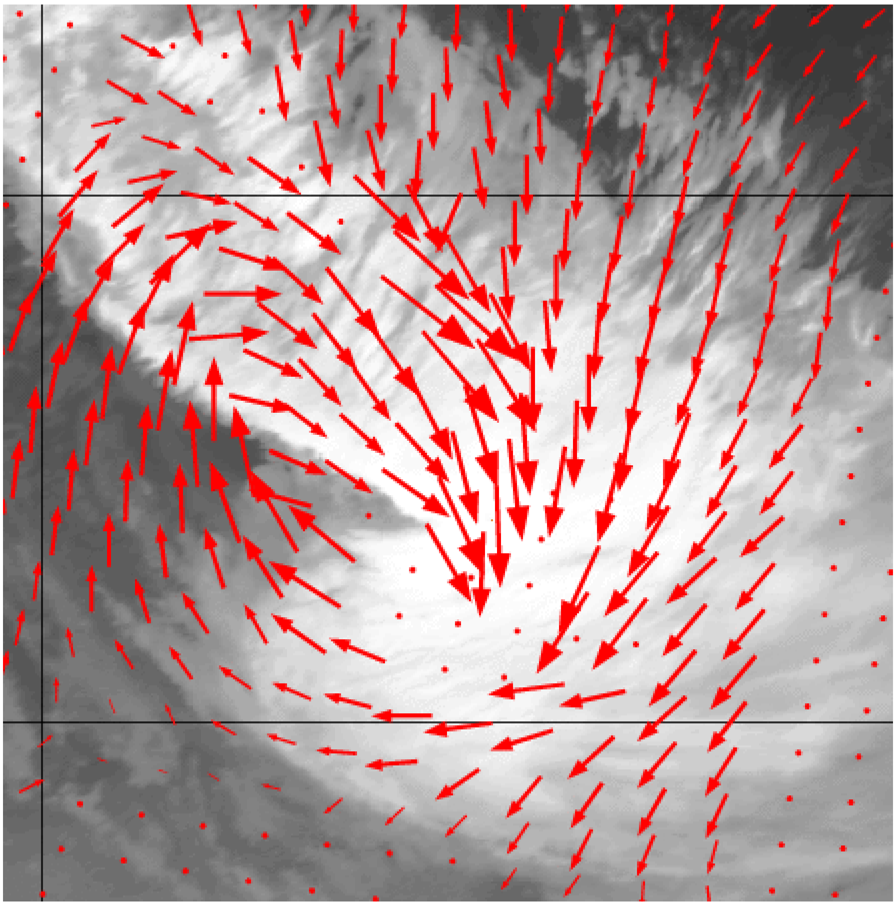
SeaWinds Product Manual



Ocean and Sea Ice SAF

Version 1.3

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DOCUMENT SIGNATURE TABLE

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Version 0.9	April 2003		Draft version.
Version 0.99	January 2004	Minor	QC flag correction, Chapter 3 from UM incorporated
Version 1.0	June 2004	Minor	Version taking in account ORR-1-B RID037: www.osi-saf.org mentioned in §1.1, overview.
Version 1.1	October 2005	Minor	Adaptation to SDP, included file name convention
Version 1.2	April 2006	Minor	Adapted web location of [Ref-6]
Version 1.3	September 2006	Minor	Use of ECMWF NWP data

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Reference: SAF/OSI/KNMI/TEC/MA/134

CONTENTS

1. Introduction

1.1. Overview

The Ocean and Sea Ice Satellite Application Facility (OSI SAF) is producing on a pre-operational basis a range of air-sea interface products, namely: wind, sea ice characteristics, Sea Surface Temperatures (SST) and radiative fluxes, Surface Solar Irradiance (SSI) and Downward Longwave Irradiance (DLI).

This document is the wind product manual dedicated to the OSI SAF wind product users. It describes the global SeaWinds products available at KNMI.

Note: useful information on this product and more generally on the whole OSI SAF project, is available on the OSI SAF web site at the following address: http://www.osi-saf.org/.

KNMI has a long experience in scatterometer processing and is developing generic software for this purpose. Processing systems for the ERS scatterometers were adopted for NSCAT, SeaWinds, and will be adopted for ASCAT on EPS. The OSI SAF purpose is to prepare the wind processing for the latter instrument.

The scatterometer is an instrument that provides information on the wind field near the ocean surface, and scatterometry is the knowledge of extracting this information from the instrument's output. Space-based scatterometry has become of great benefit to meteorology and climate in the past years (e.g., Isaksen and Stoffelen, 2000).

NASA and NOAA put available SeaWinds products; the former produces science products, whereas NOAA provides a near-real time wind product that is used as basis for further processing at KNMI. Our SeaWinds products are different from the NASA and NOAA products, since special emphasis is put on

- increasing the **reliability** of the wind vectors by Quality Control and rejection of rain-contaminated Wind Vector Cells (WVC);
- improving **accuracy** by noise reduction through spatial averaging and meteorological filtering;
- Guaranteeing **correctness** by monitoring of the operational SeaWinds data and KNMI processing; and
- **Reduce** wind direction selection **errors** by meteorologically-balanced wind direction Ambiguity Removal (AR).

These wind quality issues are further elaborated in this manual and discussed in section 6.

Over the whole globe 80% of SeaWinds products are available within 3 hours after the last satellite data acquisition. Availability includes the processing time at KNMI which is less than 10 minutes and a not very substantial part of the total delay.

The KNMI products are delivered on request through the FTP server to all users and through EUMETCast. See also http://www.knmi.nl/scatterometer/ for real-time graphical examples of the products and up-to-date information and documentation.

The easiest access to the SeaWinds products is through the OSI SAF as described in this report. Alternatively, in the context of the Numerical Weather Prediction SAF (see http://www.metoffice.gov.uk/research/interproj/nwpsaf/index.html) software is developed and maintained to produce scatterometer winds from raw backscatter data which may be implemented at the user site if special processing features are desired. The NWP SAF software is used by the OSI SAF production system. In the context of the climate (CM) SAF KNMI is developing the Scatterometer Ocean Stress (SOS) product from the OSI SAF wind product.

This user manual outlines user information for the KNMI products based on the SeaWinds scatterometers [Ref-2] [Ref-4]. Section 2 presents a brief description of the SeaWinds instruments, section 3 the processing algorithms, and section 4 gives an overview of the data processing configuration. Section 5 provides detailed information on the file content and format, while in section 6 product quality is elaborated.

1.2. References

[Ref-1] KNMI scatterometer web site: http://www.knmi.nl/scatterometer/

[Ref-2] O&SI SAF wind product documentation on http://www.osi-saf.org/:

1. Scientific documents:

   - 2D Variational Ambiguity Removal

2. Technical documents

   - Science Plan
   - OSI SAF User Requirements Document
   - OSI SAF Project Plan
   - O&SI SAF Report on Algorithm Development and Prototyping Activities
   - OSI SAF top-level Configuration Management Plan
   - OSI SAF Output Products Format Document
   - OSI SAF Software Requirements Document
   - ICD for the wind production of the OSI SAF
   - SVVP for the wind production of the OSI SAF

[Ref-3] NWP SAF website: http://www.metoffice.gov.uk/research/interproj/nwpsaf/index.html

[Ref-4] NASA SeaWinds Documentation: http://podaac.jpl.nasa.gov/quikscat/qscat_doc.html

[Ref-5] Thesis “Wind Field Retrieval from Satellite radar systems” by Marcos Portabella, available on http://www.knmi.nl/scatterometer/publications/pdf/PhD_thesis.pdf

[Ref-6] Thesis “Scatterometry” by Ad Stoffelen, available on http://igitur-archive.library.uu.nl/dissertations/01840669/inhoud.htm

[Ref-7] Leidner, M., Hoffman, R., and Augenbaum, J., “SeaWinds scatterometer real-time BUFR geophysical data product”, version 2.3.0, *NOAA/NESDIS*, June 2000, available on ftp://metroweb.nesdis.noaa.gov/pub/seawinds/bufr_v2.3.0.ps.gz.

[Ref-8] Verhoef, A. and Stoffelen, A., “Ambiguity Removal using different background wind fields”, OSI SAF Technical Report, August 2006.

2. SeaWinds Instruments

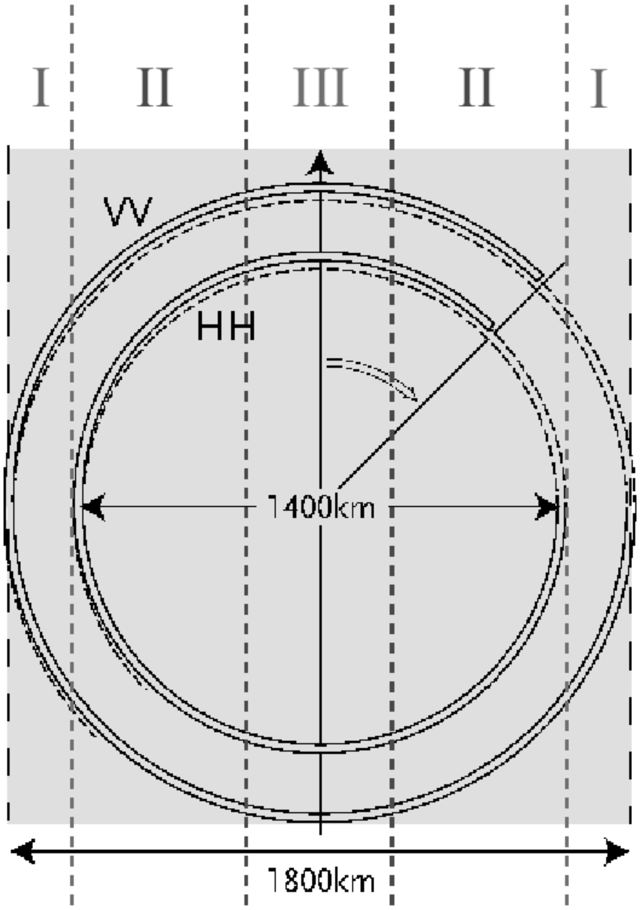

Figure 1: *Earth surface coverage of the scans of the horizontal (HH) and vertical polarisation (VV) pencil-beams of SeaWinds. As the satellite propagates towards the top of the page the swath (in grey) is illuminated, and three areas are discriminated:*

I: Outer swath: only viewed once by the VV beam in the forward direction, and once in the aft direction (2 views);

II: Sweet (inner)swath: Viewed both by the VV and HH beam, both in fore and aft direction (4 views);

III: Nadir (inner) swath: As II, but the azimuth view direction is close to the satellite propagation direction, or just opposite to it.

Scatterometers fly on polar-orbiting satellites, for SeaWinds these are the NASA/NOAA QuikScat or Japanese ADEOS-II platforms. The OSI SAF now produces pre-operationally SeaWinds scatterometer wind data. Data are read out once per orbit usually, which lasts about 100 minutes. This means that a delay of up to 100 minutes is already present at read-out. Dedicated transmission lines and fast processing are needed to limit further delays.

2.1. SeaWinds-I and SeaWinds-II

Two SeaWinds scatterometers are developed and flown. The SeaWinds on QuikSCAT mission (from NASA/NOAA) is a “quick recovery” mission to fill the gap created by the loss of data from NSCAT, when the ADEOS-1 satellite lost power in June 1997. It was launched in June 1999 and is still operational. A similar version of the instrument (SeaWinds-2) flew on the Japanese ADEOS-2 satellite, launched in December 2002, which was regrettably lost in October 2003. For detailed information on the QuikSCAT instrument and data we refer to Spencer et al. (1997), JPL (1997, 2001), and [Ref.7]. A brief description is given below.

The Seawinds instrument is a conically scanning pencil-beam scatterometer, as depicted in figure 1. It uses a rotating 1-meter dish antenna with two “spot” beams of about 25-km size on ground, a horizontal polarisation beam (HH) and a vertical polarisation beam (VV) at incidence angles of 46° and 54° respectively, that sweep the surface in a circular pattern. Due to the conical scanning, a WVC is generally viewed when looking forward (fore) and a second time when looking aft. As such, up to four measurement classes (called “beam” here) emerge: HH fore, HH aft, VV fore, and VV aft, in each wind vector cell (WVC). The 1800-km-wide swath covers 90% of the ocean surface in 24 hours and represents a substantial improvement compared to the side-looking scatterometers, where the largest coverage, given by NSCAT, is only half of SeaWinds coverage, i.e. 90% of the ocean surface within 48 hours.

On the other hand, the wind retrieval from SeaWinds data is not trivial. In contrast with the side-looking scatterometers, the number of measurements and the beam azimuth angles vary with the sub-satellite cross-track location (see figure 1). A detailed discussion is provided in [Ref-5; pages 22-23]. The wind retrieval skill will therefore depend on the position in the swath as illustrated in figure 2.

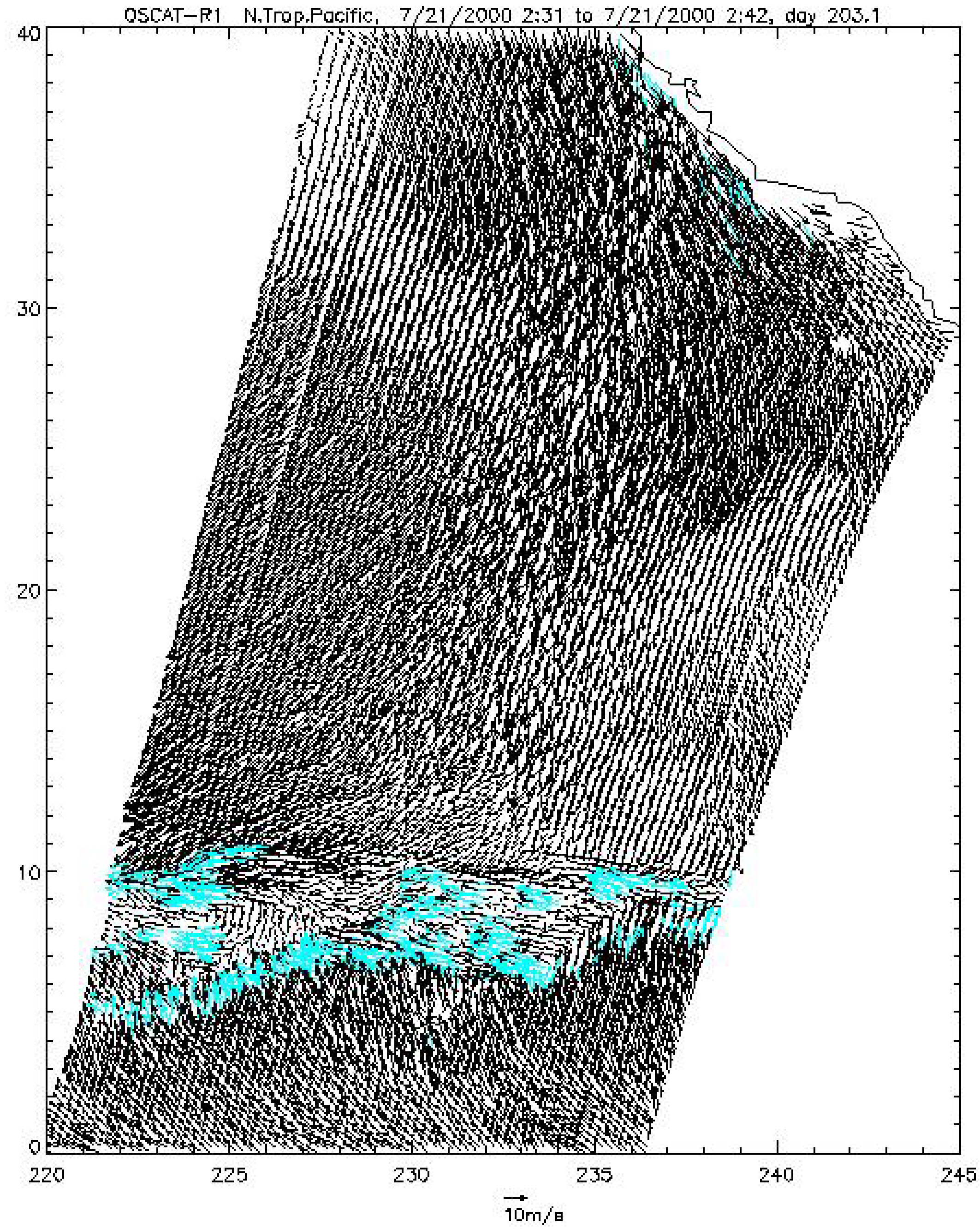

Figure 2: *SeaWinds product processed on a 25-km grid. The wind retrieval on the grid results in four solutions of which one is selected by the ambiguity removal procedure. Note the varying noise properties in the parts of the swath indicated in Figure 1. The blue patches are flagged as rain contaminated.*

In the outer swath (region I in figure 1) the two looks result in an ambiguous set of generally four wind solutions with an equal probability of about 25%. Measurement noise here results in systematic wind direction errors, which is why the outer swath is often well visible is figure 2. In the nadir swath (region III in figure 1) insufficient azimuth views are available for wind retrieval and the measurement noise causes a rather noisy wind field. As we enter the sweet swath, this noise becomes smaller, but does generally not disappear altogether. At KNMI a spatially averaged product was developed at 100 km, which strongly reduces the measurement noise, as shown in section 6. Rather uniform and high quality winds are then obtained in regions II and III. Due to a more difficult QC in region I, this region is not processed at KNMI at the time of writing this manual.

2.2. Rain problem

The NASA scatterometers work at a Ku-band radar wavelength. The atmosphere is not transparent at these wavelengths and in particular rain is detrimental for wind computation. In fact, moderate and heavy rain cause bogus wind retrievals of 15-20 m/s wind speed which need to be eliminated by a quality control step. Wind-rain discrimination is easiest to manage in the sweet swath, performs acceptable in nadir, but is problematic in the outer swath.

2.3. Sea ice detection

Due to the availability of VV and HH polarisation measurements, discrimination of water and ice surfaces is generally well possible and performed by NOAA [Ref-7].

3. Algorithms

Scatterometry was developed heuristically. It was found experimentally that the sensitivity to wind speed and direction describe well the changes in backscatter over the ocean at moderate incidence angles due to changes in surface roughness, as depicted in figure 3 (Valenzuela, 1978). In return, backscatter measurements can be used to determine the wind speed and wind direction in a WVC.

In the NWP SAF development phase the ERS scatterometer (SCAT) processing has been successfully extended to SeaWinds. A schematic illustration of the processing is given in figure 4. After defining the wind output and motivating the Geophysical Model Function that is used, the algorithms developed at KNMI are described.

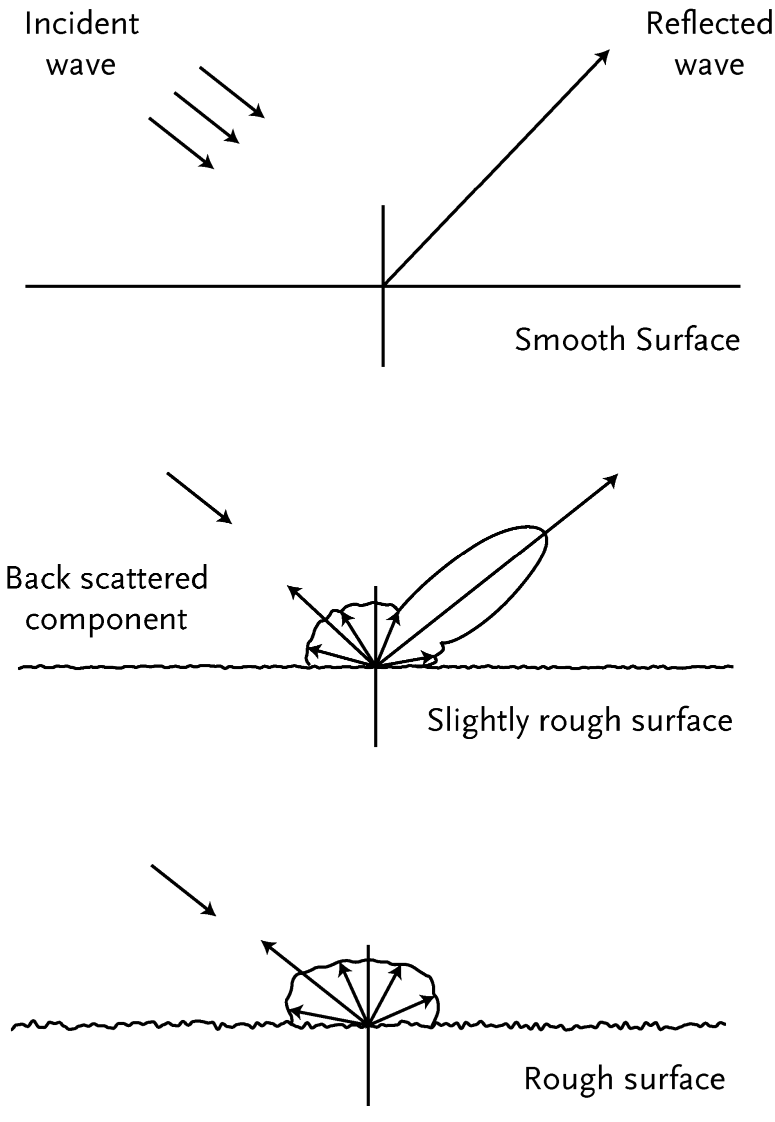

Figure 3: *Schematic representation of microwave scattering and reflection at a smooth (a), rough (b) and very rough (c) ocean surface. As the roughness increases more microwave power is returned towards the direction of the microwave source.*

3.1. Wind definition

A scatterometer measurement relates to the ocean surface roughness (see figure 3), while the scatterometer product is represented by the wind at 10m height over a wind vector cell (WVC). It is important to realize that in the approach followed here the radar backscatter measurement σ^0 is related to the wind at 10 meter height above the ocean surface, simply because such measurements are widely available for validation. This means that any effect that relates to the mean wind vector at 10 meter height is incorporated in the backscatter-to-wind relationship. As such, air stability, the appearance of surface slicks, and the amplitude of gravity or longer ocean waves, depend to some degree on the strength of the wind and may, to the same degree, be fitted by a geophysical model function, GMF ([Ref-6]; Chapter I). Stoffelen ([Ref-6]; Chapter IV) discusses a unique method to determine the accuracy of scatterometer, buoy, and NWP model winds.

3.1.1. Geophysical Model Function

For the KNMI SeaWinds product the NSCAT-2 geophysical model function (GMF) is used (Wentz and Smith, 1999). Portabella ([Ref.5]; page 153) compares the QSCAT-1 (Freilich et al, 2002) and NSCAT-2 Ku-band GMFs and found that the latter is of better quality, since the former leads to more wind solutions during wind retrieval, i.e., is more ambiguous.

At low wind speeds the wind direction and speed may vary considerably within the WVC. Locally, below a speed of roughly 2 m s^{-1} calm areas are present where little or no backscatter occurs, perhaps further extended in the presence of natural slicks that increase the water surface tension (Donelan and Pierson, 1987). However, given the variability of the wind within a footprint area of 25 or 50 km it is, even in the case of zero mean vector wind, very unlikely that there are no patches with roughness in the footprint. As the mean vector wind increases, the probability of a calm patch will quickly decrease, and the mean microwave backscatter will increase. Also, natural slicks quickly disappear as the wind speed increases, and as such the occurrence of these is correlated to the amplitude of the mean vector wind over the footprint, as modelled by the GMF. Low scatterometer wind speeds are thus providing useful information.

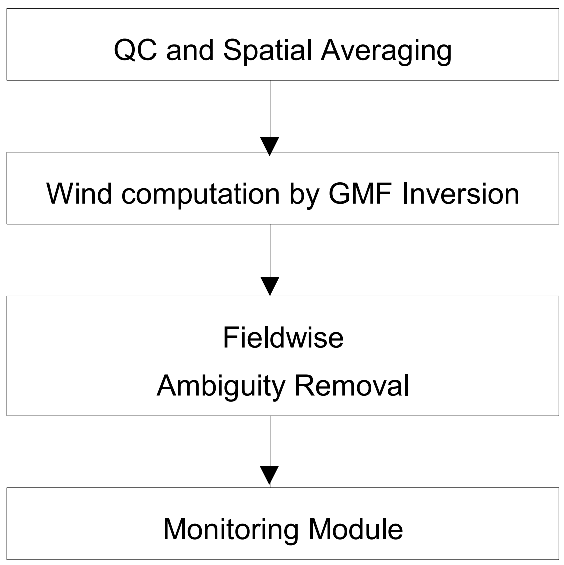

Figure 4: *Overview of SeaWinds algorithms*

At high wind speeds wave breaking will further intensify, causing air bubbles, foam and spray at the ocean surface, and a more and more complicated ocean topography. Although theoretically not obvious, it is empirically found that σ^0 keeps increasing for increasing wind speed up to 25 m/s and even higher, and that a useful wind direction dependency remains (Donelly et al, 1999).

3.2. Wind Retrieval

The GMF has two unknowns, namely wind speed and wind direction, so, if more than two backscatter measurements are available then these two unknowns may be estimated using a maximum-likelihood estimator (MLE) as the objective function for determining wind vector solutions (Pierson, 1989; 1990). The MLE is defined by

$$J = -\sum_{i=1}^{N} \frac{(\sigma_{oi} - \sigma_m(u,\chi_i))^2}{Var(\sigma_m)_i}$$

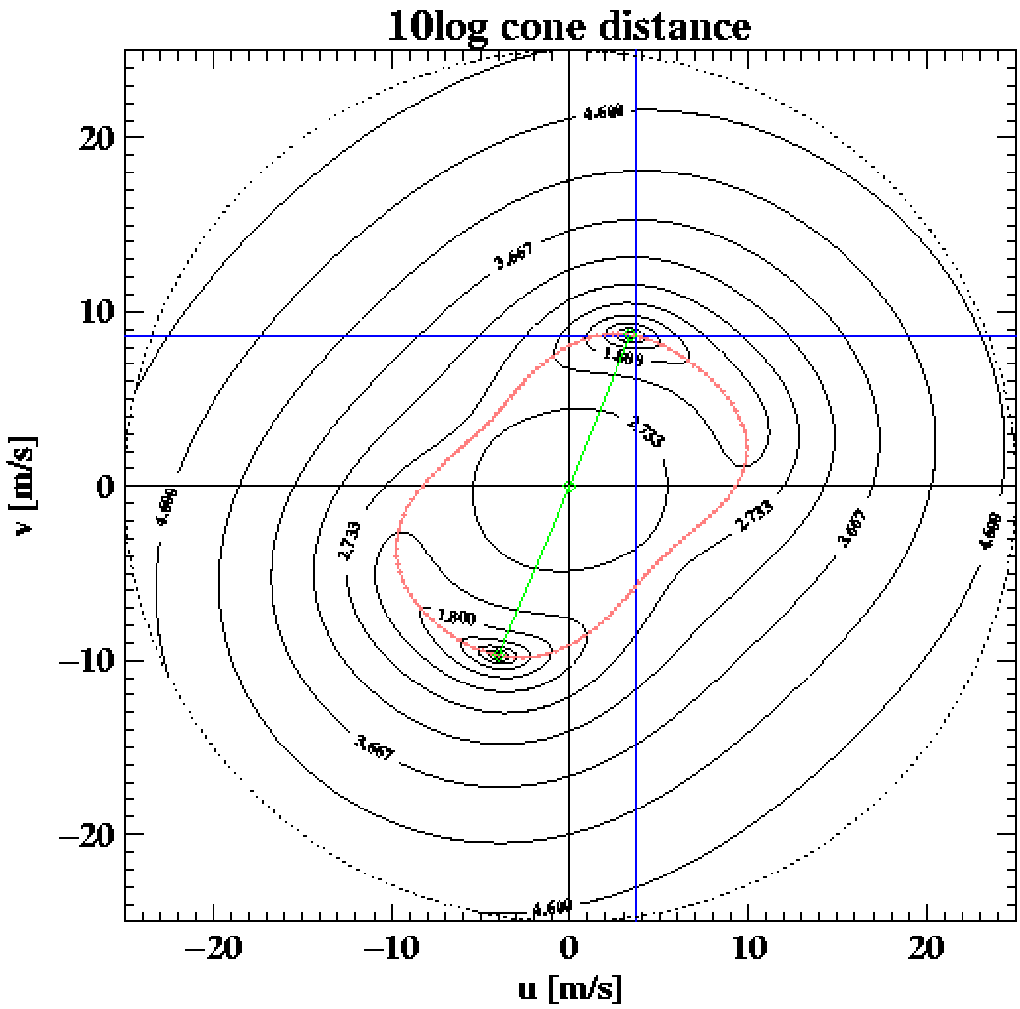

Figure 5: *The wind retrieval objective function J as a function of wind vector components u and v for four collocated fore and aft beam measurement of radar backscatter. The cross indicates the position of the most likely ambiguous solution. The other solution is opposite.*

where σ_{oi} are the backscatter measurements, $\sigma_m(u,\chi_i)$ are the model backscatter values corresponding to the measurements, and $Var(\sigma_m)_i = (K_{pi}^2 \sigma_{oi}^2)$ are the measurement variances. Note that in the NOAA product $Var(\sigma_m)_i = (K_{pi}^2 \sigma_{mi}^2)$ is used, i.e., the noise variance estimated by the modeled rather than the observed backscatter. We [Ref-5] found the latter to perform better. The local minima of J correspond to wind vector solutions. The three or more independent measurements should well sample the azimuth variation of the GMF in order to resolve the wind direction, albeit ambiguously.

The problem of ambiguity illustrated in figure 5 does generally not disappear if more measurements become available. However, multiple azimuth views and polarisation measurements do increase the probability that one of the ambiguous solutions becomes more likely than the other ones. Stoffelen et al (2000) describe that SeaWinds retrievals at 100 km resolution are much less ambiguous than retrievals at 25 km due to this (see also section 6).

3.2.1. Ambiguity Removal

SeaWinds scatterometer winds have a multiple ambiguity and there are up to four wind solutions in each wind vector cell (WVC) on the earth's surface. These ambiguities are removed by applying constraints on the spatial characteristics of the output wind field, such as on rotation and divergence. Several ambiguity removal (AR) schemes were evaluated for ERS data (Stoffelen et al., 2002). In the OSI SAF Development Phase some schemes that were developed for the SCAT were compared. In addition to the subjective comparison of AR schemes, a method for the objective comparison of AR performance among the different schemes was used. Stoffelen et al (2002) show that this way of comparison is effective to evaluate the shortcomings of AR schemes, but also reveals a more general way forward to improve AR, which is followed up during IOP by tuning 2D-VAR. For SeaWinds this tuned version of 2D-VAR is used.

3.2.2. Quality Control

Since the scatterometer wind retrieval problem is over determined, this opens up the possibility of quality control (QC) by checking the inversion residual J. The inversion residual is in theory inversely proportional to the log probability that a node is affected solely by a uniform wind. Generally this probability is low when

- Rain affects the WVC; and
- There is substantial wind variability within the cell;

As such, Portabella and Stoffelen (2000) found that the inversion residual is well capable of removing cases with extreme wind variability (at fronts or centres of lows), or with other geophysical variables affecting the radar backscatter, such as rain. QC is performed on the 25-km NASA or NOAA grids and rejection percentages vary between 1-5%. In the nadir WVCs **both** the JPL rain flag and the KNMI residual check are used for QC.

3.3. Detailed SeaWinds algorithm description

SeaWinds processing is described in some detail in [Ref-4]. The KNMI extensions to the NOAA and NASA SeaWinds processing are described in Stoffelen (2000) and in Portabella [Ref-5].

3.4. Monitoring

Automatic ways of monitoring backscatter data quality and wind products is of the utmost importance for using the data, in particular for routine use in NWP, for example. The way of monitoring at KNMI is reported in de Vries, Stoffelen and Beysens. In short, a multi-step check is used for each product (half orbit), and if

- the number of QC rejections is above a threshold, or
- the mean normalised residual J is above a threshold for those data where a wind solution can be calculated, or
- the wind speed bias against the NWP reference is above a threshold,

then the monitoring flag is raised and the output is suspicious. The false alarm rate of the monitoring flag is about 0,001 %.

4. Processing scheme

KNMI has a pre-operational processing chain running in near real-time with SeaWinds data, including visualisation on the web: http://www.knmi.nl/scatterometer/qscat_prod/. This prototype is based on the NWP SAF software. The processing includes monitoring and archiving functionalities. A global overview of the modules of our SeaWinds scatterometer processor is given below.

4.1. SeaWinds processing

Figure 2 gives an overview of the entire processing system of SeaWinds.

4.2. NWP collocation

KNMI receives NWP model data from ECMWF twice a day through the RMDCN.

NWP model sea surface temperature data is used to provide information about possible ice presence in the WVCs. WVCs with a sea surface temperature below 271.46 K (-1.7 °C) are assumed to be covered with ice and no wind information is calculated. This ice check, which is usually inactive, is done in addition to the evaluation of the JPL ice flags which are present in the NOAA input product. If the JPL ice screening fails, the ice is still detected by the SST check.

NWP forecast wind data are necessary in the ambiguity removal step of the processing. ECMWF wind forecasts are available twice a day (00 and 12 GMT analysis time) with forecast time steps of +3h, +6h, …, +36h. The 10-m model wind data are averaged with respect to time and location and put into the model wind part of each WVC, where they replace the NCEP 1000-hPa forecast winds that are present in the NOAA input product. This has a positive input on the output product quality and eases the product monitoring and validation [Ref-8].

4.3. Validation

Each step in the processing is validated separately and also the product as a whole by a quality control and monitoring scheme. The product validation step is controlled by visual inspection, and a statistical analysis is performed to control the validation steps. The inversion step is controlled in the same way. For ambiguity removal schemes an objective scheme exists that relies on initialisation with a one-day lead NWP forecast and validation of the ambiguity selection against NWP analyses, as in Stoffelen et al (2002). Moreover, de Vries and Stoffelen (2000) describe subjective comparison of the 2D-VAR and PreScat schemes by routine operational meteorologists.

4.4. Quality control and monitoring

The quality of the delivered products is controlled through an ad hoc visual examination of the graphical products and the automatic production of control parameters.

The examination of the products is done at KNMI by experts. Specific tools have been developed to help this analysis. User queries obviously lead to the inspection of suspect products. The ad hoc and user queried inspections are used for quality assurance.

An information file is made for each product. The content of the file is identical whatever the product and results from a compilation of all the global information concerning this product. From these files, various graphs are produced to visually display the confidence levels of the products and their evolution with time, some of these graphs are available on the WWW site for product quality monitoring by the users.

4.5. Software Configuration

To keep record of system configuration and releases and the history of the source files in the processing system, the development team at KNMI uses the Concurrent Version System (CVS).

4.6. Dissemination

SeaWinds BUFR products are put available on a password-protected FTP site. This password is provided to new users by E-mail request. Data are available also through the EUMETCast system.

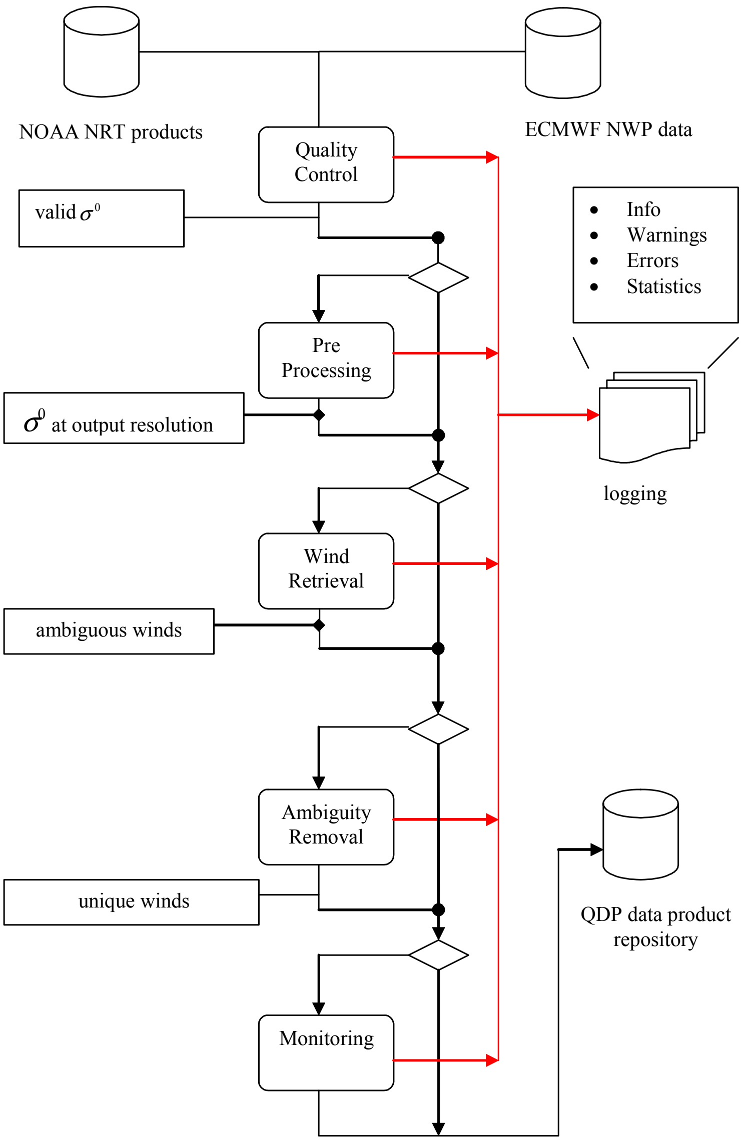

Figure 6: *SeaWinds Data Processor (de Vries, 2003).*

5. Data description

5.1. Wind product characteristics

Physical definition

Wind vector at 10m height.

Units and range

Wind speed is measured in m/s and wind direction in meteorological (WMO) convention relative to North: 0 degrees corresponds to a wind flowing to the South with a clockwise increment. The wind speed range is from 0-50 m/s, but wind speeds over 25 m/s are generally not reliable (cf Donelly et al, 1999).

Input satellite data

SeaWinds BUFR data from NOAA are described in their user manual (see [Ref-7]).

Product computed from FTPed BUFR messages issued by NOAA to the UK Met.Office, and by the UK Met.Office to KNMI, containing geolocated measurement quadruplets on a satellite swath grid of 25 km size. Portabella ([Ref-5]; section 2.4) shows that the backscatter data in the BUFR and the off-line product are of similar quality despite processing differences. The delay of the input SeaWinds data is up to 3 hours delay from observation time

Geographical definition

Satellite swath projection. Swath is located below the satellite. The QuikSCAT satellite proceeds in a near-polar orbit at 98 degrees inclination at 800 km orbit height. Equator ascending crossing time is 10 UTC. Swath width is 76 (19) 25-km (100-km) size WVC each side. At KNMI we currently only use WVC for which four backscatter measurements are available (WVCs 9-68), nominally resulting in 15 100-km size WVCs. This substantially reduces the overlap of subsequent files. Products are organised in batches of about half an orbit along track, depending on ground station visibility.

Time resolution

Polar satellites have the capability to provide data twice daily. The SeaWinds swath width of 1800 km provides full coverage twice a day for latitudes above 50 degrees. KNMI processes a 1400 km swath where above 60 degrees full coverage at least twice daily is provided. The dissemination frequency of the scatterometer data is about every 50 minutes in half orbit files. Every useful input backscatter product has a corresponding output wind product.

Coverage

Global (see http://www.knmi.nl/scatterometer/qscat_prod/).

Output product

The input product in BUFR is processed into a BUFR output product with a unique wind solution (chosen) and its corresponding ambiguities, quality information (probability of solution, quality flag, e.g., monitoring bit).

Delivery time

A wind product is available for distribution 10 minutes after the backscatter product reception at KNMI.

Expected accuracy

The expected accuracy is defined as the expected bias and standard deviation of the primary calculations. The accuracy is validated against in situ wind measurements from buoys, platforms, or ship, and against NWP data. Even better, the errors of all NWP model winds, in situ data, and scatterometer winds are computed in a triple collocation exercise ([Ref-6], Djepa, 2002). The performance is pretty constant over the globe and depends mainly on the subfootprint wind variability. The performance of the products issued by KNMI is characterised by a wind vector RMS error smaller than 3 m/s.

5.2. File formats

Wind products are in BUFR. A complete description of BUFR can be found in WMO publication No 306, Manual on Codes. The graphical display of the wind products is available and explained on the web: http://www.knmi.nl/scatterometer/qscat_prod/.

The 100km KNMI wind product is stored in exactly the same BUFR format as described in the Seawinds BUFR manual from NOAA [Ref-7]. Data are organised in files containing approximately 75-90 minutes of data. The file name convention for SeaWinds 100-km data is:

QS100_Dyyddd_Shhmm_Ehhmm_Bxxxxxxx

QS100_ - is a fixed prefix, denoting 'QuikSCAT' and 100-km resolution

Dyyddd_ - yyddd contain year (two digits) and day of year (001 - 366) at start of data acquisition in this file (GMT)

Shhmm_ - hhmm contains hour and minute of start of data acquisition in this file (GMT)

Ehhmm_ - hhmm contains hour and minute of end of data acquisition in this file (GMT)

Bxxxxxxx - contains information about satellite orbit number

Examples of file names are QS100_D05186_S2352_E0107_B3148182 or QS100_D05187_S1123_E1251_B3148889. The file name convention is applicable to the files which are available on the KNMI FTP server. The files which are disseminated through EUMETCast have a fixed prefix 'S-OSI_-KNMI-' before this file name, for example S-OSI_-KNMI-QS100_D05186_S2352_E0107_B3148182

In each node or wind vector cell (WVC) 118 data descriptors are defined. In addition some extra information/alterations have been put in place:

- In the BUFR header the value for "generating centre" is set to 99 which represents KNMI.
- The value of byte 18 in section 1, identifies the generating application.
- The Wind Vector Cell Quality Flag (table 021109) is redefined and now has the following definitions:

Description	**BUFR bit**	**Fortran bit**
Not enough good sigma-0 available for wind retrieval	1	15
Not used	2-3	14-13
Monitoring flag	4	12
Monitoring value	5	11
KNMI+JPL Quality Control (including rain)	6	10
Variational QC	7	9
Land presence	8	8
Ice presence	9	7
Not used	10	6

Description	BUFR bit	Fortran bit
Reported wind speed is greater than 30 m/s	11	5
Reported wind speed is less than or equal to 3 m/s	12	4
Not used	13	3
Rain flag algorithm detects rain	14	2
Data from at least one of the four possible beam/view combinations are not available	15	1
Not used	16	0
Missing value	All 17 set	All 17 set

In Fortran, if the Wind Vector Cell Quality Flag is stored in an integer **I** then use **BTEST(I,NDW-NB-1)** to test BUFR bit **NB**, where **NDW**=17 is the width in bits of the data element in BUFR.

If the monitoring flag is set to zero, the product is monitored. If the product is monitored and the monitoring value is set to zero, the product is valid, otherwise it is rejected by the monitoring. The monitoring flag and value are the same for all WVCs in one BUFR output file.

If the KNMI+JPL QC flag is set in a 25-km WVC then the backscatter information is not useable for various geophysical reasons like rain, confused sea-state etc, and the corresponding 100-km product bit is set. JPL rain flag information is incorporated in this flag for the nadir swath Wind Vector Cells. Moreover, this flag is set when the wind speed in one or more of the wind solutions is 50 m/s. The presence of such wind solutions has proven to be a reliable indicator for sea ice in the Wind Vector Cell. WVCs in which the KNMI+JPL QC flag is set, are not presented to the ambiguity removal step. This means that such a WVC may contain wind solutions, but it will never have a index pointing to the selected wind solution.

Land/Ice presence flag is set if at least one of the 25km WVCs in a 100km super WVC is flagged as containing land/ice in the NOAA NRT BUFR product. This may be a flag in one of the sigma0 surface flags or in the WVC quality flag of the input. If more than half of the 25km WVCs in a 100km super WVC has bits 6, 8 or 9 set, the 100km WVC is rejected (no wind is calculated).

If the Variational QC flag is set, the wind vector in the WVC is rejected during ambiguity removal due to spatial inconsistency.

For recommendations on the use of the Quality Flag, see par. 6.4.

6. Data Quality

NOAA provides a near-real time wind product that is used as basis for further processing at KNMI. Our SeaWinds products are different from the NASA and NOAA products, since special emphasis is put on

- increasing the **reliability** of the wind vectors by Quality Control and rejection of rain-contaminated Wind Vector Cells (WVC);
- improving **accuracy** by noise reduction through spatial averaging and meteorological filtering;
- Guaranteeing **correctness** by monitoring of the operational SeaWinds data and KNMI processing; and
- **Reduce** wind direction selection **errors** by meteorologically-balanced wind direction Ambiguity Removal (AR).

These wind quality issues are elaborated here.

6.1. Reliability

QC improves the quality of winds; however, at some rejection rate useful wind information may be lost. As such, QC is a compromise between rejection of useful data and accepting inferior data quality.

[Ref-5] (chapter 2) describes a method developed at KNMI for QC of SeaWinds data at 25 km resolution, based on similar methods used for the ERS and NSCAT scatterometers. We show that these methods also work in case of SeaWinds for the rejection of cases with

- extreme subfootprint wind or wave variability; and
- rain.

Concerning the latter point we compared our QC with the JPL rain flag and found

- Despite the fact that the JPL rain flag is set, KNMI accepts a 2% category of high wind speed data. However, SSMI shows no rain in this category in about 85% of cases, even if these winds are often found in the storm track region in the vicinity of intense low pressure systems. We regard these SeaWinds data of great meteorological interest.
- In the sweet swath region (see figure 1) the QC is superior and sufficient, but in the nadir part of the swath we use both the KNMI QC **and** the JPL rain flag.

6.1.1. Usable 100 km WVC

A WVC is used if for all four beams at least eight of sixteen backscatter values are present. This choice was verified to provide satisfactory wind quality and quantity. The front cover shows an example where close to the low and close to the cold front some WVC are rejected (red dots). The only further QC at 100 km resolution is performed during AR (section 6.3).

6.2. Accuracy

Figure 2 shows that SeaWinds wind variability at 25-km resolution is WVC number dependent. This is due to the effect of instrument noise dominating the wind retrieval. Obviously, we would like the true wind field to dominate the wind variability and thus a variability which is independent of WVC. At KNMI we chose to reduce the instrumental noise by spatial averaging and developed a 100-km SeaWinds product.

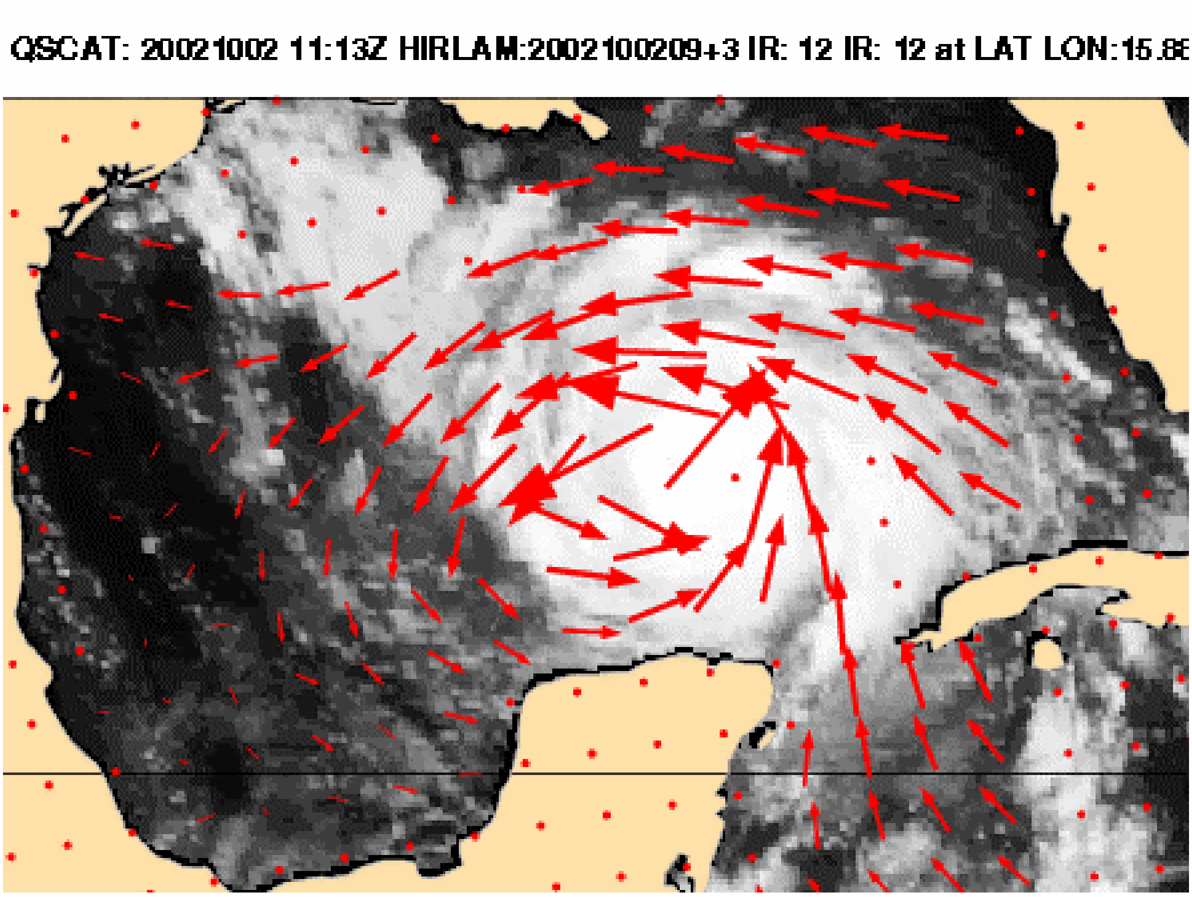

Figure 7: *KNMI SeaWinds product in the Gulf of Mexico for a tropical cyclone. A handful of points are rejected by our QC, but the cyclone structure remains clear.*

SD	KNMI	DIRTH
Speed	1.31	1.64
Direction	13.58	14.58
U	1.60	1.96
V	1.58	1.80

Table 1: *KNMI and NOAA DIRTH SeaWinds product difference with ECMWF first guess winds for a set of triple collocated wind points. Speed, direction, and wind component difference standard deviations (SD) are shown. KNMI winds verify better against ECMWF, in particular for wind speed.*

The 100km resolution wind product is of reduced resolution compared to the original NOAA 25km product, which is obtained by means of σ^0-averaging. The product is more consistent with NWP model winds than the original product, which makes it more suitable for use in NWP models. Evidence of this is given in table 1 and figures 8 and 9.

As can be seen in table 1, the 100-km product clearly compares better to the independent ECMWF winds than the NOAA SeaWinds Product.

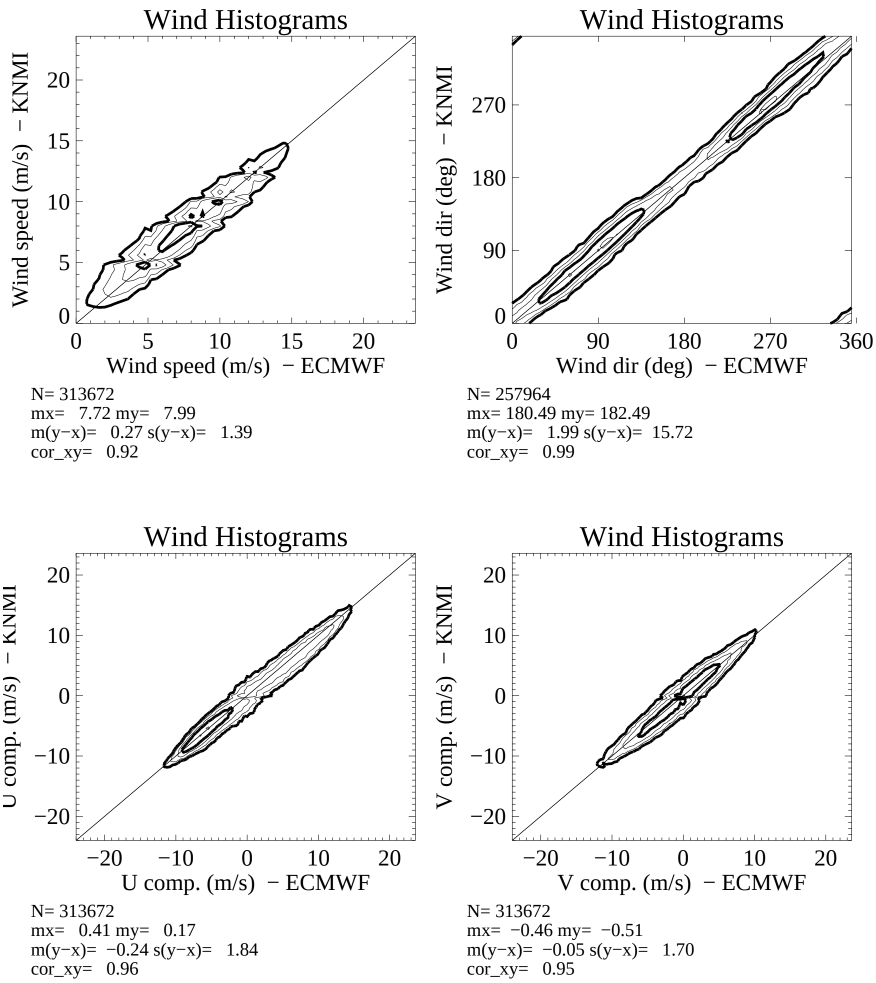

***Figure 8:** Contoured histograms of the 100km KNMI wind product*

Both figures 8 and 9 give the wind speed, direction and component statistics referenced against collocated ECMWF 10m wind analysis for the 100km KNMI wind product and the 25km NOAA product thinned to 100km resolution respectively. The data for these plots are from consecutive orbits from January 27th 2002 until February 3rd 2002. The 100km wind product was made with the QDP in default settings mode (Variational Quality Control and KNMI quality control). The thinning of the NOAA product was realized by taking winds from the nearest neighbor 25km WVC closest to the centroid of the 100km super WVC. The wind direction statistics are based on winds with wind speeds larger than 4 m/s. From the joint distributions and accompanying statistics in all plots of both figures it is evident that the random error of the difference distribution, s(y-x), is smaller for the 100km product. In addition the systematic error in the difference distribution, m(y-x), is also smaller for the 100km product except for the wind direction. The asymmetric peak in the U-component distribution in both figures is due to the systematic sampling of the trade winds. The jaggedness of the wind speed distributions is due to the fact that the retrieved scatterometer wind speeds stem from the GMF lookup table. Both figures show that currently in the trade off between resolution and noise, QuikSCAT winds at 100km resolution are the preferred product for NWP data assimilation.

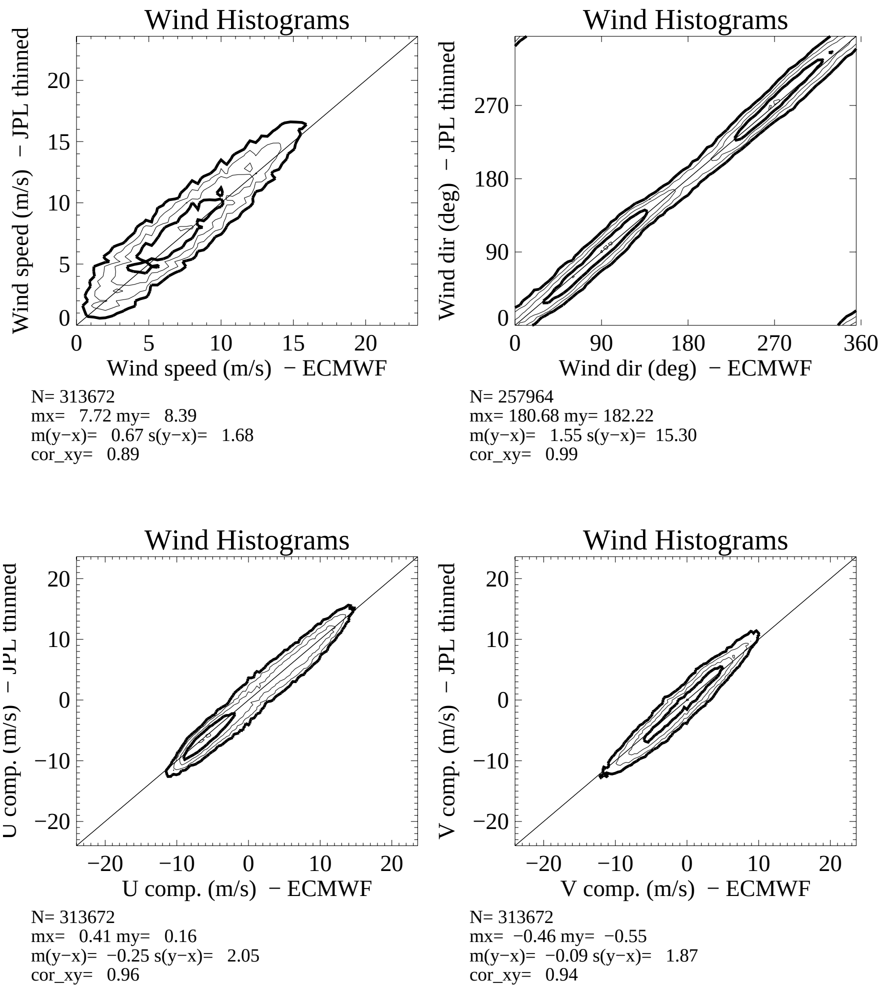

Figure 9: *As figure 8 but for the thinned NOAA product*

In our verification, the NOAA DIRTH processing tends to deliver reasonably smooth wind direction (see figure 10), but rather variable wind speeds. On the other hand, the 100-km product exhibits similar scales and variability in both wind speed and direction. This is what one may anticipate from the way both processing algorithms work.

The noise in the 100-km product is smaller than in the 25-km product and the performance more uniform over the swath, consistent with the initial objective.

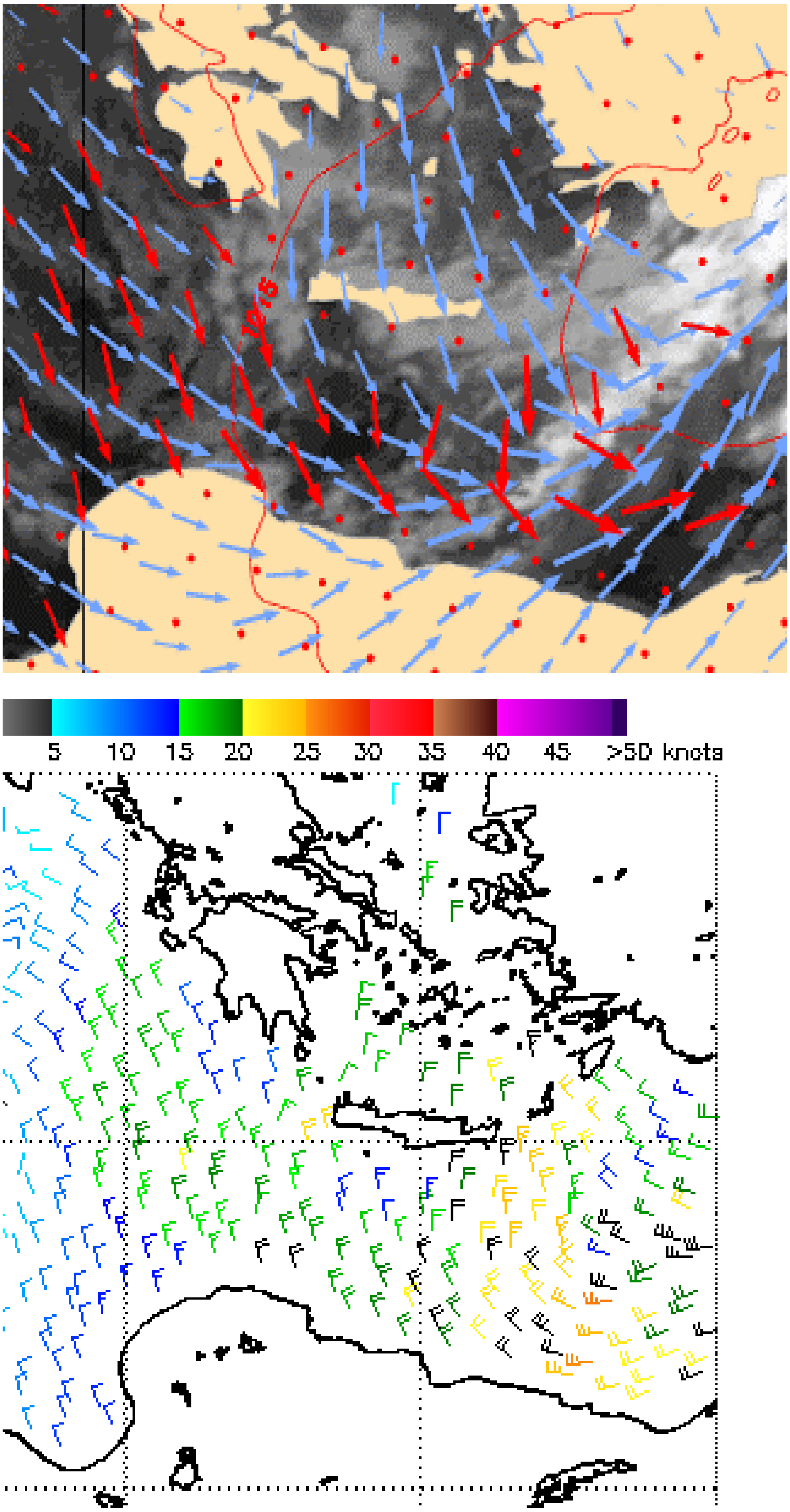

Figure 10: *KNMI SeaWinds product (top) in the Mediterranean for a trough. In the DIRTH NOAA product (bottom), the trough appears weaker due to the wind direction spatial smoothing. Blue winds are HIRLAM in the top panel, while here the background image is MeteoSat IR. Black winds did not pass the JPL rain check in the bottom panel.*

6.3. Ambiguity selection

For SeaWinds a version of 2D-VAR is used with minimal regional performance differences (de Vries, Stoffelen and Beysens). This improved version was obtained after taking into account the findings of Stoffelen et al (2002). A variational QC step is performed to reject a few 100-km WVCs, which are in meteorological unbalance with their neighbours. This rejection rate, often called gross error rate, peaks at nadir and falls off quickly by a factor of two in the sweet swath.

6.4. Quality indices and data use

We summarise the product quality indices here:

1. Rain/sea-state, ice, and land presence, resp. bits 6, 9, and 8, of WVC_QUALITY_FLAG (section 5.2); if a *selected* wind is present these flags may be ignored;
2. Monitoring flag and bit, resp. bits 4 and 5 of WVC_QUALITY_FLAG (sections 5.2 and 3.4); a selected wind may be given, but it should be suspected if bits 4 **and** 5 are set;
3. Variational QC bit 7 of WVC_QUALITY_FLAG (section 5.2); if this bit is set, the selected wind is spatially inconsistent with its neighbours and suspect.

7. Glossary

ADEOS	(Japanese) Advanced Earth Observation Satellite
AR	Ambiguity Removal
ASCAT	Advanced Scatterometer
BUFR	Binary Universal Format Representation
CM SAF	Climate SAF
DLI	Downward Longwave Radiation
EPS	Eumetsat Polar System
ERS	European Remote-Sensing Satellite
EUMETCast	EUMETSAT's Digital Video Broadcast Data Distribution System
GOES	Geostationary Operational Environmental Satellite
HDF	Hierarchical Data Format
HH	Horizontal polarisation send and receive mode
IR	InfraRed
JPL	Jet Propulsion Laboratory (NASA)
KNMI	Royal Netherlands Meteorological Institute
NASA	National (US) Air and Space Agency
NOAA	National (US) Oceanic and Atmospheric Administration
NSCAT	NASA Scatterometer
NWP	Numerical Weather Prediction
OSI SAF	Ocean and Sea Ice SAF
QC	Quality Control
QuikScat	US dedicated scatterometer mission to bridge ADEOS-I and ADEOS-II
RMDCN	Regional Meteorological Data Communication Network
SAF	Satellite Application Facility
SeaWinds	US scatterometer on-board QuikSCat and ADEOS-II platforms
SOS	Scatterometer Ocean Stress
SSI	Surface Solar Irradiance
SST	Sea Surface Temperature
SVVP	Software Verification and Validation Plan
U	West-to-east wind component
V	South-to-north wind component
VV	Vertical polarisation send and receive mode
WVC	Wind Vector Cell

8. Literature

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