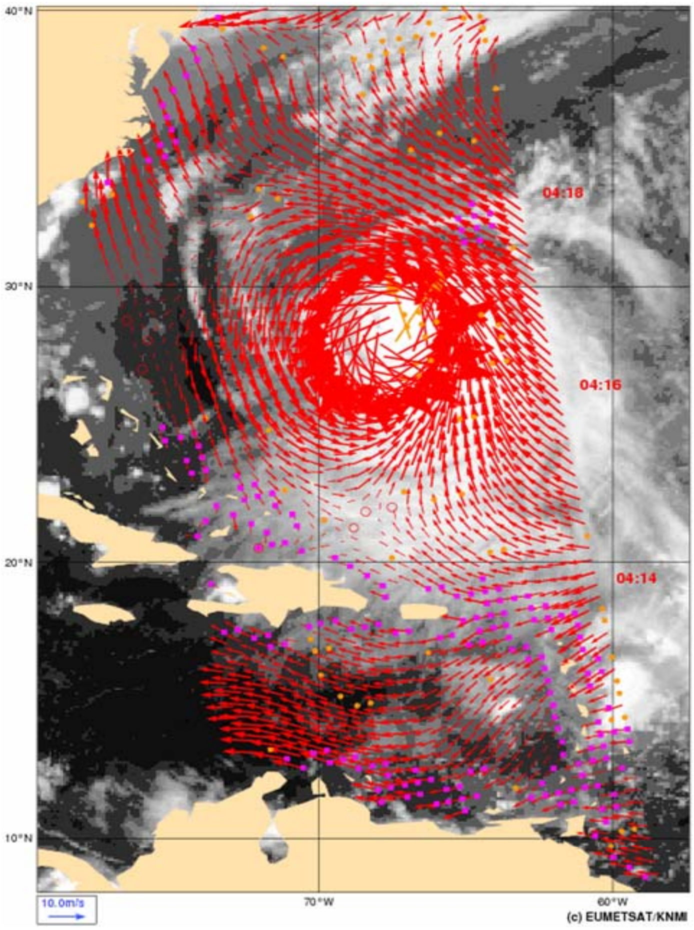
Oceansat-2
Wind Product User Manual



Ocean and Sea Ice SAF

OSI SAF 50-km wind product (OSI-105)

Version 1.1
June 2012

DOCUMENT SIGNATURE TABLE

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Issue / Revision	Date :	Change :	Description :
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KNMI, De Bilt, the Netherlands

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Cover illustration: OSCAT wind field of hurricane Katia retrieved in the western Atlantic at 50 km WVC spacing on 7 September 2011, approximately 4:15 UTC, overlaid on a GOES IR satellite image. The orange dots are rejected WVCs, the purple dots indicate WVCs for which the land flag is set. The two orange arrows near the hurricane centre failed the 2DVAR spatial consistency check.

Contents

1. Introduction

1.1. Overview

The EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) produces 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 Long wave Irradiance (DLI).

KNMI is involved in the OSI SAF as the centre where the level 1 to level 2 wind processing is carried out. This document is the Product User Manual to the Oceansat-2 wind products. Quality monitoring information on this product and more general information on the whole OSI SAF project, is available on the OSI SAF web site: http://www.osi-saf.org/. The user is strongly encouraged to register on this web site in order to receive the service messages and the latest information about the OSI SAF products.

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, see e.g. [Ref-1].

KNMI has a long experience in scatterometer processing and is developing generic software for this purpose. Processing systems have been developed for the ERS, NSCAT, SeaWinds, ASCAT and Oceansat-2 scatterometers. Scatterometer processing software is developed in the EUMETSAT Numerical Weather Prediction Satellite Application Facility (NWP SAF), whereas wind processing is performed operationally in the Ocean and Sea Ice SAF (OSI SAF).

Oceansat-2 scatterometer (OSCAT) data are acquired at the Svalbard ground station and sent to India for further processing, with a backup facility at the EUMETSAT headquarters. EUMETSAT then makes available near real-time level 2a scatterometer products through EUMETCast. These products are used as basis for further processing at KNMI. The wind products are distributed in one resolution with 50-km cell spacing. The product has a timeliness of approximately 1-1.5 hours from the last sensing time in a product file.

The OSI SAF products are delivered on request through the KNMI FTP server to the users. Currently, the OSI SAF OSCAT wind product is available only to European, non-commercial users. See also http://www.knmi.nl/scatterometer/ for real-time graphical examples of the products and up-to-date information and documentation.

This user manual outlines user information for the OSI SAF wind OSCAT product (OSI-105). Section 2 presents a brief description of the OSCAT instrument, section 3 the processing algorithms, and section 4 gives an overview of the data processing configuration. Section 5 provides details on how to access the products. Detailed information on the file content and format is given in section 6, while in section 7 the product quality is elaborated.

1.2. Disclaimer

All intellectual property rights of the OSI SAF products belong to EUMETSAT. The use of these products is granted to every interested user, free of charge. If you wish to use these products, EUMETSAT's copyright credit must be shown by displaying the words "copyright (year) EUMETSAT" on each of the products used.

The OSI SAF is much interested in receiving your feedback, would appreciate your acknowledgment in using and publishing about the data, and like to receive a copy of any publication about the application of the data. Your feedback helps us in maintaining the resources for the OSI SAF wind services.

1.3. References

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References marked with a (*) are available on http://www.knmi.nl/scatterometer/publications/.

1.4. Useful links

KNMI scatterometer web site: http://www.knmi.nl/scatterometer/

- Information on OSI SAF activities at KNMI: http://www.knmi.nl/scatterometer/osisaf/
- OSCAT visual products: http://www.knmi.nl/scatterometer/oscat_50_prod/

Information on EUMETCast: http://www.eumetsat.int/

OSI SAF wind product documentation on http://www.osi-saf.org/:

- Scientific documents
- Technical documents

NWP SAF website: http://www.nwpsaf.org/

ISRO website: http://www.isro.gov.in/

1.5. Limitations of the OSCAT winds

The following restrictions and limitations hold:

1) Although the calibration of the backscatter values in the level 2a product is already quite good, further improvements in the wind calibration and quality control can be achieved using ocean calibration methods that have been developed for ASCAT and SeaWinds.

2) The provision of the level 2a backscatter product from EUMETSAT to KNMI is not considered an operational process. Hence the OSI SAF wind product can not have a fully operational status.

3) The product monitoring flag (see section 7.2) is not yet implemented.

4) From monitoring and validation of QuikSCAT and OSCAT winds against ECMWF and buoy data, we know that the winds obtained by the NSCAT-2 GMF tend to have an increasingly positive bias for wind speeds higher than 15-20 m/s. Winds above 20 m/s should be treated with care.

5) Negative wind speed biases of the OSCAT winds have been observed for latitudes between 50° South and the Antarctic ice edge. These biases are of the order of 0.5 to 1.0 m/s. The origin of this is not yet understood.

These restrictions and limitations are subject to further study.

1.6. History of product changes

Here is an historical overview of the changes in the OSCAT wind products:

28-Jun-2011	Oceansat-2 wind products are available in BUFR format to European users with status 'in development'.
29-Aug-2011	Improvement of wind retrieval performance at low wind speeds. This is done by a calibration of the sigma0 values to correct issues in the backscatter noise subtraction. Products are available in NetCDF format as well. OWDP version is 0_2_00.
20-Dec-2011	Changes to prepare for ISRO data version 1.3 (implemented on 21 December). Calibration of sigma0 values for the low wind problems is not necessary any more and the calibration is removed. OWDP version is 1_0_01.

2. The OSCAT scatterometer instrument

The scatterometer is one of the three instruments carried on-board the Oceansat-2 polar satellite, launched and operated by the Indian Space Research Organisation (ISRO). It was launched on 23 September 2009. A similar instrument is planned to be launched in 2013 on ScatSat.

The OSCAT instrument is a conically scanning pencil-beam scatterometer, as depicted in figure 1. It uses a 1-meter dish antenna rotating at 20 rpm with two “spot” beams of about 25 km × 55 km size on the ground, a horizontal polarisation beam (HH) and a vertical polarisation beam (VV) at incidence angles of 43º and 49º respectively, that sweep the surface in a circular pattern. Note that the egg-shaped beam footprints are divided into slices by applying a modulated chirp signal. 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 like ERS, NSCAT and ASCAT.

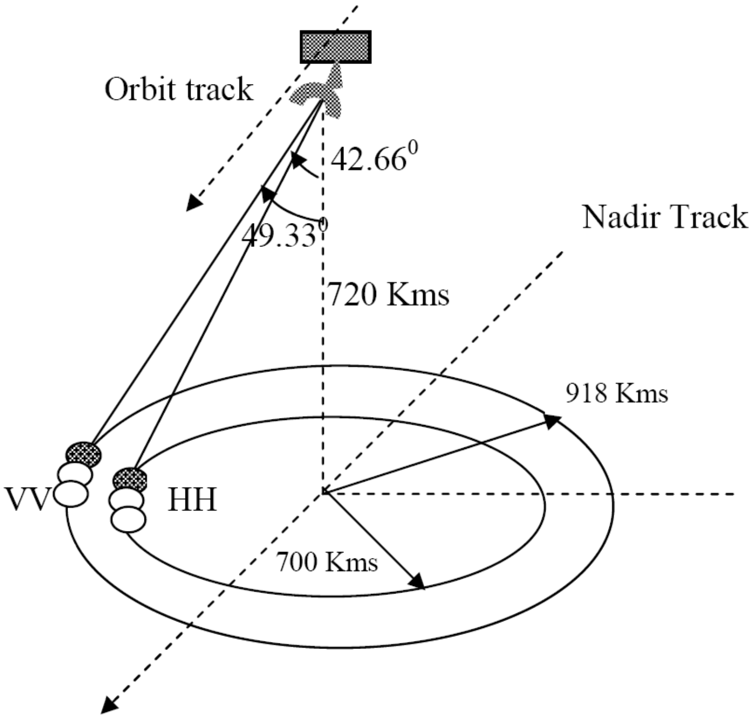

Figure 1: *OSCAT wind scatterometer geometry (source: [Ref-2]).*

On the other hand, the wind retrieval from OSCAT 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 2). A detailed discussion is provided in [Ref-3; pages 22-23]. The wind retrieval skill will therefore depend on the position in the swath.

In the outer swath (where only VV beam data are available) 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. In the nadir swath 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. Due to a more difficult QC in the outer swath, this region is not processed in the OSI SAF product at the time of writing this manual.

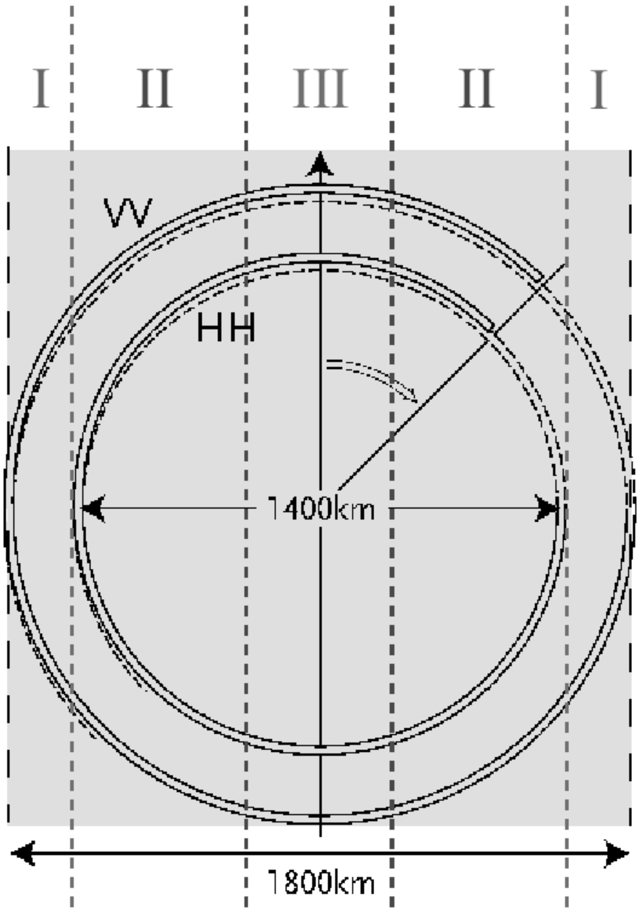

***Figure 2:** Earth surface coverage of the scans of the horizontal (HH) and vertical polarisation (VV) pencil-beams of OSCAT. As the satellite propagates towards the top of the page the swath (in grey) is illuminated, and three areas are discriminated:*

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.

The OSCAT scatterometer works at a Ku-band radar wavelength (13.515 GHz). 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.

Due to the availability of VV and HH polarisation measurements, discrimination of water and ice surfaces is generally well possible as was shown for SeaWinds [Ref-4]. The SeaWinds ice screening algorithm needs to be adapted for OSCAT and in the current OSI SAF product a filter based on NWP Sea Surface Temperature is applied to prevent erratic winds over sea ice surfaces (see section 4.3).

3. Algorithms

Scatterometry was developed heuristically. It was found experimentally that the sensitivity to wind speed and direction well describes the changes in backscatter over the ocean at moderate incidence angles due to changes in surface roughness. This is depicted in figure 3 [Ref-5]. In return, backscatter measurements can be used to determine the wind speed and wind direction in a WVC.

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.

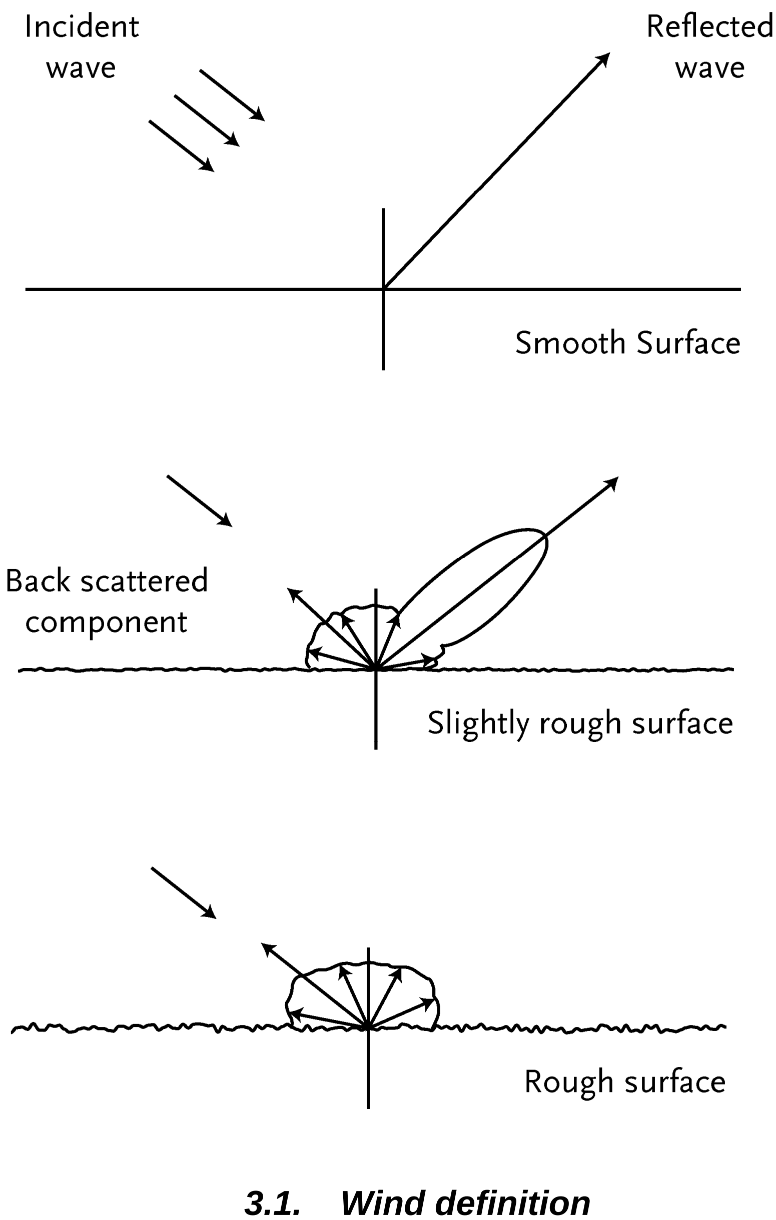

Figure 3: *Schematic representation of microwave scattering and reflection at a smooth (a), rough (b) and very rough (c) ocean surface. As the roughness increases more microwave power is returned towards the direction of the microwave source.*

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 10 meter height over a 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.

At low wind speeds the wind direction and speed may vary considerably within the WVC. Locally, below a speed of roughly 2 ms^{-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 [Ref-9]. However, given the variability of the wind within a footprint area of 25 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 [Ref-22, 23].

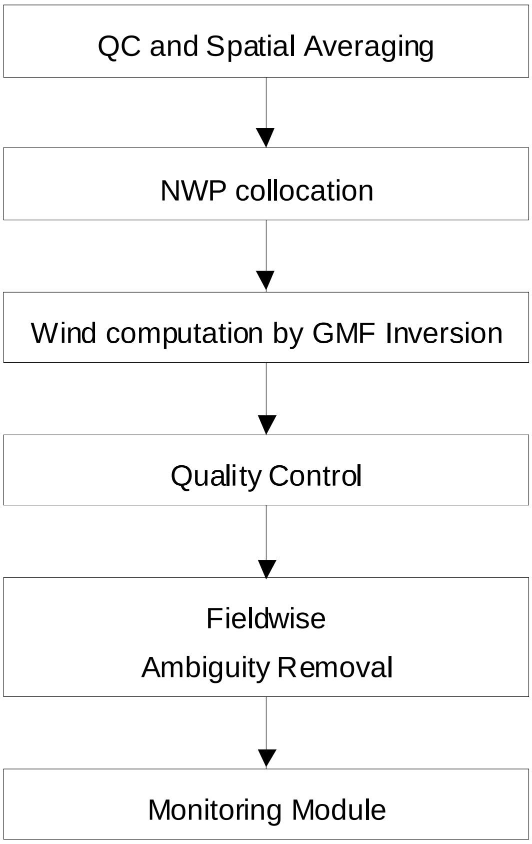

Figure 4: *Overview of wind retrieval algorithm*

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 from 25 m/s to 40 m/s, and that a useful wind direction dependency remains [Ref-10], albeit gradually weakening.

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 [Ref-11]. The MLE is defined by ([Ref-6]; Chapter II)

$$J = \sum_{i=1}^{N} \left(\frac{\sigma_{oi} - \sigma_{mi}}{SD(\sigma_{oi})} \right)^2$$

where σ_{oi} are the backscatter measurements, σ_{mi} are the model backscatter values corresponding to the measurements, and $SD(\sigma_{oi})$ are the measurement standard deviations, related to both instrument noise and geophysical noise [Ref-20, 21]. The local minima of J correspond to wind vector solutions. The three or more independent measurements well sample the azimuth variation of the GMF in order to resolve the wind direction, albeit ambiguously.

For the OSI SAF OSCAT product the NSCAT-2 GMF for calculating equivalent neutral winds is used [Ref-7]. Portabella ([Ref-3]; page 153) compared the QSCAT-1 [Ref-8] and NSCAT-2 Ku-band GMFs for SeaWinds wind retrieval. He found that the QSCAT-1 results in more wind solutions during wind retrieval, i.e., it is more ambiguous. In other words, for QSCAT-1 we generally find more minima when we look at the MLE as a function wind direction. Portabella verified that the additional minima are generally artificial and do not contribute to wind direction skill. These additional local minima in the inversion do result potentially in local minima in ambiguity removal with the Multiple Solution Scheme (MSS, see section 3.2.2), where these pre-empt 2DVAR to find the best fitting global wind field solution.

3.2.1. 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, or there is substantial wind or sea state variability within the cell [Ref-20, 21].

As such, Portabella and Stoffelen [Ref-12] 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 WVCs and rejection percentages vary between 3-7%.

3.2.2. Ambiguity removal

OSCAT scatterometer winds have a multiple ambiguity and there are up to four wind solutions in each 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 [Ref-13]. In addition to the subjective comparison of AR schemes, a method for the objective comparison of AR performance among the different schemes was used. In [Ref-8] it is shown 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 by tuning 2DVAR.

For the OSCAT wind product, a somewhat different approach called MSS (Multiple Solution Scheme) is used. In this approach, the full circle of possible wind directions is divided in 144 equal sectors of 2.5° and for each wind direction an optimal wind speed with its corresponding probability is calculated in the wind retrieval step. Subsequently, the 144 solutions of each WVC are used in the AR to select the optimal solution. In this way, the full probability density function of the wind solutions is used [Ref-14].

3.3. Oceansat-2 versus QuikSCAT

The processing algorithms for the OSCAT wind processing are heavily based on the algorithms as developed for SeaWinds. The wind processing software which was developed for OSCAT, the OSCAT Wind Data Processor (OWDP) shares its main functionality with the SeaWinds Data Processor. Processing steps like wind inversion and ambiguity removal are done in the same way and with the same generic code.

Differences between SDP and OWDP are to a great extent on a technical (data handling) level. SDP uses SeaWinds BUFR data as input which already have backscatter data accumulated to WVC level, whereas OWDP uses HDF5 level 2a backscatter data on slice level; these data are averaged to WVC level by OWDP (see section 4.1).

SeaWinds and OSCAT are comparable in many ways but they are different instruments built of different components. Moreover, they utilise different incidence angles due to the lower Oceansat-2 orbit (720 km versus 800 km). In order to handle these differences well, some parts of the processing were re-tuned for OSCAT, mainly the normalisation of the MLE and the tuning of the Quality Control [Ref-19].

4. Processing scheme

KNMI has a processing chain running in near real-time with OSCAT data, including visualisation on the internet. This processor is based on the NWP SAF software and runs in the KNMI operational environment. The processing includes monitoring and archiving functionalities. A global overview of the modules of the OSCAT scatterometer processor is given below.

4.1. Backscatter slice averaging

The level 2a backscatter data from ISRO are organised in slices, see [Ref-2]. The slices need to be beamwise accumulated to a WVC level before wind inversion can be done. The slice weights are proportional to the estimated transmitted power contained in a slice. The Sigma0 Quality Flag present in the level 2a data is evaluated and slice data with one of the following flags set are skipped:

- Bit 4: Sigma0 is poor
- Bit 5: K_p (noise value) is poor
- Bit 6: Invalid footprint
- Bit 7: Footprint contains saturated slice

4.2. Backscatter corrections and calibration

The Ku band radiation from OSCAT is attenuated by the atmosphere. Climatological values of this attenuation were determined as a function of location and time of the year [Ref-15]. The attenuation is based on a climatology water vapour. The attenuation includes atmospheric oxygen, water vapour, and nominal cloud. A mean global cloud cover of 0.1 mm is assumed.

A table containing the monthly climatological attenuations was kindly provided by NOAA. The attenuations are the same that were used for SeaWinds. The one-way nadir looking values (in dB) in the table are transformed into an attenuation correction taking the beam incidence angle into account. The attenuation correction is added to the beam backscatter value. The two-way nadir looking values (i.e., without the incidence angle correction) are stored in the BUFR output data.

The backscatter values in the level 2a product can be further calibrated by adding a WVC and beam dependent bias in dB to the incoming σ^0's. The calibration table can be obtained by fitting the actual measurements to the theoretical GMF function. More details are provided in [Ref-16]. Currently, this is not yet implemented and a constant (beam and WVC independent σ^0 correction) is used. Note that the calibrated backscatter values are only available within the wind processing software; the σ^0 data in the wind product are uncorrected values.

4.3. NWP collocation

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

NWP model sea surface temperature (SST) data are used to provide information about possible ice presence in the WVCs. The SST values of the four surrounding model grid points around the WVC location are bilinearly interpolated. Note that the ECMWF model data do not contain SST values over land; if one or more of the four surrounding grid points has missing SST data, the SST value of the grid point closest to the WVC is taken. WVCs with a sea surface temperature below 272.16 K (-1.0 °C) are assumed to be covered with ice and no wind information is calculated. Although the freezing temperature of sea water is around -1.7 °C, we keep some margin to prevent any ice contamination in the wind computation.

Land presence within each WVC is determined by using the land-sea mask available from the model data. The weighted mean value of the land fractions of all model grid points within 80 km of the WVC centre is calculated. The weight of each grid point scales with $1/r^2$, where r is the distance between the WVC centre and the model grid point. If this mean land fraction value exceeds a threshold of 0.02, no wind retrieval is performed.

NWP forecast wind data are necessary in the ambiguity removal step of the processing. Wind forecasts are available twice a day (00 and 12 GMT analysis time) with forecast time steps of +3h, +6h, …, +36h. The model wind data are linearly interpolated with respect to time and location and put into the model wind part of the WVC. Note that the ECMWF winds stored in the wind products are real winds rather than neutral winds.

4.4. Validation

Each step in the processing is validated separately 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 [Ref-13]. Moreover, de Vries et al [Ref-17] describe subjective comparison of the 2DVAR and PreScat schemes by routine operational meteorologists.

4.5. Quality control and monitoring

In each WVC, the σ^0 data is checked for quality and completeness and the inversion residual (see section 3.2.1) is checked. Degraded WVCs are flagged; see section 6.2 for more details.

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 [Ref-17]. 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. These graphs are available in near-real time if you click on the ‘Monitoring information’ link on the product visualisation web pages. Data quality is also available to the users within the products; see section 6 and 7 for a description of quality flags.

5. Helpdesk, product dissemination and archive

For a swift response management procedure, user requests on the OSI SAF data products should be issued at the Ocean and Sea Ice SAF website (http://www.osi-saf.org/).

The BUFR and NetCDF products are made available on a password-protected ftp site. This password is provided to new users by Email request. Please send your requests to scat@knmi.nl.

A BUFR reader is available at www.knmi.nl/scatterometer/bufr_reader/.

KNMI keeps an off line archive of the global products. You can send a request to scat@knmi.nl.

6. Data description

6.1. Wind product characteristics

Physical definition

Horizontal equivalent neutral wind vector at 10 m height (see section 3.1).

Units and range

Wind speed is measured in m/s. The wind speed range is from 0-50 m/s, but wind speeds over 25 m/s are generally less reliable [Ref-10]. In the BUFR products, the wind direction is in *meteorological* (WMO) convention relative to North: 0 degrees corresponds to a wind flowing to the *South* with a clockwise increment. In the NetCDF products, the wind direction is in *oceanographic* convention: 0 degrees corresponds to a wind flowing to the *North* with a clockwise increment.

Input satellite data

The generation of OSCAT level 2a data by ISRO is described in their technical documentation [Ref-2]. The global OSCAT data are acquired in Svalbard (Norway) and transmitted to India, where they are processed up to level 2a (with a backup at the EUMETSAT central processing facilities in Darmstadt). The product contains geo-located slice measurements on a satellite swath WVC grid of 50 km size.

Geographical definition

The Oceansat 2 satellite flies in a near-polar sun synchronous orbit at 98 degrees inclination at approximately 720 km orbit height. Swath width is 36 50 km size WVCs. At KNMI we currently only use those WVCs for which four backscatter measurements are available (WVCs 5-32), nominally resulting in 28 50 km size WVCs. Products are organised in files containing one orbit.

Coverage

The OSCAT product has a global coverage. The actual coverage is available on the OSI SAF product visualisation website (see http://www.knmi.nl/scatterometer/).

Output product

The input product in HDF5 is processed into a BUFR output product including a unique wind solution (chosen), its corresponding ambiguous wind solutions and quality information (distance to cone, quality flag). The products are also available in NetCDF format; see section 10 for more details.

Delivery time

A wind product is available for distribution within 10 minutes after the input product reception at KNMI. The latency between acquisition of the last data in a file and availability for the user is about one hour.

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, 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]. The performance is pretty constant over the globe and depends mainly on the sub footprint wind variability. The performance of the products issued by the OSI SAF is characterised by a wind component RMS error smaller than 2 m/s and a bias of less than 0.5 m/s in wind speed.

6.2. File formats

Wind products are in BUFR Edition 4 or in NetCDF format. A complete description of BUFR can be found in WMO publication No 306, Manual on Codes. The graphical displays of the wind products are available and explained on the web: see the links on http://www.knmi.nl/scatterometer/.

The OSI SAF wind product is stored in exactly the same BUFR format as described in the SeaWinds BUFR manual from NOAA [Ref-18], a list of descriptors (fields) contained in each WVC is provided in section 9. Data are organised in files containing approximately one orbit (100 minutes) of data.

The file name convention for the level 2 BUFR product is

S1L2BYYYYDDD_SSSSS_EEEEE.bufr

- YYYYDDD denotes the acquisition date (year and day of year) of the first data in the file
- SSSSS is the orbit number of the first data in the file
- EEEEE is the orbit number of the last data in the file

An example of a file name is S1L2B2011341_11684_11685.bufr.

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, representing KNMI.
- The products contain up to four ambiguous wind solutions, with an index to the selected wind solution. After the wind inversion step, we initially store the up to four solutions corresponding to the inversion residual (MLE) relative minima. However, subsequently the wind speed and wind direction of the after 2DVAR-selected MSS wind solution is put at the index of the selected wind solution. This index is set to the initial wind vector solution which is closest to the MSS wind vector selection obtained after 2DVAR. Thus, the former wind vector is not provided in the product, but rather the MSS selected wind vector. The ‘Formal Uncertainty in Wind Direction’ does not contain the uncertainty, but the normalised inversion residual (referred to as Rn in [Ref-3]).
- 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 Quality Control (including rain)	6	10
Variational QC	7	9
Land presence	8	8
Ice presence	9	7
Not used	10	6
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

Description	BUFR bit	Fortran bit
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 QC flag is set in a WVC, then the backscatter information is not useable for various geophysical reasons like rain, confused sea-state etc, resulting in a too large inversion residual. WVCs in which the KNMI QC flag is set, are not used in the calculation of the analysis field in the ambiguity removal step. However, after the ambiguity removal the wind solution closest to the analysis field is chosen (if wind solutions are present in the WVC). This means that such a WVC may contain a selected wind solution, but it is suspect.

Land presence flag is set if a land fraction (see section 4.3) larger than zero is calculated for the WVC. As long as the land fraction is below the limit value, a reliable wind solution may however still be present.

Ice presence flag is set if the SST calculated for the WVC (see section 4.3) is below 272.16 (-1.0 °C). No winds are computed in this WVC.

If the variational QC flag is set, the wind vector in the WVC is rejected during ambiguity removal due to spatial inconsistency. A wind solution is present, but it may be suspect.

It is recommended not to use WVCs with the monitoring flag, the KNMI quality control flag or the variational quality control flag set. See section 7.2 for more information on product reliability.

7. Data quality

7.1. Accuracy

As introduced in section 6.1, the accuracy should be better than 2 m/s in wind component RMS with a bias of less than 0.5 m/s in wind speed.

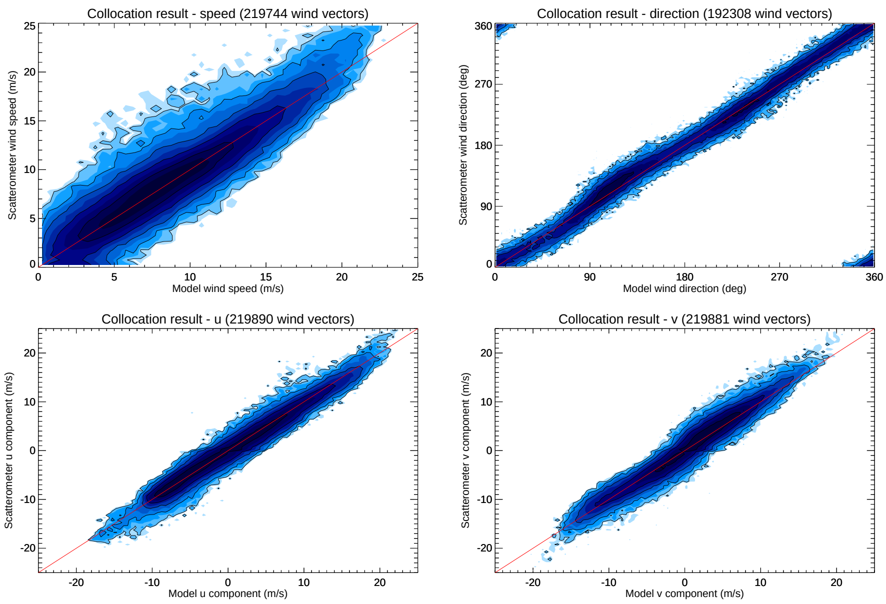

Figure 5: *Contoured histograms of the 50-km OSCAT wind product.*

Figure 5 shows two-dimensional histograms of the retrieved winds versus ECMWF 10m wind background for the 50-km wind product, with the backscatter calibration (see section 4.2) applied and after rejection of Quality Controlled (KNMI QC flagged) wind vectors. The data for these plots are from 20 consecutive orbits from 2 and 3 September 2011 (level 2a data version 1.3).

The top left plot corresponds to wind speed (bins of 0.5 m/s) and the top right plot to wind direction (bins of 2.5°). The latter are computed for ECMWF winds larger than 4 m/s. The bottom plots show the *u* and *v* wind component statistics (bins of 0.5 m/s). The contour lines are in logarithmic scale. Note that the ECMWF winds are real 10m winds, whereas the scatterometer winds are equivalent neutral 10m winds, which are on average 0.2 m/s higher.

From these results, it is clear that the spread in the distributions is small. The wind speed bias is quite small and we obtain wind component standard deviations of 1.30 in *u* and 1.35 in *v* directions.

7.2. Reliability and data use

For global coverage products, it is possible to generate a product monitoring flag, based on a multi-step check. If in one product the number of WVC Quality Control rejections, the mean residual, or the wind speed bias with respect to the NWP background is above certain threshold values, then the monitoring event flag is raised since the product is suspicious. The threshold values are based on evaluation of the product statistics over a long period [Ref-17]. This monitoring mechanism will be implemented in the future as soon as enough historic data are available.

7.3. Ambiguity selection

A version of 2DVAR is used with minimal regional performance differences [Ref-17]. This improved version was obtained after taking into account the findings of [Ref-13]. A variational QC step is performed to reject a few WVCs, which are in meteorological unbalance with their neighbours. The variational QC flagged WVCs are flagged in the output product.

8. Glossary

2DVAR	Two-dimensional Variational Ambiguity Removal
AR	Ambiguity Removal
ASCAT	Advanced Scatterometer
BUFR	Binary Universal Format Representation
ERS	European Remote-Sensing Satellite
EUMETCast	EUMETSAT’s Digital Video Broadcast Data Distribution System
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
HDF	Hierarchical Data Format
JPL	Jet Propulsion Laboratory (NASA)
KNMI	Royal Netherlands Meteorological Institute
NASA	National (US) Air and Space Agency
NetCDF	Network Common Data Form
NOAA	(US) National Oceanic and Atmospheric Administration
NSCAT	NASA Scatterometer
NWP	Numerical Weather Prediction
OSCAT	Indian Scatterometer on-board the Oceansat-2 satellite
OSI SAF	Ocean and Sea Ice SAF
OWDP	OSCAT Wind Data Processor
PO.DAAC	Physical Oceanography Distributed Active Archive Center
QC	Quality Control
QuikSCAT	US dedicated scatterometer mission
RMDCN	Regional Meteorological Data Communication Network
SAF	Satellite Application Facility
SeaWinds	US scatterometer on-board QuikSCAT platform
SST	Sea Surface Temperature
U	West-to-east wind component
UMARF	EUMETSAT Unified Meteorological Archive and Retrieval Facility
V	South-to-north wind component
WVC	Wind Vector Cell

9. BUFR data descriptors

The BUFR format used for the OSCAT data is identical to the format which is used for SeaWinds data.

Number	Descriptor	Parameter	Unit
001	(01007)	Satellite Identifier	Code Table
002	(01012)	Direction of Flight	Degree True
003	(02048)	Satellite Instrument Identifier	Code Table
004	(21119)	Wind Scatterometer GMF	Code Table
005	(25060)	Software Identification	Numeric
006	(02026)	Cross Track Resolution	m
007	(02027)	Along Track Resolution	m
008	(05040)	Orbit Number	Numeric
009	(04001)	Year	Year
010	(04002)	Month	Month
011	(04003)	Day	Day
012	(04004)	Hour	Hour
013	(04005)	Minute	Minute
014	(04006)	Second	Second
015	(05002)	Latitude (Coarse Accuracy)	Degree
016	(06002)	Longitude (Coarse Accuracy)	Degree
017	(08025)	Time Difference Qualifier	Code Table
018	(04001)	Time to Edge	Second
019	(05034)	Along Track Row Number	Numeric
020	(06034)	Cross Track Cell Number	Numeric
021	(21109)	Seawinds Wind Vector Cell Quality Flag	Flag Table
022	(11081)	Model Wind Direction At 10 M	Degree True
023	(11082)	Model Wind Speed At 10 M	m/s
024	(21101)	Number of Vector Ambiguities	Numeric
025	(21102)	Index of Selected Wind Vector	Numeric
026	(21103)	Total Number of Sigma0 Measurements	Numeric
027	(21120)	Seawinds Probability of Rain	Numeric
028	(21121)	Seawinds NOF Rain Index	Numeric
029	(13055)	Intensity Of Precipitation	kg/m**2/sec
030	(21122)	Attenuation Correction On Sigma-0 (from Tb)	dB
031	(11012)	Wind Speed At 10 M	m/s
032	(11052)	Formal Uncertainty In Wind Speed	m/s
033	(11011)	Wind Direction At 10 M	Degree True
034	(11053)	Formal Uncertainty In Wind Direction	Degree True
035	(21104)	Likelihood Computed for Wind Solution	Numeric
036	(11012)	Wind Speed At 10 M	m/s
037	(11052)	Formal Uncertainty In Wind Speed	m/s
038	(11011)	Wind Direction At 10 M	Degree True
039	(11053)	Formal Uncertainty In Wind Direction	Degree True
040	(21104)	Likelihood Computed for Wind Solution	Numeric
041	(11012)	Wind Speed At 10 M	m/s
042	(11052)	Formal Uncertainty In Wind Speed	m/s
043	(11011)	Wind Direction At 10 M	Degree True
044	(11053)	Formal Uncertainty In Wind Direction	Degree True
045	(21104)	Likelihood Computed for Wind Solution	Numeric
046	(11012)	Wind Speed At 10 M	m/s
047	(11052)	Formal Uncertainty In Wind Speed	m/s
048	(11011)	Wind Direction At 10 M	Degree True

Number	Descriptor	Parameter	Unit
049	(11053)	Formal Uncertainty In Wind Direction	Degree True
050	(21104)	Likelihood Computed for Wind Solution	Numeric
051	(02104)	Antenna Polarisation	Code Table
052	(08022)	Total Number w.r.t. accumulation or average	Numeric
053	(12063)	Brightness Temperature	K
054	(12065)	Standard Deviation Brightness Temperature	K
055	(02104)	Antenna Polarisation	Code Table
056	(08022)	Total Number w.r.t. accumulation or average	Numeric
057	(12063)	Brightness Temperature	K
058	(12065)	Standard Deviation Brightness Temperature	K
059	(21110)	Number of Inner-Beam Sigma0 (fwd of sat.)	Numeric
060	(05002)	Latitude (Coarse Accuracy)	Degree
061	(06002)	Longitude (Coarse Accuracy)	Degree
062	(21118)	Attenuation Correction On Sigma-0	dB
063	(02112)	Radar Look (Azimuth) Angle	Degree
064	(02111)	Radar Incidence Angle	Degree
065	(02104)	Antenna Polarisation	Code Table
066	(21105)	Normalized Radar Cross Section	dB
067	(21106)	Kp Variance Coefficient (Alpha)	Numeric
068	(21107)	Kp Variance Coefficient (Beta)	Numeric
069	(21114)	Kp Variance Coefficient (Gamma)	dB
070	(21115)	Seawinds Sigma-0 Quality Flag	Flag Table
071	(21116)	Seawinds Sigma-0 Mode Flag	Flag Table
072	(08018)	Seawinds Land/Ice Surface Flag	Flag Table
073	(21117)	Sigma-0 Variance Quality Control	Numeric
074	(21111)	Number of Outer-Beam Sigma0 (fwd of sat.)	Numeric
075	(05002)	Latitude (Coarse Accuracy)	Degree
076	(06002)	Longitude (Coarse Accuracy)	Degree
077	(21118)	Attenuation Correction On Sigma-0	dB
078	(02112)	Radar Look (Azimuth) Angle	Degree
079	(02111)	Radar Incidence Angle	Degree
080	(02104)	Antenna Polarisation	Code Table
081	(21105)	Normalized Radar Cross Section	dB
082	(21106)	Kp Variance Coefficient (Alpha)	Numeric
083	(21107)	Kp Variance Coefficient (Beta)	Numeric
084	(21114)	Kp Variance Coefficient (Gamma)	dB
085	(21115)	Seawinds Sigma-0 Quality Flag	Flag Table
086	(21116)	Seawinds Sigma-0 Mode Flag	Flag Table
087	(08018)	Seawinds Land/Ice Surface Flag	Flag Table
088	(21117)	Sigma-0 Variance Quality Control	Numeric
089	(21112)	Number of Inner-Beam Sigma0 (aft of sat.)	Numeric
090	(05002)	Latitude (Coarse Accuracy)	Degree
091	(06002)	Longitude (Coarse Accuracy)	Degree
092	(21118)	Attenuation Correction On Sigma-0	dB
093	(02112)	Radar Look (Azimuth) Angle	Degree
094	(02111)	Radar Incidence Angle	Degree
095	(02104)	Antenna Polarisation	Code Table
096	(21105)	Normalized Radar Cross Section	dB
097	(21106)	Kp Variance Coefficient (Alpha)	Numeric
098	(21107)	Kp Variance Coefficient (Beta)	Numeric
099	(21114)	Kp Variance Coefficient (Gamma)	dB
100	(21115)	Seawinds Sigma-0 Quality Flag	Flag Table
101	(21116)	Seawinds Sigma-0 Mode Flag	Flag Table
102	(08018)	Seawinds Land/Ice Surface Flag	Flag Table
103	(21117)	Sigma-0 Variance Quality Control	Numeric

Number	Descriptor	Parameter	Unit
104	(21113)	Number of Outer-Beam Sigma0 (aft of sat.)	Numeric
105	(05002)	Latitude (Coarse Accuracy)	Degree
106	(06002)	Longitude (Coarse Accuracy)	Degree
107	(21118)	Attenuation Correction On Sigma-0	dB
108	(02112)	Radar Look (Azimuth) Angle	Degree
109	(02111)	Radar Incidence Angle	Degree
110	(02104)	Antenna Polarisation	Code Table
111	(21105)	Normalized Radar Cross Section	dB
112	(21106)	Kp Variance Coefficient (Alpha)	Numeric
113	(21107)	Kp Variance Coefficient (Beta)	Numeric
114	(21114)	Kp Variance Coefficient (Gamma)	dB
115	(21115)	Seawinds Sigma-0 Quality Flag	Flag Table
116	(21116)	Seawinds Sigma-0 Mode Flag	Flag Table
117	(08018)	Seawinds Land/Ice Surface Flag	Flag Table
118	(21117)	Sigma-0 Variance Quality Control	Numeric

10. NetCDF data format

The OSCAT wind products are also available in the NetCDF format, with the following characteristics:

- The data format meets the NetCDF Climate and Forecast Metadata Convention version 1.4 (http://cf-pcmdi.llnl.gov/).
- The data contain, contrary to the BUFR data, only level 2 wind and sea ice information, no sigma0 nor soil moisture information. The aim was to create a compact and easy to handle product for oceanographic and climatological users.
- The data contain only the selected wind solutions, no ambiguity information.
- The wind directions are in oceanographic rather than meteorological convention (see section 6.1)
- The format is identical for OSCAT, ASCAT, QuikSCAT and any other scatterometer data.
- The data has file sizes somewhat smaller than those of the corresponding BUFR data (e.g., one orbit file of 50-km wind data is 2.2 MB in BUFR and 1 MB in NetCDF). When compressed with gzip, the size of one file in NetCDF reduces to 300 kB.
- The NetCDF data in near real-time are only available on the KNMI FTP server, but EUMETCast dissemination can be considered on user request.

The file name convention for the gzipped NetCDF product is

S1L2BYYYYDDD_SSSSS_EEEEE.nc.gz where the meaning of the fields is identical to those in the BUFR file names (see section 6.2).

Below are some meta data contained in the NetCDF data files:

```
netcdf S1L2B2011346_11746_11747 {
dimensions:
    NUMROWS = 816 ;
    NUMCELLS = 36 ;
variables:
    int time(NUMROWS, NUMCELLS) ;
        time:long_name = "time" ;
        time:units = "seconds since 1990-01-01 00:00:00" ;
    int lat(NUMROWS, NUMCELLS) ;
        lat:long_name = "latitude" ;
        lat:units = "degrees_north" ;
    int lon(NUMROWS, NUMCELLS) ;
        lon:long_name = "longitude" ;
        lon:units = "degrees_east" ;
    short wvc_index(NUMROWS, NUMCELLS) ;
        wvc_index:long_name = "cross track wind vector cell number" ;
        wvc_index:units = "1" ;
    short model_speed(NUMROWS, NUMCELLS) ;
        model_speed:long_name = "model wind speed at 10 m" ;
        model_speed:units = "m s-1" ;
    short model_dir(NUMROWS, NUMCELLS) ;
        model_dir:long_name = "model wind direction at 10 m" ;
        model_dir:units = "degree" ;
    short ice_prob(NUMROWS, NUMCELLS) ;
        ice_prob:long_name = "ice probability" ;
        ice_prob:units = "1" ;
```

```
    short ice_age(NUMROWS, NUMCELLS) ;
        ice_age:long_name = "ice age (a-parameter)" ;
        ice_age:units = "dB" ;
    int wvc_quality_flag(NUMROWS, NUMCELLS) ;
        wvc_quality_flag:long_name = "wind vector cell quality" ;
        wvc_quality_flag:coordinates = "lat lon" ;
        wvc_quality_flag:flag_masks = 64, 128, 256, 512, 1024, 2048, 4096, 8192,
16384, 32768, 65536, 131072, 262144, 524288, 1048576, 2097152, 4194304 ;
        wvc_quality_flag:flag_meanings = "distance_to_gmf_too_large
data_are_redundant no_meteorological_background_used rain_detected
rain_flag_not_usable small_wind_less_than_or_equal_to_3_m_s
large_wind_greater_than_30_m_s wind_inversion_not_successful
some_portion_of_wvc_is_over_ice some_portion_of_wvc_is_over_land
variational_quality_control_fails knmi_quality_control_fails
product_monitoring_event_flag product_monitoring_not_used
any_beam_noise_content_above_threshold poor_azimuth_diversity
not_enough_good_sigma0_for_wind_retrieval" ;
    short wind_speed(NUMROWS, NUMCELLS) ;
        wind_speed:long_name = "wind speed at 10 m" ;
        wind_speed:units = "m s-1" ;
    short wind_dir(NUMROWS, NUMCELLS) ;
        wind_dir:long_name = "wind direction at 10 m" ;
        wind_dir:units = "degree" ;
    short bs_distance(NUMROWS, NUMCELLS) ;
        bs_distance:long_name = "backscatter distance" ;
        bs_distance:units = "1" ;

// global attributes:
    :title = "Oceansat-2 OSCAT Level 2 50.0 km Ocean Surface Wind Vector Product" ;
    :title_short_name = "OSCAT-L2-50km" ;
    :Conventions = "CF-1.4" ;
    :institution = "EUMETSAT/OSI SAF/KNMI" ;
    :source = "Oceansat-2 OSCAT" ;
    :software_identification_level_1 = 200 ;
    :instrument_calibration_version = 0 ;
    :software_identification_wind = 200 ;
    :pixel_size_on_horizontal = "50.0 km" ;
    :service_type = "N/A" ;
    :processing_type = "O" ;
    :contents = "ovw" ;
    :granule_name = "S1L2B2011346_11746_11747.nc" ;
    :processing_level = "L2" ;
    :orbit_number = 11746 ;
    :start_date = "2011-12-12" ;
    :start_time = "06:12:31" ;
    :stop_date = "2011-12-12" ;
    :stop_time = "07:52:13" ;
    :equator_crossing_longitude = " 272.310" ;
    :equator_crossing_date = "2011-12-12" ;
    :equator_crossing_time = "05:48:00" ;
    :rev_orbit_period = "5958.6" ;
    :orbit_inclination = "98.3" ;
    :history = "N/A" ;
    :references = "Oceansat-2 Wind Product User Manual, http://www.osi-saf.org/,
http://www.knmi.nl/scatterometer/" ;
    :comment = "Orbit period and inclination are constant values. All wind
directions in oceanographic convention (0 deg. flowing North)" ;
    :creation_date = "2011-12-12" ;
    :creation_time = "08:44:32" ;
```