Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

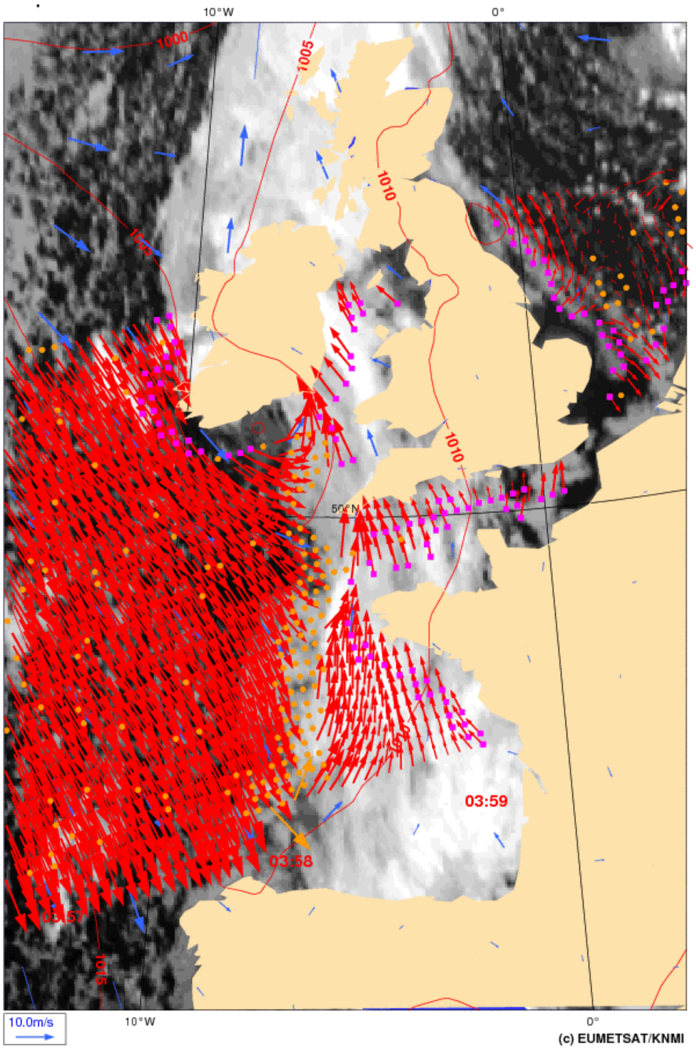
The EUMETSAT Network of Satellite Application Facilities

OSI SAF
Ocean and Sea Ice

EUMETSAT

Ocean and Sea Ice SAF

RapidScat wind Product User Manual



25 and 50 km wind products (OSI-109)

Version 1.1, March 2015

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Cover illustration: RapidScat wind field over the Atlantic Ocean and western European seas at 25 km Wind Vector Cell (WVC) spacing on 20 January 2015, approximately 4:00 UTC, overlaid on a METEOSAT infrared satellite image at 3:45 UTC. The orange dots are rejected WVCs, most likely due to rain or confused sea state. The purple dots indicate WVCs for which the land flag is set. The blue arrows show a 3-hour forecast of the winds by the KNMI High-Resolution Limited Area Model (HiRLAM).

Contents

1. Introduction

1.1. Overview

RapidScat is mounted on the International Space Station (ISS) and the data are acquired at several ground stations. The National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) collects the data and produces two orbit-based 25 km level 2a scatterometer products with different timeliness. One product is available approximately 2 hours after the sensing time of the middle of an orbit file and contains approximately 80% of the theoretical data amount. The other product is available approximately 3 hours after the sensing time of the middle of an orbit file and contains approximately 98% of the theoretical data amount. Hence the user can choose between a timely, but less complete product and a less timely, but more complete product. The level 2a files from the 2 hours and 3 hours data streams are retrieved from JPL by KNMI and processed into 25 km and 50 km level 2 wind products. This results in four different available wind products; two timeliness's and two resolutions.

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). The Product Requirements Document [1] provides an overview of the committed products and their characteristics in the current OSI SAF project phase, the Service Specification Document [2] provides specifications and detailed information on the services committed towards the users by the OSI SAF in a given stage of the project.

KNMI is involved in the OSI SAF as the centre where the level 1 to level 2 scatterometer wind processing is carried out. This document is the Product User Manual to the RapidScat wind product. More general information on the 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. More information about this product can also be found on http://www.knmi.nl/scatterometer/.

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. This is extensively described in the Algorithm Theoretical Baseline Document, see [3].

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, Oceansat-2 and RapidScat 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).

The OSI SAF products are delivered on request through the KNMI FTP server 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.

This user manual outlines user information for the OSI SAF RapidScat winds on 25 km and 50 km grid spacing, OSI-109. Section 2 presents a brief description of the SeaWinds instrument, and section 3 gives an overview of the data processing configuration. Section 4 provides details on how to access the products. Detailed information on the file content and format is given in section 5. The product quality is elaborated in section 6 and in the validation report to these products [5].

1.2. Acknowledgement

JPL kindly provides the near-real time RapidScat level 2a data which are used as input for the OSI SAF wind products.

1.3. Disclaimer

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.

1.4. Useful links

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

Information on OSI SAF activities at KNMI: http://www.knmi.nl/scatterometer/osisaf/

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

NWP SAF website: http://nwpsaf.eu/

RapidScat visual products:
http://www.knmi.nl/scatterometer/rscat_nrt_25_prod/ (25 km 2 hours)

http://www.knmi.nl/scatterometer/rscat_del_25_prod/ (25 km 3 hours)

http://www.knmi.nl/scatterometer/rscat_del_50_prod/ (50 km 3 hours)

EUMETSAT Data Centre:
http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETSATDataCentre/index.html

RapidScat information on JPL web site: http://www.jpl.nasa.gov/missions/iss-rapidscat/

1.5. Limitations and remaining issues

1) There are gaps in the data due to interruptions in data transmission from the International Space Station. These gaps appear in particular over the Indian Ocean.

2) Entire orbits of data are also missing periodically due to events such as vehicle dockings or astronaut/cosmonaut space-walks that require the RapidScat to stop operations. An overview of past and planned events can be found under ‘RapidScat scheduled outages’ in the web product viewers.

1.6. History of product changes

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

08-Dec-2014	First development version of RapidScat global wind product. PenWP version is 1_9_01.
20-Jan-2015	Change in backscatter corrections resulting in small wind speed reduction; quality control improvement. PenWP version is 1_9_02.

2. The RapidScat scatterometer

The RapidScat scatterometer instrument is a speedy and cost-effective replacement for the NASA QuikSCAT satellite, which provided a decade-long ocean vector wind observations used in, a.o., oceanography, Numerical Weather Prediction (NWP) and nowcasting. QuikSCAT's measurements were essential and when the satellite stopped collecting continuous swath-based wind data in late 2009, NASA was challenged to quickly and cost-effectively conceive of a replacement. NASA's Jet Propulsion Laboratory and the agency's station program came up with a solution that uses the framework of the International Space Station (ISS) and reuses hardware originally built to test parts of QuikSCAT, to create an instrument for a fraction of the cost and time it would take to build and launch a new satellite.

RapidScat was launched on 20 September 2014 and mounted on the International Space Station. The altitude of the space station’s orbit is 375 to 435 kilometres, and its inclination is 51.6°. The observation swath of approximately 1100 kilometres covers the majority of the oceans between 56° north and south latitude in 48 hours. The orbit, which is not sun-synchronous, gives different overpass times for each day and as such allows cross-calibration with other instruments on polar satellites, like ASCAT and HY-2A. For detailed information on the RapidScat instrument and data we refer to [6] and [7]. A brief description is given below.

The RapidScat instrument is a conically scanning pencil-beam scatterometer. It uses a 0.75-meter dish antenna rotating at 18 rpm with two “spot” beams on the ground, a horizontal polarisation beam (HH) and a vertical polarisation beam (VV) at incidence angles of 49º and 56º, respectively. The beams sweep the surface in a circular pattern as depicted in Figure 1. The ground swath of the HH beam is approximately 900 km wide and the ground swath of the VV beam is approximately 1100 km wide. Due to the conical scanning, a Wind Vector Cell (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 WVC.

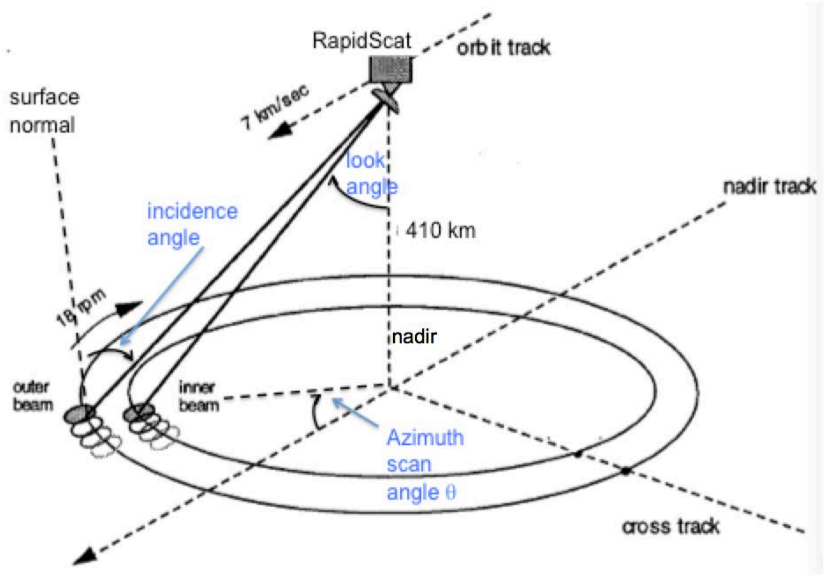

Figure 1: RapidScat pencil beam geometry (source: JPL web site).

The wind retrieval from RapidScat data is not trivial. In contrast with side-looking scatterometers like ASCAT, the number of measurements and the beam azimuth angles vary with the sub-satellite cross-track location. The wind retrieval skill will therefore depend on the position in the swath. A detailed discussion is provided in [3]. Here we only summarise some issues specific to RapidScat.

In the outer swath (where only VV beam data are available), the individual backscatter measurements (‘eggs’) contributing to the VV fore or aft beam in a specific WVC are re-distributed to form four more or less independent backscatter observations. Eggs are accumulated and averaged based on their azimuth angles. The outer swath winds have slightly reduced quality but they are still very well usable. These winds are flagged in the product and can be filtered out easily if requested, see section 5.2.

The RapidScat scatterometer operates at a Ku-band radar wavelength (13.5 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 (QC) step. Wind-rain discrimination is easiest to manage in the sweet swath, but still performs acceptably in nadir and outer swath.

The processing algorithms for the RapidScat wind processing are heavily based on the algorithms as developed for SeaWinds on QuikSCAT and OSCAT on Oceansat-2 [3]. [3]. When calibrated geophysical backscatter measurements are available, the wind processing of the different Ku-band pencil-beam scatterometers is very similar. The wind processing software which is used, the Pencil beam Wind Processor (PenWP), is the successor of the SeaWinds Data Processor (SDP) and the OSCAT Wind Data Processor (OWDP). PenWP is capable to process data from SeaWinds, OSCAT, RapidScat and HY-2A scatterometers and will eventually replace all former pencil beam Ku-band wind processing software packages in the NWP SAF.

Differences between the various rotating pencil beam scatterometers are to a great extent on a technical (data formats and handling) level. Moreover, due to different orbits and antenna geometries, incidence angles differ. PenWP utilises the NSCAT-4 Geophysical Model Function (GMF) [3], which is available for all prevailing incidence angles. In order to handle instrument differences well, particularly noise characteristics, some parts of the processing were re-tuned for RapidScat, mainly the normalisation of the Maximum Likelihood Estimator (MLE) and the tuning of the Quality Control [4].

3. Processing scheme

KNMI has a processing chain running in near-real time with RapidScat data, including visualisation on the internet. The processing software is developed in the NWP SAF and runs in the KNMI operational environment. The processing includes monitoring and archiving functionalities. General information about the scatterometer wind processing algorithms can be found in the Algorithm Theoretical Basis Document (ATBD) [3].

3.1. Backscatter egg averaging

The level 2a backscatter data from JPL are organised in eggs, each σ^0 is based on the sum of the echo energies measured among the eight centre high resolution slices in a single scatterometer pulse. The eggs are beam-wise accumulated to a WVC level before wind inversion is done. The egg weights are proportional to the estimated transmitted power contained in an egg, i.e., inversely proportional to the Kp value. The Sigma0 Quality Flag present in the level 2a data is evaluated and egg data with one of the following flags set are skipped:

- Bit 0: Measurement not usable
- Bit 1: Signal to Noise Ratio level low
- Bit 3: Data outside acceptable range
- Bit 4: Pulse quality unacceptable
- Bit 5: Location algorithm does not converge
- Bit 6: Frequency shift beyond range
- Bit 7: Temperature outside range
- Bit 8: No applicable attitude records
- Bit 9: Ephemeris data unacceptable

3.2. Backscatter calibration

No absolute instrumental instrument calibration exists for Ku-band pencil-beam scatterometers. Ku-band pencil-beam backscatter distributions should however be matched to achieve wind intercalibration of all space-borne scatterometer instruments. We thus developed methods that calibrate the winds of each scatterometer effectively to the mean winds at collocated moored buoys. No signs of azimuth (or WVC) dependent instrument biases have been found for RapidScat. Also the beam incidence angles are constant and hence we have chosen to apply backscatter corrections that are only dependent on the beam polarisation. The goal of applying backscatter corrections was to minimise wind speed biases between scatterometer winds on the one hand and buoy and NWP winds on the other hand. With this in mind, the calibration correction for VV has been obtained by looking at the outer swath data (where no HH data are available) and choosing a calibration amount that yields minimum wind speed biases. Subsequently, the swath part containing both HH and VV was considered, the VV correction was applied and a HH correction was obtained that again yields minimum biases. In this simple way, within a few iterations the two calibration coefficients could be obtained:

- For HH, 0.45 dB has been added in the 25 km products and 0.38 dB in the 50 km products
- For VV, 0.45 dB has been added in the 25 km products and 0.38 dB in the 50 km products

Note that the calibrated backscatter values are only available within the wind processing software; the σ^0 data in the BUFR wind product are uncorrected values.

3.3. 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 bi-linearly 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 -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 °, we keep some margin to prevent any ice contamination in the wind computation. Note that, due to the ISS orbit, data will not be acquired close to the poles. However, frozen seas will also occur at lower latitudes in the winter season, e.g. near Newfoundland and east of Russia.

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 50 km (60 km in the 50 km products) of the WVC centre is calculated. The weight of each grid point scales with 1/r2, 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 quadratically interpolated with respect to time and linearly interpolated with respect to location and put into the level 2 information part of each WVC (see section 5.2). Note that the ECMWF winds stored in the wind products are real winds rather than equivalent neutral winds.

3.4. Quality control and monitoring

In each WVC, the σ^0 data is checked for quality and completeness and the inversion residual [3] is checked. Degraded WVCs are flagged; see section 5.2 for more details.

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 have been produced to visually display the confidence levels of the products and their evolution with time. Any deviations from nominal behaviour would be immediately visible as steps in these graphs. Data quality is also available to the users within the products; see section 5 for a description of quality flags.

4. Helpdesk and data availability

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.

The BUFR products are disseminated on EUMETCast. Please consult http://www.eumetsat.int/, under 'Access to Data' for more information on EUMETCast dissemination and how to receive these and other EUMETSAT meteorological satellite products, or contact ops@eumetsat.int.

The BUFR and NetCDF products are also made available on a password-protected ftp site (data from the last three days only). The access details are provided to new users by email request. Please send your requests to scat@knmi.nl.

The four products can be distinguished w.r.t. timeliness and product swath grid spacing by their file names, see section 5.2.

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

~~The products are available (after registration) from the EUMETSAT Data Centre, http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETSATDataCentre/index.html~~. KNMI also keeps an off line archive of the products. You can send a request to scat@knmi.nl.

5. Data description

5.1. Wind product characteristics

Physical definition

Horizontal equivalent neutral wind vector at 10 m height, obtained using the NSCAT-4 GMF, see [3].

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 [3]. In the BUFR products, the wind direction is in *meteorological* (World Meteorological Organisation, 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 RapidScat level 2a input data [7] are kindly provided by NASA's JPL. These 'Surface Flagged Sigma0s and Attenuations in 25 km Swath Grid' data are so-called egg data, each σ^0 is based on the sum of the echo energies measured among the eight centre high resolution slices in a single scatterometer pulse. The product contains geo-located backscatter measurements on a satellite swath WVC grid of 25 km size.

Geographical definition

The altitude of the International Space Station's orbit is 375 to 435 kilometres, and its inclination is 51.6°. The observation swath of approximately 1100 kilometres covers the majority of the ocean between 56° north and south latitude in 48 hours. The orbit is not sun-synchronous. Swath width is 42 25 km size WVCs or 21 50 km size WVCs. Depending on the ISS orbit height, the leftmost and rightmost WVCs may be empty in the 25 km product. Products are organised in files containing one orbit, starting at the southernmost location of the orbits.

Output product

The input product in HDF 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.

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 [9]. 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 standard deviation smaller than 2 m/s and a bias of less than 0.5 m/s in wind speed. More validation information is available in [5], showing that the actual products are much more accurate.

5.2. 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 OSI SAF wind product is stored in exactly the same BUFR format as described in the SeaWinds BUFR manual from NOAA [8], a list of descriptors (fields) contained in each WVC is provided in section 9. Data are organised in files containing approximately one orbit (93 minutes) of data.

File name conventions

The file name convention for the level 2 BUFR product on the KNMI FTP server is

rapid_YYYYMMDD_HHMMSS_iss____ORBIT(_SRV)_T_SMPL_CONT_l2.bufr

- YYYYMMDD denotes the acquisition date (year, month and day) of the first data in the file
- HHMMSS denotes the acquisition time (hour, minute and second) of the first data in the file

- ORBIT is the orbit number of the first data in the file (00000-99999)
- SRV (optional field) is the service, it is missing for the 3 hours product and set to 2hr for the 2 hours product.
- T is the processing type (o for operational, t for test)
- SMPL is the WVC sampling (cell spacing): 250 for the 25 km and 500 for the 50 km product
- CONT refers to the product contents: always ovw for a product containing Ocean Vector Winds

Examples of file names are

rapid_20150120_031543_iss____01843_o_250_ovw_l2.bufr for a 25 km 3 hours product

rapid_20150120_031543_iss____01843_2hr_o_500_ovw_l2.bufr for a 50 km 2 hours product

The file names on EUMETCast are different from those on the FTP server and according to the WMO conventions

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,ISS+RAPIDSCAT_C_EHDB_YYYYMMDDHHMMSS_ORBIT(_SRV)_T_SMPL_CONT_l2.bin

The meaning of the acronyms in the file names is the same as for the files on FTP. Example file names are

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,ISS+RAPIDSCAT_C_EHDB_20150120031543_01843_o_250_ovw_l2.bin

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,ISS+RAPIDSCAT_C_EHDB_20150120031543_01843_2hr_o_500_ovw_l2.bin

File contents

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 (Maximum Likelihood Estimator, MLE) relative minima. However, subsequently the wind speed and wind direction of the after 2DVAR-selected Multiple Solution Scheme (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 [10]).
- 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	14
VV polarised data in more than two beams	3	13
Product monitoring not used	4	12
Product monitoring flag	5	11
KNMI Quality Control (including rain) data rejection	6	10
Variational QC data rejection	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.

The flag indicating that more than two beams contain VV polarised data, BUFR bit 3, is active in the outer part of the swath (WVCs 1-5 and 38-42 at 25 km, WVCs 1-2 and 20-21 at 50 km). It indicates that outer beam data is used to obtain four independent σ^0 values, contrary to the middle part of the swath where two beams contain VV (outer beam) data and two beams contain HH (inner beam) data. In the outer parts of the swath, the VV backscatter data present in the level 2a product are distributed to two WVC beams based on their azimuth angle such that maximum azimuth dispersion is obtained. This generally results in slightly less optimal wind retrieval; users assimilating the data into NWP models may consider to reject WVCs for which this flag is set.

If the ‘product monitoring not used’ bit is set to zero, the product is monitored. If the product is monitored and the ‘product monitoring flag’ bit is set to zero, the product is valid; otherwise it is rejected by the product monitoring [3]. This is based on a statistical check of the number of WVC QC rejections, the wind speed bias with respect to the NWP background, and the wind vector RMS difference with respect to the NWP background. The product monitoring bits have the same value 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.

The land presence flag is set if a land fraction (see section 3.3) 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 so there is normally no reason to reject WVCs with the land flag set.

Ice presence flag is set if the SST calculated for the WVC (see section 3.3) is below -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 KNMI quality control flag or the variational quality control flag set. See [3] for more information on product reliability.

6. Data quality

As stated in the OSI SAF product requirements [1], the accuracy should be better than 2 m/s in wind component standard deviation with a bias of less than 0.5 m/s in wind speed.

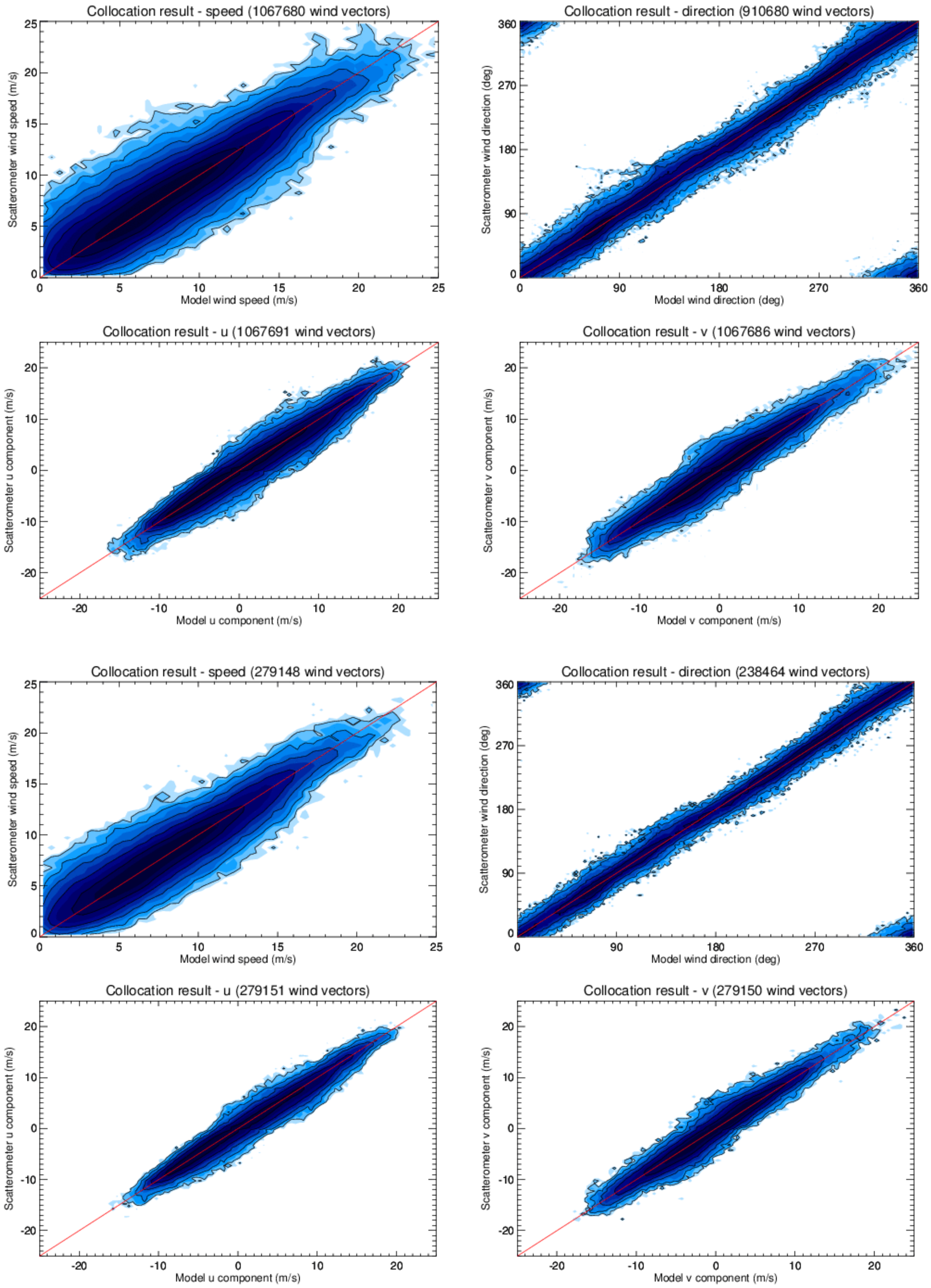

Figure 2: Two-dimensional histograms of wind speed, direction (w.r.t. wind coming from the North), *u* and *v* components of 25 km (top) and 50 km (bottom) RapidScat wind product versus the ECMWF model forecast winds from 25 and 26 January 2015.

Figure 2 shows two-dimensional histograms of the retrieved winds versus ECMWF 10 m wind background for the 25 km and 50 km wind product, after rejection of Quality Controlled (KNMI QC flagged) wind vectors. The top left plot in each panel 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 only 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 10 m winds, whereas the scatterometer winds are equivalent neutral 10 m 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 0.11 m/s for 25 km and 50 km, close to the expected value of 0.2 m/s. The wind component standard deviations are below 1.3 m/s for the 25 km product and below 1.2 m/s for the 50 km product. Much more validation information can be found in [5].

7. References

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[9] Thesis *Scatterometry* by Ad Stoffelen, 1998 (*)

[10] Thesis *Wind Field Retrieval from Satellite radar systems* by Marcos Portabella, 2002 (*)

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

8. Abbreviations and acronyms

2DVAR	Two-dimensional Variational Ambiguity Removal
ATBD	Algorithm Theoretical Basis Document
AR	Ambiguity Removal
ASCAT	Advanced Scatterometer
BUFR	Binary Universal Format Representation
DLI	Downward Long wave Irradiance
ECMWF	European Centre for Medium-Range Weather Forecasts
ERS	European Remote-Sensing Satellite
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GMF	Geophysical Model Function
HDF	Hierarchical Data Format
HH	Horizontal polarisation of sending and receiving radar antennas
ISS	International Space Station
JPL	Jet Propulsion Laboratory
KNMI	Royal Netherlands Meteorological Institute
MLE	Maximum Likelihood Estimator
MSS	Multiple Solution Scheme
NASA	National Aeronautics and Space Administration (USA)
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration (USA)
NSCAT	NASA Scatterometer
NWP	Numerical Weather Prediction
OSI SAF	Ocean and Sea Ice SAF
OWDP	OSCAT Wind Data Processor
PenWP	Pencil beam Wind Processor
RMDCN	Regional Meteorological Data Communication Network
QC	Quality Control
QuikSCAT	US Quick Scatterometer mission carrying the SeaWinds scatterometer
SAF	Satellite Application Facility
SDP	SeaWinds Data Processor
SeaWinds	Scatterometer on-board QuikSCAT platform (USA)
SSI	Surface Solar Irradiance
SST	Sea Surface Temperature
u	West-to-east (zonal) wind component
v	South-to-north (meridional) wind component
VV	Vertical polarisation of sending and receiving radar antennas
WMO	World Meteorological Organisation
WVC	Wind Vector Cell

9. Appendix A: BUFR data descriptors

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
049	(11053)	Formal Uncertainty In Wind Direction	Degree True
050	(21104)	Likelihood Computed for Wind Solution	Numeric
051	(02104)	Antenna Polarisation	Code Table

Number	Descriptor	Parameter	Unit
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
104	(21113)	Number of Outer-Beam Sigma0 (aft of sat.)	Numeric
105	(05002)	Latitude (Coarse Accuracy)	Degree
106	(06002)	Longitude (Coarse Accuracy)	Degree

Number	Descriptor	Parameter	Unit
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. Appendix B: NetCDF data format

The 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 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 5.1)
- The format is identical for SeaWinds, ASCAT 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 25 km wind data is 6.5 MB in BUFR and 2 MB in NetCDF). When compressed with gzip, the size of one file in NetCDF reduces to 0.7 MB.
- The number of cells per row for the 25 km product may be 41 or 42, depending on the orbit height which is variable for the space station.

The file name convention for the gzipped NetCDF product is

rapid_YYYYMMDD_HHMMSS_iss____ORBIT_T_SMPL_VERS_CONT_l2.nc.gz where the meaning of the fields is identical to those in the BUFR file names (see section 5.2). The VERS part of the file name denotes the PenWP software version. A file name example is:

rapid_20150121_053025_iss____01860_o_250_1902_ovw_l2.nc.gz.

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

```
dimensions:
        NUMROWS = 1624 ;
        NUMCELLS = 41 ;
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: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 = "ISS RapidScat Level 2 25.0 km Ocean Surface Wind Vector
Product" ;
                :title_short_name = "RSCAT-L2-25km" ;
                :Conventions = "CF-1.4" ;
                :institution = "EUMETSAT/OSI SAF/KNMI" ;
                :source = "ISS RapidScat" ;
                :software_identification_level_1 = 1902 ;
                :instrument_calibration_version = 0 ;
                :software_identification_wind = 1902 ;
                :pixel_size_on_horizontal = "25.0 km" ;
                :service_type = "N/A" ;
                :processing_type = "O" ;
                :contents = "ovw" ;
                :granule_name =
"rapid_20150121_053025_iss____01860_o_250_1902_ovw_l2.nc" ;
                :processing_level = "L2" ;
                :orbit_number = 1860 ;
                :start_date = "2015-01-21" ;
                :start_time = "05:30:25" ;
                :stop_date = "2015-01-21" ;
                :stop_time = "07:02:59" ;
                :equator_crossing_longitude = " 272.834" ;
                :equator_crossing_date = "2015-01-21" ;
                :equator_crossing_time = "04:20:49" ;
                :rev_orbit_period = "5567.1" ;
                :orbit_inclination = "51.6" ;
                :history = "N/A" ;
                :references = "RapidScat 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 = "2015-01-21" ;
                :creation_time = "08:50:39" ;
```