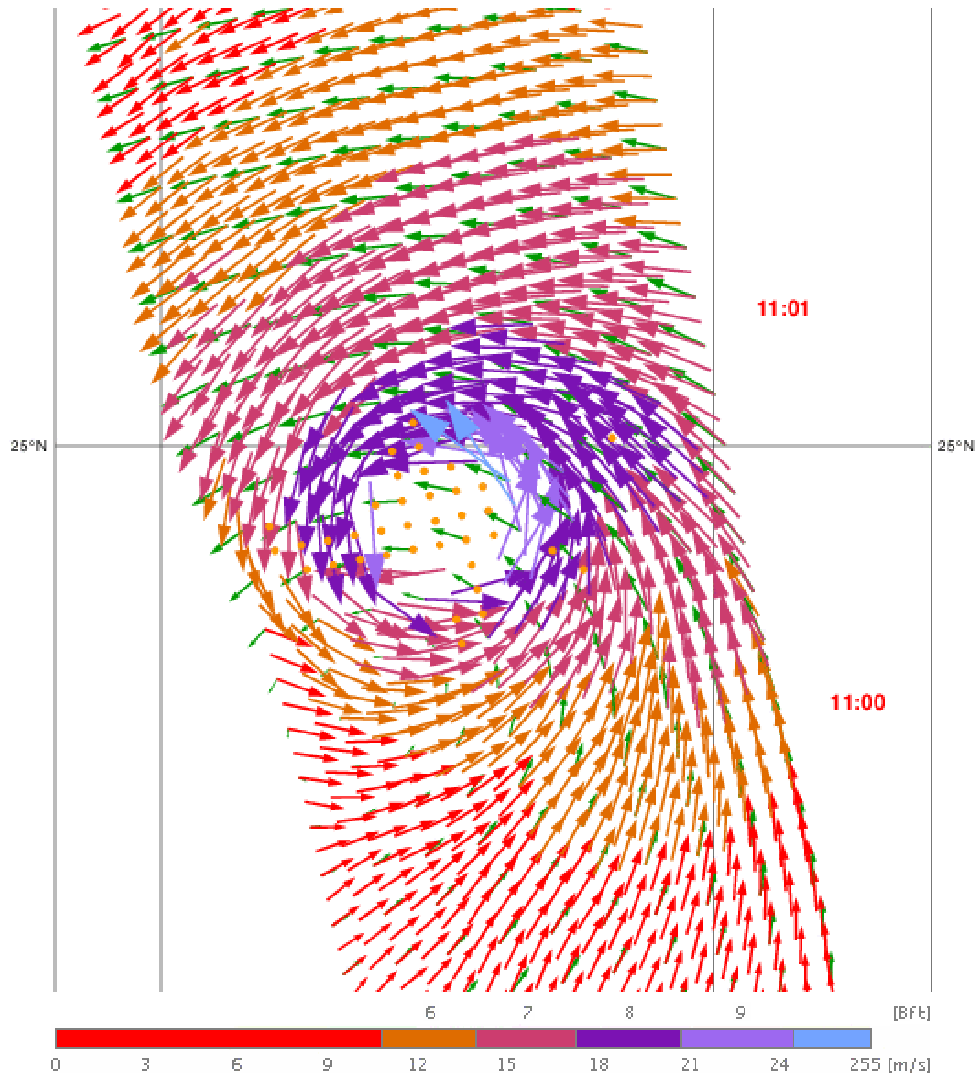
Ocean and Sea Ice SAF

ERS L2 winds Data Record Product User Manual



25 km level 2 wind products (OSI-152)

DOI: 10.15770/EUM_SAF_OSI_0009

Version 1.1, February 2017

DOCUMENT SIGNATURE TABLE

	Name	Date	Signature
Prepared by:	O&SI SAF Project Team	Feb 2017	
Approved by:	O&SI SAF Project Manager	Feb 2017	

DOCUMENTATION CHANGE RECORD

Issue / Revision	Date	Change	Description
Version 1.0	Dec 2016		First version
Version 1.1	Feb 2017	Minor	Changes resulting from comments in DRR

KNMI, De Bilt, the Netherlands
Reference: SAF/OSI/CDOP2/KNMI/TEC/MA/279

Cover illustration: ERS-1 wind field retrieved in the Pacific (24° N, 172° E) on 21 August 1993 at approximately 11:00 UTC. The scatterometer wind arrows are coloured according to their Beaufort force, the ECMWF ERA-Interim NWP winds are plotted in green. Orange dots indicate Wind Vector Cells flagged by the Quality Control due to e.g. heavy rain or confused sea state. Hurricane Keoni is clearly visible. In the NWP wind field the cyclonic structure is too weak and located at the wrong position, indicating that scatterometer winds may help to improve the wind field analysis.

Contents

1. Introduction 4
1.1. Overview 4
1.2. Disclaimer.... 4
1.3. Useful links.... 5
1.4. Limitations and remaining issues.... 5
2. The ERS scatterometer....6
3. Processing scheme 7
3.1. Input screening.... 7
3.2. Backscatter calibration 8
3.3. NWP collocation.... 8
3.4. Quality control and monitoring 8
4. Helpdesk and data availability.... 10
5. Data description.... 11
5.1. Wind product characteristics.... 11
5.2. File formats.... 11
6. References.... 14
7. Abbreviations and acronyms.... 16
8. Appendix A: BUFR data descriptors.... 17
9. Appendix B: NetCDF data format 19
10. Appendix C: Data gaps and number of files 22

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). 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 ERS wind scatterometer climate data record. 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 archived near-real time ERS-1 and ERS-2 UWI (User Wind Data) [4] files were taken from the KNMI tape archive. These data are a copy of the data available in the ECMWF MARS archive. The data span the following periods:

- ERS-1: 2 March 1992 to 2 June 1996
- ERS-2: 20 March 1996 to 15 January 2001

It was considered to use the ASPS (Advanced Scatterometer Processing System) data as reprocessed in the SCIRoCCo (SCatterometer InstRument Competence Centre, http://scirocco.sp.serco.eu) rather than the archived near-real time data for winds reprocessing. However, finally it was decided not to do this for two main reasons: firstly the ERS-1 reprocessed data were not yet released at the time the winds reprocessing started and secondly it appeared that the quality, characteristics and completeness of the ERS-2 ASPS data record did not differ significantly from the ERS-2 archived near-real time data.

The data have been processed using the ASCAT Wind Data Processor (AWDP) software version 3.0, as available in the NWP SAF [5]. The ambiguity removal and product monitoring are done using the ECMWF re-analysis (ERA) Interim winds rather than the archived ECMWF operational winds. The ERA-Interim winds are much more uniform over time than the operational winds. The OSI SAF Climate Data Records (CDRs) can be obtained from the EUMETSAT Data Centre.

This user manual outlines user information for the OSI SAF ERS Wind CDRs on 25 km grid spacing, OSI-152. Section 2 presents a brief description of the ERS 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 the validation report to this CDR [6].

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. 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/

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

ESA ERS Scatterometer information pages:

https://earth.esa.int/web/sppa/mission-performance/esa-missions/ers-1/scatterometer/sensor-description and

https://earth.esa.int/web/sppa/mission-performance/esa-missions/ers-2/scatterometer/sensor-description

ESA SCIRoCCo project: http://scirocco.sp.serco.eu/

1.4. Limitations and remaining issues

None currently known.

2. The ERS scatterometer

The Active Microwave Instrument (AMI, see the links to the ESA website in section 1.3) is one of the instruments carried on-board the European Remote Sensing Satellites (ERS-1 and ERS-2) launched by the European Space Agency (ESA) on 17 July 1991 and 20 April 1995. Both satellites were in a sun-synchronous orbit with an inclination of 98.5° and a repeat cycle of 3 days or 35 days (about 100 minutes per orbit). The local sun time at ascending node was 22:30.

The AMI incorporates two separate radars, a Synthetic-Aperture Radar (SAR) operating in image or wave mode, and a Wind Scatterometer. The Earth's surface is illuminated by four antennas and backscattered energy is received either to derive data on wind fields and wave spectra, or to produce high resolution images. The operational requirements are such that each mode needs to be operated exclusively, but the Wind and Wave Modes are also capable of interleaved operation, in so-called 'Wind/Wave Mode'.

The Wind Mode uses three antennas to generate radar beams looking 45 degrees forward, sideways, and 45 degrees backwards with respect to the satellite's flight direction. These beams illuminate a 500 km-wide swath as the satellite moves along its orbit, and each provide measurements of radar backscatter from the sea surface on a 25 km grid. The result is three independent backscatter measurements for each grid point, obtained using the three different viewing directions and separated by a short time delay. As the backscatter depends on the sea surface roughness as a function of the wind speed and direction at the ocean surface, it is possible to calculate the surface wind speed and direction by using these 'triplets' within a mathematical model.

The instrument operates at a frequency of 5.3 GHz (C-band), which makes it rather insensitive to rain.

ERS-1 has been operational from 1991 to 2000 and ERS-2 from 1995 to 2011, although since beginning of 2001 there have been problems with the satellite gyroscopes and the on-board tape recorder. Since August 2003 until the end of the mission ESA has distributed regional Wind Scatterometer data from ERS-2 within the visibility of ESA ground stations over Europe, North Atlantic, the Arctic and North America. The periods used to generate the data records are shorter however since scatterometer data are not available over the whole mission lifetimes, see section 5 for a detailed overview of available periods. The CDR spans the period of March 1992 to January 2001 with an ERS-1/ERS-2 overlap period of March to June 1996, i.e., the period of regional ERS-2 coverage was not included. Also the cal/val period of ERS-2 (before 20th March 1996) was not included although good quality winds can probably obtained [11]. These periods will again be considered in a new reprocessing which is planned in the next OSI SAF phase.

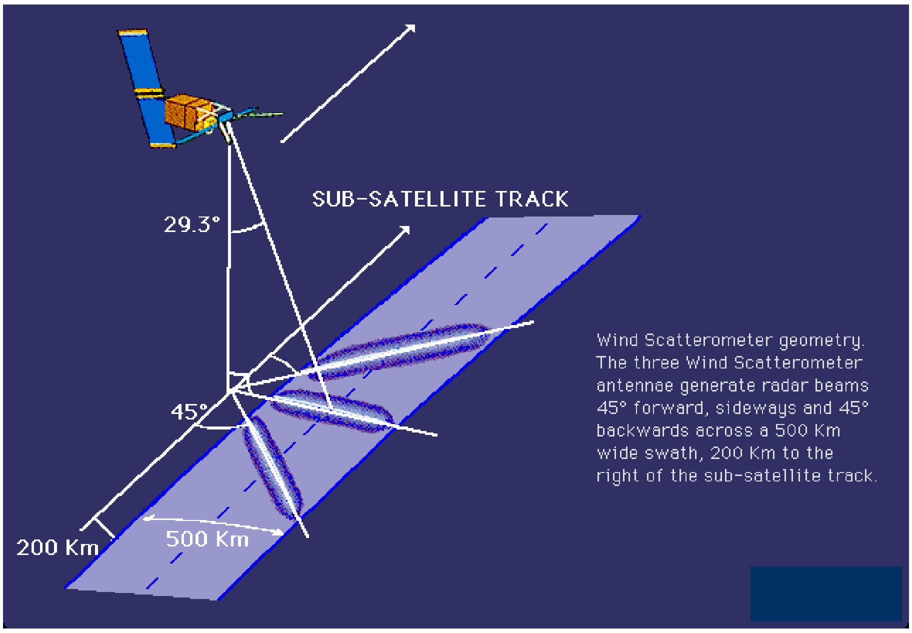


Figure 1: ERS wind scatterometer geometry (source: ESA web site).

3. Processing scheme

Figure 2 shows the system architecture to generate the wind data sets. The processing environment consists of a set of software components to collocate scatterometer data with ECMWF model data, to generate the wind data and to convert the output BUFR data into level 2 (swath) NetCDF data and level 3 (gridded to a regular lat/lon grid) NetCDF data. General information about the scatterometer wind processing algorithms can be found in the Algorithm Theoretical Basis Document (ATBD) [3].

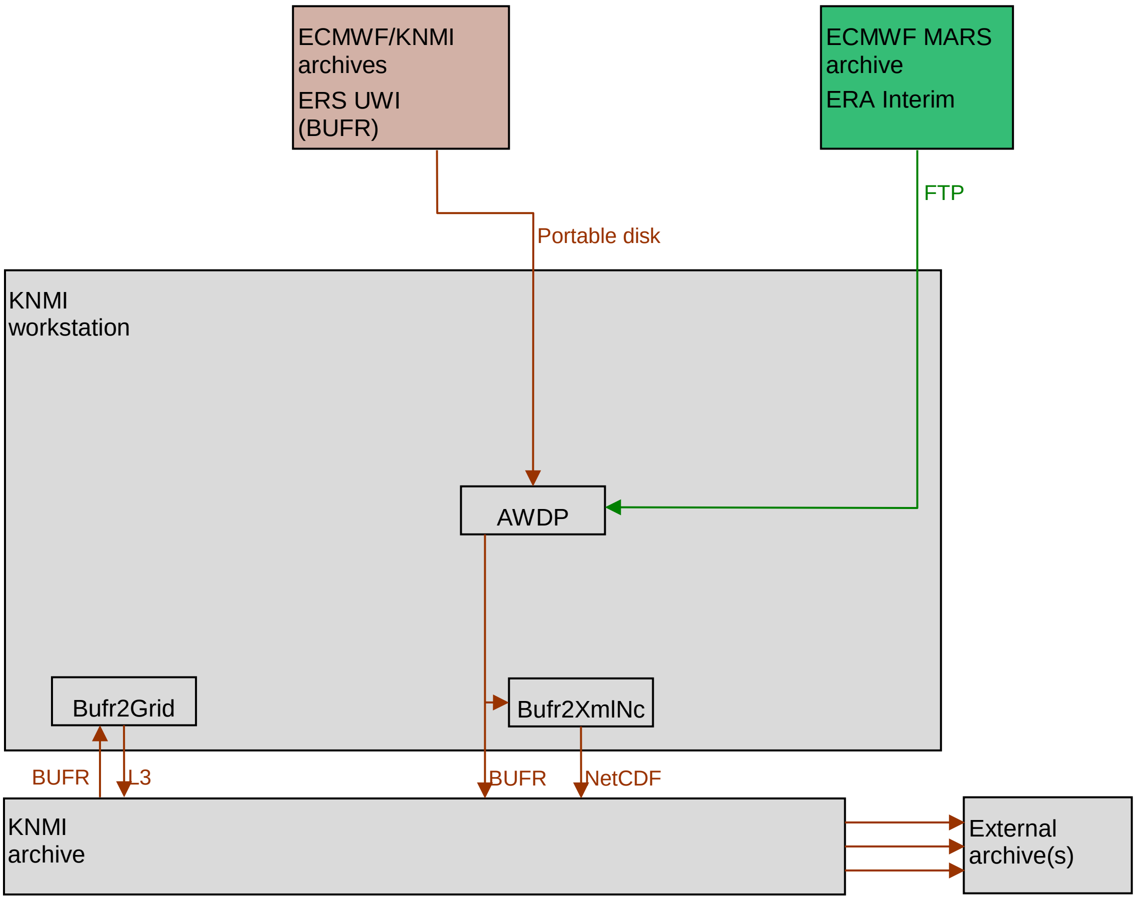


Figure 2: System architecture of reprocessing chain

The following components are shown in Figure 2.

- AWDP is the wind processing software for ASCAT and ERS data. It is publicly available in the NWP SAF, see [5].
- Bufr2XmlNc is a program to convert BUFR scatterometer data into level 2 NetCDF data. It is currently used in the near-real time OSI SAF processing.
- Bufr2Grid is a program to convert BUFR scatterometer data into level 3 NetCDF data. Two daily files are produced containing the ascending and descending parts of the orbits, respectively. It is currently used in the near-real time data processing for the Copernicus Marine Environment Service.

3.1. Input screening

Backscatter input products contain flags to denote anomalous (instrument) conditions, which are obviously checked before wind retrieval and no retrieval is done in WVCs where these flags are raised. The ERS Missing Packet Counters (MPC) and ERS ESA Quality Control flag [4] are evaluated in the BUFR input data. If the MPC value is below -18 or above 18, the beam information is rejected. The QC flags for beam arcing and frame checksum error are also evaluated and data are not used whenever these flags are set.

3.2. Backscatter calibration

The backscatter values in the input products are calibrated in two steps. First, a non-linear correction is applied which depends on beam and backscatter value. This correction ensures that the ERS backscatter values get the same distribution as those from ASCAT [7] which is considered as a reference. Second, a linear WVC and beam dependent bias in dB is added to the incoming σ^0s, the NWP Ocean Calibration (NOC). The calibration table was obtained by fitting the actual measurements to the theoretical GMF function. More details are provided in [8]. Note that the calibrated backscatter values are only available within the wind processing software; the σ^0 data in the wind product are identical to those in the input product.

During the ERS-1 and ERS-2 missions, several events and anomalies occurred which have led to changes in backscatter calibration [9], [10], [11]. NOC backscatter corrections have been obtained separately for the following periods:

- ERS-1 period 1: 2 March 1992 to 23 December 1993
- ERS-1 period 2: 24 December 1993 to 13 January 1994
- ERS-1 period 3: 14 January 1994 to 21 March 1995
- ERS-1 period 4: 22 March 1995 to 2 June 1996

- ERS-2 period 1: 20 March 1996 to 4 August 1996
- ERS-2 period 2: 6 August 1996 to 18 June 1997
- ERS-2 period 3: 19 June 1997 to 25 October 1998
- ERS-2 period 4: 26 October 1998 to 15 January 2001

3.3. NWP collocation

NWP forecast wind data are necessary in the ambiguity removal step of the processing. The scatterometer winds have been collocated with ERA-Interim wind data from ECMWF [12]. Stress equivalent (U10S) winds have been computed from the real ERA-Interim forecast 10m winds, sea surface temperature, air temperature, Charnock parameter and specific humidity, using a stand-alone implementation of the ECMWF model surface layer physics [13]. The equivalent neutral winds have been converted to stress equivalent winds (U10S) by multiplying by a correction factor of $\sqrt{(\rho/\langle\rho\rangle)}$, where ρ is the air density and $\langle\rho\rangle$ is the average air density (1.225 kg/m^3).

The correction factor follows from the fact that the surface roughness as measured by the scatterometer is more closely correlated with surface stress τ than with the actual wind speed at 10 m. The surface stress τ is proportional to the air density and to the square of the equivalent neutral 10 m wind. In order to make the NWP winds equivalent to the scatterometer winds, we need to apply a correction, i.e. multiply by the square root of the normalised density.

The air density is computed from the NWP model mean sea level pressure (*msl*), specific humidity (*q*) and air temperature (*T*) as $\rho = msl / (287.04 \times (1 + 0.6078 \times q) \times T)$ [14].

Wind forecasts are available twice a day (00 and 12 GMT analysis time) with forecast time steps of +3h, +6h, …, +18h. The model wind vector component data have been quadratically interpolated with respect to time and bi-linearly interpolated with respect to location and put into the level 2 information part of each WVC.

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 with excessive wind variability [15] are flagged; see section 5.2 for more details.

An information file is made for each product. The content of the file is identical for each 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. An example of such a graph is shown in Figure 3. It shows that the average MLE values are quite constant over time showing only some seasonal fluctuations. Data quality is also available to the users within the products; see section 5 for a description of quality flags. More information on the data quality and stability over time can be found in the validation report [6].

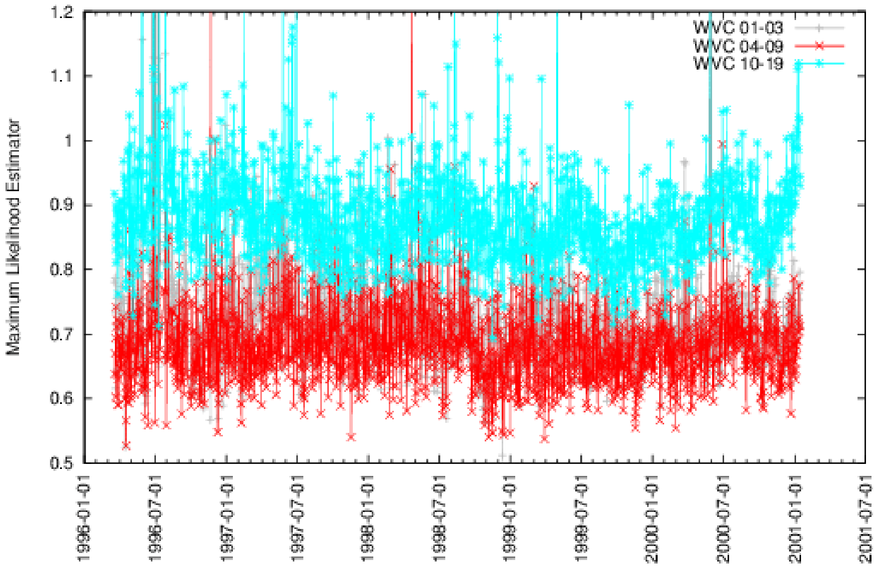


Figure 3: Daily average MLE values (1st rank wind solution) per group of WVCs (inner swath, mid swath and outer swath) of wind products over the entire reprocessing period of ERS-2.

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 (http://www.osi-saf.org/). You can also send an email to scat@knmi.nl.

A BUFR reader which is able to convert BUFR data into ASCII or NetCDF format is available at www.knmi.nl/scatterometer/bufr_reader/.

Unique Digital Object Identifiers (DOIs) are attached to the data records. A landing page containing the latest product availability information and documentation is connected to the DOI:

http://dx.doi.org/10.15770/EUM_SAF_OSI_0009

The products are available (after registration) from the EUMETSAT Data Centre, http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETSATDataCentre/index.html. The data sizes for the entire data set and per orbit file are listed in the table below. There are on average 14.33 ERS orbits per day, depending on the repeat cycle (43 orbits in 3 days or 501 orbits in 35 days).

Product	**Size of one orbit file**	**Size of 9 years data record**
25 km BUFR	1.1 MB	40 GB
25 km NetCDF (g-zipped)	320 kB	12 GB

5. Data description

5.1. Wind product characteristics

Physical definition

Horizontal stress equivalent wind vector at 10 m height, obtained using the CMOD7 GMF, see [16].

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 archived near-real time ERS 1 and ERS 2 UWI (User Wind Data) BUFR format data at 25 km swath grid were used to generate the 25 km wind product. The data were obtained from the KNMI archive and are a copy of the data in the ECMWF MARS archive. The data record covers the period from March 1992 to January 2001, see section 10 for an overview of missing data.

Geographical definition

The ERS satellites were in a near-polar sun synchronous orbit at 98 degrees inclination at approximately 780 km orbit height. The satellite swath is located to the right of the satellite ground track. The swath width is 19 25 km size WVCs, corresponding to 475 km. The data are organised in rows of 19 WVCs. Products are organised in files containing one orbit, starting at the ascending Equator pass.

Output product

The input products have been 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). See section 8 for an overview of the used descriptors in the BUFR data format. The products are also available in NetCDF format; see section 9 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 [17]. 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 [6], showing that the actual products are much more accurate. As compared to ECMWF model winds, the wind component standard deviations are approximately 1.7 to 1.9 m/s, with a wind speed bias of less than 0.2 m/s. As compared to buoy winds, the wind component standard deviations are approximately 1.8 m/s with a wind speed bias of less than 0.3 m/s.

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 file name convention for the level 2 BUFR product is

scatt_YYYYMMDD_HHMMSS_SAT_ORBIT_T_SMPL_CONT.l2.bufr or

OR1ERW025_YYYYMMDD_HHMMSS_ORBIT_ERSX.bufr (from the EUM Data Centre)

- 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
- SAT denotes the satellite name, ‘ers1__’ or ‘ers2__’ for this data record
- ERSX refers to the satellite name, ‘ERS1’ or ‘ERS2’

- ORBIT is the orbit number of the first data in the file (00000-99999)
- T is the processing type (‘o’ for operational)
- SMPL is the WVC sampling (cell spacing): it contains ‘250’ for the 25 km product
- CONT refers to the product contents: always ‘ovw’ for a product containing Ocean Vector Winds

File name examples are

scatt_19920826_193131_ers1___05828_o_250_ovw.l2.bufr or

OR1ERW025_19920826_193131_05828_ERS1.bufr (from EUM Data Centre)

The wind product is stored in the BUFR format as proposed for ASCAT and described in the WMO Manual on Codes, a list of descriptors (fields) contained in each WVC is provided in section 8.

The BUFR data contain three main sections: level 1 information (fields 1-62), level 2 Soil Moisture information (fields 63-82) and level 2 wind information (fields 83 and up). The reprocessed ERS wind products do not contain Soil Moisture information.

The NetCDF data have almost the same file name convention as the BUFR data, only the part ‘l2.bufr’ is replaced by ‘.l2.nc’, for example:

scatt_19920826_193131_ers1___05828_o_250_ovw.l2.nc or

OR1ERW025_19920826_193131_05828_ERS1.nc (from EUM Data Centre)

Contrary to the BUFR products, the NetCDF data do not contain backscatter information but only the level 2 wind (selected wind solution only) and sea ice information. They are intended to be an easy to handle wind-only product, see section 9.

Field 84 (‘Generating Application’) contains the value 91 which means that first guess model winds are used for ambiguity removal. The interpolated model winds are in the fields 85-86.

The Wind Vector Cell Quality Flag (field 89, table 021155) has the following definitions:

Description	**BUFR bit**	**Fortran bit**
Reserved	1	23
Not enough good sigma-0 available for wind retrieval	2	22
Poor azimuth diversity among sigma-0 for wind retrieval	3	21
Any beam noise content above threshold	4	20
Product monitoring not used	5	19
Product monitoring flag	6	18
KNMI quality control data rejection	7	17
Variational quality control data rejection	8	16
Some portion of wind vector cell is over land	9	15
Some portion of wind vector cell is over ice	10	14
Wind inversion not successful for wind vector cell	11	13
Reported wind speed is greater than 30 m/s	12	12
Reported wind speed is less than or equal to 3 m/s	13	11
Not used	14	10
Not used	15	9
No meteorological background used	16	8
Data are redundant	17	7
Distance to GMF too large	18	6
Reserved	19-23	5-1
Missing value	All 24 set	All 24 set

In Fortran, if the Wind Vector Cell Quality Flag is stored in an integer **I** then use **BTEST(I,NDW-NB)** to test BUFR bit **NB**, where **NDW**=24 is the width in bits of the data element in BUFR. The **BTEST** function is equivalent to **(I/2^NF) modulo 2** where **NF** is the Fortran bit number.

If the ‘product monitoring not used’ bit, Fortran bit 19, is set to zero, the product is monitored. If the product is monitored and the ‘product monitoring flag’ bit, Fortran bit 18, 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. Since all problematic data due to instrument issues already have been removed from the input data set, product monitoring rejection does not occur in these wind data records.

If the KNMI QC flag, Fortran bit 17, is set in a WVC this means that the backscatter information is of poor usability for various reasons, such as a too large inversion residual, or a too high noise value in the input product. 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, Fortran bit 15, is set if a land fraction (see section 3.2) 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.

The Bayesian ice screening algorithm as implemented in AWDP [18] was used when creating the CDRs. The ice presence flag, Fortran bit 14, is set if the Bayesian sea ice screening algorithm calculates ice for the WVC [3]. Note that the products contain wind solutions also over sea ice regions. These bogus winds are flagged both by the KNMI quality control flag and by the ice flag. Hence it is important to reject any winds with the KNMI quality control flag set when ingesting the products. Note that WVCs that are rejected due to a large inversion residual (e.g., in case of excessive local wind variability), only have the KNMI quality control flag set. On the other hand, WVCs that are rejected due to sea ice, have both the KNMI quality control flag and the ice flag set.

If the variational QC flag, Fortran bit 16, 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.

The ‘likelihood computed for solution’ (descriptor 021104) actually contains the $\log_{10}$ of the calculated likelihood for the wind solution. This is done since otherwise values close to zero will be rounded to zero in the BUFR encoding. In order to recalculate the probability, the user should compute 10 to the power <value from BUFR>.

6. References

[1] OSI SAF,
Product Requirements Document, version 3.7
SAF/OSI/CDOP2/M-F/MGT/PL/2-001, 2016

[2] OSI SAF,
Service Specification Document, version 2.9
SAF/OSI/CDOP2/M-F/MGT/PL/2-003, 2016

[3] OSI SAF,
Algorithm Theoretical Basis Document for the OSI SAF wind products, version 1.4
SAF/OSI/CDOP2/KNMI/SCI/MA/197, 2017 (*)

[4] Met Office, UK,
ERS Products, WMO FM94 BUFR format
ER-IS-UKM-GS-0001, Version 4, Issue 2, 16 February 2001

[5] Vogelzang, J., A. Verhoef, J. Verspeek, J. de Kloe and A. Stoffelen,
AWDP User Manual and Reference Guide, version 3.0
NWPSAF-KN-UD-005, 2016 (*)

[6] Verhoef, A., J. Vogelzang and A. Stoffelen,
ERS L2 winds Data Record validation report
SAF/OSI/CDOP2/KNMI/TEC/RP/278, 2016 (*)

[7] Belmonte Rivas, M., A. Stoffelen, J. Verspeek, A. Verhoef, X. Neyt and C. Anderson
Cone metrics: a new tool for the intercomparison of scatterometer records
IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., 2016, doi: 10.1109/JSTARS.2017.2647842

[8] Verspeek, J., A. Stoffelen, A. Verhoef and M. Portabella,
Improved ASCAT Wind Retrieval Using NWP Ocean Calibration
IEEE Transactions on Geoscience and Remote Sensing, 50, 7, 2488-2494, 2012, doi:10.1109/TGRS.2011.2180730

[9] Crapolicchio, R. and P. Lecomte,
The ERS Wind Scatterometer mission: routine monitoring activities and results
Proceeding of Emerging Scatterometer Application workshop, ESTEC, Noordwijk, The Netherlands 5–7 October 1998, ESA-SP-424, 1998

[10] Crapolicchio, R., G. De Chiara, A. Paciucci and P. Lecomte,
The ERS-2 scatterometer: Instrument and data performances assessment since the beginning of the mission
Proceeding of Envisat Symposium, Montreux, Switzerland 23-27 April 2007, ESA-SP-636, 2007

[11] Abdalla, S. and H. Hersbach,
The technical support for global validation of ERS Wind and Wave Products at ECMWF
ECMWF final report for ESA contract 18212/04/I-OL, 2007

[12] Dee, D. et al.,
The ERA-Interim reanalysis: configuration and performance of the data assimilation system
Quarterly Journal of the Royal Meteorological Society, 137: 553–597, 2011, doi:10.1002/qj.828

[13] Hersbach, H.,
Assimilation of scatterometer data as equivalent-neutral wind
ECMWF Technical Memorandum 629, 2010

[14] J. de Kloe, A. Stoffelen and A. Verhoef,
Improved use of scatterometer measurements by using stress-equivalent reference winds
IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens., under review, 2016

[15] Lin, W., M. Portabella, A. Stoffelen, J. Vogelzang, and A. Verhoef,
ASCAT wind quality under high subcell wind variability conditions
J. Geophys. Res. Oceans, 20, 8, 5804–5819, 2015, doi:10.1002/2015JC010861

[16] Verspeek, J. and A. Stoffelen,
CMOD7,
OSI SAF report SAF/OSI/CDOP2/KNMI/TEC/RP/237, 2015 (*)

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

[18] Belmonte Rivas, M., J. Verspeek, A. Verhoef and A. Stoffelen,
Bayesian sea ice detection with the Advanced Scatterometer
IEEE Transactions on Geoscience and Remote Sensing, 50, 7, 2649-2657, 2012,
doi:10.1109/TGRS.2011.2182356

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

7. Abbreviations and acronyms

2DVAR	Two-dimensional Variational Ambiguity Removal
AMI	Active Microwave Instrument
ATBD	Algorithm Theoretical Basis Document
AR	Ambiguity Removal
ASCAT	Advanced Scatterometer
ASPS	Advanced Scatterometer Processing System
AWDP	ASCAT Wind Data Processor
BUFR	Binary Universal Format Representation
CDR	Climate Data Record
DLI	Downward Long wave Irradiance
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA	ECMWF re-analysis
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GMF	Geophysical Model Function
KNMI	Royal Netherlands Meteorological Institute
Metop	Meteorological operational satellite
MLE	Maximum Likelihood Estimator
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
QC	Quality Control
QuikSCAT	US Quick Scatterometer mission carrying the SeaWinds scatterometer
SAF	Satellite Application Facility
SCIRoCCo	ESA SCatterometer InstRument Competence Centre
SSI	Surface Solar Irradiance
SST	Sea Surface Temperature
u	West-to-east (zonal) wind component
v	South-to-north (meridional) wind component
UWI	ERS scatterometer User Wind Data
WMO	World Meteorological Organisation
WVC	Wind Vector Cell

8. Appendix A: BUFR data descriptors

Number	Descriptor	Parameter	Unit
1	001033	Identification Of Originating/Generating Centre	Code Table
2	001034	Identification Of Originating/Generating Sub-Centre	Code Table
3	025060	Software Identification	Numeric
4	001007	Satellite Identifier	Code Table
5	002019	Satellite Instruments	Code Table
6	001012	Direction Of Motion Of Moving Observing Platform	Degree True
7	004001	Year	Year
8	004002	Month	Month
9	004003	Day	Day
10	004004	Hour	Hour
11	004005	Minute	Minute
12	004006	Second	Second
13	005001	Latitude (High Accuracy)	Degree
14	006001	Longitude (High Accuracy)	Degree
15	005033	Pixel Size On Horizontal-1	m
16	005040	Orbit Number	Numeric
17	006034	Cross Track Cell Number	Numeric
18	010095	Height Of Atmosphere Used	m
19	021157	Loss Per Unit Length Of Atmosphere Used	dB/m
20	021150	Beam Collocation	Flag Table
21	008085	Beam Identifier	Code Table
22	002111	Radar Incidence Angle	Degree
23	002134	Antenna Beam Azimuth	Degree
24	021062	Backscatter	dB
25	021063	Radiometric Resolution (Noise Value)	%
26	021158	ASCAT Kp Estimate Quality	Code Table
27	021159	ASCAT Sigma-0 Usability	Code Table
28	021160	ASCAT Use Of Synthetic Data	Numeric
29	021161	ASCAT Synthetic Data Quality	Numeric
30	021162	ASCAT Satellite Orbit And Attitude Quality	Numeric
31	021163	ASCAT Solar Array Reflection Contamination	Numeric
32	021164	ASCAT Telemetry Presence And Quality	Numeric
33	021165	ASCAT Extrapolated Reference Function	Numeric
34	021166	ASCAT Land Fraction	Numeric
35	008085	Beam Identifier	Code Table
36	002111	Radar Incidence Angle	Degree
37	002134	Antenna Beam Azimuth	Degree
38	021062	Backscatter	dB
39	021063	Radiometric Resolution (Noise Value)	%
40	021158	ASCAT Kp Estimate Quality	Code Table
41	021159	ASCAT Sigma-0 Usability	Code Table
42	021160	ASCAT Use Of Synthetic Data	Numeric
43	021161	ASCAT Synthetic Data Quality	Numeric
44	021162	ASCAT Satellite Orbit And Attitude Quality	Numeric
45	021163	ASCAT Solar Array Reflection Contamination	Numeric
46	021164	ASCAT Telemetry Presence And Quality	Numeric
47	021165	ASCAT Extrapolated Reference Function	Numeric
48	021166	ASCAT Land Fraction	Numeric
49	008085	Beam Identifier	Code Table
50	002111	Radar Incidence Angle	Degree
51	002134	Antenna Beam Azimuth	Degree

Number	Descriptor	Parameter	Unit
52	021062	Backscatter	dB
53	021063	Radiometric Resolution (Noise Value)	%
54	021158	ASCAT Kp Estimate Quality	Code Table
55	021159	ASCAT Sigma-0 Usability	Code Table
56	021160	ASCAT Use Of Synthetic Data	Numeric
57	021161	ASCAT Synthetic Data Quality	Numeric
58	021162	ASCAT Satellite Orbit And Attitude Quality	Numeric
59	021163	ASCAT Solar Array Reflection Contamination	Numeric
60	021164	ASCAT Telemetry Presence And Quality	Numeric
61	021165	ASCAT Extrapolated Reference Function	Numeric
62	021166	ASCAT Land Fraction	Numeric
63	025060	Software Identification	Numeric
64	025062	Database Identification	Numeric
65	040001	Surface Soil Moisture (Ms)	%
66	040002	Estimated Error In Surface Soil Moisture	%
67	021062	Backscatter	dB
68	021151	Estimated Error In Sigma0 At 40 Deg Incidence Angle	dB
69	021152	Slope At 40 Deg Incidence Angle	dB/Degree
70	021153	Estimated Error In Slope At 40 Deg Incidence Angle	dB/Degree
71	021154	Soil Moisture Sensitivity	dB
72	021062	Backscatter	dB
73	021088	Wet Backscatter	dB
74	040003	Mean Surface Soil Moisture	Numeric
75	040004	Rain Fall Detection	Numeric
76	040005	Soil Moisture Correction Flag	Flag Table
77	040006	Soil Moisture Processing Flag	Flag Table
78	040007	Soil Moisture Quality	%
79	020065	Snow Cover	%
80	040008	Frozen Land Surface Fraction	%
81	040009	Inundation And Wetland Fraction	%
82	040010	Topographic Complexity	%
83	025060	Software Identification	Numeric
84	001032	Generating Application	Code Table
85	011082	Model Wind Speed At 10 m	m/s
86	011081	Model Wind Direction At 10 m	Degree True
87	020095	Ice Probability	Numeric
88	020096	Ice Age (A-Parameter)	dB
89	021155	Wind Vector Cell Quality	Flag Table
90	021101	Number Of Vector Ambiguities	Numeric
91	021102	Index Of Selected Wind Vector	Numeric
92	031001	Delayed Descriptor Replication Factor	Numeric
93	011012	Wind Speed At 10 m	m/s
94	011011	Wind Direction At 10 m	Degree True
95	021156	Backscatter Distance	Numeric
96	021104	Likelihood Computed For Solution	Numeric
97	011012	Wind Speed At 10 m	m/s
98	011011	Wind Direction At 10 m	Degree True
99	021156	Backscatter Distance	Numeric
100	021104	Likelihood Computed For Solution	Numeric

Note that descriptor numbers 93-96 can be repeated 1 to 144 times, depending on the value of the Delayed Descriptor Replication Factor (descriptor number 92)

9. 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 1.6 (http://cfconventions.org/).
- 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 5.1)
- The format is identical for ERS, ASCAT, SeaWinds 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 1.2 MB in BUFR and 1 MB in NetCDF). When compressed with gzip, the size of one file in NetCDF reduces to 0.3 MB.

The file name convention for the gzipped NetCDF product is

scatt_YYYYMMDD_HHMMSS_SAT_ORBIT_ T_SMPL_VERS_CONT.l2.nc.gz or

OR1ERW025_YYYYMMDD_HHMMSS_ORBIT_ERSX.nc.gz (from EUM Data Centre) 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 AWDP software version (3000 for this data record). A file name example is: scatt_19920826_193131_ers1___05828_o_250_3000_ovw.l2.nc.gz.

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

```
dimensions:
        NUMROWS = 1597 ;
        NUMCELLS = 19 ;
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 = "ERS-1 SCAT Level 2 25.0 km Ocean Surface Wind Vector
Product" ;
                :title_short_name = "SCATT-L2-25km" ;
                :Conventions = "CF-1.6" ;
                :institution = "EUMETSAT/OSI SAF/KNMI" ;
                :source = "ERS-1 SCAT" ;
                :software_identification_level_1 = 0 ;
                :instrument_calibration_version = 0 ;
                :software_identification_wind = 3001 ;
                :pixel_size_on_horizontal = "25.0 km" ;
                :service_type = "N/A" ;
                :processing_type = "R" ;
                :contents = "ovw" ;
                :granule_name =
"scatt_19960602_122604_ers1___25535_o_250_ovw.l2.nc" ;
                :processing_level = "L2" ;
                :orbit_number = 25535 ;
                :start_date = "1996-06-02" ;
                :start_time = "12:26:04" ;
                :stop_date = "1996-06-02" ;
                :stop_time = "14:06:37" ;
                :equator_crossing_longitude = "" ;
                :equator_crossing_date = "" ;
                :equator_crossing_time = "" ;
                :rev_orbit_period = "" ;
                :orbit_inclination = "" ;
                :history = "N/A" ;
                :references = "ERS Scatterometer 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 = "2016-11-03" ;
                :creation_time = "09:57:40" ;
```

The interpretation of the wvc_quality_flag integer value is as follows. The flag_masks correspond to certain flag bits that may or may not be set. This means that e.g. the 'flag_mask' 64 corresponds to 'distance_to_gmf_too_large' and so on. The flag masks are powers of 2. The way to handle this is to take the integer value of the wvc_quality_flag and find out how it is composed of powers of 2. Suppose that one wants to test if the 'knmi_quality_control_fails' flag bit is set. This is the 12th item in the flag list, corresponding to an integer value of 131072 (=2^17) in the flag_masks table. You can test if this value is set using the function:

(integer flag value / 2^17) modulo 2

which gives 1 if the ‘knmi_quality_control_fails’ is set and 0 if the ‘knmi_quality_control_fails’ is not set. The other flag bits can be tested in the same way.

10. Appendix C: Data gaps and number of files

The ERS-1 Data Record starts at orbit 3285 on 2nd March 1992 and ends at orbit 25542 on 3rd June 1996. The ERS-2 Data Record starts at orbit 4780 on 20th March 1996 and ends at orbit 30016 on 15th January 2001. Unfortunately many orbits are missing, sometimes isolated orbits and sometimes for longer periods. The tables below show the gaps with a length of at least 10 orbits in the Data Records and the number of files (orbits) per year, respectively.

The gaps reported here are based on the resulting retrieved winds from the reprocessing. Information about instrument unavailabilities is also provided by ESA on

https://earth.esa.int/web/sppa/mission-performance/esa-missions/ers-1/scatterometer/mission-highlights and

https://earth.esa.int/web/sppa/mission-performance/esa-missions/ers-2/scatterometer/mission-highlights.

ERS-1

Start date	End date	Last orbit before gap	First orbit after gap	Number of missing orbits
1992-03-30	1992-04-14	3696	3910	213
1992-04-30	1992-05-03	4140	4183	42
1992-05-06	1992-05-07	4226	4240	13
1992-05-23	1992-05-24	4469	4483	13
1992-05-29	1992-05-30	4555	4569	13
1992-06-03	1992-06-04	4626	4641	14
1992-06-13	1992-06-17	4769	4814	44
1992-06-25	1992-06-29	4938	4995	56
1992-07-19	1992-07-24	5277	5349	71
1992-08-09	1992-08-10	5579	5593	13
1992-08-19	1992-08-21	5730	5748	17
1992-08-28	1992-08-29	5845	5867	21
1992-09-02	1992-09-03	5925	5945	19
1992-09-18	1992-09-20	6159	6181	21
1992-09-30	1992-10-01	6325	6338	12
1992-10-01	1992-10-02	6338	6349	10
1992-10-09	1992-10-14	6454	6524	69
1992-10-17	1992-10-19	6562	6593	30
1992-11-15	1992-11-16	6982	6993	10
1992-11-24	1992-11-25	7117	7131	13
1992-12-04	1992-12-06	7252	7289	36
1993-01-14	1993-01-17	7839	7891	51
1993-01-18	1993-01-19	7905	7916	10
1993-02-03	1993-02-05	8134	8162	27
1993-02-07	1993-02-08	8190	8205	14
1993-02-17	1993-02-18	8333	8348	14
1993-03-04	1993-03-05	8542	8558	15
1993-03-19	1993-03-20	8763	8777	13
1993-03-28	1993-03-29	8892	8906	13
1993-04-06	1993-04-07	9021	9035	13
1993-04-11	1993-04-12	9092	9107	14
1993-05-15	1993-05-17	9580	9599	18
1993-05-17	1993-05-18	9599	9613	13
1993-05-22	1993-05-23	9679	9694	14
1993-05-28	1993-05-31	9764	9799	34
1993-06-05	1993-06-07	9868	9899	30
1993-06-28	1993-06-30	10205	10230	24
1993-07-01	1993-07-02	10244	10255	10

Start date	End date	Last orbit before gap	First orbit after gap	Number of missing orbits
1993-07-24	1993-07-25	10578	10596	17
1993-07-27	1993-07-28	10616	10634	17
1993-08-04	1993-08-05	10733	10744	10
1993-08-21	1993-08-22	10977	10997	19
1993-08-29	1993-08-30	11090	11102	11
1993-08-31	1993-09-01	11119	11130	10
1993-10-01	1993-10-02	11564	11584	19
1993-10-03	1993-10-04	11586	11604	17
1993-10-10	1993-10-11	11694	11712	17
1993-10-18	1993-10-19	11805	11817	11
1993-10-25	1993-10-26	11907	11918	10
1993-11-28	1993-11-28	12387	12399	11
1994-01-13	1994-01-14	13050	13068	17
1994-01-15	1994-01-17	13087	13106	18
1994-01-22	1994-01-23	13184	13195	10
1994-01-29	1994-01-30	13286	13297	10
1994-03-31	1994-04-06	14150	14236	85
1994-04-23	1994-04-25	14483	14514	30
1994-09-27	1994-09-28	16741	16753	11
1994-10-06	1994-10-07	16869	16881	11
1995-03-02	1995-03-02	18973	18984	10
1995-03-21	1995-03-22	19246	19261	14
1995-04-18	1995-04-20	19658	19673	14
1995-04-21	1995-04-23	19700	19715	14
1995-04-24	1995-04-26	19743	19758	14
1995-05-10	1995-05-12	19972	19987	14
1995-07-14	1995-07-15	20889	20904	14
1995-07-17	1995-07-18	20932	20947	14
1995-08-01	1995-08-03	21161	21176	14
1995-08-12	1995-08-13	21304	21319	14
1995-08-15	1995-08-16	21347	21362	14
1995-08-26	1995-08-27	21510	21524	13
1995-08-31	1995-09-01	21576	21591	14
1995-09-06	1995-09-07	21662	21677	14
1995-09-07	1995-09-08	21677	21691	13
1995-09-09	1995-09-10	21705	21719	13
1995-09-10	1995-09-11	21720	21734	13
1995-09-11	1995-09-13	21747	21762	14
1995-09-13	1995-09-14	21762	21781	18
1995-09-16	1995-09-17	21805	21823	17

Year	Number of files
1992	3335
1993	4438
1994	4841
1995	4740
1996	2118
Total	19472

ERS-2

Start date	End date	Last orbit before gap	First orbit after gap	Number of missing orbits
1996-04-16	1996-04-17	5173	5187	13
1996-06-26	1996-06-27	6191	6206	14
1996-07-04	1996-07-05	6311	6323	11
1996-07-11	1996-07-12	6406	6419	12
1996-07-15	1996-07-26	6459	6616	156
1996-08-04	1996-08-06	6754	6775	20
1996-09-02	1996-09-03	7162	7176	13
1996-09-23	1996-10-02	7461	7592	130
1997-02-13	1997-02-15	9518	9542	23
1997-06-18	1997-06-19	11301	11312	10
1997-08-03	1997-08-04	11956	11973	16
1998-02-20	1998-02-21	14839	14857	17
1998-06-03	1998-06-07	16311	16362	50
1998-11-01	1998-11-03	18473	18497	23
1998-11-17	1998-11-18	18701	18717	15
1998-12-11	1998-12-12	19041	19064	22
1998-12-14	1998-12-15	19087	19098	10
1999-09-01	1999-09-02	22820	22831	10
1999-11-17	1999-11-18	23928	23941	12
1999-12-31	2000-01-02	24555	24586	30
2000-02-04	2000-02-05	25056	25067	10
2000-02-07	2000-02-10	25095	25147	51
2000-02-16	2000-02-17	25224	25239	14
2000-03-24	2000-03-25	25754	25772	17
2000-03-27	2000-03-30	25800	25841	40
2000-05-29	2000-05-30	26707	26723	15
2000-06-30	2000-07-06	27156	27241	84
2000-10-07	2000-10-10	28578	28624	45
2000-10-24	2000-10-25	28822	28835	12

Year	Number of files
1996	3457
1997	4995
1998	4938
1999	5060
2000	4805
2001	215
Total	23470