Product User Manual (PUM) for the HSCAT/OSCAT winds

HY-2B 25/50 km wind vectors (OSI-114-c/d)

HY-2C 25/50 km wind vectors (OSI-115-c/d)

HY-2D 25/50 km wind vectors (OSI-116-c/d)

Oceansat-3 25/50 km wind vectors (OSI-113-a/b)

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OSI SAF Winds Team

Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure
and Water Management*

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1.0		May 2024	AV	Comments from ORR reviewers included

Table of contents

List of tables

1. Introduction

1.1. Overview

The HSCAT scatterometer instrument is mounted on the HY-2B satellite which was launched on October 25th, 2018 by the Chinese National Satellite Ocean Application Service (NSOAS). The same instrument is mounted on the HY-2C satellite which was launched on September 21th, 2020, and on the HY-2D satellite which was launched on May 19th, 2021. The Ku-band HSCAT instruments on the three satellites are identical and are similar to HSCAT on HY-2A which was launched in 2011. The OSCAT scatterometer on Oceansat-3 (also known as EOS-06) was launched on November 26th, 2022 by the Indian Space Research Organisation (ISRO). Like HSCAT, it is a Ku-band rotating pencil beam instrument and it is similar to the OSCAT instruments that flew on the Oceansat-2 and on the ScatSat-1 satellites.

The level 1b HSCAT files from NSOAS and the level 1b OSCAT files from ISRO are processed by KNMI into 25 km and 50 km level 2 wind products.

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 HY-2/HSCAT and Oceansat-3/OSCAT wind products. More general information on the OSI SAF project is available on the OSI SAF website: https://osi-saf.eumetsat.int. The user is strongly encouraged to register on this website in order to receive the service messages and the latest information about the OSI SAF products. An email newsletter is available as well after subscription on https://osi-saf.eumetsat.int/newsletter. More information about this product can also be found on https://scatterometer.knmi.nl/.

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, OSCAT, RapidScat, and HSCAT scatterometers. Scatterometer processing software is distributed through the EUMETSAT Numerical Weather Prediction Satellite Application Facility (NWP SAF) website, 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 https://scatterometer.knmi.nl/ 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 HY-2B winds on 25 km (OSI-114-c) and 50 km (OSI-114-d) grid spacing, on the HY-2C winds on 25 km (OSI-115-c) and 50 km (OSI-115-d) grid spacing, on the HY-2D winds on 25 km (OSI-116-c) and 50 km (OSI-116-d) grid spacing, and on the Oceansat-3 winds on 25 km (OSI-113-a) and 50 km (OSI-113-b) grid spacing. Detailed information on the file content and format is given in section 2. Section 3 presents a brief description of the HSCAT and OSCAT instruments, and section 4 gives an overview of the data processing configuration. The product quality is elaborated in section 5 and in the validation report to these products [6].

1.2. Acknowledgement

NSOAS kindly provides the near-real time HSCAT level 1b data which are used as input for the OSI SAF wind products. ISRO kindly provides the near-real time OSCAT level 1b data which are used 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 we like to receive a copy of any publication about the application of the data. Your feedback, e.g., directed to scat@knmi.nl, helps us in maintaining the resources for the OSI SAF wind services.

1.4. Useful links

KNMI scatterometer website: https://scatterometer.knmi.nl/

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

OSI SAF wind product documentation on http://osi-saf.eumetsat.int

NWP SAF website: http://nwp-saf.eumetsat.int

HSCAT visual products:
https://scatterometer.knmi.nl/hy2b_25_prod/ (HY-2B 25 km)

https://scatterometer.knmi.nl/hy2b_50_prod/ (HY-2B 50 km)

https://scatterometer.knmi.nl/hy2c_25_prod/ (HY-2C 25 km)

https://scatterometer.knmi.nl/hy2c_50_prod/ (HY-2C 50 km)

https://scatterometer.knmi.nl/hy2d_25_prod/ (HY-2D 25 km)

https://scatterometer.knmi.nl/hy2d_50_prod/ (HY-2D 50 km)

Oceansat-3 visual products:
https://scatterometer.knmi.nl/ocsat3_25_prod/ (Oceansat-3 25 km)

https://scatterometer.knmi.nl/ocsat3_50_prod/ (Oceansat-3 50 km)

EUMETSAT Data Centre: https://www.eumetsat.int/eumetsat-data-centre

HY-2B, HY-2C, and HY-2D information on NSOAS website: http://www.nsoas.org.cn/eng/

Haiyang-2 information on the eoPortal website: https://www.eoportal.org/satellite-missions/hy-2a

Oceansat-3/EOS-06 information on the ISRO website: https://www.isro.gov.in/EOS_06.html

1.5. 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 products can be distinguished w.r.t. product swath grid spacing by their file names, see section 2.2.

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

1.6. Limitations and remaining issues

1) Since not all HSCAT satellite data are acquired through ground stations in the polar regions, the timeliness of the products is not always optimal, the products are available between ~2 hours and ~16 hours after sensing time. This is not applicable to Oceansat-3 since these data are obtained through polar ground stations and they are usually available within 2 to 3 hours.

1.7. History of product changes

Here is an historical overview of the changes in the HY-2B wind products:

28-Jan-2019 Initial version of HY-2B winds made available to the users. PenWP version is 2_2_02.

09-Apr-2019 Use improved Geophysical Model Function NSCAT4DS and apply Sea Surface Temperature corrections to backscatter to reduce systematic wind speed and direction biases.

11-Feb-2021 Reduced the gap between successive orbit files for better coverage near the south pole. The MLE values in the products now represent the MLE of the MSS-selected wind solution rather than the MLE of the closest local minimum solution. This leads to somewhat higher reported MLE values but does not change the wind characteristics. PenWP version is 2_2_04.

21-Oct-2021 The HY-2B winds are now publicly available on the KNMI FTP server with operational status.

04-Nov-2021 The HY-2B winds are available on EUMETCast.

Here is an historical overview of the changes in the HY-2C wind products:

12-Nov-2020 Initial version of HY-2C winds made available for visualisation. PenWP version is 2_2_02.

11-Feb-2021 Reduced the gap between successive orbit files for better coverage near the south pole. PenWP version is 2_2_04.

21-Oct-2021 The HY-2C winds are now publicly available on the KNMI FTP server with operational status.

04-Nov-2021 The HY-2C winds are available on EUMETCast.

Here is an historical overview of the changes in the HY-2D wind products:

09-Sep-2021 Initial version of HY-2D winds made available for visualisation. PenWP version is 2_2_05.

04-Aug-2023 The HY-2D winds have pre-operational status now. PenWP version is 4_0_02.

09-Nov-2023 The HY-2D winds are available on EUMETCast.

Here is an historical overview of the changes in the Oceansat-3 wind products:

08-Nov-2023 Initial version of Oceansat-3 winds made available for visualisation. PenWP version is 4_0_02.

28-Feb-2024 Updated NOC calibrations and added wind speed calibrations. PenWP version is 4_0_03.

26-Mar-2024 The Oceansat-3 winds are now available on the KNMI FTP server with development status. PenWP version is 4_0_04.

1.8. Reference and applicable documents

[1] OSI SAF,
Product Requirements Document,
SAF/OSI/CDOP3/MF/MGT/PL/2-001, 2023 (link)

[2] OSI SAF,
Service Specification Document,
SAF/OSI/CDOP3/MF/MGT/PL/003, 2023 (link)

[3] OSI SAF,
Algorithm Theoretical Basis Document for the scatterometer wind products,
SAF/OSI/CDOP2/KNMI/SCI/MA/197, 2024 (link)

[4] Verhoef, A. and A. Stoffelen,
Advances in Ku-band scatterometer Quality Control,
SAF/OSI/CDOP3/KNMI/SCI/TN/404, 2021 (link)

[5] Verhoef, A. and A. Stoffelen,
Quality Control of Ku-band scatterometer winds,
OSI SAF report SAF/OSI/CDOP2/KNMI/TEC/RP/194, 2012 (link)

[6] Verhoef, A., J. Verspeek and A. Stoffelen,
Scientific Validation Report (SVR) for the HSCAT/OSCAT winds,
OSI SAF report, SAF/OSI/CDOP4/KNMI/TEC/RP/434, 2024 (link)

[7] National Satellite Ocean Application Service,
HY-2A Microwave Scatterometer Data Format User's Guide
Version 2012-5-30

[8] National Satellite Ocean Application Service (NSOAS),
HY-2B Scatterometer Wind Product User Manual,
Version 1.1, December 2018

[9] DPSG, National Remote Sensing Centre, Indian Space Research Organization,
EOS-06 (SCAT-3) Data Access User Document for Scatterometer-3,
Version 1.0, June 2023

[10] de Kloe, J., A. Stoffelen and A. Verhoef,
Improved Use of Scatterometer Measurements by Using Stress-Equivalent Reference Winds,
IEEE Journal of Selected Topics in Applied Earth O, 2017, 10, 5, 2340-2347,
doi:10.1109/JSTARS.2017.2685242.

[11] Leidner, M., R. Hoffman, and J. Augenbaum,
SeaWinds scatterometer real-time BUFR geophysical data product, version 2.2.0,
NOAA/NESDIS, February 2000, available on ftp://www.scp.byu.edu/data/qscat/docs/bufr.pdf

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

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

2. Data description

2.1. Wind product characteristics

2.1.1. Physical definition

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

2.1.2. Units and range

Wind speed is measured in m/s. The wind speed range is from 0-50 m/s, but wind speeds exceeding 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.

2.1.3. Input satellite data

The HSCAT level 1b input data [8] are kindly provided by NSOAS and OSCAT level 1b input data [9] are kindly provided by ISRO. The products contain geo-located backscatter measurements in time order. In the wind processing the measurements are assigned to a satellite swath WVC grid of 25 km size or 50 km size.

2.1.4. Geographical definition

The HY-2B satellite flies in a near-polar sun-synchronous orbit at 99 degrees inclination and the HY-2C and HY-2D satellites fly in a non-sun-synchronous orbit at 66 degrees inclination. The spacecrafts are at approximately 960 km orbit height. The Oceansat-3 satellite flies in a near-polar sun-synchronous orbit at 98 degrees inclination at an orbit height of approximately 740 km. All instruments have a swath width of 1800 km; the swath is composed of 76 25 km size WVCs or 38 50 km size WVCs. HSCAT products are organised in files containing one whole orbit; from the South Pole to the South Pole. OSCAT products are organised in files containing a half orbit, North Pole to South Pole or South Pole to North Pole.

Due to the independence of the earth swath definition and the measurement swath, not all WVCs are filled with data for HSCAT. For 25 km products, there are no winds or almost no winds in the outer WVCs (1-2, 74-76). For 50 km products, there are no winds or very little winds in WVCs 1 and 38. In the OSCAT products, the outermost WVCs usually do contain wind data. The wind retrieval is only done in cases where both fore and aft views are present.

2.1.5. Output product

The input product in HDF format 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 8 for more details.

2.1.6. 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 [12]. The performance is pretty constant over the globe and depends mainly on the sub footprint wind variability. According to the OSI SAF product requirements [2] 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. More validation information is available in [6], showing that the actual product accuracy well exceeds the requirements.

2.2. 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 [11], a list of descriptors (fields) contained in each WVC is provided in section 7. Data are organised in files containing approximately one orbit (100 minutes) of HSCAT data or half an orbit (50 minutes) of OSCAT data.

2.2.1. File name conventions

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

hscat_YYYYMMDD_HHMMSS_hy_2b__ORBIT_T_SMPL_CONT_l2.bufr or

hscat_YYYYMMDD_HHMMSS_hy_2c__ORBIT_T_SMPL_CONT_l2.bufr or

hscat_YYYYMMDD_HHMMSS_hy_2d__ORBIT_T_SMPL_CONT_l2.bufr or

oscat_YYYYMMDD_HHMMSS_ocsat3_ORBIT_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)
- T is the processing type (always o for operational)
- 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

hscat_20210309_230106_hy_2b__11885_o_250_ovw_l2.bufr	for a 25 km HY-2B product
hscat_20210310_033812_hy_2c__02299_o_500_ovw_l2.bufr	for a 50 km HY-2C product
hscat_20220831_021036_hy_2d__06364_o_250_ovw_l2.bufr	for a 25 km HY-2D product
oscat_20240326_084607_ocsat3_07031_o_500_ovw_l2.bufr	for a 50 km Oceansat-3 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,HY-2B+HSCAT_C_EHDB_YYYYMMDDHHMMSS_ORBIT _T_SMPL_CONT_l2.bin or

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,HY-2C+HSCAT_C_EHDB_YYYYMMDDHHMMSS_ORBIT _T_SMPL_CONT_l2.bin

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,HY-2D+HSCAT_C_EHDB_YYYYMMDDHHMMSS_ORBIT_T_SMPL_CONT_l2.bin

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,OCEANSAT3+OSCAT_C_EHDB_YYYYMMDDHHMMSS_ORBIT_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,HY-2B+HSCAT_C_EHDB_20210309230106_11885_o_250_ovw_l2.bin

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,HY-2C+HSCAT_C_EHDB_20210310033812_02299_o_500_ovw_l2.bin

W_NL-KNMI-DeBilt,SURFACE+SATELLITE,HY-2D+HSCAT_C_EHDB_20220831021036_06364_o_250_ovw_l2.bin

W_NL-KNMI-eBilt,SURFACE+SATELLITE,OCEANSAT3+OSCAT_C_EHDB_20240326084607_07031_o_500_ovw_l2.xml

2.2.2. 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 [13]). The wind solutions (contained in BUFR fields 31 to 50) are ordered by inversion residual, starting with the lowest value.
- The Wind Vector Cell Quality Flag (table 021109) is redefined with respect to the WMO conventions and now has the following definitions:

Description	BUFR bit	Fortran bit	Integer value
Not used	1	16	
Not enough good sigma-0 available for wind retrieval	2	15	32768
Not used	3	14	16384
VV polarised data in more than two beams	4	13	8192
Product monitoring not used	5	12	4096
Product monitoring flag	6	11	2048

Description	BUFR bit	Fortran bit	Integer value
KNMI Quality Control (including rain) data rejection	7	10	1024
Variational QC data rejection	8	9	512
Land presence	9	8	256
Ice presence	10	7	128
Not used	11	6	
Reported wind speed is greater than 30 m/s	12	5	32
Reported wind speed is less than or equal to 3 m/s	13	4	16
Quality Control data rejection for visualisation and nowcasting	14	3	8
Rain flag algorithm detects rain	15	2	4
Data from at least one of the four possible beam/view combinations are not available	16	1	2
Missing value	All 17 set	All 17 set	

Table 1: Definition of flag bits in the Wind Vector Cell Quality Flag in BUFR.

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**=17 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. The last column in the table shows the integer value if only the given bit is set.

The flag indicating that more than two beams contain VV polarised data, Fortran bit 13, is active in the outer part of the swath (generally WVCs 1-9 and 68-76 at 25 km, WVCs 1-4 and 35-38 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 1b 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, Fortran bit 12, is set to zero, the product is monitored. If the product is monitored and the 'product monitoring flag' bit, Fortran bit 11, 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, Fortran bit 10, 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 wind field in the ambiguity removal step. However, the analysis wind is computed for all WVCs over the ocean. The wind solution (out of the available 144 MSS wind solutions) closest to the analysis field is chosen, if wind solutions are present in the WVC. This means that such a QC-flagged WVC may contain a selected wind solution, but it is suspect.

The land presence flag, Fortran bit 8, 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 so there is normally no reason to reject WVCs with the land flag set.

The Bayesian ice screening algorithm as implemented in PenWP is used in the processing. The ice presence flag, Fortran bit 7, 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 9, 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 automatically use WVCs with the product monitoring flag (bit 11), the KNMI quality control flag (bit 10) or the variational quality control flag (bit 9) set. See [3] for more information on product reliability. However, in visualisation, the flagged data may be inspected in their meteorological context and hence be rather useful for trained meteorologists. For visualisation applications the use of the 'Quality Control data rejection for visualisation and nowcasting' flag (bit 3) is recommended, i.e., winds with this flag set should be considered with great care. This flag rejects less data than the 'KNMI Quality Control (including rain) data rejection' but it has good skill for such use [4].

Some fields in the BUFR data do not contain the information that they were originally meant for, but are used for (internal) processing information which may or may not be relevant for the user:

- The 'Probability of Rain' BUFR field (021120) does not contain a rain probability, but the ice probability as obtained from the Bayesian ice screening model.
- The 'SeaWinds NOF Rain Index' BUFR field (021121) contains the software version from the NSOAS or ISRO input data file.
- The 'Intensity of precipitation' BUFR field (013055) contains the collocated Sea Surface Temperature from the ECMWF model. A conversion is done to fit the SST values into the numerical range for this BUFR parameter. The SST can be re-computed using the formula: SST(K) = <value> * 2000 + 260.
- The 'Attenuation correction on Sigma-0' BUFR field (021122) contains the 'ice age' parameter from the Bayesian ice screening model. Outside the polar regions, where the ice model is not active, this field contains missing values.

3. The HSCAT and OSCAT scatterometers

HY-2B, HY-2C, and HY-2D carry the same Ku-band HSCAT scatterometers which are similar to the one flown on-board HY-2A. The HY-2B spacecraft was launched on October 25th, 2018 and it is in a sun-synchronous orbit of 980 km altitude with an inclination of 99.3°. The local time of Equator crossing is about 6:00. HY-2C was launched on September 21st, 2020 and HY-2D was launched on May 19th, 2021. HY-2C and HY-2D are in non-sun-synchronous orbits with 66.0° inclination and their equator crossing times are shifting each day. As such, HY-2C and HY-2D can generate a large number of closely collocated winds with other scatterometers. The HY-2C and HY-2D measurement swaths reach a maximum latitude of about 74° N and 74° S. For detailed information on the HSCAT instrument and data we refer to [7] and [8], a brief description is given here.

The HSCAT 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 × 35 km size on the ground, a horizontal polarisation beam (HH) and a vertical polarisation beam (VV) at incidence angles of 42º and 49º respectively. Contrary to QuikSCAT and OSCAT, the HSCAT level 1b data do not provide high resolution 'slice' data but only full footprint 'egg' data. The beams sweep the surface in a circular pattern as depicted in Figure 1. 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. The ~1800-km-wide swath covers 90% of the ocean surface in 24 hours which is substantially higher than side-looking scatterometers like ERS, NSCAT and ASCAT.

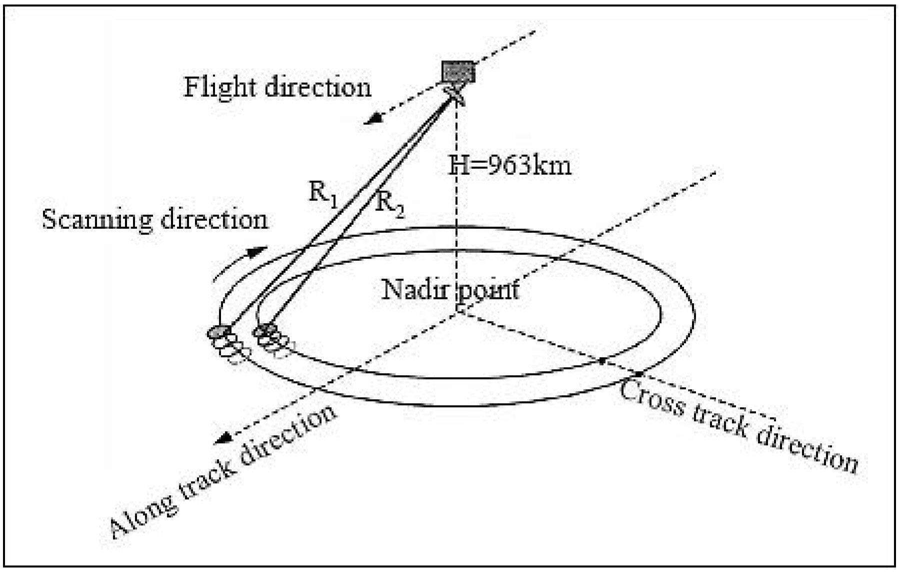


Figure 1: HSCAT pencil beam geometry (source: ESA website).

Oceansat-3, or EOS-06, is a continuity mission for the scatterometers on Oceansat-2 and ScatSat-1. Oceansat-3 was launched on November 26th, 2022 and it carries the Ku-band OSCAT scatterometer which is similar to the one flown on-board of its predecessors, with some enhanced features based on lessons learnt. The spacecraft is in a sun-synchronous orbit of 740 km altitude with an inclination of 98.3°. The local time of Equator crossing is about 12:00. For detailed information on Oceansat-3 we refer to [9].

The OSCAT instrument configuration is similar to HSCAT, but the incidence angles are different: 49.5° for the HH beam and 58.5° for the VV beam. The incidence angles are larger to obtain a similar swath width, despite the lower Oceansat-3 orbit altitude. Furthermore, the OSCAT level 1b data do provide high resolution 'slice' data, which helps to retrieve winds closer to the coast than for HSCAT.

The wind retrieval for rotating pencil beam scatterometers 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 HSCAT and OSCAT.

In the outer swath (where only VV beam data are available), the individual backscatter measurements ('eggs' or 'slices') contributing to the fore or aft beam in a specific WVC are ordered by their azimuth angles. Two groups with the same amount of measurements are formed with lower and higher azimuth angles. These groups are accumulated and averaged separately to form two independent WVC views. This is done separately for the VV fore and aft data, resulting in a total of four independent WVC views. The outer swath winds have slightly reduced quality control skill, but they are still very well usable, depending on the application. These winds are flagged in the product and can be filtered out easily if requested, see section 2.2.

The instruments operate at a Ku-band radar frequency (13.3 GHz corresponding to ~2 cm wavelength). The atmosphere is not transparent at these wavelengths and in particular rain is detrimental for wind computation. In fact, moderate and heavy rain cause bogus wind retrievals of 15-20 m/s wind speed which need to be eliminated by a Quality Control (QC) step. Wind-rain discrimination is easiest to manage in the sweet swath, but still performs acceptably in nadir and outer swath, see the figure in Section 2 of [3] for the definition of swath regions. Recently, the Ku-band Quality Control algorithm has been refined, leading to two new QC flags, a conservative (NWP QC) flag to replace the current KNMI MLE flag for NWP applications, and a new, less conservative (nowcasting QC) flag for nowcasting applications [4]. The NWP QC flag shows a better QC skill than the old MLE flag but at the same time it rejects significantly less winds. The nowcasting QC flag shows a comparable skill as the old MLE flag and it rejects even less winds.

The processing algorithms for the HSCAT and OSCAT wind processing are heavily based on the algorithms as developed for SeaWinds and RapidScat [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 HSCAT scatterometers and replaces 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-4DS 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 the individual scatterometers, mainly the normalisation of the Maximum Likelihood Estimator (MLE) and the tuning of the Quality Control [5].

4. Processing scheme

KNMI has processing chains running in near-real time with HY-2B, HY-2C, HY-2D, and Oceansat-3 data, including wind maps displayed on the OSI SAF website. The processing software is developed in the OSI 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]. The products are distributed through several means (e.g., FTP, EUMETCast, see section 1.5) and the software packages are available on the NWP SAF software portal.

4.1. Backscatter data averaging

The HSCAT level 1b backscatter data from NSOAS are organised in radar footprint 'eggs' [7], whereas the OSCAT level 1b backscatter data from ISRO are organised in 'slices' [9]. The eggs or slices are beam-wise accumulated to a WVC level before wind inversion is done. The egg/slice weights are proportional to the estimated transmitted power contained in an observation, i.e., inversely proportional to the K_p value (measurement noise estimate). The WVC lat/lon location is computed from the used backscatter data locations that fall within that WVC.

For HSCAT, poor quality backscatter data are characterised by very low σ^0 values (-299 dB or -99 dB) and such data are skipped. Also, the change in time of the antenna azimuth angle is monitored. If the antenna azimuth angle does not (significantly) change in subsequent measurements, this can be due to a problem in the rotation mechanism and such data are rejected for further processing.

For OSCAT, the Sigma0 Quality Flag present in the level 1b data is evaluated and slice data with one of the 'Sigma0 is poor' flag (bit 4) set are skipped.

4.2. Backscatter and wind speed 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 significant signs of azimuth (or WVC) dependent instrument biases have been found for HSCAT or OSCAT. Also the beam incidence angles are constant for each instrument and hence we have chosen to apply backscatter corrections that are only dependent on the beam polarisation. The goal of applying backscatter corrections is 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. It appears that in this region the wind direction biases are slightly dependent on the ratio between the VV and HH corrections, i.e., changing the VV and HH corrections in opposite directions will change the wind direction biases without affecting the wind speed biases significantly. In this way, within a few iterations the two calibration coefficients can be obtained which yield minimal wind direction and wind speed biases.

Product	HH	VV inner swath	VV outer swath
HY-2B 25 km	0.76 dB	-0.41 dB	-0.35 dB
HY-2B 50 km	0.71 dB	-0.39 dB	-0.34 dB
HY-2C 25 km	-0.96 dB	-1.07 dB	-1.07 dB
HY-2C 50 km	-1.01 dB	-1.05 dB	-1.05 dB
HY-2D 25 km	-0.20 dB	-0.10 dB	-0.06 dB
HY-2D 50 km	-0.26 dB	-0.03 dB	-0.06 dB
Oceansat-3 25 km	1.18 dB	0.04 dB	0.30 dB
Oceansat-3 50 km	0.91 dB	0.15 dB	0.24 dB

Table 2: Calibration coefficients per product and per beam category.

The table shows the calibration coefficients per product and per beam category. 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.

It appears that the different instruments have a slightly different response at varying σ^0 signal levels. This leads to varying wind speed biases for different wind speeds, in particular for wind speeds above 15 m/s the wind speed biases differ. In order to compensate for this, a higher order wind speed correction is applied after the wind retrieval [3]. This ensures that all Ku-band wind products have the same wind speed bias characteristics w.r.t. reference winds from NWP models or buoys. The reference wind speed scale is based on the wind data from moored buoys.

4.3. NWP collocation

KNMI receives NWP model data from ECMWF twice a day through the Regional Meteorological Data Communication Network (RMDCN).

NWP model sea surface temperature (SST) data are used to support the Bayesian sea ice discrimination and to correct σ^0 values for SST dependency of the wind retrieval for Ku-band [3]. 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 above 5 °C are assumed to be always open water. The Bayesian ice screening procedure may sometimes assign rainy WVCs erroneous as ice; using the extra SST criterion, WVCs in areas warmer than 5 °C will never be labelled as ice. Due to its rather 'warm' threshold value, the NWP-based SST ice screening will only be active in regions far away from the ice extents.

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 $1/r^2$, 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, +4h, +5h, …, +30h. Normally, only forecasts until +18h are needed, since after 18 hours the data from the next model run (12 hours later) will be available. The extra forecasts beyond +18h are only to ensure that model data are still available for collocation to the satellite observations, should there be any delay in the ECMWF data provision of the next run. The ECMWF data are currently provided on a Reduced Gaussian grid with 640 latitude lines between pole and equator (N640). The model wind data are 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 (see section 2.2). The ECMWF winds stored in the wind products are stress-equivalent winds [10] which have been computed from the equivalent neutral model winds.

It is important to note that scatterometer winds are being assimilated into the ECMWF model and therefore the wind field used for ambiguity removal (i.e., a forecast) is taken to be independent from the scatterometer observation. In near-real time processing the scatterometer measurement is received at approximately the same time at KNMI and ECMWF, and the scatterometer winds are produced at KNMI within a few minutes typically. Hence the observation cannot yet have been assimilated into the ECMWF model fields at the moment of processing at KNMI.

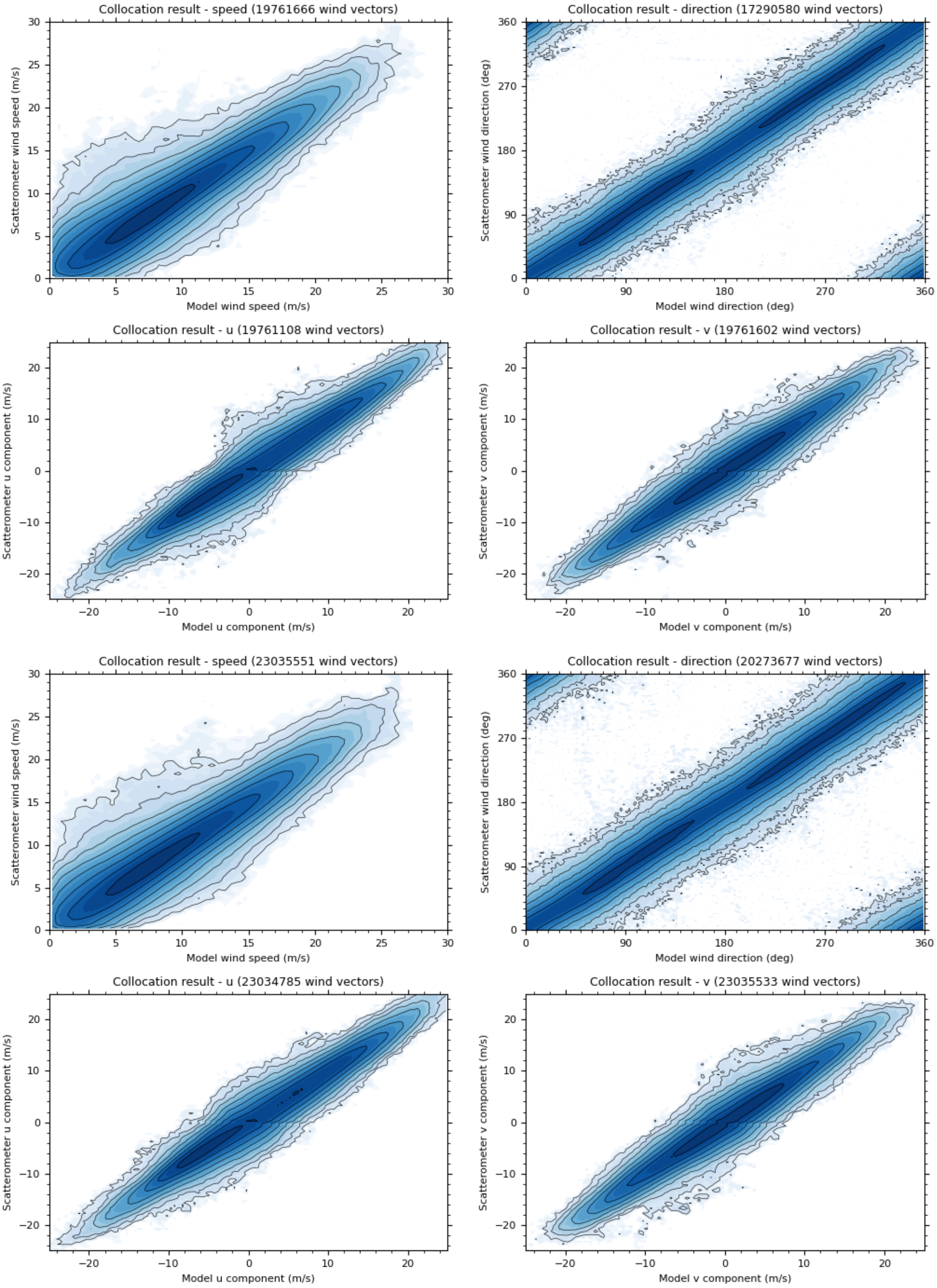
4.4. Quality control and monitoring

In each WVC, the σ^0 data is checked for quality and completeness and the inversion residual [3], called MLE, is checked. Degraded WVCs are flagged; see section 2.2 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 are produced to visually display the confidence levels of the products and their evolution with time. Any deviations from nominal behaviour will be immediately visible as steps in these graphs. Data and overall product quality is also available to the users within the products; see section 2 for a description of quality flags.

5. Data quality

As stated in the OSI SAF product requirements [2], 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.



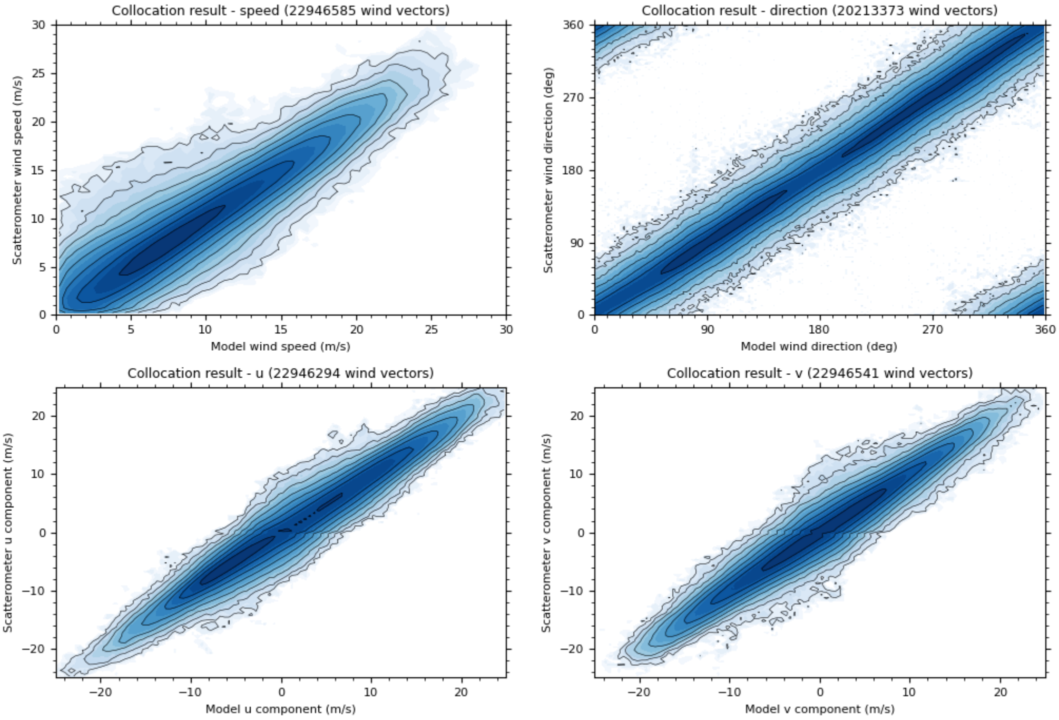


Figure 2: Two-dimensional scatter density plots of wind speed, direction (w.r.t. wind coming from the North), u and v components of 25 km HY-2B (top), HY-2C (middle), and HY-2D (bottom) wind product versus the ECMWF model stress-equivalent forecast winds from November 2022 to October 2023, first two days from each month.

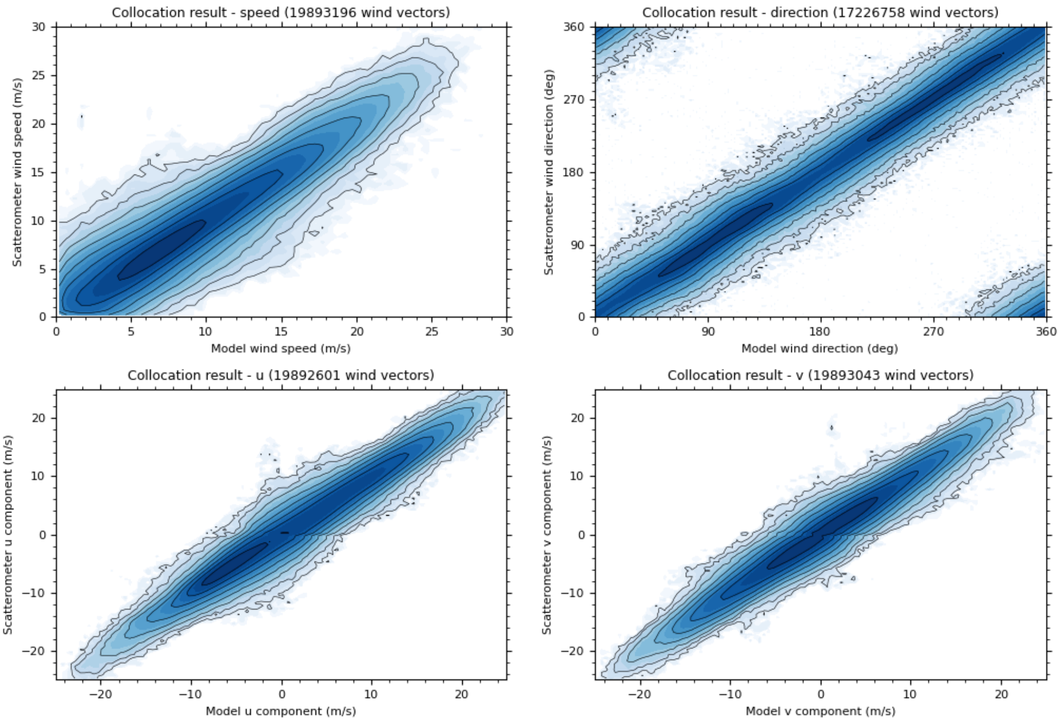


Figure 3: Two-dimensional scatter density plots of wind speed, direction (w.r.t. wind coming from the North), u and v components of 25 km Oceansat-3 wind product versus the ECMWF model stress-equivalent forecast winds from May 2023 and November 2023 to February 2024, 24 days in total.

Figure 2 and Figure 3 show two-dimensional scatter density plots of the retrieved winds versus ECMWF 10 m stress-equivalent background winds for the 25 km HY-2B, HY-2B, HY-2D, and Oceansat-3 wind products, 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 only 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.

From these results, it is clear that the spread in the distributions is small. The wind speed bias is within 0.01 m/s. The 50 km products have comparable biases. The wind component standard deviations of the differences are around 1.15 to 1.25 m/s for the 25 km products and around 1.0 m/s for the 50 km products.

	Scatterometer		Buoys		ECMWF	
	ε_u (m/s)	ε_v (m/s)	ε_u (m/s)	ε_v (m/s)	ε_u (m/s)	ε_v (m/s)
25 km HY-2B	0.59	0.39	1.30	1.38	0.84	0.88
25 km HY-2C	0.81	0.65	1.34	1.39	0.82	0.87
25 km HY-2D	0.65	0.55	1.30	1.35	0.92	0.89
25 km Oceansat-3	0.68	0.54	1.33	1.38	0.86	0.83
50 km HY-2B	0.49	0.31	1.41	1.49	0.80	0.80
50 km HY-2C	0.65	0.50	1.46	1.49	0.74	0.81
50 km HY-2D	0.52	0.42	1.41	1.45	0.84	0.82
50 km Oceansat-3	0.51	0.39	1.44	1.47	0.80	0.79

Table 3: Error standard deviations in u and v wind components from triple collocation of HY-2B, HY-2C, HY-2D, and Oceansat-3 25 km and 50 km wind products with buoy and ECMWF forecast winds, seen from the scatterometer perspective. The results were obtained for the period of January to March 2024.

The overall product error standard deviations in the zonal (u) and meridional (v) wind components at the product resolution is evaluated by triple collocation and given in the table above [6].

The 25 km products are less accurate, but provide a better representation of the buoy winds than the 50 km products. On the other hand, the latter product is more representative of global NWP models. Much more validation information can be found in [6].

6. 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
EUMETCast	EUMETSAT’s Digital Video Broadcast Data Distribution System
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
HSCAT	Scatterometer on-board the Haiyang 2 series satellites (China)
ISRO	Indian Space Research Organisation
KNMI	Royal Netherlands Meteorological Institute
Kp	Backscatter measurement noise estimate
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
NSOAS	National Satellite Ocean Application Service (China)
NWP	Numerical Weather Prediction
OSCAT	Scatterometer on-board the Oceansat-2/3 and ScatSat-1 satellites (India)
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

7. 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

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

Number	Descriptor	Parameter	Unit
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
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

8. 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://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 2.1)
- The format is identical for HSCAT, OSCAT, 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 11 MB in BUFR and 4 MB in NetCDF). When compressed with gzip, the size of one file in NetCDF reduces to 1.2 MB. For the Oceansat-3 data, the NetCDF-4 format with internal compression is used and the data size is also around 1.2 MB per orbit.

The file name convention for the gzipped NetCDF product is

hscat_YYYYMMDD_HHMMSS_SATELLITE__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 2.2). The VERS part of the file name denotes the PenWP software version. A file name example is:

hscat_20240402_072507_hy_2b__27316_o_250_4004_ovw_l2.nc.gz.

The file name convention for the Oceansat-3 NetCDF product is

oscat_YYYYMMDD_HHMMSS_SATELLITE__ORBIT_T_SMPL_VERS_CONT_l2.nc. A file name example is:

oscat_20240402_064339_ocsat3_07131_o_250_4004_ovw_l2.nc.

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

```
dimensions:
        NUMROWS = 1773 ;
        NUMCELLS = 75 ;
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
not_usable_for_visualisation 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 = "HY-2B HSCAT Level 2 25.0 km Ocean Surface Wind Vector
Product" ;
                :title_short_name = "HSCAT-L2-25km" ;
                :Conventions = "CF-1.6" ;
                :institution = "EUMETSAT/OSI SAF/KNMI" ;
                :source = "HY-2B HSCAT" ;
                :software_identification_level_1 = 4004 ;
                :instrument_calibration_version = 0 ;
                :software_identification_wind = 4004 ;
                :pixel_size_on_horizontal = "25.0 km" ;
                :service_type = "N/A" ;
                :processing_type = "O" ;
                :contents = "ovw" ;
                :granule_name =
"hscat_20240402_072507_hy_2b__27316_o_250_2204_ovw_l2.nc";
                :processing_level = "L2" ;
                :orbit_number = 27316 ;
                :start_date = "2024-04-02" ;
                :start_time = "07:25:07" ;
                :stop_date = "2024-04-02" ;
```

```
                :stop_time = "09:19:06" ;
                :equator_crossing_longitude = " 178.871" ;
                :equator_crossing_date = "2024-04-02" ;
                :equator_crossing_time = "06:11:36" ;
                :rev_orbit_period = "6266.0" ;
                :orbit_inclination = "99.3" ;
                :history = "N/A" ;
                :references = "Product User Manual for the HSCAT/OSCAT winds,
http://www.osi-saf.org/, https://scatterometer.knmi.nl/" ;
                :comment = "Orbit period and inclination are constant values. All wind
directions in oceanographic convention (0 deg. flowing North)" ;
                :creation_date = "2024-04-02" ;
                :creation_time = "10:29:42" ;
```

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. See the table below for the flag bits present in the wvc_quality_flag. The last column in the table shows the integer value if only the given bit is set. Note that the NetCDF format from the dump above is generic for level 2 wind products and it contains some flag bits which are not used in these specific data. Table 4 lists the flag bits that are actually in use, these flag bits are set identical to the corresponding flag bits used in the BUFR data Table 1.

Description	Bit number	Integer value
Not used	6	
Not used	7	
Not used	8	
Rain flag algorithm detects rain	9	512
Quality Control data rejection for visualisation and nowcasting	10	1024
Reported wind speed is less than or equal to 3 m/s	11	2048
Reported wind speed is greater than 30 m/s	12	4096
Wind inversion not successful for wind vector cell	13	8192
Some portion of wind vector cell is over ice	14	16,384
Some portion of wind vector cell is over land	15	32,768
Variational quality control data rejection	16	65,536
KNMI Quality Control (including rain) data rejection	17	131,072

Description	Bit number	Integer value
Product monitoring flag	18	262,144
Product monitoring not used	19	524,288
Not used	20	
Poor azimuth diversity among sigma-0 for wind retrieval	21	2,097,152
Not enough good sigma-0 available for wind retrieval	22	4,194,304

Table 4: Definition of flag bits in the Wind Vector Cell Quality Flag in NetCDF.