Document NWPSAF-KN-DS-003
Version 3.0.02
February 2017

AWDP Product Specification

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This documentation was developed within the context of the EUMETSAT Satellite Application Facility on Numerical Weather Prediction (NWP SAF), under the Cooperation Agreement dated 29 June, 2011, between EUMETSAT and the Met Office, UK, by one or more partners within the NWP SAF. The partners in the NWP SAF are the Met Office, ECMWF, KNMI and Météo France.

Change record			
Version	**Date**	**Author / changed by**	**Remarks**
1.0j	Jun 2007	Anton Verhoef	First draft
1.0k	Oct 2007	Anton Verhoef	Adapted for AWDP version 1.0k
1.0.13	Mar 2008	Anton Verhoef	Adapted for AWDP version 1.0.13
1.0.14	Oct 2008	Anton Verhoef	First version for external review
1.0.16	Dec 2008	Anton Verhoef	Modified according to DRI comments
1.1	Jan 2010	Anton Verhoef	Removed a few typo’s and corrected some of the diagrams in the appendices for AWDP v1.1
2.0	Aug 2010	Anton Verhoef	Modified for AWDP v2.0; added section 3.5.3, changed sections 2.3, 2.3.4, 2.4, Chapter 9 and Appendix B4
2.0.01	Nov 2010	Anton Verhoef	Modified according to DRI comments
2.2	Jun 2013	Anton Verhoef	Version for AWDP v2.2
2.3	Feb 2014	Anton Verhoef	Version for AWDP v2.3
2.4	Jun 2016	Anton Verhoef, Jur Vogelzang	Version for AWDP v2.4, split original UM into UM, PS and TLD docs
3.0	Feb 2017	Jur Vogelzang	Adapted for AWDP v3.0

Contents

1 Introduction

1.1 Aims and scope

The ASCAT Wind Data Processor (AWDP) is a software package mainly written in Fortran 90 with some parts in C for handling data from the Advanced Scatterometer (ASCAT) and European Remote Sensing satellite (ERS) scatterometer instruments. This document is the Product Specification (PS) of the AWDP software package. Section 2 provides information on the purpose, outputs, inputs and system requirements of the AWDP software. More information about the functionality of the processing steps in AWDP is available in section 3.

More information about AWDP can be found in several other documents. The User Manual and Reference Guide (UM) [1] contains more details about the installation and use of AWDP. Reading the UM and the PS should provide sufficient information to the user who wants to apply AWDP as a black box.

The Top Level Design (TLD) of the code and the Module Design (MD) of the AWDP code can be found in [2].This document is of interest to developers and users who need more specific information on how the processing is done.

Please note that any questions or problems regarding the installation or use of AWDP can be addressed at the NWP SAF helpdesk at http://nwpsaf.eu/.

1.2 Conventions

Names of physical quantities (e.g., wind speed components *u* and *v*), modules (e.g. *BufrMod*), subroutines and identifiers are printed italic.

Names of directories and subdirectories (e.g. `awdp/src)`, files (e.g. `awdp.F90`), and commands (e.g. `awdp -f input`) are printed in Courier. Software systems in general are addressed using the normal font (e.g. AWDP, genscat).

Hyperlinks are printed in blue and underlined (e.g. http://www.knmi.nl/scatterometer/).

2 AWDP product specification

2.1 Purpose of AWDP

The ASCAT Wind Data Processor (AWDP) has been developed to fully exploit σ^0 data from the ASCAT scatterometer instrument on the Metop satellites or the AMI scatterometer instrument on the European Remote Sensing (ERS) satellites, to generate surface winds. AWDP may be used for real-time data processing. The main application of AWDP is to form the core of an Observation Operator for ASCAT scatterometer data within an operational Numerical Weather Prediction System.

AWDP is also a level 2 data processor. It reads data from the EUMETSAT level 1b ASCAT BUFR or PFS product or from the ESA ERS scatterometer BUFR product. AWDP applies algorithms for inversion, quality control, and Ambiguity Removal at various spatial resolutions. These methods are mainly developed and published by KNMI. The output of AWDP is a BUFR file in ASCAT BUFR format.

2.2 Output specification

The wind vectors generated by AWDP represent the instantaneous mean surface wind at 10 m anemometer height in a 2D array of Wind Vector Cells (WVCs) with specified size (25×25 km^2, 12.5×12.5 km^2, 6.25×6.25 km^2, or about 5.6 km along track and varying across track, depending on the cell spacing of the input product, the type of the input product, and the command line options chosen). These WVCs are part of the ground swath of the instrument.

In conventional mode, the wind output for every WVC consists of up to 4 ambiguities (wind vector alternatives, with varying probabilities). The wind solutions are ordered by decreasing probability and the selected wind vector (after ambiguity removal) is indicated by a selection index pointing to the chosen solution. For every WVC additional parameters are stored. These are e.g.: latitude, longitude, time information, orbit and node numbers, background wind vector, cell quality flag, and information on the scatterometer beams including σ^0 and K_p data. The output file is structured according to the same conventions as the ASCAT level 1b input, also if ERS data are processed.

The ASCAT BUFR format consist of three main sections: one section containing level 1b information which is copied from the input data, one section containing Surface Soil Moisture (SSM) level 2 information, which is also copied from the input, and one section containing level 2 wind data, which is calculated in AWDP. The ASCAT BUFR data descriptors are listed in Appendix A.

2.3 Input specification

Input of AWDP is the ASCAT level 1b BUFR or PFS Data Product. These products are created by EUMETSAT; see [3]. Alternatively, the ERS scatterometer wind product in BUFR can be used as input; see [4].

It is also possible to reprocess level 2 ASCAT or ERS data in ASCAT BUFR format, and treat them as if they are level 1b data. To achieve this, the command line option `-handleall` needs to be set; see [1].

Apart from the scatterometer data, GRIB files containing NWP output with global coverage are necessary for the wind processing. At least three wind forecasts with constant forecast time intervals of e.g. 1 or 3 hours are necessary to perform interpolation with respect to time and location. The forecast times need to be before and after the data acquisition time, e.g. when an observation at 7:00 UTC is considered, there should be forecast wind fields available at 6:00, 7:00 and 8:00 UTC or at 3:00, 6:00 and 9:00 UTC. More details on the time interpolation are in the `gribio_module` description in [2]. Apart from this, GRIB fields of Sea Surface Temperature and Land Sea Mask are necessary for land and ice masking. These fields are not time interpolated, it is sufficient to provide only one field.

NWP model data are publicly available for example from the ECMWF ERA-Interim archive (http://www.ecmwf.int/en/research/climate-reanalysis/era-interim) and from the NOAA NCEP Global Forecasting System (http://www.nco.ncep.noaa.gov/pmb/products/gfs/).

NWP data is not needed when AWDP is used on level 2 BUFR data which already contains model winds and ice flagging, or when ambiguity removal is omitted. See the description of the command line options in [1] for more information on this.

2.4 System requirements

Table 3.1 shows the platform and compiler combinations for which AWDP has been tested. However, the software is designed to run on any Unix (Linux) based computer platform with a Fortran compiler and a C compiler. The equivalent of a modern personal computer will suffice to provide a timely NRT wind product. AWDP requires about 100-150 MB disk space when installed and compiled.

Platform	Fortran compiler	C compiler
Fedora Linux work station	Portland pgf90 GNU g95 GNU gfortran	GNU gcc
SunOS Unix	Sun Fortran	Sun C
Apple MacBook	GNU gfortran	GNU gcc

Table 3.1 Platform and compiler combinations for which AWDP has been tested.

AWDP may also run in other environments, provided that the environment variables discussed in section 2.2 are set to the proper values, and that the BUFR library is properly installed. For Windows a Linux environment like Wubi is needed. AWDP can also run on a MacOS machine (Darwin).

3 Details of functionality

3.1 BUFR IO and coding

Data sets of near-real time meteorological observations are generally coded in the Binary Universal Form for Representation (BUFR). BUFR is a machine independent data representation system (but it contains binary data, so care must be taken in reading and writing these data under different operating systems). A BUFR message (record) contains observational data of any sort in a self-descriptive manner. The description includes the parameter identification and its unit, decimal, and scaling specifications. The actual data are in binary code. The meta data are stored in BUFR tables. These tables are therefore essential to decode and encode the data.

BUFR tables are issued by the various meteorological centres. The largest part of the data descriptors specified in the BUFR tables follows the official BUFR descriptor standards maintained by the World Meteorological Organization (WMO, http://www.wmo.int/). However, for their different observational products meteorological centres do locally introduce additional descriptors in their BUFR tables.

Appendix A contains a listing of the data descriptors of the BUFR data input and the BUFR data output of AWDP in the ASCAT BUFR product format. For more details on BUFR, the reader is referred to [5].

ECMWF maintains a library of routines for reading (writing) and decoding (encoding) the binary BUFR messages. This library forms the basis of the genscat BUFR module and hence the AWDP program BUFR interface, see [2].

3.2 Product resolution

An important feature of AWDP is that it may produce a level 2 wind product on different resolutions. The resolution of the level 2 wind product is the same as that of the level 1b input product. ASCAT data are available in three different resolutions: ~50 km resolution with 25 km cell spacing (also known as the ASCAT operational product, SZO), ~30 km resolution with 12.5 km cell spacing (also known as the ASCAT research product, SZR), and full resolution (also known as SZF product) which can result in cell spacings of 25 km, 12.5 km, 6.25 km, or 5.65 km.

3.3 Use of full resolution data

AWDP offers the possibility to replace the backscatter values in the level 1b product by box averaged σ^0 data that are acquired using the full resolution ASCAT level 1 data (SZF). The beam data (σ^0 values, incidence and azimuth angles) which are read from the BUFR or PFS level 1b input file, are replaced by average values of the data from the full resolution file which are located within a certain radius (15 km for a 12.5-km grid and 7.5 km for a 6.25-km grid) from the WVC location. In this way, a coastal product can be created. See [6] for more information on how the box averaged σ^0 data are composed.

From AWDP version 3.0 onwards it is also possible to process full resolution data on a grid that is synchronised with the ASCAT mid-beam antenna pulses [7]. The resulting product, further referred to as ASCAT-5.6, has a grid size of about 5.65 km and a true spatial resolution of 19 km. Note that the ASCAT-6.25 product has a slightly better true spatial resolution of 17 km, but much poorer radar sampling characteristics.

It is important to notice that the full resolution data which are fed into AWDP (using the `–szffl` option) must span a time starting at least 150 seconds before the first data in the level 1b WVCs and ending no less than 150 seconds after the last data in the level 1b WVCs.

AWDP needs a high-resolution land-sea mask in order to determine if a full resolution backscatter measurement is over land or sea. This information is used in coastal areas to skip backscatter data over land and to use only backscatter data over sea in the averaging of full resolution data. The high resolution land-sea mask should be available in GRIB format and should have a resolution of approximately 15 km or better. The file containing the land-sea mask should be present in the list of GRIB files supplied with the `–nwpfl` command line option (see [1]).

3.4 WVC triplet completion and row merging

AWDP sorts the WVC rows in the input file by their acquisition date and time and merges WVC information if duplicate rows occur. The duplicate information is considered and the output will contain as much useful information as is available in the input WVCs. This is especially useful if direct readout data from different ground stations is processed. Sometimes a WVC from one ground station contains only fore beam information, whereas the corresponding WVC from a second ground station contains only the mid and aft beam information. For ERS data, AWDP will combine the information and it will process and write one WVC containing all three beams. For ASCAT data, the duplicate rows will be merged keeping the wind information if it is available in one of the input rows but no attempt is done to combine beam information. This is the establised mode of operation in the EUMETSAT Advanced Retransmission Service (EARS) ASCAT service.

3.5 Quality control

The quality of every WVC is controlled. Before processing the beam data, checks are done on the completeness and usability of the σ^0 data. After the wind inversion step, the distance of the first rank wind solutions to the GMF is considered. If this value is too large, the wind solutions are flagged. The K_p values are also considered. If one of the three beam K_p values is above a threshold which is wind speed dependent, the wind information is flagged 0.

3.6 Inversion

In the inversion step of wind retrieval, the radar backscatter observations in terms of the Normalized Radar Cross Sections (σ^0's) are converted into a set of ambiguous wind vector solutions. In fact, a Geophysical Model Function (GMF) is used to map a wind vector (specified in term of wind speed and wind direction) to a σ^0 value. The GMF depends not only on wind speed and wind direction but also on the measurement geometry (relative azimuth and incidence angle) and beam parameters (frequency and polarization). Currently, the CMOD7 GMF is in use, see [9].

AWDP also includes the Multiple Solution Scheme (MSS). In MSS mode, a large number of wind vector solutions is produced, typically 144. The wind vector solutions are ranked according to their probability based on the MLE and constitute the full wind vector probability density function. Subsequently, the 2DVAR Ambiguity Removal method, see, e.g., section 3.8, is applied with a much larger set of wind vector solutions. The output BUFR format can accommodate any number of wind solutions due to the use of the so-called delayed descriptor replication. Details on the KNMI inversion approach can be found in [2]. For SeaWinds, MSS compares better to an independent NWP model reference and buoys than conventional two or four-solution schemes [10], [11], but for ERS and ASCAT this needs to be investigated further.

Technical information on the KNMI inversion approach can be found in [2].

3.7 Ice screening

A Bayesian sea ice detection algorithm was developed for ASCAT [12] and this algorithm is implemented in AWDP. It is based on the probabilistic distances to ocean and sea ice geophysical model functions. When a combination of backscatter measurements is close to the wind GMF, the probability that the WVC is covered with water is high. On the other hand, when the measurement is close to the sea ice GMF, the probability that the WVC contains ice is high. Each satellite overpass over the poles will yield new measurements which contribute to an ice map containing the ice probabilities.

3.8 Ambiguity Removal

The Ambiguity Removal (AR) step of the wind retrieval is the selection of the most probable surface wind vector among the available wind vector solutions, the so-called ambiguities. Various methods have been developed for AR. More information on Ambiguity Removal is given in [2]. The default method implemented in AWDP is the KNMI 2DVAR AR scheme. A description of its implementation can be found in [2]. The Multiple Solution Scheme (MSS) offers the possibility to postpone AR to the NWP step in order to treat all information from models and measurements in the same manner. Further details on the algorithms and their validation can be found in the reports [13], [14], and [15].

From version 3.0 onwards AWDP offers the possibility to use empirical background error correlations in 2DVAR [16].

The performance of 2DVAR with meteorological balance constraints was tested and optimized for ERS, ASCAT, and QuikSCAT data. It was found to be superior to other schemes.

3.9 Setting and unsetting of WVC quality flag bits

The attributes of the WVC quality flag (see [2]) are read from the BUFR input file and they are changed only when necessary and when the relevant processing step is invoked. This means that

- The ice flag will be set or unset depending on the Sea Surface Temperature from the GRIB model input when this is available, or depending of the result of the Bayesian ice screening when this is activated through the command line. It will not be changed when no NWP SST is used and the ice screening is not used.
- The land flag will be set or unset based on the land-sea mask from the GRIB model input when this is available. It will not be changed when no GRIB land-sea mask is used.

- The KNMI QC flag and GMF distance too large flag are unset whenever the wind inversion is invoked, and set after wind inversion depending on the result. They will not be changed when the wind inversion is skipped.
- The variational QC flag is unset whenever the wind inversion or ambiguity removal are invoked, it is set after ambiguity removal depending on the result. It will not be set when the ambiguity removal is not used.

3.10 Monitoring

For the automatic ingestion of observations into their NWP systems, meteorological centres require quality checks on the NRT products. For the ASCAT wind product a monitor flag is under development, analogous to the one developed for the SeaWinds Wind Product. This flag indicates that several measures on the level of corruption of the output BUFR files are above a specified threshold. Data with the monitoring flag set should be rejected for ingestion by the NWP system. Details on the monitoring flag can be found in the NWP SAF document [14].

3.11 Details of performance

AWDP is delivered with two example BUFR input files containing data from 26 April 2007. They are named `ascat_20070426_test_250.l1_bufr` (25 km cell spacing) and `ascat_20070426_test_125.l1_bufr` (12.5 km cell spacing) and contain approximately half an orbit of data. Moreover, a set of ECMWF GRIB files containing the necessary NWP output is supplied. Table 3.2 gives the approximate times needed for processing these files under various options on a personal workstation with a 4 core 3.2 GHz Xeon processor under Linux using the GNU g95 Fortran compiler.

Cell spacing (m)	MSS?	Inversion (seconds)	AR (seconds)	BUFR IO (seconds)	GRIB IO (seconds)	Total (seconds)
25000	No	2.5	1.4	0.4	0.2	4.5
12500	No	10.0	4.5	0.9	0.3	16
12500	Yes	13.0	35.0	0.9	0.3	50

Table 3.2 Approximate times needed by AWDP to process example BUFR files under various input resolutions and options.

As can be seen from table 3.2, the use of MSS results in slightly larger processing times needed for inversion and in much larger processing times needed for AR. The computation time, of course, increases with increasing resolution.

The choice of platform, compiler and compiler settings will result in a large variation in the processing times. Using the Portland pgf90 compiler rather than the GNU g95 compiler in the examples in table 3.2 will result in processing times that are 25% to 50% smaller.

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Appendix A: ASCAT BUFR data descriptors

This appendix contains lists of descriptors for the ASCAT BUFR format.

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

Number	Descriptor	Parameter	Unit
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
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

Number	Descriptor	Parameter	Unit
99	021156	Backscatter Distance	Numeric
100	021104	Likelihood Computed For Solution	Numeric

Table A.1 List of data descriptors. 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)

Appendix B: Acronyms

Name	Description
AMI	Active Microwave Instrument, scatterometer on ERS-1 and ERS-2 satellites
AR	Ambiguity Removal
ASCAT	Advanced SCATterometer on Metop
BUFR	Binary Universal Form for the Representation of data
C-band	Radar wavelength at about 5 cm
EARS	EUMETSAT Advanced Retransmission Service
ERS	European Remote Sensing satellites
ECMWF	European Centre for Medium-range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
genscat	generic scatterometer software routines
GMF	Geophysical model function
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
Ku-band	Radar wavelength at about 2 cm
L1b	Level 1b product
Metop	Meteorological Operational Satellite
MLE	Maximum Likelihood Estimator
MSS	Multiple Solution Scheme
NCEP	United States National Centers for Environmental Prediction
NWP	Numerical Weather Prediction
OSI	Ocean and Sea Ice
PFS	Product Format Specification (native Metop file format)
QC	Quality Control
SAF	Satellite Application Facility
SSM	Surface Soil Moisture
SST	Sea Surface Temperature
WVC	Wind Vector Cell, also called node or cell

Table D.1 List of acronyms.