User Manual for the Wind product processor of the NWC/PPS: Science Part

NWC/CDOP3/PPS/AEMET/SCI/UM/Wind, Issue 0, Rev.2.0

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Applicable to NWC/PPS-HRW v7.Q

Applicable to SAFNWC/PPS version 2021.3

Applicable to the following PGEs:

Acronym	Product ID	Product name	Version number
HRW	*(demonstrational)*	High Resolution Winds	7.Q (demonstrational release)

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REPORT SIGNATURE TABLE

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
0.1d	*30 September 2020*	67	Initial version for NWC/PPS-HRW v7.P Content derived from Document “User Manuel for the Wind product processor of the NWC/GEO: Science Part”, NWC/CDOP3/GEO/AEMET/SCI/UM/Wind, v1.1
0.1e	*1 September 2021*	67	Updates due to results of PPS v2021 RR: Change the status of HRW to ‘demonstrational’.
0.1	*12 October 2021*	67	Updates after PPS v2021 DRR: Just update document references.
0.2.0	*07 November 2022*	69	Initial version for NWC/PPS-HRW v7.Q

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1. INTRODUCTION

The "EUMETSAT Satellite Application Facilities (SAFs)" are dedicated centres of excellence for the processing of satellite data, and form an integral part of the distributed "EUMETSAT Application Ground Segment". This documentation is provided by the SAF on support to Nowcasting and Very short range forecasting (NWCSAF). The main objective of the NWCSAF is to provide, develop and maintain software packages to be used with operational meteorological satellite data for Nowcasting applications. More information about the project can be found at the NWCSAF webpage, http://www.nwcsaf.org.

This document is applicable to the NWC/PPS software package for polar satellites.

1.1 Scope of the document

This document is the "User Manual (UM) for the second version of the Wind Product Processor of the NWC/PPS software package (NWC/PPS-HRW v7.Q, High Resolution Winds), which calculates Atmospheric Motion Vectors and Trajectories considering images reprojected to a static region, coming from any of the following polar satellites, radiometers and channels:

- AVHRR-3 radiometer inside NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19, Metop-A, Metop-B or Metop-C polar satellites, using 0.630 µm VIS06 visible channel and/or 10.800 µm IR108 infrared channel.
- VIIRS radiometer inside SNPP, NOAA-20 or NOAA-21 polar satellites, using 0.640 µm VIS06 visible channel and/or 10.763 µm IR108 infrared channel.
- MODIS radiometer inside EOS-1 (Terra) or EOS-2 (Aqua) polar satellites, using 0.645 µm VIS06 visible channel, 11.030 µm IR110 infrared channel, 6.715 µm WV067 water vapour channel, and/or 7.325 µm WV073 water vapour channel.
- METimage radiometer inside Metop-SG-A1, Metop-SG-A2 or Metop-SG-A3 polar satellites (when they become available), using 0.668 µm VIS06 visible channel, 10.690 µm IR108 infrared channel, 6.725 µm WV067 water vapour channel, and/or 7.325 µm WV073 water vapour channel.
- MERSI-2 radiometer inside FY3-D polar satellite, using 0.650 µm VIS06 visible channel, 10.800 µm IR108 infrared channel, and/or 7.200 µm WV072 water vapour channel.
- SLSTR radiometer inside Sentinel-3A or Sentinel-3B polar satellites (and Sentinel-3C or Sentinel-3D when they become available), using 0.659 µm VIS06 visible channel and/or 10.850 µm IR108 infrared channel.

There is a commitment so that the adaptation of NWC/PPS-HRW software to these polar satellite series is validated. The corresponding validation results are shown in the corresponding "Scientific and Validation Report" [AD.6], and as a summary also in this document.

This "User Manual" describes the goal and implementation of NWC/PPS-HRW algorithm, and a basic description of its algorithm. It also provides information on the input data and the resulting output data.

1.2 Software Version Identification

This document describes the software implemented in the second version of NWC/PPS-HRW, NWC/PPS-HRW v7.Q (with demonstrational status), included in the NWC/PPS v2021.3 software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

This is the second implementation of NWC/PPS-HRW software, for use with up to 19 polar satellites with AVHRR-3, VIIRS, MODIS, METimage, MERSI-2 and SLSTR radiometers.

Of all these, nine different additional polar satellites and three different additional radiometers have been added in the processing in this second version.

Additionally, the AMV calculation process has been extended to MODIS and METimage WV067 water vapour cloudy and clear air AMVs, and to MODIS, METimage and MERSI-2 WV072/WV073 water vapour cloudy and clear air AMVs, in a similar way water vapour AMVs are calculated in NWC/GEO-HRW geostationary software.

Additionally, NWC/PPS-CMIC product has been included in the processing, for the calculation of the “Cloud Microphysics height assignment correction”, considering the value of the “Cloud phase”, “Ice water path” and “Liquid water path”, in a similar way it is done in NWC/GEO-HRW geostationary software.

Additionally, several improvements included in NWC/GEO-HRW software between versions v6.1 (used as basis for NWC/PPS-HRW v7.P in 2020) and v7.0 (which is the latest version developed for NWC/GEO-HRW in 2022), have also been included in NWC/PPS-HRW v7.Q. These improvements include: an optimization of the running time of HRW, a better distribution of AMVs in High, Medium and Low levels, a change in the structure of the HRW netCDF output to be CF compliant and easier to process, and the correction of up to seven SPRs occurring between these versions.

Finally, many running parameters of NWC/PPS-HRW have been retuned in v7.Q, so defining better AMV densities and fewer holes in the AMV coverage.

With all this, there are even more similarities between both geostationary NWC/GEO-HRW and polar NWC/PPS-HRW AMV softwares, because for example both include now “Water vapour AMVs” and the “Cloud microphysics CCC height assignment correction”. This way, NWC/GEO-HRW AMVs and NWC/PPS-HRW AMVs are more homogeneous throughout all the world, and users should find even easier the processing of both types of AMVs together, for example in NWP or climatic applications.

1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

1.4.1 Definitions

4x4 big pixel matrix	4x4 big element matrix, in which pixels of a tracer candidate are classified at reduced resolution defining 3 different brightness classes (CLASS_n)
Atmospheric Motion Vector (AMV)	Horizontal wind calculated through the horizontal displacement between two Earth positions in two different satellite images (defined as initial image and later image), of a square segment of n x n pixels called tracer
Basic dataset	Set of tracers or AMVs, calculated with the basic or wide tracer scale (with a default value of 24 x 24 pixels). Two kinds of Basic tracers are possible: wide basic tracers (with bright big pixels in the first and last big pixel row or column) and narrow basic tracers (occurring otherwise)
Bearing angle	Angle defined by the great circle connecting two locations on the Earth
Best fit pressure level	Pressure level which minimizes the vector difference between the AMV and a NWP or Radiosounding reference wind, considering as reference the nearest NWP or Radiosounding wind value inside the two nearest wind profile levels, with a linear variation of the wind components inside these two profile levels
Big pixel	Each element of the 4x4 big pixel matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_0, CLASS_1, CLASS_2)
Bright big pixel	Big pixel inside a big pixel matrix, in which at least a 70% of its pixels is brighter than a given frontier (also called CLASS_2 big pixel)
Brightness value	Value for a given pixel of the N_Value matrices, characterized by the Normalized reflectance in the pixel for Visible channels and the Brightness temperature in the pixel in Infrared or Water vapour channel, and defined as an integer value ranging from 0 to 255
Clear air AMV	AMV defined through the horizontal displacement between two Earth positions in two different satellite images, of a tracer defined through a specific moisture feature in water vapour images
Closeness threshold	Minimum distance in lines and columns allowed between two tracer locations
Cloud type	Cloud type defined for each tracer or AMV with NWC/PPS-Cloud type output data, used for example to define which of the two calculated height levels (cloud top, cloud base) is used in the “Brightness temperature interpolation height assignment process”
Cloudy AMV	AMV defined through the horizontal displacement between two Earth positions in two different satellite images, of a tracer defined through a specific cloudiness feature in visible, infrared or water vapour images
Common Quality Index	Quality parameter, calculated with a self-contained Fortran module defined by EUMETSAT and NOAA/NESDIS, to be included as such without modifications by all AMV algorithms, and useful for a common homogeneous use of AMVs calculated with different AMV algorithms.
Consistency	Difference between an AMV and some other expected wind, quantified in probabilistic terms for the Quality Index calculation

Coverage hole	Location in the initial image in which two consecutive failures in the definition of a tracer with Gradient method have occurred, so defining a location for the tracer search with the second method, Tracer characteristics method
Dark big pixel	Big pixel inside a big pixel matrix, in which less than a 30% of its pixels is brighter than a given frontier (also called CLASS_0 big pixel)
Detailed dataset	Set of tracers or AMVs, calculated with the detailed or narrow tracer scale (with a default value of 12 x 12 pixels). Three kinds of Detailed tracers are possible: unrelated to a basic tracer, related to a wide basic tracer, related to a narrow basic tracer
Distance factor	Formula used to define which AMVs contribute to the spatial and temporal consistency tests for a given AMV, and their corresponding contribution to the consistency test
Frontier	A significant minimum in the N_Value matrix histogram for a given tracer candidate
Great circle	Trajectory between two locations on the Earth surface, which relates them considering the smallest possible distance
Haversine formula	Formula used to compute the great circle distance between two locations on the Earth surface
IND_TOPO parameter	Value of the AMV Orographic flag parameter, calculated to detect land influence in a given Atmospheric Motion Vector
Initial image	Satellite image in which tracers are defined with any of the two tracer calculation methods (Gradient or Tracer characteristics), so defining the initial position in the AMV displacement
LAT_C, LON_C	Geographical coordinates of the tracking centre in the later image, considering a given AMV
LAT_T, LON_T	Geographical coordinates of the tracer centre in the initial image, considering a given AMV
Later image	Satellite image in which tracers defined previously are tracked with any of the two tracking methods (Euclidean distance or Cross correlation), defining the later positions in the AMV displacements
Main tracking centre	Tracking centre for a given tracer, which has the best possible Euclidean distance/Cross correlation values
Maximum brightness gradient	Location of the maximum brightness value gradient inside a tracer candidate, to be defined as a tracer location with Gradient method
Maximum optimisation distance	Maximum distance in lines or columns allowed between a coverage hole used in the search of tracers with Tracer characteristics method, and the corresponding tracer location
Mixed calculation method	Alternative method available for the calculation of AMVs and Trajectories with NWC/PPS-HRW software, through which the tracer tracking is evaluated considering shorter time intervals, and the displacement is evaluated considering longer time intervals.
Neighbour AMV	AMV which is close enough to a given one in the current processing cycle, used in the Quality spatial correlation test

N_Value matrix	Normalized reflectances for Visible channels, or Brightness temperatures for Infrared or Water vapour channels, for a given image in the processing region, defined as integer values ranging from 0 to 255.
Orographic flag (dynamic)	Flag to show possible land influence in the previous positions of a given AMV. It is calculated after the static orographic flag procedure, and indicated through IND_TOPO values: 1,2,3,4,5,6.
Orographic flag (static)	Flag to show possible land influence in the position of a given AMV. Indicated through IND_TOPO values: 1,2,3,6.
Overall Quality Index	Final Quality Index, weighted sum of individual forecast, temporal and spatial consistency tests (not considering the interscale consistency test)
Parallax correction	Correction of the apparent horizontal displacement of a feature in a satellite image, due to its height over the Earth surface
Persistent tracer	Tracer related to AMVs calculated in the previous cycle, for which the tracer centre is the tracking centre of the AMV in the previous cycle
Pixel distance	Preliminary line and column separation in pixels between the tracer locations, before the readjustments made by the tracer selection methods
Pixel exclusion matrix	Ensemble of pixels inside the processing region in which additional tracers cannot be located
Predecessor AMV	AMV in the previous processing cycle, whose tracking centre is used as the tracer centre of a persistent tracer in the current processing cycle
Prior AMV	AMV in the previous processing cycle close enough to a given AMV in the current processing cycle, used in the Quality temporal correlation test
Quality index (QI)	Quality parameter used to define the quality of the generated AMVs and Trajectories. It is based on spatial, temporal and forecast consistency against other reference AMVs or the NWP wind forecast. Two kinds of Quality indices are defined: with and without forecast (with and without the contribution of the consistency against the NWP wind forecast)
Quality index threshold	Minimum value of the Quality index (with or without forecast) so that the given AMV/Trajectory can be written in the output files
S (in CC computation)	Any pixel inside a tracking candidate
Secondary tracking centre	Tracking centre for a given tracer, which does not have the best Euclidean distance or Cross correlation
Segment of the image	A set of contiguous pixels in a satellite image, defined by its size and location
Single scale procedure	Tracer selection procedure, for which only one scale of tracers is calculated
Starting location	Each a priori location of tracers throughout the initial image, in principle uniformly covering the whole processing region
Subpixel tracking	Tracking processing, through which the tracking centres in the later image are located in a non-integer location of the tracking area, and which are calculated through second order interpolation of the Euclidean distance minima/Cross correlation maxima locations
T (in CC computation)	Any pixel inside a tracer

TESO parameter	Orographic test parameter, detailing if the orographic flag could be calculated for a given AMV, and the relative results in AMVs related to the same tracer, to be added to the Quality TEST indicator
TEST parameter	Quality flag after the Quality control processing, detailing which quality consistency tests were applied for a given AMV, and the relative results of each quality consistency test for all AMVs related to the same tracer
Tracer	Square segment in the initial image with a fixed size (nxn pixels, called tracer size), identified by the location of its centre, and considered valid candidate for AMV calculation by any of the tracer calculation methods
Tracer candidate	Square segment in the initial image with a fixed size, where conditions for tracer search using "Tracer characteristics method" are evaluated
Tracer continuity	Processing option in which part of the set of tracers in the current processing cycle is defined through the tracking centres of AMVs in the previous processing cycle
Tracer location	Pixel coordinates of a tracer centre (line and column) in the initial image
Tracer selection procedure	Strategy to get a complete set of tracers throughout the desired region of the image. It consists of 2 iterations (2 methods) for the single scale procedure; 4 iterations (2 methods, 2 scales) for the two scale procedure
Tracer size	Line/column dimension of a tracer. In NWC/PPS-HRW software, both dimensions are similar defining square shaped tracers
Tracking	Determination of the best matching square segment for a given tracer in the initial image, with the same line and column dimension, inside the tracking area of a later image
Tracking area	Square segment in the later image containing the search area of a given tracer, in which all possible tracking candidates are located
Tracking candidate	Each square segment inside a tracking area of the later image, that is evaluated for the tracking of a given tracer
Tracking centre	Best matching square segment for a given tracer, with the same line and column dimension, inside the tracking area of a later image
Tracking centre location	For a tracking centre, pixel coordinates of its centre (line and column) in the later image
Trajectory	Path defining the displacement of a specific tracer throughout several satellite images
Two scale procedure	Tracer selection process considering tracers with two different tracer sizes (Basic dataset and Detailed dataset, being the line and column dimension of the second dataset half the dimension of the first dataset)
Weighted location	Location different that the centre of the tracer in the initial image or the tracking centre in the later image, relating best the displacement of the AMVs and Trajectories to the displacement of the part of the tracer with a largest contribution to the cross correlation.
Wind guess	NWP wind longitudinal and latitudinal components, through which the location of a smaller tracking area in the later image is defined for a quicker processing, although with a dependency on the NWP wind

Table 1: List of Definitions

1.4.2 Acronyms and Abbreviations

AVHRR-3	NOAA's Advanced Very High Resolution Radiometer - Third Generation
CIMSS	NOAA/UW's Cooperative Institute for Meteorological Satellite Studies
CMA	China Meteorological Administration
ECMWF	European Centre for Medium Range Weather Forecasts
EOS-1/2	NASA's Earth Observation System Satellites (Terra and Aqua), including MODIS radiometer
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FY-3D	CMA's Feng-Yun 3D polar satellite, including MERSI-2 radiometer
IR107-IR108-IR110	METImage 10.7µm Infrared channel – AVHRR-3, VIIRS, MERSI-2, SLSTR 10.8µm Infrared channel – MODIS 11.0µm Infrared channel
IWWG	International Winds Working Group
MERSI-2	CMA's Medium Resolution Spectral Imager Radiometer – Second generation
METimage	EUMETSAT's Meteorological Imager Radiometer
Metop-A/B/C	EUMETSAT's Polar System Satellites, including AVHRR-3 radiometer
MODIS	NASA's Moderate Resolution Imaging Spectroradiometer
NASA	United States' National Aeronautics and Space Administration
NOAA	United States' National Oceanic and Atmospheric Administration
NOAA-15/16/17/18/19	NOAA's Polar Operational Environmental Satellites - Fifth Generation, including AVHRR-3 radiometer
NOAA-20/21 & SNPP	NASA and NOAA's Joint Polar Satellite System satellites, including VIIRS radiometer
NWC/GEO	NWCSAF Software Package for Geostationary satellites
NWC/PPS	NWCSAF Software Package for Polar satellites
NWCSAF	EUMETSAT's Satellite Application Facility on support to Nowcasting and Very short range forecasting
Sentinel-3A/B/C/D	Copernicus' Polar satellites for Ocean and Land observation, including SLSTR radiometer
SLSTR	Copernicus' Sea and Land Surface Temperature Radiometer
UW	United States' University of Wisconsin/Madison
VIIRS	NASA's Visible/Infrared Imager Radiometer Suite radiometer
VIS06	AVHRR-3, VIIRS, MODIS, METimage, MERSI-2 and SLSTR 0.6µm Visible channel
WMO	World Meteorological Organization
WV067	MODIS and METimage 6.7µm Water vapour channel
WV072-WV073	MERSI-2 7.2µm Water vapour channel – MODIS and METimage 7.3µm Water vapour channel

Table 2: List of Acronyms and Abbreviations

1.5 REFERENCES

1.5.1 Applicable Documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]

For versioned references, subsequent amendments to or revisions of any of these publications do not apply. For unversioned references, the current edition of the referred document applies.

Current documentation can be found at the NWCSAF Helpdesk web: http://www.nwcsaf.org.

Ref.	***Title***	***Code***	***Version***
[AD.1]	Proposal for the Fourth Continuous Development and Operations Phase (CDOP4)	NWC/SAF/AEMET/MGT/CDOP4Proposal	1.0
[AD.2]	Interface Control Document for Internal and External Interfaces of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SW/ICD/1	3.2.0
[AD.3]	User Manual for the NWC/PPS application: Software Part, 2.Operation	NWC/CDOP3/PPS/SMHI/SW/UM/OPER	3.3.0
[AD.4]	System and Component Requirements Document for the NWC/PPS	NWC/CDOP3/PPS/SMHI/SW/SCRD	2.3
[AD.5]	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind	0.2.0
[AD.6]	Scientific and Validation Report for the Wind product processor of the NWC/PPS	NWC/CDOP3/PPS/AEMET/SCI/VR/Wind	0.2.0

Table 3: List of Applicable Documents

1.5.2 Reference Documents

The reference documents contain useful information related to the subject of the project. These reference documents complement the applicable ones, and can be looked up to enhance the information included in this document if it is desired. They are referenced in this document in the form [RD.X]. For dated references, subsequent amendments to or revisions of any of these publications do not apply. For undated references, the current edition of the referred document applies.

Ref.	Title
[RD.1]	J.Schmetz, K.Holmlund, J.Hoffman, B.Strauss, B.Mason, V.Gärtner, A.Koch, L. van de Berg, 1993: Operational Cloud Motion Winds from Meteosat Infrared Images (Journal of Applied Meteorology, Num. 32, pp. 1206-1225).
[RD.2]	S.Nieman, J.Schmetz, W.P.Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers (Journal of Applied Meteorology, Num. 32, pp. 1559-1568).
[RD.3]	C.M.Hayden & R.J.Purser, 1995: Recursive filter objective analysis of meteorological fields, and application to NESDIS operational processing (Journal of Applied Meteorology, Num. 34, pp. 3-15).
[RD.4]	K.Holmlund, 1998: The utilisation of statistical properties of satellite derived Atmospheric Motion Vectors to derive Quality Indicators (Weather and Forecasting, Num. 13, pp. 1093-1104).
[RD.5]	J.M.Fernández, 1998: A future product on HRVIS Winds from the Meteosat Second Generation for nowcasting and other applications. (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.6]	J.M.Fernández, 2000: Developments for a High Resolution Wind product from the HRVIS channel of the Meteosat Second Generation. (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.7]	J.M.Fernández, 2003: Enhancement of algorithms for satellite derived winds: the High Resolution and Quality Control aspects. (Proceedings 2003 Meteorological Satellite Conference, EUMETSAT Pub.39).
[RD.8]	J.García-Pereda & J.M.Fernández, 2006: Description and validation results of High Resolution Winds product from HRVIS MSG channel at the EUMETSAT Nowcasting SAF (Proceedings 8th International Wind Workshop, EUMETSAT Pub.47).
[RD.9]	J.García-Pereda, 2008: Evolution of High Resolution Winds Product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.10]	J.García-Pereda, 2010: New developments in the High Resolution Winds product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 10th International Wind Workshop, EUMETSAT Pub.56).
[RD.11]	C.M.Hayden & R.T.Merrill, 1988: Recent NESDIS research in wind estimation from geostationary satellite images (ECMWF Seminar Proceedings: Data assimilation and use of satellite data, Vol. II, pp.273-293).
[RD.12]	W.P.Menzel, 1996: Report on the Working Group on verification statistics. (Proceedings 3rd International Wind Workshop, EUMETSAT Pub.18).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.14]	Xu J. & Zhang Q., 1996: Calculation of Cloud motion wind with GMS-5 images in China. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.15]	K.Holmlund & C.S.Velden, 1998: Objective determination of the reliability of satellite derived Atmospheric Motion Vectors (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.16]	K.Holmlund, C.S.Velden & M.Rohn, 2000: Improved quality estimates of Atmospheric Motion Vectors utilising the EUMETSAT Quality Indicators and the UW/CIMSS Autoeditor (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.17]	R.Borde & R.Oyama, 2008: A direct link between feature tracking and height assignment of operational Atmospheric Motion Vectors (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.18]	J.García-Pereda, R.Borde & R.Randriamampianina, 2012: Latest developments in "NWCSAF High Resolution Winds" product (Proceedings 11th International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (WMO Publication, available at https://library.wmo.int/doc_num.php?explnum_id=10722#page=956)
[RD.20]	WMO Code Tables and Flag Tables associated with BUFR/CREX table B, version 31 (WMO Publication, available at https://library.wmo.int/doc_num.php?explnum_id=10722#page=646)
[RD.21]	P.Lean, G.Kelly & S.Migliorini, 2014: Characterizing AMV height assignment errors in a simulation study (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.22]	Á.Hernández-Carrascal & N.Bormann, 2014: Cloud top, Cloud centre, Cloud layer – Where to place AMVs? (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.23]	K.Salonen & N.Bormann, 2014: Investigations of alternative interpretations of AMVs (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.24]	D.Santek, J.García-Pereda, C.Velden, I.Genkova, S.Wanzong, D.Stettner & M.Mindock, 2014: 2014 AMV Intercomparison Study Report - Comparison of NWCSAF/HRW AMVs with AMVs from other producers (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/225)
[RD.25]	D.Santek, R.Dworak, S.Wanzong, K.Winiecki, S.Nebuda, J.García-Pereda, R.Borde & M.Carranza, 2018: 2018 AMV Intercomparison Study Report (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/5092)
[RD.26]	K.Salonen, J.Cotton, N.Bormann & M.Forsythe, 2015: Characterizing AMV height-assignment error by comparing best-fit pressure statistics from the Met Office and ECMWF data assimilation systems (Journal of Applied Meteorology and Climatology, Vol.54, Num.1).

Table 4: List of Reference Documents

2. DESCRIPTION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)

2.1 GOAL OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)

The NWC/PPS-High Resolution Winds (NWC/PPS-HRW) software aims to provide, for near real time meteorological applications, detailed sets of "Atmospheric Motion Vectors" (AMVs) and "Trajectories" from images reprojected to a static region, coming from any of the following polar satellites and radiometers:

- AVHRR-3 radiometer inside NOAA-15, NOAA-16, NOAA-17, NOAA-18, NOAA-19, Metop-A, Metop-B or Metop-C polar satellites.
- VIIRS radiometer inside SNPP, NOAA-20 or NOAA-21 polar satellites.
- MODIS radiometer inside EOS-1 (Terra) or EOS-2 (Aqua) polar satellites.
- METimage radiometer inside Metop-SG-A1, Metop-SG-A2 or Metop-SG-A3 polar satellites (when they become available).
- MERSI-2 radiometer inside FY3-D polar satellite.
- SLSTR radiometer inside Sentinel-3A or Sentinel-3B polar satellites (and Sentinel-3C or Sentinel-3D when they become available).

An "Atmospheric Motion Vector" (AMV) is the horizontal displacement between two Earth positions in two satellite images ("initial image" and "later image"), of a square "segment" of nxn pixels. A "Trajectory" is the path defined by the displacement of the same tracer throughout several satellite images. The square segment is defined through a specific cloudiness feature in visible, infrared or AVHRR-3/VIIRS/MODIS/METimage/MERSI-2/SLSTR water vapour images (and so called "cloudy AMV"), or through a specific clear air moisture feature in MODIS/METimage/MERSI-2 water vapour images (and so called "clear air AMV"). "Clear air AMVs" are calculated for the first time in this second version of NWC/PPS-HRW (HRW v7.Q).

AMVs and Trajectories are calculated throughout all hours of the day, as a dynamic information in the NWC/PPS package, considering the displacement of tracers found in four different types of satellite images:

- Visible images coming from 0.630 μm channel in AVHRR-3 radiometer, 0.640 μm channel in VIIRS radiometer, 0.645 μm channel in MODIS radiometer, 0.668 μm channel in METimage radiometer, 0.650 μm channel in MERSI-2 radiometer or 0.659 μm channel in SLSTR radiometer (VIS06 AMVs).
- Infrared images coming from 10.800 μm channel in AVHRR-3 radiometer, 10.763 μm channel in VIIRS radiometer, 11.030 μm channel in MODIS radiometer, 10.690 μm channel in METimage radiometer, 10.800 μm channel in MERSI-2 radiometer or 10.850 μm channel in SLSTR radiometer (IR107-IR108-IR110 AMVs).
- Water vapour images coming from 6.715 μm channel in MODIS radiometer or 6.725 μm channel in METimage radiometer (WV067 AMVs).
- Water vapour images coming from 7.325 μm channel in MODIS radiometer, 7.325 μm channel in METimage radiometer or 7.200 μm channel in MERSI-2 radiometer (WV072-WV073 AMVs).

NWC/PPS-HRW software output includes pressure level information, which locates in the vertical dimension the calculated AMVs and Trajectories, and a quality control flagging, which gives an indication of its error in probabilistic terms, with auxiliary indicators about how the AMVs and Trajectories were determined.

It has been developed by AEMET in the framework of the EUMETSAT Satellite Application Facility on support to Nowcasting and Very short range forecasting (NWCSAF). This software is useful in Nowcasting applications, used in synergy with other data available to the forecaster.

For example, in the watch and warning of dangerous wind situations, in the monitoring of the general flow, of low level convergence (when and where cumulus start to develop), of divergence at the top of developed systems, or other cases of small scale circulation or wind singularities.

It can also be used in form of objectively derived fields, and assimilated in Numerical Weather Prediction Models (together with many other data), as an input to Analysis, Nowcasting and Very short range forecasting applications. The quality flags should be very useful for these cases.

NWC/PPS-HRW output is equivalent to the one for NWC/GEO-HRW (so that both can be used exactly the same way by the user), and similar to other products calculating Atmospheric Motion Vectors: winds, trajectories and related parameters are calculated with a level 2 of processing. No level 3 of processing (as a grid interpolation or a meteorological analysis based on NWC/PPS-HRW output) is included.

2.2 OUTLINE OF HIGH RESOLUTION WINDS (NWC/PPS-HRW) ALGORITHM

As a whole, NWC/PPS-HRW (High Resolution Winds) software is designed in a modular way, so that it can be easy to handle and modify. The whole process includes the following steps:

1. Preprocessing:

   • Includes the reading and geolocation of the satellite image data reprojected to a static region, which are going to be used for the AMV calculation (Infrared and Water vapour brightness temperatures and Visible normalized reflectances from the mentioned satellites, reflectometers and channels, with their latitudes, longitudes, satellite and solar angles), and the reading of the corresponding NWP data and NWC/PPS-Cloud outputs (CT/Cloud Type, CTTH/Cloud Top Temperature and Height and CMIC/Cloud Microphysics) for the static region which is going to be used in the NWC/PPS-HRW processing.

2. Processing:

   • First, “tracers” are calculated in an “initial image” with two consecutive methods: Gradient and Tracer characteristics.

   • Later, these “tracers” are “tracked” in a “later image” through one of two different methods (Euclidean distance or Cross correlation), with the selection of up to three “tracking centres” for each “tracer”.

   • “Atmospheric Motion Vectors (AMVs)” and “Trajectories” are then calculated, considering the displacement between the position of each “tracer” in the “initial image” and the position of the corresponding “tracking centres” in the “later image”.

   • The pressure level of the AMVs and Trajectories is defined through one of two different methods (“Brightness temperature interpolation method” or “Cross Correlation Contribution method with/without Microphysics correction”) for their vertical location in the atmosphere.

3. Postprocessing:

   • A Quality control with EUMETSAT “Quality Indicator” method is implemented, with the choice of the “Best AMV” considering the up to three AMVs calculated for each tracer, and a Final control check to eliminate wrong AMVs and Trajectories which are very different to those in their vicinity.

   • An “Orographic flag” can also be calculated, which incorporating topographic data detects those AMVs and Trajectories affected by land influence.

Examples are presented throughout the description of the algorithm to illustrate the process. The different options and coefficients are also presented. Many of them are configurable: in such a case, this circumstance is specifically indicated.

2.2.1 Preprocessing

During the initialization process, a list of parameters is extracted from the corresponding input files, after reprojection of all these input files to the selected static processing region. All reprojection process is previous to the running of NWC/PPS-HRW, and has to be run as explained in [AD.3]. For NWC/PPS-HRW, "satellite image input files" and "satellite angle input files" are used as satellite input. Both files need to be located in `$SM_IMAGER_DIR` directory.

The "satellite image input files" share the following naming structure:
`S_NWC_<radid>_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`

where <radid> parameter is the radiometer related to the scanning and <satid> parameter is the polar satellite related to the scanning, which can adopt any of the following value pairs:

- radid = avhrr satid = noaa15/noaa16/noaa17/noaa18/noaa19/metopa/metopb/metopc
- radid = viirs satid = npp/noaa20/noaa21
- radid = modis satid = eos1/eos2
- radid = metimage satid = metopsga1/metopsga2/metopsga3
- radid = mersi2 satid = fy3d
- radid = slstr satid = sentinel3a/sentinel3b/sentinel3c/sentinel3d

<orbid>=nnnnn is a numeric code related to the satellite orbit, <tim1>=yyyymmddThhmmssdZ is the satellite initial processing time, <tim2>=yyyymmddThhmmssdZ is the satellite final processing time, and <regid> is the label identifying the static region used for the AMV calculation (for example, "europa" or "euron1").

Next parameters are extracted from the "satellite image input files", for the two images in which tracers are identified and tracked:

- Horizontal and vertical dimensions of the static region used for the reprojection of all NWC/PPS-HRW input files ("nx" and "ny" parameters).
- VIS06 normalized reflectances for each pixel ("ch_r06" parameter).
- IR107-IR108-IR110 brightness temperatures for each pixel ("ch_tb11" parameter).
- WV067 brightness temperatures for each pixel, if available ("ch_tb67" parameter).
- WV072-WV073 brightness temperatures for each pixel, if available ("ch_tb73" parameter).
- Latitudes and longitudes for each pixel ("lat" and "lon" parameters).

The "satellite angle input files" share the following naming structure:
`S_NWC_sunsatangles_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`.

Next parameters are extracted from the "satellite angle input files", for the two images in which tracers are identified and tracked:

- Solar and satellite zenith angles ("sunzenith" and "satzenith" parameters).
- Scanning time for each pixel ("time_per_pixel" parameter).

Next parameters are extracted from the "NWP input files" for the static region used for the AMV calculation. At least two NWP forecast input files related to a moment before and a moment after the images in which tracers are identified and tracked are needed for the processing. One "NWP analysis input file" up to one hour away from the moment in which AMVs are tracked is additionally needed to run Validation statistics against NWP analysis winds. The name of the "NWP input file" is identified as PPS_ECMWF_yyyymmddhhmm+fffHggM_<regid>.nc, where yyyymmddhhmm is the moment of the NWP run, fffHggM is the moment of the NWP forecast for the given file, and $SM_NWPDATA_DIR is the directory in which these "NWP input files" are located.

- NWP temperature profiles ("t" parameter).
- NWP surface pressure field ("psur" parameter), if the "Orographic flag" defined in chapter 2.2.7 is used, or if Validation statistics are to be calculated by the NWC/PPS-HRW software itself such as defined in chapter 2.2.8 (considering as reference winds NWP analysis winds or NWP forecast winds). Both options are implemented in the default configuration, but none of them are mandatory.
- NWP wind component profiles ("u" and "v" parameters), if the "Forecast consistency quality control test" defined in chapter 2.2.6 is used, or if the NWP "wind guess" for the definition of the "tracking area" in the "later image" such as defined in chapter 2.2.3 is used, or if Validation statistics are to be calculated by the NWC/PPS-HRW software itself such as defined in chapter 2.2.8 (considering as reference winds NWP analysis winds or NWP forecast winds). The three options are implemented in the default configuration, but none of them are mandatory.
- NWP geopotential profiles ("z" parameter), if the "Orographic flag" defined in chapter 2.2.7 is used (implemented in the default configuration but not mandatory).

Next parameters are extracted from the "NWP/PPS-CT (Cloud type) output files", for the static region used for the AMV calculation. The name of the "CT output files" is identified as S_NWC_CT_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc, and $SM_PRODUCT_DIR is the directory in which these "CT output files" are located.

- Grid mapping info ("grid_mapping_info" parameter), a property variable explaining the name ("grid_mapping_name" attribute) and characteristics ("comment" attribute) of the reprojection used for all NWC/PPS-HRW input files.
- NWC/PPS-CT Cloud Type output ("ct" parameter) for the image in which tracers are calculated, in case the "AMV Cloud type" is used for the "Brightness temperature interpolation method height assignment", such as defined in chapter 2.2.4 (not mandatory).
- NWC/PPS-CT Cloud Type output ("ct" parameter) for the image in which tracers are tracked, in case the "CCC method height assignment" defined in chapter 2.2.5 is used (implemented in the default configuration but not mandatory).

Next parameters are extracted from the "NWP/PPS-CTTH (Cloud Top Temperature and Height) output files", for the static region used for the AMV calculation. The name of the "CTTH output files" is identified as S_NWC_CTTH_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc, and $SM_PRODUCT_DIR is the directory in which these "CTTH output files" are located.

- NWC/PPS-CTTH Cloud Top Pressure ("ctth_press" parameter) and Cloud Top Temperature ("ctth_tempe" parameter) for the image in which tracers are tracked, in case the "CCC method height assignment" defined in chapter 2.2.5 is used (implemented in the default configuration but not mandatory).

Next parameters are extracted from the "NWP/PPS-CMIC (Cloud Microphysics) output files", for the static region used for the AMV calculation. The name of the "CMIC output files" is identified as S_NWC_CMIC_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc, and $SM_PRODUCT_DIR is the directory in which these "CMIC output files" are located.

- NWC/PPS-CMIC Cloud Phase ("cmic_phase" parameter), Liquid Water Path ("cmic_lwp" parameter) and Ice Water Path ("cmic_iwp" parameter) for the image in which tracers are tracked, in case the "Cloud Microphysics correction" is used in the "CCC method height assignment", such as defined in chapter 2.2.5 (implemented in the default configuration but not mandatory).

Next parameters are extracted from the "Physiography file" provided for the static region used for the AMV calculation. The name of this "Physiography file" is identified as `physiography.<regid>.nc`, and `$SM_STATIC_AUXILIARY_DIR` is the directory in which this "Physiography file" is located:

1. Elevation in metres for each pixel in the static region ("elevation" parameter).
2. Horizontal and vertical dimension in metres for each pixel in the static region ("xdist" and "ydist" parameters).

Here, only the "Physiography file", the "satellite image input files", the "satellite angle input files", the "NWC/PPS-CT Cloud Type output" for the requested images, and the "NWP input files" with NWP temperature data and NWP wind forecast data with a minimum number of NWP levels (defined through configurable parameter MIN_NWP_FOR_CALCULATION, with a default value of 4) are actually needed for the AMV calculation. The rest of input data contribute to a higher number of AMVs and Trajectories, and a better quality of the NWC/PPS-HRW output data. Detailed information on all configuration parameters used can be found in chapter 2.3.3. The option to calculate AMVs and Trajectories with climatological data instead of NWP data is not available, since the amount and quality of data provided would be significantly worse.

The satellite data (Normalized reflectances and Brightness temperatures) to be used in the calculation of AMVs and Trajectories are stored in so-called brightness "N_Value matrices". "N_Value matrix" data are considered as integer values ranging from 0 to 255 (inside an 8 bit data range), being 0 a predefined minimum value and 255 a predefined maximum value (different for each satellite channel).

2.2.2 Tracer calculation

Two tracer computation methods are applied: Gradient; Tracer characteristics. They are used one after the other in two different tracer selection strategies throughout the region: the 'single scale procedure' (when one scale of tracers is calculated), and the 'two scale procedure' (when two different scales of tracers are calculated: 'basic' and 'detailed', being the line and element size of the 'detailed tracers' half the size of the one for 'basic tracers').

Both methods calculate a tracer optimising its location around one of the 'starting locations' in the image. The distance between 'starting locations' is defined by a 'pixel distance' between tracers, defined by configurable parameter TRACERDISTANCE_LOW (with default value 6 pixels).

In NWC/PPS-HRW v7.Q, to maximize the number of tracers and AMVs at all levels, all tracers calculated with this 'pixel distance' are kept in the default configuration, related to configurable parameters HIGHERDENSITY_LOWTRACERS = HIGHERDENSITY_LOWTRACERS_DET = 1. However, if a smaller proportion of high level tracers and AMVs is preferred, these configurable parameters act with values higher than 1 as a multiplying factor in the 'pixel distance' of high level tracers/AMVs (at pressure levels higher than 400 hPa; the first parameter is used for the 'Basic scale' and the second one for the 'Detailed scale').

A resolution ('tracer size') of 24 pixels is proposed as baseline for the 'sin'gle scale procedure' (used as default option with configurable parameter CDET=0) for all types of tracers. The latitude and longitude limits for calculation of AMVs and Trajectories can be specified with configurable parameters LAT_MAX, LAT_MIN, LON_MAX, LON_MIN. A resolution of 24 pixels for the 'basic tracers' and 12 pixels for the 'detailed tracers' is proposed for the 'two scale procedure' (when configurable parameter CDET=1). A smaller region can be defined for the detailed scale with configurable parameters LAT_MAX_DET, LAT_MIN_DET, LON_MAX_DET, LON_MIN_DET.

With the default configuration, configured with CALCULATE_TRAJECTORIES = 1, the definition of new 'tracer locations' starts at the integer line/column location of all 'tracking centres' related to valid AMVs in the previous round, when they are available. So, a set of 'persistent tracers' is defined and tracked in several images, and the progressive locations of the tracer throughout the time define 'Trajectories'. For this, it is necessary that the conditions implied by the 'tracer method' used for the determination of the tracer in the "initial image", keep on being valid throughout all the images.

However, in contrast to NWC/GEO-HRW, where the satellite scanning region is constant for all slots so permitting the calculation of long trajectories with a persistence of even hours, in NWC/PPS-HRW it is very infrequent that an Earth location can be viewed by several consecutive polar satellite scans. Due to this, the possibility to calculate with NWC/PPS-HRW trajectories persisting for more than three satellite images is very infrequent. Due to this, in comparison, the applicability of trajectories from NWC/PPS-HRW is more limited, which has to be taken into account by the NWCSAF user.

A verification is also done checking that all 'tracer' pixels are in valid locations in the working region, with valid latitude, longitude, satellite and solar zenith angles, satellite data and NWC/PPS-CT cloud type outputs (when used, such as in the default configuration). In case any of these inputs needed for the 'tracer' definition is not available and an alternative processing exists, the alternative is used if configurable parameter KEEPDEFAULTPROCEDURE = 0. However, in the default configuration with KEEPDEFAULTPROCEDURE = 1, NWC/PPS-HRW processing stops. This was suggested by NWCSAF users, to avoid the use of alternative methods for the AMV calculation for a specific slot, different to those defined in the configuration.

2.2.3 Tracer tracking and Wind calculation

The 'tracking' method seeks for the best 'adjustment centre' of a tracer computed in an initial image, over a larger portion of the later image ('tracking area'), performing a pixel by pixel comparison of a segment of the same size ('tracking candidate'), repeatedly moving this segment over the tracking area until the best candidates are found. For this, one of next algorithms is used:

- Euclidean distance (configured with TRACKING = LP), where the sum $LP_{ij} = \Sigma\Sigma(T\text{-}S)^2$ is calculated considering the visible normalized reflectances/infrared or water vapour brightness temperatures of all tracer (T) and tracking candidate (S) pixels at correlative locations. The best locations are defined through the minimum values of the sum LP_{ij}.
- Cross correlation (configured with TRACKING = CC, default value), that computes the correlation $CC_{ij}=Cov_{TS}/(\sigma_T \cdot \sigma_S)$ where 'σ' is the standard deviation or root of the variance and 'Cov' is the covariance between the tracer and tracking candidate. The best locations are defined through the maximum values of the correlation $CC_{ij.}$

A verification is done again in the later image, checking that all 'tracking area' pixels are in valid locations in the working region, with valid latitude, longitude, satellite and solar zenith angles, satellite data, NWP data, and NWC/PPS-Cloud product outputs (CT, CTTH and CMIC, in case they are used).

In case any of these inputs needed for the "tracking area" definition is not available, and an alternative exists, the alternative is used if configurable parameter KEEPDEFAULTPROCEDURE = 0. However, in the default configuration with KEEPDEFAULTPROCEDURE = 1, NWC/PPS-HRW processing stops. As already mentioned, this was suggested by NWCSAF users to avoid the use of alternative methods for the AMV calculation for a specific slot, different to those defined in the configuration.

To increase the speed of NWC/PPS-HRW algorithm, the 'tracking area centre' is located at the position of the tracer which is forecast for the later image by the NWP wind, as defined by configurable parameter WIND_GUESS = 1. This has been defined this way due to the long time separation which can exist between the 'initial image' and the 'later image' (up to 120 minutes), which can generate very large 'tracking areas'.

However, this implies a small dependence of NWC/PPS-HRW outputs on the NWP model used. The option is kept for the NWCSAF user to remove this "wind guess" with WIND_GUESS = 0. Operationally, this can be used in NWC/PPS-HRW software when the size of the reprojected pixels is large (around 5 km), and so the size of the "tracking area" is not too large in pixels.

The line/column size in pixels of the 'tracking area' is calculated so that it is able to detect for any tracer speed differences with respect to the NWP wind guess of at least 72 km/h in any direction (value of configurable parameter MINSPEED_DETECTION), when the wind guess is used in the definition of the tracking area. When the wind guess is not used, this MINSPEED_DETECTION parameter is to be understood as the minimum displacement in any direction that NWC/PPS-HRW software is able to detect. Up to 3 'tracking centres' are retained for both tracking methods: the absolute and 2 local best positions. The line/column and latitude/longitude location of the 'tracking centres' in the later image is refined as default option with second order interpolation with USE_SUBPIXELTRACKING = 1.

The calculation of the wind components considers the displacement along the corresponding "great circle" with the "haversine formula". This procedure takes into account the real time each pixel was scanned, defined through the "satellite angle input files".

For this calculation, NWC/GEO-HRW has the option to correct the horizontal deviation in the apparent position of the tracer/tracking centre due to its height over the Earth surface, through a 'parallax correction' of the latitude and longitude values of the tracer and tracking centre. This option is however not available for the moment inside NWC/PPS-HRW software, due to the lack of equivalent procedures for 'parallax correction' inside NWC/PPS software package.

Finally, NWC/GEO-HRW algorithm also has the option through SLOT_GAP configurable parameter to calculate AMVs and Trajectories considering an "initial image" for the tracer and a "later image" for the tracking centre, which are not necessarily consecutive, meaning that there can be valid calculated locations of the tracer in intermediate images between both images. Related to this, an additional option exists in NWC/GEO-HRW called 'mixed calculation method' and implemented with configurable parameter MIXED_SCANNING, through which tracers are to be tracked considering consecutive pairs of images, but corresponding AMVs and Trajectories are calculated considering the whole displacement for all pairs of images altogether. Both options are not available in NWC/PPS-HRW algorithm, because in general they cause great reductions in the numbers of AMVs, and they can also produce AMVs related to displacements of up to several hours (due to the long time separation which has been allowed between pairs of images in NWC/PPS-HRW, up to 120 minutes).

2.2.4 Height assignment with 'Brightness temperature interpolation method'

Operatively, this method runs before the 'tracer tracking'. It is only used when so specifically defined with configurable parameter DEFINEWITHCONTRIBUTIONS = 0, when the wind guess is used to define the tracking area in the later image with configurable parameter WIND_GUESS = 1 (which is the default option for NWC/PPS-HRW), or when NWC/PPS-CT Cloud Type or NWC/PPS-CTTH Cloud Top Temperature and Pressure outputs are not available for the processing region for the image in which "tracers" are tracked if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option; in this last case, otherwise, the processing of NWC/PPS-HRW stops).

This height assignment method is only available if a NWP temperature forecast with a minimum number of NWP levels is provided (configurable parameter MIN_NWP_FOR_CALCULATION, with a default value of 4). If the number of NWP temperature levels is smaller, the processing of NWC/PPS-HRW algorithm stops, without calculating any AMVs or Trajectories

The input for the height assignment is the IR107-IR108-IR110 brightness temperature for the visible and infrared AMVs, WV067 brightness temperature for the WV067 water vapour AMVs, and WV072-WV073 brightness temperature for the WV072-WV073 water vapour AMVs.

With this, a 'base temperature' and a 'top temperature' are calculated with the brightness temperatures found inside the tracer. A temperature to pressure conversion is then inferred with these two values and the NWP temperature forecast.

After this, with configurable parameter USE_CLOUDTYPE = 1,2, if NWC/PPS-CT Cloud Type output is available for the processing region and image for which tracers were calculated, it is read to define which of the two calculated pressure values ('base pressure' or 'top pressure') represents better the displacement defined by the Atmospheric Motion Vector.

The 'AMV cloud type' is calculated as the most common value of the NWC/PPS-CT Cloud Type inside the tracer, if its presence is at least $^{3}/_{2}$ times the one for the second most common. If this condition is not fulfilled the values Cloud_type = 21 (multiple cloud types), = 22 (multiple clear air types), or = 23 (mixed cloudy/clear air types) are assigned.

Some tracers are then eliminated depending on the 'AMV cloud type' and the satellite channel used for the AMV calculation. These cases are identified inside a blue cell in *Table 5,* and are related to cloud free tracers, fractional clouds, and some cloud types for which the validation statistics are significantly worse.

In the rest of cases, the AMV pressure level is defined such as also shown in *Table 5*. If the 'AMV cloud type' has not been calculated, the 'Base pressure' is considered for all AMVs because most cloud types fit better with the 'Base pressure'.

"AMV Cloud type" values	VIS06	WV067	WV072/ WV073	IR107/ IR108/ IR110
1 Cloud free land		Top	Top	
2 Cloud free sea		Top	Top	
3 Land contaminated by snow/ice		Top	Top	
4 Sea contaminated by ice		Top	Top	
5 Very low cumulus/stratus	Base		Base	Base
6 Low cumulus/stratus	Base		Base	Base
7 Medium level cumulus/stratus	Base		Base	Base
8 High opaque cumulus/stratus	Base	Base	Base	Base
9 Very high opaque cumulus/stratus	Base	Base	Base	Base
10 Fractional clouds				
11 High semitransp. thin clouds		Top	Top	Top
12 High semitransp. meanly thick clouds	Top	Top	Top	Top
13 High semitransp. thick clouds	Base	Base	Base	Base
14 High semitransp. above other clouds		Base	Base	Top
15 High semitransp. above snow/ice		Base	Base	Top
21 Multiple cloud types	Base	Base	Base	Base
22 Multiple clear air types		Top	Top	
23 Mixed cloudy/clear air types	Base	Base	Base	Base

Table 5: AMV filtering related to the 'AMV cloud type' and the satellite channel, and consideration of the 'Cloud top pressure' or 'Cloud base pressure' in the "Brightness temperature interpolation height assignment method" for the valid cases

2.2.5 Height assignment with 'CCC method'

'CCC method - Cross Correlation Contribution method' height assignment is implemented with configurable parameters TRACKING=CC and DEFINEWITHCONTRIBUTIONS=1. It is run after the "tracking" process, and it is the default option for NWC/PPS-HRW. The method was developed by Régis Borde and Ryo Oyama in 2008, and is fully documented in the Paper "A direct link between feature tracking and height assignment of operational AMVs" [RD.17].

It requires the use of 'Cross correlation' as Tracking method, and the calculation of NWC/PPS-CT Cloud type and NWC/PPS-CTTH Cloud Top Temperature and Pressure for the selected region and slot before the running of NWC/PPS-HRW. If these outputs are not available, the "AMV pressure" and "AMV temperature" values provided by "Brightness temperature interpolation method" are used for the height assignment if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option). Otherwise, the processing of NWC/PPS-HRW stops.

It has also the advantage of including in the height assignment all elements included in the "Neural Network" process used by NWC/PPS-CTTH software for the cloud top pressure:

- Brightness temperature of satellite infrared window channels.
- Brightness temperature of water vapour channels (for radiometers for which it is available).
- Brightness temperature of carbon dioxide channel (for radiometers for which it is available).
- Texture (standard deviation inside a 5x5 big pixel) of several channels or channel differences.
- Temperature differences for each pixel, considering several different channels.
- Temperature differences between each pixel and its nearest warmest/coldest neighbour, considering the infrared window channels.
- NWP temperature at several levels, surface pressure and column integrated water vapour.

It defines the 'AMV pressure' and 'AMV temperature', considering only the pressure and temperature of the pixels contributing most to the 'Cross correlation' between the 'tracer' in the "initial image' and the 'tracking centre' in the "final image'.

For this, the 'partial contribution to the correlation' (CC_{ij}) relating each pixel inside the 'tracer' and the 'tracking centre' is defined with the following formula, in which respectively for the 'tracer' and the 'tracking centre', T_{ij}/S_{ij} are the 'N_Value brightness values' for each pixel, T_M/S_M are the mean values, σ_T/σ_S the standard deviations of the 'brightness values', and NUM is the total number of pixels inside the 'tracer' or 'tracking centre': $CC_{ij} = (T_{ij} - T_M)\cdot(S_{ij} - S_M) / NUM\cdot\sigma_T.\sigma_S$.

A separate treatment of 'Cloudy AMVs' and 'Water vapour clear air AMVs' is used here, these last ones defined as those AMVs calculated with water vapour channels for which the 'Correlation contribution sum' is larger for the group of 'Clear air pixels' than for the group of 'Cloudy pixels', considering all pixels inside the tracer for which the total contribution to the correlation is positive:

- In the 'Cloudy AMVs', a 'CCC pressure P_{CCC}' value is calculated for each 'tracking centre' considering the partial contribution to the correlation (CCij) and the NWC/PPS-CTTH Cloud top pressure (CTPij) with formula $P_{CCC}=\Sigma(CCij\cdot CTPij)/\Sigma CCij$. For the calculation, only bright pixels (in visible cases) or cold pixels (in infrared/water vapour cases) with valid CTPij values (corresponding to cloudy, non-fractional cloud types), and with CCij over a threshold (the mean correlation contribution or else zero) are considered. A similar calculation is done for the 'CCC temperature T_{CCC}'. The 'CCC cloud type CT_{CCC}' value is calculated as the one with the highest total contribution to the correlation. A 'CCC pressure error ΔP_{CCC}' value is also calculated for each 'tracking centre' with the formula $\Delta P_{CCC}=\sqrt{(\Sigma(CC_{ij}\cdot CTP_{ij}^2)/\Sigma CC_{ij} - P_{CCC}^2)}$, useful as a new Quality control parameter for the output AMVs. A maximum pressure error can be defined with configurable parameter MAXPRESSUREERROR (with default value 150 hPa).

  Here it is clear that 'CCC method' offers a direct correspondence between the pressure levels given for NWC/PPS-HRW Cloudy AMVs and Trajectories, and those given to the Cloud tops by

NWC/PPS-CTTH product. It also defines a clear correspondence between the elements considered for the pressure level calculations, and the real cloud features observed in the satellite images.

Nevertheless, several studies in 2014 (Peter Lean et al. [RD.21], Á.Hernández-Carrascal & N.Bormann [RD.22], K.Salonen & N.Bormann [RD.23]), suggest that AMVs would better be related to a pressure level lower than the Cloud top. An empirical relationship has been found to exist between the “difference between the AMV pressure level calculated with CCC method and the AMV best fit pressure level”, and the ‘CCC Liquid/Ice water path’ value, so that a correction for the ‘CCC pressure’ related to the Cloud depth can be defined.

So, with ‘CCC liquid/ice water path LWP/IWP_{CCC}’ variables, whose value are obtained with similar formulae to the previous ones for ‘CCC pressure P_{CCC}’, corrections in the ‘CCC pressure P_{CCC}’ values are obtained considering functions defined in the two-month period February-March 2020, in both regions used for the testing and validation (“EUROPA” and “EURON1/Scandinavia”), using Radiosounding winds as reference for the best fit level. The correction tables are available in the “Algorithm Theoretical Basic Document for the Wind product processor of the NWC/PPS” [AD.5].

The corrections cause an improvement in all validation parameters, and are implemented with configurable parameter USE_MICROPHYSICS = 2 or 3 (default option). However, a study made by the Hungarian Meteorological Service (OMSZ) in January 2021 (in Ticket “HRW quality issue” on date “2021/01/07” at the NWCSAF Helpdesk), showed that a small relocation is convenient in the AMV level defined by the Microphysics correction for AMVs higher than 230 hPa. AMVs at these levels were too high in the atmosphere, and a location at a lower level works better and has better validation statistics. An empirical formula shown in the ATBD document [AD.5] is used for this with configurable parameter USE_MICROPHYSICS = 3 (which is the default option for NWC/PPS-HRW).

The user has necessarily to run all NWC/PPS-Cloud products (CMA, CT, CTTH, CMIC) so that all this process can be activated. If NWC/PPS-CMIC product output is not available but the other ones are, NWC/PPS-HRW runs “CCC method height assignment without Microphysics correction” if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option). Otherwise, the processing of NWC/PPS-HRW stops.

- In the ‘Water vapour clear air AMVs’, no CTPij pressure values exist logically from NWC/GEO CTTH output for the clear air pixels. Because of this, the Brightness temperature from the corresponding channel (BTij) is used instead, considering only the pixels whose brightness temperature is colder than the threshold. A ‘CCC temperature value error, ΔT_{CCC}’ is now also calculated considering a formula similar to the one used in the previous chapter for the pressure error: $\Delta T_{CCC}=\sqrt{(\Sigma(CC_{ij}\cdot BT_{ij}^2)/\Sigma CC_{ij} - T_{CCC}^2)}$. With these data, three different temperature values are defined by next formulas: $T_{CCC} + \Delta T_{CCC}$, T_{CCC}, $T_{CCC} - \Delta T_{CCC}$. For each one of these values, a temperature to pressure conversion is obtained through interpolation to the NWP temperature forecast, giving three pressure values: P_{CCCMAX} (related to $T_{CCC} + \Delta T_{CCC}$), P_{CCC} (related to T_{CCC}) and P_{CCCMIN} (related to $T_{CCC} - \Delta T_{CCC}$). P_{CCC} is defined as the ‘CCC Pressure value’ for the clear air AMVs. $\Delta P_{CCC} = |P_{CCCMAX} - P_{CCCMIN}|/2$ is defined as the ‘CCC Pressure error value’ for the clear air AMVs (only in cases for which a vertical continuous reduction or increase of temperature is found). In the cases where the ‘CCC Pressure value’ or the ‘CCC Pressure error value’ cannot be calculated, the AMVs are discarded.

With configurable parameter DEFPOSWITHCONTRIBUTIONS = 1 (default option), the location of the AMV feature in both initial and final images is also defined not as the tracer/tracking centre but as the weighted position displacement defined with similar formulae $X_{CCC}=\Sigma(CC_{ij}\cdot X_{ij})/\Sigma CC_{ij}$, and $Y_{CCC}=\Sigma(CC_{ij}\cdot Y_{ij})/\Sigma CC_{ij}$ (where X_{ij} and Y_{ij} correspond to the line and column position of each pixel). With this relocation of the AMV, its position is related to the part of the AMV feature with largest contribution to the correlation. When trajectories are defined (with configurable parameter CALCULATE_TRAJECTORIES = 1), tracking consecutively during several slots the same tracer, this relocation of the AMV position is only calculated for the first AMV in the trajectory and keeps the same value during all the time the trajectory is alive, to avoid discontinuities in its positioning.

2.2.6 Postprocessing: Quality control and Choice of the best wind

The 'Quality Indicator' method developed by EUMETSAT (K.Holmlund, 1998, [RD.15]), and implemented in general in all AMV production centres, is used here. This method assigns a quantitative flag ('Quality Index (QI)', ranging from 0% to 100%) to any Atmospheric Motion Vector.

It is based on normalised functions fit to statistical properties in the behaviour of the AMVs. These properties are related to the expected change of the AMVs considering: temporal consistency (comparison to winds in the previous slot at the same location and level), spatial consistency (comparison to neighbour winds in the same slot at the same location and level) and consistency relative to a background (NWP wind forecast interpolated to the same slot, in the same location and level). For the 'two scale procedure', an additional 'interscale test' is computed for 'detailed AMVs' derived from a 'basic scale tracer' (compared to the corresponding 'basic scale AMV').

Several tests are applied (direction, speed and vector temporal consistency tests, vector spatial and forecast consistency tests) giving 5 different 'individual QIs'; their weighted sum provides two 'overall QIs' (after one correction affecting winds with very low speed): the 'Quality Index with forecast' and the 'Quality Index without forecast'. These "Quality index with forecast" or "Quality Index without forecast" are used for the filtering of the AMV and Trajectory data. The first one is used as default option, through configurable parameter QI_THRESHOLD_USEFORECAST = 1. The "Quality Index threshold" for the acceptance of an AMV or Trajectory as valid is defined by configurable parameter QI_THRESHOLD (with a default value of 83%).

Some differences occur here with NWC/GEO-HRW algorithm, for which the default "QI threshold" is 75% and the quality of AMVs with low "QI values" is still significant. In NWC/PPS-HRW, it is recommended instead not to use much lower values of this "QI threshold".

In spite of the common procedure in all AMV production centres, the experience in the "International Winds Workshops" has however shown that the configuration of the "Quality Indices" is very different for different AMV algorithms, and so a common homogeneous use for AMVs calculated with different algorithms was not possible up to now.

Because of this, a self-contained Fortran module defined by EUMETSAT and NOAA/NESDIS, calculating a 'Common Quality Index without forecast', was distributed by the "International Winds Working Group" cochairs Steve Wanzong and Régis Borde in May 2017, so that it would be included as such without modifications by all AMV algorithms. The use of this 'Common Quality Index' in the "2018 AMV Intercomparison Study" [RD.25] showed some skill in filtering collocated AMVs from different AMV algorithms, improving their statistical agreement.

This 'Common Quality Index without forecast' module has been implemented in NWCSAF High Resolution Winds, and the parameter is provided as an additional "Quality Index" for all AMVs and Trajectories. The differences of this 'Common Quality Index' with respect to the previous ones are:

- It is only calculated for AMVs/Trajectories with at least two trajectory sectors.
- For the "spatial consistency test" only the closest "neighbour AMV" is considered. For the "temporal consistency test" only the "prior AMV" related to the same trajectory is considered.
- Four different tests are applied: direction, speed and vector difference tests for the temporal consistency, and vector difference for the spatial consistency with a double contribution.
- It is not used for the filtering of AMVs and Trajectories by NWC/PPS-HRW algorithm.

Despite the Quality control, it is detected however sometimes that an AMV has a direction or speed completely different to the ones in its vicinity, without a clear justification. To eliminate these AMVs, which can be considered as errors, a function calculating the speed and direction histograms for all valid AMVs in small areas can be run: the 'Final Control Check' (activated as default option with configurable parameter FINALCONTROLCHECK = 1). When any of the columns of the speed or direction histograms has only one element, it is excluded: the lack in the same area of another AMV with relatively similar velocities or directions is enough to consider it an error.

2.2.7 Postprocessing: Orographic flag

Topographic information is finally incorporated to NWC/PPS-HRW algorithm, which in combination with NWP data, calculates an 'Orographic flag' to detect and reject those Atmospheric Motion Vectors affected by land influence. The reasons for this land influence can be: AMVs associated to land features incorrectly detected as cloud tracers; tracers blocked or whose flow is affected by mountain ranges; tracers associated to lee wave clouds, with atmospheric stability near mountain ranges.

The procedure reads one topographic matrix with "Representative Maximum Heights at the top of the topography around each pixel" (`$SM_STATIC_AUXILIARY_DIR/S_NWC_SFCMAX_<regid>`, being <regid> the label that identifies the static region used). If this matrix is not available, it is calculated directly from "elevation" data for each pixel, to be provided inside `$SM_STATIC_AUXILIARY_DIR/physiography.<regid>.nc` file for the processing of the given static region with NWC/PPS-HRW software. Once calculated, this matrix is stored for all runs of NWC/PPS-HRW for the given region. This matrix is then converted to the "Representative Pressure levels at the top of the topography around each pixel" (P_top), considering NWP geopotential data.

For optimisation reasons, in NWC/PPS-HRW v7.Q similar "Representative pressure levels at the surface of the topography" (P_sfc) is directly provided by the NWP surface pressure at each pixel.

With these P_sfc/P_top values, the 'Static orographic flag' is calculated at the position of each tracer. Its possible values are:

- Ind_topo=0: The 'Orographic flag' could not be calculated.
- Ind_topo=1: AMV wrongly located below the surface pressure level in the current AMV position (mainly due to the Microphysics correction in the "AMV pressure value").
- Ind_topo=2: Very important orographic influence found in the current AMV position.
- Ind_topo=3: Important orographic influence found in the current AMV position.
- Ind_topo=6: No orographic influence found in the current AMV position.

The 'Dynamic orographic flag' is then calculated: values of 'Ind_topo' are modified to verify the possibility of a previous in time orographic influence. This part only happens if Ind_topo = 6 and the tracer is related to predecessor AMVs in previous slots. The value of Ind_topo = 6 is then modified considering the next conditions:

- Ind_topo = 0: The "Orographic flag" could not be calculated.
- Ind_topo = 4: Very important orographic influence found at a previous position of the AMV.
- Ind_topo = 5: Important orographic influence found at a previous position of the AMV.
- Ind_topo = 6: No orographic influence is found in any current/previous position of the AMV.

With configurable parameter USE_TOPO = 1, the Orographic flag is calculated and incorporated to the output file, and AMVs with Ind_topo = 1 are eliminated. With USE_TOPO = 2 (which is the default option), all AMVs and Trajectories with any Orographic influence (i.e. with Ind_topo = 1 to 5) are eliminated from the output files.

2.2.8 Postprocessing: Autovalidation of NWC/PPS-HRW algorithm

NWC/PPS-HRW offers the same way as NWC/GEO-HRW software the option to calculate the validation statistics for the AMVs with the software itself (using as reference NWP analysis or forecast rectangular components of the wind, such as defined in Chapter 4.1 of this document, interpolated to the AMV final location and level). This is implemented with configurable parameter NWPVAL_STATISTICS = 1,2,3,4. Depending on its value, statistics for the different layers and satellite channels are provided separately or not, such as defined in the following list:

- 1: Statistics provided for all layers and satellite channels together.
- 2: Statistics provided for all layers together and each satellite channel separately.
- 3: Statistics provided for each layer separately and all satellite channels together.
- 4: Statistics provided for each layer and satellite channel separately (default option).

The validation statistics can be calculated using NWP forecast winds in real time processes, and using NWP forecast or analysis winds in reprocessing processes. The use of NWP analysis is implemented with configurable parameter NWPVAL_ANALYSIS = 1 (which is not the default option). Here, validation statistics will only be provided for NWC/PPS-HRW runs for which both "initial image" and "later image" are less than an hour away from the analysis date and hour (i.e., only NWC/PPS-HRW runs with both "initial image" and "later image" between 11:00Z and 13:00Z will be validated against a 12:00Z analysis run for the given day). When NWP forecast winds are used, the validation statistics are provided for all runs of NWC/PPS-HRW software instead.

The validation statistics are calculated at the end of the process of each NWC/PPS-HRW run, and the results are written in the running log of NWC/PPS-HRW, and also in a specific file under the name `S_NWC_HRW-STAT_<satid>_<regid>_yyyymmddT.txt` in `$SM_PRODUCT_DIR` directory. Here, <satid> is the identifier of the satellite used, <regid> is the identifier of the region used, and yyyymmddT is the date for which statistics are provided (validation statistics for all outputs from the same day are included in the same file).

The following content is added to this file each time the validation statistics are run: several lines with the following format, showing the validation parameters mentioned in Chapter 5 of this document (NC, SPD, NBIAS, NMVD, NRMSVD) for the considered AMV scale "BBB" (defined as BAS, DET), AMV type "TTTTT" (defined as TOTAL, CLOUD, CLEAR), layer "LLL" (defined as ALL, HIG, MED, LOW) and satellite channel for which AMVs have been calculated "CCCCC" (defined as TOTAL, VIS06, IR108, WV067, WV073). The date and time of the NWC/PPS-HRW run, of the "model configuration file" used in the process, and if the validation statistics have been run against the NWP analysis or forecast winds (parameter "GGG", defined as ANA, FOR) are also specified:

```
yyyy-mm-ddThh:mm:ssZ  PPS-HRW  7.Q  XXXXX  [S]  HRWDATE:YYYYMMDDTHHMMSSZ
HRWCONF:FFFFF.CFM  NWPCONF:GGG  ***  AMV:BBBTTTTT  CH:CCCCC  LAYER:LLL
*** NC:RRRRRR SPD[M/S]:SSS.SS NBIAS:±T.TTT NMVD:U.UUU NRMSVD:V.VVV
```

The parameters shown here can be used by the NWCSAF user as an option for the quality monitoring of the calculated NWC/PPS-HRW data.

Two additional elements are available in the validation process of NWC/PPS-HRW algorithm:

- The first one, activated with configurable parameter NWPVAL_NWPDIFFERENCE = 1 (implemented as default option) calculates also for each AMV the "Vector difference with the NWP reference wind". It can be used in nowcasting tasks, so that the user is able to detect in which cases the AMV is very different to the NWP forecast wind, and may be aware for example if a warning is needed due to strong winds unforeseen by the NWP forecast.

- The second one, activated with configurable parameter NWPVAL_NWPBESTFITLEVEL = 1 (implemented also as default option) calculates also for each AMV the "NWP reference wind at the best fit pressure level" (defined by its speed, direction and pressure). It can be used in verification tasks, to know in which cases there is more or less agreement between the pressure level defined by NWC/PPS-HRW, and the one suggested by the NWP model.

2.3 DESCRIPTION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW) OUTPUTS

One file for the single AMV scale, or two different files for two different AMV scales (related to 'Basic AMVs/Trajectories', and to 'Detailed AMVs/Trajectories' when so configured with configurable parameter CDET = 1), in form of BUFR or netCDF bulletins, are produced for each processed static region for every running slot. If AMVs/Trajectories have been calculated for different satellite channels, they are all included in the same bulletin.

Three different types of outputs are possible for NWC/PPS-High Resolution Winds, depending on the value of configurable parameter OUTPUT_FORMAT. This parameter is defined as a list of options separated by commas, so that several options can be used at the same time. The available options are:

1. OUTPUT_FORMAT = NWC: NWC/PPS-HRW output defined as two different BUFR bulletins (for AMVs and Trajectories), related to the ones used as default option in all previous versions of NWC/GEO-HRW software.
2. OUTPUT_FORMAT = IWWG (included in the default option): NWC/PPS-HRW output defined as one BUFR bulletin, whose format has been defined in 2018 by the "International Winds Working Group", and which is becoming the new standard AMV BUFR format for all AMV processing centres. This option also permits NWCSAF users to have a similar processing for the NWC/PPS-HRW outputs, for NWC/GEO-HRW outputs, and for AMV outputs from other AMV processing centres around the world.
3. OUTPUT_FORMAT = NCF (included in the default option): NWC/PPS-HRW output defined as one netCDF bulletin. The structure of netCDF output has changed with respect to the one defined in the previous version NWC/PPS-HRW v7.P, now being "CF compliant" and easier to process (following recommendations from NWCSAF users).

These options are equivalent to those provided for NWC/GEO-HRW vMTG software (v7.0), which will be released to users when MTG-I satellite becomes operational, so that the processing of outputs from both applications can be exactly equivalent.

The name of the NWC/PPS-HRW output files can besides be configured to be:

- Equivalent to the rest of output files provided by other NWC/GEO software package products, which is convenient for NWC/GEO users who also want to use NWC/PPS-HRW software (with configurable parameter OUTPUT_NAMESTYLE = GEO).
- Or equivalent to the rest of output files provided by other NWC/PPS software package products, which is convenient for NWC/PPS users who also want to use NWC/PPS-HRW software (with configurable parameter OUTPUT_NAMESTYLE = PPS, which is the default option).

2.3.1. HRW output as BUFR bulletins with NWCSAF specific format (AMVs)

When OUTPUT_FORMAT = NWC, a BUFR bulletin equivalent to the one used as default option in all versions of NWC/GEO-HRW software is written in `$SM_PRODUCT_DIR` directory.

For the "Single/Basic AMV scale" the name of this file can be:

- `S_NWC_HRW-WIND_<satid>_<regid>-BS_YYYYMMDDThhmmssZ.bufr` (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWbs_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ_<regid>_NWC.bufr` (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

For the "Detailed AMV scale" the name of this file can be:

- `S_NWC_HRW-WIND_<satid>_<regid>-DS_YYYYMMDDThhmmssZ.bufr` (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWds_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ_<regid>_NWC.bufr` (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

Here, "satid" is the identifier of the satellite used for the "later image" and "regid" is the identifier of the region used. "YYYYMMDDThhmmssZ" with NWC/GEO name style is the date and time (up to the seconds) of the start of the scanning of the "later image" used for the AMV calculation (as in other NWC/GEO products). "YYYYMMDDThhmmssdZ" with NWC/PPS name style is respectively the date and time (up to the tenths of second) of the start and end of the scanning of the "later image" used for the AMV calculation (as in other NWC/PPS products).

The BUFR variables used for the writing of NWC/PPS-HRW AMVs considering this format are explained in Table 6. These variables are partially based on BUFR Master Table number 0, Version number 31, and are exactly equivalent to the ones used for the latest version of NWC/GEO-HRW software (v6.2) and NWC/PPS-HRW software (v7.P). However, the coding of the BUFR outputs has changed from using BUFRDC to ECCODES library with this NWC/PPS-HRW implementation.

To correctly define the BUFR bulletins, the user has to define respectively the Originating Centre and Subcentre of the Information through configurable parameters BUFR_SUPERCENTRE_OR and BUFR_CENTRE_OR (both with a default value of 214, which is valid only for NWCSAF Headquarters in Madrid; numeric codes for other locations are available at the "WMO Common Code Table C-1" [RD.19]). Formally, several different BUFR messages with AMVs calculated for an only satellite channel (VIS06 or IR107-IR108-IR110 or WV067 or WV072-WV073), in each case with an only Subset of up to 1000 AMVs, are included in this AMV BUFR output file.

In *Table 6*, for all variables used for the AMV output with the NWCSAF specific BUFR format:

- *The first column shows the "Descriptor code".*
- *The second column shows the "Descriptor Name".*
- *The third column shows the "Unit used for the codification of the parameter" (in some cases identified through a Code Table).*
- *The fourth column shows the "Scale, the number of decimals used in the codification of the parameter" (where a value of 1 is used for a precision of one decimal place and a value of -1 is used for a precision only up to the tens).*
- *The fifth column shows the "Reference, the default value of the parameter".*
- *The sixth column shows the "Number of bits used for the parameter codification", and so, the maximum value the parameter can have (for example, for parameter 060203/Number of available wind guess levels, the maximum value of the parameter is $2^7 -1 = 127$).*

Descriptor	Name	Units	Scale	Reference	Number of bits
001007	SATELLITE IDENTIFIER	CODE TABLE 01007	0	0	10
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	CODE TABLE 01031	0	0	16
001032	GENERATING APPLICATION	CODE TABLE 01032	0	0	8
002023	SATELLITE DERIVED WIND COMPUTATION METHOD	CODE TABLE 02023	0	0	4
002057	ORIGIN OF FIRST GUESS INFORMATION	CODE TABLE 02057	0	0	4
002152	SATELLITE INSTRUMENT USED IN DATA PROCESSING	FLAG TABLE 02152	0	0	31
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz	-8	0	26
002154	SATELLITE CHANNEL BAND WIDTH	Hz	-8	0	26
004001	YEAR	YEAR	0	0	12
004002	MONTH	MONTH	0	0	4
004003	DAY	DAY	0	0	6
004004	HOUR	HOUR	0	0	5
004005	MINUTE	MINUTE	0	0	6
004025	TIME PERIOD OR DISPLACEMENT	MINUTE	0	-2048	12
005044	SATELLITE CYCLE NUMBER (IN NWC/PPS-HRW, IDENTIFIED AS ORBITNUMBER%1000)	NUMERIC	0	0	11
033035	MANUAL/AUTOMATIC QUALITY CONTROL	CODE TABLE 33035	0	0	4
060000	SEGMENT SIZE AT NADIR IN X DIRECTION (PIXELS)	PIX	0	0	7
060001	SEGMENT SIZE AT NADIR IN Y DIRECTION (PIXELS)	PIX	0	0	7
139000	REPLICATION OPERATOR (39 VARIABLES TO BE REPLICATED)	-	0	0	0
031002	EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR (NUMBER OF REPLICATIONS = WINDS)	NUMERIC	0	0	16
060100	WIND SEQUENCE NUMBER	NUMERIC	0	0	24
060101	PRIOR WIND SEQUENCE NUMBER	NUMERIC	0	0	24
002028	SEGMENT SIZE AT NADIR IN X DIRECTION	M	-1	0	18
002029	SEGMENT SIZE AT NADIR IN Y DIRECTION	M	-1	0	18
002164	TRACER CORRELATION METHOD	CODE TABLE 02164	0	0	3
005001	LATITUDE (HIGH ACCURACY)	DEGREE	5	-9000000	25
006001	LONGITUDE (HIGH ACCURACY)	DEGREE	5	-18000000	26
005011	LATITUDE INCREMENT (HIGH ACCURACY)	DEGREE	5	-9000000	25
006011	LONGITUDE INCREMENT (HIGH ACCURACY)	DEGREE	5	-18000000	26
007004	PRESSURE	PA	-1	0	14
011001	WIND DIRECTION	DEGREE TRUE	0	0	9
011002	WIND SPEED	M/S	1	0	12
012001	TEMPERATURE	K	1	0	12
033007	PER CENT CONFIDENCE (WITH FORECAST TEST)	%	0	0	7
033007	PER CENT CONFIDENCE (WITHOUT FORECAST TEST)	%	0	0	7
033007	PER CENT CONFIDENCE (COMMON QI WITHOUT FORECAST TEST)	%	0	0	7
060104	TRACER TYPE	CODE TABLE 60104	0	0	2
060103	HEIGHT ASSIGNMENT METHOD	CODE TABLE 60103	0	0	4
060200	NUMBER OF WINDS COMPUTED FOR THE TRACER	NUMERIC	0	0	3
060201	CORRELATION TEST	CODE TABLE 60201	0	0	3
060202	APPLIED QUALITY TESTS	CODE TABLE 60202	0	0	11
060203	NUMBER OF AVAILABLE NWP WIND GUESS LEVELS	NUMERIC	0	0	7
060204	NUMBER OF PREDECESSOR WINDS	NUMERIC	0	0	7
060205	OROGRAPHIC INDEX	CODE TABLE 60205	0	0	3
060206	CLOUD TYPE (NWCSAF)	CODE TABLE 60206	0	0	5
060207	AMV CHANNEL (NWCSAF)	CODE TABLE 60207	0	0	5
060208	CORRELATION	%	0	0	7
060209	PRESSURE ERROR	PA	-1	-8000	14
060210	PRESSURE CORRECTION	PA	-1	-8000	14

Descriptor	Name	Units	Scale	Reference	Number of bits
060211	NWP WIND DIRECTION (AT AMV LEVEL)	DEGREE TRUE	0	0	9
060212	NWP WIND SPEED (AT AMV LEVEL)	M/S	1	0	12
060213	NWP WIND DIRECTION (AT BEST FIT LEVEL)	DEGREE TRUE	0	0	9
060214	NWP WIND SPEED (AT BEST FIT LEVEL)	M/S	1	0	12
060215	NWP WIND BEST FIT LEVEL	PA	-1	0	14
060216	DIRECTION DIFFERENCE WITH NWP WIND (AT AMV LEVEL)	DEGREE TRUE	0	0	9
060217	SPEED DIFFERENCE WITH NWP WIND (AT AMV LEVEL)	M/S	1	0	12
060218	DIRECTION DIFFERENCE WITH NWP WIND (AT BEST FIT LEVEL)	DEGREE TRUE	0	0	9
060219	SPEED DIFFERENCE WITH NWP WIND (AT BEST FIT LEVEL)	M/S	1	0	12
060220	VALIDATION AGAINST NWP ANALYSIS OR FORECAST	CODE TABLE 60220	0	0	2

White entries: Fixed factors
Grey entries: Replicated factors

Table 6: Variables used for the AMV output with the NWCSAF specific BUFR format

The "general common variables" in BUFR Master Table number 0, Version number 31, are identified with codes smaller than 60000. Their explanation can be found in the "WMO FM94 BUFR Table B for Classification of elements and table", available in document [RD.20].

The "local specific variables" for NWC/PPS-HRW bulletins in this table are those with codes 60000 or higher. The Code Tables for these NWC/PPS-HRW local specific variables are explained here.

Descriptor	Description
060103	Height assignment method Values 0 to 3 are related to 'Brightness temperature interpolation height assignment method'. Values 4 to 15 are related to 'CCC height assignment method'. Possible values: 0: 'NWP interpolation using Top pressure in Clear air AMV' 1: 'NWP interpolation using Top pressure in Cloudy AMV' 2: unused 3: 'NWP interpolation using Base pressure in Cloudy AMV' 4: 'CCC method using lower threshold and cold branch in a Clear air AMV' 5: 'CCC method using higher threshold and cold branch in a Clear air AMV' 6: 'CCC method using lower threshold and cold/bright branch in Cloudy AMV with undefined phase' 7: 'CCC method using higher threshold and cold/bright branch in Cloudy AMV with undefined phase' 8: 'CCC method using lower threshold and cold/bright branch in Cloudy AMV with liquid phase' 9: 'CCC method using higher threshold and cold/bright branch in a Cloudy AMV with liquid phase' 10: 'CCC method with microphysics correction using lower threshold and cold/bright branch in Cloudy AMV with liquid phase' 11: 'CCC method with microphysics correction using higher threshold and cold/bright branch in Cloudy AMV with liquid phase' 12: 'CCC method using lower threshold and cold/bright branch in a Cloudy AMV with ice phase' 13: 'CCC method using higher threshold and cold/bright branch in a Cloudy AMV with ice phase' 14: 'CCC method with microphysics correction using lower threshold and cold/bright branch in Cloudy AMV with ice phase' 15: 'CCC method with microphysics correction using higher threshold and cold/bright branch in Cloudy AMV with ice phase'.
060104	Type of tracer Possible values: 0: 'Basic tracer' 1: 'Detailed tracer related to a Narrow basic tracer' 2: 'Detailed tracer related to a Wide basic tracer' 3: 'Detailed tracer unrelated to a Basic tracer'.

Descriptor	Description
060201	Correlation test. Possible values: 0: 'Wind not selected as the Best wind for a tracer not having the Best correlation value' 1: 'Wind not selected as the Best wind for a tracer having the Best correlation value' 2: 'Wind selected as the Best wind for a tracer not having the Best correlation value' 3: 'Wind selected as the Best wind for a tracer having the Best correlation value'.
060202	Applied Quality tests: For each one the next Quality flags (Orographic flag, Forecast quality flag, Spatial quality flag, Temporal quality flag, Interscale quality flag), next possible values: 0: 'Wind for which the corresponding quality test could not be calculated' 1: 'Wind whose corresponding quality test is at least a 21% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is at least two units lower than for the wind calculated for the same tracer with the best orographic flag)' 2: 'Wind whose corresponding quality test is up to a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the wind calculated for the same tracer with the best orographic flag)' 3: 'Wind with the best corresponding quality test among the winds calculated for a tracer'.
060205	Orographic index Possible values: The values of this parameter are between 0 and 6, corresponding to those defined for "Ind_topo" parameter in chapter 2.2.7 of this document.
060206	Cloud type associated to the tracer Possible values: The values of this parameter are between 0 and 23, corresponding to those defined in *Table 5* of this document.
060207	Flag indicating the satellite channel used for the wind calculation (Updated table for NWC/PPS-HRW v7.Q). Possible values: 2: AVHRR/3/VIS06, VIIRS/VIS06, MODIS/VIS06, METimage/VIS06, MERSI-2/VIS06, SLSTR/VIS06 11: MODIS/WV067, METimage/WV067 12: MODIS/WV073, METimage/WV073, MERSI-2/WV072 16: AVHRR/3/IR108, VIIRS/IR108, MODIS/IR110 METimage/IR107, MERSI-2/IR108, SLSTR/IR108
060220	Validation against NWP analysis or forecast Possible values: 0: NWC/PPS-HRW autovalidation statistics against "NWP model analysis". 1: NWC/PPS-HRW autovalidation statistics against "NWP model forecast". 3: NWC/PPS-HRW autovalidation statistics not calculated.

Table 7: Description of "local specific variables" in the "NWCSAF specific BUFR format"

2.3.2. HRW output as BUFR bulletins with NWCSAF specific format (Trajectories)

When OUTPUT_FORMAT = NWC, if the calculation of trajectories is activated with configurable parameter CALCULATE_TRAJECTORIES = 1, a Trajectory BUFR bulletin equivalent to the one used as default option in all versions of NWC/GEO-HRW software is written in `$SM_PRODUCT_DIR` directory.

For the "Single/Basic AMV scale" the name of this file can be:

- `S_NWC_HRW-TRAJ_<satid>_<regid>-BS_YYYYMMDDThhmmssZ.bufr`
  (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWTRAJbs_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ_<regid>_NWC.bufr`
  (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

For the "Detailed AMV scale" the name of this file can be:

- `S_NWC_HRW-TRAJ_<satid>_<regid>-DS_YYYYMMDDThhmmssZ.bufr`
  (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWTRAJds_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ_<regid>_NWC.bufr`
  (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

Again, "satid" is the identifier of the satellite used for the "later image" and "regid" is the identifier of the region used. "YYYYMMDDThhmmssZ" with NWC/GEO name style is the date and time (up to the seconds) of the start of the scanning of the "later image" used for the AMV calculation (as in other NWC/GEO products). "YYYYMMDDThhmmssdZ" with NWC/PPS name style is respectively the date and time (up to the tenths of second) of the start and end of the scanning of the "later image" used for the AMV calculation (as in other NWC/PPS products).

The BUFR variables used for the writing of the NWC/PPS-HRW Trajectories considering this format are explained in Table 8. Again, these variables are partially based on BUFR Master Table number 0, Version number 31, and are equivalent to the ones used for the latest versions of NWC/GEO-HRW software (v6.2) and NWC/PPS-HRW software (v7.P). As already said, the coding of the BUFR outputs has changed from using BUFRDC to ECCODES library with this NWC/PPS-HRW implementation.

As previously also seen, to correctly define the BUFR bulletins, the user has to define respectively the Originating Centre and Subcentre of the Information through configurable parameters BUFR_SUPERCENTRE_OR and BUFR_CENTRE_OR (both with a default value of 214, which is valid for NWCSAF Headquarters in Madrid; the numeric codes for other locations are available at the "WMO Common Code Table C-1" [RD.19]).

Formally, different BUFR messages with an only subset with one Trajectory each (with up to 24 Trajectory sectors in the trajectory), are included in this Trajectory BUFR output file.

The explanation of the "general common variables" and "local specific variables" used for the writing of the Trajectory BUFR output is equivalent to the one for the AMV BUFR output in the previous chapter.

Descriptor	Name	Units	Scale	Reference	Number of bits
001007	SATELLITE IDENTIFIER	CODE TABLE 01007	0	0	10
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	CODE TABLE 01031	0	0	16
001032	GENERATING APPLICATION	CODE TABLE 01032	0	0	8
002023	SATELLITE DERIVED WIND COMPUTATION METHOD	CODE TABLE 02023	0	0	4
002057	ORIGIN OF FIRST GUESS INFORMATION	CODE TABLE 02057	0	0	4
002152	SATELLITE INSTRUMENT USED IN DATA PROCESSING	FLAG TABLE 02152	0	0	31
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz	-8	0	26
002154	SATELLITE CHANNEL BAND WIDTH	Hz	-8	0	26
004001	YEAR	YEAR	0	0	12
004002	MONTH	MONTH	0	0	4
004003	DAY	DAY	0	0	6
004004	HOUR	HOUR	0	0	5
004005	MINUTE	MINUTE	0	0	6
004025	TIME PERIOD OR DISPLACEMENT	MINUTE	0	-2048	12
005044	SATELLITE CYCLE NUMBER (IN NWC/PPS-HRW, IDENTIFIED AS ORBITNUMBER%1000)	NUMERIC	0	0	11
033035	MANUAL/AUTOMATIC QUALITY CONTROL	CODE TABLE 33035	0	0	4
060000	SEGMENT SIZE AT NADIR IN X DIRECTION (PIXELS)	PIX	0	0	7
060001	SEGMENT SIZE AT NADIR IN Y DIRECTION (PIXELS)	PIX	0	0	7
060102	TRAJECTORY SEQUENCE NUMBER	NUMERIC	0	0	24
119000	REPLICATION OPERATOR (19 VARIABLES TO BE REPLICATED)	-	0	0	0
031002	EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR (1 REPLICATION = 1 TRAJECTORY)	NUMERIC	0	0	16
002164	TRACER CORRELATION METHOD	CODE TABLE 02164	0	0	3
005001	LATITUDE (HIGH ACCURACY)	DEGREE	5	-9000000	25
006001	LONGITUDE (HIGH ACCURACY)	DEGREE	5	-18000000	26
005011	LATITUDE INCREMENT (HIGH ACCURACY)	DEGREE	5	-9000000	25
006011	LONGITUDE INCREMENT (HIGH ACCURACY)	DEGREE	5	-18000000	26
007004	PRESSURE	PA	-1	0	14
011001	WIND DIRECTION	DEGREE TRUE	0	0	9
011002	WIND SPEED	M/S	1	0	12
012001	TEMPERATURE	K	1	0	12
033007	PER CENT CONFIDENCE (WITH FORECAST TEST)	%	0	0	7
033007	PER CENT CONFIDENCE (WITHOUT FORECAST TEST)	%	0	0	7
033007	PER CENT CONFIDENCE (COMMON QI WITHOUT FORECAST TEST)	%	0	0	7
060103	HEIGHT ASSIGNMENT METHOD	CODE TABLE 60103	0	0	4
060205	OROGRAPHIC INDEX	CODE TABLE 60205	0	0	3
060206	CLOUD TYPE (NWCSAF)	CODE TABLE 60206	0	0	5
060207	AMV CHANNEL (NWCSAF)	CODE TABLE 60207	0	0	5
060208	CORRELATION	%	0	0	7
060209	PRESSURE ERROR	PA	-1	-8000	14
060210	PRESSURE CORRECTION	PA	-1	-8000	14

White entries: Fixed factors
Grey entries: Replicated factors

Table 8: Variables used for the Trajectory output with the "NWCSAF specific BUFR format"

2.3.3. HRW output as BUFR bulletins with the 2018 IWWG format (AMVs)

When OUTPUT_FORMAT = IWWG (implemented in the default option), an AMV BUFR bulletin equivalent to the one defined in 2018 as common AMV output format by the "International Winds Working Group (IWWG)" for all AMV production centres, is written in `$SM_PRODUCT_DIR` directory.

For the "Single/Basic AMV scale" the name of this file can be:

- `S_NWC_HRW-WINDIWWG_<satid>_<regid>-BS_YYYYMMDDThhmmssZ.bufr` (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWIWWGbs_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ_<regid>.bufr` (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

For the "Detailed AMV scale" the name of this file can be:

- `S_NWC_HRW-WINDIWWG_<satid>_<regid>-DS_YYYYMMDDThhmmssZ.bufr` (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWIWWGds_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ_<regid>.bufr` (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

Again, "satid" is the identifier of the satellite used for the "later image" and "regid" is the identifier of the region used. "YYYYMMDDThhmmssZ" with NWC/GEO name style is the date and time (up to the seconds) of the start of the scanning of the "later image" used for the AMV calculation (as in other NWC/GEO products). "YYYYMMDDThhmmssdZ" with NWC/PPS name style is respectively the date and time (up to the tenths of second) of the start and end of the scanning of the "later image" used for the AMV calculation (as in other NWC/PPS products).

The BUFR variables used for the writing of the NWC/PPS-HRW AMVs considering this format are explained in Table 9, with some explanations in red about how some variables are defined by NWC/PPS-HRW software.

The variables are based on BUFR Master Table number 0, Version number 31. These variables correspond exactly to "Sequence 310077 – satellite derived winds" included in the corresponding "sequence table", and are equivalent to the ones used for the latest versions of NWC/GEO-HRW software (v6.2) and NWC/PPS-HRW software (v7.P). Again, the coding of the BUFR outputs has changed from using BUFRDC to ECCODES library with this NWC/PPS-HRW implementation.

Again, to correctly define the BUFR bulletins, the user has to define the Originating Centre and Subcentre of the Information through configurable parameters BUFR_SUPERCENTRE_OR and BUFR_CENTRE_OR (both with a default value of 214, which is valid for NWCSAF Headquarters in Madrid; the numeric codes for other locations are available at the WMO Common Code Table C-1 [RD.19]).

Several different BUFR messages with up to 100 subsets with an only AMV each, all of them related to the same satellite channel (VIS06 or IR107-IR108-IR110 or WV067 or WV072-WV073), are included in this AMV BUFR output file.

This format is a kind a blend of the NWCSAF AMV and Trajectory BUFR specific formats, because of including at the same time information related to the reference AMV to be used, and to the up to four latest AMVs in the NWC/PPS-HRW trajectory which were used for the AMV calculation (when "mixed calculation method" is used).

It is recommended for NWCSAF users to adopt progressively this format for all applications, because this format will become the reference format for AMVs coming from all AMV production centres in the coming months/years. Nevertheless, the larger size of the corresponding files is also to be taken into account.

Descriptor	Name	Units
PROCESSING INFORMATION		
001033	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR_SUPERCENTRE_OR)	CODE TABLE 01033
001034	IDENTIFICATION OF ORIGINATING/GENERATING SUBCENTRE (configurable parameter BUFR_CENTRE_OR)	CODE TABLE 01034
025061	SOFTWARE IDENTIFICATION AND VERSION NUMBER ("NWC/HRW V7.Q")	CCITTIA5
025062	DATABASE IDENTIFICATION (not used)	NUMERIC
SATELLITE INSTRUMENT IDENTIFICATION		
001007	SATELLITE IDENTIFIER	CODE TABLE 01007
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz
001012	DIRECTION OF MOTION OF MOVING OBSERVING PLATFORM (not used)	DEGREE
201138	CHANGE DATA WIDTH (22 BITS PER PARAMETER)	-
002026	CROSS-TRACK RESOLUTION (not used)	M
002027	ALONG-TRACK RESOLUTION (not used)	M
201000	CHANGE DATA WIDTH (CANCEL)	-
METHODS		
002028	SEGMENT SIZE AT NADIR IN X-DIRECTION (up to a limit of 262140 m)	M
002029	SEGMENT SIZE AT NADIR IN Y-DIRECTION (up to a limit of 262140 m)	M
002161	WIND PROCESSING METHOD	FLAG TABLE 02161
002164	TRACER PROCESSING METHOD	CODE TABLE 02164
002023	SATELLITE-DERIVED WIND COMPUTATION METHOD	CODE TABLE 02023
008012	LAND/SEA QUALIFIER (not used)	CODE TABLE 08012
008013	DAY/NIGHT QUALIFIER (not used)	CODE TABLE 08013
FINAL AMV DATA		
001124	GRID POINT IDENTIFIER (not used)	NUMERIC
005001	LATITUDE (HIGH ACCURACY)	DEGREE
006001	LONGITUDE (HIGH ACCURACY)	DEGREE
004001	YEAR	YEAR
004002	MONTH	MONTH
004003	DAY	DAY
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
004086	LONG TIME PERIOD OR DISPLACEMENT (respect to the "Reference time")	SECOND
002162	EXTENDED HEIGHT ASSIGNMENT METHOD	CODE TABLE 02162
007004	PRESSURE	PA
011001	WIND DIRECTION	DEGREE TRUE
011002	WIND SPEED	M/S
011003	U-COMPONENT	M/S
011004	V-COMPONENT	M/S
012001	TEMPERATURE/AIR TEMPERATURE	K
020014	HEIGHT OF TOP OF CLOUD (not used in NWC/PPS-HRW)	M
007024	SATELLITE ZENITH ANGLE	DEGREE
001023	OBSERVATION SEQUENCE NUMBER (0 = "Reference image" number in Image information group)	NUMERIC
104000	DELAYED REPLICATION OF 4 DESCRIPTORS	-
031001	DELAYED DESCRIPTOR REPLICATION FACTOR (ONCE)	NUMERIC
002162	EXTENDED HEIGHT ASSIGNMENT METHOD	CODE TABLE 02162
007004	PRESSURE	PA
012001	TEMPERATURE/AIR TEMPERATURE	K
020014	HEIGHT OF TOP OF CLOUD (not used in NWC/PPS-HRW)	M

Descriptor	Name	Units
IMAGE INFORMATION		
113000	DELAYED REPLICATION OF 13 DESCRIPTORS	-
031001	DELAYED DESCRIPTOR REPLICATION FACTOR (TWO TO FIVE TIMES)	NUMERIC
004086	LONG TIME PERIOD OR DISPLACEMENT (respect to the "Reference time")	SECOND
002020	SATELLITE CLASSIFICATION	CODE TABLE 02020
001007	SATELLITE IDENTIFIER	CODE TABLE 01007
002019	SATELLITE INSTRUMENTS	CODE TABLE 02019
005042	CHANNEL NUMBER	NUMERIC
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz
005040	ORBIT NUMBER (not used)	NUMERIC
007024	SATELLITE ZENITH ANGLE (for the tracer in each image)	DEGREE
005021	BEARING OR AZIMUTH (not used)	DEGREE
002162	EXTENDED HEIGHT ASSIGNMENT METHOD (not used for the initial image)	CODE TABLE 02162
007004	PRESSURE (not used for the initial image)	PA
012001	TEMPERATURE/AIR TEMPERATURE (not used for the initial image)	K
020014	HEIGHT OF TOP OF CLOUD (not used in NWC/PPS-HRW)	M
INTERMEDIATE VECTORS (FOR EACH COMPONENT)		
119000	DELAYED REPLICATION OF 19 DESCRIPTORS	-
031001	DELAYED DESCRIPTOR REPLICATION FACTOR (ONE TO FOUR TIMES)	NUMERIC
004086	LONG TIME PERIOD OR DISPLACEMENT (for the AMV initial image respect to the Reference time)	SECOND
004086	LONG TIME PERIOD OR DISPLACEMENT (for the AMV final image respect to the Reference time)	SECOND
005001	LATITUDE (HIGH ACCURACY)	DEGREE
006001	LONGITUDE (HIGH ACCURACY)	DEGREE
011003	U-COMPONENT	M/S
011004	V-COMPONENT	M/S
011113	TRACKING CORRELATION OF VECTOR (only used with "Correlation method" tracking)	NUMERIC
025148	COEFFICIENT OF VARIATION (not used)	NUMERIC
103000	DELAYED REPLICATION OF 3 DESCRIPTORS	-
031001	DELAYED DESCRIPTOR REPLICATION FACTOR (ONCE)	NUMERIC
008023	FIRST ORDER STATISTICS (4 = MEAN VALUE)	CODE TABLE 08023
011003	U-COMPONENT (not used)	M/S
011004	V-COMPONENT (not used)	M/S
008023	FIRST ORDER STATISTICS (63 = CANCEL)	CODE TABLE 08023
103000	DELAYED REPLICATION OF 3 DESCRIPTORS	-
031001	DELAYED DESCRIPTOR REPLICATION FACTOR (ONCE)	NUMERIC
020111	X-AXIS ERROR ELLIPSE MAJOR COMPONENT (not used)	M
020112	Y-AXIS ERROR ELLIPSE MAJOR COMPONENT (not used)	M
020114	ANGLE OF X-AXIS IN ERROR ELLIPSE (not used)	DEGREE
CORRESPONDING FORECAST DATA		
001033	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (98 = ECMWF)	CODE TABLE 01033
008021	FORECAST SIGNIFICANCE (27 = FIRST GUESS)	CODE TABLE 08021
007004	PRESSURE (for NWP data at AMV guess level, if calculated)	PA
011095	U-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV guess level, if calculated)	M/S
011096	V-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV guess level, if calculated)	M/S
008021	FORECAST SIGNIFICANCE (4 = FORECAST)	CODE TABLE 08021
007004	PRESSURE (for NWP data at AMV level)	PA
011095	U-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV level)	M/S
011096	V-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV level)	M/S
008021	FORECAST SIGNIFICANCE (31 = CANCEL)	CODE TABLE 08021
008086	VERTICAL SIGNIFICANCE FOR NWP (10 = BEST FIT LEVEL)	FLAG TABLE 08086
007004	PRESSURE (for NWP data at AMV best fit level, if calculated)	PA
011095	U-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
011096	V-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
008086	VERTICAL SIGNIFICANCE FOR NWP (4095 = CANCEL)	CODE TABLE 08086

Descriptor	Name	Units
FINAL AMV QUALITY		
102004	REPLICATE 2 DESCRIPTORS 4 TIMES	-
001044	GENERATING APPLICATION (4 = COMMON IWWG QI) (5 – QI WITHOUT FORECAST) (6 – QI WITH FORECAST) (255 – MISSING)	CODE TABLE 01044
033007	PERCENT CONFIDENCE (if calculated)	%
008092	MEASUREMENT UNCERTAINTY EXPRESSION (0 = STD UNCERTAINTY)	CODE TABLE 08092
007004	PRESSURE (AMV pressure error, if calculated)	PA
011003	U-COMPONENT (not used)	M/S
011004	V-COMPONENT (not used)	M/S
008092	MEASUREMENT UNCERTAINTY EXPRESSION (31 = CANCEL)	CODE TABLE 08092
033066	AMV QUALITY FLAG (not used)	FLAG TABLE 33066
CLOUD DATA AND MICROPHYSICS		
020081	CLOUD AMOUNT IN SEGMENT (percentage of cloudy pixels with a contribution to CCC method calculations, if calculated)	%
020012	CLOUD TYPE	CODE TABLE 20012
020056	CLOUD PHASE	CODE TABLE 20056
117000	DELAYED REPLICATION OF 17 DESCRIPTORS	-
031001	DELAYED DESCRIPTOR REPLICATION FACTOR (ONCE)	NUMERIC
008023	FIRST ORDER STATISTICS (4 = MEAN VALUE)	CODE TABLE 08023
020016	PRESSURE AT TOP OF CLOUD (not used)	PA
008092	MEASUREMENT UNCERTAINTY EXPRESSION (0 = STD UNCERTAINTY)	CODE TABLE 08092
008003	VERTICAL SIGNIFICANCE (2 = TOP OF CLOUD)	CODE TABLE 08003
012001	TEMPERATURE/AIR TEMPERATURE (not used)	K
008003	VERTICAL SIGNIFICANCE (63 = CANCEL)	CODE TABLE 08003
020016	PRESSURE AT TOP OF CLOUD (not used)	PA
008092	MEASUREMENT UNCERTAINTY EXPRESSION (31 = CANCEL)	CODE TABLE 08092
025149	OPTIMAL ESTIMATION COST (not used)	NUMERIC
020016	PRESSURE AT TOP OF CLOUD (not used)	PA
020014	HEIGHT OF TOP OF CLOUD (not used)	M
013093	CLOUD OPTICAL THICKNESS (not used)	NUMERIC
013109	ICE/LIQUID WATER PATH (Up to a limit of 1.020 kg/m2)	KG/M2
040038	CLOUD PARTICLE SIZE (0 = MISSING)	M
008011	METEOROLOGICAL FEATURE (12 = CLOUD)	CODE TABLE 08011
014050	EMISSIVITY (not used)	%
008011	METEOROLOGICAL FEATURE (63 = CANCEL)	CODE TABLE 08011
008023	FIRST ORDER STATISTICS (63 = CANCEL)	CODE TABLE 08023

Table 9: Variables used for the AMV output with the "2018 IWWG BUFR format"

2.3.4. HRW output as netCDF bulletins

When OUTPUT_FORMAT = NCF (implemented in the default option), an AMV and Trajectory netCDF output bulletin is written in `$SM_PRODUCT_DIR` directory.

For the "Single/Basic AMV scale" the name of this file can be:

- `S_NWC_HRW_<satid>_<regid>-BS_YYYYMMDDThhmmssZ.nc`
  (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWbs_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ _<regid>.nc`
  (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

For the "Detailed AMV scale" the name of this file can be:

- `S_NWC_HRW_<satid>_<regid>-DS_YYYYMMDDThhmmssZ.nc`
  (if NWC/GEO name style is used, with OUTPUT_NAMESYLE=GEO).
- `S_NWC_HRWds_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ _<regid>.nc`
  (if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

Again, "satid" is the identifier of the satellite used for the "later image" and "regid" is the identifier of the region used. "YYYYMMDDThhmmssZ" with NWC/GEO name style is the date and time (up to the seconds) of the start of the scanning of the "later image" used for the AMV calculation (as in other NWC/GEO products). "YYYYMMDDThhmmssdZ" with NWC/PPS name style is respectively the date and time (up to the tenths of second) of the start and end of the scanning of the "later image" used for the AMV calculation (as in other NWC/PPS products).

As already said, the structure of the NWC/PPS-HRW netCDF output has changed with respect to the one defined in the previous version NWC/PPS-HRW v7.P, now being "CF compliant" and easier to process (following recommendations from NWCSAF users).

The structure of the netCDF output variables and dimensions is shown in *Table 10*. The structure of the netCDF output attributes is shown in *Table 11*. The two dimensions defined in the netCDF output are the following ones:

- Observations: total number of AMVs included in the netCDF output (it is also the dimension of each one of the variable arrays).
- Time: defined as "seconds since 01-01-1970" for the corresponding slot.

Each AMV is defined as a "set of 40 variables" which describes together all characteristics of the AMV. The equivalence with the variables used for the AMVs in the "BUFR bulletin with NWCSAF specific format" (in chapter 2.3.1), the "Valid range" for each variable and the "Fill value" for each variable are also included in *Table 10*.

About the inclusion of the Trajectories in the NWC/PPS-HRW netCDF output file (when configurable parameter CALCULATE_TRAJECTORIES = 1), a survey was made in 2021 with NWCSAF users to check if they preferred that the netCDF output would be smaller and more simple to process (although this way the Trajectories would be extracted with some additional software processing), or if they preferred that the new netCDF output includes explicitly the Trajectories (despite so defining a larger and more complex output). The first option was preferred and seen as more convenient. This way, the procedure defined to extract the Trajectories from the netCDF output files is as follows:

- "number_of_trajectory_segments = n" identifies the number of trajectory segments that can be built for the trajectory related to a given AMV.
- "wind_prev_id" (for an AMV in the netCDF file for the last slot) and "wind_id" (for an AMV in the netCDF file for the second last slot) have the same value for two consecutive AMVs/segments in the same trajectory. This step used progressively backwards in time "n times" connects all segments in the same Trajectory (until number_of_trajectory_segments reduces to the value of 1).
- "lat", "latitude_increment", "lon" and "longitude_increment" variables for each AMV inside each netCDF file identify the displacement related to each AMV/Trajectory segment.

A Trajectory with a total of "number_of_trajectory_segments = n" is so built.

Parameter types	***"NWC BUFR Equivalence" – [Valid Range] – Fill Value***
Variables:	
32-bit unsigned int wind_id	// 060100 WIND SEQUENCE NUMBER – [0-16777215] – 16777216
32-bit unsigned int wind_prev_id	// 060101 PRIOR WIND SEQUENCE NUMBER – [0-16777215] – 16777216
unsigned byte number_of_winds	// 060200 NUMBER OF WINDS COMPUTER FOR THE TRACER – [0-3] – 8
unsigned byte correlation_test	// 060201 CORRELATION TEST – [0-3] – 8
16-bit unsigned int quality_test	// 060202 APPLIED QUALITY TESTS – [0-1024] – 2048
32-bit unsigned int segment_x	// 002028 SEGMENT SIZE IN X DIRECTION (M) – [0-2621439] – 2621440
32-bit unsigned int segment_y	// 002029 SEGMENT SIZE IN Y DIRECTION (M) – [0-2621439] – 2621440
unsigned byte segment_x_pix	// 060000 SEGMENT SIZE IN X DIRECTION (PIX) – [0-127] – 128
unsigned byte segment_y_pix	// 060001 SEGMENT SIZE IN Y DIRECTION (PIX) – [0-127] – 128
double lat (STANDARD NAME: latitude)	// 005001 LATITUDE – [-90.00000-+90.00000] – +245.54432
double lon (STANDARD NAME: longitude)	// 006001 LONGITUDE – [-180.00000-+179.99999] – +491.08864
double latitude_increment	// 005001 LATITUDE INCREMENT – [-90.00000-+90.00000] – +245.54432
double longitude_increment	// 006011 LONGITUDE INCREMENT – [-180.00000-+179.99999] – +491.08864
double air_temperature	// 012001 TEMPERATURE – [0.0-409.5] – 409.6
double air_pressure	// 007004 PRESSURE – [0.0-163839.0] – 163840.0
double air_pressure_error	// 007004 PRESSURE ERROR – [-80000.0-+80000.0] – +83840.0
double air_pressure_correction	// 007004 PRESSURE CORRECTION – [-80000.0-+80000.0] – +83840.0
double air_pressure_nwp_at_best_fit_level	// 060215 NWP WIND BEST FIT LEVEL – [0-163839.0] – 163840.0
double wind_speed	// 011002 WIND SPEED – [0.0-409.5] – 409.6
double wind_from_direction	// 011001 WIND DIRECTION – [0.00000-359.99999] – 512.0
double wind_speed_nwp_at_amv_level	// 060211 NWP WIND SPEED (AT AMV LEVEL) – [0.0-409.5] – 409.6
double wind_from_direction_nwp_at_amv_level	// 060212 NWP WIND DIRECTION (AT AMV LEVEL) – [0.0-359.99999] – 512.0
double wind_speed_nwp_at_best_fit_level	// 060213 NWP WIND SPEED (AT BEST FIT LEVEL) – [0.0-409.5] – 409.6
double wind_from_direction_nwp_at_best_fit_level	// 060214 NWP WIND DIRECTION (AT BEST FIT LEVEL) – [0.0-359.99999] – 512.0
double wind_speed_difference_nwp_at_amv_level	// 060216 DIR. DIFF. WITH NWP (AT AMV LEVEL) – [0.0-409.5] – 409.6
double wind_from_direction_difference_nwp_at_amv_level	// 060217 SPD. DIFF. WITH NWP (AT AMV LEVEL) – [0.0-359.99999] – 512.0
double wind_speed_difference_nwp_at_best_fit_level	// 060218 DIR. DIFF. WITH NWP (BEST FIT LEVEL) – [0.0-409.5] – 409.6
double wind_from_direction_difference_nwp_at_best_fit_level	// 060219 SPD. DIFF. WITH NWP (BEST FIT LEVEL) – [0.0-359.99999] – 512.0
unsigned byte quality_index_with_forecast	// 033007 PER CENT CONFIDENCE (WITH FORECAST) – [0-100] – 128
unsigned byte quality_index_without_forecast	// 033007 PER CENT CONFIDENCE (WITHOUT FORECAST) – [0-100] – 128
unsigned byte quality_index_iwwg_value	// 033007 PER CENT CONFIDENCE (IWWG VALUE) – [0-100] – 128
unsigned byte tracer_correlation_method	// 002164 TRACER CORRELATION METHOD – [0-2] – 8
unsigned byte tracer_type	// 060104 TRACER TYPE – [0-3] – 8
unsigned byte height_assignment_method	// 060103 HEIGHT ASSIGNMENT METHOD – [0-15] – 16
unsigned byte orographic_index	// 060205 OROGRAPHIC INDEX – [0-6] – 8
unsigned byte cloud_type	// 060206 CLOUD TYPE – [1-23] – 255
unsigned byte correlation	// 060208 CORRELATION – [0-100] – 128
double barometric_altitude_in_hectofeet	// 060222 BAROMETRIC ALTITUDE IN HECTOFEET – [-40.0-1030.0] – 2048.0
unsigned byte satellite_channel, including as attributes: - band_central_radiation_frequency_Hz - band_central_radiation_width_Hz	// 060207 AMV CHANNEL – [0-18] – 31 - 002153 SATELLITE CHANNEL CENTRE FREQUENCY - 002154 SATELLITE CHANNEL BAND WIDTH Range: [0-6710886300000000]; Fill Value: - 6710886400000000
unsigned byte number_of_trajectory_segments	// 060221 NUMBER OF TRAJECTORY SEGMENTS – [1-24] – 32
Dimensions:	
32-bit unsigned int observations	// Total Number of AMVs included in the *nc file Range [0-16777215]; Fill Value: 16777216
32-bit int time	// Seconds since 01-01-1970; Range [0-4294967295]; Fill Value: 4294967296

Table 10: Detailed specification of the NWC/PPS-HRW netCDF output variables and dimensions

Attribute name	*Value*
Conventions	CF-1.6
_NCProperties	version=2,netcdf=4.7.3,hdf5libversion=1.10.5
cdm_data_type	Bulletin
centre_projection_longitude	Not applicable
comment	→ Copyright "year", EUMETSAT, All Rights reserved
contact	safnwchd@aemet.es
creator_email	safnwchd@aemet.es
creator_name	Agencia Estatal de Meteorologia (AEMET)
creator_url	http://www.aemet.es
date_created	→ Corresponding "date/time string" of creation of NWC/PPS-HRW netCDF file
featureType	point
first_guess	Medium range forecast model
history	→ "creation date" "creation user" Product created by NWC/PPS-HRW 7.Q "creation date" "creation user" "creation script" (FALTA CFM)
id	→ Corresponding NWC/PPS-HRW netCDF file name >> SOBRA EL DIRECTORIO!!
input_ct	→ Corresponding NWC/PPS-CT file name used by HRW
input_ctth	→ Corresponding NWC/PPS-CTTH file name used by HRW
input_cmic	→ Corresponding NWC/PPS-CMIC file name used by HRW
institution	Agencia Estatal de Meteorología (AEMET)
keywords	Atmospheric Motion Vectors, Satellite winds, Satellite trajectories
keywords_vocabulary	GCMD Science Keywords
license	→ Produced by NWCSAF/PPS software. Software under copyright "year" EUMETSAT
long_name	NWC/PPS High Resolution Winds
manual_automatic_quality_control	Automatic Quality Control passed and not manually checked
naming_authority	Agencia Estatal de Meteorología (AEMET)
nominal_product_time	Not applicable
number_of_nwp_wind_levels	→ Corresponding NWP model "number of NWP wind levels"
orbit_number_later_image	→ Corresponding "orbit number for later image"
orbit_number_initial_image	→ Corresponding "orbit number for initial image"
platform_later_image	→ Corresponding "satellite for later image"
platform_initial_image	→ Corresponding "satellite for initial image"
processing_level	Level 2
product_algorithm_version	7.Q
product_completeness	→ Corresponding "percentage of AMVs" written in the netCDF output, with respect to the theoretical value of AMVs defined by the algorithm at all preliminary locations. The parameter gives an idea of how many AMVs were successfully calculated, defined as a percentage value (from 0% to 100%).
product_name	HRW
product_quality	→ Corresponding "mean Quality index" (with/without forecast, depending on the value of configurable parameter QI_THRESHOLD_USEFORECAST), of all AMVs written in the netCDF output file. This parameter gives an idea of the mean quality of all AMVs, defined as a percentage value (from 0% to 100%).
project	NWC/PPS°
references	http://nwc-saf.eumetsat.int
region_id	→ Corresponding "region id" (f.ex. europa)
region_name	→ Corresponding "region name" (f.ex. europa)
saf	NWC/PPS
sampling_interval	→ Corresponding "time difference in minutes between initial and final image"
satellite_cycle_initial_image	Not applicable
satellite_cycle_later_image	Not applicable
satellite_identifier	Not applicable

source	NWC/PPS-HRW version 7.Q
spatial_resolution	➔ Corresponding satellite "low resolution pixel size" in km.
sub-satellite_longitude	Not applicable
summary	High Resolution Winds Product of the NWC/PPS. Detailed sets of Atmospheric Motion Vectors and Trajectories.
time_coverage_end	➔ Corresponding "date/time string" for coverage end of later image
time_coverage_end_initial_image	➔ Corresponding "date/time string" for coverage end of initial image
time_coverage_start	➔ Corresponding "date/time string" for coverage start of later image
time_coverage_start_initial_image	➔ Corresponding "date/time string" for coverage start of initial image
title	NWC/PPS-High Resolution Winds Product
validation_nwp_forecast_or_analysis	➔ NWP analysis / NWP forecast / Not applicable
wind_computation_method	Wind derived from motion observed in visible/infrared/water vapour channels

Table 11: Detailed specification of the NWC/PPS-HRW netCDF output attributes

2.3.5. Output data filterings

Several output data filterings are included during NWC/PPS-HRW algorithm running, which depend on the value of several configurable parameters in the "NWC/PPS-HRW model configuration file". These configurable parameters are:

- AMV_BANDS: defines the channels for which AMVs and Trajectories are calculated. The default option for NWC/PPS-HRW v7.Q (value = VIS06,IR108,WV067,WV073) defines the AMV calculation for all possible channels.
- QI_THRESHOLD: defines the "Quality index threshold" for the AMVs and Trajectories in the output files (default value = 83%). Depending on configurable parameter QI_THRESHOLD_USEFORECAST, the "Quality index with forecast" (default option with value = 1) or the "Quality index without forecast" are respectively used for the AMV filtering).
- MAXPRESSUREERROR: defines the maximum "AMV pressure error" (in hPa) allowed in the output AMVs and Trajectories, when "CCC height assignment method" has been used (default value = 150 hPa).
- MIN_CORRELATION: defines the minimum correlation in the output AMVs and Trajectories, when the "Cross Correlation tracking" has been used (default value = 40%).
- FINALFILTERING: defines several filterings in the output AMVs and Trajectories, depending on its value:
  - With FINALFILTERING>0 and VERYLOWINFRAREDAMVS=0, infrared AMVs below 900 hPa are eliminated.
  - With FINALFILTERING>1 (which is the default option with FINALFILTERING = 2), the "AMV cloud type" filtering defined in Table 5 is additionally implemented.
  - With FINALFILTERING>2, AMVs with "spatial quality flag"=1,2 are additionally eliminated.
  - With FINALFILTERING=4, AMVs with "spatial quality flag"=0 are additionally eliminated.

3. IMPLEMENTATION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)

Two main steps are identified. The user manually interacts with the NWC/PPS software package during the installation step, and the NWC/PPS-HRW execution step is automatically monitored by the NWC/PPS running step (such as for example defined in [AD.3]).

3.1 INSTALLATION AND PREPARATION OF NWC/PPS SOFTWARE PACKAGE

The right to use, copy or modify this software is in accordance with EUMETSAT policy for the NWC/PPS software package. Once the user has obtained the permissions to download the software package, the software installation procedure does not require any special resources. It is limited to:

- Define some environment variables which are needed for the installation and definition of directories for NWC/PPS-HRW software. This can be done through command "export" in the terminal or in the working "profile" file:

```
# Specific environment variables for NWC/PPS-HRW installation
export TZ=UTC
export SAFNWC=(dir where NWC/PPS-HRW is to be installed)
export ECCODES_DEFINITION_PATH=`codes_info -d`
export SM_ECCODES_DIR=(dir where local /share/eccodes/definitions are defined)
export CC=gcc
export FC=gfortran
export CFLAGS="-O3 -DPPSHRW"
export FFLAGS="-O3"
export ARCH=linux
export PATH=$SAFNWC/bin:$PATH

# Specific environment variables for NWC/PPS-HRW directory location
export SM_HRWTEMP_DIR=(dir where HRW temporal files are to be located)
export SM_CONFIG_DIR=(dir where HRW configuration files are located)
export SM_HRWAUX_DIR=(dir where HRW auxiliary files are located)
export SM_STATIC_AUXILIARY_DIR=(dir where HRW static region files are located)
export SM_NWPDATA_DIR=(dir where NWP data are to be located)
export SM_PRODUCT_DIR=(dir where NWC/PPS-Clouds+HRW outputs are to be located)
export SM_SUNSATANGLES_DIR=(dir where "sunsatangles" data are to be located)
export SM_IMAGER_DIR=(dir where "avhrr/viirs/modis/metimage/mersi2/slstr" data
are to be located)
```

- Decompress and install the NWC/PPS distribution files, which successfully build the executable (`PPS-HRW-v7Q` file), to be stored into the `$SAFNWC/bin` directory such as defined in [AD.3].

3.2 RUNNING OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)

Before running `PPS-HRW-v7Q` executable, several steps have to be taken.

First, the corresponding region has to be prepared, using:

```
python ppsPhysOnRegion_nc.py <regid>
```

Then, NWC/PPS-Cloud products have to be run and remapped to the defined region, including the remapping of some additional files with:

```
ppsRemapNwp.py --nwp_file –area
ppsHrwPrepare --anglesfile –area
```

Finally, NWC/PPS-HRW is to be run. Using NWC/PPS commands, this can be done with:

```
ppsHrw.py  --anglesfile –area
```

which is equivalent to:

```
PPS-HRW-v7Q <current_sunsatangles_NetCDF_file> <model_conf_file>
```

where the `PPS-HRW-v7Q` executable is related to the required parameters ("satellite angle input file(s)" and "model configuration file", to be found in the corresponding directories `$SM_SUNSATANGLES_DIR` and `$SM_CONFIG_DIR`).

As already mentioned, the "satellite angle input files" (and all other needed input files) has to comply with the name and characteristics defined in Chapter 2.2.1 of this User Manual. Because of this, all these files need to correspond to reprojections to the selected static processing region, considering the reprojection process explained in [AD.3] and run before the running of NWC/PPS-HRW software.

Here, the NWCSAF user defines through the defined "satellite angle input files" the "later image" for the AMV calculation, and the NWC/PPS-HRW software defines by itself which is the "initial image" which fits best for the image calculation. For this, the following conditions are to be met among all "satellite angle input files" available in `$SM_SUNSATANGLES_DIR` directory:

- The "initial image" time has to be before the "later image" time, inside POLAR_MAX_TIME_SEP and POLAR_MIN_TIME_SEP limits (120 minutes and 12 minutes).
- The percentage of image data available inside the static processing region for both "initial image" and "later image" (i.e. the real portion of the static processing region in which AMVs can be calculated for the defined slot) has to be over a configurable threshold (POLAR_MINIMUM_COMMON_SCANNING, with a default value of 10%).
- The following formula has to be a minimum for the selected "initial image":

(WTimeSep*RatioOfTimeSeparation + WCommonScan(1-PercofPixelsCommonlyScanned))*NumberofChannelsFactor

  - "WTimeSep", "WCommonScan" are the weights of both elements in the formula (which correspond to configurable parameters WEIGHT_OPTIMAL_TIME_SEPARATION and WEIGHT_MINIMUM_COMMON_SCANNING, both with a default value of 1),
  - "RatioOfTimeSeparation" defines the ratio of the time separation of the defined "initial image" to the optimal time separation (which corresponds to configurable parameter POLAR_OPTIMAL_TIME_SEPARATION, with a default value of 24 minutes), with respect to the maximum possible time separation to the optimal time separation (related to POLAR_MAX_TIME_SEP for images before the "optimal time separation", and related to POLAR_MIN_TIME_SEP for images after the "optimal time separation"). Considering the value of the corresponding weight, the value of this element is between 0 (best possible value) and 1 (worst possible value).
  - "PercofPixelsCommonlyScanned" defines the percentage of pixels inside the static processing region, commonly scanned by both "initial image" and "later image". Considering the value of the corresponding weight, the value of this element is between 0 (best possible value) and 1 (worst possible value).
  - A new element is included in NWC/PPS-HRW v7.Q: "NumberofChannelsFactor", related to the number of satellite channels with which AMVs can be calculated. Its value is 1 when both VIS06 and IR107-IR108-IR110 channels can be used, 0.667 when additionally WV072-WV073 channel can be used (when both satellite images are related to MODIS, METimage or MERSI-2 radiometers), and 0.500 when additionally WV067 channel can be used (when both satellite images are related to MODIS or METImage radiometers). This way, a preference is included for the satellite image combinations with which water vapour AMVs can be calculated.

The best option for the pair "initial image"/"later image" is so defined considering three elements: the time separation between images, the percentage of common scanning in the static processing region, and the number of satellite channels with which AMVs can be calculated. This way the processing of NWC/PPS-HRW optimizes the calculation of AMVs with polar satellites, maximizing the quantity and quality of AMVs. If no "initial image" is defined as valid for the processing (because none of the "satellite angle input files" available in $SM_SUNSATANGLES_DIR directory complies with both of the first two conditions defined here), only tracers are calculated for the defined image.

Other option is however possible to run `PPS-HRW-v7Q` executable through:

```
PPS-HRW-v7Q <current_sunsatangles_NetCDF_file> <previous_sunsatangles_NetCDF_file> <model_conf_file>
```

Here, the NWCSAF user decides through both “satellite angle input files” the “later image” and the “initial image” for the AMV calculation. If both files are the same one, only tracers are calculated for that defined image.

Considering this, *Figures 1 to 3* in the following pages summarise how the tasks to generate the High Resolution Winds (NWC/PPS-HRW) are performed by the `PPS-HRW-v7Q` executable.

3.3 DOCUMENTATION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)

In NWC/PPS-HRW, a detailed description of the whole algorithm, involved interfaces and data types, is provided through comments included within the code of NWC/PPS-HRW v7.Q software.

Every single step throughout all functions of NWC/PPS-HRW algorithm has been commented in detail, so that any AMV developer can know in detail all the process of the algorithm, having a look to the corresponding C/Fortran functions.

For a quicker reference, a “Diagram tree” of all functions of NWC/PPS-HRW algorithm is also provided in the “Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO” document [AD.5]. This “Diagram tree” allows NWCSAF users to quickly know at a glance how it works.

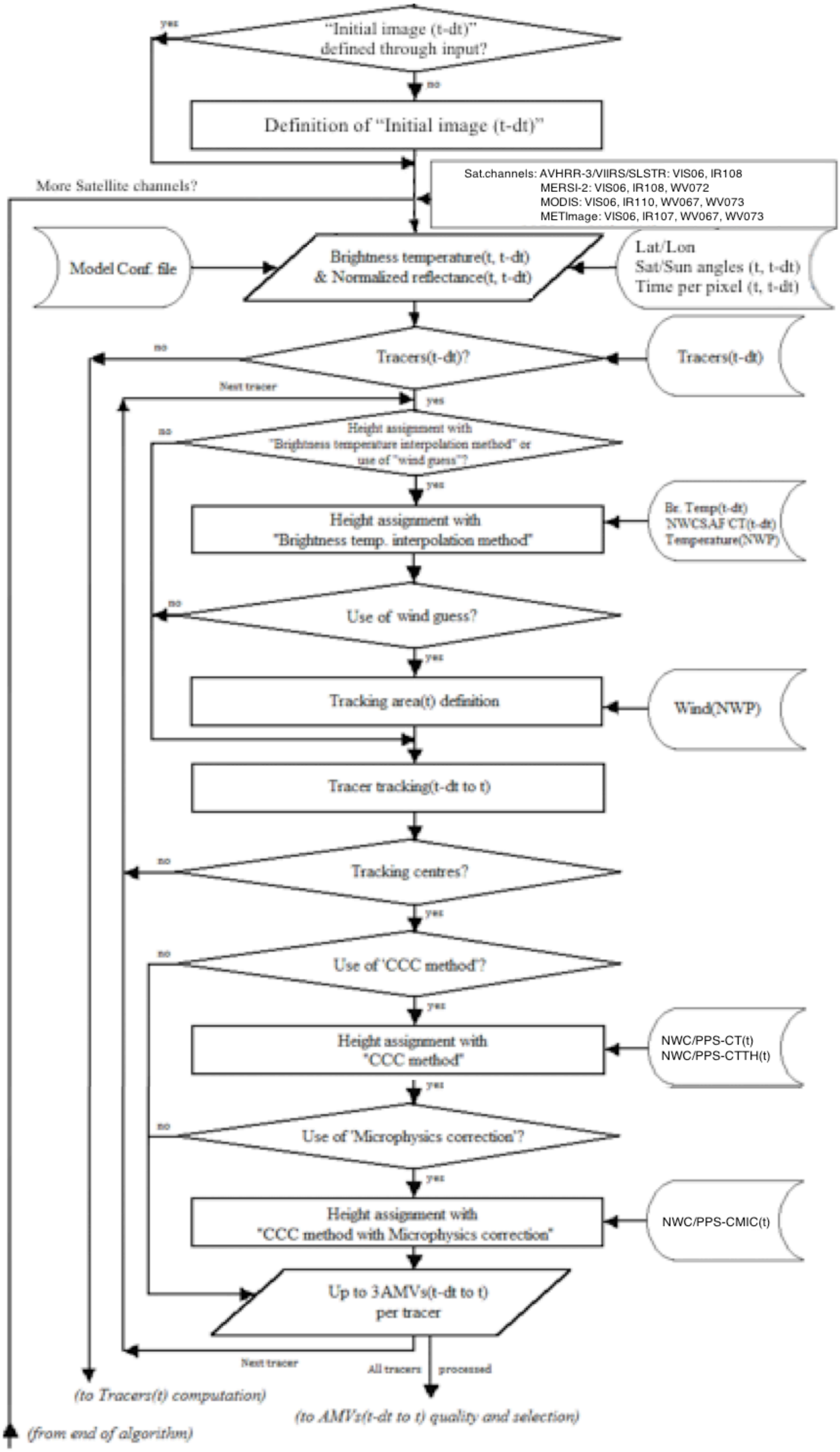

Figure 1: NWC/PPS-HRW implementation: Part 1, Preprocessing and AMV computation

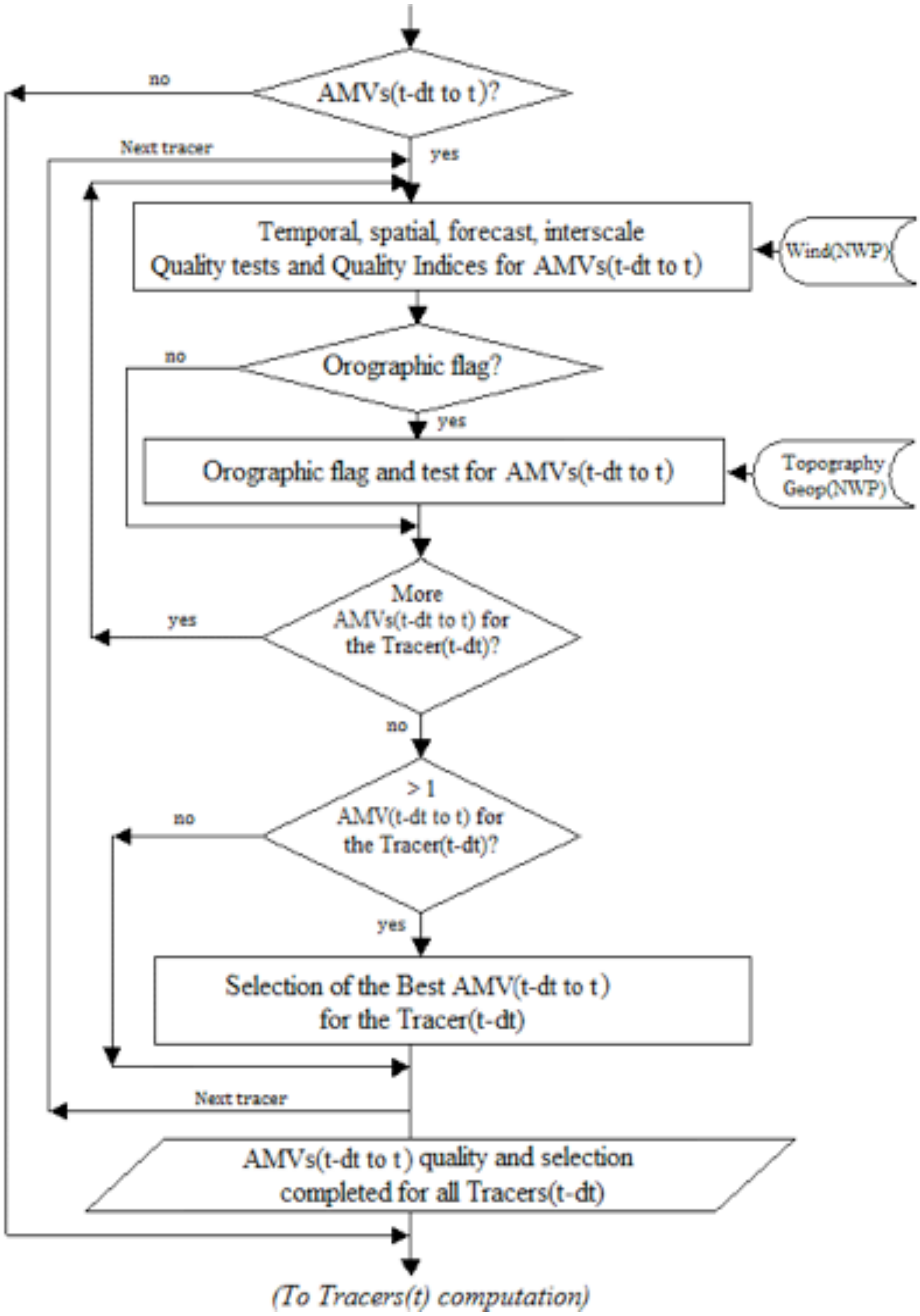

Figure 2: NWC/PPS-HRW implementation: Part 2, AMV quality and selection

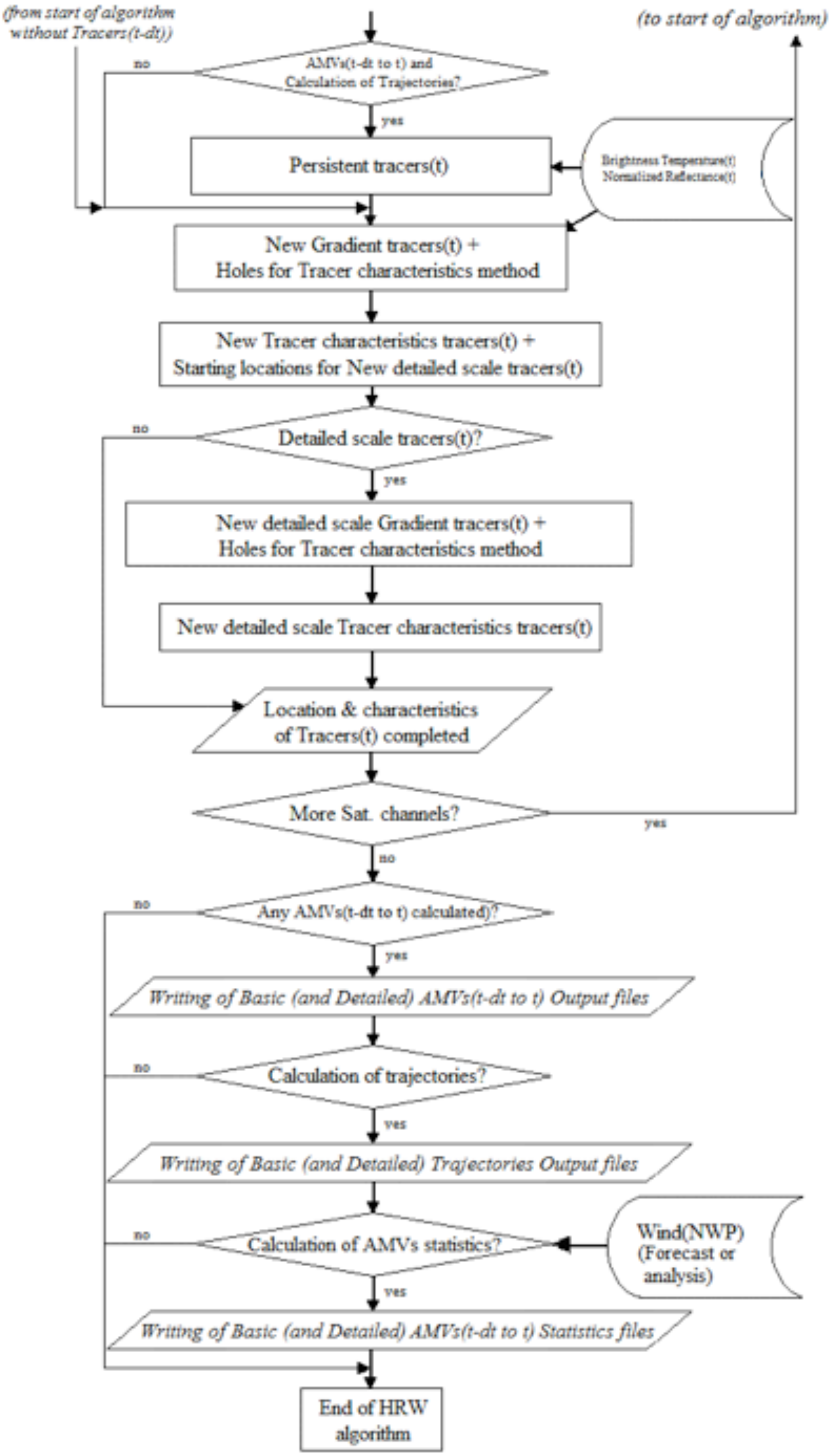

Figure 3: NWC/PPS-HRW implementation: Part 3, Tracer computation and writing of output files

3.4 List of Errors for High Resolution Winds (NWC/PPS-HRW)

The following *Table 12* shows the whole list of errors and warnings that can appear during the running of NWC/PPS-HRW software, the reasons causing the errors and warnings, and the way the NWCSAF user can try to solve them. In any case, if the errors or warnings persist, the NWCSAF Helpdesk should be contacted.

Error	Message	Reason	Recovery action
E - 150	"Environment variable $*** has not been defined; Update for correct processing"	An environment variable defining some working directory has not been defined	Update environment variable for correct processing
E - 151	"Usage of NWC/PPS-HRW executable"	Input parameters are incorrect	Check instructions to start the run of NWC/PPS-HRW executable
E - 152	"Error allocating memory for tracers related to the previous/current slot"	Unable to allocate required memory for "tracer" struct	There are memory problems to run NWC/PPS-HRW executable in the defined region with the defined configuration and computer. Use a larger computer or a smaller region.
E - 153	"Error allocating memory for a tracer_wind struct"	Unable to allocate required memory for "tracer_wind" struct	
E - 154	"Error allocating memory for a wind_channel_info struct"	Unable to allocate required memory for "wind_channel_info" struct	
E - 155	"Error allocating memory for the NWP grids for each variable"	Unable to allocate required memory for NWP grids	
E - 156	"Error allocating memory for the Quality control Image correlation grid"	Unable to allocate required memory for Image Correlation Grid	
E - 157	"Satellite data for current/previous slot do not include valid values for any pixel"	Satellite data are not valid for the working satellite channel	Verify if there is any problem with the satellite data used by NWC/PPS-HRW
E - 158	"The defined satellite for the current/previous slot is not correct, or does not belong to NOAA-15/21, SNPP, METOP-A/C, EOS-1/2, METOP-SG-A1/3, FY3-D or SENTINEL-3A/D series"	The defined satellite is not correct or does not belong to a processable polar satellite	Use NWC/PPS-HRW v7.Q with a correctly defined NOAA-15/21, SNPP, METOP-A/C, EOS-1/2, METOP-SG-A1/3, FY3-D or SENTINEL-3A/B satellite
E - 160	"Error: The region/projection defined for both satellite images is different"	The user has defined in the input command two sunsatangles files related to different regions or projections	Use in the input command two sunsatangles files related to the same region and projection
E - 163	"Error reading Parameters from the HRW configuration file"	Error after hrw_ReadData/ hrw_ReadDataPPS functions	Verify that the HRW configuration file in $SAFNWC/cfg directory used for running NWC/PPS-HRW is correct
E - 164	"Error reading Pressure levels from the NWP configuration file"	Error after NwcNwpReadPLevel function	Verify that the NWP configuration file ($SAFNWC/cfg/nwp_conf_file) used for running NWC/PPS-HRW is correct
E - 165	"Unable to initialize the NWP *** profile"	Error after NwcNwpInitProfile function	Verify that the HRW and NWP configuration files in $SAFNWC/cfg directory used for running NWC/PPS-HRW are correct

Error	Message	Reason	Recovery action
E - 166	"NWP *** data cannot be read" or "Minimum NWP *** levels for calculation" are larger than available NWP levels	Error after hrw_NwcPPSNWPInterpolate functions	Verify that valid and large enough NWP input files have been provided for the running of NWC/PPS-HRW in $SAFNWC/import/NWP_data directory
E - 167	"Orographic flag cannot be calculated because Orography cannot be converted to surface pressure"	Error after NwcPPSAuxReadGridF function	Verify that a valid S_NWC_SFCMAX* file has been provided in the corresponding subdirectory in $SAFNWC/import/ Aux_data/Common directory
E - 170	"Error setting the Processing region and the Satellite info"	Error after NwcPPSRegionSet function	Verify that the sunsatangles file defined in the input command to run NWC/PPS-HRW is correct
E - 171	"Error defining the previous slot for NWC/PPS-HRW"	Error after hrw_DefinePreviousSlotPPS function	All these errors are caused by the running of NWC/PPS-HRW executable, and cannot be solved by the NWCSAF user. Nevertheless, as a whole, they should occur in less than a 0.5% of the cases. If the frequency is higher than that, please contact NWCSAF Helpdesk.
E - 172	"Error reading latitude, longitude, and satellite and sun angles matrices"	Error after hrw_GetAncillaryDataPPS function	
E - 173	"Error reading satellite data for current/previous slot"	Error after hrw_ReadSatelliteData function	
E - 174	"Error reading tracers from previous slot"	Error after hrw_ReadTracers function	
E - 175	"Error reading trajectories from previous slot"	Error after hrw_ReadTrajectories function	
E - 176	"Error during the AMV Tracking process"	Error after hrw_GetWinds function	
E - 177	"Error during the AMV Quality Control"	Error after hrw_Qc function	
E - 178	"Error writing Predecessor winds in $SAFNWC/tmp directory"	Error after hrw_WritePredWinds function	
E - 179	"Error writing Trajectories in $SAFNWC/tmp directory"	Error after hrw_WriteTrajectories function	
E - 180	"Error calculating tracers for current slot"	Error after hrw_GetTracers function	
E - 181	"Error writing tracers in $SAFNWC/tmp directory"	Error after hrw_WriteTracers function	
E - 182	"Error writing the AMVs/Trajectories in the *** output file"	Error after hrw_Encode*** functions	
E - 183	"Error reading Cloud *** data"	Some output parameter from NWC/PPS-CT, CTTH, CMIC products cannot be read.	
E - 184	"NWP data to be used cannot be defined"	Error after NwcPPSNWPDefine function	

Table 12: List of errors for NWC/PPS-HRW v7.Q software

4. INPUTS AND CONFIGURABLE PARAMETERS

4.1 LIST OF INPUTS FOR HIGH RESOLUTION WINDS (NWC/PPS-HRW)

For NWC/PPS-HRW all input files share the same naming structure, in which <radid> parameter is the radiometer related to the scanning and <satid> parameter is the polar satellite related to the scanning, which can adopt any of the following value pairs:

- radid = avhrr satid = noaa15/noaa16/noaa17/noaa18/noaa19/metopa/metopb/metopc
- radid = viirs satid = npp/noaa20/noaa21
- radid = modis satid = eos1/eos2
- radid = metimage satid = metopsga1/metopsga2/metopsga3
- radid = mersi2 satid = fy3d
- radid = slstr satid = sentinel3a/sentinel3b/sentinel3c/sentinel3d

Additionally, <orbid>=nnnnn is the satellite orbit number, <tim1>=yyyymmddThhmmssZ is the satellite initial processing time, <tim2>=yyyymmddThhmmssZ is the satellite final processing time, and <regid> is the label identifying the static region used for the AMV calculation (for example, "europa" or "euron1").

Considering this, the full list of input files for the running of NWC/PPS-HRW software is as follows. All these input files have to be reprojected to the selected static processing region before the running of NWC/PPS-HRW, considering the reprojection process explained in [AD.3].

- The "satellite image input files", for the two images in which tracers are identified and tracked. The name of these "satellite image input files" is identified as `S_NWC_<radid>_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`, where `$SM_IMAGER_DIR` is the directory in which these files are located.

- The "satellite angle input files", for the two images in which tracers are identified and tracked. The name of the "satellite angle input files" is identified as `S_NWC_sunsatangles_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`, where `$SM_SUNSATANGLES_DIR` is the directory in which these files are located.

- The "NWP input files" for the static region used for the AMV calculation. At least two "NWP forecast input files" related to a moment before and a moment after the images in which tracers are identified and tracked are needed for the processing. One "NWP analysis input file" up to one hour away from the moment in which tracers are identified and tracked is additionally needed to run Validation statistics against NWP analysis winds. The name of the "NWP input file" is identified as `PPS_ECMWF_yyyymmddhhmm+fffHggM_<regid>.nc`, where `yyyymmddhhmm` is the moment of the NWP run, `fffHggM` is the moment of the NWP forecast for the given file, and `$SM_NWPDATA_DIR` is the directory in which these files are located.

  Here, ECMWF NWP model is used as option for NWC/PPS software package, although other NWP models could be used by NWCSAF users for processing after some adaptation. A time step between NWP files of at most 6 hours (preferably a NWP time step of 1 hour), for a minimum of four (defined by configurable parameter MIN_NWP_FOR_CALCULATION) and preferably for as many as possible of the following pressure levels: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10 hPa, should be provided for the following NWP variables:

  - NWP Forecast Fields of temperatures ("t").
  - NWP Forecast Fields of rectangular components of the wind ("u" and "v"), needed for the "Quality control forecast test", if the NWP wind guess has to be used for the definition of the "tracking area centre", or if Validation statistics are to be calculated by the NWC/PPS-HRW software itself considering as reference winds the NWP forecast winds.

- NWP Analysis Fields of rectangular components of the wind ("u" and "v"), needed if Validation statistics are to be calculated by the NWC/PPS-HRW software itself considering as reference winds the NWP analysis winds.
- NWP Forecast Fields of geopotential heights ("z"), needed if the "Orographic flag" is calculated.
- NWP Forecast Field of surface pressure ("psur"), needed if the "Orographic flag" is calculated.

• The "NWP/PPS-CT (Cloud type) output files" for the static region used for the AMV calculation, for the image in which tracers are calculated (in case the "Brightness temperature interpolation height assignment with Cloud products" is used) and/or for the image in which tracers are tracked (in case "CCC height assignment method" is used). The name of these "CT output files" is identified as `S_NWC_CT_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`, where `$SM_PRODUCT_DIR` is the directory where these files are located.

• The "NWP/PPS-CTTH (Cloud Top Temperature and Height) output file" for the static region used for the AMV calculation, for the image in which tracers are tracked, in case "CCC height assignment method" is used. The name of this "CTTH output file" is identified as `S_NWC_CTTH_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`, where `$SM_PRODUCT_DIR` is the directory in which this file is located.

• The "NWP/PPS-CMIC (Cloud Microphysics) output file" for the static region used for the AMV calculation, for the image in which tracers are tracked, in case "CCC height assignment method with Microphysics correction" is used. The name of this "CMIC output file" is identified as `S_NWC_CMIC_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`, where `$SM_PRODUCT_DIR` is the directory in which this file is located.

• The "physiography file" for the static region used for the AMV calculation. The name of this "physiography file" is `physiography.<regid>.nc` and `$SM_STATIC_AUXILIARY_DIR` is the directory in which this "Physiography file" is located.

Here, the "physiography file", the "satellite image input files", the "satellite angle input files" and the "NWP input files" with NWP temperature and wind forecast data with a minimum number of NWP levels (defined by configurable parameter MIN_NWP_FOR_CALCULATION, with a default value of 4) are strictly needed for the AMV calculation. Remaining input data contribute to a higher number of AMVs and Trajectories and a better quality of the output data, and are actually used in the default configuration.

The option to calculate AMVs and Trajectories with climatological data instead of NWP data is not available, since the amount and quality of data provided would be significantly worse.

4.2 LIST OF CONFIGURABLE PARAMETERS FOR HIGH RESOLUTION WINDS (NWC/PPS-HRW)

The High Resolution Winds Model configuration file holds the configurable parameters needed for the running of NWC/PPS-HRW executable (`PPS-HRW-v7Q`). It must be located in `$SM_CONFIG_DIR` directory. One reference Model Configuration File is included as example for the operational use with polar satellites: `safnwc_HRW_POLAR.cfm`.

A description of the configurable parameters is shown in the following table. They are basically equivalent to those used with NWC/GEO-HRW (for a common use of both applications). Only 5 additional parameters are defined for NWC/PPS-HRW, which are not used by NWC/GEO-HRW (in green in the table). 9 parameters used by NWC/GEO-HRW are not used by NWC/PPS-HRW because the corresponding option does not exist in this version of NWC/PPS-HRW (in yellow in the table). A few parameters (for example the QI_THRESHOLD) have different values for each implementation.

Keyword	*Description*	*Type*	*Default Value(s)*
Identification parameters			
PGE_ID	NWCSAF Software Element identification. This keyword is optional, but it should not be changed by the user.	Chain of characters	`PPS-HRW`
SAT_BANDS	A list of satellite bands that can be used for the calculation of AMVs and Trajectories with NWC/PPS-HRW software. This keyword is optional, but should not be changed. It defines the maximum value of bands for which AMVs can be calculated. Values defined in a list separated by commas.	Chain of characters	`VIS06,IR108,WV067,WV073`
AMV_BANDS	A list of satellite bands really used for the calculation of AMVs and Trajectories with NWC/PPS-HRW software. As possible values, it can include any of the bands shown by the previous parameter, separated by commas.	Chain of characters	`VIS06,IR108,WV067,WV073`
SLOT_GAP	Ordering number of the previous satellite image, from which tracers are to be considered for the AMV processing (Unused in NWC/PPS-HRW).	Integer	`1`
MIXED_SCANNING	Flag to decide if the "Mixed method" is used in AMV processing (Unused in NWC/PPS-HRW).	Integer	`0`
CDET	Flag to define if "Detailed AMVs and Trajectories" are calculated.	Integer	`0`
Polar specific identification parameters			
POLAR_OPTIMAL_ TIME_SEPARATION	Optimal time separation in minutes between the "initial image" and the "later image"	Integer	`24`
WEIGHT_OPTIMAL_ TIME_SEPARATION	Weight of the "Optimal time separation" in the formula deciding the "initial image" for a given "later image"	Integer	`1`
POLAR_MINIMUM_ COMMON_SCANNING	Minimum common scanning in % between the "initial image" and the "later image"	Integer	`10`
WEIGHT_MINIMUM_ COMMON_SCANNING	Weight of the "Minimum common scanning" in the formula deciding the "initial image" for a given "later image"	Integer	`1`
OUTPUT_NAMESTYLE	Option to decide if NWC/PPS-HRW output files are provided with "GEO" or "PPS" name styles	Chain of characters	`PPS`
Output parameters			
BUFR_SUPERCENTRE_OR	Originating centre and Subcentre of the BUFR file, as defined in WMO Common Code Table C-1 ([RD.19]). It is to be modified with the code related to the corresponding centre (e.g. the default value 214 means Madrid).	Integer	`214`
BUFR_CENTRE_OR			`214`
OUTPUT_FORMAT	A list of output file formats, with several options possible. Elements in the list are to be separated by commas: - NWC: AMV & Trajectories BUFR files, using the specific NWCSAF format. - IWWG: AMV BUFR files, using the new IWWG BUFR format. - NCF: AMV netCDF files (CF compliant)	Chain of characters	`IWWG,NCF`

Output filtering parameters			
QI_THRESHOLD	Quality Index threshold for the AMVs.	Integer	83
QI_THRESHOLD_USEFORECAST	Option to define if the Quality index threshold used in the wind output filtering includes the Quality forecast test.	Integer	1
QI_IWWG_VALUE_CALCULATION	Option to define if the Common Quality Index is calculated.	Integer	1
QI_BEST_WIND_SELECTION	Criterion for Best wind selection (Values: 0/1, as defined in the ATBD document).	Integer	1
CLEARAIRWINDS	Flag to decide if Clear air AMVs are calculated.	Integer	1
CALCULATE_TRAJECTORIES	Flag to decide if Trajectories are calculated.	Integer	1
FINALFILTERING	Flag for a final filtering of AMVs based on: - Their Height level (if > 0), - Their Cloud type (if > 1), - Their Quality spatial test (1,2 as invalid values if > 2; 0,1,2 as invalid values if > 3).	Integer	2
USE_TOPO	Flag for calculation of Orographic flag (if positive), and for its AMV filtering (if = 2).	Integer	2
MAXPRESSUREERROR	Maximum pressure error in the AMVs (hPa), when 'CCC height assignment method' used.	Integer	150
VERYLOWINFRAREDAMVS	Flag showing if very low infrared AMVs (at levels lower than 900 hPa) are included in the AMV output files.	Integer	1
FINALCONTROLCHECK	Flag to decide the use of Final Control Check.	Integer	1
CORRELATIONMATRICES	(Formally unused in both NWC/GEO-HRW and NWC/PPS-HRW algorithms).	Integer	0
Working area description parameters			
LAT_MIN	Latitude and longitude borders (in degrees) for the processing region (Basic AMVs).	Integer	-90
LAT_MAX		Integer	90
LON_MIN		Integer	-180
LON_MAX		Integer	180
LAT_MIN_DET	Latitude and longitude borders (in degrees) for the processing region (Detailed AMVs).	Integer	-90
LAT_MAX_DET		Integer	90
LON_MIN_DET		Integer	-180
LON_MAX_DET		Integer	180
FRAC_DAY_SCENE	Minimum fraction of area illuminated by the sun needed to calculate the visible AMVs (in NWC/PPS-HRW, for VIS06 channel).	Integer	8
SUN_ZEN_THRES	Sun zenith angle threshold (degrees).	Integer	87
SAT_ZEN_THRES	Satellite zenith angle threshold (degrees).	Integer	80
Tracer parameters			
USE_OLDERSLOT_FORTRACERS	Flag defining if using an older slot for the "initial image", if the corresponding one is not available (Unused in NWC/PPS-HRW). (Suggested by Yu-heng He, Hong Kong Observatory).	Integer	0
MAX_TRACERS	Maximum number of tracers.	Integer	600000
TRACERSIZE_VERYHIGH	Tracer line and column dimension in pixels, when respectively using satellite images with very high, high and low resolution. (NWC-PPS/HRW using low resolution only).	Integer	24
TRACERSIZE_HIGH		Integer	24
TRACERSIZE_LOW		Integer	24
BRIGHTNESS_THR_VIS	1 byte reflectance threshold for visible tracers.	Integer	120
BRIGHTNESS_THR_OTHER	1 byte brightness temperature threshold for infrared and water vapour tracers.	Integer	240
GVAL_VIS	Minimum 1 byte reflectance contrast for visible tracers.	Integer	60
GVAL_OTHER	Minimum 1 byte brightness temperature contrast for infrared and water vapour tracers.	Integer	48
TRACERDISTANCE_VERYHIGH	Nominal separation in pixels between tracers, when respectively using satellite images with very high, high and low resolution. (NWC-PPS/HRW using low resolution only).	Integer	24
TRACERDISTANCE_HIGH		Integer	12
TRACERDISTANCE_LOW		Integer	6
HIGHERDENSITY_ LOWTRACERS	Relative density between tracers related to other cloud types, and the one for high level clouds (for Basic and Detailed scale respectively)	Integer	1
HIGHERDENSITY_ LOWTRACERS_DET		Integer	1

Tracking parameters			
TRACKING	Tracking method. Possible values: LP: Euclidean difference CC: Cross correlation.	Chain of characters	`CC`
TRACKING_GAP	Initial pixel gap in the Tracking process for the calculation of Euclidean distance or Cross correlation	Integer	`8`
DEFINECONTRIBUTIONS	Flag to decide if "CCC height assignment" is to be used (requires also TRACKING=CC).	Integer	`1`
DEFPOSCONTRIBUTIONS	Flag to decide if the position of the AMV in the target is relocated to the position of maximum correlation contribution defined by "CCC height assignment" (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).	Integer	`1`
USE_CLOUDTYPE	Flag to decide if - The Tracer cloud type is calculated by the old "Brightness temperature interpolation height assignment method" (if positive), - And if the Tracer cloud type is taken into account for the calculation of the Tracer temperature (if = 2).	Integer	`2`
USE_MICROPHYSICS	Flag to decide if Microphysics correction is to be calculated to "CCC height assignment" Possible values: - 0: Not used. - 1: Microphysics correction calculated but not included in the AMV pressure. - 2: Microphysics correction calculated and included in the AMV pressure. - 3: Microphysics correction (including OMSZ contribution for highest AMVs) calculated and included in the AMV pressure.	Integer	`3`
MIN_CORRELATION	Minimum correlation acceptable (if TRACKING=CC).	Integer	`40`
WIND_GUESS	Flag to decide if the Wind guess is used for the definition of the Tracking area.	Integer	`1`
MINSPEED_DETECTION	When the wind guess is not used in the definition of the Tracking area, displacement in any direction (in km/h) which the process is at least able to detect for AMVs/Trajectories. When the wind guess is used in the definition of the Tracking area, difference in speed with respect to the one of the NWP wind guess (in km/h) which the process is at least able to detect for the AMVs/Trajectories.	Integer	`72`
USE_SUBPIXELTRACKING	Flag to decide if the subpixel tracking is used.	Integer	`1`
USE_PARALLAXCORRECTION	Flag to decide if the parallax correction is applied to the latitude/longitude of the tracer and tracking centre, for the calculation of the wind, considering the AMV height in metres (Unused in NWC/PPS-HRW).	Integer	`0`
KEEPDEFAULTPROCEDURE	Flag to decide if the default procedure is to be used in all cases, even when some of the input data are not available (if = 1), or an alternative option for AMV calculation can be used without the missing input data (if = 0).	Integer	`1`

NWP validation parameters			
NWPVAL_STATISTICS	Flag to decide if Validation statistics against NWP model winds are to be calculated. Possible values: - 1: Statistics provided for all layers and satellite channels together. - 2: Statistics provided for all layers together and each satellite channel separately. - 3: Statistics provided for each layer separately and all satellite channels together. - 4: Statistics provided for each layer and satellite channel separately.	Integer	4
NWPVAL_ANALYSIS	Flag to decide if the Validation statistics are to be computed against NWP analysis winds.	Integer	0
NWPVAL_NWPDIFFERENCE	Flag to decide if Vector difference between each AMV and the related NWP model wind is to be written in the output files.	Integer	1
NWPVAL_NWPBESTFITLEVEL	Flag to decide if the NWP model wind at the best fit pressure level for each AMV is to be written in the output files.	Integer	1
NWP parameters			
MIN_NWP_FOR_CALCULATION	Minimum number of NWP levels needed for NWC/PPS-HRW processing.	Integer	4
NWP_PARAM	NWP parameters requested by NWC/PPS-HRW software: * NWP_T: Temperature at several levels (K) * NWP_UW: Longitudinal wind velocity at several levels, u component (m/s) * NWP_VW: Latitudinal wind velocity at several levels, v component (m/s) * NWP_GEOP: Geopotential height at several levels (m) * NWP_SP: Pressure at surface level (Pa) Sampling rate:1 Interpolation method: NEI (neighbour) (Both parameters unused in NWC/PPS-HRW)	Chain of characters	`NWP_T 1 NEI`
NWP_PARAM		Chain of characters	`NWP_UW 1 NEI`
NWP_PARAM		Chain of characters	`NWP_VW 1 NEI`
NWP_PARAM		Chain of characters	`NWP_GEOP 1 NEI`
NWP_PARAM		Chain of characters	`NWP_SP 1 NEI`

Table 13: NWC/PPS-HRW v7.Q Model Configuration File Description

The "NWC/PPS-HRW Model configuration file" is an ASCII file, so further modifications can be easily performed with a text editor.

For a given NWC/PPS-HRW Model configuration file, the running time depends basically on two parameters:

- The size in pixels of the reprojected region used for the processing (a larger size in pixels means a longer processing time).
- The size in kilometres of the pixels in this reprojected region (a smaller size in km of the pixels means the use of larger "tracking areas" to look for the tracers in the "later image", and due to this, a longer processing time).

If the user has the need to reduce the NWC/PPS-HRW running time, especially when working with a slow platform, several options can be recommended:

- To reduce the number of tracers and AMVs, increasing the distance between them (with larger values of TRACERDISTANCE_LOW parameter).
- To reduce the size of the "tracking area", with smaller values of MINSPEED_DETECTION parameter. However, care is needed here so that NWC/PPS-HRW software keeps on having the option to calculate all AMVs, including those which are significantly different to the NWP wind (when the wind guess is used), or those which are significantly fast (when the wind guess is not used).

5. VALIDATION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)

NWCSAF/High Resolution Winds software is validated for its NWC/GEO-HRW implementation since the year 2018 considering both Radiosounding winds and NWP analysis winds as reference winds. This procedure has also been used in the validation of the NWC/PPS-HRW implementation.

The default validation statistics against Radiosounding winds and NWP analysis winds for NWC/PPS-HRW v7.Q Basic AMVs are shown here as a summary. A comparison with equivalent statistics for NWC/PPS-HRW v7.P Basic AMVs is also shown to check the evolution of results between both software versions.

The criteria defined at the Third International Winds Workshop (Ascona, Switzerland, 1996) for the comparison of satellite winds with Radiosounding winds have been followed here, as for all versions of NWC/GEO-HRW algorithm. Additional Validation statistics can be obtained in the "Scientific and Validation Report" for NWC/PPS-HRW [AD.6].

The statistical parameters used in the process of validation are:

- NC: "Number of collocations" between NWC/PPS-HRW AMVs and the reference winds.
- SPD: "Mean speed of the reference winds in m/s".
- NBIAS: "Normalized bias".
- NMVD: "Normalized mean vector difference".
- NRMSVD: "Normalized root mean square vector difference".

Information about how these validation statistical parameters can be calculated can be obtained in the same "Scientific and Validation Report" for NWC/PPS-HRW [AD.6].

The same dataset of AMVs is validated for all satellite series against both reference winds, to detect differences in the validation against both references.

5.1 VALIDATION OF NWC/PPS-HRW FOR POLAR SATELLITES

For the validation of this second NWC//PPS-HRW version with polar satellites, a validation period of three months between April and June 2020 has been defined. Here, satellite images from ten different polar satellites (Metop-A, Metop-B, Metop-C, NOAA-18, NOAA-19, NOAA-20, SNPP, EOS-1, EOS-2, FY3-D) have been reprojected over two static regions ("EURON1 - Scandinavia", shown in *Figure 4*, and "EUROPA", shown in *Figure 6*), between 07:00Z and 13:00Z for the 91 days inside this validation period, and all AMVs for all related slots between 11:00Z and 13:00Z have been validated against both Radiosounding winds and NWP analysis winds at 12:00Z.

The configuration considers the conditions defined in the default "model configuration file" `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm.` For this process, all NWC/PPS-Cloud products (CMA, CT, CTTH and CMIC) have to be produced in both reprojected validation regions before the running of NWC/PPS-HRW.

Comparing the statistics for NWC/PPS-HRW v7.Q against Radiosounding winds and ECMWF NWP analysis in *Table 14* (considering all layers together) and in *Table 16* (considering three layers separately), it can be seen that the NMVD and NRMSVD parameters are significantly smaller (around a 30% smaller) against NWP analysis winds. A conclusion can be taken here, that the general scale and behaviour of AMV winds is more similar to the one for NWP analysis winds than to the one for Radiosounding winds. This behaviour can also be observed in the statistics for the previous version of NWC/PPS-HRW, v7.P in the same validation period (April-June 2020), shown as reference in *Table 15* (considering all layers together) and in *Table 17* (considering three layers separately), and in general in all versions of NWC/GEO-HRW software.

Considering the evolution of AMV statistics between NWC/PPS-HRW v7.P and v7.Q, there are increases in the number of AMVs of 2.6 times in "EURON1 – Scandinavia" region and of 3.7 times in "EUROPA" region. This is a very important improvement, caused by the retuning of many running parameters in NWC/PPS-HRW software mentioned in Chapter 1.3 (Improvements from previous versions), which defines better AMV densities and fewer holes in the AMV coverage. Additionally, with the increase in the number of AMVs there is at least a 7% reduction of NMVD and NRMSVD validation parameters considering all layers together, which is also very positive.

Considering the different layers separately, the main difference between NWC/PPS-HRW v7.P and v7.Q is the better distribution of AMVs in the high/medium/low layer for v7.Q. In v7.P, the distribution was 43%/22%/35% for "EURON1 – Scandinavia" region and 60%/24%/16% for "EUROPA" region. In v7.Q, the distribution is 37%/26%/37% for "EURON1 – Scandinavia" region and 43%/22%/35% for "EUROPA" region with increases in the number of AMVs at all layers. Additionally all validation parameters (NBIAS, NMVD, NRMSVD) reduce in general in each layer for both validation regions; in some case up to a 27%. All this causes a better representation of atmospheric winds in all tropospheric levels with NWC/PPS-HRW v7.Q algorithm.

Comparing the statistics for the different layers, we see the highest values of the validation statistics are for the medium layer (400-700 hPa), while the lowest values for the validation statistics are for the high layer (100-400 hPa) against Radiosounding winds and the low layer (700-1000 hPa) against NWP analysis winds in both NWC/PPS-HRW v7.Q and v7.P versions. This result is different to the one observed in all versions of NWC/GEO-HRW software, for which the highest values of the validation statistics are related to the low layer and the lowest values of the validation statistics are related to the high layer.

Considering the statistics for the new satellite channels for which AMV can be calculated with NWC/PPS-HRW v7.Q (Cloudy and Clear air water vapour AMVs), the main element is that the proportion of these Cloudy and Clear air Water vapour AMVs is very small (between 0.5% and 1.5%), basically because only three out of the ten validated satellites include water vapour channels in their options, and so the probability that both initial and final image include water vapour channels is less than 10%. With this, the importance of Water vapour AMVs will be in general smaller in polar AMVs than in geostationary AMVs. Considering corresponding statistics, NMVD and NRMSVD parameters are also worse for water vapour AMVs than those for visible and infrared AMVs (up to a 15% against

Radiosounding winds and up to a 35% against NWP winds), which can also be caused by the small amount of water vapour AMVs and their fewer references in the Quality control process.

Considering the differences in the AMVs for regions "EUROPA" and "EURON1", using respectively pixels of 5 km size and 1 km size, in general AMVs for region "EUROPA" have slightly smaller validation parameters (up to a 5% smaller), which can be related to the fact of using tracers of larger size which are more persistent in time. It can also be seen that NBIAS values have different sign in both regions, being positive in "EURON1 – Scandinavia" region and negative in "EUROPA" region. This can also be related to the fact of using tracers of larger size in "EUROPA" region.

Finally, while for NWC/PPS-HRW v7.P algorithm the Product Requirement Table "Target accuracy" defined up to now for all "High Resolution Winds" versions is reached in all layers, the improvements in NWC/PPS-HRW v7.Q do not only keep these values, but also make that the low layer reaches the "Optimal accuracy". Considering this, NWC/PPS-HRW outputs can be perfectly used by NWCSAF users the same way they are using NWC/GEO-HRW outputs, in spite of being defined only as "demonstrational version".

NWC/PPS-HRWv7.Q AMVs (Apr 2020-Jun 2020)	"EURON1-Scandinavia" region VIS	IR	cloudy WV	clear air WV	all AMVs	"EUROPA" region VIS	IR	cloudy WV	clear air WV	all AMVs
NC	99279	106702	914	35	206930	160274	247727	4886	591	413478
SPD [m/s]	15.87	20.02	36.77	21.60	18.10	15.68	18.79	24.36	16.31	17.64
NBIAS (ALL LAYERS)	+0.03	+0.03	+0.09	-0.01	+0.03	-0.04	-0.02	+0.05	+0.00	-0.02
NMVD (100-1000 hPa)	0.36	0.34	0.39	0.35	0.35	0.34	0.34	0.35	0.40	0.34
NRMSVD	0.46	0.41	0.47	0.50	0.43	0.41	0.41	0.44	0.53	0.41
NC	99279	106702	914	35	206930	160274	247727	4886	591	413478
SPD [m/s]	16.20	20.12	37.23	21.24	18.31	15.76	18.67	25.21	15.86	17.61
NBIAS (ALL LAYERS)	+0.01	+0.03	+0.08	+0.00	+0.02	-0.05	-0.02	+0.02	+0.02	-0.03
NMVD (100-1000 hPa)	0.25	0.25	0.34	0.31	0.25	0.24	0.23	0.28	0.31	0.23
NRMSVD	0.34	0.32	0.42	0.41	0.33	0.29	0.29	0.37	0.39	0.29

Table 14: Validation parameters for NWC/PPS-HRW v7.Q AMVs, considering all layers together, against Radiosounding winds in light green and against ECMWF NWP analysis winds in dark green. (Basic AMVs in nominal configuration; Apr-Jun 2020 between 11:00 and 13:00 UTC; Polar satellites with AVHRR-3, VIIRS, MODIS and MERSI-2 radiometers). Statistics for region "EURON1 - Scandinavia" on the left side; region "EUROPA" on the right side.

NWC/PPS-HRWv7.P AMVs (Apr 2020-Jun 2020)	"EURON1-Scandinavia" region VIS	IR	All AMVs	"EUROPA" region VIS	IR	All AMVs
NC	38628	39990	78618	34105	75800	109905
SPD [m/s]	14.75	20.67	17.76	15.89	20.51	19.08
NBIAS (ALL LAYERS)	+0.03	+0.03	+0.03	-0.07	-0.04	-0.05
NMVD (100-1000 hPa)	0.38	0.35	0.36	0.37	0.36	0.36
NRMSVD	0.50	0.43	0.46	0.45	0.43	0.44
NC	38628	39990	78618	34105	75800	109905
SPD [m/s]	15.11	20.68	17.94	15.98	20.23	18.91
NBIAS (ALL LAYERS)	+0.01	+0.03	+0.02	-0.07	-0.03	-0.04
NMVD (100-1000 hPa)	0.28	0.27	0.27	0.27	0.26	0.26
NRMSVD	0.38	0.34	0.36	0.34	0.31	0.32

Table 15: Validation parameters for NWC/PPS-HRW v7.P AMVs, considering all layers together, against Radiosounding winds in light blue and against ECMWF NWP analysis winds in dark blue. (Basic AMVs in nominal configuration; Apr-Jun 2020 between 11:00 and 13:00 UTC; Polar satellites with AVHRR-3, VIIRS and MODIS radiometers). Statistics for region "EURON1 - Scandinavia" on the left side; region "EUROPA" on the right side.

	“EURON1-Scandinavia” region					“EUROPA” region				
NWC/PPS-HRWv7.Q AMVs			**cloudy**	**clear air**	**All**			**cloudy**	**clear air**	**All**
(Apr 2020-Jun 2020)	**VIS**	**IR**	**WV**	**WV**	**AMVs**	**VIS**	**IR**	**WV**	**WV**	**AMVs**
NC	25504	50740	740	0	76984	50091	137702	3450	0	191243
SPD [m/s]	26.79	26.78	39.24		26.90	22.73	23.39	27.34		23.28
NBIAS (HIGH LAYER)	+0.03	+0.03	+0.08		+0.03	-0.05	-0.03	+0.04		-0.03
NMVD (100-400 hPa)	0.33	0.31	0.39		0.31	0.33	0.33	0.34		0.33
NRMSVD	0.40	0.37	0.47		0.38	0.38	0.38	0.42		0.38
NC	24669	29087	174	35	53965	55400	67479	1436	591	124906
SPD [m/s]	15.70	19.24	26.23	21.60	17.64	13.79	13.98	17.19	16.31	13.94
NBIAS (MEDIUM LAYER)	+0.01	+0.04	+0.17	-0.01	+0.02	-0.04	-0.02	+0.11	+0.00	-0.02
NMVD (400-700 hPa)	0.37	0.37	0.38	0.35	0.37	0.36	0.37	0.39	0.40	0.36
NRMSVD	0.45	0.45	0.44	0.50	0.45	0.43	0.44	0.49	0.53	0.43
NC	49106	26875	0	0	75981	54783	42546	0	0	97329
SPD [m/s]	10.27	11.35			10.65	11.16	11.56			11.33
NBIAS (LOW LAYER)	+0.05	+0.03			+0.04	-0.02	-0.02			-0.02
NMVD (700-1000 hPa)	0.39	0.38			0.38	0.34	0.34			0.34
NRMSVD	0.46	0.45			0.45	0.39	0.40			0.40
NC	25504	50740	740	0	76984	50091	137702	3450	0	191243
SPD [m/s]	26.78	26.69	39.84		26.84	22.41	22.95	28.40		22.90
NBIAS (HIGH LAYER)	+0.03	+0.04	+0.07		+0.03	-0.04	-0.01	+0.00		-0.01
NMVD (100-400 hPa)	0.26	0.24	0.34		0.24	0.24	0.23	0.28		0.23
NRMSVD	0.32	0.29	0.42		0.30	0.28	0.27	0.37		0.27
NC	24669	29087	174	35	53965	55400	67479	1436	591	124906
SPD [m/s]	15.83	16.32	26.12	21.24	16.13	14.03	14.14	17.55	15.86	14.13
NBIAS (MEDIUM LAYER)	+0.00	+0.04	+0.18	+0.00	+0.02	-0.06	-0.04	+0.09	+0.02	-0.04
NMVD (400-700 hPa)	0.27	0.27	0.34	0.31	0.27	0.24	0.25	0.30	0.31	0.24
NRMSVD	0.34	0.34	0.40	0.41	0.34	0.29	0.30	0.38	0.39	0.29
NC	49106	26875	0	0	75981	54783	42546	0	0	97329
SPD [m/s]	10.89	11.85			11.23	11.44	12.01			11.69
NBIAS (LOW LAYER)	-0.00	-0.01			-0.00	-0.05	-0.06			-0.05
NMVD (700-1000 hPa)	0.23	0.24			0.24	0.22	0.22			0.22
NRMSVD	0.28	0.28			0.28	0.26	0.25			0.26

Table 16: Validation parameters for NWC/PPS-HRW v7.Q AMVs,
considering respectively the high, medium and low layer,
against Radiosounding winds in light green and against ECMWF NWP analysis winds in dark green.
(Basic AMVs in nominal configuration; Apr-Jun 2020 between 11:00 and 13:00 UTC;
Polar satellites with AVHRR-3, VIIRS, MODIS and MERSI-2 radiometers).
Statistics for region “EURON1 - Scandinavia” on the left side; region “EUROPA” on the right side.

	"EURON1-Scandinavia" region			"EUROPA" region		
NWC/PPS-HRWv7.P AMVs (Feb 2020-Apr 2020)	VIS06	IR108/ IR110	All AMVs	VIS06	IR108/ IR110	All AMVs
NC	10581	23220	33801	13621	52438	66059
SPD [m/s]	25.89	25.54	25.65	24.01	24.36	24.29
NBIAS (HIGH LAYER)	+0.01	+0.03	+0.02	-0.09	-0.05	-0.06
NMVD (100-400 hPa)	0.36	0.34	0.35	0.34	0.35	0.34
NRMSVD	0.43	0.40	0.41	0.39	0.40	0.40
NC	6808	10242	17050	10316	15669	25985
SPD [m/s]	14.79	15.72	15.35	12.57	13.12	12.90
NBIAS (MEDIUM LAYER)	+0.01	+0.05	+0.03	-0.06	-0.01	-0.03
NMVD (400-700 hPa)	0.40	0.39	0.39	0.40	0.39	0.40
NRMSVD	0.52	0.47	0.49	0.48	0.48	0.48
NC	21239	6528	27767	10168	7693	17861
SPD [m/s]	9.19	11.10	9.64	8.38	9.33	8.79
NBIAS (LOW LAYER)	+0.07	+0.03	+0.06	-0.02	-0.02	-0.02
NMVD (700-1000 hPa)	0.40	0.37	0.40	0.48	0.47	0.48
NRMSVD	0.47	0.44	0.46	0.54	0.55	0.55
NC [m/s]	10581	23220	33801	13621	52438	66059
NBIAS (HIGH LAYER)	25.69	25.41	25.50	23.67	23.80	23.77
NMVD (100-400 hPa)	+0.02	+0.04	+0.03	-0.07	-0.07	-0.04
NRMSVD	0.28	0.26	0.27	0.26	0.25	0.25
	0.35	0.32	0.33	0.31	0.30	0.30
NC	6808	10242	17050	10316	15669	25985
SPD [m/s]	14.89	15.76	15.41	12.83	13.40	13.17
NBIAS (MEDIUM LAYER)	+0.01	+0.04	+0.03	-0.08	-0.03	-0.05
NMVD (400-700 hPa)	0.31	0.30	0.30	0.28	0.27	0.28
NRMSVD	0.39	0.37	0.38	0.33	0.33	0.33
NC	21239	6528	27767	10168	7693	17861
SPD [m/s]	9.91	11.54	10.29	8.88	9.86	9.30
NBIAS (LOW LAYER)	+0.00	-0.00	-0.00	-0.07	-0.07	-0.07
NMVD (700-1000 hPa)	0.26	0.25	0.26	0.31	0.27	0.29
NRMSVD	0.30	0.30	0.30	0.36	0.32	0.34

*Table 17: Validation parameters for NWC/PPS-HRW v7.P AMVs,
considering respectively the high, medium and low layer,
against Radiosounding winds in light blue and against ECMWF NWP analysis winds in dark blue.
(Basic AMVs in nominal configuration; Apr-Jun 2020 between 11:00 and 13:00 UTC;
Polar satellites with AVHRR-3, VIIRS and MODIS radiometers).
Statistics for region "EURON1 - Scandinavia" on the left side; region "EUROPA" on the right side.*

6. ASSUMPTIONS AND LIMITATIONS IN NWC/PPS-HRW

The main circumstance that has to be taken into account when using NWC/PPS-High Resolution Winds software is the variability with time of the amount of available AMV and Trajectory data. This is related to the evolution with time of cloudy areas in the processing region (as in NWC/GEO-HRW), but additionally also related to the facts that the portion of image scanned at the same time by the "initial image" and the "later image" is very variable for each pair of images, and that the time interval between this pair of images is also very variable (with smaller amounts of AMVs for the longest time intervals). The deformation of the images caused by the reprojection process to the static working region can also have an impact, especially when the satellite zenith angles for a pixel are very different in the "initial image" and the "later image", causing a reduction in the amount of calculated AMVs.

Due to this, for a region which is well observed by a geostationary satellite, the usability of NWC/GEO-HRW AMVs can be much better than the one for NWC/PPS-HRW AMVs, due to the better continuity of AMV observations. However, for regions which are not well observed by a geostationary satellite, and for which there cannot be NWC/GEO-HRW AMVs (for example in Europe for Iceland or Central and Northern parts of Scandinavia), NWC/PPS-HRW AMVs compensate the lack of AMVs from the geostationary version.

Considering this, and taking into account that the latest version of NWC/GEO-HRW (v6.2) is able to calculate AMVs throughout all areas of the world with MSG satellites (in Europe, Africa and Western Asia with IODC service), with Himawari-8/9 satellites (in Eastern Asia and the Western Pacific), and with GOES-16/17/18 satellites (in the Americas and the Eastern Pacific), NWC/PPS-HRW adds the option to calculate AMVs in Arctic and Antarctic areas, so giving the option to calculate AMVs with the same AMV algorithm throughout all the world (which is rather uncommon, and can be important for example for NWP assimilation in global models or in climatic studies).

Considering this second version of NWC/PPS-HRW software (v7.Q):

- It has added the calculation of Cloudy and Clear air AMVs from water vapour channels, and the inclusion of NWC/PPS-CMIC outputs for the "Microphysics correction in CCC method height assignment". With this, the differences between NWC/GEO-HRW and NWC/PPS-HRW algorithms reduce even more, and now very few differences remain between them, being the most important one the option to correct the parallax in the NWC/GEO-HRW AMVs and Trajectories, which does not exist for NWC/PPS-HRW AMVs and Trajectories.
- It has also added the option to process three more radiometers and nine more polar satellites. This increases the frequency of satellite polar scans in each working region, and so it improves the quality of the calculated AMVs, due to the smaller time separations this implies between the "initial image" and the "later image".
- It has also included a better distribution of AMVs in high/medium/low levels, and a retuning of many running parameters of NWC/PPS-HRW which defines better AMV densities and fewer holes in the AMV coverage.
- Finally, a change has been made in the structure of the HRW netCDF output, now being CF compliant and so easier to process.

Considering the validation of NWC/PPS-HRW v7.Q, comparing its statistics with those for the previous version NWC/PPS-HRW v7.P, it has been seen that the amount of AMVs increases between two and four times in both validation regions, with also a better distribution of AMVs in the high, medium and low layer. So, there is a much better representation of tropospheric wind observations with NWC/PPS-HRW v7.Q. Additionally, validation statistics (NBIAS, NMVD, NRMSVD) improve in general against both references (Radiosounding winds and NWP analysis winds) considering all layers together and each layer separately. And not only the "Target accuracy" defined up to now for all NWCSAF/High Resolution Winds versions is reached in all layers, but also the "Optimal accuracy" is reached in the low layer. Considering this, NWC/PPS-HRW outputs can be perfectly used by NWCSAF users the same way they are using NWC/GEO-HRW outputs, in spite of being defined only as a "demonstrational version". And NWC/PPS-HRW v7.Q should be used instead of NWC/PPS-HRW v7.P due to its significant improvements.

About the AMVs calculated by NWC/PPS-HRW, the main source of errors is related to inconsistencies between the NWP model used and the true atmosphere. This is especially important:

- In the definition of the "tracking area" and in the Quality control, related to inconsistencies in the NWP wind data. On the one hand, tracers may not be found in areas where the displacement is different to the one defined by the forecast. On the other hand, the errors in the NWP forecast winds can cause the AMVs to have a worse "forecast Quality Index" than the one they should, and because of this some good AMVs might be rejected.

  The first problem is solved not using the NWP wind guess (with WIND_GUESS = 0). However, the long running time this can cause in NWC/PPS-HRW software, especially with high resolution regions and long time differences between the "initial image" and the "later image", forces to be careful with the implementation of this change in operational environments.

  The second problem is solved using the "Quality index without forecast" in the operation of NWC/PPS-HRW software (implemented with QI_THRESHOLD_USEFORECAST = 0), which avoids the influence of the NWP model in the Quality of the AMVs (nevertheless, this option has not been considered as the default one).

- In the height assignment (in general the main remaining challenge that scientists are currently facing with AMV extraction). If the "HRW Brightness temperature interpolation height assignment" is used, small errors in the temperature profile can cause important errors in the heights assigned to the tracers. Besides, the assumption is taken here that the temperature is supposed to diminish constantly with higher levels throughout the atmosphere. Due to this, problems in the level assignment appear when a temperature inversion is present. This problem is solved using the "CCC height assignment method" (the default option), in which the thermal inversion problem is solved by NWC/GEO-CTTH product output data.

In any case, the use of the NWP model is considered to be mandatory for the AMV height assignment (directly through the "Brightness temperature interpolation height assignment", or indirectly through the NWC/GEO-CTTH Cloud top pressure output related to "CCC height assignment").

Considering the calculation of Trajectories through the successive tracking of the same tracer in consecutive images, the most important limitation is that the number of consecutive passes of the different polar satellites over the same tracer can be very limited. Due to this, after three consecutive slots only around a 10% of the tracers persist in the "Basic scale", and around a 5% of the tracers persist in the "Detailed scale". This is an issue that users should also have into account when using the Trajectories calculated by NWC/PPS-HRW software.

Other elements also occurring in NWC/GEO-HRW software for the definition of the Trajectories, like the persistence in time of the tracers (especially when these tracers are small), or the impact of the different meteorological situations (in which the temporal change of the atmospheric structures is quicker or slower), can have also an impact in the calculation of Trajectories with NWC/PPS-HRW, although their effect is much smaller than the one mentioned in the previous paragraph.

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7. VISUALIZATION EXAMPLES OF NWC/PPS-HRW

Real time graphic displays of NWC/PPS-HRW software outputs, generated by the NWC/PPS Reference System with polar satellite series, are available at the NWCSAF Helpdesk website (http://www.nwcsaf.org). Following figures show typical displays of NWC/PPS-HRW v7.Q in the regions used for validation, ("EURON1 - Scandinavia" and "EUROPA"), considering the default configuration for polar satellites, but with AMVs calculated for both AMV scales ("Basic scale" and "Detailed scale", obtained with configurable parameter CDET = 1; if this parameter is not changed, only "Basic scale" AMVs are calculated). For the region "EURON1 – Scandinavia" in *Figures 4 and 5*, and for the region "EUROPA" in *Figures 6 and 7*.

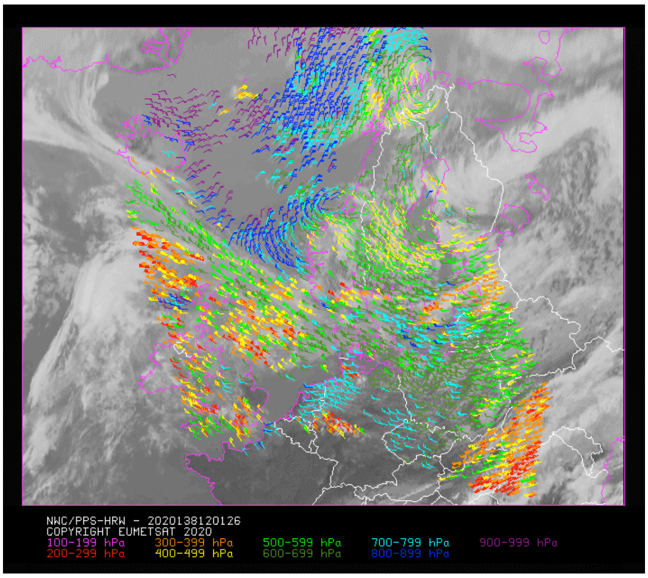

Figure 4: NWC/PPS-High Resolution Winds v7.Q "Basic AMV" output example in the region "EURON1 - Scandinavia" (17 May 2020 12:01:26 UTC for EOS-2 satellite, with tracers calculated at 11:44:19 UTC for NOAA-20 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model configuration file. Colour coding based on the AMV pressure level*

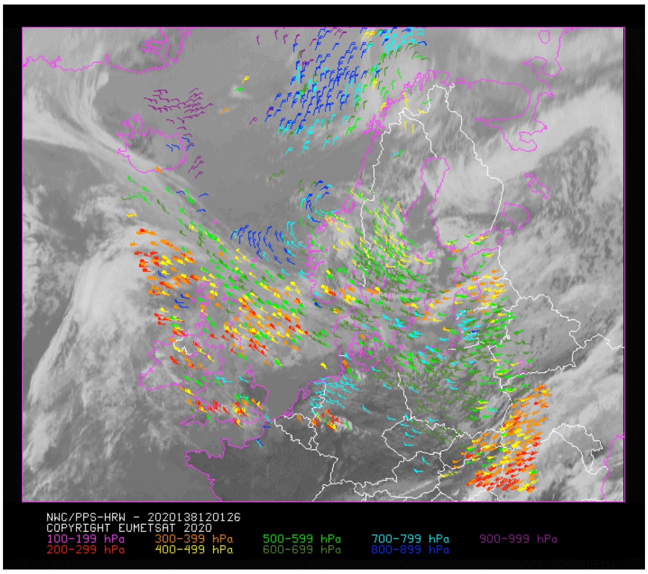

Figure 5: NWC/PPS-High Resolution Winds v7.Q "Detailed AMV" output example in the region "EURON1 - Scandinavia" (17 May 2020 12:01:26 UTC for EOS-2 satellite, with tracers calculated at 11:44:19 UTC for NOAA-20 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model configuration file and configurable parameter CDET=1. Colour coding based on the AMV pressure level*

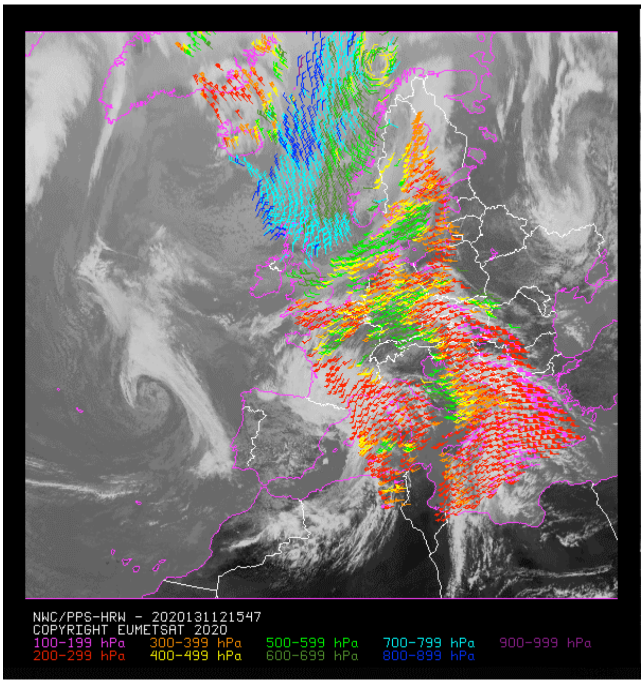

Figure 6: NWC/PPS-High Resolution Winds v7.Q "Basic AMV" output example in the region "EUROPA" (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` model configuration file. Colour coding based on the AMV pressure level

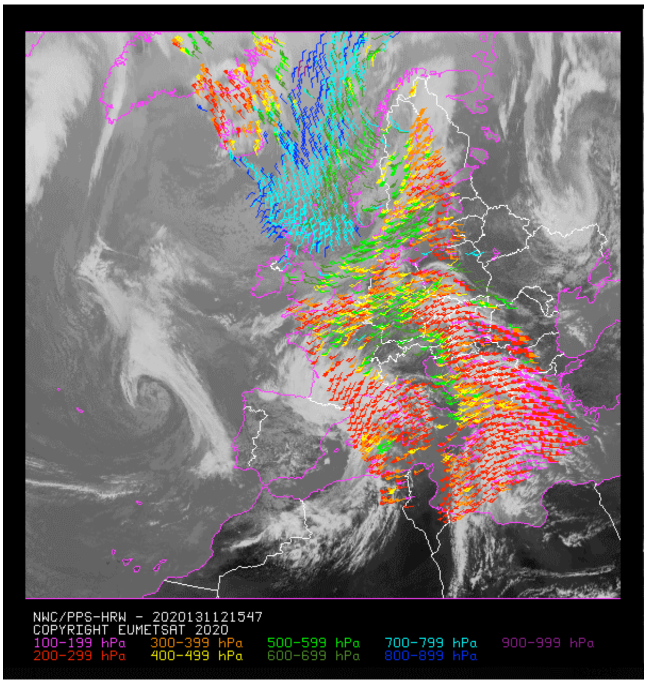

Figure 7: NWC/PPS-High Resolution Winds v7.Q "Detailed AMV" output example in the region "EUROPA" (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` model configuration file and configurable parameter CDET=1. Colour coding based on the AMV pressure level