EUMETSAT NWC SAF

SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING

Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS

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

7 November 2022

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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DOCUMENT CHANGE RECORD

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0.1d	*30 September 2020*	94	Initial version for NWC/PPS-HRW v7.P Content derived from Document "Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS", NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind, v2.2
0.1e	*1 September 2021*	94	Updates due to results of PPS v2021 RR: Change the status of HRW to 'demonstrational'.
0.1	*12 October 2021*	94	Updates after PPS v2021 DRR: Just update document references.
0.2.0	*7 November 2022*	97	Initial version for NWC/PPS-HRW v7.Q

List of contents

List of Tables

List of Figures

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 "Algorithm Theoretical Basis Document (ATBD) 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 "Algorithm Theoretical Basis Document" describes in detail the objectives and physics of the problem, together with the mathematical description and the implementation of NWC/PPS-HRW software. It also provides information on the input data and 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 assigment 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 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 nxn 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 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 positions in the AMV displacements
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 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
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, added to Quality TEST indicator after Quality Control
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 (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 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	Pixel coordinates of a tracking centre (line and column) in the later image
Trajectory	Path defining the displacement of a 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/2 Radiometer
METimage	EUMETSAT's Meteorological Imager Radiometer
Metop-A/B/C	EUMETSAT's Polar System Satellites, including AVHRR-3 radiometer
Metop-SG-A1/2/3	EUMETSAT's Polar System - Second Generation, including METimage 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]	User Manual for the Wind product processor of the NWC/PPS: Software part	NWC/CDOP3/PPS/AEMET/SCI/UM/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, 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.
- 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. The square segment is defined through a specific cloudiness feature in visible, infrared or MODIS/METimage/MERSI-2 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).

"Atmospheric Motion Vectors" are associated with the horizontal wind in the atmosphere. Specific exceptions exist to this, generally related to clouds which are blocked or whose flow is affected by orography, or to lee wave clouds with atmospheric stability near mountain ranges. These exceptions are identified and discarded, such as later explain in chapter 2.2.2.11 of this document.

The square "segment" of nxn pixels inside an image used for the AMV calculation is called "tracer", has a fixed size (called "tracer size"), and is identified by the pixel location of its centre (called "tracer location"). Tracers are identified in the "initial image" and tracked in the "later image", so defining the AMV displacement between those images. A "Trajectory" is the path defined by the displacement of the same tracer throughout several satellite images.

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).

In contrast to NWC/GEO-HRW, in NWC/PPS-HRW the “initial image” and “later image” do not necessarily need to be related to the same satellite; this way it is possible to define AMVs and Trajectories considering data from different satellites at the same time. However, logically, as water vapour channels are only provided by MODIS, METImage or MERSI-2 radiometers, water vapour AMVs can only be calculated if both “initial image” and “later image” are related to these radiometers.

The 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’s 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 atmospheric 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), or as an input to Analysis, Nowcasting and Very short range forecasting applications.

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 in NWC/PPS-HRW output) is included.

2.2 THEORETICAL DESCRIPTION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)

This section discusses the physics of deriving "Atmospheric Motion Vectors (AMVs)" and "Trajectories" from satellite imagery. The theoretical basis and practical implementation of the corresponding algorithm is also described.

2.2.1 Physics of the problem

In order to forecast the weather, conventional observations are sparse, whereas satellite based observations provide near global coverage at frequent time intervals. The derivation of Atmospheric Motion Vectors (AMVs) from satellite images, which correspond to the displacement between two satellite images of cloud or moisture features, is an important source of global wind information, especially over the oceans and in remote continental areas.

AMV algorithms started to be used in the decade of the 1970's in the United States, Europe and Japan using imagery from geostationary satellites, which monitor a constant region of the Earth. Since the decade of the 2000's, satellite winds have also been produced using imagery from polar orbiters, as they provide coverage in the polar regions.

The Atmospheric Motion Vector general calculation process is composed of the following main steps:

1. The reading and preprocessing of the satellite data.

   A data rectification is important for satellite visible images, for which illumination conditions vary with the solar angle, and for polar satellites images, for which the position and orientation of each Earth location with respect to the satellite changes for each satellite image. Due to this, it is important that both images used for the AMV calculation can be reprojected to the same satellite scanning geometry.

2. The location of suitable "tracers" in an "initial image".

   Suitable scenes (regions containing traceable cloud or moisture features) are selected in the initial image.

3. The location of those tracers in a "later image".

   Each selected feature in the initial image is then "tracked" in successive images in order to determine the displacement of the feature. Clouds or moisture patterns can change shape or even disappear, but enough of them survive to produce a significant number of AMVs. With shorter time intervals, the problem is smaller and more vectors are calculated.

4. The "height assignment" of the tracers.

   The pressure level of the feature must be determined to locate the AMVs in a tridimensional position in the atmosphere. This is the step throughout the AMV derivation in which errors can be more important. Several methods of height assignment are available: the comparison of the infrared brightness temperature of the tracer with the forecast temperature of a NWP model, radiance ratioing and water vapour/infrared window intercept techniques for the height assignment of semitransparent clouds, statistical assignment schemes,…

5. The calculation of the AMV vectors and Trajectories.

   Considering the geographical displacement between the "tracers" in the "initial image" and their corresponding "tracking centres" in the "later image".

6. A quality control.

   An internal quality control scheme performs a selection, so that only the AMVs with a better quality are accepted.

2.2.2 Mathematical Description of High Resolution Winds (NWC/PPS-HRW)

2.2.2.1 Outline of the Software

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 (Brightness temperatures and Normalized reflectances from the mentioned satellites and reflectometers, 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"), 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.

2.2.2.2 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>=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").

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 2.2.2.11 is used, or if Validation statistics are to be calculated by the NWC/PPS-HRW software itself such as defined in chapter 2.3.1.2 (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 2.2.2.10 is used, or if the NWP "wind guess" for the definition of the "tracking area" in the "later image" such as defined in chapter 2.2.2.4 is used, or if Validation statistics are to be calculated by the NWC/PPS-HRW software itself such as defined in chapter 2.3.1.2 (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 2.2.2.11 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 2.2.2.5 (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 chapters 2.2.2.6 and 2.2.2.8 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 chapters 2.2.2.6 and 2.2.2.8 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 2.2.2.7 (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).

2.2.2.3 Tracer search

The process of NWC/PPS-HRW starts with the calculation of "tracers" (square "segments" of nxn pixels, used as initial positions of an AMV and trajectory sector, and identified by a specific cloudiness feature or moisture feature) throughout the processing region in an "initial image". This "initial image" is defined such as explained in chapter 2.3.7.2. The calculated tracers are stored in temporal files in `$SM_HRWTEMP_DIR` directory.

If no "tracers" are available for the AMV calculation for the defined "initial image" (including the case in which the running of the software starts), the tracer calculation is the only process which is activated for that image, skipping all other processes in NWC/PPS-HRW software. Once tracers from a previous run identified as "initial image" are available and AMVs can be calculated, the following tracer calculation process activates as the final step of the defined NWC/PPS-HRW run.

Two "tracer" computation methods are applied: "Gradient" and "Tracer characteristics". Both calculate a tracer optimising the location of a "tracer candidate" around one of their "starting locations". Gradient method is by far more efficient in computing terms. Tracer characteristics method is more specific: it defines additional tracers in still empty areas, with a longer but still reasonable computing time.

These tracer computation methods are used one after the other in two different "tracer selection" strategies throughout the region: the "single scale procedure" (in which one scale of tracers is calculated), and the "two scale procedure" (in which two different scales of tracers are calculated: "basic scale" and "detailed scale", being the line and column size of the detailed tracers half the size the one for basic tracers).

A "single scale procedure" calculating only "basic tracers" with a line and column "tracer size" of 24 pixels is proposed as default configuration. This configuration is specified with configurable parameter CDET = 0. NWC/PPS-HRW is defined to work with square shaped tracers, so similar values for the line and column "tracer size" are kept for the processing. Additionally, the latitude and longitude limits for calculation of AMVs and Trajectories can also be specified with configurable parameters LAT_MAX, LAT_MIN, LON_MAX, LON_MIN.

A "tracer size" of 24 pixels for "basic tracers" and 12 pixels for "detailed tracers" is proposed as baseline for the "two scale procedure". This is activated with configurable parameter CDET = 1. The latitude and longitude limits for the calculation of detailed AMVs and Trajectories can also be specified with configurable parameters LAT_MAX_DET, LAT_MIN_DET, LON_MAX_DET, LON_MIN_DET.

Considering the size of the pixels in the reprojected images used with NWC/PPS-HRW software (normally between 1 and 5 km), these resolutions define tracer scales between 12 and 120 km. So, between 'mesoscale ß' and 'mesoscale γ' meteorological dimensions. The nominal time separation between the "initial image" and the "later image" allowed by NWC/PPS-HRW software (defined by parameters POLAR_MIN_TIME_SEP and POLAR_MAX_TIME_SEP between 12 and 120 minutes) is enough to track the majority of features with these sizes, although in some cases like small cumulus over land, their lifecycle might be a bit short for these limits.

In any case, the line and column "tracer size" in pixels of the "single or basic scale" can be defined through configurable parameter TRACERSIZE_LOW.

FIRST METHOD: GRADIENT

Starting from the upper left corner of the working region of the image, "starting locations" for the tracer search with Gradient method are defined. Similar to the method defined by CIMSS/NOAA at Hayden & Merrill, 1988 [RD.11], it has following steps:

1. To look for a "brightness value" (identified as any of the pixel values of the corresponding "N_Value matrix", inside a "tracer candidate" located in a "starting location"), greater than

configurable parameter BRIGHTNESS_THR_VIS (for visible cases, with default value 120) or smaller than BRIGHTNESS_THR_OTHER (for other cases, with default value 240).

2. To verify if a difference exists between the maximum and minimum "brightness value" in the "tracer candidate", greater than configurable parameter GVAL_VIS (for visible cases, with default value 60) or GVAL_OTHER (for infrared and water vapour cases, with default value 48).
3. To compute inside the "tracer candidate" the value and location of the "maximum brightness gradient" |ΔN_Value(Δx) + ΔN_value(Δy)|, where Δ means a distance of 5 pixels in both line and column directions. This "maximum brightness gradient" cannot be located on the edges of the "tracer candidate".

If all previous processes have been successful, a valid "tracer" is defined at the location of the "maximum brightness gradient". The "starting location" for the subsequent "tracer" is established 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").

After one failure in the definition of a tracer location with "Gradient method", the "pixel distance" is reduced to a half. Two consecutive failures defining a tracer location define a "coverage hole".

SECOND METHOD: TRACER CHARACTERISTICS

The centres of "coverage holes" are the "starting locations" for the tracer search in a second iteration with the "Tracer characteristics method". It is based on new development. It is useful especially in the visible cases, where many potential tracers can present fainter edges than in the infrared images, because of cloudiness at different levels with a similar brightness.

It evaluates "tracer candidates" at increasing distances from the "starting locations" (every 3 lines and columns), inside a "maximum optimisation distance" (whose line and column size is half the "tracer size"), until a valid "tracer" is found.

Two tests are applied in sequence for the tracer definition with this method:

1. "Frontier definition in the N_Value Histogram test":

   It includes two parts, both based on histogram classification of the "N_Value matrix" pixels in a "tracer candidate".

   In its first part, a "significant brightness contrast" is to be found in the pixels of the "tracer candidate". Considering the values of the different centiles of the "N_Value matrix histogram" (CENT_nn%), it is necessary that:

   1. CENT_90% > 0.95·MIN_BRIGHTNESS_THR and CENT_10%>0;

   2a. CENT_97%-CENT_03%>LARGE_CONTRAST if CENT_97%>1.25·MIN_BRIGHTNESS_THR or

   2b. CENT_97%-CENT_03%>SMALL_CONTRAST if CENT_97%<1.25·MIN_BRIGHTNESS_THR.

The last condition allows that "tracer candidates" related to extended cloudiness can have less contrast in their brightness. It is mandatory that these conditions be met at the "starting location" of the "tracer candidate". If not, the "tracer candidate" is skipped.

In the second part, one or more significant histogram minima or "frontiers"' are to be found in the "N_Value matrix histogram" for the "tracer candidate". The default running of NWC/PPS-HRW keeps only the most significant "frontier" in the processing.

The "frontier" defines for the "tracer candidate" a group of "bright pixels" (defined as those pixels brighter than the given frontier) and a group of "dark pixels" (defined as those pixels darker than the given frontier).

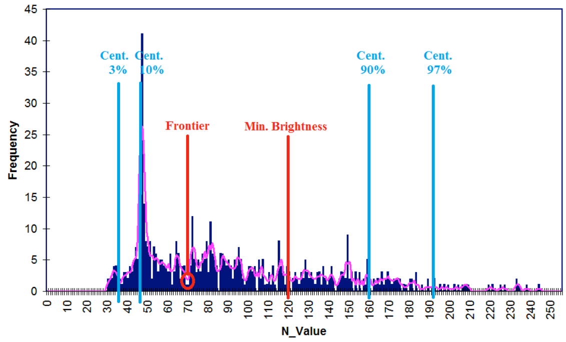


Figure 1: Example of "N_Value matrix histogram" (unsmoothed in violet and smoothed in pink) for a valid visible "tracer candidate". The minimum brightness threshold, the algorithm centiles and the defined frontier are also shown

2. "Big pixel brightness variability test":

   The "tracer candidate" is now considered as a coarse structure of 4x4 pixels (called "big pixels"), to be classified according to the brightness of their pixel population. Three classes are possible:

   CLASS_0: 'dark big pixel', < 30% of its pixels are "bright pixels";

   CLASS_2: 'bright big pixel', > 70% of its pixels are "bright pixels";

   CLASS_1: 'undefined big pixel', intermediate case.

   It is requested to avoid ambiguous cases that both CLASS_0 and CLASS_2 appear at least once in the "4x4 big pixel matrix", while the incidence of CLASS_1 being less than twice the less frequent of the other ones.

   The "4x4 big pixel matrix" is also checked for enough brightness variability in the different directions. At least two CLASS_0 to CLASS_2 or CLASS_2 to CLASS_0 transitions must exist along all four main directions in the "4x4 big pixel matrix": rows, columns and ascending and descending diagonal directions. For this, all linear arrays are checked in the row and column directions, while only linear arrays with at least 3 elements are checked in the diagonal directions.

   In the case the "Big pixel brightness variability test" is not successful but just along one direction, and no other frontiers can be selected, the frontier is retained as an "almost good frontier" and a tracer is still defined at this location.

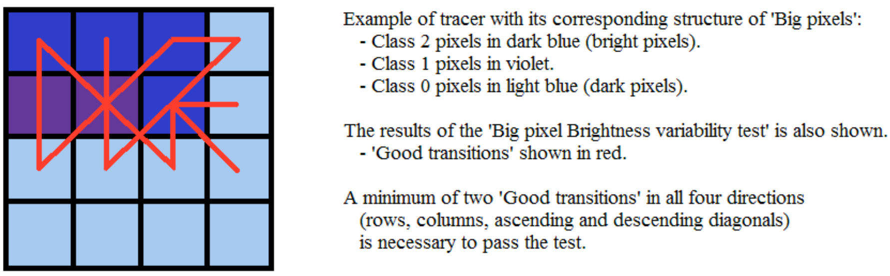


Figure 2: Example of running of the 'Big pixel brightness variability test' for a valid tracer candidate

TRACER VALIDITY CONDITIONS

A verification is 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.

No tracer is retained if it is found too close to a previously computed one ("closeness threshold"). So, each time a tracer is computed, all pixels located nearer than the "closeness threshold" are added to a "pixel exclusion matrix", and excluded as potential tracer locations. Considering this, with "Gradient method" the "maximum brightness gradient" is not evaluated at locations inside the "pixel exclusion matrix". With "Tracer characteristics method" no computations are evaluated for a "starting location" with pixels inside the "pixel exclusion matrix".

An additional condition is verified here, through which all pixels inside a "tracer" must have a satellite zenith angle (and a solar zenith angle in the case of visible channels) smaller than a maximum threshold (configurable parameters SAT_ZEN_THRES and SUN_ZEN_THRES respectively, with default values 80º and 87º). This guarantees that the illumination and satellite visualization conditions are good enough for the definition of the tracers.

DETAILED TRACERS IN THE TWO SCALE PROCEDURE

The "Basic scale" in the "two scale procedure" works in a similar way than the procedure here described for the "single scale procedure", while additionally defining "starting locations" for the "Detailed scale", when one of following conditions are met:

- No "Basic tracer" has been found, but at the "starting location" of a "tracer candidate" following condition occurs: CENT_97%>0.85*MIN_BRIGHTNESS_THR. A "Detailed tracer unrelated to a Basic tracer" is so defined, with a slightly lower brightness threshold.
- A "Wide basic tracer" has been found, in which CLASS_2 values appear in both first and last row or column of the "4x4 big pixel matrix" used in the "Big pixel brightness variability test". In this case four starting locations are defined for the "Detailed scale". Each of them is located at the corners of a "Detailed tracer" whose centre is the centre of the "Basic tracer".
- A "Narrow basic tracer" has been found, in which CLASS_2 values do not appear in both first and last row or column of the "4x4 big pixel matrix" in the "Big pixel brightness variability test". In this case, only one starting location is defined for the "Detailed scale", whose centre is defined by the weighted location of the "Big pixels" in the "4x4 big pixel matrix".

TRAJECTORIES

With the default configuration, with configurable parameter 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. A set of "persistent tracers" is so defined and tracked throughout several images, and the progressive locations of the tracer 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.

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. And in comparison, the applicability of trajectories from NWC/PPS-HRW is much more limited, which has to be taken into account by the NWCSAF user.

EXAMPLES OF AMVs RELATED TO DIFFERENT TYPES OF TRACERS

Examples of AMVs related to different types of tracers with NWC/PPS-HRW software, considering the tracer method and the tracer type, are shown next. In *Figure 3*, "Basic tracers" considering the tracer method: "Gradient tracers" and "Tracer characteristics tracers". In *Figure 4*, "Basic and Detailed tracers" considering the tracer type: "Basic tracers", "Detailed tracers unrelated to Basic tracers", "Detailed tracers related to wide basic tracers" and "Detailed tracers related to narrow basic tracers".

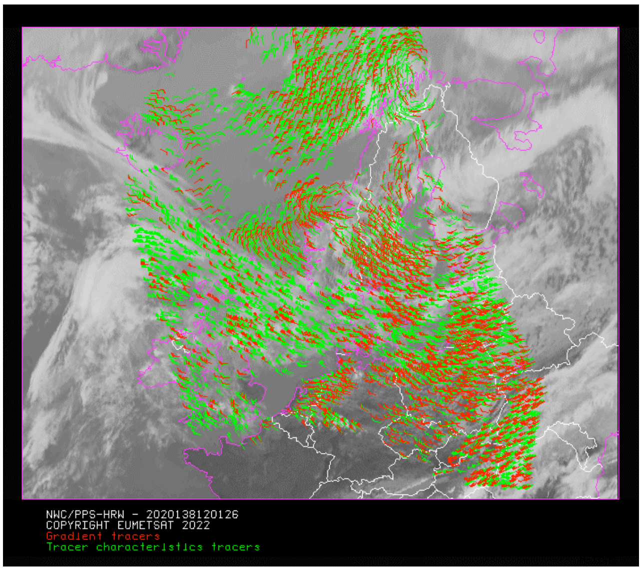


Figure 3: "Basic scale AMVs" (in red and green, considering the Tracer calculation method used for their extraction), in the Single scale NWC/PPS-HRW example defined for the region "EURON1 - Scandinavia" in Figure 19 with the default `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model configuration file (17 May 2020 12:01:26 UTC for EOS-2 satellite, with tracers calculated at 11:44:19 UTC for NOAA-20 satellite)*

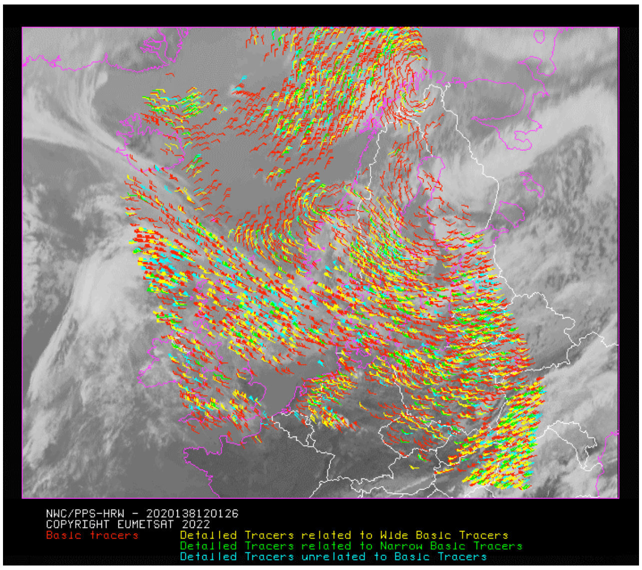


Figure 4: "Basic scale AMVs" (in red), and "Detailed scale AMVs" (in yellow, green and blue, considering their relationship with the Basic scale AMVs), in a Two scale NWC/PPS-HRW example, defined for the region "EURON1 - Scandinavia" in Figures 19 and 20 with the default `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model configuration file and parameter CDET=1 (17 May 2020 12:01:26 UTC for EOS-2 satellite, with tracers calculated at 11:44:19 UTC for NOAA-20 satellite)*

2.2.2.4 Tracer tracking

The "tracking" process looks for the location of a "tracer" computed in an "initial image", inside a portion ("tracking area") of a "later image". The process performs a pixel by pixel comparison between the tracer "brightness values" and those of a square "segment" of the same size ("tracking candidate"), repeatedly moving this "tracking candidate" throughout the "tracking area".

For a "tracking candidate (i,j)" inside this "tracking area", the algorithm used for the "tracking" process is one of the well known methods:

- Euclidean distance (configured through TRACKING = LP), in which the sum $LP_{ij} = \Sigma\Sigma(T-S)^2$ is calculated. T/S correspond to the "N_Value brightness values" for the "tracer" and the "tracking candidate" pixels at correlative locations.

  The best "tracking locations" are defined through the minimum values of the sum LP_{ij}.

- Cross correlation (configured with TRACKING = CC, which is the default option), in which the normalized correlation value $CC_{ij} = COV_{T,S}/(\sigma_T.\sigma_S)$ is calculated. T/S correspond to the "N_Value brightness values" for the "tracer" and the "tracking candidate" pixels at correlative locations; COV is the covariance between their "brightness values"; σ is the standard deviation or the "tracer" and "tracking candidate" "N_Value brightness values".

  The best tracking locations are defined through the maximum values of the correlation CC_{ij}. Operatively, the tracking CC_{ij} is implemented through the derived expression (with a better computing efficiency, in which NUM is the total number of pixels inside the "tracer"):

$$CC_{ij} = \frac{[\Sigma\Sigma T^2 + \Sigma\Sigma S^2 - \Sigma\Sigma(T-S)^2]/2 - \Sigma\Sigma T \cdot \Sigma\Sigma S/NUM}{\sqrt{[\Sigma\Sigma T^2 - (\Sigma\Sigma T)^2/NUM]} \cdot \sqrt{[\Sigma\Sigma S^2 - (\Sigma\Sigma S)^2/NUM]}}$$

The centre of the "tracking area" can preliminarily be defined through a "wind guess" obtained from the NWP forecast of the rectangular wind components, interpolated to the tracer location and level. This permits to reduce the "tracking area" size and the running time of NWC/PPS-HRW, and is applied using configurable parameter WIND_GUESS = 1.

In contrast to NWC/GEO-HRW software, the "wind guess" is implemented as default option for NWC/PPS-HRW, causing so some dependence of the calculated AMVs on the NWP model winds included in the processing. This is mostly caused by 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" and due to this a very slow NWC/PPS-HRW process.

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 and column size in pixels of the "tracking area" is calculated so that NWC/PPS-HRW software is able to detect for the tracer differences in displacement with the NWP wind 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 that NWC/PPS-HRW software is able to detect for the tracer in any direction.

The calculation of the "tracking area" has been optimized in this NWC/PPS-HRW version considering the real dimension of each pixel (through the reading of "xdist" and "ydist" parameters in the "Physiography file", which provide the real longitudinal/latitudinal dimension of each pixel).

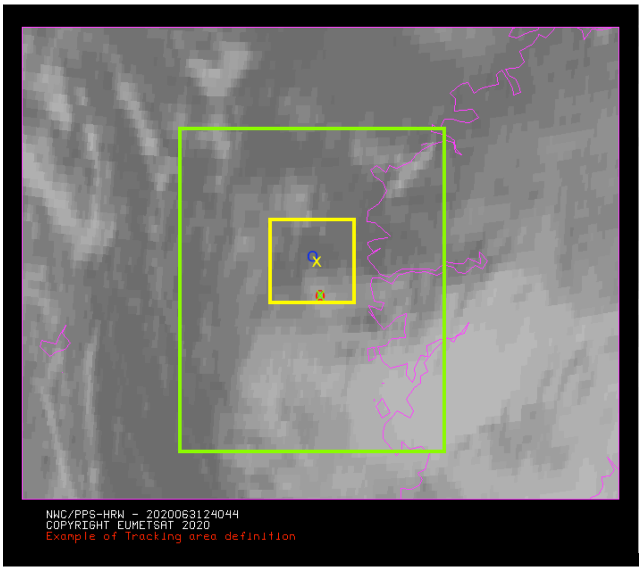


Figure 5: A tracer location for 3 March 2020 at 12:20:09 UTC for EOS-2 satellite (O red mark), its position defined by NWP wind guess at 12:40:44 UTC (X yellow mark), and its true tracking position at 12:40:44 UTC for SNPP satellite defined by NWC/PPS-HRW software (O blue mark), for an example case. The "yellow tracking area" (with its centre at the position defined by the NWP wind guess at 12:40:44 UTC) corresponds to the option using wind guess for the definition of the tracking area. The "green tracking area" (with its centre at the position of the tracer at 12:20:09 UTC) corresponds to the option not using wind guess for the definition of the tracking area. The larger size of the tracking area when the wind guess has not been used is to be noticed, which causes a longer time for the running of NWC/PPS-HRW software, but at the same time reduces the dependence from the NWP model

To avoid the computation of LP_{ij}/CC_{ij} in all (i,j) locations in the "tracking area", a gradual approach is performed in four iterations, based on the idea that the Euclidean distance and Correlation change slowly (Xu and Zhang, 1996) [RD.14]:

- In a first iteration, a pixel computation related to configurable parameter TRACKING_GAP = 8 is applied: LP/CC_{ij} is evaluated only at (1,1),(1,9),…(9,1),(9,9),… pixel locations inside the "tracking area". The four locations with the best LP/CC_{ij} values are retained for the following iteration.
- In the second, third and fourth iterations, LP_{ij}/CC_{ij} is only evaluated if possible at four locations around each one of the four best locations retained in the previous iteration, defined by:

  $(i_{max}$-TRACKING_GAP, j_{max}-TRACKING_GAP), …,
  $(i_{max}$+TRACKING_GAP, j_{max}+TRACKING_GAP),

  for which TRACKING_GAP reduces to a half in each one of the iterations until reaching value 1.

After all four iterations, the three "tracking centres" (MAX_NUM_WINDS) with the best Euclidean distance/Cross Correlation values are retained. With Cross correlation, it is also requested that the absolute maximum correlation value be greater than configurable parameter MIN_CORRELATION (with a default value of 40% in NWC/PPS-HRW v7.Q; less restrictive to increase the number of calculated AMVs while keeping very similar validation statistics).

In the default configuration, the line/column and latitude/longitude location of the three best "tracking centres" is refined through second order interpolation with "subpixel tracking" process (with configurable parameter USE_SUBPIXELTRACKING = 1). Considering for example "Cross correlation tracking method", being POS_REAL and POS the line/column location of the "tracking centre" after and before this interpolation, and CC_{-1}, CC_{+1}, CC the correlation values one position up/left from, down/right from, and at the "tracking centre":

$$POS\_REAL = POS + (CC_{-1} - CC_{+1}) / [2\cdot(CC_{-1} + CC_{+1} - 2\cdot CC)].$$

SELECTION OF THE MAIN TRACKING CENTRE

The reason to preserve more than one "tracking centre" is that the one with best Euclidean distance/Cross correlation values (the "main tracking centre") could not be the right one.

The other "secondary tracking centres" are so promoted to "main tracking centre" if following conditions occur for them:

- 'Brightness temperature mean difference and standard deviation difference" between the "tracer" and the "secondary tracking centre" smaller than 2 K.
- 'Big pixel class difference', defined as the sum of squared differences in the amounts of each "big pixel class" (CLASS_0, CLASS_1, CLASS_2) between the "tracer" and the "secondary tracking centre" smaller than 4.
- 'Centile difference', defined as the difference in the location of the "frontier" inside the 'brightness centiles' between the "tracer" and the "secondary tracking centre" smaller than 20%.

If the 'centile difference' is larger than 20%, the "secondary tracking centre" can still be promoted to "main tracking candidate" if, defining a new "frontier" value as the mean value of the frontiers in the "tracer" and the "secondary tracking centre", and recomputing the "Big pixel class difference", its value is smaller than 6.

If no "secondary tracking centre" is complying with these conditions, the procedure is still tried relaxing "Brightness temperature difference" and "Big pixel class difference" limits to double values.

SLOT GAP AND MIXED CALCULATION METHOD IN NWC/PPS-HRW

NWC/GEO-HRW algorithm 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 the minimal separation between pairs of images, but the corresponding AMVs and Trajectories are calculated considering the whole displacement considering several pairs of images together only.

Both options are not available in NWC/PPS-HRW algorithm, because in general they cause great reductions in the numbers of AMVs, and in the most extreme cases, 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 2 hours). In contrast, in NWC/GEO-HRW both methods always relate to displacements of up to one hour only.

TRACKING VALIDITY CONDITIONS

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. 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.

2.2.2.5 "Brightness temperature interpolation method" height assignment

"Brightness temperature interpolation method" height assignment method is used 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, 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 software 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" is computed with $T_{Base} = T_{Average} + SIGMA\_FACTOR \cdot \sigma_{Cloud}$, where $T_{Average}$ is the mean value and σ_{Cloud} the standard deviation of the brightness temperature for the tracer pixels. SIGMA_FACTOR is a statistically fitted factor, with a value of 1.2 for the visible channel and 0.0 for the infrared and water vapour channels.
- The "Top temperature" is computed through the coldest class in the brightness temperature histogram for the tracer pixels, with at least 3 pixels after histogram smoothing. If no value is found, the coldest class with at least 2 pixels is considered.

A conversion of these two temperature values to pressure values ("Base pressure" and "Top pressure") is then done through interpolation inside the nearest NWP temperature forecast profile. For this, a vertical interpolation inside the lowest pressure interval containing the desired temperature, with temporal interpolation inside the two nearest time values for which NWP profiles have been provided, are considered. 1000 or 100 hPa pressure limits are also defined (MAX_PRESSURE_BOUNDARY and MIN_PRESSURE_BOUNDARY) for this height assignment process.

With configurable parameter USE_CLOUDTYPE = 1, if NWC/PPS-CT Cloud Type output is available for the processing region for the image with which tracers were calculated, it is read to define which of the calculated pressure values ("Base pressure" or "Top pressure") relates best to the displacement defined by the AMV.

For this, the "AMV cloud type" parameter is defined as the most common value of NWC/PPS-Cloud Type output inside the tracer pixels, if its presence is at least $^{3}/_{2}$ times the one of the second most common value. If this condition does not occur, the values AMV cloud type = 21 (multiple cloudy types), = 22 (multiple clear air types), or = 23 (mixed cloudy/clear air types) are defined, respectively when the two most common cloud types inside the tracer pixels are both cloudy types, both clear air types, or any other case. If USE_CLOUDTYPE = 0, or NWC/PPS-CT Cloud Type output is not available, the AMV cloud type is defined as "not processed". All possible values for the "AMV cloud type" parameter are in *Table 5*.

Some tracers are eliminated depending on the "AMV cloud type" and the satellite channel used for the AMV calculation. These cases are identified in a blue cell in *Table 6*, and are related to: cloud free tracers in visible and infrared channels (with less than a 2.5% of cloudy pixels), fractional clouds, and cloud types for which the validation statistics are significantly worse. In the rest of cases, the "AMV pressure" is defined such as also shown in *Table 6*. If the "AMV cloud type" has not been calculated, the "Base pressure" is used for all AMVs because most cloud types fit better with the "Base pressure".

Operationally, this height assignment method runs before the "tracking" process. When the wind guess option is used for the definition of the "tracking area", the "tracking area centre" is calculated through the displacement of the "tracer centre" location, considering the NWP rectangular wind components at the pressure level defined by this height assignment method.

Possible values of the "Tracer cloud type" parameter	
1 Cloud free land	11 High semitransparent thin clouds
2 Cloud free sea	12 High semitransparent meanly thick clouds
3 Land contaminated by snow/ice	13 High semitransparent thick clouds
4 Sea contaminated by ice	14 High semitransparent above other clouds
5 Very low cumulus/stratus	15 High semitransparent above snow/ice
6 Low cumulus/stratus	21 Multiple cloudy types
7 Medium level cumulus/stratus	22 Multiple clear air types
8 High opaque cumulus/stratus	23 Mixed cloudy/clear air types
9 Very high opaque cumulus/stratus	31 Unprocessed cloud type (BUFR output)
10 Fractional clouds	255 Unprocessed cloud type (netCDF output)

Table 5: Possible values of the "AMV cloud type" parameter

"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 6: 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

2.2.2.6 "CCC method" height assignment (Cloudy cases)

"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 software. 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 outputs for the processing region and the image in which tracers are tracked, before the running of NWC/PPS-HRW software. If these outputs are not available, NWC/PPS-HRW software skips this method and uses the "AMV pressure" and "AMV temperature" values provided by "Brightness temperature interpolation method" if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option). Otherwise, the processing of NWC/PPS-HRW stops.

In case the "wind guess" has been used for the definition of the "tracking area" (with configurable parameter WIND_GUESS = 1), the "AMV pressure" and "AMV temperature" values calculated by "CCC method" replace the values calculated by "Brightness temperature interpolation method".

"CCC method" has the advantage of including in the height assignment all elements included in NWC/PPS-CTTH for the cloud top pressure, all of them inside the "Neural Network" process used by NWC/PPS-CTTH for this calculation:

- 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.

"CCC method" 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}) from 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 and σ_T/σ_S the standard deviations of the "N_Value brightness values", and NUM is the total number of pixels inside the "tracer" or "tracking centre":

$$CC_{ij} = (T_{ij} - T_M)\cdot(S_{ij} - S_M) / NUM\cdot\sigma_T.\sigma_S.$$

The graph 'Normalized reflectance(Partial contribution to the correlation)' for the visible channels, or the graph 'Brightness temperature(Partial contribution to the correlation)' for the infrared/water vapour channels has in general the shape of the letter 'C', as shown by the lower graphs in *Figures 6 and 7* (which correspond respectively to a visible and an infrared case). In these graphs with two branches, the largest "partial contribution to the correlation" is given by the brightest and darkest pixels (for the visible channel), and by the warmest and coldest pixels (for the infrared channel).

"AMV pressure" and "AMV temperature" are calculated considering only the pixels whose "partial contribution to the correlation" is higher than a "CCC calculation threshold" inside the bright branch of the 'Normalized reflectance(Partial contribution to the correlation)' graph in the visible cases. In the infrared cases, considering only the pixels whose "partial contribution to the correlation" is higher than the "CCC calculation threshold" inside the cold branch of the 'Brightness temperature(Partial contribution to the correlation)' graph. The "CCC calculation threshold" is defined as the mean "partial contribution to correlation", or zero if so no pixels are kept. The original procedure defined in document [RD.17] is so kept, so that the pressure level corrections implemented later in chapter 2.2.2.7 can be understood as "cloud depth corrections" respect to the "cloud top level".

Considering this, the "AMV pressure value, P_{CCC}" and "AMV temperature value, T_{CCC}" are calculated considering the "partial contribution to the correlation" (CC_{ij}), the CTTH Cloud Top Pressure (CTP_{ij}) and the Cloud Top Temperature (CTT_{ij}) outputs for the pixels defined before inside the "tracking centre", with the formulae:

$$P_{CCC}=\Sigma(CC_{ij}\cdot CTP_{ij})/\Sigma CC_{ij} \qquad T_{CCC}=\Sigma(CC_{ij}\cdot CTT_{ij})/\Sigma CC_{ij}.$$

The procedure is repeated for the up to three "tracking centres" defined for each tracer. The "AMV cloud type" value is calculated as the one with the highest sum of "partial contributions to the correlation". The "AMV pressure error value, ΔP_{CCC}" is also calculated with the formula:

$$\Delta P_{CCC}=\sqrt{(\Sigma(CC_{ij}\cdot CTP_{ij}^2)/\Sigma CC_{ij} - P_{CCC}^2)},$$

useful as a possible "Quality control" parameter for the filtering of AMVs and Trajectories. For this, a maximum "AMV pressure error" is defined with configurable parameter MAXPRESSUREERROR (with default value 150 hPa). Images in *Figures 6 and 7* show two examples of the running of "CCC method" (as already said, for a visible AMV on the left side, and an infrared AMV in the right side).

In the first row of the images, the "brightness values" for the "tracer" pixels in the "initial image" and for its "tracking centre" pixels in the "later image" are shown. Comparing the images, it is visually clear that the same feature is being observed in both cases. In the second row, the "Cloud type" and "Cloud Top Pressure" outputs related to the "tracking centre" pixels are shown. In the third row, the "partial contributions to the correlation" for the "tracking centre" pixels are shown: on the left considering all pixels and on the right considering only those pixels defined as valid by the "CCC calculation threshold" (which in these cases is the "mean contribution to the correlation").

As already explained, the last row of the images shows respectively the 'Normalized reflectance(Pixel correlation contribution)' graph and the 'Brightness temperature(Pixel correlation contribution)' graph for these cases, with the "CCC calculation threshold" defined by the method as a vertical purple line.

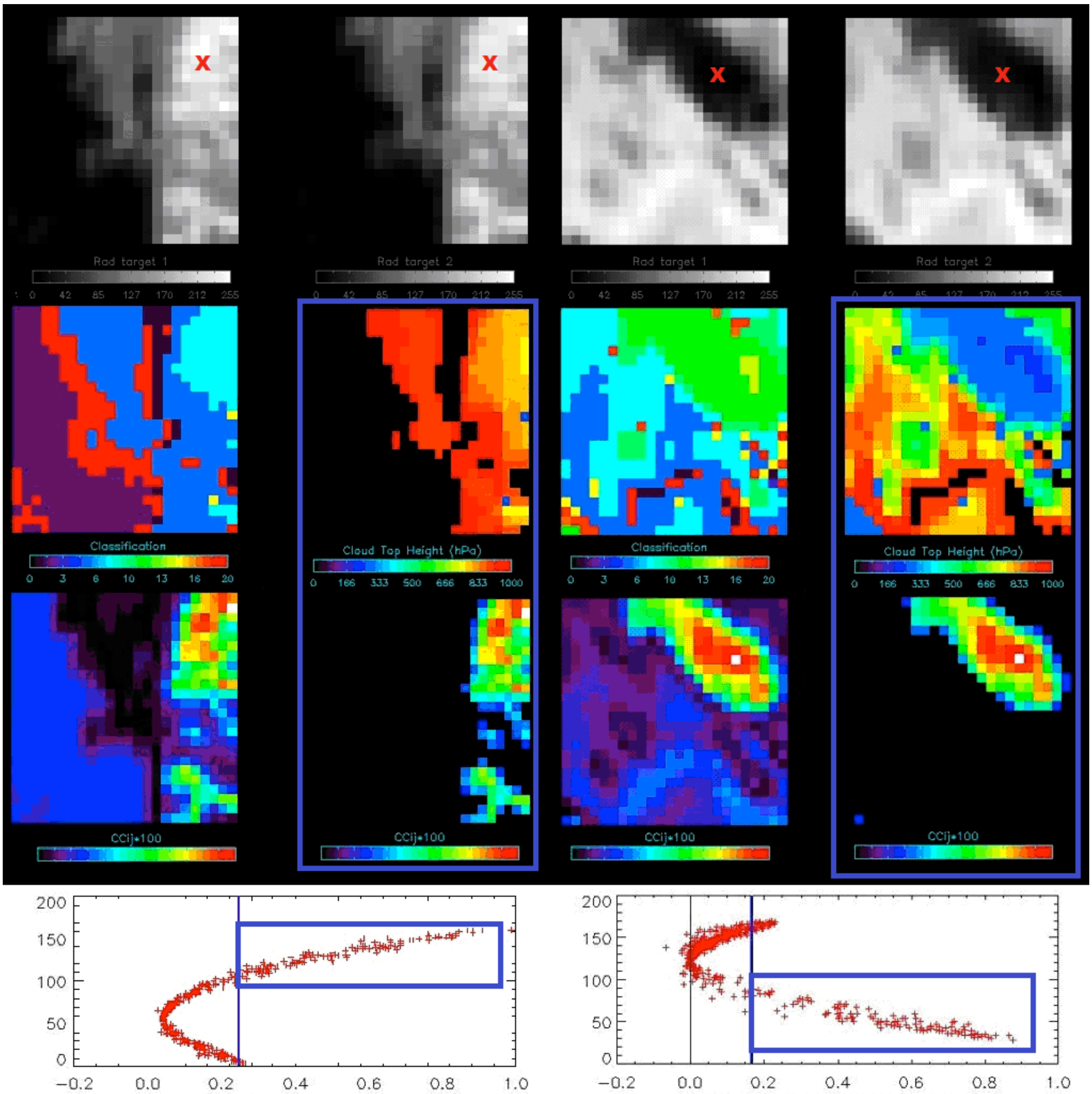
Only those pixels having a valid value in the blue boxes in both graphs of *Figures 6 and 7* are used in the calculations of P_{CCC} and ΔP_{CCC}. In the visible example, these pixels correspond to the very low and low cloud in the right part of the "tracking centre". In the infrared example, these pixels correspond to the high cloud in the upper right corner of the "tracking centre".

With configurable parameter DEFPOSWITHCONTRIBUTIONS = 1, which is the default option, the displacement by the AMV between the "tracer" and the "tracking centre" is not considered between the centres of the "tracer" and the "tracking centre", but between the "weighted locations" defined with similar formulae (where X_{ij} and Y_{ij} correspond to the line and column position of each pixel inside the "tracer" and the "tracking centre"):

$$X_{CCC}=\Sigma(CC_{ij}\cdot X_{ij})/\Sigma CC_{ij} \qquad Y_{CCC}=\Sigma(CC_{ij}\cdot Y_{ij})/\Sigma CC_{ij}.$$

The "weighted locations" relate the displacement of the AMVs and Trajectories to the displacement of the part of the tracer with the "largest contribution to the cross correlation". These weighted locations are identified in *Figures 6 and 7* as red crosses.

When trajectories are calculated with configurable parameter CALCULATE_TRAJECTORIES = 1, tracking consecutively during several images the same tracer, the calculation of these "weighted locations" occurs only for the first AMV in the trajectory, and keeps the same value during all the time the Trajectory is alive, to avoid spatial discontinuities in the Trajectory.



Figures 6 and 7: Matrices and graphs used in the calculation of "CCC method height assignment", for a visible example in the left side and an infrared example in the right side, as explained in the text. The weighted location of the AMV in the "initial image" and "later image", as defined with configurable parameter DEFPOSWITHCONTRIBUTIONS = 1, is shown as a red cross in the images in the first row

2.2.2.7 "CCC method" height assignment (Cloudy cases with Microphysics correction)

"CCC method" height assignment offers a direct correspondence between the pressure levels defined for NWC/PPS-HRW cloudy AMVs and Trajectories, and those given to the "cloud tops" by NWC/PPS-CTTH output, eliminating any possible incongruence between both outputs. It also defines a clear correspondence between the elements considered for the AMV pressure level calculations and the real features observed in the satellite images.

Taking this into account, several studies in 2014 (Peter Lean et al. [RD.21], Á.Hernández-Carrascal & N.Bormann [RD.22], K.Salonen & N.Bormann [RD.23]), have suggested that AMVs are better related to a pressure level different from the "cloud top".

An empirical relationship has been found in NWC/PPS-HRW between the "difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level" on one side, and the "cloud depth" represented by the "AMV Liquid/Ice water path" values on the other side. So, a correction of the "AMV pressure level" can be defined with these Microphysics parameters.

For this procedure, the output of NWC/PPS-CMIC (Cloud microphysics product) is used, considering the "Cloud phase, CPh_{ij}" for each cloud pixel, the "Liquid water path, LWP_{ij}" for each liquid cloud pixel and the "Ice water path, IWP_{ij}" for each ice cloud pixel. The "AMV cloud phase" value is defined in a similar way to the one used for the "AMV cloud type" value in previous chapter, as the phase with the highest sum of "partial contributions to the correlation". It has three possible values: "Liquid phase", "Ice phase" and "Undefined phase". Here, the Liquid phase and the Ice phase are considered for the Microphysics correction.

The "AMV liquid water path LWP_{CCC}" value is then calculated for "Liquid phase AMVs", and the "AMV ice water path IWP_{CCC}" value is calculated for "Ice phase AMVs", considering the parameters provided by NWC/PPS-CMIC output and similar formulae to the ones used in the previous chapter for the "AMV pressure level":

$$LWP_{CCC}=\Sigma(CC_{ij}\cdot LWP_{ij})/\Sigma CC_{ij} \qquad IWP_{CCC}=\Sigma(CC_{ij}\cdot IWP_{ij})/\Sigma CC_{ij},$$

In these formulae, the liquid cloud pixels inside the "tracking centre" in the first formula, and the ice cloud pixels inside the "tracking centre" in the second formula, are considered.

The empirical relationship between the "difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level" and the "AMV liquid/ice water path" has been defined in NWC/PPS-HRW for visible AMVs on one side, and infrared AMVs on the other side, considering AMVs calculated with all possible polar satellite inputs between 11:00 and 13:00 UTC in both "EUROPA" and "EURON1/Scandinavia" validation regions, in the period February-March 2020. A specific relationship has not been defined for Water vapour cloudy AMVs, due to the small number of AMVs it relates to; for Water vapour AMVs the infrared option is used.

Defining then separate procedures for Liquid and Ice Cloud Visible AMVs, and for Liquid and Ice Cloud Infrared AMVs, *Figures 8 to 11* in the following pages are obtained. The reference wind data used for the calculation of the "best fit pressure level" have been "Radiosounding wind" data at 12:00 UTC (with up to one hour difference with the AMV calculation time). The empirical relationship has been fitted to a third/fourth grade polinominal, depending on the case.

The "difference between the AMV pressure level calculated with CCC method and the best fit pressure level" is always smaller than 105 hPa, and in general negative, meaning that the "best fit pressure level" is in most cases at a lower level (nearer to the ground), than the "AMV pressure level" calculated with "CCC method". The main exception to this is related to small values of the Ice water path (< 0.05 kg/m3), for which the difference is positive.

The "difference between the AMV pressure level calculated with CCC method and the best fit pressure level" shows also a different behaviour to the one shown in NWC/GEO-CTTH product for geostationary satellites. This is caused by the different processes used in NWC/GEO-CTTH and NWC/PPS-CTTH products for the cloud top calculation: opaque cloud top pressure retrieval with infrared window channels and semitransparent cloud top pressure retrieval with radiance radioing and intercept methods in the first one, and a purely neural network process in the second one.

Defining a "Microphysics correction of the AMV pressure level", based on this relationship between the "difference between the AMV pressure level calculated with CCC method and the best fit pressure level" and the "AMV liquid/ice water path", it is implemented such as shown in *Table 7*. This correction locates then in general the AMVs in a level nearer to the ground, with the main exceptions commented previously. A control is later defined through the "Orographic flag" to avoid that with the correction, AMVs are located at a level below the ground.

Verifying AMV statistics for a different period (the reference AMV Validation period used for this second version of NWC/PPS-HRW: April-June 2020, in both EUROPA and EURON1/Scandinavia regions, the "Microphysics correction" causes a reduction in all validation parameters (NBIAS, NMVD and NRMSVD).

"CCC method with Microphysics correction" is implemented with configurable parameter USE_MICROPHYSICS = 2 or 3. It is activated in the default option with USE_MICROPHYSICS = 3. Option USE_MICROPHYSICS = 1 calculates the value of the Microphysics correction, but does not correct the "AMV pressure value" with it.

The user has necessarily to run all NWC/PPS-Cloud executables (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 with "CCC method without Microphysics correction" height assignment only if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option). Otherwise, the processing of NWC/PPS-HRW stops.

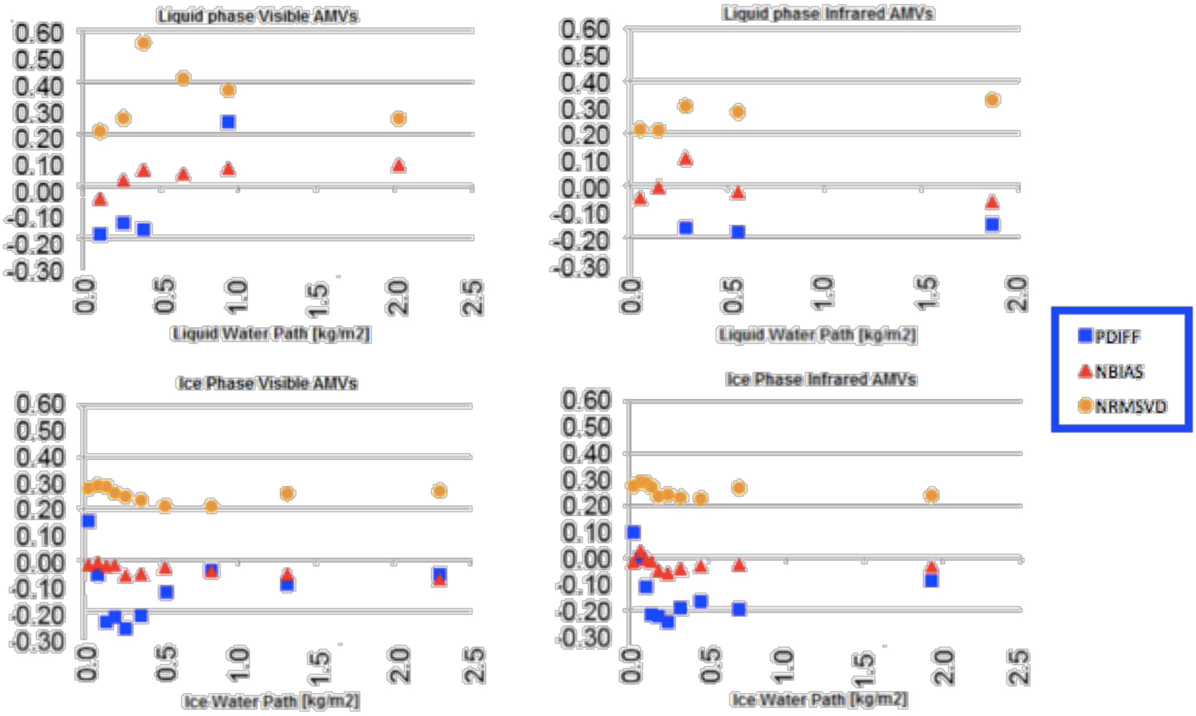
Additionally, considering a study done by the Hungarian Meteorological Service/OMSZ in January 2021 with a previous version NWC/GEO-HRW v6.1 (defined in Ticket "HRW quality issue" sent by "btoms user (OMSZ)" on date "2021/01/07 at 09:41:44" at NWCSAF Helpdesk), it was checked that a relocation is needed in the AMV level defined by the Microphysics correction for AMVs at levels higher than 230 hPa.

It has been verified through a comparison with the "Radiosounding wind best fit level" that AMVs at these levels are too high in the atmosphere, and a relocation to a lower level works better and has better validation statistics. The following empirical formula is used for this relocation:

1. if $p < 88$ hPa, $p = p + 97$ hPa.
2. else if $p < 230$ hPa, $p = p + (0.00004295 * p^3 - 0.02105417 * p^2 + 2.53726626 * p + 7.33016013)$ hPa.

Through this, all AMVs between 0-230 hPa are located to a lower level. The relocation reduces progressively from its highest value of +97 hPa at the highest levels, to 0 hPa near 230 hPa. This relocation is implemented with configurable parameter USE_MICROPHYSICS = 3 (default option for NWC/PPS-HRW).

The correction was studied for MSG satellites and has been used for homogeneity for all geostationary and polar satellites. The assumption has been then made here that the relocation is similar for all these satellites (in spite of the differences in corresponding satellite channels and cloud products), but through the fact that the number of polar affected AMVs is small, and that the validation for AMVs with pressure < 230 hPa shows similar RMSVD values after the relocation, this assumption can be considered as valid.



Figures 8 to 11: Graphs relating for NWC/PPS-HRW product the "Difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level (in hundreds of hPa)" in blue (PDIFF), the Normalized BIAS in red (NBIAS), and the Normalized RMSVD in blue, with the "AMV Ice/Liquid Water Path (in kg/m^2)", for Visible AMVs (left) and Infrared AMVs (right). 11:00 to 13:00 UTC polar cloudy AMVs for February-March 2020 in the "EUROPA" and "EURON1/Scandinavia" regions have been used for the tuning, and 12:00 UTC Radiosouding winds have been used as reference

Correction for the "AMV pressure level [in hPa]" based on the "AMV Liquid and Ice water path [in]" for polar satellites	
VISIBLE LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 0 if LWP=0 or LWP > 2.3116 kg/m^2 MIC.CORR[hPa] = -18+324LWP -737LWP^2+552LWP^3-127LWP^4 if LWP < 2.3116 kg/m^2	VISIBLE ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 0 if IWP=0 or IWP > 2.1920 kg/m^2 MIC.CORR[hPa] = -21+286IWP -421IWP^2+135LWP^3 if IWP < 2.1920 kg/m^2
INFRARED LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 0 if LWP=0 kg/m^2 MIC.CORR[hPa] = -22+454LWP -1464LWP^2+1653LWP^3-524LWP^4 if LWP < 0.5589 kg/m^2 MIC.CORR[hPa] = 12 if LWP > 0.5589 kg/m^2	INFRARED ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 0 if IWP=0 or IWP > 1.8998 kg/m^2 MIC.CORR[hPa] = 77-343IWP +536IWP^2-198IWP^3 if IWP < 1.8998 kg/m^2

Table 7: Correction for AMV pressure level [in hPa] based on the AMV Liquid and Ice water path [in kg/m^2] for polar satellite series

2.2.2.8 "CCC method" height assignment (Water vapour clear air cases)

The adaptation of "CCC method" existing in NWC/GEO-HRW algorithm for use with "Water vapour clear air AMVs" has also been included in this second version of NWC/PPS-HRW for the calculation of its "Water vapour clear air AMVs", so that both products calculate them in an equivalent way. As it was already commented previously, "Water vapour clear air AMVs" are only available in NWC/PPS-HRW when both "initial image" and "later image" are related to MODIS, METimage or MERSI-2 radiometers.

A "Water vapour clear air AMV" is defined as a "Water vapour AMV" for which the sum of "partial contributions to the correlation" is larger for the group of "clear air pixels" (Cloud type 1 to 4) than for the group of "cloudy pixels" (Cloud type 5 to 9 and 11 to 15), considering all pixels inside the "tracking centre" for which the "partial contribution to the correlation" is positive. This way, the feature that is actually being tracked between the initial and the later image is a clear air feature (in spite of any presence of cloudy pixels).

The "AMV cloud type" value and the "AMV temperature" value are calculated in a way similar to the one described in chapter 2.2.2.6 for the cloudy water vapour AMVs, although now the Brightness temperature for each pixel (BT_{ij}) from the corresponding satellite image is used instead of the NWC/PPS-CTTH Cloud Top Temperature.

An "AMV temperature error ΔT_{CCC}" value is now also calculated considering a formula similar to the one used in the previous chapter for the "AMV pressure error" value:

$$\Delta T_{CCC}=\sqrt{(\Sigma(CC_{ij}\cdot BT_{ij}^2)/\Sigma CC_{ij} - T_{CCC}^2)},$$

Three different temperature values are defined by following formulae: $T_{CCC}+\Delta T_{CCC}$, T_{CCC}, $T_{CCC}-\Delta T_{CCC}$. For each one of these values, a temperature to pressure conversion is done through interpolation inside the nearest NWP temperature forecast profile, providing three pressure values: P_{CCC} (related to T_{CCC}), P_{CCCMAX} (related to $T_{CCC} + \Delta T_{CCC}$), and P_{CCCMIN} (related to $T_{CCC} - \Delta T_{CCC}$).

P_{CCC} is defined as the "AMV pressure" value for the "clear air AMVs". $\Delta P_{CCC} = |P_{CCCMAX} - P_{CCCMIN}|/2$ is defined as the "AMV pressure error" value for the "clear air AMVs" when a vertical reduction or increase of temperature occurs throughout all three corresponding pressure levels. In the cases in which the "AMV pressure" value or the "AMV pressure error" value cannot be calculated, the AMV is discarded.

EXAMPLE OF AMV CLOUD TYPE DEFINED BY CCC HEIGHT ASSIGNMENT

An example of AMVs for NWC/PPS-HRW software is shown in *Figure 12*, considering the "AMV cloud type" defined by "CCC method height assignment".

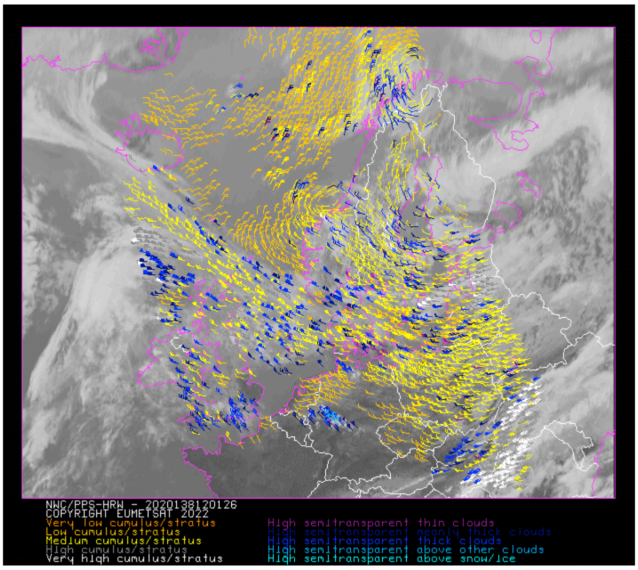


Figure 12: "AMV cloud type values" (as defined by "CCC method height assignment") for the NWC/PPS-HRW example defined in Figure 19 (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite),

EXAMPLE OF AMVs RELATED TO DIFFERENT OPTIONS OF CCC HEIGHT ASSIGNMENT

An example of AMVs for NWC/PPS-HRW software is shown in *Figure 13*, considering the different options for "CCC method height assignment" (using high or low CCC method calculation threshold).

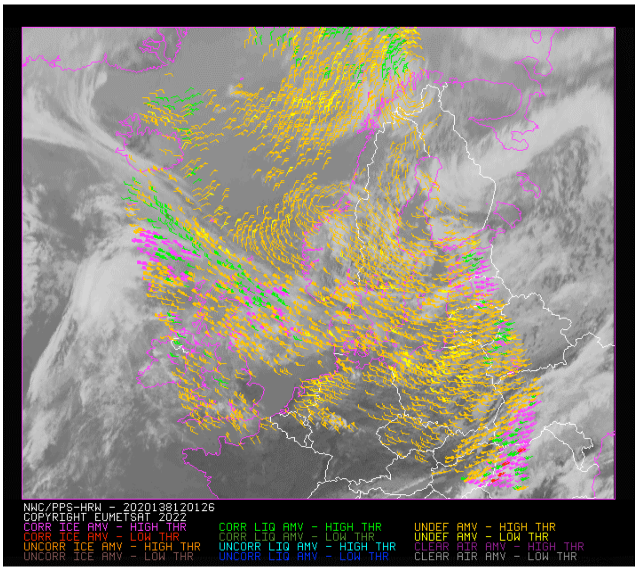


Figure 13: AMV height assignment option used by the different AMVs for the NWC/PPS-HRW example defined in Figure 19 (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite),

EXAMPLE OF AMV PRESSURE CORRECTION DEFINED BY MICROPHYSICS CORRECTION

An example of AMVs for NWC/PPS-HRW software is shown in *Figure 14* considering the "AMV pressure correction" defined by "CCC method height assignment with Microphysics correction".

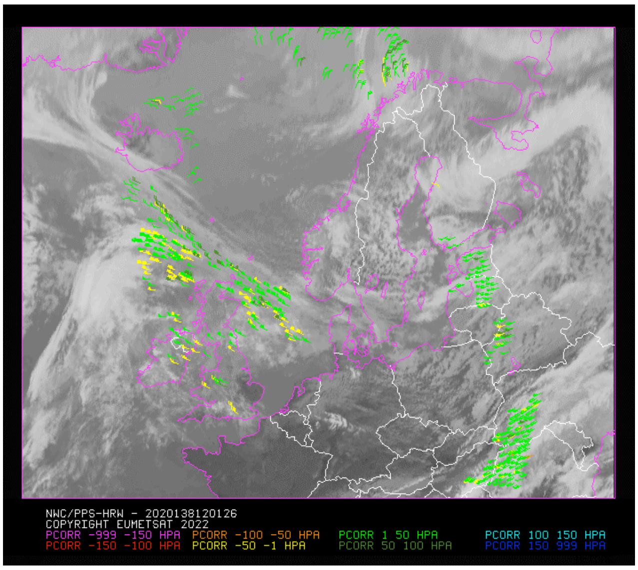


Figure 14: AMV pressure correction (for the cases in which "CCC height assignment method with Microphysics correction" has been used), for the NWC/PPS-HRW example defined in Figure 19 (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite),

2.2.2.9 Wind calculation

Once the latitude and longitude are known for a "tracer" in the "initial image" (the "tracer centre" or the "weighted location" defined by DEFPOSWITHCONTRIBUTIONS configurable parameter), and for its up to three "tracking centre locations" in the "later image" (defined by the "tracking centre" or the "weighted location" defined by DEFPOSWITHCONTRIBUTIONS configurable parameter, together with the non-integer/integer displacement of the "tracking centre" inside the "tracking area" with/without the "subpixel tracking", as defined by USE_SUBPIXELTRACKING configurable parameter), the rectangular coordinates of the wind (in m/s) related to the displacements are calculated.

The wind components are calculated considering the displacement along the corresponding "great circle" with the "haversine formula". The "haversine formula" uses the following procedure to calculate the angular distance in degrees (ANG) and the wind speed (SPD) between the "tracer location" and the "tracking centre location". The initial latitude and longitude values (LAT1, LON1), the final latitude and longitude values (LAT2, LON2), the latitude and longitude differences (ΔLAT, ΔLON), and the time difference in hours between the "tracer" in the "initial image" and the "tracking centre" in the "later image" (T_INT) are used for this calculation process. The coefficient CONVERSION_DEGH2MS converts º/hour to m/s.

$$A = \sin^2(\Delta LAT/2) + \cos(LAT1) \cdot \cos(LAT2) \cdot \sin^2(\Delta LON/2)$$

$$ANG = 2 \cdot RAD2DEG \cdot atan^2(\sqrt{A}, \sqrt{(1-A)})$$

$$SPD = CONVERSION\_DEGH2MS \cdot ANG / T\_INT$$

The "bearing angle" (DIR) for the related "great circle" is calculated with the following formulae:

$$HOR = \cos(LAT1) \cdot \sin(LAT2) - \sin(LAT1) \cdot \cos(LAT2) \cdot \cos(\Delta LON)$$

$$VER = \sin(\Delta LON) \cdot \cos(LAT2)$$

$$DIR = atan^2(HOR, VER)$$

The west-to-east and south-to-north wind components in m/s (U, V) are then simply calculated as:

$$U = SPD \cdot \cos(DIR) \qquad V = SPD \cdot \sin(DIR)$$

T_INT is the real time difference in hours, between the scanning time of the pixel related to the "tracer location" in the "initial image" and the "tracking centre location" in the "later image". For this, the procedure takes simply into account the scanning time for each pixel provided in the satellite input data files ("time_per_pixel").

The location of the "tracking area centre" in the "later image" when the "wind guess" is used with WIND_GUESS = 1, calculated through the displacement of the tracer location with the rectangular NWP wind components, uses also an equivalent procedure with a displacement along the corresponding "great circle".

PARALLAX CORRECTION OF THE TRACER AND TRACKING CENTRE LOCATION

NWC/GEO-HRW algorithm 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 (LAT1, LON1, LAT2, LON2).

This option is 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.

2.2.2.10 Quality control and Choice of the best wind

The "Quality Indicator method" developed by EUMETSAT, and implemented for its Atmospheric Motion Vectors computed at the MPEF/Meteosat Product Extraction Facility (K.Holmlund, 1998), is used here.

This method assigns a quantitative quality flag to all AMVs and Trajectories: "Quality Index or QI" (ranging from 0% to 100%). It is based on normalized functions, related to the expected change of the AMVs considering: "temporal consistency" (comparison to a "prior AMV" in the previous image at the same location and level), "spatial consistency" (comparison to a "neighbour AMV" in the current image at the same location and level), and "consistency relative to a background" (NWP wind forecast at the same location and level).

Up to five different tests are applied: direction, speed and vector difference tests for the temporal consistency and only vector difference for the other ones, so giving five "Individual Quality Indices". The weighted sum of these consistency tests provides two overall values: the "Quality Index with forecast" and the "Quality index without forecast".

For the two scale procedure, an additional "interscale spatial consistency" is computed for detailed AMVs derived from a basic scale tracer (comparing to the corresponding basic scale AMV).

The different "Individual Quality Indices" are given by the following formulae, in which SPD is the average wind speed between the evaluated AMV and the reference wind, and DIF is the absolute change in speed, direction or module of the vector difference:

$QI_1 = 1 - [\tanh[DIF/(20 \cdot \exp(-SPD/10)+10]]^4$ (in the "temporal direction consistency" test)

$QI_2 = 1 - [\tanh[DIF/(\max(0.4 \cdot SPD, 0.01))+1]]^2$ (in the "forecast vector consistency" test)

$QI_i = 1 - [\tanh[DIF/(\max(0.2 \cdot SPD, 0.01))+1]]^3$ (in the rest of consistency tests).

The procedure is repeated for up to 3 "neighbour AMVs" (L_CHECK_NUMBUDDIES) in the spatial consistency and up to 3 "prior AMVs" (T_CHECK_NUMPREDEC) in the temporal consistency. The contribution from each one of the reference AMVs to the value of the spatial or temporal consistency depends (as defined by L_CHECK_DISTWEIGHT and T_CHECK_DISTWEIGHT) on a "distance factor" to the evaluated AMV.

The "distance factor" is given by the following formulae, in which SPD/DIR/LAT are the speed/direction/latitude of the evaluated AMV, LATDIF/LONDIF are the latitude/longitude difference with respect to the reference AMV, and ER is the Earth radius in kilometres:

$alpha = 200 + 3.5 \cdot SPD$

$beta = 200 + 3.5 \cdot SPD$

$gamma = ER \cdot \sqrt{(LATDIF^2+LONDIF^2)} \cdot \cos(270–DIR–\mathrm{atan}(\cos(LAT)+LATDIF/LONDIF))$

$delta = ER \cdot \sqrt{(LATDIF^2+LONDIF^2)} \cdot \sin(270–DIR–\mathrm{atan}(\cos(LAT)+LATDIF/LONDIF))$

distance factor $= (gamma/alpha)^2 + (delta/beta)^2$

Only reference AMVs with a "distance factor" smaller than 1, a pressure difference smaller than 25 hPa (L_CHECK_PRESS_DIFF/T_CHECK_PRESS_DIFF) and a latitude/longitude difference smaller than half a degree (L_CHECK_LAT_DIFF/T_CHECK_LAT_DIFF) are valid. The reference AMVs with the smallest "distance factor" are considered for the quality control.

In NWC/PPS-HRW v7.Q, the process to define the reference AMVs with the smallest "distance factors" has changed for optimisation reasons. The lists of "neighbour AMVs" and "prior AMVs" (sorted according to latitude) are now checked starting with the AMVs with the nearest latitudes and alternatively moving North and South in the list. Once a limit of L_CHECK_WRONGAMVS/ T_CHECK_WRONGAMVS = 40 of consecutive invalid AMVs in the search of reference AMVs is reached, the process stops. This makes the Quality control faster.

The weight of the different quality consistency tests in the overall "Quality Indices" is defined as follows: W_SPD = 0 (temporal speed consistency test weight), W_DIR = 0 (temporal direction consistency test weight), W_VEC = 1 (temporal vector consistency test weight), W_LC = 3 (spatial vector consistency test weight), W_FC = 1 or 0 (forecast vector consistency test weight), W_TC = 0 (interscale spatial vector consistency test). Considering the weight W_FC, the value 1 provides a "Quality index with forecast" and the value 0 provides a "Quality index without forecast".

This way, only the temporal, spatial and forecast vector consistency tests (this last one only in the "Quality index with forecast") are activated in the Quality control as default option. This is the same situation than for example the EUMETSAT/MPEF AMVs (for which however the weight of the spatial and temporal vector consistency test is 2).

One correction is nevertheless applied in the overall "Quality Index" values before using it: the reduction of the Quality of the AMVs with a speed lower than 2.5 m/s, multiplying the "Overall Quality Index" with factor SPD/SPEED_THR (where SPD = speed of the evaluated AMV, SPEED_THR = 2.5 m/s).

Other correction exists in NWC/GEO-HRW Quality Control, which cannot be implemented in NWC/PPS-HRW Quality Control: the "Image correlation test", which affects visible and infrared AMVs with a pressure higher than C_CHECK_PRESS_THR = 500 hPa. This correction cannot be used here due to the lack of water vapour channels in the processing of NWC/PPS-HRW software for many of the processable radiometers (it could be available for AMVs calculated with MODIS, METimage and MERSI-2 radiometers, but for homogeneity it is deactivated in all cases).

The "Quality index with forecast" or "Quality Index without forecast" is used for the filtering of the AMV and Trajectory data, before writing them in the output files. 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% in NWC/PPS-HRW v7.Q), This value is different to what is being considered inside NWC/GEO-HRW algorithm, which uses a default value of 75%, and to what was used in the previous NWC/PPS-HRW version, which used a default value of 80%.

An additional difference with NWC/GEO-HRW algorithm is that with polar satellites the quality of the AMVs reduces quickly for lower values of the "Quality Index threshold", so it is not recommended using significantly lower values for this threshold. Some additional considerations on the "Quality Control" are shown here:

- Each one of the 3 AMVs calculated per tracer has its own "Quality index".
- All calculated AMVs are considered valid for the spatial comparison test, disregarding their "Quality Indices".
- It is frequent that a quality consistency test cannot be calculated, for example if no reference AMV was found for the comparison. The "Overall Quality index" will include only the available tests.
- Only one AMV per tracer is selected for the AMV and Trajectory outputs. The suggested option is (through configurable parameter BEST_WIND_SELECTION = 1): the best AMV for the tracer for most of following criteria: interscale spatial quality test, temporal quality test, spatial quality test, forecast quality test and correlation (with a triple contribution). If this is not definitive the best AMV for the forecast quality test. If this is also not definitive the AMV with the best correlation.
- "TEST parameter" reflects, apart from the number of quality consistency tests that each AMV has passed, whether the AMV has been the best (value = 3), slightly worse (value = 2), or fairly worse (value = 1) than other AMVs calculated for the same tracer for each available criterion. If any of the quality consistency tests could not be calculated, this is identified with value = 0.
- For the temporal consistency of successive AMVs related to the same trajectory, some limits are defined in the speed difference (MEANVEC_SPEED_DIF = 10 m/s), direction difference (MEANVEC_DIR_DIF = 20º) and pressure level difference (MEANVEC_PRESSURE_DIF = 50 hPa).

EXAMPLE OF AMV QUALITY INDICES WITH/WITHOUT FORECAST

An example of AMVs for NWC/PPS-HRW software is shown in *Figures 15 and 16,* considering respectively the "Quality index with forecast" and the "Quality index without forecast".

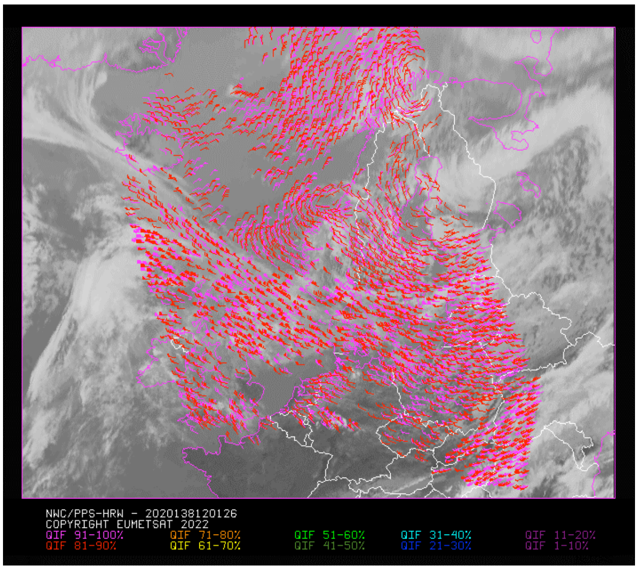


Figure 15: "Quality index with forecast"
for the NWC/PPS-HRW example defined in Figure 19
(10 May 2020 12:15:47 UTC for NOAA-20 satellite,
with tracers calculated at 11:55:19 UTC for EOS-2 satellite),
Only values of "Quality index with forecast" ≥ 83% are present,
because of the use of this parameter for the AMV filtering.

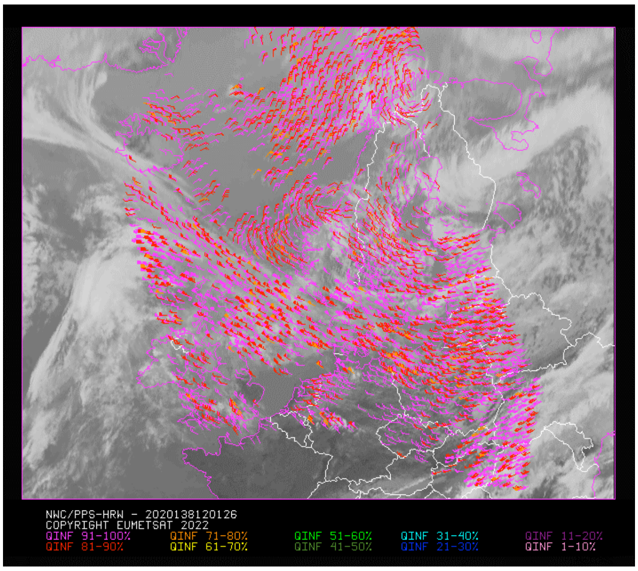


Figure 16: "Quality index without forecast"
for the NWC/PPS-HRW example defined in Figure 19
(10 May 2020 12:15:47 UTC for NOAA-20 satellite,
with tracers calculated at 11:55:19 UTC for EOS-2 satellite),
All values are formally possible for the "Quality index without forecast",
but because of its connection with the "Quality index with forecast",
only values of "Quality index without forecast" ≥ 78% are really present for this example.

COMMON QUALITY INDEX WITHOUT FORECAST

Through the experience in the "International Winds Workshops", it was clearly concluded 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.

A self-contained Fortran module, defined by EUMETSAT and NOAA/NESDIS and calculating a "Common Quality Index without forecast", was so 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 experience of use of this "Common Quality Index without forecast" 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 NWC/GEO-HRW and NWC/PPS-HRW algorithms, and the parameter is provided as an additional third "Quality Index" for all AMVs and Trajectories. The main differences with the previous ones are summarized next:

- 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: the direction, speed and vector difference tests for the temporal consistency, and the vector difference for the spatial consistency with a double contribution. Some parameters in the formulae for calculation of the "Individual Quality Indices" are also slightly different.
- It is not used for the filtering of AMVs and Trajectories by NWC/PPS-HRW software, so all values between 1% and 100% are possible in the AMV/Trajectory output. For AMVs and Trajectories for which it could not be calculated, an "unprocessed value" is defined.

EXAMPLE OF AMV COMMON QUALITY INDEX WITHOUT FORECAST

An example of AMVs for NWC/PPS-HRW software is shown in *Figure 17* considering the "Common Quality Index without forecast".

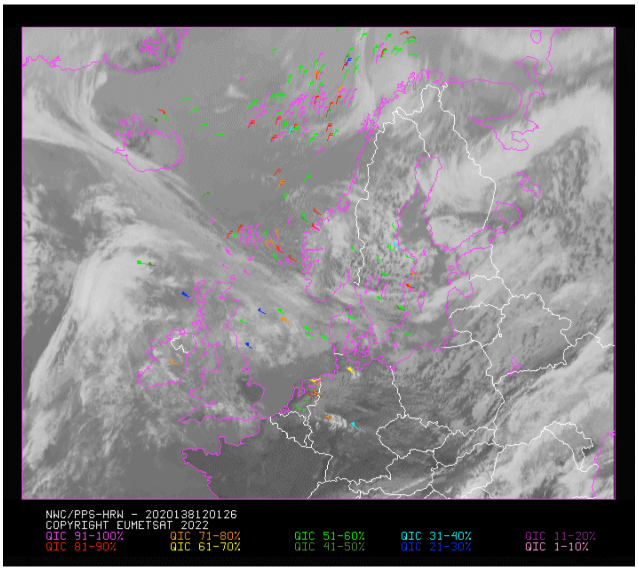


Figure 17: "Common Quality index without forecast" for the NWC/PPS-HRW example defined in Figure 19 (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite). All values are possible for the "Common Quality index without forecast". The difference with Figures 15 and 16, and the fact that only a part of AMVs has a valid value for the "Common Quality index without forecast" (a 1% of AMVs for this example) are to be noticed.

2.2.2.11 Orographic flag

With configurable parameter USE_TOPO > 0, an "Orographic flag" is calculated for each AMV and Trajectory. The "Orographic flag" incorporates topographic information, which in combination with NWP data, detects and rejects those AMVs and Trajectories affected by land influence.

The reasons for this land influence may 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. These tracers present displacements, which do not correspond with the general atmospheric flow. The corresponding AMVs are not considered as valid.

The procedure to calculate the "Orographic flag" implies the reading of NWP geopotential data and of one topography matrix for the static region used for the AMV calculation (being <regid> the label identifying this static region): `$SM_STATIC_AUXILIARY_DIR/S_NWC_SFCMAX_<regid>`. This matrix defines the 97% centile of the topography histogram for each pixel, in which data up to one degree away are considered. It is called the "Representative height matrix at the top of the topography" around each pixel.

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 "Representative surface pressure matrix at the top of the topography" with NWP geopotential data. To do this, the "Height matrix" is converted to geopotential values (multiplying by a constant value of gravity), and the geopotential is then inversely interpolated to pressure to define the "Representative surface pressure at the top of the topography" around each pixel (P_top). This value defines the representative surface pressure at the highest locations in the topography up to one degree away of each pixel of the image. For optimisation reasons, in NWC/GEO-HRW v7.Q a similar "Representative surface pressure at the pixel topography" is directly provided by the NWP surface pressure at each pixel (P_sfc).

After this, the "Static orographic flag" (IND_TOPO) is calculated at the initial position of each AMV. It is calculated considering P_sfc, P_top values and parameters TOPO_PR_DIFF = ½ (Representative pressure level of the location) and TOPO_PR_SUP = 25 hPa (Pressure layer needed to avoid orographic influence). Possible values are:

- *IND_TOPO = 0: Orographic flag could not be calculated.*
- *IND_TOPO = 1: P_AMV > P_sfc*

  AMV wrongly located below the surface pressure level in the current AMV position (mainly due to Microphysics corrections in the "AMV pressure value").
- *IND_TOPO = 2: P_AMV > P_top + TOPO_PR_DIFF*(P_sfc-P_top)*

  Very important orographic influence found in the current AMV position.
- *IND_TOPO = 3: P_AMV > P_top - TOPO_PR_SUP*

  Important orographic influence found in the current AMV position.
- *IND_TOPO = 6: P_AMV < P_top - TOPO_PR_SUP*

  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 happens if IND_TOPO = 6 and the tracer is related to a "predecessor AMV" in the previous image. The value of IND_TOPO is so modified considering the following conditions:

- *IND_TOPO = 4: Very important orographic influence was found at a previous position of the AMV (for which IND_TOPO = 2 or 4).*
- *IND_TOPO = 5: Important orographic influence was found at a previous position of the AMV (for which IND_TOPO = 3 or 5)*
- *IND_TOPO = 6: No orographic influence is found in any current or previous position of the AMV.*

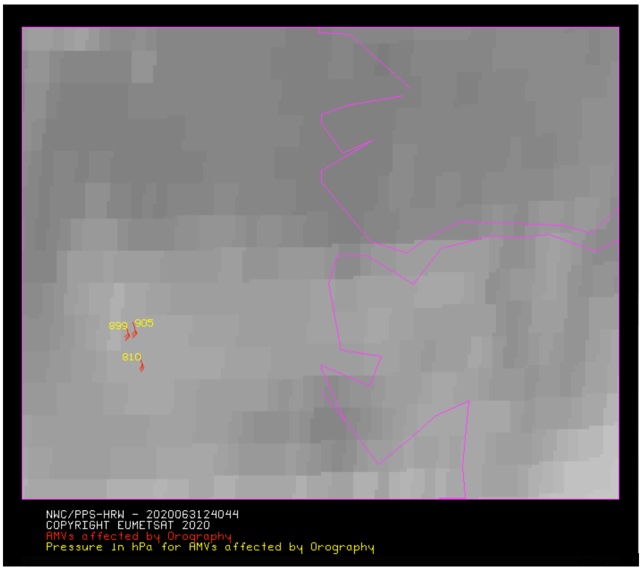


Figure 18: Pressure values in hPa for AMVs affected by orography (i.e. with "Orographic flag" values between 1 and 5) in a zoomed area in the Southwestern coast of Norway around Sognefjord, for the NWC/PPS-HRW example defined in Figure 19 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region "EURON1 - Scandinavia"). Orographic effects are caused by the mountains in the area, reaching more than 1600m of altitude

"TESO parameter", similar to "TEST parameter" explained in previous chapter to compare the different values a quality consistency test can have for the different AMVs related to a same tracer, is also calculated considering the "Orographic flag". Its possible values are:

- *TESO = 3: IND_TOPO for the AMV chosen as best wind, is the highest for all AMVs related to the same tracer.*
- *TESO = 2: IND_TOPO for the AMV chosen as best wind, is one unit smaller than the best value for all AMVs related to the same tracer.*
- *TESO = 1: IND_TOPO for the AMV chosen as best wind, is at least two units smaller than the best value for all AMVs related to the same tracer.*
- *TESO = 0: IND_TOPO could not be calculated for the AMV chosen as best wind.*

With configurable parameter USE_TOPO = 1, IND_TOPO and TESO parameters are calculated and incorporated to the AMV and Trajectory output files. AMVs with IND_TOPO = 1 are eliminated.

With configurable parameter 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.

2.2.2.12 Final Control Check and Output data filtering

After the "Quality control", sometimes an AMV is detected to have a direction or velocity completely different to the ones in its immediate vicinity, without clearly justifying the reason for such changes in direction or velocity. They can be considered as errors.

To eliminate these errors, a function called "Final Control Check" can be run after the "Quality control" using configurable parameter FINALCONTROLCHECK = 1 (which is the default option).

This function calculates the velocity and direction histograms for all valid AMVs calculated with the same satellite channel in small areas inside the working region (square boxes of 5x5 degrees of latitude and longitude). When any of the columns of the velocity or direction histograms has only one element, the AMV is excluded. The procedure considers that the lack in the same area of another AMV with relatively similar velocities or directions is enough to consider the AMV as an error.

Several output data filterings are additionally considered in this step, 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 6* 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.

2.3 PRACTICAL CONSIDERATIONS ON HIGH RESOLUTION WINDS (NWC/PPS-HRW)

2.3.1 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".
- 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.

2.3.1.1 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 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 8* (considering all layers together) and in *Table 10* (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 9* (considering all layers together) and in *Table 11* (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”.

	“EURON1-Scandinavia” region					“EUROPA” region				
NWC/PPS-HRWv7.Q AMVs (Apr 2020-Jun 2020)	VIS	IR	cloudy WV	clear air WV	all AMVs	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 8: 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.

	“EURON1-Scandinavia” region			“EUROPA” region		
NWC/PPS-HRWv7.P AMVs (Apr 2020-Jun 2020)	VIS	IR	All AMVs	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 9: 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 (Apr 2020-Jun 2020)	**VIS**	**IR**	**cloudy WV**	**clear air WV**	**All AMVs**	**VIS**	**IR**	**cloudy WV**	**clear air WV**	**All 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 10: 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		**IR108/**	**All**		**IR108/**	**All**
(Feb 2020-Apr 2020)	**VIS06**	**IR110**	**AMVs**	**VIS06**	**IR110**	**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 11: 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.

2.3.1.2 Autovalidation process of NWC/PPS-HRW software

NWC/PPS-HRW offers the same way as NWC/GEO-HRW software the option to calculate the validation statistics for the AMVs with the NWC/PPS-HRW software itself (using as reference NWP analysis or forecast rectangular components of the wind (u, v), such as defined in chapter 2.3.2 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_<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 in the same region 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 previously (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 are 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:

```
yyyymmddThhmmssZ  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. The NWP analysis or forecast wind with validates each AMV (defined by its speed and direction), is also added to the NWC/PPS-HRW output files. This allows NWCSAF users a quick recalculation of the NWC/PPS-HRW validation parameters for different sampling and filtering options of the data, including for example monthly or yearly totalizations.

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

- The first one, activated with configurable parameter NWPVAL_NWPDIFFERENCE = 1 (implemented as a default option) calculates also for each AMV the "Vector difference with the NWP reference wind", and adds this "Vector difference" (defined by its speed and direction) to the NWC/PPS-HRW output files.

  This "Vector difference" can be used for example in Nowcasting tasks, so that the NWCSAF 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 in some specific region or moment due to strong winds unforeseen by the NWP forecast.

- The second one, activated with configurable parameter NWPVAL_NWPBESTFITLEVEL = 1 (implemented also as a default option) calculates also for each AMV the "NWP reference wind at the best fit pressure level" and adds this "NWP reference wind at the best fit pressure level" (defined by its speed, direction and pressure level) to the NWC/PPS-HRW output files.

  This "NWP model wind at the best fit pressure level" can be used for example for verification tasks of the "AMV height assignment method", to know in which cases there is more or less agreement between the AMV pressure level defined for the AMVs and Trajectories, and the one suggested by the NWP model reference.

  The calculation of the "NWP reference wind at the best fit pressure level" consists of two steps: first, the model level with the smallest vector difference between the observation and the model background wind is to be found. Then, the minimum is calculated by using a parabolic fit to the vector difference for this model level and the two neighbouring levels.

  The calculation is based on the procedure defined by K.Salonen, J. Cotton, N.Bormann & M.Forsythe at [RD.26], and is only defined at some specific circumstances, to avoid broad best fit pressure values which are not very meaningful: The minimum vector difference between the observed and the NWP reference wind at best fit pressure level has to be less than 4 m/s, and the vector difference has to be greater than the minimum difference plus 2 m/s outside a band that encompasses the best fit pressure ± 100 hPa. This way, only around a 40%-50% of the AMVs have a defined value for the "NWP reference wind at the best fit pressure level".

NWP analysis winds or NWP forecast winds can be used here for both procedures (calculation of the "Vector difference with the NWP reference wind" and calculation of the "NWP reference wind at the best fit pressure level"), depending on the value of configurable parameter NWPVAL_ANALYSIS. In case of using NWP analysis winds, both parameters are only provided for the specific runs for which the NWP analysis is defined as valid for the AMV autovalidation process (for NWC/PPS-HRW runs up to an hour away from the NWP analysis date and time).

2.3.2 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 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.

2.3.3 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 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		Integer	`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 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 admitted 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).	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 12: 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).

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

The following *Table 13* 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 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/B 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 for the related satellite 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 13: List of errors for NWC/PPS-HRW-v7.Q software

2.3.5 Outputs of High Resolution Winds (NWC/PPS-HRW)

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 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 permits NWCSAF users to have a similar processing for 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 the 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).

2.3.5.1 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 14*. 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 versions 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 respectivey 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 14*, 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 14: 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' 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 more than 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 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 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 2.2.2.11 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 15: Description of “local specific variables” in the “NWCSAF specific BUFR format”

2.3.5.2 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 16*. 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 (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 16: Variables used for the Trajectory output with the "NWCSAF specific BUFR format"

2.3.5.3 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 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 17*, 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 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	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 17: Variables used for the AMV output with the "2018 IWWG BUFR format"

2.3.5.4 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 18*. The structure of the netCDF output attributes is shown in *Table 19*. 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 2.3.5.1), the "Valid range" for each variable and the "Fill value" for each variable are also included in *Table 18*.

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 18: 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 19: Detailed specification of the NWC/PPS-HRW netCDF output attributes

2.3.6 Examples of High Resolution Winds (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, 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 19 and 20*, and for the region "EUROPA" in *Figures 21 and 22*.

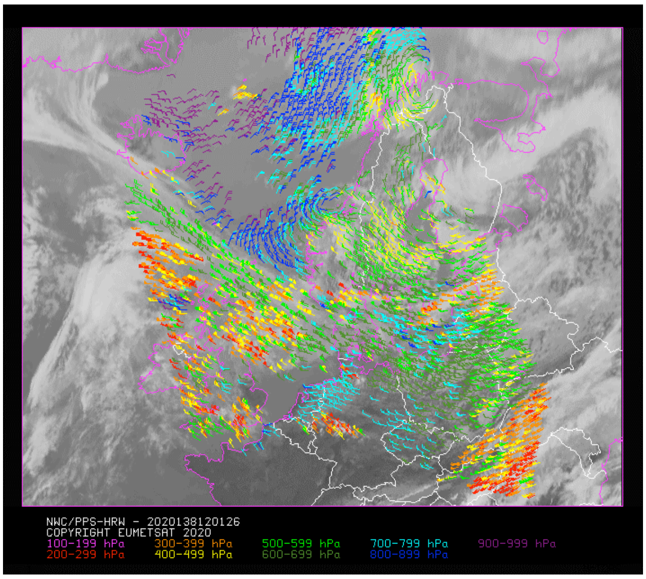


Figure 19: NWC/PPS-High Resolution Winds v7.Q "Basic AMV" output example in the region "EURON1 - Scandinavia" (17 May 2020 12:01:26 UTC for EOS-2 satellite, with tracers calculated at 11:44:19 UTC for NOAA-20 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model configuration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

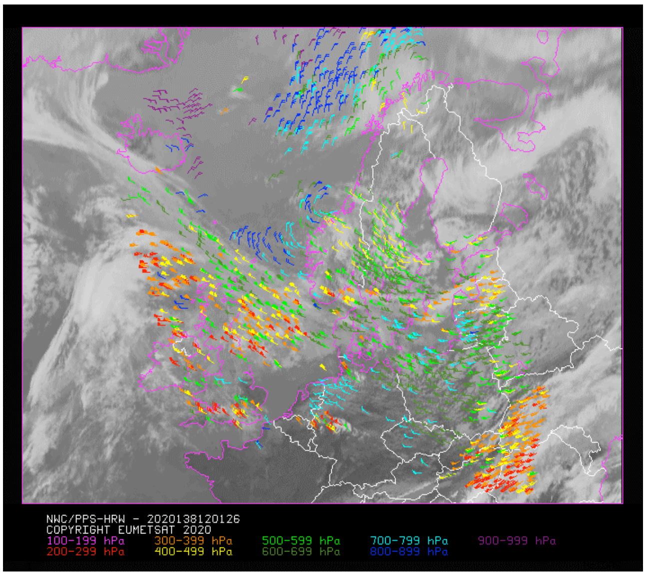


Figure 20: NWC/PPS-High Resolution Winds v7.Q "Detailed AMV" output example in the region "EURON1 - Scandinavia" (17 May 2020 12:01:26 UTC for EOS-2 satellite, with tracers calculated at 11:44:19 UTC for NOAA-20 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model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

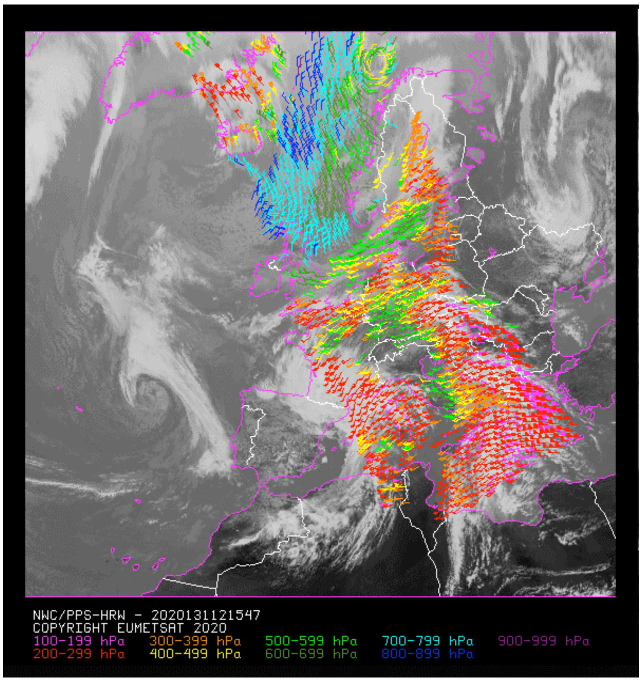


Figure 21: NWC/PPS-High Resolution Winds v7.Q "Basic AMV" output example in the region "EUROPA" (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model configuration file. Colour coding based on the AMV pressure level*

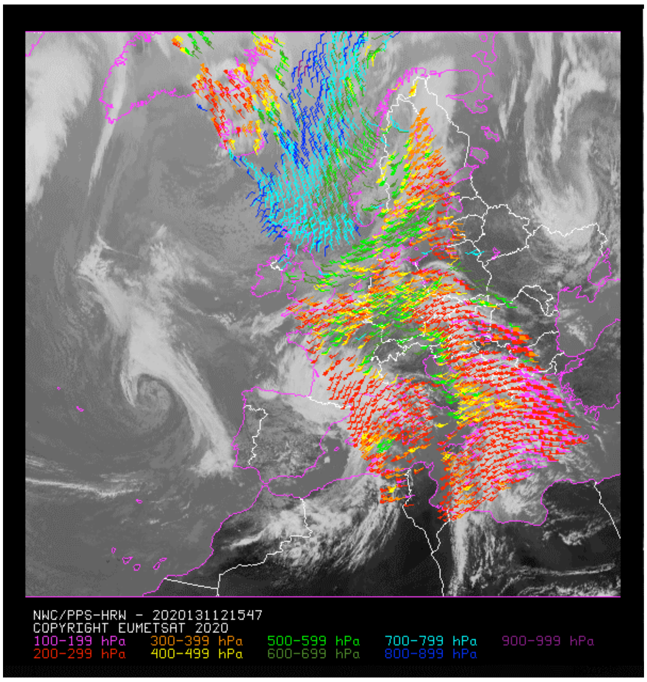


Figure 22: NWC/PPS-High Resolution Winds v7.Q "Detailed AMV" output example in the region "EUROPA" (10 May 2020 12:15:47 UTC for NOAA-20 satellite, with tracers calculated at 11:55:19 UTC for EOS-2 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` *model configuration file and configurable parameter CDET=1. Colour coding based on the AMV pressure level*

2.3.7 Use 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]).

2.3.7.1 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`), to be stored in `$SAFNWC/bin` directory, such as defined in [AD.3].

2.3.7.2 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 product 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 2.2.2.2 of this ATBD. 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 values) 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 values) 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:

```
PPS-HRW-v7P <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 all this, *Figures 23 to 25* 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.

2.3.7.3 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, the main goal of all functions of NWC/PPS-HRW algorithm and their relationships is also provided in a "Diagram tree" shown in *Table 20*. This Diagram tree allows NWC/PPS users and developers to quickly know at a glance how the algorithm works, and where each process is considered.

To be noticed, this "Diagram tree" includes all functions for both NWC/GEO-HRW and NWC/PPS-HRW, and is valid at the same time for both implementations. Common functions for both implementations are shown in white; specific functions for NWC/PPS-HRW are shown in green; specific functions for NWC/GEO-HRW are shown in yellow.

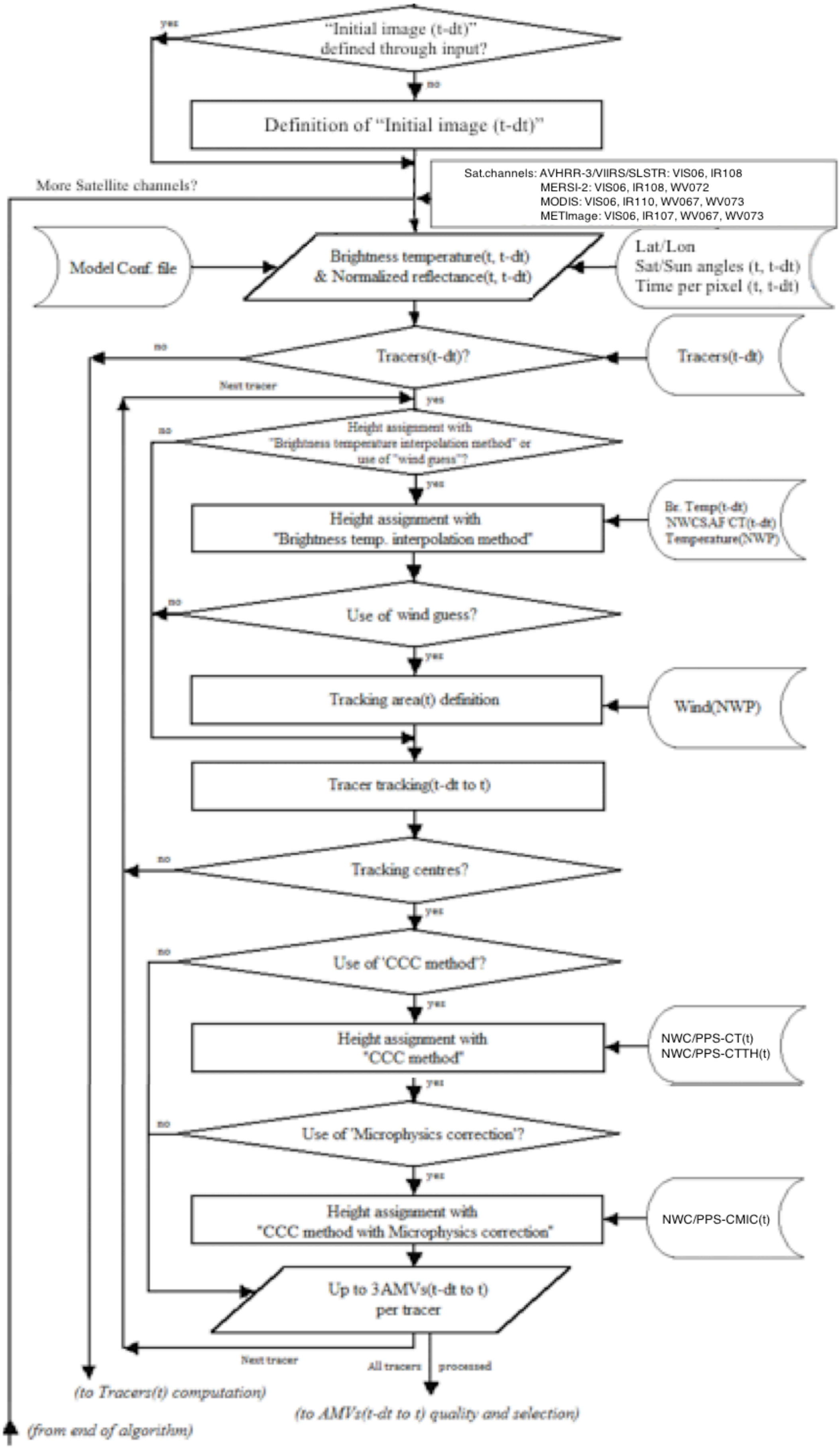


Figure 23: NWC/PPS-HRW implementation: Part 1, Preprocessing and AMV computation

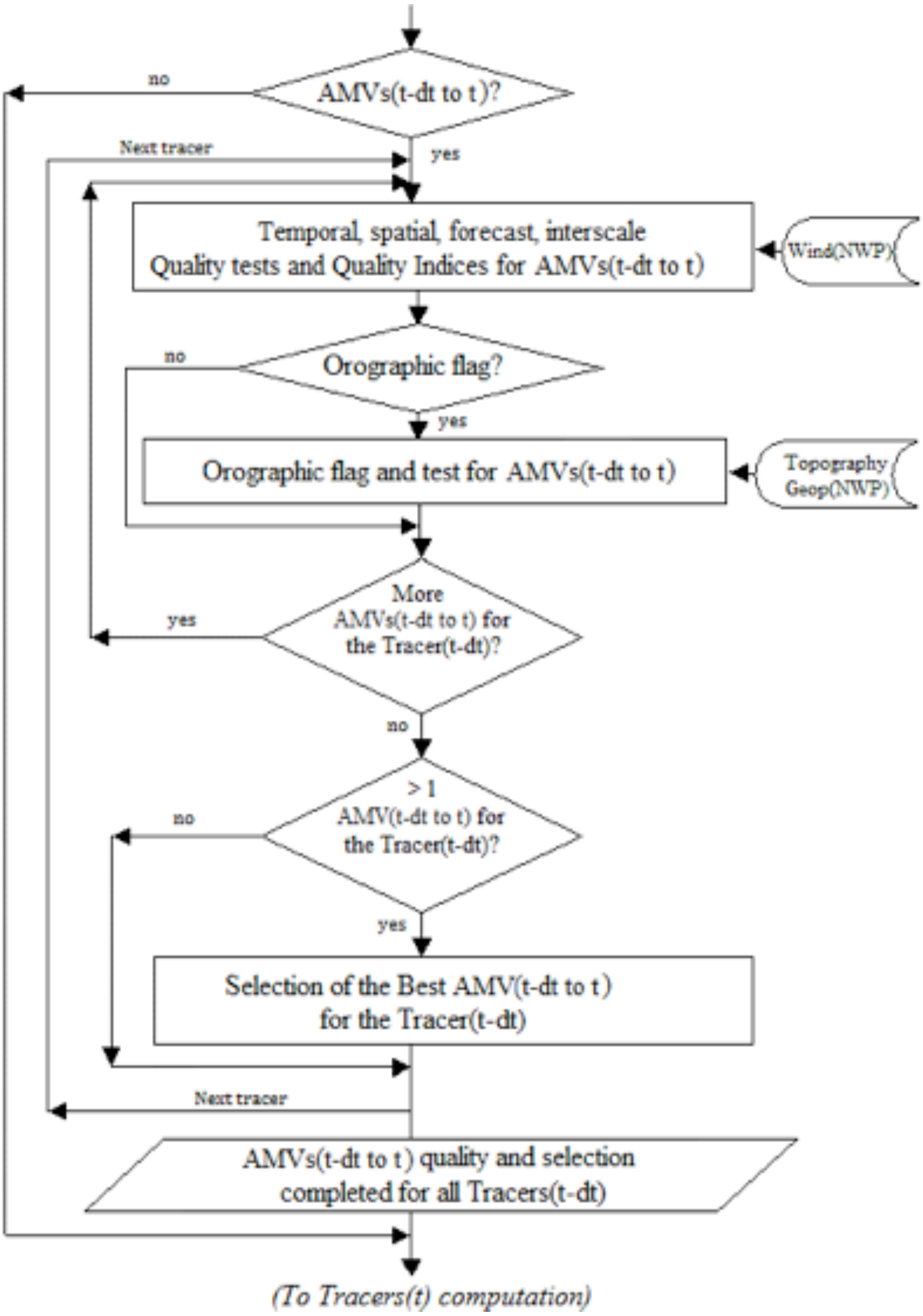


Figure 24: NWC/PPS-HRW implementation: Part 2, AMV quality and selection

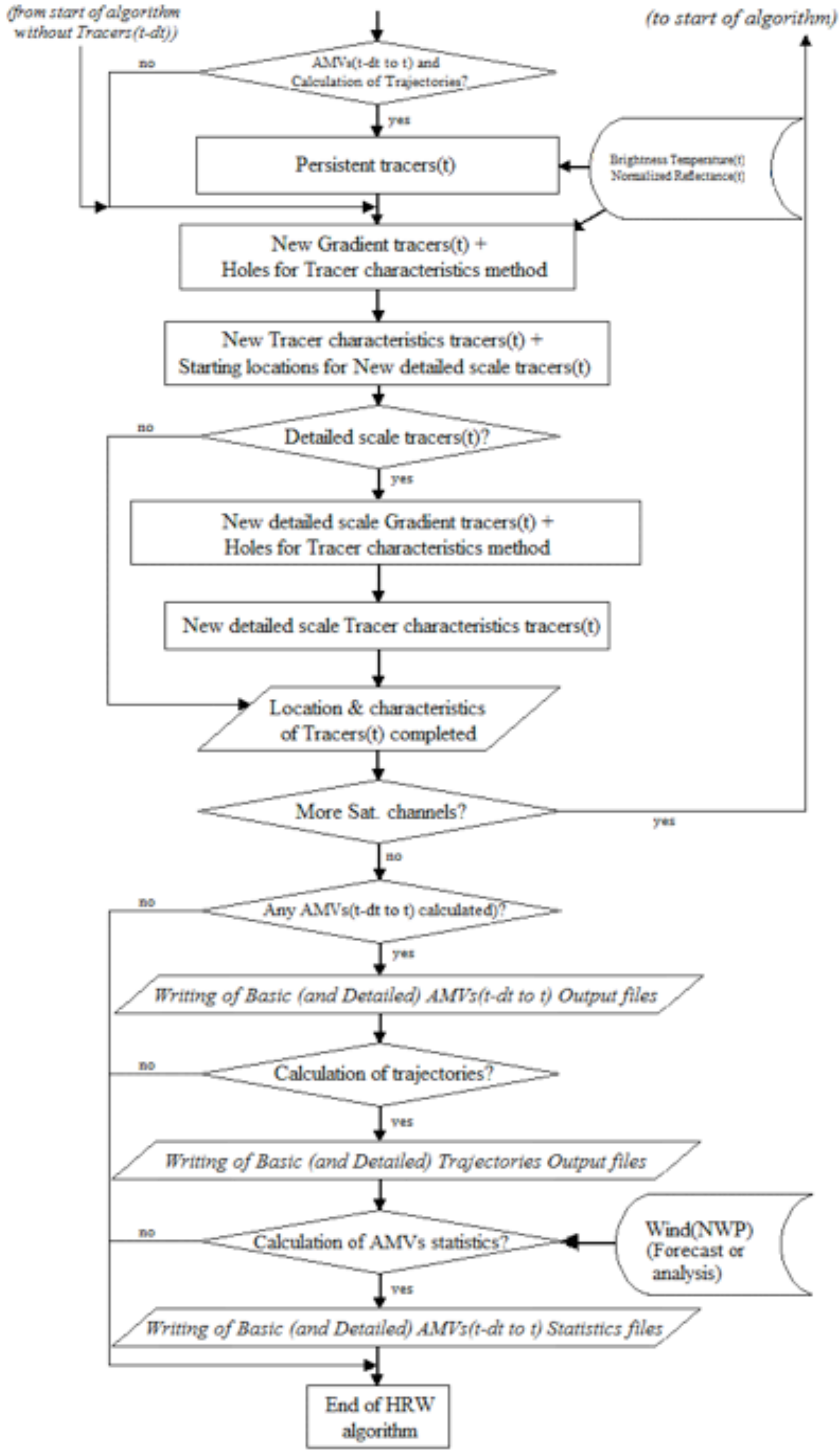


Figure 25: NWC/PPS-HRW implementation: Part 3, Tracer computation and writing of output

Table 20: Diagram Tree of NWC/GEO-HRW and NWC/PPS-HRW functions

HRW.c	=> Main NWC/HRW function, for the generation of the High Resolution Winds AMVs and Trajectories
*** NwcPPSRegionSet	=> In NWC/PPS, reads from “satellite files” parameters defining “Satellite_info” and “Region” structs
*** hrw_ReadDataPPS	=> In NWC/PPS, reads specific parameters for PPS from the NWC/HRW “model configuration file”
***_hrw_DefinePreviousSlotPPS	=> In NWC/PPS, the best processing option for “initial image” is decided when not defined by the user
*** NwcPPSProdReadDataQSigned	=> In NWC/PPS, “satellite zenith angle” is read for later/initial images to calculate common scanning
*** NwcPPSProdReadStatic	=> In NWC/PPS, “elevation” and “pixel dimension” are read from “physiography static file”
*** NwcTimeDiff	=> In NWC/PPS, calculates “repeating cycle” and “error” with the nominal time for initial/later image
*** NwcCFReadSat	=> In NWC/GEO, reads from the “satellite configuration file” parameters for “Satellite_info” struct
*** NwcRegionSet	=> In NWC/GEO, reads from the “region configuration file” parameters defining “Region” struct
*** hrw_ReadData	=> Reads the values of variables defined in the NWC/HRW “model configuration file”
*** hrw_TimeSetStr	=> In NWC/GEO, reads the “later image time” directly from the input command
*** hrw_TimeAdd	=> In NWC/GEO, calculates “initial image time” with “later image time” and configuration parameters
*** NwcSatInit	=> In NWC/GEO, initializes Satellite data
*** hrw_ReadSatelliteData	=> Reads Satellite data (VIS Reflectances, WV/IR Brightness temperatures)
*** NwcPPSProdReadOpen	=> In NWC/PPS, opens “satellite file” for reading of “satellite bands” for initial and later image
*** NwcPPSProdReadDataImage	=> In NWC/PPS, reads one “satellite band” from “satellite file”
*** NwcSatReadBand	=> In NWC/GEO, reads one “satellite band” from satellite input data
*** hrw_GetAncillaryDataPPS	=> In NWC/PPS, gets latitude/longitude/satellite and solar zenith angles for the pixels in the region
*** NwcPPSNavGetLatLon	=> In NWC/PPS, gets latitude/longitude for the pixels in the working region
*** NwcPPSNavGetSatAngles	=> In NWC/PPS, gets satellite zenith angles in initial and later image for the pixels in the region
*** NwcPPSNavGetSunAngles	=> In NWC/PPS, gets solar zenith angles in initial and later image for the pixels in the region
*** hrw_GetAncillaryData	=> In NWC/GEO, gets latitude/longitude/satellite and solar zenith angles for the pixels in the region
*** NwcNavGetLatLon	=> In NWC/GEO, gets latitude/longitude for the pixels in the working region
*** NwcNavGetSatAngles	=> In NWC/GEO, gets satellite zenith angles for the pixels in the working region
*** NwcNavGetSunAngles	=> In NWC/GEO, gets solar zenith angles in initial and later image for the pixels in the region
*** hrw_ImageCheckingInfrared	=> Checks and redefines Satellite brightness temperature/radiance values
*** hrw_ImageChecking	=> Checks and redefines Satellite image values
*** NwcNwpReadPLevel	=> Defines the NWP pressure level list from “NWP configuration file”
*** NwcPPSNWPDefine	=> In NWC/PPS, defines the specific “NWP input files” used in the processing
*** NwcPPSNWPInterpolate	=> In NWC/PPS, reads and temporally interpolates the NWP variables used in the processing
*** NwcPPSNWPInterpolateSurface	=> In NWC/PPS, reads and temporally interpolates the NWP surface pressure used in the processing
*** hrw_NWPSearch	=> In NWC/GEO, reads the NWP data related to one NWP parameter
*** hrw_NWPSearchSurface	=> In NWC/GEO, reads the NWP data related to NWP surface pressure
*** NwcNwpInitProfile	=> Initializes NWP profile variables used in the processing
*** hrw_TimeAdd	=> In NWC/PPS, transforms time to calculate the corresponding “NWP Analysis time”

```
*** NwcPPSAuxReadGridF                                 => In NWC/PPS, reads the "Significant Surface matrices" from $SM_STATIC_AUXILIARY_DIR directory
*** NwcPPSProdReadOpen                                 => In NWC/PPS, opens corresponding "NWC/PPS-CT/CTTH" output files from $SM_PRODUCT_DIR directory
*** NwcAuxReadGridF                                    => In NWC/GEO, reads the "Significant Surface matrices" from $SM_HRWTEMP_DIR directory
*** NwcProdReadOpen                                    => In NWC/GEO, opens corresponding "NWC/GEO-CT/CTTH/CMIC" output files from $SAFNWC/export directory
*** NwcProdReadDataC                                   => Reading of CT/Cloud type and CMIC/Cloud phase for HRW processing
*** NwcProdReadDataQ                                   => Reading of CTTH/Pressure/Temperature/Height and CMIC/Liquid and Ice Water paths for HRW processing
*** NwcProdReadClose                                   => Closes "NWC/GEO-CT/CTTH/CMIC" output files
*** hrw_ReadTracers                                    => Reads the Tracer data from a file located in $SAFNWC/tmp directory
*** hrw_ReadPredWinds                                  => Reads the Predecessor AMV data from a file located in $SAFNWC/tmp directory
*** hrw_ReadTrajectories                               => Reads the Trajectory data from a file located in $SAFNWC/tmp directory
*** hrw_GetWinds                                       => Calculates the AMVs for the current image considering the tracers calculated previously
     *** NwcPPSProdReadOpen                            => In NWC/PPS, opens "sunsatangles file" for reading or "time_per_pixel" for initial and later image
     *** NwcProdReadDataD                              => In NWC/PPS, reads "time_per_pixel" for initial and later image from "sunsatangles file"
     *** NwcProdReadClose                              => In NWC/PPS, closes "sunsatangles file"
     *** NwcTimeDiff                                   => In NWC/PPS, calculates the time difference for the Tracer location between the initial/later image
     *** hrw_Alloc_Winds                               => Allocates memory for variables used in hrw_GetWinds module
     *** hrw_TracerCharacteristics                     => Stores "tracer" variable information into the corresponding "tracer_wind" variable
     *** hrw_SetModifTempGridValues                    => Fills "modiftempgrid" with IR/WV BT values for the "Brightness temperature height assignment"
     *** hrw_GetCldhgt                                 => Calculates Tracer Top temperature/pressure with "Brightness temperature height assignment"
          *** hrw_NWPInvInterpolation                  => Converts the Tracer top Temperature to Pressure using NWP data
     *** hrw_SetImageGridValues                        => Fills "imagegrid" with VIS Reflectances or IR/WV BT values in the tracer position
     *** hrw_CalcTempCloudtype                         => Recalculates Tracer temperature mean/sigma with Cloud type info (for Tracer base temperature)
     *** hrw_NWPInvInterpolation                       => Converts Tracer base Temperature to pressure using NWP data and modified mean/sigma values
     *** hrw_TracerWindLevel                           => Defines the Tracer pressure level (with cloud top or cloud base) depending on its cloud type
     *** hrw_NWPDirInterpolation                       => Calculates the tracer pressure level using the tracer temperature
     *** hrw_WindGuess                                 => Calculates the NWP wind guess at the tracer position
          *** hrw_NWPDirInterpolation                  => Calculates the NWP wind at the tracer level considering the AMV pressure level calculated
          *** hrw_WindModDir                           => Calculates the speed module and direction for the NWP wind guess at the tracer position
     *** NwcNavGetPixelTime                            => In NWC/GEO, calculates "time_per_pixel" for initial and later image
     *** NwcTimeDiff                                   => In NWC/GEO, calculates the time difference for the Tracer location between the initial/later image
     *** hrw_WindDisplace                              => Calculates the tracking centre position forecast in the later image with the NWP wind guess
          *** hrw_WindModDir                           => Calculates the speed module and direction for the NWP wind guess at the tracer position
          *** NwcPPSNavConvertLL2XY                    => In NWC/PPS, converts a Latitude/Longitude position to Line/Column position in the working region
          *** NwcNavConvertLL2XY                       => In NWC/GEO, converts a Latitude/Longitude position to Line/Column position in the working region
```

```
*** hrw_TrueTrackCentre                              => Calculates the true tracking centre position in the later image
     *** hrw_SetImageArrayValues                     => Fills an array with VIS Reflectances or IR/WV BTs in tracer/tracking position for the tracking
     *** hrw_SetCTTHMicroArrayValues                 => Fills an array with CTTH Temperature/pressure/height, CMIC Liquid/Ice water path for "CCC method"
     *** hrw_SetCtypeArrayValues                     => Fills an array with CT Cloud type/CMIC Cloud phase for "CCC method" height assignment
     *** hrw_Track                                   => Calculates the true tracking positions in later image with "Euclidean distance/Cross correlation"
          *** hrw_TrackCorrInitial                   => Computes the tracking first step considering only pixels separated by a gap interval
          *** hrw_TrackCorrBetter                    => Calculates the Euclidean distance minimums/Correlation maximums considering the previous positions
          *** hrw_TrackCorrAround                    => Calculates the Euclidean distance/Correlation values only around the previous minimums/maximums
          *** hrw_TrackCorrCentres                   => Defines the Euclidean distance minimum centres/Correlation maximum centres
               *** hrw_TrackCorrCentresPosition      => Defines a non integer position of the Tracking centres through a quadratic interpolation
     *** hrw_GetSegmentSize                          => Computes the line and column dimension of the tracer in m
*** hrw_TrackCentreCharacteristics                   => Calculates the "tracer characteristics" in the Tracking centres in the later image
     *** hrw_SetImageGridValues                      => Fills an array with VIS Reflectances or IR/WV BTs in the Tracking centres
     *** hrw_Frontier_Centile                        => Defines the frontier in the BT/Reflectance histogram considering a given centile
     *** hrw_Centile_Frontier                        => Defines the centile in the BT/Reflectance histogram considering a given frontier
     *** hrw_TracerDiffSearch                        => Runs the “Big pixel brightness variability test” in the Tracking centres
          *** hrw_TracerPixelCharacterization        => Calculates the “Big pixel brightness values” in the Tracking centres
          *** hrw_TracerHorizontalDiff               => Considers the Line direction study in the “Big pixel brightness variability test”
          *** hrw_TracerVerticalDiff                 => Considers the Column direction study in the “Big pixel brightness variability test”
          *** hrw_TracerDescDiff                     => Considers the Descending direction study in the “Big pixel brightness variability test”
          *** hrw_TracerAscDiff                      => Considers the Ascending direction study in the “Big pixel brightness variability test”
     *** hrw_SetTempGridValues                       => Fills “tempgrid” with IR/WV BT values in the Tracking centres
     *** hrw_CalcTemp                                => Calculates the temperature mean/sigma in the Tracking centres
     *** hrw_TrackCentreCorrection                   => Evaluates if the reference tracking centre must be changed or not
          *** hrw_TracerDiffSearch                   => Reruns the “Big pixel brightness variability test” in the Tracking centres with new frontiers
               *** hrw_TracerPixelCharacterization   => Calculates the “Big pixel brightness values” in the tracking centres with new frontiers
               *** hrw_TracerHorizontalDiff          => Considers the Line direction study in the “Big pixel brightness variability test”
               *** hrw_TracerVerticalDiff            => Considers the Column direction study in the “Big pixel brightness variability test”
               *** hrw_TracerDescDiff                => Considers the Descending direction study in the “Big pixel brightness variability test”
               *** hrw_TracerAscDiff                 => Considers the Ascending direction study in the “Big pixel brightness variability test”
```

```
    *** hrw_WindCalculation                   => Calculates parameters related to a tracking position, including "CCC method" parameters
       *** hrw_Erase_Wind                     => Erases information stored inside an invalid “wind” data
       *** NwcPPSNavConvertXY2LL              => In NWC/PPS, converts a Line/Column position in the working region to Latitude/Longitude position
       *** NwcNavConvertXY2LL                 => In NWC/GEO, converts a Line/Column position in the working region to Latitude/Longitude position
       *** NwcNavGetPixelTime                 => In NWC/GEO, calculates the time for Tracer in initial image and Tracking position in later image
       *** NwcTimeDiff                        => In NWC/GEO, calculates the time difference between the Tracer and the Tracking position
       *** hrw_NWPInvInterpolation            => Converts Clear air AMV tracking position temperatures to pressure considering NWP data
       *** hrw_NWPDirInterpolation            => Calculates Clear air AMV height considering the NWP geopotential at AMV pressure level
       *** NwcMetParallax                     => In NWC/GEO, initial/final latitude/longitude positions of the AMV are parallax corrected
       *** hrw_Ymvuv                          => Calculates the wind components considering the initial/final latitude/longitude positions
       *** hrw_WindModDir                     => Calculates the wind module and direction for the calculated AMVs
    *** hrw_WindGuess                         => Recalculates the wind guess/analysis at initial/final position for Quality Control and validation
       *** hrw_NWPDirInterpolation            => Calculates the NWP wind at the AMV level considering the final AMV pressure level
       *** hrw_WindModDir                     => Calculates speed module and direction for the NWP wind guess/analysis at initial/final position
    *** hrw_WindModDir                        => Calculates speed module and direction for difference with the NWP wind guess/analysis
    *** hrw_WindGuessBestFit                  => Calculates the wind guess/analysis at best fit level at final position for validation
       *** hrw_WindModDir                     => Calculates speed module and direction for the NWP wind guess at final position
    *** hrw_WindModDir                        => Calculates speed module and direction for difference with the NWP wind guess/analysis at best fit
    *** hrw_Free_Winds                        => Deallocates memory for variables used in hrw_GetWinds module
 *** hrw_Qc                                   => Calculates the Quality indices and the Orographic flag for the calculated AMVs/Trajectories
    *** hrw_QcAlloc_Short, _Float, _Parameters => Three functions allocating memory for variables in hrw_Qc module
    *** hrw_QcSortLatitude                    => Sorts the current and predecessor AMV data considering their latitudes in their final positions
       *** hrw_QcSort                         => Sorts an array of data considering one of its variables
          *** hrw_QcSortCompare               => Decides how to compare the elements to be sorted
    *** hrw_QcPhase1                          => Calculates the individual (forecast/temporal/spatial) quality tests and total quality indices
       *** hrw_QcPhase1_Alloc                 => Allocates memory for variables in hrw_QcPhase1 module
       *** hrw_QcGetSpatialTest               => Calculates the spatial quality test for a defined AMV
       *** hrw_QcGetTemporalTest              => Calculates the temporal quality test for a defined AMV
          *** hrw_WindModDir                  => Calculates the speed and direction for the predecessor AMV data
       *** hrw_QcPhase1_Free                  => Deallocates memory for variables in hrw_QcPhase1 module
    *** hrw_Meters2Press                      => Converts Orographic data to Surface pressure data
       *** hrw_NWPInvInterpolation            => Converts Geopotential to Surface pressure data using NWP data
    *** hrw_IndTopoAssign                     => Calculates the Static orographic flag at the initial position of a current AMV
    *** hrw_IndTopoReassign                   => Calculates the Dynamic orographic flag at the initial position of a current AMV
    *** hrw_QcBestWindSelection               => Selects the best AMV for each tracer and calculates the quality flags
    *** hrw_FinalControlCheck                 => Runs a Final speed and direction homogeneity check for the AMVs
```

```
    *** hrw_ProcessforQcCommonIWWG                    => Prepares for the running of self-contained module for calculation of the IWWG Common Quality Index
        *** hrw_QcCommonIWWG_Function                 => Runs the EUMETSAT/NOAA self-contained module for calculation of the IWWG Common Quality Index
    *** hrw_QcFree_Short, _Float, _Parameters         => Three functions deallocating memory for variables in hrw_Qc modul
*** hrw_WritePredWinds                                => Writes the AMV data file for the current image in $SAFNWC/tmp directory
*** hrw_WriteTrajectories                             => Writes the Trajectory data file for the current image in $SAFNWC/tmp directory
*** hrw_WriteWindChannelInfo                          => Writes all AMV/Trajectory info in "wind_channel_info" data, calculating the AMV channel statistics
    *** hrw_CalculateChannelStatistics                => Calculates the AMV validation statistics for one satellite channel, using NWP forecast or analysis
        *** hrw_Ymvuv                                 => Calculates the wind components considering the initial/final latitude/longitude positions
*** NwcPPSProdReadOpen                                => In NWC/PPS, opens corresponding “NWC/PPS-CT” output file from $SM_PRODUCT_DIR directory
*** NwcProdReadOpen                                   => In NWC/GEO, opens corresponding “NWC/GEO-CT” output file from $SAFNWC/export directory
*** NwcProdReadDataC                                  => CT/Cloud type read for processing by hrw_GetTracers function
*** NwcProdReadClose                                  => Closes “NWC/GEO-CT” output file
*** hrw_GetTracers                                    => Calculates the tracers for the current image
    *** hrw_Alloc_Tracers                             => Allocates memory for variables in hrw_GetTracers module
    *** hrw_SetImageGridValues                        => Fills “imagegrid” with VIS Reflectances or IR/WV BTs in a tracer position for the tracer search
    *** hrw_SearchTracerGradient                      => Looks for tracers considering the “Gradient method”
        *** hrw_GradientMax                           => Calculates the tracer position considering the gradient maximum
        *** hrw_SetImageGridValues                    => Fills “modifimagegrid” with VIS Reflectances or IR/WV BTs in the modified tracer position
        *** hrw_Hisfron                               => Computes the VIS Reflectance or IR/WV BT histogram in the tracer area and its frontiers
        *** hrw_SetTempGridValues                     => Fills “tempgrid” with IR/WV BT values in the modified tracer position
        *** hrw_CalcTemp                              => Calculates the temperature mean/sigma in the modified tracer position
    *** hrw_SearchTracerCharacteristics               => Looks for tracers considering the “Tracer characteristics method”
        *** hrw_SetImageGridValues                    => Fills “imagegrid” with VIS Reflectances or IR/WV BTs in a tracer position for the tracer search
        *** hrw_Hisfron                               => Computes the VIS Reflectance or IR/WV BT histogram in the tracer area and its frontiers
        *** hrw_SetTempGridValues                     => Fills “tempgrid” with IR/WV BT values in the tracer position
        *** hrw_CalcTemp                              => Calculates the temperature mean/sigma in the tracer position
        *** hrw_TracerDiffSearch                      => “Big pixel brightness variability test”, run here for “Tracer characteristics method” tracers
            *** hrw_TracerPixelCharacterization       => Calculates the “Big pixel brightness values” in the tracer position
            *** hrw_TracerHorizontalDiff              => Considers the Line direction study in the “Big pixel variability test”
            *** hrw_TracerVerticalDiff                => Considers the Column direction study in the “Big pixel variability test”
            *** hrw_TracerDescDiff                    => Considers the Descending direction study in the “Big pixel variability test”
            *** hrw_TracerAscDiff                     => Considers the Ascending direction study in the “Big pixel variability test”
        *** hrw_SetImageGridValues                    => Refills “imagegrid” with VIS Reflectances or IR/WV BTs if the previous candidate was not good
```

```
          *** hrw_TracerDiffSearch                         => "Big pixel brightness variability test", rerun here for new "Tracer characteristics method" tracer
               *** hrw_TracerPixelCharacterization         => Calculates the "Big pixel brightness values" in the modified tracer position
               *** hrw_TracerHorizontalDiff                => Considers the Line direction study in the "Big pixel variability test"
               *** hrw_TracerVerticalDiff                  => Considers the Column direction study in the "Big pixel variability test"
               *** hrw_TracerDescDiff                      => Considers the Descending direction study in the "Big pixel variability test"
               *** hrw_TracerAscDiff                       => Considers the Ascending direction study in the "Big pixel variability test"
     *** hrw_CloudTypeCalculation                          => Calculates the Cloud type related to the tracer
     *** hrw_TracerDiffSearch                              => "Big pixel brightness variability test", run here for "Gradient method" tracers
                    *** hrw_TracerPixelCharacterization => Calculates the "Big pixel brightness values" in the tracer position
                    *** hrw_TracerHorizontalDiff           => Considers the Line direction study in the "Big pixel brightness variability test"
                    *** hrw_TracerVerticalDiff             => Considers the Column direction study in the "Big pixel brightness variability test"
                    *** hrw_TracerDescDiff                 => Considers the Descending direction study in the "Big pixel brightness variability test"
                    *** hrw_TracerAscDiff                  => Considers the Ascending direction study in the "Big pixel brightness variability test"
     *** hrw_TracersDetailedDiscrimination                 => Defines if a Basic tracer can also work as Detailed tracer
     *** hrw_Centile_Frontier                              => Defines the centile in the BT/Reflectance histogram considering a given frontier
     *** hrw_Free_Tracers                                  => Deallocates memory for variables in hrw_GetTracers module
*** hrw_WriteTracers                                       => Writes the Tracer data file for the current image in $SAFNWC/tmp directory
*** hrw_Free_Satellite                                     => Deallocates memory for Satellite data
     *** NwcSatFreeBand                                    => Deallocates memory for the different satellite bands used
*** hrw_Free_TWinds                                        => Deallocates memory for "tracer wind" data
*** hrw_Free_PredWinds                                     => Deallocates memory for "predecessor_wind" data
*** hrw_Free_Trajectories                                  => Deallocates memory for "trajectory" data
*** hrw_Free_LevelsandGuesses                              => Deallocates memory for NWP variables
*** NwcNwpFreeProfile                                      => Deallocates memory for NWP profiles
*** hrw_CalculateTotalStatistics                           => Calculates the AMV total statistics respect to the related NWP model analysis/forecast winds
     *** hrw_Ymvuv                                         => Calculates the wind components considering the initial/final latitude/longitude positions
*** hrw_EncodeBufrNWCEC                                    => Writes the "AMV/Trajectory BUFR output file with NWCSAF template"
     *** hrw_EncodeAllChannelsforBUFRNWCEC                 => Writes information for all AMVs/Trajectories related to "Basic/Detailed scale" in the BUFR output
          *** hrw_SetChannelInfoforBUFRNWCEC               => Writes information for all AMVs related to one satellite channel in the BUFR output
               *** hrw_SetAMVInfoforBUFRNWCEC              => Writes information for one AMV in the "AMV BUFR output file"
                    *** hrw_Ymvuv                          => Calculates wind components for AMVs calculated with "mixed scanning" process
                    *** hrw_WindModDir                     => Calculates speed module and direction for AMVs calculated with "mixed scanning" process
          *** hrw_SetChannelInfoforBUFRTRAJEC              => Writes information for all Trajectories related to one satellite channel in the BUFR output
               *** hrw_SetTrajectoryInfoforBUFRTRAJEC      => Writes information for one Trajectory in the BUFR output
```

```
 *** hrw_EncodeBufrIWWGEC                             => Writes the "AMV BUFR output file with new IWWG template"
      *** hrw_EncodeAllChannelsforBUFRIWWGEC          => Writes information for all AMVs related to "Basic/Detailed scale" in the BUFR output file
           *** hrw_SetChannelInfoforBUFRIWWGEC        => Writes information for all AMVs related to one satellite channel in the BUFR output file
                *** hrw_SetAMVInfoforBUFRIWWGEC       => Writes information for one AMV in the BUFR output file
                     *** hrw_Ymvuv                    => Calculates wind components for AMVs calculated with "mixed scanning" process
                     *** hrw_WindModDir               => Calculates speed module and direction for AMVs calculated with "mixed scanning" process
*** hrw_DefineGlobalAtt                               => Defines the Global Attributes for the AMV netCDF output file
 *** hrw_EncodeNetCDFNew                              => Writes the AMV netCDF output file in $SAFNWC/export/HRW directory
     *** hrw_WriteGlobalAtt                           => Writes the Global Attributes in the AMV netCDF output file
     *** hrw_WriteNetCDFNew                           => Calls the different functions filling the sections that compose the netCDF bulletin
           *** hrw_Netcdfwindsecver_Initialize        => Initializes a "netcdfwindsecver struct" with all netCDF dimensions/variables/attributes
           *** hrw_WriteNcVarNew                      => Fills "netcdfwindsecver struct" with all related data
                *** hrw_SetWindNetCDF                 => Defines specific information for each AMV in the netCDF bulletin
                     *** hrw_Ymvuv                    => Calculates the wind components considering the initial/final latitude/longitude positions
                     *** hrw_WindModDir               => Calculates the speed module and direction of the mean AMV for its writing in the netCDF output
                *** hrw_Netcdfwindsecver_Fill         => Fills all netCDF dim/Sensions/variables/attributes for the netCDF output file
           *** hrw_Netcdfwindsecver_Write             => Writes all netCDF dimensions/variables/attributes in the netCDF output file
           *** hrw_Netcdfwindsecver_Free              => Frees "netcdfwindsecver struct"  with all netCDF dimensions/variables/attributes data
 *** hrw_WriteStatistics                              => Writes the AMV validation statistics in the HRW log file and the Statistics output file
 *** hrw_Free_WindData                                => Deallocates memory for "wind_channel_info" data
      *** hrw_Free_TWinds                             => Deallocates memory for "tracer wind" data
      *** hrw_Free_PredWinds                          => Deallocates memory for "predecessor_wind" data
      *** hrw_Free_Trajectories                       => Deallocates memory for "trajectory" data
 *** hrw_Free_Satellite                               => Deallocates memory for satellite data
 *** NwcRegionFree                                    => Deallocates memory for "region" data
```

2.4 ASSUMPTIONS AND LIMITATIONS IN HIGH RESOLUTION WINDS (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 that 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, or 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 in seven 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/PPS-CTTH 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/PPS-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 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.