



EUMETSAT

NWCSAF

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.1



12 October 2021

Applicable to NWC/PPS-HRW v7.P

Applicable to SAFNWC/PPS version 2021



Applicable to the following PGEs:

Acronym	Product ID	Product name	Version number
HRW	<i>(demonstrational)</i>	High Resolution Winds	7.P (demonstrational release)

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 2/94
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REPORT SIGNATURE TABLE

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 	<p>Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS</p>	<p>Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 3/94</p>
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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
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List of contents

1. INTRODUCTION	8
1.1 SCOPE OF THE DOCUMENT	8
1.2 SOFTWARE VERSION IDENTIFICATION	9
1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS	9
1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS	10
1.4.1. <i>Definitions</i>	10
1.4.2. <i>Acronyms and Abbreviations</i>	14
1.5 REFERENCES	15
1.5.1 <i>Applicable documents</i>	15
1.5.2 <i>Reference Documents</i>	16
2. DESCRIPTION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW).....	17
2.1 GOAL OF HIGH RESOLUTION WINDS (NWC/PPS-HRW).....	17
2.2 THEORETICAL DESCRIPTION OF HIGH RESOLUTION WINDS (NWC/PPS-HRW)	19
2.2.1 <i>Physics of the problem</i>	19
2.2.2 <i>Mathematical Description of High Resolution Winds (NWC/PPS-HRW)</i>	20
2.2.2.1 Outline of the Software	20
2.2.2.2 Preprocessing.....	21
2.2.2.3 Tracer search	23
2.2.2.4 Tracer tracking	28
2.2.2.5 “Brightness temperature interpolation method” height assignment.....	32
2.2.2.6 “CCC method” height assignment (Cloudy cases).....	34
2.2.2.7 “CCC method” height assignment (Cloudy cases with Microphysics correction)	37
2.2.2.8 “CCC method” height assignment (Water vapour clear air cases)	37
2.2.2.9 Wind calculation.....	39
2.2.2.10 Quality control and Choice of the best wind.....	40
2.2.2.11 Orographic flag.....	44
2.2.2.12 Final Control Check and Output data filtering.....	46
2.3 PRACTICAL CONSIDERATIONS ON HIGH RESOLUTION WINDS (NWC/PPS-HRW).....	47
2.3.1 <i>Validation of High Resolution Winds (NWC/PPS-HRW)</i>	47
2.3.1.1 Validation of NWC/PPS-HRW for Polar satellites.....	48
2.3.1.2 Autovalidation process of NWC/PPS-HRW software	52
2.3.2 <i>List of Inputs for High Resolution Winds (NWC/PPS-HRW)</i>	54
2.3.3 <i>List of Configurable parameters for High Resolution Winds (NWC/PPS-HRW)</i>	56
2.3.4 <i>List of Errors for High Resolution Winds (NWC/PPS-HRW)</i>	60
2.3.5 <i>Outputs of High Resolution Winds (NWC/PPS-HRW)</i>	63
2.3.5.1 HRW output as BUFR bulletins with NWC SAF specific format (AMVs)	64
2.3.5.2 HRW output as BUFR bulletins with NWC SAF specific format (Trajectories)	68
2.3.5.3 HRW output as BUFR bulletins with the previous IWWG format (AMVs)	70
2.3.5.4 HRW output as BUFR bulletins with the 2018 IWWG format (AMVs).....	71
2.3.5.5 HRW output as netCDF bulletin	75
2.3.6 <i>Examples of High Resolution Winds (NWC/PPS-HRW)</i>	78
2.3.7 <i>Use of High Resolution Winds (NWC/PPS-HRW)</i>	80
2.3.7.1 Installation and preparation of NWC/PPS Software package.....	80
2.3.7.2 Running of High Resolution Winds (NWC/PPS-HRW).....	80
2.3.7.3 Documentation of High Resolution Winds (NWC/PPS-HRW).....	85
2.4 ASSUMPTIONS AND LIMITATIONS IN HIGH RESOLUTION WINDS (NWC/PPS-HRW).....	93



List of Tables

Table 1: List of Definitions	13
Table 2: List of Acronyms and Abbreviations	14
Table 3: List of Applicable Documents.....	15
Table 4: List of Reference Documents	16
Table 5: Possible values of the “AMV cloud type” parameter.....	33
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.....	33
Table 7: Validation parameters for NWC/PPS-HRW v7.P 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; Feb 2020-Apr 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.	49
Table 8: Validation parameters for NWC/GEO-HRW v6.1 AMVs (latest NWC/GEO-HRW version), considering all layers together, against Radiosounding winds in light blue and against ECMWF NWP analysis winds in dark blue. (Basic AMVs in nominal configuration; Jul 2009-Jun 2010 at 12:00 UTC; MSG-2 satellite; “European and Mediterranean” region).	49
Table 9: Validation parameters for NWC/PPS-HRW v7.P 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; Feb 2020-Apr 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.....	50
Table 10: Validation parameters for NWC/GEO-HRW v6.1 AMVs (latest NWC/GEO-HRW version), 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; Jul 2009-Jun 2010 at 12:00 UTC; MSG-2 satellite; “European and Mediterranean” region).....	51
Table 11: NWC/PPS-HRW v7.P Model Configuration File Description	59
Table 12: List of errors for NWC/PPS-HRW-v7.P software	62
Table 13: Variables used for the AMV output with the “NWC SAF specific BUFR format”	66
Table 14: Description of “local specific variables” in the “NWC SAF specific BUFR format”	67
Table 15: Variables used for the Trajectory output with the “NWC SAF specific BUFR format”	69
Table 16: Variables used for the AMV output with the “2018 IWWG BUFR format”	74
Table 17: High Level specification of the NWC/PPS-HRW netCDF output.....	75
Table 18: Detailed specification of the NWC/PPS-HRW netCDF output	77
Table 19: Diagram Tree of NWC/GEO-HRW and NWC/PPS-HRW functions.....	86

List of Figures

- Figure 1: Example of “N_Value matrix histogram” (unsmoothed in violet and smoothed in pink) for a valid Low resolution visible “tracer candidate”. The minimum brightness threshold, the algorithm centiles and the defined frontier are also shown25
- Figure 2: Example of running of the ‘Big pixel brightness variability test’ for a valid tracer candidate25
- 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 16 with the default \$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm model configuration file (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite)27
- 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 16 and 17 with the default \$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm model configuration file and parameter CDET=1 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite).....27
- 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 model29
- Figure 6: AMVs considering the satellite channel used for the AMV calculation, for the NWC/PPS-HRW example defined in Figure 16 (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”).....31
- Figure 7: AMVs considering the satellite channel used for the AMV calculation, for the NWC/PPS-HRW example defined in Figure 18 (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 “EUROPA”)31
- Figures 8 and 9: 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 row36
- Figure 10: “AMV cloud type values” (as defined by “CCC method height assignment”) for the NWC/PPS-HRW example defined in Figure 16 (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”).....38

Figure 11: AMV height assignment (“CCC method height assignment using high/low calculation threshold”), for the NWC/PPS-HRW example defined in Figure 16 (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”)	38
Figure 12: “Quality index with forecast” for the NWC/PPS-HRW example defined in Figure 16 (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”). Only values of “Quality index with forecast” $\geq 80\%$ are present, because of the use of this parameter for the AMV filtering.....	42
Figure 13: “Quality index without forecast” for the NWC/PPS-HRW example defined in Figure 16 (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”). 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” $\geq 75\%$ are really present for this example.....	42
Figure 14: “Common Quality index without forecast” for the NWC/PPS-HRW example defined in Figure 16 (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”). All values are possible for the “Common Quality index without forecast”. The difference with Figures 12 and 13, and the fact that only a part of AMVs has a valid value for the “Common Quality index without forecast” (a 5% of AMVs for this example) are to be noticed.	43
Figure 15: 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 16 (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”).	45
Figure 16: NWC/PPS-High Resolution Winds “Basic AMV” output example in the region “EURON1 - Scandinavia” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 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.....	78
Figure 17: NWC/PPS-High Resolution Winds “Detailed AMV” output example in the region “EURON1 - Scandinavia” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 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.....	78
Figure 18: NWC/PPS-High Resolution Winds “Basic AMV” output example in the region “EUROPA” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 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.....	79
Figure 19: NWC/PPS-High Resolution Winds “Detailed AMV” output example in the region “EUROPA” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 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.....	79
Figure 20: NWC/PPS-HRW implementation: Part 1, Preprocessing and AMV computation.....	82
Figure 21: NWC/PPS-HRW implementation: Part 2, AMV quality and selection.....	83
Figure 22: NWC/PPS-HRW implementation: Part 3, Tracer computation and writing of output..	84

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 8/94
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1. INTRODUCTION

The “EUMETSAT Satellite Application Facilities (SAFs)” are dedicated centres of excellence for the processing of satellite data, and form an integral part of the distributed “EUMETSAT Application Ground Segment”. This documentation is provided by the SAF on support to Nowcasting and Very short range forecasting (NWC SAF). The main objective of the NWC SAF 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 NWC SAF 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 Wind Product Processor of the NWC/PPS” software package (NWC/PPS-HRW, 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 or NOAA-20 polar satellites, using 0.672 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 and/or 11.030 μm IR110 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.12], 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.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 9/94
---	--	---

1.2 SOFTWARE VERSION IDENTIFICATION



This document describes the software implemented in the NWC/PPS-HRW v7.P (demonstrational release) of the NWC/PPS v2021 software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

This is the first implementation of NWC/PPS-HRW software, for use with 12 polar satellites including AVHRR/3, VIIRS and MODIS radiometers.

The whole AMV calculation algorithm, and most of the HRW code, derive directly from NWC/GEO-HRW v6.1 software, included in NWC/GEO v2018.1 software package, which is defined for the AMV calculation with MSG, GOES-N, GOES-R and Himawari-8/9 geostationary satellite series. (91% of HRW code is common to both NWC/GEO and NWC/PPS implementations; only 5% of the code is specific to NWC/GEO, and 4% of it is specific to NWC/PPS).



This way, with the application to polar satellites defined here through NWC/PPS-HRW v7.P, the option appears for the first time to calculate AMVs throughout all the world, including polar areas, with the same algorithm (using both implementations HRW v6.1 and v7.P) This is rather uncommon in general, and can be used for example for NWP assimilation of AMVs all throughout the world calculated with the same AMV algorithm, or for climatic studies of the wind throughout all the world.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 10/94
---	--	--



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 three different brightness classes (CLASS_n)
Atmospheric Motion Vector (AMV)	Horizontal wind calculated through the horizontal displacement between two Earth positions in two different satellite images (defined as initial image and later image), of a square segment of 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 reference wind, considering as reference wind the nearest NWP wind profile or nearest Radiosounding wind profile, with a linear variation of the wind components between 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 humidity feature in water vapour images
Closeness threshold	Minimum distance in lines and columns allowed between two tracer locations
Cloud type	Cloud type defined for each tracer or AMV with NWC/PPS-CT 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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 11/94
---	--	--

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 for a given Atmospheric Motion Vector
Initial image	Satellite image in which tracers are defined with any of the two tracer calculation methods (Gradient or Tracer characteristics), so defining the initial position in the AMV 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 NWC/PPS-HRW software, through which the tracer tracking is evaluated considering shorter time intervals, and the displacement is evaluated considering longer time intervals.
Neighbour AMV	AMV which is close enough to a given one in the current processing cycle, used in the Quality spatial correlation test

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 12/94
---	--	--

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 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/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 is 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 NWC/PPS-HRW software both dimensions are similar defining square shaped tracers
Tracking	Determination of the best matching square segment for a given tracer in the initial image, with the same line and column dimension, inside the tracking area of a later image
Tracking area	Square segment in the later image containing the search area of a given tracer, in which all possible tracking candidates are located
Tracking candidate	Each square segment inside a tracking area of the later image, that is evaluated for the tracking of a given tracer
Tracking centre	Best matching square segment for a given tracer, with the same line and column dimension, inside the tracking area of a later image
Tracking centre location	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

AMV	Atmospheric Motion Vector
AVHRR/3	NOAA's Advanced Very High Resolution Radiometer - 3rd Generation
BUFR	Binary Universal Form for the Representation of meteorological data
CDOP2	NWC SAF Second Continuous Development and Operations Phase
CDOP3	NWC SAF Third Continuous Development and Operations Phase
CIMSS	UW's Cooperative Institute for Meteorological Satellite Studies
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
IR108 & IR110	AVHRR/3 and VIIRS 10.8 μ m Infrared channel – MODIS 11.0 μ m Infrared channel
IWWG	International Winds Working Group
Metop-A/B/C	EUMETSAT's Polar Meteorological Operational Satellites, including AVHRR/3 radiometer
MODIS	NASA's Moderate resolution Imaging Spectroradiometer
NASA	United States' National Aeronautics and Space Administration
NOAA	United States' National Oceanic and Atmospheric Administration
NOAA-15/16/17/18/19	NOAA's Polar Operational Environmental Satellites - 5th Generation, including AVHRR/3 radiometer
NOAA-20 & SNPP	NASA and NOAA's Joint Polar Satellite System satellites, including VIIRS radiometer
NWC/GEO	NWC SAF Software Package for Geostationary satellites
NWC/GEO-HRW	NWC/GEO Software Element for the High Resolution Winds
NWC/PPS	NWC SAF Software Package for Polar satellites
NWC/PPS-HRW	NWC/PPS Software Element for the High Resolution Winds
NWC SAF	EUMETSAT's Satellite Application Facility on support to Nowcasting and Very short range forecasting
NWP	Numerical Weather Prediction Model
SCI	NWC SAF Scientific Report
SMR	NWC SAF Software Modification Report
SPR	NWC SAF Software Problem Report
UW	United States' University of Wisconsin/Madison
VIIRS	NASA's Visible/Infrared Imager Radiometer Suite radiometer
VIS06	AVHRR/3, VIIRS and MODIS 0.6 μ m Visible channel
WMO	World Meteorological Organization

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 document referred applies.

Current documentation can be found at the NWC SAF Helpdesk web: <http://www.nwcsaf.org>

<i>Ref.</i>	<i>Title</i>	<i>Code</i>	<i>Version</i>
[AD.1]	Proposal for the Third Continuous Development and Operations Phase (CDOP3)	NWC/CDOP3/SAF/AEMET/MGT/PRO	1.0
[AD.2]	Project Plan for the NWC SAF CDOP3 Phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.5
[AD.3]	Configuration Management Plan for the NWC SAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.1
[AD.4]	NWC SAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.4
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/PPS	NWC/CDOP3/PPS/SMHI/SW/ICD/1	3.0
[AD.6]	User Manual for the NWC/PPS application: Software Part, 2.Operation	NWC/CDOP3/PPS/SMHI/SW/UM/OPER	3.0
[AD.7]	System and Component Requirements Document for the NWC/PPS	NWC/CDOP3/PPS/SMHI/SW/SCRD	2.3
[AD.8]	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind	2.2
[AD.9]	User Manual for the Wind product processor of the NWC/GEO: Software part	NWC/CDOP3/GEO/AEMET/SCI/UM/Wind	1.1
[AD.10]	User Manual for the Wind product processor of the NWC/PPS: Software part	NWC/CDOP3/PPS/AEMET/SCI/UM/Wind	0.1
[AD.11]	Scientific and Validation Report for the Wind product processor of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/VR/Wind	1.1
[AD.12]	Scientific and Validation Report for the Wind product processor of the NWC/PPS	NWC/CDOP3/PPS/AEMET/SCI/VR/Wind	0.1

Table 3: List of Applicable Documents



 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 16/94
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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 document referred 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 4 th 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 5 th 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 8 th 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 9 th 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 10 th 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 3 rd International Wind Workshop, EUMETSAT Pub.18).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3 rd 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 3 rd 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 4 th 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 5 th 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 9 th International Wind Workshop, EUMETSAT Pub.51).
[RD.18]	J.García-Pereda, R.Borde & R.Randriamampianina, 2012: Latest developments in “NWC SAF High Resolution Winds” product (Proceedings 11 th International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (WMO Publication, available at https://www.wmo.int/pages/prog/www/WMOcodes/WMO306_v12/LatestVERSION/WMO306_v12_CommonTable_en.pdf)
[RD.20]	WMO Code Tables and Flag Tables associated with BUFR/CREX table B, version 31 (WMO Publication, available at www.wmo.int/pages/prog/www/WMOcodes/WMO306_v12/PrevVERSIONS/20181107/WMO306_v12_BUFRCREX_CodeFlag_en.pdf)
[RD.21]	P.Lean, G.Kelly & S.Migliorini, 2014: Characterizing AMV height assignment errors in a simulation study (Proceedings 12 th 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 12 th International Wind Workshop, EUMETSAT Pub.63).
[RD.23]	K.Salonen & N.Bormann, 2014: Investigations of alternative interpretations of AMVs (Proceedings 12 th 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 NWC SAF/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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 17/94
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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 or NOAA-20 polar satellites.
- MODIS radiometer inside EOS-1 (Terra) or EOS-2 (Aqua) polar satellites.

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 $n \times n$ pixels. The square segment is defined through a specific cloudiness feature in visible or infrared images (and so called “cloudy AMV”). Water vapour images have not been considered for the calculation of AMVs in this first version of NWC/PPS-HRW software, in contrast to the currently operational version of NWC/GEO-HRW software (HRW v6.1), due to the lack of water vapour channels in both AVHRR/3 and VIIRS radiometers.

“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 $n \times n$ 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 two different types of satellite images:



- Visible images coming from 0.630 μm channel in AVHRR-3 radiometer, 0.672 μm channel in VIIRS radiometer or 0.645 μm channel in MODIS radiometer (VIS06 AMVs).
- Infrared images coming from 10.800 μm channel in AVHRR-3 radiometer, 10.763 μm channel in VIIRS radiometer or 11.030 μm channel in MODIS radiometer (IR108/IR110 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.

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 (NWC SAF)”. 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.

 	<p>Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS</p>	<p>Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 18/94</p>
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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 that of 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.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 19/94
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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 humidity 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 humidity 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 humidity 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.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 20/94
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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 and CTTH) for the same static region that are also 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.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 21/94
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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.6].

For NWC/PPS-HRW all input files share the same naming structure, in which `<satid>=eos1/eos2/metopa/metob/metopc/noaa15/noaa16/noaa17/noaa18/noaa19/noaa20/npp` is the polar satellite related to the scanning, `<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”). Considering this:

Next parameters are extracted from the “satellite image input file”, for the two images in which tracers are identified and tracked. The name of the “satellite image input file” is identified as `S_NWC_<avhrr.viirs.modis>_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`, and `$SM_IMAGER_DIR` is the directory in which these “satellite image input files” are located:

1. Horizontal and vertical dimensions (“nx” and “ny”) of the static region used for the reprojection of all NWC/PPS-HRW input files.
2. VIS06 normalized reflectances for each pixel.
3. IR108/IR110 brightness temperatures for each pixel.
4. Latitudes and longitudes for each pixel (“lat” and “lon”).



Next parameters are extracted from the “satellite angle input file”, for the images in which tracers are identified and tracked. The name of the “satellite angle input file” is identified as `S_NWC_sunsatangles_<satid>_<orbid>_<tim1>_<tim2>_<regid>.nc`, and `$SM_SUNSATANGLES_DIR` is the directory in which these “satellite angle input files” are located:

5. Solar and satellite zenith angles (“sunzenith” and “satzenith”).
6. Scanning time for each pixel (“time_per_pixel”).

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_yyyyymmddhhmm+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,

7. NWP temperature profiles (“t”).
8. NWP wind component profiles (“u” and “v”), 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 first and third options are implemented in the default configuration, but none of them are mandatory.
9. NWP geopotential profiles (“z”), 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:

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 22/94
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10. Grid mapping info (“grid_mapping_info”), a property variable explaining the name (“grid_mapping_name”) and characteristics (“comment”) of the reprojection used for all NWC/PPS-HRW input files.
11. NWC/PPS-CT Cloud Type output (“ct”) 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).
12. NWC/PPS-CT Cloud Type output (“ct”) for the image in which tracers are tracked, in case the “CCC method height assignment” defined in chapter 2.2.2.6 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:



13. NWC/PPS-CTTH Cloud Top Temperature and Pressure outputs (“ctth_tempe” and “ctth_press”) for the image in which tracers are tracked, in case the “CCC method height assignment” defined in chapter 2.2.2.6 is used (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:

14. Elevation in metres for each pixel in the static region, “elevation”.
15. Horizontal and vertical dimension in metres for each pixel in the static region, “xdist” and “ydist”.

Here, the “Physiography file”, the “satellite image input files”, the “satellite angle input files” and the “NWC/PPS-CT Cloud Type output” for the requested images, and the “NWP input files” with NWP temperature 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. Other data contribute to a higher number of AMVs and Trajectories and a better quality of the 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).

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 23/94
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2.2.2.3 Tracer search

The process of NWC/PPS-HRW starts with the calculation of “tracers” (square “segments” of $n \times n$ pixels, used as initial positions of an AMV and trajectory sector, and identified by a specific cloudiness feature or humidity 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 considered by NWC/PPS software for the images reprojected for use with NWC/PPS-HRW software (normally between 1 and 5 km), these resolutions define tracer scales between 12 and 120 km. So, between ‘mesoscale β ’ 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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 24/94
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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” $|\Delta N_Value(\Delta x) + \Delta N_value(\Delta y)|$, 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). However, to avoid that tracers and AMVs are excessively separated, this “pixel distance” is reduced when the minimum pixel size of the reprojected images is more than 3 km (defined by parameter POLAR_HIGHERDENSITYOFTRACERS_PIXELSIZETHRESHOLD).

All tracers related to very low and low cloud types calculated with this “pixel distance” are kept. Considering tracers related to other cloud types (if so defined by configurable parameters HIGHERDENSITY_LOWTRACERS = 2 and HIGHERDENSITY_LOWTRACERS_DET = 2, which is the default option), only one of every two tracers is kept. With this new procedure, the spatial density of AMV data related to very low and low clouds is narrower, due to the smaller “pixel distance” between those low level tracers.

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. $CENT_{90\%} > 0.95 \cdot MIN_BRIGHTNESS_THR$ and $CENT_{10\%} > 0$;
- 2a. $CENT_{97\%} - CENT_{03\%} > LARGE_CONTRAST$ if $CENT_{97\%} > 1.25 \cdot MIN_BRIGHTNESS_THR$ or
- 2b. $CENT_{97\%} - CENT_{03\%} > SMALL_CONTRAST$ if $CENT_{97\%} < 1.25 \cdot MIN_BRIGHTNESS_THR$.

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).

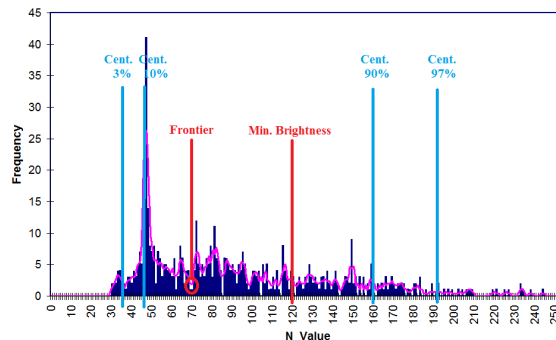


Figure 1: Example of “N_Value matrix histogram” (unsmoothed in violet and smoothed in pink) for a valid Low resolution visible “tracer candidate”. The minimum brightness threshold, the algorithm centiles and the defined frontier are also shown

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”;

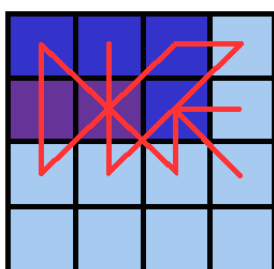
CLASS_2: 'bright big pixel', > 70% of its pixels are “bright pixels”;

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.



Example of tracer with its corresponding structure of 'Big pixels':



- Class 2 pixels in dark blue (bright pixels).
- Class 1 pixels in violet.
- Class 0 pixels in light blue (dark pixels).

The results of the 'Big pixel Brightness variability test' is also shown.

- 'Good transitions' shown in red.

A minimum of two 'Good transitions' in all four directions (rows, columns, ascending and descending diagonals) is necessary to pass the test.

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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 26/94
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TRACER CLOSENESS CONDITION

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 80° and 87°). 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 in both first and last 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, nor in both first and last column, of the “4x4 big pixel matrix” used 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” can so successively be defined and tracked in several images, and the progressive locations of the tracer throughout the time define “Trajectories”. For this, it is necessary that the conditions implied by the “tracer method” used for the determination of the tracer in the “initial image”, keep on being valid throughout all the images.

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

Due to this, in comparison, the applicability of trajectories from NWC/PPS-HRW is much more limited, which has to be taken into account by the NWC SAF 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”.

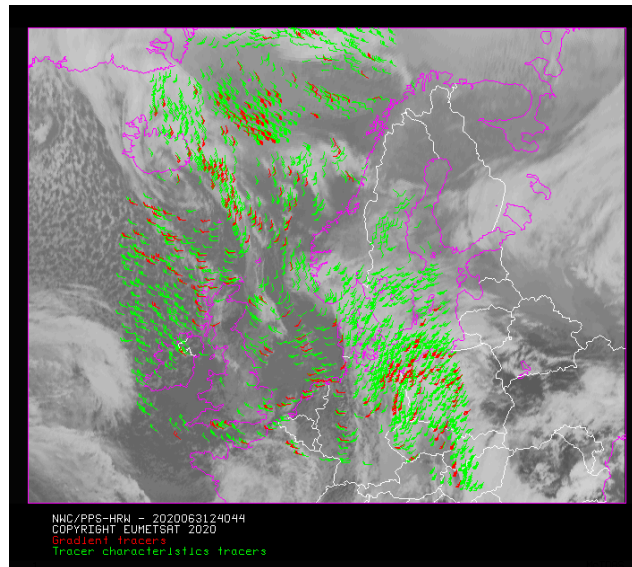


Figure 3: “Basic scale AMVs” (in red and green, considering the Tracer calculation method used for their extraction), in the Single scale NWC/PPS-HRW example defined for the region “EURON1 - Scandinavia” in Figure 16 with the default \$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm model configuration file (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite)

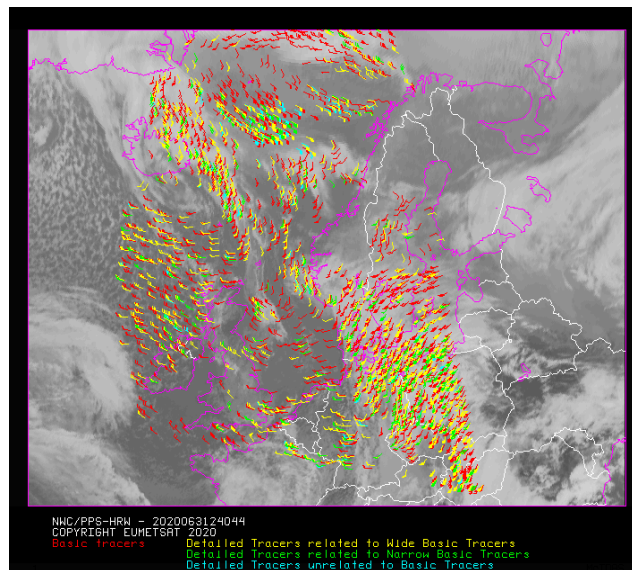




Figure 4: “Basic scale AMVs” (in red), and “Detailed scale AMVs” (in yellow, green and blue, considering their relationship with the Basic scale AMVs), in a Two scale NWC/PPS-HRW example, defined for the region “EURON1 - Scandinavia” in Figures 16 and 17 with the default \$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm model configuration file and parameter CDET=1 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite)

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 28/94
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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 $LP_{ij} = \sum \sum (T-S)^2$ is calculated. T/S correspond to the “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 $CC_{ij} = COV_{T,S}/(\sigma_T \cdot \sigma_S)$ is calculated. T/S correspond to the “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” “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”):

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

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 NWC SAF 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.

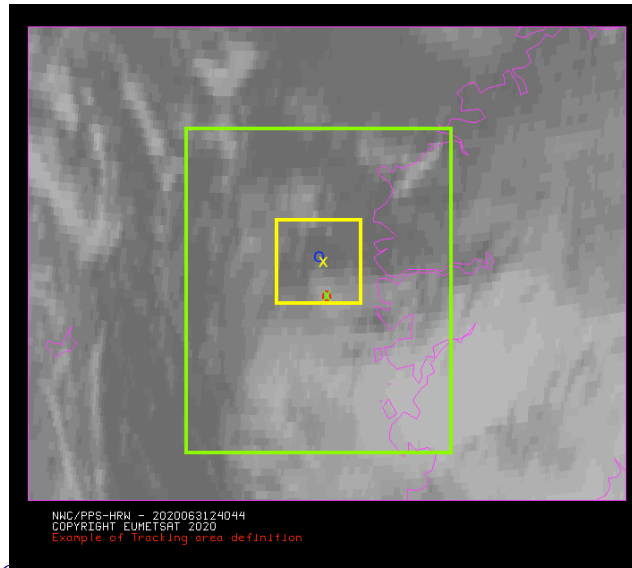


Figure 5: A tracer location for 5 March 2020 at 12:20:09 UTC for EOS-2 satellite (O red mark), its position defined by NWP wind guess at 12:40:44 UTC (X yellow mark), and its true tracking position at 12:40:44 UTC for SNPP satellite defined by NWC/PPS-HRW software (O blue mark), for an example case. 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 $GAP = 8$ is applied: LP/CC_{ij} is evaluated only at $(1,1),(1,9),\dots(9,1),(9,9),\dots$ 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:



$$(i_{\max}-GAP, j_{\max}-GAP), \dots, (i_{\max}+GAP, j_{\max}+GAP),$$

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

After all four iterations, the three “tracking centres” (MAX_NUM_WINDS) with the best Euclidean distance/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 80%).

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”:

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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 30/94
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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 optimal configuration for the selection of valid pairs of images, but the corresponding AMVs and Trajectories are calculated considering the whole displacement considering several pairs of images altogether 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 120 minutes). In contrast, in NWC/GEO-HRW both methods always relate to displacements of up to one hour only.

EXAMPLES OF AMV TRACKING FOR THE DIFFERENT SATELLITE CHANNELS

Examples of AMVs with NWC/PPS-HRW software are shown in *Figures 6 and 7* for the regions “EURONI - Scandinavia” and “EUROPA”, considering the satellite channel used for the AMV calculation.

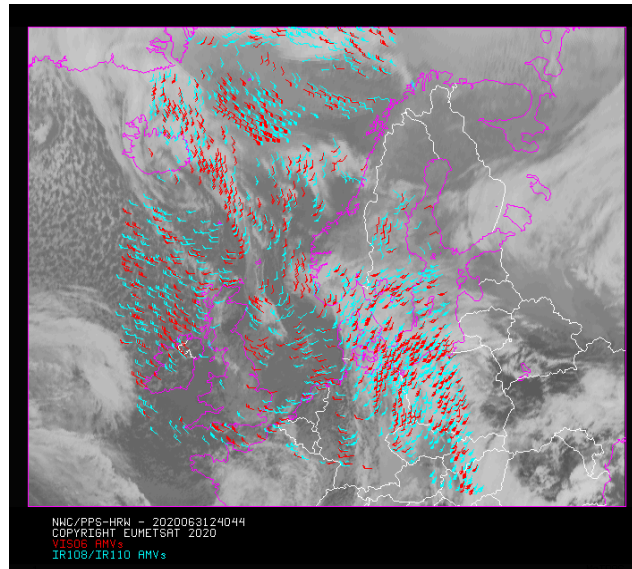


Figure 6: AMVs considering the satellite channel used for the AMV calculation, for the NWC/PPS-HRW example defined in Figure 16 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region “EURONI - Scandinavia”)

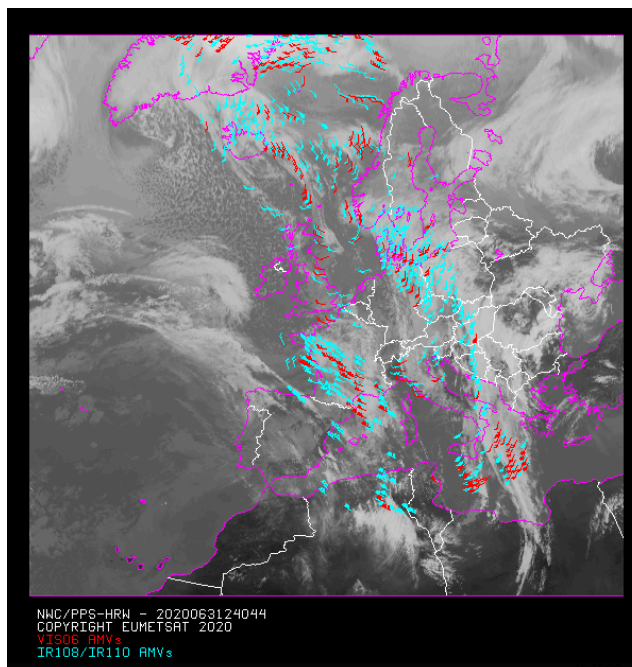




Figure 7: AMVs considering the satellite channel used for the AMV calculation, for the NWC/PPS-HRW example defined in Figure 18 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region “EUROPA”)

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 32/94
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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”.

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 IR108/IR110 brightness temperature. With this:

- A “Base temperature” is computed with $T_{\text{Base}} = T_{\text{Average}} + \text{SIGMA_FACTOR} \cdot \sigma_{\text{Cloud}}$, 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 VIS06 visible channel and 0.0 for IR108/IR110 infrared channel.
- 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, 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 $\frac{3}{2}$ times the one of the second most common value. If this condition does not occur, 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 NWC/PPS-CT Cloud Type output is not available or `USE_CLOUDTYPE = 0`, 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” value and the satellite channel with which they have been calculated. 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 level is defined such as also shown in *Table 6*. If the “AMV cloud type” has not been calculated, the “Base pressure” is considered for all AMVs because most cloud types fit better with the “Base pressure”.



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 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 Type Values	VIS06 Channel	IR108/IR110 Channel
1 Cloud free land		
2 Cloud free sea		
3 Land contaminated by snow/ice		
4 Sea contaminated by ice		
5 Very low cumulus/stratus	Cloud Base Pressure	Cloud Base Pressure
6 Low cumulus/stratus	Cloud Base Pressure	Cloud Base Pressure
7 Medium cumulus/stratus	Cloud Base Pressure	Cloud Base Pressure
8 High opaque cumulus/stratus	Cloud Base Pressure	Cloud Base Pressure
9 Very high opaque cumulus/stratus	Cloud Base Pressure	Cloud Base Pressure
10 Fractional clouds		
11 High semitransparent thin clouds		Cloud Top Pressure
12 High semitransparent meanly thick clouds	Cloud Top Pressure	Cloud Top Pressure
13 High semitransparent thick clouds	Cloud Base Pressure	Cloud Base Pressure
14 High semitransparent above other clouds		Cloud Top Pressure
15 High semitransparent above snow/ice		Cloud Top Pressure
21 Multiple cloud types	Cloud Base Pressure	Cloud Base Pressure
22 Multiple clear air types		
23 Mixed cloudy/clear air types	Cloud Base Pressure	Cloud Base Pressure

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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 34/94
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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 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”. 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 previously 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 “brightness values” for each pixel, T_M/S_M are the mean values and σ_T/σ_S the standard deviations of the “brightness values”, and NUM is the total number of pixels inside the “tracer” or “tracking centre”:

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

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 8 and 9* (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

		Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 35/94
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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:

$$P_{CCC} = \frac{\sum(CC_{ij} \cdot CTP_{ij})}{\sum CC_{ij}} \quad T_{CCC} = \frac{\sum(CC_{ij} \cdot CTT_{ij})}{\sum CC_{ij}}$$

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:

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

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 (default value 150 hPa).

Images in *Figures 8 and 9* 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 object 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 8 and 9* 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”.

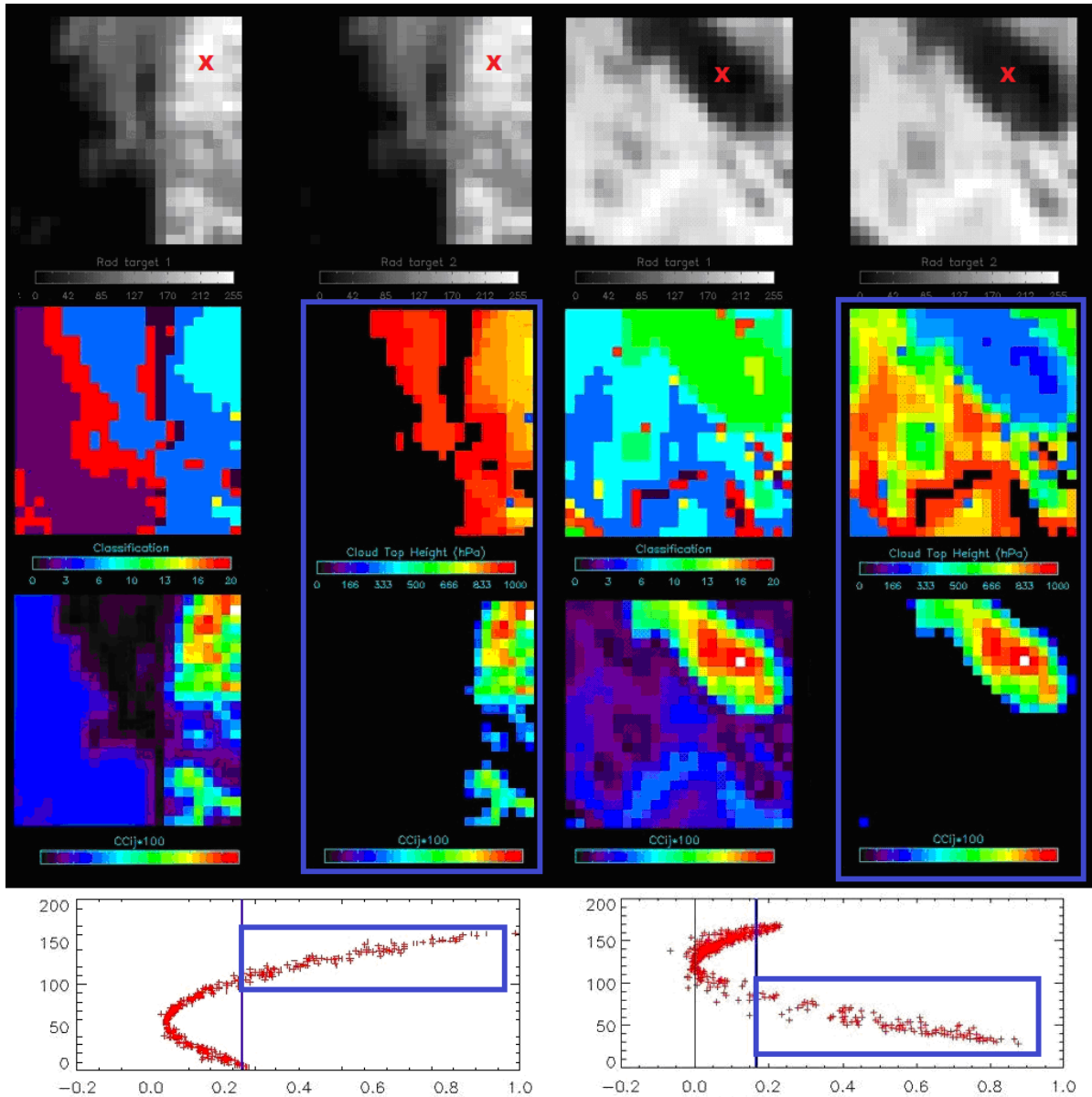
With configurable parameter DEFPOSWITHCONTRIBUTIONS = 1, which is the default option, the displacement by the AMV between the “tracer” and the “tracking centre” is not considered between the centres of the “tracer” and the “tracking centre”, but between the “weighted locations” defined with similar formulae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

$$X_{CCC} = \frac{\sum(CC_{ij} \cdot X_{ij})}{\sum CC_{ij}} \quad Y_{CCC} = \frac{\sum(CC_{ij} \cdot Y_{ij})}{\sum CC_{ij}}$$



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 8 and 9* 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.

“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.



Figures 6 and 7. Matrices and graphs used in the calculation of CC method neighbor 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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 37/94
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2.2.2.7 “CCC method” height assignment (Cloudy cases with Microphysics correction)

In contrast to NWC/GEO-HRW algorithm, which has the option to correct the AMV pressure value taking into account the depth of the cloud related to the AMV through the NWC/GEO-CMIC (Cloud microphysics) software output, this version of NWC/PPS-HRW does not process NWC/PPS-CMIC and so the corresponding “Microphysics correction” of “CCC method height assignment” is not available.

This is caused by the fact that NWC/PPS-CMIC software was in process of being updated for all polar satellite series through the time NWC/PPS-HRW was being developed. It has been preferred to leave this inclusion of NWC/PPS-CMIC outputs in NWC/PPS-HRW software for a later release in around one year time.

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

As in previous case, in contrast to NWC/GEO-HRW algorithm, which has the option to calculate Clear air AMVs with water vapour channels, this version of NWC/PPS-HRW has not the option to process Clear air AMVs. Due to this, the options implemented in the chapter 2.2.2.8 of NWC/GEO-HRW ATBD are not available here.

As already commented, this is caused by the fact that both AVHRR/3 and VIIRS radiometers have not any water vapour channel, and only EOS-1 and EOS-2 satellites with MODIS radiometer could be used for calculation of water vapour AMVs (including Clear air AMVs), which would be very infrequent. Due to this, it has been preferred to leave this option for a later release in around one year time, when the use for AMV calculation of satellites with MODIS and additionally MERSI/2 radiometer will allow more frequent water vapour AMVs (and Clear air AMVs).

EXAMPLE OF AMV CLOUD TYPE DEFINED BY CCC HEIGHT ASSIGNMENT

An example of AMVs for NWC/PPS-HRW software is shown in *Figure 10*, considering the “AMV cloud type” defined by “CCC method height assignment”.

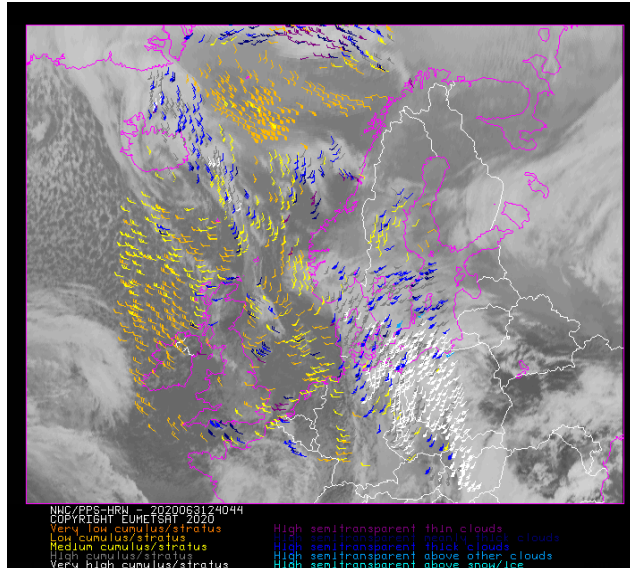


Figure 10: “AMV cloud type values” (as defined by “CCC method height assignment”) for the NWC/PPS-HRW example defined in Figure 16 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region “EURON1 - Scandinavia”)

EXAMPLE OF AMVs RELATED TO DIFFERENT OPTIONS OF CCC HEIGHT ASSIGNMENT

An example of AMVs for NWC/PPS-HRW software is shown in *Figure 11*, considering the different options for “CCC method height assignment” (using high or low CCC method calculation threshold).

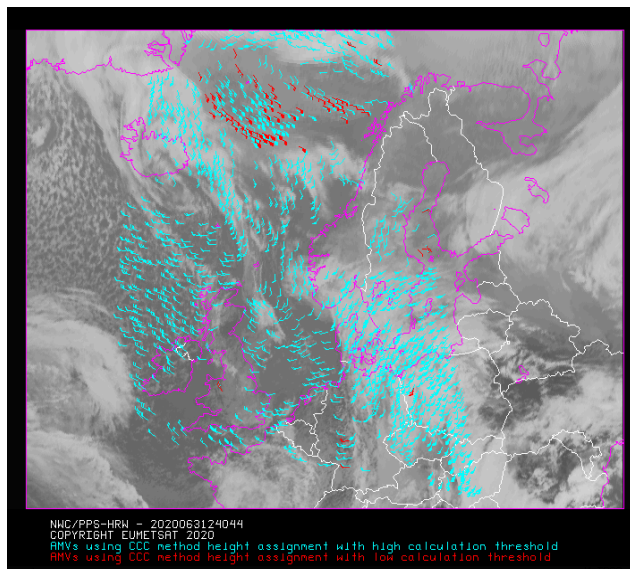




Figure 11: AMV height assignment (“CCC method height assignment using high/low calculation threshold”), for the NWC/PPS-HRW example defined in Figure 16 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region “EURON1 - Scandinavia”)

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 39/94
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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 “tracer centre” or the “weighted location” defined by DEFPOSWITHCONTRIBUTIONS configurable parameter, together with the non-integer/integer displacement of the “tracer 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 (Δ LAT, Δ LON), 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 °/hour to m/s.

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

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

$$\text{SPD} = \text{CONVERSION_DEGH2MS} \cdot \text{ANG} / \text{T_INT}$$

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

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

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

$$\text{DIR} = \text{atan}^2(\text{HOR}, \text{VER})$$

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

$$U = \text{SPD} \cdot \cos(\text{DIR}) \quad V = \text{SPD} \cdot \sin(\text{DIR})$$



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.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 40/94
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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:

$$QI_1 = 1 - [\tanh[DIF/(20 \cdot \exp(-SPD/10)+10)]]^4 \quad (\text{in the “temporal direction consistency” test})$$

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

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

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:

$$\alpha = 200 + 3.5 \cdot SPD$$

$$\beta = 200 + 3.5 \cdot SPD$$



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

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

$$\text{distance factor} = (\gamma/\alpha)^2 + (\delta/\beta)^2$$

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 1.35° (L_CHECK_LAT_DIFF/T_CHECK_LAT_DIFF) are valid. The reference AMVs with the smallest “distance factor” are considered for the quality control.

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 = 3 (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”.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 41/94
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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 is being implemented 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.

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 80%), This value is different to what is being considered inside NWC/GEO-HRW algorithm, which uses a default value of 70%.

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 to use significantly lower values for this threshold (in NWC/GEO-HRW, the use of values up to 1% is instead acceptable).

Some additional considerations on the “Quality Control”, specific for NWC/PPS-HRW software, 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 when no reference AMV was found for the comparison. The “Overall Quality index” will thus 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 the 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 besides defined in the speed difference (MEANVEC_SPEED_DIF = 10 m/s), direction difference (MEANVEC_DIR_DIF = 20°) 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 12 and 13*, considering respectively the “Quality index with forecast” and the “Quality index without forecast”.

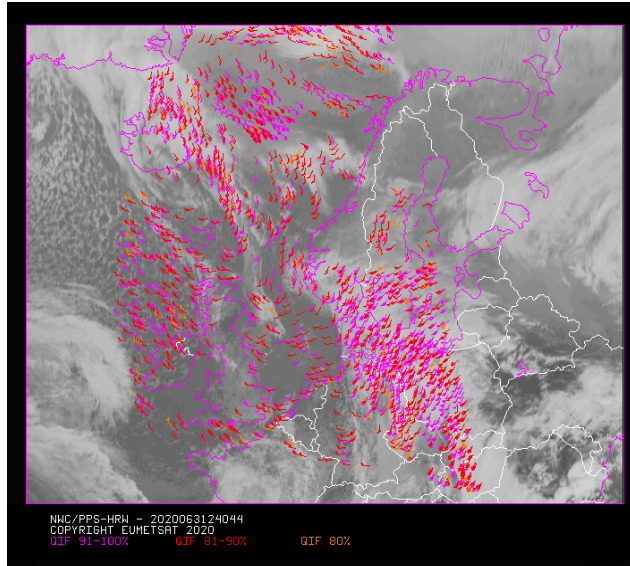


Figure 12: “Quality index with forecast” for the NWC/PPS-HRW example defined in Figure 16 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region “EURON1 - Scandinavia”). Only values of “Quality index with forecast” $\geq 80\%$ are present, because of the use of this parameter for the AMV filtering.

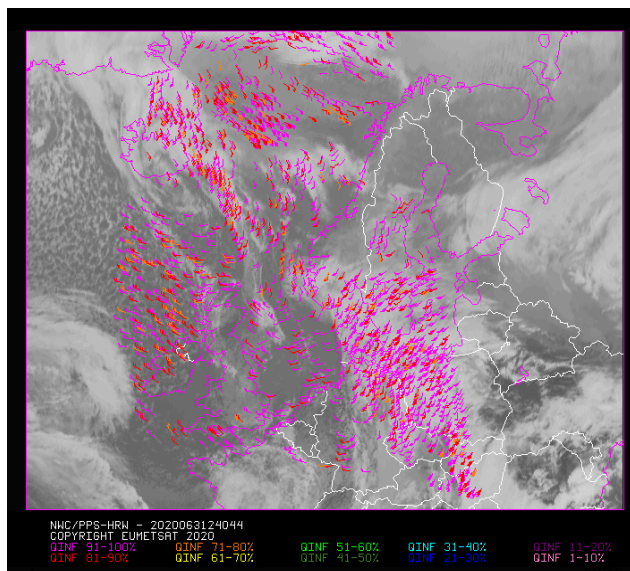


Figure 13: “Quality index without forecast” for the NWC/PPS-HRW example defined in Figure 16 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region “EURON1 - Scandinavia”). All values are formally possible for the “Quality index without forecast”, but because of its connection with the “Quality index with forecast”, only values of “Quality index without forecast” $\geq 75\%$ 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 14*, considering the “Common Quality Index without forecast”.

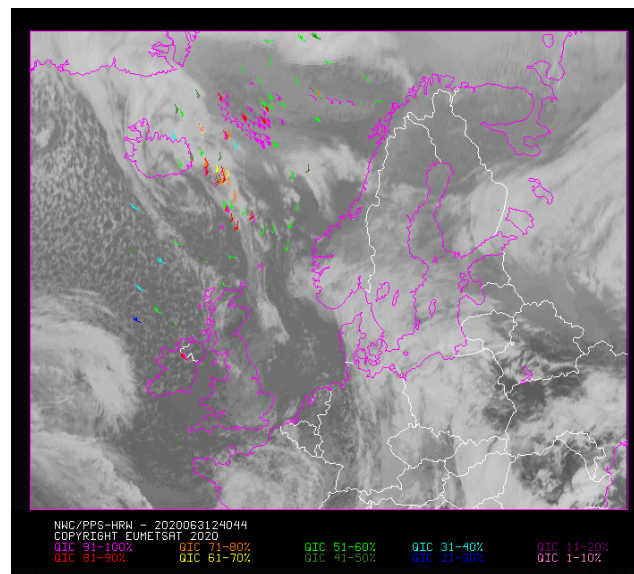




Figure 14: “Common Quality index without forecast” for the NWC/PPS-HRW example defined in Figure 16 (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite, in the region “EURON1 - Scandinavia”). All values are possible for the “Common Quality index without forecast”. The difference with Figures 12 and 13, and the fact that only a part of AMVs has a valid value for the “Common Quality index without forecast” (a 5% of AMVs for this example) are to be noticed.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 44/94
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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 two topography matrices for the static region used for the AMV calculation (being `<regid>` the label identifying this static region): `$SM_STATIC_AUXILIARY_DIR/S_NWC_SFCCMIN_<regid>` and `$SM_STATIC_AUXILIARY_DIR/S_NWC_SFCCMAX_<regid>`. These matrices define the 3% and 97% centiles of the topography histogram for each pixel, in which data up to 1 degree away are considered. They are called the “Representative Minimum and Maximum height matrices” in each pixel. If these matrices are not available, they are 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, these matrices are stored for all runs of NWC/PPS-HRW for the given region.

These matrices are then converted to “Representative Maximum and Minimum surface pressure matrices” with NWP geopotential data. To do this, these matrices are converted to geopotential values, and the geopotentials are inversely interpolated to pressure to define the “Representative Maximum and Minimum surface pressure” values for each pixel (`P_sfccmin`, `P_sfccmax`). These values represent the highest and lowest representative surface pressure values up to one degree away of each pixel.

After this, the “Static orographic flag” (`IND_TOPO`) is calculated at the initial position of each AMV. It is calculated considering `P_sfccmin`, `P_sfccmax` values and parameters `TOPO_PR_DIFF = 1/2` (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.*
- $IND_TOPO = 1$: $P_{AMV} > P_{sfccmin}$
AMV wrongly located below the lowest representative pressure level.
- $IND_TOPO = 2$: $P_{AMV} > P_{sfccmax} + TOPO_PR_DIFF * (P_{sfccmin} - P_{sfccmax})$
Very important orographic influence found in the current AMV position.
- $IND_TOPO = 3$: $P_{AMV} > P_{sfccmax} - TOPO_PR_SUP$
Important orographic influence found in the current AMV position.
- $IND_TOPO = 6$: $P_{AMV} < P_{sfccmax} - TOPO_PR_SUP$
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.*

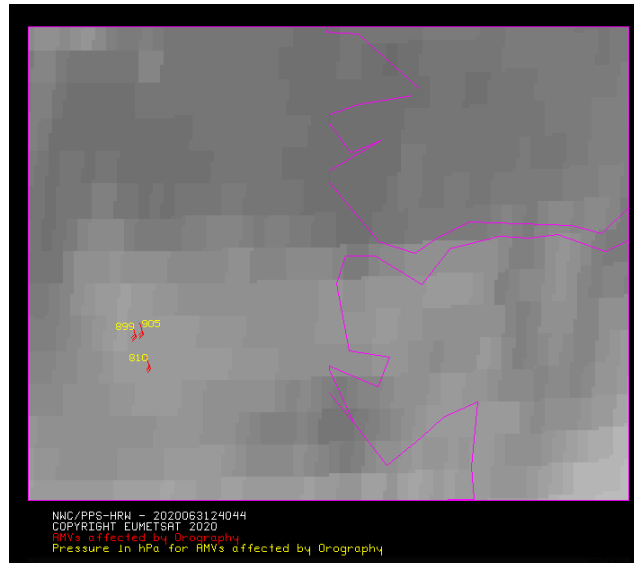


Figure 15. Pressure values in hPa for AMVs affected by orography (i.e. with “Orographic flag” values between 1 and 5) in a zoomed area in the Southwestern coast of Norway around Sognefjord, for the NWC/PPS-HRW example defined in Figure 16 (3 March 2020 12:40:44 UTC for SNPP satellite,

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.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 46/94
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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 (default value VIS06,IR108 for NWC/PPS-HRW), which defines the channels for which AMVs and Trajectories are calculated.
- QI_THRESHOLD: defines the “Quality index threshold” for the AMVs and Trajectories in the output files. Depending on configurable parameter QI_THRESHOLD_USEFORECAST, the “Quality index with forecast” (which is the default option) 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.
- MIN_CORRELATION: defines the minimum correlation (as a percentage value) in the output AMVs and Trajectories, when the “Cross Correlation tracking” has been used.
- 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 through FINALFILTERING = 2), the “AMV cloud type” filtering defined in *Table 6* is additionally implemented.
 - With FINALFILTERING > 2, AMVs with a “spatial quality flag” = 1,2 are additionally eliminated.
 - With FINALFILTERING = 4, AMVs with a “spatial quality flag” = 0 are additionally eliminated.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 47/94
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2.3 PRACTICAL CONSIDERATIONS ON HIGH RESOLUTION WINDS (NWC/PPS-HRW)

2.3.1 Validation of High Resolution Winds (NWC/PPS-HRW)

NWC SAF/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 this first implementation of NWC/PPS-HRW software.



The default validation statistics against Radiosounding winds and NWP analysis winds for NWC/PPS-HRW Basic AMVs, are shown here as a summary. 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.12].

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.12].

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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 48/94
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2.3.1.1 Validation of NWC/PPS-HRW for Polar satellites

For the validation of this first NWC//PPS-HRW version with polar satellites, a validation period of three months (February 2020-April 2020) has been defined. Here, all polar satellite scanings over two reprojected static regions (“EURON1 - Scandinavia”, shown in *Figure 16*, and “EUROPA”, shown in *Figure 18*), have been processed between 09:00Z and 13:00Z for 88 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, NWC/PPS-CMA/CT/CTTH in both reprojected validation regions have to be produced before the running of NWC/PPS-HRW.

Comparing the statistics for NWC/PPS-HRW against Radiosounding winds and ECMWF NWP analysis in *Table 7* (considering all layers together) and in *Table 9* (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 that of NWP analysis winds than to that of Radiosounding winds. This behaviour can also be observed in the statistics for the latest version of NWC/GEO-HRW, shown as reference in *Table 8* (considering all layers together) and in *Table 10* (considering three layers separately). For NWC/GEO-HRW, AMV statistics for MSG satellite for IR108 channel, for HRVIS channel (only visible channel for which statistics are calculated for all layers), and for all channels together are shown for the comparison.

Considering differences in NWC/PPS-HRW for VIS06 and IR108 channel, statistics for IR108 AMVs are slightly better (with NMVD and NRMSVD values up to a 10% better for IR108 channel in region “EURON1”). This could in general be explained by the generally low solar elevation in these Northern regions throughout the used validation period (around the Spring Equinox), which limits the illumination conditions in the visible channels. However, it is also to be remarked that the differences in the AMV statistics for both VIS06 and IR108 channels are not so significant in spite of this.

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 “EURON1” have smaller NBIAS values, which can be related to the fact of using smaller tracers due to smaller pixel sizes. Instead, NMVD and NRMSVD values are slightly higher for region “EURON1”. Both results are general results for all AMV calculation processes when using smaller tracers.

Comparing the distribution of AMVs in the different layers, NWC/PPS-HRW shows a value of 69%/20%/11% for the High/Medium/Low layer in the region “EUROPA” and a value of 52%/25%/23% in the region “EURON1”. Meanwhile, NWC/GEO-HRW shows also a value of 52%/25%/23% in the “European and Mediterranean” region, considering all AMVs for all possible channels. Some improvement could be needed in future NWC/PPS-HRW versions to increase a bit the distribution of low level AMVs in the region “EUROPA”, to better characterize the behaviour of the wind in the different levels of the troposphere.

Considering the different layers, the validation parameters are progressively higher for the high layer, medium layer and low layer, as for NWC/GEO-HRW algorithm. Comparing the statistics of NWC/PPS-HRW and NWC/GEO-HRW (respectively in *Tables 7/9* and *Tables 8/10*), NWC/PPS-HRW shows cases in which the values of NMVD and NRMSVD parameters can be up to a 20% higher. In spite of this, while for NWC/GEO-HRW algorithm the Product Requirement Table “Optimal accuracy” is reached in the High layer (with a value of 0.35 against Radiosounding winds), and the Product Requirement Table “Target accuracy” is reached in the Medium and Low layer (with values respectively of 0.50 and 0.56 against Radiosounding winds), in comparison, for this first version of NWC/PPS-HRW algorithm, the Product Requirement Table “Target accuracy” is reached for both validation regions for all layers, and the Product Requirement Table “Optimal accuracy” is even reached in the Low layer for region “EURON1” (with a value of 0.45 against Radiosounding winds). Considering this, NWC/PPS-HRW outputs can be perfectly used by NWC SAF users the same way they are using NWC/GEO-HRW outputs, in spite of being defined as “demonstrational version”.

NWC/PPS-HRWv7.P AMVs (Feb 2020-Apr 2020)	“EURONI-Scandinavia” region			“EUROPA” region		
	IR108/		All	IR108/		All
	VIS06	IR110	AMVs	VIS06	IR110	AMVs
NC	199190	294099	493289	136348	508408	644756
SPD [m/s]	21.75	25.00	23.69	20.25	23.76	23.02
NBIAS (ALL LAYERS)	+0.00	+0.02	+0.01	-0.08	-0.06	-0.06
NMVD (100-1000 hPa)	0.34	0.32	0.33	0.31	0.32	0.32
NRMSVD	0.44	0.40	0.42	0.39	0.39	0.39
NC	199190	294099	493289	136348	508408	644756
SPD [m/s]	21.70	25.08	23.71	19.88	23.77	22.95
NBIAS (ALL LAYERS)	+0.00	+0.02	+0.01	-0.06	-0.06	-0.06
NMVD (100-1000 hPa)	0.26	0.25	0.25	0.24	0.23	0.23
NRMSVD	0.35	0.31	0.33	0.31	0.29	0.30

Table 7: Validation parameters for NWC/PPS-HRW v7.P 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; Feb 2020-Apr 2020 between 11:00 and 13:00 UTC; Polar satellites with AVHRR/3, VIIRS and MODIS radiometers). Statistics for region “EURONI - Scandinavia” on the left side; region “EUROPA” on the right side.

NWC/GEO-HRW v6.1 AMVs (Jul 2010-Jun 2020, MSG sat.)	European/Mediterranean region		
	HRVIS		All
	IR108	AMVs	
NC	67288	226314	1097907
SPD [m/s]	12.87	17.50	17.23
NBIAS (ALL LAYERS)	-0.03	-0.08	-0.07
NMVD (100-1000 hPa)	0.35	0.30	0.32
NRMSVD	0.42	0.37	0.39
NC	67288	226314	1097907
SPD [m/s]	12.72	17.19	16.91
NBIAS (ALL LAYERS)	-0.02	-0.07	-0.05
NMVD (100-1000 hPa)	0.22	0.20	0.22
NRMSVD	0.28	0.25	0.27



Table 8: Validation parameters for NWC/GEO-HRW v6.1 AMVs (latest NWC/GEO-HRW version), considering all layers together, against Radiosounding winds in light blue and against ECMWF NWP analysis winds in dark blue. (Basic AMVs in nominal configuration; Jul 2009-Jun 2010 at 12:00 UTC; MSG-2 satellite; “European and Mediterranean” region).

NWC/PPS-HRWv7.P AMVs (Feb 2020-Apr 2020)	“EURONI-Scandinavia” region			“EUROPA” region		
	IR108/		All	IR108/		All
	VIS06	IR110	AMVs	VIS06	IR110	AMVs
NC	82514	172397	254911	71182	373464	444646
SPD [m/s]	32.80	30.29	31.10	28.10	27.22	27.36
NBIAS (HIGH LAYER)	+0.00	+0.02	+0.01	-0.09	-0.06	-0.07
NMVD (100-400 hPa)	0.31	0.31	0.31	0.28	0.30	0.30
NRMSVD	0.38	0.37	0.38	0.34	0.36	0.36
NC	43130	82440	125570	29585	96716	126301
SPD [m/s]	19.44	19.39	19.41	14.90	15.96	15.71
NBIAS (MEDIUM LAYER)	-0.00	+0.02	+0.01	-0.06	-0.03	-0.04
NMVD (400-700 hPa)	0.38	0.38	0.38	0.37	0.42	0.41
NRMSVD	0.49	0.46	0.47	0.46	0.51	0.50
NC	73546	39262	112808	35581	38228	73809
SPD [m/s]	10.72	13.55	11.70	8.99	9.73	9.37
NBIAS (LOW LAYER)	+0.00	-0.01	-0.00	-0.02	+0.02	-0.00
NMVD (700-1000 hPa)	0.38	0.33	0.36	0.43	0.44	0.44
NRMSVD	0.45	0.39	0.43	0.50	0.51	0.51
NC	82514	172397	254911	71182	373464	444646
SPD [m/s]	32.51	30.28	31.00	27.28	27.11	27.13
NBIAS (HIGH LAYER)	+0.01	+0.02	+0.02	-0.07	-0.06	-0.06
NMVD (100-400 hPa)	0.25	0.24	0.24	0.23	0.23	0.23
NRMSVD	0.31	0.29	0.30	0.28	0.28	0.28
NC	43130	82440	125570	29585	96716	126301
SPD [m/s]	19.64	19.73	19.70	14.75	16.12	15.80
NBIAS (MEDIUM LAYER)	-0.01	+0.01	+0.00	-0.05	-0.04	-0.05
NMVD (400-700 hPa)	0.28	0.28	0.28	0.27	0.27	0.27
NRMSVD	0.36	0.35	0.35	0.33	0.33	0.33
NC	73546	39262	112808	35581	38228	73809
SPD [m/s]	10.78	13.45	11.71	9.35	10.48	9.93
NBIAS (LOW LAYER)	+0.00	-0.00	-0.00	-0.06	-0.05	-0.05
NMVD (700-1000 hPa)	0.25	0.23	0.25	0.28	0.25	0.27
NRMSVD	0.31	0.28	0.30	0.33	0.29	0.31

Table 9: Validation parameters for NWC/PPS-HRW v7.P 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; Feb 2020-Apr 2020 between 11:00 and 13:00 UTC; Polar satellites with AVHRR/3, VIIRS and MODIS radiometers). Statistics for region “EURONI - Scandinavia” on the left side; region “EUROPA” on the right side.

European/Mediterranean region			
NWC/GEO-HRW v6.1 AMVs	All		
(Jul 2010-Jun 2020, MSG sat.)	HRVIS	IR108	AMVs
NC	15919	119091	566718
SPD [m/s]	21.13	21.85	22.19
NBIAS (HIGH LAYER)	-0.03	-0.07	-0.05
NMVD (100-400 hPa)	0.25	0.26	0.26
NRMSVD	0.30	0.32	0.32
NC	15447	65544	276959
SPD [m/s]	12.88	14.29	13.91
NBIAS (MEDIUM LAYER)	-0.05	-0.09	-0.08
NMVD (400-700 hPa)	0.35	0.35	0.36
NRMSVD	0.42	0.43	0.44
NC	35922	41679	254230
SPD [m/s]	9.21	10.11	9.79
NBIAS (LOW LAYER)	-0.02	-0.11	-0.09
NMVD (700-1000 hPa)	0.45	0.40	0.42
NRMSVD	0.53	0.48	0.50
NC	15919	119091	566718
SPD [m/s]	20.87	21.54	21.83
NBIAS (HIGH LAYER)	-0.01	-0.06	-0.04
NMVD (100-400 hPa)	0.16	0.17	0.17
NRMSVD	0.19	0.22	0.21
NC	15447	65544	276959
SPD [m/s]	12.58	13.95	13.56
NBIAS (MEDIUM LAYER)	-0.03	-0.07	-0.05
NMVD (400-700 hPa)	0.25	0.25	0.26
NRMSVD	0.31	0.31	0.33
NC	35922	41679	254230
SPD [m/s]	9.17	9.86	9.58
NBIAS (LOW LAYER)	-0.01	-0.09	-0.07
NMVD (700-1000 hPa)	0.28	0.27	0.28
NRMSVD	0.34	0.33	0.34

Table 10: Validation parameters for NWC/GEO-HRW v6.1 AMVs (latest NWC/GEO-HRW version), 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; Jul 2009-Jun 2010 at 12:00 UTC; MSG-2 satellite; "European and Mediterranean" region).

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 52/94
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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 the values of this parameter, statistics for the different layers and satellite channels are provided separately or not. Please check chapter 2.3.3 for more information on this parameter. The default option (`NWPVAL_STATISTICS = 4`) provides statistics for all layers and the different satellite channels separately. The validation statistics can be calculated using NWP forecast winds in real time processes, and using NWP forecast or analysis winds in reprocessing processes.

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

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

The following content is added to this file each time the validation statistics are run: several lines with the following format, showing the validation parameters mentioned previously (NC, SPD, NBIAS, NMVD, NRMSVD) for the considered AMV scale “BBB” (defined as BAS, DET), AMV type “TTTTT” (defined as TOTAL, CLOUD), layer “LLL” (defined as ALL, HIG, MED, LOW) and satellite channel for which AMVs are calculated “CCCCC” (defined as TOTAL, VIS06, IR108).

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:

```

yyyymmddThh:mm:ssZ PPS-HRW 7.P XXXXX [S] HRWDATE:YYYYMMDDTHHMMSSZ
HRWCONF:FFFFFF.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 NWC SAF 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 NWC SAF 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 NWC SAF 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).

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 54/94
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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 `<satid>=eos1/eos2/metopa/metob/metopc/noaa15/noaa16/noaa17/noaa18/noaa19/noaa20/npp` is the polar satellite related to the scanning, `<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”).

Considering this, the full list of input files for the running of NWC/PPS-HRW software with polar satellites 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.6].

- 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_<avhrr·viirs·modis>_<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 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_yyyyymmddhhmm+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 NWC SAF 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.
- 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 `$SM_PRODUCT_DIR` is the directory in which this file is located.
- The “physiography file” for the static region used for the AMV calculation. The name of this “physiography file” is `physiography.<regid>.nc` and `$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 “NWC/PPS-CT Cloud Type output” files for the requested images, and the “NWP input files” with NWP temperature data with a minimum number of NWP levels (defined by configurable parameter `MIN_NWP_FOR_CALCULATION`, with a default value of 4) are actually 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.

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.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 56/94
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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-v7P). 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). 11 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.

<i>Keyword</i>	<i>Description</i>	<i>Type</i>	<i>Default Value(s)</i>
Identification parameters			
PGE_ID	NWC SAF 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 to run 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
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,
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_CENTRE_OR	Originating centre 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
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 NWC SAF format. - IWWG: AMV BUFR files, using the new IWWG BUFR format. - NET: AMV netCDF files	Chain of characters	IWWG, NET

<i>Output filtering parameters</i>			
QI_THRESHOLD	Quality Index threshold for the AMVs.	Integer	80
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 calculated (Unused in NWC/PPS-HRW).	Integer	0
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
<i>Working area description parameters</i>			
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
<i>Tracer parameters</i>			
USE_OLDERSLOT_FORTRACERS	Flag defining if using an older slot for the "initial image", if the corresponding one is not available (Unused in NWC/PPS-HRW). (Suggested by Yu-heng He, Hong Kong Observatory).	Integer	0
MAX_TRACERS	Maximum number of tracers.	Integer	600000
TRACERSIZE_VERYHIGH	Tracer line and column dimension in pixels, when respectively using satellite images with very high, high and low resolution. (NWC-PPS/HRW using low resolution only).	Integer	24
TRACERSIZE_HIGH		Integer	24
TRACERSIZE_LOW		Integer	24
BRIGHTNESS_THR_VIS	1 byte reflectance threshold for visible tracers.	Integer	120
BRIGHTNESS_THR_OTHER	1 byte brightness temperature threshold for infrared and water vapour tracers.	Integer	240
GVAL_VIS	Minimum 1 byte reflectance contrast for visible tracers.	Integer	60
GVAL_OTHER	Minimum 1 byte brightness temperature contrast for infrared and water vapour tracers.	Integer	48
TRACERDISTANCE_VERYHIGH	Nominal separation in pixels between tracers, when respectively using satellite images with very high, high and low resolution. (NWC-PPS/HRW using low resolution only).	Integer	24
TRACERDISTANCE_HIGH		Integer	12
TRACERDISTANCE_LOW		Integer	6
HIGHERDENSITY_LOWTRACERS	Option to decide the nominal ratio in the separation between other tracers and tracers related to very low and low clouds (for Basic and Detailed tracers)	Integer	2
HIGHERDENSITY_LOWTRACERS_DET		Integer	2

<i>Tracking parameters</i>			
TRACKING	Tracking method. Possible values: LP: Euclidean difference CC: Cross correlation.	Chain of characters	CC
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" (Unused in NWC/PPS-HRW)	Integer	0
MIN_CORRELATION	Minimum correlation acceptable (if TRACKING=CC).	Integer	80
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
<i>NWP validation parameters</i>			
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

<i>NWP parameters</i>			
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: Wind velocity at several levels, u component (m/s) * NWP_VW: Wind velocity at several levels, v component (m/s) * NWP_GEOP: Geopotential height at several levels (m)	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	Sampling rate used in NWC/GEO-HRW: 1 Interpolation method used in NWC/GEO-HRW: NEI (neighbour)	Chain of characters	NWP_GEOP 1 NEI

Table 11: NWC/PPS-HRW v7.P 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 image used for the processing (a larger size means a longer processing time).
- The size in kilometres of the pixels in this reprojected image (a smaller size 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 increase the distance between tracers (with larger values of TRACERDISTANCE_LOW parameter), or the ratio in the distance between high/medium tracers with respect to the distance between low tracers (with larger values of HIGHERDENSITY_LOWTRACERS and HIGHERDENSITY_LOWTRACERS_DET parameters).
- 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 quick (when the wind guess is not used).

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



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

<i>Error (E) or Warning (W)</i>	<i>Message</i>	<i>Reason</i>	<i>Recovery action</i>
E - 150	"Error: Environment variable <variable> has not been defined; Update for correct processing"	Some environment variable has to be defined for correct processing.	Update the value of corresponding environment variable through command "export" in the terminal or in the working "profile" file
E - 151	"Usage of PPS-HRW-v7P executable: ... or ..."	Input parameters are incorrect	Check instructions to start the run of NWC/PPS-HRW software in chapter 2.3.7.2 of this document
E - 152	"Error allocating memory for tracers"	Unable to allocate required memory for "tracer" struct	There are memory problems to run NWC/PPS-HRW software in the defined region with the defined configuration and computer. Use a larger computer or a smaller configuration.
E - 153	"Error allocating memory for tracer_wind struct, relating tracers and AMVs"	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 Grids (Only used in NWC/GEO-HRW)	
E - 157	"Satellite data for current/previous slot do not include valid values for any pixel"	Satellite data are not valid	Verify if there is any problem with the satellite data used by NWC/PPS-HRW software
E - 158	"The defined satellite for the current slot is not correct, or does not belong to NOAA-15/20 or SNPP or METOP-A/C or EOS-1/2 series"	Satellite data are not related to a valid polar satellite series	Run NWC/PPS-HRW with any of the valid polar satellite series

<i>Error (E) or Warning (W)</i>	<i>Message</i>	<i>Reason</i>	<i>Recovery action</i>
E - 160	"The region/projection defined for both satellite images is different"	The region/projection defined for both satellite images is different	Verify that the region and projection used for the "initial image" and "later image" are similar
E - 161	"Error reading Parameters from Satellite configuration file"	Error after NwcCFReadSat function (Only used in NWC/GEO-HRW)	Verify that the file \$SM_CONFIG_DIR/sat_conf_file used for running NWC/PPS-HRW software is correct
E - 162	"Error in date format (%s). Required format: YYYYMMDDThhmmssZ"	Error after NwcTimeSetStr function (Only used in NWC/GEO-HRW)	Verify that the date format used for running NWC/PPS-HRW software is correct
E - 163	"Error reading Parameters from the HRW configuration file (model_conf_file)"	Error after hrw_ReadData function	Verify that the file \$SM_CONFIG_DIR/model_conf_file used for running NWC/PPS-HRW software is correct
E - 164	"Error reading Pressure levels from the NWP configuration file"	Error after NwcNwpReadPLevel function	Verify that the file \$SM_CONFIG_DIR/nwp_conf_file used for running NWC/PPS-HRW software is correct
E - 165	"Unable to initialize the NWP profiles"	Error after NwcNwpInitProfile function	Verify that the files \$SM_CONFIG_DIR/nwp_conf_file, \$SM_CONFIG_DIR/model_conf_file used for running NWC/PPS-HRW software are correct
E - 166	"NWP temperature/ surface pressure data cannot be read".	AMVs cannot be calculated because NWP data could not be read	Verify that NWP Surface pressure data and NWP temperature data for at least MIN_NWP_FOR_CALCULATION levels (with a default value of 4) have been provided for the running of NWC/PPS-HRW software in \$SM_NWPDATA_DIR directory

<i>Error (E) or Warning (W)</i>	<i>Message</i>	<i>Reason</i>	<i>Recovery action</i>
E - 170	"Error defining the previous slot for NWC/PPS-HRW algorithm"	The "initial image" for the running of NWC/PPS-HRW cannot be defined	<p>All these errors are caused by the running of NWC/PPS-HRW software, and cannot be solved by the NWC SAF user.</p> <p>Nevertheless, as a whole, they should occur in less than a 0.5% of the cases.</p> <p>If the frequency is higher than that, please contact NWC SAF Helpdesk.</p>
E - 171	"Error setting the Processing region and the Satellite info"	Error after NwcPPSRegionSet function	
E - 172	"Error getting latitude / longitude / sun angles for the High resolution region"	Error after hrw_GetAncillaryDataPPS function	
E - 173	"Error reading satellite data for current/previous slot"	Error after NwcSatInit or hrw_ReadSatelliteData functions	
E - 174	"Error reading tracers from previous slot"	Error after hrw_ReadTracers function	
E - 175	"Error reading Trajectories for the 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 NWCSAF tmp directory"	Error after hrw_WritePredWinds function	
E - 179	"Error writing Trajectories in NWCSAF 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 NWCSAF tmp directory"	Error after hrw_WriteTracers function	
E - 182	"Error writing the AMVs/Trajectories in the BUFR/NETCDF output file"	Error after hrw_EncodeBUFRNWCEC, hrw_EncodeBUFRWWGEC, hrw_EncodeNetCDF function	
E - 183	"NWP data to be used cannot be defined; HRW AMVs cannot be calculated"	Error after NwcPPSNWPDefine function	

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

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 63/94
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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 both VIS06 and IR108/IR110 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; in the default configuration all options are provided as NWC/PPS-HRW output. 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 NWC SAF 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 = NET (included in the default option): NWC/PPS-HRW output defined as one netCDF bulletin. This option was requested during the “2010 Madrid Users' Workshop” and the “Consolidated Report on 2010 User Survey and Users' Workshop” document (SAF/NWC/IOP/INM/MGT/2010-US+WS) for NWC/GEO-HRW software, and has also been implemented for NWC/PPS-HRW software.

All these options are equivalent to those provided for the last version of NWC/GEO-HRW software (v6.1), 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).

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 64/94
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2.3.5.1 **HRW output as BUFR bulletins with NWC SAF specific format (AMVs)**

When OUTPUT_FORMAT = NWC, a BUFR bulletin equivalent to the one used as default option in the latest version of NWC/GEO-HRW software (v6.1) 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 13*. These variables are partially based on BUFR Master Table number 0, Version number 31, and are exactly equivalent to the ones used for the latest version of NWC/GEO-HRW software (v6.1). However, the coding of the BUFR outputs has changed from using BUFRDC library to ECCODES library with this NWC/PPS-HRW implementation.

To correctly define the BUFR bulletins, the user has to define the Originating Centre of the Information through configurable parameter BUFR_CENTRE_OR (with a default value of 214, which is valid only for NWC SAF 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 IR108/IR110), in each case with an only Subset of up to 1000 AMVs, are included in this AMV BUFR output file.

In *Table 13*, for all variables used for the AMV output with the NWC SAF 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 (NWC SAF)	CODE TABLE 60206	0	0	5
060207	AMV CHANNEL (NWC SAF)	CODE TABLE 60207	0	0	5
060208	CORRELATION	%	0	0	7
060209	PRESSURE ERROR	PA	-1	-8000	14
060210	PRESSURE CORRECTION (IN NWC/PPS-HRW, NOT USED)	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 13: Variables used for the AMV output with the “NWC SAF 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	<p>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’. In this implementation of NWC/PPS-HRW software, only values between 0 and 5 are actually used.</p> <p>Possible values:</p> <ul style="list-style-type: none"> 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	<p>Type of tracer</p> <p>Possible values:</p> <ul style="list-style-type: none"> 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 <i>Table 5</i> of this document.
060207	Flag indicating the satellite channel used for the wind calculation (Updated table for NWC/PPS-HRW v7.P). Possible values: 2: AVHRR/3/VIS06 or VIIRS/VIS06 or MODIS/VIS06 16: AVHRR/3/IR108 or VIIRS/IR108 or MODIS/IR110
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 14: Description of "local specific variables" in the "NWC SAF specific BUFR format"

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 68/94
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2.3.5.2 **HRW output as BUFR bulletins with NWC SAF 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 in the latest version 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 15*. 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 version of NWC/GEO-HRW software (v6.1). However, the coding of the BUFR outputs has changed from using BUFRDC library to ECCODES library with this NWC/PPS-HRW implementation.

As previously also seen, to correctly define the BUFR bulletins, the user has to define the Originating Centre of the Information through configurable parameter BUFR_CENTRE_OR (with a default value of 214, which is valid for NWC SAF 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 that 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 (NWC SAF)	CODE TABLE 60206	0	0	5
060207	AMV CHANNEL (NWC SAF)	CODE TABLE 60207	0	0	5
060208	CORRELATION	%	0	0	7
060209	PRESSURE ERROR	PA	-1	-8000	14
060210	PRESSURE CORRECTION (IN NWC/PPS-HRW, NOT USED)	PA	-1	-8000	14

White entries: Fixed factors

Grey entries: Replicated factors

Table 15: Variables used for the Trajectory output with the "NWC SAF specific BUFR format"

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 70/94
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2.3.5.3 HRW output as BUFR bulletins with the previous IWWG format (AMVs)

The latest version of NWC/GEO-HRW software (v6.1) has the option to write the AMV output through an AMV BUFR bulletin equivalent to the one defined previously as common AMV output format by the “International Winds Working Group (IWWG)” for all AMV production centres (through OUTPUT_FORMAT = EUM).

However, this option was expected by the “International Winds Working Group (IWWG)” to be superseded by the one defined in chapter 2.3.5.4 of this ATBD, following next actions and recommendations from the 2018/14th International Winds Workshop:

- IWW14 – WG1 – Action 6: AMV producers and users to adopt the new AMV BUFR template. Due date: 30 April 2019.
- IWW14 – WG2 – Recommendation 4: AMV producers to provide heritage AMV BUFR dissemination until at least July 2019.
- IWW14 – WG2 – Recommendation 5: NWP users to aim to have switched to the new AMV BUFR by 2020.

Considering this, and taking into account that NWC/PPS-HRW is being released to users in 2021, it has been considered convenient to remove this option from NWC/PPS-HRW software, so that NWC SAF users who want to process similarly AMVs from different AMV producers use for this the “NWC/PPS-HRW BUFR output using the 2018 IWWG format”, described in chapter 2.3.5.4 of this ATBD.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 71/94
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2.3.5.4 **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_HRWbs_<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_HRWds_<satid>_<orbit>_YYYYMMDDThhmmssdZ_YYYYMMDDThhmmssdZ_<regid>.bufr
(if NWC/PPS name style is used, with OUTPUT_NAMESYLE=PPS).

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

The BUFR variables used for the writing of the NWC/PPS-HRW AMVs considering this format, are explained in *Table 16*, 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”.

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

Formally, several different BUFR messages with up to 100 subsets with an only AMV each, all of them related to the same satellite channel, are included in this AMV BUFR output file.

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

It is recommended for NWC SAF 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 (not used)	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.P")	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	HOURLY	HOURLY
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/m ²)	KG/M ²
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 16: Variables used for the AMV output with the "2018 IWWG BUFR format"

2.3.5.5 **HRW output as netCDF bulletin**

When `OUTPUT_FORMAT = NET` (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).

The High level structure of the netCDF output for the NWC/PPS-High Resolution Winds is shown in *Table 17*. It contains one series of data, containing all the AMVs/Trajectories derived for all satellite channels in the corresponding run of NWC/PPS-HRW. The dimension of the series of data is defined by “number_of_observations_XXXXX” parameter, which contains the amount of AMVs calculated for the given run of NWC/PPS-HRW for “XXXXX” satellite channel. In *Table 17*, label “XXXXX” is to be modified with the different satellite channels for which AMVs and Trajectories are calculated: “VIS06” or “IR108”.

If configurable parameter `CALCULATE_TRAJECTORIES = 1`, the trajectories related to the corresponding AMV scale are also included in this netCDF output file. Each trajectory contains “nb_sect” groups, with the corresponding trajectory sectors.

Parameter types	Content
Types:	
compound Segment	// Structure to contain 1 Segment data
Segment(*) Trajectory	// Structure to contain n Segment data (1 Trajectory)
compound Wind	// Structure to contain 1 Data (including AMV and Trajectory)
Variables:	
Wind wind_XXXXX(number_of_observations_XXXXX)	// Wind data for channel XXXXX
Dimensions:	
number_of_observations_XXXXX	// Number of AMVs for channel XXXXX
Attributes	

Table 17: High Level specification of the NWC/PPS-HRW netCDF output

The detailed structure of the netCDF output for the NWC/PPS-High Resolution Winds and Trajectories is shown in *Table 18*. The “BUFR Code Tables” used are described in chapter 2.3.5.1 of this document.

The list of common attributes described in the “Data Output Format for the NWC/PPS” document [AD.6] is also to be taken here into account. Considering these “Common attributes” and NWC/PPS-HRW outputs:

- The "product_quality" is the "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%).
- The "product_completeness" is the "percentage of AMVs" written in the netCDF output file, with respect to the theoretical value of AMVs defined by the software at all preliminary locations. This parameter gives an idea of how many AMVs were successfully calculated, defined also as a percentage value (from 0% to 100%).

Parameter types	Content
Types:	
compound segment	// Structure to contain 1 Trajectory Segment
float latitude	// Latitude (degree north)
float longitude	// Longitude (degree east)
float latitude increment	// Latitude Increment (degree north)
float longitude increment	// Longitude Increment (degree east)
float air temperature	// Air Temperature (K)
float air pressure	// Air Pressure (Pa)
float air pressure error	// Air Pressure Error (Pa)
float air pressure correction	// Air Pressure Correction (Pa) (not used in NWC/PPS-HRW)
float air pressure_nwp_best_fit_level	// Air Pressure NWP Model at Best Fit Level (Pa)
float wind speed	// Wind Speed (m/s)
float wind from direction	// Wind Direction (from which wind is blowing) (°)
unsigned byte quality_index_with_forecast	// Quality Index with Forecast Test (% , [0,100])
unsigned byte quality_index_without_forecast	// Quality Index without Forecast Test (% , [0,100])
unsigned byte quality_index_iwvg_value	// Quality Index with common IWVG quality index (% , [0,100])
unsigned byte tracer_correlation_method	// Tracer Correlation method (BUFR code table 002164)
unsigned byte tracer_type	// Tracer Type (BUFR code table 060102)
unsigned byte height_assignment_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte orographic_index	// Orographic index (BUFR code table 060205)
unsigned byte cloud_type	// NWC SAF/Cloud Type (BUFR code table 060206)
unsigned byte correlation	// Correlation (% , [0,100])
compound wind	
unsigned int wind_idx	// Wind sequence Number
unsigned int previous_wind_idx	// Prior wind sequence number
unsigned byte number_of_winds	// Number of winds computed for the tracer
unsigned byte correlation_test	// Correlation test (BUFR code table 060201)
unsigned short quality_test	// Applied Quality tests (BUFR code table 060202)
unsigned int segment_x	// Segment size at nadir in X direction (meters)
unsigned int segment_y	// Segment size at nadir in Y direction (meters)
unsigned int segment_x_pix	// Segment size at nadir in X direction (pixels)
unsigned int segment_y_pix	// Segment size at nadir in Y direction (pixels)
float latitude	// Latitude (degree north)
float longitude	// Longitude (degree east)
float latitude increment	// Latitude increment (degree north)
float longitude increment	// Longitude increment (degree east)
float air temperature	// Air Temperature (K)
float air pressure	// Air Pressure (Pa)
float air pressure error	// Air Pressure Error (Pa)
float air pressure correction	// Air Pressure Correction (Pa) (not used in NWC/PPS-HRW)
float air pressure_nwp_at_best_fit_level	// Air Pressure NWP Model at Best Fit Level (Pa)
float wind speed	// Wind Speed (m/s)
float wind from direction	// Wind Direction (from which wind is blowing) (°)
float wind speed_nwp_at_amv_level	// Wind Speed of NWP Model at AMV Level (m/s)
float wind from direction_nwp_at_amv_level	// Wind Direction of NWP Model at AMV Level (°)
float wind speed_nwp_at_best_fit_level	// Wind Speed of NWP Model at Best Fit Level (m/s)
float wind from direction_nwp_best_fit_level	// Wind Direction of NWP Model at Best Fit Level (°)
float wind speed_difference_nwp_at_amv_level	// Wind Speed of Difference with NWP model (m/s)
float wind from direction_difference_nwp_at_amv_level	// Wind Direction of Difference with NWP model (°)
float wind speed_difference_nwp_at_best_fit_level	// Wind Speed of Difference with NWP model best fit (m/s)
float wind from direction_difference_nwp_at_best_fit_level	// Wind Direction of Difference with NWP model best fit (°)
unsigned byte quality_index_with_forecast	// Quality Index with Forecast Test (% , [0,100])
unsigned byte quality_index_without_forecast	// Quality Index without Forecast Test (% , [0,100])
unsigned byte quality_index_iwvg_value	// Quality Index with common IWVG quality index (% , [0,100])
unsigned byte tracer_correlation_method	// Tracer Correlation method (BUFR code table 002164)
unsigned byte tracer_type	// Tracer Type (BUFR code table 060102)
unsigned byte height_assignment_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte orographic_index	// Orographic index (BUFR code table 060205)
unsigned byte cloud_type	// NWCSAF/Cloud Type (BUFR code table 060206)
unsigned byte correlation	// Correlation (% , [0,100])
segment(*) trajectory	// Trajectory defined as a variable-length array of Segment structures
Variables:	
Wind wind_XXXXX(number_of_observations_XXXXX)	// Wind (AMV + Trajectory) data
Dimensions:	
number_of_observations_XXXXX	// Number of AMVs for channel XXXXX
Attributes:	
cycle	// In NWC/PPS-HRW, used as Satellite orbit number
first_guess	// Origin of the first guess BUFR code table 025202)
long_name	"NWC/PPS High Resolution Winds"
manual_automatic_quality_control	// Manual/automatic quality control (BUFR code table 033035)
number_of_nwp_wind_levels	// NWP wind levels used for processing
sensor_band_central_radiation_frequency	// Satellite channel centre frequency (Hz)
sensor_band_central_radiation_width	// Satellite channel band width (Hz)
sensor_band_identifier	// Satellite channel id
standard_name	"Atmospheric winds"
time_period	// Time period between satellite images
validation_nwp_forecast_or_analysis	// Validation NWP analysis/forecast (BUFR code table 060220)
wind_computation_method	// Satellite wind comp. method (BUFR code table 002023)

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

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 NWC SAF Helpdesk website (<http://www.nwcsaf.org>). Following figures show typical displays of NWC/PPS-HRW v7.P 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”). For the region “EURON1 – Scandinavia” in *Figures 16 and 17*, and for the region “EUROPA” in *Figures 18 and 19*.

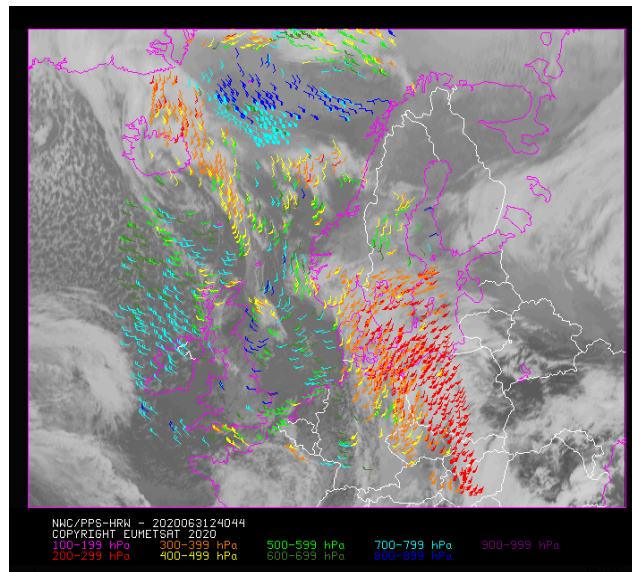


Figure 16: NWC/PPS-High Resolution Winds “Basic AMV” output example in the region “EURON1 - Scandinavia” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite), considering conditions defined in \$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm model configuration file. Colour coding based on the AMV pressure level

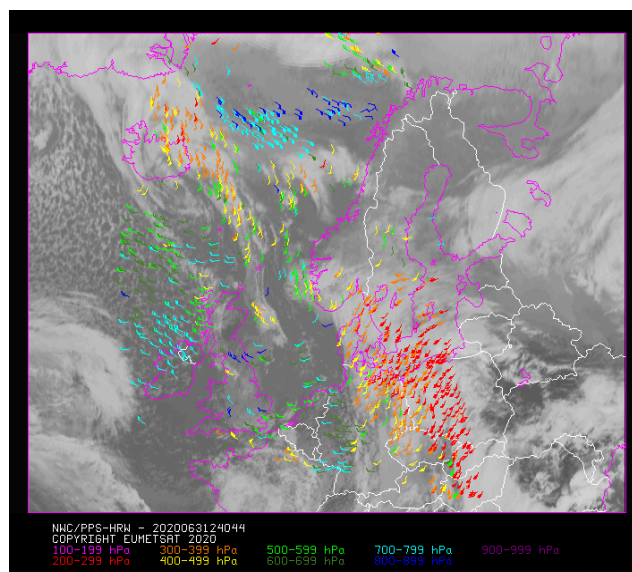


Figure 17: NWC/PPS-High Resolution Winds “Detailed AMV” output example in the region “EURON1 - Scandinavia” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite), considering conditions defined in \$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm model configuration file and configurable parameter CDET=1. Colour coding based on the AMV pressure level

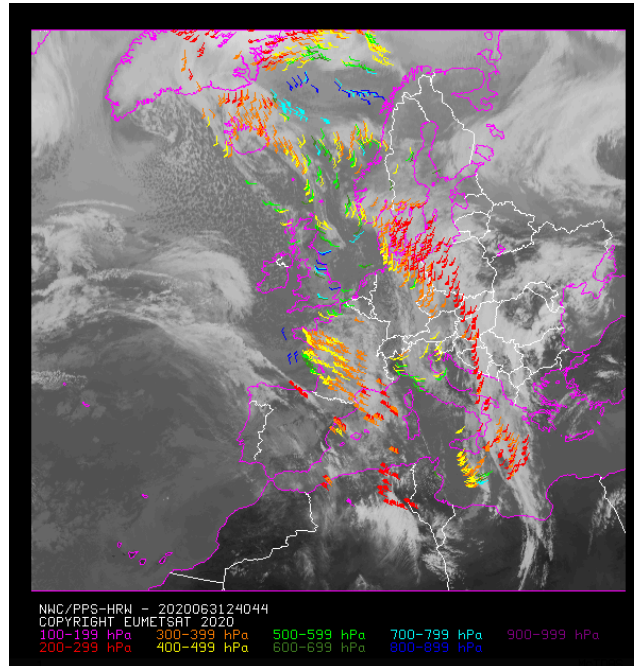


Figure 18: NWC/PPS-High Resolution Winds “Basic AMV” output example in the region “EUROPA” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` model configuration file. Colour coding based on the AMV pressure level

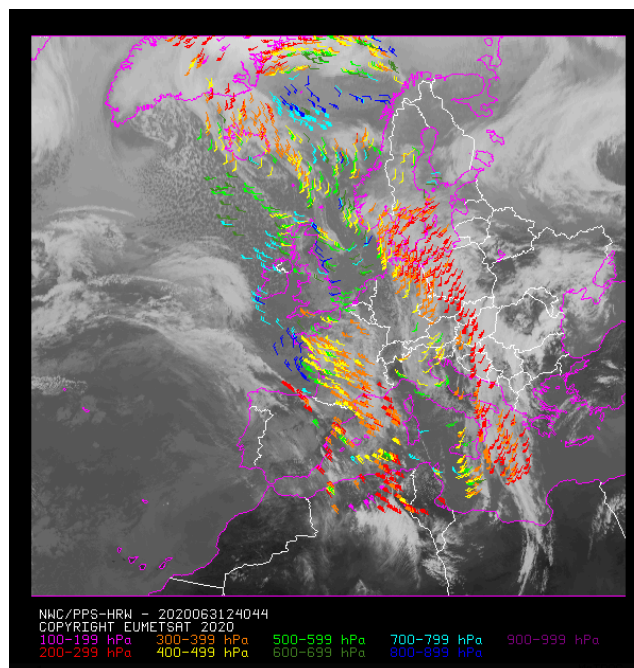




Figure 19: NWC/PPS-High Resolution Winds “Detailed AMV” output example in the region “EUROPA” (3 March 2020 12:40:44 UTC for SNPP satellite, with tracers calculated at 12:20:09 UTC for EOS-2 satellite), considering conditions defined in `$SM_CONFIG_DIR/safnwc_HRW_POLAR.cfm` model configuration file and configurable parameter `CDET=1`. Colour coding based on the AMV pressure level

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 80/94
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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.6]).

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_HRW_AUX_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_SUNSATANGLES_DIR=(dir where "sunsatangles" data are to be located)
export SM_IMAGER_DIR=(dir where "avhrr/viirs/modis" data are to be located)
export SM_PRODUCT_DIR=(dir where NWC/PPS-Clouds+HRW outputs are to be located)
```

- Decompress and install the NWC/PPS distribution files, which successfully build the executable (PPS-HRW-v7P), to be stored in \$SAFNWC/bin directory, such as defined in [AD.6].

2.3.7.2 Running of High Resolution Winds (NWC/PPS-HRW)

Before running PPS-HRW-v7P 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-v7P <current_sunsatangles_NetCDF_file> <model_conf_file>
```


 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 81/94
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where the PPS-HRW-v7P 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.6] and run before the running of NWC/PPS-HRW software.

Here, the NWC SAF 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”:

$$WTimeSep * RatioOfTimeSeparation + WCommonScan(1 - PercOfPixelsCommonlyScanned)$$

- o “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),
- o “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).
- o “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).

The best option for the pair “initial image”/“later image” is so defined considering the time separation between images and the percentage of common scanning in the static processing region. 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 possible to run PPS-HRW-v7P executable through:

```
PPS-HRW-v7P <current_sunsatangles_NetCDF_file> <previous_sunsatangles_NetCDF_file> <model_conf_file>
```

Here, the NWC SAF 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 20 to 22* summarise how the tasks to generate the High Resolution Winds (NWC/PPS-HRW) are performed by the PPS-HRW-v7P executable:

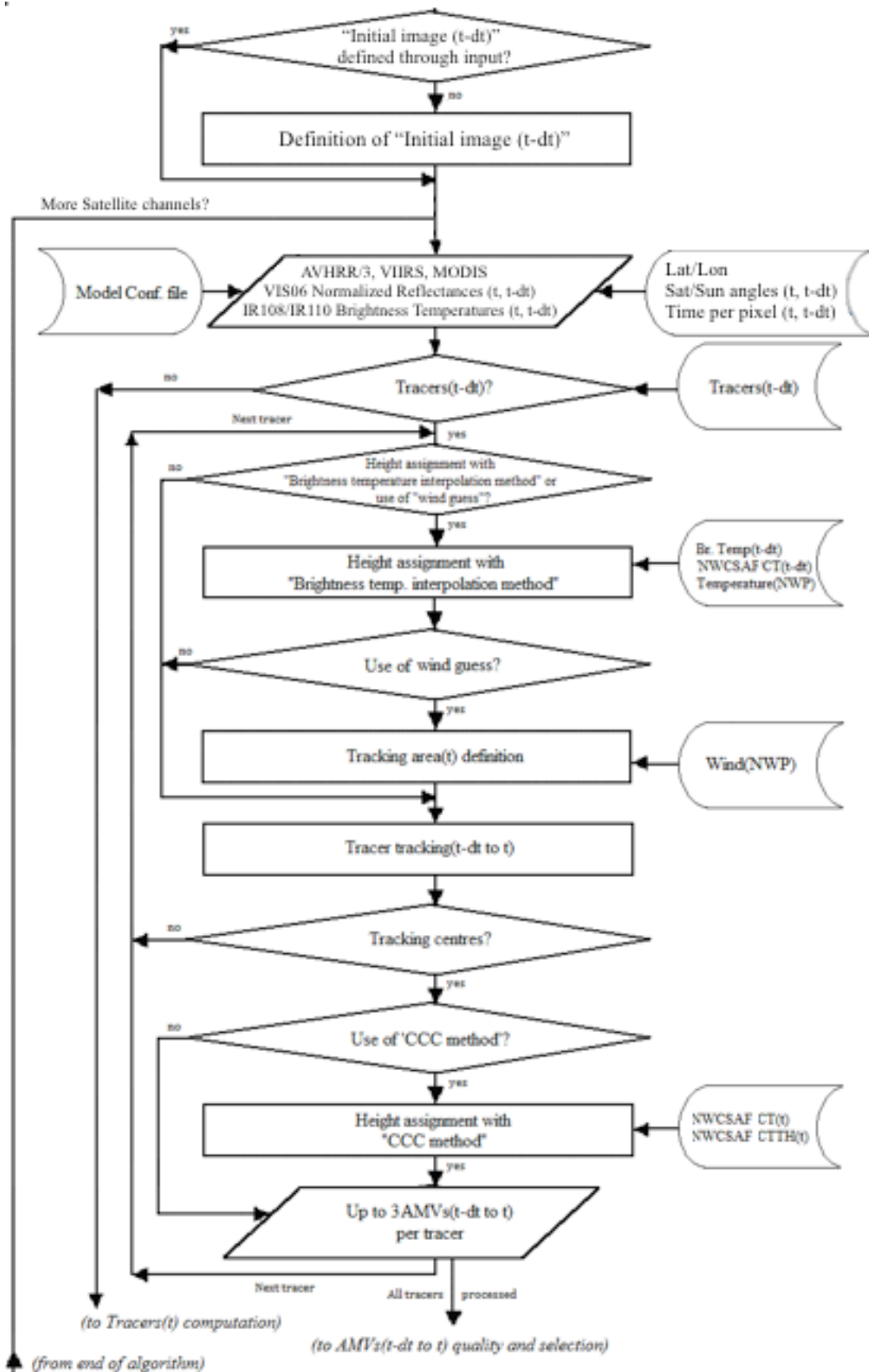


Figure 20: NWC/PPS-HRW implementation: Part 1, Preprocessing and AMV computation

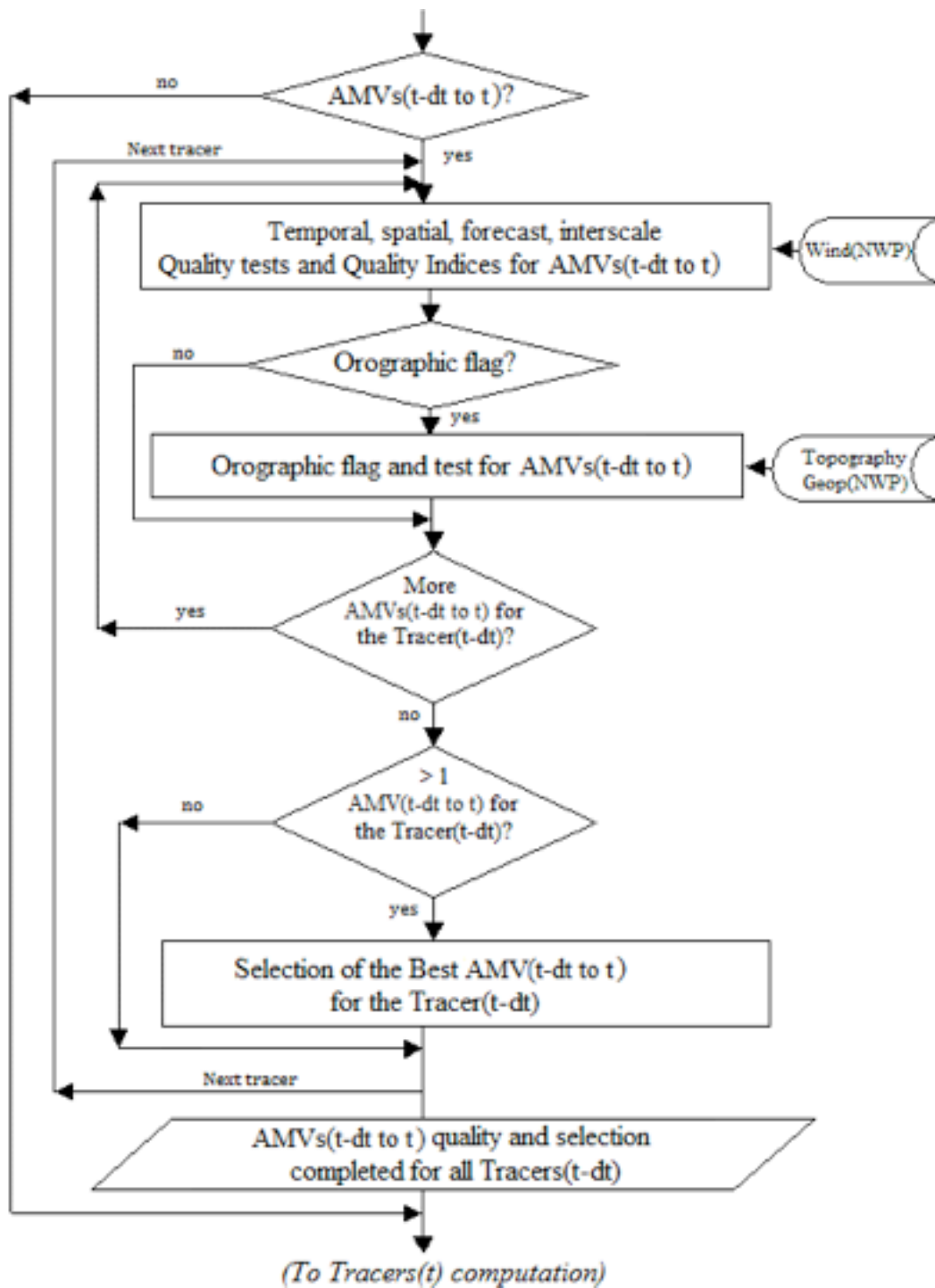


Figure 21: NWC/PPS-HRW implementation: Part 2, AMV quality and selection

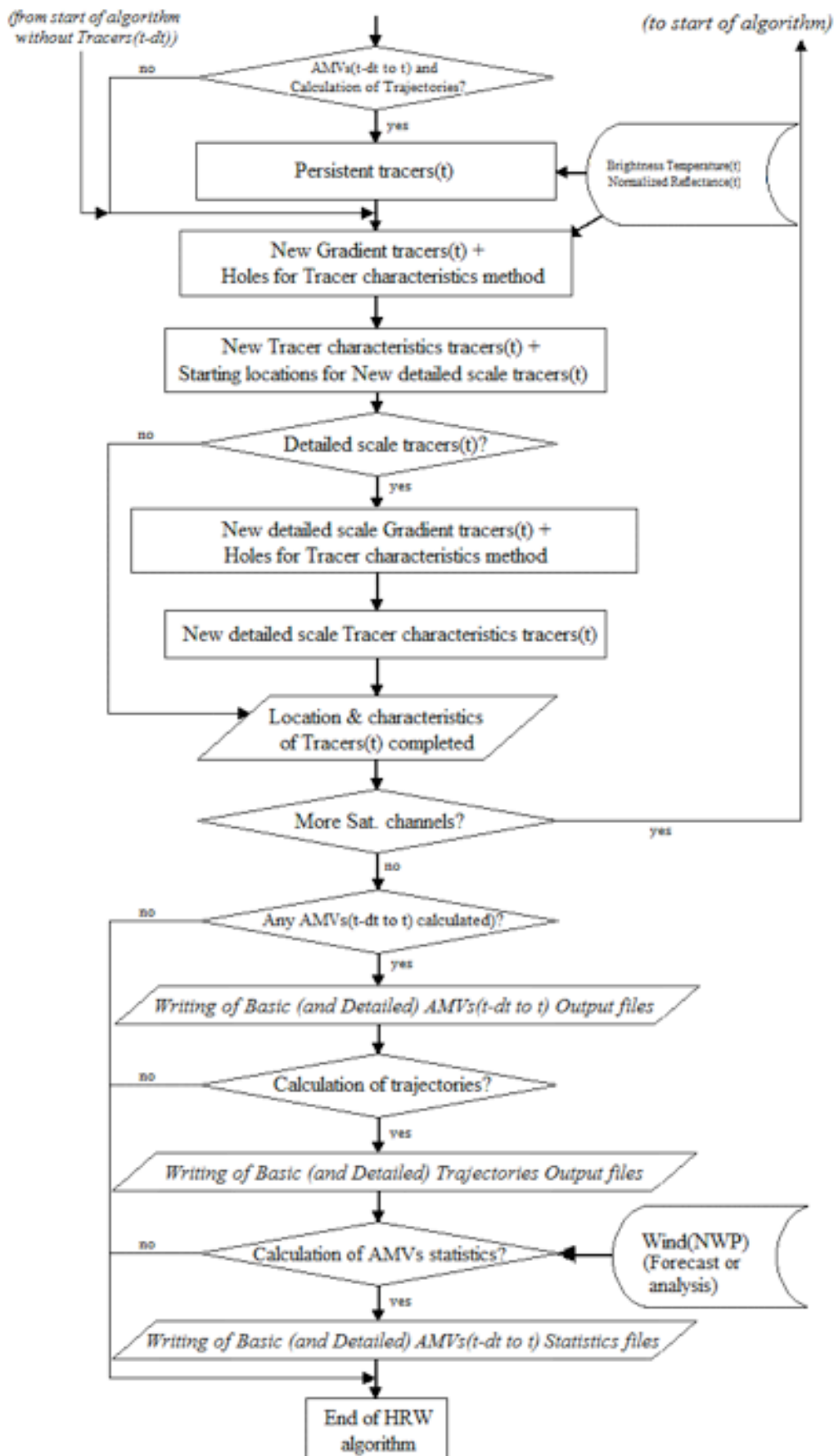




Figure 22: NWC/PPS-HRW implementation: Part 3, Tracer computation and writing of output

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 85/94
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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.P 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 the following pages. 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.

Table 19: 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 “last image time” directly from the input command
*** hrw_TimeAdd	=> In NWC/GEO, calculates “initial image time” with “last 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”
*** NwcPPSProdReadClose	=> In NWC/PPS, closes “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_ImageChecking	=> Checks and redefines Satellite image values
*** NwcNwpReadPLLevel	=> 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 => CT/Cloud type (and in NWC/GEO CMIC/Cloud phase) read for processing in HRW algorithm
*** NwcProdReadDataQ => CTTH/Pressure/Temp/Height (and in NWC/GEO CMIC/Water paths) read for processing in HRW algorithm
*** 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 position in the initial and 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_GetClhdgt
        *** 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
        *** 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 the time for Tracer position in initial image and later image
    *** NwcTimeDiff => In NWC/GEO, calculates the time difference for the Tracer position in the initial and 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 => In NWC/GEO, converts Clear air AMV tracking position temperatures to pressure considering NWP data
*** hrw_NWPDDirInterpolation => In NWC/GEO, 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_NWPDDirInterpolation => 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_EncodeBufnrNWCEC => Writes the "AMV/Trajectory BUFR output file with NWC SAF 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
            *** NwcTimeDiff => Calculates time difference for each image in the AMV calculation with respect to the Output time
            *** 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
            *** NwcTimeDiff => Calculates time difference for each image in the AMV calculation with respect to the Output time
        *** hrw_SetChannelInfoforBUFRTRAJEC => Writes information for all Trajectories related to one satellite channel in the BUFR output
            *** NwcTimeDiff => Calculates time difference for each image in the AMV calculation with respect to the Output time
            *** hrw_SetTrajectoryInfoforBUFRTRAJEC => Writes information for one Trajectory in the BUFR output

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*** 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
            *** NwcTimeDiff => Calculates time difference for each image in the AMV calculation with respect to the Output time
              *** NwcCFRead => Reads the "parameter list" from the "NWP Configuration file" used
                *** NwcCFGetStr => Reads from the "NWP Configuration file" the NWP Identification for the NWP model used
*** hrw_EncodeNetCDF => Writes the "AMV netCDF output file"
  *** NwcProdWriteInit => Opens the "AMV netCDF output file"
  *** hrw_WriteNetCDF => Calls the different functions filling the sections that compose the netCDF output file
    *** hrw_InitialiseNetCDF => Creates all defined netCDF dimensions/types/variables/attributes
      *** hrw_CheckNcErr => Checks that the status output of a netCDF function is not an error
        *** hrw_WriteNcVarAtt => Writes the NWC/HRW Attributes in the netCDF output file
          *** hrw_WriteNcVar => Writes the AMV data for a defined satellite channel in the netCDF output file
            *** hrw_SetWindNetCDF => Writes specific information for a defined AMV in the netCDF output file
              *** 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
          *** NwcProdWriteClose => Closes the "AMV netCDF output file"
*** hrw_WriteStatistics => Writes the AMV validation statistics in the HRW log file and the Statistics output file
  *** NwcTimeNow => Defines the current time
*** 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
*** NwcRegionFree => Deallocates memory for "region" data

```

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 93/94
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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 generally smaller amounts of AMVs for the longest time intervals).

The deformation of the images caused by the reprojection process to the static working region can also have an impact, especially when the satellite zenith angles for a pixel are very different in the “initial image” and the “later image”, causing a reduction in the amount of calculated AMVs.



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

Considering this, and taking into account that the latest version of NWC/GEO-HRW (v6.1) 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 satellite (in the Americas), NWC/PPS-HRW adds the option to calculate AMVs in Arctic and Antarctic areas, so adding more options to calculate AMVs with the same AMV algorithm throughout all the world (which is rather uncommon).

An issue remains in the Eastern Pacific areas, for which NWC/GEO software package is not operational with GOES-17 satellite (due to the problems observed in the cooling system of its ABI imager and the instabilities in its image output). A solution for this issue is expected for 2022 with the launch and normal operation of GOES-T satellite, allowing to calculate AMVs with NWC SAF/High Resolution Winds algorithm in all areas of the world, which can be important for example for NWP assimilation in global models or for climate studies.

Considering this first version of NWC/PPS-HRW software, some elements remain to be included in the processing for a total equivalence with NWC/GEO-HRW software (for example, 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”), but these elements are expected to be included in a second version of NWC/PPS-HRW software in around one year time.

Considering the validation of NWC/PPS-HRW, comparing its statistics with those for NWC/GEO-HRW software, it has been seen that the values of NMVD and NRMSVD parameters can be up to a 20% higher. In spite of this, while for NWC/GEO-HRW software the Product Requirement Table “Optimal accuracy” is reached in the High layer and the “Target accuracy” is reached in the Medium and Low layer, for this first version of NWC/PPS-HRW software, the Product Requirement Table “Target accuracy” is still reached for all layers. Considering this, NWC/PPS-HRW outputs can be perfectly used by NWC SAF users the same way they are using NWC/GEO-HRW outputs, in spite of being defined only as a “demonstrational version”.

 	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/PPS	Code: NWC/CDOP3/PPS/AEMET/SCI/ATBD/Wind Issue: 0.1 Date: 12 October 2021 File: NWC-CDOP3-PPS-AEMET-SCI-ATBD-Wind_v0.1.docx Page: 94/94
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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 QI 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 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”, around a 5% of the tracers persist in the “Detailed scale”. This is an issue that users should also have into account when using the Trajectories calculated by NWC/PPS-HRW software.

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