



User Manual

for the Wind product processor

of the NWC/GEO: Science Part

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List of contents

1. INTRODUCTION	7
1.1 SCOPE OF THE DOCUMENT	7
1.2 SOFTWARE VERSION IDENTIFICATION	8
1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS	8
1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS	10
1.4.1 Definitions	10
1.4.2 Acronyms and Abbreviations	14
1.5 REFERENCES	15
1.5.1 Applicable Documents	15
1.5.2 Reference Documents	16
2. DESCRIPTION OF HIGH RESOLUTION WINDS (NWC/GEO-HRW)	17
2.1 GOAL OF HIGH RESOLUTION WINDS (NWC/GEO-HRW)	17
2.2 OUTLINE OF THE ALGORITHM	19
2.2.1 Preprocessing	20
2.2.2 Tracer calculation	21
2.2.3 Tracer tracking and Wind Calculation	21
2.2.4 Height assignment with 'Brightness temperature interpolation method'	23
2.2.5 Height assignment with 'CCC method'	25
2.2.6 Postprocessing: Quality control and Choice of the best wind	27
2.2.7 Postprocessing: Orographic flag	28
2.2.8 Postprocessing: Autovalidation of NWC/GEO-HRW algorithm	29
2.3 DESCRIPTION OF HIGH RESOLUTION WINDS (GEO-HRW) OUTPUTS	31
2.3.1 HRW output as BUFR bulletins with NWCSAF specific format (AMVs)	32
2.3.2 HRW output as BUFR bulletins with NWCSAF specific format (Trajectories)	36
2.3.3 HRW output as BUFR bulletins with the previous IWWG format (AMVs)	38
2.3.4 HRW output as BUFR bulletins with the 2018 IWWG format (AMVs)	43
2.3.5 HRW output as netCDF bulletins	47
2.3.6 Output data filterings	49
3. IMPLEMENTATION OF NWC/GEO-HRW PRODUCT	50
3.1 NWC/GEO SOFTWARE PACKAGE INSTALLATION AND PREPARATION	50
3.2 NWC/GEO-HRW EXECUTION STEP	51
3.3 NWC/GEO-HRW DOCUMENTATION	55
3.4 NWC/GEO-HRW ERROR MESSAGES	56
4. INPUTS AND CONFIGURABLE PARAMETERS	58
4.1 LIST OF INPUTS FOR HIGH RESOLUTION WINDS	58
4.2 LIST OF HIGH RESOLUTION WINDS CONFIGURABLE PARAMETERS	60
5. NWC/GEO-HRW ASSUMPTIONS AND LIMITATIONS	64
6. VISUALISATION EXAMPLES OF HIGH RESOLUTION WINDS	66

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: AMV filtering related to the ‘AMV cloud type’ and each channel, and consideration of the ‘top pressure’ or ‘base pressure’ in the Brightness temperature interpolation height assignment method for the valid cases	24
Table 6: Variables used for the AMV output with the NWCSAF specific BUFR format	34
Table 7: Description of “local variables” in the NWCSAF specific BUFR format	35
Table 8: Variables used for the Trajectory output with the NWCSAF specific BUFR format.....	37
Table 9: Variables used for the AMV output with the previous IWWG BUFR format.....	42
Table 10: Variables used for the AMV output with the 2018 IWWG BUFR format	46
Table 11: High Level specification of the NWC/GEO-HRW netCDF output	47
Table 12: Detailed specification of the NWC/GEO-HRW netCDF output.....	48
Table 13: AMV filtering related to the Height level and each satellite channel	49
Table 14: List of errors for NWC/GEO-HRW	57
Table 15: NWC/GEO-HRW Model Configuration File Description	63

List of Figures

Figure 1: NWC/GEO-HRW implementation: Part 1, Preprocessing and AMV computation	52
Figure 2: NWC/GEO-HRW implementation: Part 2, AMV quality and selection	53
Figure 3: NWC/GEO-HRW implementation: Part 3, Tracer computation and writing of output files	54
Figure 4: NWC/GEO High Resolution Winds Basic AMV output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG-2 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file. Colour coding based on the AMV pressure level.....	66
Figure 5: NWC/GEO High Resolution Winds Detailed AMV output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG-2 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file and configurable parameter <code>CDET = 1</code> . Colour coding based on AMV pressure level.....	66
Figure 6: NWC/GEO High Resolution Winds Basic AMV output example in the Continental United States region (1 Jul 2010 17:45 UTC, GOES-13 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file. Colour coding based on the AMV pressure level.....	67
Figure 7: NWC/GEO High Resolution Winds Detailed AMV output example in the Continental United States region (1 Jul 2010 17:45 UTC, GOES-13 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file and configuration parameter <code>CDET = 1</code> . Colour coding based on the AMV pressure level.....	67
Figure 8: NWC/GEO High Resolution Winds Basic AMV output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file. Colour coding based on the AMV pressure level. Himawari-8 HSD original data used as input	68
Figure 9: NWC/GEO High Resolution Winds Detailed AMV output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file and configurable parameter <code>CDET=1</code> . Colour coding based on the AMV pressure level. Himawari-8 HSD original data used as input	68
Figure 10: NWC/GEO High Resolution Winds Basic AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file. Colour coding based on the AMV pressure level.....	69
Figure 11: NWC/GEO High Resolution Winds Detailed AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file and configuration parameter <code>CDET = 1</code> . Colour coding based on the AMV pressure level.....	69
Figure 12: NWC/GEO High Resolution Winds Basic AMV output example in the Eastern Pacific region (29 April 2021, 00:00 UTC, GOES-17 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file. Colour coding based on the AMV pressure level.....	70
Figure 13: NWC/GEO High Resolution Winds Detailed AMV output example in the Eastern Pacific region (29 April 2021, 00:00 UTC, GOES-17 satellite), considering default conditions defined in <code>safnwc_HRW.cfm</code> model configuration file and configuration parameter <code>CDET = 1</code> . Colour coding based on the AMV pressure level.....	70

1. INTRODUCTION

The “EUMETSAT Satellite Application Facilities (SAFs)” are dedicated centres of excellence for the processing of satellite data, and form an integral part of the distributed “EUMETSAT Application Ground Segment”. This documentation is provided by the “SAF on support to Nowcasting and Very short range forecasting (NWCSAF)”.

The main objective of the NWCSAF is to provide, develop and maintain software packages to be used with operational meteorological satellite data for Nowcasting applications. More information about the project can be found at the NWCSAF webpage, <https://nwc-saf.eumetsat.int>.

This document is applicable to the NWC/GEO software package for geostationary satellites.

1.1 SCOPE OF THE DOCUMENT

This document is the “User Manual (UM) for the Wind Product Processor of the NWC/GEO” software package (NWC/GEO-HRW, High Resolution Winds), which calculates Atmospheric Motion Vectors and Trajectories considering:

- Up to seven channels from MSG/SEVIRI imager: six 3 km low resolution visible, water vapour and infrared channels (VIS06 0.635 μm , VIS08 0.810 μm , WV062 6.250 μm , WV073 7.350 μm , IR108 10.800 μm and IR120 12.000 μm), and the 1 km high resolution visible channel (HRVIS 0.750 μm).
- Up to three channels from GOES-N/IMAGER: two 4 km low resolution water vapour and infrared channels (WV065 6.550 μm and IR107 10.700 μm), and the 1 km high resolution visible channel (VIS07 0.650 μm).
- Up to six channels from Himawari-8/9/AHI imager: four 2 km low resolution water vapour and infrared channels (WV062 6.250 μm , WV069 6.950 μm , WV073 7.350 μm and IR112 11.200 μm), one 1 km high resolution visible channel (VIS08 0.860 μm), and the 0.5 km very high resolution visible channel (VIS06 0.645 μm).
- Up to six channels from GOES-R/ABI imager: four 2 km low resolution water vapour and infrared channels (WV062 6.150 μm , WV070 7.000 μm , WV074 7.400 μm and IR112 11.200 μm), one 1 km high resolution visible channel (VIS08 0.860 μm), and the 0.5 km very high resolution visible channel (VIS06 0.640 μm).

The adaptation for GOES-R satellite series has been extended in this version to GOES-17 satellite with some limitations: AMVs and Trajectories are calculated by NWC/GEO-HRW in the default mode for GOES-16 and GOES-17, only when Full Disk images in “Mode 6” are provided (with images every 10 minutes), for areas in the image where NWC/GEO-Cloud products could be calculated and the quality flag for the satellite channel used for AMV calculation is zero (optimal) for all pixels implied in the AMV calculation. This way, the quality of the AMVs and Trajectories is guaranteed, and the problems related to the cooling issue in the GOES-17 ABI imager are avoided, although this also implies that NWC/GEO-HRW output is not available 24 hours per day all days of the year.

With all this, NWC/GEO-HRW v6.2 is able to cover with five different simultaneous geostationary satellites the whole Earth, and AMVs and Trajectories can be calculated simultaneously throughout the whole planet, except in the moments around the Equinoxes in which GOES-17 cannot be processed.

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

There is a commitment so that the adaptation of NWC/GEO-HRW algorithm to all these geostationary satellite series (MSG, GOES-N, Himawari-8/9 and GOES-R) is fully validated. The validation results for NWC/GEO-HRW v6.2 (calculated for MSG, GOES-13, Himawari-8, GOES-16 and GOES-17) and the conclusions related to the update to NWC/GEO-HRW v6.2, are available in the corresponding “Scientific and Validation Report” [AD.8].

1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithm implemented in NWC/GEO-HRW v6.2, Product Id NWC-086, of the NWC/GEO v2021 software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

The main improvements related to NWC/GEO-HRW v6.2 are the following ones:

1. The extension of NWC/GEO-HRW algorithm to Himawari-9 and GOES-17 satellites, as for all other NWC/GEO products. Considering GOES-17 satellite, a specific adaptation of NWC/GEO-HRW code has been done to cope with the "cooling issues" in the GOES-17/ABI radiometer.
2. Optimisation of the running time of NWC/GEO-HRW product. With MSG, Himawari-8/9 and GOES-R satellites, a similar number of AMVs is calculated now in the default configurations with an up to 30% reduction in the running time with respect to NWC/GEO-HRW v6.1.
 - This has been done with the use of more effective operations and functions in the code (for example, avoiding multiplications and divisions by variable parameters when their value is one, using more effective operations and functions like the change of divisions and power operations for multiplications when possible, avoiding the repetitive use of the same costly operation more than once, etc.).
 - The optimisation has also been reached using equivalent but more effective processes in the parts of the code that were more time consuming (for example, making the "tracking" faster by defining the "tracking area" with the real dimensions of corresponding pixels). These specific processes used in the optimisation have been identified in the text.
3. Better distribution of AMVs in High/medium/low levels. For all satellites the proportion of medium+low level AMVs has increased at least a 9%, and for MSG satellites an optimal distribution of high/medium/low level AMVs of 35%/32%33% has been reached. This is useful for a better characterization of all levels of the troposphere in which AMVs are calculated (approximately between 140 and 1000 hPa).
4. The update of six SPRs occurring since the release of the previous NWC/GEO-HRW v6.1 version:
 - SPR-696 (Issue occurring in around 1% of cases).
 - SPR-697 (NWP management with missing levels).
 - SPR-706 (Option so that the satellite visible channels can be received in any resolution).
 - SPR-712 (Update of some HRW files so that the running keeps equivalent to previous versions under similar input data conditions).
 - SPR-717 (Error occurring when HRW is run in night conditions, related to updates included in HRW v6.2 and HRW vMTG).
 - SPR-721 (Small update of HRW height assignment for AMVs between 0-230 hPa; related to a study by the Hungarian Meteorological Service (OMSZ) in January 2021).

Comparing with NWC/GEO-HRW vMTG day-1, which will be the following version to be released, both codes are exactly equivalent with only the following seven differences:

1. Logically, NWC/GEO-HRW vMTG day-1 will be the first version supporting MTG-I satellite series, while NWC-GEO v6.2 still does not support it.
2. NWC/GEO-HRW v6.2 is the last version in which GOES-N satellite series is supported. In NWC/GEO-HRW vMTG day-1, processing in the Americas and Eastern Pacific will only be provided through GOES-R satellite series.
3. NWC/GEO-HRW v6.2 is the last version providing as output the BUFR bulletin based on the previous "International Winds Working Group (IWWG)" format (explained in chapter 2.3.3). This format is being replaced by the BUFR bulletin based on the "2018 IWWG format" (explained in chapter 2.3.4). The IWWG gave AMV producers and users the recommendation in its 2018 Workshop to adopt this new AMV BUFR template (through action IWW14 – WG1 – Action 6)

within one year after the definition of this new format, and in 2021 all AMV users should already be used to the new format.

4. In NWC/GEO-HRW v6.2, GRIB-API library is used for the encoding of the HRW BUFR bulletins. In NWC/GEO-HRW vMTG day-1, ECCODES library is used for the encoding of the HRW BUFR bulletins.
5. The structure of the NWC/GEO-HRW netCDF output changes between these two versions. In NWC/GEO-HRW vMTG day-1, the structure of this netCDF output will be CF compliant and easier to process (following recommendations from NWCSAF users).
6. The definition of the Earth ellipsoid changes for different satellites in NWC/GEO-HRW vMTG day-1, being defined as configurable parameters in different configuration files. In NWC/GEO-HRW v6.2, these parameters are similar for all satellites, so causing some small differences in the satellite navigation. This change affects all NWC/GEO products.
7. The structure of \$SAFNWC temporal directory changes a bit between versions. This change affects all NWC/GEO products.

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 n x n pixels called tracer
Basic dataset	Set of tracers or AMVs, calculated with the basic or wide tracer scale (with a default value of 24 x 24 pixels). Two kinds of Basic tracers are possible: wide basic tracers (with bright big pixels in the first and last big pixel row or column) and narrow basic tracers (occurring otherwise)
Bearing angle	Angle defined by the great circle connecting two locations on the Earth
Best fit pressure level	Pressure level which minimizes the vector difference between the AMV and a reference wind, considering as reference wind the nearest NWP wind profile or nearest Radiosounding wind profile
Big pixel	Each element of the 4x4 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 are 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 8-bit 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/GEO-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

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 are 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/GEO-HRW, through which the tracer tracking is evaluated considering shorter time intervals, and the displacement is evaluated considering longer time intervals.
Neighbour AMV	AMV which is close enough to a given one in the current processing cycle, used in the Quality spatial correlation test

N_Value matrix	Normalized reflectances for Visible channels, or Brightness temperatures for Infrared or Water vapour channels, for a given image in the processing region, defined as 8-bit 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 is defined as valid and is written in the output files
S (in tracking 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 values
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 locations
T (in tracking computation)	Any pixel inside a tracer

TESO parameter	Orographic test parameter, detailing if the orographic flag could be calculated for a given AMV, and the relative results in AMVs related to the same tracer, to be added to the Quality TEST indicator
TEST parameter	Quality flag after the Quality control processing, detailing which quality consistency tests were applied for a given AMV, and the relative results of each quality consistency test for all AMVs related to the same tracer
Tracer	Square segment in the initial image with a fixed size (nxn pixels, called tracer size), identified by the location of its centre, and considered valid candidate for AMV calculation by any of the tracer calculation methods
Tracer candidate	Square segment in the initial image with a fixed size, where conditions for tracer search using “Tracer characteristics method” are evaluated
Tracer continuity	Processing option in which part of the set of tracers in the current processing cycle is defined through the tracking centres of AMVs in the previous processing cycle
Tracer location	Pixel coordinates of a tracer centre (line and column) in the initial image
Tracer selection procedure	Strategy to get a complete set of tracers throughout the desired region of the image. It consists of 2 iterations (2 methods) for the single scale procedure; 4 iterations (2 methods, 2 scales) for the two scale procedure
Tracer size	Line/column dimension of a tracer. In NWC/GEO-HRW algorithm, 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
BUFR	Binary Universal Form for the Representation of meteorological data
CDOP	NWCSAF Continuous Development and Operations Phase
CDOP2	NWCSAF Second Continuous Development and Operations Phase
CDOP3	NWCSAF Third Continuous Development and Operations Phase
CIMSS	NOAA/UW's Cooperative Institute for Meteorological Satellite Studies
ECMWF	European Centre for Medium Range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GOES	NOAA's Geostationary Operational Environmental Satellite series
HRVIS, VIS06, VIS07, VIS08	MSG HRVIS 0.7 μm – MSG & Himawari-8/9 & GOES-R 0.6 μm - GOES-N 0.7 μm - MSG & Himawari-8/9 & GOES-R 0.8 μm Visible channels
IOP	NWCSAF Initial Operations Phase
IR107, IR108, IR112, IR120	GOES-N 10.7 μm - MSG 10.8 μm - Himawari-8/9 & GOES-R 11.2 μm - MSG 12.0 μm Infrared channels
IWWG	International Winds Working Group
JMA	Japan Meteorological Agency
MSG	EUMETSAT's Meteosat Second Generation Satellite series
MTG-I	EUMETSAT's Meteosat Third Generation Satellite (Imager)
NOAA	United States' National Oceanic and Atmospheric Administration
NWC/GEO	NWCSAF Software Package for Geostationary satellites
NWC/GEO-HRW	NWCSAF Product Generation Element for the High Resolution Winds
NWCSAF	EUMETSAT's Satellite Application Facility on support to Nowcasting and Very short range forecasting
NWP	Numerical Weather Prediction Model
SCI	NWCSAF Scientific Report
SMR	NWCSAF Software Modification Report
SPR	NWCSAF Software Problem Report
TM	NWC/GEO Task Manager
UW	United States' University of Wisconsin/Madison
WMO	World Meteorological Organization
WV062, WV065, WV069, WV070, WV073, WV074	MSG & Himawari-8/9 & GOES-R 6.2 μm - GOES-N 6.5 μm - Himawari-8/9 6.9 μm - GOES-R 7.0 μm - MSG & Himawari-8/9 7.3 μm - GOES-R 7.4 μm Water vapour channels

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 NWCSAF Helpdesk web: <https://nwc-saf.eumetsat.int>.

<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 NWCSAF CDOP3 Phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.6
[AD.3]	Configuration Management Plan for the NWCSAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.1
[AD.4]	NWCSAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.5
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/1	2.0.1
[AD.6]	Data Output Format for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/DOF	2.0.1
[AD.7]	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/ATBD/Wind	1.0.1
[AD.8]	Scientific and Validation Report for the Wind product processor of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/VR/Wind	2.0.1

Table 3: List of Applicable Documents

1.5.2 Reference Documents

The reference documents contain useful information related to the subject of the project. These reference documents complement the applicable ones, and can be looked up to enhance the information included in this document if it is desired. They are referenced in this document in the form [RD.X]. For dated references, subsequent amendments to, or revisions of any of these publications do not apply. For undated references, the current edition of the 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 "NWCSAF 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://library.wmo.int/doc_num.php?explnum_id=10722#page=956)
[RD.20]	WMO FM94 BUFR Table B for Classification of elements, version 31 (WMO Publication, available at https://library.wmo.int/doc_num.php?explnum_id=10722#page=252)
[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 NWCSAF/HRW AMVs with AMVs from other producers (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/225)
[RD.25]	D.Santek, R.Dworak, S.Wanzong, K.Winięcki, 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]	D.J.Seidel, B.Sun, M.Petty & A.Reale, 2011: Global radiosonde balloon drift statistics (Journal of Geophysical Research, Num. 116).

Table 4: List of Reference Documents

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

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

The NWCSAF High Resolution Winds (NWC/GEO-HRW) product aims to provide, for near real time meteorological applications, detailed sets of “Atmospheric Motion Vectors” (AMVs) and “Trajectories” calculated from EUMETSAT’s Meteosat Second Generation (MSG), NOAA’s Geostationary Operational Environmental Satellite series (GOES-N and GOES-R) and JMA’s Himawari-8/9 geostationary satellite series images.

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, infrared or water vapour images (and so called “cloudy AMV”) or through a specific humidity feature in cloudless areas in water vapour images (and so called “clear air AMV”). 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, considering the displacement of tracers found in up to seven MSG/SEVIRI channel images:

- The high resolution visible channel (HRVIS),
- 2 low resolution 0.6 μ m and 0.8 μ m visible channels (VIS06, VIS08),
- 2 low resolution 10.8 μ m and 12.0 μ m infrared channels (IR108, IR120),
- 2 low resolution 6.2 μ m and 7.3 μ m water vapour channels (WV062, WV073).

in up to three GOES-N/IMAGER channel images:

- The high resolution 0.7 μ m visible channel (VIS07),
- 1 low resolution 10.7 μ m infrared channel (IR107),
- 1 low resolution 6.5 μ m water vapour channel (WV065).

in up to six Himawari-8/9/AHI channel images:

- The very high resolution 0.6 μ m visible channel (VIS06),
- 1 high resolution 0.8 μ m visible channel (VIS08),
- 1 low resolution 11.2 μ m infrared channel (IR112),
- 3 low resolution 6.2 μ m, 6.9 μ m and 7.3 μ m water vapour channel (WV062, WV069, WV073).

or in up to six GOES-R/ABI channel images:

- The very high resolution 0.6 μ m visible channel (VIS06),
- 1 high resolution 0.8 μ m visible channel (VIS08),
- 1 low resolution 11.2 μ m infrared channel (IR112),
- 3 low resolution 6.2 μ m, 7.0 μ m and 7.4 μ m water vapour channel (WV062, WV070, WV074).

NWC/GEO-HRW 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 product was determined.

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

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

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

NWC/GEO-HRW output is similar to other products calculating Atmospheric Motion Vectors: winds, trajectories and related parameters are calculated with a level 2 of processing. No level 3 of processing (as a grid interpolation or a meteorological analysis based on NWC/GEO-HRW output) is included.

2.2 OUTLINE OF THE ALGORITHM

As a whole, NWCSAF/High Resolution Winds algorithm (NWC/GEO-HRW) 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 data (Brightness temperatures and Normalized reflectances from MSG, GOES-N, Himawari-8/9 or GOES-R images, with their latitudes, longitudes, satellite and solar angles), and the reading of the NWP data and NWC/GEO product outputs (CT, CTTH, CMIC) that are also going to be used in the NWC/GEO-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.

The code was progressively developed with GOES, MFG and MSG satellite data. Examples with MSG, GOES-N, Himawari-8/9 and GOES-R satellite series 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.

In NWC/GEO-HRW v6.2, the default configuration implies the use of images separated by 10 minutes with Himawari-8/9 and GOES-R series, by 15 minutes with MSG series, and by 15 or 30 minutes with GOES-N series for the definition and tracking of the tracers, and so for the calculation of AMVs and Trajectories. An additional option for “Rapid scan mode” with MSG satellites is possible (with images separated by 10 minutes). No “Rapid scan mode” option has been defined for use with the other satellite series.

Additionally, considering a suggestion by Yuheng He from Hong Kong Observatory, an additional option has been included with configurable parameter `USE_OLDER_SLOT_FOR_TRACERS = 1`, through which the “initial image” related to the tracer calculation can be one more step backwards, in case the default one is not available. This is helpful for processing when some satellite slot is missing. However, this option is not implemented as default one.

2.2.1 Preprocessing

During the initialization process, next parameters are extracted for the selected region:

1. Normalized reflectances for any MSG, GOES-N, Himawari-8/9 or GOES-R visible channel to be used; brightness temperatures for any MSG, GOES-N, Himawari-8/9 or GOES-R infrared or water vapour channel to be used; radiances for MSG/IR108 and WV62, GOES-N/IR107 and WV65, Himawari-8/9 & GOES-R/IR112 and WV62 channels for the ‘Quality Control’.
2. Latitude and longitude, and solar and satellite zenith angle matrices for the satellite region to be used (which are calculated by NWC/GEO-NWCLIB library).
3. NWP temperature profiles. NWP wind component profiles are also extracted for the ‘forecast consistency quality test’, for the definition of the tracking area in the later image if the wind guess is used, or for the calculation of validation statistics with NWC/GEO-HRW algorithm itself. NWP geopotential profiles can also be extracted if the ‘Parallax correction’ of the AMV location or the ‘Orographic flag’ is calculated. NWP surface pressure field can also be extracted if the ‘Orographic flag’ is calculated. All of them are implemented in the default configuration.
4. NWC/GEO-CT Cloud Type output for the previous slot and selected region, in case the ‘AMV Cloud type’ is calculated by the ‘Brightness temperature interpolation height assignment method’. NWC/GEO-CT Cloud Type and NWC/GEO-CTTH Cloud Top Temperature and Pressure outputs for the current slot and selected region, in case the ‘CCC height assignment method’ is used. NWC/GEO-CMIC Cloud Phase, Liquid Water Path and Ice Water Path outputs for the current slot and selected region, in case the Microphysics correction is to be used inside ‘CCC height assignment method’. The three last ones are implemented in the default configuration.

Only the satellite data for the requested channels and the NWP temperature and wind profiles are strictly needed for the calculation of AMVs and Trajectories. All other data contribute to a higher number of AMVs and Trajectories and a better quality of the output data.

Throughout the AMV and Trajectory calculation, a verification is done checking that all pixels processed for the calculation of an AMV or Trajectory (in the “tracer” in the initial image and the “tracking area” in the later image) are in valid locations in the working region, with valid latitude, longitude, satellite and solar zenith angles, satellite data and NWC/GEO-CT/CTTH/CMIC outputs (when used, such as in the default configuration). In case of GOES-17 satellite, this also implies that the “GOES-17 quality flag” for all pixels is nominal (i.e., zero).

In case any of the inputs needed for the AMV or Trajectory calculation is not available and an alternative processing exists, it is used if configurable parameter `KEEPDEFAULTPROCEDURE = 0`. However, in the default configuration with `KEEPDEFAULTPROCEDURE = 1`, NWC/GEO-HRW processing stops. This was suggested by NWC/GEO users, to avoid the use of alternative methods for the AMV calculation for a specific slot, different to those defined in the default configuration.

2.2.2 Tracer calculation

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

Both methods calculate a tracer optimising its location around one of the 'starting locations' in the image. In NWC/GEO-HRW v6.2 default configuration, the distance between starting locations for tracers related to very low/low/medium level cloud types is four times narrower than for other cloud types to maximize the amount of AMVs related to these cloud types (defined with configurable parameters HIGHERDENSITY_LOWTRACERS/HIGHERDENSITY_LOWTRACERS_DET = 4). With this change the proportion of medium+low level AMVs increases at least a 9% for all satellites, such as requested by NWC/GEO users for a better characterization of all troposphere levels in which AMVs are calculated (approximately between 140 and 1000 hPa). For MSG satellites, an optimal distribution of High/medium/low level AMVs of 35%/32%33% has even been reached.

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

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

2.2.3 Tracer tracking and Wind Calculation

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

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

To increase the speed of GEO-HRW algorithm, the ‘tracking area centre’ can be located at the position of the tracer which is forecast for the later image by the NWP wind, if so defined with configurable parameter WIND_GUESS = 1. Nevertheless, NWC/GEO-HRW algorithm has been optimised not to use this as default option, to reduce the dependence of the algorithm from the NWP model used.

The line/column size in pixels of the “tracking area” is calculated so that it is able to detect displacements of the tracer of at least 272 km/h in any direction (value of configurable parameter MINSPEED_DETECTION) when the wind guess is not used in the definition of the tracking area.

When the wind guess is used, this `MINSPEED_DETECTION` parameter is to be understood as the minimum difference in speed with respect to that of the NWP wind guess that the NWC/GEO-HRW algorithm is able to detect (a value of `MINSPEED_DETECTION = 72 km/h` is here recommended).

The calculation of the “tracking area” is optimised since NWC/GEO-HRW v6.2 considering the real dimension of each pixel (through the reading of `DISTX/DISTY` matrices for the corresponding satellite, which provide the real longitudinal/latitudinal dimension of each pixel). In previous versions, the nominal dimensions of the subsatellite pixel were used for all pixels, so defining larger “tracking areas” and a slower “tracking” process.

Up to 3 ‘tracking centres’ are retained for both tracking methods: the absolute best and 2 local best positions. The line/column and latitude/longitude location of the ‘tracking centres’ in the later image is refined as default option with second order interpolation with `USE_SUBPIXELTRACKING = 1`.

For this calculation, in NWC/GEO-HRW v6.2, a ‘parallax correction’ of the latitude and longitude values of the tracer and tracking centre is also used as default option through configurable parameter `USE_PARALLAXCORRECTION = 1`. This ‘parallax correction’ corrects the horizontal deviation in the apparent position of the tracer/tracking centre due to its height over the Earth surface. The general effect of this is a very slight reduction in the AMV/Trajectory speed, more significant when at higher levels of the atmosphere and when nearer to the edge of the Earth disk. With configurable parameter `USE_PARALLAXCORRECTION = 2`, NWC/GEO-HRW output file names include additionally the label “_PLAX” at the end of the file name to identify in it that the “parallax correction” took place.

In contrast, “predecessor wind temporal files” used by NWC/GEO-EXIM and Convection products for their processing of NWC/GEO-HRW never include this “parallax correction”, for an optimal processing of these NWC/GEO products.

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

MIXED CALCULATION METHOD

In NWC/GEO-HRW v6.2, a “mixed calculation method” considering short and long time intervals of images at the same time is also available with configurable parameter `MIXED_SCANNING = 1,2` (not used as default option), through which tracers are tracked considering the minimum time interval possible, but corresponding AMVs and Trajectories are calculated considering the displacements in longer time intervals (defined by parameter `SLOT_GAP = 2,3,4`). This “mixed calculation” is useful to increase the quality of the AMVs calculated with high resolution images, and to improve the quality of all AMVs. This is caused by the smaller changes in the features evaluating the tracking in shorter time intervals (and so the smaller possibilities for a wrong tracking), and the smaller problems with the spatial resolution evaluating displacements in longer time intervals.

For the AMVs related to this “mixed calculation method”, latitude and longitude, speed and direction are calculated considering the first and final location of the tracer only. Other parameters are calculated considering the mean value of the parameter for all corresponding intermediate AMVs (the tracer size, the satellite zenith angle, the correlation, the temperature and height, the pressure values, the liquid/ice water path). All other parameters are calculated considering the value of that parameter for the last intermediate AMV only (quality parameters and all absolute categories like the cloud type).

2.2.4 Height assignment with ‘Brightness temperature interpolation method’

Operatively, this method runs before the ‘[tracer tracking](#)’. This method was available in NWC/GEO-HRW algorithm in all versions up to now. Now it is only used when so specifically defined with configurable parameter `DEFINewithCONTRIBUTIONS = 0`, when the wind guess is used to define the tracking area in the later image with configurable parameter `WIND_GUESS = 1`, or when NWC/GEO-CT Cloud Type or NWC/GEO-CTTH Cloud Top Temperature and Pressure outputs are not available for the processing region for the image in which “tracers” are tracked if configurable parameter `KEEPDEFAULTPROCEDURE = 0` (which is not the default option); in this last case, otherwise, the processing of NWC/GEO-HRW stops, not calculating any AMVs or Trajectories.

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/GEO-HRW algorithm also stops, without calculating any AMVs or Trajectories.

The input for the height assignment is the corresponding brightness temperature for each one of the infrared and water vapour channels; IR108 brightness temperature is used for the MSG visible channels, IR107 brightness temperature is used for the GOES-N visible channels, and IR112 brightness temperature is used for the Himawari-8/9 and GOES-R visible channels. A ‘base temperature’ and a ‘top temperature’ are so calculated with the corresponding brightness temperatures. A temperature to pressure conversion is then inferred with these two values and the NWP temperature forecast.

After this, with configurable parameter `USE_CLOUDTYPE = 1,2`, if NWC/GEO Cloud Type output is available for the processing region and image for which tracers were calculated, it is read to define which of the two calculated pressure values (‘base pressure’ or ‘top pressure’) represents better the displacement defined by the Atmospheric Motion Vector. The ‘AMV cloud type’ is calculated as the most common value of the NWC/GEO CT Cloud Type inside the tracer, if its presence is at least $\frac{3}{2}$ times the one of the second most common. If this condition is not fulfilled, the values `Cloud_type = 21` (multiple cloud types), `= 22` (multiple clear air types), or `= 23` (mixed cloudy/clear air types) are assigned.

Some tracers are then eliminated depending on this ‘AMV cloud type’ and the satellite channel they have been calculated with. These cases are identified inside a blue cell in *Table 5*, and are related to cloud free tracers in the visible and infrared channels, fractional clouds, and some cloud types for which the validation statistics are significantly worse.

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

MSG channels	HRVIS	VIS06	VIS08	WV62	WV73	IR108	IR120
GOES-N channels	VIS07			WV65		IR107	
Himawari-8/9	VIS06	VIS08		WV62	WV69	WV73	IR112
GOES-R channels	VIS06	VIS08		WV62	WV70	WV74	IR112
1. Cloud free land				Top	Top	Top	
2. Cloud free sea				Top	Top	Top	
3. Land contaminated by snow/ice				Top	Top	Top	
4. Sea contaminated by ice				Top	Top	Top	
5. Very low cumulus/stratus	Base	Base	Base			Base	Base
6. Low cumulus/stratus	Base	Base	Base			Base	Base
7. Medium level cumulus/stratus	Base	Base	Base			Base	Base
8. High opaque cumulus/stratus	Base	Base		Base	Base	Base	
9. Very high opaque cumulus/stratus	Base	Base		Base	Base	Base	
10. Fractional clouds							
11. High semitransp. thin clouds				Top	Top	Top	Top
12. High semitransp. meanly thick clouds	Top	Top		Top	Top	Top	Top
13. High semitransp. thick clouds	Base	Base		Base	Base	Base	Base
14. High semitransp. above other clouds				Base	Base	Base	Top
15. High semitransp. above snow/ice				Base	Base	Base	Top
21. Multiple cloud types	Base	Base		Base	Base	Base	Base
22. Multiple clear air types				Top	Top	Top	
23. Mixed cloudy/clear air types	Base	Base		Base	Base	Base	Base

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

2.2.5 Height assignment with ‘CCC method’

‘CCC method - Cross Correlation Contribution method’ height assignment is implemented with configurable parameters TRACKING=CC and DEFINEWITHCONTRIBUTIONS=1. It is run after the “tracking” process, and it is the default option for all satellite series. 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/GEO-CT Cloud type and NWC/GEO-CTTH Cloud Top Temperature and Pressure for the selected region and slot before the running of GEO-HRW product. If these outputs are not available, the “AMV pressure” and “AMV temperature” values provided by “Brightness temperature interpolation method” are used for the height assignment if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option). Otherwise, the processing of NWC/GEO-HRW stops.

It has also the advantage of including in the height assignment all procedures included in NWC/GEO-CTTH product for the Cloud pressure calculation, which are common methods used by other AMV producers, including:

- Opaque cloud top pressure retrieval from Window 10.8 μm and 12.0 μm brightness temperatures, with simulation of radiances with RTTOV, and ability of thermal inversion processing.
- Semitransparent cloud top pressure retrieval with Radiance ratioing technique and water vapour/infrared window intercept method, considering 6.2 μm , 7.3 μm and 13.4 μm channels.

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

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

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

- In the ‘Cloudy AMVs’, a ‘CCC pressure P_{CCC} ’ value is calculated for each ‘tracking centre’ considering the partial contribution to the correlation (CC_{ij}) and the NWC/GEO-CTTH Cloud top pressure (CTP_{ij}) with formula $P_{CCC} = \sum(CC_{ij} \cdot CTP_{ij}) / \sum CC_{ij}$. For the calculation, only bright pixels (in visible cases) or cold pixels (in infrared cases) with valid CTP_{ij} values (corresponding to cloudy, non-fractional cloud types), and with CC_{ij} over a threshold (the mean correlation contribution or else zero) are considered. A similar calculation is done for the ‘CCC temperature T_{CCC} ’ and ‘CCC height H_{CCC} ’ values (this one in the case of use of the ‘parallax correction’). The ‘CCC cloud type C_{tCCC} ’ value is calculated as the one with the highest total contribution to the correlation.

A ‘CCC pressure error ΔP_{CCC} ’ value is also calculated for each ‘tracking centre’ with the formula $\Delta P_{CCC} = \sqrt{(\sum(CC_{ij} \cdot CTP_{ij}^2) / \sum CC_{ij} - P_{CCC}^2)}$, useful as a new Quality control parameter for the output AMVs. A maximum pressure error can be defined with configurable parameter MAXPRESSUREERROR (with default value 150 hPa).

Here it is clear that ‘CCC method’ offers a direct correspondence between the pressure levels given for GEO-HRW Cloudy AMVs and Trajectories, and those given to the Cloud tops by NWC/GEO-CTTH product. It also defines a clear correspondence between the elements considered for the pressure level calculations, and the real cloud features observed in the satellite images.

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

So, with ‘CCC liquid/ice water path LWP/IWP_{CCC}’ variables, whose value are obtained with similar formulae to the previous ones for ‘CCC pressure P_{CCC}’, corrections in the ‘CCC pressure P_{CCC}’ values are obtained considering functions defined in a yearly tuning period between July 2010 and June 2011 in the European and Mediterranean region for MSG satellites, and a four-month tuning period between November 2017 and February 2018 in the China/Korea/Japan region for Himawari-8/9 satellites, using Radiosounding winds as reference for the best fit level. Due to the similarities, the same empirical relationship has been used for Himawari-8/9 and GOES-R series. The correction tables are available in the “Algorithm Theoretical Basic Document for the Wind product processor of the NWC/GEO” [AD.7].

The corrections cause an improvement in all Validation parameters, and are implemented as default option with MSG, Himawari-8/9 and GOES-R satellites with configurable parameter USE_MICROPHYSICS = 2 (not with GOES-N satellite series because of the lack of NWC/CMIC product with this satellite series). However, a study made by the Hungarian Meteorological Service (OMSZ) in January 2021 with previous NWC/GEO-HRW v6.1 version (in Ticket “HRW quality issue” on date “2021/01/07” at the NWCSAF Helpdesk), showed that a small relocation is convenient in the AMV level defined by the Microphysics correction for AMVs higher than 230 hPa. AMVs at these levels were too high in the atmosphere, and a location at a lower level works better and has better validation statistics. An empirical formula shown in the ATBD document [AD.7] is used for this with configurable parameter USE_MICROPHYSICS = 2 (default option for all satellites using the Microphysics correction; all of them except GOES-N series).

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

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

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

2.2.6 Postprocessing: Quality control and Choice of the best wind

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

It is based on normalised functions fit to statistical properties in the behaviour of the AMVs. These properties are related to the expected change of the AMVs considering: temporal consistency (comparison to ‘prior AMVs’ in the previous slot at the same location and level), spatial consistency (comparison to ‘neighbour AMVs’ in the same slot at the same location and level) and consistency relative to a background (NWP wind forecast interpolated to the same slot, in the same location and level). For the ‘two scale procedure’, an additional ‘interscale test’ is computed for ‘detailed AMVs’ derived from a ‘basic scale tracer’ (compared to the corresponding ‘basic scale AMV’). In NWC/GEO-HRW v6.2, the process to define the ‘prior AMVs’ and ‘neighbour AMVs’ has been optimised. Corresponding lists of AMVs (sorted according to latitude) are now checked starting with the AMVs with the nearest latitudes. Once a limit of 40 consecutive invalid AMVs in the search of the reference AMVs is reached, the process stops making the Quality control faster.

Several tests are applied (direction, speed and vector temporal consistency tests, vector spatial and forecast consistency tests) giving 5 different ‘individual QIs’; their weighted sum provides two ‘overall QIs’ (after two corrections affecting respectively winds with very low speed, and low winds with a low correlation between infrared and water vapour channels): the ‘Quality Index with forecast’ and the ‘Quality Index without forecast’. These “Quality index with forecast” or “Quality Index without forecast” are used for the filtering of the AMV and Trajectory data. The first one is used as default option, through configurable parameter `QI_THRESHOLD_USEFORECAST = 1`. The “Quality Index threshold” for the acceptance of an AMV or Trajectory as valid is defined by configurable parameter `QI_THRESHOLD` (with a default value of 75% in NWC/GEO-HRW v6.2 and a minimum value of 1%).

In spite of the common procedure in all AMV production centres, the experience in the “International Winds Workshops” has shown that the configuration of the “Quality Indices” is very different for different AMV algorithms, and so a common homogeneous use for AMVs calculated with different algorithms was not possible. Because of this, a self-contained Fortran module defined by EUMETSAT and NOAA/NESDIS, calculating a ‘Common Quality Index without forecast’, was distributed by the “International Winds Working Group” cochairs Steve Wanzong and Régis Borde in May 2017, so that it would be included as such without modifications by all AMV algorithms. The use of this ‘Common Quality Index’ in the “2018 AMV Intercomparison Study” [RD.25] showed some skill in filtering collocated AMVs from different AMV algorithms, improving their statistical agreement.

This ‘Common Quality Index without forecast’ module is implemented in NWC/GEO-HRW, and the parameter is provided as an additional “Quality Index” for all AMVs and Trajectories. The differences of this ‘Common Quality Index’ with respect to the previous ones are:

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

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

2.2.7 Postprocessing: Orographic flag

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

The procedure reads one topographic matrix with representative “Maximum Heights” (S_NWC_SFCMAX*raw, located in \$SAFNWC/import/Aux_data/Common directory), which is then converted to the “Representative surface pressure matrix at the top of topography” considering NWP geopotential data (P_top). For optimisation, in NWC/GEO-HRW v6.2 a similar “Representative surface pressure at the pixel topography” is directly provided by the NWP surface pressure at each pixel (P_sfc).

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

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

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

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

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

More information on the calculations of the ‘Orographic flag’ is available in the “Algorithm Theoretical Basic Document for the Wind product processor of the NWC/GEO” [AD.7].

2.2.8 Postprocessing: Autovalidation of NWC/GEO-HRW algorithm

Considering requests from NWCSAF users, NWC/GEO-HRW offers the option to calculate validation statistics for the AMVs with the algorithm itself (using as reference NWP analysis or forecast rectangular components of the wind, such as defined in Chapter 4.1 of this document, interpolated to the AMV final location and level).

This is implemented with configurable parameter `NWPVAL_STATISTICS = 1,2,3,4`. Depending on the values of this parameter, statistics for the different layers and satellite channels are provided separately or not, such as defined in the following list:

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

The validation statistics can be calculated using NWP forecast winds in real time processes, and using NWP forecast or analysis winds in reprocessing processes. In the last case, the use of NWP analysis is implemented with configurable parameter `NWPVAL_ANALYSIS = 1` (which is not the default option), and so, validation statistics will only be provided for the specific runs for which a NWP analysis with the same date and time is available. When NWP forecast winds are used, the validation statistics are provided for all runs of NWC/GEO-HRW algorithm.

The validation statistics are calculated at the end of the process of each NWC/GEO-HRW run, and the results are written in the running log of NWC/GEO-HRW, and also in a specific file under the name `S_NWC_HRW-STAT_<satid>_<regionid>_YYYYMMDDT.txt` in `$SAFNWC/export/HRW` directory.

Here, “satid” is the identifier of the satellite used, “regionid” is the identifier of the region used, and “YYYYMMDD” 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 parameters used for the validation (NC, SPD, NBIAS, NMVD, NRMSVD) for the considered AMV scale “BBB” (defined as BAS, DET), AMV type “TTTTT” (defined as TOTAL, CLOUD, CLEAR), layer “LLL” (defined as ALL, HIG, MED, LOW) and satellite channel for which AMVs have been calculated “CCCCC” (defined as TOTAL,HRVIS, VIS06,VIS07,VIS08,IR107,IR108,IR112,IR120,WV062,WV065,WV069,WV070,WV073,WV074).

The date and time of the NWC/GEO-HRW run, the name of the “model configuration file” used in the process, and if the validation statistics have been run against the NWP analysis or forecast winds (parameter “GGG”, defined as ANA, FOR) are also specified:

```
yyyy-mm-ddThh:mm:ssZ GEO-HRW 6.2 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 definition of the parameters used for the validation is as follows:

1. NC: “Number of collocations” between NWC/GEO-HRW AMVs and the reference winds.
2. SPD: “Mean speed of the reference winds”.
3. NBIAS: “Normalized bias”.
4. NMVD: “Normalized mean vector difference”.
5. NRMSVD: “Normalized root mean square vector difference”.

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

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

- The first one, activated with configurable parameter `NWPVAL_NWPDIFFERENCE = 1` (implemented as default option) calculates also for each AMV the “Vector difference with the NWP reference wind”.

This “Vector difference” can be used for example in Nowcasting tasks, so that the NWCSAF user is able to detect in which cases the AMV is very different to the NWP forecast wind, and may be aware for example if a warning is needed in some specific region or moment due to strong winds unforeseen by the NWP forecast.

- The second one, activated with configurable parameter `NWPVAL_NWPBESTFITLEVEL = 1` (implemented also as default option) calculates also for each AMV the “NWP reference wind at the best fit pressure level” (defined by its speed, direction and pressure).

This “NWP model wind at the best fit pressure level” can be used for example in 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 NWP level with the smallest vector difference between the AMV and the NWP wind is to be found. Then, the minimum is calculated by using a parabolic fit to the vector difference for this NWP 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 AMV 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 a NWP analysis with the same date and time is available.

2.3 DESCRIPTION OF HIGH RESOLUTION WINDS (GEO-HRW) OUTPUTS

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

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

1. OUTPUT_FORMAT = NWC (included in the default option): NWC/GEO-HRW output defined as two different BUFR bulletins (for AMVs and Trajectories), related to the ones used as default option in all previous versions of NWC/GEO-HRW algorithm.
2. OUTPUT_FORMAT = EUM: NWC/GEO-HRW output defined as one BUFR bulletin, whose format was defined several years ago by the “International Winds Working Group”, and which has been used in general by most AMV processing centres. This option permits NWCSAF users to have a similar processing for the NWC/GEO-HRW outputs than the one for other AMV processing centres of the world.
3. OUTPUT_FORMAT = IWWG: NWC/GEO-HRW output defined as one BUFR bulletin, whose format has been defined in 2018 by the “International Winds Working Group”. This option also permits NWCSAF users to have a similar processing for the NWC/GEO-HRW outputs than the one for other AMV processing centres of the world.
4. OUTPUT_FORMAT = NET (included in the default option): NWC/GEO-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).

Additionally to these types of outputs, NWC/GEO-HRW creates three different types of temporal files in \$SAFNWC/tmp directory, which contain tracer/predecessor wind/trajectory information that will be used as input for processing in the following NWC/GEO-HRW slot:

S_NWC_HRW-tracers_<satid>_<bandid>_<regionid>_YYYYMMDDThhmmssZ

S_NWC_HRW-predwinds_<satid>_<bandid>_<regionid>_YYYYMMDDThhmmssZ

S_NWC_HRW-trajectories_<satid>_<bandid>_<regionid>_YYYYMMDDThhmmssZ

where <bandid> is the satellite channel used for the AMV calculation (with values HRVIS/VIS06/VIS07/VIS08/WV062/WV065/WV069/WV070/WV073/WV074/IR107/IR108/IR112/IR120), and <satid> is the satellite used for the AMV calculation, and <regionid> is the region used for the AMV calculation.

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

When `OUTPUT_FORMAT = NWC`, a BUFR bulletin related to the ones used as default option in all previous versions of NWC/GEO-HRW algorithm is written in `SAFNWC/export/HRW` directory for the “Single/Basic AMV scale” with the name `S_NWC_HRW-WIND_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr`, or for the “Detailed AMV scale” with the name `S_NWC_HRW-WIND_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.bufr`.

With configurable parameter `USE_PARALLAXCORRECTION = 2`, the output file name finishes with format `*YYYYMMDDThhmmssZ_PLAX.bufr` to explicitly remark that the AMV latitudes/longitudes/speeds/directions have been corrected with parallax.

Here, “`satid`” is the identifier of the satellite used, “`regionid`” is the identifier of the region used, and “`YYYYMMDDThhmmssZ`” is the date and time of the image used for the AMV calculation. This BUFR bulletin is exactly equivalent to the one defined in the previous NWC/GEO-HRW v6.1 version.

The BUFR variables used for the writing of the AMVs considering this format (identified in “BUFR local variable table” `B0000021400000031096.TXT` in `SAFNWC/import/Aux_data/HRW` directory) are explained in *Table 6*. These variables are partially based on BUFR Master Table number 0, Version number 31.

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 NWCSAF Headquarters in Madrid; numeric codes for other locations are available at the “WMO Common Code Table C-1” [RD.19]).

An additional “BUFR local sequence table” (identified as `D0000021400000031096.TXT` file in `SAFNWC/import/Aux_data/HRW` directory) is also requested for the generation of the BUFR files, but due to the fact that no specific sequences have been identified for the processing, this additional file is provided as an empty file.

Formally, several different BUFR messages with AMVs calculated for an only satellite channel, in each case with an only Subset of up to 1000 AMVs, are included in this AMV BUFR output file.

For all variables used for the AMV output with the NWCSAF specific BUFR format:

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

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

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

White entries: Fixed factors

Grey entries: Replicated factors

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

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

The “local variables” for NWC/GEO-HRW bulletins with NWCSAF BUFR specific format are those with codes 60000 or higher. The Code Tables for these NWC/GEO-HRW “local variables” are explained in Table 7.

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’. Due to the actual implementation of HRW algorithm, Value 2 is never 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	<p>Correlation test.</p> <p>Possible values:</p> <ul style="list-style-type: none"> 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	<p>Applied Quality tests:</p> <p>For each one the next Quality flags (Orographic flag, Forecast quality flag, Spatial quality flag, Temporal quality flag, Interscale quality flag), next possible values:</p> <ul style="list-style-type: none"> 0: 'Wind for which the corresponding quality test could not be calculated' 1: 'Wind whose corresponding quality test is more than a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is at least two units lower than for the wind calculated for the same tracer with the best orographic flag)' 2: 'Wind whose corresponding quality test is up to a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the wind calculated for the same tracer with the best orographic flag)' 3: 'Wind with the best corresponding quality test among the winds calculated for a tracer'.
060205	<p>Orographic index</p> <p>Possible values:</p> <p>The values of this parameter are between 0 and 6, corresponding to those defined for "Ind_topo" parameter in chapter 2.2.7 of this document.</p>
060206	<p>Cloud type associated to the tracer</p> <p>Possible values:</p> <p>The values of this parameter are between 0 and 23, corresponding to those defined in <i>Table 5</i> of this document.</p>
060207	<p>Flag indicating the satellite channel used for the wind calculation</p> <p>Possible values:</p> <ul style="list-style-type: none"> 2: MSG/VIS06 or GOES-N/VIS07 or Himawari-8/9 VIS06 or GOES-R VIS06 3: MSG/VIS08 or Himawari-8/9 VIS08 or GOES-R VIS08 5: MSG/HRVIS 10: MSG/WV062 or GOES-N/WV065 or Himawari-8/9 WV062 or GOES-R WV062 11: Himawari-8/9 or WV069 or GOES-R WV070 12: MSG/WV073 or Himawari-8/9 WV073 or GOES-R WV074 16: MSG/IR108 or GOES-N/IR107 or Himawari-8/9 IR112 or GOES-R IR112 17: MSG/IR120
060220	<p>Validation against NWP analysis or forecast</p> <p>Possible values:</p> <ul style="list-style-type: none"> 0: GEO-HRW autovalidation statistics against "NWP model analysis". 1: GEO-HRW autovalidation statistics against "NWP model forecast". 3: GEO-HRW autovalidation statistics not calculated.

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

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

When `OUTPUT_FORMAT = NWC`, if the calculation of trajectories is activated with configurable parameter `CALCULATE_TRAJECTORIES = 1` (which is the default option), a Trajectory BUFR bulletin related to the ones used in previous versions of NWC/GEO software package is written under the name `S_NWC_HRW-TRAJ_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr` for the “Single or Basic scale”, or the name `S_NWC_HRW-TRAJ_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.bufr` for the “Detailed scale” in `$SAFNWC/export/HRW` directory.

With configurable parameter `USE_PARALLAXCORRECTION = 2`, the output file name finishes with format `*YYYYMMDDThhmmssZ_PLAX.bufr` to explicitly remark that the AMV latitudes/longitudes/speeds/directions have been corrected with parallax.

Again, “satid” is the identifier of the satellite used, “regionid” is the identifier of the region used, and “YYYYMMDDYhhmmssZ” is the date and time of the image used for the Trajectory calculation. This BUFR bulletin is exactly equivalent to the one defined in the previous NWC/GEO-HRW v6.1 version.

The BUFR variables used for the writing of the Trajectories considering this bulletin are explained in *Table 8*. They are also based on the “BUFR local variable table” `B0000021400000031096.TXT` and the “BUFR local sequence table” `D0000021400000031096.TXT` used in the previous chapter for the AMV output. Again, these variables are partially based on BUFR Master Table number 0, Version number 31.

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

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

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

White entries: Fixed factors

Grey entries: Replicated factors

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

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

When `OUTPUT_FORMAT = EUM`, 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, and used for example for years by the Meteosat Product Extraction Facility/MPEF in EUMETSAT, is written under the name `S_NWC_HRW-WINDEUM_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr` for the “Single or Basic AMV scale”, or the name `S_NWC_HRW-WINDEUM_<satid>_b<regionid>-DS_YYYYMMDDThhmmssZ.bufr` for the “Detailed AMV scale”, in `$SAFNWC/export/HRW` directory.

With configurable parameter `USE_PARALLAXCORRECTION = 2`, the output file name finishes with format `*YYYYMMDDThhmmssZ_PLAX.bufr` to explicitly remark that the AMV latitudes/longitudes/speeds/directions have been corrected with parallax.

Again, “`satid`” is the identifier of satellite used, “`regionid`” is the identifier of the region used and “`YYYYMMDDThhmmssZ`” is the date and time for which the AMVs have been calculated. This BUFR bulletin is exactly equivalent to the one defined in the previous NWC/GEO-HRW v6.1 version.

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

The variables are based on BUFR Master Table number 0, Version number 31 (identified in “variable table” `B00000000000000031000.TXT` and “sequence table” `D0000000000000031000.TXT` in `$SAFNWC/import/Aux_data/HRW` directory).

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 NWCSAF 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 NWCSAF 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/GEO-HRW trajectory which were used for the AMV calculation (when “mixed calculation” process was used).

It is recommended to use this option to write the NWC/GEO-HRW output only when the main interest is the assimilation of the AMVs in NWP models or other applications, together with other AMV outputs with an equivalent format.

Specifically, as already said in the introduction, this version of NWC/GEO-HRW is the last one providing as output this format of BUFR bulletin. The format is being replaced by the BUFR bulletin based on the “2018 IWWG format” (explained in chapter 2.3.4). The “International Winds Working Group (IWWG)” gave AMV producers and users the recommendation in its 2018 Workshop to adopt the “2018 IWWG format” (through action IWW14 – WG1 – Action 6) within one year after the definition of this new format, and in 2021 all AMV users should already be used to the new format.

Descriptor	Name	Units
INFORMATION RELATED TO THE AMV TO BE USED		
001007	SATELLITE IDENTIFIER	CODE TABLE 01007
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	CODE TABLE 01031
002020	SATELLITE CLASSIFICATION	CODE TABLE 02020
002028	SEGMENT SIZE AT NADIR IN X DIRECTION	M
002029	SEGMENT SIZE AT NADIR IN Y DIRECTION	M
004001	YEAR (for the AMV to be used)	YEAR
004002	MONTH (for the AMV to be used)	MONTH
004003	DAY (for the AMV to be used)	DAY
004004	HOUR (for the AMV to be used)	HOUR
004005	MINUTE (for the AMV to be used)	MINUTE
004006	SECOND (for the AMV to be used)	SECOND
005001	LATITUDE (HIGH ACCURACY) (for the AMV to be used)	DEGREE
006001	LONGITUDE (HIGH ACCURACY) (for the AMV to be used)	DEGREE
002152	SATELLITE INSTRUMENT DATA USED IN PROCESSING	FLAG TABLE 02152
002023	SATELLITE DERIVED WIND COMPUTATION METHOD	CODE TABLE 02023
007004	PRESSURE (for the AMV to be used)	PA
011001	WIND DIRECTION (for the AMV to be used)	DEGREE TRUE
011002	WIND SPEED (for the AMV to be used)	M/S
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz
002154	SATELLITE CHANNEL BAND WIDTH	Hz
012071	COLDEST CLUSTER TEMPERATURE (not used)	K
002163	HEIGHT ASSIGNMENT METHOD (for the AMV to be used)	CODE TABLE 02163
002164	TRACER CORRELATION METHOD (for the AMV to be used)	CODE TABLE 02164
008012	LAND/SEA QUALIFIER (not used)	CODE TABLE 08012
007024	SATELLITE ZENITH ANGLE (for the AMV to be used)	DEGREE
002057	ORIGIN OF FIRST GUESS INFORMATION	CODE TABLE 02057
INFORMATION RELATED TO TIME		
008021	TIME SIGNIFICANCE (not used)	CODE TABLE 08021
004001	YEAR (not used)	YEAR
004002	MONTH (not used)	MONTH
004003	DAY (not used)	DAY
004004	HOUR (not used)	HOUR
008021	TIME SIGNIFICANCE (time series)	CODE TABLE 08021
004024	TIME PERIOD OR DISPLACEMENT (time between images used)	MINUTE

Descriptor	Name	Units
INFORMATION RELATED TO TRAJECTORY SECTORS (ONLY IN CASE OF MIXED CALCULATION PROCESS)		
008021	TIME SIGNIFICANCE (starting time for latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
008021	TIME SIGNIFICANCE (ending time for latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
011001	WIND DIRECTION (for latest trajectory sector)	DEGREE TRUE
011002	WIND SPEED (for latest trajectory sector)	M/S
008021	TIME SIGNIFICANCE (starting time for second latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
008021	TIME SIGNIFICANCE (ending time for second latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
011001	WIND DIRECTION (for second latest trajectory sector)	DEGREE TRUE
011002	WIND SPEED (for second latest trajectory sector)	M/S
008021	TIME SIGNIFICANCE (starting time for third latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
008021	TIME SIGNIFICANCE (ending time for third latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
011001	WIND DIRECTION (for third latest trajectory sector)	DEGREE TRUE
011002	WIND SPEED (for third latest trajectory sector)	M/S
008021	TIME SIGNIFICANCE (starting time for fourth latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
008021	TIME SIGNIFICANCE (ending time for fourth latest trajectory sector)	CODE TABLE 08021
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
011001	WIND DIRECTION (for fourth latest trajectory sector)	DEGREE TRUE
011002	WIND SPEED (for fourth latest trajectory sector)	M/S
INFORMATEON RELATED TO HEIGHT ASSIGNMENT OF THE AMV TO BE USED		
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (not used)	PA
012001	TEMPERATURE/AIR TEMPERATURE (not used)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (for the AMV to be used)	PA
012001	TEMPERATURE/AIR TEMPERATURE (for the AMV to be used)	K

Descriptor	Name	Units
INFORMATEON RELATED TO HEIGHT ASSIGNMENT OF TRAJECTORY SECTORS (IN CASE OF MIXED CALCULATION)		
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (not used)	PA
012001	TEMPERATURE/AIR TEMPERATURE (not used)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (for latest trajectory sector)	PA
012001	TEMPERATURE/AIR TEMPERATURE (for latest trajectory sector)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (not used)	PA
012001	TEMPERATURE/AIR TEMPERATURE (not used)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (for second latest trajectory sector)	PA
012001	TEMPERATURE/AIR TEMPERATURE (for second latest trajectory sector)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (not used)	PA
012001	TEMPERATURE/AIR TEMPERATURE (not used)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (for third latest trajectory sector)	PA
012001	TEMPERATURE/AIR TEMPERATURE (for third latest trajectory sector)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (not used)	PA
012001	TEMPERATURE/AIR TEMPERATURE (not used)	K
002163	HEIGHT ASSIGNMENT METHOD (not used)	CODE TABLE 02163
007004	PRESSURE (for fourth latest trajectory sector)	PA
012001	TEMPERATURE/AIR TEMPERATURE (for fourth latest trajectory sector)	K
INFORMATION RELATED TO QUALITY CONTROL BIT MAP, DEFINING VARIABLES AFFECTED BY QUALITY CONTROL		
222000	QUALITY INFORMATION FOLLOWS	-
236000	DEFINE BIT-MAP	-
031031	DATA PRESENT INDICATOR (103 TIMES) (Descriptor repeated 103 times, with A value of ZERO for 17th, 18th, 78th and 79th element, affecting respectively the Wind direction, Wind speed, Pressure and Temperature of the AMV to be used, and a value of ONE for all other elements, unaffected).	FLAG TABLE 31031
INFORMATION RELATED TO QUALITY CONTROL		
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (1 = QC USING FORECAST)	CODE TABLE 01032
033007	PERCENT CONFIDENCE (for Wind direction of AMV to be used)	%
033007	PERCENT CONFIDENCE (for Wind speed of AMV to be used)	%
033007	PERCENT CONFIDENCE (for Pressure of AMV to be used)	%
033007	PERCENT CONFIDENCE (for Temperature of AMV to be used)	%
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (1 = QC USING FORECAST)	CODE TABLE 01032
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Wind direction of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Wind speed of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Pressure of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Temperature of AMV to be used)	CODE TABLE 33035
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (1 = QC USING FORECAST)	CODE TABLE 01032
033036	NOMINAL CONFIDENCE THRESHOLD (for Wind direction of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Wind speed of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Pressure of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Temperature of AMV to be used)	%

Descriptor	Name	Units
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (2 = QC NOT USING FORECAST)	CODE TABLE 01032
033036	PERCENT CONFIDENCE (for Wind direction of AMV to be used)	%
033036	PERCENT CONFIDENCE (for Wind speed of AMV to be used)	%
033036	PERCENT CONFIDENCE (for Pressure of AMV to be used)	%
033036	PERCENT CONFIDENCE (for Temperature of AMV to be used)	%
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (2 = QC NOT USING FORECAST)	CODE TABLE 01032
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Wind direction of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Wind speed of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Pressure of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Temperature of AMV to be used)	CODE TABLE 33035
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (2 = QC NOT USING FORECAST)	CODE TABLE 01032
033036	NOMINAL CONFIDENCE THRESHOLD (for Wind direction of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Wind speed of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Pressure of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Temperature of AMV to be used)	%
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (4 = QC USING COMMON IWWG QI)	CODE TABLE 01032
033036	PERCENT CONFIDENCE (for Wind direction of AMV to be used)	%
033036	PERCENT CONFIDENCE (for Wind speed of AMV to be used)	%
033036	PERCENT CONFIDENCE (for Pressure of AMV to be used)	%
033036	PERCENT CONFIDENCE (for Temperature of AMV to be used)	%
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (4 = QC USING COMMON IWWG QI)	CODE TABLE 01032
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Wind direction of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Wind speed of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Pressure of AMV to be used)	CODE TABLE 33035
033035	MANUAL-AUTOMATIC QUALITY CONTROL (for Temperature of AMV to be used)	CODE TABLE 33035
222000	QUALITY INFORMATION FOLLOWS	-
237000	REUSE PREVIOUSLY DEFINED BIT-MAP	-
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)	CODE TABLE 01031
001032	GENERATING APPLICATION (4 = QC USING COMMON IWWG QI)	CODE TABLE 01032
033036	NOMINAL CONFIDENCE THRESHOLD (for Wind direction of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Wind speed of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Pressure of AMV to be used)	%
033036	NOMINAL CONFIDENCE THRESHOLD (for Temperature of AMV to be used)	%

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

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

When `OUTPUT_FORMAT = IWWG`, 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 under the name `S_NWC_HRW-WINDIWWG_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr` for the “Single or Basic AMV scale”, or the name `S_NWC_HRW-WINDIWWG_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.bufr` for the “Detailed AMV scale”, in `§SAFNWC/export/HRW` directory.

With configurable parameter `USE_PARALLAXCORRECTION = 2`, the output file name finishes with format `*YYYYMMDDThhmmssZ_PLAX.bufr` to explicitly remark that the AMV latitudes/longitudes/speeds/directions have been corrected with parallax.

Again, “`satid`” is the identifier of satellite used, “`regionid`” is the identifier of the region used and “`YYYYMMDDThhmmssZ`” is the date and time for which the AMVs have been calculated. This BUFR bulletin is exactly equivalent to the one defined in the previous NWC/GEO-HRW v6.1 version.

The BUFR variables used for the writing of the NWC/GEO-HRW AMVs considering this format, are explained in *Table 10*, with some explanations in red about how some variables are defined by NWC/GEO-HRW algorithm.

The variables are based on BUFR Master Table number 0, Version number 31 (identified in “variable table” `B00000000000000031000.TXT` and “sequence table” `D0000000000000031000.TXT` in `§SAFNWC/import/Aux_data/HRW` directory). The AMV output corresponds exactly to “Sequence 310077 – satellite derived winds” included in that “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 NWCSAF 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 also a kind a blend of the NWCSAF AMV and Trajectory BUFR specific formats, because of including at the same time information related to the reference AMV to be used, and the up to four latest AMVs in the NWC/GEO-HRW trajectory which were used for the AMV calculation (when “mixed calculation method” was used).

Compared to the format described in the previous chapter, it has the advantage of including much more information useful for the processing of AMVs, already available for NWC/GEO-HRW or to be included in the coming years with the progressive addition of values to more parameters in it. Nevertheless, the larger size of the corresponding files is also to be taken into account.

It is recommended for NWCSAF users to adopt progressively this format for all applications, because this format will become the reference format for AMVs coming from all AMV production centres in the coming years. As already said in previous chapter, the “International Winds Working Group (IWWG)” gave AMV producers and users the recommendation in its 2018 Workshop to adopt this “2018 IWWG BUFR format” within one year after the definition of the format, and in 2021 all AMV users should already be used to the new format.

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 ("HRW")	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 (time between the initial and final position of tracer)	SECOND
002162	EXTENDED HEIGHT ASSIGNMENT METHOD	CODE TABLE 02162
007004	PRESSURE (including microphysics correction, if calculated)	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 (used as AMV height, if calculated)	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 (not including microphysics correction)	PA
012001	TEMPERATURE/AIR TEMPERATURE	K
020014	HEIGHT OF TOP OF CLOUD (used as AMV height, if calculated)	M

Descriptor	Name	Units
IMAGE INFORMATION		
113000	DELAYED REPLICATION OF 13 DESCRIPTORS	-
031001	DELAYED DESCRIPTOR REPLICATION FACTOR (TWO TO FIVE TIMES)	NUMERIC
004086	LONG TIME PERIOD OR DISPLACEMENT (respect to the "Reference time")	SECOND
002020	SATELLITE CLASSIFICATION	CODE TABLE 02020
001007	SATELLITE IDENTIFIER	CODE TABLE 01007
002019	SATELLITE INSTRUMENTS	CODE TABLE 02019
005042	CHANNEL NUMBER	NUMERIC
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz
005040	ORBIT NUMBER (not used)	NUMERIC
007024	SATELLITE ZENITH ANGLE (for the tracer in each image)	DEGREE
005021	BEARING OR AZIMUTH (not used)	DEGREE
002162	EXTENDED HEIGHT ASSIGNMENT METHOD (used for all images except the initial image)	CODE TABLE 02162
007004	PRESSURE (used for all images except the initial image)	PA
012001	TEMPERATURE/AIR TEMPERATURE (used for all images except the initial image)	K
020014	HEIGHT OF TOP OF CLOUD (used for all images except the initial image)	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; 85 = MF; 7 = NOAA/NCEP; 255 = other)	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 (4 = BEST FIT LEVEL)	FLAG TABLE 08086
007004	PRESSURE (for NWP data at AMV best fit level, if calculated)	PA
011095	U-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
011096	V-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
008086	VERTICAL SIGNIFICANCE FOR NWP (4095 = CANCEL)	CODE TABLE 08086

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

Table 10: Variables used for the AMV output with the 2018 IWWG BUFR format

2.3.5. HRW output as netCDF bulletins

When `OUTPUT_FORMAT = NET`, an AMV and Trajectory netCDF output bulletin is written under the name `S_NWC_HRW_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.nc` (for the “Single or Basic scale”), or `S_NWC_HRW_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.nc` (for the “Detailed scale”) in `SAFNWC/export/HRW` directory. With configurable parameter `USE_PARALLAXCORRECTION = 2`, the output file name finishes with format `*YYYYMMDDThhmmssZ_PLAX.nc` to explicitly remark that the AMV latitudes/longitudes/speeds/directions have been corrected with parallax.

Again, “`satid`” is the identifier of satellite used, “`regionid`” is the identifier of the region used and “`YYYYMMDDThhmmssZ`” is the date and time for which the AMVs have been calculated. This NetCDF output is equivalent to the one defined in the previous NWC/GEO-HRW v6.1 version.

The High level structure of the netCDF output for the NWC/GEO High Resolution Winds is shown in *Table 11*. It contains several series of data, containing all the AMVs/Trajectories derived for each satellite channel in the corresponding run of NWC/GEO-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/GEO-HRW algorithm for “`XXXXX`” satellite channel:

- “HRVIS”, “VIS06”, “VIS08”, “IR108”, “IR120”, “WV062” or “WV073” for MSG satellite series.
- “VIS06”, “IR107” or “WV065” for GOES-N satellite series.
- “VIS06”, “VIS08”, “IR112”, “WV062”, “WV069” or “WV073” for Himawari-8/9 satellite series.
- “VIS06”, “VIS08”, “IR112”, “WV062”, “WV070” or “WV074” for GOES-R satellite series.

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 several 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(<i>number_of_observations_XXXXX</i>)	// Wind data for channel XXXXX
Dimensions:	
<i>number_of_observations_XXXXX</i>	// Number of AMVs for channel XXXXX
Attributes	

Table 11: High Level specification of the NWC/GEO-HRW netCDF output

The detailed structure of the netCDF output for the NWC/GEO High Resolution Winds and Trajectories is shown in *Table 12*. The “BUFR Code Tables” used are described in chapter 2.3.1 of this document.

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

- 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 algorithm 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)
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 iwgg value	// Quality Index with common IWGG 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/GEO-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)
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 iwgg value	// Quality Index with common IWGG 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/GEO-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	// Satellite cycle number
first guess	// Origin of the first guess BUFR code table 025202)
long name	"NWC GEO 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 12: Detailed specification of the NWC/GEO-HRW netCDF output

2.3.6. Output data filterings

Several output data filterings are included during NWC/GEO-HRW algorithm running, which depend on the value of several configurable parameters. These configurable parameters are:

- AMV_BANDS (default value HRVIS,VIS06,WV062,WV073,IR108 for MSG satellites; VIS07,WV065,IR107 for GOES-N satellites; VIS08,WV062,WV069,WV073,IR112 for Himawari-8/9 satellites; VIS08,WV062,WV070,WV074,IR112 for GOES-R satellites), which defines the channels for which AMVs and Trajectories are calculated. In NWC/GEO-HRW v6.2 the calculation of VIS08 AMVs is preferred instead of VIS06 AMVs as default option for Himawari-8/9 and GOES-R series, due to narrower densities of AMVs and the faster calculation.
- QI_THRESHOLD: defines the “Quality index threshold” for the AMVs and Trajectories in the output files (default value = 75%). Depending on configurable parameter QI_THRESHOLD_USEFORECAST, the “Quality index with forecast” (default option with value = 1) or the “Quality index without forecast” are respectively used for the AMV filtering).
- CLEARAIRWINDS: defines if the “Clear air water vapour AMVs” are to be included in the output files (implemented as default option with value = 1).
- MAXPRESSUREERROR: defines the maximum “AMV pressure error” (in hPa) in the output AMVs and Trajectories, when “CCC height assignment method” is used (default value 150 hPa).
- MIN_CORRELATION: defines the minimum correlation (as a percentage value) in the output AMVs and Trajectories, when the “Cross Correlation tracking” has been used (default value 80% for all satellites, except GOES-N series with 50%).
- FINALFILTERING: defines several filterings in the AMVs/Trajectories, depending on its value:
 - With FINALFILTERING>0, the “AMV pressure level” filtering defined in *Table 13* is implemented (in which the blue layers for the different channels are eliminated; light blue layers are eliminated only for “Clear air AMVs and Trajectories”; very dark blue layers are only eliminated if configurable parameter VERYLOWINFRAREDAMVS = 0, which is not implemented as default option).
 - With FINALFILTERING>1 (which is the default option with FINALFILTERING = 2), the “AMV cloud type” filtering defined in *Table 6* is also implemented.
 - With FINALFILTERING>2, AMVs with “spatial quality flag”=1,2 are also eliminated.
 - With FINALFILTERING=4, AMVs with “spatial quality flag”=0 are also eliminated.

MSG sat.	HRVIS		VIS06	VIS08	IR108	IR120	WV62		WV73
GOES-N sat.	VIS07				IR107		WV65		
Himawari-8/9 sat.	VIS06	VIS08			IR112		WV62	WV69	WV73
GOES-R sat.	VIS06	VIS08			IR112		WV62	WV70	WV74
100-199 hPa									
200-299 hPa									
300-399 hPa									
400-499 hPa									
500-599 hPa									
600-699 hPa									
700-799 hPa									
800-899 hPa									
900-999 hPa									

Table 13: AMV filtering related to the Height level and each satellite channel

3. IMPLEMENTATION OF NWC/GEO-HRW PRODUCT

Two main steps are identified. The user manually interacts with the NWC/GEO software package during the installation step, and the NWC/GEO-HRW execution step is automatically monitored by the Task Manager (if real time environment is selected).

3.1 NWC/GEO SOFTWARE PACKAGE INSTALLATION AND PREPARATION

The right to use, copy or modify this software is in accordance with EUMETSAT policy for the NWC/GEO software package.

Once the user has obtained the necessary permissions to download the software package, the software installation procedure does not require any special resources. It is limited to decompress and install the NWC/GEO distribution files (gzip compressed tar files), which successfully build the executable (GEO-HRW-v62 file), to be stored into the \$SAFNWC/bin directory.

3.2 NWC/GEO-HRW EXECUTION STEP

The execution step is the processing of satellite images with NWC/GEO-HRW executable in the region defined by the user. The running scheduling relies on the Programmed Task Definition File. This process consists in the running of the command `$SAFNWC/bin/GEO-HRW-v62` with the required parameters (required image time, Region configuration file and Model configuration file) by the Task manager, in the following way:

```
GEO-HRW-v62 YYYY-MM-DDTHH:MM:SSZ file.cfg safnwc_HRW.cfm
```

1. Year (YYYY), month (MM), day (DD), hour (HH), minute (MM) and second (SS) parameters are to be provided for the definition of the image time to be processed.
2. `$SAFNWC/config/file.cfg` is the Region configuration file, to be defined such as shown in document [AD.5].
3. `$SAFNWC/config/safnwc.HRW.cfm` is the NWC/GEO-HRW Model configuration file, to be defined such as shown in chapter 4.2 of this document. Different reference NWC/GEO-HRW Model Configuration Files `safnwc_HRW.cfm` are defined as default option for operational use with MSG satellite series, GOES-N satellite series, Himawari-8/9 satellite series, and GOES-R satellite series. Each one of them is provided in the corresponding subdirectories inside `$SAFNWC/config` directory, related to each satellite series.

Each configuration file is an ASCII file, so further modifications can be easily performed with a text editor. The implementation of the running mode depends also on the satellite configuration through the corresponding `$SAFNWC/config/sat_conf_file` used.

To have NWC/GEO-Cloud Type, Cloud Top Temperature and Pressure and Cloud Microphysics outputs available for their use by NWC/GEO-HRW executable, it is also necessary to run `GEO-CMA`, `GEO-CT`, `GEO-CTTH` and `GEO-CMIC` executables before `GEO-HRW-v62` executable for the same image and region.

If everything is correct with the running of NWC/GEO-HRW executable, the following message is received:

```
YYYY-MM-DDThh:mm:ssZ GEO-HRW 6.2 <pid> [I] Process finished correctly
```

Figures 1 to 3 summarise how the tasks to generate the High Resolution Winds (NWC/GEO-HRW) are performed by the `GEO-HRW-v62` executable.

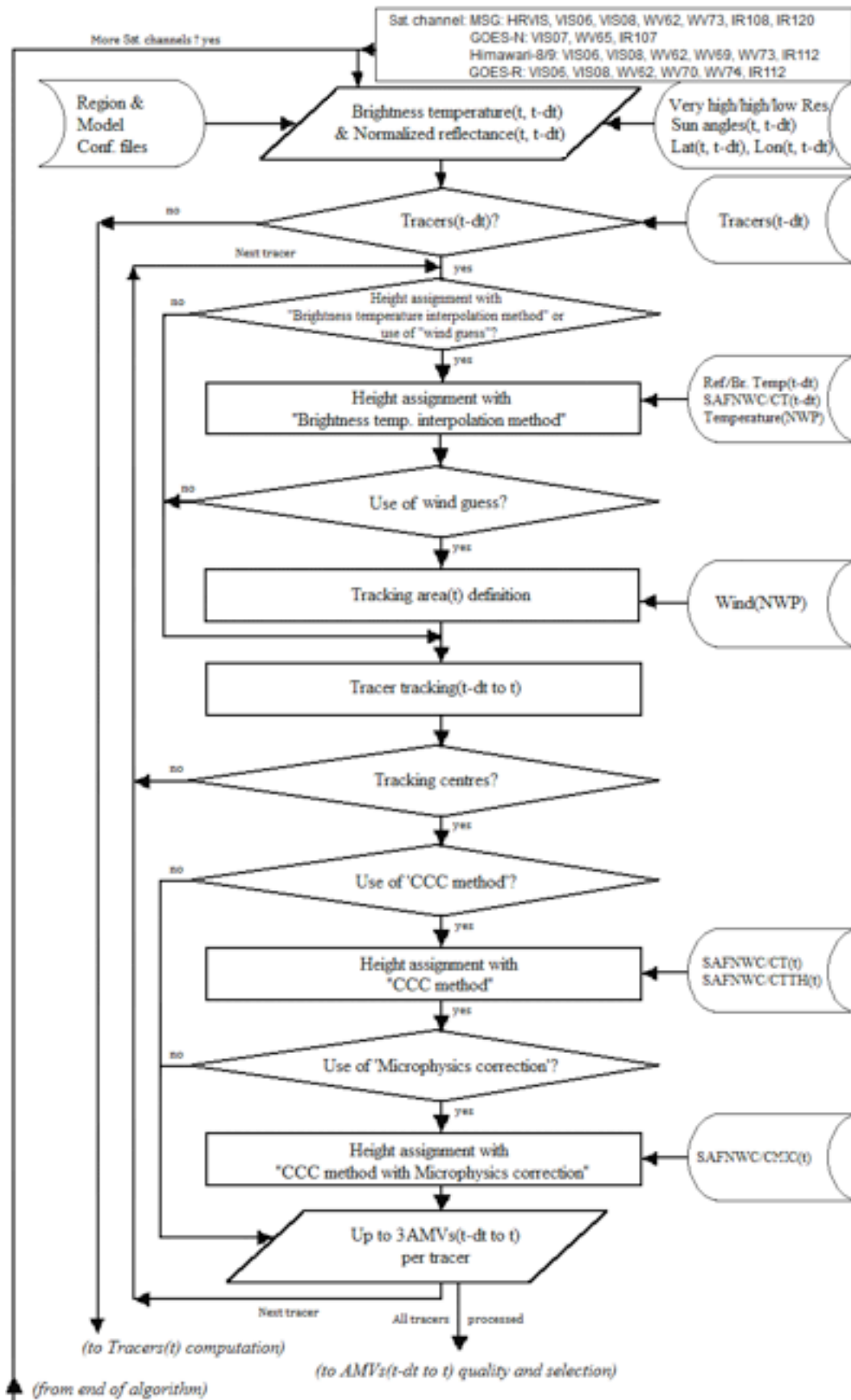


Figure 1: NWC/GEO-HRW implementation: Part 1, Preprocessing and AMV computation

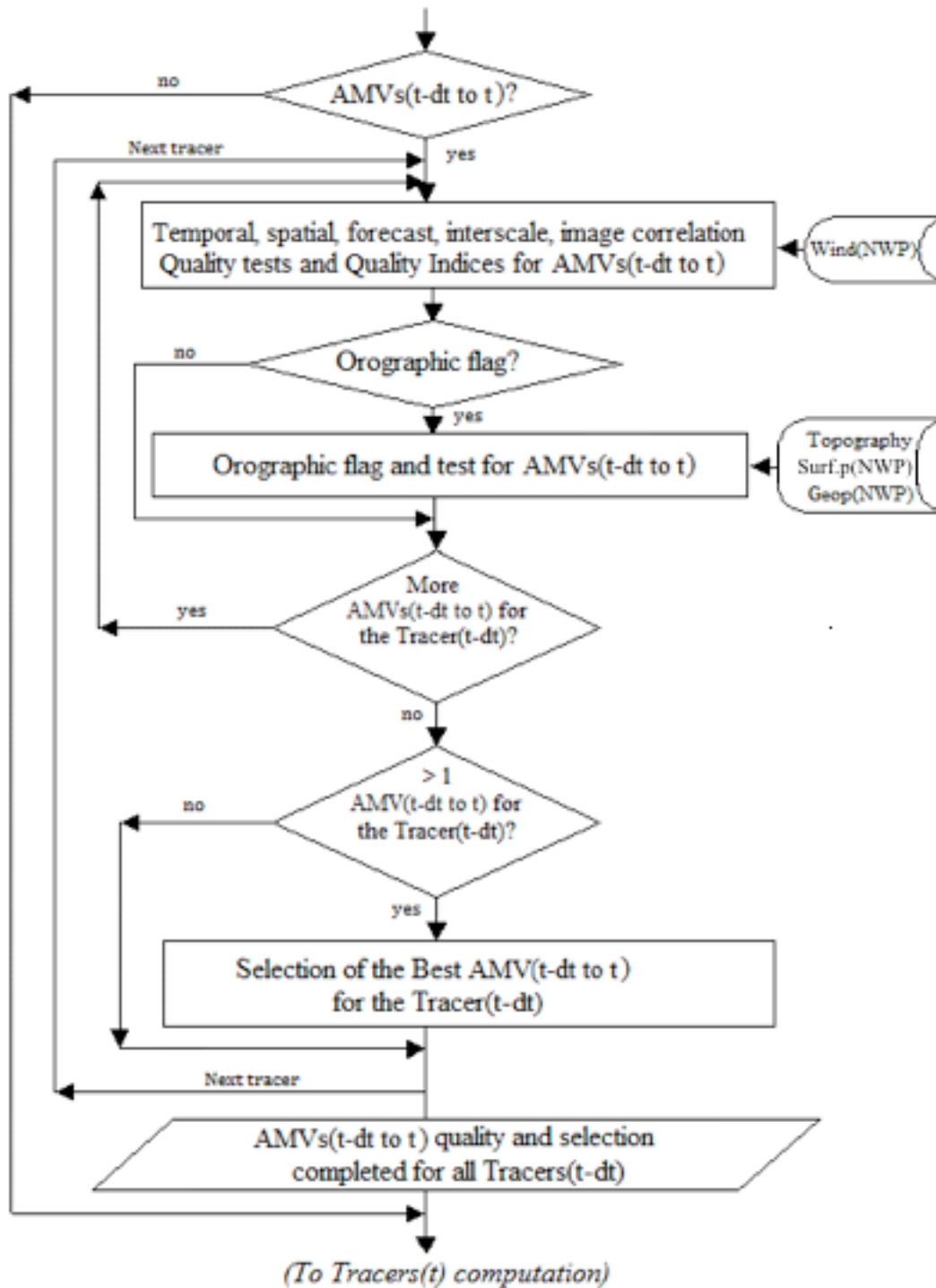


Figure 2: NWC/GEO-HRW implementation: Part 2, AMV quality and selection

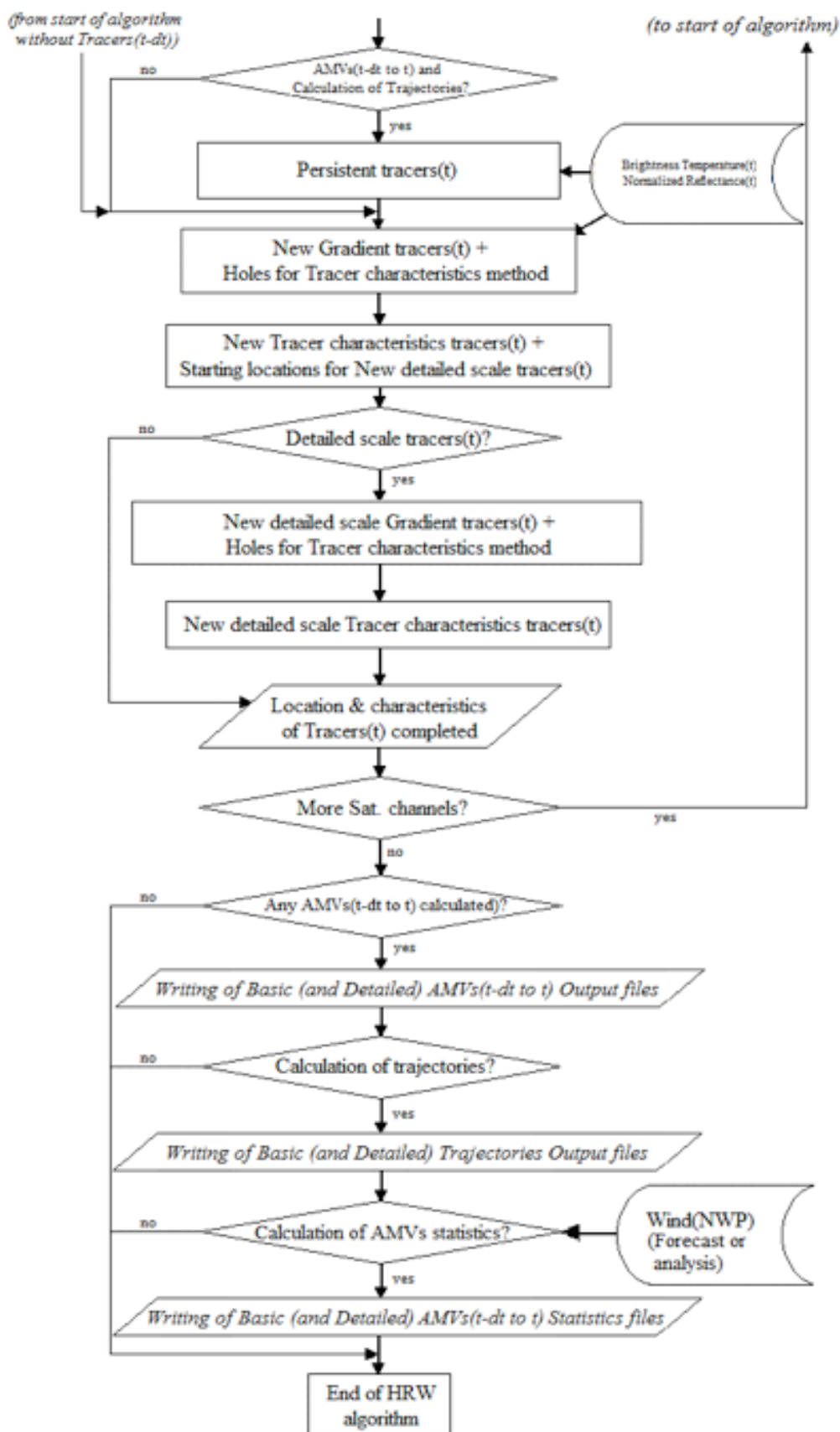


Figure 3: NWC/GEO-HRW implementation: Part 3, Tracer computation and writing of output files

3.3 NWC/GEO-HRW DOCUMENTATION

A detailed description of all NWC/GEO algorithms, involved interfaces and data types, is provided in html format with the support of Doxygen tool, from comments included within the code of the products. Documentation for NWC/GEO-HRW v6.2 is provided in the zipped file:

`NWC-CDOP3-GEO-AEMET-SW-ACDD-Wind_html_v2.0.zip`

Once this file is decompressed, next link is to be opened with a web browser to navigate throughout this documentation:

`NWC-CDOP3-GEO-AEMET-SW-ACDD-Wind_html_v2.0/HRW_html/index.html`

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

For a quicker reference, a Diagram tree of all functions of NWC/GEO-HRW algorithm and their relationships is also provided in the “Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO” document [AD.7]. This Diagram tree allows NWC/GEO users and developers to quickly know at a glance how it works.

3.4 NWC/GEO-HRW ERROR MESSAGES

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

<i>Error</i>	<i>Message</i>	<i>Reason</i>	<i>Recovery action</i>
E - 150	“Environment variable \$*** has not been defined; Update for correct processing”	An environment variable defining some working directory has not been defined	Update environment variable for correct processing
E - 151	“Usage of NWC/GEO-HRW executable”	Input parameters are incorrect	Check instructions to start the run of NWC/GEO-HRW executable
E - 152	"Error allocating memory for tracers related to the previous/current slot"	Unable to allocate required memory for "tracer" struct	There are memory problems to run NWC/GEO-HRW executable in the defined region with the defined configuration and computer. Use a larger computer or a smaller region.
E - 153	"Error allocating memory for tracer_wind struct"	Unable to allocate required memory for "tracer_wind" struct	
E - 154	"Error allocating memory for a wind_channel_info struct"	Unable to allocate required memory for "wind_channel_info" struct	
E - 155	"Error allocating memory for the NWP grids for each variable"	Unable to allocate required memory for NWP grids	
E - 156	“Error allocating memory for the Quality control Image correlation grid”	Unable to allocate required memory for Image Correlation Grid	
E - 157	"Satellite data for current/previous slot do not include valid values for any pixel"	Satellite data are not valid for the working satellite channel	Verify if there is any problem with the satellite data used by NWC/GEO-HRW
E - 158	“The defined satellite is not correct, or does not belong to MSG-1/2/3/4, GOES-13/14/15/16/17 or HIMAWARI-08/09 series”	The defined satellite is not correct or does not belong to a processable geostationary series	Use NWC/GEO-HRW v6.2 with a correctly defined MSG-1/2/3/4, GOES-13/14/15/16/17 or HIMAWARI-08/09 satellite
E - 161	"Error reading Parameters from Satellite configuration file"	Error after NwcCFReadSat function	Verify that the \$SAFNWC/config/sat_conf_file used for running NWC/GEO-HRW is correct
E - 162	“Error in date format (%s). Required format: YYYY-MM-DDT hh:mm:ssZ”	Error after NwcTimeSetStr function	Verify that the date format used for running NWC/GEO-HRW is correct
E - 163	"Error reading Parameters from the HRW configuration file"	Error after hrw_ReadData function	Verify that the \$SAFNWC/config/model_conf_file used for running NWC/GEO-HRW is correct
E - 164	"Error reading Pressure levels from the Model configuration file"	Error after NwcNwpReadPLevel function	Verify that the \$SAFNWC/config/nwp_conf_file used for running NWC/GEO-HRW is correct
E - 165	“Unable to initialize the NWP *** profile”	Error after NwcNwpInitProfile function	Verify that the \$SAFNWC/config/nwp_conf_file & \$SAFNWC/config/model_conf_file used for running NWC/GEO-HRW are correct

<i>Error</i>	<i>Message</i>	<i>Reason</i>	<i>Recovery action</i>
E - 166	“NWP *** data cannot be read” or “Minimum NWP *** levels for calculation” are larger than available NWP levels	Error after hrw_NWPSearch or hrw_NWPSearchSurface functions	Verify that valid and large enough NWP input files have been provided for the running of NWC/GEO-HRW in \$SAFNWC/import/NWP_data directory
E - 167	“Orographic flag cannot be calculated because Orography cannot be converted to surface pressure”	Error after NwcAuxReadGridF function	Verify that a valid S_NWC_SFCMAX* file has been provided in the corresponding subdirectory for the related satellite in \$SAFNWC/import/Aux_data/Common directory
E - 171	“Error setting the Processing region”	Error after NwcRegionSet function	Verify that the \$SAFNWC/config/region_conf_file used for running NWC/GEO-HRW is correct
E - 172	"Error reading latitude, longitude, and sun angles matrices"	Error after hrw_GetAncillaryData function	<p>All these errors are caused by the running of NWC/GEO-HRW executable, and cannot be solved by the NWCSAF 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 NWCSAF Helpdesk.</p>
E - 173	"Error reading satellite data for current/previous slot "	Error after NwcSatInit or hrw_ReadSatelliteData function	
E - 174	"Error reading tracers from previous slot"	Error after hrw_ReadTracers function	
E - 175	"Error reading trajectories from 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 \$SAFNWC/tmp directory"	Error after hrw_WritePredWinds function	
E - 179	“Error writing Trajectories in \$SAFNWC/tmp directory”	Error after hrw_WriteTrajectories function	
E - 180	"Error calculating tracers for current slot"	Error after hrw_GetTracers function	
E - 181	"Error writing tracers in \$SAFNWC/tmp directory"	Error after hrw_WriteTracers function	
E - 182	"Error writing the AMVs in the *** output file"	Error after hrw_Encode*** functions	
E - 183	"Error reading Cloud *** data”	Some output parameter from NWC/GEO-CT, CTH, CMIC products cannot be read.	

Table 14: List of errors for NWC/GEO-HRW

4. INPUTS AND CONFIGURABLE PARAMETERS

4.1 LIST OF INPUTS FOR HIGH RESOLUTION WINDS

The full list of inputs for the running of NWC/GEO-HRW product is as follows:

- Considering MSG satellite series: full resolution uncompressed original HRIT data for the processing region, for the images in which tracers are calculated and tracked, for all MSG channels to be used. These data are to be located in `$SAFNWC/import/Sat_data` directory. IR108 channel is additionally needed for the visible channel processing when the old “Brightness temperature interpolation height assignment” is to be used. IR108 and WV062 channels are additionally needed if the default configuration of the Quality control is kept (including the “Image correlation test”).
- Considering GOES-N satellite series: full resolution uncompressed original GVAR data for the processing region, for the images in which tracers are calculated and tracked. These data are to be located in `$SAFNWC/import/Sat_data` directory, and have first to be converted with the provided `$SAFNWC/src/SAT2NC/SAT2NCconversion.ksh` java tool to NWC/GEO netCDF satellite input data format. The output files from this conversion tool are also located in `$SAFNWC/import/Sat_data` directory. IR107 channel is in any case needed for the visible channel processing when the old “Brightness temperature interpolation height assignment” is to be used. IR107 and WV065 channels are in any case needed if the default configuration of the Quality control is kept (including the “Image correlation test”).
- Considering Himawari-8/9 satellite series: full resolution uncompressed original HSD data (HSD format), or low resolution uncompressed EUMETSAT HRIT data (EHH format), for the processing region, for the images in which tracers are calculated and tracked. These data are to be located in `$SAFNWC/import/Sat_data` directory, and have first to be converted to NWC/GEO netCDF satellite input data format (FSD format) with the provided `$SAFNWC/bin/start_nwcsdi` daemon. The output files from this conversion tool are located in `$SAFNWC/import/Sdi_data` directory. IR112 channel is in any case needed for the visible channel processing when the old “Brightness temperature interpolation height assignment” is to be used. IR112 and WV062 channels are in any case needed if the default configuration of the Quality control is kept (including the “Image correlation test”).
- Considering GOES-R satellite series: full resolution uncompressed original netCDF data for the processing region, for the images in which tracers are calculated and tracked. The data have to be included in `$SAFNWC/import/Sat_data` directory. IR112 channel is in any case needed for the visible channel processing when the old “Brightness temperature interpolation height assignment” is to be used. IR112 and WV062 channels are in any case needed if the default configuration of the Quality control is kept (including the “Image correlation test”).
- NWP data, for the region in which NWC/GEO-HRW is run, with an horizontal resolution of at most 0.5° and a NWP time step of at most 6 hours (preferably a NWP time step of 1 hour), for a minimum of four (defined by configurable parameter `MIN_NWP_FOR_CALCULATION`) and preferably for as many as possible of the following pressure levels: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10 hPa, in `$SAFNWC/import/NWP_data` directory:
 - NWP Forecast Fields of temperatures.
 - NWP Forecast Fields of rectangular components of the wind (u,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 NWC/GEO-HRW considering as reference winds the NWP forecast winds.
 - NWP Analysis Fields of rectangular components of the wind (u,v), needed if Validation statistics are to be calculated by NWC/GEO-HRW considering as reference winds the NWP analysis winds.

- NWP Forecast Fields of geopotential heights, needed if the “Orographic flag” is calculated.
- NWP Forecast Field of surface pressure, needed if the “Orographic flag” is calculated.

ECMWF NWP model is used as default option for NWC/GEO software package, although many other NWP models have been used by NWCSAF users for the processing.

- NWC/GEO-CT and CTTH output files for the processing region, for the image in which tracers are tracked, in `$(SAFNWC)/export/CT` and `$(SAFNWC)/export/CTTH` directories, in case “CCC height assignment method” is used.
- NWC/GEO-CMIC output file for the processing region, for the image in which tracers are tracked, in `$(SAFNWC)/export/CMIC` directory, in case the “microphysics correction” is used inside “CCC height assignment method” (used with all satellite series except GOES-N).
- NWC/GEO-CT output file for the processing region, for the image in which tracers are calculated, in `$(SAFNWC)/export/CT` directory, in case the “Brightness temperature interpolation height assignment with Cloud products” is used.

Of all these data, only uncompressed satellite data (MSG/HRIT, GOES-N/GVAR, Himawari-8/9/HSD or Himawari-8/9/HRIT, or GOES-R/netCDF data), and the NWP temperature and NWP wind forecast profiles are strictly needed for the running of NWC/GEO-HRW product. However, considering the default configuration defined for NWCSAF users, all items mentioned here are mandatory so that the full process of NWC/GEO-HRW product takes place.

Additionally, the full list of configuration files needed for the running of NWC/GEO-HRW product is as follows:

- The NWC/GEO-HRW Model Configuration File `safnwc_HRW.cfm` located in `$(SAFNWC)/config` directory, to be used such as explained in Chapter 4.2 of this document.
- The Auxiliary data for NWC/GEO-HRW located in `$(SAFNWC)/import/Aux_data/HRW` directory.
- The Satellite Configuration File `sat_conf_file` located in `$(SAFNWC)/config` directory.
- The NWP Configuration File `nwp_conf_file` located in `$(SAFNWC)/config` directory.
- The System Configuration File `*.cfs` located in `$(SAFNWC)/config` directory.
- The Run Configuration Files `*cfr` located in `$(SAFNWC)/config` directory.
- The Region Configuration Files `*.cfg` located in `$(SAFNWC)/config` directory.

Information on these configurable files is available in the “Data Output Format for the NWC/GEO” document [AD.6].

4.2 LIST OF HIGH RESOLUTION WINDS CONFIGURABLE PARAMETERS

The High Resolution Winds Model configuration file holds the configurable parameters needed for the running of GEO-HRW-v62 executable. It must be located in \$SAFNWC/config directory. A brief description of the configurable parameters included in the files is shown in the following table. Four different reference NWC/GEO-HRW Model Configuration Files are defined as default option with the name safnwc_HRW.cfm, for operational use with MSG satellite series, GOES-N satellite series, Himawari-8/9 satellite series and GOES-R satellite series. Each of them is provided in the corresponding subdirectories inside \$SAFNWC/config directory, related to each satellite.

These parameters are basically equivalent to those used by NWC/PPS-HRW (for a common use of “High Resolution Winds” product with geostationary and polar satellites). Only 5 parameters are defined for NWC/PPS-HRW, which are not used by NWC/GEO-HRW (in green in the table).

<i>Keyword</i>	<i>Description</i>	<i>Type</i>	<i>Default Value(s)</i>
Identification parameters			
PGE_ID	PGE identification. This keyword is optional, but should not be changed by the user.	Chain of characters	GEO-HRW
SAT_BANDS	A list of satellite bands that can be used for the calculation of AMVs and Trajectories. 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	HRVIS, VIS06, VIS08, IR108, IR120, WV062, WV073 (MSG) VIS07, IR107, WV065 (GOES-N) VIS06, VIS08, IR112, WV062, WV069, WV073 (HIMAWARI) VIS06, VIS08, IR112, WV062, WV070, WV074 (GOES-R)
AMV_BANDS	A list of satellite bands really used for the calculation of AMVs and Trajectories. As possible values, it can include any of the bands shown by the previous parameter, separated by commas.	Chain of characters	HRVIS, VIS06, IR108, WV062, WV073 (MSG) VIS07, IR107, WV065 (GOES-N) VIS08, IR112, WV062, WV069, WV073 (HIMAWARI) VIS08, IR112, WV062, WV070, WV074 (GOES-R)
SLOT_GAP	Ordering number of the previous satellite image, from which tracers are to be considered for the AMV processing. The value for “Rapid scan mode” is one unit more than the value defined by the parameter.	Integer	1
MIXED_SCANNING	Flag to decide if the “Mixed method” is implemented in the processing.	Integer	0
CDET	Flag to define if “Detailed AMVs and Trajectories” are calculated.	Integer	0
NWC/PPS-HRW Polar specific parameters (Unused in NWC/GEO-HRW)			
POLAR_OPTIMAL_TIME_SEPARATION	“Optimal time separation” in minutes between the “initial image” and the “later image”	Integer	10
WEIGHT_OPTIMAL_TIME_SEPARATION	Weight of the “Optimal time separation” in the formula defining 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 defining the “initial image” for a given “later image”	Integer	1
OUTPUT_NAMESTYLE	Option to decide if NWC/PPS-HRW output files provided with “GEO”/“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 possible output file formats. Elements in the list separated by commas: - NWC: AMV & Trajectories BUFR files, using the specific NWCSAF format. - EUM: AMV BUFR files, using the previous IWWG BUFR format. - IWWG: AMV BUFR files, using the new IWWG BUFR format. - NET: AMV netCDF files	Chain of characters	NWC, NET

<i>Output filtering parameters</i>			
QI_THRESHOLD	Quality Index threshold for the AMVs.	Integer	75
QI_THRESHOLD_USEFORECAST	Flag to define if the Quality index threshold used in the wind output filtering includes the Quality forecast test.	Integer	1
QI_IWWG_VALUE_CALCULATION	Flag 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.	Integer	1
CALCULATE_TRAJECTORIES	Flag to decide if Trajectories calculated.	Integer	1
FINALFILTERING	Flag for a final filtering of AMVs based on: - Their Height level (if > 0), - Their Cloud type (if > 1), - Their Quality spatial test (1,2 as invalid values if > 2; 0,1,2 as invalid values if = 4).	Integer	2
USE_TOPO	Flag for calculation of Orographic flag (if = 1,2), 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	This parameter is formally deactivated in NWC/GEO-HRW algorithm.	Integer	0
<i>Working area description parameters</i>			
LAT_MIN	Latitude and longitude borders (in degrees) for the processing region (Basic AMVs).	Integer	-75
LAT_MAX		Integer	75
LON_MIN		Integer	-180
LON_MAX		Integer	180
LAT_MIN_DET	Latitude and longitude borders (in degrees) for the processing region (Detailed AMVs).	Integer	-75
LAT_MAX_DET		Integer	75
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 (HRVIS, VIS06, VIS07, VIS08 channels).	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_OLDER_SLOT_FOR_TRACERS	Option to use as "initial image" with tracers one additional slot backwards, if the default one is not available	Integer	0
MAX_TRACERS	Maximum number of tracers.	Integer	200000
TRACERSIZE_VERYHIGH	Tracer line and column dimension in pixels, when respectively using satellite images with very high, high and low resolution.	Integer	24 (HIMAWARI, GOES-R)
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. Depending on value of HIGHERDENSITY_LOWTRACERS, this separation applies to all tracers (if = 1) or only to tracers related to very low/low/medium level clouds (if > 1).	Integer	18 (HIMAWARI, GOES-R)
TRACERDISTANCE_HIGH		Integer	3 (GOES-N) 9 (MSG, HIMAWARI, GOES-R)
TRACERDISTANCE_LOW		Integer	2 (GOES-N) 3 (MSG) 4 (HIMAWARI, GOES-R)
HIGHERDENSITY_LOWTRACERS HIGHERDENSITY_LOWTRACERS_DET	Relative density between tracers related to very low/low/medium level clouds, and the one between tracers related to other cloud types (for Basic and Detailed scale)	Integer	4 4

Tracking parameters			
TRACKING	Tracking method. Possible values: LP: Euclidean difference CC: Cross correlation.	Chain of characters	CC
TRACKING_GAP	Initial Pixel gap in the Tracking process for the calculation of Euclidean distance or Cross correlation	Integer	8
DEFINewithCONTRIBUTIONS	Flag to decide if "CCC height assignment" is to be used (requires also TRACKING=CC).	Integer	1
DEFPOSwithCONTRIBUTIONS	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 AMV cloud type is calculated by the old "Brightness temperature interpolation height assignment method" (if = 1,2), - And if the AMV cloud type is taken into account for the calculation of the AMV pressure (if = 2).	Integer	2
USE_MICROPHYSICS	Flag to decide if Microphysics correction is to be calculated in "CCC height assignment" (if = 1,2), and if this Microphysics correction is applied to the final AMV pressure (if = 2) (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).	Integer	2 (MSG, HIMAWARI, GOES-R) 0 (GOES-N)
MIN_CORRELATION	Minimum correlation acceptable (if TRACKING=CC).	Integer	80 (MSG, HIMAWARI, GOES-R) 50 (GOES-N)
WIND_GUESS	Flag to decide if the Wind guess is used for the definition of the Tracking area.	Integer	0
MINSPEED_DETECTION	When the wind guess is not used in the definition of the Tracking area, displacement (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	272
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 (if = 1,2), and if "_PLAX" label is included in NWC/GEO-HRW output file names to explicitly identify in these file names that the parallax correction took place (if = 2).	Integer	1
KEEPDEFAULTPROCEDURE	Flag to decide if the default procedure is to be used in all cases, even when some of the input data are not available (if = 1), or an alternative option for AMV calculation can be used without the missing input data (if = 0).	Integer	1

<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/GEO-HRW processing.	Integer	4
NWP_PARAM	NWP parameters requested by NWC/GEO-HRW: * 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) * NWP_SP: Pressure at surface level (Pa) Sampling rate used: 1 Interpolation method used: NEI (neighbour)	Chain of characters	NWP_T 1 NEI
NWP_PARAM		Chain of characters	NWP_UW 1 NEI
NWP_PARAM		Chain of characters	NWP_VW 1 NEI
NWP_PARAM		Chain of characters	NWP_GEOP 1 NEI
NWP_PARAM		Chain of characters	NWP_SP 1 NEI

Table 15: NWC/GEO-HRW Model Configuration File Description

If the user has the need to reduce the NWC/GEO-HRW running time, especially when working with a slow platform, it is recommended to reduce the amount of channels for which AMVs are calculated.

This issue applies specially with MSG satellite data because of its larger amount of channels. Because of the general similarity on one side between IR108 and IR120 AMVs, and on the other side between VIS06 and VIS08 AMVs, the first recommendation to reduce NWC/GEO-HRW running time is to keep the five MSG channels defined in the default configuration (with AMV_BANDS = HRVIS,VIS06,WV062,WV073,IR108). If further reductions in NWC/GEO-HRW running time are needed, it would be recommended at least to keep four channels (with AMV_BANDS = HRVIS,WV062,WV073,IR108).

With GOES-N satellite data, it should always be possible to keep the calculation of AMVs and Trajectories for the three suggested channels: AMV_BANDS = VIS07,WV065,IR107.

With Himawari-8/9 and GOES-R satellite data, if there is the need to reduce the running time, the first recommendation would be to remove the highest resolution visible channel with AMV_BANDS = VIS08,WV62,WV069,WV073,IR112 and VIS08,WV062,WV070,WV074,IR112 respectively as in the default configuration. The second recommendation would be to keep two water vapour channels only, with AMV_BANDS = VIS08,WV062,WV073,IR112 and VIS08,WV062,WV074,IR112 respectively.

5. NWC/GEO-HRW ASSUMPTIONS AND LIMITATIONS

The main circumstance that has to be taken into account when using NWC/GEO-HRW (High Resolution Winds) 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 or cloudless areas with humidity patterns in the working region.

Nevertheless, the situation has improved with the progressive versions of NWC/GEO-HRW:

- Initially, the applicability of NWC/GEO-HRW algorithm was limited to cloudy areas in European, African and Atlantic areas with MSG satellite data.
- Since the year 2011, AMVs related to humidity patterns in the MSG water vapour channels started to show wind vectors in clear air areas.
- Since the year 2012, the possibility to calculate AMVs with up to seven different MSG satellite channels increases significantly the density of possible AMV data throughout all the day.
- The additional option to calculate AMVs in “Rapid scan mode” with MSG satellite series also permits to obtain new AMVs in shorter time frames of five minutes with every new satellite image, increasing the amount of available AMVs by a factor of 3 respect to the MSG “Nominal scan mode”.
- Since the year 2018, the option exists to calculate AMVs and Trajectories in Asian and West Pacific areas with Himawari-8/9 satellite series.
- Since the year 2020, the option exists to calculate AMVs and Trajectories in the American regions with GOES-16 satellite.
- And since the year 2021, AMVs and Trajectories can be calculated in the Eastern Pacific and Western North American regions with GOES-17 satellite. In both cases (GOES-16, GOES-17) the processing is restricted in the default configuration to Full Disk images in “Mode 6” (with images every 10 minutes), for areas where NWC/GEO-Cloud products could be calculated and the quality flag for the satellite channel used for AMV calculation is zero (optimal) for all pixels. This way, the quality of the AMVs and Trajectories is guaranteed and the problems related to the cooling issue in the GOES-17 ABI imager are avoided, although this also implies that NWC/GEO-HRW output is not available 24 hours per day all days of the year.

With all this, the latest version of NWC/GEO-HRW (v6.2) is able to cover with five different simultaneous geostationary satellites the whole Earth, and AMVs and Trajectories can be calculated simultaneously throughout the whole planet, in general only excepting the moments around the Equinoxes in which GOES-17 data cannot be processed. This fulfills the expected plan to calculate AMVs and Trajectories with geostationary satellites covering all areas of the world with an only AMV algorithm, which is an important milestone for NWC/GEO-HRW algorithm.

With all these elements, the progressive improvements have reduced the limitations this algorithm could previously have. Especially, the presence of geographical areas inside the working region where NWC/GEO-HRW algorithm does not find any AMV vector is now smaller. However, because the presence of humidity patters in the clear air areas where tracers can adequately be defined and tracked is not guaranteed, and because in general clear air AMVs have worse validation statistics, the presence of areas where no AMVs are available and no information can be extracted is still possible. The users should evaluate, which implications this might have when using NWC/GEO-HRW algorithm.

The experience had since 2018 with the new generation satellites (Himawari-8/9 and GOES-R), is also very useful for the development of the AMV algorithm for MTG-Imager satellite series, for which the main issues seem to be related to the density and quality of AMVs at low levels.

For future work, an effort is needed to reduce the size of the code and the use of memory by NWC/GEO-HRW algorithm, and to allow the parallelization of the calculation of AMVs and Trajectories (doing calculations for different satellite channels with different processors), to reduce the running time of the algorithm. Some studies were done on this during the summer of 2018, showing clearly that more time was needed for this.

About the calculated AMVs, 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, as implemented in the default configuration). The second problem is solved using the “Quality index without forecast” in the operation of NWC/GEO-HRW algorithm (implemented with QI_THRESHOLD_USEFORECAST = 0), which avoids the influence of the NWP model in the Quality of the AMVs. Another option can be to use the “Common IWWG Quality index”, especially when AMV outputs from different algorithms are used, for which the use of this parameter has proved to be useful.

- 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/GEO-CTTH product output data.

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

The quality of the height assignment inferred in previous versions of NWC/GEO-HRW without use of NWP data is considered not to be good enough to be used anymore, and so the option to calculate AMVs without NWP data has been eliminated in NWC/GEO-HRW algorithm.

Considering the calculation of Trajectories through the successive tracking of the same tracer in consecutive images, the most important limitation is the persistence in time of the tracers for the definition of the Trajectories. Because of the temporal evolution of the tracers, after one hour only between 30% and 50% of the tracers persist; after three hours only between 5% and 15% of the tracers persist. The persistence is also smaller due to the smaller size of the tracers in the “Detailed scale”.

The persistence of the tracers is also different considering different meteorological situations, in which the temporal change of the atmospheric structures is quicker or slower. Considering this, the density of trajectories can be very different in different parts of a same region. This is an issue that users should also have into account when using the trajectories calculated by NWC/GEO-HRW.

6. VISUALISATION EXAMPLES OF HIGH RESOLUTION WINDS

Following figures show typical displays of NWC/GEO-HRW, considering the default configuration for the different satellites, but with AMVs calculated for all possible satellite channels.

First, with MSG-2 satellite data in the European and Mediterranean region (*Figures 4 and 5*). Second, with GOES-13 satellite data in the Continental United States region (*Figures 6 and 7*). Third, with Himawari-8 satellite data in the China, Korea and Japan region (*Figures 8 and 9*). Fourth, with GOES-16 satellite data in the Continental United States region (*Figures 10 and 11*). Finally, with GOES-17 satellite data in the Eastern Pacific region (*Figures 12 and 13*).

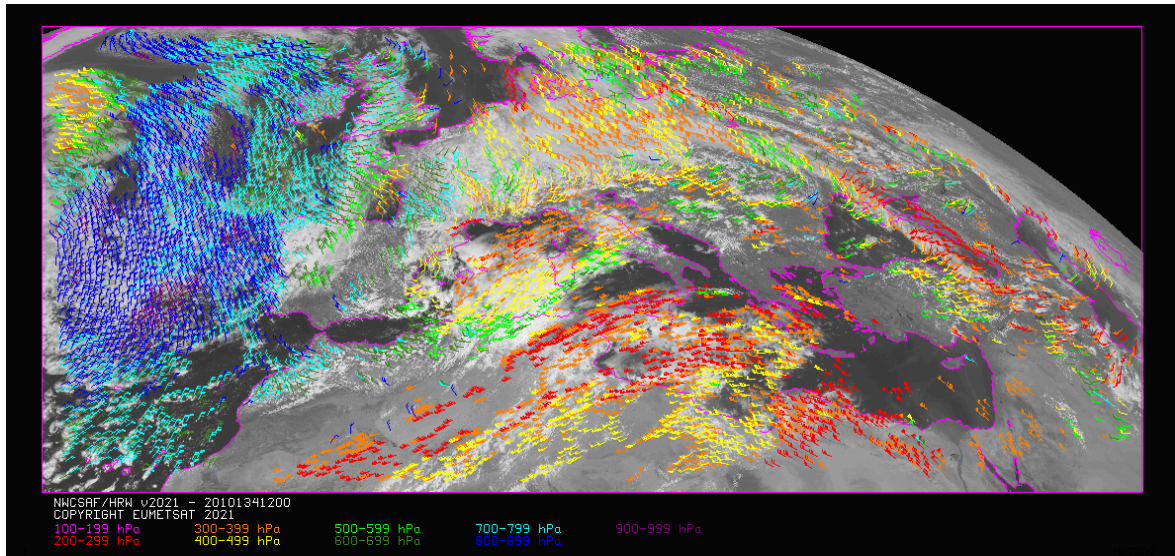


Figure 4: NWC/GEO High Resolution Winds Basic AMV output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG-2 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file.

Colour coding based on the AMV pressure level

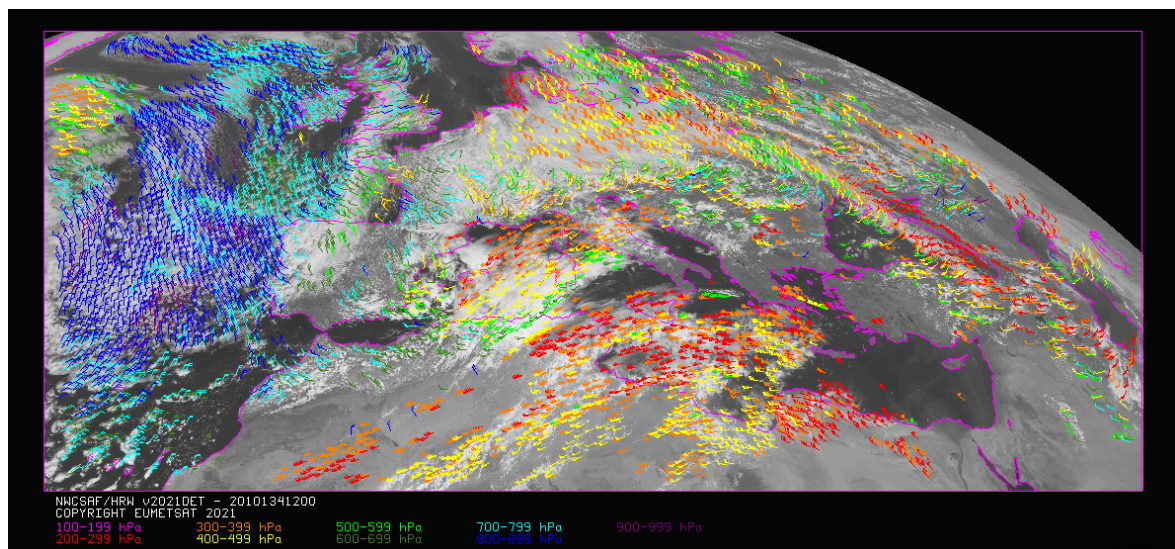


Figure 5: NWC/GEO High Resolution Winds Detailed AMV output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG-2 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file and configurable parameter `CDET = 1`. Colour coding based on the AMV pressure level

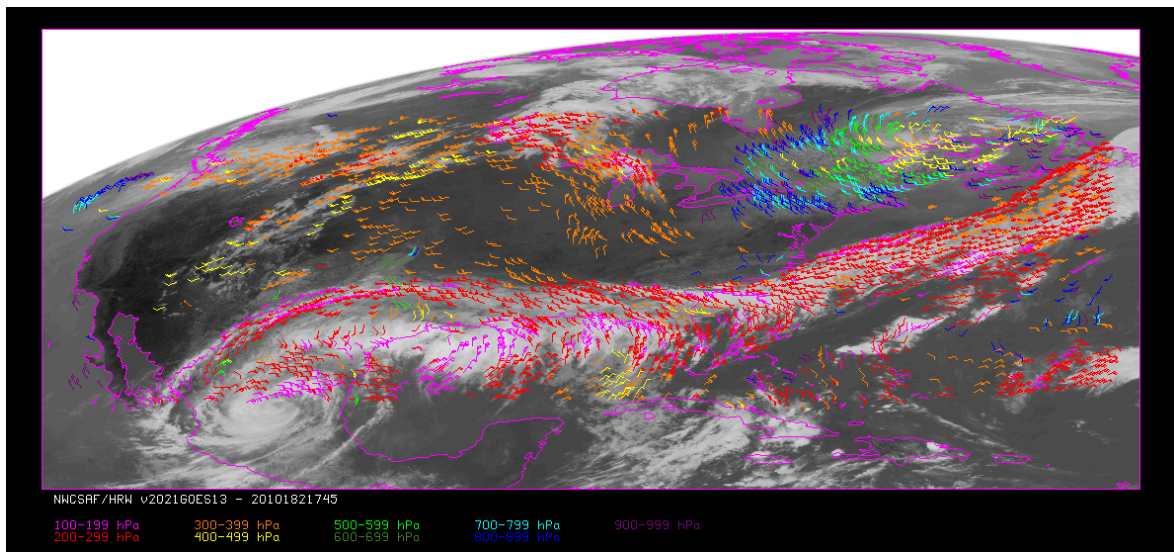


Figure 6: NWC/GEO High Resolution Winds Basic AMV output example in the Continental United States region (1 Jul 2010 17:45 UTC, GOES-13 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

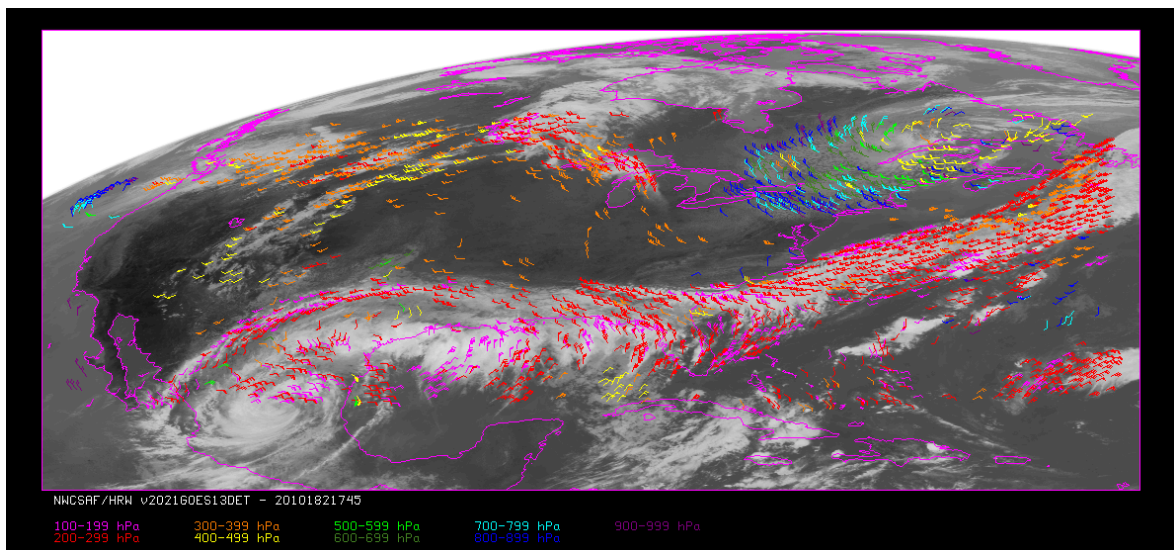


Figure 7: NWC/GEO High Resolution Winds Detailed AMV output example in the Continental United States region (1 Jul 2010 17:45 UTC, GOES-13 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file and configuration parameter `CDET = 1`. Colour coding based on the AMV pressure level

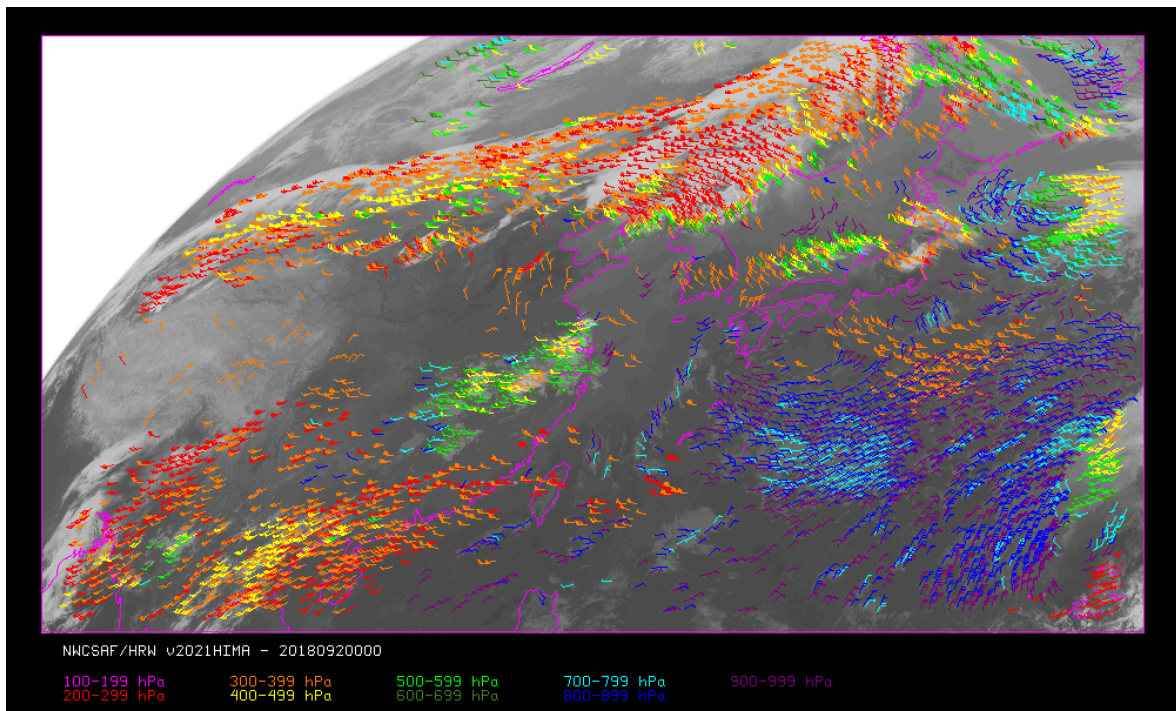


Figure 8: NWC/GEO High Resolution Winds Basic AMV output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level. Himawari-8 HSD original data used as input

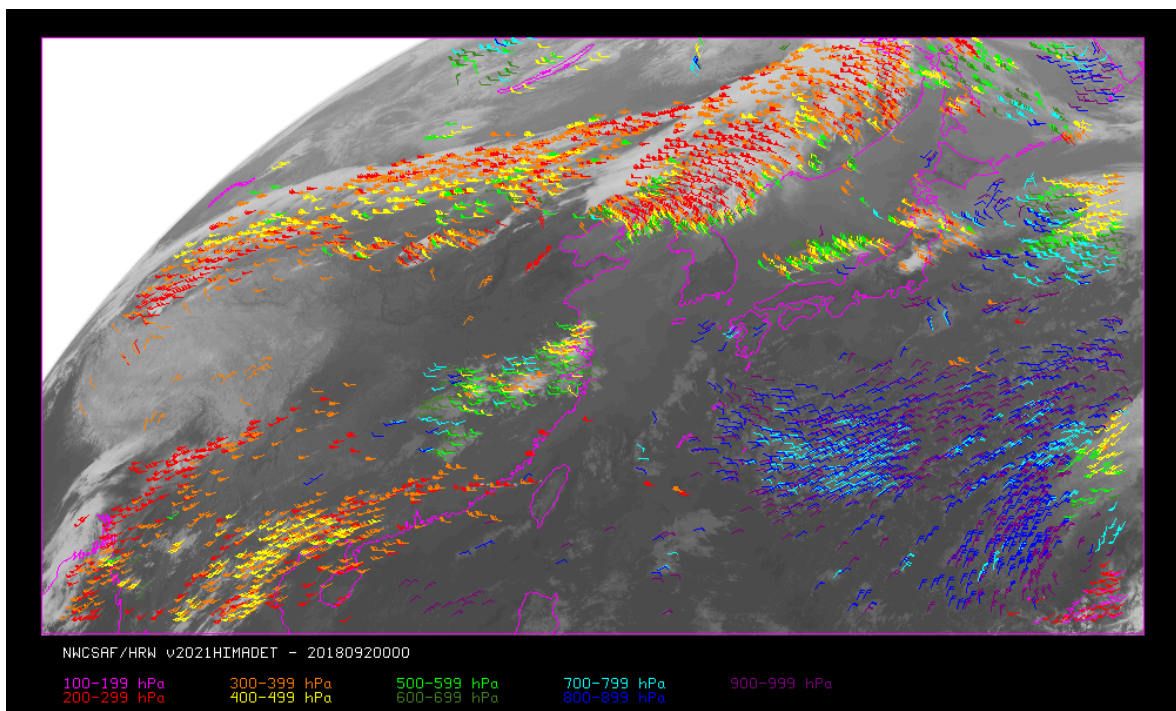


Figure 9: NWC/GEO High Resolution Winds Detailed AMV output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file and configurable parameter `CDET=1`. Colour coding based on the AMV pressure level. Himawari-8 HSD original data used as input

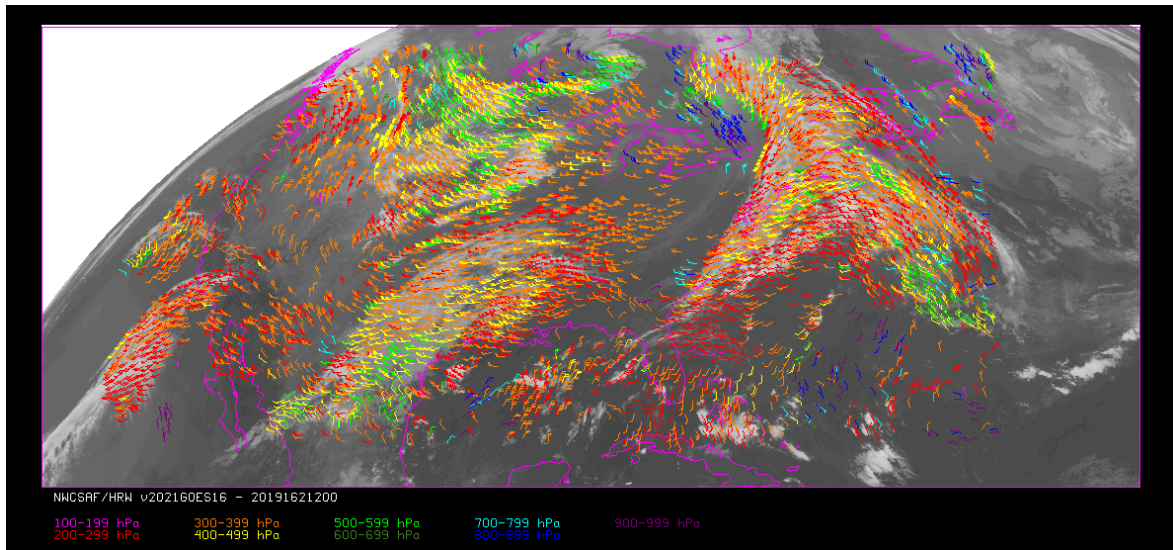


Figure 10: NWC/GEO High Resolution Winds Basic AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

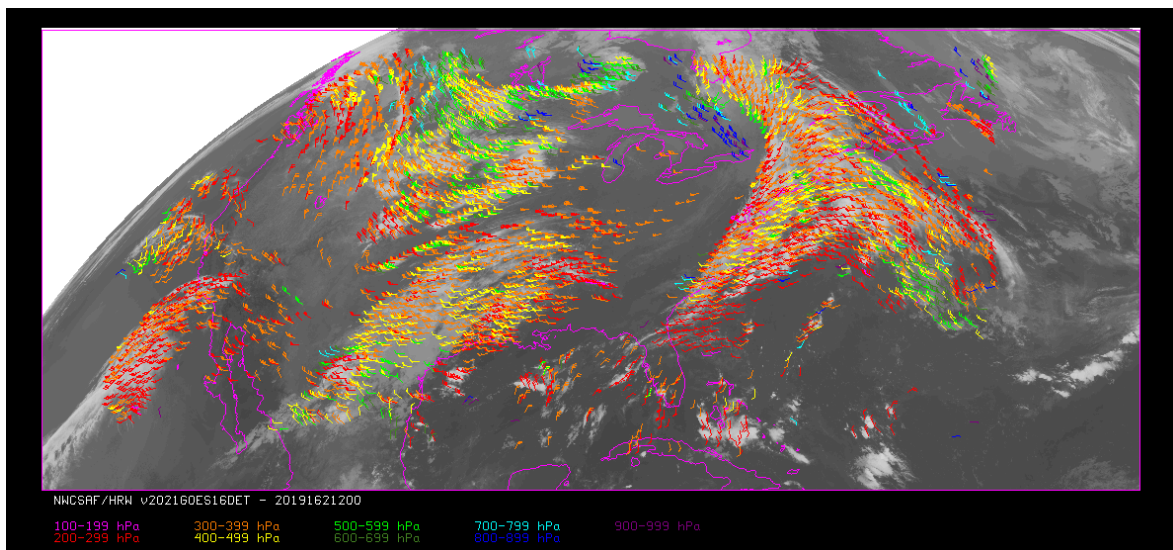


Figure 11: NWC/GEO High Resolution Winds Detailed AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file and configuration parameter `CDET = 1`. Colour coding based on the AMV pressure level

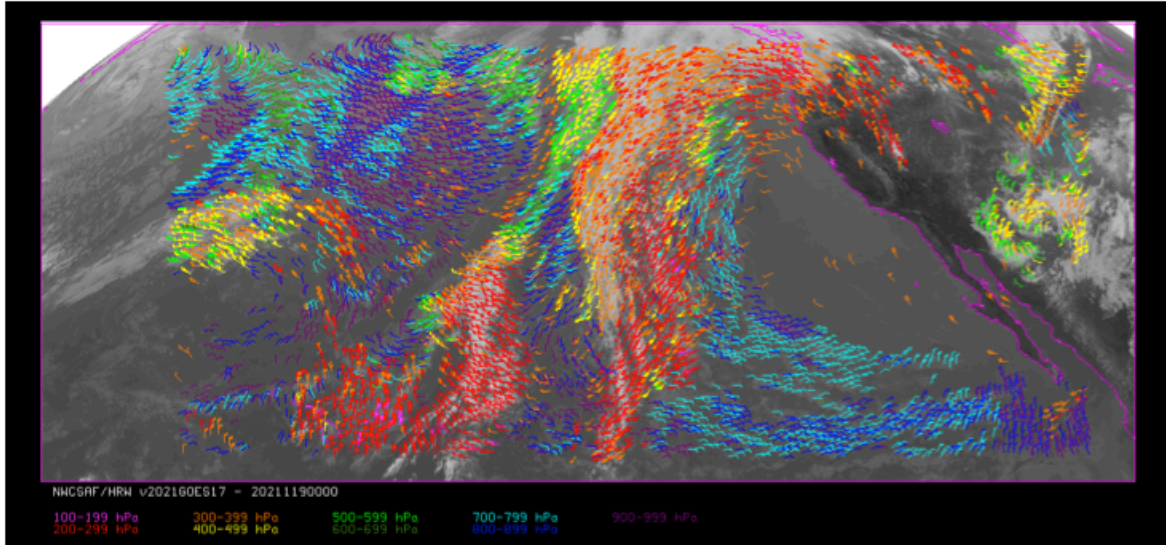


Figure 12: NWC/GEO High Resolution Winds Basic AMV output example in the Eastern Pacific region (29 April 2021, 00:00 UTC, GOES-17 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

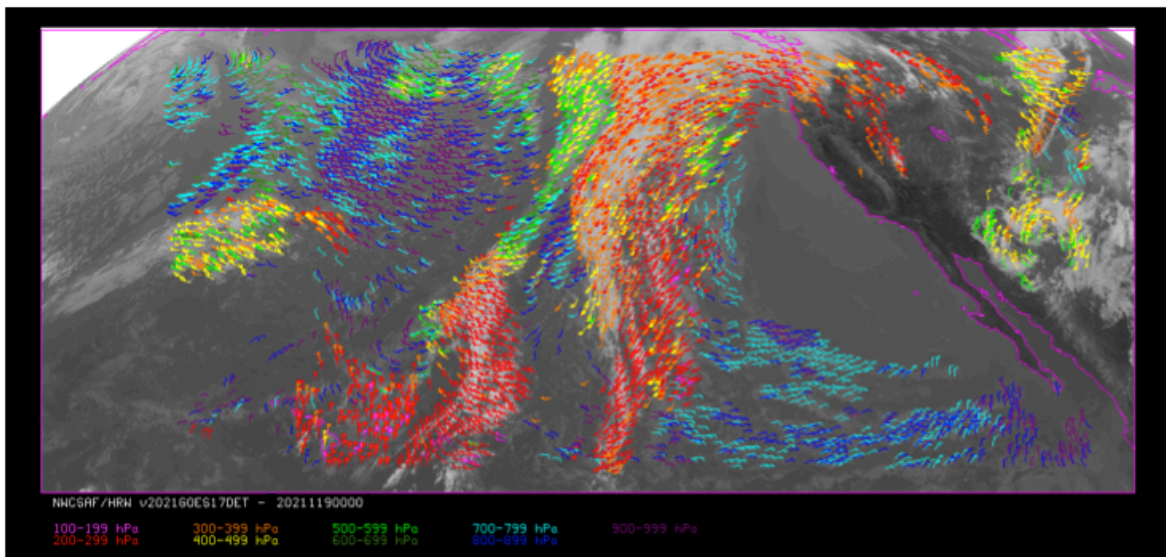


Figure 13: NWC/GEO High Resolution Winds Detailed AMV output example in the Eastern Pacific region (29 April 2021, 00:00 UTC, GOES-17 satellite), considering default conditions defined in `safnwc_HRW.cfm` model configuration file and configuration parameter $CDET = 1$. Colour coding based on the AMV pressure level