User Manual for the Wind product processor of the NWC/GEO (MTG-I day-1): Science Part

NWC/CDOP3/MTG/AEMET/SCI/UM/Wind, Issue 1, Rev. 2.1

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Applicable to NWC/GEO-HRW-v7.0 (NWC-039)
(NWC/GEO-HRW MTG-I day-1)

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0	*13 November 2020*	60	Initial version for NWC/GEO MTG-I day-1 STRR1 review. Content derived from Document "User Manual for the Wind product processor of the NWC/GEO (NWC/GEO-HRW v6.1)", NWC/CDOP3/GEO/AEMET/SCI/UM/Wind v1.1, and Document "Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO (MTG-I day-1)", NWC/CDOP2/MTG/AEMET/SCI/ATBD/Wind v1.1.
1.1.0	*3 February 2023*	63	Updated version for NWC/GEO MTG-I day-1 ORR1 review.
1.2.0	*31 March 2025*	67	Updated version for NWC/GEO MTG-I day-1 ORR2 review.
1.2.1	*30 May 2025*	67	Reviewed version for NWC/GEO-HRW v7.0 in NWC/GEO v2025 (vMTG-I day-1), after Operational Readiness Review 2 (ORR-2)

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1. INTRODUCTION

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

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

This document is applicable to the adaptation of NWC/GEO software package for geostationary satellites to MTG-I satellite series: NWC/GEO v2025 (vMTG-I day-1).

1.1 SCOPE OF THE DOCUMENT

This document is the "User Manual (UM) for the Wind Product Processor of the NWC/GEO vMTG-I day-1" software package, herein called NWC/GEO-HRW - High Resolution Winds, which calculates Atmospheric Motion Vectors and Trajectories considering:

- Up to six channels from MTG-I/FCI imager: four 2 km low resolution water vapour and infrared channels (WV063 6.300 µm, WV073 7.350 µm, IR105 10.500 µm and IR123 12.300 µm), and two 1 km high resolution visible channels (VIS06 0.640 µm and VIS08 0.865 µm).
- 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 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 to GOES-R satellite series, available for GOES-16, GOES-17, GOES-18 and GOES-19 satellites, considers Full Disk images in "Mode 6" (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 the AMV calculation is zero (optimal) for all pixels implied in the AMV calculation. This way the problems related to the cooling issue in the GOES-17 ABI imager are avoided.

With all this, NWC/GEO-HRW vMTG-I day-1 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.

NWC/GEO-HRW algorithm adaptation to MSG, Himawari-8/9 and GOES-R was already implemented and validated at previous versions of NWC/GEO up to NWC/GEO v2021. The principal task of NWC/GEO v2025 (vMTG-I day-1) is the adaptation and full validation of NWC/GEO-HRW algorithm to MTG-Imager satellite series.

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

1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithm implemented in NWC/GEO-HRW v7.0, Product Id NWC-039, in NWC/GEO v2025 (vMTG-I day-1) software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

The main changes related to NWC/GEO-HRW v7.0 with respect to the previous version (NWC/GEO-HRW v6.2 in NWC/GEO v2021 software package) are the following ones.

Specific to NWC/GEO-HRW v7.0:

1. The structure of the NWC/GEO-HRW netCDF outputs changes between these two versions. In NWC/GEO-HRW v7.0, the structure of the netCDF outputs (with two different files for NWC/GEO-HRW AMVs and Trajectories) is "CF compliant" and easier to process (following the recommendations from NWCSAF users).
2. The update from BUFRDC to ECCODES library for the writing of NWC/GEO-HRW BUFR output files (as recommended by ECMWF).
3. NWC/GEO-HRW v7.0 does not provide anymore as output the BUFR bulletin based on the "previous International Winds Working Group (IWWG) format". This format is replaced by the BUFR bulletin based on the "2018 IWWG format". 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 2025 all AMV users should already be used to the new format.

Common to all NWC/GEO vMTG day-1 products:

4. The extension of NWC/GEO-HRW processing to the MTG-I (MTG-Imager) satellite series.
5. NWC/GEO-HRW does not support GOES-N satellite series anymore. Processing in the Americas and Eastern Pacific is only provided through GOES-R satellite series.
6. The definition of the Earth ellipsoid changes for the different satellites in NWC/GEO vMTG day-1 software package, being defined as configurable parameters in different configuration files. In NWC/GEO v2021 software package, these parameters were similar for all satellites, so causing some small differences in the satellite navigation.
7. The structure of $SAFNWC/tmp temporal directory changes, defining now different subdirectories for different parameter types.

1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

1.4.1 Definitions

4x4 big pixel matrix	4x4 big element matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_n)
Atmospheric Motion Vector (AMV)	Horizontal wind calculated through the horizontal displacement between two Earth positions in two different satellite images (defined as initial image and later image), of a square segment of nxn pixels called tracer
Basic dataset	Set of tracers or AMVs, calculated with the basic or wide tracer scale (with a default value of 24 x 24 pixels). Two kinds of Basic tracers are possible: wide basic tracers (with bright big pixels in the first and last big pixel row or column) and narrow basic tracers (occurring otherwise)
Bearing angle	Angle defined by the great circle connecting two locations on the Earth
Best fit pressure level	Pressure level which minimizes the vector difference between the AMV and a reference wind, considering as reference wind the nearest NWP wind profile or nearest Radiosounding wind profile
Big pixel	Each element of the 4x4 big pixel matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_0, CLASS_1, CLASS_2)
Bright big pixel	Big pixel inside a big pixel matrix, in which at least a 70% of its pixels 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
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, added to Quality TEST indicator after Quality Control
TEST parameter	Quality flag after the Quality control processing, detailing which quality consistency tests were applied for a given AMV, and the relative results of each quality consistency test for all AMVs related to the same tracer
Tracer	Square segment in the initial image with a fixed size (nxn pixels, called tracer size), identified by the location of its centre, and considered valid candidate for AMV calculation by any of the tracer calculation methods
Tracer candidate	Square segment in the initial image with a fixed size, where conditions for tracer search using “Tracer characteristics method” are evaluated
Tracer continuity	Processing option in which part of the set of tracers in the current processing cycle is defined through the tracking centres of AMVs in the previous processing cycle
Tracer location	Pixel coordinates of a tracer (line and column) in the initial image
Tracer selection procedure	Strategy to get a complete set of tracers throughout the desired region of the image. It consists of 2 iterations (2 methods) for the single scale procedure; 4 iterations (2 methods, 2 scales) for the two scale procedure
Tracer size	Line/column dimension of a tracer. In NWC/GEO-HRW, 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 to 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	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
HRVIS, VIS06, VIS08	MSG HRVIS 0.7 µm - MSG & MTG-I & Himawari-8/9 & GOES-R 0.6µm - MSG & MTG-I & Himawari-8/9 & GOES-R 0.8µm Visible channels
IOP	NWCSAF Initial Operations Phase
IR105, IR108, IR112, IR120, IR123	MTG-I 10.5µm - MSG 10.8µm - Himawari-8/9 & GOES-R 11.2µm - MSG 12.0µm - MTG-I 12.3µm Infrared channels
IWWG	International Winds Working Group
JMA	Japan Meteorological Agency
MSG	EUMETSAT's Meteosat Second Generation Satellite
MTG-I	EUMETSAT's Meteosat Third Generation Imager Satellite
NOAA	United States' National Oceanic and Atmospheric Administration
NWC/GEO	NWCSAF Software Package for Geostationary satellites
NWC/GEO-HRW	NWC/GEO 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, WV063, WV069, WV070, WV073, WV074	MSG & Himawari-8/9 & GOES-R 6.2µm – MTG-I 6.3µm - Himawari-8/9 6.9 µm - GOES-R 7.0µm - MSG & MTG-I & Himawari-8/9 7.3µm - GOES-R 7.4µm 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 referred document applies.

Current documentation can be found at the NWCSAF Helpdesk web: https://nwc-saf.eumetsat.int.

Ref.	*Title*	*Code*	*Version*
[AD.1]	Proposal for the Fourth Continuous Development and Operations Phase (CDOP4)	NWC/SAF/AEMET/MGT/CDO4Proposal	1.0
[AD.2]	NWCSAF Project Plan	NWC/CDOP4/SAF/AEMET/MGT/PP	3.0.0
[AD.3]	Configuration Management Plan for the NWCSAF	NWC/CDOP4/SAF/AEMET/MGT/CMP	1.2.0
[AD.4]	NWCSAF Product Requirements Document	NWC/CDOP4/SAF/AEMET/MGT/PRD	3.0.0
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO MTG-I day-1	NWC/CDOP2/MTG/AEMET/SW/ICD/1	1.4.0
[AD.6]	Data Output Format for the NWC/GEO MTG-I day-1	NWC/CDOP2/MTG/AEMET/SW/DOF	1.4.0
[AD.7]	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO MTG-I day-1	NWC/CDOP2/MTG/AEMET/SCI/ATBD/Wind	1.1.1
[AD.8]	Scientific and Validation Report for the Wind product processor of the NWC/GEO (MTG-I day-1)	NWC/CDOP4/MTG/AEMET/SCI/VR/Wind	1.0.1

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 referred document applies.

Ref.	Title
[RD.1]	J.Schmetz, K.Holmlund, J.Hoffman, B.Strauss, B.Mason, V.Gärtner, A.Koch, L. van de Berg, 1993: Operational Cloud Motion Winds from Meteosat Infrared Images (Journal of Applied Meteorology, Num. 32, pp. 1206-1225).
[RD.2]	S.Nieman, J.Schmetz, W.P.Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers (Journal of Applied Meteorology, Num. 32, pp. 1559-1568).
[RD.3]	C.M.Hayden & R.J.Purser, 1995: Recursive filter objective analysis of meteorological fields, and application to NESDIS operational processing (Journal of Applied Meteorology, Num. 34, pp. 3-15).
[RD.4]	K.Holmlund, 1998: The utilisation of statistical properties of satellite derived Atmospheric Motion Vectors to derive Quality Indicators (Weather and Forecasting, Num. 13, pp. 1093-1104).
[RD.5]	J.M.Fernández, 1998: A future product on HRVIS Winds from the Meteosat Second Generation for nowcasting and other applications. (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.6]	J.M.Fernández, 2000: Developments for a High Resolution Wind product from the HRVIS channel of the Meteosat Second Generation. (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.7]	J.M.Fernández, 2003: Enhancement of algorithms for satellite derived winds: the High Resolution and Quality Control aspects. (Proceedings 2003 Meteorological Satellite Conference, EUMETSAT Pub.39).
[RD.8]	J.García-Pereda & J.M.Fernández, 2006: Description and validation results of High Resolution Winds product from HRVIS MSG channel at the EUMETSAT Nowcasting SAF (Proceedings 8th International Wind Workshop, EUMETSAT Pub.47).
[RD.9]	J.García-Pereda, 2008: Evolution of High Resolution Winds Product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.10]	J.García-Pereda, 2010: New developments in the High Resolution Winds product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 10th International Wind Workshop, EUMETSAT Pub.56).
[RD.11]	C.M.Hayden & R.T.Merrill, 1988: Recent NESDIS research in wind estimation from geostationary satellite images (ECMWF Seminar Proceedings: Data assimilation and use of satellite data, Vol. II, pp.273-293).
[RD.12]	W.P.Menzel, 1996: Report on the Working Group on verification statistics. (Proceedings 3rd International Wind Workshop, EUMETSAT Pub.18).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.14]	Xu J. & Zhang Q., 1996: Calculation of Cloud motion wind with GMS-5 images in China. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.15]	K.Holmlund & C.S.Velden, 1998: Objective determination of the reliability of satellite derived Atmospheric Motion Vectors (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.16]	K.Holmlund, C.S.Velden & M.Rohn, 2000: Improved quality estimates of Atmospheric Motion Vectors utilising the EUMETSAT Quality Indicators and the UW/CIMSS Autoeditor (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.17]	R.Borde & R.Oyama, 2008: A direct link between feature tracking and height assignment of operational Atmospheric Motion Vectors (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.18]	J.García-Pereda, R.Borde & R.Randriamampianina, 2012: Latest developments in "NWCSAF High Resolution Winds" product (Proceedings 11th International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (Available as "CCT-2023-11-30/C01.csv" at https://wmoomm.sharepoint.com/:u:/s/wmocpdb/EZquJmm_PHZIln14DDl81PEB-lFNAAE2GEVNAgYxMbyLQA?e=kSj2LK)
[RD.20]	WMO Code Tables and Flag Tables associated with BUFR/CREX table B, version 31 (Available as "BUFR4-41/fromWeb/BUFRCREX_31_0_0/ BUFRCREX_31_0_0_TableB_en.txt" at https://wmoomm.sharepoint.com/:u:/s/wmocpdb/Ee_T4lZfisNJjj-vN5AZmGEBYtW-yZa3oHv4YZXemPussg?e=fANZXz)
[RD.21]	P.Lean, G.Kelly & S.Migliorini, 2014: Characterizing AMV height assignment errors in a simulation study (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.22]	Á.Hernández-Carrascal & N.Bormann, 2014: Cloud top, Cloud centre, Cloud layer – Where to place AMVs? (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.23]	K.Salonen & N.Bormann, 2014: Investigations of alternative interpretations of AMVs (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.24]	D.Santek, J.García-Pereda, C.Velden, I.Genkova, S.Wanzong, D.Stettner & M.Mindock, 2014: 2014 AMV Intercomparison Study Report - Comparison of NWCSAF/HRW AMVs with AMVs from other producers (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/225)
[RD.25]	D.Santek, R.Dworak, S.Wanzong, K.Winiecki, S.Nebuda, J.García-Pereda, R.Borde & M.Carranza, 2018: 2018 AMV Intercomparison Study Report (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/5092)
[RD.26]	K.Salonen, J.Cotton, N.Bormann & M.Forsythe, 2015: Characterizing AMV height-assignment error by comparing best-fit pressure statistics from the Met Office and ECMWF data assimilation systems (Journal of Applied Meteorology and Climatology, Vol.54, Num.1).

Table 4: List of Reference Documents

2. DESCRIPTION OF HIGH RESOLUTION WINDS

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

The NWCSAF High Resolution Winds (NWC/GEO-HRW) aims to provide, for near real time meteorological applications, detailed sets of "Atmospheric Motion Vectors" (AMVs) and "Trajectories" from EUMETSAT's Meteosat Second Generation and Meteosat Third Generation Imager (MSG and MTG-I), JMA's Himawari-8/9 geostationary satellite series, and NOAA's Geostationary Operational Environmental (GOES-R) satellite series.

An "Atmospheric Motion Vector" (AMV) is the horizontal displacement between two Earth positions in two satellite images ("initial image" and "later image"), of a square "segment" of nxn pixels. The square segment is defined through a specific cloudiness feature in visible, infrared or 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").

"Atmospheric Motion Vectors" are associated with the horizontal wind in the atmosphere. Specific exceptions exist to this, generally related to clouds which are blocked or whose flow is affected by orography, or to lee wave clouds with atmospheric stability near mountain ranges. These exceptions are identified and discarded, such as later explain in chapter 2.2.7 of this document.

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

AMVs and Trajectories are calculated throughout all hours of the day, as dynamic information in the NWC/GEO package, considering the displacement of tracers in up to six MTG-I/FCI channel images:

- Two high resolution 0.6µm and 0.8µm visible channels (VIS06, VIS08),
- Two low resolution 10.5µm and 12.3µm infrared channels (IR105, IR123),
- Two low resolution 6.3µm and 7.3µm water vapour channels (WV063, WV073).

in up to seven MSG/SEVIRI channel images:

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

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

- The very high resolution 0.6µm visible channel (VIS06),
- One high resolution 0.8µm visible channel (VIS08),
- One low resolution 11.2µm infrared channel (IR112),
- Three low resolution 6.2µm, 6.9µm, 7.3µm water vapour channels (WV062, WV069, WV073).

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

- The very high resolution 0.6µm visible channel (VIS06),
- One high resolution 0.8µm visible channel (VIS08),
- One low resolution 11.2µm infrared channel (IR112),
- Three low resolution 6.2µm, 7.0µm, 7.4µm water vapour channels (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 output 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), or as an input to Analysis, Nowcasting and Very short range forecasting applications.

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 (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:

   • It includes the reading and geolocation of the Satellite data (Brightness temperatures and Normalized reflectances from MTG-I, MSG, 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-Cloud 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 centre" 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 one of 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 MTG-I, MSG, Himawari-8/9 and GOES-R satellite series are presented throughout the description of the algorithm to illustrate the process.

Many of the options and coefficients are configurable in the "NWC/GEO-HRW model configuration file", such as explained in detail in Chapter 4.2. For example, the satellite channels for which AMVs are to be extracted are defined by configurable parameter 'WIND_CHANNEL'.

In NWC/GEO-HRW vMTG, the default configuration implies the use of consecutive images (separated by 10 minutes with MTG-I, Himawari-8/9 and GOES-R series, and by 15 minutes with MSG series) in "Nominal scan mode", and the use of alternate images (one out of every two, separated by 10 minutes) in "Rapid scan mode" with MSG satellites.

Additionally, considering a suggestion by Yuheng He from Hong Kong Observatory, an additional option has been included with configurable parameter USE_OLDERSLOT_FORTRACERS = 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 the processing when some satellite slot is missing. However, this option is not implemented as default one.

2.2.1 Preprocessing

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

1. Normalized reflectances for any MTG-I, MSG, Himawari-8/9 or GOES-R visible channel to be used; brightness temperatures for any MTG-I, MSG, Himawari-8/9 or GOES-R infrared or water vapour channel to be used; radiances for MTG-I/IR105 and WV063, MSG/IR108 and WV062, Himawari-8/9 & GOES-R/IR112 and WV062 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 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, or for the calculation of validation statistics for the AMVs with NWC/GEO-HRW executable itself. NWP geopotential profiles and NWP surface pressure are also extracted if the 'Parallax correction' of the AMV location or the 'Orographic flag' are calculated. All these options except the use of the NWP wind for the definition of the tracking area are implemented for all satellite series 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 in 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 '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'. All these data except the NWC/GEO-CT Cloud Type output for the previous slot are implemented for the calculation of AMVs and Trajectories in the default configuration.

Throughout the AMV and Trajectory calculation, a verification is also 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 data, satellite and solar zenith angles and valid NWC/GEO-CT/CTTH/CMIC outputs (when used). 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 and Tracer characteristics. They are used one after the other in two different tracer selection strategies throughout the region: the 'single scale procedure' (when one scale of tracers is calculated), and the 'two scale procedure' (when two different scales of tracers are calculated: "basic" and "detailed", being the line and element size of the "detailed tracers" half the size 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 v7.0 default configuration, the distance between starting locations for tracers related to high level cloudy tracers is three times wider than for other cloud types for MTG-I satellite series, and four times wider for the rest of satellite series, to maximize the amount of AMVs related to the rest of tracer types (defined with configurable parameters HIGHERDENSITY_LOWTRACERS/HIGHERDENSITY_LOWTRACERS_DET = 3 for MTG-I and 4 for all other satellite series). With this change the proportion of medium+low level AMVs increases for all satellites, such as requested by NWC/GEO users for a better characterization of all troposphere levels in which AMVs are calculated.

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). 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' with configurable parameter CDET=1. A specific region can also 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, 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. 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".

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 of 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 $LP_{ij}= \Sigma\Sigma(T-S)^2$ 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 $CC_{ij}=Cov_{TS}/(\sigma_T \cdot \sigma_S)$ 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 Cross correlation CC_{ij}.

To increase the speed of NWC/GEO-HRW, the 'tracking area centre' can be located at the position of the tracer which is forecast for the later image by the NWP wind, with configurable parameter WIND_GUESS = 1. However, NWC/GEO-HRW is optimized not to use this in general as default option, to reduce the dependence of the algorithm from the NWP model.

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 the one of the NWP wind guess that the 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 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 configurable parameter USE_SUBPIXELTRACKING = 1.

For this calculation, in NWC/GEO-HRW v7.0, 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 NWC/GEO-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 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, 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. None of these options are included now in the default configuration; now, when the last circumstance occurs, 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 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. For visible channels, IR105 brightness temperature is used for MTG-I satellite, IR108 brightness temperature is used for MSG satellite, and IR112 brightness temperature is used for Himawari-8/9 and GOES-R satellites. 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 for the image in 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 $^{3}/_{2}$ 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'.

MTG-I channels	VIS06	VIS08			WV63		WV73	IR105	IR123
MSG channels		HRVIS	VIS06	VIS08	WV62		WV73	IR108	IR120
Himawari-8/9 channels	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 level cumulus/stratus	**Base**	**Base**	**Base**	**Base**			**Base**	**Base**	**Base**
6 Low level cumulus/stratus	**Base**	**Base**	**Base**	**Base**			**Base**	**Base**	**Base**
7 Medium level cumulus/stratus	**Base**	**Base**	**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**	**Top**
12 High semitransp. meanly thick clouds	**Top**	**Top**			**Top**	**Top**	**Top**	**Top**	**Top**
13 High semitransp. thick clouds	**Base**	**Base**			**Base**	**Base**	**Base**	**Base**	**Base**
14 High semitransp. above other clouds					**Base**	**Base**	**Base**	**Top**	**Top**
15 High semitransp. above snow/ice					**Base**	**Base**	**Base**	**Top**	**Top**
21 Multiple cloud types	**Base**	**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**	**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 NWC/GEO-HRW product. If these outputs are not available, "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 executable for the Cloud pressure calculation, which are common methods used by other AMV producers, including:

- Opaque cloud top pressure retrieval considering Infrared Window channels, with simulation of radiances with RTTOV, and ability of thermal inversion processing.
- Semitransparent cloud top pressure retrieval with the Radiance ratioing technique and the Water vapour/infrared window intercept method, considering water vapour and carbon dioxide 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}) for 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': $CC_{ij} = (T_{ij} - T_M)\cdot(S_{ij} - S_M) / NUM\cdot\sigma_T.\sigma_S$.

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

- In the 'Cloudy AMVs', a 'CCC pressure P_{CCC}' value is calculated for each 'tracking centre' considering the partial contribution to the correlation (CC_{ij}) and the NWC/GEO-CTTH Cloud top pressure (CTPij) with formula $P_{CCC}=\Sigma(CC_{ij}\cdot CTP_{ij})/\Sigma CC_{ij}$. 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 last one only in the case of use of the 'parallax correction'). The 'CCC cloud type CT_{CCC}' value is calculated as the one with the highest total contribution to the correlation.

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

  Here it is clear that 'CCC method' offers a direct correspondence between the pressure levels given for NWC/GEO-HRW Cloudy AMVs and Trajectories, and those given to the Cloud tops by NWC/GEO-CTTH output. It also defines a clear correspondence between the elements considered for the pressure level calculation, and the real 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]), suggested 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 NWC/GEO-CMIC liquid/ice water path variables (LWP/IWP), 'CCC liquid/ice water path values (LWP_{CCC}/IWP_{CCC})' are obtained with similar formulae to the previous ones used for 'CCC pressure P_{CCC}', and corrections in the 'CCC pressure P_{CCC}' are defined considering empiric functions based on these LWP_{CCC}/IWP_{CCC} values. The empiric functions were defined using 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 function has been used for Himawari-8/9, GOES-R and MTG-I satellite series. The functions are available in the "Algorithm Theoretical Basic Document for the Wind product processor of the NWC/GEO (MTG-I day-1)" [AD.7].

The corrections cause an improvement in all Validation parameters, and are implemented as default option with all satellite series with configurable parameter USE_MICROPHYSICS = 2. 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).

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

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

2.2.6 Postprocessing: Quality control and Choice of the best wind

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

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

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 into NWC/GEO-HRW, 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, since 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 location (mainly due to the Microphysics correction of the 'AMV pressure' value).*
- *Ind_topo=2: Very important orographic influence found in the current AMV location.*
- *Ind_topo=3: Important orographic influence found in the current AMV location.*
- *Ind_topo=6: No orographic influence found in the current AMV location.*

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 location of the AMV.
- Ind_topo = 5: Important orographic influence found at a previous location of the AMV.
- Ind_topo = 6: No orographic influence is found in any current or previous location 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 (MTG-I day-1)" [AD.7].

2.2.8 Postprocessing: Autovalidation of NWC/GEO-HRW

Considering requests from NWCSAF users, NWC/GEO-HRW offers the option to calculate validation statistics for the AMVs with the executable itself (using as reference NWP analysis or forecast rectangular components of the wind, 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.

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, VIS08,IR105,IR108,IR112,IR120,IR123,WV062,WV063,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:

```
yyyymmddThhmmssZ  GEO-HRW  7.0  XXXXX  [S]  HRWDATE:YYYYMMDDTHHMMSSZ
HRWCONF:FFFFF.CFM  NWPCONF:GGG  ***  AMV:BBBTTTTT  CH:CCCCC  LAYER:LLL
*** NC:RRRRRR SPD[M/S]:SSS.SS NBIAS:±T.TTT NMVD:U.UUU NRMSVD:V.VVV
```

The 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 AMVs.

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

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

- 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 with 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 [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 wind 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. The NWP forecast wind is used as default option for all running slots with NWPVAL_ANALYSIS = 0.

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

One file for the single AMV scale, or two different files for the 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-HRW v7.0, 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:

Considering BUFR outputs:

1. OUTPUT_FORMAT = NWC (included in the default configuration): NWC/GEO-HRW output defined as two different types of BUFR bulletins for AMVs and Trajectories, related to the ones used as default option in all previous versions of NWC/GEO-HRW.
2. OUTPUT_FORMAT = IWWG (not included in the default configuration): NWC/GEO-HRW output defined as one BUFR bulletin for AMVs, whose format has been defined in 2018 by the "International Winds Working Group". This option permits NWCSAF users to have a similar processing for the NWC/GEO-HRW outputs and for the AMV outputs from other AMV processing centres of the world.

Considering netCDF outputs:

3. OUTPUT_FORMAT = NCF (included in the default configuration): NWC/GEO-HRW output defined as one netCDF bulletin for AMVs. The structure of this NWC/GEO-HRW netCDF output has changed with respect to the one defined in the previous version NWC/GEO-HRW v6.2, now being "CF compliant" and easier to process (following recommendations from NWCSAF users).
4. OUTPUT_FORMAT = NCT (included in the default configuration): NWC/GEO-HRW output defined as one netCDF bulletin for Trajectories. This NWC/GEO-HRW netCDF Trajectory output is new since this version NWC/GEO-HRW v7.0, being "CF compliant" and making netCDF Trajectories easier to process (following recommendations from NWCSAF users).

Additionally to these types of outputs, NWC/GEO-HRW creates three different types of temporal files in `$SAFNWC/tmp/HRW` directory, which contain tracer/predecessor wind/trajectory information that will be used as input for the processing of NWC/GEO-HRW product in the following NWC/GEO-HRW slot, and also in the processing of NWC/GEO Convection and Extrapolation products in the same 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 `<satid>` is the satellite used for the AMV calculation, `<bandid>` is the satellite channel used for the AMV calculation (with values HRVIS/VIS06/VIS08/WV062/WV063/WV069/WV070/WV073/WV074/IR105/IR108/IR112/IR120/IR123), `<regionid>` is the region used for the AMV calculation, and `YYYYMMDDThhmmssZ` is the nominal date and time for the corresponding slot. These files are not expected to be used by the NWCSAF users.

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

When OUTPUT_FORMAT = NWC, an AMV BUFR bulletin related to the ones used as default option in all previous versions of NWC/GEO-HRW 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`. This option is included in the default configuration.

With configurable parameter USE_PARALLAXCORRECTION = 2, the output file name finishes instead with format `*YYYYMMDDThhmmssZ_PLAX.bufr` to 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 later image used for the AMV calculation.

This BUFR bulletin is exactly equivalent to the one defined in the previous NWC/GEO-HRW v6.2 version, although in NWC/GEO-HRW v7.0 version ECCODES library is used instead of BUFRDC library for the writing of the BUFR output file, such as recommended by ECMWF.

The BUFR variables used for the writing of the AMVs considering this format are explained in *Table 6*. These variables are partially based on BUFR Master Table number 0, Version number 31.

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

Formally, several different BUFR messages, each one with up to 1000 AMVs for the same satellite channel, 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	0	0	18
002029	SEGMENT SIZE AT NADIR IN Y DIRECTION	M	0	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	3
060103	HEIGHT ASSIGNMENT METHOD	CODE TABLE 60103	0	0	5
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 (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

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

Descriptor	Description
060201	Correlation test. Possible values: 0: 'Wind not selected as the Best wind for a tracer not having the Best correlation value' 1: 'Wind not selected as the Best wind for a tracer having the Best correlation value' 2: 'Wind selected as the Best wind for a tracer not having the Best correlation value' 3: 'Wind selected as the Best wind for a tracer having the Best correlation value'.
060202	Applied Quality tests: For each one the next Quality flags (Orographic flag, Forecast quality flag, Spatial quality flag, Temporal quality flag, Interscale quality flag), next possible values: 0: 'Wind for which the corresponding quality test could not be calculated' 1: 'Wind whose corresponding quality test is at least a 21% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is at least two units lower than for the wind calculated for the same tracer with the best orographic flag)' 2: 'Wind whose corresponding quality test is up to a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the wind calculated for the same tracer with the best orographic flag)' 3: 'Wind with the best corresponding quality test among the winds calculated for a tracer'.
060205	Orographic index Possible values: The values of this parameter are between 0 and 6, corresponding to those defined for "Ind_topo" parameter in chapter 2.2.7 of this document.
060206	Cloud type associated to the tracer Possible values: The values of this parameter are between 0 and 23, corresponding to those defined in *Table 5* of this document.
060207	Flag indicating the satellite channel used for the wind calculation (Updated table for NWC/GEO-HRW v7.0). Possible values: 2: MTG-I/VIS06 or MSG/VIS06 or Himawari-8/9 VIS06 or GOES-R VIS06 3: MTG-I/VIS08 or MSG/VIS08 or Himawari-8/9 VIS08 or GOES-R VIS08 5: MSG/HRVIS 10: MTG-I/WV063 or MSG/WV062 or Himawari-8/9 WV062 or GOES-R WV062 11: Himawari-8/9 WV069 or GOES-R WV070 12: MTG-I/WV073 or MSG/WV073 or Himawari-8/9 WV073 or GOES-R WV074 16: MTG-I/IR105 or MSG/IR108 or Himawari-8/9 IR112 or GOES-R IR112 17: MTG-I/IR123 or MSG/IR120
060220	Validation against NWP analysis or forecast. Possible values: 0: NWC/GEO-HRW autovalidation statistics against "NWP model analysis". 1: NWC/GEO-HRW autovalidation statistics against "NWP model forecast". 3: NWC/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 bulletin 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. This option is included in the default configuration.

With configurable parameter USE_PARALLAXCORRECTION = 2, the output file name finishes instead with format `*YYYYMMDDThhmmssZ_PLAX.bufr` to 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 `YYYYMMDDThhmmssZ` is the date and time of the final image used for the Trajectory calculation.

This BUFR bulletin is exactly equivalent to the one defined in the previous NWC/GEO-HRW v6.2 version, although in NWC/GEO-HRW v7.0 version ECCODES library is used instead of BUFRDC library for the writing of the BUFR output file, such as recommended by ECMWF.

The BUFR variables used for the writing of the Trajectories considering this format are explained in *Table 8*. These variables are also partially based on BUFR Master Table number 0, Version number 31. The explanation of the "general variables" and "local variables" used for the writing of the Trajectory BUFR output is equivalent to the one for the AMV BUFR output in the previous chapter.

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

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

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
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 (NUMBER OF REPLICATIONS = SEGMENTS IN THE 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	5
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 bulletin 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. This option is not included in the default configuration.

With configurable parameter USE_PARALLAXCORRECTION = 2, the output file name finishes instead with format `*YYYYMMDDThhmmssZ_PLAX.bufr` to 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 of the later image used for the AMV calculation.

This BUFR bulletin is exactly equivalent to the one defined in the previous NWC/GEO-HRW v6.2 version, although in NWC/GEO-HRW v7.0 version ECCODES library is used instead of BUFRDC library for the writing of the BUFR output file, such as recommended by ECMWF.

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

Formally, several different BUFR messages, each one with up to 100 AMVs related to the same satellite channel, are included in this AMV BUFR output file.

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. The variables are fully based on BUFR Master Table number 0, Version number 31. The AMV output corresponds exactly to "Sequence 310077 – satellite derived winds" included in the corresponding "sequence table".

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 AMV to be used, and up to the four latest AMVs in corresponding NWC/GEO-HRW trajectory which were used for the AMV calculation when "mixed calculation method" is used.

It has the advantage of including 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. This format became besides in the latest years the reference format for AMVs coming from all AMV production centres.

Descriptor	Name	Units
PROCESSING INFORMATION		
001033	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR_SUPERCENTRE_OR)	CODE TABLE 01033
001034	IDENTIFICATION OF ORIGINATING/GENERATING SUBCENTRE (configurable parameter BUFR_CENTRE_OR)	CODE TABLE 01034
025061	SOFTWARE IDENTIFICATION AND VERSION NUMBER ("NWC/HRW V7.0")	CCITTIA5
025062	DATABASE IDENTIFICATION (not used)	NUMERIC
SATELLITE INSTRUMENT IDENTIFICATION		
001007	SATELLITE IDENTIFIER	CODE TABLE 01007
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz
001012	DIRECTION OF MOTION OF MOVING OBSERVING PLATFORM (not used)	DEGREE
201138	CHANGE DATA WIDTH (22 BITS PER PARAMETER)	-
002026	CROSS-TRACK RESOLUTION (not used)	M
002027	ALONG-TRACK RESOLUTION (not used)	M
201000	CHANGE DATA WIDTH (CANCEL)	-
METHODS		
002028	SEGMENT SIZE AT NADIR IN X-DIRECTION (up to a limit of 262140 m)	M
002029	SEGMENT SIZE AT NADIR IN Y-DIRECTION (up to a limit of 262140 m)	M
002161	WIND PROCESSING METHOD	FLAG TABLE 02161
002164	TRACER PROCESSING METHOD	CODE TABLE 02164
002023	SATELLITE-DERIVED WIND COMPUTATION METHOD	CODE TABLE 02023
008012	LAND/SEA QUALIFIER (not used)	CODE TABLE 08012
008013	DAY/NIGHT QUALIFIER (not used)	CODE TABLE 08013
FINAL AMV DATA		
001124	GRID POINT IDENTIFIER (not used)	NUMERIC
005001	LATITUDE (HIGH ACCURACY)	DEGREE
006001	LONGITUDE (HIGH ACCURACY)	DEGREE
004001	YEAR	YEAR
004002	MONTH	MONTH
004003	DAY	DAY
004004	HOUR	HOUR
004005	MINUTE	MINUTE
004006	SECOND	SECOND
004086	LONG TIME PERIOD OR DISPLACEMENT (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 (2 = BEST FIT LEVEL)	FLAG TABLE 08086
007004	PRESSURE (for NWP data at AMV best fit level, if calculated)	PA
011095	U-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
011096	V-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
008086	VERTICAL SIGNIFICANCE FOR NWP (4095 = CANCEL)	CODE TABLE 08086

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

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

2.3.4. HRW output as netCDF bulletin (AMVs)

When OUTPUT_FORMAT = NCF, an AMV 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. This option is included in the default configuration.

With configurable parameter USE_PARALLAXCORRECTION = 2, the output file name finishes instead with format *YYYYMMDDThhmmssZ_PLAX.nc to 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 of the later image used for the AMV calculation.

As already said, the structure of this NWC/GEO-HRW netCDF AMV output has changed with respect to the one defined in the previous version NWC/GEO-HRW v6.2, now being "CF compliant" and easier to process (following recommendations from the NWCSAF users).

The structure of the netCDF AMV output variables and dimensions is shown in *Table 10*. The structure of the netCDF output attributes is shown in *Table 11*. Each AMV is defined as a "set of 41 variables" which describe together all characteristics of the AMV. The equivalence with the variables used for the AMVs in the "BUFR bulletin with NWCSAF specific format" (in chapter 2.3.1), the "Valid range" for each variable and the "Fill value" for each variable are also included in *Table 10*.

The netCDF output includes two dimensions, also shown in *Table 10*:

- Time: defined as "seconds since 01-01-1970" for the corresponding slot.
- Observations: total number of AMVs included in the netCDF output.

Parameter types	*"NWC BUFR Equivalence" – [Valid Range] – Fill Value*
Variables:	
double time(time)	// *** (Seconds since 1/JAN/1970) – [1.0-2147483646.0] – 0.0
uint wind_id(observations)	// 060100 WIND SEQUENCE NUMBER – [0-16777214] – 16777215
uint wind_prev_id(observations)	// 060101 PRIOR WIND SEQUENCE NUMBER – [0-16777214] – 16777215
ubyte number_of_winds(observations)	// 060200 NUMBER OF WINDS COMPUTER FOR THE TRACER – [0-3] – 7
ubyte correlation_test(observations)	// 060201 CORRELATION TEST – [0-3] – 7
ushort quality_test(observations)	// 060202 APPLIED QUALITY TESTS – [0-1024] – 2047
uint segment_x(observations)	// 002028 SEGMENT SIZE IN X DIRECTION (M) – [0-262140] – 262143
uint segment_y(observations)	// 002029 SEGMENT SIZE IN Y DIRECTION (M) – [0-262140] – 262143
ubyte segment_x_pix(observations)	// 060000 SEGMENT SIZE IN X DIRECTION (PIX) – [0-126] – 127
ubyte segment_y_pix(observations)	// 060001 SEGMENT SIZE IN Y DIRECTION (PIX) – [0-126] – 127
double lat(observations) (STANDARD NAME: latitude)	// 005001 LATITUDE – [-90.0-+90.0] – +245.0
double lon(observations) (STANDARD NAME: longitude)	// 006001 LONGITUDE – [-180.0-+179.99999] – +491.0
double latitude_increment(observations)	// 005001 LATITUDE INCREMENT – [-90.0-+90.0] – +245.0
double longitude_increment(observations)	// 006011 LONGITUDE INCREMENT – [-180.0-+179.99999] – +491.0
double air_temperature(observations)	// 012001 TEMPERATURE – [0.0-409.4] – 409.5
double air_pressure(observations)	// 007004 PRESSURE – [0.0-163829.0] – 163830.0
double air_pressure_error(observations)	// 007004 PRESSURE ERROR – [-80000.0-+80000.0] – +83830.0
double air_pressure_correction(observations)	// 007004 PRESSURE CORRECTION – [-80000.0-+80000.0] – +83830.0
double air_pressure_nwp_at_best_fit_level(observations)	// 060215 NWP WIND BEST FIT LEVEL – [0-163829.0] – 163830.0
double barometric_altitude_in_hectofeet(observations)	// *** – [-40.0-1030.0] – 2047.0
double wind_speed(observations)	// 011002 WIND SPEED – [0.0-409.4] – 409.5
double wind_from_direction(observations)	// 011001 WIND DIRECTION – [0.0-359.99999] – 511.0
double wind_speed_nwp_at_amv_level(observations)	// 060211 NWP WIND SPEED (AT AMV LEVEL) – [0.0-409.4] – 409.5
double wind_from_direction_nwp_at_amv_level(observations)	// 060212 NWP WIND DIRECTION (AT AMV LEVEL) – [0.0-359.99999] – 511.0
double wind_speed_nwp_at_best_fit_level(observations)	// 060213 NWP WIND SPEED (AT BEST FIT LEVEL) – [0.0-409.4] – 409.5
double wind_from_direction_nwp_at_best_fit_level (observations)	// 060214 NWP WIND DIRECTION (AT BEST FIT LEVEL) – [0.0-359.99999] – 511.0
double wind_speed_difference_nwp_at_amv_level(observations)	// 060216 DIR. DIFF. WITH NWP (AT AMV LEVEL) – [0.0-409.4] – 409.5
double wind_from_direction_difference_nwp_at_amv_level (observations)	// 060217 SPD. DIFF. WITH NWP (AT AMV LEVEL) – [0.0-359.99999] – 511.0
double wind_speed_difference_nwp_at_best_fit_level (observations)	// 060218 DIR. DIFF. WITH NWP (BEST FIT LEVEL) – [0.0-409.4] – 409.5
double wind_from_direction_difference_nwp_at_best_fit_level (observations)	// 060219 SPD. DIFF. WITH NWP (BEST FIT LEVEL) – [0.0-359.99999] – 511.0
ubyte quality_index_with_forecast(observations)	// 033007 PER CENT CONFIDENCE (WITH FORECAST) – [0-100] – 127
ubyte quality_index_without_forecast(observations)	// 033007 PER CENT CONFIDENCE (WITHOUT FORECAST) – [0-100] – 127
ubyte quality_index_iwwg_value(observations)	// 033007 PER CENT CONFIDENCE (IWWG VALUE) – [0-100] – 127
ubyte tracer_correlation_method(observations)	// 002164 TRACER CORRELATION METHOD – [0-2] – 7
ubyte tracer_type(observations)	// 060104 TRACER TYPE – [0-3] – 7
ubyte height_assignment_method(observations)	// 060103 HEIGHT ASSIGNMENT METHOD – [0-15] – 31
ubyte orographic_index(observations)	// 060205 OROGRAPHIC INDEX – [0-6] – 7
ubyte cloud_type(observations)	// 060206 CLOUD TYPE – [1-23] – 255
ubyte correlation(observations)	// 060208 CORRELATION – [0-100] – 127
ubyte number_of_trajectory_points(observations)	// *** (Number of trajectory segments + 1) – [0-25] – 31
ubyte satellite_channel(observations)	// 060207 AMV CHANNEL – [0-18] – 31
Dimensions:	
double time	// *** (Seconds since 1/JAN/1970) – [1.0-2147483646.0] – 0.0
uint observations	// *** (Total Number of AMVs) – [0-16777214] – 16777215

Table 10: Specification of the NWC/GEO-HRW netCDF AMV output variables and dimensions

Attribute name	*Value*
Conventions	CF-1.7
cdm_data_type	Bulletin
centre_projection_longitude	➔ Corresponding satellite "centre projection longitude"
comment	➔ Copyright "year", EUMETSAT, All Rights reserved
contact	safnwchd@aemet.es
creator_email	➔ Corresponding "institution email"
creator_name	➔ Corresponding "institution"
creator_url	➔ Corresponding "institution web page"
date_created	➔ Corresponding "date/time string" of creation of NWC/GEO-HRW netCDF file
featureType	point
first_guess	Medium range forecast model
history	➔ "creation date" "creation user" Product created by NWC/GEO vMTG "creation date" "creation user" "creation script"
id	➔ Corresponding NWC/GEO-HRW netCDF file name
input_ct	➔ Corresponding NWC/GEO-CT file name used by HRW
input_ctth	➔ Corresponding NWC/GEO-CTTH file name used by HRW
input_cmic	➔ Corresponding NWC/GEO-CMIC file name used by HRW
institution	➔ Corresponding "institution"
keywords	Atmospheric Motion Vectors or Trajectories, Satellite winds or trajectories
keywords_vocabulary	GCMD Science Keywords
license	EUMETSAT user policy
long_name	NWC/GEO High Resolution Winds
manual_automatic_quality_control	Automatic Quality Control passed and not manually checked
naming_authority	➔ Corresponding "institution"
nominal_product_time	➔ Corresponding slot "nominal product time"
number_of_nwp_wind_levels	➔ Corresponding NWP model "number of NWP wind levels"
orbit_number_later_image	0
orbit_number_initial_image	0
platform_later_image	(Not used)
platform_initial_image	(Not used)
processing_level	Level 2
product_algorithm_version	7.0
product_completeness	➔ Corresponding "percentage of AMVs" written in the netCDF output, with respect to the theoretical value of AMVs defined by the algorithm at all preliminary locations. The parameter gives an idea of how many AMVs were successfully calculated, defined as a percentage value (from 0% to 100%).
product_name	HRW
product_quality	➔ Corresponding "mean Quality index" (with/without forecast, depending on the value of configurable parameter QI_THRESHOLD_USEFORECAST), of all AMVs written in the netCDF output file. This parameter gives an idea of the mean quality of all AMVs, defined as a percentage value (from 0% to 100%).
project	NWC/GEO
references	http://nwc-saf.eumetsat.int
region_id	➔ Corresponding "region id" (f.ex. Europe)
region_name	➔ Corresponding "region name" (f.ex. Europe)
saf	NWC/GEO
sampling_interval	➔ Corresponding "time difference in minutes between initial and final image"
satellite_cycle_initial_image	➔ Corresponding "satellite cycle of initial image"
satellite_cycle_later_image	➔ Corresponding "satellite cycle of later image"
satellite_identifier	➔ Corresponding "satellite identifier"

source	NWC/GEO version vMTG
spatial_resolution	➔ Corresponding satellite "low resolution pixel size" in km.
sub-satellite_longitude	➔ Corresponding satellite "subsatellite longitude"
summary	High Resolution Winds Product of the NWC/GEO. Detailed sets of Atmospheric Motion Vectors or Trajectories throughout all hours of the day, considering visible, infrared and water vapour channel data
time_coverage_end	➔ Corresponding "date/time string" for coverage end of later image
time_coverage_end_ initial_image	➔ Corresponding "date/time string" for coverage end of initial image
time_coverage_start	➔ Corresponding "date/time string" for coverage start of later image
time_coverage_start_ initial_image	➔ Corresponding "date/time string" for coverage start of initial image
title	NWC/GEO-High Resolution Winds Product
validation_ nwp_forecast_or_analysis	➔ NWP analysis / NWP forecast / ""
wind_computation_method	Wind derived from motion observed in VIS/IR/WV channels

Table 11: Specification of the NWC/GEO-HRW netCDF AMV output attributes

2.3.5. HRW output as netCDF bulletin (Trajectories)

When OUTPUT_FORMAT = NCT, a Trajectory netCDF output bulletin is written under the name `S_NWC_HRW-TRAJ_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.nc` (for the "Single or Basic scale"), or `S_NWC_HRW-TRAJ_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.nc` (for the "Detailed scale") in `$SAFNWC/export/HRW` directory. This option is included in the default configuration.

With configurable parameter USE_PARALLAXCORRECTION = 2, the output file name finishes instead with format `*YYYYMMDDThhmmssZ_PLAX.nc` to 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 `YYYYMMDDThhmmssZ` is the date and time of the final image used for the Trajectory calculation.

This NWC/GEO-HRW netCDF Trajectory output is new since this version NWC/GEO-HRW v7.0, being "CF compliant" and making netCDF Trajectories easier to process (following recommendations from NWCSAF users).

The structure of the netCDF Trajectory output variables and dimensions is shown in *Table 12*. The structure of the netCDF output attributes is shown in *Table 13*. Each trajectory is defined as a "set of 22 variables" which describe together all characteristics of the trajectory. The equivalence with the variables used for the trajectories in the "BUFR bulletin with NWCSAF specific format" (in chapter 2.3.2), the "Valid range" for each variable and the "Fill value" for each variable are also included in *Table 12*.

The netCDF output includes three dimensions, also shown in *Table 12*:

- Time: defined as "seconds since 01-01-1970" for the corresponding slot.
- Trajectory: total number of Trajectories included in the netCDF output
- Observations: total number of Trajectory points included per Trajectory in the netCDF output.

To be "CF compliant", trajectories in this netCDF output file have to be defined as "trajectory points". Comparing with the "GEO-HRW Trajectory BUFR with NWCSAF specific format" in chapter 2.3.2, where the trajectories are defined as sets of "n trajectory segments", here trajectories are defined as sets of "n+1 trajectory points", in which the initial point has only values for obs_time/lat/lon variables (related to the position of the tracer in the initial image of the trajectory), and all other points have values for all variables (where variables for "i+1 trajectory point" are related to those for "i trajectory segment" in the "GEO-HRW Trajectory BUFR with NWCSAF specific format").

Additionally, all trajectories in this netCDF output file need to have a fixed length to be "CF compliant", while NWC/GEO-HRW Trajectories can have variable lengths. Due to this, NWC/GEO-HRW trajectories with the whole length have obs_time/lat/lon values for all points in the trajectory, while shorter NWC/GEO-HRW trajectories leave empty the initial points, and fill all later points until the last one, which needs to be filled for all trajectories in the netCDF output.

Parameter types	"NWC BUFR Equivalence" – [Valid Range] – Fill Value
Variables:	
double time(time)	// *** (Seconds since 1/JAN/1970) – [1.0-2147483646.0] – 0.0
ubyte number_of_trajectory_points(trajectory)	// *** (Number of trajectory segments + 1) – [0-25] – 31
ubyte satellite_channel(trajectory)	// 060207 AMV CHANNEL – [0-18] – 31
double obs_time(trajectory,observations)	// *** (Seconds since 1/JAN/1970 for the point) – [1.0-2147483646.0] – 0.0
double lat(trajectory,observations) (STANDARD NAME: latitude)	// 005001 LATITUDE – [-90.0-+90.0] – +245.0
double lon(trajectory,observations) (STANDARD NAME: longitude)	// 006001 LONGITUDE – [-180.0-+179.99999] – +491.0
double air_temperature(trajectory,observations)	// 012001 TEMPERATURE – [0.0-409.4] – 409.5
double air_pressure(trajectory,observations)	// 007004 PRESSURE – [0.0-163829.0] – 163830.0
double air_pressure_error(trajectory,observations)	// 007004 PRESSURE ERROR – [-80000.0-+80000.0] – +83830.0
double air_pressure_correction(trajectory,observations)	// 007004 PRESSURE CORRECTION – [-80000.0-+80000.0] – +83830.0
double barometric_altitude_in_hectofeet (trajectory,observations)	// *** – [-40.0-1030.0] – 2047.0
double wind_speed(trajectory,observations)	// 011002 WIND SPEED – [0.0-409.4] – 409.5
double wind_from_direction(trajectory,observations)	// 011001 WIND DIRECTION – [0.0-359.99999] – 511.0
ubyte quality_index_with_forecast(trajectory,observations)	// 033007 PER CENT CONFIDENCE (WITH FORECAST) – [0-100] – 127
ubyte quality_index_without_forecast (trajectory,observations)	// 033007 PER CENT CONFIDENCE (WITHOUT FORECAST) – [0-100] – 127
ubyte quality_index_iwwg_value(trajectory,observations)	// 033007 PER CENT CONFIDENCE (IWWG VALUE) – [0-100] – 127
ubyte tracer_correlation_method(trajectory,observations)	// 002164 TRACER CORRELATION METHOD – [0-2] – 7
ubyte tracer_type(trajectory,observations)	// 060104 TRACER TYPE – [0-3] – 7
ubyte height_assignment_method(trajectory,observations)	// 060103 HEIGHT ASSIGNMENT METHOD – [0-15] – 31
ubyte orographic_index(trajectory,observations)	// 060205 OROGRAPHIC INDEX – [0-6] – 7
ubyte cloud_type(trajectory,observations)	// 060206 CLOUD TYPE – [1-23] – 255
ubyte correlation(trajectory,observations)	// 060208 CORRELATION – [0-100] – 127
Dimensions:	
double time	// *** (Seconds since 1/JAN/1970) – [1.0-2147483646.0] – 0.0
uint trajectory	// *** (Total Number of Trajectories) – [0-16777214] – 16777215
ubyte observations	// *** (Total Number of Trajectory points) – [0-25] – 31

Table 12: Specification of the NWC/GEO-HRW netCDF Trajectory output variables and dimensions

Attribute name	***Value***
Conventions	CF-1.7
cdm_data_type	Bulletin
centre_projection_longitude	➔ Corresponding satellite "centre projection longitude"
comment	➔ Copyright "year", EUMETSAT, All Rights reserved
contact	safnwchd@aemet.es
creator_email	➔ Corresponding "institution email"
creator_name	➔ Corresponding "institution"
creator_url	➔ Corresponding "institution web page"
date_created	➔ Corresponding "date/time string" of creation of NWC/GEO-HRW netCDF file
featureType	trajectory
first_guess	Medium range forecast model
history	➔ "creation date" "creation user" Product created by NWC/GEO vMTG "creation date" "creation user" "creation script"
id	➔ Corresponding NWC/GEO-HRW netCDF file name
institution	➔ Corresponding "institution"
keywords	Atmospheric Motion Vectors or Trajectories, Satellite winds or trajectories
keywords_vocabulary	GCMD Science Keywords
license	EUMETSAT user policy
long_name	NWC/GEO High Resolution Winds
manual_automatic_ quality_control	Automatic Quality Control passed and not manually checked
naming_authority	➔ Corresponding "institution"
nominal_product_time	➔ Corresponding slot "nominal product time"
number_of_nwp_wind_levels	➔ Corresponding NWP model "number of NWP wind levels"
processing_level	Level 2
product_algorithm_version	7.0
product_completeness	➔ Corresponding "percentage of Trajectories" written in the netCDF output file, with respect to the theoretical value defined by the algorithm at all preliminary locations. The parameter gives an idea of how many Trajectories were successfully calculated, defined as a percentage value (from 0% to 100%).
product_name	HRW
product_quality	➔ Corresponding "mean Quality index" (with/without forecast, depending on the value of configurable parameter QI_THRESHOLD_USEFORECAST), of all Trajectories written in the netCDF output file. This parameter gives an idea of the mean quality of all Trajectories, defined as a percentage value (from 0% to 100%).
project	NWC/GEO
references	http://nwc-saf.eumetsat.int
region_id	➔ Corresponding "region id" (f.ex. Europe)
region_name	➔ Corresponding "region name" (f.ex. Europe)
saf	NWC/GEO
sampling_interval	➔ Corresponding "time difference in minutes between images"
satellite_identifier	➔ Corresponding "satellite identifier"
source	NWC/GEO version vMTG
spatial_resolution	➔ Corresponding satellite "low resolution pixel size" in km
sub-satellite_longitude	➔ Corresponding satellite "subsatellite longitude"
summary	High Resolution Winds Product of the NWC/GEO. Detailed sets of Atmospheric Motion Vectors or Trajectories throughout all hours of the day, considering visible, infrared and water vapour channel data
time_coverage_end	➔ Corresponding "date/time string" for coverage end of final image
time_coverage_start	➔ Corresponding "date/time string" for coverage start of final image
title	NWC/GEO-High Resolution Winds Product
validation_ nwp_forecast_or_analysis	➔ NWP analysis / NWP forecast / ""
wind_computation_method	Wind derived from motion observed in VIS/IR/WV channels

Table 13: Specification of the NWC/GEO-HRW netCDF Trajectory output attributes

2.3.6. Output data filterings

Several output data filterings are additionally considered in this step, which depend on the value of several configurable parameters. These configurable parameters are:

- AMV_BANDS (default value VIS08,WV063,WV073,IR105 for MTG-I satellites; HRVIS,VIS06,WV062,WV073,IR108 for MSG 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. The calculation of VIS08 AMVs is preferred instead of VIS06 AMVs as default option due to the faster calculation process for Himawari-8/9 and GOES-R satellite series, and for coherence with these ones for MTG-I satellite series.
- QI_THRESHOLD: defines the "Quality index threshold" for the AMVs and Trajectories in the output files (with 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 (included in the default option with value = 1).
- MAXPRESSUREERROR: defines the maximum "AMV pressure error" 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" is used (default value = 80%).
- FINALFILTERING: defines several filterings in the AMVs/Trajectories, depending on its value:
  - With FINALFILTERING > 0, the "AMV pressure level" filtering defined in *Table 14* 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 eliminated with configurable parameter VERYLOWINFRAREDAMVS = 1, which is not implemented as default option).
  - With FINALFILTERING > 1 (which is the default option with FINAL_FILTERING = 2), the "AMV cloud type" filtering defined in *Table 5* 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.

MTG-I sat.	VIS06	VIS08			IR105	IR123	WV63		WV73
MSG sat.		HRVIS	VIS06	VIS08	IR108	IR120	WV62		
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 14: AMV filtering related to the Height level and each satellite channel

3. IMPLEMENTATION OF NWC/GEO-HRW

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-v70` file), to be stored into the `$SAFNWC/bin` directory.

3.2 NWC/GEO SOFTWARE 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-v70` with the required parameters (required image time, Region configuration file and Model configuration file) by the Task manager, in the following way:

```
GEO-HRW-v70 YYYYMMDDTHHMMSSZ file.cfg file.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. Four different reference NWC/GEO-HRW Model Configuration Files `safnwc_HRW.cfm` are defined as default option for operational use with MTG-I satellite series, MSG satellite series, Himawari-8/9 satellite series and GOES-R satellite series respectively. 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 and 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-v70` 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 7.0 <pid> [I] Process finished correctly
```

Figures 1 to 3 summarise how the tasks to generate the AMVs and Trajectories are performed by the `GEO-HRW-v70` executable:

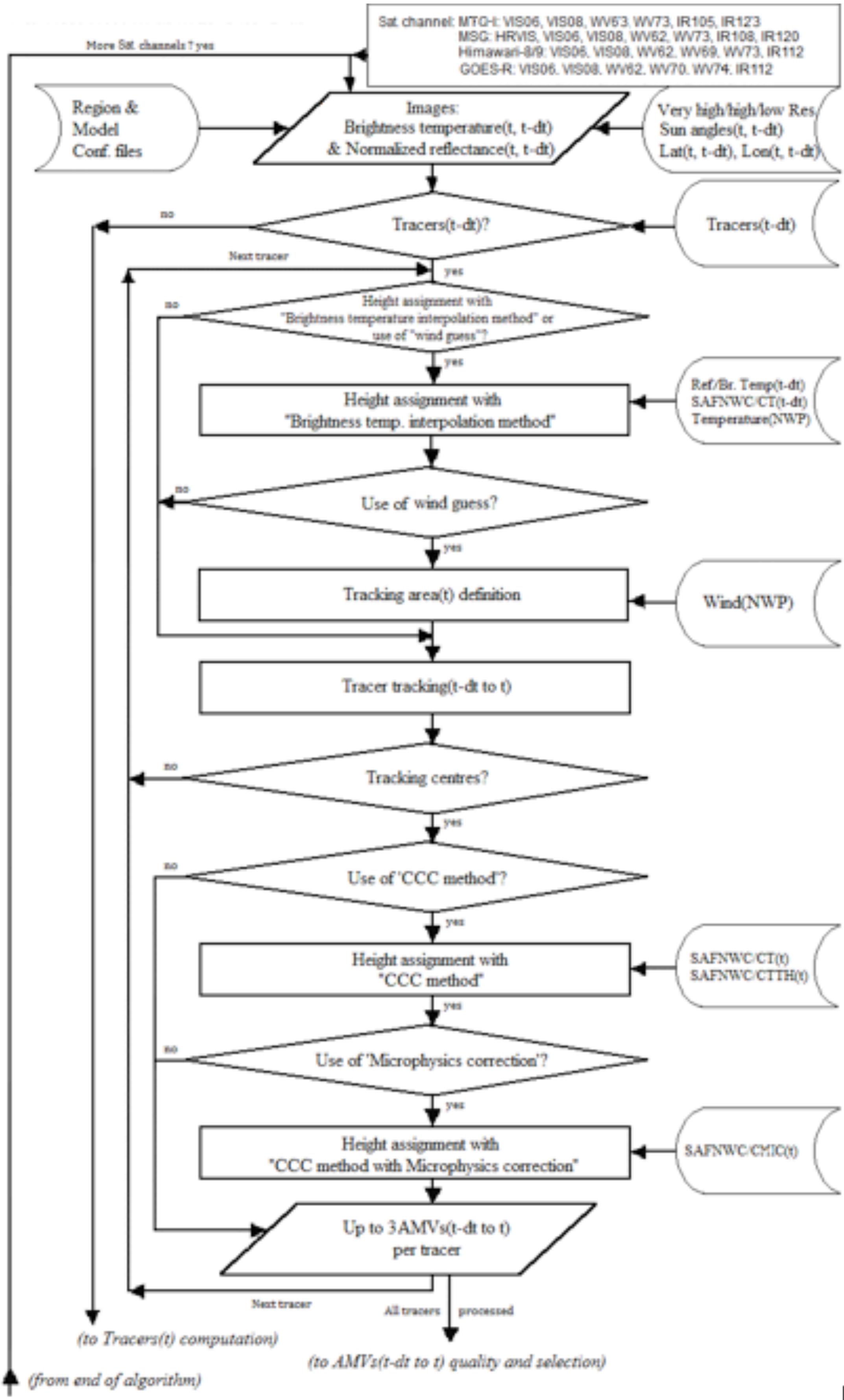

Figure 1: NWC/GEO-HRW implementation: Part 1, Preprocessing and AMV computation

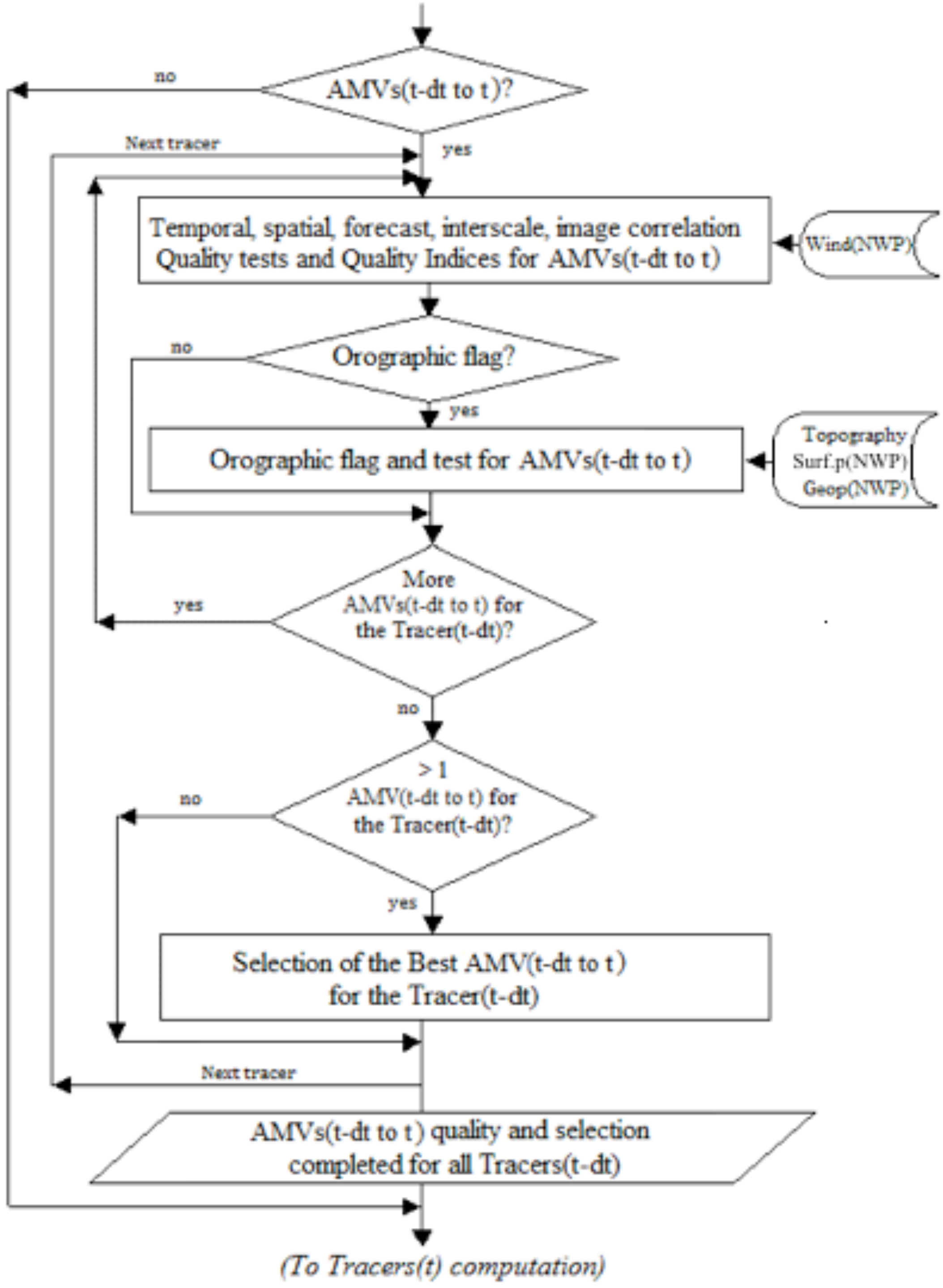

Figure 2: NWC/GEO-HRW implementation: Part 2, AMV quality and selection

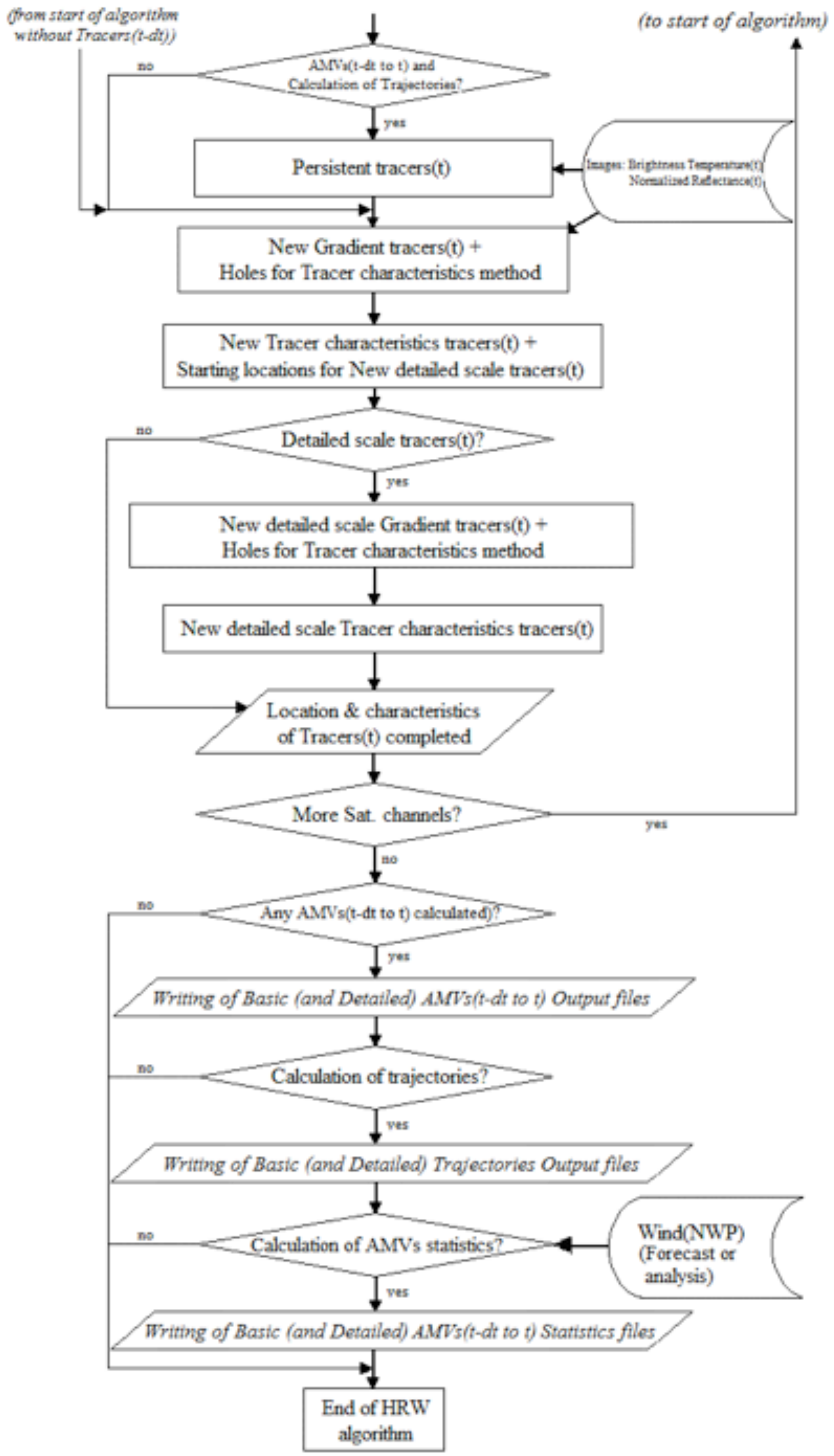

Figure 3: NWC/GEO-HRW implementation: Part 3, Tracer computation and writing of output

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 algorithms. Documentation for NWC/GEO-HRW is provided in the zipped file:

`NWC-CDOP2-MTG-AEMET-SW-ACDD-Wind_html_v1.3.0.zip`

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

`NWC-CDOP2-MTG-AEMET-SW-ACDD-Wind_html_v1.3.0/HRW_html/index.html`

Every single step throughout all functions of NWC/GEO-HRW 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, the main goal of all functions of NWC/GEO-HRW algorithms and their relationships is also provided in a Diagram Tree shown in the “Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO (MTG-I day-1)” 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 RUNNING ERRORS

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, the NWCSAF Helpdesk should be contacted.

Error	*Message*	*Reason*	*Recovery action*
E - 150	"Environment variable $*** has not been defined; Update for correct processing"	Some environment variable is undefined for correct processing	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 Quality Control Correlation matrix	
W- 157	"Satellite data for current/previous slot do not include valid values for any pixel"	Satellite data are not valid	Verify if there is any problem with the satellite data used by NWC/GEO-HRW
E - 158	"The defined satellite is not correct, or does not belong to MSG-1/2/3/4, MTG-I1, GOES-16/17/18/19 or HIMAWARI-08/09 series"	Satellite date are not related to a valid satellite series	Use NWC/GEO-HRW v7.0 with a correctly defined MTG-I1, MSG-1/2/3/4, GOES-16/17/18/19 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: YYYYMMDDT hhmmssZ"	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 NWP 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

Error	*Message*	*Reason*	*Recovery action*
E - 166	"Minimum NWP *** levels for calculation are larger than available NWP levels" or "NWP *** data cannot be read"	AMVs cannot be calculated because NWP data could not be read	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 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 satellite and sun angles matrices"	Error after hrw_GetAncillaryData function	All these errors are caused by the running of NWC/GEO-HRW executable, and cannot be solved by the NWCSAF user. Nevertheless, as a whole, they should occur in less than a 0.5% of the cases. If the frequency is higher, please contact NWCSAF Helpdesk.
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 previous slot"	Error after hrw_ReadTrajectories function	
E - 176	"Error during the AMV Tracking process"	Error after hrw_GetWinds function	
E - 177	"Error during the AMV Quality Control"	Error after hrw_Qc function	
E - 178	"Error writing Predecessor winds in NWCSAF tmp directory"	Error after hrw_WritePredWinds function	
E - 179	"Error writing Trajectories in NWCSAF tmp directory"	Error after hrw_WriteTrajectories function	
E - 180	"Error calculating tracers for current slot"	Error after hrw_GetTracers function	
E - 181	"Error writing tracers in NWCSAF tmp directory"	Error after hrw_WriteTracers function	
E - 182	"Error writing *** in the *** output file"	Error after hrw_Encode*** functions	
E - 183	"Error reading Cloud *** data"	Some output parameter from NWCSAF/Cloud products cannot be read	

Table 15: List of errors for NWC/GEO-HRW

4. INPUTS AND CONFIGURABLE PARAMETERS

4.1 INPUTS FOR HIGH RESOLUTION WINDS (NWC/GEO-HRW)

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

- Considering MTG-I satellite series: full resolution original FCI netCDF data for the processing region, for the images in which tracers are calculated and tracked. These data are to be located in `$SAFNWC/import/Sat_data` directory, and then have to be converted to NWC/GEO "netCDF satellite specific NWC/GEO input data format (FSD format)" with the provided `$SAFNWC/bin/start_nwcsdi` daemon. The output files from this conversion tool are located in `$SAFNWC/import/Sdi_data` directory. IR105 channel is in any case needed for the visible channel processing when the old "Brightness temperature interpolation height assignment" is to be used. IR105 and WV063 channels are in any case needed if the default configuration of the Quality control is kept (including the "Image correlation test").
- Considering MSG satellite series: full resolution uncompressed original HRIT data for the processing region, for the images in which tracers are calculated and tracked. These data are to be located in `$SAFNWC/import/Sat_data` directory. 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 Himawari-8/9 satellite series: full resolution original HSD data (HSD format), or low resolution 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 `$SAFNWC/import/Sat_data` directory, and then have to be converted to NWC/GEO "netCDF satellite specific NWC/GEO input data format (FSD format)" with the provided `$SAFNWC/bin/start_nwcsdi` daemon. The output files from this conversion tool are located in `$SAFNWC/import/Sdi_data` directory. IR112 channel is in any case needed for the visible channel processing when the old "Brightness temperature interpolation height assignment" is to be used. IR112 and WV062 channels are in any case needed if the default configuration of the Quality control is kept (including the "Image correlation test").
- Considering GOES-R satellite series: full resolution original netCDF data for the processing region, for the images in which tracers are calculated and tracked. The data have to be included in `$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 0.5º and a NWP time step of at most 6 hours (preferably with 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, 950, 925, 900, 850, 800, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10, 7, 5, 3, 2, 1 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.

The default number of levels in ECMWF NWP model has also been increased in this software version NWC/GEO v2025 (vMTG day-1) from 15 to 25 levels, because it has been verified that it has a positive effect in the NWC/GEO-Cloud product validation, and correspondingly, also in NWC/GEO-HRW AMV validation.

- 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 files for the processing region for the image in which tracers are tracked, in `$SAFNWC/export/CMIC` directory, in case the "microphysics correction" is used inside "CCC height assignment method".
- NWC/GEO-CT output file for the processing region for the image in which tracers are calculated, in `$SAFNWC/export/CT` directory, in case the "Brightness temperature interpolation height assignment with Cloud products" is used.

Of all these data, only satellite data (MTG-I/FCI/netCDF, MSG/HRIT, Himawari-8/9/HSD or Himawari-8/9/HRIT, or GOES-R/netCDF data), and the NWP temperature and NWP wind forecast profiles are formally needed for the running of NWC/GEO-HRW product. However, considering the default configuration defined for NWCSAF users, all items mentioned here except the NWC/GEO-CT output file for the processing region for the image in which tracers were calculated are mandatory so that the full process of NWC/GEO-HRW product can take 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 `$SAFNWC/config` directory, to be used such as explained in Chapter 4.2 of this document.
- The Satellite Configuration File `sat_conf_file` located in `$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.
- The Auxiliary data for NWC/GEO-HRW located in `$SAFNWC/import/Aux_data/HRW` directory.
- The Auxiliary data for the different geostationary satellites used, located in `$SAFNWC/import/Aux_data/Common` directory.

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

4.2 CONFIGURABLE PARAMETERS FOR HIGH RESOLUTION WINDS (NWC/GEO-HRW)

The High Resolution Winds Model configuration file holds the configurable parameters needed for the running of `GEO-HRW-v70` executable. It must be located in `$SAFNWC/config` directory. A brief description of the configurable parameters included in the file is shown in the following table. Four different reference NWC/GEO-HRW Model Configuration Files are defined as default option with the name `safnwc_HRW.cfm`, for operational use with MTG-I satellite series, MSG satellite series, Himawari-8/9 satellite series and GOES-R satellite series. Each of them is provided in the corresponding subdirectories inside `$SAFNWC/config` directory, related to each satellite series. 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).

Keyword	***Description***	***Type***	***Default Value(s)***
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	`VIS06,VIS08, IR105,IR123,WV063,WV073 (MTG-I)`
			`HRVIS,VIS06,VIS08, IR108,IR120,WV062,WV073 (MSG)`
			`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	`VIS08,IR105,WV063,WV073 (MTG-I)`
			`HRVIS,VIS06,IR108,WV062,WV073 (MSG)`
			`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	`GEO`
Output parameters			
BUFR_CENTRE_OR BUFR_SUPERCENTRE_OR	Originating subcentre and 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 values 214 mean Madrid).	Integer	`214` `214`
OUTPUT_FORMAT	A list of possible output file formats. Elements in the list separated by commas: - NWC: AMV & Trajectory BUFR files, using the specific NWCSAF format. - IWWG: AMV BUFR files, using the new IWWG BUFR format. - NCF: CF compliant AMV netCDF files. - NCT: CF compliant Trajectory netCDF files	Chain of characters	`NWC,NCF,NCT`

Output filtering parameters			
QI_THRESHOLD	Quality Index threshold for the AMVs.	Integer	75
QI_THRESHOLD_USEFORECAST	Option to define if the Quality index threshold used in the wind output filtering includes the Quality forecast test.	Integer	1
QI_IWWG_VALUE_CALCULATION	Option to define if the Common Quality Index is calculated.	Integer	1
QI_BEST_WIND_SELECTION	Criterion for Best wind selection (Values: 0/1, as defined in the ATBD document).	Integer	1
CLEARAIRWINDS	Flag to decide if Clear air AMVs calculated.	Integer	1
CALCULATE_TRAJECTORIES	Flag to decide if Trajectories calculated.	Integer	1
FINALFILTERING	Flag for a final filtering of AMVs based on: - Their Height level (if > 0), - Their Cloud type (if > 1), - Their Quality spatial test (1,2 as invalid values if > 2; 0,1,2 as invalid values if > 3).	Integer	2
USE_TOPO	Flag for calculation of Orographic flag (if positive), and for its AMV filtering (if = 2).	Integer	2
MAXPRESSUREERROR	Maximum pressure error in the AMVs (hPa), when 'CCC height assignment method' used.	Integer	150
VERYLOWINFRAREDAMVS	Flag showing if very low infrared AMVs (at levels lower than 900 hPa) are admitted in the AMV output files.	Integer	1
FINALCONTROLCHECK	Flag to decide the use of Final Control Check.	Integer	1
CORRELATIONMATRICES	This parameter is formally deactivated in NWC/GEO-HRW algorithm.	Integer	0
Working area description parameters			
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, VIS08 channels).	Integer	8
SUN_ZEN_THRES	Sun zenith angle threshold (degrees).	Integer	87
SAT_ZEN_THRES	Satellite zenith angle threshold (degrees).	Integer	80
Tracer parameters			
USE_OLDERSLOT_FORTRACERS	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	500000
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 low level/medium level/clear air tracers (if > 1).	Integer	18 (HIMAWARI & GOES-R)
TRACERDISTANCE_HIGH		Integer	6 (MTG-I) 9 (MSG, HIMAWARI-8/9 & GOES-R)
TRACERDISTANCE_LOW		Integer	3 (MTG-I) 4 (MSG, HIMAWARI-8/9 & GOES-R)
HIGHERDENSITY_LOWTRACERS HIGHERDENSITY_LOWTRACERS_DET	Relative density between low level/medium level/clear air tracers, and the one between tracers related to other cloud types (for Basic and Detailed scale)	Integer	3 (MTG-I) 4 (MSG, HIMAWARI-8/9 & GOES-R)

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	`16`
DEFINECONTRIBUTIONS	Flag to decide if "CCC height assignment" is to be used (requires also TRACKING=CC).	Integer	`1`
DEFPOSCONTRIBUTIONS	Flag to decide if the position of the AMV in the target is relocated to the position of maximum correlation contribution defined by "CCC height assignment" (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).	Integer	`1`
USE_CLOUDTYPE	Flag to decide if - The Tracer cloud type is calculated by the old "Brightness temperature interpolation height assignment method" (if positive), - And if the Tracer cloud type is taken into account for the calculation of the Tracer temperature (if = 2).	Integer	`2`
USE_MICROPHYSICS	Flag to decide if Microphysics correction is to be calculated to "CCC height assignment" (if positive), and if this Microphysics correction is applied to the final AMV pressure (if = 2) (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).	Integer	`2`
MIN_CORRELATION	Minimum correlation acceptable (if TRACKING=CC).	Integer	`80`
WIND_GUESS	Flag to decide if the Wind guess is used for the definition of the Tracking area.	Integer	`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 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`

NWP validation parameters			
NWPVAL_STATISTICS	Flag to decide if Validation statistics against NWP model winds are to be calculated. Possible values: - 1: Statistics provided for all layers and satellite channels together. - 2: Statistics provided for all layers together and each satellite channel separately. - 3: Statistics provided for each layer separately and all satellite channels together. - 4: Statistics provided for each layer and satellite channel separately.	Integer	4
NWPVAL_ANALYSIS	Flag to decide if the Validation statistics are to be computed against NWP analysis winds.	Integer	0
NWPVAL_NWPDIFFERENCE	Flag to decide if Vector difference between each AMV and the related NWP model wind is to be written in the output files.	Integer	1
NWPVAL_NWPBESTFITLEVEL	Flag to decide if the NWP model wind at the best fit pressure level for each AMV is to be written in the output files.	Integer	1
NWP parameters			
MIN_NWP_FOR_CALCULATION	Minimum number of NWP levels needed for NWC/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 16: 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 the running time is to keep the five MSG channels in the default configuration (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 = VIS06,WV062,WV073,IR108).

With MTG-I satellite data, again because of the general similarity between IR105 and IR123 AMVs and between VIS06 and VIS08 AMVs, the recommendation to reduce NWC/GEO-HRW running time is to keep the four MTG-I channels in the default configuration (AMV_BANDS = VIS08,WV063,WV073,IR105). No more reductions in the amount of channels are recommended, to keep the representation of the calculated AMVs and Trajectories throughout all the atmospheric layers.

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 as in the default configuration, with respectively AMV_BANDS = VIS08,WV062,WV069,WV073,IR112 and VIS08,WV062,WV070,WV074,IR112. The second option would be to keep two water vapour channels with AMV_BANDS = VIS08,WV062,WV073,IR112 and VIS08,WV062,WV074,IR112.

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 regions 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 and GOES-19 satellites. And since the year 2021, the option exists to calculate AMVs and Trajectories in the Eastern Pacific and Western North American regions with GOES-17 and GOES-18 satellites. In both cases the processing is restricted in the default configuration to Full Disk images in “Mode 6” (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. 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.
- With the adaptation to MTG-I satellite provided now, the continuity of NWC/GEO-HRW and the corresponding AMV and Trajectory data in European, African and Atlantic areas is guaranteed for the coming two decades, with improved radiometric, spatial and temporal resolutions.

With all this, NWC/GEO-HRW v7.0 inside NWC/GEO v2025 (vMTG-I day-1) software package is able to cover with five different geostationary satellites the whole Earth, and AMVs and Trajectories can be calculated simultaneously throughout the whole planet. 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 executable 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.

The experience acquired since 2018 with the new generation satellites (Himawari-8/9 and GOES-R) has also been very useful for the development of the AMV algorithm for MTG-Imager satellite series.

For future work, an effort is needed to reduce the size of the code and the use of memory by NWC/GEO-HRW executable, 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 executable. Some studies were done on this during the summer of 2018, showing clearly that more effort 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). The second problem is solved using the “Quality index without forecast” in the operation of NWC/GEO-HRW (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 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 NWC/GEO-HRW

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 Meteosat-12 (MTG-I1) satellite data in the European and Mediterranean region (*Figures 4 and 5*). Second, with Meteosat-10 satellite data in the European and Mediterranean region (*Figures 6 and 7*). The same date has been used, so that the AMV outputs from MSG and MTG-I satellites can be compared. 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*).

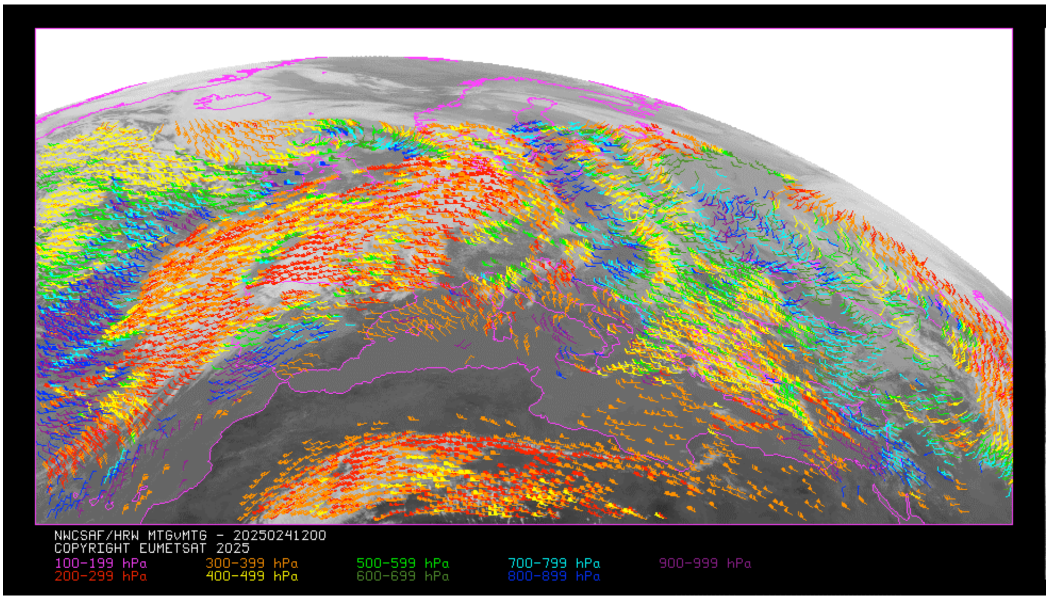

Figure 4: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, Meteosat-12 (MTG-I1) satellite), considering default conditions in `$SAFNWC/config/MTI*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

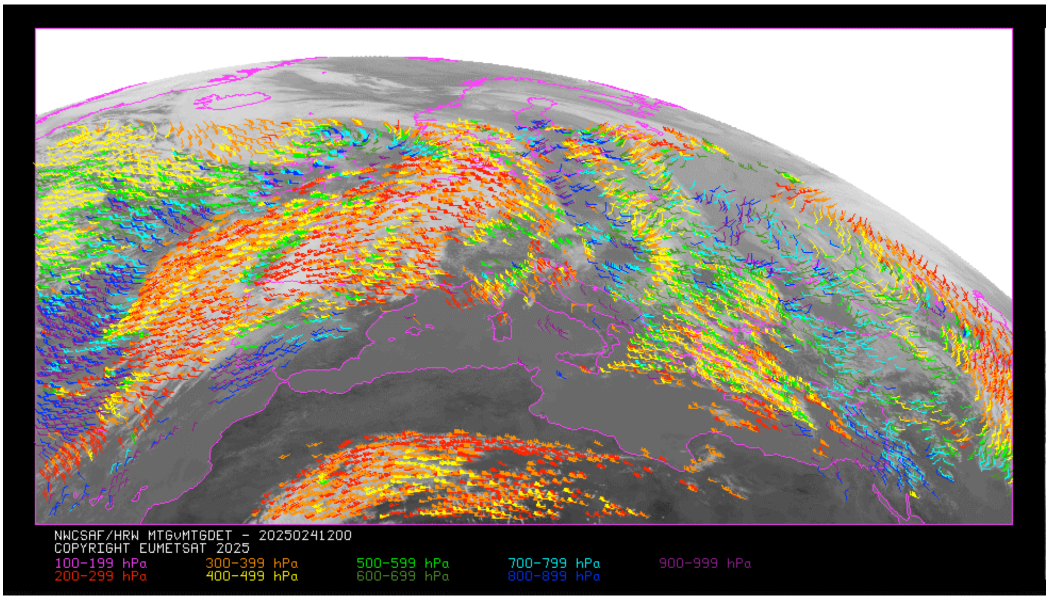

Figure 5: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, Meteosat-12 (MTG-I1) satellite), considering default conditions in `$SAFNWC/config/MTI*/safnwc_HRW.cfm` model configuration file and configurable parameter CDET = 1. Colour coding based on the AMV pressure level

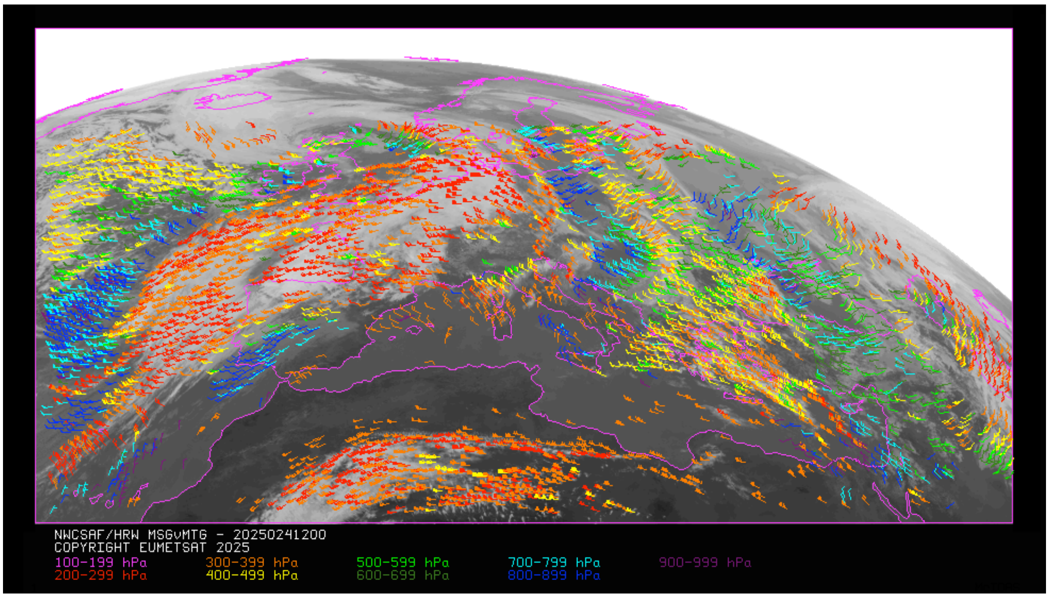

Figure 6: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, Meteosat-10 satellite), considering default conditions in `$SAFNWC/config/MSG*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

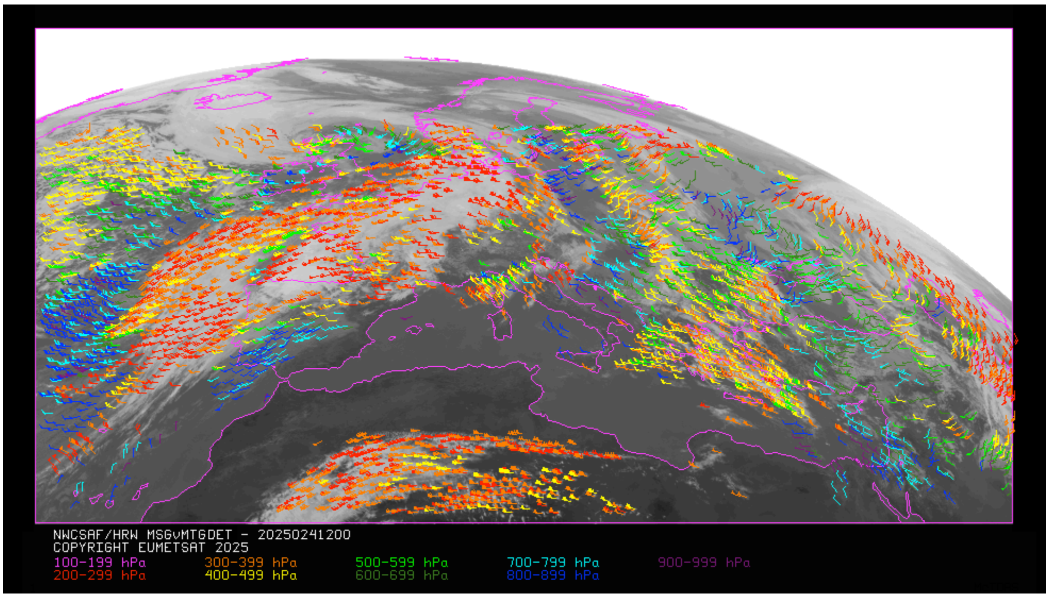

Figure 7: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, Meteosat-10 satellite), considering default conditions in `$SAFNWC/config/MSG*/safnwc_HRW.cfm` model configuration file and configurable parameter CDET = 1. Colour coding based on the AMV pressure level

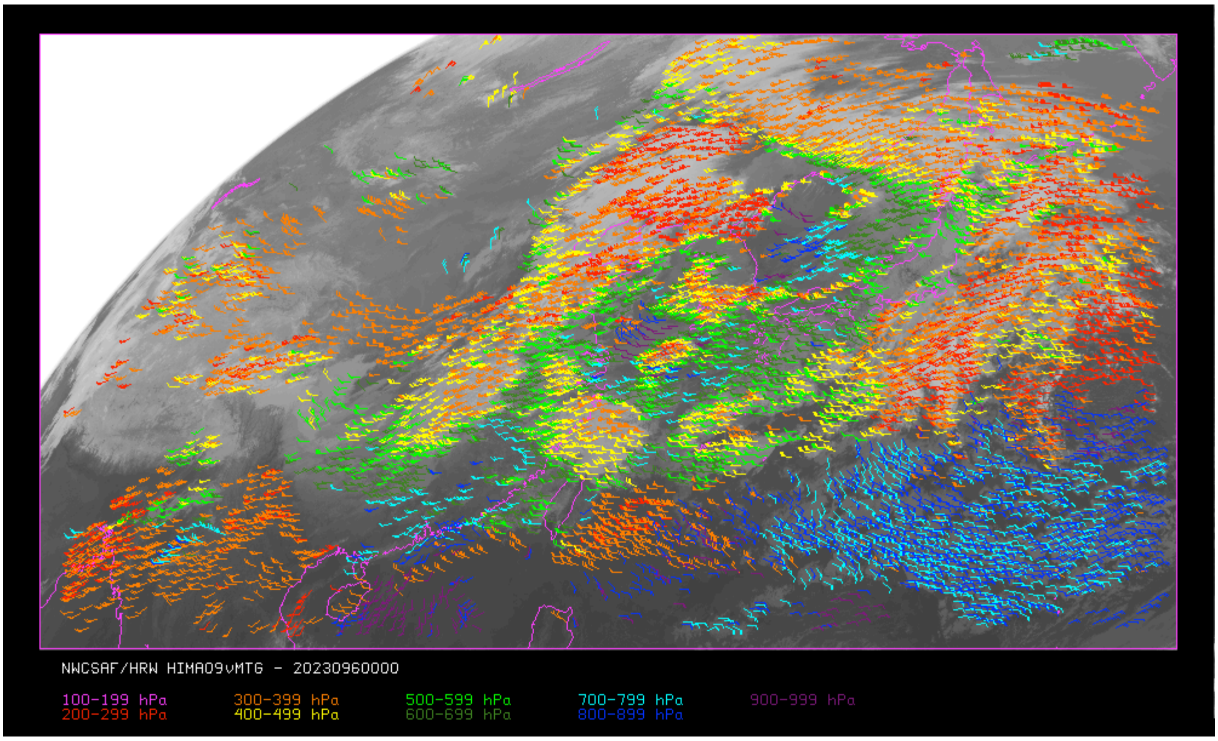

Figure 8: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the China/Korea/Japan region (6 April 2023 00:00 UTC, Himawari-9 satellite), considering default conditions in `$SAFNWC/config/HIMA*/safnwc_HRW.cfm` *model configuration file. Colour coding based on the AMV pressure level*

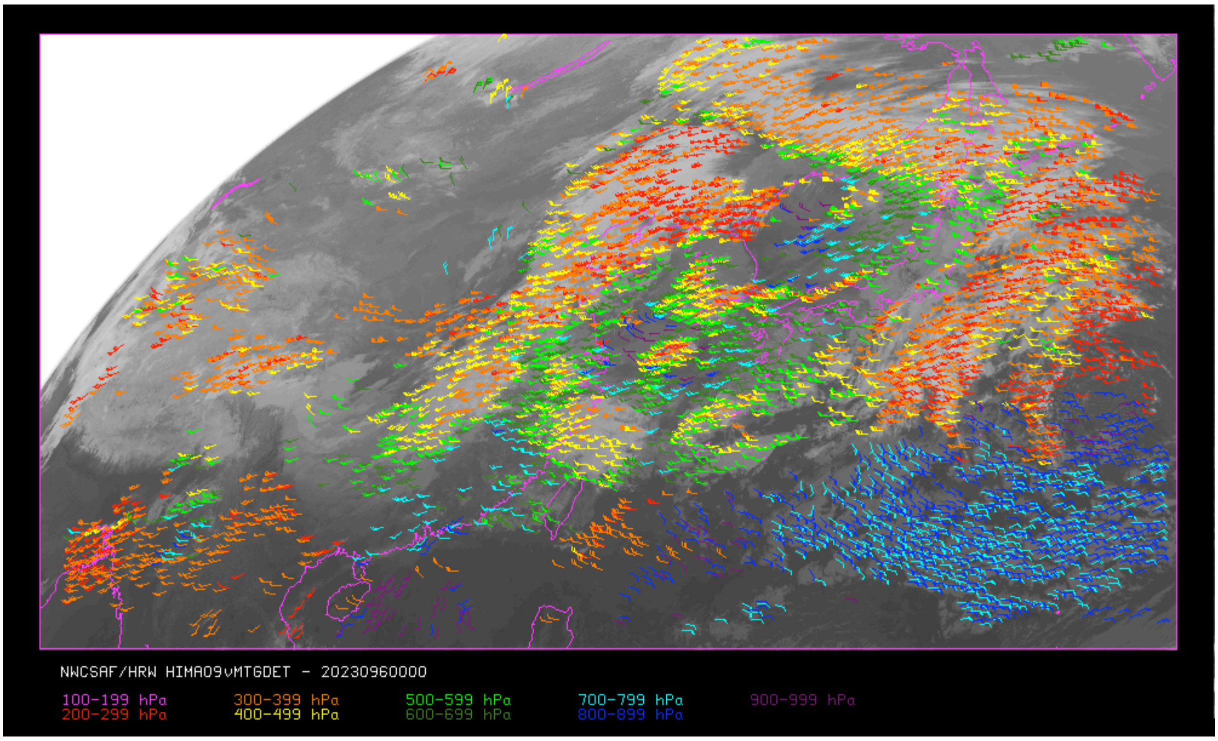

Figure 9: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the China/Korea/Japan region (6 April 2023 00:00 UTC, Himawari-9 satellite), considering default conditions in `$SAFNWC/config/HIMA*/safnwc_HRW.cfm` *model configuration file and configurable parameter CDET = 1. Colour coding based on the AMV pressure level*

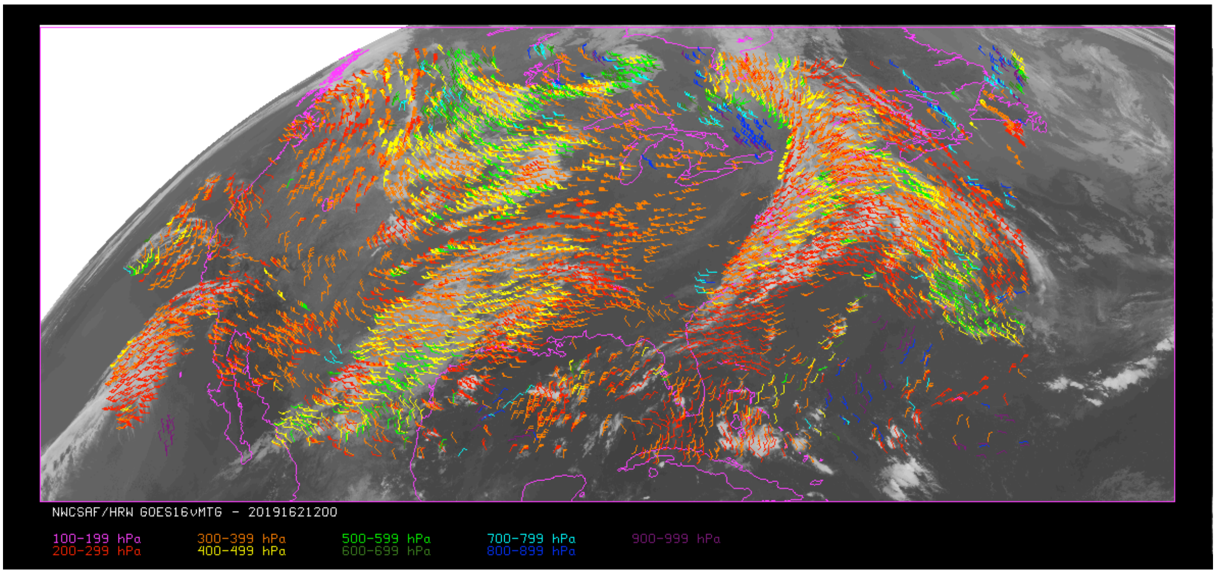

Figure 10: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions in `$SAFNWC/config/GOES*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

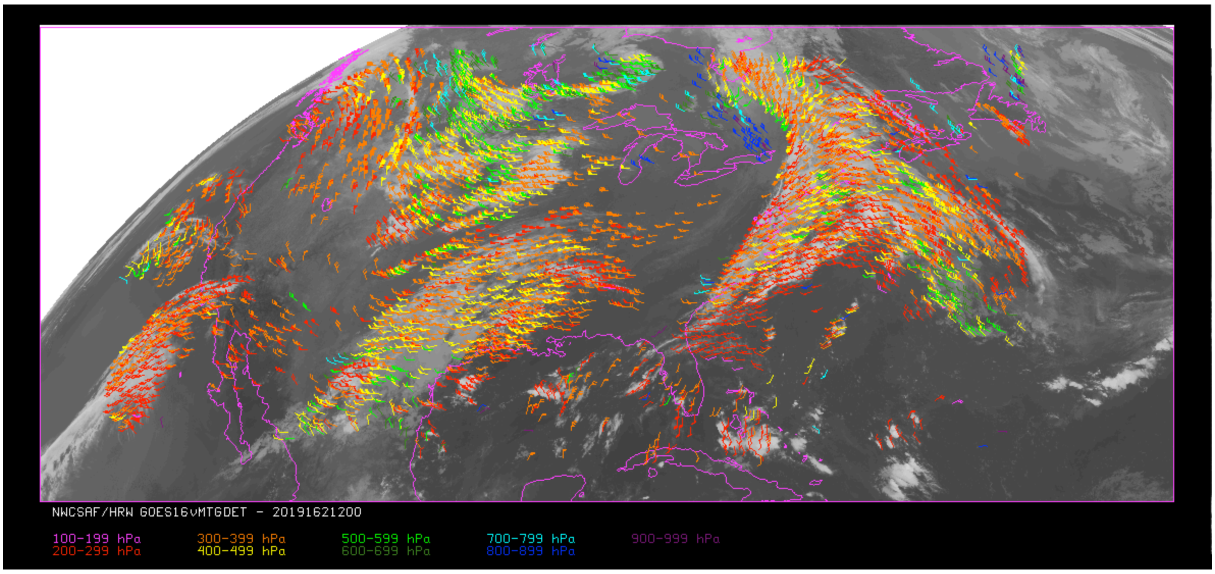

Figure 11: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions in `$SAFNWC/config/GOES*/safnwc_HRW.cfm` model configuration file and configurable parameter CDET = 1
Colour coding based on the AMV pressure level