Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO (MTG-I day-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	*28 February 2017*	89	Initial version after NWC/GEO MTG-I day-1 PDCR review. Content derived from Document "Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO (NWC/GEO-HRW v5.0)", NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind v2.0
1.1	*13 November 2020*	89	Updated version for NWC/GEO MTG-I day-1 STRR1 review. Merged with Document "Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO (NWC/GEO-HRW v6.1)", NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind v2.2, with content related to the adaptation of NWC/GEO-HRW to the New Generation geostationary satellite series (Himawari-8/9, GOES-R, MTG-I satellites).
1.1.1	*31 March 2025*	97	Updated version for NWC/GEO MTG-I day-1 ORR2 review.

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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 "Algorithm Theoretical Basis Document (ATBD) 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 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 Algorithm Theoretical Basis Document describes in detail the algorithm of NWC/GEO-HRW product, its goal and its implementation. 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 v7.0 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]	User Manual for the Wind product processor of the NWC/GEO MTG-I day-1 (Science Part)	NWC/CDOP3/MTG/AEMET/SCI/UM/Wind	1.2.0

Table 3: List of Applicable Documents

1.5.2 Reference Documents

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

Ref.	Title
[RD.1]	J.Schmetz, K.Holmlund, J.Hoffman, B.Strauss, B.Mason, V.Gärtner, A.Koch, L. van de Berg, 1993: Operational Cloud Motion Winds from Meteosat Infrared Images (Journal of Applied Meteorology, Num. 32, pp. 1206-1225).
[RD.2]	S.Nieman, J.Schmetz, W.P.Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers (Journal of Applied Meteorology, Num. 32, pp. 1559-1568).
[RD.3]	C.M.Hayden & R.J.Purser, 1995: Recursive filter objective analysis of meteorological fields, and application to NESDIS operational processing (Journal of Applied Meteorology, Num. 34, pp. 3-15).
[RD.4]	K.Holmlund, 1998: The utilisation of statistical properties of satellite derived Atmospheric Motion Vectors to derive Quality Indicators (Weather and Forecasting, Num. 13, pp. 1093-1104).
[RD.5]	J.M.Fernández, 1998: A future product on HRVIS Winds from the Meteosat Second Generation for nowcasting and other applications. (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.6]	J.M.Fernández, 2000: Developments for a High Resolution Wind product from the HRVIS channel of the Meteosat Second Generation. (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.7]	J.M.Fernández, 2003: Enhancement of algorithms for satellite derived winds: the High Resolution and Quality Control aspects. (Proceedings 2003 Meteorological Satellite Conference, EUMETSAT Pub.39).
[RD.8]	J.García-Pereda & J.M.Fernández, 2006: Description and validation results of High Resolution Winds product from HRVIS MSG channel at the EUMETSAT Nowcasting SAF (Proceedings 8th International Wind Workshop, EUMETSAT Pub.47).
[RD.9]	J.García-Pereda, 2008: Evolution of High Resolution Winds Product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.10]	J.García-Pereda, 2010: New developments in the High Resolution Winds product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 10th International Wind Workshop, EUMETSAT Pub.56).
[RD.11]	C.M.Hayden & R.T.Merrill, 1988: Recent NESDIS research in wind estimation from geostationary satellite images (ECMWF Seminar Proceedings: Data assimilation and use of satellite data, Vol. II, pp.273-293).
[RD.12]	W.P.Menzel, 1996: Report on the Working Group on verification statistics. (Proceedings 3rd International Wind Workshop, EUMETSAT Pub.18).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.14]	Xu J. & Zhang Q., 1996: Calculation of Cloud motion wind with GMS-5 images in China. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.15]	K.Holmlund & C.S.Velden, 1998: Objective determination of the reliability of satellite derived Atmospheric Motion Vectors (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.16]	K.Holmlund, C.S.Velden & M.Rohn, 2000: Improved quality estimates of Atmospheric Motion Vectors utilising the EUMETSAT Quality Indicators and the UW/CIMSS Autoeditor (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.17]	R.Borde & R.Oyama, 2008: A direct link between feature tracking and height assignment of operational Atmospheric Motion Vectors (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.18]	J.García-Pereda, R.Borde & R.Randriamampianina, 2012: Latest developments in "NWCSAF High Resolution Winds" product (Proceedings 11th International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (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 (NWC/GEO-HRW)

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) satellite series, JMA's Himawari-8/9 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 2.2.2.11 of this document.

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

AMVs and Trajectories are calculated throughout all hours of the day, as 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 THEORETICAL DESCRIPTION OF HIGH RESOLUTION WINDS (NWC/GEO-HRW)

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

2.2.1 Physics of the problem

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

Traditionally, AMVs are generated using imagery from geostationary satellites, which monitor a constant region of the Earth. More recently, satellite winds have also been produced using imagery from polar orbiters, as they provide coverage in the polar regions.

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

1. The reading and preprocessing of the satellite data.

   A data rectification is especially important considering satellite visible channels, for which illumination conditions vary with the solar angle.

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

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

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

   Each selected feature in the initial image is then "tracked" in successive images in order to determine the displacement of the feature. Clouds or humidity patterns can change shape or even disappear, but enough of them survive to produce a significant number of AMVs. With shorter time intervals up to 10 and 15 minutes, the problem is smaller and more vectors are calculated.

4. The "height assignment" of the tracers.

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

5. The calculation of the AMV vectors and Trajectories.

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

6. A quality control.

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

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

2.2.2.1 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 centres” in the “later image”.
    - The pressure level of the AMVs and Trajectories is defined through one of two different methods (“Brightness temperature interpolation method” or “Cross Correlation Contribution method”) for their vertical location in the atmosphere.
3. Postprocessing:
    - A Quality control with EUMETSAT “Quality Indicator” method is implemented, with the choice of the “Best AMV” considering 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 through the “NWC/GEO-HRW Model configuration file”, such as explained in detail in Chapter 2.3.3. For example, the satellite channels for which AMVs are to be extracted are defined by configurable parameter ‘WIND_CHANNEL’.

2.2.2.2 Preprocessing

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

1. Reflectances (which have been normalized by NWC/GEO library taking into account the distance to the Sun) for the visible images with which tracers are calculated and tracked, for all MTG-I, MSG, Himawari-8/9 or GOES-R visible channels to be used: MTG-I/VIS06 and VIS08; MSG/HRVIS, VIS06 and VIS08; Himawari/VIS06 and VIS08; GOES-R/VIS06 or VIS08.
2. Brightness temperatures for the infrared/water vapour images with which tracers are calculated and tracked, for all MTG-I, MSG, Himawari-8/9 or GOES-R infrared/water vapour channels to be used: MTG-I/IR105, IR123, WV063 and WV073; MSG/IR108, IR120, WV062 and WV073; Himawari/IR112, WV062, WV069 and WV073; GOES-R/IR112, WV062, WV070 and WV074.
3. Radiances for the images with which tracers are calculated and tracked (for MTG-I/IR105 and WV063; MSG/IR108 and WV062; Himawari/IR112 and WV062; GOES-R/IR112 and WV062), if the "Image correlation quality control test" defined in chapter 2.2.2.10 is used (implemented in the default configuration but not mandatory).
4. Latitude and longitude matrices, and solar and satellite zenith angle matrices for the image pixels in which tracers are calculated and tracked (which are calculated by NWC/GEO library).
5. NWP temperature profiles for the processing region in which NWC/GEO-HRW is run.
6. NWP wind component profiles for the processing region in which NWC/GEO-HRW is run, if the "Forecast consistency quality control test" defined in chapter 2.2.2.10 is used, or if the NWP "wind guess" for the definition of the "tracking area" in the "later image" such as defined in chapter 2.2.2.4 is used, or if Validation statistics are to be calculated by NWC/GEO-HRW itself such as defined in chapter 2.3.1 (considering as reference winds NWP analysis winds or NWP forecast winds). All these options except the use of the NWP "wind guess" for the definition of the tracking area are implemented for all satellite series in the default configuration.
7. NWP geopotential profiles for the whole processing region in which NWC/GEO-HRW is run, if the "Parallax correction" defined in chapter 2.2.2.9 or the "Orographic flag" defined in chapter 2.2.2.11 are used (implemented in the default configuration but not mandatory).
8. NWP surface pressure for the whole processing region in which NWC/GEO-HRW is run, if the "Orographic flag" defined in chapter 2.2.2.11 is used (implemented in the default configuration but not mandatory).
9. NWC/GEO-CT Cloud Type output for the image in which tracers are calculated, in case the "AMV Cloud type" is used for the "Brightness temperature interpolation method height assignment", such as defined in chapter 2.2.2.5 (not mandatory).
10. NWC/GEO-CT Cloud Type and CTTH Cloud Top Temperature and Pressure outputs for the image in which tracers are tracked, in case the CCC method height assignment defined in chapters 2.2.2.6 to 2.2.2.8 is used (implemented in the default configuration but not mandatory).
11. NWC/GEO-CMIC Cloud Phase, Liquid Water Path and Ice Water Path outputs for the image in which tracers are tracked, in case the Microphysics correction for CCC Method height assignment defined in chapter 2.2.2.7 is used (implemented in the default configuration but not mandatory).

Only the satellite data for the requested channels, and NWP temperature and NWP wind forecast data with a minimum number of NWP levels (defined through configurable parameter MIN_NWP_FOR_CALCULATION, with a default value of 4) are mandatory for the processing. All other data contribute however to a higher number of AMVs and Trajectories and a better quality of the output data. Detailed information on all configuration parameters can be found in chapter 2.3.3.

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

2.2.2.3 Tracer search

The process of NWC/GEO-HRW starts with the calculation of "tracers" (square "segments" of nxn pixels, used as initial positions of AMVs and Trajectory sectors, and identified by a specific cloudiness feature or humidity feature) throughout the processing region in an "initial image". The calculated tracers are stored in temporal files in `$SAFNWC/tmp/HRW` directory.

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

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

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

A "single scale procedure" calculating only "basic tracers" with a line and column "tracer size" of 24 pixels is proposed as default configuration. This configuration is specified with configurable parameter CDET = 0. The latitude and longitude limits for calculation of AMVs and Trajectories can also be specified with configurable parameters LAT_MAX, LAT_MIN, LON_MAX, LON_MIN.

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

These resolutions define different tracer scales between 48 to 72 km at subsatellite point (in the "basic low resolution image scale") and 6 to 12 km at subsatellite point (in the "detailed highest resolution image scale"), with highest values related to MSG satellite series and lowest values related to Himawari-8/9 or GOES-R satellite series. So, between 'mesoscale ß' and 'mesoscale γ' meteorological dimensions.

The nominal observation frequency of 10 to 15 minutes is enough to track the majority of features with these sizes, although in some cases like small cumulus over land related to the "detailed highest resolution channel scale", their lifecycle might be a bit short for this image frequency. The use of NWC/GEO-HRW in the "Rapid scan mode" with MSG satellites can be better to track tracers of this small size.

In any case, the line and column "tracer size" in pixels of the "single or basic scale" can be defined through configurable parameters TRACERSIZE_VERYHIGH for the Himawari-8/9 or GOES-R 0.5 km very high resolution images, TRACERSIZE_HIGH for the 1 km high resolution images (available in all satellite series), and TRACERSIZE_LOW for the 2 to 3 km low resolution images (available in all satellite series). NWC/GEO-HRW is defined to work with square shaped tracers, so similar values for the line and column "tracer size" are kept for the processing.

FIRST METHOD: GRADIENT

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

1. To look for a "brightness value" (identified as any of the pixel values of the corresponding "N_Value matrix", inside a "tracer candidate" located in a "starting location"), greater than configurable parameter BRIGHTNESS_THR_VIS (for visible cases, with default value 120) or smaller than BRIGHTNESS_THR_OTHER (for other cases, with default value 240).
2. To verify if a difference exists between the maximum and minimum "brightness value" in the "tracer candidate", greater than configurable parameter GVAL_VIS (for visible cases, with default value 60) or GVAL_OTHER (for infrared and water vapour cases, with default value 48).
3. To compute inside the "tracer candidate" the value and location of the "maximum brightness gradient" |ΔN_Value(Δx) + ΔN_value(Δy)|, where Δ means a distance of 5 pixels in both line and column directions. This "maximum brightness gradient" cannot be located on the edges of the "tracer candidate".

If all previous processes have been successful, a valid "tracer" is defined at the location of the "maximum brightness gradient". The "starting location" for the subsequent "tracer" is established by a "pixel distance" between tracers, defined for Very high, High and Low resolution images respectively by configurable parameters TRACERDISTANCE_VERYHIGH, TRACERDISTANCE_HIGH and TRACERDISTANCE_LOW.

This "pixel distance" is kept for all low level, medium level and clear air high level tracers. Considering cloudy high level tracers, one of every HIGHERDENSITY_LOWTRACERS/ HIGHERDENSITY_LOWTRACERS_DET is kept only (with a default value of 3 for MTG-I and 4 for all other satellite series). With this new procedure, the spatial density of AMV data related to low/medium/clear air high level tracers is narrower than the one obtained in NWC/GEO-HRW v6.1 and previous versions, and 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.

SECOND METHOD: TRACER CHARACTERISTICS

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

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

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

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

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

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

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

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

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

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

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

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

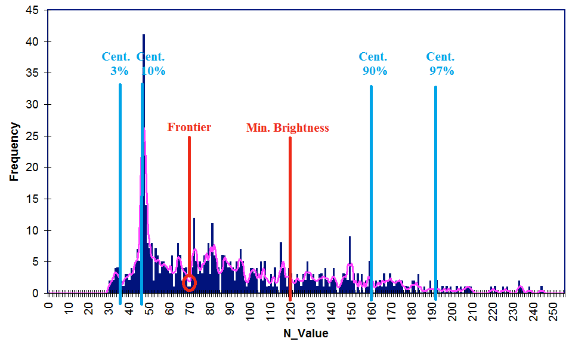


Figure 1: Example of "N_Value matrix histogram" (unsmoothed in violet and smoothed in pink) for a valid low resolution "tracer candidate". The minimum brightness threshold, the algorithm centiles and the defined frontier are also shown

2. "Big pixel brightness variability test":

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

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

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

CLASS_1: 'undefined big pixel', intermediate case.

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

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

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

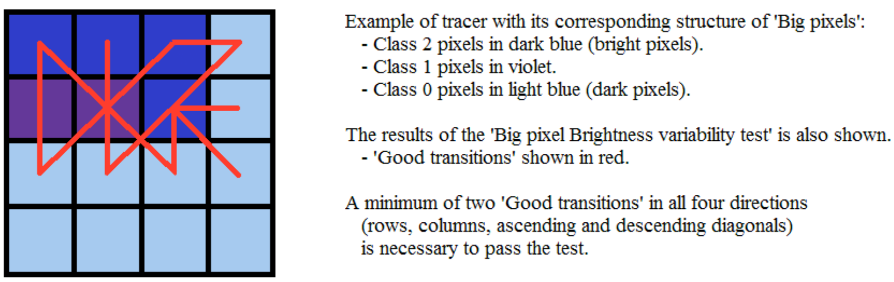


Figure 2: Example of running of the 'Big pixel brightness variability test' for a valid tracer candidate

TRACER VALIDITY CONDITIONS

A verification is done checking that all "tracer" pixels are in valid locations in the working region, with valid latitude, longitude, satellite and solar zenith angles, satellite data and NWC/GEO-CT cloud type outputs (when used, such as in the default configuration). In case of GOES-17 satellite, this also implies in the default configuration that the "GOES-17 quality flag" for all tracer pixels is nominal (i.e., zero), and that cloud type values could be calculated for all tracer pixels. In case any of these inputs needed for the "tracer" definition is not available and an alternative processing exists, the alternative is used if configurable parameter KEEPDEFAULTPROCEDURE = 0. However, in the default configuration with KEEPDEFAULTPROCEDURE = 1, NWC/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 configuration.

A tracer is neither retained if it is found too close to a previously computed one ("closeness threshold"). So, each time a tracer is computed, all pixels located nearer than the "closeness threshold" are added to a "pixel exclusion matrix", and excluded as potential tracer locations. Considering this, with "Gradient method" the "maximum brightness gradient" is not evaluated at locations inside the "pixel exclusion matrix". With "Tracer characteristics method" no computations are evaluated for a "starting location" with pixels inside the "pixel exclusion matrix".

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

DETAILED TRACERS IN THE TWO SCALE PROCEDURE

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

- No "Basic tracer" has been found, but at the "starting location" of a "tracer candidate" the following condition occurs: CENT_97%>0.85*MIN_BRIGHTNESS_THR. A "Detailed tracer unrelated to a Basic tracer" is so defined, with a slightly lower brightness threshold.
- A "Wide basic tracer" has been found, in which CLASS_2 values appear in both first and last row, or in both first and last column, of the "4x4 big pixel matrix" used in the "Big pixel brightness variability test". In this case four starting locations are defined for the "Detailed scale". Each of them is located at the corners of a "Detailed tracer" whose centre is the centre of the "Basic tracer".
- A "Narrow basic tracer" has been found, in which CLASS_2 values do not appear neither in both first and last row, nor in both first and last column, of the "4x4 big pixel matrix" used in the "Big pixel brightness variability test". In this case, only one starting location is defined for the "Detailed scale", whose centre is defined by the weighted location of the "Big pixels" in the "4x4 big pixel matrix".

TRAJECTORIES

With the default configuration, with configurable parameter CALCULATE_TRAJECTORIES = 1, the definition of new "tracer locations" starts at the integer line/column location of all "tracking centres" related to valid AMVs in the previous round, when they are available.

A set of "persistent tracers" can so successively be defined and tracked in several images, and the progressive locations of the tracer throughout the time define "Trajectories". For this, it is necessary that the conditions implied by the "tracer method" used for the determination of the tracer in the "initial image", keep on being valid throughout all the images.

EXAMPLES OF AMVs RELATED TO DIFFERENT TYPES OF TRACERS

Examples of AMVs related to different types of tracers for MTG-I satellite series, considering the tracer method and the tracer type, are shown next. In *Figure 3*, "Basic tracers" considering the tracer method ("Gradient tracers" and "Tracer characteristics tracers"). In *Figure 4*, "Basic and Detailed tracers" considering the tracer type ("Basic tracers", "Detailed tracers unrelated to Basic tracers", "Detailed tracers related to Wide basic tracers", and "Detailed tracers related to Narrow basic tracers").

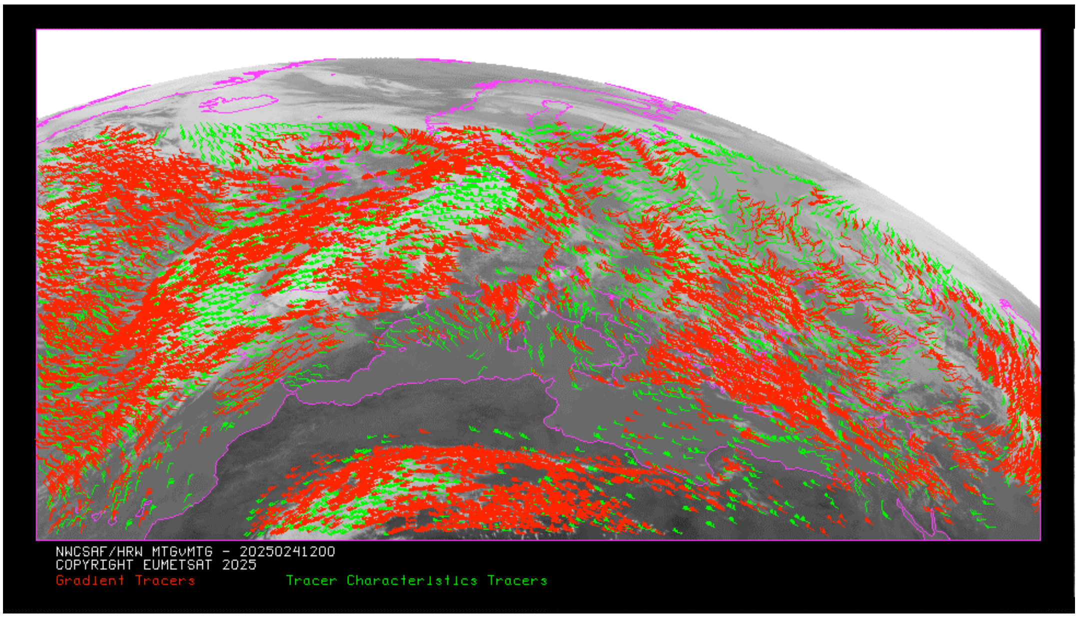


Figure 3: "Basic scale AMVs" (in red and green, considering the Tracer calculation method used for their extraction), in a Single scale NWC/GEO-HRW example defined in the European and Mediterranean region with default model configuration file `$SAFNWC/config/MTI*/safnwc_HRW.cfm` *(24 January 2025, 12:00 UTC, MTG-I/1 satellite)*

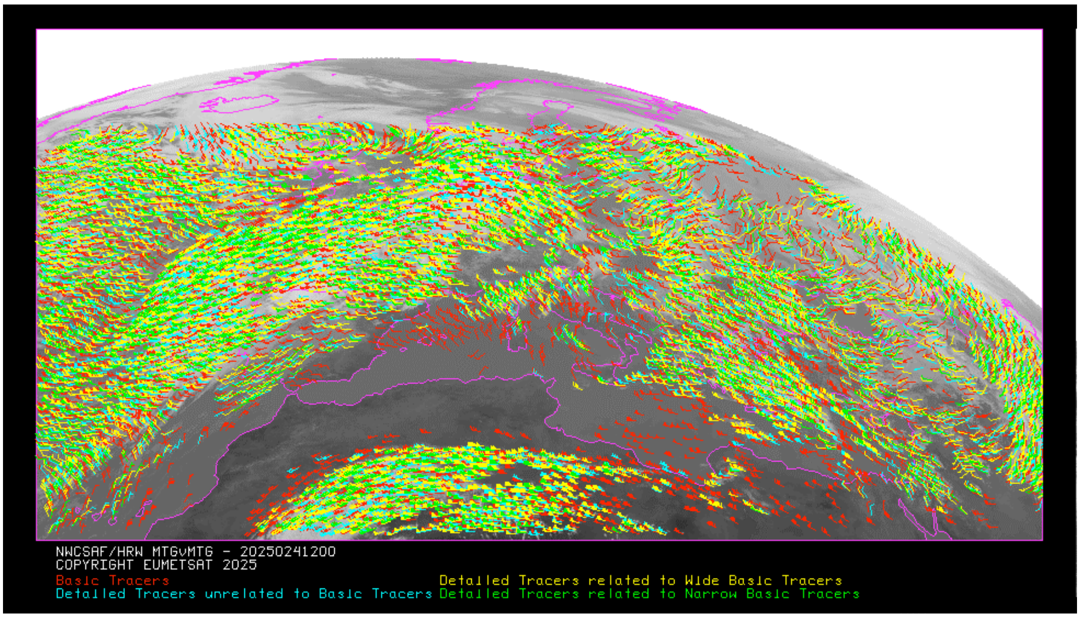


Figure 4: "Basic scale AMVs" (in red), and "Detailed scale AMVs" (in yellow, green and blue, considering their relationship with the Basic scale AMVs), in a Two scale NWC/GEO-HRW example, defined in the European and Mediterranean region with default model configuration file `$SAFNWC/config/MTI*/safnwc_HRW.cfm` *and configurable parameter CDET = 1 (24 January 2025, 12:00 UTC, MTG-I/1 satellite)*

2.2.2.4 Tracer tracking

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

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

- Euclidean distance (configured through TRACKING = LP), in which the sum $LP_{ij} = \Sigma\Sigma(T-S)^2$ is calculated. T/S correspond to the "N_Value brightness values" for the "tracer" and the "tracking candidate" pixels at correlative locations. The best "tracking locations" are defined through the minimum values of the sum LP_{ij}.
- Cross correlation (configured with TRACKING = CC, which is the default option), in which the normalized correlation value $CC_{ij} = COV_{T,S}/(\sigma_T.\sigma_S)$ is calculated. T/S correspond to the "N_Value brightness values" for the "tracer" and the "tracking candidate" pixels at correlative locations; COV is the covariance between their "N_Value brightness values"; σ is the standard deviation or the "tracer" and "tracking candidate" "N_Value brightness values".

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

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

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

Nevertheless, NWC/GEO-HRW is optimized not to use the "wind guess", so reducing the dependence of the calculated AMVs from any NWP model. Although the running time can be around two to three times longer, it is recommended for time separations between the "initial image" and "later image" up to 15 minutes to skip operationally the use of "wind guess" with configurable parameter WIND_GUESS = 0. This is defined as default option for all satellite series.

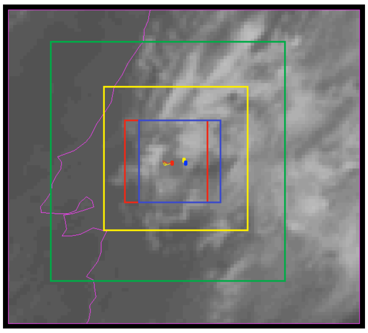


Figure 5: A low resolution tracer at 11:45 UTC (O red mark), its position defined by NWP wind guess at 12:00 UTC (O yellow mark), and its true tracking position at 12:00 UTC defined by HRW algorithm (O blue mark), for an example case (Basic AMVs in Nominal scan mode, MSG-2 satellite). The "yellow tracking area" (with its centre at the position defined by the NWP wind guess at 12:00 UTC) corresponds to the option using wind guess for the definition of the tracking area. The "green tracking area" (with its centre at the position of the tracer at 11:45 UTC) corresponds to the option not using wind guess for the definition of the tracking area. The larger size of the tracking area when the wind guess has not been used is to be noticed, which causes a longer time for the running of HRW algorithm, but at the same time reduces the dependence from the NWP model

The line and column size in pixels of the "tracking area" is calculated so that it is able to detect displacements of the tracer of at least 272 km/h in any direction (value of configurable parameter MINSPEED_DETECTION), when the wind guess is not used in the definition of the tracking area. When the wind guess is used, this MINSPEED_DETECTION parameter is to be understood as the minimum difference in speed with respect to that of the NWP wind guess that NWC/GEO-HRW is able to detect; a value here of 72 km/h is recommended.

The calculation of the "tracking area" is optimized 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.

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

- In a first iteration, a computation gap defined by configurable parameter TRACKING_GAP = 16 is applied: LP/CC_{ij} is evaluated only at (1,1)…(1,17),…(17,1)…(17,17) pixel locations in the "tracking area". The four locations with best LP/CC_{ij} values are retained for following iteration.
- In the following iterations, LP_{ij}/CC_{ij} is only evaluated if possible at four locations around each one of the four best locations retained in the previous iteration, defined by:

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

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

After all five iterations, the three "tracking centres" (configurable parameter MAX_NUM_WINDS) with the best Euclidean distance/Correlation values are retained. With Cross correlation, it is also requested that the absolute maximum correlation value be greater than configurable parameter MIN_CORRELATION (with a default value of 80%).

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

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

SELECTION OF THE MAIN TRACKING CENTRE

The reason to preserve more than one "tracking centre" is that the one with best Euclidean distance/Cross correlation values (the "main tracking centre") could not be the right one. The "secondary tracking centres" are so promoted to "main tracking centre" if following conditions occur:

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

If the 'centile difference' is larger than 20%, the "secondary tracking centre" can still be promoted to "main tracking candidate" if, defining a new "frontier" value as the mean value of the frontiers in the "tracer" and "secondary tracking centre" and recomputing the "Big pixel class difference", its value is smaller than 6. If no "secondary tracking centre" is complying with this, the procedure is still tried relaxing "Brightness temperature difference" and "Big pixel class difference" limits to the double.

SEPARATION OF AMV CALCULATION IMAGES AND MIXED CALCULATION METHOD

The "initial image" related to the tracer calculation and the "later image" related to the tracking centre calculation are not necessarily consecutive, and depend on the value of configurable parameter SLOT_GAP. In NWC/GEO-HRW the default configuration implies the use of consecutive images (separated by 10 minutes for MTG-I, Himawari-8/9 and GOES-R satellite series, and 15 minutes for MSG satellite series in "Nominal scan mode"), and the use of alternate images (one out of every two, separated by 10 minutes) for MSG satellite series in "Rapid scan mode". No "Rapid scan mode" option has been defined for the moment for use with the other satellite series.

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

In NWC/GEO-HRW a "mixed calculation method" considering short and long time intervals at the same time is also available with configurable parameter MIXED_SCANNING = 1,2 (not used as default option), through which tracers are to be tracked considering the minimum time interval possible, but the corresponding AMVs and Trajectories are calculated considering the displacements in longer time intervals (defined by parameter SLOT_GAP = 2,3,4).

MIXED_SCANNING = 1 option writes AMVs and Trajectories for every slot since the first long time interval is reached. MIXED_SCANNING = 2 writes AMVs and Trajectories only every SLOT_GAP slots instead.

This "mixed calculation method" is useful for the calculation of AMVs with high resolution images, and for the improvement of the quality of the calculated 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 the displacements in longer time intervals.

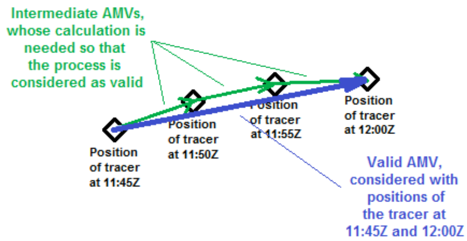


Figure 6: Example of processing with the "mixed calculation method" for MSG satellite series "Rapid scan mode", in which the tracers are tracked every 5 minutes (so providing three intermediate AMVs) but the valid AMVs are calculated every 15 minutes (considering the initial and final position of the tracer only)

For the AMVs related to this "mixed calculation method", the latitude and longitude are calculated considering the location of the initial tracer. The latitude and longitude increment, the speed and direction are calculated considering the initial 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 in metres, 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 the parameter for the last intermediate AMV only (the quality parameters and all absolute categories like the cloud type).

This "mixed calculation method" implies an AMV calculation process more similar to the one defined in general by other AMV calculation centres, in which all AMVs are related to the calculation of several intermediate AMVs (when the "mixed calculation method" is not activated in NWC/GEO-HRW, not all AMVs are related to the calculation of several intermediate AMVs).

TRACKING VALIDITY CONDITIONS AND EXAMPLES OF THE AMV TRACKING

A verification is done again in the later image checking that all "tracking area" pixels are in valid locations in the working region, with valid latitude, longitude, satellite and solar zenith angles, satellite data, NWP data, and NWC/GEO-Cloud product outputs (NWC/GEO-CT, CTTH and CMIC, in case they are used). In case of GOES-17 satellite, this also implies in the default configuration that the "GOES-17 quality flag" for all "tracking area" pixels is nominal (i.e., zero), and that all NWC/GEO-CT, CTTH and CMIC product outputs could be calculated for all "tracking area" pixels.

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

Examples of AMVs for MTG-I, MSG, Himawari-8/9 and GOES-R satellites are shown next in *Figures 7 to 10*, considering the satellite channel used for the AMV calculation, and their consideration as Cloudy AMVs or Clear air AMVs.

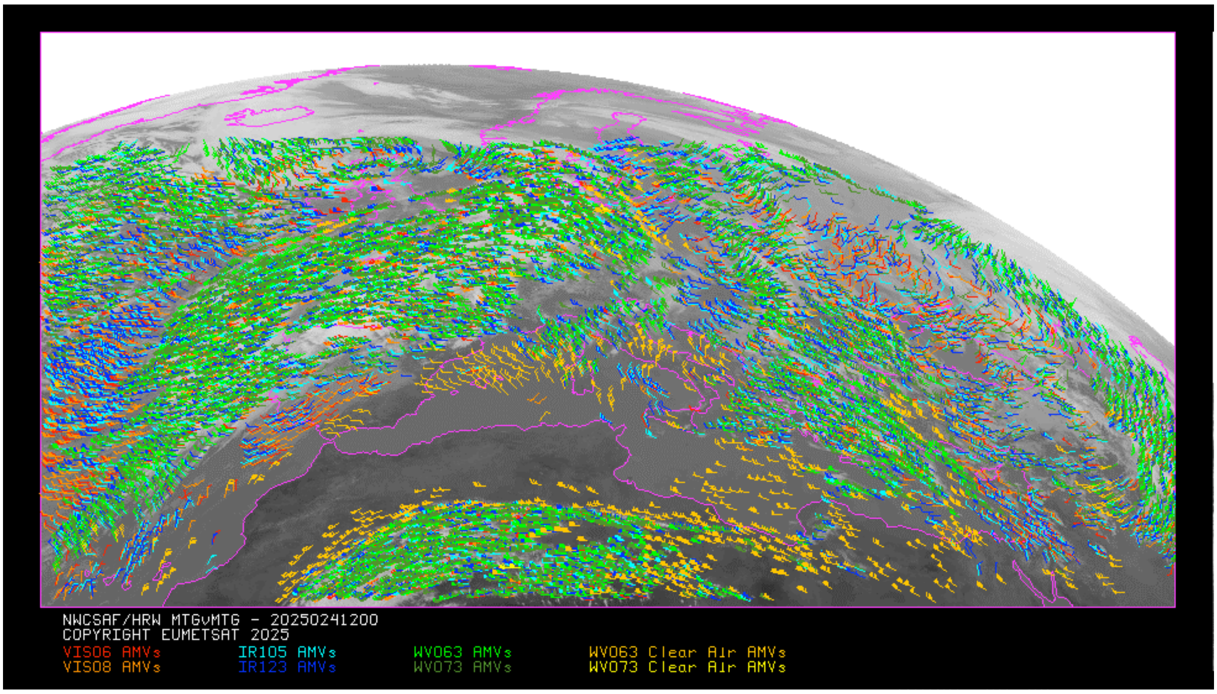


Figure 7: AMVs considering the satellite channel used for the AMV calculation, for the MTG-I series High Resolution Winds example defined in Figure 32 (24 January 2025, 12:00 UTC, MTG-I/1 satellite)

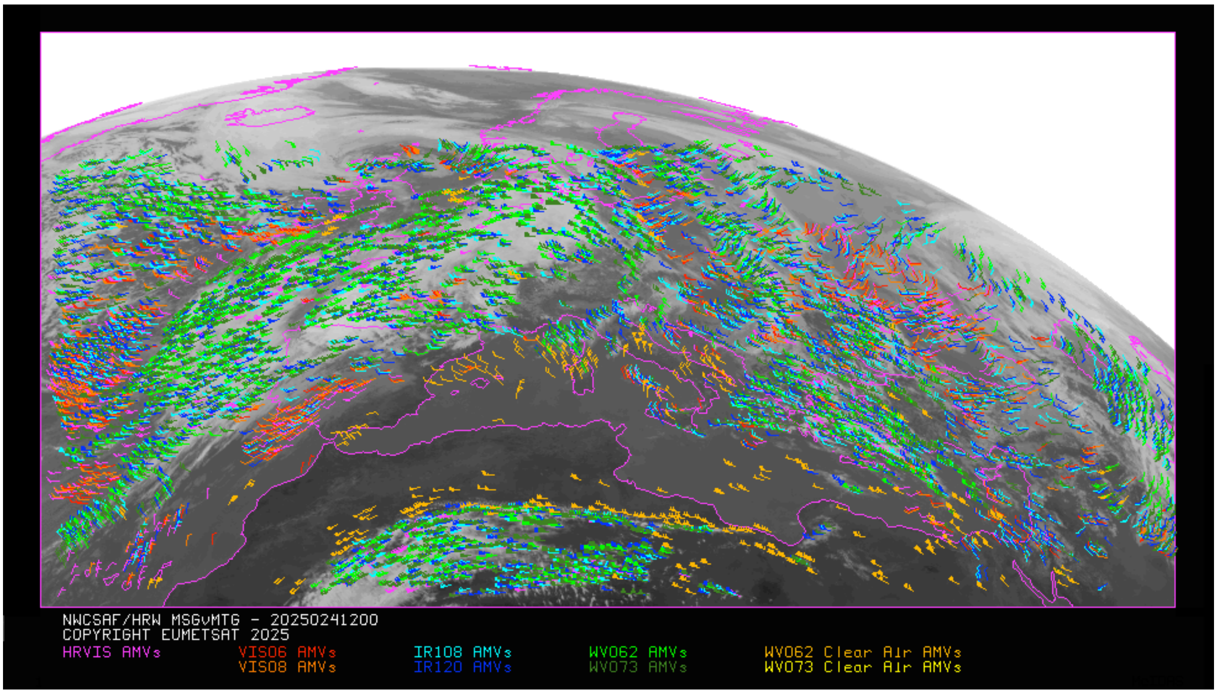


Figure 8: AMVs considering the satellite channel used for the AMV calculation, for the MSG series High Resolution Winds example defined in Figure 34 (24 January 2025, 12:00 UTC, MSG-3 satellite)

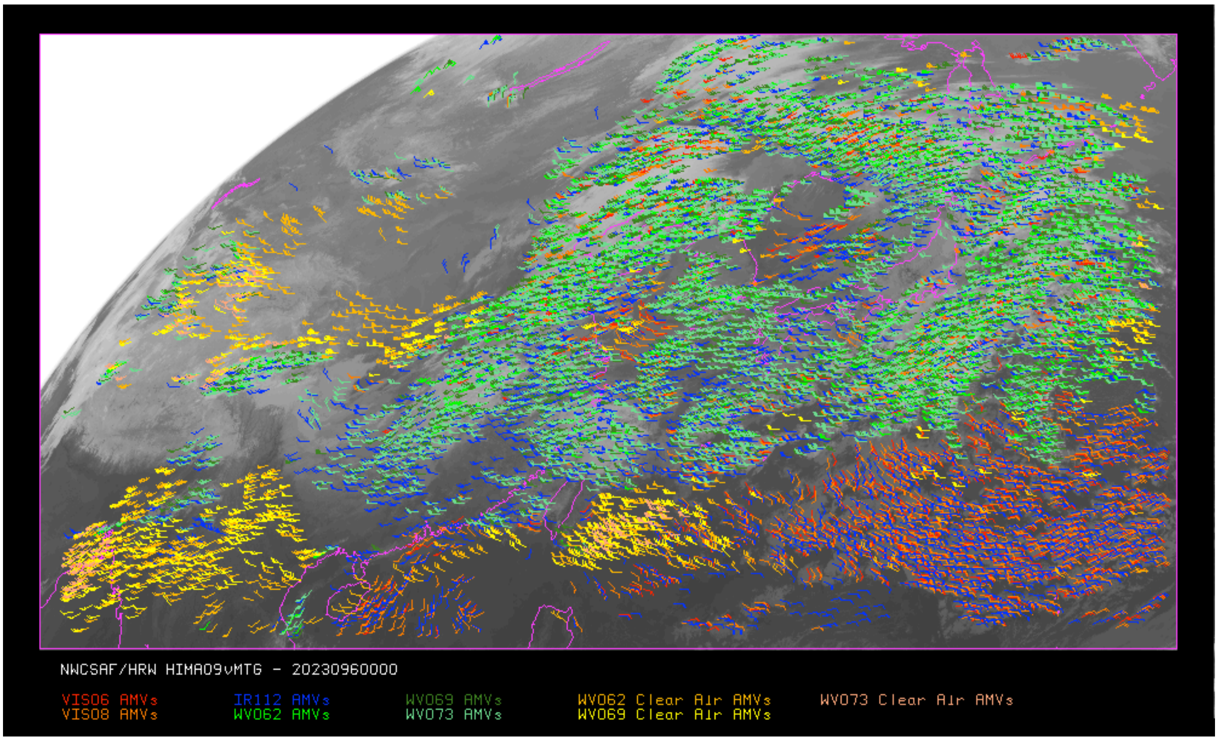


Figure 9: AMVs considering the satellite channel used for the AMV calculation, for the Himawari-9 High Resolution Winds example defined in Figure 36 (6 April 2023 00:00 UTC, Himawari-9 satellite)

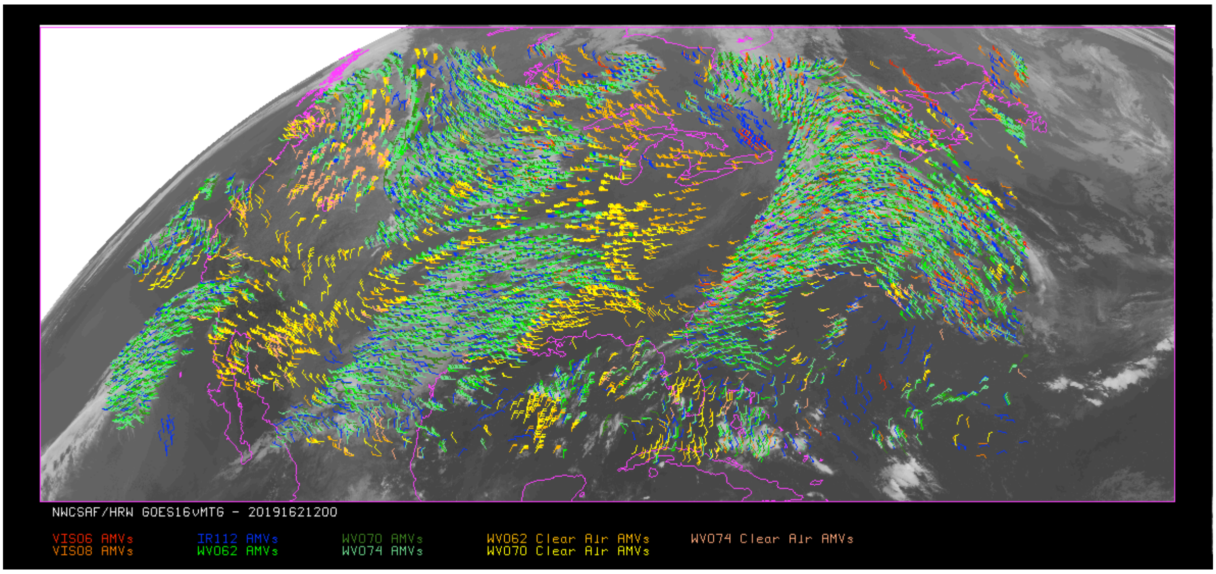


Figure 10: AMVs considering the satellite channel used for the AMV calculation, for the GOES-16 High Resolution Winds example defined in Figure 38 (11 June 2019 12:00 UTC, GOES-16 satellite)

2.2.2.5 "Brightness temperature interpolation method" height assignment

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. With these data:

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

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

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

For this, the "AMV cloud type" parameter is defined as the most common value of NWC/GEO-CT Cloud Type output inside the tracer pixels, if its presence is at least $^3/_2$ times the one of the second most common value. If this condition does not occur, values "AMV cloud type" = 21 (multiple cloudy types), = 22 (multiple clear air types), or = 23 (mixed cloudy/clear air types) are defined, respectively when the two most common cloud types inside the tracer pixels are both cloudy types, both clear air types, or any other case. All possible values for the "AMV cloud type" parameter are in *Table 5*.

After this, some tracers are eliminated depending on the "AMV cloud type" value and the satellite channel with which they have been calculated. These cases are identified in a blue cell in *Table 6*, and are related to: cloud free tracers in visible and infrared channels (with less than a 2.5% of cloudy pixels), fractional clouds, and cloud types for which the validation statistics are significantly worse.

If NWC/GEO-CT Cloud Type output is not available or USE_CLOUDTYPE = 0, the "AMV cloud type" is defined as "unprocessed".

After this, the AMV pressure level is defined such as also shown in *Table 6*. If the "AMV cloud type" has not been calculated, the "Base pressure" is considered for all AMVs because most cloud types fit better with the "Base pressure".

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

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

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

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 cumulus/stratus	**Base**	**Base**	**Base**	**Base**			**Base**	**Base**	**Base**
6 Low 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 6: AMV filtering related to the "AMV cloud type" and the satellite channel, and consideration of the "top pressure" or "base pressure" in the "Brightness temperature interpolation height assignment method" for the valid cases

2.2.2.6 "CCC method" height assignment (Cloudy cases)

"CCC method - Cross Correlation Contribution method" height assignment is implemented with configurable parameters TRACKING=CC and DEFINEWITHCONTRIBUTIONS=1. It is run after the "tracking" process, and it is the default option for 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 outputs for the processing region and the image in which tracers are tracked, before the running of NWC/GEO-HRW executable. If these outputs are not available, NWC/GEO-HRW skips this method and uses the "AMV pressure" and "AMV temperature" values provided by "Brightness temperature interpolation method" if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option). In the default configuration with KEEPDEFAULTPROCEDURE = 1, the processing of NWC/GEO-HRW stops, without calculating any AMVs or Trajectories.

In case the "wind guess" has been used for the definition of the "tracking area" (with configurable parameter WIND_GUESS = 1; not used in the default configuration), the "AMV pressure" and "AMV temperature" values calculated by "CCC method" replace the values calculated previously by "Brightness temperature interpolation method".

"CCC method" has the advantage of including in the height assignment all procedures included in NWC/GEO-CTTH output for the cloud top pressure calculation, and 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.

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

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

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

The graph 'Normalized reflectance(Partial contribution to the correlation)' for the visible channels, or the graph 'Brightness temperature(Partial contribution to the correlation)' for the infrared/water vapour channels has in general the shape of the letter 'C', as shown by the lower graphs in *Figures 11 and 12* (corresponding to a MSG/VIS08 and a MSG/IR108 case). In these graphs with two branches, the largest "partial contribution to the correlation" is given by the brightest and darkest pixels (for the visible channels), and by the warmest and coldest pixels (for the infrared/water vapour channels).

"AMV pressure" and "AMV temperature" are calculated considering only the pixels whose "partial contribution to the correlation" is higher than a "CCC calculation threshold" inside the bright branch of the 'Normalized reflectance(Partial contribution to the correlation)' graph in the visible cases. In the infrared and water vapour cloudy cases, the pixels whose "partial contribution to the correlation" is higher than the "CCC calculation threshold" inside the cold branch of the 'Brightness temperature(Partial contribution to the correlation)' graph are considered. The "CCC calculation threshold" is defined as the mean "partial contribution to correlation", or zero if so no pixels are kept.

The original procedure defined in document [RD.17] is so kept, so that the pressure level corrections implemented later in chapter 2.2.2.7 can be understood as "cloud depth corrections" respect to the "cloud top level".

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

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

The procedure is repeated for the up to three "tracking centres" defined for each tracer. If "parallax correction" is considered later in chapter 2.2.2.9 for the position of the tracers/tracking centres, a similar calculation is done for the "AMV height value, H_{CCC}", considering the Cloud Top Height (CTH_{ij}) and the equivalent formula $H_{CCC}=\Sigma(CC_{ij}\cdot CTH_{ij})/\Sigma CC_{ij.}$

The "AMV cloud type" value is calculated as the one with the highest sum of "partial contributions to the correlation". The "AMV pressure error value, ΔP_{CCC}" is also calculated with the formula:

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

useful as a possible "Quality control" parameter for the filtering of AMVs and Trajectories. For this, a maximum "AMV pressure error" is defined with configurable parameter MAXPRESSUREERROR (default value 150 hPa).

Images in *Figures 11 and 12* show two examples of the running of "CCC method" (as already said, for a MSG/VIS08 AMV on the left side, and a MSG/IR108 AMV in the right side). In the first row of the images, the "N_Value brightness values" for the "tracer" pixels in the "initial image" and for its "tracking centre" pixels in the "later image" are shown. Comparing the images, it is visually clear that the same feature is being observed in both cases. In the second row, the NWC/GEO-CT Cloud type and NWC/GEO-CTTH Cloud Top Pressure related to the "tracking centre" pixels are shown. In the third row, the "partial contributions to the correlation" for the "tracking centre" pixels are shown: on the left considering all pixels and on the right considering only those pixels defined as valid by the "CCC calculation threshold" (which in these cases have a contribution to the correlation larger than the "mean contribution to the correlation").

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

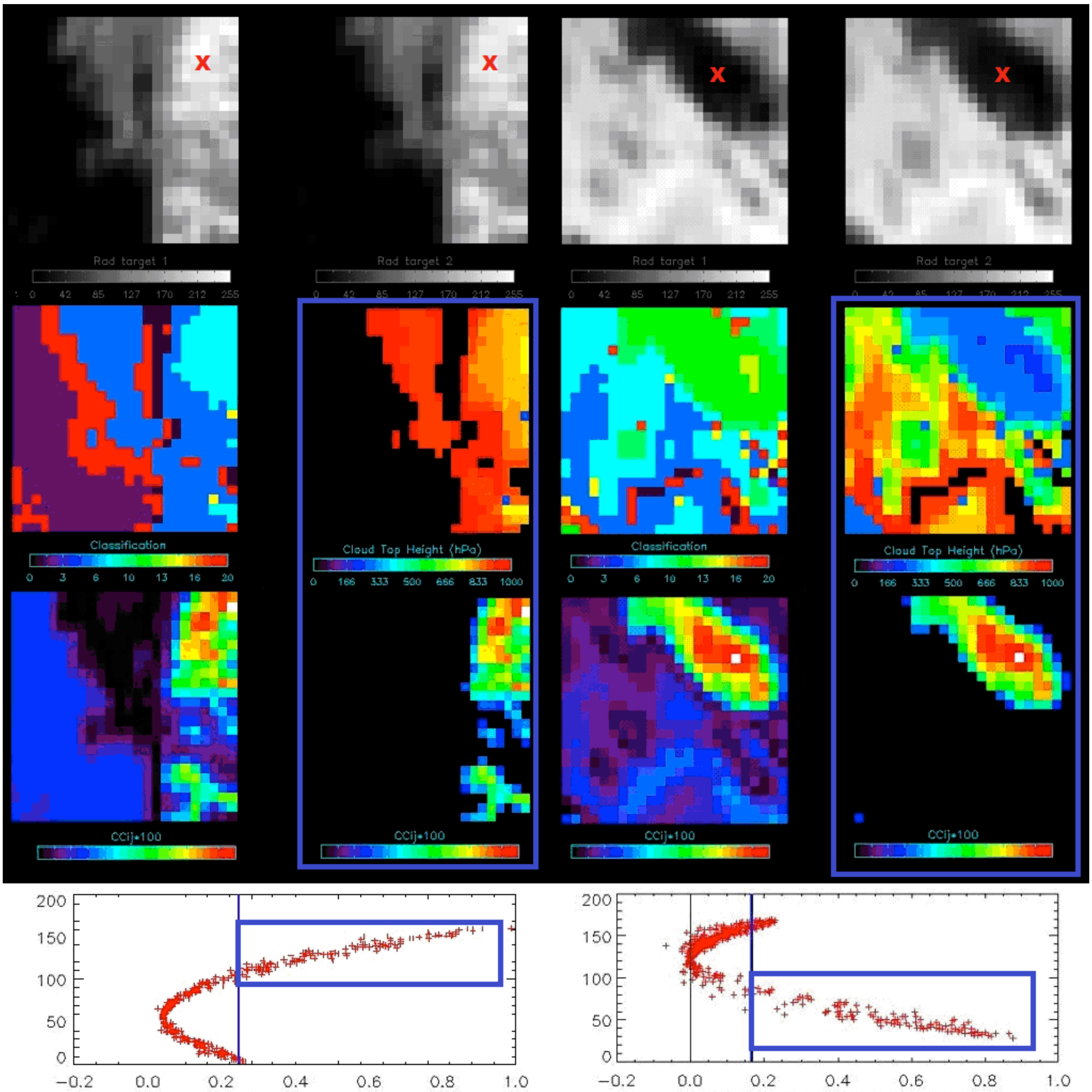
Only those pixels having a valid value in the blue boxes in both graphs of *Figures 11 and 12* are used in the calculations of P_{CCC} and ΔP_{CCC}. In the MSG/VIS08 example these pixels correspond to the very low and low cloud in the right part of the "tracking centre", defining values of P_{CCC}=834 hPa and ΔP_{CCC}=27 hPa. In the MSG/IR108 case these pixels correspond to the high cloud in the upper right corner of the "tracking centre", defining values of P_{CCC}=286 hPa and ΔP_{CCC}=24 hPa.

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

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

The "weighted locations" relate the displacement of the AMVs and Trajectories to the displacement of the part of the tracer with the "largest contribution to the cross correlation". These weighted locations are identified in *Figures 11 and 12* as red crosses.

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



Figures 11 and 12: Matrices and graphs used in the calculation of ”CCC method height assignment”, for a MSG/VIS08 case in the left side and a MSG/IR108 case in the right side, as explained in the text. The weighted location of the AMV in the “initial image” and “later image” as defined with configurable parameter DEFPOSWITHCONTRIBUTIONS = 1, is shown as a red cross in the images in the first row

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

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

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

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

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

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

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

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

The empirical relationship between the "difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level" and the "AMV Ice/Liquid water path" has been tuned in NWC/GEO-HRW for MSG and Himawari-8/9 satellite series. For GOES-R and MTG-I series, due to the similarities with Himawari-8/9, the same empirical relationship is used.

It considers 12:00 UTC Cloudy AMVs for MSG-2 satellite between July 2010 and June 2011 in the European and Mediterranean region for MSG series, and 00:00 UTC Cloudy AMVs for Himawari-8 satellite between November 2017 and February 2018 in the China/Korea/Japan region for Himawari-8/9 series.

Defining separate procedures for Ice/Liquid Cloud Visible AMVs, for Ice/Liquid Cloud Infrared AMVs and for Ice/Liquid Cloud Water vapour AMVs, *Figures 13 to 18* for MSG and *Figures 19 to 24* for Himawari-8/9 in the following page are obtained. The reference wind data used for the calculation of the "best fit pressure level" have been "Radiosounding wind" data. The empirical relationship has been fitted to a double linear/constant regression. This double linear/constant regression works better than a simple linear regression in all possible cases.

The "difference between the AMV pressure level calculated with CCC method and the "best fit pressure level" is in general negative, meaning that the "best fit pressure level" is in most cases at a lower level (nearer to the ground), than the "AMV pressure level" calculated with "CCC method". The difference is in general more negative with larger "AMV Ice/Liquid water path" values (for deeper clouds). The Normalized bias (NBIAS) has a similar behaviour. The Normalized root mean square vector difference (NRMSVD) becomes larger with larger "AMV Ice water path" values, although not with larger "AMV Liquid water path" values.

Defining a "Microphysics correction of the AMV pressure level" based on the "AMV liquid/ice water path" with these regressions, it is implemented such as shown in *Tables 7 and 8*, respectively for MSG and Himawari-8/9. This correction locates the AMVs in a level nearer to the ground, with the exception only of AMVs with very small Ice/Liquid water path values. A control is later defined through the "Orographic flag" to avoid that AMVs with corrected pressure levels are located at a level below the ground.

Verifying AMV statistics for a different period for the same satellites (the reference AMV Validation period July 2009-June 2010 in the European and Mediterranean region for MSG-2 satellite, and the reference AMV Validation period March 2018-August 2018 in the China/Korea/Japan region for Himawari-8 satellite), the "Microphysics correction" causes a reduction in all validation parameters (NBIAS, NMVD, NRMSVD), which is largest for the NBIAS.

The "Microphysics correction" for MSG and Himawari-8/9 satellites for NWC/GEO-HRW are different due to the differences in the NWC/GEO-Cloud algorithms for these satellites. In general, "Pressure correction" for Himawari-8/9 satellites is to lower levels for Liquid clouds and to higher levels for Ice clouds.

"CCC method with Microphysics correction" height assignment is implemented with configurable parameter USE_MICROPHYSICS = 2. In NWC/GEO-HRW this is activated as default option for all satellite series. Option USE_MICROPHYSICS = 1 calculates the value of the Microphysics correction, but does not correct the "AMV pressure value" with it.

The user has necessarily to run all NWC/GEO-Cloud executables (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, NWC/GEO-HRW runs with "CCC method without Microphysics correction" height assignment if configurable parameter KEEPDEFAULTPROCEDURE = 0 (which is not the default option). In the default configuration with KEEPDEFAULTPROCEDURE = 1, the processing of NWC/GEO-HRW stops, not calculating any AMVs or Trajectories.

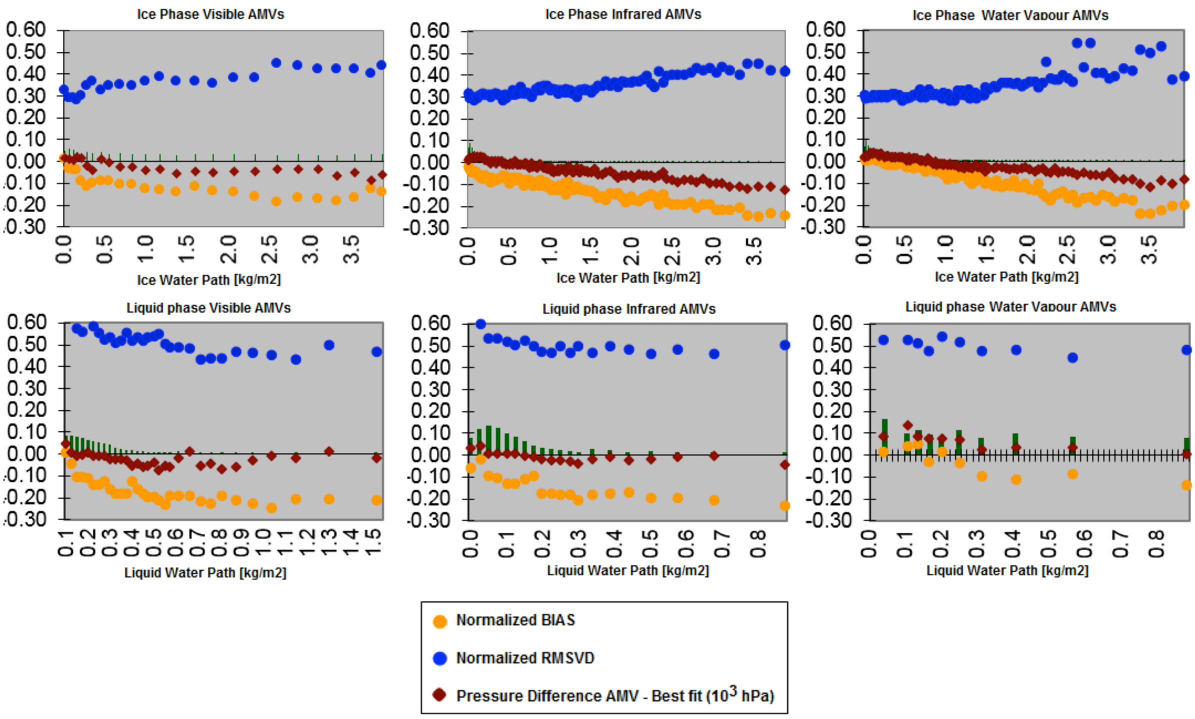
Besides this, in previous NWC/GEO-HRW version v6.1 in NWC/GEO v2018.1 software package, considering a study made by the Hungarian Meteorological Service/OMSZ in January 2021 (defined in Ticket "HRW quality issue" by "btoms user (OMSZ)" on date "07/Jan/2021 09:41:44" at NWCSAF Helpdesk), it was checked that a relocation is needed in the AMV level defined by the Microphysics correction for AMVs at levels higher than 230 hPa.

It has been verified through a comparison with the Radiosounding wind best fit level in the European and Mediterranean region used for NWC/GEO-HRW validation with MSG satellites in the yearly period July 2010-June 2011 (different period to the one used for validation), that AMVs at these levels were too high in the atmosphere, and a relocation to a lower level works better and has better validation statistics. The following empirical formula is used for this relocation:

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

Through this, all AMVs between 0-230 hPa are located to a lower level, with better AMV statistics and no more AMVs between 0 and 140 hPa. The relocation reduces progressively from its highest value of +97 hPa at the highest levels, to 0 hPa near 230 hPa. This relocation is implemented with configurable parameter USE_MICROPHYSICS = 2 (default option for all satellites).

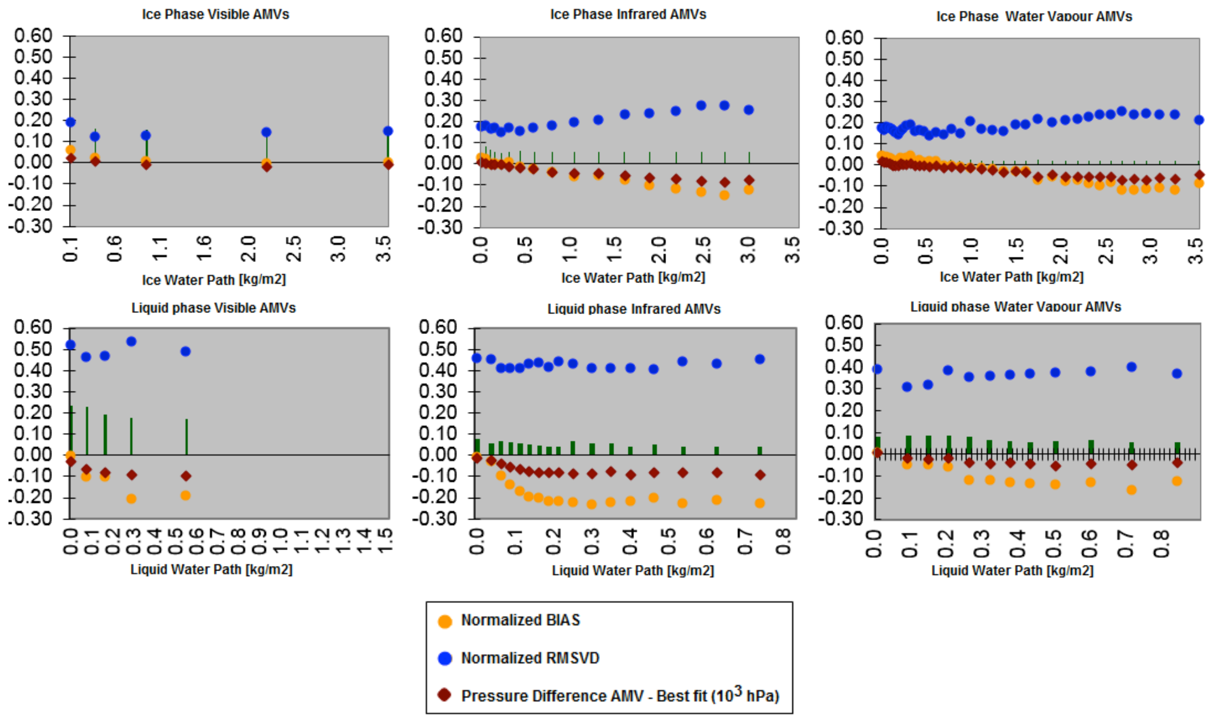
The correction has been studied for MSG satellites and used for all satellite series. The assumption has been made here that the relocation is similar for all these satellites (in spite of the differences in corresponding satellite channels and NWC/GEO-Cloud products), but through the fact that the number of affected AMVs is small (less than 13% of the whole dataset of AMVs for all satellite series), and that the validation for AMVs with pressure < 230 hPa shows similar RMSVD values for all these satellites after the relocation, this assumption can be considered as valid.



Figures 13 to 18: Graphs relating for MSG satellite series the "Difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level (in 10^3 hPa)" in red, the Normalized BIAS in yellow, and the Normalized RMSVD in blue, with the "AMV Ice/Liquid Water Path (in kg/m^2)", for Visible AMVs (left), Infrared AMVs (centre) and Water vapour AMVs (right). 12:00 UTC Cloudy AMVs for MSG-2 satellite for July 2010-June 2011 in the European and Mediterranean region have been used for the tuning

Correction for the "AMV pressure level [in hPa]" based on the "AMV Ice/Liquid water path" for MSG satellite series	
VISIBLE ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 51 without IWP MIC.CORR[hPa] = -14+48*IWP[kg/m^2] if IWP < 1.3542 kg/m^2 MIC.CORR[hPa] = 51 if IWP > 1.3542 kg/m^2	VISIBLE LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 16 without LWP MIC.CORR[hPa] = -42+226*LWP[kg/m^2] if LWP < 0.3540 kg/m^2 MIC.CORR[hPa] = 38 if LWP > 0.3540 kg/m^2
INFRARED ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 10 without IWP MIC.CORR[hPa] = -16+37*IWP[kg/m^2] if IWP < 3.3514 kg/m^2 MIC.CORR[hPa] = 108 if IWP > 3.3514 kg/m^2	INFRARED LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 9 without LWP MIC.CORR[hPa] = -36+251*LWP[kg/m^2] if LWP < 0.2271 kg/m^2 MIC.CORR[hPa] = 21 if LWP > 0.2271 kg/m^2
WATER VAPOUR ICE PHASE AMVs MIC.CORR[hPa] = -7 without IWP MIC.CORR[hPa] = -29+34*IWP[kg/m^2] if IWP < 3.3824 kg/m^2 MIC.CORR[hPa] = 86 if IWP > 3.3824 kg/m^2	WATER VAPOUR LIQUID PHASE AMVs MIC.CORR[hPa] = -56 without LWP MIC.CORR[hPa] = -109+202*LWP[kg/m^2] if LWP < 0.5149 kg/m^2 MIC.CORR[hPa] = -5 if LWP > 0.5149 kg/m^2

Table 7: Correction for AMV pressure level [in hPa] based on the AMV Ice/Liquid water path for MSG satellite series



Figures 19 to 24: Graphs relating for Himawari-8/9 satellites the "Difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level (in 10^3 hPa)" in red, the Normalized BIAS in yellow, and the Normalized RMSVD in blue, with the "AMV Ice/Liquid Water Path (in kg/m^2)" for Visible AMVs (left), Infrared AMVs (centre) and Water vapour AMVs (right). 00:00 UTC Cloudy AMVs for Himawari-8 satellite for November 2017-February 2018 in the China/Korea/Japan region have been used for the tuning

Correction for the "AMV pressure level [in hPa]" based on the "AMV Ice/Liquid water path" for Himawari-8/9, GOES-R and MTG-I satellite series	
VISIBLE ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 11 without IWP MIC.CORR[hPa] = -33+66*IWP[kg/m^2] if IWP < 0.6667 kg/m^2 MIC.CORR[hPa] = 11 if IWP > 0.6667 kg/m^2	VISIBLE LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 88 without LWP MIC.CORR[hPa] = 12+480*LWP[kg/m^2] if LWP < 0.1583 kg/m^2 MIC.CORR[hPa] = 88 if LWP > 0.1583 kg/m^2
INFRARED ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 45 without IWP MIC.CORR[hPa] = -2+38*IWP[kg/m^2] if IWP < 2.1316 kg/m^2 MIC.CORR[hPa] = 79 if IWP > 2.1316 kg/m^2	INFRARED LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 78 without LWP MIC.CORR[hPa] = 465*LWP[kg/m^2] if LWP < 0.1677 kg/m^2 MIC.CORR[hPa] = 78 if LWP > 0.1677 kg/m^2
WATER VAPOUR ICE PHASE AMVs MIC.CORR[hPa] =20 without IWP MIC.CORR[hPa] = -11+29*IWP[kg/m^2] if IWP < 2.5517 kg/m^2 MIC.CORR[hPa] = 63 if IWP > 2.5517 kg/m^2	WATER VAPOUR LIQUID PHASE AMVs MIC.CORR[hPa] = 50 without LWP MIC.CORR[hPa] = -8+161*LWP[kg/m^2] if LWP < 0.3602 kg/m^2 MIC.CORR[hPa] = 50 if LWP > 0.3602 kg/m^2

Table 8: Correction for AMV pressure level [in hPa] based on the AMV Ice/Liquid water path for Himawari-8/9, GOES-R and MTG-I satellite series

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

An adaptation of "CCC method" has been done for its use with the "Water vapour clear air AMVs", because logically no pressure values can be extracted from the NWC/GEO-CTTH Cloud Top Pressure output for "Clear air pixels".

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

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

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

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

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

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

EXAMPLE OF AMV CLOUD TYPE DEFINED BY CCC HEIGHT ASSIGNMENT

An example of AMVs for MTG-I satellite series is shown in *Figure 25*, considering the "AMV cloud type" defined by "CCC method height assignment".

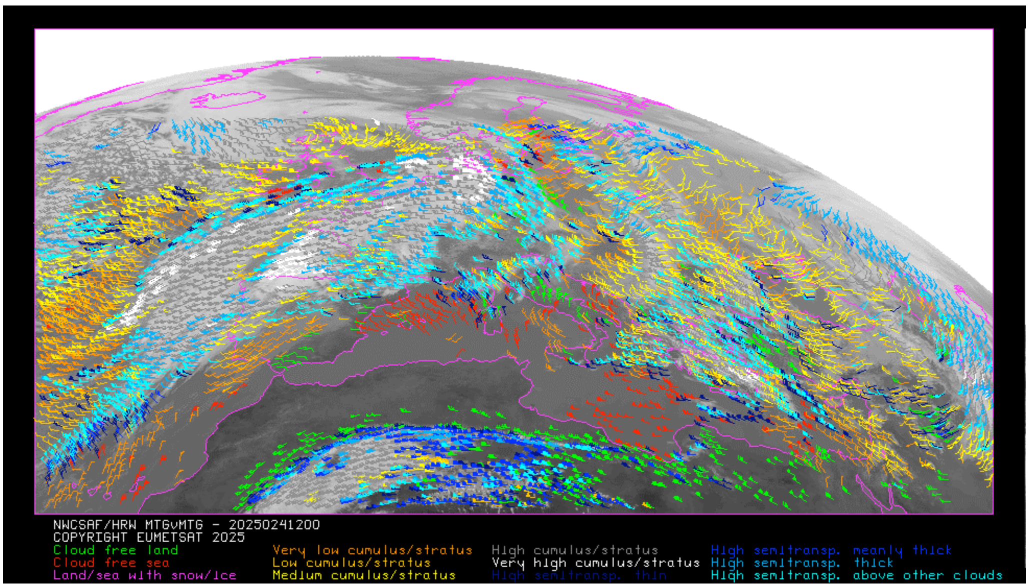


Figure 25: "AMV cloud type values" (as defined by "CCC method height assignment") for the High Resolution Winds example defined in Figure 32 (24 January 2025 12:00 UTC, MTG-I/1 satellite)

EXAMPLE OF AMVs RELATED TO DIFFERENT OPTIONS OF CCC HEIGHT ASSIGNMENT

An example of AMVs for MTG-I satellite series is shown in *Figure 26* considering the different options for "CCC method height assignment" (with/without Microphysics correction; using high/low calculation threshold), and the corresponding cloud phase (ice, liquid, mixed/undefined, clear air).

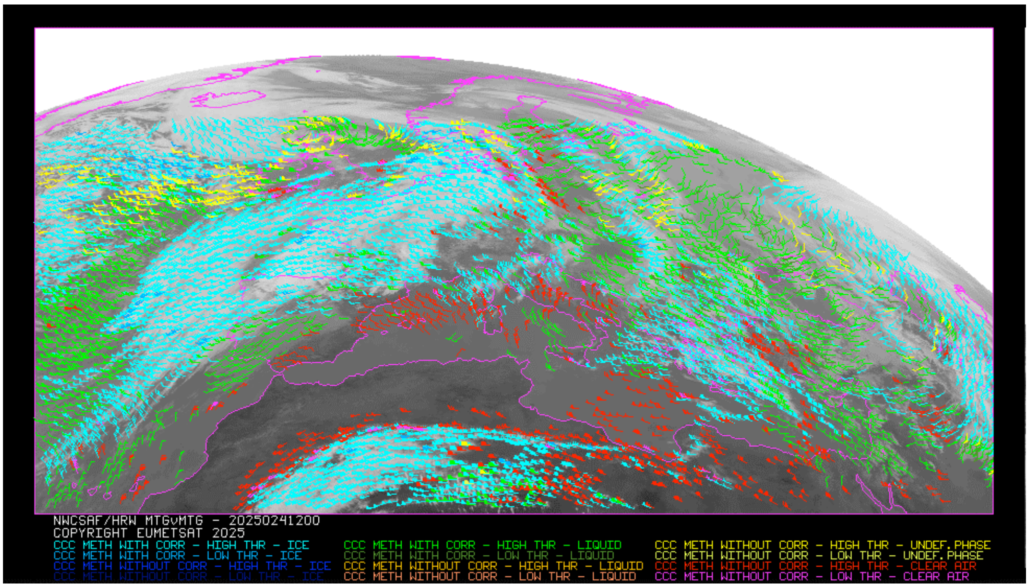


Figure 26: AMV height assignment ("CCC method height assignment with/without Microphysics correction", using "CCC method high/low calculation threshold"), and AMV Cloud phase ("Ice phase", "Liquid phase", "Mixed/Undefined phase", "Clear air") for the High Resolution Winds example defined in Figure 32 (24 January 2025 12:00 UTC, MTG-I/1 satellite)

EXAMPLE OF AMV PRESSURE CORRECTION DEFINED BY MICROPHYSICS CORRECTION

An example of AMVs for MTG-I satellite series is shown in *Figure 27* considering the "AMV pressure correction" defined by "CCC method height assignment with Microphysics correction".

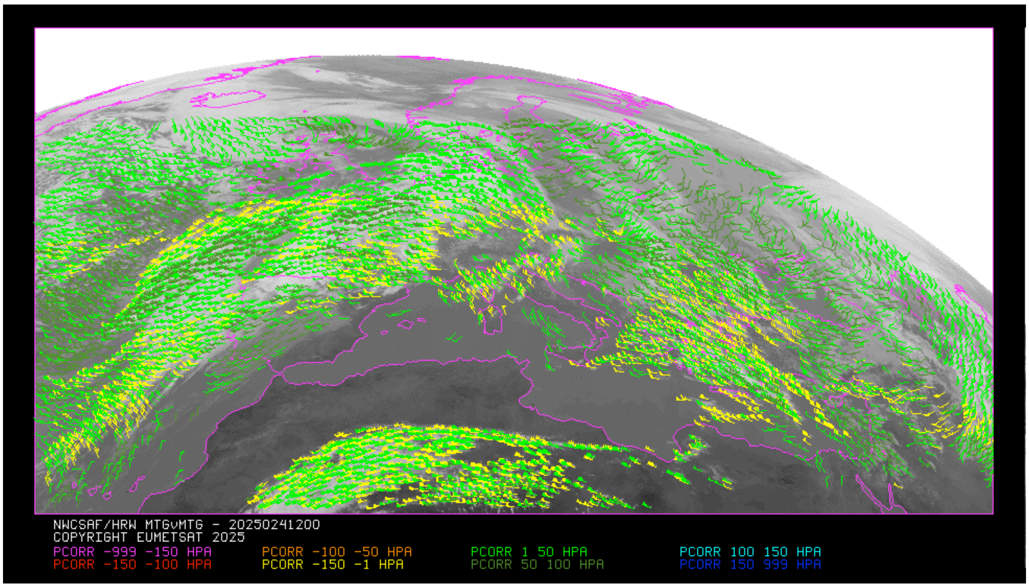


Figure 27: AMV pressure correction (for the cases in which "CCC height assignment method with Microphysics correction" has been used), for the High Resolution Winds example defined in Figure 32 (24 January 2025 12:00 UTC, MTG-I/1 satellite)

2.2.2.9 Wind calculation

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

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

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

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

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

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

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

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

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

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

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

T_INT is the real time difference in hours, between the scanning time of the line defining the "tracer location" in the "initial image" and the "tracking centre location" in the "later image". For MSG satellite series, this procedure takes into account the real time the image scanning began and the time needed to scan each image line. For the other satellite series the procedure is easier, taking simply into account the scanning time for each pixel provided in the satellite input data files.

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

PARALLAX CORRECTION OF THE TRACER AND TRACKING CENTRE LOCATION

In NWC/GEO-HRW, a "parallax correction" of the latitude and longitude values of the tracer and tracking centre (LAT1, LON1, LAT2, LON2) is 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. This parallax correction is considered through NWC/GEO library functions, taking into account the "AMV height value H_{CCC}" calculated with CCC method for Cloudy AMVs, or the geopotential for the "AMV pressure" defined by the NWP geopotential field in all other cases. The general effect of this "parallax correction" is a very slight reduction in the AMV/Trajectory speed, more significant when at higher levels of the atmosphere and when nearer to the edge of the Earth disk. With configurable parameter USE_PARALLAXCORRECTION = 2, NWC/GEO-HRW output file names include additionally the label "_PLAX" at the end of the file name to identify in it that the "parallax correction" took place.

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

2.2.2.10 Quality control and Choice of the best wind

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Only reference AMVs with a "distance factor" smaller than 1, a pressure difference smaller than 25 hPa (L_CHECK_PRESS_DIFF/T_CHECK_PRESS_DIFF) and a latitude/longitude difference smaller than 1.35º (L_CHECK_LAT_DIFF/T_CHECK_LAT_DIFF) are valid. The reference AMVs with the smallest "distance factor" are considered for the quality control.

Since NWC/GEO-HRW v6.2, the process to define the reference AMVs with the smallest "distance factors" has changed for optimization reasons. The lists of "neighbour AMVs" and "prior AMVs" (sorted according to latitude) are now checked starting with the AMVs with the nearest latitudes and alternatively moving North and South in the list. Once a limit of L_CHECK_WRONGAMVS/ T_CHECK_WRONGAMVS = 40 of consecutive invalid AMVs in the search of reference AMVs is reached, the process stops. This makes the Quality control faster.

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

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

Two corrections are nevertheless applied in the overall "Quality Index" values before using them:

- One correction reduces the Quality of the AMVs with a speed lower than 2.5 m/s, multiplying the "Overall Quality Index" with factor SPD/SPEED_THR (where SPD = speed of the evaluated AMV, SPEED_THR = 2.5 m/s).
- The other correction has the name of "Image correlation test" and affects visible and infrared AMVs with a pressure higher than C_CHECK_PRESS_THR = 500 hPa. It is a factor defined by the following formula, in which CORR(IR,WV) is the correlation of IR105/WV063 images for MTG-I satellites, the correlation of IR108/WV062 images for MSG satellites, or the correlation of IR112/WV062 images for Himawari-8/9 and GOES-R satellites, at the location of the "tracking centre" defining the AMV:

  $1 - [\tanh[(\max(0, CORR(IR,WV))/0.2)]]^{200}$.

The "Quality index with forecast" or "Quality Index without forecast" is used for the filtering of the AMV and Trajectory data, before writing them in the output files. The first one is used as default option, through configurable parameter QI_THRESHOLD_USEFORECAST = 1. The "Quality Index threshold" for the acceptance of an AMV or Trajectory as valid is defined by configurable parameter QI_THRESHOLD (with a default value of 75%, and a minimum value of 1%).

Some additional considerations on the Quality Control, specific for NWC/GEO-HRW, are shown here:

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

EXAMPLE OF AMV QUALITY INDICES WITH/WITHOUT FORECAST

An example of AMVs for MTG-I satellite series is shown in *Figures 28 and 29*, considering respectively the "Quality index with forecast" and the "Quality index without forecast".

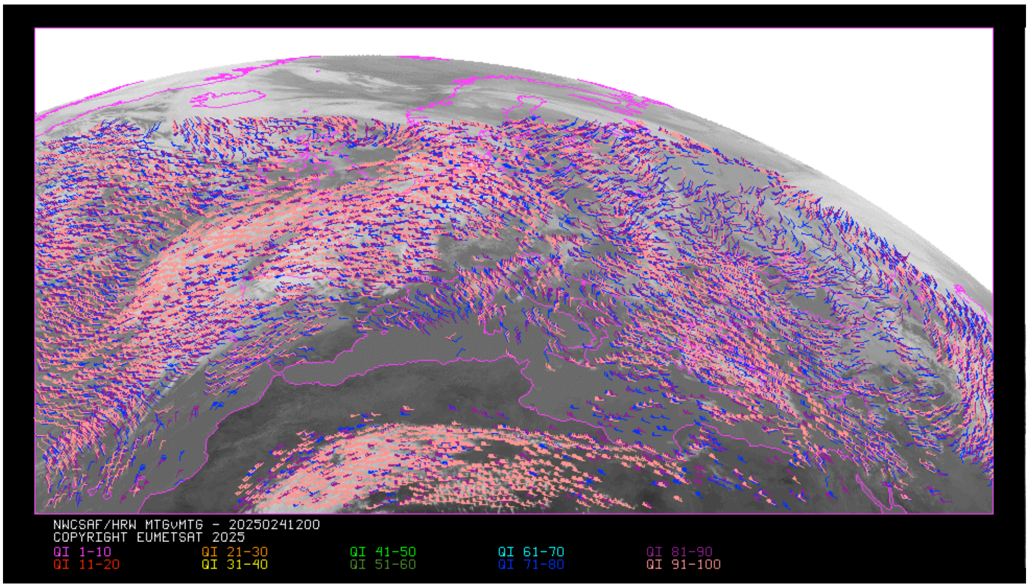


Figure 28: "Quality index with forecast" for the High Resolution Winds example defined in Figure 32 (24 January 2025 12:00 UTC, MTG-I/1 satellite). Only values of "Quality index with forecast" ≥ 75% are present because of the use of this parameter for the AMV filtering.

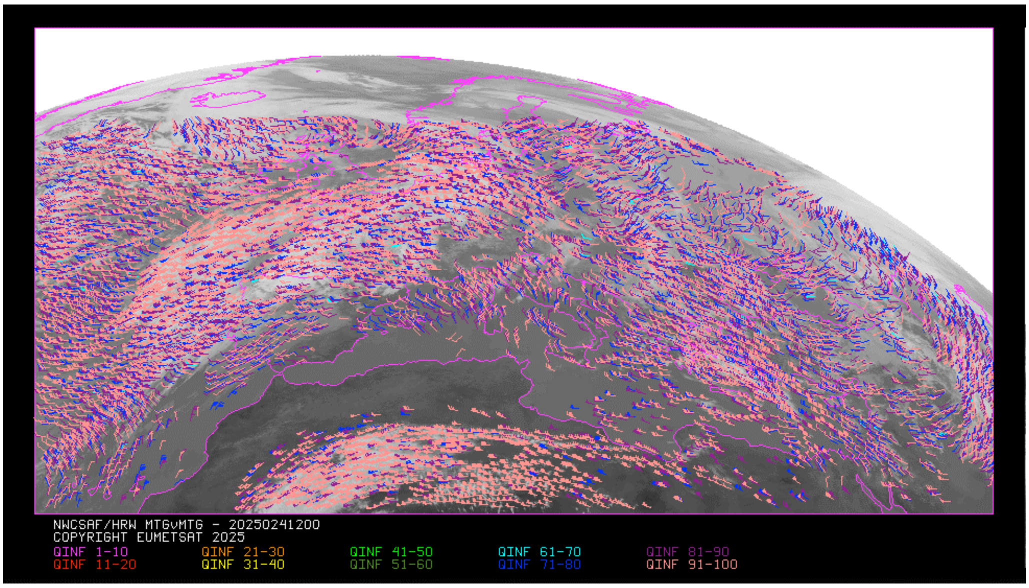


Figure 29: "Quality index without forecast" for the High Resolution Winds example defined in Figure 32 (24 January 2025 12:00 UTC, MTG-I/1 satellite). All values are formally possible for the "Quality index without forecast", but because of its connection with the "Quality index with forecast", only values of "Quality index without forecast" ≥ 67% are here really present.

COMMON QUALITY INDEX WITHOUT FORECAST

Through the experience in the "International Winds Workshops", it was clearly concluded that the configuration of the "Quality Indices" is very different for different AMV algorithms, and so a common homogeneous use for AMVs calculated with different algorithms was not possible up to now.

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

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

- It is only calculated for AMVs/Trajectories with at least two trajectory sectors.
- For the "spatial consistency test" only the closest "neighbour AMV" is considered. For the "temporal consistency test" only the "prior AMV" related to the same trajectory is considered.
- Four different tests are applied: the direction, speed and vector difference tests for the temporal consistency, and the vector difference for the spatial consistency with a double contribution. Some parameters in the formulae for calculation of the "Individual Quality Indices" are also slightly different.
- It is not used for the filtering of AMVs and Trajectories by NWC/GEO-HRW, so all values between 1% and 100% are possible. For AMVs and Trajectories for which it could not be calculated, an "unprocessed value" is defined.

EXAMPLE OF AMV COMMON QUALITY INDEX WITHOUT FORECAST

An example of AMVs for MTG-I satellite series is shown in *Figure 30*, considering the "Common Quality Index without forecast".

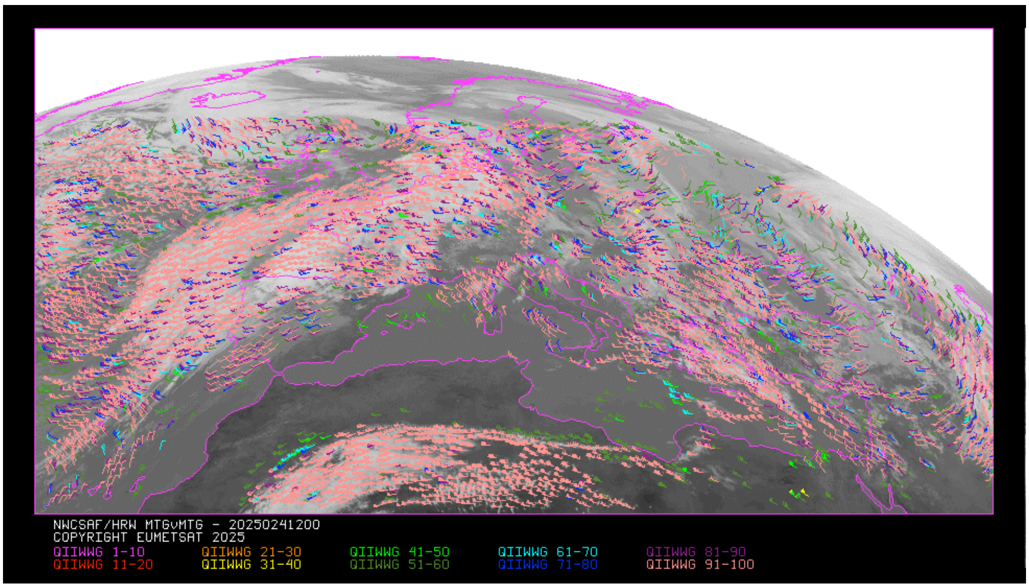


Figure 30: "Common Quality index without forecast" for the High Resolution Winds example defined in Figure 32 (24 January 2025 12:00 UTC, MTG-I/1 satellite). All values are possible for the "Common Quality index without forecast". The difference with Figures 28 and 29, and the fact that not all AMVs have a valid value for the "Common Quality index without forecast" are to be noticed.

2.2.2.11 Orographic flag

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

The reasons for this land influence may be: AMVs associated to land features incorrectly detected as cloud tracers; tracers blocked or whose flow is affected by mountain ranges; tracers associated to lee wave clouds with atmospheric stability near mountain ranges. These tracers present displacements, which do not correspond with the general atmospheric flow. Because of this, the corresponding AMVs are not considered as valid.

The procedure to calculate the "Orographic flag" implies the reading of NWP geopotential data and of one topography matrix for the defined satellite and positioning (`S_NWC_SFCMAX*raw`, located in `$SAFNWC/import/Aux_data/Common` directory). This matrix defines the 97% centile of the topography histogram for each pixel, in which data up to 1 degree away are considered. It is called the "Representative height matrix at the top of topography" around each pixel.

This matrix is then converted to "Representative surface pressure matrix at the top of topography" with NWP geopotential data. To do this, the "Height matrix" is converted to geopotential values (multiplying by a constant value of gravity), and the geopotential is then inversely interpolated to pressure to define the "Representative surface pressure at the top of topography" around each pixel (P_top). This value represents the representative surface pressure at the highest locations in the topography up to one degree away of each pixel of the image. For optimization reasons, 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).

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

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

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

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

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

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

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

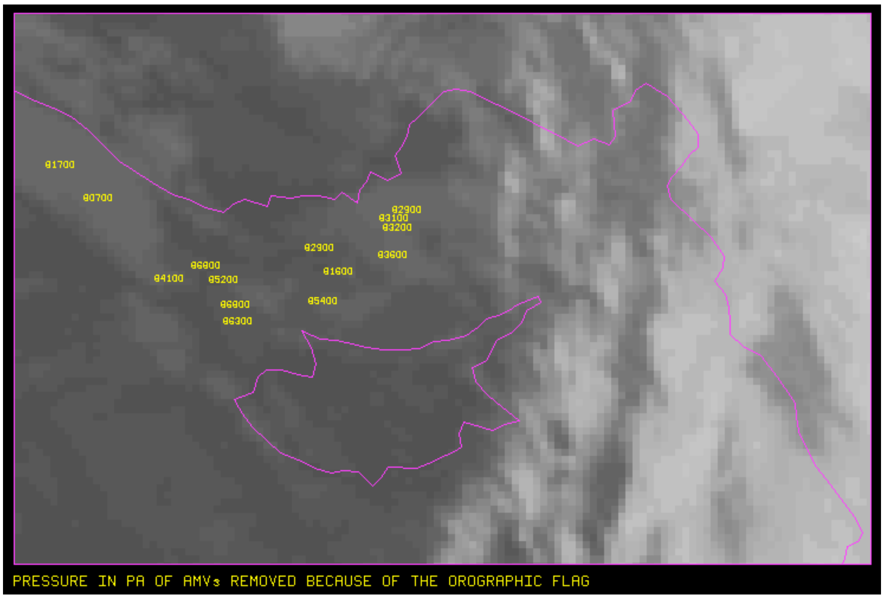


Figure 31: Pressure values in Pa for AMVs affected by orography (i.e. with "Orographic flag" values between 1 and 5) in a zoomed area around the island of Cyprus for an example case (Basic AMVs, MSG-2 satellite). Orographic effects are caused by the mountains in Cyprus and Turkey, reaching respectively 2000 m and more than 3000 m

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

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

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

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

2.2.2.12 Final Control Check and Output data filtering

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

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

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

Several output data filterings are additionally considered in this step, which depend on the value of several configurable parameters. 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.
- 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 9* is implemented (in which the blue layers for the different channels are eliminated; light blue layers are eliminated only for "Clear air AMVs and Trajectories"; very dark blue layers are only eliminated if configurable parameter VERYLOWINFRAREDAMVS = 1, which is not implemented as default option).
  - With FINALFILTERING > 1 (which is the default option with FINALFILTERING = 2), the "AMV cloud type" filtering defined in *Table 6* is also implemented.
  - With FINALFILTERING > 2, AMVs with a "spatial quality flag" = 1,2 are also eliminated.
  - With FINALFILTERING = 4, AMVs with a "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 9: AMV filtering related to the Pressure level and Satellite channel

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

2.3.1 Autovalidation process 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 (u,v), 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 with 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 in NWC/GEO-HRW:

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

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

- The second one, activated with configurable parameter NWPVAL_NWPBESTFITLEVEL = 1 (implemented also as a default option) calculates also for each AMV the "NWP reference wind at the best fit pressure level" (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 at [RD.26], and is only defined at some specific circumstances, to avoid broad best fit pressure values which are not very meaningful: The minimum vector difference between the AMV 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 again 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.

2.3.2 List of 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 `$SAFNWC/import/Sdi_data` directory. IR105 channel is additionally needed for the visible channel processing when the old "Brightness temperature interpolation height assignment" is to be used. IR105 and WV063 channels are in any case needed if the default configuration of the Quality control is kept (including the "Image correlation test").
- Considering MSG satellite series: full resolution uncompressed original HRIT data for the processing region, for the images in which tracers are calculated and tracked. These data are to be located in `$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 uncompressed EUMETSAT HRIT data (EHH format), for the processing region, for the images in which tracers are calculated and tracked. These data are to be located in `$SAFNWC/import/Sat_data` directory, and then have to be converted to NWC/GEO "netCDF satellite specific NWC/GEO input data format (FSD format)" with the provided `$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 Clouds" 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. 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 takes place.

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

- The NWC/GEO-HRW Model Configuration File `safnwc_HRW.cfm` located in `$SAFNWC/config` directory, to be used such as explained in Chapter 2.3.3 of this document.
- The Satellite Configuration File `sat_conf_file` located in `$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].

2.3.3 List of Configurable parameters for High Resolution Winds (NWC/GEO-HRW)

The NWC/GEO-HRW 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 10: 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, 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.

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

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 the 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, MTGI-1, 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 MTGI-1, 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 11: List of errors for NWC/GEO-HRW

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

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 AMV 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.

2.3.5.1 HRW output as BUFR bulletins 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 implemented 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 12*. 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 12: 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 13*.

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 more than a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is at least two units lower than for the wind calculated for the same tracer with the best orographic flag)' 2: 'Wind whose corresponding quality test is up to a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the wind calculated for the same tracer with the best orographic flag)' 3: 'Wind with the best corresponding quality test among the winds calculated for a tracer'.
060205	Orographic index. Possible values: The values of this parameter are between 0 and 6, corresponding to those defined for "Ind_topo" parameter in chapter 2.2.2.11 of this document.
060206	Cloud type associated to the tracer. Possible values: The values of this parameter are between 0 and 23, corresponding to those defined in *Table 5* of this document.
060207	Flag indicating the satellite channel used for the wind calculation (Updated table for NWC/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 13: Description of "local variables" in the NWCSAF specific BUFR format

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

When OUTPUT_FORMAT = NWC, if the calculation of trajectories is activated with configurable parameter CALCULATE_TRAJECTORIES = 1 (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 implemented 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 14*. 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 parameter 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 14: Variables used for the Trajectory output with the NWCSAF specific BUFR format

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

When OUTPUT_FORMAT = IWWG, 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 15*, 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 (4 = BEST FIT LEVEL)	FLAG TABLE 08086
007004	PRESSURE (for NWP data at AMV best fit level, if calculated)	PA
011095	U-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
011096	V-COMPONENT OF THE MODEL WIND VECTOR (for NWP data at AMV best fit level, if calculated)	M/S
008086	VERTICAL SIGNIFICANCE FOR NWP (4095 = CANCEL)	FLAG 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 15: Variables used for the AMV output with the 2018 IWWG BUFR format

2.3.5.4 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 version, 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 16.* The structure of the netCDF output attributes is shown in *Table 17.* 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 2.3.5.1), the “Valid range” for each variable and the “Fill value” for each variable are also included in *Table 16*.

The netCDF output includes two dimensions, also shown in *Table 16*:

- 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 16: 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 17: Specification of the NWC/GEO-HRW netCDF AMV output attributes

2.3.5.5 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 18.* The structure of the netCDF output attributes is shown in *Table 19.* 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 2.3.5.2), the "Valid range" for each variable and the "Fill value" for each variable are also included in *Table 18.*

The netCDF output includes three dimensions, also shown in *Table 18*:

- 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 2.3.5.2, 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 18: 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 19: Specification of the NWC/GEO-HRW netCDF Trajectory output attributes

2.3.6 Examples of High Resolution Winds (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 MTG-I satellite data in the European and Mediterranean region (*Figures 32 and 33*). Second, with MSG-2 satellite data in the European and Mediterranean region (*Figures 34 and 35*). 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 36 and 37*). Fourth, with GOES-16 satellite data in the Continental United States region (*Figures 38 and 39*).

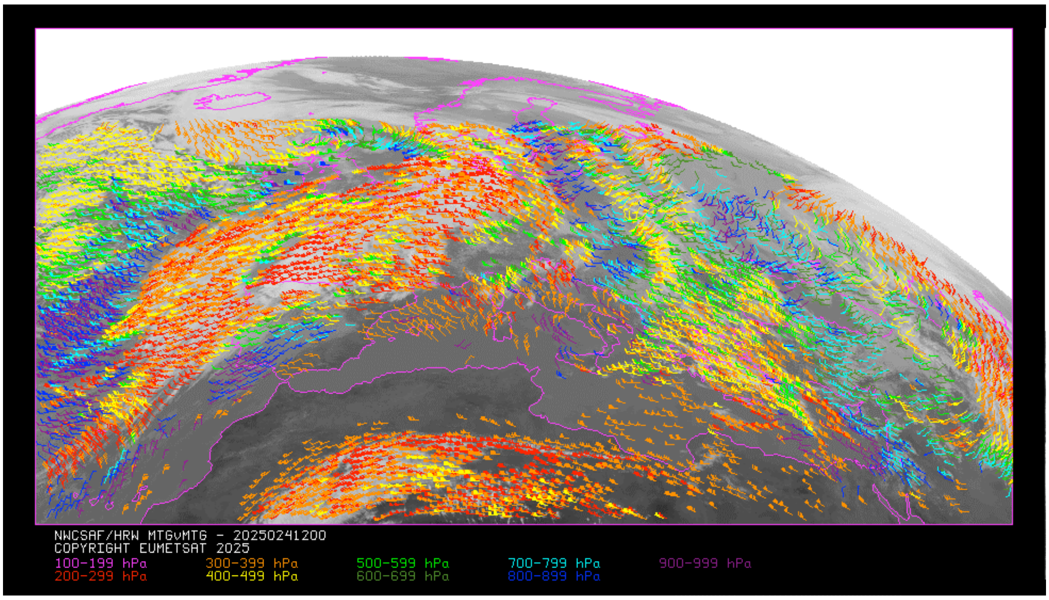


Figure 32: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, MTG-I/1 satellite data), considering default conditions in `$SAFNWC/config/MTI*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

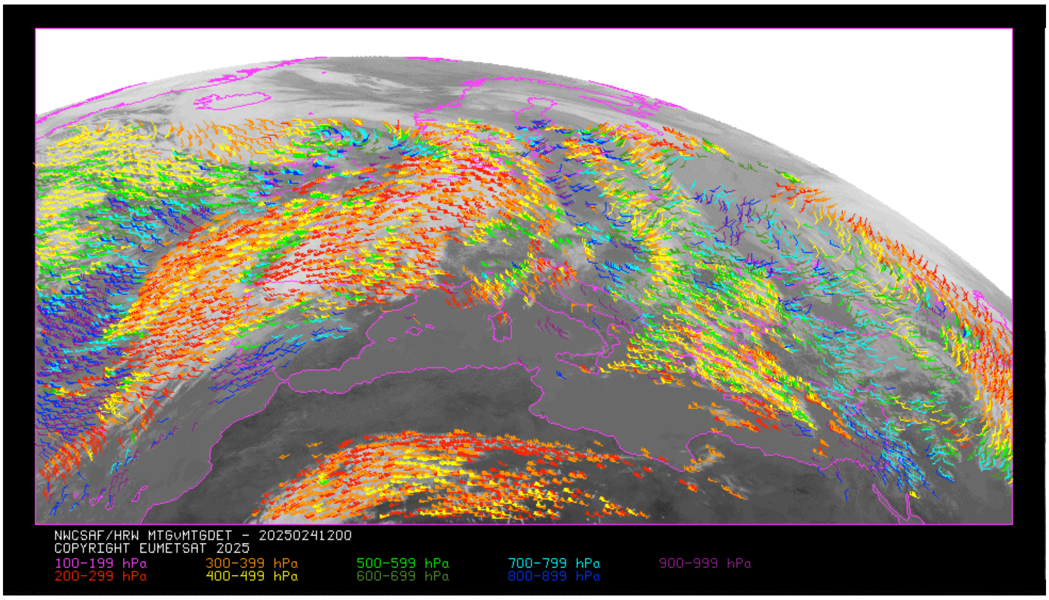


Figure 33: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, MTG-I/1 satellite data), considering default conditions in `$SAFNWC/config/MTI*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

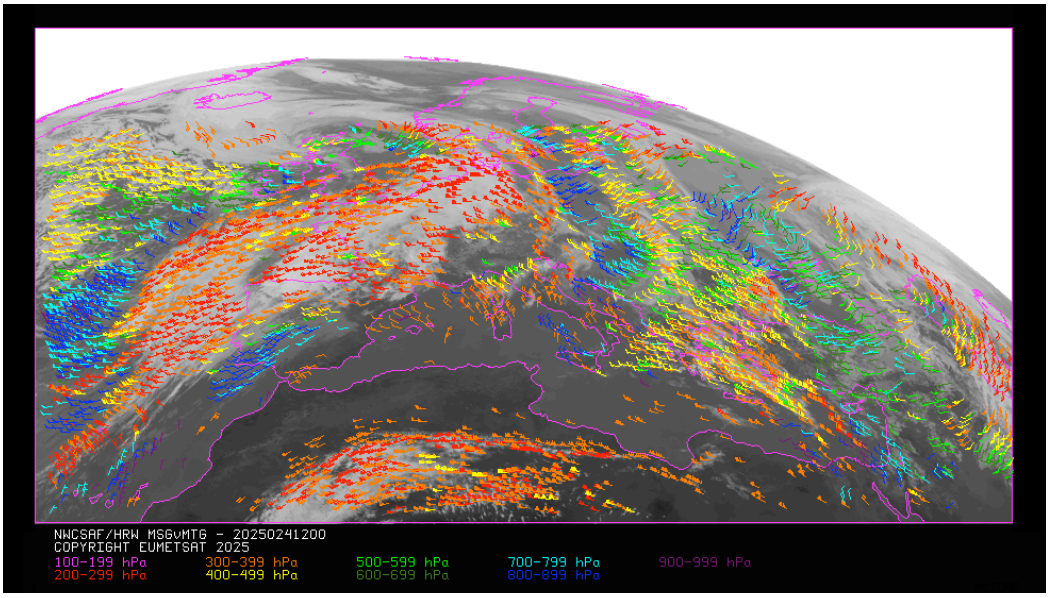


Figure 34: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, MSG-3 satellite), considering default conditions in `$SAFNWC/config/MSG*/safnwc_HRW.cfm` *model configuration file. Colour coding based on the AMV pressure level*

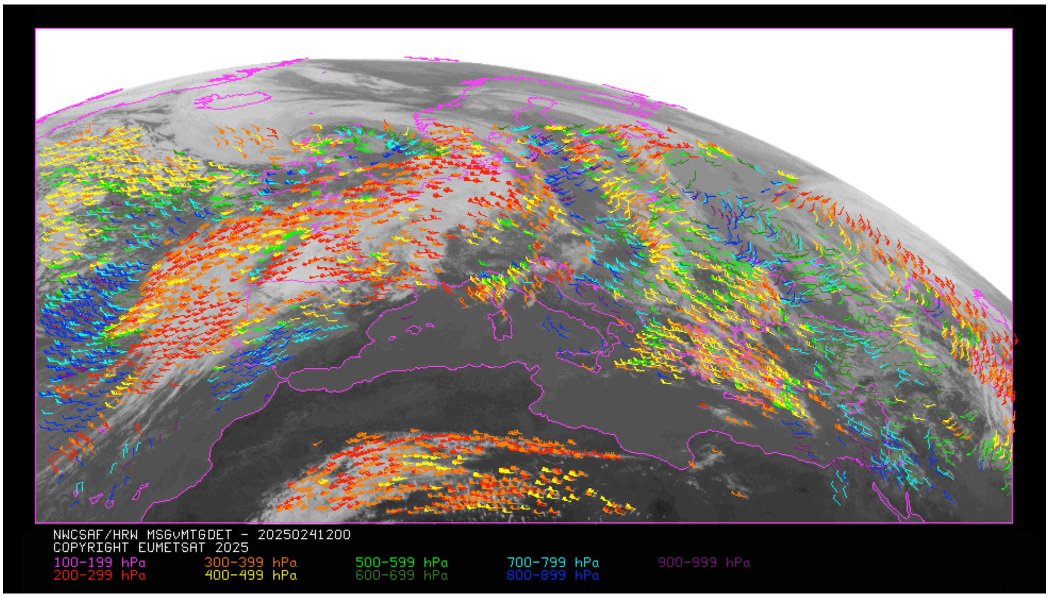


Figure 35: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the European and Mediterranean region (24 January 2025 12:00 UTC, MSG-3 satellite), considering default conditions in `$SAFNWC/config/MSG*/safnwc_HRW.cfm` *model configuration file and configurable parameter CDET = 1. Colour coding based on the AMV pressure level*

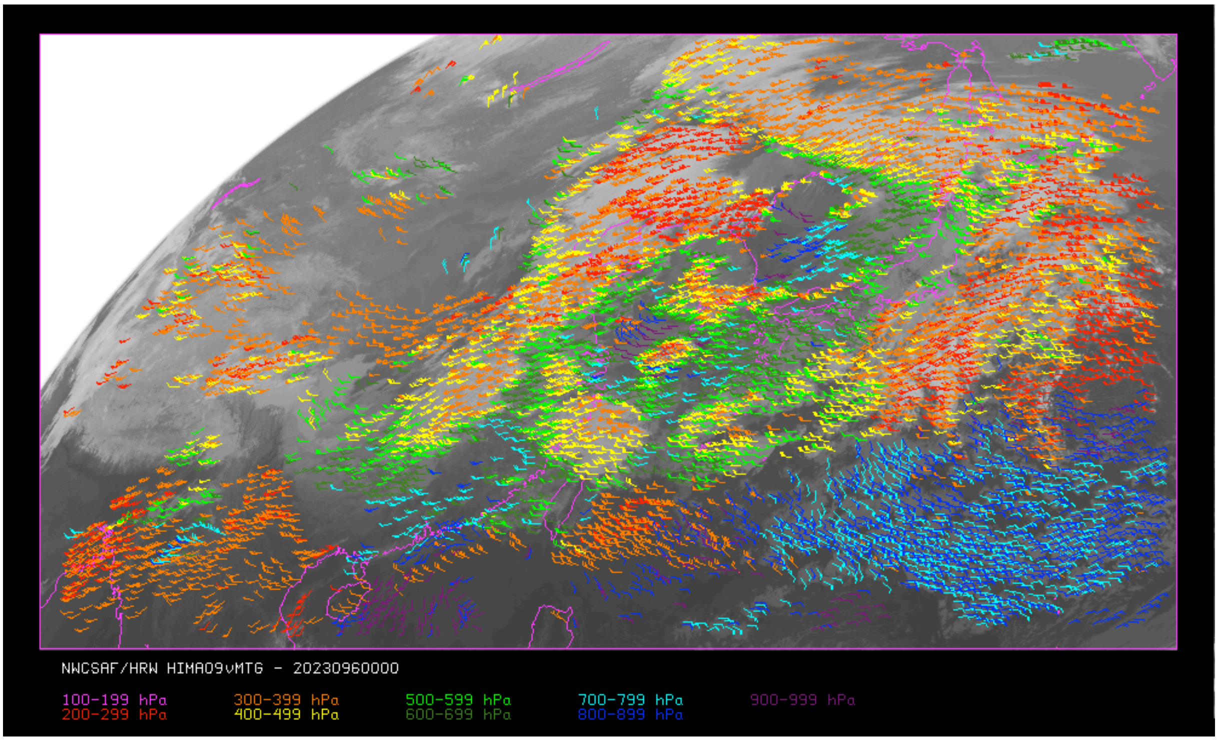


Figure 36: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the China/Korea/Japan region (6 April 2023 00:00 UTC, Himawari-9 satellite), considering default conditions in `$SAFNWC/config/HIMA*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

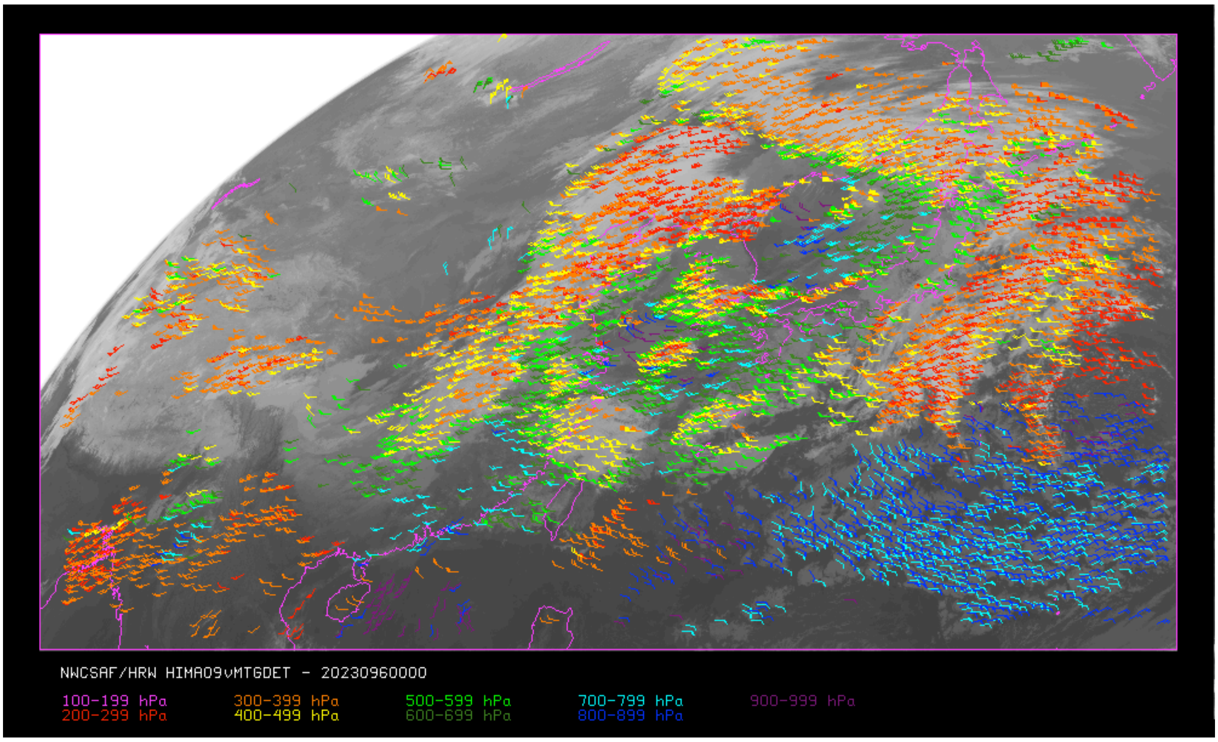


Figure 37: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the China/Korea/Japan region (6 April 2023 00:00 UTC, Himawari-9 satellite), considering default conditions in `$SAFNWC/config/HIMA*/safnwc_HRW.cfm` model configuration file and configurable parameter CDET = 1. Colour coding based on the AMV pressure level

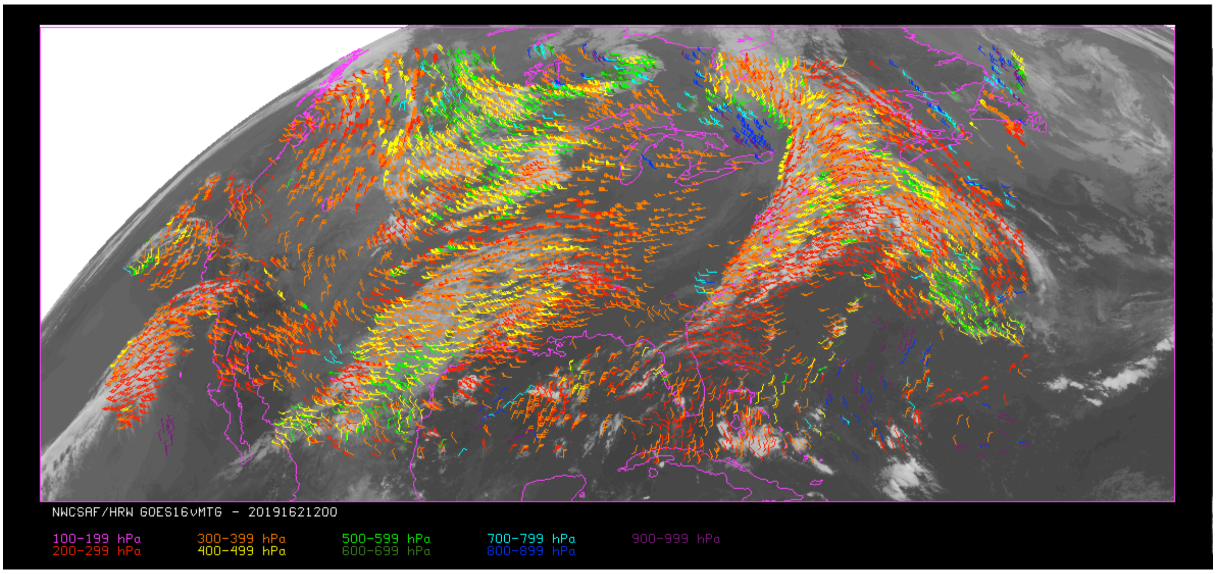


Figure 38: NWC/GEO-High Resolution Winds v7.0 Basic AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions in `$SAFNWC/config/GOES*/safnwc_HRW.cfm` *model configuration file. Colour coding based on the AMV pressure level*

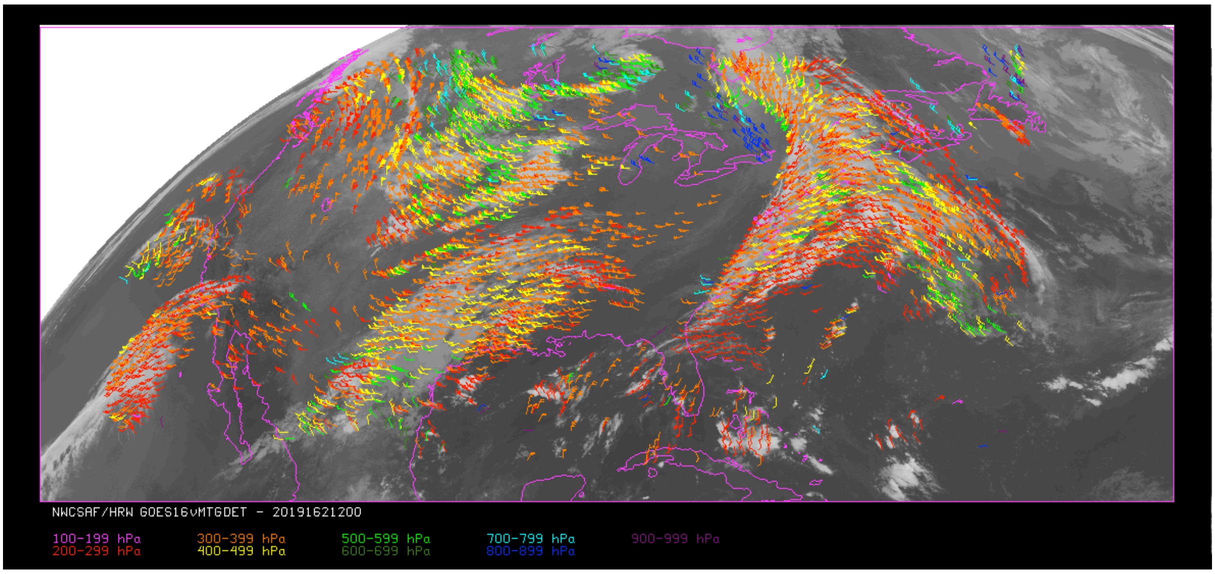


Figure 39: NWC/GEO-High Resolution Winds v7.0 Detailed AMV output example in the Continental United States region (11 June 2019 12:00 UTC, GOES-16 satellite), considering default conditions in `$SAFNWC/config/GOES*/safnwc_HRW.cfm` *model configuration file and configurable parameter CDET = 1. Colour coding based on the AMV pressure level*

2.3.7 Use of High Resolution Winds (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).

2.3.7.1 Installation and preparation of NWC/GEO Software package

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.

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

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/NWC/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 2.3.3 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 through the corresponding `$SAFNWC/config/sat_conf_file` used.

To have NWC/GEO Cloud Type, Cloud Top Temperature and Pressure and Cloud Microphysics outputs available for their use by NWC/GEO-HRW executable, it is also necessary to run `GEO-CMA`, `GEO-CT`, `GEO-CTTH` and `GEO-CMIC` executables before `GEO-HRW-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 40 to 42 summarise how the tasks to generate the AMVs and Trajectories are performed by the `GEO-HRW-v70` executable:

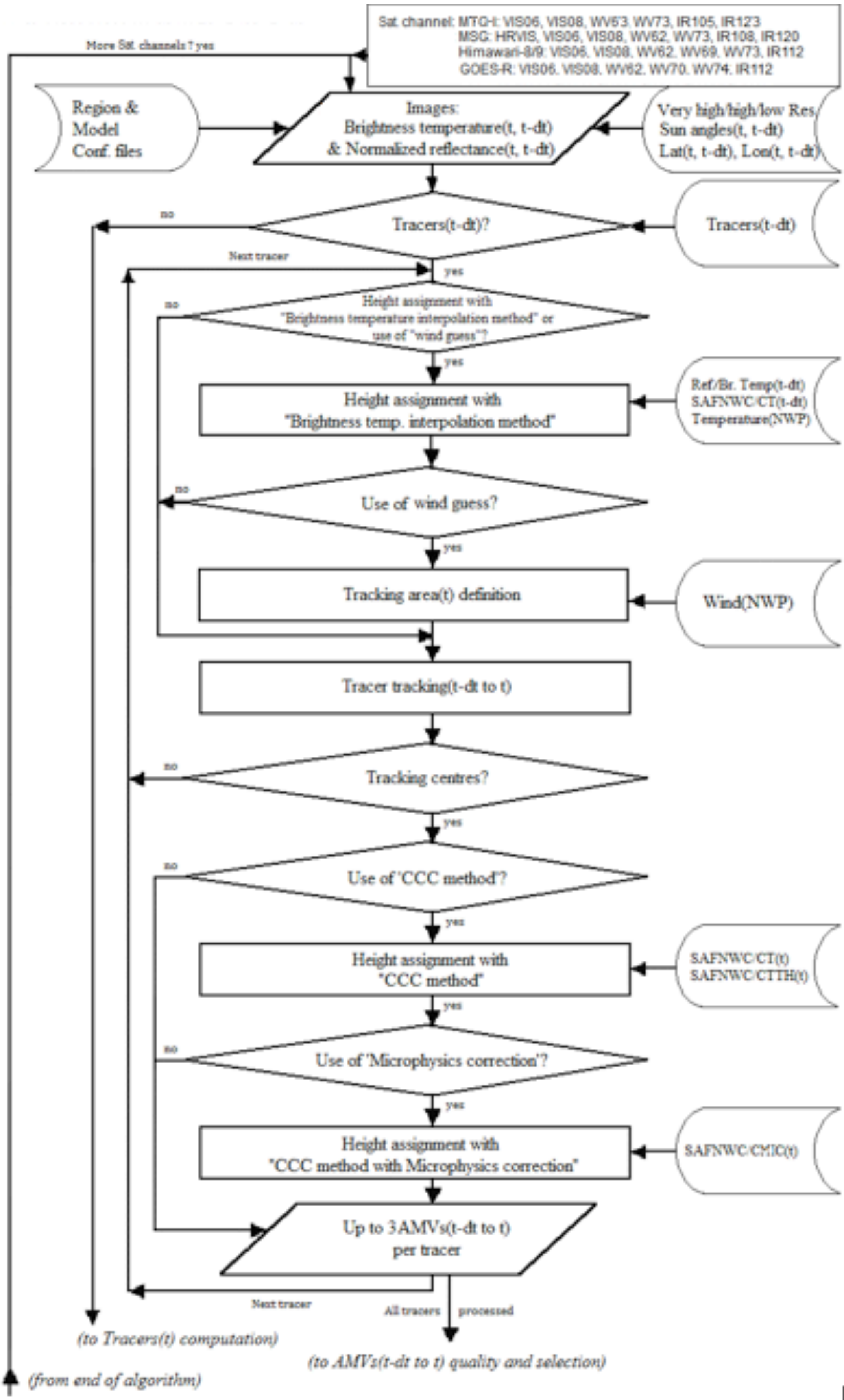


Figure 40: NWC/GEO-HRW implementation: Part 1, Preprocessing and AMV computation

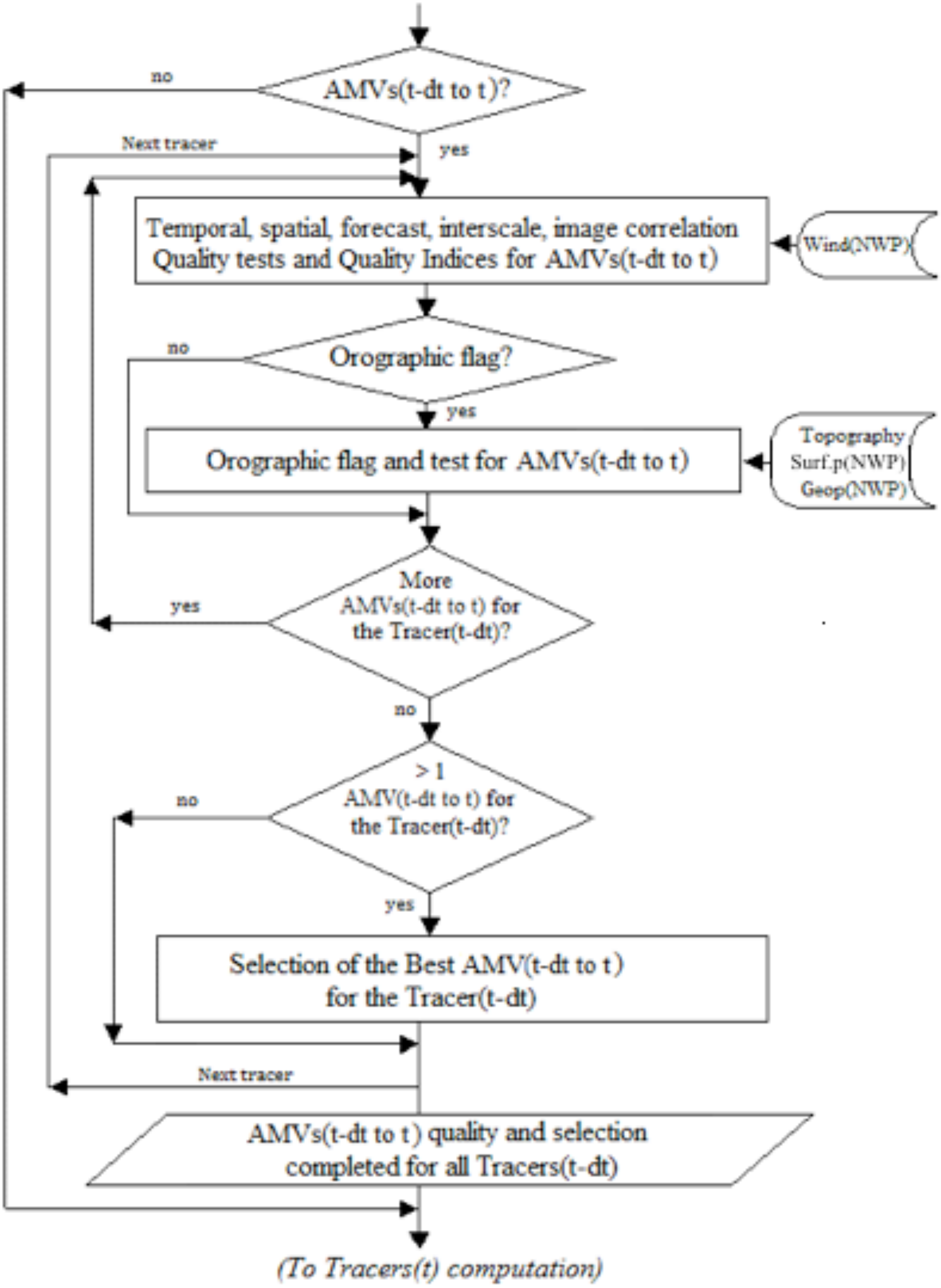


Figure 41: NWC/GEO-HRW implementation: Part 2, AMV quality and selection

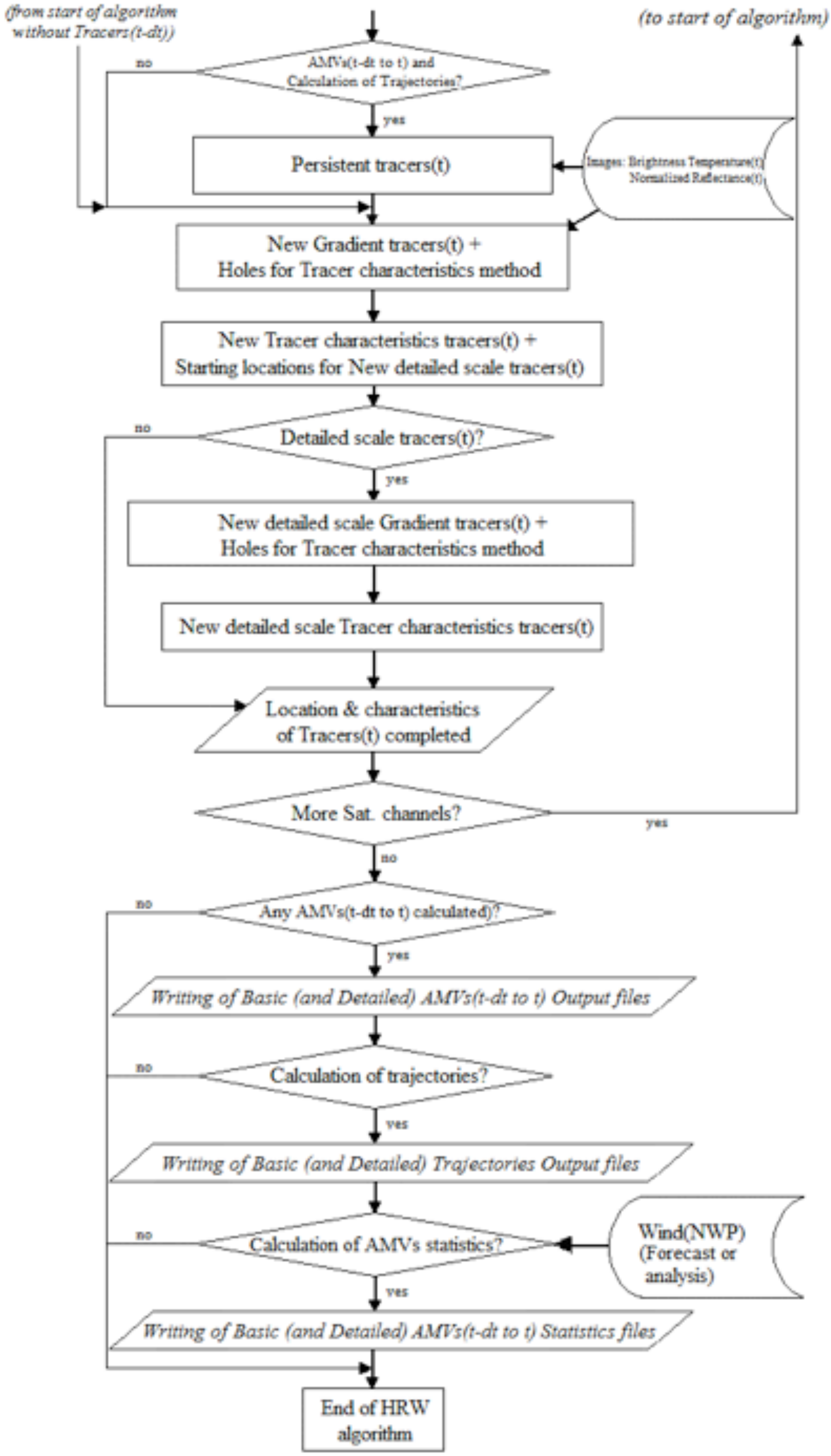


Figure 42: NWC/GEO-HRW implementation: Part 3, Tracer computation and writing of output

2.3.7.3 Documentation of High Resolution Winds (NWC/GEO-HRW)

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 algorithm and their relationships is also provided in a Diagram tree shown in following pages. This Diagram tree allows NWC/GEO users and developers to quickly know at a glance how it works.

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

```
HRW.c                                                    => Main NWC/GEO-HRW function, for the generation of the High Resolution Winds AMVs and Trajectories
 *** hrw_ReadData                                        => Reads the values of variables defined in the NWC/GEO-HRW Model configuration file
 *** hrw_ReadSatelliteData                               => Reads and initializes Satellite data (VIS Reflectances, WV/IR Brightness temperatures)
 *** hrw_GetAncillaryData                                => Gets latitude/longitude/satellite zenith angles/solar zenith angles for the pixels in the Region
 *** hrw_ImageCheckingInfrared                           => Checks and redefines Satellite brightness temperature/radiance values
 *** hrw_ImageChecking                                   => Checks and redefines Satellite image values
 *** hrw_NWPSearch                                       => Reads the NWP profile data related to one NWP parameter
 *** hrw_NWPSearchSurface                                => Reads the NWP surface data
 *** hrw_ReadTracers                                     => Reads the Tracer data from a file located in $SAFNWC/tmp/HRW directory
 *** hrw_ReadPredWinds                                   => Reads the Predecessor AMV data from a file located in $SAFNWC/tmp/HRW directory
 *** hrw_ReadTrajectories                                => Reads the Trajectory data from a file located in $SAFNWC/tmp/HRW directory
 *** hrw_GetWinds                                        => Calculates the AMVs for the current image considering the tracers calculated previously
      *** hrw_Alloc_Winds                                => Allocates memory for variables used in hrw_GetWinds module
      *** hrw_TracerCharacteristics                      => Stores "tracer" variable information into the corresponding "tracer_wind" variable
      *** hrw_SetModifTempGridValues                     => Fills "modiftempgrid" with IR/WV BT values for the "Brightness temperature height assignment"
      *** hrw_GetCldhgt                                  => Calculates Tracer Top temperature/pressure with "Brightness temperature height assignment"
           *** hrw_NWPInvInterpolation                   => Converts the Tracer top Temperature to Pressure using NWP data
      *** hrw_SetImageGridValues                         => Fills "imagegrid" with VIS Reflectances or IR/WV BT values in the tracer position
      *** hrw_CalcTempCloudtype                          => Recalculates Tracer temperature mean/sigma with Cloud type info (for Tracer base temperature)
      *** hrw_NWPInvInterpolation                        => Converts Tracer base Temperature to pressure using NWP data and modified mean/sigma values
      *** hrw_TracerWindLevel                            => Defines the Tracer pressure level (with cloud top or cloud base) depending on its cloud type
      *** hrw_NWPDirInterpolation                        => Calculates the tracer pressure level using the tracer temperature
      *** hrw_WindGuess                                  => Calculates the NWP wind guess at the tracer position
           *** hrw_NWPDirInterpolation                   => Calculates the NWP wind at the tracer level considering the AMV pressure level calculated
           *** hrw_WindModDir                            => Calculates the speed module and direction for the NWP wind guess at the tracer position
     *** hrw_WindDisplace                                => Calculates the tracking centre position forecast in the later image with the NWP wind guess
           *** hrw_WindModDir                            => Calculates the speed module and direction for the NWP wind guess at the tracer position
```

```
*** hrw_TrueTrackCentre                         => Calculates the true tracking centre position in the later image
      *** hrw_SetImageArrayValues               => Fills an array with VIS Reflectances or IR/WV BTs in tracer/tracking position for the tracking
      *** hrw_SetCTTHMicroArrayValues           => Fills an array with CTTH Temperature/pressure, CMIC Water path for "CCC method" height assignment
      *** hrw_SetCtypeArrayValues               => Fills an array with CT Cloud type/CMIC Cloud phase for "CCC method" height assignment
      *** hrw_Track                             => Calculates the true tracking positions in later image with "Euclidean distance/Cross correlation"
          *** hrw_TrackCorrInitial              => Computes the tracking first step considering only pixels separated by a gap interval
          *** hrw_TrackCorrBetter               => Calculates the Euclidean distance minimums/Correlation maximums considering the previous positions
          *** hrw_TrackCorrAround               => Calculates the Euclidean distance/Correlation values only around the prior minimums/maximums
          *** hrw_TrackCorrCentres              => Defines the Euclidean distance minimum centres/Correlation maximum centres
              *** hrw_TrackCorrCentresPosition  => Defines a non integer position of the tracking centres through a quadratic interpolation
      *** hrw_GetSegmentSize                    => Computes the line and column dimension of the tracer in m
   *** hrw_TrackCentreCharacteristics           => Calculates the "tracer characteristics" in the tracking positions in the later image
      *** hrw_SetImageGridValues                => Fills an array with VIS Reflectances or IR/WV BTs in the final tracking position
      *** hrw_Frontier_Centile                  => Defines the frontier in the BT/Reflectance histogram considering a given centile
      *** hrw_Centile_Frontier                  => Defines the centile in the BT/Reflectance histogram considering a given frontier
      *** hrw_TracerDiffSearch                  => Runs the “Big pixel brightness variability test” in the tracking positions
          *** hrw_TracerPixelCharacterization   => Calculates the “Big pixel brightness values” in the tracking positions
          *** hrw_TracerHorizontalDiff          => Considers the Line direction study in the “Big pixel brightness variability test”
          *** hrw_TracerVerticalDiff            => Considers the Column direction study in the “Big pixel brightness variability test”
          *** hrw_TracerDescDiff                => Considers the Descending direction study in the “Big pixel brightness variability test”
          *** hrw_TracerAscDiff                 => Considers the Ascending direction study in the “Big pixel brightness variability test”
      *** hrw_SetTempGridValues                 => Fills “tempgrid” with IR/WV BT values in the tracking positions
      *** hrw_CalcTemp                          => Calculates the temperature mean/sigma in the tracking positions
      *** hrw_TrackCentreCorrection             => Evaluates if the reference tracking centre must be changed or not
          *** hrw_TracerDiffSearch              => Reruns the “Big pixel brightness variability test” in the tracking positions with new frontiers
              *** hrw_TracerPixelCharacterization => Calculates the “Big pixel brightness values” in the tracking positions with new frontiers
              *** hrw_TracerHorizontalDiff      => Considers the Line direction study in the “Big pixel brightness variability test”
              *** hrw_TracerVerticalDiff        => Considers the Column direction study in the “Big pixel brightness variability test”
              *** hrw_TracerDescDiff            => Considers the Descending direction study in the “Big pixel brightness variability test”
              *** hrw_TracerAscDiff             => Considers the Ascending direction study in the “Big pixel brightness variability test”
   *** hrw_WindCalculation                      => Calculates parameters related to a tracking position, including "CCC method" parameters
      *** hrw_Erase_Wind                        => Erases information stored inside an invalid “wind” data
      *** hrw_NWPInvInterpolation               => Converts the Clear air tracking position temperatures to pressure values using NWP data
      *** hrw_Ymvuv                             => Calculates the wind components considering the initial/final latitude/longitude positions
      *** hrw_WindModDir                        => Calculates the wind module and direction for the calculated AMVs
```

```
     *** hrw_WindGuess                                     => Recalculates the wind guess/analysis at initial/final position for Quality Control and validation
          *** hrw_NWPDirInterpolation                      => Calculates the NWP wind at the AMV level considering the final AMV pressure level
          *** hrw_WindModDir                               => Calculates speed module and direction for the NWP wind guess/analysis at initial/final position
     *** hrw_WindModDir                                    => Calculates speed module and direction for difference with the NWP wind guess/analysis
     *** hrw_WindGuessBestFit                              => Calculates the wind guess/analysis at best fit level at final position for validation
          *** hrw_WindModDir                               => Calculates speed module and direction for the NWP wind guess at final position
     *** hrw_Free_Winds                                    => Deallocates memory for variables used in hrw_GetWinds module
     *** hrw_WindModDir                                    => Calculates speed module and direction for difference with the NWP wind guess/analysis at best fit
*** hrw_Qc                                                 => Calculates the Quality indices and the Orographic flag for the calculated AMVs/Trajectories
     *** hrw_QcAlloc_Short, _Float, _Parameters            => Three functions allocating memory for variables in hrw_Qc module
     *** hrw_QcSortLatitude                                => Sorts the current and predecessor AMV data considering their latitudes in their final positions
          *** hrw_QcSort                                   => Sorts an array of data considering one of its variables
               *** hrw_QcSortCompare                       => Decides how to compare the elements to be sorted
     *** hrw_QcPhase1                                      => Calculates the individual (forecast/temporal/spatial) quality tests and total quality indices
          *** hrw_QcPhase1_Alloc                           => Allocates memory for variables in hrw_QcPhase1 module
          *** hrw_QcGetSpatialTest                         => Calculates the spatial quality test for a defined AMV
          *** hrw_QcGetTemporalTest                        => Calculates the temporal quality test for a defined AMV
               *** hrw_WindModDir                          => Calculates the speed and direction for the predecessor AMV data
          *** hrw_QcPhase1_Free                            => Deallocates memory for variables in hrw_QcPhase1 module
     *** hrw_Meters2Press                                  => Converts Orographic data to Surface pressure data
          *** hrw_NWPInvInterpolation                      => Converts Geopotential to Surface pressure data using NWP data
     *** hrw_IndTopoAssign                                 => Calculates the Static orographic flag at the initial position of a current AMV
     *** hrw_IndTopoReassign                               => Calculates the Dynamic orographic flag at the initial position of a current AMV
     *** hrw_QcBestWindSelection                           => Selects the best AMV for each tracer and calculates the quality flags
     *** hrw_FinalControlCheck                             => Runs a Final speed and direction homogeneity check for the AMVs
     *** hrw_ProcessforQcCommonIWWG                        => Prepares for the running of self-contained module for calculation of the IWWG Common Quality Index
          *** hrw_QcCommonIWWG_Function                    => Runs the EUMETSAT/NOAA self-contained module for calculation of the IWWG Common Quality Index
     *** hrw_QcFree_Short, _Float, _Parameters             => Three functions deallocating memory for variables in hrw_Qc module
*** hrw_WritePredWinds                                     => Writes the AMV data file for the current image in $SAFNWC/tmp/HRW directory
*** hrw_WriteTrajectories                                  => Writes the Trajectory data file for the current image in $SAFNWC/tmp/HRW directory
*** hrw_WriteWindChannelInfo                               => Writes all AMV/Trajectory info in "wind_channel_info" data, calculating the AMV channel statistics
     *** hrw_CalculateChannelStatistics                    => Calculates the AMV validation statistics for one satellite channel, using NWP forecast or analysis
          *** hrw_Ymvuv                                    => Calculates the wind components considering the initial/final latitude/longitude positions
```

```
*** hrw_GetTracers                                 => Calculates the tracers for the current image
     *** hrw_Alloc_Tracers                         => Allocates memory for variables in hrw_GetTracers module
     *** hrw_SetImageGridValues                    => Fills “imagegrid” with VIS Reflectances or IR/WV BTs in a tracer position for the tracer search
     *** hrw_SearchTracerGradient                  => Looks for tracers considering the “Gradient method”
          *** hrw_GradientMax                      => Calculates the tracer position considering the gradient maximum
          *** hrw_SetImageGridValues               => Fills “modifimagegrid” with VIS Reflectances or IR/WV BTs in the modified tracer position
          *** hrw_Hisfron                          => Computes the VIS Reflectance or IR/WV BT histogram in the tracer area and its frontiers
          *** hrw_SetTempGridValues                => Fills “tempgrid” with IR/WV BT values in the modified tracer position
          *** hrw_CalcTemp                         => Calculates the temperature mean/sigma in the modified tracer position
          *** hrw_SearchTracerCharacteristics      => Looks for tracers considering the “Tracer characteristics method”
          *** hrw_SetImageGridValues               => Fills “imagegrid” with VIS Reflectances or IR/WV BTs in a tracer position for the tracer search
          *** hrw_Hisfron                          => Computes the VIS Reflectance or IR/WV BT histogram in the tracer area and its frontiers
          *** hrw_SetTempGridValues                => Fills “tempgrid” with IR/WV BT values in the tracer position
          *** hrw_CalcTemp                         => Calculates the temperature mean/sigma in the tracer position
          *** hrw_TracerDiffSearch                 => “Big pixel brightness variability test”, run here for “Tracer characteristics method” tracers
               *** hrw_TracerPixelCharacterization => Calculates the “Big pixel brightness values” in the tracer position
               *** hrw_TracerHorizontalDiff        => Considers the Line direction study in the “Big pixel variability test”
               *** hrw_TracerVerticalDiff          => Considers the Column direction study in the “Big pixel variability test”
               *** hrw_TracerDescDiff              => Considers the Descending direction study in the “Big pixel variability test”
               *** hrw_TracerAscDiff               => Considers the Ascending direction study in the “Big pixel variability test”
          *** hrw_SetImageGridValues               => Refills “imagegrid” with VIS Reflectances or IR/WV BTs if the previous candidate was not good
          *** hrw_TracerDiffSearch                 => “Big pixel brightness variability test”, run here for “Tracer characteristics method” tracers
               *** hrw_TracerPixelCharacterization => Calculates the “Big pixel brightness values” in the modified tracer position
               *** hrw_TracerHorizontalDiff        => Considers the Line direction study in the “Big pixel variability test”
               *** hrw_TracerVerticalDiff          => Considers the Column direction study in the “Big pixel variability test”
               *** hrw_TracerDescDiff              => Considers the Descending direction study in the “Big pixel variability test”
               *** hrw_TracerAscDiff               => Considers the Ascending direction study in the “Big pixel variability test”
     *** hrw_CloudTypeCalculation                  => Calculates the Cloud type related to the tracer
     *** hrw_TracerDiffSearch                      => “Big pixel brightness variability test”, run here for “Gradient method” tracers
               *** hrw_TracerPixelCharacterization => Calculates the “Big pixel brightness values” in the tracer position
               *** hrw_TracerHorizontalDiff        => Considers the Line direction study in the “Big pixel brightness variability test”
               *** hrw_TracerVerticalDiff          => Considers the Column direction study in the “Big pixel brightness variability test”
               *** hrw_TracerDescDiff              => Considers the Descending direction study in the “Big pixel brightness variability test”
               *** hrw_TracerAscDiff               => Considers the Ascending direction study in the “Big pixel brightness variability test”
     *** hrw_TracersDetailedDiscrimination         => Defines if a Basic tracer can also work as Detailed tracer
     *** hrw_Centile_Frontier                      => Defines the centile in the BT/Reflectance histogram considering a given frontier
     *** hrw_Free_Tracers                          => Deallocates memory for variables in hrw_GetTracers module
```

```
*** hrw_WriteTracers                            => Writes the Tracer data file for the current image in $SAFNWC/tmp/HRW directory
*** hrw_Free_Satellite                          => Deallocates memory for Satellite data
*** hrw_Free_TWinds                             => Deallocates memory for "tracer wind" data
*** hrw_Free_PredWinds                          => Deallocates memory for "predecessor_wind" data
*** hrw_Free_Trajectories                       => Deallocates memory for "trajectory" data
*** hrw_Free_LevelsandGuesses                   => Deallocates memory for NWP data
*** hrw_CalculateTotalStatistics                => Calculates the AMV Statistics for the whole AMV dataset altogether
     *** hrw_Ymvuv                              => Calculates the wind components considering the initial/final latitude/longitude positions
*** hrw_EncodeBufrNWCEC                         => Writes the AMV/Trajectory BUFR output file using NWCSAF template in $SAFNWC/export/HRW directory
     *** hrw_EncodeAllChannelsforBUFRNWCEC      => Calls the different functions filling the sections that compose the BUFR bulletin
          *** hrw_SetChannelInfoforBUFRNWCEC    => Stores in AMV BUFR output the information related to one satellite channel using NWCSAF template
               *** hrw_SetAMVInfoforBUFRNWCEC   => Stores in AMV BUFR output the information related to one AMV using NWCSAF template
          *** hrw_SetChannelInfoforBUFRTRAJEC   => Stores in TRAJ BUFR output the information related to one satellite channel using NWCSAF template
               *** hrw_SetTrajectoryInfoforBUFRTRAJEC => Stores in TRAJ BUFR output the information related to one Trajectory using NWCSAF template
*** hrw_EncodeBufrIWWGEC                        => Writes the AMV BUFR output file using IWWG template in $SAFNWC/export/HRW directory
     *** hrw_EncodeAllChannelsforBUFRIWWGEC     => Calls the different functions filling the sections that compose the BUFR bulletin
          *** hrw_SetChannelInfoforBUFRIWWGEC   => Stores in AMV BUFR output the information related to one satellite channel using IWWG template
               *** hrw_SetAMVInfoforBUFRIWWGEC  => Stores in AMV BUFR output the information related to one AMV using IWWG template
*** hrw_DefineGlobalAtt                         => Defines the Global Attributes for the AMV netCDF output file
*** hrw_EncodeNetCDFNew                         => Writes the AMV netCDF output file in $SAFNWC/export/HRW directory
    *** hrw_WriteGlobalAtt                      => Writes the Global Attributes in the AMV netCDF output file
    *** hrw_WriteNetCDFNew                      => Calls the different functions filling the sections that compose the netCDF AMV bulletin
          *** hrw_Netcdfsecverwind_Initialize   => Initializes a “netcdfsecverwind struct” with all netCDF dimensions/variables/attributes
          *** hrw_WriteNcVarNew                 => Fills “netcdfsecverwind struct” with all related data
               *** hrw_SetNetCDF                => Defines specific information for each AMV in the netCDF bulletin
                    *** hrw_Ymvuv               => Calculates the wind components considering the initial/final latitude/longitude positions
                    *** hrw_WindModDir          => Calculates the speed module and direction of the mean AMV for its writing in the netCDF output
               *** hrw_Netcdfsecverwind_Fill    => Fills all netCDF dimensions/variables/attributes for the netCDF AMV output file
                    *** hrw_WriteDataUb1D       => Writes an unsigned byte 1D variable in the netCDF AMV output file
                    *** hrw_WriteDataUs1D       => Writes an unsigned short 1D variable in the netCDF AMV output file
                    *** hrw_WriteDataUi1D       => Writes an unsigned int 1D variable in the netCDF AMV output file
                    *** hrw_WriteDataD1D        => Writes a double 1D variable in the netCDF AMV output file
          *** hrw_Netcdfsecverwind_Write        => Writes all netCDF dimensions/variables/attributes in the netCDF AMV output file
          *** hrw_Netcdfsecverwind_Free         => Frees “netcdfwindsecver struct”  with all netCDF dimensions/variables/attributes data
```

```
*** hrw_DefineGlobalAtt                               => Defines the Global Attributes for the Trajectory netCDF output file
*** hrw_EncodeNetCDFNew                               => Writes the Trajectory netCDF output file in $SAFNWC/export/HRW directory
    *** hrw_WriteGlobalAtt                            => Writes the Global Attributes in the Trajectory netCDF output file
    *** hrw_WriteNetCDFNew                            => Calls the different functions filling the sections that compose the netCDF Trajectory bulletin
          *** hrw_Netcdfsecvertraj_Initialize         => Initializes a “netcdfsecvertraj struct” with all netCDF dimensions/variables/attributes
          *** hrw_WriteNcVarNew                       => Fills “netcdfsecvertraj struct” with all related data
               *** hrw_SetNetCDF                      => Defines specific information for each Trajectory in the netCDF bulletin
                    *** hrw_Ymvuv                     => Calculates the wind components considering the initial/final latitude/longitude positions
                    *** hrw_WindModDir                => Calculates the speed module and direction of the mean AMV for its writing in the netCDF output
               *** hrw_Netcdfsecvertraj_Fill          => Fills all netCDF dimensions/variables/attributes for the netCDF Trajectory output file
                    *** hrw_WriteDataUb1D             => Writes an unsigned byte 1D variable in the netCDF Trajectory output file
                    *** hrw_WriteDataUb2D             => Writes an unsigned byte 2D variable in the netCDF Trajectory output file
                    *** hrw_WriteDataD2D              => Writes a double 2D variable in the netCDF Trajectory output file
          *** hrw_Netcdfsecvertraj_Write              => Writes all netCDF dimensions/variables/attributes in the netCDF Trajectory output file
          *** hrw_Netcdfsecvertraj_Free               => Frees “netcdfsecvertraj struct”  with all netCDF dimensions/variables/attributes data
*** hrw_WriteTotalStatistics                          => Writes the AMV validation statistics in the HRW log file and the Statistics output file
*** hrw_Free_WindData                                 => Deallocates memory for "wind_channel_info" data
     *** hrw_Free_TWinds                              => Deallocates memory for "tracer wind" data
     *** hrw_Free_PredWinds                           => Deallocates memory for "predecessor_wind" data
     *** hrw_Free_Trajectories                        => Deallocates memory for "trajectory" data
*** hrw_Free_Satellite                                => Deallocates memory for Satellite data structs, satellite/solar angles and latitudes/longitudes
```

2.4 ASSUMPTIONS AND LIMITATIONS IN HIGH RESOLUTION WINDS (NWC/GEO-HRW)

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

The experience had 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 time was needed for this.

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

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

  The first problem is solved not using the NWP wind guess (with WIND_GUESS = 0). 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.