The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Algorithm Theoretical Basis Document for the Wind product processors of the NWC/GEO (version MTG-I day-1)

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Applicable to NWC/GEO-HRW-MTG (version MTG-I day-1) (NWC-039)

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1.0d	*12 January 2017*	89	Initial (draft) version for NWC/GEO version MTG-I day-1 PDCR Content derived from Document "Algorithm Theoretical Basis Document for the Wind product processors of the NWC/GEO (NWC/GEO-HRW v5.0)", NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind v2.0d

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1. INTRODUCTION

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

The main objective of the NWC SAF is to provide, develop and maintain software packages to be used with operational meteorological satellite data for Nowcasting applications. More information about the project can be found at the NWC SAF webpage, http://www.nwcsaf.org.

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

1.1 SCOPE OF THE DOCUMENT

This document is the "Algorithm Theoretical Basis Document (ATBD) for the Wind Product Processor of the NWC/GEO (version MTG-I day-1)" software package (NWC/GEO-HRW-MTG, High Resolution Winds), which calculates Atmospheric Motion Vectors and Trajectories considering:

- 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, WV62 6.250 µm, WV73 7.350 µm, IR108 10.800 µm and IR120 12.000 µm), and the 1 km high resolution visible channel (HRVIS 0.750 µm).
- Six channels from MTG-I/FCI imager: four 2 km low resolution water vapour and infrared channels (WV62 6.300 µm, WV73 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).
- Six channels from Himawari-8/9/AHI imager: four 2 km low resolution water vapour and infrared channels (WV62 6.250 µm, WV70 6.950 µm, WV73 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).
- Three channels from GOES-N/IMAGER: two 4 km low resolution water vapour and infrared channels (WV65 6.550 µm and IR107 10.700 µm), and the 1 km high resolution visible channel (VIS07 0.650 µm).

NWC/GEO-HRW-MTG algorithm adaptation to MSG, GOES-N and Himawari-8/9 satellite series is to be fully implemented and validated at the previous versions of NWC/GEO up to NWC/GEO v2018. NWC/GEO v2018 is not available at the moment of writing this ATBD document for NWC/GEO version MTG-I day-1, which is prepared at least two years before the actual launch of MTG-I1 satellite.

The principal task of NWC/GEO MTG-I day-1 version, fully commited, is going to be the adaptation and full validation of NWC/GEO-HRW-MTG algorithm to MTG-Imager satellite series.

There is also an option, not commited and never delaying the release of NWC/GEO MTG-I day-1 version for use with MTG-I satellite series, that NWC/GEO-MTG might also be adapted to GOES-R satellite series, considering six channels from GOES-R/ABI imager: four 2 km low resolution water vapour and infrared channels (WV62 6.150 µm, WV70 7.000 µm, WV74 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).

This Algorithm Theoretical Basis Document describes in detail the objectives and physics of the problem, together with the mathematical description and the implementation of the NWC/GEO-HRW-MTG algorithm. It also provides information on the input data and resulting output data.

1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithm implemented in the NWC/GEO-HRW-MTG (Product Id NWC-039) of the NWC/GEO (version MTG-I day-1) software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

The improvements related to NWC/GEO-HRW-MTG algorithm are the following ones:

1. The extension of NWC/GEO-HRW algorithm processing to the MTG-I (MTG Imager) satellite series (fully commited, fully validated).
2. The optional extension of NWC/GEO-HRW algorithm processing to the GOES-R satellite series (uncommited).

1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

1.4.1. Definitions

4x4 big pixel matrix	4x4 big element matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_n)
Atmospheric Motion Vector (AMV)	Horizontal wind calculated through the horizontal displacement between two Earth positions in two different satellite images (defined as initial image and later image), of a square segment of n x n pixels called tracer
Basic dataset	Set of tracers or AMVs, calculated with the basic or wide tracer scale (with a default value of 24 x 24 pixels). Two kinds of Basic tracers are possible: wide basic tracers (with bright big pixels in the first and last big pixel row or column) and narrow basic tracers (occurring otherwise)
Bearing angle	Angle defined by the great circle connecting two locations on the Earth
Best fit pressure level	Pressure level which minimizes the vector difference between the AMV and a NWP reference wind, considering as reference wind the nearest NWP wind profile or nearest Radiosounding wind profile, with a linear variation of the wind components between profile levels
Big pixel	Each element of the 4x4 big pixel matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_0, CLASS_1, CLASS_2)
Bright big pixel	Big pixel inside a big pixel matrix, in which at least a 70% of its pixels is brighter than a given frontier (also called CLASS_2 big pixel)
Brightness value	Value for a given pixel of the N_Value matrices, characterized by the Normalized reflectance in the pixel for Visible channels and the Brightness temperature in the pixel in Infrared or Water vapour channel, and defined as an integer value ranging from 0 to 255
Clear air AMV	AMV defined through the horizontal displacement between two Earth positions in two different satellite images, of a tracer defined through a specific humidity feature in water vapour images
Closeness threshold	Minimum distance in lines and columns allowed between two tracer locations
Cloud type	Cloud type defined for each tracer or AMV with NWC/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
Consistency	Difference between an AMV and some other expected wind, quantified in probabilistic terms for the Quality Index calculation
Coverage hole	Location in the initial image in which two consecutive failures in the definition of a tracer with Gradient method have occurred, so defining a location for the tracer search with the second method, Tracer characteristics method

Dark big pixel	Big pixel inside a big pixel matrix, in which less than a 30% of its pixels is brighter than a given frontier (also called CLASS_0 big pixel)
Detailed dataset	Set of tracers or AMVs, calculated with the detailed or narrow tracer scale (with a default value of 12 x 12 pixels). Three kinds of Detailed tracers are possible: unrelated to a basic tracer, related to a wide basic tracer, related to a narrow basic tracer
Distance factor	Formula used to define which AMVs contribute to the spatial and temporal consistency tests for a given AMV, and their corresponding contribution to the consistency test
Frontier	A significant minimum in the N_Value matrix histogram for a given tracer candidate
Great circle	Trajectory between two locations on the Earth surface, which relates them considering the smallest possible distance
Haversine formula	Formula used to compute the great circle distance between two locations on the Earth surface
IND_TOPO parameter	Value of the AMV Orographic flag parameter, calculated to detect land influence 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
Neighbour AMV	AMV which is close enough to a given one in the current processing cycle, used in the Quality spatial correlation test
N_Value matrix	Normalized reflectances for Visible channels, or Brightness temperatures for Infrared or Water vapour channels, for a given image in the processing region, defined as integer values ranging from 0 to 255.
Orographic flag (dynamic)	Flag to show possible land influence in the previous positions of a given AMV. It is calculated after the static orographic flag procedure, and indicated through IND_TOPO values: 1,2,3,4,5,6.
Orographic flag (static)	Flag to show possible land influence in the position of a given AMV. Indicated through IND_TOPO values: 1,2,3,6.

Overall Quality Index	Final Quality Index, weighted sum of individual forecast, temporal and spatial consistency tests (not considering the interscale consistency test)
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 horizontal and vertical 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 exist: with/without forecast (with/without the contribution of the consistency against the NWP wind forecast)
Quality index threshold	Minimum value of the Quality index (with/without forecast) so that the given AMV/Trajectory can be written in the output files
S (in CC computation)	Any pixel inside a tracking candidate
Secondary tracking centre	Tracking centre for a given tracer, which does not have the best Euclidean distance or Cross correlation
Segment of the image	A set of contiguous pixels in a satellite image, defined by its size and location
Single scale procedure	Tracer selection procedure, for which only one scale of tracers is calculated
Starting location	Each a priori location of tracers throughout the initial image, in principle uniformly covering the whole processing region
Subpixel tracking	Tracking processing, through which the tracking centres in the later image are located in a non-integer location of the tracking area, and which is calculated through second order interpolation of the Euclidean distance minima/Cross correlation maxima locations
T (in CC computation)	Any pixel inside a tracer
TESO parameter	Orographic test parameter, detailing if the orographic flag could be calculated for a given AMV, and the relative results in AMVs related to the same tracer, to be added to the Quality TEST indicator after Quality Control
TEST parameter	Quality flag after the Quality control processing step, 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 the AMV calculation by any of the two 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	For a tracer, pixel coordinates of its centre (line and column) in the initial image
Tracer selection procedure	Strategy to get a complete set of tracers throughout the desired region of the image. It consists of 2 iterations (2 methods) for the single scale procedure; 4 iterations (2 methods, 2 scales) for the two scale procedure
Tracer size	Line/column dimension of a tracer. In NWC/GEO-HRW-MTG algorithm, both dimensions are similar defining square shaped tracers
Tracking	Determination of the best matching square segment for a given tracer in the initial image, with the same horizontal and vertical 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 the initial image, 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 in the initial image, with the same horizontal and vertical dimension, inside the tracking area of a later image
Tracking centre location	For a tracking centre, pixel coordinates of its centre (line and column) in the later image
Trajectory	Path defining the displacement of a specific 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 horizontal and vertical dimension of the second dataset half the dimension of the first dataset)
Weighted location	Location different that the centre of the tracer in the initial image or the tracking centre in the later image, relating best the displacement of the AMVs and Trajectories to the displacement of the part of the tracer with a largest contribution to the cross correlation.
Wind guess	NWP wind horizontal and vertical components, through which the location of a smaller tracking area in the later image is defined for a quicker processing, although with e dependent on the NWP data

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	NWC SAF Continuous Development and Operations Phase
CDOP2	NWC SAF Second Continuous Development and Operations Phase
CIMSS	NOAA/UW's Cooperative Institute for Meteorological Satellite Studies
ECMWF	European Centre for Medium Range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GOES	NOAA's Geostationary Operational Environmental Satellite
HRVIS, VIS06, VIS07, VIS08	MSG 0.7 µm - MSG & MTG-I & Himawari-8/9 & GOES-R 0.6µm - GOES-N 0.7µm - MSG & MTG-I & Himawari-8/9 & GOES-R 0.8µm Visible channels
HRW	NWC/GEO High Resolution Winds
IOP	NWC SAF Initial Operations Phase
IR105, IR107, IR108, IR112, IR120, IR123	MTG-I 10.5µm - GOES-N 10.7µm - MSG 10.8µm - Himawari-8/9 & GOES-R 11.2µm - MSG 12.0µm - MTG-I 12.3µm Infrared channels
JMA	Japan Meteorological Agency
MPEF	EUMETSAT's Meteorological Product Extraction Facility
MSG	EUMETSAT's Meteosat Second Generation Satellite
NOAA	United States' National Oceanic and Atmospheric Administration
NWC/GEO	NWC SAF Software Package for Geostationary satellites
NWC/GEO-HRW-MTG	NWC SAF Product Generation Element for the High Resolution Winds
NWCLIB	NWC/GEO-Common Software Library
NWC SAF	EUMETSAT's Satellite Application Facility on support to Nowcasting and Very short range forecasting
NWP	Numerical Weather Prediction Model
SCI	NWC SAF Scientific Report
SMR	NWC SAF Software Modification Report
SPR	NWC SAF Software Problem Report
SW	Software
TM	NWC/GEO Task Manager
UW	United States' University of Wisconsin/Madison
WMO	World Meteorological Organization
WV62, WV65, WV70, WV73	MSG & MTG-I & Himawari-8/9 & GOES-R 6.2µm - GOES-N 6.5µm - Himawari-8/9 & GOES-R 7.0µm - MSG & MTG-I & Himawari-8/9 & GOES-R 7.3µm Water vapour channels

Table 2: List of Acronyms and Abbreviations

1.5 REFERENCES

1.5.1 Acronyms and Abbreviations

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]

For versioned references, subsequent amendments to, or revisions of, any of these publications do not apply. For unversioned references, the current edition of the document referred applies.

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

Ref.	*Title*	*Code*	*Version*
[AD.1]	Proposal for the Second Continuous Development and Operations Phase (CDOP2)	NWC/CDOP2/MGT/AEMET/PRO	1.0
[AD.2]	NWC SAF CDOP-2 Project Plan	NWC/CDOP2/SAF/AEMET/MGT/PP	1.10
[AD.3]	Configuration Management Plan for NWC SAF	NWC/CDOP2/SAF/AEMET/MGT/CMP	1.4
[AD.4]	NWC SAF Product Requirements Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.10d
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/MTG/AEMET/SW/ICD/1	1.0d
[AD.6]	Data Output Format for the NWC/GEO	NWC/CDOP2/MTG/AEMET/SW/DOF	1.0d
[AD.7]	System Version Document for the NWC/GEO	NWC/CDOP2/MTG/AEMET/SW/SCVD	1.0d
[AD.8]	Estimation of computer environment needs to run NWC SAF products operatively in 'Rapid scan mode'	NWC/CDOP/INM/SW/RP/01	1.0
[AD.9]	Validation Report for "High Resolution Winds" (HRW – PGE09 v2.2)	NWC/CDOP/INM/SCI/VR/05	1.0
[AD.10]	Validation Report for "High Resolution Winds" (HRW – PGE09 v3.0)	NWC/CDOP/INM/SCI/VR/07	1.0
[AD.11]	Validation Report for "High Resolution Winds" (HRW – PGE09 v3.1)	NWC/CDOP/INM/SCI/VR/09	1.0
[AD.12]	Validation Report for "High Resolution Winds" (HRW – PGE09 v3.2)	NWC/CDOP/INM/SCI/VR/10	1.0
[AD.13]	Validation Report for "High Resolution Winds" (HRW – PGE09 v4.0)	NWC/CDOP2/INM/SCI/VR/13	1.0
[AD.14]	User Manual for the Wind product processors of the NWC/GEO: Software part	NWC/CDOP2/GEO/AEMET/SCI/UM/Wind	1.0
[AD.15]	Scientific and Validation Report for the Wind product processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/VR/Wind	1.0
[AD.16]	User Manual of the GOES2NC tool	NWC/CDOP2/GEO/AEMET/SW/UM/GOES2NC	1.0

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 document referred applies.

Ref.	Title
[RD.1]	J.Schmetz, K.Holmlund, J.Hoffman, B.Strauss, B.Mason, V.Gärtner, A.Koch, L. van de Berg, 1993: Operational Cloud Motion Winds from Meteosat Infrared Images (Journal of Applied Meteorology, Num. 32, pp. 1206-1225).
[RD.2]	S.Nieman, J.Schmetz, W.P.Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers (Journal of Applied Meteorology, Num. 32, pp. 1559-1568).
[RD.3]	C.M.Hayden & R.J.Purser, 1995: Recursive filter objective analysis of meteorological fields, and application to NESDIS operational processing (Journal of Applied Meteorology, Num. 34, pp. 3-15).
[RD.4]	K.Holmlund, 1998: The utilisation of statistical properties of satellite derived Atmospheric Motion Vectors to derive Quality Indicators (Weather and Forecasting, Num. 13, pp. 1093-1104).
[RD.5]	J.M.Fernández, 1998: A future product on HRVIS Winds from the Meteosat Second Generation for nowcasting and other applications. (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24, pp.281-288).
[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, pp.209-214).
[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, pp.176-182).
[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, pp.17-19).
[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, pp.71-79).
[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, pp.45-52).
[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, pp.215-224).
[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, pp.72-80).
[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 "NWC SAF High Resolution Winds" product (Proceedings 11th International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (WMO Publication, available at https://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/LatestVERSION/WMO306_vI2_CommonTable_en.pdf)
[RD.20]	M.Dragosavac, 2007: BUFR Reference Manual (ECMWF Operations Department Publication, available at https://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/ECMWF/bufr_reference_manual.pdf)
[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 NWC SAF/HRW AMVs with AMVs from other producers (NWC SAF Visiting Scientist Report, available at http://www.nwcsaf.org/HD/files/vsadoc/CIMSS_AMV_Comparison_FinalReport_04July2014.pdf)
[RD.25]	D.J.Seidel, B.Sun, M.Pettey & A.Reale, 2011: Global radiosonde balloon drift statistics (Journal of Geophysical Research, Num. 116).

Table 4: List of Reference Documents

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

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

The NWC SAF High Resolution Winds (NWC/GEO-HRW-MTG) product 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 Satellite (GOES-N and optionally GOES-R) satellite series.

An "Atmospheric Motion Vector" (AMV) is a horizontal wind calculated through 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"). 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 a tracer throughout several satellite images.

AMVs and Trajectories are calculated throughout all hours of the day, considering the displacement of tracers found in up to seven MSG/SEVIRI channel images:

- The high resolution visible channel (HRVIS),
- 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 (WV62, WV73),

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 channel (WV62, WV73),

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 and 7.3µm water vapour channel (WV62, WV70, WV73),

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

- The high resolution 0.7µm visible channel (VIS07),
- One low resolution 10.7µm infrared channel (IR107),
- One low resolution 6.5µm water vapour channel (WV65),

and optionally 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 and 7.4µm water vapour channel (WV62, WV70, WV73).

The product includes pressure level information, which locates in the vertical dimension the calculated AMVs and Trajectories, and a quality control flagging, which gives an indication of its error in probabilistic terms, with auxiliary indicators about how the product was determined.

It has been developed by AEMET in the framework of the EUMETSAT Satellite Application Facility on support to Nowcasting and Very short range forecasting (NWC SAF). This product is useful as a dynamic information 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-MTG 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-MTG output) is included.

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

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 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 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 tridimensional position in the atmosphere. This is the step throughout the AMV derivation in which errors can be more important. Several methods of height assignment are available: the comparison of the infrared brightness temperature of the tracer with the forecast temperature of a NWP model, radiance ratioing and H20/IRW 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-MTG)

2.2.2.1 Outline of the Algorithm

As a whole, NWC SAF/High Resolution Winds algorithm (NWC/GEO-HRW-MTG) is designed in a modular way, so that it can be easy to handle and modify. The whole process includes the corresponding following steps:

1. Preprocessing:

   • Includes the reading and geolocation of the Satellite data (Brightness temperatures and Normalized reflectances from MSG, MTG-I, Himawari-8/9, GOES-N and optionally GOES-R, with their latitudes, longitudes, satellite and solar angles), and the reading of the NWP data and NWC/GEO product outputs (CT, CTTH, CMIC) that are also going to be used in the NWC/GEO-HRW-MTG processing.

2. Processing:

   • First, "tracers" are calculated in an "initial image" with two consecutive methods: Gradient and Tracer characteristics.

   • Later, these "tracers" are "tracked" in a "later image" through one of two different methods (Euclidean distance or Cross correlation), with the selection of up to three "tracking centres" for each "tracer".

   • "Atmospheric Motion Vectors (AMVs)" and "Trajectories" are then calculated, considering the displacement between the position of each "tracer" in the "initial image" and the position of the corresponding "tracking centres" in the "later image".

   • The pressure level of the AMVs and Trajectories is defined through one of two different methods (Brightness temperature interpolation method or Cross Correlation Contribution method) for their vertical location in the atmosphere.

3. Postprocessing:

   • A Quality control with EUMETSAT "Quality Indicator" method is implemented, with the choice of the "Best AMV" considering the up to three AMVs calculated for each tracer, and a Final control check to eliminate wrong AMVs and Trajectories which are very different to those in their vicinity.

   • An "Orographic flag" can also be calculated, which incorporating topographic data detects those AMVs and Trajectories affected by land influence.

The code was progressively developed with GOES, MFG and MSG satellite data. Examples with MSG series and GOES-N series are presented throughout the description of the algorithm to illustrate the process. The different options and coefficients are also presented. Many of them are configurable: in such a case, this circumstance is specifically indicated.

2.2.2.2 Preprocessing

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

1. Reflectances (which have been normalized by NWC/GEO library taking into account the distance to the Sun) for the images with which tracers are calculated and tracked, for all MSG, MTG-I, Himawari-8/9, GOES-N and optionally GOES-R Visible channels to be used: MSG/HRVIS, VIS06 and VIS08; MTG-I/VIS06 and VIS08; Himawari-8/9/VIS06 and VIS08; GOES-N/VIS07; GOES-R/VIS06 or VIS08.
2. Brightness temperatures for the images with which tracers are calculated and tracked, for all MSG, MTG-I, Himawari-8/9, GOES-N and optionally GOES-R Infrared or Water vapour channels to be used: MSG/IR108, IR120, WV62 and WV73; MTG-I/IR105, IR123, WV62 and WV73; Himawari-8/9/IR112, WV62, WV70 and WV73; GOES-N/IR107 and WV65; GOES-R/IR112, WV62, WV70 and WV73.
3. Radiances for the images with which tracers are calculated and tracked (for MSG/IR108 and WV62; MTG-I/IR105 and WV62; Himawari-8/9/IR112 and WV62; GOES-N/IR107 and WV65; optionally GOES-R/IR112 and WV62), if the "Image correlation quality control test" defined in chapter 2.2.2.10 is used (this is implemented in the default configuration but it is not mandatory).
4. Latitude and longitude matrices and solar and satellite zenith angle matrices for the image locations in which tracers are calculated and tracked (which are calculated by NWC/GEO library).
5. NWP temperature profiles.
6. NWP wind component profiles, if the "Forecast consistency quality control test" defined in chapter 2.2.2.10 is used, or if the NWP "wind guess" for the definition of the "tracking area" in the "later image" such as defined in chapter 2.2.2.4 is used, or if Validation statistics are to be calculated by the NWC/GEO-HRW-MTG algorithm itself such as defined in chapter 2.3.1.3 (considering as reference winds the NWP analysis winds or the NWP forecast winds). The first and third option are implemented in the default configuration, but none of them are mandatory.
7. NWP geopotential profiles, if the "Orographic flag" defined in chapter 2.2.2.11 is used (this is implemented in the default configuration but it is not mandatory).
8. 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 (this is not mandatory).
9. 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 (this is implemented in the default configuration but it is not mandatory).
10. NWC/GEO-CMIC Cloud Phase, Liquid Water Path and Ice Water Path outputs for the image with which tracers are tracked, in case the Microphysics correction for "CCC Method height assignment" defined in chapter 2.2.2.7 is used (this is implemented in the default configuration but it is not mandatory).

Only the satellite data for the requested channels, and NWP temperature data with a minimum number of NWP levels (defined through configurable parameter MIN_NWP_FOR_CALCULATION, with a default value of 4) are strictly needed for the calculation of AMVs and Trajectories. All other data contribute to a higher number of AMVs and Trajectories and a better quality of the output data. Detailed information on all configuration parameters used throughout this document 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 value matrices" or "N_Value matrices". "N_Value matrix" data are integer values ranging from 0 to 255 (with 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-MTG starts with the calculation of "tracers" (square "segments" of nxn pixels, used as initial positions of an AMV and trajectory sector, and identified by a specific cloudiness feature or humidity feature) throughout the processing region in an "initial image". The calculated tracers are stored in temporal files in `$SAFNWC/tmp` directory.

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

The "initial image" related to the tracer calculation and the "later image" related to the AMV calculation are not necessarily consecutive, and depend on the value of configurable parameter SLOT_GAP.

This parameter has a default value of 1 in "Nominal scan mode", implying the use of images separated by 10 minutes with Himawari-8/9 and MTG-I satellite series, by 15 minutes with MSG and optionally GOES-R series, and by 15 or 30 minutes with GOES-N series (respectively when working in the United States or North America region).

This parameter has a default value of 2 in "Rapid scan mode", implying the use of images separated by 5 minutes with Himawari-8/9 series, and by 10 minutes with MSG and GOES-R series. No "Rapid scan mode" option has been defined in the default configuration for this version of NWC/GEO-HRW-MTG algorithm for the use with MTG-I or GOES-N satellite series.

A mixed method considering both "Nominal scan mode" and "Rapid scan mode" at the same time is also available since NWC/GEO-HRW v6.0 for MSG and Himawari-8/9 satellite series, through which AMVs will be calculated considering "Nominal scan cycle", but with tracking process verified using "Rapid scan cycles". This way, an increase in the amount and the quality of the AMVs and Trajectories is expected respect to the ones calculated using the "Nominal scan mode" only, due to the smaller change in the tracers occurred in the 2.5 to 5 minute interval between consecutive images, and the triple (with MSG and GOES-R) to quadruple (with Himawari-8/9) verification of the AMV quality occurring inside each "Nominal scan cycle". This mixed method is implemented with configurable parameter MIXED_SCANNING = 1 (not used as default option).

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 horizontal and vertical size of the detailed tracers half the size the one for basic tracers).

A "single scale procedure" calculating only "basic tracers" with a horizontal and vertical "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 tracer scales between 48 to 96 km at subsatellite point (in the "basic low resolution images") and 6 to 12 km at subsatellite point (in the "detailed highest resolution images"), with lowest values related to Himawari-8/9 and GOES-R satellite series, and highest values related to GOES-N satellite series. So, between 'mesoscale ß' and 'mesoscale γ' meteorological dimensions.

The nominal observation frequency of 10 to 30 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 product in the "Rapid scan mode" can be better to track tracers of this small size.

In any case, the horizontal and vertical "tracer size" in pixels of the "single or basic scale" can be defined through configurable parameters TRACERSIZE_VERYHIGH for Himawari-8/9 and 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 4 km low resolution images (available in all satellite series). NWC/GEO-HRW-MTG product is prepared to work with square shaped tracers, so similar values for the horizontal and vertical "tracer size" are kept.

FIRST METHOD: GRADIENT

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

1. To look for a "brightness value" (identified as any of the pixel values of the corresponding "N_Value matrix", inside a "tracer candidate" located in a "starting location"), greater than configurable parameter MIN_BRIGHTNESS_VIS (for visible cases, with default value 120) or MIN_BRIGHTNESS_OTHER (for infrared and water vapour cases, with default value 60).
2. To verify if a difference exists between the maximum and minimum "brightness value" in the "tracer candidate", greater than configurable parameter GVAL_VIS (for visible cases, with default value 60) or GVAL_OTHER (for infrared and water vapour cases, with default value 48).
3. To compute inside the "tracer candidate" the value and location of the "maximum brightness gradient" $|\Delta N\_Value(\Delta x) + \Delta N\_value(\Delta y)|$, where Δ means a distance of 5 pixels in both line and column directions. This "maximum brightness gradient" cannot be located on the edges of the "tracer candidate".

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

All tracers related to very low and low cloud types calculated with this "pixel distance" are kept. Considering tracers related to other cloud types (if so defined by configurable parameter HIGHERDENSITY_LOWTRACERS = 1, which is the default option), only one of every two tracers is kept. With this new procedure, the spatial density of AMV data related to very low and low clouds is larger than the one obtained with the previous versions of NWC/GEO-HRW-MTG algorithm, due to the in general similar to smaller "pixel distance" between tracers.

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

SECOND METHOD: TRACER CHARACTERISTICS

The centres of "coverage holes" are the "starting locations" for the tracer search in a second iteration with the "Tracer characteristics method". It is based on new development. It is useful especially in the visible cases, where many potential tracers can present fainter edges than in the infrared image, 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 horizontal and vertical 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 and CENT_10% > 0;

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

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

   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-MTG algorithm keeps only the most significant "frontier" in the processing, although the option exists to calculate more than one "frontier".

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

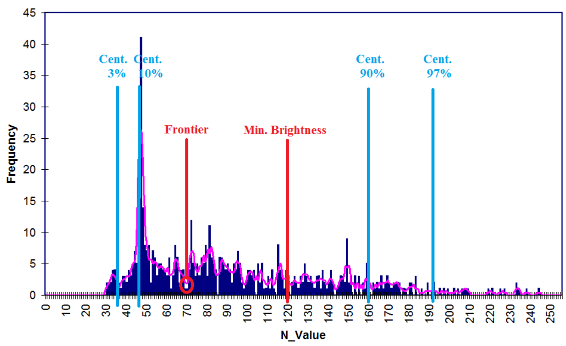


Figure 1: Example of "N_Value matrix histogram" (unsmoothed in violet and smoothed in pink) for a valid Low resolution visible "tracer candidate". The minimum brightness threshold, the algorithm centiles and the defined frontier are also shown

2. "Big pixel brightness variability test":

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

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

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

   CLASS_1: 'undefined big pixel', intermediate case.

   It is requested to avoid ambiguous cases that both CLASS_0 and CLASS_2 appear at least once in the "4x4 big pixel matrix", while the incidence of CLASS_1 be 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.

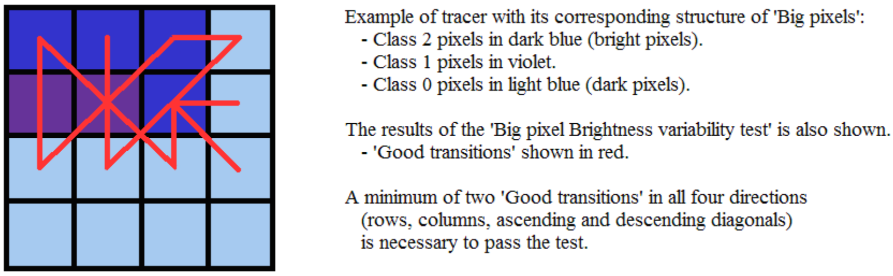


Figure 2: Example of running of the 'Big pixel brightness variability test' for a valid tracer candidate

TRACER CLOSENESS CONDITION

No tracer is retained if it is found too close to a previously computed one ("closeness threshold"). So, each time a tracer is computed all pixels located nearer than the "closeness threshold" are added to a "pixel exclusion matrix", and excluded as potential tracer locations.

Considering this, with "Gradient method" the "maximum brightness gradient" is not evaluated at locations inside the "pixel exclusion matrix". With "Tracer characteristics method" no computations are evaluated for a "starting location" with pixels inside the "pixel exclusion matrix".

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

DETAILED TRACERS IN THE TWO SCALE PROCEDURE

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

- No "Basic tracer" has been found, but at the "starting location" of a "tracer candidate" following condition occurs: CENT_97% > 0.85*MIN_BRIGHTNESS. In this case a "Detailed tracer unrelated to a Basic tracer" is defined, with a slightly lower maximum brightness.
- A "Wide basic tracer" has been found, in which CLASS_2 values appear in both first and last row, or in both first and last column, of the "4x4 big pixel matrix" used in the "Big pixel brightness variability test". In this case four starting locations are defined for the "Detailed scale". Each of them is located at the corners of a "Detailed tracer" whose centre is the centre of the "Basic tracer".
- A "Narrow basic tracer" has been found, in which CLASS_2 values do not appear in both first and last row, nor in both first and last column, of the "4x4 big pixel matrix" used in the "Big pixel brightness variability test". In this case, only one starting location is defined for the "Detailed scale", whose centre is defined by the weighted location of the "Big pixels" in the "4x4 big pixel matrix".

TRAJECTORIES

With the default configuration, with configurable parameter CALCULATE_TRAJECTORIES = 1, the definition of new "tracer locations" starts anyway 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.

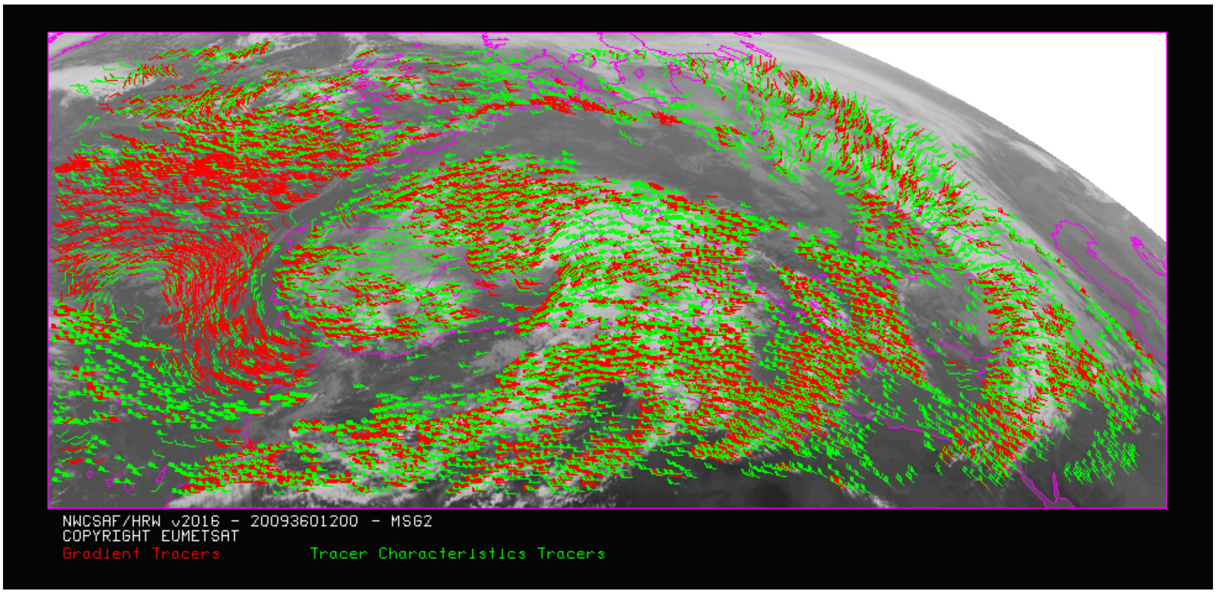


Figure 3: "Basic scale AMVs" (in red and green, considering the Tracer calculation method used for their extraction), in a NWC/GEO-HRW-MTG example defined in European & Mediterranean region with the default `$SAFNWC/config/safnwc_HRW_MSG15MIN.cfm` *model configuration file (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)*

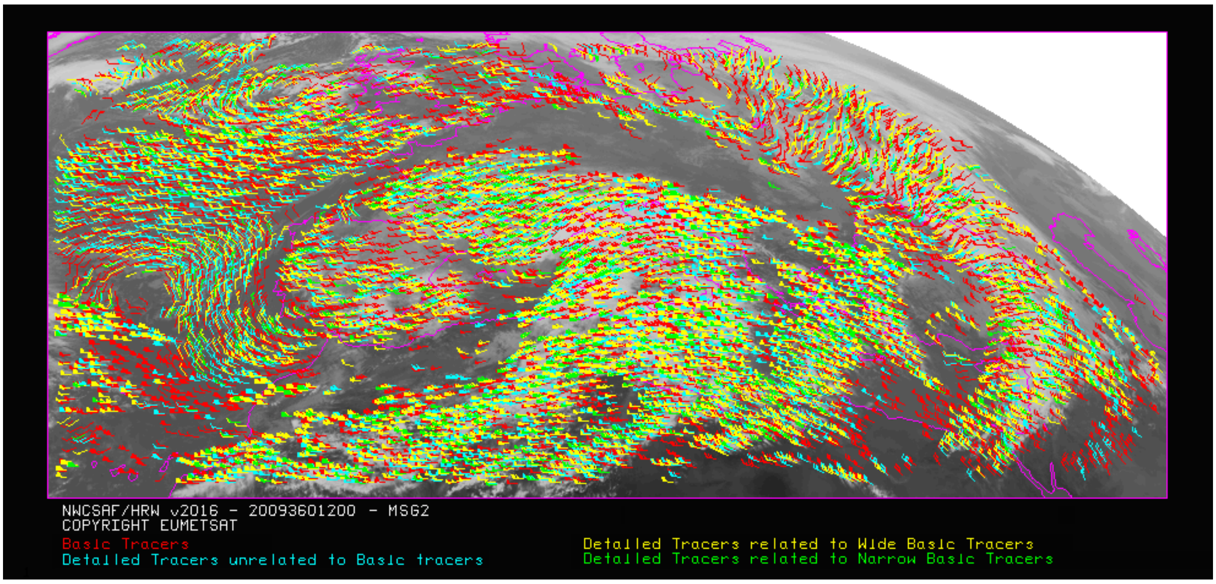


Figure 4: "Basic scale AMVs" (in red), and "Detailed scale AMVs" (in yellow, green and blue, considering their relationship with the Basic scale AMVs), in a Two scale NWC/GEO-HRW-MTG example defined in the European and Mediterranean region with option CDET = 1 in default `$SAFNWC/config/safnwc_HRW_MSG15MIN.cfm` *model configuration file (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)*

2.2.2.4 Tracer tracking

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

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

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

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

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

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

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

The centre of the "tracking area" can preliminarily be defined through a "wind guess" obtained from the NWP forecast of the rectangular 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-MTG algorithm, and is applied using configurable parameter WIND_GUESS = 1.

Nevertheless, NWC/GEO-HRW-MTG algorithm is optimized not to use the "wind guess" as default option, so reducing the dependence of the calculated AMVs from any NWP model used. Although the running time can be around two to three times longer, it is recommended to keep operationally the configuration without use of "wind guess" with configurable parameter WIND_GUESS = 0.

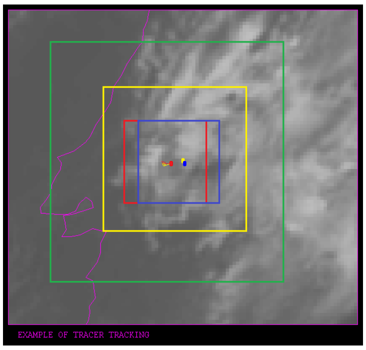


Figure 5: A low resolution tracer at 1145Z (O red mark), its position defined by the NWP wind guess at 1200Z (O yellow mark), and its true tracking position at 1200Z defined by NWC/GEO-HRW-MTG algorithm (O blue mark), for an example case in Figure 22 (26 December 2009, Nominal scan mode, MSG2 satellite). The "yellow tracking area" (with its centre at the position defined by the NWP wind guess at 1200Z) 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 1145Z) corresponds to the option not using wind guess for the definition of the tracking area. The larger size of the tracking area needed when the wind guess has not been used is to be noticed, which causes a longer time for the running of NWC/GEO-HRW-MTG algorithm, but at the same time reduces the dependence from the NWP model

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

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

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

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

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

After all four iterations, the three "tracking centres" (MAX_NUM_WINDS) with the best Euclidean distance/Cross Correlation values are retained. With Cross correlation, it is also requested that the absolute maximum correlation value be greater than configurable parameter MIN_CORRELATION (with a default value of 80% for all satellite series, except GOES-N with 50%).

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

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

SELECTION OF THE MAIN TRACKING CENTRE

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

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

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

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

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

Examples of AMVs calculated with MSG and GOES-N satellite series are shown in *Figures 6 and 7*, considering the satellite channel used for the AMV calculation, and their consideration as Cloudy AMVs or Clear air AMVs. AMVs calculated with Himawari-8/9 satellite series will be shown for the release of NWC/GEO v2018 software version in 2018. AMVs calculated with MTG-I satellite series will be shown when the satellite MTG-I1 is launched.

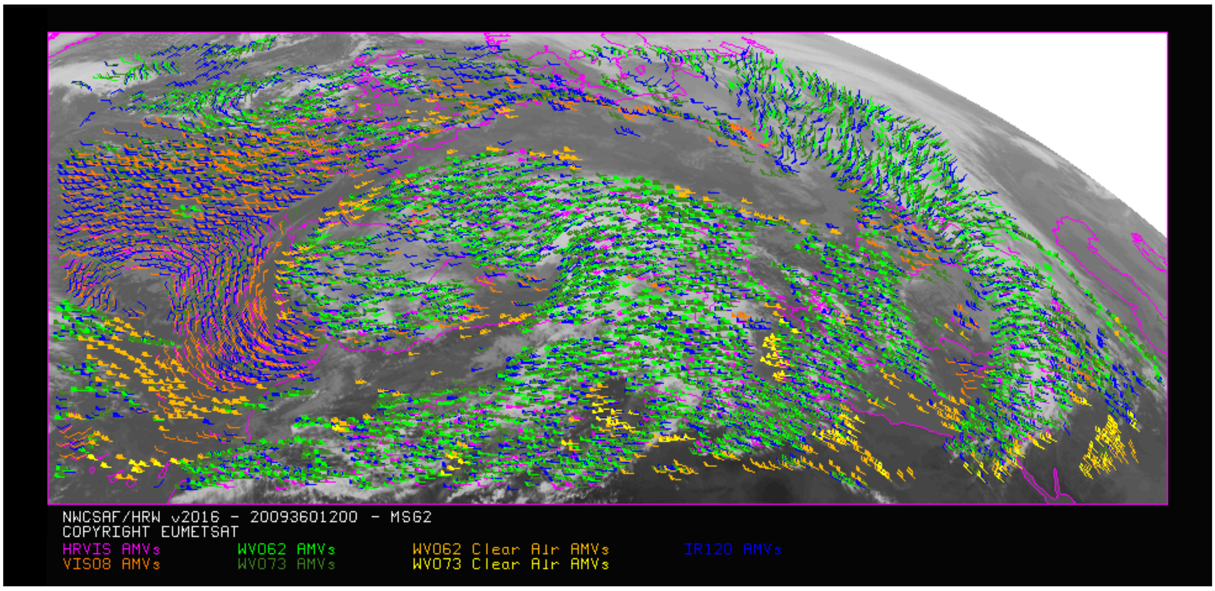


Figure 6: AMVs considering the satellite channel used for the AMV calculation, for the MSG series High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)

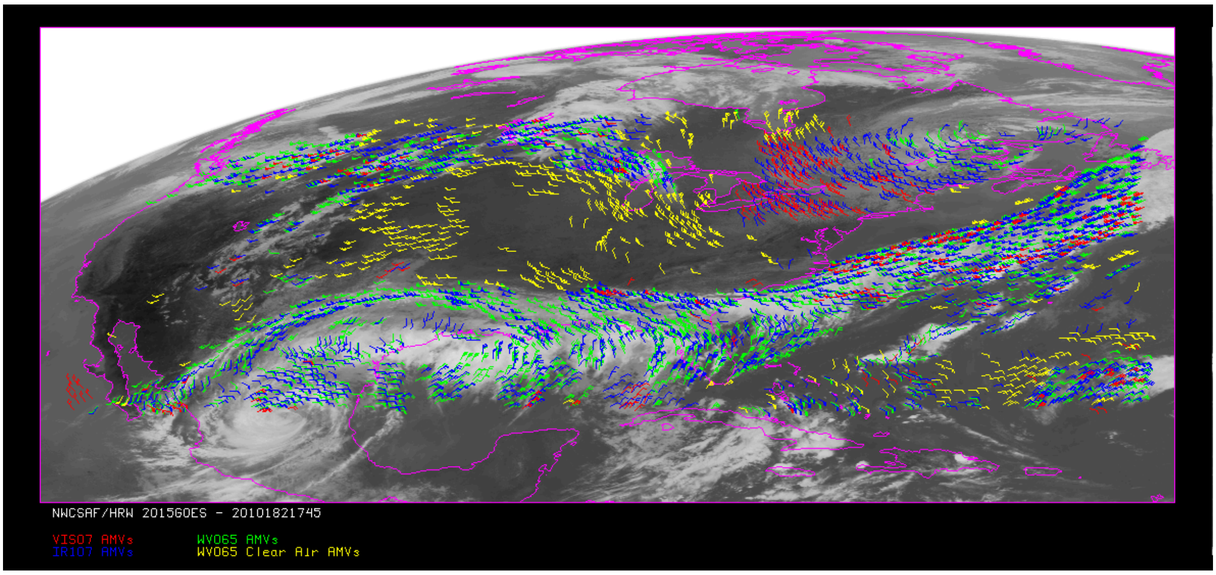


Figure 7: AMVs considering the satellite channel used for the AMV calculation, for the GOES-N series High Resolution Winds example defined in Figure 24 (1 July 2010 1745Z, GOES13 satellite)

2.2.2.5 "Brightness temperature interpolation method" height assignment

"Brightness temperature interpolation method" height assignment method is used with configurable parameter DEFINEWITHCONTRIBUTIONS = 0, when the wind guess is used to define the "tracking area" in the later image with configurable parameter WIND_GUESS = 1, or when NWC/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.

This height assignment method is only available if a NWP temperature forecast with a minimum number of NWP levels is provided (configurable parameter MIN_NWP_FOR_CALCULATION, with a default value of 4). If the number of NWP temperature levels is smaller, the processing of NWC/GEO-HRW algorithm 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 the visible channels, IR108 brightness temperature is used with MSG, IR105 brightness temperature is used with MTG-I, IR107 brightness temperature is used with GOES-N, and IR112 brightness temperature is used with Himawari-8/9 and optionally with GOES-R satellite series. 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, vertical interpolation inside the lowest pressure interval containing the desired temperature, with temporal interpolation inside the two nearest time values for which NWP profiles have been provided, are considered. 1000 or 50 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-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.

If NWC/GEO-CT Cloud Type output is not available or USE_CLOUDTYPE = 0, the "AMV cloud type" is defined as "not processed". All possible values for the "AMV cloud type" parameter are in *Table 5*.

Considering the statistical study shown in the "Validation Report for High Resolution Winds (HRW v3.2), [AD.12]", 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 5% of cloudy pixels), and cloud types for which the validation statistics are significantly worse.

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

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

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

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

MSG channels		HRVIS	VIS06	VIS08	WV62		WV73	IR108	IR120
MTG-I channels	VIS06	VIS08			WV62		WV73	IR105	IR123
Himawari-8/9 channels	VIS06	VIS08			WV62	WV70	WV73	IR112	
GOES-N channels		VIS07			WV65			IR107	
GOES-R channels (optionally)	VIS06	VIS08			WV62	WV70	WV73	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 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 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 product. If these outputs are not available, NWC/GEO-HRW product tries to use the "AMV pressure" and "AMV temperature" values calculated by "Brightness temperature interpolation method".

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

"CCC method" has the advantage of including in the height assignment all procedures included in NWC/GEO-CTTH product for the cloud top pressure calculation, which are common methods used by other AMV producers, including:

- Opaque cloud top pressure retrieval considering Infrared Window channels, with simulation of radiances with RTTOV, and possibility of thermal inversion processing.
- Semitransparent cloud top pressure retrieval with the Radiance ratioing technique and the H20/IRW intercept method, considering Water Vapour and Carbon Dioxide channels.

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

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

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

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 and water vapour channels has in general the shape of the letter 'C', as shown by the lower graphs in *Figures 9 and 10* (which correspond to a MSG/VIS08 and 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 and 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, only the pixels whose "partial contribution to the correlation" is higher than the "CCC calculation threshold" inside the cold branch of the 'Brightness temperature(Partial contribution to the correlation)' graph 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}), the CTTH Cloud Top Pressure (CTP_{ij})

and the Cloud Top Temperature (CTT_{ij}) outputs for the pixels defined before inside the "tracking centre", having valid $CTP_{ij}/CTT_{ij}/CT_{ij}$ values and related to cloudy non fractional cloud types, with the formulae:

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

The procedure is repeated for the up to three "tracking centres" defined for each tracer.

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

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

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

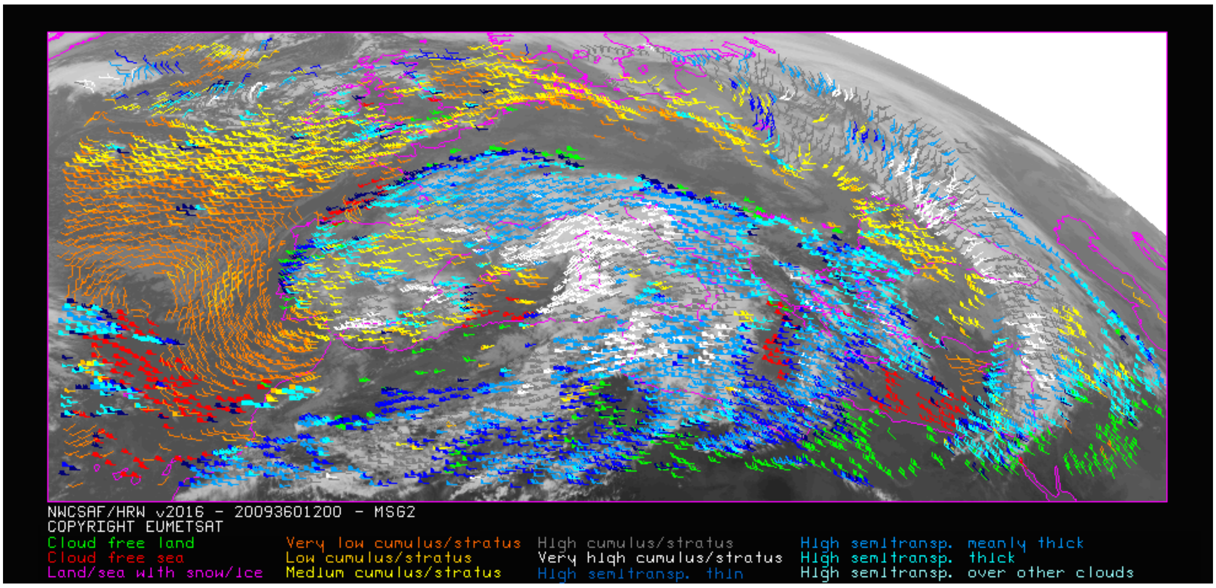


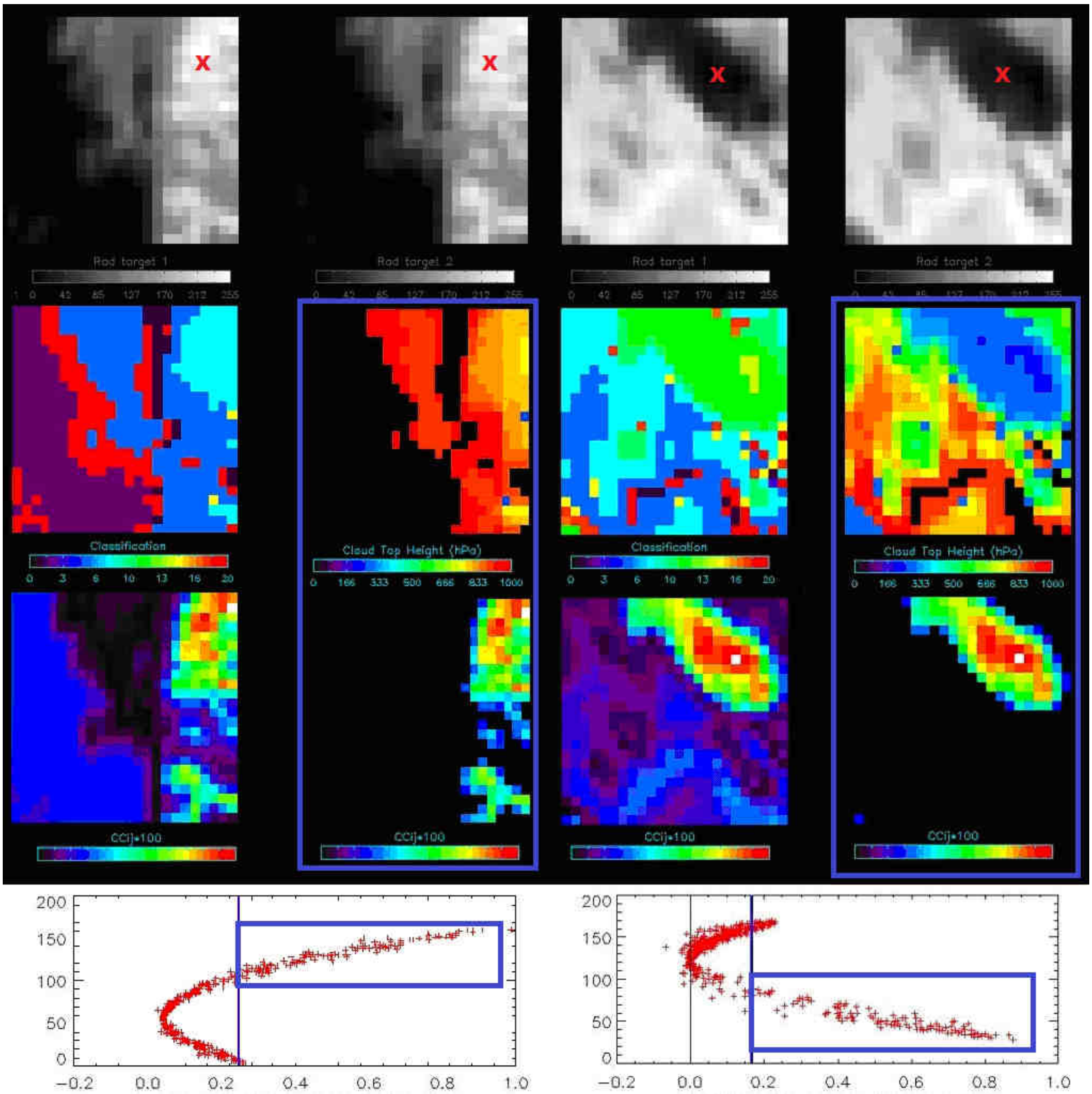
Figure 8: "AMV cloud type values" (as defined by "CCC method height assignment") for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)

Images in *Figures 9 and 10* 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 "brightness values" for the "tracer" pixels in the "initial image" and for its "tracking centre" pixels in the "later image" are shown. In the second row, the NWC/GEO-CT Cloud type and 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 is the "mean contribution to the correlation").

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

Only those pixels having at the same time a valid value in the blue boxes in *Figures 9 and 10* 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.



Figures 9 and 10: 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

With configurable parameter DEFPOSWITHCONTRIBUTIONS = 1, which is the default option, the displacement by the AMV between the "tracer" and the "tracking centre" does not consider the centres of the "tracer" and the "tracking centre", but 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".

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.

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-MTG cloudy AMVs and Trajectories, and those given to the "cloud tops" by NWC/GEO-CTTH product, eliminating any possible incongruence between both products. It also defines a clear correspondence between the elements considered for the AMV pressure level calculations and the real features observed in the satellite images.

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

For this procedure, the output of the NWC/GEO-CMIC or 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 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.

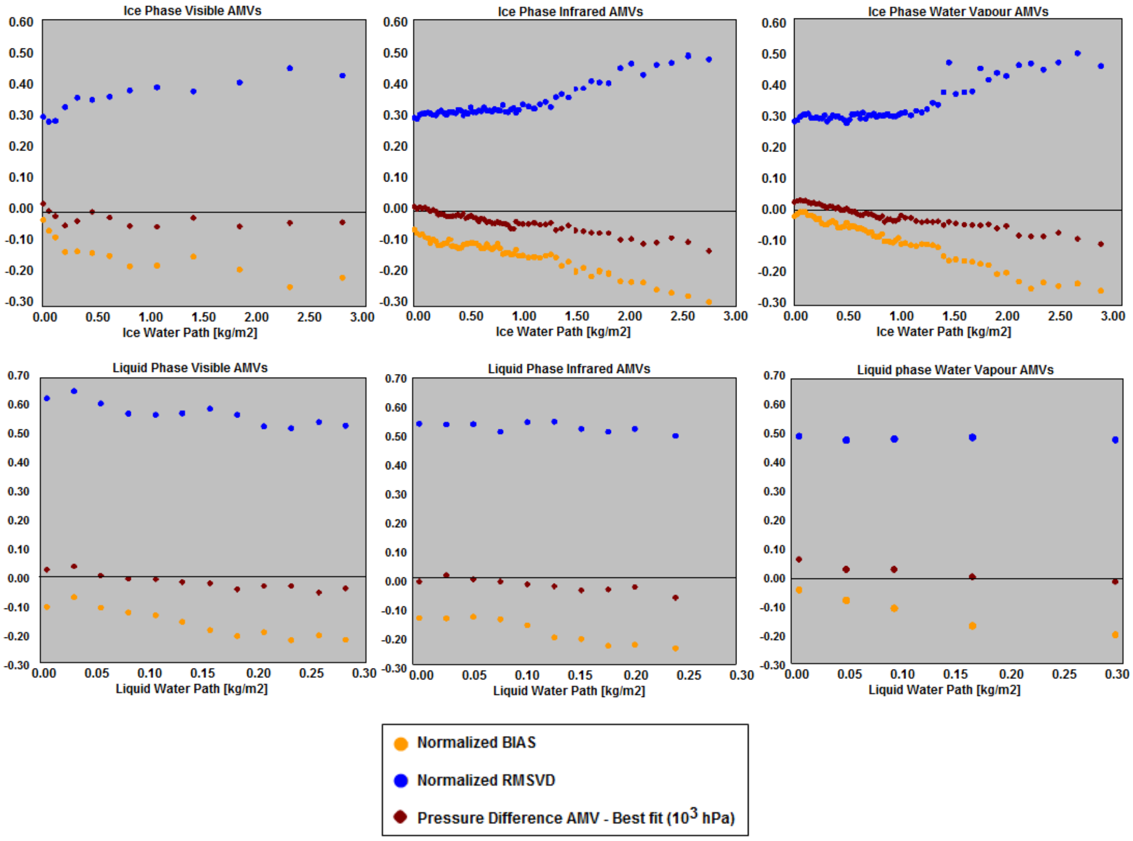
The empirical relationship between the "difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level" and the "AMV Ice/Liquid water path" has been tuned at this moment for MSG satellite series. It is going to be implemented for Himawari-8/9 satellite series for the release of NWC/GEO v2018 software package in 2018. It is also going to be implemented for MTG-I (and optionally for GOES-R satellite series) for the release of NWC/GEO MTG-I day-1 software package.

For MSG satellite series, it considers 1200Z Cloudy AMVs between July 2010 and June 2011 in the European and Mediterranean region. Defining separate procedures for Ice and Liquid Cloud Visible AMVs, for Ice and Liquid Cloud Infrared AMVs and for Ice and Liquid Cloud Water vapour AMVs, *Figures 11 to 16* in the following page are obtained. The reference wind data used for the calculation of the "best fit pressure level" have been "Radiosouding 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 six possible cases.

The "difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level" is in general negative, meaning that the "Radiosounding best fit pressure level" is in most cases at a lower level, i.e. nearer to the ground, than the "AMV pressure level" calculated with "CCC method". The difference is more negative with larger "AMV Ice/Liquid water path values". 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" with these regressions, it is implemented such as shown in *Table 7*. This correction locates the AMVs in a level nearer to the ground, with the exception of AMVs with very small Ice/Liquid water path values. A control is later defined through the "Orographic flag" to avoid that the AMVs are located below the ground.

Verifying AMV statistics for a different period (the reference AMV Validation period July 2009-June 2010 in the European and Mediterranean region with MSG2 satellite), the "Microphysics correction" causes a reduction in all validation parameters (NBIAS, NMVD, NRMSVD), which is largest for the NBIAS. Detailed information about the effect in the Validation statistics of the "Microphysics correction" is available in the Validation report for NWC/GEO-HRW v5.0 (document [AD.15]).



Figures 11 to 16: Graphs relating 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 MSG Visible AMVs (left), MSG Infrared AMVs (centre) and MSG Water vapour AMVs (right). 1200Z Cloudy AMVs for MSG2 satellite during the July 2010-June 2011 period 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"	
VISIBLE ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 29 without IWP MIC.CORR[hPa] = -26+295*IWP[kg/m^2] if IWP < 0.2271 kg/m^2 MIC.CORR[hPa] = 41 if IWP > 0.2271 kg/m^2	VISIBLE LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 12 without LWP MIC.CORR[hPa] = -30+316*LWP[kg/m^2] if LWP < 0.2594 kg/m^2 MIC.CORR[hPa] = 52 if LWP > 0.2594 kg/m^2
INFRARED ICE PHASE CLOUDY AMVs MIC.CORR[hPa] = 16 without IWP MIC.CORR[hPa] = -5+45*IWP[kg/m^2] if IWP < 3.0444 kg/m^2 **MIC.CORR[hPa] = 132 if IWP > 3.0444 kg/m^2**	INFRARED LIQUID PHASE CLOUDY AMVs MIC.CORR[hPa] = 17 without LWP MIC.CORR[hPa] = -8+261*LWP[kg/m^2] if LWP < 0.1685 kg/m^2 MIC.CORR[hPa] = 36 if LWP > 0.1685 kg/m^2
WATER VAPOUR ICE PHASE AMVs MIC.CORR[hPa] = -6 without IWP MIC.CORR[hPa] = -22+45*IWP[kg/m^2] if IWP < 2.7555 kg/m^2 MIC.CORR[hPa] = 102 if IWP >2.7555 kg/m^2	WATER VAPOUR LIQUID PHASE AMVs MIC.CORR[hPa] = -31 without LWP MIC.CORR[hPa] = -63+245*LWP[kg/m^2] if LWP < 0.2571 kg/m^2 MIC.CORR[hPa] = 0 if LWP > 0.2571 kg/m^2

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

"CCC method with Microphysics correction" height assignment is implemented with configurable parameter USE_MICROPHYSICS = 2. As already said, in NWC/GEO MTG-I day-1 software release it is going to be activated for MSG, MTG-I, Himawari-8/9 and optionally GOES-R satellites series. Option USE_MICROPHYSICS = 1 calculates the value of the Microphysics correction, but does not correct the "AMV pressure value" with it. The "AMV pressure correction" value is provided in the AMV output files as the "Pressure correction" parameter.

The user has necessarily to run all NWC/GEO-Cloud products (CMA, CT, CTTH, CMIC) so that all this process can be activated. If NWC/GEO-CMIC product output is not available but the other ones are, NWC/GEO-HRW-MTG runs "CCC method without Microphysics correction" height assignment.

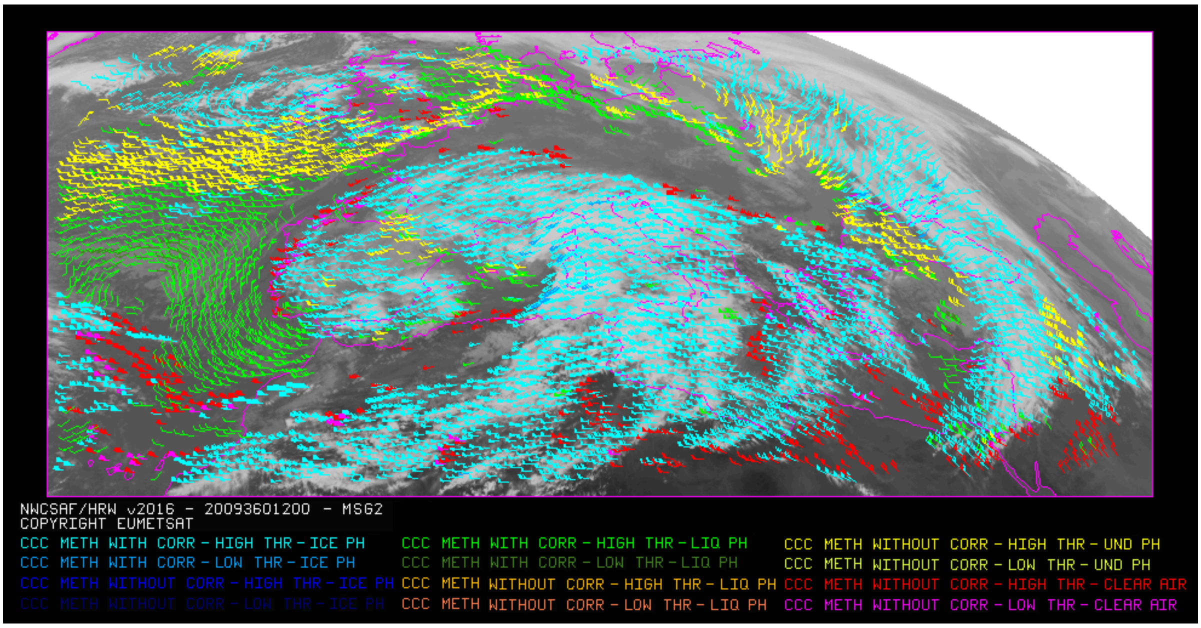


Figure 17: AMV height assignment ("CCC height assignment method with/without Microphysics correction", using "CCC method high/low calculation threshold"), and AMV Cloud phase ("Ice phase", "Liquid phase", "Mixed/Undefined phase", "Clear air") for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)

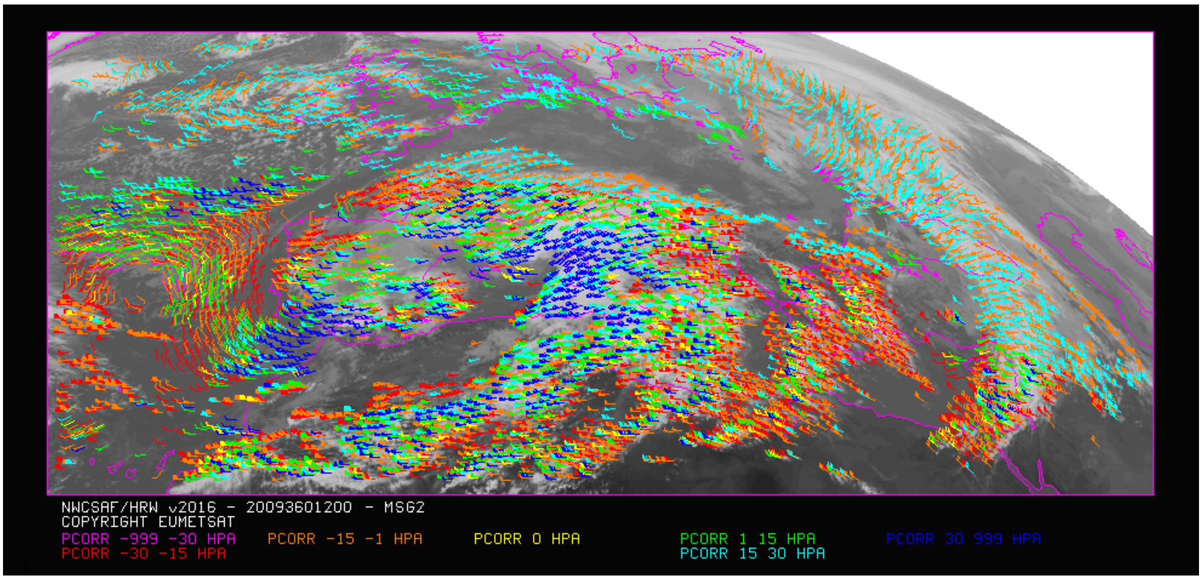


Figure 18: AMV pressure level corrections (for the cases in which "CCC height assignment method with Microphysics correction" has been used), for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)

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 process identifies that a "Water vapour AMV" is a "clear air AMV" when its group of clear air pixels has the largest contribution to correlation. And so, 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 these "clear air AMVs", in the cases for which a vertical reduction or increase of temperature is found throughout all three temperature values.

In the cases in which the "AMV pressure" value or the "AMV pressure error" value cannot be calculated, the AMV is discarded.

2.2.2.9 Wind calculation

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

Although the difference with the calculation procedure used in previous versions is completely negligible, since NWC/GEO-HRW v5.0 the calculation of the wind components considering the displacement along the corresponding "great circle" with the "haversine formula" is used.

The "haversine formula" uses the following procedure to calculate the angular distance in degrees (ANG) and the corresponding 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 °/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:

$$U = SPD \cdot \cos(DIR)$$

$$V = SPD \cdot \sin(DIR)$$

T_INT is the real time difference in hours, between the scanning time of the lines 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 with WIND_GUESS = 1, calculated through the displacement of the tracer location with the rectangular NWP wind components, uses also an equivalent procedure with a displacement along the corresponding "great circle".

2.2.2.10 Quality control and Choice of the best wind

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

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

Five different tests are applied (direction, speed and vector difference tests for the temporal consistency; only vector difference for the other ones) giving five "Individual Quality Indices". The weighted sum of these consistency tests provides the "Overall Quality Index".

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 AMVs).

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 respect to the reference AMV, and ER is the Earth radius in kilometres:

$alpha = 200 + 3.5 \cdot SPD$

$beta = 200 + 3.5 \cdot SPD$

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

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

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

Only reference AMVs with a "distance factor" smaller than 1, a pressure difference smaller than 25 hPa (L_CHECK_PRESS_DIFF/T_CHECK_PRESS_DIFF) and a latitude/longitude difference smaller than 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.

The weight of the different quality consistency tests in the "Overall Quality Index" is defined as: 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).

The weighted sum of these consistency tests define the "Overall Quality Index" of the AMVs and related Trajectories. Considering the weight W_FC, the value 1 provides a "Quality index with forecast" and the value 0 provides a "Quality index without forecast".

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 IR108/WV62 images for MSG satellites, the correlation of IR105/WV62 images for MTG-I satellites, the correlation of IR112/WV62 images for Himawari-8/9 satellites, the correlation of IR107/WV65 for GOES-N satellites, or optionally the correlation of IR112/WV62 images for 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 70%).

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

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

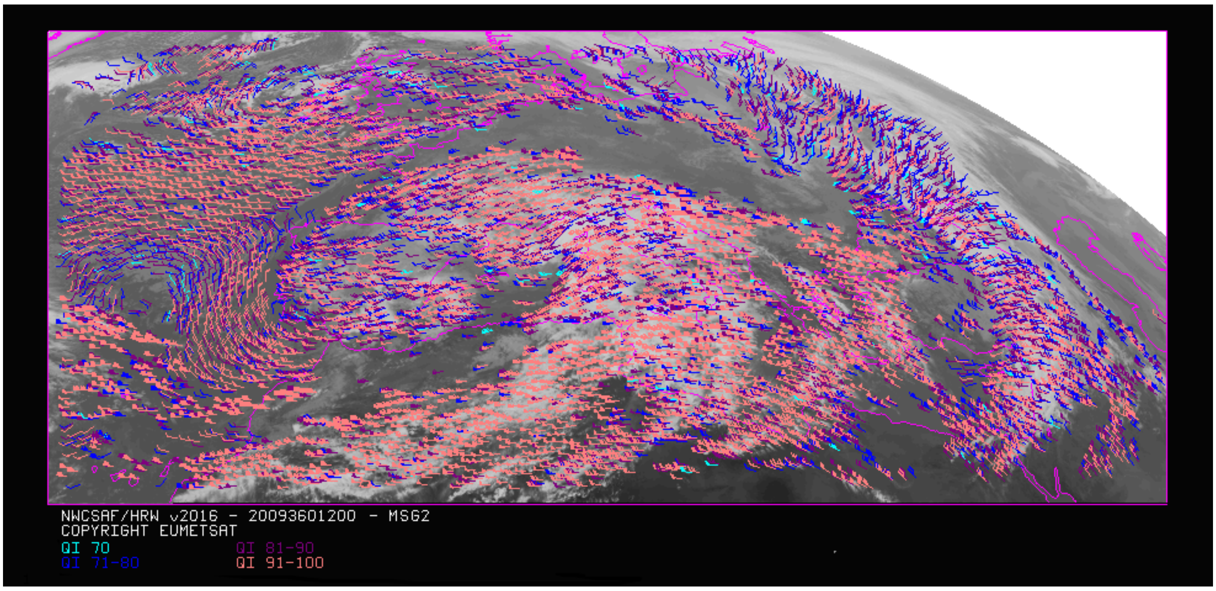


Figure 19: "Quality index with forecast" for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

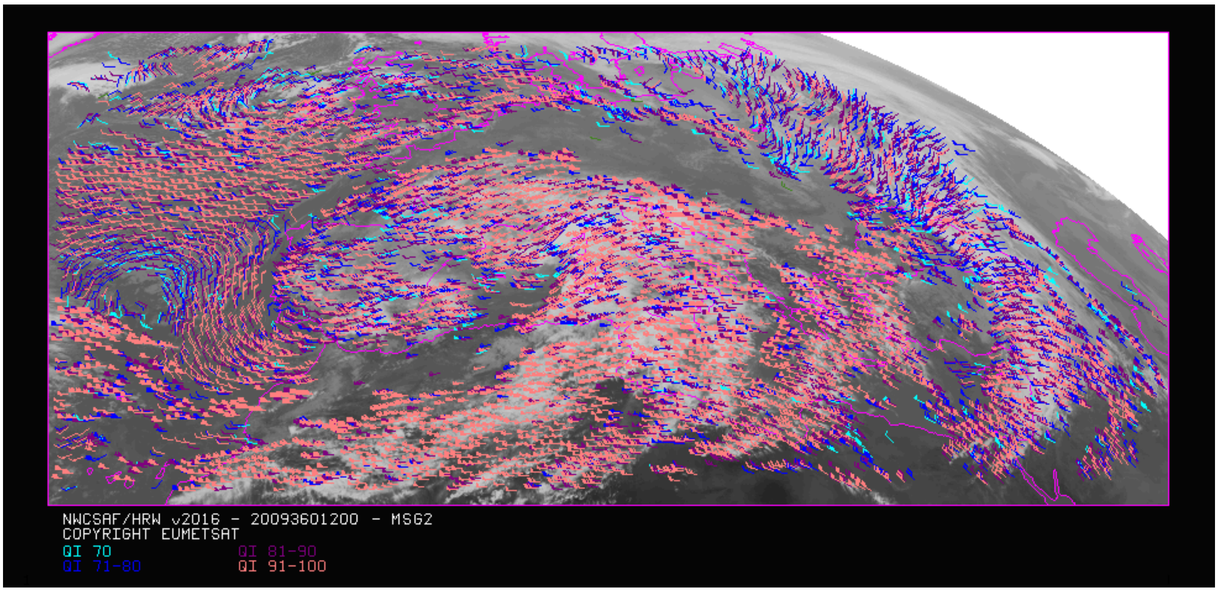


Figure 20: "Quality index without forecast" for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

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 two topography matrices for the defined satellite and positioning (`S_NWC_SFCMIN*raw`, `S_NWC_SFCMAX*raw`), located in `$SAFNWC/import/Aux_data/Common` directory. These matrices define the 3% and 97% centiles of the topography histogram for each pixel, in which data up to 1 degree away are considered. They are called the "Representative Minimum and Maximum height matrices" in each pixel.

This matrices are then converted to "Representative Maximum and Minimum Surface pressure matrices" with NWP geopotential data. The "Height matrices" are converted to geopotential values (multiplying by a constant value of gravity), and the geopotentials are then inversely interpolated to pressure to define the "Representative Maximum and Minimum Surface pressure" values for each pixel (P_sfcmin, P_sfcmax). These values represent the highest and lowest representative surface pressure values in locations up to one degree away of each pixel of the image.

After this, the "Static orographic flag" (IND_TOPO) is calculated at the initial position of each AMV. It is calculated considering P_sfcmin, P_sfcmax 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_sfcmin*

  AMV wrongly located below the lowest representative pressure level (mainly due to Microphysics corrections in the "AMV pressure value").
- *IND_TOPO = 2: P_AMV > P_sfcmax + TOPO_PR_DIFF*(P_sfcmin-P_sfcmax)*

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

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

  No orographic influence found in the current AMV position.

The "Dynamic orographic flag" is then calculated: values of IND_TOPO are modified to verify the possibility of a previous in time orographic influence. This happens if IND_TOPO = 6 and the tracer is related to a "predecessor AMV" in the previous image. The value of IND_TOPO is so modified considering the following conditions:

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

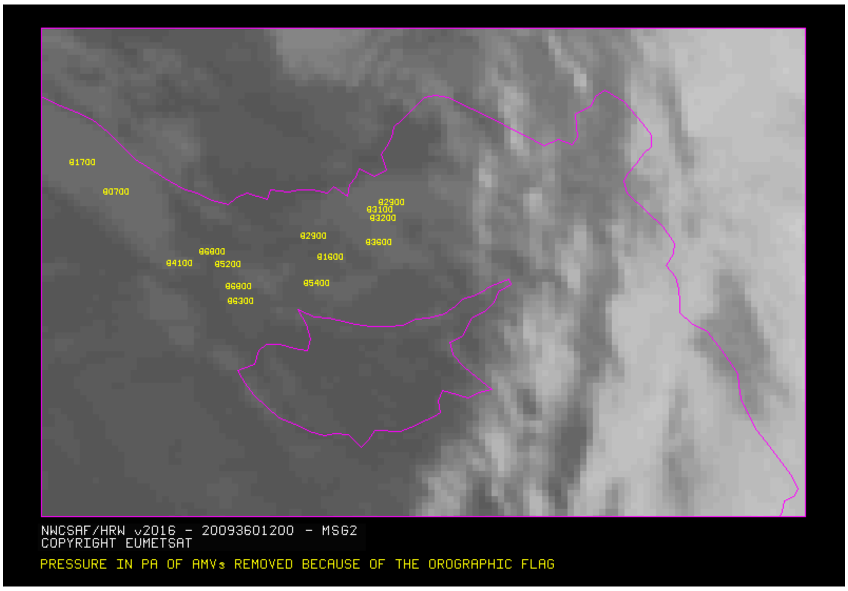


Figure 21: Pressure values in Pa for AMVs affected by orography (i.e. with "Orographic flag" values between 1 and 5) in a zoomed area around the island of Cyprus in the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite). Orographic effects 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 for all AMVs related to the same tracer.*
- *TESO = 2: IND_TOPO for the AMV chosen as best wind, is one unit smaller than the best value for all AMVs related to the same tracer.*
- *TESO = 1: IND_TOPO for the AMV chosen as best wind, is at least two units smaller than the best value for all AMVs related to the same tracer.*
- *TESO = 0: IND_TOPO could not be calculated for the AMV chosen as best wind.*

With configurable parameter USE_TOPO = 1, IND_TOPO and TESO parameters are calculated and incorporated to the AMV and Trajectory output files, and 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 HRVIS,VIS06,WV62,WV73,IR108 for MSG satellite series; VIS06,WV62,WV73,IR105 for MTG-I satellite series; VIS06,WV62,WV70,WV73,IR112 for Himawari-8/9 satellite series; VIS07,WV65,IR107 for GOES-N satellite series; optionally VIS06,WV62,WV70,WV73,IR112 for GOES-R satellite series), which defines the channels for which AMVs and Trajectories are calculated.
- QI_THRESHOLD: defines the "Quality index threshold" for the AMVs and Trajectories in the output files. Depending on configurable parameter QI_THRESHOLD_USEFORECAST, the "Quality index with forecast" (which is the default option) or the "Quality index without forecast" are respectively used for the AMV filtering.
- CLEARAIRWINDS: defines if the "Clear air water vapour AMVs" are to be included in the output files (in the default option they are included).
- MAXPRESSUREERROR: defines the maximum "AMV pressure error" (in hPa) allowed in the output AMVs and Trajectories, when "CCC height assignment method" has been used.
- MIN_CORRELATION: defines the minimum correlation (as a percentage value) in the output AMVs and Trajectories, when the "Cross Correlation tracking" has been used.
- FINALFILTERING: defines several filterings in the output AMVs and Trajectories, depending on its value:
  - With FINALFILTERING > 0, the "AMV pressure level" filtering defined in *Table 8* 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), the "AMV cloud type" filtering defined in *Table 6* is additionally implemented.
  - With FINALFILTERING > 2, AMVs with a "spatial quality flag" = 1,2 are additionally eliminated.
  - With FINALFILTERING = 4, AMVs with a "spatial quality flag" = 0 are additionally eliminated.

MSG sat.		HRVIS	VIS06	VIS08	WV62		WV73	IR108	IR120
MTG-I sat.	VIS06	VIS08			WV62		WV73	IR105	IR123
Himawari-8/9 sat.	VIS06	VIS08			WV62	WV70	WV73	IR112	
GOES-N sat.		VIS07			WV65			IR107	
GOES-R sat. (optionally)	VIS06	VIS08			WV62	WV70	WV73	IR112	
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 8: AMV filtering related to the Pressure level and Satellite channel

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

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

NWC/GEO-HRW-MTG is validated considering both Radiosounding winds and NWP analysis winds as reference winds.

The main validation statistics against Radiosounding winds for NWC/GEO-HRW-MTG Basic AMVs, following the criteria defined at the Third International Winds Workshop (Ascona, Switzerland, 1996) for the comparison of satellite winds, are shown here.

At this moment, statistics are available for MSG and GOES-N satellite series. Validation statistics for Himawari-8/9 satellite series against Radiosounding winds, and for MSG, GOES-N and Himawari-8/9 satellite series against NWP analysis winds, will be provided before the release of NWC/GEO v2018 software package in 2018.

Validation statistics for MTG-I and optionally GOES-R satellite series against Radiosounding winds and NWP analysis winds will be provided before the release of NWC/GEO MTG-I day-1 software package.

In all cases, cloudy AMVs in the layer 100-1000 hPa and clear air AMVs in the layer 100-425 hPa, with a Quality index with forecast ≥ 70 for the High and Medium layer and a Quality index with forecast ≥ 75 for the Low layer, are considered.

The statistical parameters used in the process of validation are:

1. NC: “Number of collocations” between NWC/GEO-HRW-MTG 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”.

Information about how these validation statistical parameters can be calculated can be obtained in the “Validation report for GEO-HRW v5.0” (document [AD.15]).

2.3.1.1 Validation of High Resolution Winds (NWC/GEO-HRW-MTG) for MSG satellites

For MSG satellite series, the Validation statistics correspond to the reference period used since some years ago for NWC/GEO-HRW algorithm: July 2009–June 2010 at 12:00 UTC, with MSG2 satellite data, in an area covering Europe and the Mediterranean Sea, such as shown in *Figure 22*.

Two different configurations are shown in the validation: the first one considering the conditions defined in the default `$SAFNWC/config/safnwc_HRW_MSG15MIN.cfm` "Model configuration file", in which "CCC height assignment with Microphysics correction" is considered, and for which NWC/GEO-Cloud product outputs (CMA, CT, CTTH, CMIC) have to be available. The other one considers the running of NWC/GEO-HRW with the same configuration file, but without the provision of NWC/GEO-Cloud product outputs, so considering "Brightness temperature interpolation height assignment without cloud products".

The statistics for both height assignment methods are supplied, to show that when NWC/GEO-Cloud product outputs are not available and "Brightness temperature interpolation height assignment without Cloud products" has to be used, AMV quality is basically similar: NMVD and NRMSVD parameters are less than a 10% larger, although with a reduction of about a 25% in the amount of AMV data.

Comparing the statistics for the different satellite channels, the MVD and NRMSVD seem very different considering all layers together, with changes larger than the 50% between the best case (Cloudy WV62 AMVs) and the worst case (Cloudy VIS08). Nevertheless, this is only caused by the different proportion of AMVs in the different layers for each channel. Inside each one of the layers, differences of NMVD and NRMSVD for the different channels are much smaller.

Considering the different layers, NWC/GEO-HRW Product Requirement Table Optimal accuracy (with a value of 0.35) is reached in the High layer, and the NWC/GEO-HRW-MTG Product Requirement Table Target accuracy (with values respectively of 0.50 and 0.56) is reached in the Medium and Low layer, both using and not using NWC/GEO Cloud products as input.

The results of the 2014 AMV Intercomparison Study Report ("Comparison of NWC SAF/HRW AMVs with AMVs from other producers" [RD.24]) are also important to be taken into account for the validation of NWC/GEO-HRW algorithm. In this study, AMVs calculated with NWC/GEO-HRW algorithm were compared to AMVs calculated by six other institutions (EUMETSAT/MPEF, NOAA, Japan Meteorological Agency - JMA, China Meteorological Administration - CMA, Korea Meteorological Administration - KMA and the Weather Forecast and Climatic Studies Centre from the Brazilian National Spatial Research Institute - CPTEC/INPE) using the same MSG satellite and ECMWF NWP model data. The report shows that NWC/GEO-HRW AMVs together with the EUMETSAT/MPEF AMVs have the two best validation statistics in the AMV intercomparison, both using "CCC method" for the AMV height assignment.

NWC/GEO-HRW AMVs (Jul 2009-Jun 2010)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy WV62	Cloudy WV73	Cloudy IR108	Cloudy IR120	Clear Air	All AMVs
NC	31630	97221	87177	256951	331831	313072	317120	48509	1483511
SPD [m/s]	16.64	10.51	10.48	22.78	20.80	18.53	18.67	16.64	18.70
NBIAS (ALL LAYERS)	-0.04	-0.14	-0.15	-0.04	-0.07	-0.09	-0.08	-0.00	-0.08
NMVD (100-1000 hPa)	0.29	0.41	0.42	0.26	0.28	0.29	0.29	0.32	0.30
NRMSVD	0.35	0.49	0.49	0.32	0.35	0.35	0.35	0.39	0.36
NC	14748			235550	238459	186143	193173	41261	909334
SPD [m/s]	21.77			23.31	23.15	22.16	22.11	17.19	22.48
NBIAS (HIGH LAYER)	-0.03			-0.04	-0.08	-0.08	-0.07	-0.01	-0.07
NMVD (100-400 hPa)	0.24			0.26	0.26	0.26	0.26	0.31	0.26
NRMSVD	0.29			0.31	0.32	0.32	0.31	0.38	0.32
NC	8532	37419	34188	21401	84678	86936	86010	7248	366412
SPD [m/s]	14.64	12.08	11.94	16.90	15.10	14.61	14.69	13.51	14.35
NBIAS (MEDIUM LAYER)	-0.05	-0.18	-0.18	+0.02	-0.05	-0.12	-0.11	+0.09	-0.10
NMVD (400-700 hPa)	0.31	0.38	0.38	0.37	0.37	0.35	0.35	0.40	0.36
NRMSVD	0.48	0.46	0.45	0.46	0.45	0.43	0.43	0.47	0.44
NC	8350	59802	52989		8694	39993	37937		207765
SPD [m/s]	9.64	9.52	9.54		12.09	10.14	10.18		9.88
NBIAS (LOW LAYER)	-0.02	-0.12	-0.12		-0.09	-0.12	-0.12		-0.11
NMVD (700-1000 hPa)	0.44	0.44	0.44		0.38	0.41	0.40		0.43
NRMSVD	0.52	0.51	0.52		0.46	0.48	0.48		0.50

Table 9: Validation parameters for NWC/GEO-HRW-MTG (Jul 2009-Jun 2010, MSG2 satellite, 12:00 UTC, European and Mediterranean area; Basic AMVs; Cross correlation tracking; CCC height assignment with Microphysics parameters)

NWC/GEO-HRW AMVs (Jul 2009-Jun 2010)	HRVIS	VIS06	VIS08	WV62	WV73	IR108	IR120	All AMVs
NC	23855	74554	69975	317904	321140	149190	162831	1119449
SPD [m/s]	16.08	11.59	11.63	22.11	18.04	16.84	16.78	17.98
NBIAS (ALL LAYERS)	-0.01	-0.06	-0.06	-0.04	+0.02	+0.02	+0.02	-0.00
NMVD (100-1000 hPa)	0.31	0.38	0.38	0.27	0.34	0.31	0.32	0.32
NRMSVD	0.38	0.46	0.45	0.33	0.42	0.38	0.39	0.39
NC	8417			310650	132497	40419	45913	537896
SPD [m/s]	22.48			22.19	21.24	24.78	24.57	22.36
NBIAS (HIGH LAYER)	-0.02			-0.03	+0.02	-0.00	-0.00	-0.01
NMVD (100-400 hPa)	0.24			0.27	0.29	0.25	0.25	0.27
NRMSVD	0.29			0.33	0.34	0.30	0.30	0.33
NC	9037	30312	29333	7254	191643	65549	70573	403701
SPD [m/s]	14.35	14.65	14.62	18.80	15.83	16.22	15.96	15.76
NBIAS (MEDIUM LAYER)	-0.00	-0.07	-0.07	-0.19	+0.02	+0.06	+0.07	+0.02
NMVD (400-700 hPa)	0.35	0.34	0.34	0.43	0.40	0.34	0.35	0.37
NRMSVD	0.43	0.41	0.40	0.53	0.49	0.42	0.43	0.45
NC	6401	44242	40642			43222	46345	180852
SPD [m/s]	10.11	9.49	9.47			10.35	10.31	9.92
NBIAS (LOW LAYER)	-0.00	-0.04	-0.05			-0.03	-0.04	-0.04
NMVD (700-1000 hPa)	0.43	0.42	0.42			0.38	0.38	0.40
NRMSVD	0.51	0.50	0.50			0.45	0.45	0.48

Table 10: Validation parameters for NWC/GEO-HRW-MTG
(Jul 2009-Jun 2010, MSG2 satellite, 12:00 UTC, European and Mediterranean area;
Basic AMVs; Cross correlation tracking;
Brightness temperature interpolation height assignment without Cloud products;
No distinction between Cloudy and Clear air Water vapour AMVs due to the lack of Cloud products)

2.3.1.2 Validation of High Resolution Winds (NWC/GEO-HRW-MTG) for GOES-N satellites

For GOES-N satellites, validation statistics correspond to the yearly period July 2010–June 2011, with GOES-13 satellite data, in an area covering the Continental Unites States such as shown in *Figure 24*.

Two different configurations are shown in the validation: the first one considering the conditions defined in the default `$SAFNWC/config/safnwc_HRW.cfm.GOES15MIN` configuration file, in which "CCC height assignment without Microphysics correction" is considered, and for which NWC/GEO-CMA, CT and CTTH product outputs have to be available. The other one considers the running of NWC/GEO-HRW-MTG with the same configuration file, but without the provision of NWC/GEO-Cloud product outputs, so considering "Brightness temperature interpolation height assignment without cloud products".

Radiosounding data for all main synoptic hours (00:00, 06:00, 12:00 and 18:00 UTC) are used for the statistics to increase the amount of comparisons. In any case, dawn or dusk occurs at the main synoptic hours 00:00 and 12:00 with the largest number of Radiosounding observations, because of which the number of visible AMVs is much smaller in the comparisons. AMVs at 23:45, 05:45, 11:45 and 17:45 are used for the comparisons, because no GOES-13 images exist exactly at the main synoptic hours.

Comparing with the equivalent statistics for MSG (shown in *Table 9 and 10*), statistics for GOES-N AMVs (NBIAS, NMVD, NRMSVD) are very similar, and in some cases even slightly better. Considering the different GOES-N channels (VIS07, WV65, IR107) there are no remarkable differences with the equivalent MSG channels.

These result mean that NWC/GEO-HRW algorithm can perfectly be used operatively with GOES-N satellite series, proving the validity of exporting GEO-HRW algorithm to other geostationary satellite series.

Considering the different layers, the NWC/GEO-HRW Product Requirement Table Optimal accuracies (respectively 0.35, 0.40 and 0.45 for High, Medium and Low layer) are reached for all layers with GOES-N satellite series when "Brightness temperature interpolation height assignment without Cloud products" is used.

Very slightly higher values of the NRMSVD parameter cause that using "CCC height assignment without Microphysics correction" the Product Requirement Table Optimal accuracy is not reached by a small margin at the High and Low layer (showing the fact that the Cloud products had to be calculated with only five channels for GOES-N satellites instead of the twelve channels used for MSG satellites). In spite of this, and considering the specific study done on which assignment method is better for GOES-N satellite series in the "Validation report for GEO-HRW v5.0" (document [AD.15]), "CCC height assignment without Microphysics correction" is still preferred as default option for the running of GEO-HRW algorithm with GOES-N satellite series.

As a final comment, it is necessary to remark that the Target accuracy is widely reached in all conditions for both MSG and GOES-N satellite series.

NWC/GEO-HRW AMVs (Jul 2009-Jun 2010)	Cloudy VIS07	Cloudy WV65	Cloudy IR107	Clear Air	All AMVs
NC	5849	205757	208726	47253	467585
SPD [m/s]	22.34	24.46	22.98	15.31	23.00
NBIAS (ALL LAYERS)	+0.00	-0.03	-0.08	-0.00	-0.05
NMVD (100-1000 hPa)	0.25	0.27	0.29	0.35	0.28
NRMSVD	0.31	0.33	0.36	0.48	0.36
NC	4694	191878	173848	47253	417673
SPD [m/s]	24.71	24.68	24.33	15.31	23.47
NBIAS (HIGH LAYER)	+0.00	-0.03	-0.09	-0.00	-0.05
NMVD (100-400 hPa)	0.24	0.27	0.28	0.35	0.28
NRMSVD	0.29	0.33	0.35	0.47	0.36
NC	460	13879	25067		39406
SPD [m/s]	18.10	21.43	18.60		19.59
NBIAS (MEDIUM LAYER)	-0.03	-0.00	-0.06		-0.04
NMVD (400-700 hPa)	0.28	0.29	0.32		0.31
NRMSVD	0.36	0.36	0.40		0.38
NC	695		9811		10506
SPD [m/s]	9.17		10.24		10.17
NBIAS (LOW LAYER)	-0.06		-0.10		-0.10
NMVD (700-1000 hPa)	0.35		0.39		0.38
NRMSVD	0.43		0.48		0.48

Table 11: Validation parameters for NWC/GEO-HRW-MTG
(Jul 2010-Jun 2011, GOES13 satellite, 00/06/12/18:00 UTC, Continental United States area;
Basic AMVs; Cross correlation tracking;
CCC height assignment without Microphysics correction)

NWC/GEO-HRW AMVs (Jul 2009-Jun 2010)	VIS07	WV65	IR107	All AMVs
NC	8176	281224	77701	367101
SPD [m/s]	18.61	21.91	21.87	21.83
NBIAS (ALL LAYERS)	+0.05	-0.00	+0.02	+0.00
NMVD (100-1000 hPa)	0.30	0.29	0.29	0.29
NRMSVD	0.38	0.36	0.35	0.36
NC	3834	252275	36889	292998
SPD [m/s]	23.37	22.05	26.92	22.68
NBIAS (HIGH LAYER)	+0.06	+0.00	+0.00	+0.00
NMVD (100-400 hPa)	0.28	0.28	0.26	0.28
NRMSVD	0.35	0.35	0.32	0.35
NC	2530	28949	28624	60103
SPD [m/s]	17.94	20.65	19.91	20.18
NBIAS (MEDIUM LAYER)	+0.07	-0.07	+0.06	-0.00
NMVD (400-700 hPa)	0.32	0.32	0.32	0.32
NRMSVD	0.40	0.41	0.39	0.40
NC	1812		12188	14000
SPD [m/s]	9.49		11.19	10.97
NBIAS (LOW LAYER)	-0.02		-0.03	-0.03
NMVD (700-1000 hPa)	0.35		0.35	0.35
NRMSVD	0.44		0.42	0.42

Table 12: Validation parameters for NWC/GEO-HRW-MTG
(Jul 2010-Jun 2011, GOES13 satellite, 00/06/12/18:00 UTC, Continental United States area;
Basic AMVs; Cross correlation tracking;
Brightness temperature interpolation height assignment without Cloud products;
No distinction between Cloudy and Clear air Water vapour AMVs due to the lack of Cloud products)

2.3.1.3 Validation process of High Resolution Winds inside NWC/GEO-HRW-MTG algorithm

Considering requests from NWC SAF users, NWC/GEO-HRW-MTG has the option to calculate the Validation statistics with the NWC/GEO-HRW-MTG algorithm itself (using NWP winds as reference winds, interpolated to the tracer location and level). This is implemented with configurable parameter NWPVAL_STATISTICS = 1 (which is the default option).

The statistics are calculated using NWP forecast winds in real time processes, and can be calculated using NWP analysis winds or NWP forecast winds in reprocessing processes. In the last case, the use of NWP analysis winds 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-MTG algorithm.

The validation statistics are calculated at the end of the process of the NWC/GEO-HRW-MTG algorithm, and the results are written in a specific file in `$SAFNWC/export/HRW` directory under the name `S_NWC_HRW-STAT_<satid>_<regionid>-BS_YYYYMMDD.txt` (for the "Single or Basic AMV scale"), or the name `S_NWC_HRW-STAT_<satid>_<regionid>-DS_YYYYMMDD.txt` (for the "Detailed AMV scale"). Here, "satid" is the identifier of the satellite used, "regionid" is the identifier of the region used, and "YYYYMMDD" is the year, month and date of the data used for the AMV calculation (validation statistics for all data from the same day are included in the same output file).

The following content is added to this file each time the validation statistics are run: several lines with the following format, showing the validation parameters mentioned previously (NC, SPD, NBIAS, NMVD, NRMSVD) for each layer (defined as ALL, HIG, MED, LOW) and for each channel for which AMVs have been calculated, with the specification of the date and time of the NWC/GEO-HRW-MTG run, of the *.cfm model configuration file used in the process (more info on this file later in chapter 2.3.3), and if the validation statistics have been run against the NWP analysis or forecast winds (defined as ANA, FOR):

```
yyyy-mm-ddThh:mm:ssZ GEO-HRW-MTG fffff.cfm [S] *** NWP:mmm CH:ccccc LAYER:lll *** NC:rrrrrr SPD[M/S]:sss.ss NBIAS:±t.ttt NMVD:u.uuu NRMSVD:v.vvv
```

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

The NWP analysis or forecast winds used for each AMV in this validation process (defined by their speed and direction), are also added to the NWC/GEO-HRW-MTG output files (excepting the BUFR bulletin with format equivalent to the one defined for the EUMETSAT's MPEF/Meteosat Product Extraction Facility AMVs, inside which there is no possible location for these parameters). This allows NWC SAF users a quick recalculation of the NWC/GEO-HRW-MTG validation parameters for different sampling and filtering options of the data, including for example monthly/yearly totalizations.

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

1. The first one, activated with configurable parameter NWPVAL_NWPDIFFERENCE = 1 (implemented as a default option) calculates for each AMV the "Vector difference with the NWP reference wind", and adds this "Vector difference" (defined by its speed and direction) to the NWC/GEO-HRW-MTG output files (excepting again the BUFR bulletin with format equivalent to the one defined for the EUMETSAT's MPEF/Meteosat Product Extraction Facility AMVs, inside which there is no possible location for these parameters).

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

2. The second one, activated with configurable parameter NWPVAL_NWPBESTFITLEVEL = 1 (implemented also as a default option) calculates for each AMV the "NWP reference wind at the best fit pressure level" and adds this "NWP model wind at the best fit pressure level" (defined by its speed, direction and pressure level) to the NWC/GEO-HRW-MTG output files (excepting again the BUFR bulletin with format equivalent to the one defined for the EUMETSAT's MPEF/Meteosat Product Extraction Facility AMVs, inside which there is no possible location for these parameters).

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

NWP analysis winds or NWP forecast winds can be used here for both procedures (calculation of the "Vector difference with the NWP reference wind" and calculation of the "NWP reference wind at the best fit pressure level"), depending on the value of configurable parameter NWPVAL_ANALYSIS. In case of using NWP analysis winds, both parameters are only provided for the specific runs for which a NWP analysis with the same date and time is available.

2.3.2 List of Inputs for High Resolution Winds (NWC/GEO-HRW-MTG)

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

- Considering MSG satellite series: full resolution uncompressed "HRIT original data" for the processing region, for the images in which tracers are calculated and tracked, for all MSG channels to be used. These data are to be located in `$SAFNWC/import/Sat_data` directory. IR108 channel is additionally needed for the visible channel processing when the old "Brightness temperature interpolation height assignment" is to be used. IR108 and WV62 channels are additionally needed if the default configuration of the Quality control is kept (including the "Image correlation test").

- Considering MTG-I satellite series: full resolution uncompressed "netCDF original data" for the processing region, for the images in which tracers are calculated and tracked, for all MTG-I channels to be used. These data are to be located in `$SAFNWC/import/Sat_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 WV62 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 uncompressed "Himawari-8/9 Standard Data" for the processing region, for the images in which tracers are calculated and tracked. "Himawari-8/9 Standard Data" have first to be converted to "NWC/GEO netCDF satellite input data format", with the provided GOES2NC java tool (more information about this can be extracted from the document "User Manual of the GOES2NC tool" [AD.16]), and after this process 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 WV62 channels are in any case needed if the default configuration of the Quality control is kept (including the "Image correlation test").

- Considering GOES-N satellite series: full resolution uncompressed "GVAR data" for the processing region, for the images in which tracers are calculated and tracked. GOES-N GVAR data have first to be converted to "NWC/GEO netCDF satellite input data format", with the provided GOES2NC java tool (more information about this can be extracted from the document "User Manual of the GOES2NC tool" [AD.16]), and after this process included in `$SAFNWC/import/Sat_data` directory. IR107 channel is in any case needed for the visible channel processing when the old "Brightness temperature interpolation height assignment" is to be used. IR107 and WV65 channels are in any case needed if the default configuration of the Quality control is kept (including the "Image correlation test").

- Optionally, considering GOES-R satellite series: full resolution uncompressed "GOES-R netCDF original data" for the processing region, for the images in which tracers are calculated and tracked. "GOES-R netCDF original data" have first to be converted to "NWC/GEO netCDF satellite input data format", with the provided GOES2NC java tool (more information about this can be extracted from the document "User Manual of the GOES2NC tool" [AD.16]), and after this process 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 WV62 channels are in any case needed if the default configuration of the Quality control is kept (including the "Image correlation test").

- NWP data: Fields of temperatures covering at least the processing region, with an horizontal resolution of 0.5° and a NWP time step of at most 6 hours (preferably a NWP time step of 1 hour), for a minimum of four (defined by configurable parameter MIN_NWP_FOR_CALCULATION) and preferably for as many as possible of the following pressure levels: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10 hPa, in `$SAFNWC/import/NWP_data` directory. The NWP fields of rectangular components of the wind (u,v) are also needed for the "Quality control forecast test", if the NWP wind guess has to be used for the definition of the "tracking area centre", or if Validation statistics are to be calculated by the NWC/GEO-HRW-MTG algorithm itself (considering as reference winds the NWP analysis winds or the NWP forecast winds). In case the "Orographic flag" should also be calculated, the NWP fields of geopotential heights are also required.

- 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 NWP wind guess has to be used for the definition of the "tracking area centre", or the "Brightness temperature interpolation height assignment with Cloud products" is used.

Of all these data, only full resolution uncompressed satellite data (MSG/HRIT, MTG-I/netCDF, Himawari-8/9/Standard Data, GOES-N/GVAR, optionally GOES-R/netCDF original data), and the NWP temperature profiles are strictly needed for the running of NWC/GEO-HRW-MTG algorithm.

It is important here to remember that NWC/GEO software will only be able to process MSG/HRIT and MTG-I/netCDF original data as such. Satellite data from the other satellite series have to be converted to "NWC/GEO netCDF satellite input data format" with the provided GOES2NC java tool, to enable the processing.

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

The High Resolution Winds Model configuration file holds the configurable parameters needed for the running of NWC/GEO-HRW-MTG executable. It must be located in `$SAFNWC/config` directory.

Up to eight different reference Model Configuration Files are included in the NWC/GEO package for the operational use with the different satellite series:

1. MSG in "Nominal scan mode" (`safnwc_HRW_MSG15MIN.cfm`) every 15 minutes.
2. MSG in "Rapid scan mode" (`safnwc_HRW_MSG05MIN.cfm`) every 5 minutes.
3. MTG-I in "Nominal scan mode" (`safnwc_HRW_MTG10MIN.cfm`) every 10 minutes.
4. Himawari-8/9 in "Nominal scan mode" (`safnwc_HRW_HIMA10MIN.cfm`) every 10 minutes.
5. Himawari-8/9 in "Rapid scan mode" (`safnwc_HRW_HIMA02MIN.cfm`) every 2.5 minutes.
6. GOES-N in the Continental United States (`safnwc_HRW_GOES15MIN.cfm`) every 15 minutes.
7. GOES-N in North America (`safnwc_HRW_GOES30MIN.cfm`) every 30 minutes.
8. Optionally, also GOES-R in "Nominal scan mode" (`safnwc_HRW_GOESRS15MIN.cfm`) every 15 minutes.
9. Optionally, also GOES-R in "Rapid scan mode" (`safnwc_HRW_GOESRS05MIN.cfm`) every 5 minutes.

A brief description of the configurable parameters included in the files is shown in the following 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-MTG
SAT_BANDS	Satellite bands that can be used to run for the calculation of AMVs and Trajectories with NWC/GEO-HRW-MTG algorithm. This keyword is optional, but should not be changed. It defines the maximum value of bands for which AMVs can be calculated.	Chain of characters	HRVIS,VIS06,VIS08,WV62, WV73,IR108,IR120(MSG) VIS06,VIS08,WV62,WV73, IR105,IR123(MTG-I) VIS06,VIS08,WV62,WV70, WV73,IR112 (Himawari/GOESR) VIS07,WV65,IR107(GOESN)
AMV_BANDS	Satellite bands really used for the calculation of AMVs and Trajectories with NWC/GEO-HRW-MTG algorithm. As possible values, it can include any of the bands shown by the previous parameter separated by commas (not by spaces).	Chain of characters	HRVIS,VIS06,WV62,WV73, IR108(MSG) VIS06,WV62,WV73,IR105 (MTG-I) VIS06,WV62,WV70,WV73, IR112(Himawari/GOESR) VIS07,WV65,IR107(GOESN)
SLOT_GAP	Ordering number of the previous satellite image, for which tracers are to be considered for the AMV processing.	Integer	1 (MSG/MTG-I/Himawari/ GOESR Nominal mode) 2 (MSG/Himawari/GOESR Rapid scan mode) 1 (GOESN 15/30min mode)
MIXED_SCANNING	Flag to decide if a Mixed method is implemented for the processing of AMVs and Trajectories, through which AMVs and Trajectories are calculated considering "Nominal scan cycles", but with verification of the tracking process using "Rapid scan cycles".	Integer	0
CDET	Flag to define if Detailed AMVs and Trajectories calculated.	Integer	0

Output parameters			
BUFR_CENTRE_OR	Originating centre of the BUFR file, as defined in WMO Common Code Table C-1 ([RD.19]). It is to be modified with the code related to the corresponding centre (e.g. 214 is default value for Madrid).	Integer	214
OUTPUT_FORMAT	Output file format. Possible values: - NWC: AMV & Trajectories BUFR files, with the specific NWC SAF format. - EUM: AMV BUFR files, with the EUMETSAT/MPEF BUFR format. - NET: AMV netCDF files - ALL: All previous files together	Chain of characters	NWC
Output filtering parameters			
QI_THRESHOLD	Quality Index threshold for the AMVs.	Integer	70
QI_THRESHOLD_USEFORECAST	Option to show if the Quality index threshold used in the wind output filtering includes the Quality forecast test.	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 (when > 0), - Their Cloud type (when > 1), - Their Quality spatial test (1,2 as invalid values when > 2; 0,1,2 as invalid values when > 3).	Integer	2
USE_TOPO	Flag for calculation of Orographic flag (when positive), and for its AMV filtering (when 2).	Integer	2
USE_MEANWIND	Flag showing if the mean value of the latitude increment, longitude increment, speed, direction, temperature, pressure, pressure error and correlation related to an AMV and its predecessor (in case it exists), are used.	Integer	0
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
Working area description parameters			
LAT_MIN	Latitude and longitude borders (in degrees) for the processing region (Basic AMVs).	Real	-75.0
LAT_MAX		Real	75.0
LON_MIN		Real	-179.0
LON_MAX		Real	179.0
LAT_MIN_DET	Latitude and longitude borders (in degrees) for the processing region (Detailed AMVs).	Real	-75.0
LAT_MAX_DET		Real	75.0
LON_MIN_DET		Real	-179.0
LON_MAX_DET		Real	179.0
FRAC_DAY_SCENE	Minimum fraction of area illuminated by the sun needed to calculate the visible AMVs (HRVIS, VIS06, VIS07, VIS08 channels).	Integer	8
SUN_ZEN_THRES	Sun zenith angle threshold (degrees).	Double	87.0
SAT_ZEN_THRES	Satellite zenith angle threshold (degrees).	Double	80.0
Tracer parameters			
MAX_TRACERS	Maximum number of tracers.	Integer	120000
MIN_BRIGHTNESS_VIS	Minimum acceptable 1 byte reflectance value in the visible tracers.	Double	120.0
MIN_BRIGHTNESS_OTHER	Minimum acceptable 1 byte brightness temperature value in the infrared and water vapour tracers.	Double	60.0
GVAL_VIS	Minimum acceptable 1 byte reflectance contrast in the visible tracers.	Double	60.0
GVAL_OTHER	Minimum acceptable 1 byte brightness temperature contrast in The infrared and water vapour tracers.	Double	48.0

Tracer size and density parameters			
TRACERSIZE_VERYHIGH	Tracer line and column dimension in pixels, when respectively using satellite images with very high, high and low resolution.	Integer	`24 (Himawari/GOESR)`
TRACERSIZE_HIGH		Integer	`24`
TRACERSIZE_LOW		Integer	`24`
TRACERDISTANCE_VERYHIGH	Minimum separation in pixels between tracers, when respectively using satellite images with very high, high and low resolution. Depending on value of HIGHERDENSITY_LOWAMVS, this separation applies to all tracers (when = 0) or only to tracers related to very low and low clouds (when = 1).	Integer	`24 (Himawari/GOESR)`
TRACERDISTANCE_HIGH		Integer	`12`

TRACERDISTANCE_LOW		Integer	`3 (GOES-N)`
			`4 (MSG)`
			`6 (MTG-I/Himawari/ GOESR)`

HIGHERDENSITY_LOWTRACERS	Option to decide if minimum separation between tracers related to very low and low clouds is half the one between tracers related to other cloud types.	Integer	`1`
Tracking parameters			
TRACKING	Tracking method. Possible values: LP: Euclidean difference CC: Cross correlation.	Chain of characters	`CC`
DEFINECONTRIBUTIONS	Flag to decide if "CCC height assignment" is to be used (requires also TRACKING=CC).	Integer	`1`
DEFPOSCONTRIBUTIONS	Flag to decide if the position of the AMV in the target is relocated to the position of maximum correlation contribution defined by "CCC height assignment" (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).	Integer	`1`
USE_CLOUDTYPE	Flag to decide if - The Tracer cloud type is calculated by the old "Brightness temperature interpolation height assignment method" (when positive), - And if the Tracer cloud type is taken into account for the calculation of the Tracer temperature (when = 2).	Integer	`2`
USE_MICROPHYSICS	Flag to decide if Microphysics correction is to be calculated to "CCC height assignment" (when positive), and if this Microphysics corrections is applied to the final AMV pressure (when = 2) (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).	Integer	`2 (MSG/MTG-I/ Himawari/GOESR)` `0 (GOESN)`
MIN_CORRELATION	Minimum correlation acceptable in the Tracking process (if Cross correlation method used).	Double	`80.0 (MSG/MTG-I/ Himawari/GOESR)` `50.0 (GOESN)`
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 any direction (in km/h) which the process is at least able to detect for AMVs/Trajectories. When the wind guess is used in the definition of the Tracking area, difference in speed with respect to the one of the NWP wind guess (in km/h) which the process is at least able to detect for the AMVs/Trajectories.	Double	`272.0`
USE_SUBPIXELTRACKING	Flag to decide if Subpixel tracking is used.	Integer	`1`
NWP validation parameters			
NWPVAL_STATISTICS	Flag to decide if Validation statistics against NWP model winds are to be calculated.	Integer	`1`
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-MTG processing.	Integer	4
NWP_PARAM	NWP parameters requested by NWC/GEO-HRW-MTG algorithm: * NWP_PT: 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) Sampling rate used: 1 Interpolation method used: NEIGHBOUR	Chain of characters	`NWP_PT,1,NEIGHBOUR`
NWP_PARAM		Chain of characters	`NWP_UW,1,NEIGHBOUR`
NWP_PARAM		Chain of characters	`NWP_VW,1,NEIGHBOUR`
NWP_PARAM		Chain of characters	`NWP_GEOP,1,NEIGHBOUR`

Table 13: NWC/GEO-HRW-MTG Model Configuration File Description

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

This issue applies specially with MSG satellite data because of its larger amount of channels. It can be very useful to keep the calculation of AMVs and Trajectories with seven different MSG channels (AMV_BANDS = HRVIS,VIS06,VIS08,WV62,WV73,IR108,IR120), as seen in the "Validation report for NWC/GEO-HRW v3.2" [AD.12]). Nevertheless, because of the general similarity on one side between IR108 and IR120 AMVs, and on the other side between VIS06 and VIS08 AMVs, the first recommendation to reduce NWC/GEO-HRW-MTG running time is to keep the five MSG channels in the default configuration (AMV_BANDS = HRVIS,VIS08,WV62,WV73,IR120). If further reductions in NWC/GEO-HRW-MTG running time are needed, it would be recommended at least to keep four channels (with AMV_BANDS = HRVIS,WV62,WV73,IR120).

With MTG-I satellite data, it is also useful to keep the calculation of AMVs and Trajectories with six channels (AMV_BANDS = VIS06,VIS08,WV62,WV73,IR105,IR123), in a similar way as seen for MSG satellite series. But again, because of the general similarity that there is on one side between IR105 and IR123 AMVs, and on the other side between VIS06 and VIS08 AMVs, the recommendation to reduce NWC/GEO-HRW-MTG running time is to keep the four MTG-I channels in the default configuration (AMV_BANDS = VIS06,WV62,WV73,IR105). No more reductions in the amount of channels are recommended with MTG-I satellite series, to keep the representation of the calculated AMVs and Trajectories throughout all the atmospheric layers.

With Himawari-8/9 or GOES-R satellite data, it is also very useful to keep the calculation of AMVs and Trajectories with six channels (AMV_BANDS = VIS06,VIS08,WV62,WV70,WV73,IR112). This way, AMVs and Trajectories related to visible images with two different resolutions, and related to three different water vapour images which look to three different layers in the atmosphere, are obtained. Nevertheless, if there is the need to reduce the NWC/GEO-HRW-MTG running time, the first recommendation would be to remove the lower resolution visible channel, as in the default configuration, with AMV_BANDS = VIS06,WV62,WV70,WV73,IR112. The second recommendation would be to keep at least two water vapour channels, with AMV_BANDS = VIS06,WV62,WV73,IR112.

With GOES-N satellite data, it should always be possible to keep the calculation of AMVs and Trajectories for the three suggested channels: AMV_BANDS = VIS07,WV65,IR107.

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

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

Error (E) or Warning (W)	*Message*	*Reason*	*Recovery action*
E - 151	"Usage of HRW executable: HRW <slot> <region_conf_file> <model_conf_file>"	Input parameters are incorrect	Check instructions to start the run of NWC/GEO-HRW-MTG product
E - 152	"Error allocating memory for tracers related to the previous slot"	Unable to allocate required memory for "tracer" struct	There are memory problems to run NWC/GEO-HRW-MTG product 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, relating tracers and AMVs"	Unable to allocate required memory for "tracer_wind" struct	
E - 154	"Error allocating memory for structs related to 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	"Satellite data for current slot are not valid"	Satellite data are not valid	Verify if there is any problem with the satellite data used by NWC/GEO-HRW-MTG product
E - 161	"Error reading Parameters from Satellite configuration file"	Error after NwcCFReadSat function	Verify that $SAFNWC/config/sat_conf_file file for running NWC/GEO-HRW-MTG product is correct
E - 162	"Error in date format (%s). Required (YYYY-MM-DDThh:mm:ssZ)"	Error after NwcTimeSetStr function	Verify that the date format used for running NWC/GEO-HRW-MTG product is correct
E - 163	"Error setting Processing region"	Error after NwcRegionSet function	Verify that $SAFNWC/config/region_conf_file for running NWC/GEO-HRW-MTG product is correct
E - 164	"Error reading Pressure levels from the Model configuration file"	Error after NwcNwpReadPLevel function	Verify that $SAFNWC/config/nwp_conf_file for running NWC/GEO-HRW-MTG product is correct
E - 165	"Unable to initialize the NWP Temperature / Wind / Geopotential NWP profile"	Error after NwcNwpInitProfile function	Verify that $SAFNWC/config/nwp_conf_file & $SAFNWC/config/model_conf_file for running NWC/GEO-HRW-MTG product are correct
E - 166	"Error allocating memory for wind_channel_info struct"	Error after NwcSatInit function	There are memory problems to run NWC/GEO-HRW-MTG product in the defined region with the defined configuration and computer. Use a larger computer or a smaller region.

Error (E) or Warning (W)	*Message*	*Reason*	*Recovery action*
E - 171	"Error reading Parameters from the HRW configuration file"	Error after hrw_ReadData function	Verify that $SAFNWC/config/model_conf_file for running NWC/GEO-HRW-MTG product is correct
E - 172	"Error getting latitude / longitude / sun angles for the High resolution region"	Error after hrw_GetAncillaryData function	All these errors are caused by the running of NWC/GEO-HRW-MTG product, and cannot be solved by the NWCSAF user. Nevertheless, as a whole, they should occur in less than a 0.5% of the cases. If the frequency is higher than that, please contact NWC SAF Helpdesk.
E - 173	"Error reading satellite data for current slot"	Error after hrw_ReadSatelliteData function	
E - 174	"Error reading tracers from previous slot"	Error after hrw_ReadTracers function	
E - 175	"Error reading Trajectories for the previous slot"	Error after hrw_ReadTrajectories function	
E - 176	"Error during the AMV Tracking process"	Error after hrw_GetWinds function	
E - 177	“Error during the AMV Quality Control"	Error after hrw_Qc function	
E - 178	"Error writing Predecessor winds in SAFNWC/tmp directory"	Error after hrw_WritePredWinds function	
E - 179	“Error writing Trajectories in SAFNWC/tmp directory"	Error after hrw_WriteTrajectories function	
E - 180	"Error calculating tracers for current slot"	Error after hrw_GetTracers function	
E - 181	"Error writing tracers in SAFNWC/tmp directory"	Error after hrw_WriteTracers function	
E - 182	"Error writing the AMVs in the netCDF output file"	Error after hrw_EncodeNetCDF function	
E - 191	"NWP temperature data are not available; Winds cannot be calculated"	AMVs cannot be calculated because NWP data could not be read	Verify that NWP temperature data for at least MIN_NWP_FOR_CALCULATION levels (with a default value of 4) have been provided for the running of NWC/GEO-HRW-MTG product in $SAFNWC/import/NWP_data directory

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

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

Three different types of outputs are possible for NWC/GEO High Resolution Winds, depending on the value of configurable parameter OUTPUT_FORMAT:

1. OUTPUT_FORMAT = NWC (default option): NWC/GEO-HRW-MTG output defined as two different BUFR bulletins (for AMVs and Trajectories), related to the ones used as default option in all previous versions of NWC/GEO software package.
2. OUTPUT_FORMAT = EUM: NWC/GEO-HRW-MTG output defined as one BUFR bulletin, whose format is equivalent to the one defined for the EUMETSAT/MPEF (Meteosat Product Extraction Facility) AMVs. This option permits NWC SAF users to have a similar processing for the NWC/GEO-HRW-MTG outputs than for the MPEF AMVs.
3. OUTPUT_FORMAT = NET: NWC/GEO-HRW-MTG output defined as one netCDF bulletin. This option is available since NWC/GEO v2016. It was requested during the "2010 Madrid Users' Workshop" and the "Consolidated Report on 2010 User Survey and Users' Workshop" document (SAF/NWC/IOP/INM/MGT/2010-US+WS).

All these outputs have exactly a similar format to the ones provided in the previous NWC/GEO-HRW v2018 algorithm, so that the processing of AMVs and Trajectories for MTG-I satellite series with NWC/GEO-HRW-MTG algorithm does not involve any adaptation process for the reading and processing of its AMVs and Trajectories.

2.3.5.1 HRW output as BUFR bulletins with NWC SAF specific format (AMVs)

When OUTPUT_FORMAT = NWC a BUFR bulletin related to the ones used as default option in all previous versions of NWC/GEO software package is written in `$SAFNWC/export/HRW` directory under the name `S_NWC_HRW-WIND_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr` (for the "Single or Basic AMV scale") or under the name `S_NWC_HRW-WIND_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.bufr` (for the "Detailed AMV scale"), as AMV output file. Here, "satid" is the identifier of the satellite used, "regionid" is the identifier of the region used, and "YYYYMMDDThhmmssZ" is the date and time of the image used for the AMV calculation.

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

The BUFR table used for the writing of the AMVs considering this format (identified as `$SAFNWC/import/Aux_data/HRW/B0000000000214012096.TXT`) is the following one. It is based on BUFR Master Table number 0, Version number 12. For all parameters in the table:

- The first column shows the "Parameter identification code".
- The second column shows the "Parameter description".
- 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 "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 "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).

001007	SATELLITE IDENTIFIER	CODE TABLE 001007	0	0	10
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	CODE TABLE 001031	0	0	16
001032	GENERATING APPLICATION (CODE TABLE 001032)	CODE TABLE 001032	0	0	8
002023	SATELLITE DERIVED WIND COMPUTATION METHOD	CODE TABLE 002023	0	0	4
002057	ORIGIN OF FIRST GUESS INFORMATION	CODE TABLE 002057	0	0	4
002152	SATELLITE INSTRUMENT USED IN DATA PROCESSING	CODE TABLE 002152	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 033035	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
127000	REPLICATION OPERATOR	-	0	0	0
031002	EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR:WINDS	NUMERIC	0	0	16
060100	WIND SEQUENCE NUMBER	NUMERIC	0	0	24
060101	PRIOR WIND SEQUENCE NUMBER	NUMERIC	0	0	24
002028	SEGMENT SIZE AT NADIR IN X DIRECTION	M	-1	0	18
002029	SEGMENT SIZE AT NADIR IN Y DIRECTION	M	-1	0	18
002164	TRACER CORRELATION METHOD	CODE TABLE 002164	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
060102	TRACER TYPE (CODE TABLE 060102)	CODE TABLE 060102	0	0	2
060103	HEIGHT ASSIGNMENT METHOD (CODE TABLE 060103)	CODE TABLE 060103	0	0	4
060200	NUMBER OF WINDS COMPUTED FOR THE TRACER	NUMERIC	0	0	3
060201	CORRELATION TEST (CODE TABLE 060201)	CODE TABLE 060201	0	0	3
060202	APPLIED QUALITY TESTS (CODE TABLE 060202)	CODE TABLE 060202	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 060205)	CODE TABLE 060205	0	0	3
060206	CLOUD TYPE (NWC/GEO) (CODE TABLE 060206)	CODE TABLE 060206	0	0	5
060207	WIND CHANNEL (CHANNEL ID) (CODE TABLE 060207)	CODE TABLE 060207	0	0	5
060208	CORRELATION	%	0	0	7
060209	PRESSURE ERROR	PA	-1	-8000	14
060210	PRESSURE CORRECTION	PA	-1	-8000	14
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 PRESSURE LEVEL	DEGREE TRUE	0	0	9
060214	NWP WIND SPEED AT BEST FIT PRESSURE LEVEL	M/S	1	0	12
060215	NWP WIND BEST FIT PRESSURE	PA	-1	0	14
060216	NWP WIND DIFFERENCE DIRECTION	DEGREE TRUE	0	0	9
060217	NWP WIND DIFFERENCE SPEED	M/S	1	0	12
060218	NWP WIND ANALYSIS OR FORECAST FLAG	CODE TABLE 060218	0	0	2

Table 15: BUFR table for NWC/GEO-MTG AMV BUFR output files with NWC SAF specific BUFR format

The Code Tables used for all parameters in this table except those characterized as 060xxx (which are specific for NWC/GEO-HRW-MTG bulletins) are described in the BUFR Reference Manual [RD.20]. The Code Tables for the NWC/GEO-HRW-MTG specific parameters are explained here:

- Code Table 060102, Tracer type:

  0 for "Basic tracer"

  1 for "Detailed tracer related to a Narrow basic tracer"

  2 for "Detailed tracer related to a Wide basic tracer"

  3 for "Detailed tracer unrelated to a Basic tracer".

- Code Table 060103, Height assignment method:

  Values 0 to 3 are related to "Brightness temperature interpolation height assignment method" and values 4 to 15 are related to "CCC height assignment method". Due to the actual implementation of NWC/GEO-HRW-MTG algorithm, value 2 is never used.

  0: "NWP interpolation using Top pressure in a Clear air AMV"

  1: "NWP interpolation using Top pressure in a Cloudy AMV"

  3: "NWP interpolation using Base pressure in a Cloudy AMV"

  4: "CCC method using low correlation threshold and cold branch in a Clear air AMV"

  5: "CCC method using high correlation threshold and cold branch in a Clear air AMV"

  6: "CCC method using low correlation threshold and cold/bright branch, in a Cloudy AMV with undefined phase"

  7: "CCC method using high correlation threshold and cold/bright branch, in a Cloudy AMV with undefined phase"

  8: "CCC method using low correlation threshold and cold/bright branch, in a Cloudy AMV with liquid phase"

  9: "CCC method using high correlation threshold and cold/bright branch, in a Cloudy AMV with liquid phase"

  10: "CCC method with microphysics correction using low correlation threshold and cold/bright branch, in a Cloudy AMV with liquid phase"

  11: "CCC method with microphysics correction using high correlation threshold and cold/bright branch, in a Cloudy AMV with liquid phase"

  12: "CCC method with low correlation threshold and cold/bright branch, in a Cloudy AMV with ice phase"

  13: "CCC method with high correlation threshold and cold/bright branch, in aCloudy AMV with ice phase"

  14: "CCC method with microphysics correction using low correlation threshold and cold/bright branch, in a Cloudy AMV with ice phase"

  15: "CCC method with microphysics correction using high correlation threshold and cold/bright branch, in a Cloudy AMV with ice phase".

- Code Table 060201, Correlation test:

  0 for "AMV not selected as the Best AMV for a tracer, not having the Best correlation value"

  1 for "AMV not selected as the Best AMV for a tracer, having the Best correlation value"

  2 for "AMV selected as the Best AMV for a tracer, not having the Best correlation value"

  3 for "AMV selected as the Best AMV for a tracer, having the Best correlation value".

- Code Table 060202, Applied Quality tests:

  For each one of the Quality flags: Orographic flag, Forecast quality flag, Spatial quality flag, Temporal quality flag, Interscale quality flag:

  0 for "AMV for which the corresponding quality test could not be calculated"

  1 for "AMV whose corresponding quality test is at least a 21% worse than for the AMV 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 AMV calculated for the same tracer with the best orographic flag)"

  2 for "AMV whose corresponding quality test is up to a 20% worse than for the AMV for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the AMV calculated for the same tracer with the best orographic flag)"

  3 for "AMV with the best corresponding quality test among the AMVs for the same tracer".

- Code Table 060205, Orographic flag:

  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.

- Code Table 060206, Cloud type:

  The values of this parameter are between 0 and 23, corresponding to those defined in *Table 6* of this document.

- Code Table 060207, Wind channel (satellite channel used for the AMV/Trajectory calculation):

MSG values:	5 for "HRVIS"	2 for "VIS06"	3 for "VIS08"	
	10 for "WV62"	12 for "WV73"	16 for "IR108"	17 for "IR120".
MTG-I values:	2 for "VIS06"	3 for "VIS08"	10 for "WV62"	
	12 for "WV73"	16 for "IR105"	17 for "IR123".	
Himawari-8/9 values:	2 for "VIS06"	3 for "VIS08"	10 for "WV62"	
	11 for "WV70"	12 for "WV73"	16 for "IR112".	
GOES-N values:	2 for "VIS07"	10 for "WV65"	16 for "IR107".	
GOES-R values:	2 for "VIS06"	3 for "VIS08"	10 for "WV62"	
	11 for "WV70"	12 for "WV73"	16 for "IR112".	

- Code Table 060218, defining if the NWP model data used for NWC/GEO-HRW-MTG validation statistics corresponds to NWP model analysis (value 0), NWP model forecast (value 1; default value) or if the validation statistics were not calculated (value 3).

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

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

When OUTPUT_FORMAT = NWC, if the calculation of trajectories is activated with configurable parameter CALCULATE_TRAJECTORIES = 1 (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. Again, "satid" is the identifier of the satellite used, "regionid" is the identifier of the region used, and "YYYYMMDDYhhmmssZ" is the date and time of the image used for the Trajectory calculation.

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

The BUFR specific table used for the writing of the Trajectories in the BUFR output file (identified as `$SAFNWC/import/Aux_data/HRW/B0000000000214012099.TXT`) is the following one.

It is very similar to the one used for the writing of the AMVs. It is also based on BUFR Master Table number 0, Version number 12, with the same code tables and specific parameters for NWC/GEO-HRW-MTG bulletins identified as 060xxx in previous chapter.

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

001007	SATELLITE IDENTIFIER	CODE TABLE 001007	0	0	10
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	CODE TABLE 001031	0	0	16
001032	GENERATING APPLICATION (CODE TABLE 001032)	CODE TABLE 001032	0	0	8
002023	SATELLITE DERIVED WIND COMPUTATION METHOD	CODE TABLE 002023	0	0	4
002057	ORIGIN OF FIRST GUESS INFORMATION	CODE TABLE 002057	0	0	4
002152	SATELLITE INSTRUMENT USED IN DATA PROCESSING	CODE TABLE 002152	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 033035	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
060104	TRAJECTORY SEQUENCE NUMBER	NUMERIC	0	0	24
117000	REPLICATION OPERATOR	-	0	0	0
031002	EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR:TRAJS	NUMERIC	0	0	16
002164	TRACER CORRELATION METHOD	CODE TABLE 002164	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
060103	HEIGHT ASSIGNMENT METHOD (CODE TABLE 060103)	CODE TABLE 060103	0	0	4
060205	OROGRAPHIC INDEX (CODE TABLE 060205)	CODE TABLE 060205	0	0	3
060206	CLOUD TYPE (CODE TABLE 060206)	CODE TABLE 060206	0	0	5
060207	WIND CHANNEL (CODE TABLE 060207)	CODE TABLE 060207	0	0	5
060208	CORRELATION	%	0	0	7
060209	PRESSURE ERROR	PA	-1	-8000	14
060210	PRESSURE CORRECTION	PA	-1	-8000	14
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 PRESSURE LEVEL	DEGREE TRUE	0	0	9
060214	NWP WIND SPEED AT BEST FIT PRESSURE LEVEL	M/S	1	0	12
060215	NWP WIND BEST FIT PRESSURE	PA	-1	0	14
060216	NWP WIND DIFFERENCE DIRECTION	DEGREE TRUE	0	0	9
060217	NWP WIND DIFFERENCE SPEED	M/S	1	0	12
060218	NWP WIND ANALYSIS OR FORECAST FLAG	CODE TABLE 060218	0	0	2

Table 16: BUFR table for NWC/GEO-HRW-MTG Trajectory BUFR output files with NWC SAF specific BUFR format

2.3.5.3 HRW output as BUFR bulletins with EUMETSAT/MPEF format

When OUTPUT_FORMAT = EUM, an AMV BUFR bulletin equivalent to those defined for the AMV extraction at the Meteosat Product Extraction Facility in EUMETSAT is written under the name `S_NWC_HRW-WINDEUM_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr` (for the "Single or Basic AMV scale"), or the name `S_NWC_HRW-WINDEUM_<satid>_b<regionid>-DS_YYYYMMDDThhmmssZ.bufr` (for the "Detailed AMV scale") in `$SAFNWC/export/HRW` directory. Again, "satid" is the identifier of satellite used, "regionid" is the identifier of the region used and "YYYMMDDThhmmssZ" is the date and time for which the AMVs have been calculated.

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

The BUFR template used for the writing of the NWC/GEO-HRW-MTG AMVs with this format (which is similar to the ones described for the MPEF AMVs at EUMETSAT website at http://www.eumetsat.int/website/home/Data/Products/Formats/index.html), is the following one, with some explanation underlined and in italics of the content of the different parameters when used by NWC/GEO-HRW-MTG algorithm.

This template is exactly BUFR Master Table number 0, Version number 12 (identified as `$SAFNWC/import/Aux_data/HRW/B0000000000000012000.TXT`).

Formally, the EUMETSAT/MPEF AMV BUFR format is a kind a blend of the NWC SAF AMV and Trajectory BUFR specific formats, because of including at the same time information related to the reference AMV to be used and the up to four latest AMVs in any NWC/GEO-HRW-MTG trajectory.

It is recommended to use this option to write the NWC/GEO-HRW-MTG output only when the main interest is the assimilation of the AMVs in NWP models or other applications (possibly together with the EUMETSAT/MPEF AMVs). The main reason for this is that part of the information calculated with the AMVs cannot be included using this format (for example the "cloud type", the "orographic flag", the "correlation value", or all parameters related to the NWP model at the AMV level or the best fit level), and so these parameters cannot be used operationally. Moreover, the size of the AMV BUFR bulletins with the EUMETSAT/MPEF format is much larger, and can imply more important storage problems.

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

```
001007 SATELLITE IDENTIFIER
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
002020 SATELLITE CLASSIFICATION
002028 SEGMENT SIZE AT NADIR IN X DIRECTION (Not used)
002029 SEGMENT SIZE AT NADIR IN Y DIRECTION (Not used)
004001 YEAR (For the reference AMV to be used)
004002 MONTH (For the reference AMV to be used)
004003 DAY (For the reference AMV to be used)
004004 HOUR (For the reference AMV to be used)
004005 MINUTE (For the reference AMV to be used)
004006 SECOND (For the reference AMV to be used)
005001 LATITUDE/HIGH ACCURACY (For the reference AMV to be used)
006001 LONGITUDE/HIGH ACCURACY (For the reference AMV to be used)
002152 SATELLITE INSTRUMENT DATA USED IN PROCESSING
002023 SATELLITE DERIVED WIND COMPUTATION METHOD
007004 PRESSURE (For the reference AMV to be used)
011001 WIND DIRECTION (For the reference AMV to be used)
011002 WIND SPEED (For the reference AMV to be used)
002153 SATELLITE CHANNEL CENTRE FREQUENCY
002154 SATELLITE CHANNEL BAND WIDTH
012071 COLDEST CLUSTER TEMPERATURE (Not used)
002163 HEIGHT ASSIGNMENT METHOD (For the reference AMV to be used)
002164 TRACER CORRELATION METHOD (For the reference AMV to be used)
008012 LAND/SEA QUALIFIER (Not used)
007024 SATELLITE ZENITH ANGLE (For the reference AMV to be used)
002057 ORIGIN OF FIRST GUESS INFORMATION
---
008021 TIME SIGNIFICANCE (Not used)
004001 YEAR (Not used)
004002 MONTH (Not used)
004003 DAY (Not used)
004004 HOUR (Not used)
008021 TIME SIGNIFICANCE (Time series)
004024 TIME PERIOD OR DISPLACEMENT (Between images, in minutes)
008021 TIME SIGNIFICANCE (Starting time for the latest AMV in the trajectory)
004004 HOUR
004005 MINUTE
004006 SECOND
008021 TIME SIGNIFICANCE (Ending time for the latest AMV in the trajectory)
004004 HOUR
004005 MINUTE
004006 SECOND
011001 WIND DIRECTION (For the latest AMV in the trajectory)
011002 WIND SPEED (For the latest AMV in the trajectory)
008021 TIME SIGNIFICANCE (Starting time for the second latest AMV in the trajectory)
004004 HOUR
004005 MINUTE
004006 SECOND
008021 TIME SIGNIFICANCE (Ending time for the second latest AMV in the trajectory)
004004 HOUR
004005 MINUTE
004006 SECOND
011001 WIND DIRECTION (For the second latest AMV in the trajectory, when available)
011002 WIND SPEED (For the second latest AMV in the trajectory, when available)
008021 TIME SIGNIFICANCE (Starting time for the third latest AMV in the trajectory)
004004 HOUR
004005 MINUTE
004006 SECOND
008021 TIME SIGNIFICANCE (Ending time for the third latest AMV in the trajectory)
004004 HOUR
004005 MINUTE
004006 SECOND
```

011001 WIND DIRECTION *(For the third latest AMV in the trajectory, when available)*
011002 WIND SPEED *(For the third latest AMV in the trajectory, when available)*
008021 TIME SIGNIFICANCE *(Starting time for the fourth latest AMV in the trajectory)*
004004 HOUR
004005 MINUTE
004006 SECOND
008021 TIME SIGNIFICANCE *(Ending time for the fourth latest AMV in the trajectory)*
004004 HOUR
004005 MINUTE
004006 SECOND
011001 WIND DIRECTION *(For the fourth latest AMV in the trajectory, when available)*
011002 WIND SPEED *(For the fourth latest AMV in the trajectory, when available)*

002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(Not used)*
012001 TEMPERATURE/DRY BULB TEMPERATURE *(Not used)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(Not used)*
012001 TEMPERATURE/DRY BULB TEMPERATURE *(Not used)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(Not used)*
012001 TEMPERATURE/DRY BULB TEMPERATURE *(Not used)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(For the latest AMV in the trajectory)*
012001 TEMPERATURE *For the latest AMV in the trajectory)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(Not used)*
012001 TEMPERATURE/DRY BULB TEMPERATURE *(Not used)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(For the second latest AMV in the trajectory, when available)*
012001 TEMPERATURE *For the second latest AMV in the trajectory, when available)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(Not used)*
012001 TEMPERATURE/DRY BULB TEMPERATURE *(Not used)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(For the third latest AMV in the trajectory, when available)*
012001 TEMPERATURE *For the third latest AMV in the trajectory, when available)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(Not used)*
012001 TEMPERATURE/DRY BULB TEMPERATURE *(Not used)*
002163 HEIGHT ASSIGNMENT METHOD *(Not used)*
007004 PRESSURE *(For the fourth latest AMV in the trajectory, when available)*
012001 TEMPERATURE *For the fourth latest AMV in the trajectory, when available)*

222000 QUALITY INFORMATION FOLLOWS
236000 DEFINE BIT-MAP
031031 DATA PRESENT INDICATOR *(Descriptor repeated 103 times, not used)*

001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION *(Quality Control using forecast)*
033007 % CONFIDENCE *(For the latest AMV in the trajectory)*
033007 % CONFIDENCE *(For the second latest AMV in the trajectory, when available)*
033007 % CONFIDENCE *(For the third latest AMV in the trajectory, when available)*
033007 % CONFIDENCE *(For the fourth latest AMV in the trajectory, when available)*
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION *(Quality Control using forecast)*
033035 MANUAL-AUTOMATIC QUALITY CONTROL *(For the latest AMV in the trajectory)*
033035 MANUAL-AUTOMATIC QUALITY CONTROL *(For the second latest AMV in the trajectory)*
033035 MANUAL-AUTOMATIC QUALITY CONTROL *(For the third latest AMV in the trajectory)*
033035 MANUAL-AUTOMATIC QUALITY CONTROL *(For the fourth latest AMV in the trajectory)*
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP

```
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION (Quality Control using forecast)
033036 NOMINAL CONFIDENCE THRESHOLD (For the latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the second latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the third latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the fourth latest AMV in the trajectory)
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION (Quality Control not using forecast)
033007 % CONFIDENCE (For the latest AMV in the trajectory)
033007 % CONFIDENCE (For the second latest AMV in the trajectory, when available)
033007 % CONFIDENCE (For the third latest AMV in the trajectory, when available)
033007 % CONFIDENCE (For the fourth latest AMV in the trajectory, when available)
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION (Quality Control not using forecast)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the latest AMV in the trajectory)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the second latest AMV in the trajectory)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the third latest AMV in the trajectory)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the fourth latest AMV in the trajectory)
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION (Quality Control not using forecast)
033036 NOMINAL CONFIDENCE THRESHOLD (For the latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the second latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the third latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the fourth latest AMV in the trajectory)
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION (Quality Control only using forecast)
033007 % CONFIDENCE (For the latest AMV in the trajectory)
033007 % CONFIDENCE (For the second latest AMV in the trajectory, when available)
033007 % CONFIDENCE (For the third latest AMV in the trajectory, when available)
033007 % CONFIDENCE (For the fourth latest AMV in the trajectory, when available)
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION (Quality Control only using forecast)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the latest AMV in the trajectory)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the second latest AMV in the trajectory)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the third latest AMV in the trajectory)
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the fourth latest AMV in the trajectory)
222000 QUALITY INFORMATION FOLLOWS
237000 REUSE PREVIOUSLY DEFINED BIT-MAP
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
001032 GENERATING APPLICATION (Quality Control only using forecast)
033036 NOMINAL CONFIDENCE THRESHOLD (For the latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the second latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the third latest AMV in the trajectory)
033036 NOMINAL CONFIDENCE THRESHOLD (For the fourth latest AMV in the trajectory)
```

Table 17: BUFR table for NWC/GEO-HRW-MTG AMV BUFR output files with EUMETSAT/MPEF BUFR format

2.3.5.4 HRW output as netCDF bulletins

When OUTPUT_FORMAT = NET, an AMV and Trajectory netCDF output bulletin is written under the name `S_NWC_HRW-WIND_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.nc` (for the "Single or Basic scale"), or the name `S_NWC_HRW-WIND_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.nc` (for the "Detailed scale") in `$SAFNWC/export/HRW` directory. Again, "satid" is the identifier of satellite used, "regionid" is the identifier of the region used and "YYYMMDDThhmmssZ" is the date and time for which the AMVs have been calculated.

The High level structure of the netCDF output for the NWC/GEO High Resolution Winds is shown in *Table 18*. It contains one series of data, containing all the AMVs/Trajectories derived for all satellite channels in the corresponding run of NWC/GEO-HRW-MTG algorithm. The dimension of the series of data is defined by "nb_winds" parameter, which contains the amount of AMVs calculated for the given run of NWC/GEO-HRW-MTG algorithm.

If configurable parameter CALCULATE_TRAJECTORIES = 1, the trajectories related to the "Basic scale" and the "Detailed scale" are also included in this netCDF output file. Each trajectory contains "nb_sect" groups, with the corresponding trajectory sectors.

Parameter types	*Content*
Dimensions:	
number_of_observations	Total number of AMVs for the run of NWC/GEO-HRW
Types:	
compound Segment	// Structure to contain 1 Trajectory Segment
Segment(*) Trajectory	// Trajectory defined as a variable-length Array of Segments structures
compound Wind	// Structure to contain 1 AMV
Variables:	
Wind wind(*number_of_observations*)	// Wind data
Attributes	

Table 18: High Level specification of the NWC/GEO-HRW-MTG netCDF output

The detailed structure of the netCDF output for the NWC/GEO High Resolution Winds and Trajectories is shown in *Table 19*. The "BUFR Code Tables" used are described in the BUFR Reference Manual [RD.20], except those characterized as 060xxx, which are explained in Chapter 2.3.5.1 of this document. The list of common attributes described in Chapter 4.3 of the "Data Output Format for the NWC/GEO" document [AD.6] is also to be taken here into account.

Parameter types	Content
Dimensions:	
number_of_observations	Total number of AMVs for the run of NWC/GEO-HRW-MTG
Types:	
compound Segment	**// Structure to contain 1 Trajectory Segment**
float latitude	// Latitude (degree_north)
float longitude	// Longitude (degree_east)
float latitude_increment	// Latitude Increment (degree_north)
float longitude_increment	// Longitude Increment (degree_east)
float air_temperature	// Air Temperature (K)
float air_pressure	// Air Pressure (Pa)
float air_pressure_error	// Air Pressure Error (Pa)
float air_pressure_correction	// Air Pressure Correction (Pa)
float air_pressure_nwp_best_fit_level	// Air Pressure NWP Model at Best Fit Level (Pa)
float wind_speed	// Wind Speed (m/s)
float wind_from_direction	// Wind Direction from which the wind blows (degree)
unsigned byte quality_index_with_forecast	// Quality Index With Forecast Test (%, [0,100])
unsigned byte quality_index_without_forecast	// Quality Index Without Forecast Test (%, [0,100])
unsigned byte tracer_correlation_method	// Tracer Correlation method (BUFR code table 002164)
unsigned byte tracer_type	// Tracer Type (BUFR code table 060102)
unsigned byte height_assignment_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte orographic_index	// Orographic index (BUFR code table 060205)
unsigned byte cloud_type	// NWC/GEO-Cloud Type (BUFR code table 060206)
unsigned byte correlation	// Correlation (%, [0,100])
Segment(*) Trajectory	**// Trajectory defined as a variable-length array of Segments structures**
compound Wind	**// Structure to contain 1 AMV**
unsigned int wind_id	// Wind sequence Number
unsigned int previous_wind_id	// Prior wind sequence number
unsigned byte number_of_winds	// Number of winds computed for the tracer
unsigned byte correlation_test	// Correlation test (BUFR code table 060201)
unsigned short quality_test	// Applied Quality tests (BUFR code table 060202)
unsigned int segment_x	// Segment size at nadir in X direction (meters)
unsigned int segment_y	// Segment size at nadir in Y direction (meters)
unsigned int segment_x_pix	// Segment size at nadir in X direction (pixels)
unsigned int segment_y_pix	// Segment size at nadir in Y direction (pixels)
float latitude	// Latitude (degree_north)
float longitude	// Longitude (degree_east)
float latitude_increment	// Latitude increment (degree_north)
float longitude_increment	// Longitude increment (degree_east)
float air_temperature	// Air Temperature (K)
float air_pressure	// Air Pressure (Pa)
float air_pressure_error	// Air Pressure Error (Pa)
float air_pressure_correction	// Air Pressure Correction (Pa)
float air_pressure_nwp_best_fit_level	// Air Pressure NWP Model at Best Fit Level (Pa)
float wind_speed	// Wind Speed (m/s)
float wind_from_direction	// Wind Direction from which the wind blows (degree)
float wind_speed_nwp_at_amv_level	// Wind Speed of NWP Model at AMV Level (m/s)
float wind_from_direction_nwp_at_amv_level	// Wind Direction of NWP Model at AMV Level (degree)
float wind_speed_nwp_at_best_fit_level	// Wind Speed of NWP Model at Best Fit Level (m/s)
float wind_from_direction_nwp_best_fit_level	// Wind Direction of NWP Model at Best Fit Level (degree)
float wind_speed_nwp_difference	// Wind Speed of Difference with NWP model (m/s)
float wind_from_direction_nwp_difference	// Wind Direction of Difference with NWP model (degree)
unsigned byte quality_index_with_forecast	// Per cent confidence with forecast test
unsigned byte quality_index_without_forecast	// Per cent confidence without forecast test
unsigned byte tracer_correlation_method	// Tracer Correlation method (BUFR code table 002164)
unsigned byte tracer_type	// Tracer Type (BUFR code table 060102)
unsigned byte height_assignment_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte orographic_index	// Orographic index (BUFR code table 060205)
unsigned byte cloud_type	// NWC/GEO-Cloud Type (BUFR code table 060206)
unsigned byte correlation	// Correlation (%, [0,100])
Variables:	
Wind wind(number_of_observations)	// Wind (AMV+Trajectory) data
Attributes:	
standard_name	Atmospheric winds
long_name	"NWC-GEO High Resolution Winds"
wind_computation_method	// Satellite derived wind computation method (BUFR code table 002023)
first_guess	// Origin of the first guess (BUFR code table 025202)
sensor_band_identifier	// Satellite channel id
sensor_band_central_radiation_frequency	// Satellite channel centre frequency (s-1)
sensor_band_central_radiation_width	// Satellite channel band width (s-1)
cycle	// Satellite cycle number
manual_automatic_quality_control	// Manual/automatic quality control (BUFR code table 033035)
time_period	// Time period or displacement (seconds)
number_of_nwp_wind_levels	// Number of available NWP wind guess levels
nwp_forecast_or_analysis	// Flag showing if NWP model used in validation is forecast or analysis (BUFR code table 060208)

Table 19: Detailed specification of the NWC/GEO-HRW-MTG netCDF output

2.3.6 Examples of High Resolution Winds (NWC/GEO-HRW-MTG)

Real time graphic displays of the High Resolution Winds product, generated by the NWC/GEO Reference System, are available at the NWC SAF Help Desk website (http://www.nwcsaf.org). Following figures show typical displays of NWC/GEO-HRW for AMVs and Trajectories considering the default configurations; a colour coding based on the AMV and Trajectory pressure level is used.

First, with MSG2 satellite data in the European and Mediterranean region used for NWC/GEO-HRW validation (*Figures 22 and 23*). Later, with GOES13 satellite data in the Continental United States region also used for NWC/GEO-HRW validation (*Figures 24 and 25*). Visualization with Himawari-8 satellite data will be provided for the release of NWC/GEO v2018 software version. Visualization with MTG-I satellite data (and optionally with GOES-R satellite data) will be provided for the release of NWC/GEO version MTG-I day-1.

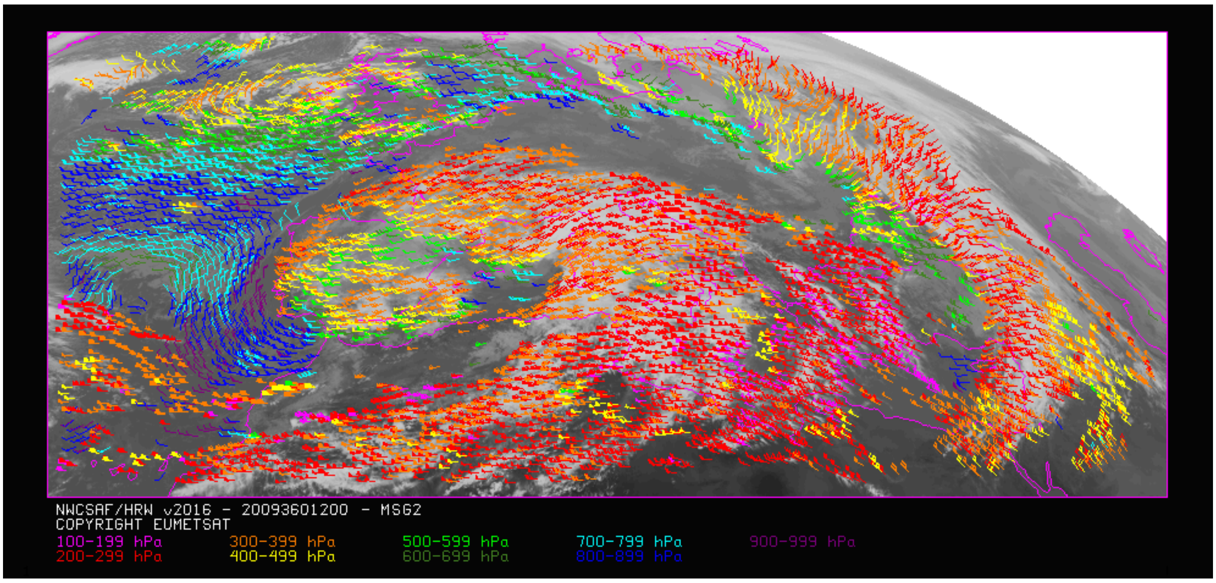


Figure 22: NWC/GEO-HRW-MTG AMV output in the European and Mediterranean region (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), considering conditions defined in `$SAFNWC/config/safnwc_HRW_MSG15MIN.cfm` file. Colour based on the AMV pressure level

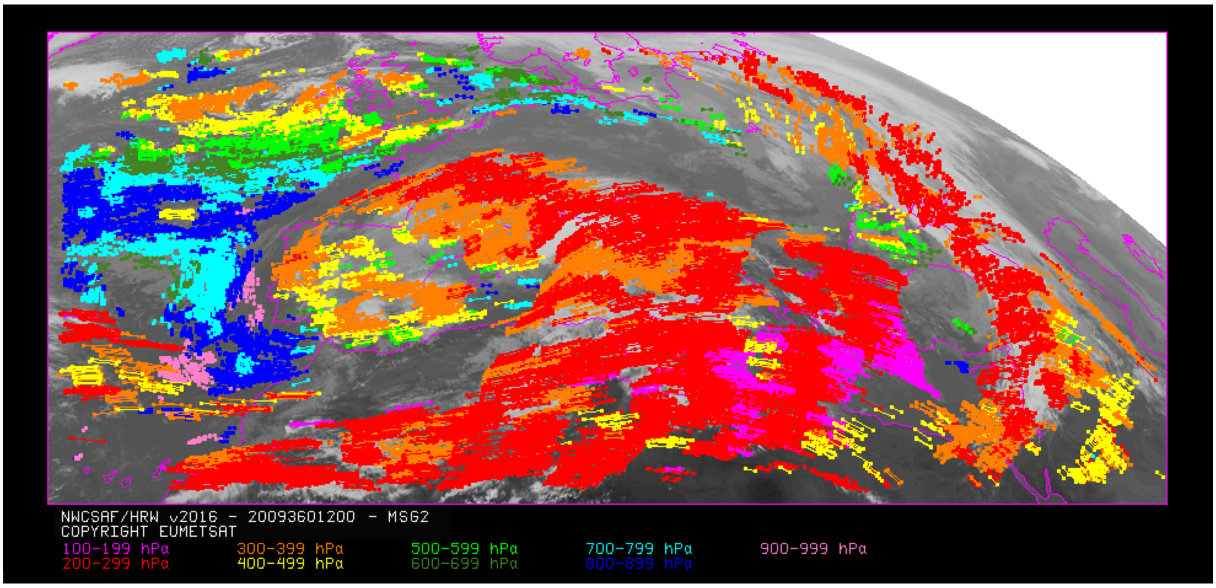


Figure 23: NWC/GEO-HRW-MTG Trajectory output in the European and Mediterranean region (trajectories lasting one hour, for 26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), considering conditions defined in `$SAFNWC/config/safnwc_HRW_MSG15MIN.cfm` file. Colour based on the AMV pressure level

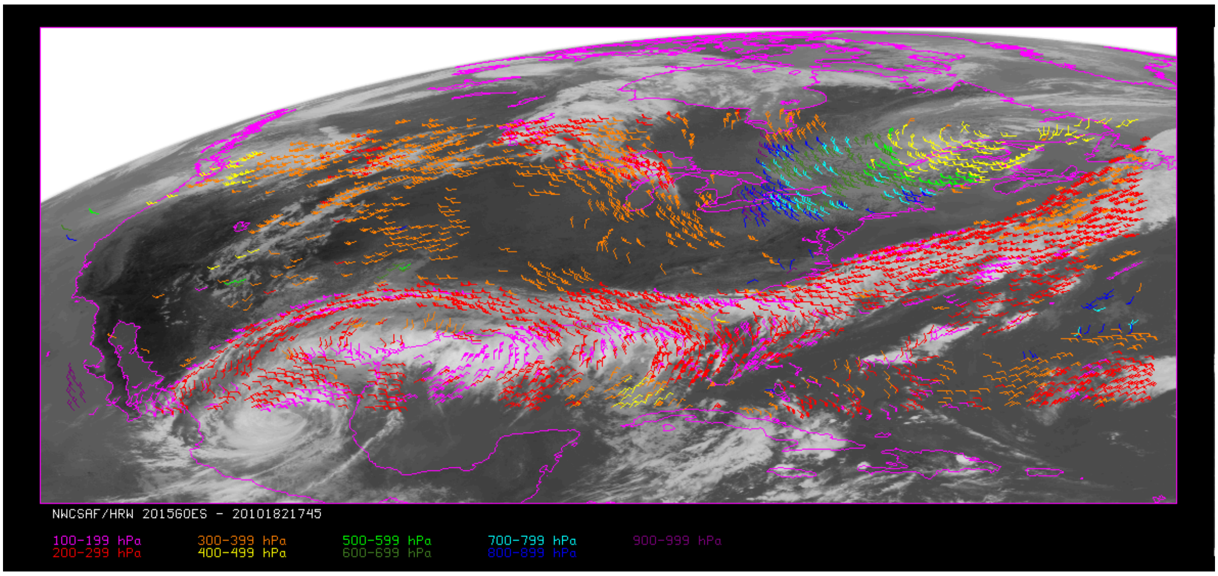


Figure 24: NWC/GEO-HRW-MTG AMV output in the Continental United States region (1 July 2010 1745Z, GOES13 satellite), considering conditions defined in `$SAFNWC/config/safnwc_HRW_GOES15MIN.cfm` file. Colour based on the AMV pressure level

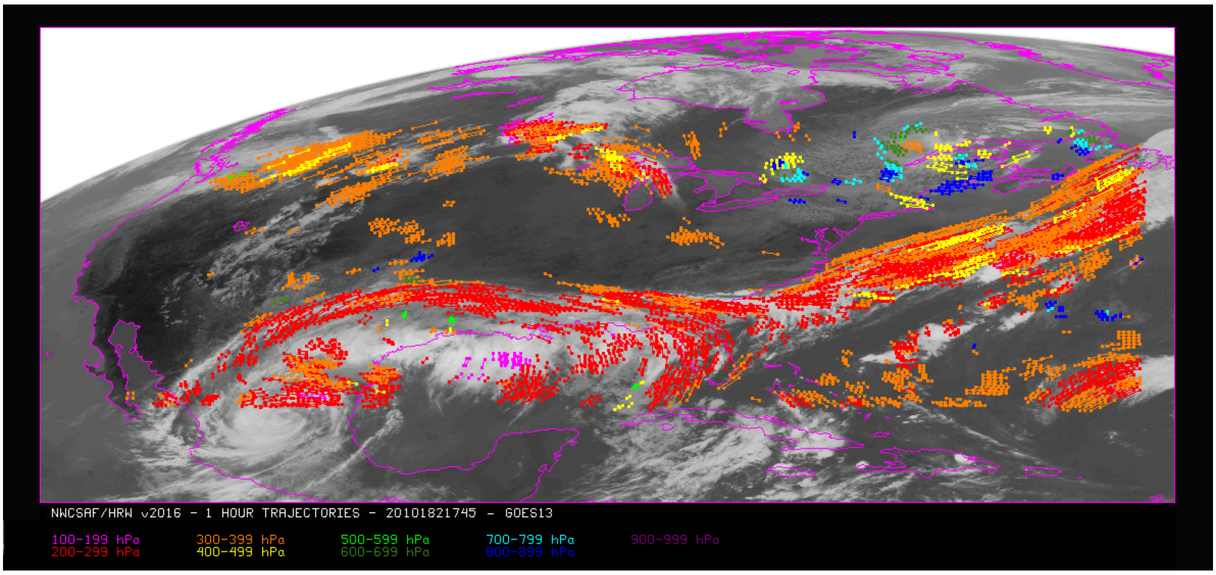


Figure 25: NWC/GEO-HRW-MTG Trajectory output in the Continental United States region (trajectories lasting one hour, for 1 July 2010 1745Z, GOES 13 satellite), considering conditions defined in `$SAFNWC/config/safnwc_HRW_GOES15MIN.cfm` file. Colour based on the AMV pressure level

2.3.7 Use of High Resolution Winds (NWC/GEO-HRW-MTG)

Two main steps are identified. The user manually interacts with the NWC/GEO software package during the installation step, and the NWC/GEO-HRW-MTG 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-MTG` executable file), to be stored into the `$SAFNWC/bin` directory. The installation steps for NWC/GEO must follow the document "System Version Document for the NWC/GEO" [AD.7].

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

The execution step is the processing of satellite images with NWC/GEO-HRW-MTG algorithm, 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-MTG` along with the required parameters (required image time, Region configuration file and Model configuration file) by the Task manager, in the following way:

```
GEO-HRW-MTG YYYY-MM-DDTHH:MM:SSZ $SAFNWC/config/file.cfg $SAFNWC/config/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/file.cfm` is the Model configuration file, to be defined such as shown in Chapter 2.3.3 of this document. Six different default Model configuration files are included in NWC/GEO software package for the running of `GEO-HRW-MTG` executable:
   - `safnwc_HRW_MSG15MIN.cfm` and `safnwc_HRW_MSG05MIN.cfm`, to be used with MSG satellite data in "Nominal scan mode" and "Rapid Scan mode", with calculation of AMVs and Trajectories every 15 and 5 minutes respectively.
   - `safnwc_HRW_MTG10MIN.cfm`, to be used with MTG-I satellite data in "Nominal scan mode", with calculation of AMVs and Trajectories every 10 minutes.
   - `safnwc_HRW_HIMA10MIN.cfm` and `safnwc_HRW_HIMA02MIN.cfm`, to be used with Himawari-8/9 satellite data in "Nominal scan mode" and "Rapid Scan mode", with calculation of AMVs and Trajectories every 10 and 2.5 minutes respectively.
   - `safnwc_HRW_GOES15MIN.cfm` and `safnwc_HRW_GOES30MIN.cfm`, to be used with GOES-N satellite data in the Continental United States region and the North America region, with calculation of AMVs and Trajectories every 15 and 30 minutes respectively.
   - `safnwc_HRW_GOESRS15MIN.cfm` and `safnwc_HRW_GOESRS05MIN.cfm`, optionally to be used with GOES-R satellite data in "Nominal scan mode" and "Rapid Scan mode", with calculation of AMVs and Trajectories every 15 and 5 minutes respectively.

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

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

The "Rapid Scan mode" with MSG, Himawari-8/9 or optionally GOES-R satellite series is only recommended to be used in small areas ("National areas"), if all NWC/GEO products have to run together and a relatively small environment was used for the installation of NWC/GEO software. With the time running constraint imposed by the MSG, Himawari-8/9 or GOES-R "Rapid scan modes" (5, 2.5 and 5 minutes respectively), these circumstances permit the repeating of the process with all available satellite images. In a "Continental area" it is generally not possible to run all NWC/GEO products operatively in "Rapid scan mode" unless a powerful environment is used. [AD.8] document could be verified for more information on this issue, related to MSG satellite series.

Figures 26 to 28 summarise how the tasks to generate the High Resolution Winds (NWC/GEO-HRW-MTG) are performed by the `GEO-HRW-MTG` executable:

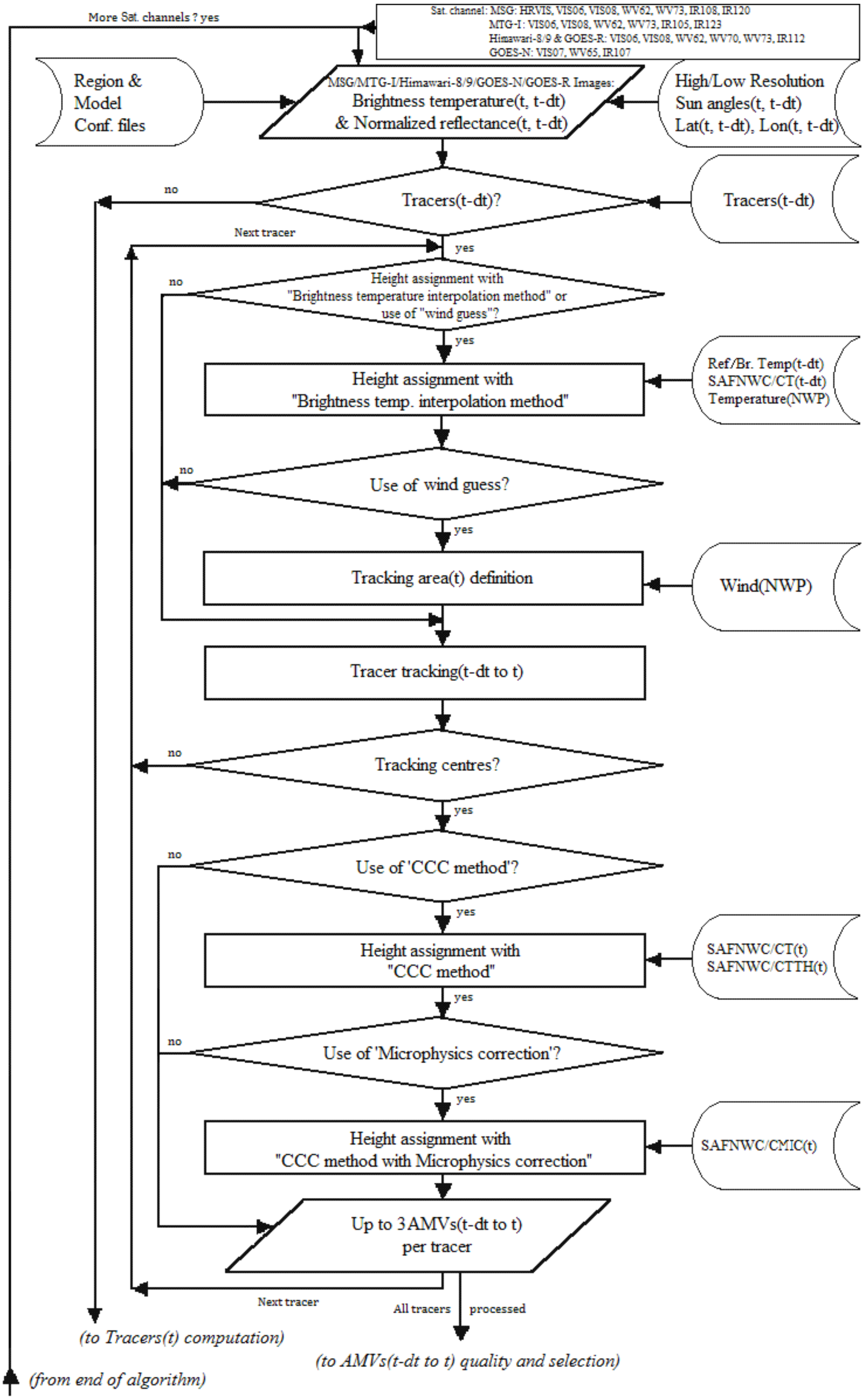


Figure 26: NWC/GEO-HRW-MTG implementation: Part 1, AMV computation

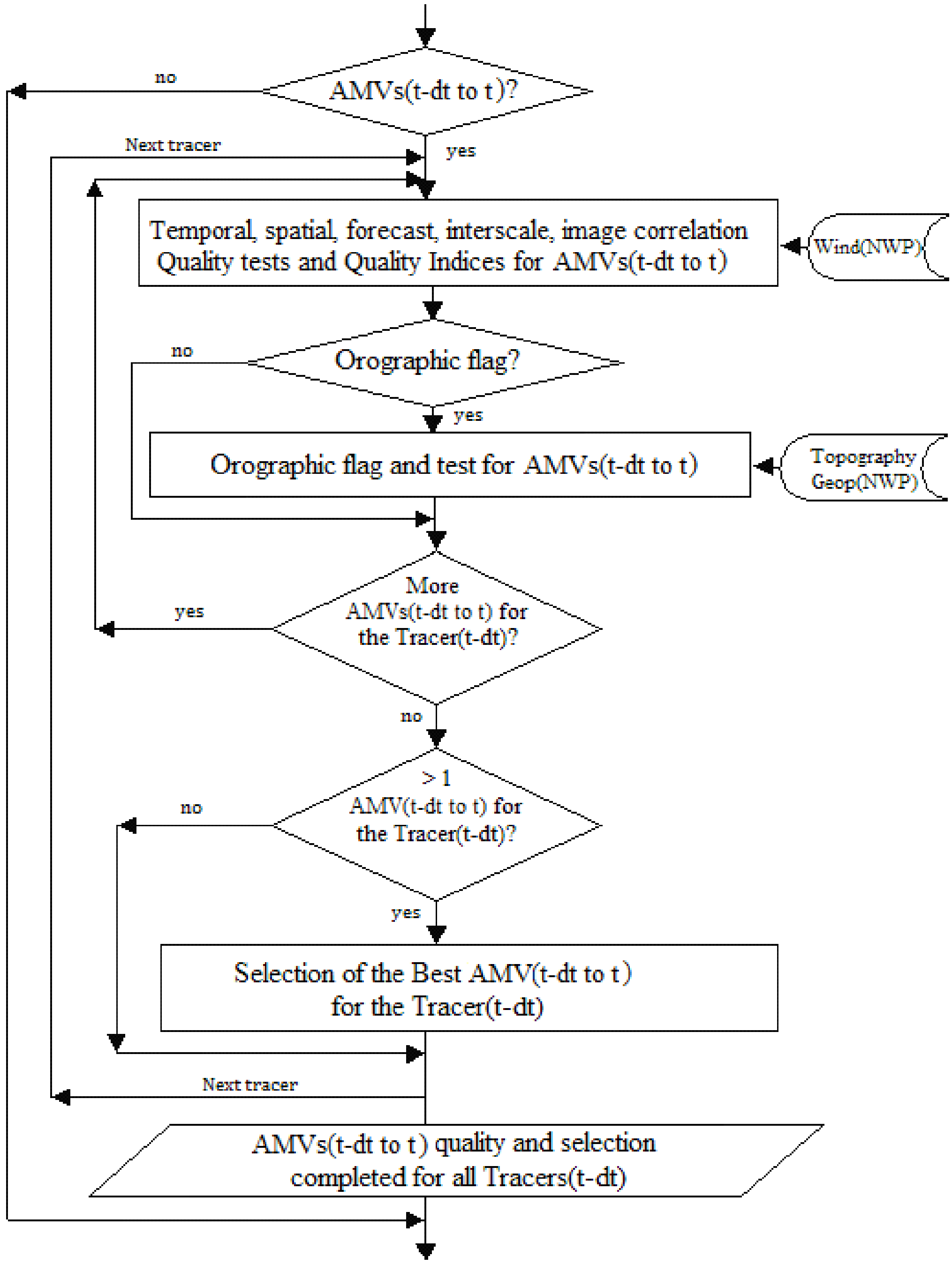


Figure 27: NWC/GEO-HRW-MTG implementation: Part 2, AMV quality and selection

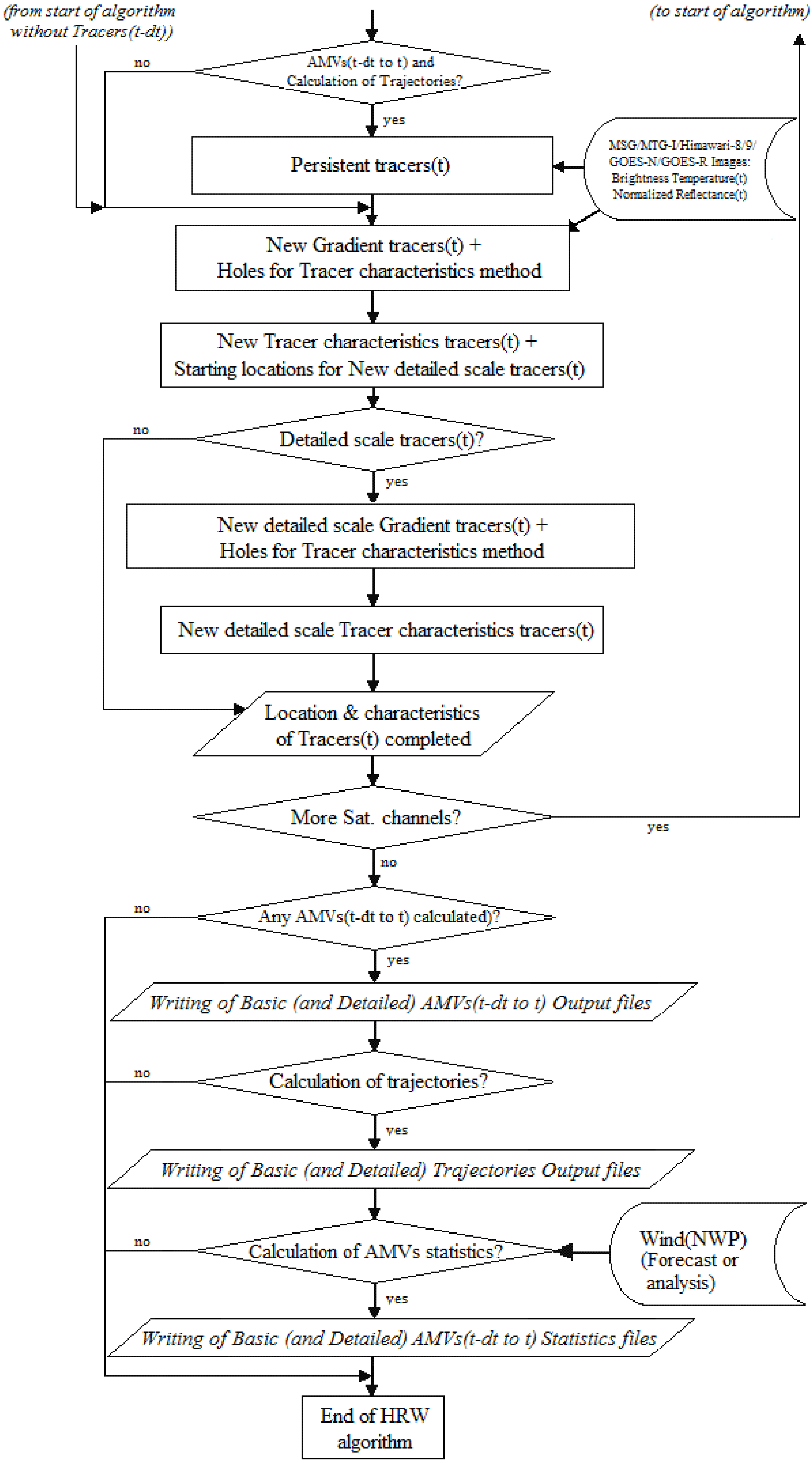


Figure 28: NWC/GEO-HRW-MTG implementation: Part 3, Tracer computation and writing of output

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

Since NWC/GEO v2016 software package, a detailed description of all algorithms, involved interfaces and data types, is provided in html format with the support of Doxygen tool, from comments included within the code of the products. Documentation for NWC/GEO-HRW-MTG product is to be provided at the moment of the NWC/GEO v2018 DRR in the zipped file:

`NWC-CDOP2-MTG-AEMET-SW-ACDD-Wind_html_v1.0d.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_v1.0d/HRW_html/index.html`

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

For a quicker reference, the main goal of all functions of NWC/GEO-HRW-MTG 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_ImageChecking                                    => Checks and redefines satellite image values
 *** hrw_NWPSearch                                        => Reads the NWP data related to one NWP parameter
 *** hrw_Meters2Press                                     => Converts Orographic data to Surface pressure data
      *** hrw_NWPInvInterpolation                         => Converts Geopotential to Surface pressure data using NWP data
 *** hrw_ReadTracers                                      => Reads the Tracer data from a file located in $SAFNWC/tmp directory
 *** hrw_ReadPredWinds                                    => Reads the Predecessor AMV data from a file located in $SAFNWC/tmp directory
 *** hrw_ReadTrajectories                                 => Reads the Trajectory data from a file located in $SAFNWC/tmp directory
 *** hrw_GetWinds                                         => Calculates the AMVs for the current image considering the tracers calculated previously
      *** 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_CloudTypeCalculation                        => Calculates AMV Cloud type as defined in the "Brightness temperature height assignment"
      *** 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_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_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 horizontal/vertical 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 Horizontal direction study in the “Big pixel brightness variability test”
           *** hrw_TracerVerticalDiff     => Considers the Vertical 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 Horizontal direction study in the “Big pixel brightness variability test”
                *** hrw_TracerVerticalDiff => Considers the Vertical 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_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_NWPInvInterpolation         => Converts the Clear air tracking position temperatures to pressure values using NWP data
```

```
    *** hrw_WindGuess                              => Recalculates the wind guess at the tracer position considering the "CCC method" new pressure level
        *** hrw_NWPDirInterpolation                => Calculates the NWP wind at the tracer level considering the new pressure level calculated
        *** hrw_WindModDir                         => Calculates the speed module and direction for the NWP wind guess at the tracer position
    *** hrw_Free_Winds                             => Deallocates memory for variables used in hrw_GetWinds module
*** hrw_Qc                                         => Calculates the Quality indices and the Orographic flag for the calculated AMVs/Trajectories
    *** hrw_QcAlloc_Short, _Float, _Parameters     => Three functions allocating memory for variables in hrw_Qc module
    *** hrw_QcSortLatitude                         => Sorts the current and predecessor AMV data considering their latitudes in their final positions
        *** hrw_QcSort                             => Sorts an array of data considering one of its variables
    *** hrw_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_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_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 directory
*** hrw_WriteTrajectories                          => Writes the Trajectory data file for the current iamge in $SAFNWC/tmp directory
*** 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 Horizontal direction study in the “Big pixel variability test”
               *** hrw_TracerVerticalDiff           => Considers the Vertical 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 Horizontal direction study in the “Big pixel variability test”
                    *** hrw_TracerVerticalDiff      => Considers the Vertical 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_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 Horizontal direction study in the “Big pixel brightness variability test”
                    *** hrw_TracerVerticalDiff      => Considers the Vertical direction study in the “Big pixel brightness variability test”
                    *** hrw_TracerDescDiff          => Considers the Descending direction study in the “Big pixel brightness variability test”
                    *** hrw_TracerAscDiff           => Considers the Ascending direction study in the “Big pixel brightness variability test”
     *** hrw_TracersDetailedDiscrimination          => Defines if a Basic tracer can also work as Detailed tracer
     *** hrw_Centile_Frontier                       => Defines the centile in the BT/Reflectance histogram considering a given frontier
     *** hrw_Free_Tracers                           => Deallocates memory for variables in hrw_GetTracers module
*** hrw_WriteTracers                                => Writes the Tracer data file for the current image in $SAFNWC/tmp directory
*** hrw_Free_Satellite                              => Deallocates memory for MSG/GOES-N satellite data
*** hrw_Free_TWind                                  => Deallocates memory for "tracer wind" data
*** hrw_Free_Trajectories                           => Deallocates memory for "trajectory" data
*** hrw_Free_LevelsandGuesses                       => Deallocates memory for NWP data
```

```
*** hrw_EncodeBufrNWC                             => Writes the AMV and Trajectory BUFR output with NWCSAF template in $SAFNWC/export/HRW directory
     *** hrw_WriteElementsNWC                     => Calls the different functions filling the sections that compose the BUFR bulletin
          *** hrw_SetBUFRSection0NWC              => Codifies Section 0 of the BUFR output file using NWCSAF template
          *** hrw_SetBUFRSection1NWC              => Codifies Section 1 of the BUFR output file using NWCSAF template
          *** hrw_SetBUFRSection2NWC              => Codifies Section 2 of the BUFR output file using NWCSAF template
          *** hrw_SetBUFRSection3NWC              => Codifies Section 3 of the BUFR output file using NWCSAF template
          *** hrw_WriteValuesNWC                  => Codifies AMV BUFR output for a defined satellite channel using NWCSAF template
               *** hrw_SetReplicatedDescNWC       => Codifies specific information for each AMV, for the BUFR output writing using NWCSAF template
                    *** hrw_WindModDir            => Calculates the speed module and direction of the mean AMV for its writing in the BUFR output
               *** hrw_SetFixedDescNWC            => Codifies common information for all AMVs, for their BUFR output writing using NWCSAF template
               *** hrw_WriteBufrNWC               => Encodes the AMV BUFR output in $SAFNWC/export/HRW directory using NWCSAF template
          *** hrw_WriteValuesTRAJ                 => Codifies Trajectory BUFR output for a defined satellite channel using NWCSAF template
               *** hrw_SetReplicatedDescTRAJ      => Codifies specific information for each Trajectory, for the BUFR writing using NWCSAF template
               *** hrw_SetFixedDescNWC            => Codifies common information for all Trajectories, for the BUFR writing using NWCSAF template
               *** hrw_WriteBufrTRAJ              => Encodes the Trajectory BUFR output in $SAFNWC/export/HRW directory using NWCSAF template
*** hrw_EncodeBufrEUM                             => Writes the AMV BUFR output with EUMETSAT/MPEF template in $SAFNWC/export/HRW directory
     *** hrw_WriteElementsEUM                     => Calls the different functions filling the sections that compose the BUFR bulletin
          *** hrw_SetBUFRSection0EUM              => Codifies Section 0 of the BUFR output file using EUMETSAT/MPEF template
          *** hrw_SetBUFRSection1EUM              => Codifies Section 1 of the BUFR output file using EUMETSAT/MPEF template
          *** hrw_SetBUFRSection2EUM              => Codifies Section 2 of the BUFR output file using EUMETSAT/MPEF template
          *** hrw_WriteValuesEUM                  => Codifies AMV BUFR output for a defined satellite channel using EUMETSAT/MPEF template
               *** hrw_SetFixedDescEUM            => Defines the information for one AMV for its BUFR output writing using EUMETSAT/MPEF template
                    *** hrw_WindModDir            => Calculates the speed module and direction of the mean AMV for its writing in the BUFR output
               *** hrw_SetBUFRSection3EUM         => Codifies Section 3 of the BUFR output file using EUMETSAT/MPEF template
               *** hrw_WriteBufrEUM               => Encodes the AMV BUFR output in $SAFNWC/export/HRW directory using EUMETSAT/MPEF template
*** hrw_EncodeNetCDF                              => Writes the AMV NetCDF output in $SAFNWC/export/HRW directory
     *** hrw_WriteNetCDF                          => Calls the different functions filling the sections that compose the NetCDF bulletin
          *** hrw_InitialiseNetCDF                => Creates all defined NetCDF dimensions/types/variables/attributes
               *** hrw_CheckNcErr                 => Checks that the status output of a NetCDF function is not an error
               *** hrw_WriteNcVarAtt              => Writes the NWC/GEO-HRW Attributes in the NetCDF bulletin
          *** hrw_WriteNcVar                      => Writes the AMV data in the NetCDF bulletin
               *** hrw_SetWindNetCDF              => Writes specific information for each AMV in the NetCDF bulletin
                    *** hrw_WindModDir            => Calculates the speed module and direction of the mean AMV for its writing in the NetCDF output
*** hrw_Wind_Statistics                           => Calculates the AMV statistics respect to the related NWP model analysis/forecast winds
*** hrw_Free_WindData                             => Deallocates memory for "wind_channel_info" data
     *** hrw_Free_TWind, hrw_Free_Trajectories    => Deallocates memory for "tracer_wind" and "trajectory" data
```

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

The main circumstance that has to be taken into account when using NWC/GEO High Resolution Winds product, 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 new versions of NWC/GEO-HRW algorithm. Initially, the applicability of NWC/GEO-HRW algorithm was limited to cloudy areas in European, African and Atlantic areas with MSG satellite data. Since NWC/GEO-HRW v2011, AMVs related to humidity patterns in the MSG water vapour channels started to show wind vectors in clear air areas. Since NWC/GEO-HRW v2012, the possibility to calculate AMVs with up to seven different MSG satellite channels increased significantly the density of possible AMV data throughout all the day.

Additionally, since NWC/GEO-HRW v2016 the option exists to calculate AMVs and Trajectories in the American and East Pacific areas (with GOES-N and optionally GOES-R satellite series), and in Asian and West Pacific areas (with Himawari-8/9 satellite series). So, the geographical range of NWC/GEO-HRW AMVs and Trajectories has extended throughout all the globe.

Finally, with NWC/GEO-HRW version MTG-I day-1, it has been guaranteed that NWC/GEO-HRW algorithm has time continuity for the AMVs and Trajectories calculated in European, African and Atlantic areas, with the new EUMETSAT's MTG-Imager geostationary satellite series.

The option to calculate AMVs in "Rapid scan mode" with MSG, Himawari-8/9 and optionally GOES-R satellite data also permits to obtain new AMVs even every five or two and a half minutes, increasing the amount of available AMVs lapse by a factor of 3 to 4 respect to the "Nominal scan mode".

With all of this, the presence of geographical areas inside the working region where NWC/GEO-HRW-MTG algorithm does not find any AMV vector is now smaller. Nevertheless, 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 (causing the filtering of valid clear air AMVs to be more demanding than the filtering of cloudy AMVs), the presence of areas inside the working region 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-MTG algorithm.

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), which despite the increases in the running time of NWC/GEO-HRW-MTG algorithm it implies (because of using larger "tracking areas"), the optimizations included since NWC/GEO-HRW v2013 make this configuration fully operative as the default option for NWC/GEO-HRW-MTG algorithm. Users should keep this configuration, so reducing the dependence of the AMVs on the NWP model.

  The second problem is solved using the "Quality index without forecast" in the operation of NWC/GEO-HRW-MTG algorithm (implemented with QI_THRESHOLD_USEFORECAST = 0), which avoids the influence of the NWP model in the Quality of the AMVs. Nevertheless, this option has not been considered as the default one because the impact of the NWP model in the Quality of the AMVs is considered to be generally more positive than negative.

- 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", in which the thermal inversion problem is solved by NWC/GEO-CTTH product output data.

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

The quality of the height assignment inferred in previous versions of NWC/GEO-HRW-MTG algorithm 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-MTG algorithm.

With all these elements, the progressive improvements in NWC/GEO-HRW-MTG versions have reduced the limitations this algorithm could previously have.

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-MTG algorithm.