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 processor of the NWC/GEO

NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind, Issue 2, Rev. 1

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Applicable to GEO-HRW v6.0 (NWC-038)

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0	*29 November 2013*	68	Initial version for NWC/GEO v2016 PDCR. Content derived from Document "Algorithm Theoretical Basis Document for High Resolution Winds (HRW - PGE09 v4.0)", SAF/NWC/CDOP/INM/SCI/ATBD/09
1.1	*15 October 2016*	81	Updated version after NWC/GEO v2016 STRR & DRR. It includes: • Changes proposed at NWC/GEO v2016 STRR/DRR • An updated list of "Model configuration files" • An updated validation with the latest changes in NWC/GEO libraries, Cloud and HRW algorithms • A table with the list of possible errors caused by GEO-HRW-v5.0 algorithm
2.0	*27 February 2017*	88	Updated version for NWC/GEO v2018 RR/PCR. It includes: • Changes proposed at NWC/GEO v2018 RR/PCR. • A clearer description of the contents of the whole document.
2.1	*21 January 2019*	101	Updated version after NWC/GEO v2018 DRR. It includes changes proposed by the Developer and the Reviewers at the NWC/GEO v2018 DRR.

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1. INTRODUCTION

The "EUMETSAT Satellite Application Facilities (SAFs)" are dedicated centres of excellence for the processing of satellite data, and form an integral part of the distributed "EUMETSAT Application Ground Segment". This documentation is provided by the SAF on support to Nowcasting and Very short range forecasting (NWC SAF). The main objective of the NWC SAF is to provide, develop and maintain software packages to be used with operational meteorological satellite data for Nowcasting applications. More information about the project can be found at the NWC SAF webpage, http://www.nwcsaf.org.

This document is applicable to the NWC/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" software package (NWC/GEO-HRW, High Resolution Winds), which calculates Atmospheric Motion Vectors and Trajectories considering:

- Up to seven channels from MSG/SEVIRI imager: six 3 km low resolution visible, water vapour and infrared channels (VIS06 0.635 μm, VIS08 0.810 μm, 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).

- Up to 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).

- Up to 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).

There is a commitment so that the adaptation of NWC/GEO-HRW algorithm to the three geostationary satellite series (MSG, GOES-N and Himawari-8/9) in NWC/GEO v2018 software package is fully validated. The corresponding validation results are shown in the corresponding "Scientific and Validation Report" [AD.15], and as a summary also in this document.

The adaptation of NWC/GEO-HRW to GOES-R satellite series and the corresponding validation, not committed for this version, is under way and will be delivered as a patch for NWC/GEO v2018 software package throughout the year 2019.

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 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 v6.0 (Product Id NWC-038) of the NWC/GEO v2018 software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

The main improvements related to NWC/GEO-HRW v6.0 algorithm are the following ones:
1. The extension of NWC/GEO-HRW algorithm for the processing of Himawari-8/9 satellite series.
2. The option to increase the spatial density of AMVs at low levels. This is done with a more detailed evaluation of the spatial density of low level tracers.
3. The implementation of a "Mixed calculation method", considering at the same time short and long time intervals, through which the tracking process is verified in short time intervals, but the AMVs are calculated considering displacements in long time intervals. This process is useful for the calculation of AMVs with high resolution images, and to improve the quality of the calculated AMVs.
4. The calculation of the "Common Quality Index without forecast", to be used by all AMV production centres, as defined by the "International Winds Working Group".
5. The autovalidation of NWC/GEO-HRW algorithm with respect to NWP model analysis or forecast winds, including the calculation of the NWP wind at "best fit pressure level" and the "difference with the NWP winds".

1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

1.4.1. Definitions

4x4 big pixel matrix	4x4 big element matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_n)
Atmospheric Motion Vector (AMV)	Horizontal wind calculated through the horizontal displacement between two Earth positions in two different satellite images (defined as initial image and later image), of a square segment of nxn pixels called tracer
Basic dataset	Set of tracers or AMVs, calculated with the basic or wide tracer scale (with a default value of 24 x 24 pixels). Two kinds of Basic tracers are possible: wide basic tracers (with bright big pixels in the first and last big pixel row or column) and narrow basic tracers (occurring otherwise)
Bearing angle	Angle defined by the great circle connecting two locations on the Earth
Best fit pressure level	Pressure level which minimizes the vector difference between the AMV and a NWP reference wind, considering as reference wind the nearest NWP wind profile or nearest Radiosounding wind profile, with a linear variation of the wind components between profile levels
Big pixel	Each element of the 4x4 big pixel matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_0, CLASS_1, CLASS_2)
Bright big pixel	Big pixel inside a big pixel matrix, in which at least a 70% of its pixels is brighter than a given frontier (also called CLASS_2 big pixel)
Brightness value	Value for a given pixel of the N_Value matrices, characterized by the Normalized reflectance in the pixel for Visible channels and the Brightness temperature in the pixel in Infrared or Water vapour channel, and defined as an integer value ranging from 0 to 255
Clear air AMV	AMV defined through the horizontal displacement between two Earth positions in two different satellite images, of a tracer defined through a specific humidity feature in water vapour images
Closeness threshold	Minimum distance in lines and columns allowed between two tracer locations
Cloud type	Cloud type defined for each tracer or AMV with NWC/GEO-CT output data, used for example to define which of the two calculated height levels (cloud top, cloud base) is used in the "Brightness temperature interpolation height assignment process"
Cloudy AMV	AMV defined through the horizontal displacement between two Earth positions in two different satellite images, of a tracer defined through a specific cloudiness feature in visible, infrared or water vapour images
Common Quality Index	Quality parameter, calculated with a self-contained Fortran module defined by EUMETSAT and NOAA/NESDIS, to be included as such without modifications by all AMV algorithms, and useful for a common homogeneous use of AMVs calculated with different AMV algorithms.
Consistency	Difference between an AMV and some other expected wind, quantified in probabilistic terms for the Quality Index calculation

Coverage hole	Location in the initial image in which two consecutive failures in the definition of a tracer with Gradient method have occurred, so defining a location for the tracer search with the second method, Tracer characteristics method
Dark big pixel	Big pixel inside a big pixel matrix, in which less than a 30% of its pixels is brighter than a given frontier (also called CLASS_0 big pixel)
Detailed dataset	Set of tracers or AMVs, calculated with the detailed or narrow tracer scale (with a default value of 12 x 12 pixels). Three kinds of Detailed tracers are possible: unrelated to a basic tracer, related to a wide basic tracer, related to a narrow basic tracer
Distance factor	Formula used to define which AMVs contribute to the spatial and temporal consistency tests for a given AMV, and their corresponding contribution to the consistency test
Frontier	A significant minimum in the N_Value matrix histogram for a given tracer candidate
Great circle	Trajectory between two locations on the Earth surface, which relates them considering the smallest possible distance
Haversine formula	Formula used to compute the great circle distance between two locations on the Earth surface
IND_TOPO parameter	Value of the AMV Orographic flag parameter, calculated to detect land influence for a given Atmospheric Motion Vector
Initial image	Satellite image in which tracers are defined with any of the two tracer calculation methods (Gradient or Tracer characteristics), so defining the initial position in the AMV displacements
LAT_C, LON_C	Geographical coordinates of the tracking centre in the later image, considering a given AMV
LAT_T, LON_T	Geographical coordinates of the tracer centre in the initial image, considering a given AMV
Later image	Satellite image in which tracers defined previously are tracked with any of the two tracking methods (Euclidean distance or Cross correlation), defining the later positions in the AMV displacements
Main tracking centre	Tracking centre for a given tracer, which has the best possible Euclidean distance/Cross correlation values
Maximum brightness gradient	Location of the maximum brightness value gradient inside a tracer candidate, to be defined as a tracer location with Gradient method
Maximum optimisation distance	Maximum distance in lines or columns allowed between a coverage hole used in the search of tracers with Tracer characteristics method, and the corresponding tracer location
Mixed calculation method	Alternative method available for the calculation of AMVs and Trajectories with NWC/GEO-HRW algorithm, through which the tracer tracking is evaluated considering shorter time intervals, and the displacement is evaluated considering longer time intervals.
Neighbour AMV	AMV which is close enough to a given one in the current processing cycle, used in the Quality spatial correlation test

N_Value matrix	Normalized reflectances for Visible channels, or Brightness temperatures for Infrared or Water vapour channels, for a given image in the processing region, defined as integer values ranging from 0 to 255.
Orographic flag (dynamic)	Flag to show possible land influence in the previous positions of a given AMV. It is calculated after the static orographic flag procedure, and indicated through IND_TOPO values: 1,2,3,4,5,6.
Orographic flag (static)	Flag to show possible land influence in the position of a given AMV. Indicated through IND_TOPO values: 1,2,3,6.
Overall Quality Index	Final Quality Index, weighted sum of individual forecast, temporal and spatial consistency tests (not considering the interscale consistency test)
Parallax correction	Correction of the apparent horizontal displacement of a feature in a satellite image, due to its height over the Earth surface
Persistent tracer	Tracer related to AMVs calculated in the previous cycle, for which the tracer centre is the tracking centre of the AMV in the previous cycle
Pixel distance	Preliminary line and column separation in pixels between the tracer locations, before the readjustments made by the tracer selection methods
Pixel exclusion matrix	Ensemble of pixels inside the processing region in which additional tracers cannot be located
Predecessor AMV	AMV in the previous processing cycle, whose tracking centre is used as the tracer centre of a persistent tracer in the current processing cycle
Prior AMV	AMV in the previous processing cycle close enough to a given AMV in the current processing cycle, used in the Quality temporal correlation test
Quality index (QI)	Quality parameter used to define the quality of the generated AMVs and Trajectories. It is based on spatial, temporal and forecast consistency against reference AMVs or the NWP wind forecast. Two kinds of Quality indices are defined: with and without forecast (with and without the contribution of the consistency against the NWP wind forecast)
Quality index threshold	Minimum value of the Quality index (with/without forecast) so that the given AMV/Trajectory can be written in the output files
S (in CC computation)	Any pixel inside a tracking candidate
Secondary tracking centre	Tracking centre for a given tracer, which does not have the best Euclidean distance or Cross correlation
Segment of the image	A set of contiguous pixels in a satellite image, defined by its size and location
Single scale procedure	Tracer selection procedure, for which only one scale of tracers is calculated
Starting location	Each a priori location of tracers throughout the initial image, in principle uniformly covering the whole processing region
Subpixel tracking	Tracking processing, through which the tracking centres in the later image are located in a non-integer location of the tracking area, and which is calculated through second order interpolation of the Euclidean distance minima/Cross correlation maxima
T (in CC computation)	Any pixel inside a tracer

TESO parameter	Orographic test parameter, detailing if the orographic flag could be calculated for a given AMV, and the relative results in AMVs related to the same tracer, added to Quality TEST indicator after Quality Control
TEST parameter	Quality flag after the Quality control processing, detailing which quality consistency tests were applied for a given AMV, and the relative results of each quality consistency test for all AMVs related to the same tracer
Tracer	Square segment in the initial image with a fixed size (nxn pixels, called tracer size), identified by the location of its centre, and considered valid candidate for AMV calculation by any of the tracer calculation methods
Tracer candidate	Square segment in the initial image with a fixed size, where conditions for tracer search using "Tracer characteristics method" are evaluated
Tracer continuity	Processing option in which part of the set of tracers in the current processing cycle is defined through the tracking centres of AMVs in the previous processing cycle
Tracer location	Pixel coordinates of a tracer (line and column) in the initial image
Tracer selection procedure	Strategy to get a complete set of tracers throughout the desired region of the image. It consists of 2 iterations (2 methods) for the single scale procedure; 4 iterations (2 methods, 2 scales) for the two scale procedure
Tracer size	Line/column dimension of a tracer. In NWC/GEO-HRW algorithm, both dimensions are similar defining square shaped tracers
Tracking	Determination of the best matching square segment for a given tracer in the initial image, with the same line and column dimension, inside the tracking area of a later image
Tracking area	Square segment in the later image containing the search area of a given tracer, in which all possible tracking candidates are located
Tracking candidate	Each square segment inside a tracking area of the later image, that is evaluated for the tracking of a given tracer
Tracking centre	Best matching square segment for a given tracer, with the same line and column dimension, inside the tracking area of a later image
Tracking centre location	Pixel coordinates of a tracking centre (line and column) in the later image
Trajectory	Path defining the displacement of a tracer throughout several satellite images
Two scale procedure	Tracer selection process considering tracers with two different tracer sizes (Basic dataset and Detailed dataset, being the line and column dimension of the second dataset half the dimension of the first dataset)
Weighted location	Location different that the centre of the tracer in the initial image or the tracking centre in the later image, relating best the displacement of the AMVs and Trajectories to the displacement of the part of the tracer with a largest contribution to the cross correlation.
Wind guess	NWP wind longitudinal and latitudinal components, through which the location of a smaller tracking area in the later image is defined for a quicker processing, although with a dependency on the NWP wind

Table 1: List of Definitions

1.4.2. Acronyms and Abbreviations

AMV	Atmospheric Motion Vector
BUFR	Binary Universal Form for the Representation of meteorological data
CDOP	NWC SAF Continuous Development and Operations Phase
CDOP2	NWC SAF Second Continuous Development and Operations Phase
CDOP3	NWC SAF Third Continuous Development and Operations Phase
CIMSS	UW's Cooperative Institute for Meteorological Satellite Studies
ECMWF	European Centre for Medium Range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GOES	NOAA's Geostationary Operational Environmental Satellite
HRVIS	MSG HRVIS High Resolution Visible channel
IOP	NWC SAF Initial Operations Phase
IR107, IR108, IR112, IR120	GOES-N 10.7µm - MSG 10.8µm - Himawari-8/9 11.2µm MSG 12.0µm Infrared channels
IWWG	International Winds Working Group
JMA	Japan Meteorological Agency
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	NWC/GEO 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
VIS06, VIS07, VIS08	MSG & Himawari-8/9 0.6µm - GOES-N 0.7µm - MSG & Himawari-8/9 0.8µm Visible channels
WMO	World Meteorological Organization
WV62, WV65, WV70, WV73	MSG & Himawari-8/9 6.2µm - GOES-N 6.5µm - Himawari-8/9 6.9µm - MSG & Himawari-8/9 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 Third Continuous Development and Operations Phase (CDOP3)	NWC/CDOP3/SAF/AEMET/MGT/PRO	1.0
[AD.2]	Project Plan for the NWC SAF CDOP3 Phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.0
[AD.3]	Configuration Management Plan for the NWC SAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.0
[AD.4]	NWC SAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.0
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/1	1.0
[AD.6]	Data Output Format for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/DOF	1.0
[AD.7]	System and Component Requirements Document for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/SCRD	2.1
[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 processor of the NWC/GEO: Software part	NWC/CDOP3/GEO/AEMET/SCI/UM/Wind	1.0
[AD.15]	Scientific and Validation Report for the Wind product processor of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/VR/Wind	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).
[RD.6]	J.M.Fernández, 2000: Developments for a High Resolution Wind product from the HRVIS channel of the Meteosat Second Generation. (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.7]	J.M.Fernández, 2003: Enhancement of algorithms for satellite derived winds: the High Resolution and Quality Control aspects. (Proceedings 2003 Meteorological Satellite Conference, EUMETSAT Pub.39).
[RD.8]	J.García-Pereda & J.M.Fernández, 2006: Description and validation results of High Resolution Winds product from HRVIS MSG channel at the EUMETSAT Nowcasting SAF (Proceedings 8th International Wind Workshop, EUMETSAT Pub.47).
[RD.9]	J.García-Pereda, 2008: Evolution of High Resolution Winds Product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.10]	J.García-Pereda, 2010: New developments in the High Resolution Winds product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 10th International Wind Workshop, EUMETSAT Pub.56).
[RD.11]	C.M.Hayden & R.T.Merrill, 1988: Recent NESDIS research in wind estimation from geostationary satellite images (ECMWF Seminar Proceedings: Data assimilation and use of satellite data, Vol. II, pp.273-293).
[RD.12]	W.P.Menzel, 1996: Report on the Working Group on verification statistics. (Proceedings 3rd International Wind Workshop, EUMETSAT Pub.18).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.14]	Xu J. & Zhang Q., 1996: Calculation of Cloud motion wind with GMS-5 images in China. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.15]	K.Holmlund & C.S.Velden, 1998: Objective determination of the reliability of satellite derived Atmospheric Motion Vectors (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.16]	K.Holmlund, C.S.Velden & M.Rohn, 2000: Improved quality estimates of Atmospheric Motion Vectors utilising the EUMETSAT Quality Indicators and the UW/CIMSS Autoeditor (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.17]	R.Borde & R.Oyama, 2008: A direct link between feature tracking and height assignment of operational Atmospheric Motion Vectors (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.18]	J.García-Pereda, R.Borde & R.Randriamampianina, 2012: Latest developments in "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]	WMO Code Tables and Flag Tables associated with BUFR/CREX table B, version 29 (WMO Publication, available at http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/PrevVERSIONS/20171108/WMO306_vI2_BUFRCREX_CodeFlag_en.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 (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/225)
[RD.25]	D.Santek, R.Dworak, S.Wanzong, K.Winiecki, S.Nebuda, J.García-Pereda, R.Borde & M.Carranza, 2018: 2018 AMV Intercomparison Study Report (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/5092)
[RD.26]	K.Salonen, J.Cotton, N.Bormann & M.Forsythe, 2015: Characterizing AMV height-assignment error by comparing best-fit pressure statistics from the Met Office and ECMWF data assimilation systems (Journal of Applied Meteorology and Climatology, Vol.54, Num.1).

Table 4: List of Reference Documents

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

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

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

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

"Atmospheric Motion Vectors" are associated with the horizontal wind in the atmosphere. Specific exceptions exist to this, generally related to clouds which are blocked or whose flow is affected by orography, or to lee wave clouds with atmospheric stability near mountain ranges. These exceptions are identified and discarded, such as later explain in chapter 2.2.2.11 of this document.

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

A "Trajectory" is the path defined by the displacement of the same tracer throughout several satellite images.

AMVs and Trajectories are calculated throughout all hours of the day, as a dynamic information in the NWC/GEO package, 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 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).

or 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).

As already said in the Introduction, the adaptation of NWC/GEO-HRW to GOES-R satellite series is under way and will be delivered as a patch for NWC/GEO v2018 software package throughout the year 2019.

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's Satellite Application Facility on support to Nowcasting and Very short range forecasting (NWC SAF)". This product is useful in Nowcasting applications, used in synergy with other data available to the forecaster.

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

It can also be used in form of objectively derived fields, and assimilated in Numerical Weather Prediction Models (together with many other data), or as an input to Analysis, Nowcasting and Very short range forecasting applications.

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

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

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

2.2.1 Physics of the problem

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

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

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

1. The reading and preprocessing of the satellite data.

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

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

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

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

   Each selected feature in the initial image is then "tracked" in successive images in order to determine the displacement of the feature. Clouds or humidity patterns can change shape or even disappear, but enough of them survive to produce a significant number of AMVs. With shorter time intervals up to 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 water vapour/infrared window intercept techniques for the height assignment of semitransparent clouds, statistical assignment schemes,…

5. The calculation of the AMV vectors and Trajectories.

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

6. A quality control.

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

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

2.2.2.1 Outline of the Algorithm

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

1. Preprocessing:

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

2. Processing:

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

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

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

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

3. Postprocessing:

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

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

The code was progressively developed with GOES, MFG and MSG satellite data. Examples with MSG, GOES-N and Himawari-8/9 satellite series are presented throughout the description of the algorithm to illustrate the process. The different options and coefficients are also presented. Many of them are configurable: in such a case, this circumstance is specifically indicated.

2.2.2.2 Preprocessing

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

1. Reflectances (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, GOES-N or Himawari-8/9 visible channels to be used: MSG/HRVIS, VIS06 or VIS08; GOES-N/VIS07; Himawari-8/9/VIS06 or VIS08.

2. Brightness temperatures for the images with which tracers are calculated and tracked, for all MSG, GOES-N or Himawari-8/9 Infrared or Water vapour channels to be used: MSG/IR108, IR120, WV62 or WV73; GOES-N/IR107 or WV65; Himawari-8/9/IR112, WV62, WV70 or WV73.

3. Radiances for the images with which tracers are calculated and tracked, for MSG/IR108 and WV62, GOES-N/IR107 and WV65, or Himawari-8/9/IR112 and WV62, if the "Image correlation quality control test" defined in chapter 2.2.2.10 is used (implemented in the default configuration but not mandatory).

4. Latitude and longitude matrices and solar and satellite zenith angle matrices for the image locations in which tracers are calculated and tracked (which are calculated by NWC/GEO library).

5. NWP temperature profiles for the whole processing region in which NWC/GEO-HRW is run.

6. NWP wind component profiles for the whole processing region in which NWC/GEO-HRW is run, if the "Forecast consistency quality control test" defined in chapter 2.2.2.10 is used, or if the NWP "wind guess" for the definition of the "tracking area" in the "later image" such as defined in chapter 2.2.2.4 is used, or if Validation statistics are to be calculated by the NWC/GEO-HRW algorithm itself such as defined in chapter 2.3.1.4 (considering as reference winds NWP analysis winds or NWP forecast winds). The first and third option are implemented in the default configuration, but none of them are mandatory.

7. NWP geopotential profiles for the whole processing region in which NWC/GEO-HRW is run, if the "Parallax correction" defined in chapter 2.2.2.9 or the "Orographic flag" defined in chapter 2.2.2.11 are used (implemented in the default configuration but not mandatory).

8. NWC/GEO-CT Cloud Type output for the image in which tracers are calculated, in case the "AMV Cloud type" is used for the "Brightness temperature interpolation method height assignment", such as defined in chapter 2.2.2.5 (not mandatory).

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 (implemented in the default configuration but 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 (implemented in the default configuration but 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). 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 can be found in chapter 2.3.3. The option to calculate AMVs and Trajectories with climatological data instead of NWP data, possible with previous NWC/GEO-HRW versions, is not available anymore, since the amount and quality of data provided in previous releases with the climatological data was significantly worse.

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

2.2.2.3 Tracer search

The process of NWC/GEO-HRW starts with the calculation of "tracers" (square "segments" of nxn pixels, used as initial positions of 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 software (including the case in which the running of the software starts), the tracer calculation is the only process of NWC/GEO-HRW algorithm which is activated for that image, skipping all other processes in the NWC/GEO-HRW algorithm. Once tracers from a previous run identified as "initial image" are available and AMVs can be calculated, the following tracer calculation processes activate as the final step of each NWC/GEO-HRW algorithm run.

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

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

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

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

These resolutions define different tracer scales between 48 to 96 km at subsatellite point (in the "basic low resolution image scale") and 6 to 12 km at subsatellite point (in the "detailed highest resolution image scale"), with highest values related to GOES-N satellite series and lowest values related to Himawari-8/9 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" with MSG satellites can be better to track tracers of this small size.

In any case, the line and column "tracer size" in pixels of the "single or basic scale" can be defined through configurable parameters TRACERSIZE_VERYHIGH for the Himawari-8/9 0.5 km very high resolution images, TRACERSIZE_HIGH for the 1 km high resolution images (available in the three satellite series), and TRACERSIZE_LOW for the 2 to 4 km low resolution images (available in the three satellite series). NWC/GEO-HRW is defined to work with square shaped tracers, so similar values for the line and column "tracer size" are kept for the processing.

FIRST METHOD: GRADIENT

Starting from the upper left corner of the working region of the image, "starting locations" for the tracer search with Gradient method are defined. Similar to the method defined by CIMSS/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 BRIGHTNESS_THR_VIS (for visible cases, with default value 120) or smaller than BRIGHTNESS_THR_OTHER (for other cases, with default value 240).

2. To verify if a difference exists between the maximum and minimum "brightness value" in the "tracer candidate", greater than configurable parameter GVAL_VIS (for visible cases, with default value 60) or GVAL_OTHER (for infrared and water vapour cases, with default value 48).

3. To compute inside the "tracer candidate" the value and location of the "maximum brightness gradient" $|\Delta N\_Value(\Delta x) + \Delta N\_value(\Delta y)|$, where Δ means a distance of 5 pixels in both line and column directions. This "maximum brightness gradient" cannot be located on the edges of the "tracer candidate".

If all previous processes have been successful, a valid "tracer" is defined at the location of the "maximum brightness gradient". The "starting location" for the subsequent "tracer" is established by a "pixel distance" between tracers, defined 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 algorithm, due to the generally smaller "pixel distance" between those low level tracers.

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

SECOND METHOD: TRACER CHARACTERISTICS

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

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

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

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

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

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

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

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

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

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

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

The "frontier" defines for the "tracer candidate" a group of "bright pixels" (defined as those pixels brighter than the given frontier) and a group of "dark pixels" (defined as those pixels darker than the given frontier).
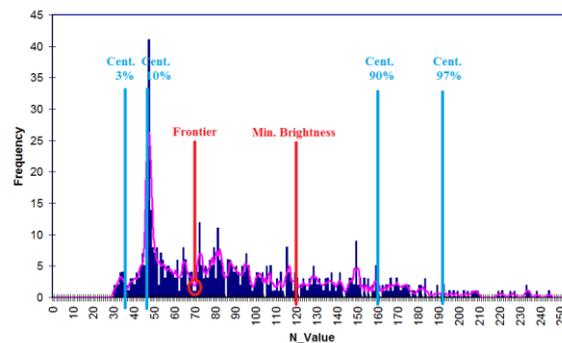
Figure 1: Example of "N_Value matrix histogram" (unsmoothed in violet and smoothed in pink) for a valid Low resolution visible "tracer candidate". The minimum brightness threshold, the algorithm centiles and the defined frontier are also shown

2. "Big pixel brightness variability test":

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

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

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

CLASS_1: 'undefined big pixel', intermediate case.

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

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

In the case the "Big pixel brightness variability test" is not successful but just along one direction, and no other frontiers can be selected, the frontier is retained as an "almost good frontier" and a tracer is still defined at this location.
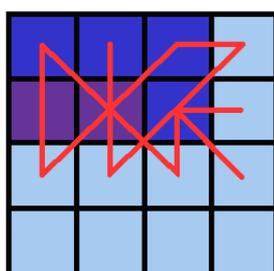
Example of tracer with its corresponding structure of 'Big pixels':
- Class 2 pixels in dark blue (bright pixels).
- Class 1 pixels in violet.
- Class 0 pixels in light blue (dark pixels).

The results of the 'Big pixel Brightness variability test' is also shown.
- 'Good transitions' shown in red.

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

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

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_THR. A "Detailed tracer unrelated to a Basic tracer" is so defined, with a slightly lower brightness threshold.

- A "Wide basic tracer" has been found, in which CLASS_2 values appear in both first and last row, or in both first and last column, of the "4x4 big pixel matrix" used in the "Big pixel brightness variability test". In this case four starting locations are defined for the "Detailed scale". Each of them is located at the corners of a "Detailed tracer" whose centre is the centre of the "Basic tracer".

- A "Narrow basic tracer" has been found, in which CLASS_2 values do not appear in both first and last row, nor in both first and last column, of the "4x4 big pixel matrix" used in the "Big pixel brightness variability test". In this case, only one starting location is defined for the "Detailed scale", whose centre is defined by the weighted location of the "Big pixels" in the "4x4 big pixel matrix".

TRAJECTORIES

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

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

EXAMPLES OF AMVs RELATED TO DIFFERENT TYPES OF TRACERS

Examples of AMVs related to different types of tracers for MSG satellite series, considering the tracer method and the tracer type, are shown next. In *Figure 3*, "Basic tracers" considering the tracer method ("Gradient tracers" and "Tracer characteristics tracers"). In *Figure 4*, "Basic and Detailed tracers" considering the tracer type ("Basic tracers", "Detailed tracers unrelated to Basic tracers", "Detailed tracers related to Wide basic tracers", and "Detailed tracers related to Narrow basic tracers").
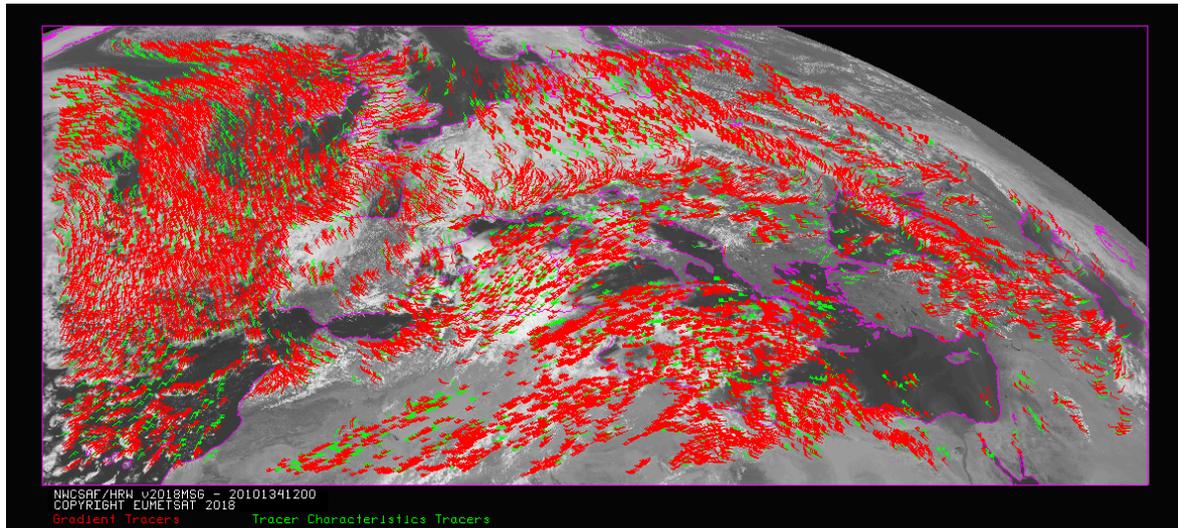
Figure 3: "Basic scale AMVs" (in red and green, considering the Tracer calculation method used for their extraction), in the Single scale NWC/GEO-HRW example defined in the European and Mediterranean region with the default `$SAFNWC/config/safnwc_HRW_MSG.cfm` *model configuration file (14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite)*
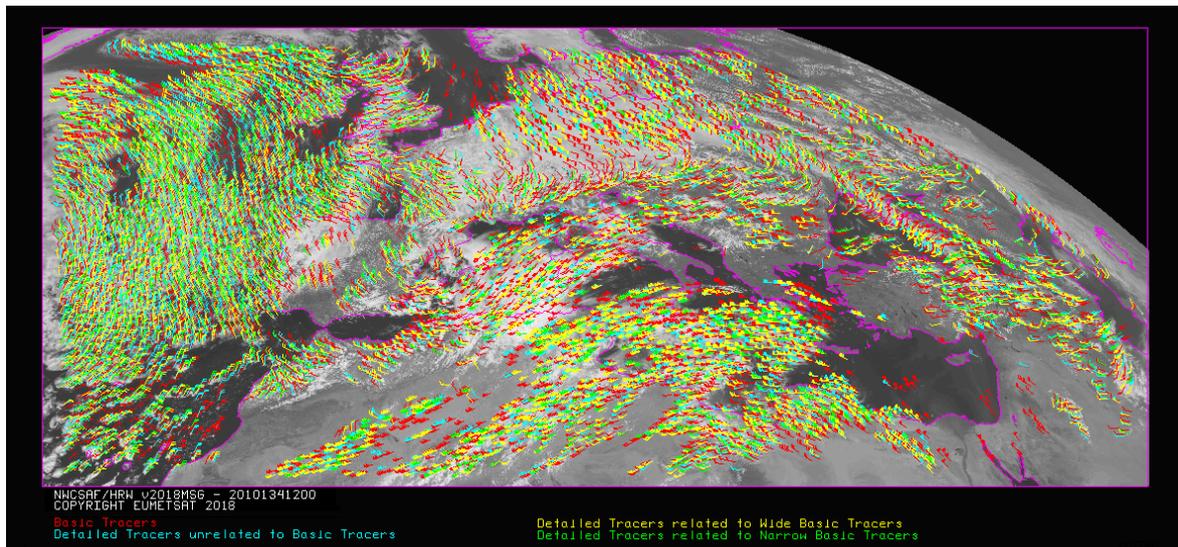
Figure 4: "Basic scale AMVs" (in red), and "Detailed scale AMVs" (in yellow, green and blue, considering their relationship with the Basic scale AMVs), in a Two scale NWC/GEO-HRW example, defined in the European and Mediterranean region with the default `$SAFNWC/config/safnwc_HRW_MSG.cfm` *model configuration file with parameter CDET = 1 (14 May 2010 12:00 UTC, 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 $LP_{ij} = \Sigma\Sigma(T-S)^2$ 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 algorithm, and is applied using configurable parameter WIND_GUESS = 1.

Nevertheless, NWC/GEO-HRW algorithm has been 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 operatively the configuration without use of "wind guess" with configurable parameter WIND_GUESS = 0.
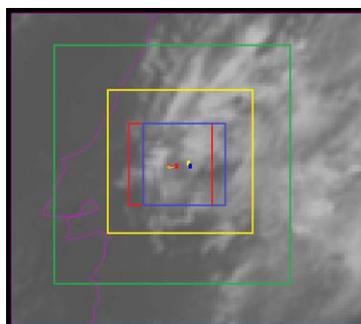
Figure 5: A low resolution tracer at 11:45 UTC (O red mark), its position defined by NWP wind guess at 12:00 UTC (O yellow mark), and its true tracking position at 12:00 UTC defined by HRW algorithm (O blue mark), for an example case (Basic AMVs in Nominal scan mode, MSG2 satellite). The "yellow tracking area" (with its centre at the position defined by the NWP wind guess at 12:00 UTC) corresponds to the option using wind guess for the definition of the tracking area. The "green tracking area" (with its centre at the position of the tracer at 11:45 UTC) corresponds to the option not using wind guess for the definition of the tracking area. The larger size of the tracking area when the wind guess has not been used is to be noticed, which causes a longer time for the running of HRW algorithm, but at the same time reduces the dependence from the NWP model

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

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

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/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 MSG and Himawari-8/9 satellite series, and 50% for GOES-N satellite series).

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":

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

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.

MIXED CALCULATION METHOD

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

In NWC/GEO-HRW v6.0, the default configuration implies the use of consecutive images (separated by 10 minutes with Himawari-8/9 series, by 15 minutes with MSG series, and by 15 or 30 minutes with GOES-N series) in "Nominal scan mode", and the use of alternate images (one out of every two, separated by 10 minutes) in "Rapid scan mode" with MSG satellites. No "Rapid scan mode" option has been defined for use with GOES-N or Himawari-8/9 satellite series.

In NWC/GEO-HRW v6.0, a "mixed calculation method" considering short and long time intervals at the same time is available for the first time with configurable parameter MIXED_SCANNING = 1,2 (not used as default option), through which tracers are to be tracked considering the minimum time interval possible, but the corresponding AMVs and Trajectories are calculated considering the displacements in longer time intervals (defined by parameter SLOT_GAP = 2,3,4).

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

This "mixed calculation method" is useful for the calculation of AMVs with high resolution images, and for the improvement of the quality of the calculated AMVs. This is caused by the smaller changes in the features evaluating the tracking in shorter time intervals (and so the smaller possibilities for a wrong tracking), and the smaller problems with the spatial resolution evaluating the displacements in longer time intervals.
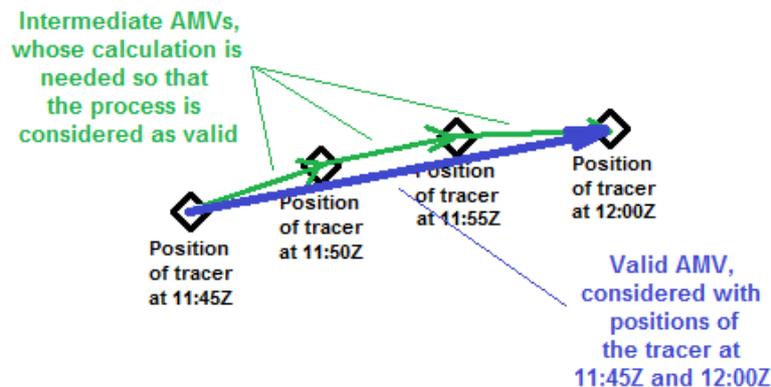
Figure 6: Example of processing with the "mixed calculation method" for
MSG satellite series "Rapid scan mode", in which the tracers are tracked every 5 minutes
(so providing three intermediate AMVs) but the valid AMVs are calculated every 15 minutes
(considering the initial and final position of the tracer only)

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

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

EXAMPLES OF AMV TRACKING FOR THE DIFFERENT SATELLITES

Examples of AMVs for MSG, GOES-N and Himawari-8/9 satellites are shown next in *Figures 7, 8 and 9*, considering the satellite channel used for the AMV calculation, and their consideration as Cloudy AMVs or Clear air AMVs.
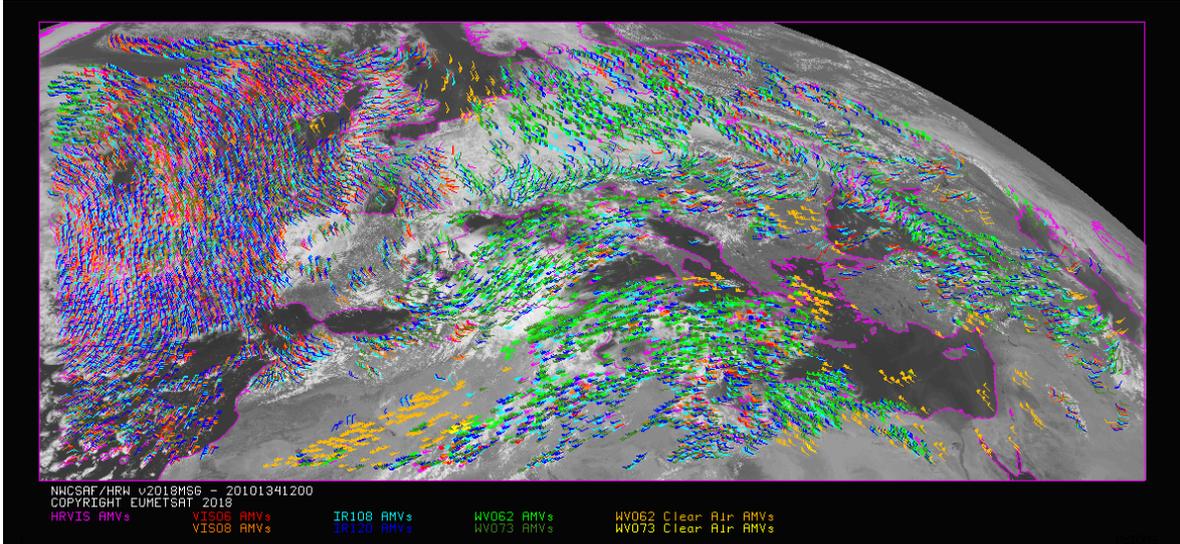
Figure 7: AMVs considering the satellite channel used for the AMV calculation, for the MSG series High Resolution Winds example defined in Figure 31 (14 May 2010, 12:00 UTC, MSG2 satellite)
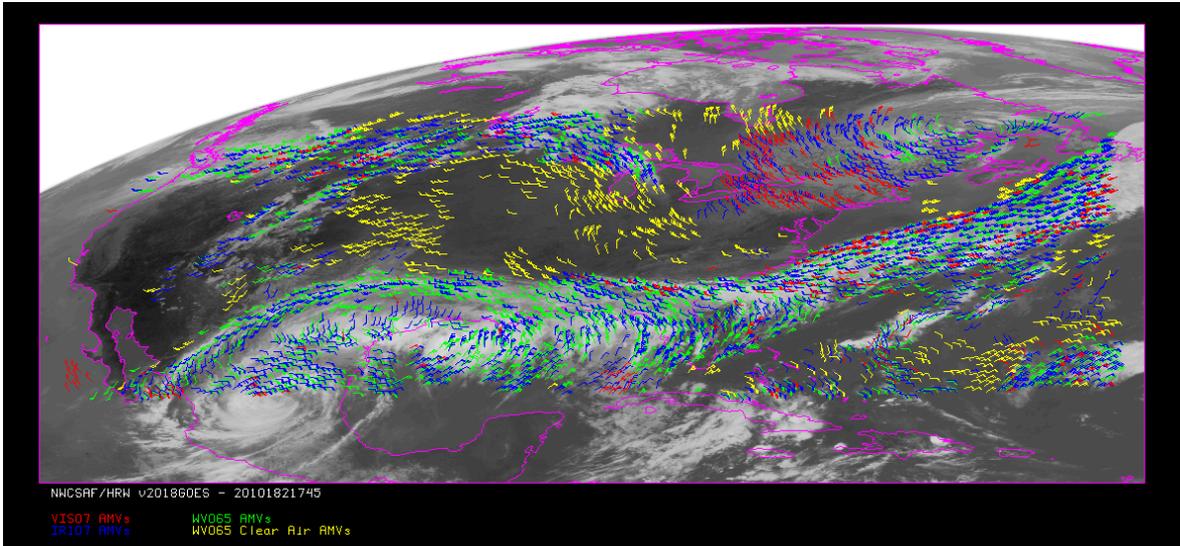
Figure 8: AMVs considering the satellite channel used for the AMV calculation, for the GOES-N series High Resolution Winds example defined in Figure 33 (1 July 2010 17:45 UTC, GOES13 satellite)
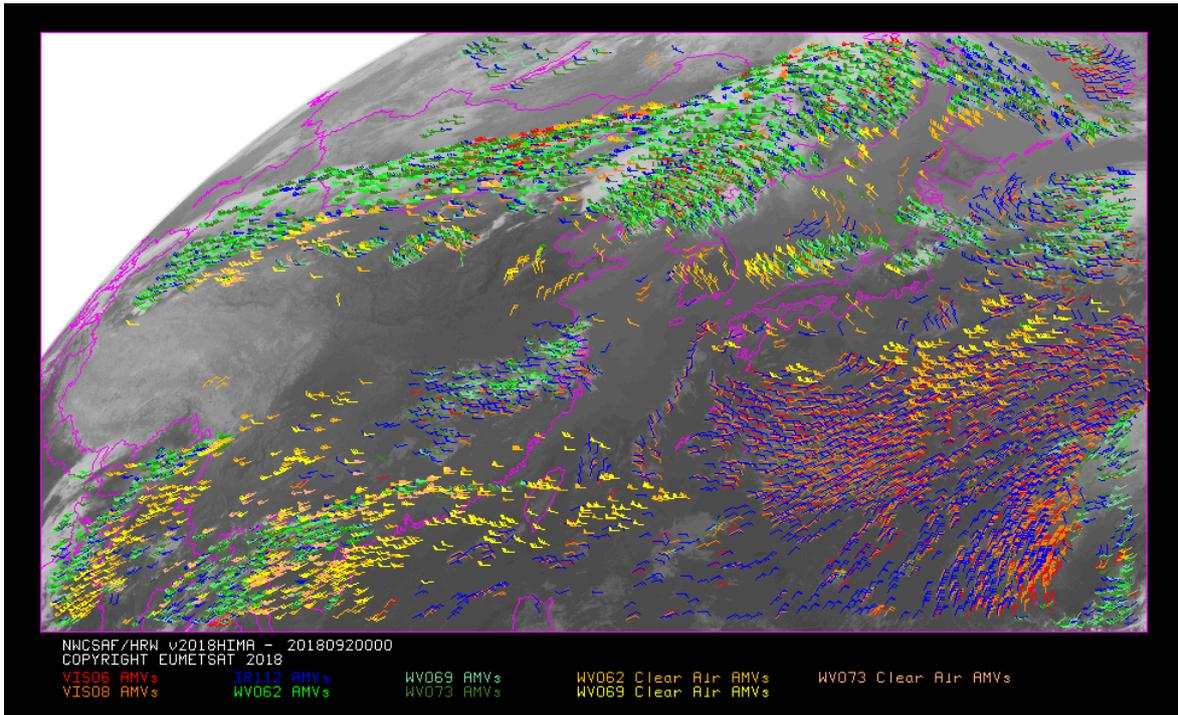
Figure 9: AMVs considering the satellite channel used for the AMV calculation, for the Himawari-8/9 series High Resolution Winds example defined in Figure 35 (2 April 2018 00:00 UTC, Himawari-8 satellite)

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; IR108 brightness temperature is used for the MSG visible channels, IR107 brightness temperature is used for the GOES-N visible channels, and IR112 brightness temperature is used for the Himawari-8/9 visible channels. 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 100 hPa pressure limits are also defined (MAX_PRESSURE_BOUNDARY and MIN_PRESSURE_BOUNDARY) for this height assignment process.

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

For this, the "AMV cloud_type" parameter is defined as the most common value of NWC/GEO-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 2.5% of cloudy pixels), fractional clouds, and cloud types for which the validation statistics are significantly worse.

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

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

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

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

MSG channels		HRVIS	VIS06	VIS08	WV62		WV73	IR108	IR120
GOES-N channels		VIS07			WV65			IR107	
Himawari-8/9 channels	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 skips this method and uses the "AMV pressure" and "AMV temperature" values provided by "Brightness temperature interpolation method".

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

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

- Opaque cloud top pressure retrieval considering Infrared Window channels, with simulation of radiances with RTTOV, and possibility of thermal inversion processing.

- Semitransparent cloud top pressure retrieval with the Radiance ratioing technique and the Water vapour/infrared window intercept method, considering Water Vapour and Carbon Dioxide channels.

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

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

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

The graph 'Normalized reflectance(Partial contribution to the correlation)' for the visible channels, or the graph 'Brightness temperature(Partial contribution to the correlation)' for the infrared/water vapour channels has in general the shape of the letter 'C', as shown by the lower graphs in *Figures 10 and 11* (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/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, considering only the pixels whose "partial contribution to the correlation" is higher than the "CCC calculation threshold" inside the cold branch of the 'Brightness temperature(Partial contribution to the correlation)' graph. The "CCC calculation threshold" is defined as the mean "partial contribution to correlation", or zero if so no pixels are kept.

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

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

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

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

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

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

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

Images in *Figures 10 and 11* 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. Comparing the images, it is visually clear that the same object is being observed in both cases. 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 a valid value in the blue boxes in both graphs of *Figures 10 and 11* are used in the calculations of P_{CCC} and ΔP_{CCC}. In the MSG/VIS08 example these pixels correspond to the very low and low cloud in the right part of the "tracking centre", defining values of P_{CCC}=834 hPa and ΔP_{CCC}=27 hPa. In the MSG/IR108 case these pixels correspond to the high cloud in the upper right corner of the "tracking centre", defining values of P_{CCC}=286 hPa and ΔP_{CCC}=24 hPa.

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

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

The "weighted locations" relate the displacement of the AMVs and Trajectories to the displacement of the part of the tracer with the "largest contribution to the cross correlation". These weighted locations are identified in *Figures 10 and 11* as red crosses.

When trajectories are calculated with configurable parameter CALCULATE_TRAJECTORIES = 1, tracking consecutively during several images the same tracer, the calculation of these "weighted locations" occurs only for the first AMV in the trajectory, and keeps the same value during all the time the Trajectory is alive, to avoid spatial discontinuities in the Trajectory.
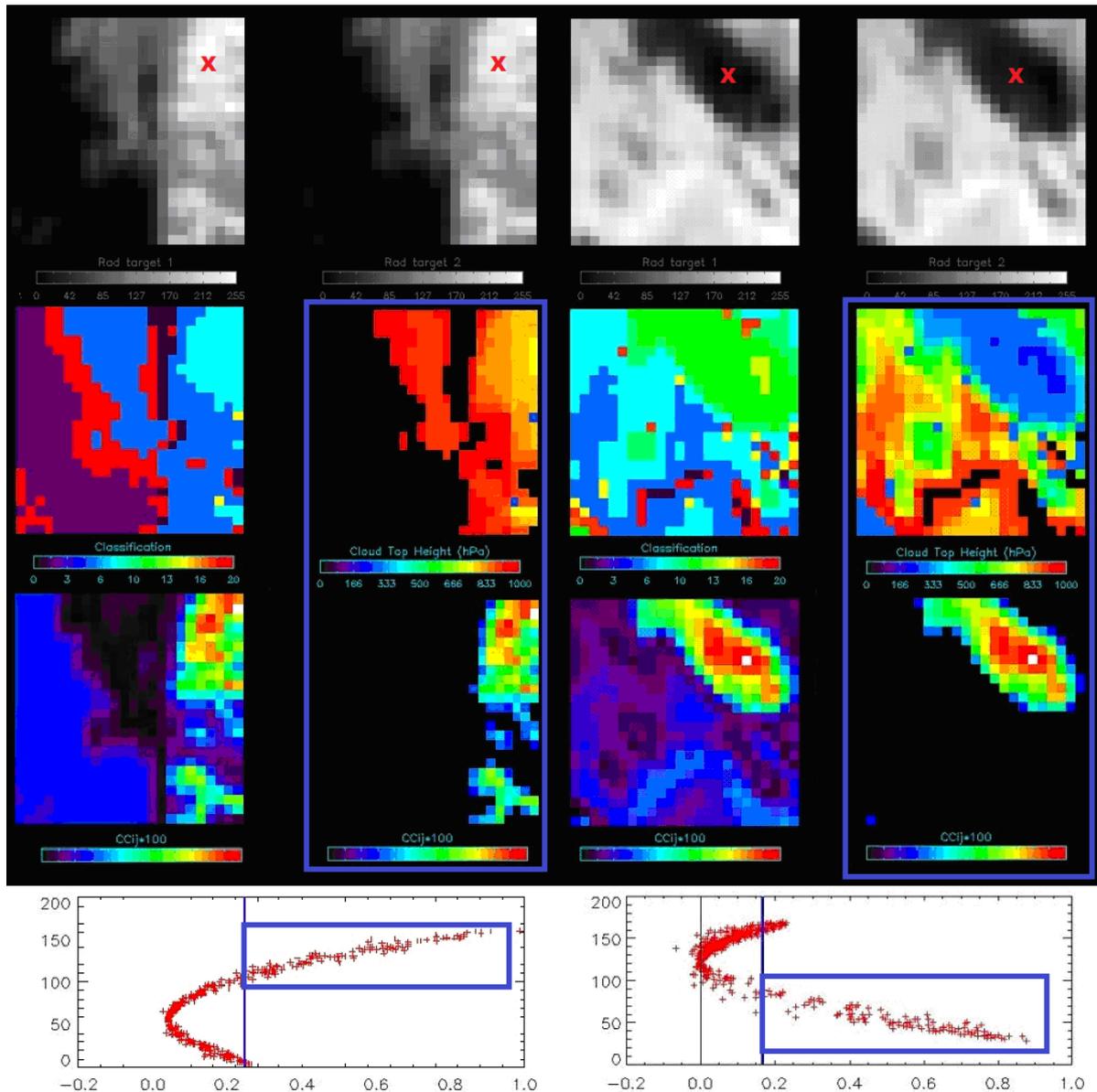
Figures 10 and 11: Matrices and graphs used in the calculation of "CCC method height assignment",
for a MSG/VIS08 case in the left side and a MSG/IR108 case in the right side, as explained in the text.
The weighted location of the AMV in the "initial image" and "later image",
as defined with configurable parameter DEFPOSWITHCONTRIBUTIONS = 1,
is shown as a red cross in the images in the first row

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

"CCC method" height assignment offers a direct correspondence between the pressure levels defined for NWC/GEO-HRW cloudy AMVs and Trajectories, and those given to the "cloud tops" by NWC/GEO-CTTH 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 the parameters provided by NWC/GEO-CMIC output and similar formulae to the ones used in previous chapter for the "AMV pressure level":

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

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

The empirical relationship between the "difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level" and the "AMV Ice/Liquid water path" has been tuned in NWC/GEO-HRW v6.0 for both MSG and Himawari-8/9 satellite series. It considers 12:00 UTC Cloudy AMVs for MSG2 satellite between July 2010 and June 2011 in the European and Mediterranean region for MSG series, and 00:00 UTC Cloudy AMVs for Himawari-8 satellite between November 2017 and February 2018 in the China/Korea/Japan region for Himawari-8/9 series.

Defining separate procedures for Ice/Liquid Cloud Visible AMVs, for Ice/Liquid Cloud Infrared AMVs and for Ice/Liquid Cloud Water vapour AMVs, *Figures 12 to 17* for MSG and *Figures 18 to 23* for Himawari-8/9 in the following page are obtained. The reference wind data used for the calculation of the "best fit pressure level" have been "Radiosounding wind" data. The empirical relationship has been fitted to a double linear/constant regression. This double linear/constant regression works better than a simple linear regression in all possible cases.

The "difference between the AMV pressure level calculated with CCC method and the "best fit pressure level" is in general negative, meaning that the "best fit pressure level" is in most cases at a lower level, 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" based on the "AMV liquid/ice water path" with these regressions, it is implemented such as shown in *Tables 7 and 8*, respectively for MSG and Himawari 8/9. This correction locates the AMVs in a level nearer to the ground, with the exception only of AMVs with very small Ice/Liquid water path values. A control is later defined through the "Orographic flag" to avoid that with the correction AMVs are located at a level 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 for MSG2 satellite, and the reference AMV Validation period March 2018-August 2018 in the China/Korea/Japan region for Himawari-8 satellite), the "Microphysics correction" causes a reduction in all validation parameters (NBIAS, NMVD, NRMSVD), which is largest for the NBIAS.

The "Microphysics correction" for MSG satellites defined for NWC/GEO-HRW v6.0 is different to the one for the previous version of NWC/GEO-HRW, due to the higher values of Liquid Water Path and Ice Water Path shown by the new NWC/GEO-CMIC product. In any case, differences in "Pressure correction values" with respect to those the previous version of NWC/GEO-HRW, are smaller than 30 hPa for the 89% of Water Path values and smaller than 60 hPa for the 100% of Water Path values.

The "Microphysics correction" for MSG and Himawari-8/9 satellites for NWC/GEO-HRW v6.0 are more different, due to the differences in the NWC/GEO-Cloud product algorithms for both satellites. In general, "Pressure correction" for Himawari satellites is to lower levels for Liquid clouds and to higher levels for Ice clouds. Considering differences in "Pressure correction values" with respect to those for MSG satellites, they are larger than 30 hPa for the 62% of Water Path values and larger than 60 hPa for the 4% of Water Path values.

"CCC method with Microphysics correction" height assignment is implemented with configurable parameter USE_MICROPHYSICS = 2. As already said, in NWC/GEO-HRW v6.0 this is activated as default option for MSG and Himawari-8/9 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 the default AMV output format as "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 runs "CCC method without Microphysics correction" height assignment.
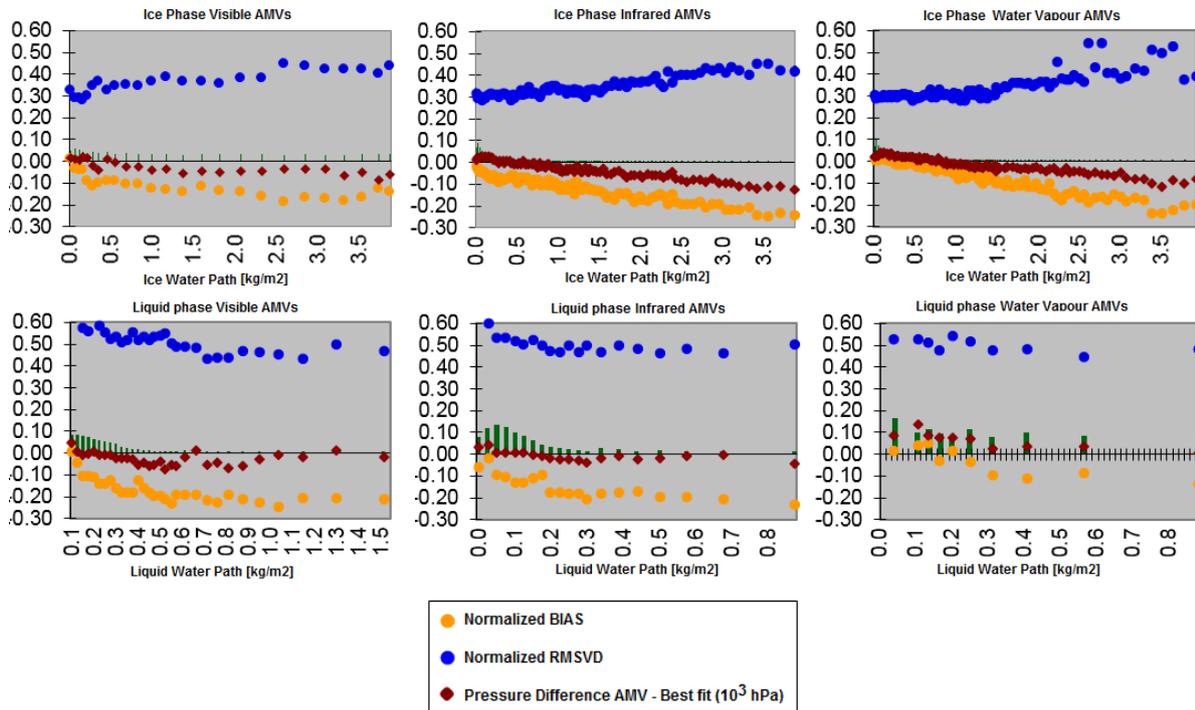
Figures 12 to 17: Graphs relating for MSG satellite series
the "Difference between the AMV pressure level calculated with CCC method and the Radiosounding best fit pressure level (in 10^3 hPa)" in red, the Normalized BIAS in yellow,
and the Normalized RMSVD in blue, with the "AMV Ice/Liquid Water Path (in kg/m^2)",
for Visible AMVs (left), Infrared AMVs (centre) and Water vapour AMVs (right).
12:00 UTC Cloudy AMVs for MSG2 satellite for July 2010-June 2011
in the European and Mediterranean region have been used for the tuning

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

Table 7: Correction for AMV pressure level [in hPa] based on the AMV Ice/Liquid water path for MSG satellite series
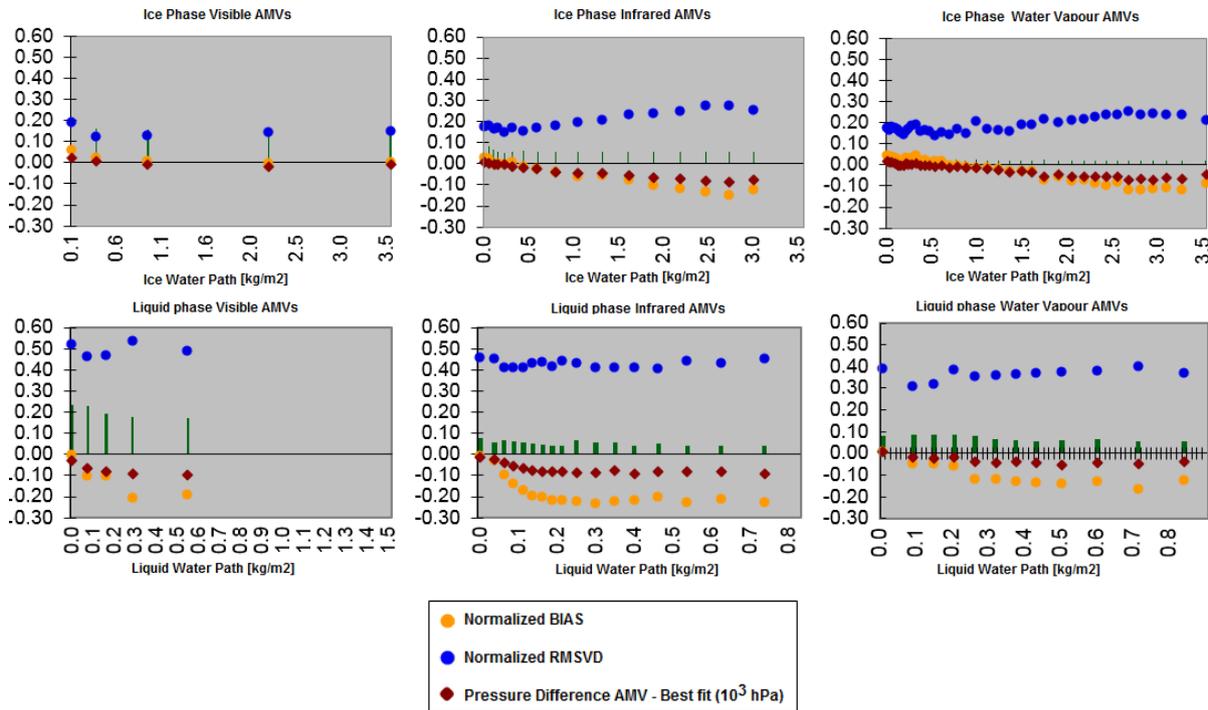
Figures 18 to 23: Graphs relating for Himawari-8/9 satellites
the "Difference between the AMV pressure level calculated with CCC method and the Radiosounding
best fit pressure level (in 10^3 hPa)" in red, the Normalized BIAS in yellow,
and the Normalized RMSVD in blue, with the "AMV Ice/Liquid Water Path (in kg/m^2)",
for Visible AMVs (left), Infrared AMVs (centre) and Water vapour AMVs (right).
00:00 UTC Cloudy AMVs for Himawari-8 satellite for November 2017-February 2018
in the China/Korea/Japan region have been used for the tuning

Correction for the "AMV pressure level [in hPa]" based on the "AMV Ice/Liquid water path" for Himawari-8/9 satellite series	

VISIBLE ICE PHASE CLOUDY AMVs
MIC.CORR[hPa] = 11 without IWP
MIC.CORR[hPa] = -33+66*IWP[kg/m^2]
   if IWP < 0.6667 kg/m^2
MIC.CORR[hPa] = 11 if IWP > 0.6667 kg/m^2
	VISIBLE LIQUID PHASE CLOUDY AMVs
	MIC.CORR[hPa] = 88 without LWP
	MIC.CORR[hPa] = 12+480*LWP[kg/m^2]
	   if LWP < 0.1583 kg/m^2
	MIC.CORR[hPa] = 88 if LWP > 0.1583 kg/m^2

INFRARED ICE PHASE CLOUDY AMVs
MIC.CORR[hPa] = 45 without IWP
MIC.CORR[hPa] = -2+38*IWP[kg/m^2]
   if IWP < 2.1316 kg/m^2
MIC.CORR[hPa] = 79 if IWP > 2.1316 kg/m^2
	INFRARED LIQUID PHASE CLOUDY AMVs
	MIC.CORR[hPa] = 78 without LWP
	MIC.CORR[hPa] = 465*LWP[kg/m^2]
	   if LWP < 0.1677 kg/m^2
	MIC.CORR[hPa] = 78 if LWP > 0.1677 kg/m^2

WATER VAPOUR ICE PHASE AMVs
MIC.CORR[hPa] =20 without IWP
MIC.CORR[hPa] = -11+29*IWP[kg/m^2]
   if IWP < 2.5517 kg/m^2
MIC.CORR[hPa] = 63 if IWP > 2.5517 kg/m^2
	WATER VAPOUR LIQUID PHASE AMVs
	MIC.CORR[hPa] = 50 without LWP
	MIC.CORR[hPa] = -8+161*LWP[kg/m^2]
	   if LWP < 0.3602 kg/m^2
	MIC.CORR[hPa] = 50 if LWP > 0.3602 kg/m^2

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

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

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

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

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

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

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

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

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

EXAMPLE OF AMV CLOUD TYPE DEFINED BY CCC HEIGHT ASSIGNMENT

An example of AMVs for MSG satellite is shown in *Figure 24*, considering the "AMV cloud type" defined by "CCC method height assignment".
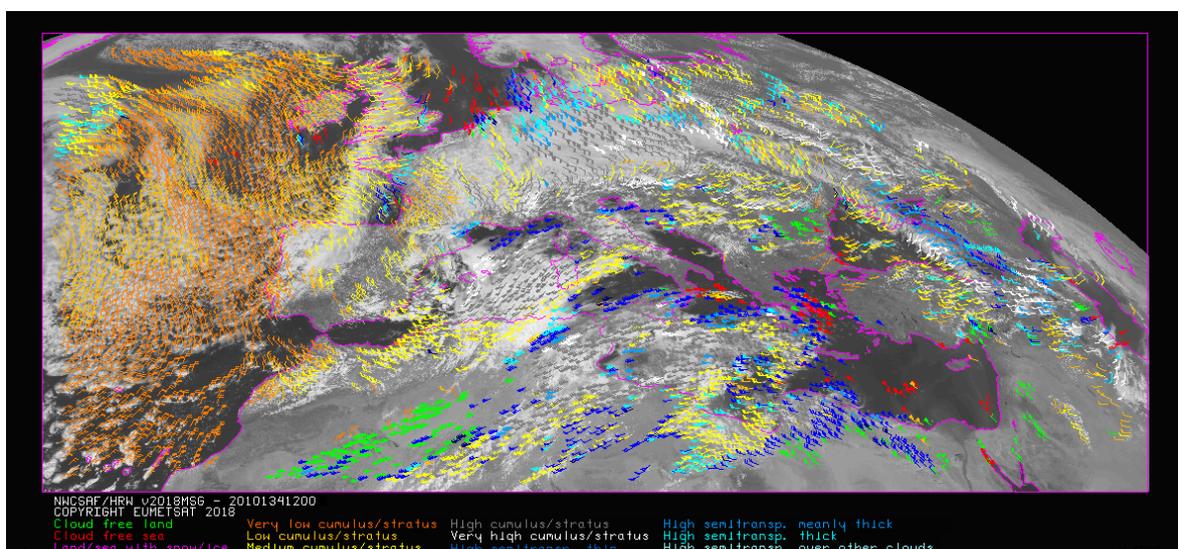
Figure 24: "AMV cloud type values" (as defined by "CCC method height assignment")
for the High Resolution Winds example defined in Figure 31
(14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite)

EXAMPLE OF AMVs RELATED TO DIFFERENT OPTIONS OF CCC HEIGHT ASSIGNMENT

An example of AMVs for MSG satellite is shown in *Figure 25*, considering the different options for "CCC method height assignment" (with/without Microphysics correction; using high/low calculation threshold), and the corresponding cloud phase (ice, liquid, mixed/undefined, clear air).
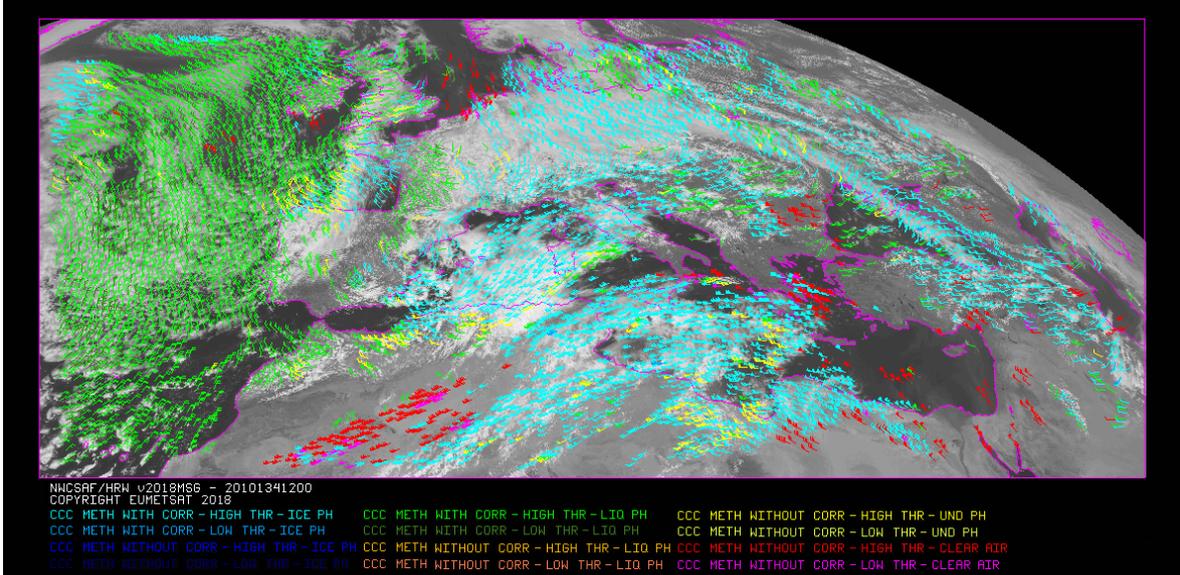
Figure 25: AMV height assignment ("CCC method height assignment with/without Microphysics correction", using "CCC method high/low calculation threshold"), and AMV Cloud phase ("Ice phase", "Liquid phase", "Mixed/Undefined phase", "Clear air") for the High Resolution Winds example defined in Figure 31 (14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite)

EXAMPLE OF AMV PRESSURE CORRECTION DEFINED BY MICROPHYSICS CORRECTION

An example of AMVs for MSG satellite is shown in *Figure 26*, considering the "AMV pressure correction" defined by "CCC method height assignment with Microphysics correction".
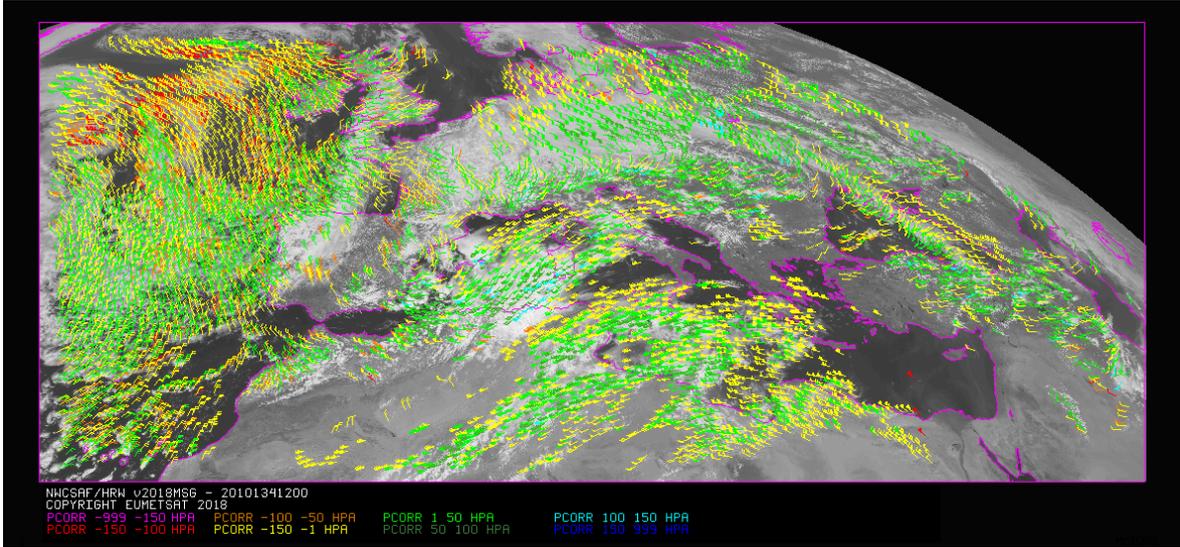
Figure 26: AMV pressure correction (for the cases in which "CCC height assignment method with Microphysics correction" has been used), for the High Resolution Winds example defined in Figure 31 (14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite)

2.2.2.9 Wind calculation

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

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 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:

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

T_INT is the real time difference in hours, between the scanning time of the line defining the "tracer location" in the "initial image" and the "tracking centre location" in the "later image". For MSG satellite series, this procedure takes into account the real time the image scanning began and the time needed to scan each image line. For GOES-N and Himawari-8/9 satellite series the proc7edure 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 since NWC/GEO-HRW v5.0 an equivalent procedure with a displacement along the corresponding "great circle".

PARALLAX CORRECTION OF THE TRACER AND TRACKING CENTRE LOCATION

Since NWC/GEO-HRW v6.0, a "parallax correction" of the latitude and longitude values of the tracer and tracking centre (LAT1, LON1, LAT2, LON2) is used as default option through configurable parameter USE_PARALLAXCORRECTION = 1. This parallax correction corrects the horizontal deviation in the apparent position of the tracer/tracking centre due to its height over the Earth surface. This parallax correction is considered through NWC/GEO library functions, taking into account the "AMV height value H_{CCC}" calculated with CCC method for Cloudy AMVs, or the geopotential for the "AMV pressure" defined by the NWP geopotential field in all other cases. The general effect of this "parallax correction" is a very slight reduction in the AMV/Trajectory speed, more significant when at higher levels of the atmosphere and when nearer to the edge of the Earth disk.

2.2.2.10 Quality control and Choice of the best wind

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

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

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

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

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

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

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

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

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

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

alpha $= 200 + 3.5 \cdot SPD$

beta $= 200 + 3.5 \cdot SPD$

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

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

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

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

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

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

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

- One correction reduces the Quality of the AMVs with a speed lower than 2.5 m/s, multiplying the "Overall Quality Index" with factor SPD/SPEED_THR (where SPD = speed of the evaluated AMV, SPEED_THR = 2.5 m/s).

- The other correction has the name of "Image correlation test" and affects visible and infrared AMVs with a pressure higher than C_CHECK_PRESS_THR = 500 hPa. It is a factor defined by the following formula, in which CORR(IR,WV) is the correlation of IR108/WV62 images for MSG satellites, the correlation of IR107/WV65 for GOES-N satellites, or the correlation of IR112/WV62 images for Himawari-8/9 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%, and a minimum value of 1%).

Some additional considerations on the "Quality Control", specific for NWC/GEO-HRW 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 besides defined in the speed difference (MEANVEC_SPEED_DIF = 10 m/s), direction difference (MEANVEC_DIR_DIF = 20°) and pressure level difference (MEANVEC_PRESSURE_DIF = 50 hPa).

EXAMPLE OF AMV QUALITY INDICES WITH/WITHOUT FORECAST

An example of AMVs for MSG satellite is shown in *Figures 27 and 28*, considering respectively the "Quality index with forecast" and the "Quality index without forecast".
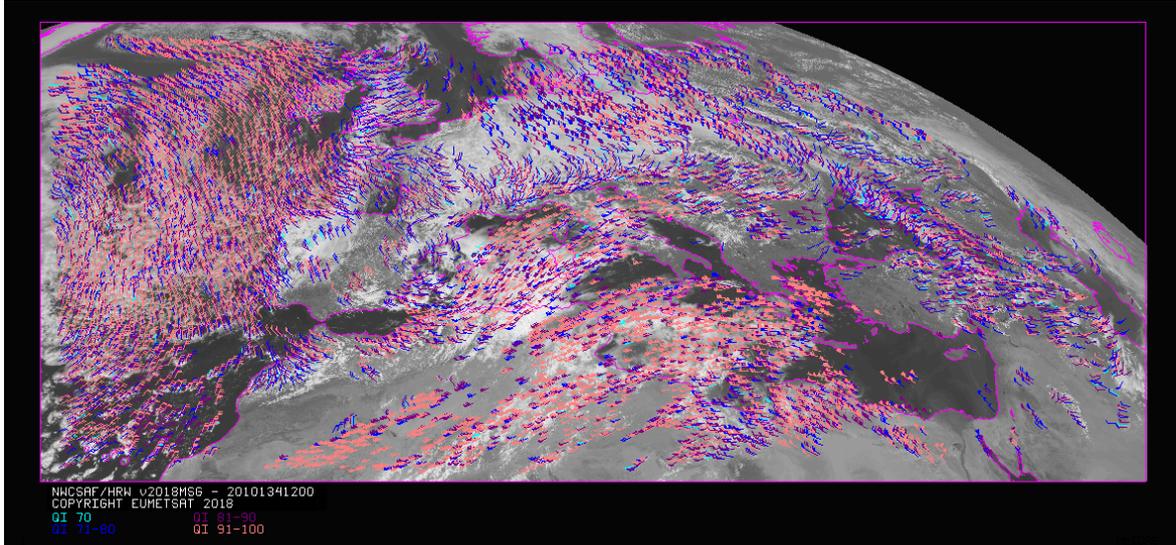
Figure 27: "Quality index with forecast" for the High Resolution Winds example defined in Figure 31 (14 May 2010, 12:00 UTC, Nominal scan mode, MSG2 satellite). Only values of "Quality index with forecast" ≥ 70% are present, because of the use of this parameter for the AMV filtering.
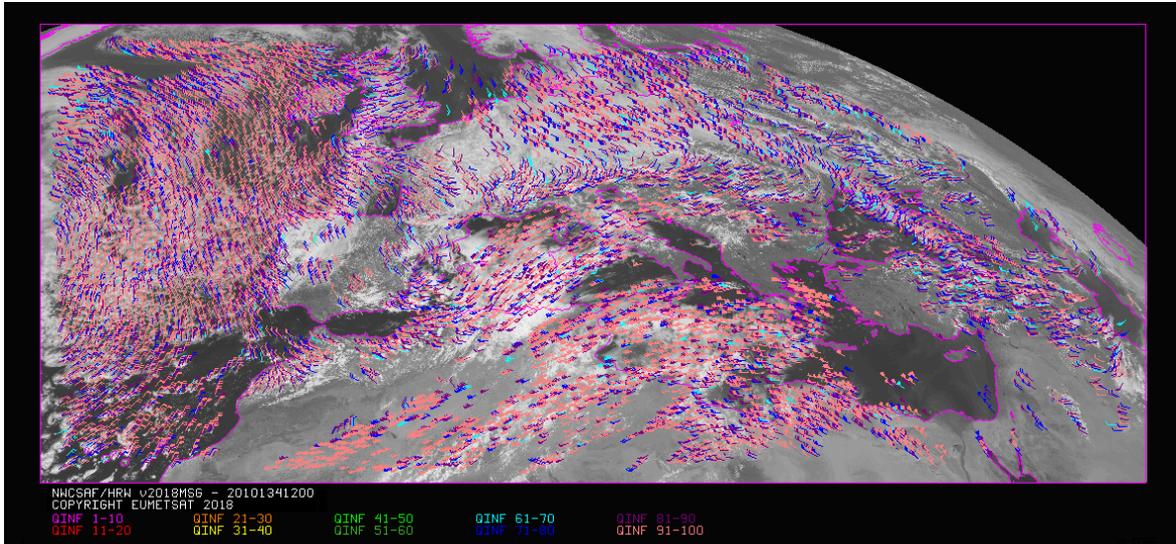
Figure 28: "Quality index without forecast" for the High Resolution Winds example defined in Figure 31 (14 May 2010, 12:00 UTC, Nominal scan mode, MSG2 satellite). All values are formally possible for the "Quality index without forecast", but because of its connection with the "Quality index with forecast", only values of "Quality index without forecast" ≥ 60% are really present.

COMMON QUALITY INDEX WITHOUT FORECAST

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

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

This "Common Quality Index without forecast" module has been implemented in NWC/GEO-HRW algorithm v6.0, and the parameter is provided as an additional third "Quality Index" for all AMVs and Trajectories. The main differences of this "Common Quality Index without forecast" with respect to the previous ones are summarized next:

- It is only calculated for AMVs/Trajectories with at least two trajectory sectors.

- For the "spatial consistency test" only the closest "neighbour AMV" is considered. For the "temporal consistency test" only the "prior AMV" related to the same trajectory is considered.

- Four different tests are applied: the direction, speed and vector difference tests for the temporal consistency, and the vector difference for the spatial consistency with a double contribution. Some parameters in the formulae for calculation of the "Individual Quality Indices" are also slightly different.

- It is not used for the filtering of AMVs and Trajectories by NWC/GEO-HRW algorithm, so all values between 1% and 100% are possible in the AMV/Trajectory output. For AMVs and Trajectories for which it could not be calculated, an "unprocessed value" is defined.

EXAMPLE OF AMV COMMON QUALITY INDEX WITHOUT FORECAST

An example of AMVs for MSG satellite is shown in *Figure 29*, considering the "Common Quality Index without forecast".
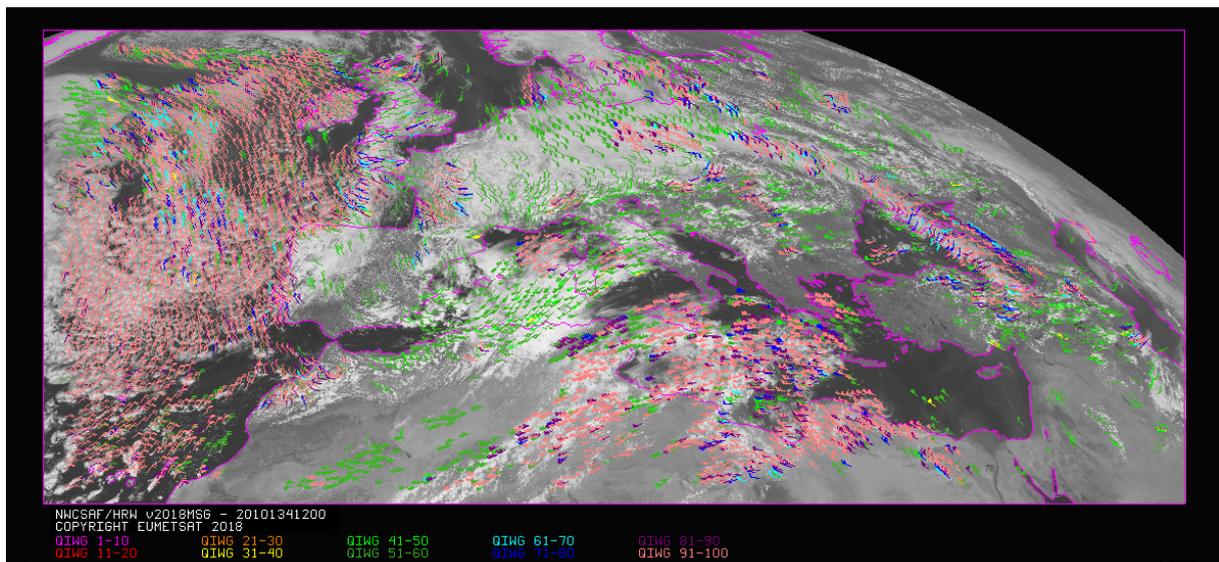
Figure 29: "Common Quality index without forecast" for the High Resolution Winds example defined in Figure 31 (14 May 2010, 12:00 UTC, Nominal scan mode, MSG2 satellite).
All values are possible for the "Common Quality index without forecast".
The difference with Figures 29 and 30, and the fact that not all AMVs have a valid value for the "Common Quality index without forecast" are to be noticed.

2.2.2.11 Orographic flag

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

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

The procedure to calculate the "Orographic flag" implies the reading of NWP geopotential data and of 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. To do this, 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 a previous position of the AMV (for which IND_TOPO = 2 or 4).*

- *IND_TOPO = 5: Important orographic influence was found at a previous position of the AMV (for which IND_TOPO = 3 or 5)*

- *IND_TOPO = 6: No orographic influence is found in any current or previous position of the AMV.*
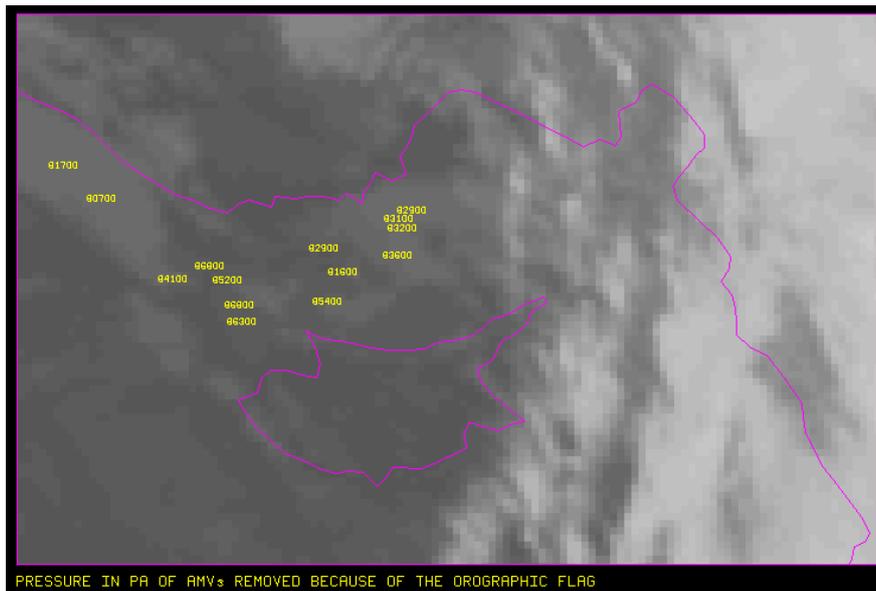
Figure 30: Pressure values in Pa for AMVs affected by orography
(i.e. with "Orographic flag" values between 1 and 5) in a zoomed area around the island of Cyprus
for an example case (Basic AMVs in Nominal scan mode, MSG2 satellite).
Orographic effects are caused by the mountains in Cyprus and Turkey,
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. 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; VIS07,WV65,IR107 for GOES-N satellite series; VIS06,WV62,WV70,WV73,IR112 for Himawari-8/9 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 (included in the default option).

- 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 9* is implemented (in which the blue layers for the different channels are eliminated; light blue layers are eliminated only for "Clear air AMVs and Trajectories"; very dark blue layers are only eliminated if configurable parameter VERYLOWINFRAREDAMVS = 1, which is not implemented as default option).

  - With FINALFILTERING > 1 (which is the default option), 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	IR108	IR120	WV62		WV73
GOES-N sat.		VIS07			IR107		WV65		
Himawari-8/9 sat.	VIS06	VIS08			IR112		WV62	WV70	WV73
100-199 hPa			blue	blue					
200-299 hPa			blue	blue					
300-399 hPa			blue	blue					
400-499 hPa							light blue		
500-599 hPa							blue	light blue	light blue
600-699 hPa							blue	light blue	light blue
700-799 hPa							blue	blue	light blue
800-899 hPa							blue	blue	blue
900-999 hPa					dark blue	dark blue	blue	blue	blue

Table 9: AMV filtering related to the Pressure level and Satellite channel

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

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

NWC/GEO-HRW is validated for the first time considering both Radiosounding winds and NWP analysis winds as reference winds, in this version v6.0.

The default validation statistics against Radiosounding winds and NWP analysis winds for NWC/GEO-HRW Basic AMVs, are shown here as a summary for MSG, GOES-N and Himawari-8/9 satellite series. The criteria defined at the Third International Winds Workshop (Ascona, Switzerland, 1996) for the comparison of satellite winds with Radiosounding winds have been followed here, as in previous versions of the algorithm. Additional Validation statistics can be obtained in the "Scientific and Validation Report" for GEO-HRW v6.0, document [AD.15].

The statistical parameters used in the process of validation are:

- NC: "Number of collocations" between NWC/GEO-HRW AMVs and the reference winds.

- SPD: "Mean speed of the reference winds".

- NBIAS: "Normalized bias".

- NMVD: "Normalized mean vector difference".

- NRMSVD: "Normalized root mean square vector difference".

Information about how these validation statistical parameters can be calculated can be obtained in the "Scientific and Validation Report" for GEO-HRW v6.0 (document [AD.15]).

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

2.3.1.1 Validation of High Resolution Winds for MSG satellites

For MSG satellite series, the Validation statistics correspond to the reference yearly period used since several years ago for NWC/GEO-HRW algorithm: July 2009–June 2010 at 12:00 UTC, with MSG2 satellite data, in a region covering Europe and the Mediterranean Sea, such as shown in *Figure 31*. Cloudy AMVs in the layer 100-1000 hPa and clear air AMVs in the layer 100-400 hPa with a Quality index with forecast ≥ 70%, are considered as valid for this validation.

The configuration considers the conditions defined in the default "model configuration file" $SAFNWC/config/safnwc_HRW_MSG.cfm, in which "CCC method with microphysics correction" for the height assignment, and a "higher density for tracers related to low and very low clouds" are used. For this, all NWC/GEO-Cloud product outputs (CMA, CT, CTTH, CMIC) have to be produced before the running of NWC/GEO-HRW algorithm. All possible satellite channels are considered for the AMV calculation.

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis in *Table 10* (considering all layers together) and in *Table 11* (considering the three layers separately), it can be seen that the NWP analysis wind mean speed is slightly smaller, and the NBIAS, NMVD and NRMSVD parameters are significantly smaller (around a 30% smaller). A conclusion can be taken here, that the general scale and behaviour of the AMV winds is more similar to that of NWP analysis winds than to that of Radiosounding winds.

Considering the different satellite channels, as for the previous version of NWC/GEO-HRW algorithm, 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 AMVs). 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, the validation parameters are progressively higher for the high layer, medium layer and low layer. As for the previous version of NWC/GEO-HRW algorithm, NWC/GEO-HRW Product Requirement Table "Optimal accuracy" (with a value of 0.35 against Radiosounding winds) is reached in the High layer, and the NWC/GEO-HRW Product Requirement Table "Target accuracy" (with values respectively of 0.50 and 0.56 against Radiosounding winds) is reached in the Medium and Low layer.

A quick comparison of the statistics against Radiosounding winds with those for the previous version of NWC/GEO-HRW algorithm (shown in white colours in *Tables 10 and 11*), the main element to be taken into account is that the distribution of AMVs in the different layers has changed significantly, going from a value of 61%/25%/14% for the High/Medium/Low layer in the previous version, to a more homogeneous value in the new version of 52%/25%/23% (considering validated AMVs) and 45%/23%/32% (considering calculated AMVs). This helps to better characterize the behaviour of the wind in the different levels of the troposphere. The change is caused by the higher density of tracers related to low and very low clouds, with both an absolute and relative increase in the low level AMVs, such as requested by the NWC SAF users.

Considering the high and medium layer there is however a reduction in the number of AMVs, caused by the need to keep the running time of NWC/GEO-HRW algorithm in similar values, while increasing the density of the low level AMVs. This reduction is also seen in the total number of AMVs (a 26% smaller).

Comparing the validation parameters for the new and previous version of NWC/GEO-HRW, and considering all layers together in *Table 10*, there is a small increase of the NMVD and NRMSVD values (up to a 10%), which is only caused by the larger proportion now of low layer AMVs, with worse validation parameters. Considering each layer separately in *Table 11*, the NMVD and NRMSVD keep similar values in all of them, while the NBIAS reduces around a 20% with the new version in all layers.

NWC/GEO-HRWv6.0 AMVs (Jul 2009-Jun 2010, MSG2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC	67288	98861	90082	226314	228664	139042	227273	20383	1097907
SPD [m/s]	12.87	10.28	10.25	17.50	17.72	22.78	20.14	17.42	17.23
NBIAS (ALL LAYERS)	-0.03	-0.13	-0.13	-0.08	-0.07	-0.02	-0.05	+0.01	-0.07
NMVD (100-1000 hPa)	0.35	0.41	0.42	0.30	0.30	0.26	0.29	0.30	0.32
NRMSVD	0.42	0.49	0.49	0.37	0.37	0.32	0.36	0.37	0.39
NC	67288	98861	90082	226314	228664	139042	227273	20383	1097907
SPD [m/s]	12.72	9.99	9.98	17.19	17.41	22.37	19.76	17.23	16.91
NBIAS (ALL LAYERS)	-0.02	-0.10	-0.11	-0.07	-0.06	-0.01	-0.03	+0.02	-0.05
NMVD (100-1000 hPa)	0.22	0.28	0.29	0.20	0.20	0.17	0.19	0.22	0.22
NRMSVD	0.28	0.35	0.35	0.25	0.25	0.21	0.24	0.28	0.27
NC	31630	97221	87177	313072	317120	256951	331831	48509	1483511
SPD [m/s]	16.64	10.51	10.48	18.53	18.67	22.78	20.80	16.64	18.70
NBIAS (ALL LAYERS)	-0.04	-0.14	-0.15	-0.09	-0.08	-0.04	-0.07	-0.00	-0.08
NMVD (100-1000 hPa)	0.29	0.41	0.42	0.29	0.29	0.26	0.28	0.32	0.30
NRMSVD	0.35	0.49	0.49	0.35	0.35	0.32	0.35	0.39	0.36

Table 10: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering all layers together against Radiosounding winds in light green; against ECMWF NWP analysis winds in light blue) and NWC/GEO-HRW v5.0 AMVs (against Radiosounding winds in white) (Jul 2009-Jun 2010, MSG2 satellite, 12:00 UTC, European and Mediterranean region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction). Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs.

NWC/GEO-HRWv6.0 AMVs (Jul 2009-Jun 2010, MSG2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC	15919			119091	124905	128731	157689	20383	566718
SPD [m/s]	21.13			21.85	21.81	23.23	22.63	17.42	22.19
NBIAS (HIGH LAYER)	-0.03			-0.07	-0.06	-0.03	-0.06	+0.01	-0.05
NMVD (100-400 hPa)	0.25			0.26	0.26	0.26	0.26	0.30	0.26
NRMSVD	0.30			0.32	0.32	0.32	0.32	0.37	0.32
NC	15447	31346	29700	65544	64179	10311	60432		276959
SPD [m/s]	12.88	11.72	11.49	14.29	14.44	17.13	14.95		13.91
NBIAS (MEDIUM LAYER)	-0.05	-0.15	-0.16	-0.09	-0.08	+0.04	-0.02		-0.08
NMVD (400-700 hPa)	0.35	0.38	0.38	0.35	0.35	0.36	0.37		0.36
NRMSVD	0.42	0.45	0.46	0.43	0.43	0.44	0.46		0.44
NC	35922	67515	60382	41679	39580		9152		254230
SPD [m/s]	9.21	9.61	9.63	10.11	10.14		11.51		9.79
NBIAS (LOW LAYER)	-0.02	-0.11	-0.11	-0.11	-0.10		-0.02		-0.09
NMVD (700-1000 hPa)	0.45	0.43	0.44	0.40	0.40		0.41		0.42
NRMSVD	0.53	0.51	0.51	0.48	0.47		0.48		0.50
NC	15919			119091	124905	128731	157689	20383	566718
SPD [m/s]	20.87			21.54	21.50	22.81	22.22	17.23	21.83
NBIAS (HIGH LAYER)	-0.01			-0.06	-0.05	-0.01	-0.04	+0.02	-0.04
NMVD (100-400 hPa)	0.16			0.17	0.17	0.16	0.17	0.22	0.17
NRMSVD	0.19			0.22	0.21	0.20	0.21	0.28	0.21
NC	15447	31346	29700	65544	64179	10311	60432		276959
SPD [m/s]	12.58	11.33	11.11	13.95	14.09	16.83	14.65		13.56
NBIAS (MEDIUM LAYER)	-0.03	-0.12	-0.13	-0.07	-0.06	+0.06	-0.00		-0.05
NMVD (400-700 hPa)	0.25	0.28	0.28	0.25	0.25	0.26	0.28		0.26
NRMSVD	0.31	0.34	0.34	0.31	0.31	0.32	0.35		0.33
NC	35922	67515	60382	41679	39580		9152		254230
SPD [m/s]	9.17	9.37	9.42	9.86	9.91		11.21		9.58
NBIAS (LOW LAYER)	-0.01	-0.09	-0.10	-0.09	-0.08		+0.00		-0.07
NMVD (700-1000 hPa)	0.28	0.28	0.29	0.27	0.27		0.31		0.28
NRMSVD	0.34	0.35	0.35	0.33	0.33		0.38		0.34
NC	14748			186143	193173	235550	238459	41261	909334
SPD [m/s]	21.77			22.16	22.11	23.31	23.15	17.19	22.48
NBIAS (HIGH LAYER)	-0.03			-0.08	-0.07	-0.04	-0.08	-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			0.32	0.31	0.31	0.32	0.38	0.32
NC	8532	37419	34188	86936	86010	21401	84678	7248	366412
SPD [m/s]	14.64	12.08	11.94	14.61	14.69	16.90	15.10	13.51	14.35
NBIAS (MEDIUM LAYER)	-0.05	-0.18	-0.18	-0.12	-0.11	+0.02	-0.05	+0.09	-0.10
NMVD (400-700 hPa)	0.31	0.38	0.38	0.35	0.35	0.37	0.37	0.40	0.36
NRMSVD	0.48	0.46	0.45	0.43	0.43	0.46	0.45	0.47	0.44
NC	8350	59802	52989	39993	37937		8694		207765
SPD [m/s]	9.64	9.52	9.54	10.14	10.18		12.09		9.88
NBIAS (LOW LAYER)	-0.02	-0.12	-0.12	-0.12	-0.12		-0.09		-0.11
NMVD (700-1000 hPa)	0.44	0.44	0.44	0.41	0.40		0.38		0.43
NRMSVD	0.52	0.51	0.52	0.48	0.48		0.46		0.50

Table 11: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering three separate layers against Radiosounding winds in light green; against ECMWF NWP analysis winds in light blue) and NWC/GEO-HRW v5.0 AMVs (against Radiosounding winds in white) (Jul 2009-Jun 2010, MSG2 satellite, 12:00 UTC, European and Mediterranean region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction). Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs.

2.3.1.2 Validation of High Resolution Winds for GOES-N satellites

For GOES-N satellites, the Validation statistics correspond to the reference yearly period also used for the previous version of NWC/GEO-HRW algorithm: July 2010–June 2011, with GOES13 satellite data, in an area covering the Continental Unites States such as shown in *Figure 33*. Cloudy AMVs in the layer 100-1000 hPa and clear air AMVs in the layer 100-400 hPa with a Quality index with forecast ≥ 70% are considered as valid for this validation.

The configuration considers the conditions defined in the default "model configuration file" $SAFNWC/config/safnwc_HRW_GOESN.cfm, in which "CCC method without microphysics correction" for the height assignment, and a "higher density for tracers related to low and very low clouds" are used. For this, NWC/GEO-CMA, CT and CTTH product outputs have to be produced before the running of NWC/GEO-HRW algorithm. All possible satellite channels are considered for the AMV calculation. As a reminder, the "microphysics correction" cannot be implemented with GOES-N satellite series because NWC/GEO-CMIC product cannot be calculated with it.

With GOES13 satellite, dawn or dusk occurs at the main synoptic hours (00:00 and 12:00 UTC), with the largest number of Radiosounding observations. Because of this, the number of comparisons for visible AMVs is small. To improve this, validation statistics for all synoptic hours are considered here for the validation. However, AMVs at 23:45, 05:45, 11:45 and 17:45 UTC have to be used for these comparisons, because no GOES13 images exist exactly at the main synoptic hours.

Validation statistics against Radiosounding winds are considered in *Table 12* (considering all layers together) and in *Table 13* (considering the three layers separately). No validation statistics are provided against ECMWF NWP analysis winds this time, because no GOES13 images exist exactly at the NWP analysis hours.

Comparing with the equivalent statistics for MSG (shown in *Table 10 and 11*), validation statistics for GOES-N AMVs are similar (with differences up to a 15% in general); in many cases better. Considering the different GOES-N channels (VIS07, WV65, IR107) there are no remarkable differences with the equivalent MSG channels.

Considering the different layers, as in MSG case, NWC/GEO-HRW Product Requirement Table "Optimal accuracy" (with a value of 0.35 against Radiosounding winds) is reached in the High layer, and the NWC/GEO-HRW Product Requirement Table "Target accuracy" (with values respectively of 0.50 and 0.56 against Radiosounding winds) is reached in the Medium and Low layer. These result mean that NWC/GEO-HRW algorithm can perfectly be used operatively with GOES-N satellite series.

A quick comparison of the statistics against Radiosounding winds with those for the previous version of NWC/GEO-HRW algorithm (shown in white colours in *Tables 12 and 13*), the main elements to be taken into account are: on one side the larger population of AMVs, with increments between 20% and 25% in the High and Medium layer, and more significantly up to 380% in the Low layer (which is directly related to the "higher density for tracers related to low and very low clouds"). On the other side, because of these changes in the population of AMVs the distribution of AMVs in the different layers has also changed, going from a value of 89%/9%/2% for the High/Medium/Low layer in the previous version, to a more homogeneous value in the new version of 86%/7%/7% (considering validated AMVs) and 69%/12%/19% (considering calculated AMVs). The distribution between different layers has so improved, although it is less significant than in the MSG case.

Comparing validation parameters for the new and previous version of NWC/GEO-HRW, considering all layers together in *Table 12*, the validation statistics are exactly equivalent. So, the fact that more AMVs are calculated with similar statistics is a positive evolution of the GOES-N series AMVs with this version. Considering each layer separately in *Table 13*, the variations in NMVD and NRMSVD parameters are smaller than a 10%, while the NBIAS reduces up to a 25%.

NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC	9282	287572	247350	64486	608690
SPD [m/s]	21.33	21.82	25.22	14.64	22.43
NBIAS (ALL LAYERS)	-0.01	-0.08	-0.04	+0.04	-0.05
NMVD (100-1000 hPa)	0.24	0.29	0.26	0.37	0.28
NRMSVD	0.31	0.37	0.33	0.49	0.36
NC	5849	208726	205757	47253	467585
SPD [m/s]	22.34	22.98	24.46	15.31	23.00
NBIAS (ALL LAYERS)	+0.00	-0.08	-0.03	-0.00	-0.05
NMVD (100-1000 hPa)	0.25	0.29	0.27	0.35	0.28
NRMSVD	0.31	0.36	0.33	0.48	0.36

Table 12: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering all layers together against Radiosounding winds in light green) and NWC/GEO-HRW v5.0 AMVs (against Radiosounding winds in white) (Jul 2010-Jun 2011, GOES13 satellite, 05:45/11:45/17:45/23:45 UTC, Continental United States region; Basic AMVs; Cross correlation; Higher density related to low and very low clouds; CCC height assignment without Microphysics). Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs

NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC	6828	215848	235439	64486	522601
SPD [m/s]	25.28	24.74	25.44	14.64	23.82
NBIAS (HIGH LAYER)	-0.01	-0.09	-0.04	+0.04	-0.05
NMVD (100-400 hPa)	0.23	0.28	0.26	0.37	0.28
NRMSVD	0.28	0.35	0.33	0.49	0.35
NC	243	33933	11911		46087
SPD [m/s]	18.29	17.04	20.84		18.03
NBIAS (MEDIUM LAYER)	-0.11	-0.05	+0.00		-0.03
NMVD (400-700 hPa)	0.34	0.35	0.29		0.33
NRMSVD	0.45	0.43	0.37		0.41
NC	2211	37791			40002
SPD [m/s]	9.46	9.44			9.44
NBIAS (LOW LAYER)	-0.02	-0.09			-0.09
NMVD (700-1000 hPa)	0.35	0.40			0.39
NRMSVD	0.43	0.49			0.49
NC	4694	173848	191878	47253	417673
SPD [m/s]	24.71	24.33	24.68	15.31	23.47
NBIAS (HIGH LAYER)	+0.00	-0.09	-0.03	-0.00	-0.05
NMVD (100-400 hPa)	0.24	0.28	0.27	0.35	0.28
NRMSVD	0.29	0.35	0.33	0.47	0.36
NC	460	25067	13879		39406
SPD [m/s]	18.10	18.60	21.43		19.59
NBIAS (MEDIUM LAYER)	-0.03	-0.06	-0.00		-0.04
NMVD (400-700 hPa)	0.28	0.32	0.29		0.31
NRMSVD	0.36	0.40	0.36		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 13: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering three separate layers against Radiosounding winds in light green) and NWC/GEO-HRW v5.0 AMVs (against Radiosounding winds in white) (Jul 2010-Jun 2011, GOES13 satellite, 05:45/11:45/17:45/23:45 UTC, Continental United States region; Basic AMVs; Cross correlation; Higher density related to low and very low clouds; CCC height assignment without Microphysics). Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs

2.3.1.3 Validation of High Resolution Winds for Himawari-8/9 satellites

The validation of NWC/GEO-HRW-v60 algorithm for Himawari-8/9 satellite series is based on the validation of AMVs calculated during 166 days of the half-yearly period March – August 2018 at 00:00 UTC, with Himawari-8 satellite images, in a region covering China, Korea, Japan and the adjacent parts of the Pacific Ocean. This region is shown in *Figure 35*. Infrared and visible cloudy AMVs in the layer 100-1000 hPa, water vapour cloudy AMVs in the layer 100-700 hPa, and water vapour clear air AMVs in the layer 100-400 hPa, with a Quality index with forecast $\geq 70\%$, are considered for this validation.

The configuration considers the conditions defined in the default "model configuration file" `$SAFNWC/config/safnwc_HRW_HIMA.cfm,` in which "CCC method with microphysics correction" for the height assignment, and a "higher density for tracers related to low and very low clouds" are used. NWC/GEO Cloud product outputs (CMA, CT, CTTH and CMIC) in the processing region have to be available so that NWC/GEO-HRW can fully process the conditions defined in the model configuration file.

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis in *Table 14* (considering all layers together) and in *Table 15* (considering the three layers separately), the NBIAS, NMVD and NRMSVD parameters are once again around a 25% smaller against NWP analysis winds.

Considering the different layers, as in previous cases the validation parameters are progressively higher for the high layer, medium layer and low layer. The NWC/GEO-HRW Product Requirement Table "Optimal accuracy" is reached in the High layer, while the NWC/GEO-HRW Product Requirement Table "Target accuracy" is reached in the Medium and Low layer. These result mean that NWC/GEO-HRW algorithm can perfectly be used operatively with Himawari satellites.

Comparing the statistics of NWC/GEO-HRW v6.0 default configuration for Himawari-8/9 satellites with those for MSG satellites, an equivalent number of AMVs is calculated for both satellites for regions of similar sizes. So the density of AMV data is similar for both satellites.

Considering the distribution of AMVs in the different layers, it has a value for the High/Medium/Low layer of 82%/14%/4% (considering validated AMVs) and 78%/14%/8% (considering calculated AMVs). The concentration of AMVs in the High layer is caused by the China/Korea/Japan region used for the validation (with large high altitude and desert areas, and so less frequent low clouds). Considering for example AMVs calculated in the Himawari Full Disk for IR112 channel in the same validation period, the distribution in the High/Medium/Low layer is 52%/15%/33%, which is similar to that obtained by other AMV algorithms.

Comparing the validation parameters for both satellites, considering all layers together Himawari satellite shows better NMVD and NRMSVD values (up to a 10% smaller), which is only caused by its larger proportion of High layer AMVs, with better validation parameters. It is remarkable to see that NBIAS parameter shows similar values but with an opposite sign. Considering each layer separately, validation parameters are more or less similar for MSG and Himawari satellites in the High layer. NMVD and NRMSVD parameters are however up to a 15% worse for the Medium and Low layer for Himawari. In spite of the differences of NWC/GEO-HRW algorithm for MSG and Himawari, the operability of NWC/GEO-HRW algorithm for both satellites is equivalent.

Comparatively, there is however room for improvement for the AMVs with Himawari, trying to reduce its errors in the Medium and Low layer, and trying to increase the proportion of AMVs in the Low layer for a better characterization of the wind throughout all the troposphere. As GOES-R and MTG-Imager satellite series are very similar to Himawari, any improvement in these aspects will be positive for the three new generation satellite series.

NWC/GEO-HRWv6.0 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV73	Clear Air	All AMVs
NC	36841	71618	287147	189457	246356	280899	85148	1197466
SPD [m/s]	21.70	19.95	19.58	23.60	22.58	21.94	19.32	21.46
NBIAS (ALL LAYERS)	+0.00	-0.00	+0.04	+0.06	+0.06	+0.04	+0.06	+0.05
NMVD (100-1000 hPa)	0.24	0.26	0.27	0.26	0.27	0.26	0.30	0.28
NRMSVD	0.29	0.31	0.35	0.32	0.33	0.33	0.38	0.35
NC	36841	71618	287147	189457	246356	280899	85148	1197466
SPD [m/s]	21.72	19.97	19.60	23.65	22.62	21.96	19.56	21.50
NBIAS (ALL LAYERS)	-0.00	-0.00	+0.04	+0.06	+0.06	+0.04	+0.05	+0.05
NMVD (100-1000 hPa)	0.17	0.18	0.20	0.19	0.21	0.20	0.23	0.21
NRMSVD	0.21	0.23	0.25	0.24	0.25	0.25	0.30	0.26

Table 14: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering all layers against Radiosounding winds (in light green) and ECMWF NWP analysis winds (in light blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction)

NWC/GEO-HRWv6.0 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV73	Clear Air	All AMVs
NC	26769	48276	196718	183124	214714	229291	85148	984040
SPD [m/s]	25.83	24.52	22.61	23.73	23.44	23.31	19.32	23.06
NBIAS (HIGH LAYER)	-0.01	-0.01	+0.04	+0.06	+0.05	+0.03	+0.06	+0.04
NMVD (100-400 hPa)	0.22	0.23	0.25	0.26	0.26	0.25	0.30	0.25
NRMSVD	0.26	0.27	0.31	0.31	0.31	0.30	0.38	0.31
NC	4200	9507	65466	6333	31642	51608		168756
SPD [m/s]	14.67	14.18	14.68	20.08	16.72	15.85		15.60
NBIAS (MEDIUM LAYER)	+0.10	+0.09	+0.05	+0.17	+0.21	+0.11		+0.11
NMVD (400-700 hPa)	0.32	0.33	0.35	0.36	0.43	0.38		0.37
NRMSVD	0.40	0.42	0.49	0.47	0.54	0.50		0.50
NC	5872	13835	24963					44670
SPD [m/s]	7.90	7.97	8.53					8.27
NBIAS (LOW LAYER)	-0.03	+0.03	-0.01					+0.00
NMVD (700-1000 hPa)	0.44	0.47	0.43					0.45
NRMSVD	0.54	0.58	0.53					0.55
NC	26769	48276	196718	183124	214714	229291	85148	984040
SPD [m/s]	25.81	24.51	22.73	23.77	23.51	23.39	19.56	23.14
NBIAS (HIGH LAYER)	-0.01	-0.01	+0.04	+0.06	+0.05	+0.03	+0.05	+0.04
NMVD (100-400 hPa)	0.16	0.16	0.18	0.19	0.19	0.18	0.23	0.19
NRMSVD	0.19	0.20	0.23	0.24	0.23	0.22	0.30	0.23
NC	4200	9507	65466	6333	31642	51608		168756
SPD [m/s]	14.75	14.15	14.44	20.11	16.57	15.60		15.40
NBIAS (MEDIUM LAYER)	+0.09	+0.09	+0.07	+0.17	+0.22	+0.13		+0.12
NMVD (400-700 hPa)	0.23	0.24	0.26	0.29	0.36	0.30		0.29
NRMSVD	0.30	0.31	0.33	0.36	0.44	0.38		0.38
NC	5872	13835	24963					44670
SPD [m/s]	8.08	8.13	8.48					8.32
NBIAS (LOW LAYER)	+0.01	+0.01	-0.00					+0.00
NMVD (700-1000 hPa)	0.25	0.29	0.30					0.29
NRMSVD	0.33	0.36	0.39					0.37

Table 15: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering three layers against Radiosounding winds (in light green) and ECMWF NWP analysis winds (in light blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction)

2.3.1.4 Autovalidation process of NWC/GEO-HRW algorithm

Considering requests from NWC SAF users, NWC/GEO-HRW v6.0 offers for the first time the option to calculate the validation statistics for the AMVs with the NWC/GEO-HRW algorithm itself (using as reference NWP analysis or forecast rectangular components of the wind (u,v), such as defined in chapter 2.3.2 of this document, interpolated to the AMV final location and level).

This is implemented with configurable parameter NWPVAL_STATISTICS = 1,2,3,4. Depending on the values of this parameter, statistics for the different layers and satellite channels are provided separately or not. Please check chapter 2.3.3 for more information on this parameter. The default option (NWPVAL_STATISTICS = 2) provides statistics for all layers together and the different satellite channels separately.

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

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

The following content is added to this file each time the validation statistics are run: several lines with the following format, showing the validation parameters mentioned previously (NC, SPD, NBIAS, NMVD, NRMSVD) for the considered AMV scale "BBB" (defined as BAS,DET), AMV type "TTTTT" (defined as TOTAL,CLOUD,CLEAR), layer "LLL" (defined as ALL,HIG,MED,LOW) and satellite channel for which AMVs have been calculated "CCCCC" (defined as TOTAL,HRVIS,VIS06,VIS07,VIS08,IR107,IR108,IR112,WV062,WV069,WV073). The date and time of the NWC/GEO-HRW run, of the "model configuration file" used in the process, and if the validation statistics have been run against the NWP analysis or forecast winds (parameter "GGG", defined as ANA, FOR) are also specified:

```
yyyy-mm-ddThh:mm:ssZ GEO-HRW 6.0 XXXXX [S] HRWDATE:YYYYMMDDTHHMMSSZ
HRWCONF:FFFFF.CFM NWPCONF:GGG *** AMV:BBBTTTTT CH:CCCCC LAYER:LLL
*** NC:RRRRRR SPD[M/S]:SSS.SS NBIAS:±T.TTT NMVD:U.UUU NRMSVD:V.VVV
```

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

The NWP analysis or forecast wind with validates each AMV (defined by its speed and direction), is also added to the NWC/GEO-HRW output files (excepting the BUFR bulletin with the previous "International Winds Working Group" format, OUTPUT_FORMAT = EUM, inside which there is no possible location for these parameters). This allows NWC SAF users a quick recalculation of the NWC/GEO-HRW validation parameters for different sampling and filtering options of the data, including for example monthly or yearly totalizations.

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

- The first one, activated with configurable parameter NWPVAL_NWPDIFFERENCE = 1 (implemented as a default option) calculates also for each AMV the "Vector difference with the NWP reference wind", and adds this "Vector difference" (defined by its speed and direction) to the NWC/GEO-HRW output files (excepting again the BUFR bulletin with the

previous "International Winds Working Group" format, OUTPUT_FORMAT = EUM, 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.

- • The second one, activated with configurable parameter NWPVAL_NWPBESTFITLEVEL = 1 (implemented also as a default option) calculates also for each AMV the "NWP reference wind at the best fit pressure level" and adds this "NWP reference wind at the best fit pressure level" (defined by its speed, direction and pressure level) to the NWC/GEO-HRW output files (excepting again the BUFR bulletin with the previous "International Winds Working Group" format, OUTPUT_FORMAT = EUM, 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.

The calculation of the "NWP reference wind at the best fit pressure level" consists of two steps: first, the model level with the smallest vector difference between the observation and the model background wind is to be found. Then, the minimum is calculated by using a parabolic fit to the vector difference for this model level and the two neighbouring levels.

The calculation is based on the procedure defined by K.Salonen, J. Cotton, N.Bormann & M.Forsythe at [RD.26], and is only defined at some specific circumstances, to avoid broad best fit pressure values which are not very meaningful: The minimum vector difference between the observed and the NWP reference wind at best fit pressure level has to be less than 4 m/s, and the vector difference has to be greater than the minimum difference plus 2 m/s outside a band that encompasses the best fit pressure ± 100 hPa. This way, only around a 40%-50% of the AMVs have a defined value for the "NWP reference wind at the best fit pressure level".

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

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

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

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

- Considering GOES-N satellite series: full resolution uncompressed 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 SAT2NC java tool), 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").

- Considering Himawari-8/9 satellite series: full resolution uncompressed HSD data for the processing region, for the images in which tracers are calculated and tracked. Himawari-8/9 HSD data can be used directly or through conversion to NWC/GEO netCDF satellite input data format (with the provided SAT2NC java tool). The data to be processed have to be included in $SAFNWC/import/Sat_data directory. IR112 channel is in any case needed for the visible channel processing when the old "Brightness temperature interpolation height assignment" is to be used. IR112 and WV62 channels are in any case needed if the default configuration of the Quality control is kept (including the "Image correlation test").

- NWP data, for the whole processing region in which NWC/GEO-HRW product is run, with an horizontal resolution of 0.5º and a NWP time step of at most 6 hours (preferably a NWP time step of 1 hour), for a minimum of four (defined by configurable parameter MIN_NWP_FOR_CALCULATION) and preferably for as many as possible of the following pressure levels: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10 hPa, in $SAFNWC/import/NWP_data directory:

  - NWP Forecast Fields of temperatures.

  - NWP Forecast Fields of rectangular components of the wind (u,v), needed for the "Quality control forecast test", if the NWP wind guess has to be used for the definition of the "tracking area centre", or if Validation statistics are to be calculated by the NWC/GEO-HRW algorithm itself considering as reference winds the NWP forecast winds.

  - NWP Analysis Fields of rectangular components of the wind (u,v), needed if Validation statistics are to be calculated by the NWC/GEO-HRW algorithm itself considering as reference winds the NWP analysis winds.

  - NWP Forecast Fields of geopotential heights, needed if the "Orographic flag" is calculated.

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

- NWC/GEO-CT and CTTH output files for the processing region, for the image in which tracers are tracked, in $SAFNWC/export/CT and $SAFNWC/export/CTTH directories, in case "CCC height assignment method" is used.

- NWC/GEO-CMIC output files for the processing region, for the image in which tracers are tracked, in `$SAFNWC/export/CMIC` directory, in case the "microphysics correction" is used inside "CCC height assignment method".

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

Of all these data, only MSG/HRIT or GOES-N/GVAR or Himawari-8/9/HSD data and the NWP temperature profiles are strictly needed for the running of NWC/GEO-HRW algorithm.

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

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

Three different reference Model Configuration Files are included in the NWC/GEO package for the operational use with:

1. MSG satellite series (`safnwc_HRW_MSG.cfm`).

2. GOES-N satellite series (`safnwc_HRW_GOESN.cfm`).

3. Himawari-8/9 satellite series (`safnwc_HRW_HIMA.cfm`).

A brief description of the configurable parameters included in the files is shown in the following table. The configurable parameters have been simplified with respect to those defined for previous versions of NWC/GEO-HRW algorithm.

Keyword	*Description*	*Type*	*Default Value(s)*
Identification parameters			
PGE_ID	PGE identification. This keyword is optional, but should not be changed by the user.	Chain of characters	`GEO-HRW`

SAT_BANDS	A list of satellite bands that can be used to run for the calculation of AMVs and Trajectories with NWC/GEO-HRW algorithm.
	This keyword is optional, but should not be changed. It defines the maximum value of bands for which AMVs can be calculated.
	Values defined in a list separated by commas.
		Chain of characters	`HRVIS,VIS06,VIS08,`
			`IR108,IR120,WV062,WV073`
			`(MSG)`
			
			`VIS07,IR107,WV065`
			`(GOES-N)`
			
			`VIS06,VIS08,IR112,`
			`WV062,WV069,WV073`
			`(HIMAWARI)`

AMV_BANDS	A list of satellite bands really used for the calculation of AMVs and Trajectories with NWC/GEO-HRW algorithm.
	As possible values, it can include any of the bands shown by the previous parameter, separated by commas.
		Chain of characters	`HRVIS,VIS06,IR108,`
			`WV062,WV073 (MSG)`
			
			`VIS07,IR107,WV065`
			`(GOES-N)`
			
			`VIS06,IR112,WV062,`
			`WV069,WV073`
			`(HIMAWARI)`

SLOT_GAP	Ordering number of the previous satellite image, for which tracers are to be considered for the AMV processing. The value for "Rapid scan mode" is one unit more than the value defined by the parameter.	Integer	`1`
MIXED_SCANNING	Flag to decide if the "Mixed method" is implemented for the processing of AMVs and Trajectories.	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. the default value 214 means Madrid).	Integer	`214`
OUTPUT_FORMAT	A list of output file formats, with several options possible. Elements in the list are to be separated by commas: - NWC: AMV & Trajectories BUFR files, using the specific NWC SAF format. - EUM: AMV BUFR files, using the IWWG BUFR format. - NET: AMV netCDF files	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 (if > 0),
	 - Their Cloud type (if > 1),
	 - Their Quality spatial test
	   (1,2 as invalid values if > 2;
	   0,1,2 as invalid values if > 3).
		Integer	2

USE_TOPO	Flag for calculation of Orographic flag (if positive), and for its AMV filtering (if = 2).	Integer	2
MAXPRESSUREERROR	Maximum pressure error in the AMVs (hPa), when 'CCC height assignment method' used.	Integer	150
VERYLOWINFRAREDAMVS	Flag showing if very low infrared AMVs (at levels lower than 900 hPa) are admitted in the AMV output files.	Integer	1
FINALCONTROLCHECK	Flag to decide the use of Final Control Check.	Integer	1
CORRELATIONMATRICES	This parameter is formally deactivated in the NWC/GEO-HRW v6.0 algorithm.	Integer	0
Working area description parameters			
LAT_MIN		Integer	−75
LAT_MAX	Latitude and longitude borders (in degrees)	Integer	75
LON_MIN	for the processing region (Basic AMVs).	Integer	−180
LON_MAX		Integer	180
LAT_MIN_DET		Integer	−75
LAT_MAX_DET	Latitude and longitude borders (in degrees)	Integer	75
LON_MIN_DET	for the processing region (Detailed AMVs).	Integer	−180
LON_MAX_DET		Integer	180
FRAC_DAY_SCENE	Minimum fraction of area illuminated by the sun needed to calculate the visible AMVs (HRVIS, VIS06, VIS07, VIS08 channels).	Integer	8
SUN_ZEN_THRES	Sun zenith angle threshold (degrees).	Integer	87
SAT_ZEN_THRES	Satellite zenith angle threshold (degrees).	Integer	80
Tracer parameters			
MAX_TRACERS	Maximum number of tracers.	Integer	100000
TRACERSIZE_VERYHIGH	Tracer line and column dimension in pixels,	Integer	24 (HIMAWARI ONLY)
TRACERSIZE_HIGH	when respectively using satellite images with	Integer	24
TRACERSIZE_LOW	very high, high and low resolution.	Integer	24
BRIGHTNESS_THR_VIS	1 byte reflectance threshold for visible tracers.	Integer	120
BRIGHTNESS_THR_OTHER	1 byte brightness temperature threshold for infrared and water vapour tracers.	Integer	60
GVAL_VIS	Minimum 1 byte reflectance contrast for visible tracers.	Integer	60
GVAL_OTHER	Minimum 1 byte brightness temperature contrast for infrared and water vapour tracers.	Integer	48
TRACERDISTANCE_VERYHIGH	Nominal separation in pixels between tracers, when respectively using satellite images with very high, high and low resolution.	Integer	24 (HIMAWARI ONLY)
TRACERDISTANCE_HIGH	Depending on value of HIGHERDENSITY_LOWTRACERS,	Integer	12
TRACERDISTANCE_LOW	this separation applies to all tracers (if = 0) or only to tracers related to very low and low clouds (if = 1).	Integer	3 (GOES-N) 4 (MSG) 6 (HIMAWARI)
HIGHERDENSITY_LOWTRACERS	Option to decide if the nominal 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" (if positive), - And if the Tracer cloud type is taken into account for the calculation of the Tracer temperature (if = 2).	Integer	`2`
USE_MICROPHYSICS	Flag to decide if Microphysics correction is to be calculated to "CCC height assignment" (if positive), and if this Microphysics corrections is applied to the final AMV pressure (if = 2) (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).	Integer	`2  (MSG & HIMAWARI)` `0  (GOES-N)`
MIN_CORRELATION	Minimum correlation acceptable (if TRACKING=CC).	Integer	`80  (MSG & HIMAWARI)` `50  (GOES-N)`
WIND_GUESS	Flag to decide if the Wind guess is used for the definition of the Tracking area.	Integer	`0`
MINSPEED_DETECTION	When the wind guess is not used in the definition of the Tracking area, displacement in direction (in km/h) which the process is at least able to detect for AMVs/Trajectories. When the wind guess is used in the definition of the Tracking area, difference in speed with respect to the one of the NWP wind guess (in km/h) which the process is at least able to detect for the AMVs/Trajectories.	Integer	`272`
USE_SUBPIXELTRACKING	Flag to decide if the subpixel tracking is used.	Integer	`1`
USE_PARALLAXCORRECTION	Flag to decide if the parallax correction is applied to the latitude/longitude of the tracer and tracking centre, for the calculation of the wind, considering the AMV height in metres.	Integer	`1`
NWP validation parameters			
NWPVAL_STATISTICS	Flag to decide if Validation statistics against NWP model winds are to be calculated. Possible values: - 1: Statistics provided for all layers and satellite channels together. - 2: Statistics provided for all layers together and each satellite channel separately. - 3: Statistics provided for each layer separately and all satellite channels together. - 4: Statistics provided for each layer and satellite channel separately.	Integer	`2`
NWPVAL_ANALYSIS	Flag to decide if the Validation statistics are to be computed against NWP analysis winds.	Integer	`0`
NWPVAL_NWPDIFFERENCE	Flag to decide if Vector difference between each AMV and the related NWP model wind is to be written in the output files.	Integer	`1`
NWPVAL_NWPBESTFITLEVEL	Flag to decide if the NWP model wind at the best fit pressure level for each AMV is to be written in the output files.	Integer	`1`

NWP parameters			
MIN_NWP_FOR_CALCULATION	Minimum number of NWP levels needed for NWC/GEO-HRW processing.	Integer	4
NWP_PARAM	NWP parameters requested by NWC/GEO-HRW algorithm: * NWP_T: Temperature at several levels (K)	Chain of characters	NWP_T 1 NEI
NWP_PARAM	* NWP_UW: Wind velocity at several levels, u component (m/s)	Chain of characters	NWP_UW 1 NEI
NWP_PARAM	* NWP_VW: Wind velocity at several levels, v component (m/s) * NWP_GEOP: Geopotential height at several levels (m)	Chain of characters	NWP_VW 1 NEI
NWP_PARAM	Sampling rate used: 1 Interpolation method used: NEI (neighbour)	Chain of characters	NWP_GEOP 1 NEI

Table 16: NWC/GEO-HRW v6.0 Model Configuration File Description

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

This issue applies specially with MSG satellite data because of its larger amount of channels. 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 running time is to keep the five MSG channels in the default configuration (AMV_BANDS = HRVIS,VIS06,WV62,WV73,IR108). If further reductions in NWC/GEO-HRW running time are needed, it would be recommended at least to keep four channels (with AMV_BANDS = HRVIS,WV62,WV73,IR108).

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

With Himawari-8/9 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 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 two water vapour channels only, with AMV_BANDS = VIS06,WV62,WV73,IR112.

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

The following table shows the whole list of errors and warnings that can appear during the running of NWC/GEO-HRW 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, the 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 product
E - 152	"Error allocating memory for tracers"	Unable to allocate required memory for "tracer" struct	There are memory problems to run NWC/GEO-HRW 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 product
E - 157	"Error allocating memory for the Quality control Image correlation grid"	Unable to allocate required memory for Image Correlation Grids	There are memory problems to run NWC/GEO-HRW product in the defined region with the defined configuration and computer. Use a larger computer or a smaller region
E - 161	"Error reading Parameters from Satellite configuration file"	Error after NwcCFReadSat function	Verify that the $SAFNWC/config/sat_conf_file used for running NWC/GEO-HRW 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 product is correct
E - 163	"Error setting Processing region"	Error after NwcRegionSet function	Verify that the $SAFNWC/config/region_conf_file used for running NWC/GEO-HRW product is correct
E - 164	"Error reading Pressure levels from the Model configuration file"	Error after NwcNwpReadPLevel function	Verify that the $SAFNWC/config/nwp_conf_file used for running NWC/GEO-HRW product is correct
E - 165	"Unable to initialize the NWP Temperature / Wind / Geopotential NWP profile"	Error after NwcNwpInitProfile function	Verify that the $SAFNWC/config/nwp_conf_file & $SAFNWC/config/model_conf_file used for running NWC/GEO-HRW product are correct

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 the $SAFNWC/config/model_conf_file used for running NWC/GEO-HRW 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 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 product in $SAFNWC/import/NWP_data directory

Table 17: List of errors for NWC/GEO-HRW-v60 algorithm

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

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

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

1. OUTPUT_FORMAT = NWC (default option): NWC/GEO-HRW output defined as two different BUFR bulletins (for AMVs and Trajectories), related to the ones used as default option in all previous versions of NWC/GEO software package.

2. OUTPUT_FORMAT = EUM: NWC/GEO-HRW output defined as one BUFR bulletin, whose format was defined several years ago by the "International Winds Working Group", and which has been used for example 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 outputs than for other AMV processing centres of the world.

3. OUTPUT_FORMAT = NET: NWC/GEO-HRW output defined as one netCDF bulletin. This option is available since NWC/GEO-HRW v5.0. 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).

Note: An additional BUFR format for Atmospheric Motion Vectors, defined by "BUFR Sequence 310067" was approved by the World Meteorological Organization in November 2017. This new BUFR format was to be implemented throughout the year 2018 as common format by all AMV algorithms through an action defined by the "International Winds Working Group". Considering this, this new BUFR format had been included in NWC/GEO-HRW v2018 algorithm.

However, the defined sequence was not accepted by some users, because it could not be used with an automatic framework. A different "BUFR Sequence 310077" has so been proposed by WMO to correct the problem, but in November 2018 it was not formally approved.

Considering this, for the moment, "BUFR sequence 310067" has been deactivated in NWC/GEO-HRW v2018 code and documentation. Once the situation becomes clear on this, NWC/GEO-HRW v2018 code will be properly updated in the Spring 2019 (together with the patch for GOES-R satellite series).

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 for the "Single/Basic AMV scale" with the name `S_NWC_HRW-WIND_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr`, or for the "Detailed AMV scale" with the name `S_NWC_HRW-WIND_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.bufr`, 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.

The BUFR variables used for the writing of the AMVs considering this format (identified in "BUFR local variable table" `B0000021400000029096.TXT` in `$SAFNWC/import/Aux_data/HRW` directory) are explained in *Table 18*.

These variables are partially based on BUFR Master Table number 0, Version number 29, and have some differences with the ones used for previous versions of NWC/GEO-HRW algorithm, which is to be taken into account by the NWC SAF users for the processing of the new BUFR output files.

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]).

An additional "BUFR local sequence table" (identified as `D0000021400000029096.TXT` file in `$SAFNWC/import/Aux_data/HRW` directory) is also requested for the generation of the BUFR files, but due to the fact that no specific sequences have been identified for the processing, this additional file is provided as an empty file.

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

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

- The first column shows the "Descriptor code".

- The second column shows the "Descriptor Name".

- The third column shows the "Unit used for the codification of the parameter" (in some cases identified through a Code Table).

- The fourth column shows the "Scale, the number of decimals used in the codification of the parameter" (where a value of 1 is used for a precision of one decimal place and a value of -1 is used for a precision only up to the tens).

- The fifth column shows the "Reference, the default value of the parameter".

- The sixth column shows the "Number of bits used for the parameter codification", and so, the maximum value the parameter can have (for example, for parameter 060203/Number of available wind guess levels, the maximum value of the parameter is $2^7 - 1 = 127$).

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

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

White entries: Fixed factors
Grey entries: Replicated factors

Table 18: Variables used for the AMV output with the NWC SAF specific BUFR format

The "general common variables" in BUFR Master Table number 0, Version number 29, are identified with codes smaller than 60000. Their explanation can be found in the "WMO FM94 BUFR Table B for Classification of elements and table", available in document [RD.20].

The "local specific variables" for NWC/GEO-HRW bulletins in this table are those with codes 60000 or higher. The Code Tables for these NWC/GEO-HRW local specific variables are explained here:

Descriptor	Description

060103	Height assignment method
	Values 0 to 3 are related to 'Brightness temperature interpolation height assignment method'.
	Values 4 to 15 are related to 'CCC height assignment method'.
	Due to the actual implementation of HRW algorithm, Value 2 is never used.
	
	Possible values:
	  0: 'NWP interpolation using Top pressure in Clear air AMV'
	  1: 'NWP interpolation using Top pressure in Cloudy AMV'
	  3: 'NWP interpolation using Base pressure in Cloudy AMV'
	  4: 'CCC method using lower threshold and cold branch in a Clear air AMV'
	  5: 'CCC method using higher threshold and cold branch in a Clear air AMV'
	  6: 'CCC method using lower threshold and cold/bright branch in Cloudy AMV with undefined phase'
	  7: 'CCC method using higher threshold and cold/bright branch in Cloudy AMV with undefined phase'
	  8: 'CCC method using lower threshold and cold/bright branch in Cloudy AMV with liquid phase'
	  9: 'CCC method using higher threshold and cold/bright branch in a Cloudy AMV with liquid phase'
	  10: 'CCC method with microphysics correction using lower threshold and cold/bright branch in Cloudy AMV with liquid phase'
	  11: 'CCC method with microphysics correction using higher threshold and cold/bright branch in Cloudy AMV with liquid phase'
	  12: 'CCC method using lower threshold and cold/bright branch in a Cloudy AMV with ice phase'
	  13: 'CCC method using higher threshold and cold/bright branch in a Cloudy AMV with ice phase'
	  14: 'CCC method with microphysics correction using lower threshold and cold/bright branch in Cloudy AMV with ice phase'
	  15: 'CCC method with microphysics correction using higher threshold and cold/bright branch in Cloudy AMV with ice phase'.

060104	Type of tracer
	
	Possible values:
	  0: 'Basic tracer'
	  1: 'Detailed tracer related to a Narrow basic tracer'
	  2: 'Detailed tracer related to a Wide basic tracer'
	  3: 'Detailed tracer unrelated to a Basic tracer'.

Descriptor	Description

060201	Correlation test.
	
	Possible values:
	  0: 'Wind not selected as the Best wind for a tracer not having the Best correlation value'
	  1: 'Wind not selected as the Best wind for a tracer having the Best correlation value'
	  2: 'Wind selected as the Best wind for a tracer not having the Best correlation value'
	  3: 'Wind selected as the Best wind for a tracer having the Best correlation value'.

060202	Applied Quality tests:
	
	For each one the next Quality flags (Orographic flag, Forecast quality flag, Spatial quality flag, Temporal quality flag, Interscale quality flag), next possible values:
	  0: 'Wind for which the corresponding quality test could not be calculated'
	  1: 'Wind whose corresponding quality test is more than a 21% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is at least two units lower than for the wind calculated for the same tracer with the best orographic flag)'
	  2: 'Wind whose corresponding quality test is up to a 21% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the wind calculated for the same tracer with the best orographic flag)'
	  3: 'Wind with the best corresponding quality test among the winds calculated for a tracer'.

060205	Orographic index. Possible values : The values of this parameter are between 0 and 6, corresponding to those defined for "Ind_topo" parameter in chapter 2.2.2.11 of this document.
060206	Cloud type associated to the tracer. Possible values: The values of this parameter are between 0 and 23, corresponding to those defined in *Table 5* of this document.

060207	Flag indicating the satellite channel used for the wind calculation
	(Updated table for NWC/GEO v2018).
	
	Possible values:
	  2: MSG/VIS06 or GOES-N/VIS07 or Himawari-8/9 VIS06
	  3: MSG/VIS08 or Himawari-8/9 VIS08
	  5: MSG/HRVIS
	  10: MSG/WV062 or GOES-N/WV065 or Himawari-8/9 WV062
	  11: Himawari-8/9 WV070
	  12: MSG/WV073 or Himawari-8/9 WV073
	  16: MSG/IR108 or GOES-N/IR107 or Himawari-8/9 IR112
	  17: MSG/IR120

060220	Validation against NWP analysis or forecast.
	
	Possible values:
	  0: GEO-HRW autovalidation statistics against "NWP model analysis".
	  1: GEO-HRW autovalidation statistics against "NWP model forecast".
	  3: GEO-HRW autovalidation statistics not calculated.

Table 19: Description of "local specific variables" in the "local variable table"
$SAFNWC/import/Aux_data/HRW/B00000214000000029096.TXT

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.

The BUFR variables used for the writing of the Trajectories considering this are explained in *Table 19*. They are also based on the "BUFR local variable table" `B0000021400000029096.TXT` and the "BUFR local sequence table" `B0000021400000029096.TXT` used in the previous chapter for the AMV output.

Again, these variables are partially based on BUFR Master Table number 0, Version number 29, and have some differences with the ones used for previous versions of NWC/GEO-HRW algorithm, which is to be taken into account by the NWC SAF users for the processing of the new BUFR output files.

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

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

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

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

White entries: Fixed factors

Grey entries: Replicated factors

Table 20: Variables used for the Trajectory output with the NWC SAF specific BUFR format

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

When OUTPUT_FORMAT = EUM, an AMV BUFR bulletin equivalent to the one defined previously as common AMV output format by the "International Winds Working Group (IWWG)" for all AMV production centres, and used for example by the Meteosat Product Extraction Facility/MPEF in EUMETSAT, is written under the name `S_NWC_HRW-WINDEUM_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr` for the "Single or Basic AMV scale", or the name `S_NWC_HRW-WINDEUM_<satid>_b<regionid>-DS_YYYYMMDDThhmmssZ.bufr` for the "Detailed AMV scale", in `$SAFNWC/export/HRW` directory. Again, "satid" is the identifier of satellite used, "regionid" is the identifier of the region used and "YYYYMMDDThhmmssZ" is the date and time for which the AMVs have been calculated.

The BUFR variables used for the writing of the NWC/GEO-HRW AMVs considering this format, are explained in *Table 21*, with some explanations in red about how some variables are defined by NWC/GEO-HRW algorithm.

The variables are based on BUFR Master Table number 0, Version number 29 (identified in "variable table" `B0000000000000029000.TXT` and "sequence table" `D0000000000000029000.TXT` in `$SAFNWC/import/Aux_data/HRW` directory). The AMV output is very similar to the one defined for the previous version of NWC/GEO-HRW algorithm, with some small changes related to "mixed calculation" process.

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

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

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

It is recommended to use this option to write the NWC/GEO-HRW output only when the main interest is the assimilation of the AMVs in NWP models or other applications, together with other AMV outputs with an equivalent format (for example, EUMETSAT/MPEF AMVs). The main reason for this is that part of the information calculated with the AMVs cannot be included using this format (the "cloud type", the "orographic flag", the "correlation value", or all new parameters included for the first time in NWC/GEO-HRW-v6.0 related to the NWP model at the AMV level or the best fit level), and so cannot be used operationally. For other uses, it is preferable to use any of the other available formats, which provide more information.

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

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

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

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

Table 21: Variables used for the AMV output with the IWWG BUFR format

2.3.5.4 HRW output as netCDF bulletin

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

The High level structure of the netCDF output for the NWC/GEO High Resolution Winds is shown in *Table 22*. It contains one series of data, containing all the AMVs/Trajectories derived for all satellite channels in the corresponding run of NWC/GEO-HRW algorithm. The dimension of the series of data is defined by "number_of_observations_XXXXX" parameter, which contains the amount of AMVs calculated for the given run of NWC/GEO-HRW algorithm for "XXXXX" satellite channel.

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

In *Table 22*, label "XXXX" is to be modified with the different satellite channels for which AMVs and Trajectories are calculated:

- "HRVIS", "VIS06", "VIS08", "IR108", "IR120", "WV062" or "WV073" for MSG satellite series.

- "VIS06", "IR107" or "WV065" for GOES-N satellite series.

- "VIS06", "VIS08", "IR112", "WV062", "WV069" or "WV073" for Himawari-8/9 satellite series.

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

Table 22: High Level specification of the NWC/GEO-HRW netCDF output

The detailed structure of the netCDF output for the NWC/GEO High Resolution Winds and Trajectories is shown in *Table 23*. The "BUFR Code Tables" used are described in chapter 2.3.5.1 of this document.

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

- The "product_quality" is the "mean Quality index" (with/without forecast, depending on the value of configurable parameter QI_THRESHOLD_USEFORECAST), of all AMVs written in the netCDF output file. This parameter gives an idea of the mean quality of all AMVs, defined as a percentage value (from 0% to 100%).

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

Parameter types	*Content*
Types:	
compound segment	// Structure to contain 1 Trajectory Segment
float latitude	// Latitude (degree north)
float longitude	// Longitude (degree_east)
float latitude_increment	// Latitude Increment (degree_north)
float longitude_increment	// Longitude Increment (degree_east)
float air_temperature	// Air Temperature (K)
float air_pressure	// Air Pressure (Pa)
float air_pressure_error	// Air Pressure Error (Pa)
float air_pressure_correction	// Air Pressure Correction (Pa)
float air_pressure_nwp_best_fit_level	// Air Pressure NWP Model at Best Fit Level (Pa)
float wind_speed	// Wind Speed (m/s)
float wind_from_direction	// Wind Direction (from which wind is blowing) (°)
unsigned byte quality_index_with_forecast	// Quality Index with Forecast Test (%, [0,100])
unsigned byte quality_index_without_forecast	// Quality Index without Forecast Test (%, [0,100])
unsigned byte quality_index_iwwg_value	// Quality Index with common IWWG quality index (%, [0,100])
unsigned byte tracer_correlation_method	// Tracer Correlation method (BUFR code table 002164)
unsigned byte tracer_type	// Tracer Type (BUFR code table 060102)
unsigned byte height_assignment_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte orographic_index	// Orographic index (BUFR code table 060205)
unsigned byte cloud_type	// NWC/GEO-Cloud Type (BUFR code table 060206)
unsigned byte correlation	// Correlation (%, [0,100])
compound wind	// Structure to contain 1 AMV data
unsigned int wind_idx	// Wind sequence Number
unsigned int previous_wind_idx	// Prior wind sequence number
unsigned byte number_of_winds	// Number of winds computed for the tracer
unsigned byte correlation_test	// Correlation test (BUFR code table 060201)
unsigned short quality_test	// Applied Quality tests (BUFR code table 060202)
unsigned int segment_x	// Segment size at nadir in X direction (meters)
unsigned int segment_y	// Segment size at nadir in Y direction (meters)
unsigned int segment_x_pix	// Segment size at nadir in X direction (pixels)
unsigned int segment_y_pix	// Segment size at nadir in Y direction (pixels)
float latitude	// Latitude (degree_north)
float longitude	// Longitude (degree_east)
float latitude_increment	// Latitude increment (degree_north)
float longitude_increment	// Longitude increment (degree_east)
float air_temperature	// Air Temperature (K)
float air_pressure	// Air Pressure (Pa)
float air_pressure_error	// Air Pressure Error (Pa)
float air_pressure_correction	// Air Pressure Correction (Pa)
float air_pressure_nwp_at_best_fit_level	// Air Pressure NWP Model at Best Fit Level (Pa)
float wind_speed	// Wind Speed (m/s)
float wind_from_direction	// Wind Direction (from which wind is blowing) (°)
float wind_speed_nwp_at_amv_level	// Wind Speed of NWP Model at AMV Level (m/s)
float wind_from_direction_nwp_at_amv_level	// Wind Direction of NWP Model at AMV Level (°)
float wind_speed_nwp_at_best_fit_level	// Wind Speed of NWP Model at Best Fit Level (m/s)
float wind_from_direction_nwp_best_fit_level	// Wind Direction of NWP Model at Best Fit Level (°)
float wind_speed_difference_nwp_at_amv_level	// Wind Speed of Difference with NWP model (m/s)
float wind_from_direction_difference_nwp_at_amv_level	// Wind Direction of Difference with NWP model (°)
float wind_speed_difference_nwp_at_best_fit_level	// Wind Speed of Difference with NWP model best fit (m/s)
float wind_from_direction_difference_nwp_at_best_fit_level	// Wind Direction of Difference with NWP model best fit (°)
unsigned byte quality_index_with_forecast	// Quality Index with Forecast Test (%, [0,100])
unsigned byte quality_index_without_forecast	// Quality Index without Forecast Test (%, [0,100])
unsigned byte quality_index_iwwg_value	// Quality Index with common IWWG quality index (%, [0,100])
unsigned byte tracer_correlation_method	// Tracer Correlation method (BUFR code table 002164)
unsigned byte tracer_type	// Tracer Type (BUFR code table 060102)
unsigned byte height_assignment_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte orographic_index	// Orographic index (BUFR code table 060205)
unsigned byte cloud_type	// NWC/GEO-Cloud Type (BUFR code table 060206)
unsigned byte correlation	// Correlation (%, [0,100])
segment(*) trajectory	// Trajectory defined as a variable-length array of Segment structures
Variables:	
Wind wind_XXXXX(*number of observations XXXXX*)	// Wind (AMV + Trajectory) data
Dimensions:	
number of observations XXXXX	// Number of AMVs for channel XXXXX
Attributes:	
cycle	// Satellite cycle number
first_guess	// Origin of the first guess BUFR code table 025202)
long_name	"NWC GEO High Resolution Winds"
manual_automatic_quality_control	// Manual/automatic quality control (BUFR code table 033035)
number_of_nwp_wind_levels	// NWP wind levels used for processing
sensor_band_central_radiation_frequency	// Satellite channel centre frequency (Hz)
sensor_band_central_radiation_width	// Satellite channel band width (Hz)
sensor_band_identifier	// Satellite channel id
standard_name	"Atmospheric winds"
time_period	// Time period between satellite images
validation_nwp_forecast_or_analysis	// Validation NWP analysis/forecast (BUFR code table 060220)
wind_computation_method	// Satellite wind comp. method (BUFR code table 002023)

Table 23: Detailed specification of the NWC/GEO-HRW netCDF output

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

Real time graphic displays of NWC/GEO-HRW product, generated by the NWC/GEO Reference System with MSG satellite series, are available at the NWC SAF Help Desk website (http://www.nwcsaf.org). Following figures show typical displays of NWC/GEO-HRW v6.0 considering the default configuration for the different satellites, but with AMVs calculated for all possible satellite channels and both AMV scales. A colour coding based on the pressure level is used.

First, with MSG2 satellite data in the European and Mediterranean region used for validation (*Figures 31 and 32*). Second, with GOES13 satellite data in the Continental United States region used for validation (*Figures 33 and 34*). Finally, with Himawari-8 satellite data in the China/Korea/Japan region used for validation (*Figures 35 and 36*).
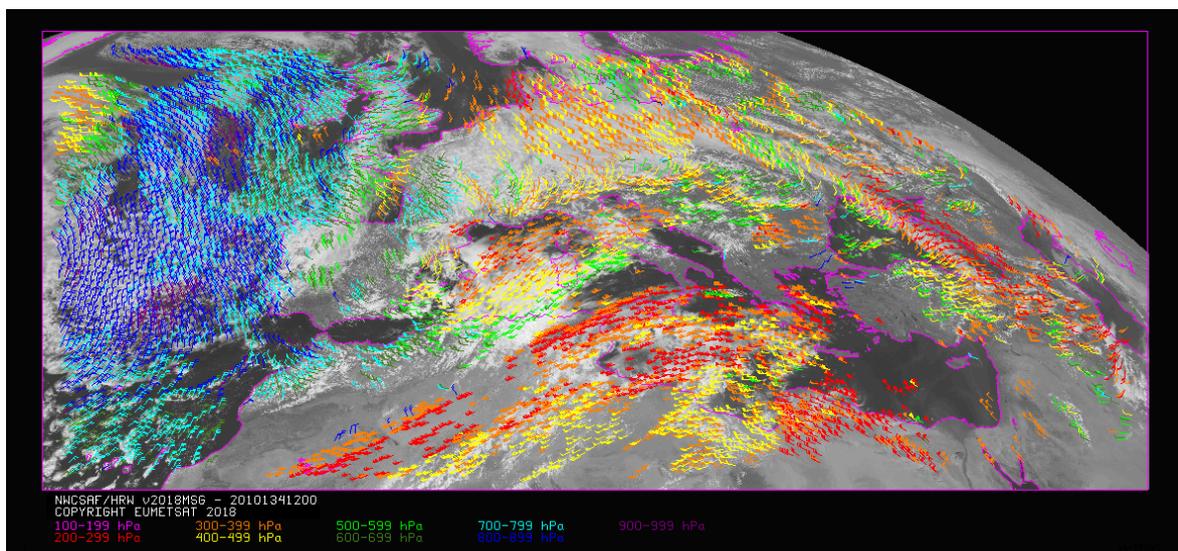
Figure 31: NWC/GEO High Resolution Winds "Basic AMV" output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite), considering conditions defined in `$SAFNWC/config/safnwc_HRW_MSG.cfm` *model configuration file. Colour coding based on the AMV pressure level*
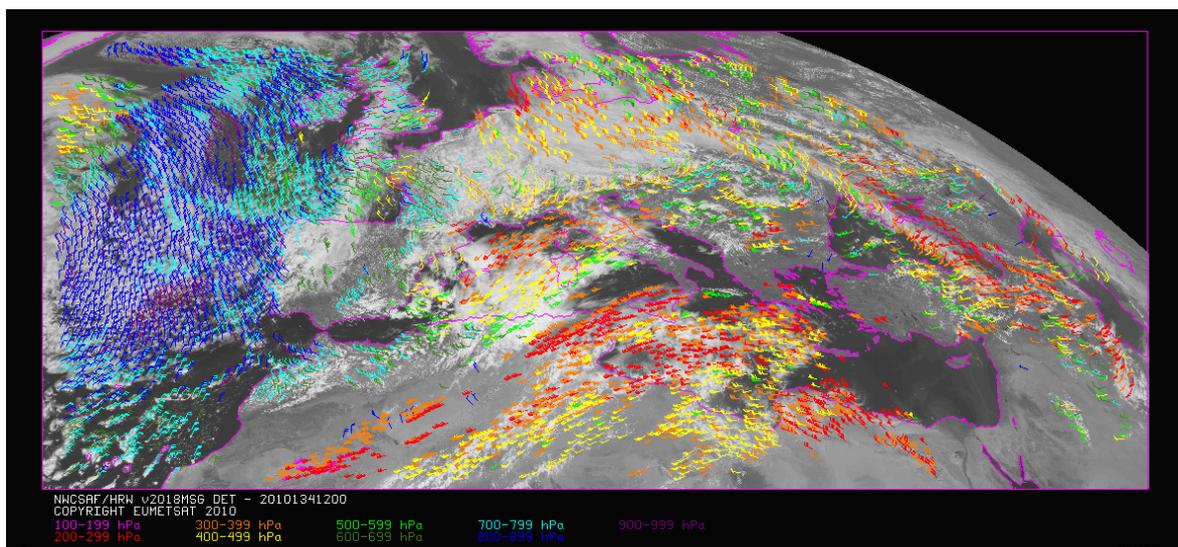
Figure 32: NWC/GEO High Resolution Winds "Detailed AMV" output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite), considering conditions defined in `$SAFNWC/config/safnwc_HRW_MSG.cfm` *model configuration file with configurable parameter CDET=1. Colour coding based on the AMV pressure level*

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		File: NWC-CDOP2-GEO-AEMET-SCI-ATBD-Wind_v2.1
		Page: 86/101
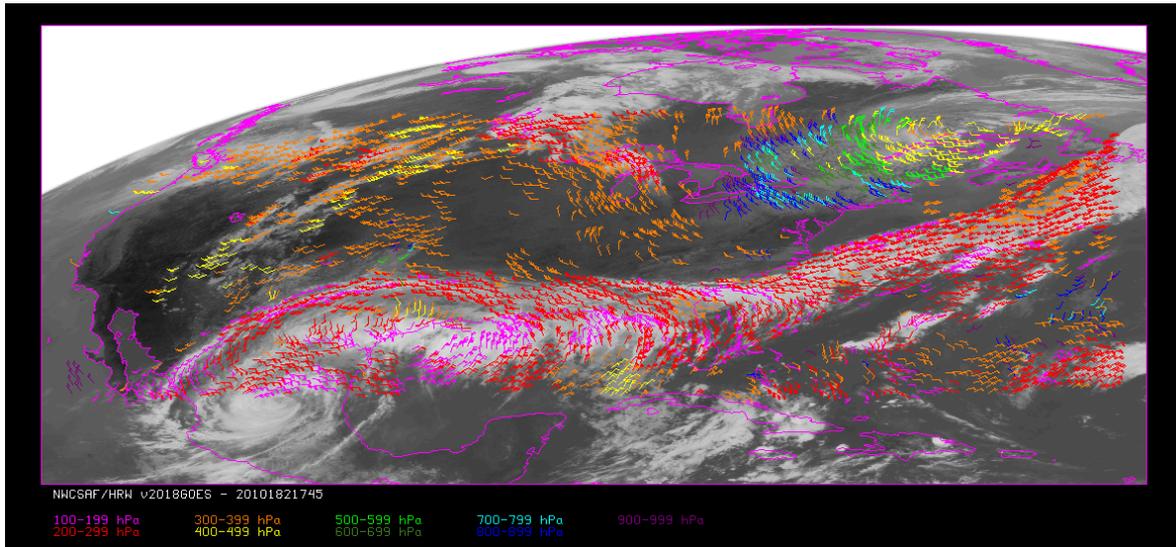
Figure 33: NWC/GEO High Resolution Winds "Basic AMV" output example in the Continental United States region (1 July 2010 17:45 UTC, GOES13 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_GOESN.cfm model configuration file. Colour coding based on the AMV pressure level
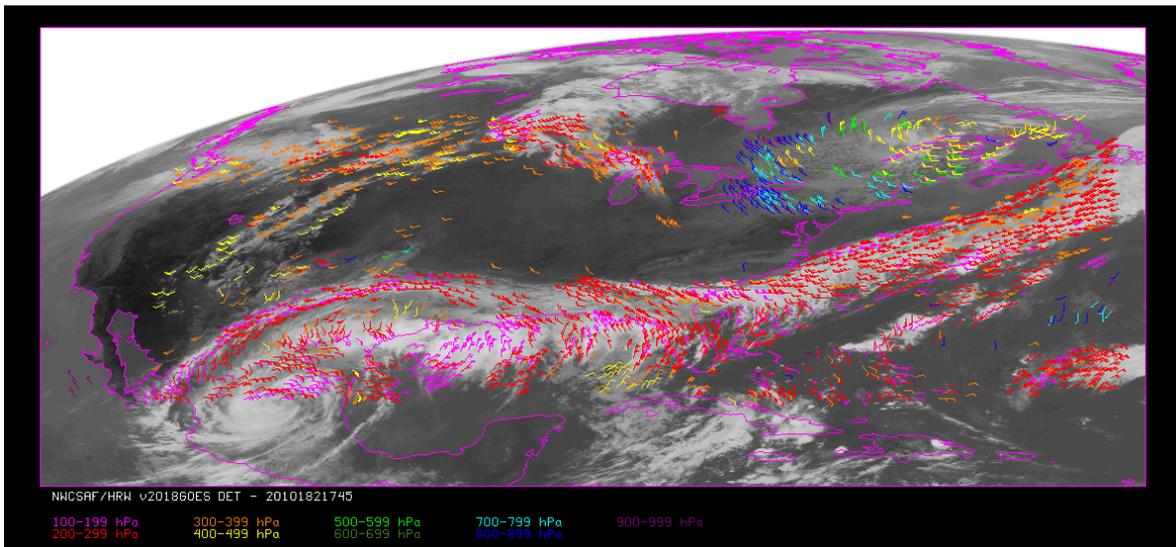
Figure 34: NWC/GEO High Resolution Winds "Detailed AMV" output example in the Continental United States region (1 July 2010 17:45 UTC, GOES 13 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_GOESN.cfm model configuration file with configurable parameter CDET=1. Colour coding based on the AMV pressure level
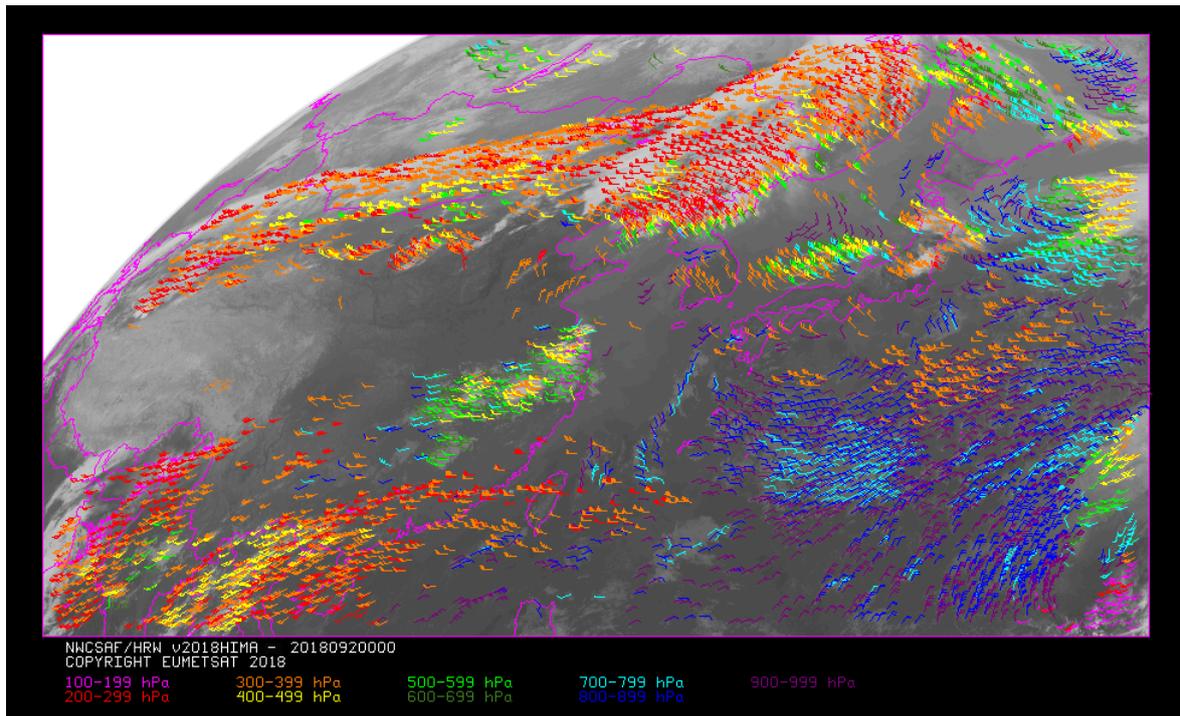
Figure 35: NWC/GEO High Resolution Winds "Basic AMV" output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_HIMA.cfm model configuration file. Colour coding based on the AMV pressure level
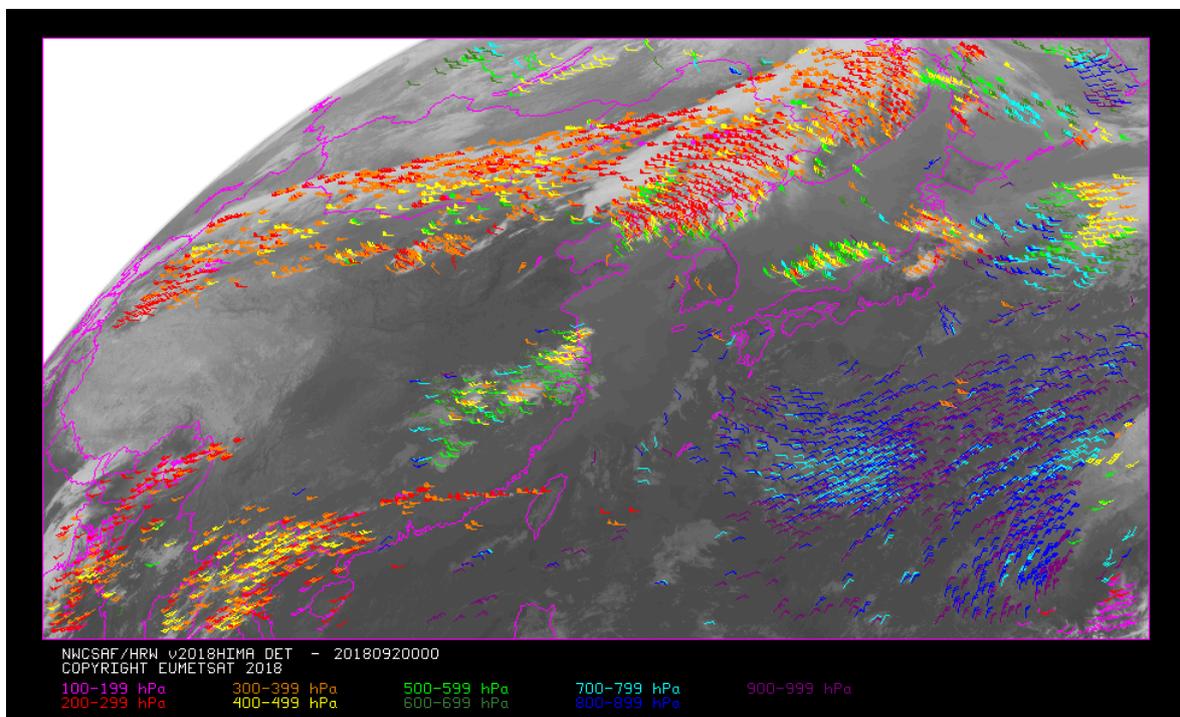
Figure 36: NWC/GEO High Resolution Winds "Detailed AMV" output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_HIMA.cfm model configuration file with configurable parameter CDET=1. Colour coding based on the AMV pressure level

2.3.7 Use of High Resolution Winds (NWC/GEO)

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

2.3.7.1 Installation and preparation of NWC/GEO Software package

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

Once the user has obtained the necessary permissions to download the software package, the software installation procedure does not require any special resources. It is limited to decompress and install the NWC/GEO distribution files (gzip compressed tar files), which successfully build the executable (GEO-HRW-v60 executable file), to be stored into the $SAFNWC/bin directory.

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

The execution step is the processing of satellite images with NWC/GEO-HRW-v60 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-v60` 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-v60 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. Three different default Model configuration files are included in NWC/GEO software package for the running of `GEO-HRW-v60` executable:

   - `safnwc_HRW_MSG.cfm`, to be used with MSG satellite series in "Nominal scan mode" and "Rapid Scan mode".

   - `safnwc_HRW_GOESN.cfm`, to be used with GOES-N satellite data in "Nominal scan mode" 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_HIMA.cfm`, to be used with Himawari-8/9 satellite data in "Nominal scan mode", with calculation of AMVs and Trajectories every 10 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 algorithm, it is also necessary to run `GEO-CMA-v50`, `GEO-CT-v40`, `GEO-CTTH-v40` and `GEO-CMIC-v20` executables before `GEO-HRW-v60` executable for the same image and region.

The "Rapid Scan mode" with MSG 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 "Rapid scan mode" (5 minutes), 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 37 to 39 summarise how the tasks to generate the High Resolution Winds (NWC/GEO-HRW) are performed by the `GEO-HRW-v60` executable:
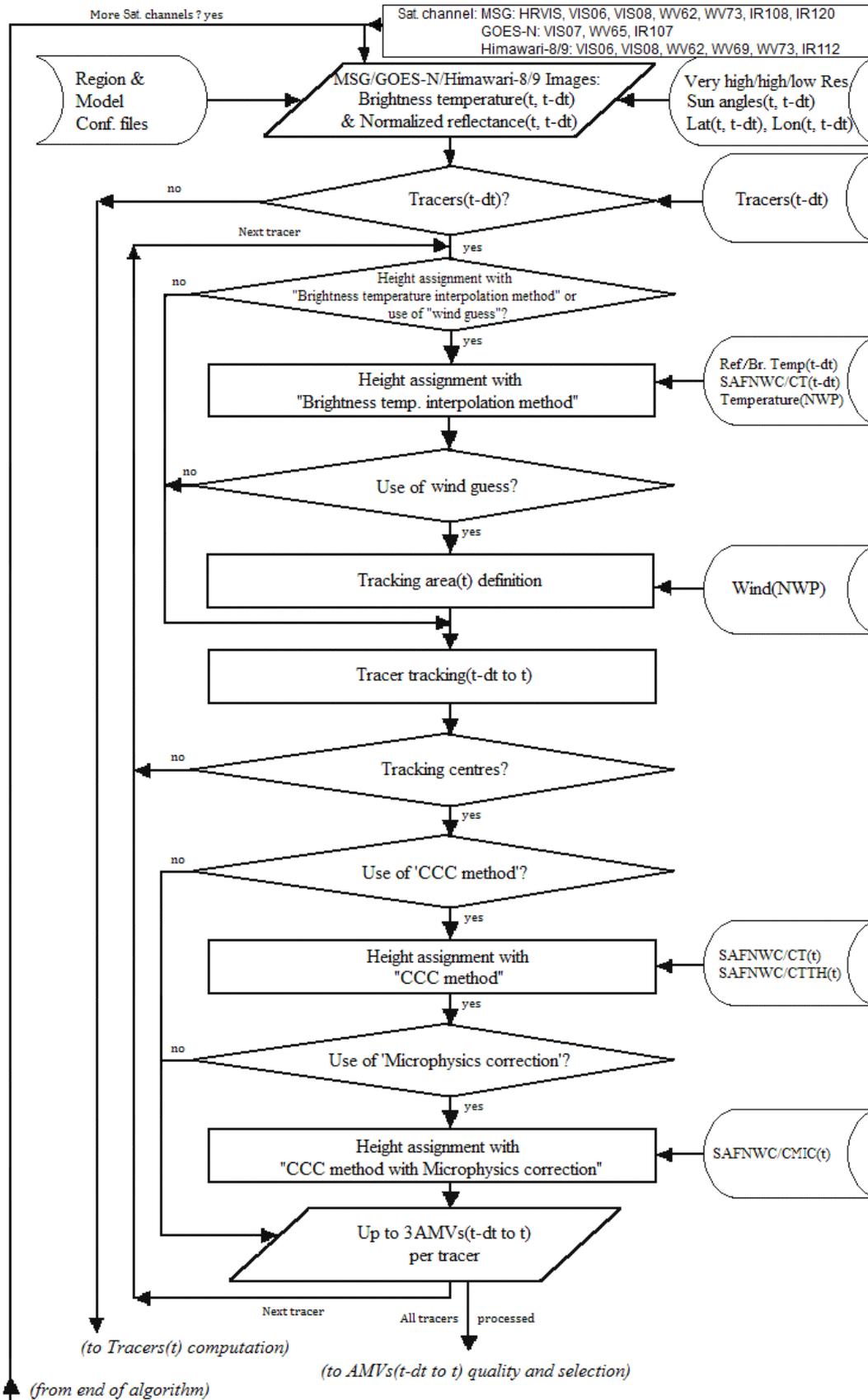
Figure 37: NWC/GEO-HRW implementation: Part 1, Preprocessing and AMV computation

	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO	Code: NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind
		Issue: 2.1 Date: 21 January 2019
		File: NWC-CDOP2-GEO-AEMET-SCI-ATBD-Wind_v2.1
		Page: 91/101
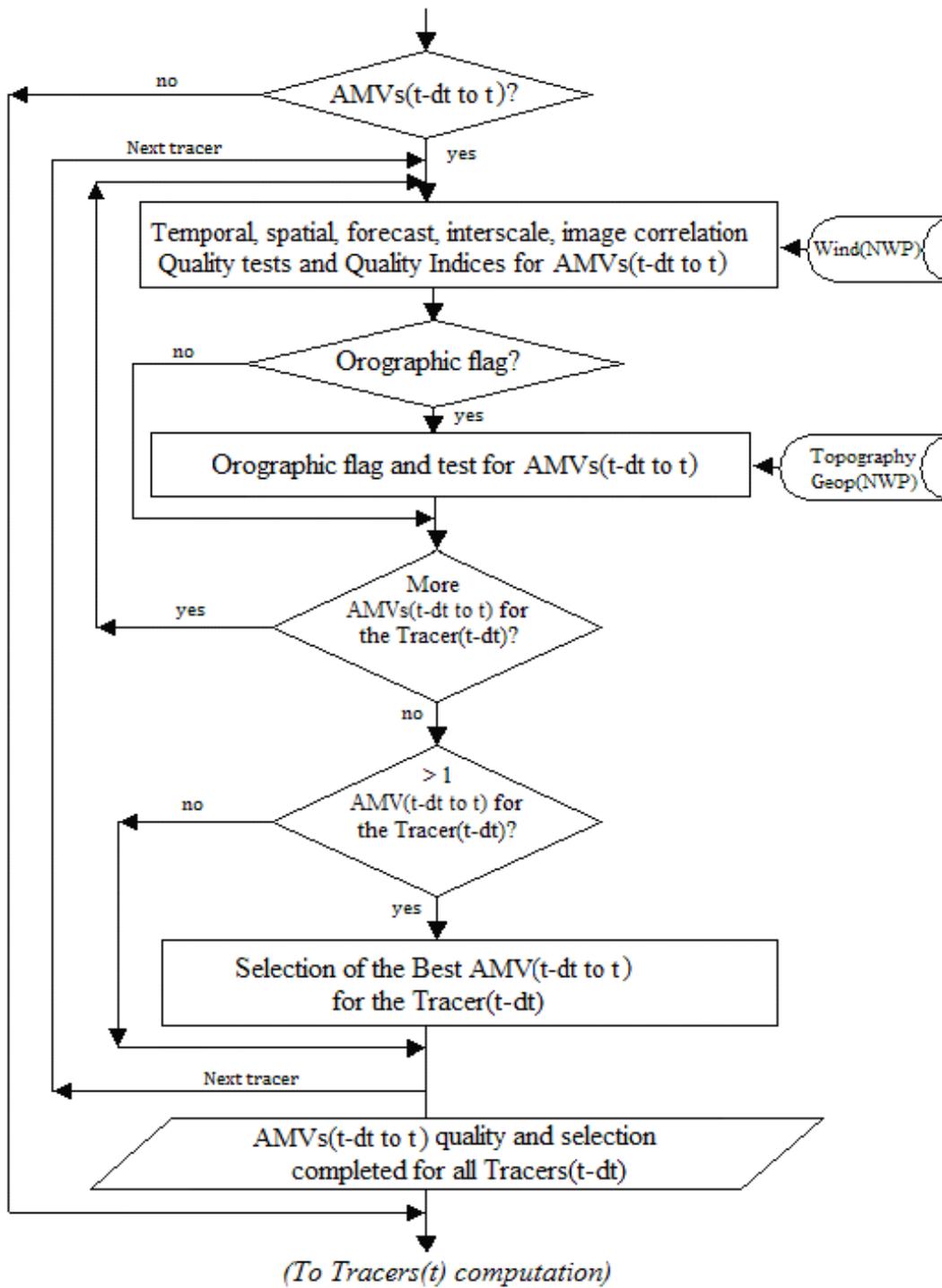
Figure 38: NWC/GEO-HRW implementation: Part 2, AMV quality and selection
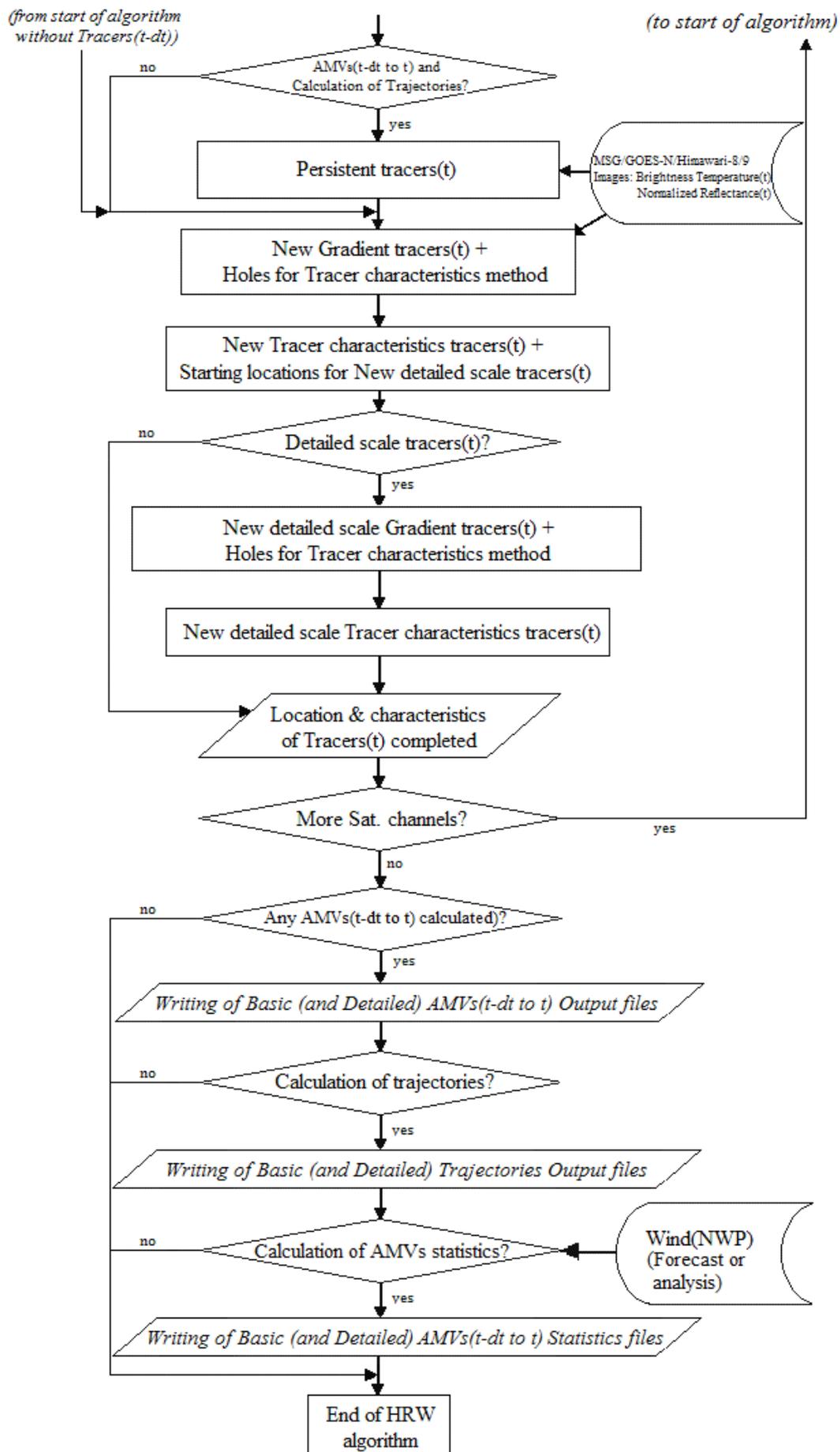
Figure 39: NWC/GEO-HRW implementation: Part 3, Tracer computation and writing of output

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

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-v60 product is provided in the zipped file:

> NWC-CDOP3-GEO-AEMET-SW-ACDD-Wind_html_v1.0.zip.

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

> NWC-CDOP3-GEO-AEMET-SW-ACDD-Wind_html_v1.0/HRW_html/index.html

Every single step throughout all functions of NWC/GEO-HRW-v60 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 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 24: 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 MSG/GOES-N/Himawari 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 MSG/GOES-N/Himawari 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_SetModifTempGridValues          => Fills "modiftempgrid" with IR/WV BT values for the "Brightness temperature height assignment"
    *** hrw_GetCldhgt                       => Calculates Tracer Top temperature/pressure with "Brightness temperature height assignment"
       *** hrw_NWPInvInterpolation          => Converts the Tracer top Temperature to Pressure using NWP data
    *** hrw_SetImageGridValues              => Fills "imagegrid" with VIS Reflectances or IR/WV BT values in the tracer position
    *** hrw_CalcTempCloudtype               => Recalculates Tracer temperature mean/sigma with Cloud type info (for Tracer base temperature)
    *** hrw_NWPInvInterpolation             => Converts Tracer base Temperature to pressure using NWP data and modified mean/sigma values
    *** hrw_TracerWindLevel                 => Defines the Tracer pressure level (with cloud top or cloud base) depending on its cloud type
    *** hrw_NWPDirInterpolation             => Calculates the tracer pressure level using the tracer temperature
    *** hrw_WindGuess                       => Calculates the NWP wind guess at the tracer position
       *** hrw_NWPDirInterpolation          => Calculates the NWP wind at the tracer level considering the AMV pressure level calculated
       *** hrw_WindModDir                   => Calculates the speed module and direction for the NWP wind guess at the tracer position
    *** hrw_WindDisplace                    => Calculates the tracking centre position forecast in the later image with the NWP wind guess
       *** hrw_WindModDir                   => Calculates the speed module and direction for the NWP wind guess at the tracer position
```

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

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

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

```
*** hrw_WriteTracers                        => Writes the Tracer data file for the current image in $SAFNWC/tmp directory
*** hrw_Free_Satellite                      => Deallocates memory for MSG/GOES-N/Himawari satellite data
*** hrw_Free_TWinds                         => Deallocates memory for "tracer wind" data
*** hrw_Free_PredWinds                      => Deallocates memory for "predecessor_wind" data
*** hrw_Free_Trajectories                   => Deallocates memory for "trajectory" data
*** hrw_Free_LevelsandGuesses               => Deallocates memory for NWP data
*** hrw_EncodeBufrNWC                       => Writes the AMV/Trajectory BUFR output file using 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 BUFR output writing using NWCSAF template
                *** hrw_Ymvuv               => Calculates the wind components considering the initial/final latitude/longitude positions
                *** hrw_WindModDir          => Calculates the speed module and direction of the mean AMV for its writing in the BUFR output
            *** hrw_SetFixedDescNWC         => Codifies common information for all AMVs, for 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 MSG/GOES-N/Himawari channel using NWCSAF template
            *** hrw_SetReplicatedDescTRAJ   => Codifies specific information for each Trajectory, for BUFR output writing using NWCSAF template
            *** hrw_SetFixedDescNWC         => Codifies common information for all Trajectories, for 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 file using the IWWG 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 the IWWG template
        *** hrw_SetBUFRSection1EUM          => Codifies Section 1 of the BUFR output file using the IWWG template
        *** hrw_SetBUFRSection2EUM          => Codifies Section 2 of the BUFR output file using the IWWG template
        *** hrw_WriteValuesEUM              => Codifies AMV BUFR output for a defined satellite channel using the IWWG template
            *** hrw_SetFixedDescEUM         => Defines the information for one AMV for its BUFR output writing using the IWWG template
                *** hrw_Ymvuv               => Calculates the wind components considering the initial/final latitude/longitude positions
                *** hrw_WindModDir          => Calculates the speed module and direction of the mean AMV for its writing in the BUFR output
            *** hrw_SetBUFRSection3EUM      => Codifies Section 3 of the BUFR output file using the IWWG template
            *** hrw_WriteBufrEUM            => Encodes the AMV BUFR output in $SAFNWC/export/HRW directory using the IWWG template
```

```
*** hrw_EncodeNetCDF                          => Writes the AMV NetCDF output file 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_Ymvuv             => Calculates the wind components considering the initial/final latitude/longitude positions
                    *** hrw_WindModDir        => Calculates the speed module and direction of the mean AMV for its writing in the NetCDF output
 *** hrw_CalculateTotalStatistics            => Calculates the AMV total statistics respect to the related NWP model analysis/forecast winds
     *** hrw_Ymvuv                            => Calculates the wind components considering the initial/final latitude/longitude positions
 *** hrw_WriteTotalStatistics                => Writes the AMV validation statistics in the HRW log file and the Statistics output file
 *** hrw_Free_WindData                       => Deallocates memory for "wind_channel_info" data
     *** hrw_Free_TWinds                      => Deallocates memory for "tracer wind" data
     *** hrw_Free_PredWinds                   => Deallocates memory for "predecessor_wind" data
     *** hrw_Free_Trajectories                => Deallocates memory for "trajectory" data
```

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

The main circumstance that has to be taken into account when using NWC/GEO 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 the version of year 2011, AMVs related to humidity patterns in the MSG water vapour channels started to show wind vectors in clear air areas.

- Since the version of year 2012, the possibility to calculate AMVs with up to seven different MSG satellite channels increases significantly the density of possible AMV data throughout all the day. The additional option to calculate AMVs in "Rapid scan mode" with MSG satellite series also permits to obtain new AMVs in shorter time frames of five minutes with every new satellite image, increasing the amount of available AMVs by a factor of 3 respect to the MSG "Nominal scan mode".

- Since the version of year 2018, the option exists to calculate AMVs and Trajectories in Asian and West Pacific areas with Himawari-8/9 satellite series. The planned extension to GOES-R satellite series in the year 2019 will finally allow for the operational calculation of AMVs and Trajectories with geostationary satellites covering all areas of the world with an only AMV algorithm, which will be an important milestone for NWC/GEO-HRW algorithm. The experience with these two new generation satellites (Himawari-8/9 now and GOES-R next year), will also be very useful for the development of the AMV algorithm for MTG-Imager satellite series, for which the main issues seem to be related to the density and quality of AMVs at low levels.

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

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

For future work, an effort is needed to reduce the size of the code and the use of memory by NWC/GEO-HRW algorithm, and to allow the parallelization of the calculation of AMVs and Trajectories (doing calculations for different satellite channels with different processors), to drastically reduce the running time of the algorithm. Some studies were done on this during the summer of 2018 for NWC/GEO-HRW v6.0 version, showing clearly that more time was needed for this.

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

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

  The first problem is solved not using the NWP wind guess (with WIND_GUESS = 0), which despite the increases in the running time of NWC/GEO-HRW algorithm it implies (because of

using larger "tracking areas"), the optimizations included in the algorithm make this configuration fully operational as the default option for NWC/GEO-HRW 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 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 in NWC/GEO-HRW algorithm). Other option can be to use the "Common IWWG Quality index", especially when AMV outputs from different algorithms are used, for which the use of this parameter has proved to be useful.

▪ In the height assignment (in general the main remaining challenge that scientists are currently facing with AMV extraction). If the "HRW Brightness temperature interpolation height assignment" is used, small errors in the temperature profile can cause important errors in the heights assigned to the tracers. Besides, the assumption is taken that the temperature is supposed to diminish constantly with higher levels throughout the atmosphere. Due to this, problems in the level assignment appear when a temperature inversion is present. This problem is solved using the "CCC height assignment method" (the default option), in which the thermal inversion problem is solved by NWC/GEO-CTTH product output data.

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

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

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

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