

The EUMETSAT  
Network of  
Satellite Application  
Facilities



**NWC SAF**

Support to Nowcasting and  
Very Short Range Forecasting

# Algorithm Theoretical Basis Document for the Wind product processors of the NWC/GEO

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

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*Applicable to GEO-HRW v5.0 (NWC-037)*

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## DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0	29 November 2013	68	Initial version; 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: <ul style="list-style-type: none"> <li>• Changes proposed at NWC/GEO v2016 STRR/DRR</li> <li>• An updated list of “Model configuration files”</li> <li>• An updated validation with the latest changes in NWC/GEO libraries, Cloud and HRW algorithms</li> <li>• A table with the list of possible errors caused by GEO-HRW-v5.0 algorithm</li> </ul>

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## Introduction

The EUMETSAT Satellite Application Facilities (SAF) are dedicated centres of excellence for the processing of satellite data, and form an integral part of the distributed EUMETSAT Application Ground Segment.

This documentation is provided by the SAF on support to Nowcasting and Very short range forecasting (NWC SAF). The main objective of the NWC SAF is to provide, develop and maintain software packages to be used with operational meteorological satellite data for Nowcasting applications. More information about the project can be found at the NWC SAF webpage, <http://www.nwcsaf.org>.

This document is applicable to the NWC SAF processing package for the geostationary meteorological satellites, NWC/GEO.

### 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 (GEO-HRW, High Resolution Winds), which calculates Atmospheric Motion Vectors and Trajectories considering:

- Up to seven channels from MSG series SEVIRI imager: the 3 km Low Resolution Visible channels (VIS06 0.6  $\mu\text{m}$  and VIS08 0.8  $\mu\text{m}$ ), Water Vapour channels (WV062 6.2  $\mu\text{m}$  and WV073 7.3  $\mu\text{m}$ ), Infrared channels (IR108 10.8  $\mu\text{m}$  and IR120 12.0  $\mu\text{m}$ ), and the 1 km High Resolution Visible channel (HRVIS 0.7  $\mu\text{m}$ ).
- Up to three channels from GOES-N series Imager: the 4 km Low Resolution Water Vapour channel (WV065, 6.5  $\mu\text{m}$ ) and Infrared channel (IR107, 10.7  $\mu\text{m}$ ), and the 1 km High Resolution Visible channel (VIS07, 0.7  $\mu\text{m}$ ).

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 algorithm. It also provides information on the needed input data and the resulting output data.

### 1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithm implemented in the GEO-HRW-v5.0 (Product Id NWC-037) of the NWC/GEO v2016 software package release.

### 1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

The main improvements related to GEO-HRW-v5.0 algorithm are the next ones:

1. The redefinition of the whole GEO-HRW algorithm considering the new NWCLIB library inside NWC/GEO software, which simplifies the way of processing additional geostationary satellites, and provides a series of common tools to be used by all NWC/GEO products.
2. The provision for the first time of a detailed documentation of all GEO-HRW code, through a specific file in html format with the support of Doxygen tool, and through comments inside the C/Fortran code explaining every single step of the algorithm.
3. The inclusion in “CCC height assignment method” of a pressure level correction physically based on the cloud depth, considering new parameters provided by NWC/GEO Cloud Microphysics (CMIC) product (the liquid water path for liquid clouds and the ice water path for ice clouds).
4. The extension of GEO-HRW algorithm processing to the GOES-N satellite series (GOES-13, GOES-14 and GOES-15), considering the calculation of AMVs with up to three channels from the corresponding GOES Imager: the 4 km Low Resolution Water Vapour channel (6.5  $\mu\text{m}$ ) and Infrared channel (10.7  $\mu\text{m}$ ), and the 1 km High Resolution Visible channel (0.7  $\mu\text{m}$ ).

## 1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

### 1.4.1. Definitions

4x4 array	Big array used in the “Big pixel brightness variability test”, defining a coarse structure in the tracer candidates
Adjustment centre	Local or absolute CC maximum or LP minimum in the tracking area
Basic dataset	Winds for the algorithm wide tracer scale
Big pixel	Each element of the 4x4 array classifying the tracer candidate at reduced resolution in the “Big pixel brightness variability test”, defining three different brightness classes (CLASS_n)
Big pixel class difference	Difference in the sum of squared differences of “Big pixel” class values, between the initial tracer location and a later adjustment centre
Bright big pixel	When its N_Value is equal or higher than a given frontier
CC	Cross correlation coefficient
CENT_N%	Brightness centile in the N_Value histogram
CLASS_n	“Big pixel class”, according to its population of bright pixels (three different classes with n values = 0,1,2)
Closeness threshold	Minimum distance (line, element) allowed between tracer locations
Cloud type	Cloud type defined for each tracer with NWC/GEO CT Cloud type 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”.
Coarse/basic scale	Tracer size for the basic dataset in the two scale tracer selection option
Consistency	Wind difference compared to some expected wind, quantified in probabilistic terms for the Quality Index calculation
COV	Covariance
Deepest frontier	The frontier more largely exceeding the DEPTH_THRESHOLD
DEPTH_THRESHOLD	Threshold for histogram minima in the “Frontier definition” in the “N_Value histogram test”
Detailed dataset	Winds for the algorithm narrow tracer scale
DIF	Parameter difference or module of vector difference, in the Quality Index computation
Exclusion array	Places of the image which cannot be tracer locations because of the failing closeness threshold
Fine/detailed scale	Tracer size for the detailed dataset in the two scale detailed tracer selection option (half the size of the coarse/basic scale)
First (tracking) candidate	Preferred tracking candidate for a tracer after the definition of the correlation centres, before the Quality Index calculation
FREQ(j)	Frequency in the histogram for summed classes j-1 to j+1
Frontier	A significant minimum in the N_Value histogram

GAP	Line and element distance separating tracking candidates in the gradual approach calculation process
Gradient method	First tracer computation method
Gradual approach	Iterative approach to reduce the number of tracking candidates to be evaluated in the tracking area in the later image for a given tracer
Ind_topo	Value of the Algorithm Orographic flag parameter, calculated to detect land influence on the Atmospheric Motion Vectors
Interscale test (in the QI test)	Consistency of the detailed winds respect to the basic scale related winds
LAT_C, LON_C	Coordinates at correlation centre
LAT_T, LON_T	Coordinates at tracer centre
LP	Euclidean distance
Marked starting locations	Starting locations defined in the basic scale part for the detailed scale part, in the two scale procedure
Maximum optimisation distance	Maximum distance (line or element) allowed between the starting location and the final tracer location
Narrow basic tracer	A basic tracer where CLASS_2 values are not found in the left and right column neither in the upper and lower row, in the Big pixel structure in the “Big pixel brightness variability test”
Neighbour wind	Close enough wind to a given one
New tracers	Tracers unrelated to AMVs calculated in the previous cycle, in the tracer continuity option
Not closed adjustment centre	Adjustment centre in the border of the tracking area
NUM	Total of pixels in the tracer or in the tracking candidate
N_Value	Matrix used for the calculation of the tracers, defined as 1 byte Brightness temperature values in infrared and water vapour cases, and 1 byte Normalized Reflectance values in visible cases
Optimisation gap	Maximum line and element distance, at which tracer candidates are evaluated in the Tracer characteristics method
Orographic flag (dynamic)	Flag to show possible land influence in the previous positions of the tracer. It is calculated after the static orographic flag procedure, and indicated through parameter Ind_topo (Values: 1,2,3,4,5,6)
Orographic flag (static)	Flag to show possible land influence in the tracer position. Indicated through parameter Ind_topo (Values 1,2,6)
Overall QI	Final Quality Index, weighted sum of QI of individual tests except the two scale test
Persistent tracers	Tracers related to AMVs calculated in the previous cycle, specific to the tracer continuity option
POS	Integer location (integer line and element) of a correlation centre, more specifically in the centre of a pixel

POS_REAL	Non integer location (non integer line and element) of a correlation centre, at any position inside a pixel
Predecessor wind	The one for which the final tracer location is the starting location of a new tracer in the tracer continuity option
Prior wind	Close enough AMVs from the previous image to the current tracer location and level, used in the Quality temporal correlation test
Quality indicator (or QI)	Consistency method to flag the quality of the generated Atmospheric motion vectors
S (in CC computation)	Any pixel in a given tracking candidate
Secondary centre	Secondary adjustment centre for a tracer after the selection of the correlation centres, that can be promoted to first candidate before the Quality Index
Segment of the image	A set of contiguous pixels defined by its size and location
Single scale procedure	Tracer selection procedure with only wide (basic) scale tracers
SPD	Time averaged wind speed
Starting location (in the initial image)	Each a priori tracer location throughout the search region. In principle uniformly covering the defined region of the image.
$T_{Average}$ , $T_{Base}$	Mean Brightness temperature for a tracer, and corrected value used for the calculation of the cloud base pressure, with the “Brightness temperature interpolation height assignment method”
T (in CC computation)	Any pixel in the tracer
TESO indicator	Orographic test parameter, detailing if the orographic flag was calculated and the relative results in winds for the same tracer, to be added to the Quality TEST indicators
TEST indicator	Values of flags after the quality control processing steps, detailing which tests were applied and the relative results for winds of the same tracer
Test on Frontier definition in the N_Value histogram	The first test included in the “Tracer characteristics method”
Test on Big pixel brightness variability	The second test included in the “Tracer characteristics method”

Tracer	Square segment of the image of fixed size (tracer size), identified by the location of its centre, and considered valid candidate for the AMV calculation by any of the two tracer calculation methods
Tracer candidate	Square segment in the image of fixed size, where conditions for tracer search using “Tracer characteristics method” are evaluated
Tracer continuity	Processing option where part of the set of tracers is defined through the final position of the AMVs in the previous cycle
Tracer characteristics method	Second tracer computation method
Tracer location	Tracer image coordinates (line and element of its centre).
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 side/size	Line or element dimension of the tracer
Tracking	Determination of the best adjustment centre inside the tracking area of a later image, to a given tracer in a prior image
Tracking area	Square segment in the final image containing the search area for a given tracer, and where all tracking candidates are located
Tracking candidate	Each square segment in the final image that has to be evaluated for the tracking of a given tracer, and its centre
Two scale procedure	Tracer selection for tracers of two different tracer sizes (basic and detailed), being the size of the second one half of the first
Variability (of a tracer candidate)	Variation criteria in the “Big pixel brightness variability test” (based on 0 to 2 or 2 to 0 changes in CLASS <sub>n</sub> , along the linear arrays of Big pixels inside the tracer)
Wide basic tracer	A basic tracer where simultaneously CLASS <sub>2</sub> values are found in the left and right column and/or in the upper and lower row, in the Big pixel structure in the “Big pixel brightness variability test”
Z <sub>SUN</sub>	Sun zenith angle
$\sigma$	Standard deviation
$\sigma_{\text{Cloud}}$	Brightness temperature standard deviation for the pixels of the tracer

Table 1: List of Definitions

## 1.4.2. Acronyms and Abbreviations

AMV	Atmospheric Motion Vector
BUFR	Binary Universal Form for the Representation of meteorological data
CDOP	NWC SAF Continuous Development and Operations Phase
CDOP2	NWC SAF Second Continuous Development and Operations Phase
CIMSS	NOAA & UW's Cooperative Institute for Meteorological Satellite Studies
EBBT	Equivalent Black Body Temperature
ECMWF	European Centre for Medium Range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GEO-HRW	NWC SAF Product Generation Element for the High Resolution Winds
GOES	NOAA's Geostationary Operational Environmental Satellite
HRVIS/VIS07	MSG HRVIS/GOES-N 0.7 $\mu$ m High Resolution Visible channel
HRW	NWC/GEO High Resolution Winds
IOP	NWC SAF Initial Operations Phase
IR108/IR107, IR120	MSG 10.8 $\mu$ m/GOES-N 10.7 $\mu$ m and MSG 12.0 $\mu$ m Infrared channels
MPEF	EUMETSAT's Meteorological Product Extraction Facility
MSG	EUMETSAT's Meteosat Second Generation Satellite
NOAA	United States' National Oceanic and Atmospheric Administration
NWC/GEO	NWC SAF Software Package for Geostationary satellites
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
PGE	NWC SAF Product Generation Element
RID	Review Item Discrepancy
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	University of Wisconsin/Madison
VIS06, VIS08	MSG 0.6 $\mu$ m and 0.8 $\mu$ m Low Resolution Visible channels
WMO	World Meteorological Organization
WV62/WV65, WV73	MSG 6.2 $\mu$ m/GOES-N 6.5 $\mu$ m and MSG 7.3 $\mu$ m Water vapour channels

Table 2: List of Acronyms and Abbreviations

## 1.5 REFERENCES

### 1.5.1 Applicable Documents

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

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

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

<i>Ref.</i>	<i>Title</i>	<i>Code</i>	<i>Version</i>
[AD.1]	Proposal for the Second Continuous Development and Operations Phase (CDOP2)	NWC/CDOP2/MGT/AEMET/PRO	1.0
[AD.2]	NWC SAF CDOP-2 Project Plan	NWC/CDOP2/SAGF/AEMET/MGT/PP	1.9
[AD.3]	Configuration Management Plan for NWC SAF	NWC/CDOP2/SAF/AEMET/MGT/CMP	1.4
[AD.4]	NWC SAF Product Requirements Document	NWC/CDOP2/SAF/AEMET/MGT/PRD	1.9
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP2/AEMET/SW/ICD/1	1.1
[AD.6]	Data Output Format for the NWC/GEO	NWC/CDOP2/AEMET/SW/DOF	1.1
[AD.7]	System Version Document for the NWC/GEO	NWC/CDOP2/AEMET/SW/SCVD	1.1
[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 processors of the NWC/GEO: Software part	NWC/CDOP2/GEO/AEMET/SCI/UM/Wind	1.0
[AD.15]	Scientific and Validation Report for the Wind product processors of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SCI/VR/Wind	1.0
[AD.16]	User Manual of the GOES2NC tool	NWC/CDOP2/GEO/AEMET/SW/UM/GOES2NC	1.0

*Table 3: List of Applicable Documents*

## 1.5.2 Reference Documents

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

Ref.	Title
[RD.1]	J.Schmetz, K.Holmlund, J.Hoffman, B.Strauss, B.Mason, V.Gärtner, A.Koch, L. van de Berg, 1993: Operational Cloud-Motion Winds from Meteosat Infrared Images (Journal of Applied Meteorology, Num. 32, pp. 1206-1225).
[RD.2]	S.Nieman, J.Schmetz, W.P.Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers (Journal of Applied Meteorology, Num. 32, pp. 1559-1568).
[RD.3]	C.M.Hayden & R.J.Purser, 1995: Recursive filter objective analysis of meteorological fields, and application to NESDIS operational processing (Journal of Applied Meteorology, Num. 34, pp. 3-15).
[RD.4]	K.Holmlund, 1998: The utilisation of statistical properties of satellite derived Atmospheric Motion Vectors to derive Quality Indicators (Weather and Forecasting, Num. 13, pp. 1093-1104).
[RD.5]	J.M.Fernández, 1998: A future product on HRVIS Winds from the Meteosat Second Generation for nowcasting and other applications. (Proceedings 4 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.24, pp.281-288).
[RD.6]	J.M.Fernández, 2000: Developments for a High Resolution Wind product from the HRVIS channel of the Meteosat Second Generation. (Proceedings 5 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.28, pp.209-214).
[RD.7]	J.M.Fernández, 2003: Enhancement of algorithms for satellite derived winds: the High Resolution and Quality Control aspects. (Proceedings 2003 Meteorological Satellite Conference, EUMETSAT Pub.39, pp.176-182).
[RD.8]	J.García-Pereda & J.M.Fernández, 2006: Description and validation results of High Resolution Winds product from HRVIS MSG channel at the EUMETSAT Nowcasting SAF (Proceedings 8 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.47).
[RD.9]	J.García-Pereda, 2008: Evolution of High Resolution Winds Product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 9 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.51).
[RD.10]	J.García-Pereda, 2010: New developments in the High Resolution Winds product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 10 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.56).
[RD.11]	C.M.Hayden & R.T.Merrill, 1988: Recent NESDIS research in wind estimation from geostationary satellite images (ECMWF Seminar Proceedings: Data assimilation and use of satellite data, Vol. II, pp.273-293).
[RD.12]	W.P.Menzel, 1996: Report on the Working Group on verification statistics. (Proceedings 3 <sup>rd</sup> International Wind Workshop, EUMETSAT Pub.18, pp.17-19).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3 <sup>rd</sup> international winds workshop, EUMETSAT Pub.18, pp.71-79).
[RD.14]	Xu J. & Zhang Q., 1996: Calculation of Cloud motion wind with GMS-5 images in China. (Proceedings 3 <sup>rd</sup> international winds workshop, EUMETSAT Pub.18, pp.45-52).
[RD.15]	K.Holmlund & C.S.Velden, 1998: Objective determination of the reliability of satellite derived Atmospheric Motion Vectors (Proceedings 4 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.24, pp.215-224).
[RD.16]	K.Holmlund, C.S.Velden & M.Rohn, 2000: Improved quality estimates of Atmospheric Motion Vectors utilising the EUMETSAT Quality Indicators and the UW/CIMSS Autoeditor (Proceedings 5 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.28, pp.72-80).
[RD.17]	R.Borde & R.Oyama, 2008: A direct link between feature tracking and height assignment of operational Atmospheric Motion Vectors (Proceedings 9 <sup>th</sup> 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 11 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (WMO Publication, available at <a href="http://www.wmo.int/pages/prog/www/WMOcodes/WMO306_v12/LatestVERSION/WMO306_v12_CommonTable_en.pdf">http://www.wmo.int/pages/prog/www/WMOcodes/WMO306_v12/LatestVERSION/WMO306_v12_CommonTable_en.pdf</a> )
[RD.20]	M.Dragosavac, 2007: BUFR Reference Manual (ECMWF Operations Department Publication, available at <a href="https://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/ECMWF/bufr_reference_manual.pdf">https://www.wmo.int/pages/prog/gcos/documents/gruanmanuals/ECMWF/bufr_reference_manual.pdf</a> )
[RD.21]	P.Lean, G.Kelly & S.Migliorini, 2014: Characterizing AMV height assignment errors in a simulation study (Proceedings 12 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.63).
[RD.22]	A.Hernández-Carrascal & N.Bormann, 2014: Cloud top, Cloud centre, Cloud layer – Where to place AMVs? (Proceedings 12 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.63).
[RD.23]	K.Salonen & N.Bormann, 2014: Investigations of alternative interpretations of AMVs (Proceedings 12 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.63).
[RD.24]	D.Santek, J.García-Pereda, C.Velden, I.Genkova, S.Wanzong, D.Stettner & M.Mindock, 2014: 2014 AMV Intercomparison Study Report - Comparison of NWC SAF/HRW AMVs with AMVs from other producers (NWC SAF Visiting Scientist Report, available at <a href="http://www.nwcsaf.org/HD/files/vsadoc/CIMSS_AMV_Comparison_FinalReport_04July2014.pdf">http://www.nwcsaf.org/HD/files/vsadoc/CIMSS_AMV_Comparison_FinalReport_04July2014.pdf</a> )
[RD.25]	D.J.Seidel, B.Sun, M.Petty & A.Reale, 2011: Global radiosonde balloon drift statistics (Journal of Geophysical Research, Num. 116).

Table 4: List of Reference Documents

## 2. HIGH RESOLUTION WINDS (GEO-HRW) DESCRIPTION

### 2.1 HIGH RESOLUTION WINDS (GEO-HRW) OVERVIEW

The High Resolution Winds 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 series) and NOAA's Geostationary Operational Environmental Satellite (GOES-N series) geostationary satellites, considering up to seven MSG/SEVIRI channel data (High resolution visible and Low resolution 0.6 $\mu$ m/0.8 $\mu$ m visible, 10.8 $\mu$ m/12.0 $\mu$ m Infrared and 6.2 $\mu$ m/7.3 $\mu$ m Water vapour channels: HRVIS, VIS06, VIS08, IR108, IR120, WV62, WV73) and up to three GOES-N channel data (High resolution 0.7 $\mu$ m visible and Low resolution 10.7 $\mu$ m Infrared and 6.5 $\mu$ m Water vapour channels: VIS07, IR107, WV65) throughout all hours of the day, as a dynamic information in the NWC/GEO package.

The product includes pressure level information, and a quality control flagging giving some indication of its error in probabilistic terms, with auxiliary indicators about how the product was determined. GEO-HRW also provides trajectories considering the successive tracking of the same tracers in consecutive images.

It has been developed by AEMET in the framework of the EUMETSAT Satellite Application Facility on support to Nowcasting and Very short range forecasting (NWC SAF). This product is useful 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 flow, of low level convergence (when and where cumulus start to develop), of divergence at the top of developed systems, or other cases of small scale circulation or wind singularities. It can also be used in form of objectively derived fields, and assimilated in Numerical Weather Prediction Models (together with many other data), as an input to Analysis, Nowcasting and Very short range forecasting applications. The quality flags should be very useful for these cases.

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

## 2.2 HIGH RESOLUTION WINDS (GEO-HRW) THEORETICAL DESCRIPTION

This section discusses the physics of deriving Atmospheric Motion Vectors (AMVs) from satellite imagery, and identifies some sources of error. In this section the theoretical basis and practical implementation of the corresponding algorithms are 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, where the winds correspond to the displacement of cloud features or water vapour gradient features in consecutive satellite images, is an important source of global wind information, especially over the oceans and 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 several steps:

1. The reading and preprocessing of the satellite data.

A data rectification is especially important considering satellite visible channels, where illumination conditions vary with time.

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

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

3. The correlation between images to locate the same features in a later image.

Each selected feature in the initial image is then tracked in successive images in order to determine the displacement vector for the feature. Clouds can change shape or even disappear, but enough tracers survive to produce AMVs. With shorter time intervals up to 15 minutes, the problem is smaller and more vectors are produced.

4. The height assignment of the tracers.

The height of the feature must be determined to locate the AMVs in a tridimensional position. This is the step where errors can be more important throughout the AMV derivation. Several methods of height assignment are available: the comparison of the infrared brightness temperature of the tracer to a forecast temperature profile, radiance ratioing and H<sub>2</sub>O/IRW intercept techniques for the height assignment of semitransparent clouds, statistical assignment schemes,...

5. The calculation of the vectors.

Considering the geographical displacement of the tracers between both images.

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 the algorithm

### 2.2.2.1 Algorithm outline

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

#### 1. Preprocessing:

- The initialization of data: calculation of latitude/longitude/solar zenith angle/satellite zenith angle matrices; reading of NWP data; Brightness temperature data for the MSG or GOES-N infrared and water vapour channels to be used; Normalized reflectance data for the MSG or GOES-N visible channels to be used. Outputs from several NWC/GEO products are also to be read if so configured: CT (Cloud Type), CTTH (Cloud Top Temperature and Pressure), and CMIC (Cloud phase, Liquid water path and Ice water path).

#### 2. Processing:

- First, tracers are calculated in an initial image with two consecutive methods: Gradient, Tracer characteristics.
- Later, these tracers are tracked in a later image through one of two different methods (Euclidean distance, Cross correlation), with the selection of up to three possible correlation centres per tracer.
- Atmospheric Motion Vectors (AMVs, winds) and Trajectories are calculated, considering the displacement between the position of each tracer and the corresponding correlation centres in consecutive images.
- The pressure level of the AMVs and Trajectories is defined through one of two different methods:
  - “Brightness temperature interpolation method”, which calculates the ‘Top pressure’ and ‘Base pressure’ related to the AMV, interpolating the Brightness temperature of the corresponding channel (using infrared 12.0 $\mu$ m in the MSG case and 10.7 $\mu$ m in the GOES-N case for the visible channels) to the NWP vertical temperature profile, and defining the pressure level with one of these two possible levels. NWC/GEO CT Cloud type output related to the AMV can be used in the procedure if it is available and it has so been configured, to define which of these two levels is used.
  - “Cross Correlation Contribution method (CCC method)” (for Cross correlation tracking if NWC/GEO CT Cloud type and CTTH Cloud top temperature and pressure outputs are available), which defines the AMV pressure considering only the pressure of the pixels contributing most to the image correlation. A pressure correction related to the cloud depth can also be considered for Cloudy AMVs, if NWC/GEO CMIC Cloud phase, Liquid water path and Ice water path have also been calculated.

#### 3. Postprocessing:

- A Quality control with “EUMETSAT Quality Indicator” method is implemented, with the choice of the “Best AMV” considering the several AMVs calculated for each tracer, and a Final control check to eliminate wrong winds very different to those in their vicinity.
- An “orographic flag” can also be calculated if so configured, which incorporating topographic data detects those AMVs affected by land influence.

The code was progressively developed with GOES, MFG and MSG data. Examples with MSG and GOES-N data 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. The channels for which AMVs are to be extracted are for example defined by configurable parameter ‘WIND\_CHANNEL’ (with value

‘HRVIS,VIS06,VIS08,IR108,IR120,WV62,WV73’ when AMVs from all possible MSG/SEVIRI channels are extracted; value ‘VIS07,IR107,WV65’ when AMVs from all possible GOES-N channels are extracted).

The AMVs can be calculated considering different image repetition cycles (defined by configurable parameter SLOT\_GAP). For example, when MSG satellites are considered, consecutive images (15 minutes apart, defined by SLOT\_GAP=1) are recommended to be considered for the initial tracer calculation and their later tracking under ‘Nominal scan mode’ configuration. Under ‘Rapid scan mode’ configuration, alternate images (10 minutes apart, defined by SLOT\_GAP=2) are recommended to be considered for the initial tracer calculation and their later tracking to maximize the amount of calculated winds with the best possible validation statistics.

When GOES-N satellites are considered, two default configurations are provided for the calculation of AMVs: every 15 minutes (for example, for the “Continental United States region” with GOES-East satellite) and every 30 minutes (for example, for the “North America region” with GOES-East satellite). In this cases, SLOT\_GAP=1 is also defined.

	<p>Algorithm Theoretical Basis Document for the Wind product processors of the NWC/GEO</p>	<p><b>Code:</b> NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind <b>Issue:</b> 1.1 <b>Date:</b> 15 October 2016 <b>File:</b> NWC-CDOP2-GEO-AEMET-SCI-ATBD-Wind_v1.1.doc <b>Page:</b> 20/81</p>
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### 2.2.2.2 Preprocessing

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

- Reflectances (which have been normalized taking into account the distance to the Sun) for any MSG/SEVIRI or GOES-N visible channel to be used.
- Brightness temperatures for any MSG/SEVIRI or GOES-N Infrared or Water vapour channel to be used.
- MSG/SEVIRI IR108 and WV062 or GOES-N/IR107 and WV065 radiances if the “Image correlation quality control test” is used (not mandatory).
- NWP temperature profiles.
- NWP wind component profiles (not mandatory, but recommended for the calculation of the “Forecast consistency quality control test”, and needed if the NWP wind guess is to be used for the definition of the tracking area in the later image).
- NWP geopotential profiles, if the “Orographic flag” is to be calculated (not mandatory).
- NWC/GEO CT Cloud Type for previous slot and region (when tracers were calculated), in case the “AMV Cloud type” is used for the “Brightness temperature interpolation method height assignment” (not mandatory).
- NWC/GEO CT Cloud Type and CTTTH Cloud Top Temperature and Pressure outputs for current slot and region, in case “CCC method height assignment” is used (not mandatory but recommended).
- NWC/GEO CMIC Cloud Phase, Liquid Water Path and Ice Water Path outputs for current slot, in case the Microphysics correction is used inside “CCC Method height assignment” (not mandatory).
- Latitude, longitude, solar and satellite zenith angle matrices (calculated by NWC/GEO library with the provided data).

NWC/GEO software is able to calculate AMV and Trajectory data providing only mandatory data (i.e., satellite data for the requested channels and NWP temperature profiles). In any case, the more additional data used contribute to a higher number and better quality of the AMV and Trajectory outputs.

The option to calculate AMVs and Trajectories with Climatological profiles (instead of NWP data) has been eliminated in GEO-HRW-v50, since the amount and quality of data provided in previous releases with the Climatological profiles was significantly worse.

Once all previous data are read or calculated, ‘N\_Value’ matrix contains the image data used for the calculation of tracers. As mentioned, for the visible channels (MSG/SEVIRI HRVIS, VIS06 or VIS08; GOES-N VIS07) the matrix contains Reflectances which have been normalized due to the variable illumination with the solar zenith angle and the variable distance to the Sun, considering NWC/GEO library tools. In the infrared and water vapour channels (MSG/SEVIRI IR108, IR120, WV62 or WV73; GOES-N IR107 or WV65), ‘N\_Value’ matrix contains Brightness temperatures.

In both cases, ‘N\_Value’ matrix data are considered as an integer variable with values ranging from 0 to 255 (8 bit data range), being 0 a predefined minimum value and 255 a predefined maximum value (different for each channel). When ‘N\_Value’ matrix value does not exist for a pixel, it is considered non valid.

	Algorithm Theoretical Basis Document for the Wind product processors of the NWC/GEO	<b>Code:</b> NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind <b>Issue:</b> 1.1 <b>Date:</b> 15 October 2016 <b>File:</b> NWC-CDOP2-GEO-AEMET-SCI-ATBD-Wind_v1.1.doc <b>Page:</b> 21/81
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### 2.2.2.3 Tracer calculation

Two tracer computation methods are applied: Gradient; Tracer characteristics. They are used one after the other in two different tracer selection strategies: the “single scale procedure” (one set of tracers is calculated), and the “two scale procedure” (two different sets of tracers are calculated: “Basic” and “Detailed”, being the line and element dimension of the “Detailed tracers” half the size the one of the “Basic tracers”).

Both methods calculate a tracer optimising its location around one of the 'starting locations'. The starting locations are at fixed uniform distances of lines and elements throughout the image. The first method is by far more efficient in computing terms. The second is more specific: it gets additional tracers in still empty areas (with a longer but still reasonable computing time), adding some information about the tracers.

The target scale defined as first option for the High Resolution Winds product is 24 pixels for the “Single scale procedure” for all types of tracers. A resolution of 24 pixels for the “Basic tracers” and 12 pixels for the “Detailed tracers” is proposed as baseline for the “Two scale procedure”. These resolutions define different tracer scales at subsatellite point between 72 km for MSG satellites/96 km for GOES-N satellites (“Basic low resolution channel scale”) and 12 km (“Detailed high resolution channel scale”), so between the ‘mesoscale  $\beta$ ’ and the ‘mesoscale  $\gamma$ ’ dimensions. The nominal observation frequency of 15 minutes is enough to track the majority of objects with these sizes, although in some few cases like small cumulus over land related to the smallest size (“detailed MSG/HRVIS or GOES-N/VIS07 scale”), their lifecycle might be a bit short if a 15 minute image frequency is used. The use for example of GEO-HRW product with MSG satellites in the ‘Rapid scan mode’ configuration can be better to track tracers of this small size.

In any case, different values can be defined for the tracer size for the High resolution visible channel (MSG/HRVIS or GOES-N/VIS07) through configurable parameters LSIZ\_HRV and ESIZ\_HRV, and for the Low resolution channels (all other channels) through configurable parameters LSIZ\_OTHER and ESIZ\_OTHER.

#### FIRST METHOD: GRADIENT

Similar to the method defined by CIMSS/NOAA at Hayden & Merrill, 1988 [RD.11], it has next steps:

1. To look for an ‘N\_Value’ inside a square segment centred in a starting location, greater than configurable parameter MIN\_BRIGHTNESS\_VIS (for visible channels, with default value 120) or MIN\_BRIGHTNESS\_OTHER (for infrared and water vapour cases, with default value 60).
2. To define if a difference exists between the maximum and minimum ‘N\_Value’ in the square segment greater than configurable parameter GVAL\_VIS (for visible cases, with default value 60) and GVAL\_OTHER (for infrared and water vapour cases, with default value 48).
3. To compute throughout the segment the gradient  $|\Delta N\_Value(\Delta x) + \Delta N\_value(\Delta y)|$ , where  $\Delta$  means differences at a 5 pixel distance in element and line directions, and define the position of its maximum as the tracer location, when it is not in the boundary of the square segment.

#### SECOND METHOD: TRACER CHARACTERISTICS

It is based on new development. It is useful especially in the visible cases, where many potential tracers could present less sharp edges than in the infrared image, because of cloudiness at different levels presenting a similar brightness. It evaluates 'tracer candidates' located at increasing distances of the starting locations until a 'good tracer' is found inside a 'maximum optimisation distance'. Two series of tests: the “Frontier definition in the N\_Value histogram test” and the “Big pixel brightness variability test” are then applied in sequence:

## 1. “Frontier definition in the N Value Histogram test”:

It includes two parts, both based on histogram classification of the ‘N Value pixels’ in the tracer candidate. In its first part, a ‘sufficient N Value contrast’ is to be found in the candidate. Considering the values of the different centiles of the ‘N Value histogram’ (CENT\_n%), it is necessary:

1. CENT\_90% > 0.95·MIN\_BRIGHTNESS and CENT\_10% > 0;
- 2a. CENT\_97% - CENT\_3% > LARGE\_CONTRAST if CENT\_97% > 1.25·MIN\_BRIGHTNESS or
- 2b. CENT\_97% - CENT\_3% > SMALL\_CONTRAST if CENT\_97% < 1.25·MIN\_BRIGHTNESS;

The SMALL\_CONTRAST (value of 20 for visible channels and 30 for infrared and water vapour channels) permits less contrasted ‘tracer candidates’ with extended cloudiness. It is mandatory that these conditions be met for the candidate centred at the starting location: if not, the evaluation is not pursued around it.

In the second part, one or more significant histogram minima or ‘frontiers’ are to be found in the ‘N Value histogram’ for the tracer candidate. The default running of GEO-HRW algorithm keeps only the most significant frontier in the processing, although the option exists to calculate more than one frontier. Each frontier defines then in the corresponding tracer 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).

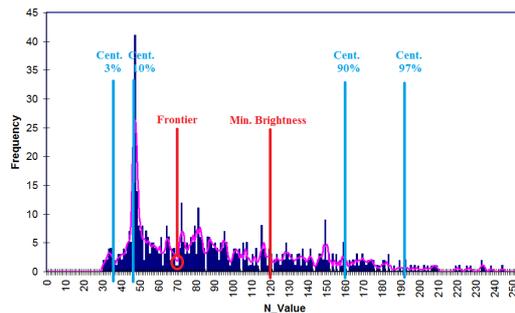


Figure 1: Example of ‘N Value histogram’ (unsmoothed in violet and smoothed in pink) for a valid Low resolution visible tracer candidate. The minimum brightness threshold, the algorithm centiles and the defined frontier is also shown

## 2. “Big pixel brightness variability test”:

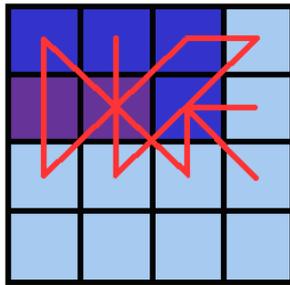
The ‘tracer candidate’ is then considered as a coarse structure of 4x4 pixel arrays (‘big pixels’), to be classified according to the brightness of its pixel population. Three classes are possible:

- 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 array, while occurrences of CLASS\_1 be less than twice the less frequent of the others.

The 4x4 array is then checked for enough brightness variability in different directions: at least 2 transitions (CLASS\_0 to CLASS\_2 or CLASS\_2 to CLASS\_0) must exist along any linear array of the 4x4 array, considering each of the 4 main directions: rows, columns, ascending and descending diagonal directions (with all linear arrays checked for the row and column directions, and only the linear arrays with at least three elements for 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 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'). This condition is checked a priori, i.e. each time a tracer is computed all pixels located nearer than the 'closeness threshold' to its centre are added to an 'exclusion array', and excluded as potential tracer locations. Considering this:

- In the 'Gradient method', the  $\Delta$  differences are not evaluated at pixels inside the 'exclusion array'. In case of a failure in the Gradient test, the procedure is restarted excluding the last proposed location and pixels around, and so on until a definitive gradient test failure or a tracer is finally accepted after all tests.
- In the 'Tracer characteristics method' it is even easier. There is no need to enter computations for a starting location inside the 'exclusion array'.

An additional condition is verified here, through which all pixels inside the tracer must have a satellite zenith angle (and a solar zenith angle in the case of using visible channels) smaller than a maximum threshold (configurable parameters MSG\_ZEN\_THRES and ZEN\_THRES respectively, with default values 87° and 80°).

### SINGLE SCALE PROCEDURE

This option is selected if configurable parameter CDET is empty (default value). The 'tracer sides' are here in all cases defined by configurable parameters LSIZ\_HRV/ESIZ\_HRV for the High resolution channel and LSIZ\_OTHER/ESIZ\_OTHER for the Low resolution channels; with a default value of 24 pixels in all cases.

Starting from the upper left corner of the chosen region of the image, starting locations for the location of tracers are defined, separated by a distance defined respectively by configurable parameter TRACER\_SEARCH\_STEP\_HRV/TRACER\_SEARCH\_STEP\_OTHER for High and Low resolution channels. In the first of two iterations the 'Gradient method' is applied. After one failure in the definition of a tracer the distance is reduced to a half. Two consecutive failures (left to right) in the first iteration, define a 'hole'.

The centres of holes are the starting locations in the second iteration with the 'Tracer characteristics method', where 'tracer candidates' are evaluated every 3 lines and elements (defined by parameter T\_CHAR\_SEARCH\_GAP), in an area around the starting location whose side is half the 'tracer side'.

### TWO SCALE PROCEDURE

This option is selected if configurable parameter CDET is set to 'ALL' or 'RANGE'. The procedure defines a 'Basic scale tracer size' defined as seen in the previous section with LSIZ\_HRV/ESIZ\_HRV and LSIZ\_OTHER/ESIZ\_OTHER configurable parameters (with a default value of 24), and a 'Detailed scale tracer size' (automatically selected to be the half of the 'Basic scale', with a default value of 12), for which the procedure is similar although with some different thresholds.

	Algorithm Theoretical Basis Document for the Wind product processors of the NWC/GEO	<b>Code:</b> NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind <b>Issue:</b> 1.1 <b>Date:</b> 15 October 2016 <b>File:</b> NWC-CDOP2-GEO-AEMET-SCI-ATBD-Wind_v1.1.doc <b>Page:</b> 24/81
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The 'Basic scale' works similarly to the procedure described for the single scale, and additionally defines 'marked starting locations' for the 'Detailed scale', when one of next three conditions are met:

- No 'Basic tracer' has been found, but at the starting location of the tracer candidate:

1.  $CENT_{97\%} > 0.85 * MIN\_BRIGHTNESS$
2.  $CENT_{97\%} < MAX\_BRIGHTNESS$

In this case a 'Detailed tracer unrelated to a Basic tracer' is defined, characterized by a slightly lower maximum brightness.

- A 'Wide basic tracer' has been found, in which CLASS\_2 values appear in both first and last row, or in both first and last column, of the 4x4 array used in the "Big pixel brightness variability test".

In this case up to 4 starting locations are defined for the 'Detailed scale', each of them located in the corners of a 'Detailed tracer' whose centre is the centre of the 'Basic tracer' (having so under the default configuration a 12 pixel line and element separation between them).

- A 'Narrow basic tracer' has been found, in which CLASS\_2 values do not appear in both first and last row, nor both first and last column, of the 4x4 element "Big pixel brightness variability test array".

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 element "Big pixel brightness variability test array".

A smaller processing region ('subregion') can be introduced as option in the GEO-HRW model configuration file for the 'Detailed scale' (the 'Basic winds' will always be computed in the whole region). This is done by specifying CDET as 'RANGE', and defining the starting position and size of the detailed region with LIN\_D, ELE\_D, NUML\_D and NUME\_D configurable parameters.

## CALCULATION OF TRAJECTORIES

With configurable parameter CALCULATE\_TRAJECTORIES = 1 (which is the default option), the definition of new tracer centres starts at the integer final line/column position of all 'adjustment centres' calculated for valid AMVs in the previous round for the same slot, when they are available. A set of 'persistent tracers' is so successively tracked in consecutive images, and the progressive positions of the tracer throughout the time are later specifically written defining trajectories in a specific output file.

In these cases, tracer locations are only defined considering final locations of good quality 'predecessor winds' (i.e. AMVs included in the output file for the same slot, with a QI value over the QI threshold, and all additional criteria for the valid AMV filtering). It is additionally necessary for these tracer locations to be considered as valid that they fulfill the conditions defined by the specific "tracer determination method" used for the corresponding 'predecessor wind'.

However, the 'starting locations' defined now for these 'persistent tracers' are kept as such without the modifications in position which both 'Gradient method' and 'Tracer Characteristics method' could define in other cases, to keep the continuity in the integer line/column positions of the 'persistent tracers' in each slot.

Only slight differences in the latitude/longitude are possible comparing for a same trajectory the initial position of the "tracer centre for the later AMV" (which must always be located in the centre of a pixel) and the "adjustment centre for the previous AMV". In the case configurable parameter USE\_SUBPIXELTRACKING = 1 is used, the "adjustment centre for the previous AMV" can be located in any position of the same pixel, so causing these small differences in latitude/longitude. In any case, it is always confirmed that the integer line/column position of both "tracer centre for the next AMV" and the "adjustment centre for the previous AMV" are always the same ones.

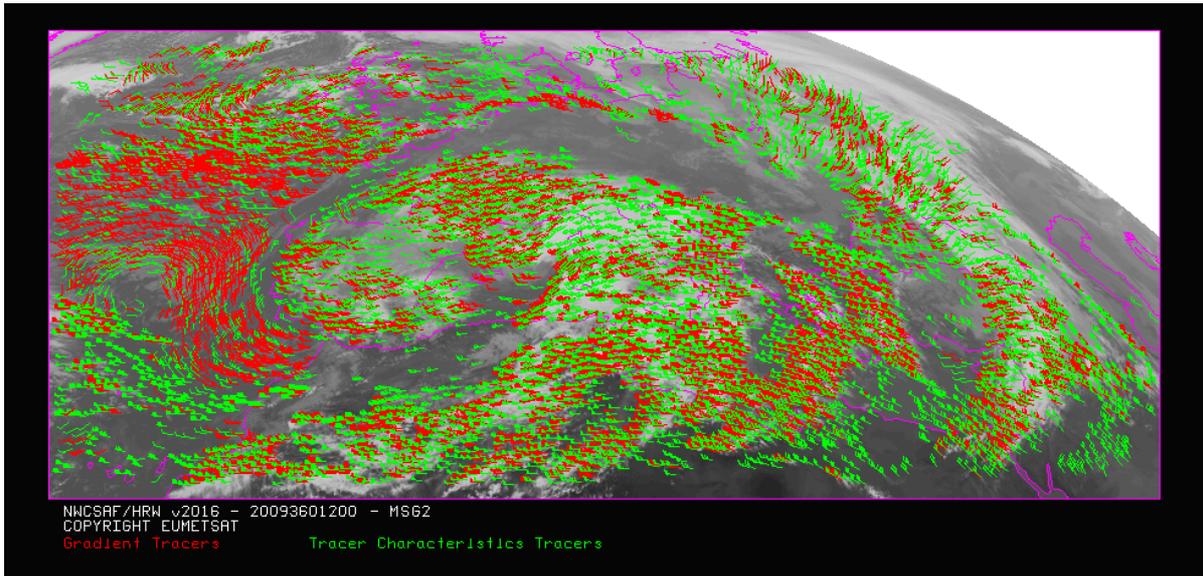


Figure 3: ‘Basic scale AMVs’ (in red and green, considering the Tracer calculation method used for their extraction), in a One scale GEO-HRW-v50 example defined in the European and Mediterranean region with the default \$SAFNWC/config/safnwc\_HRW.cfm.MSG15MIN model configuration file (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)

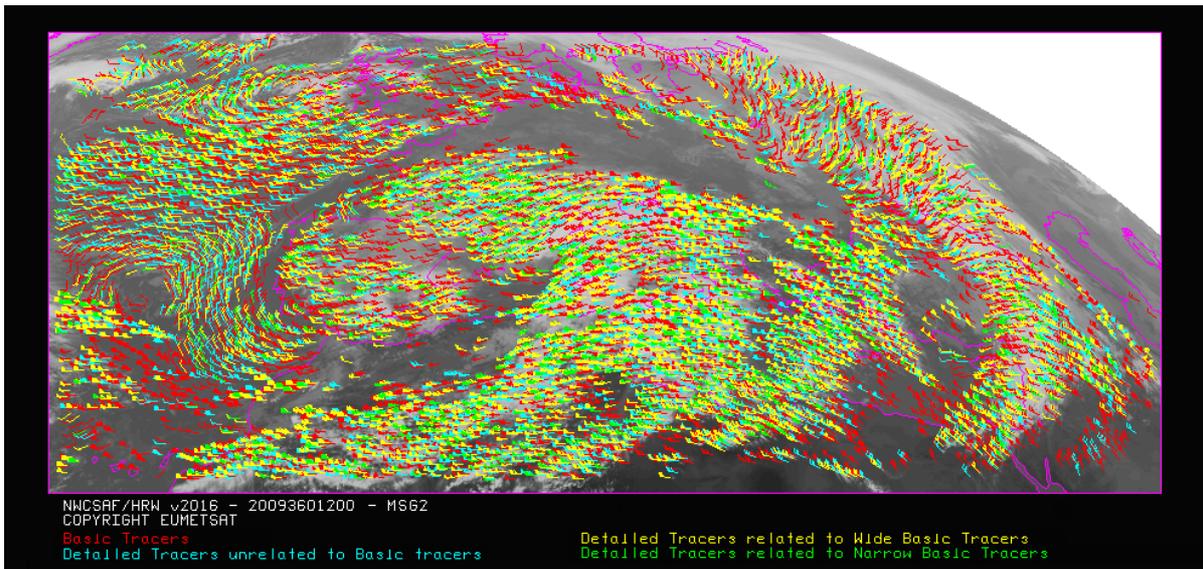


Figure 4: ‘Basic scale AMVs’ (in red), and ‘Detailed scale AMVs’ (in yellow, green and blue, considering their relationship with the Basic scale AMVs), in a Two scale GEO-HRW-v50 example defined in the European and Mediterranean region with option CDET ALL in the default \$SAFNWC/config/safnwc\_HRW.cfm.MSG15MIN model configuration file (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)

### 2.2.2.4 Tracer tracking

The tracking method looks for the best adjustment position of a tracer computed at the initial image, over a larger portion of the following image (tracking area), performing a pixel by pixel comparison to a segment of the same size at same relative positions (tracking candidate), repeatedly moving this segment over the tracking area. For a given centre (i,j) inside this tracking area, the algorithms used are the well known:

- Euclidean distance (configured through TRACKING = LP), where the sum  $LP_{ij} \equiv \sum \sum (T-S)^2$  is calculated, where T, S correspond to the 'N\_Value pixels' for the tracer and the tracking candidate of the same size, at correlative locations. Sums are in the range of the tracer size. The best locations are defined through the minimum values of the sum  $LP_{ij}$ .
- Cross correlation (configured with TRACKING = CC, default value), where the normalized correlation value  $CC_{ij} = COV_{T,S} / (\sigma_T \cdot \sigma_S)$  is calculated. T,S refer to the 'tracer' and 'tracking candidate' segments; COV is the covariance between these ones;  $\sigma$  is the standard deviation or root of the variance. The best locations are defined through the maximum values of the correlation  $CC_{ij}$ . Operatively, the tracking  $CC_{ij}$  is implemented through the derived expression (deemed to have a better computing efficiency, with NUM as the total number of pixels in each array):

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

The 'tracking area centre' position can be preliminarily be defined through a wind guess obtained with the NWP forecast of the rectangular wind components, interpolated to the tracer location and level. This reduces the 'tracking area size' and the running time, and is applied using configurable parameter WIND\_GUESS = 1.

Nevertheless, GEO-HRW algorithm has been optimized not to use the wind guess as default option, so reducing the dependence of the calculated AMVs from the NWP model used. Although the running time can be around two to three times longer than using the wind guess it is recommended for the users to keep operationally the configuration without use of the wind guess (with configurable parameter WIND\_GUESS = 0).

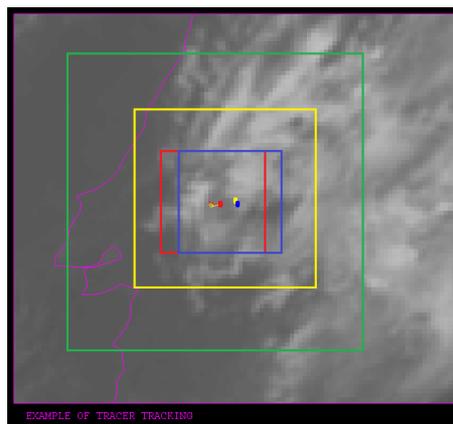


Figure 5: A low resolution visible tracer case at 1145Z (O red mark), its position defined by the NWP wind guess at 1200Z (O yellow mark), and its true tracking position at 1200Z defined by GEO-HRW algorithm (O blue mark), for the High Resolution Winds example defined in Figure 22 (26 December 2009,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

The ‘tracking area size’ is defined through configurable parameters LLAG\_HRV/ELAG\_HRV for the High resolution visible channel and LLAG\_OTHER/ELAG\_OTHER for the Low resolution channels. Considering tracer and tracking images 15 minutes apart and the default configuration not using the wind guess, the recommended values of these parameters are LLAG\_HRV=ELAG\_HRV=136, LLAG\_OTHER=ELAG\_OTHER=46 (MSG/SEVIRI cases) and LLAG\_OTHER=ELAG\_OTHER=34 (GOES-N cases), which permit to detect displacements of at least 272 km/h in any direction, completely independently of the direction of the NWP wind guess.

To avoid additionally computing  $LP_{ij}/CC_{ij}$  for all (i,j) locations in the ‘tracking area’, a gradual approach of 3 iterations with the idea that the correlation changes slowly (Xu and Zhang, 1996) [RD.14], is performed:

- In a first iteration, a GAP = 8 is applied: only at (1,1), (1,9),... (9,1), (9,9),...  $LP/CC_{ij}$  is evaluated. The 4 locations (value of CORR\_ITERATIONS parameter) with the best  $LP/CC_{ij}$  values are retained for the next iteration.
- In the second, third and fourth iterations,  $LP_{ij}/CC_{ij}$  is only computed if possible at 4 locations around each best position retained in the previous iteration, defined by:

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

with GAP reduced to a half in each one of the iterations until having the value 1.

After all 4 iterations, up to 3 ‘adjustment centres’ (value of MAX\_NUM\_WINDS parameter) are retained: the absolute ‘best value’ and 2 ‘local best values’. The line/column and latitude/longitude location of the 3 ‘adjustment centres’ in the later image are additionally refined by second order interpolation if configurable parameter USE\_SUBPIXELTRACKING = 1 is used (which is the default option). Considering for example ‘Cross correlation tracking method’, with POS\_REAL and POS being the line and element location of the correlation centres after and before interpolation, and  $CC_{-1}$ ,  $CC_{+1}$ ,  $CC$  the correlation values one position up/left, down/right and at the centre:

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

For ‘Cross correlation method’ it is also requested that the correlation in the absolute maximum be greater than configurable parameter MIN\_CORRELATION (with a default value of 80% in MSG/SEVIRI cases and 50% in GOES-N cases).

### TEST AND SELECTION OF THE CORRELATION CENTRE

The reason to preserve more than one ‘adjustment centre’ is that the first choice could not be the right one. With the procedure implemented, a ‘first candidate’ is defined. The conditions for a ‘secondary centre’ to be promoted to ‘first candidate’ are:

- Brightness temperature mean difference and standard deviation difference, between the initial tracer and the ‘secondary centre’, smaller than 2K (CORR\_CENTRE\_TEMP\_LIMIT).
- ‘Big pixel class difference’, defined as the sum of squared differences of big pixel classes between the initial tracer location and the ‘secondary centre’ location (being CLASS\_n values=0,1,2), smaller than 4 (CORR\_CENTRE\_ARRAY\_LIMIT).
- ‘Centile difference’, defined as the centile difference between the frontier position in the initial tracer location and the ‘secondary centre’, not exceeding 20% (CORR\_CENTRE\_CORR\_LIMIT).
- In the case the ‘Centile difference’ is greater than 20%, the ‘secondary centre’ can still be promoted to ‘first candidate’ recomputing the ‘Big pixel class difference’. The ‘Big pixel class difference’ must be smaller than 6 (CORR\_CENTRE\_ARRAY\_LIMIT+2), considering a CLASS\_n ‘frontier’ defined by the mean value of the frontiers considered in the ‘initial tracer’ and the ‘secondary centre’.

If no secondary centre is complying, the procedure is still tried with ‘Temperature difference’ and ‘Big pixel class difference’ limits relaxed to the double.

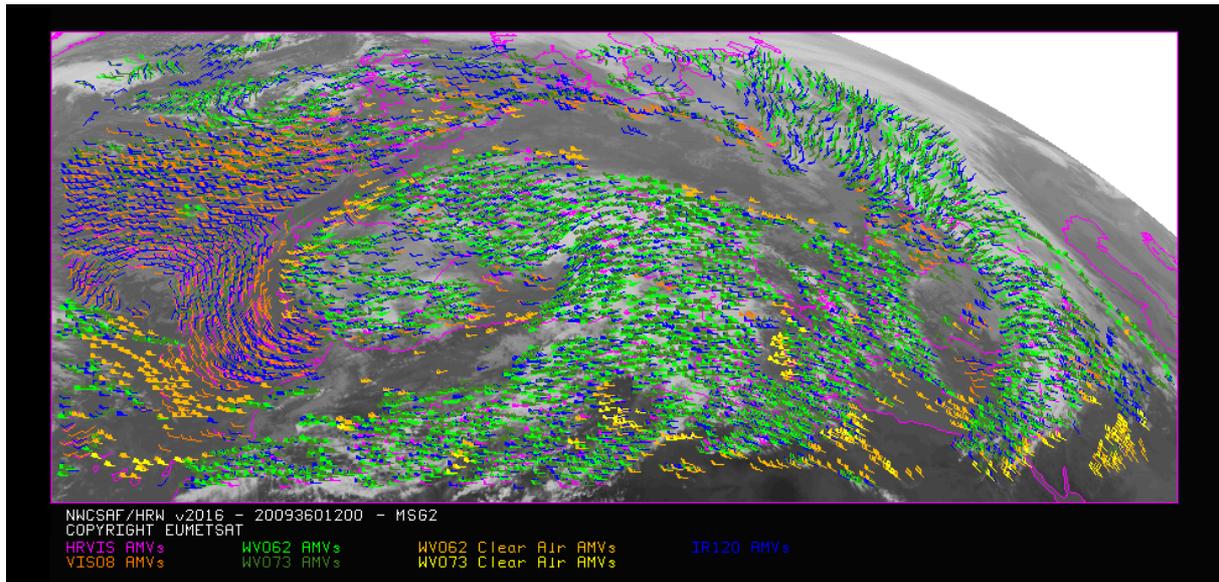


Figure 6: AMVs considering the satellite channel used for the AMV calculation, for the MSG series High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)

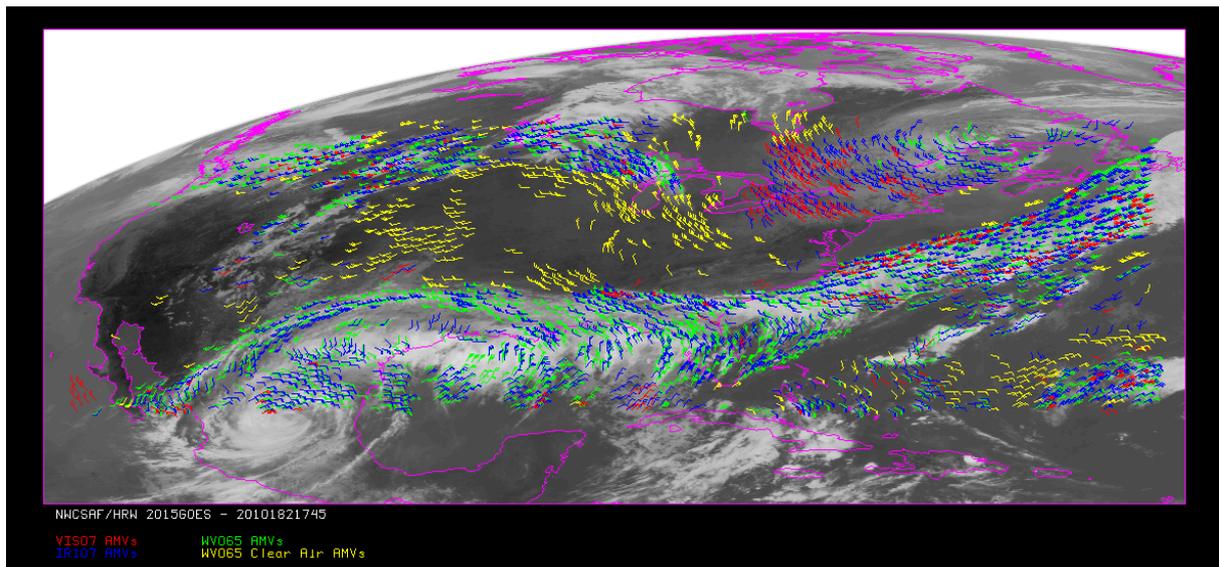


Figure 7: AMVs considering the satellite channel used for the AMV calculation, for the GOES-N series High Resolution Winds example defined in Figure 24 (1 July 2010 1745Z, GOES13 satellite)

### 2.2.2.5 'Brightness temperature interpolation method' height assignment

This method is used when configurable parameter `DEFINewithCONTRIBUTIONS = 0`, when the wind guess is used to define the tracking position 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 current slot. It is additionally only available if a NWP temperature forecast is provided, with a minimum number of NWP levels defined by the user through configurable parameter `MIN_NWP_FOR_CALCULATION`, with a default value of 4 (if the number of provided NWP temperature levels is smaller than this, the processing of 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 (MSG/IR108,IR120,WV62,WV73 or GOES-N/IR107,WV65); IR120 brightness temperature is used in the MSG/SEVIRI case and IR107 brightness temperature in the GOES-N case for the visible channels. With these data:

- The 'Base temperature' is computed with  $T_{\text{Base}} = T_{\text{Average}} + \text{SIGMA\_FACTOR} \cdot \sigma_{\text{Cloud}}$ , where  $T_{\text{Average}}$  is the mean value and  $\sigma_{\text{Cloud}}$  the standard deviation of the brightness temperature. `SIGMA_FACTOR` has been statistically adjusted to have the best possible validation statistics, with `SIGMA_FACTOR=1.2` for the Visible channels and 0.0 in the rest of cases.
- The 'Top temperature' is computed through the Brightness temperature of the coldest class in the tracer temperature histogram, represented at least by 3 pixels after histogram smoothing. If no value is found, the coldest class represented at least by 2 pixels is considered.

A temperature to pressure conversion is then obtained through the interpolation of these two values to the NWP forecast model. For this procedure, there is a vertical interpolation inside the first pressure interval containing the desired temperature (starting from the lowest level); temporal interpolation is considered inside the two nearest time values for which NWP data have been provided; horizontally the value of the nearest grid point is taken. If the temperature is too high or too low, 1000 or 50 hPa values are assigned (`MAX_PRESSURE_BOUNDARY` and `MIN_PRESSURE_BOUNDARY`).

After this, with configurable parameter `USE_CLOUDTYPE = 1` and if NWC/GEO CT Cloud Type output is available for the selected region and prior slot (when the tracers were calculated), it is read to define which of the calculated pressure values ('base pressure', 'top pressure') represents best the displacement defined by the AMV.

The tracer cloud type is defined for each tracer as the most common value of the NWC/GEO Cloud Type output inside the tracer, if its presence is at least  $\frac{3}{2}$  times that of the second most common. If this condition does not occur, values Tracer cloud type = 21 (multiple cloudy types), = 22 (multiple clear air types), or = 23 (mixed cloudy/clear air types) are defined, when respectively the two most common cloud types inside the tracer are both cloudy types, both clear air types, or none of these two cases. A tracer is additionally only considered as valid in the visible and infrared cases when at least a 5% of its pixels are defined as cloudy. If NWC/GEO CT Cloud Type output is not available or `USE_CLOUDTYPE = 0`, the value "not processed" is defined for the 'Tracer cloud type'. All possible values are those shown 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 tracer cloud type and the channel they have been calculated with. These cases are identified inside a blue cell in *Table 6*, and are related to: cloud free tracers in the visible and infrared channels, fractional clouds in all cases (which in general show worse validation statistics), and cloud types for which the Root mean square vector difference (RMSVD) is at least a 25% worse than for the channel with the best statistics for that Cloud type.

Considering the rest of cases, the height assignment is defined through: the 'top pressure' in Water vapour clear air tracers, in tracers related to "High semitransparent thin clouds" and "High semitransparent meanly thick clouds", and in tracers related to "High semitransparent clouds above other clouds or above snow/ice" in the infrared channels (identified with 'Top' in *Table 6*). In all other cases, the height assignment is defined through the 'base pressure' (identified with 'Base' in *Table 6*).

If USE\_CLOUDTYPE = 0 or NWC/GEO CT Cloud Type output is not available, because most cloud types fit better with the ‘base pressure’, the ‘base pressure’ is considered for all tracers.

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 Tracer cloud type parameter

MSG channels	HRVIS	VIS06	VIS08	WV062	WV073	IR108	IR120
GOES-N channels	VIS07			WV065		IR107	
1 Cloud free land				Top	Top		
2 Cloud free sea				Top	Top		
3 Land contaminated by snow/ice				Top	Top		
4 Sea contaminated by ice				Top	Top		
5 Very low cumulus/stratus	Base	Base	Base		Base	Base	Base
6 Low cumulus/stratus	Base	Base	Base		Base	Base	Base
7 Medium cumulus/stratus	Base	Base	Base		Base	Base	Base
8 High opaque cumulus/stratus	Base			Base	Base		
9 Very high opaque cumulus/stratus	Base			Base	Base		
10 Fractional clouds							
11 High semitransp. thin clouds				Top	Top	Top	Top
12 High semitransp. meanly thick clouds	Top			Top	Top	Top	Top
13 High semitransp. thick clouds	Base			Base	Base	Base	Base
14 High semitransp. above other clouds				Base	Base	Top	Top
15 High semitransp. above snow/ice				Base	Base	Top	Top
21 Multiple cloud types	Base			Base	Base	Base	Base
22 Multiple clear air types				Top	Top		
23 Mixed cloudy/clear air types	Base			Base	Base	Base	Base

Table 6: AMV filtering related to the ‘AMV cloud type’ and each channel, and consideration of the ‘top pressure’ or ‘base pressure’ in the “Brightness temperature interpolation height assignment method” for the valid cases

Operationally, this Height assignment method is run before the ‘tracer tracking’. When the wind guess option is considered for the calculation of the ‘tracking area centre’, this ‘tracking area centre’ is also calculated through the extrapolation of the NWP rectangular wind components at the given location, at the pressure level defined for the AMV by this height assignment method (even in the case the AMV pressure level is later recalculated with the other Height assignment method, “CCC method”).

### 2.2.2.6 'CCC method' height assignment (Cloudy cases)

This method ('Cross Correlation Contribution method') was developed by Régis Borde and Ryo Oyama and is documented in the 2008 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 selected region and slot before the running of GEO-HRW product (if their outputs are not available, GEO-HRW product skips this method using the AMV pressure values provided by the 'Brightness temperature interpolation method').

The method defines the AMV pressure level considering the pressure of the pixels contributing most to the image correlation. It has the advantage of including in the height assignment all procedures defined in CTTH product for the Cloud pressure calculation:

- Opaque cloud top pressure retrieval from Window IR108 and IR120 brightness temperatures, with simulation of radiances with RTTOV, and ability for thermal inversion processing,
- Semitransparent cloud top pressure retrieval with the Radiance ratioing technique and the H<sub>2</sub>O/IRW intercept method, considering WV62, WV73 and IR133 channels,

which are common methods used by other AMV producers.

The implementation of 'CCC method' is defined through configurable parameters TRACKING=CC and DEFINEWITHCONTRIBUTIONS=1, and it is run after the tracer tracking. In case the wind guess is also used for the definition of the tracking area (with WIND\_GUESS = 1), the AMV pressure and temperature values calculated by 'CCC method' replace the values calculated previously by 'Brightness temperature interpolation method'. In case DEFINEWITHCONTRIBUTIONS=0, or NWC/GEO CT Cloud Type or NWC/GEO CTTH Cloud Top Temperature and Pressure outputs are not available, 'CCC method' is skipped by GEO-HRW algorithm and the other pressure and temperature values are kept.

A 'CCC pressure value' and 'CCC temperature value' are calculated for each 'tracking adjustment centre' considering the partial contribution to the correlation (CC<sub>ij</sub>), CTTH Cloud Top Pressure (CTP<sub>ij</sub>) and Cloud Top Temperature (CTT<sub>ij</sub>) for pixels inside the tracking 'adjustment centre' image, with:

$$P_{CCC} = \frac{\sum(CC_{ij} \cdot CTP_{ij})}{\sum CC_{ij}} \quad T_{CCC} = \frac{\sum(CC_{ij} \cdot CTT_{ij})}{\sum CC_{ij}}$$

A 'CCC Cloud type' is also calculated as the one with the highest sum of partial contributions to correlation. A 'CCC pressure error value' is also calculated with the formula:

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

useful as a possible Quality control parameter for the output AMVs. A maximum pressure error can be defined with the configurable parameter MAXPRESSUREERROR (default value 150 hPa). For these calculations, 'CC<sub>ij</sub> partial contributions to correlation' from each pixel are calculated with the formula:

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

where T<sub>ij</sub>/S<sub>ij</sub> are the 'N\_Value matrix' values for each pixel inside the tracer and the adjustment centre respectively, NUM is the total number of pixels, T<sub>M</sub>/S<sub>M</sub> are the mean values and σ<sub>T</sub>/σ<sub>S</sub> the standard deviations of the corresponding 'N\_Value matrices'. Only pixels with valid CTP<sub>ij</sub>/CTT<sub>ij</sub>/CT<sub>ij</sub> values, corresponding to cloudy non fractional cloud types, and with CC<sub>ij</sub> over a threshold (the mean correlation contribution or zero if so no pixels are kept) are considered in all these sums. The procedure has to be repeated for the up to three 'adjustment centres' defined for each tracer.

Considering the calculations defined by 'CCC method', the pixels are distributed inside a graph Reflectance(Pixel correlation contribution) or Brightness temperature(Pixel correlation contribution), used respectively for the visible channels and for the infrared/water vapour channels. This graph has in general the shape of the letter 'C' with two branches, as shown by the lower graphs in *Figures 9 and 10* (corresponding to a MSG/VIS08 and MSG/IR108 case). In this graph with two branches, the largest partial contributions to correlation are given by the brightest and darkest pixels (for the visible channels), and by the warmest and coldest pixels (for the infrared/water vapour channels).

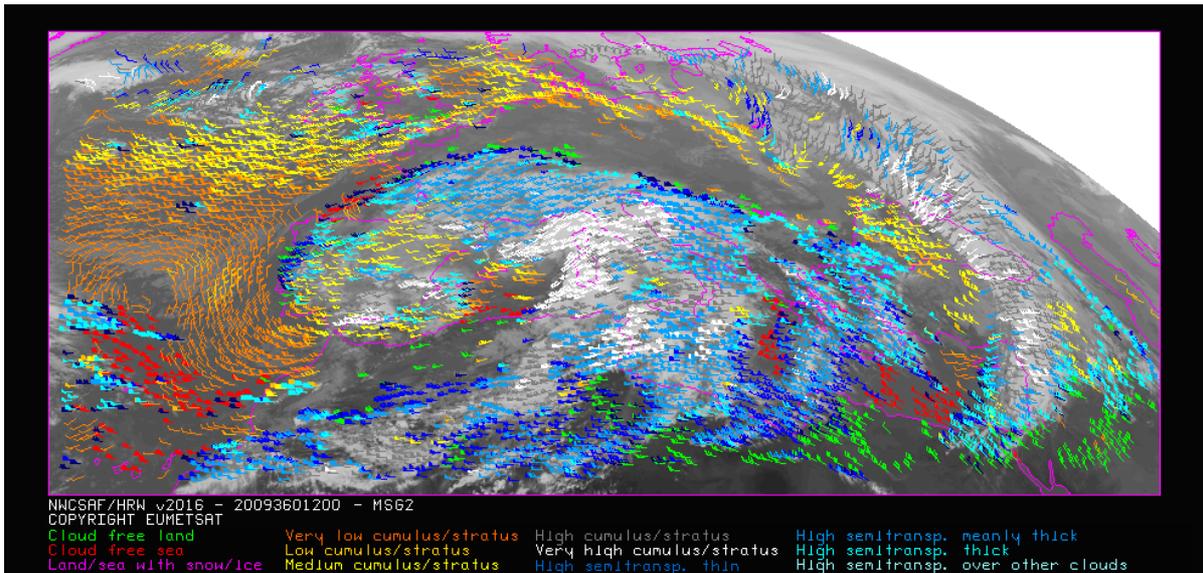
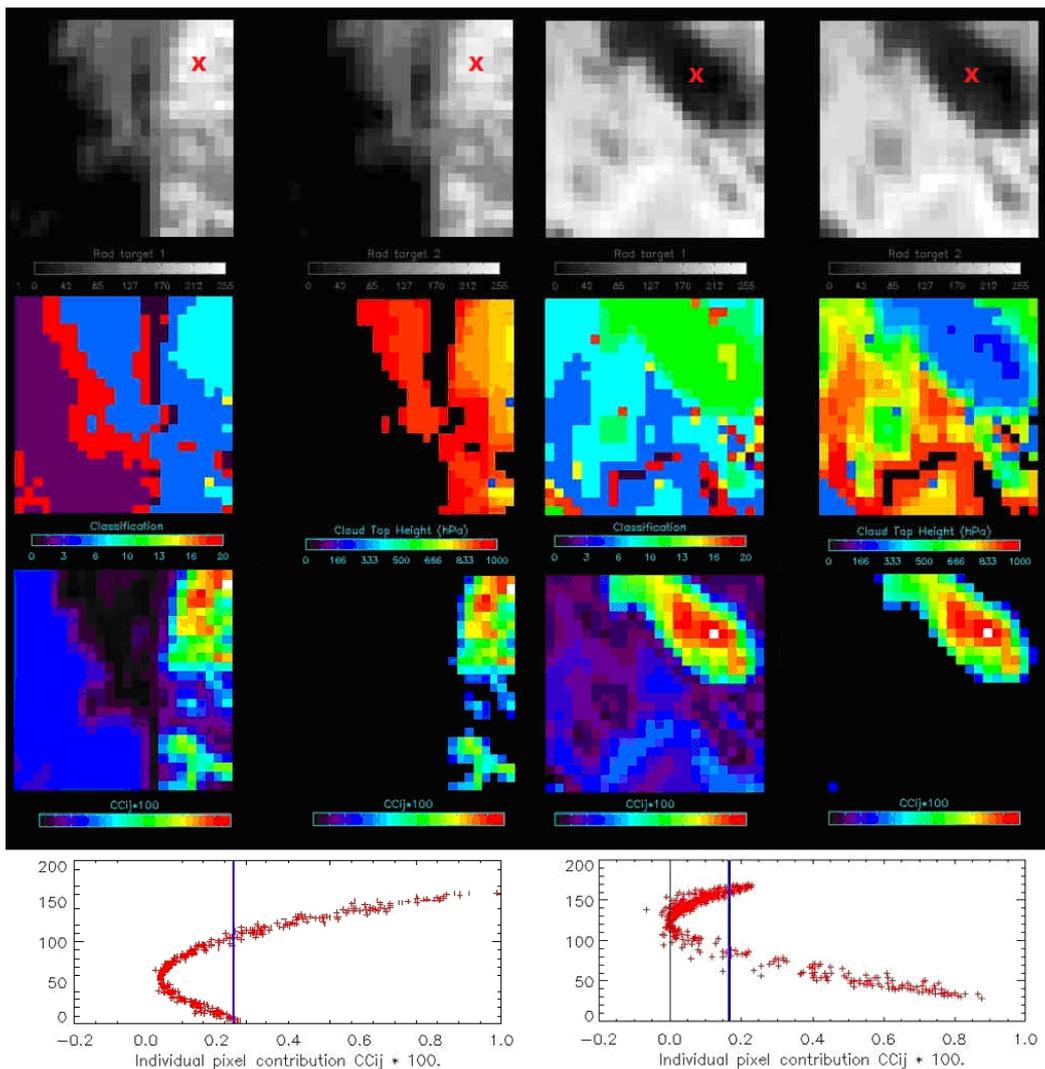


Figure 8: AMV cloud type values (as defined by “CCC height assignment method”) for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)



Figures 9 and 10: Matrices and graphs used in the calculation of “CCC height assignment method”, 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 position of the tracer and the tracking centre as defined with  $DEFPOSWITHCONTRIBUTIONS = 1$ , are shown as a red cross in the images in the first row

In GEO-HRW-v50, the original calculations defined for ‘CCC method’ in [RD.17] document are considered, so that the pressure level corrections that can be implemented later in Chapter 2.2.2.7 can be understood as ‘cloud depth corrections’ respect to the ‘cloud top level’. This way, ‘CCC method’ considers only the pixels whose reflectance is higher than the threshold in the visible cases (i.e. inside the “bright branch of the Reflectance(Pixel correlation contribution) graph”), or whose brightness temperature is colder than the threshold in the infrared and water vapour cloudy cases (i.e. inside the “cold branch of the Brightness temperature(Pixel correlation contribution) graph”). This last procedure changes respect to the one used in the previous version of GEO-HRW algorithm.

Some more elements useful to understand ‘CCC method’ are shown in *Figures 9 and 10*. In the first row, the ‘N\_Value’ matrices for the ‘tracer’ in the initial image and for the corresponding ‘adjustment centre’ in the second image are shown. In the second row, the NWC/GEO CT Cloud type and CTTH Cloud Top Pressure corresponding to the ‘adjustment centre’ are shown. In the third row, the ‘CCij matrix’ values (partial contributions to correlation for each pixel) are shown; in the left considering all pixels and in the right considering only those over the threshold (which in these cases is the mean contribution to the correlation).

Only those pixels contributing most to the image correlation, and having both a value in the right middle and lower matrices of *Figures 9 and 10* are used in the sums  $P_{CCC}$ ,  $T_{CCC}$ ,  $\Delta P_{CCC}$ . In the MSG/VIS08 example, these pixels correspond only to the cloudy bright pixels in the right part of the tracer, whose cloud types are “very low and low cumulus/stratus”, defining values of  $P_{CCC}=834$  hPa and  $\Delta P_{CCC}=27$  hPa. In the MSG/IR108 case, these pixels correspond only to the high level cloud in the upper right corner of the tracer, defining values of  $P_{CCC}=286$  hPa and  $\Delta P_{CCC}=24$  hPa.

Since GEO-HRW-v40, and with configurable option `DEFPOSWITHCONTRIBUTIONS = 1` (which is the default option), the location of the AMV inside the tracer in both initial and final images is defined not as the tracer/tracking centre but as the weighted position displacement defined with the similar formulae (where  $X_{ij}$  and  $Y_{ij}$  correspond to the line and column position of each pixel):

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

With this relocation of the AMV, its position is related to the part of the tracer with a largest correlation contribution. When trajectories are defined (as already told with configurable parameter `CALCULATE_TRAJECTORIES = 1`), tracking consecutively during several slots the same tracer, this relocation of the AMV position is only calculated for the first AMV in the trajectory and keeps the same value during all the time the trajectory is alive, to avoid discontinuities in its positioning.

This height assignment method is defined as the default option for GOES-N satellite series (for which NWC/GEO Cloud Mask, Cloud Type and Cloud Top Temperature and Height can be calculated, but not NWC/GEO Cloud Microphysics).

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

In the examples shown in the previous chapter, it is clear that 'CCC method' offers a direct correspondence between the pressure levels given for GEO-HRW Cloudy AMVs and Trajectories, and those given to the Cloud tops by NWC/GEO CTTH product, eliminating any possible incongruence between both products. It also defines a clear correspondence between the elements considered for the pressure level calculations, and the real cloud/humidity 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 would better be related to a pressure level different than the Cloud top. A study has been done for the development of GEO-HRW-v50, suggesting that the "difference between the AMV pressure level calculated with CCC method and the AMV best fit pressure level" can be related to the Cloud depth.

For this study, GEO-HRW-v50 makes use of a new product included in NWC/GEO v2016 software package: CMIC or Cloud microphysics, which provides (among other parameters) the "Cloud phase" for each cloudy pixel, the "Liquid water path" for each liquid cloud pixel and the "Ice water path" for each ice cloud pixel (these two last parameters being related to the cloud depth).

The 'CCC Cloud phase' is then defined in a way similar to the one used for the 'CCC Cloud type' in the previous chapter (as the phase with the highest sum of partial contributions to correlation), with four possible values: Liquid phase, Ice phase, Mixed phase, Undefined phase. The 'CCC Liquid water path value' is then calculated for Liquid phase AMVs, and the 'CCC Ice water path value' is then calculated for Ice phase AMVs, considering the parameters provided by CMIC output and the formulae used in the previous chapter for example for the AMV pressure:

$$LWP_{CCC} = \frac{\sum(CC_{ij} \cdot LWP_{ij})}{\sum CC_{ij}} \quad IWP_{CCC} = \frac{\sum(CC_{ij} \cdot IWP_{ij})}{\sum CC_{ij}}$$

considering only Liquid pixels in the first formula and Ice pixels in the second formula.

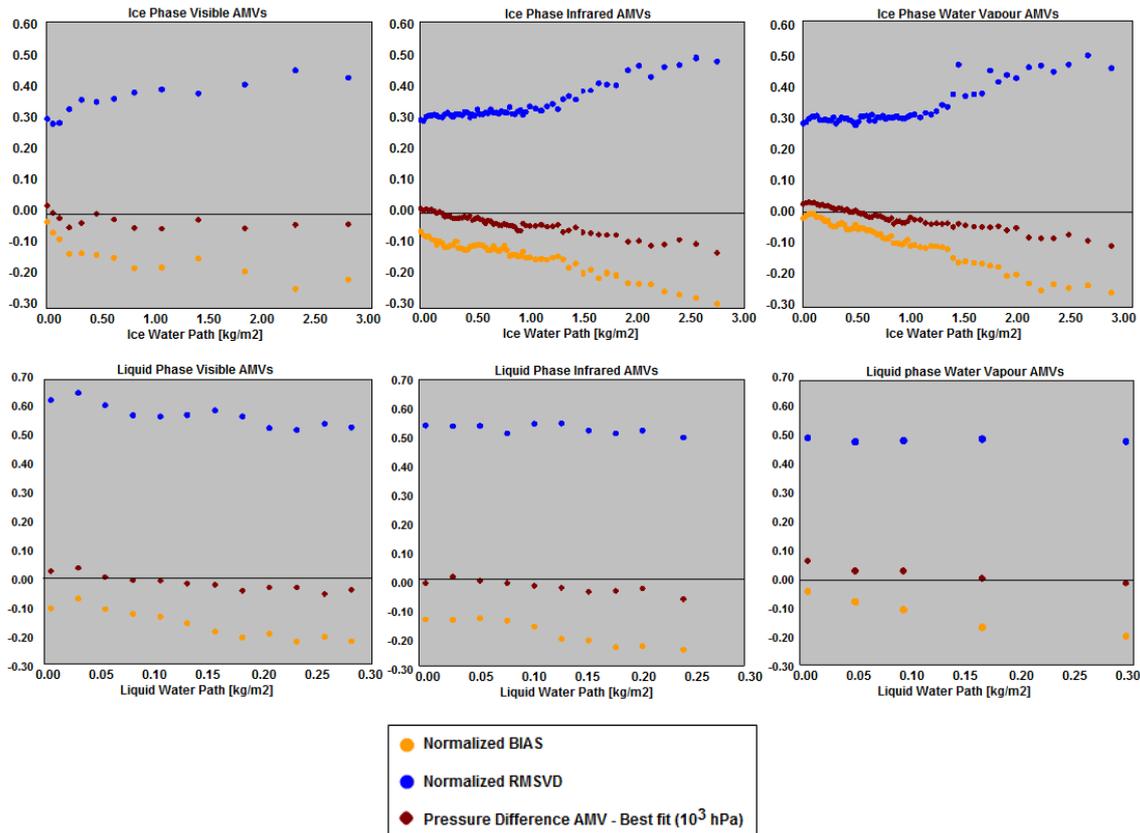
An empirical relationship has been found to exist between the "difference between the AMV pressure level calculated with CCC method and the AMV best fit pressure level", and the "CCC Liquid/Ice water path value" for the AMV, so that a correction for the "AMV pressure level" can be defined. Using for the tuning of this experimental relationship the 1200Z Cloudy AMVs for MSG2 satellite between July 2010 and June 2011 in the European and Mediterranean region, and defining different procedures for Liquid/Ice Cloud Visible AMVs, for Liquid/Ice Cloud Infrared AMVs and for Liquid/Ice Cloud Water vapour AMVs, Figures 11 to 16 in next page are obtained. The reference used for the definition of the best fit level have been Radiosounding wind data.

The "difference between the AMV pressure level calculated with CCC method and the AMV best fit pressure level" is in general negative, meaning that the "AMV 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".

The empirical relationship between the "difference between the AMV pressure level calculated with CCC method and the AMV best fit pressure level" and the "AMV liquid/ice water path" values has been fitted through a double linear/constant regression, considering separately liquid/ice phase AMVs, calculated with visible/infrared/water vapour channels. This double linear/constant regression has shown to work better than a simple linear regression in all the cases.

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 *Table 7*. As already mentioned, this correction is in general positive (excepting only AMVs with very small liquid/ice water path values), so locating in general the AMVs in a level nearer to the ground. A control is later defined through the "Orographic flag" to avoid that this correction locates the AMVs at a level below the ground.

Verifying AMV statistics for a different period (like the Reference AMV Validation period of July 2009-June 2010 in the European and Mediterranean region with MSG2 satellite used in several GEO-HRW versions up to now), it can be seen that the Microphysics corrections cause a reduction in all validation parameters (NBIAS, NMVD, NRMSVD), which are largest for the NBIAS. More information about the effect in the Validation statistics of the Microphysics correction can be found in the Validation report for GEO-HRW v5.0 (document [AD.15]).



Figures 11 to 16: Graphs relating the “difference between the AMV pressure level calculated with CCC method and the AMV best fit pressure level” (in 10<sup>3</sup> hPa) in red, the Normalized BIAS in yellow, and the Normalized RMSVD in blue, with the ‘CCC Ice/Liquid Water Path value’ (in kg/m<sup>2</sup>), for Visible AMVs (left), Infrared AMVs (centre) and Water vapour AMVs (right). 1200Z Cloudy AMVs for MSG2 satellite during the July 2010-June 2011 period in the European and Mediterranean region have been used for this study

Correction for the AMV pressure level [in hPa] based on the Cloud microphysics	
<b>VISIBLE LIQUID PHASE CLOUDY AMVs</b> MIC.CORR[hPa] = 12 without LWP MIC.CORR[hPa] = -30+316*LWP[kg/m <sup>2</sup> ] if LWP < 0.2594 kg/m <sup>2</sup> MIC.CORR[hPa] = 52 if LWP > 0.2594 kg/m <sup>2</sup>	<b>VISIBLE ICE PHASE CLOUDY AMVs</b> MIC.CORR[hPa] = 29 without IWP MIC.CORR[hPa] = -26+295*IWP[kg/m <sup>2</sup> ] if IWP < 0.2271 kg/m <sup>2</sup> MIC.CORR[hPa] = 41 if IWP > 0.2271 kg/m <sup>2</sup>
<b>INFRARED LIQUID PHASE CLOUDY AMVs</b> MIC.CORR[hPa] = 17 without LWP MIC.CORR[hPa] = -8+261*LWP[kg/m <sup>2</sup> ] if LWP < 0.1685 kg/m <sup>2</sup> MIC.CORR[hPa] = 36 if LWP > 0.1685 kg/m <sup>2</sup>	<b>INFRARED ICE PHASE CLOUDY AMVs</b> MIC.CORR[hPa] = 16 without IWP MIC.CORR[hPa] = -5+45*IWP[kg/m <sup>2</sup> ] if IWP < 3.0444 kg/m <sup>2</sup> MIC.CORR[hPa] = 132 if IWP > 3.0444 kg/m <sup>2</sup>
<b>WATER VAPOUR LIQUID PHASE AMVs</b> MIC.CORR[hPa] = -31 without LWP MIC.CORR[hPa] = -63+245*LWP[kg/m <sup>2</sup> ] if LWP < 0.2571 kg/m <sup>2</sup> MIC.CORR[hPa] = 0 if LWP > 0.2571 kg/m <sup>2</sup>	<b>WATER VAPOUR ICE PHASE AMVs</b> MIC.CORR[hPa] = -6 without IWP MIC.CORR[hPa] = -22+45*IWP[kg/m <sup>2</sup> ] if IWP < 2.7555 kg/m <sup>2</sup> MIC.CORR[hPa] = 102 if IWP > 2.7555 kg/m <sup>2</sup>

Table 7: Correction for the AMV pressure level [in hPa], based on the Cloud microphysics

“CCC height assignment method with microphysics correction” is implemented as default option with MSG satellites, with configurable parameter `USE_MICROPHYSICS = 2`. The option `USE_MICROPHYSICS = 1` calculates the value of the Microphysics correction, but does not correct the AMV pressure value with it. In both cases, the Microphysics correction values is provided in the output files as the “Pressure error or 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, GEO-HRW tries to run “CCC method height assignment without Microphysics correction”.

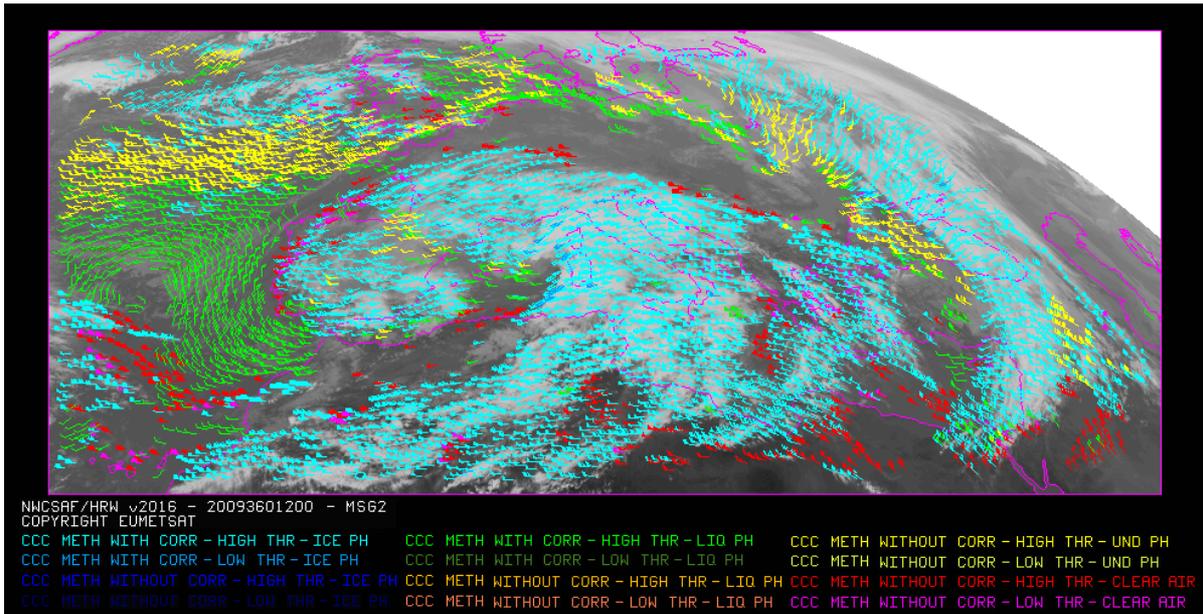


Figure 17: AMV height assignment (“CCC height assignment method with Microphysics correction”, using “CCC method high/low calculation threshold”), and AMV microphysics characterization (as “Ice cloud”, “Liquid cloud”, “Undefined phase cloud”, “Clear air”) for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)

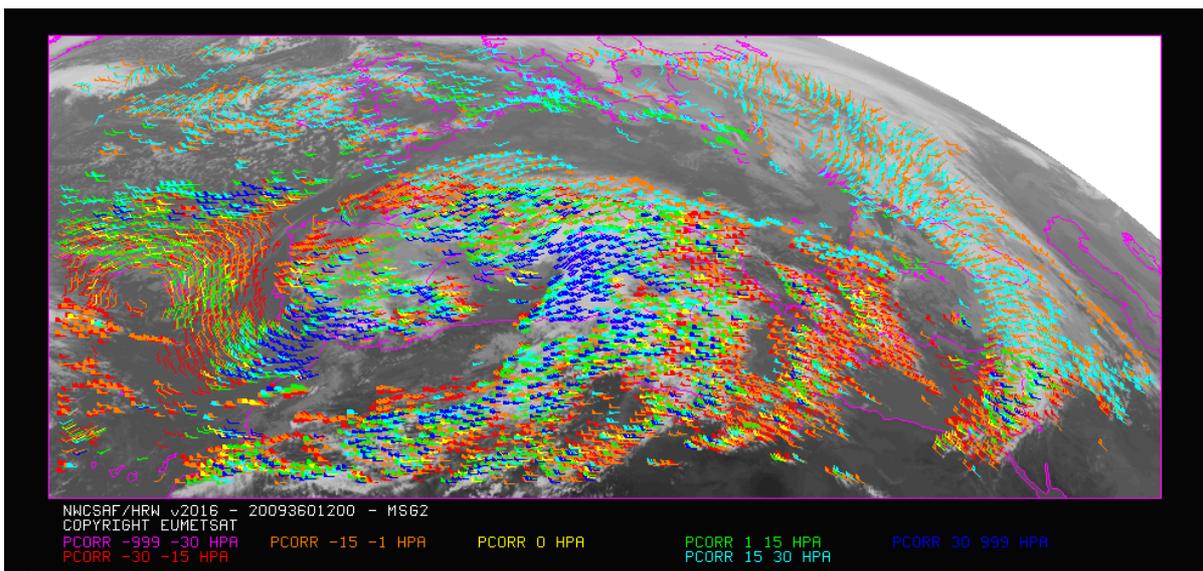


Figure 18: AMV pressure corrections (for the cases in which “CCC height assignment method with Microphysics correction” has been used), for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, MSG2 satellite)

### **2.2.2.8 ‘CCC method’ height assignment (Water vapour clear air cases)**

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

A "Water vapour clear air AMV" is defined as a "Water vapour AMV" for which the sum of “partial contributions to the correlation” is larger for the group of “clear air pixels” (Cloud type 1 to 4) than for the group of “cloudy pixels” (Cloud type 5 to 9 and 11 to 15), considering all pixels inside the “tracking centre” for which the “partial contribution to the correlation” is positive.

This process identifies that a "Water vapour AMV" is a "clear air AMV" when its group of clear air pixels has the largest contribution to correlation. And so the feature that is actually being tracked between the initial and later image is a clear air feature (in spite of any presence of cloudy pixels).

After this, the ‘CCC Cloud type’ and the ‘CCC Temperature,  $T_{CCC}$ ’ are calculated in a way similar to the one described in Chapter 2.2.2.6 for the cloudy cases, although now the Brightness temperature from the corresponding channel for each pixel ( $BT_{ij}$ ) is used instead of the CTTH Cloud Top Temperature, and only the pixels whose brightness temperature is colder than the threshold are considered (i.e., only the pixels located inside the “cold branch of the Brightness temperature(Pixel correlation contribution) graph”). A ‘CCC temperature value error,  $\Delta T_{CCC}$ ’ is now also calculated considering a formula similar to the one used in the previous chapter for the pressure error:

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

Considering these data, three different temperature values are defined by next 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 then obtained through the interpolation to the NWP temperature forecast, giving three pressure values:  $P_{CCC_{MAX}}$  (related to  $T_{CCC} + \Delta T_{CCC}$ ),  $P_{CCC}$  (related to  $T_{CCC}$ ) and  $P_{CCC_{MIN}}$  (related to  $T_{CCC} - \Delta T_{CCC}$ ).

$P_{CCC}$  is defined as the ‘CCC Pressure value’ for the clear air AMVs.  $\Delta P_{CCC} = |P_{CCC_{MAX}} - P_{CCC_{MIN}}|/2$  is also defined as the ‘CCC Pressure error value’ for the clear air AMVs (only in cases for which a vertical reduction or increase of temperature is found between all three temperature values). In the cases where the ‘CCC Pressure value’ or the ‘CCC Pressure error value’ cannot be calculated, the AMVs are discarded.

### 2.2.2.9 Wind calculation

Once the latitude and longitude corresponding to the initial tracer location (defined as the tracer centre with/without the weighted position displacement defined by ‘CCC method’, depending of the value of DEFPOSWITHCONTRIBUTIONS configurable parameter), and the up to three ‘adjustment centres’ are defined (defined as the non-integer/integer position of the tracer centre in the later image with/without the position displacement defined by ‘CCC method’, and with/without the subpixel tracking process implemented, depending on the value of DEFPOSWITHCONTRIBUTIONS and USE\_SUBPIXELTRACKING configurable parameters), the rectangular coordinates of the corresponding winds (in m/s) are calculated.

Although the difference with the calculation procedure used in previous versions is completely negligible, since GEO-HRW-v50 the calculation of speed components considering the displacement along the corresponding ‘great circle’ with the ‘haversine formula’ is used.

The ‘haversine formula’ uses next procedure to calculate the Angular distance in degrees between the tracer and the adjustment centre positions (AND), and the Wind speed (SPD), considering the Initial latitude and longitude values (LAT1, LON1), the final latitude and longitude values (LAT2, LON2), the latitude and longitude differences ( $\Delta$ LAT,  $\Delta$ LON) and the time difference in hours between the tracer in the initial image and the adjustment centre in the later image (T\_INT). The coefficient CONVERSION\_DEGH2MS converts °/hour to m/s.

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

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

$$\text{SPD} = \text{CONVERSION\_DEGH2MS} \cdot \text{AND} / \text{T\_INT}$$

The bearing angle (DIR) corresponding to the given ‘great circle’ is calculated with next formulas:

$$\text{HOR} = \cos(\text{LAT1}) \cdot \sin(\text{LAT2}) - \sin(\text{LAT1}) \cdot \cos(\text{LAT2}) \cdot \text{COS}(\Delta\text{LON})$$

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

$$\text{DIR} = \text{atan}^2(\text{HOR}, \text{VER})$$

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

$$U = \text{SPD} \cdot \text{COS}(\text{DIR})$$

$$V = \text{SPD} \cdot \text{SIN}(\text{DIR})$$

Since GEO-HRW-v50, T\_INT is the real time difference in hours, between the scanning time for the lines defining the tracer location in the initial image and the adjustment centre location in the later tracking image. For MSG satellite series, this procedure takes into account the real time the image scanning began for the given slot and the time needed to scan the image lines. For GOES-N satellite series the procedure is easier, taking simply into account the scanning time for each pixel provided in the satellite input data files.

The definition of the position of the tracking area centre in the later image when the wind guess is used with WIND\_GUESS = 1, through displacement of the tracer position in the initial image with the rectangular NWP wind components, uses also since GEO-HRW-v50 an equivalent procedure with a displacement along the corresponding ‘great circle’.

### 2.2.2.10 Quality control and Choice of the best wind

Basically, the Quality Indicator method developed by EUMETSAT and implemented for the Atmospheric Motion Vectors computed at the Meteosat Product Extraction Facility/MPEF (K.Holmlund, 1998), is used here. An update has been included since GEO-HRW-v40, with some additional elements included in the MPEF/AMV algorithm, which were previously unused.

This method assigns a quantitative flag to any Atmospheric Motion Vector: Quality Index (QI, ranging from 0% to 100%). It is based on normalized functions, analytically fit to statistical properties in the behaviour of the winds. These properties relate to the expected change of the AMVs considering: temporal consistency (comparison to AMVs in the previous slot in the same location and level), spatial consistency (comparison to neighbour AMVs in the same slot in the same location and level), and consistency relative to a background (NWP forecast wind interpolated to the same slot, in the same location and level). In the two scale procedure, the GEO-HRW Quality Control is split in two different steps, representative of the 'Basic scale' and the 'Detailed scale'.

5 tests are applied (direction, speed and vector difference tests for the temporal consistency; only vector difference for the others) giving 5 individual QI; its weighted sum provides the overall QI. For the two scale procedure, an additional 'interscale spatial test' is defined for the 'Detailed AMVs' derived from a 'Basic scale tracer' (comparing to the corresponding 'Basic scale AMVs').

- The QI (0% to 100%) for the temporal direction consistency is given by:

$$QI_1 = 1 - [\tanh[DIF/(A \cdot \exp(-SPD/B) + C \cdot SPD + D)]]^E,$$

where SPD, DIF are the time-averaged wind speed, the absolute change in the parameter (in this case in direction, 0 to 180°); and the coefficients A, B, C, D, E are respectively 20, 10, 0, 10 and 4.

- The 4 QI<sub>i</sub> (0% to 100%) for the 4 other parameters (temporal speed consistency, temporal vector consistency, spatial vector consistency, forecast vector consistency) are:

$$QI_i = 1 - [\tanh[DIF/(\max(A \cdot SPD, B) + C)]]^P,$$

where DIF is the absolute speed difference or the absolute module of the vector difference, and the coefficients A, B, C, D are respectively 0.2 (0.4 for the forecast consistency test), 0.01, 1 and 3 (2 for the forecast consistency test).

This procedure is repeated in the spatial and temporal consistency for up to 3 reference AMVs in the current and previous slot (defined respectively with parameters L\_CHECK\_NUMBUDDIES and T\_CHECK\_NUMPREDEC). The weight of the contributions from each one of these reference AMVs to the final value of the spatial or temporal consistency can depend (as currently defined by L\_CHECK\_DISTWEIGHT and T\_CHECK\_DISTWEIGHT parameters) or not from a distance factor to the evaluated AMV. The distance factor to the evaluated AMV (which also defines which other AMVs in the current and previous slot are used as reference ones) is defined with formulae:

$$\alpha = A1 + A2 \cdot SPD$$

$$\beta = B1 + B2 \cdot SPD$$

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

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

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

with A1, B1 = 200; A2, B2 = 3.5; SPD, DIR, LAT = speed, direction, latitude of the evaluated AMV;

LATDIF, LONDIF = latitude and longitude difference with respect to the reference AMVs;

ER = Earth radius in kilometres.

Only reference AMVs with a distance factor smaller than 1, a pressure difference smaller than 25 hPa (defined by parameters L\_CHECK\_PRESS\_DIFF/T\_CHECK\_PRESS\_DIFF) and a latitude/longitude

difference smaller than 1.35° (defined by parameters 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 value of all these parameters is defined in `/include/HRW/hrw_QualitySchema.h` file. Additionally, a weight on the different quality tests is defined through parameters W\_SPD/W\_SPD\_HRVIS (temporal speed consistency test weight, with default value 0), W\_DIR/W\_DIR\_HRVIS (temporal direction consistency test weight, with default value 0), W\_VEC/W\_VEC\_HRVIS (temporal vector consistency test weight, with default value 3), W\_LC (spatial vector consistency test weight, with default value 3), W\_FC (forecast vector consistency test weight, with default value 1) and W\_TC (interscale spatial vector consistency test, with default value 0). With all of this, only the temporal, spatial and forecast vector consistency tests are activated in the Quality control as default option, which is the same situation than for the EUMETSAT/MPEF AMVs (although with different weights for the different quality tests; in the EUMETSAT/MPEF case the weight of the spatial and temporal vector consistency test is 2).

The user can nevertheless evaluate the impact of all these parameters in the GEO-HRW outputs, changing their corresponding values and recompiling again `$SAFNWC/bin/GEO-HRW-v50` executable file with `make clean` and `make all` at `$SAFNWC/src/HRW` directory. The weighted sum of the mentioned Quality tests defines the ‘Quality Index (QI)’ of the different AMVs, which is used for their filtering for their writing in the AMV and Trajectory output files. Two corrections are nevertheless included in this QI value before declaring it valid:

- One correction reduces the Quality of the AMVs with very low speed, and multiplies the QI with factor SPD/SPEED\_THR (where SPD = speed of the evaluated wind, SPEED\_THR = 2.5 m/s), so affecting only AMVs with a speed lower than 2.5 m/s.
- The other correction affects visible and infrared AMVs with a pressure higher than parameter C\_CHECK\_PRESS\_THR = 500 hPa only, and is a factor defined by formula:

$$1 - [\tanh[(\max(A, \text{CORR}(\text{IR108}, \text{WV62}))/B)]]^C,$$

where `CORR(IR108,WV62)` is the correlation of IR108/IR107 and WV62/WV65 channels at the location of the ‘adjustment centre’ related to the evaluated wind, and the coefficients A, B, C are respectively 0, 0.2 and 200. This correction has the name of “Image correlation test”.

Two different Quality Indices are defined for each AMV and written in the BUFR or netCDF output files: one with contribution of the forecast consistency test (Quality index with forecast) and another one without contribution of the forecast consistency test (Quality index without forecast). The Quality Index threshold for the acceptance of an AMV as valid is defined by configurable parameter QI\_THRESHOLD (with a default value of 70%). The user can also decide if the Quality index with forecast or else without forecast is used for the AMV output filtering (through configurable parameter QI\_THRESHOLD\_USEFORECAST, with a default value of 1).

Some additional considerations on the Quality Control, specific for GEO-HRW algorithm, are shown next:

- Each ‘adjustment centre’ will be flagged at this stage (with up to 3 AMVs per tracer), and all AMVs available are considered valid for the spatial comparison disregarding their Quality Index.
- It is frequent that a quality test cannot be calculated (i.e. no wind was found for the comparison). The overall QI will thus include only the available tests.
- Only one wind per tracer is selected for the AMV and Trajectory outputs. The suggested option (selected with configurable parameter BEST\_WIND\_SELECTION = 1) is: the best AMV for the tracer for the most of next 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 (significantly, with a difference larger than 20%). If this is also not definitive the AMV with the best correlation. In this case TEST output parameter will reflect, apart from the number of quality tests that each AMV has passed, whether the wind has been the best (value = 3), slightly worse (value = 2, with a percentage difference larger than the 1%), or fairly worse (value = 1, with a percentage difference larger than 20%) than other AMVs

calculated for the same tracer for each available criterion. If any of the quality tests could not be calculated, this is identified with the value 0.

- A different option for the best AMV selection, defined with `BEST_WIND_SELECTION = 0`, is: the best AMV for the tracer for interscale QI. If this is not definitive the best for the temporal plus spatial QIs if larger than 85%. If this is also not definitive, the AMV with the best overall QI.
- For the temporal consistency of successive AMVs related to the same trajectory, some limits are defined in the speed difference (`MEANVEC_SPEED_DIF = 10 m/s`), direction difference (`MEANVEC_DIR_DIF = 20°`) and the pressure level difference (`MEANVEC_PRESSURE_DIF = 50 hPa`), for two consecutive AMVs related to the same trajectory. These limits must be obeyed so that additional sectors can be added to the trajectory.
- With winds related to a ‘predecessor wind’, if configurable parameter `USE_MEANWIND = 1` is used, a correction of the AMV outputs for the current slot is done with the corresponding ‘predecessor wind’ for the same trajectory (when it exists), in which the mean value of speed, direction, correlation, quality, temperature, pressure and pressure error considering both AMVs is used. Nevertheless, this option is not used as the default one.

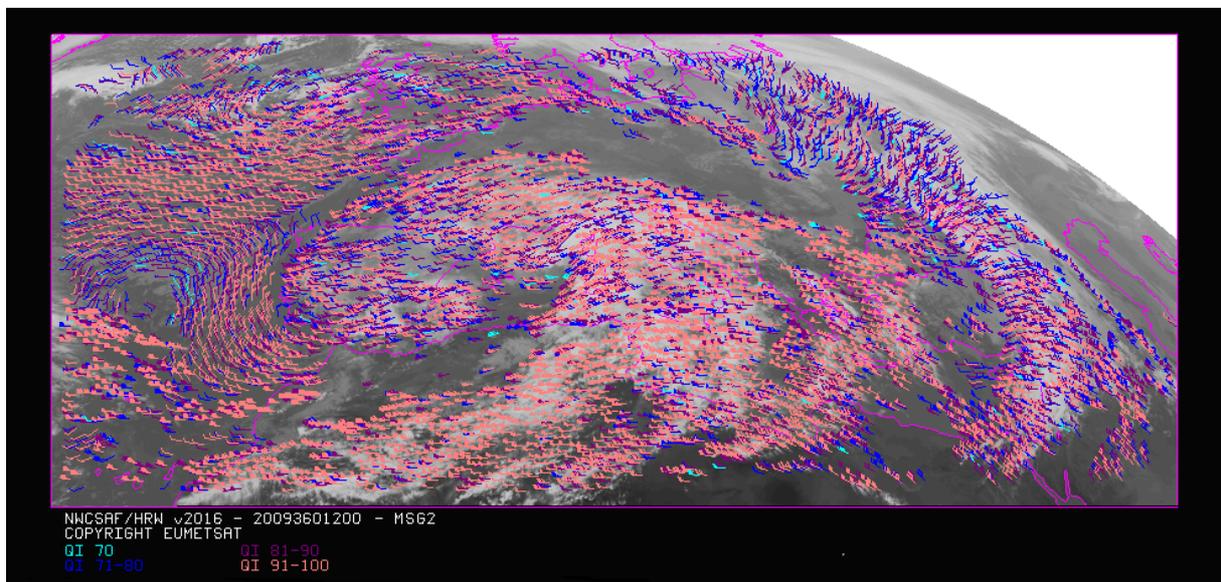


Figure 19: Quality index including forecast for the High Resolution Winds case defined in Figure 22 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

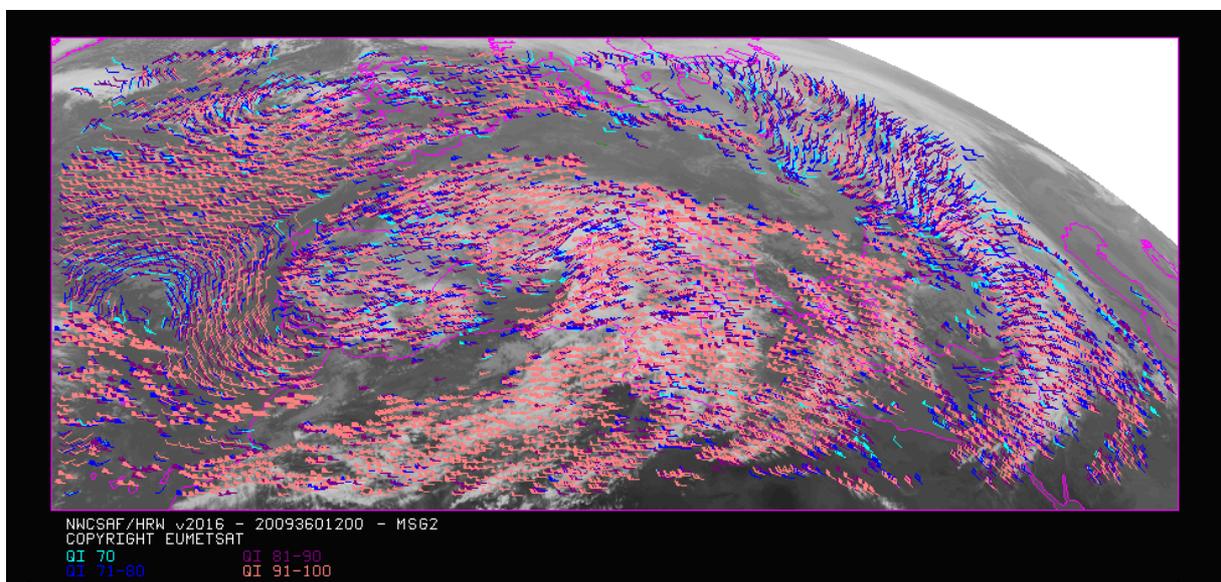


Figure 20: Quality index not including forecast for the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

### 2.2.2.11 Orographic flag

The main objective of this part of the algorithm is to incorporate topographic information, which in combination with NWP data can detect and reject those Atmospheric Motion Vectors affected by land influence. The reasons for this land influence may be:

- AMVs associated to land features, incorrectly detected as cloud tracers.
- Tracers which are blocked or whose flow is affected by mountain ranges.
- Tracers associated to lee wave clouds in the vicinity of mountain ranges.

The effect on these tracers is to present AMVs whose displacement does not correspond with the general atmospheric flow. Because of this, they should not be considered. In this part of the algorithm, with configurable parameter `USE_TOPO > 0`, an ‘orographic flag’ is calculated for each AMV with the intention of detecting this land influence.

The procedure to calculate the ‘Orographic flag’ has been simplified since GEO-HRW-v50, and needs the reading of NWP geopotential data to be available. It starts with the reading of two topography matrices for the defined satellite and positioning (`S_NWC_SFCMIN*raw`, `S_NWC_SFCMAX*raw`), to be 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. These matrices define the Representative Minimum and Maximum heights around each location.

After this, the “Representative Minimum and Maximum height matrices” are converted to “Representative Maximum and Minimum Surface pressure matrices” with NWP geopotential data. So, the “Height matrices” are converted to geopotential (multiplying by a constant value of gravity), and the provided geopotentials are inversely interpolated to pressure to define the “Representative Maximum and Minimum Surface pressure” in each pixel (`P_sfcmin`, `P_sfcmax`).

A verification is done to control that the needed NWP geopotential data are available and that the Height matrices are not located below the lowest NWP level. These “Representative Maximum and Minimum Surface pressure” matrices represent then the lowest and highest surface pressure values in locations up to one degree away of each location 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` and parameters `TOPO_PR_DIFF = 1/2` (Representative pressure level of the location) and `TOPO_PR_SUP = 25 hPa` (Pressure margin over `P_sfcmax` 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).*
- *IND\_TOPO = 2:  $P_{traz} > P_{sfcmax} + TOPO\_PR\_DIFF * (P_{sfcmin} - P_{sfcmax})$   
Very important orographic influence found.*
- *IND\_TOPO = 3:  $P_{traz} > P_{sfcmax} - TOPO\_PR\_SUP$   
Important orographic influence found.*
- *IND\_TOPO = 6:  $P_{traz} < P_{sfcmax} - TOPO\_PR\_SUP$   
No orographic influence found in the current AMV position: the AMV is over the level without orographic influence.*

The “Dynamic orographic flag” is then calculated: values of `IND_TOPO` are modified to verify the possibility of a previous in time orographic influence. This part only happens if `IND_TOPO = 6` and the tracer is related to predecessor AMVs in the previous slots. The value of `IND_TOPO = 6` is so modified considering the next conditions:

- IND\_TOPO = 0: Orographic flag was not calculated at the previous position of the AMV.
- IND\_TOPO = 4: Very important static or dynamic orographic influence was found at the previous position of the AMV ( $IND\_TOPO = 2$  or  $4$ ).
- IND\_TOPO = 5: Important static or dynamic orographic influence was found at the previous position of the AMV ( $IND\_TOPO = 3$  or  $5$ ).
- IND\_TOPO = 6: No orographic influence is found in any current or previous position of the AMV.

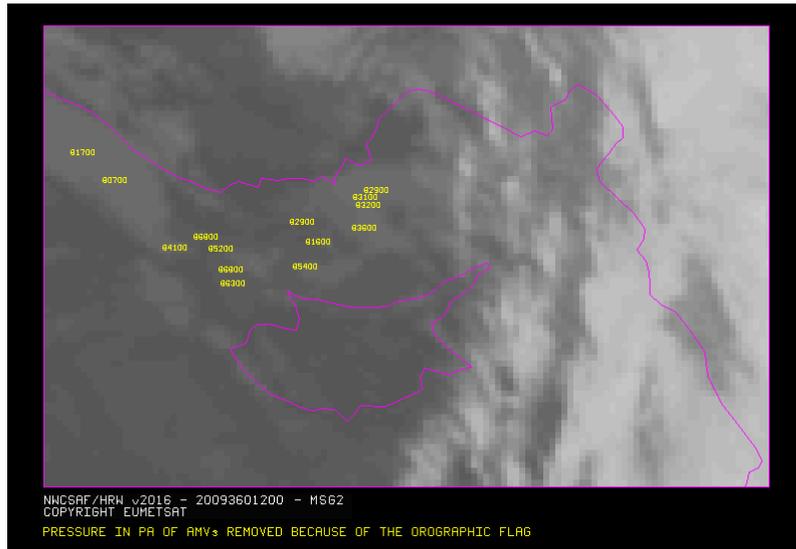


Figure 21: Pressure values in Pa for AMVs affected by orography (i.e. with Orographic flag values between 1 and 5) in a zoomed area around the island of Cyprus in the High Resolution Winds example defined in Figure 22 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite). Orographic effects are caused by the mountains in Cyprus and Turkey, reaching respectively 2000 m and more than 3000 m

Because the different ‘adjustment centres’ related to a same AMV can have different initial positions in the initial image (because of different values in the weighted position displacement defined by ‘CCC method’ with  $DEFPOSWITHCONTRIBUTIONS = 1$  configurable parameter), the up to three AMVs calculated for the same tracer can have a different ‘Orographic flag’. On the contrary, if  $DEFPOSWITHCONTRIBUTIONS = 0$ , all AMVs calculated for the same tracer have similar values in the ‘Orographic flag’.

Taking this into account, a comparison test similar to the ones in section 2.2.2.10 is calculated to compare the different AMVs for the same tracer related to orography. Possible values are:

- TESO = 3:  $IND\_TOPO$  for the AMV chosen as best wind, is the highest for all winds for the same tracer.
- TESO = 2:  $IND\_TOPO$  for the AMV chosen as best wind, is one unit smaller than for the wind for the same tracer with the best  $IND\_TOPO$ .
- TESO = 1:  $IND\_TOPO$  for the AMV chosen as best wind, is at least two units smaller than for the wind for the same tracer with the best  $IND\_TOPO$ .
- TESO = 0:  $IND\_TOPO$  could not be calculated for the AMV chosen as best wind.

With configurable parameter  $USE\_TOPO = 1$ ,  $IND\_TOPO$  and  $TESO$  variables are calculated and incorporated to the netCDF or BUFR output files. Additionally, all AMVs related to  $IND\_TOPO = 1$  are eliminated from the output files because of being located below the lowest representative pressure level. With configurable parameter  $USE\_TOPO = 2$  (which is the default option), all AMVs with any Orographic influence (i.e. all AMVs 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 it has been detected that an Atmospheric Motion Vector has a direction or velocity completely different to the ones in its immediate vicinity. It has been seen that these AMVs make statistical results worse, without justifying clearly the reason for such big changes in direction or velocity. Because of this, they can be considered as errors. To eliminate these errors, a function called “Final Control Check” can be run after the Quality Control if using configurable parameter FINALCONTROLCHECK = 1 (which is the default option).

It calculates the velocity and direction histograms with all valid AMVs calculated with the same channel in relatively 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, it is excluded (the amplitude of the columns is defined by parameters SPEED\_AMPLITUDE, DIRECTION\_AMPLITUDE).

This process might eliminate some good AMVs, but fundamentally these errors defined before. The procedure considers that the lack in the same area of another AMV with relatively similar velocities or directions is enough to consider a wind as an error, and to take it out from the output file.

Additionally, several output data filterings are included during GEO-HRW algorithm running, which sometimes depend on the value of several configurable parameters in the GEO-HRW model configuration file. These parameters are:

- WIND\_CHANNEL (default value HRVIS,VIS08,IR120,WV62,WV73 for MSG/SEVIRI satellite series; VIS07,IR107,WV62 for GOES-N satellite series), which defines the channels for which AMVs (and trajectories) are generated.
- QI\_THRESHOLD: defines the Quality index threshold for the AMVs in the output files. Depending on the value of QI\_THRESHOLD\_USEFORECAST (default value 1), the “Quality index with forecast” 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 (default value 1, meaning yes).
- MAXPRESSUREERROR: defines the maximum pressure error (in hPa) permitted in the output AMVs, when “CCC height assignment method” has been used.
- MIN\_CORRELATION: defines the minimum correlation (as a %) in the output AMVs, when the “Cross Correlation tracking” has been used.
- FINALFILTERING: defines several filterings in the output AMVs, depending on its value.
  - With FINALFILTERING > 0, the AMV pressure level filtering defined in *Table 8* is implemented (where blue layers for the different channels are eliminated; light blue layers are eliminated only for ‘Clear air AMVs’ and very dark blue layers are only eliminated if configurable parameter VERYLOWINFRAREDAMVS = 0). These cases with elimination of data correspond to AMVs with NRMSVD values at least one sixth higher than for the satellite channel with a minimum NRMSVD.
  - With FINALFILTERING > 1 (which is the default option), the Cloud type filtering defined in *Table 6* is implemented for the different satellite channels.
  - With FINALFILTERING > 2, AMVs with a “Spatial quality flag” = 1,2 are also eliminated.
  - Finally, with FINALFILTERING = 4, AMVs with a “Spatial quality flag” = 0 are also eliminated.

MSG sat.	HRVIS	VIS06	VIS08	IR108	IR120	WV62	WV73
GOES-N sat.	VIS07			IR107		WV65	
100-199 hPa							
200-299 hPa							
300-399 hPa							
400-499 hPa							
500-599 hPa							
600-699 hPa							
700-799 hPa							
800-899 hPa							
900-999 hPa							

*Table 8: AMV filtering related to the Pressure level and Satellite channel*

## 2.3 HIGH RESOLUTION WINDS (GEO-HRW) PRACTICAL CONSIDERATIONS

### 2.3.1 High Resolution Winds Validation for MSG satellite series

The main GEO-HRW-v50 Validation statistics against Radiosounding winds for GEO-HRW-v50 Basic AMVs, following the criteria defined at the Third International Winds Workshop (Ascona, Switzerland, 1996) for the comparison of satellite winds, are shown next. Additional Validation statistics can be obtained in the “Validation report for GEO-HRW v5.0” (document [AD.15]).

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

Two different configurations are shown in the validation: the first one considering the conditions defined in the default `$SAFNWC/config/safnwc_HRW.cfm.MSG15MIN` configuration file, in which “CCC height assignment with Microphysics correction” is considered, and for which NWC/GEO Cloud product outputs (CMA, CT, CTTH, CMIC) have to be available. The other one considers the running of GEO-HRW-v50 with the same configuration file, but without the provision of NWC/GEO Cloud product outputs, so considering “Brightness temperature interpolation height assignment without cloud products”.

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

The validation parameters shown are: NC (Number of collocations between GEO-HRW AMVs and Radiosounding data), SPD (Mean speed of Radiosounding data), NBIAS (Normalized bias), NMVD (Normalized mean vector difference), and NRMSVD (Normalized root mean square vector difference”).

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

Comparing the statistics for the different satellite channels, the MVD and NRMSVD seems very different considering all layers together, with changes larger than the 50% between the best case (Cloudy WV062 AMVs) and the worst case (Cloudy VIS08). Nevertheless, this is only caused by the different proportion of AMVs in the different layers for each channel. Inside each one of them, differences of NMVD and NRMSVD for the different channels are much smaller.

Doing the comparison with GEO-HRW-v40 AMV Validation (available for example in the Validation report for GEO-HRW v5.0, document [AD.15]), it can be seen that with the default circumstances for both algorithms (Basic AMVs; Cross correlation tracking; CCC height assignment; Microphysics correction implemented in GEO-HRW-v50 procedure), the Validation results for GEO-HRW-v50 algorithm improves for all Validation parameters, with:

- An increase in the amount of compared AMVs of about a 17% (from 1239492 to 1483511),
- A reduction in the NBIAS of about a 20% (from -0.10 to -0.08),
- Smaller reductions in the NMVD (from 0.31 to 0.30) and NRMSVD (from 0.38 to 0.36).

So, the evolution of GEO-HRW-v50 respect to previous versions of the algorithm is positive, with more AMV data with a better quality. Considering the different layers, the GEO-HRW Product Requirement Table Optimal accuracy (with a value of 0.35) is reached in the High layer, and the GEO-HRW Product Requirement Table Target accuracy (with values respectively of 0.50 and 0.56) is reached in the Medium and Low layer, both using and not using NWC/GEO Cloud products as input.

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

The report shows that NWC/GEO-HRW AMVs together with the EUMETSAT/MPEF AMVs have the two best validation statistics in the AMV intercomparison, using “CCC method” for the AMV height assignment.

GEO-HRW-v50 AMVs (Jul 2009-Jun 2010)	Cloudy	Clear	All						
	HRVIS	VIS06	VIS08	WV62	WV73	IR108	IR120	Air	AMVs
NC	31630	97221	87177	256951	331831	313072	317120	48509	1483511
SPD [m/s]	16.64	10.51	10.48	22.78	20.80	18.53	18.67	16.64	18.70
NBIAS (ALL LAYERS)	-0.04	-0.14	-0.15	-0.04	-0.07	-0.09	-0.08	-0.00	-0.08
NMVD (100-1000 hPa)	0.29	0.41	0.42	0.26	0.28	0.29	0.29	0.32	0.30
NRMSVD	0.35	0.49	0.49	0.32	0.35	0.35	0.35	0.39	0.36
NC	14748			235550	238459	186143	193173	41261	909334
SPD [m/s]	21.77			23.31	23.15	22.16	22.11	17.19	22.48
NBIAS (HIGH LAYER)	-0.03			-0.04	-0.08	-0.08	-0.07	-0.01	-0.07
NMVD (100-400 hPa)	0.24			0.26	0.26	0.26	0.26	0.31	0.26
NRMSVD	0.29			0.31	0.32	0.32	0.31	0.38	0.32
NC	8532	37419	34188	21401	84678	86936	86010	7248	366412
SPD [m/s]	14.64	12.08	11.94	16.90	15.10	14.61	14.69	13.51	14.35
NBIAS (MEDIUM LAYER)	-0.05	-0.18	-0.18	+0.02	-0.05	-0.12	-0.11	+0.09	-0.10
NMVD (400-700 hPa)	0.31	0.38	0.38	0.37	0.37	0.35	0.35	0.40	0.36
NRMSVD	0.48	0.46	0.45	0.46	0.45	0.43	0.43	0.47	0.44
NC	8350	59802	52989		8694	39993	37937		207765
SPD [m/s]	9.64	9.52	9.54		12.09	10.14	10.18		9.88
NBIAS (LOW LAYER)	-0.02	-0.12	-0.12		-0.09	-0.12	-0.12		-0.11
NMVD (700-1000 hPa)	0.44	0.44	0.44		0.38	0.41	0.40		0.43
NRMSVD	0.52	0.51	0.52		0.46	0.48	0.48		0.50

*Table 9: Validation parameters for GEO-HRW-v50  
(Jul 2009-Jun 2010, MSG2 satellite, 12:00 UTC, European and Mediterranean area;  
Basic AMVs; Cross correlation tracking;  
CCC height assignment with Microphysics parameters)*

GEO-HRW-v50 AMVs								All
(Jul 2009-Jun 2010)	HRVIS	VIS06	VIS08	WV62	WV73	IR108	IR120	AMVs
NC	23855	74554	69975	317904	321140	149190	162831	1119449
SPD [m/s]	16.08	11.59	11.63	22.11	18.04	16.84	16.78	17.98
NBIAS (ALL LAYERS)	-0.01	-0.06	-0.06	-0.04	+0.02	+0.02	+0.02	-0.00
NMVD (100-1000 hPa)	0.31	0.38	0.38	0.27	0.34	0.31	0.32	0.32
NRMSVD	0.38	0.46	0.45	0.33	0.42	0.38	0.39	0.39
NC	8417			310650	132497	40419	45913	537896
SPD [m/s]	22.48			22.19	21.24	24.78	24.57	22.36
NBIAS (HIGH LAYER)	-0.02			-0.03	+0.02	-0.00	-0.00	-0.01
NMVD (100-400 hPa)	0.24			0.27	0.29	0.25	0.25	0.27
NRMSVD	0.29			0.33	0.34	0.30	0.30	0.33
NC	9037	30312	29333	7254	191643	65549	70573	403701
SPD [m/s]	14.35	14.65	14.62	18.80	15.83	16.22	15.96	15.76
NBIAS (MEDIUM LAYER)	-0.00	-0.07	-0.07	-0.19	+0.02	+0.06	+0.07	+0.02
NMVD (400-700 hPa)	0.35	0.34	0.34	0.43	0.40	0.34	0.35	0.37
NRMSVD	0.43	0.41	0.40	0.53	0.49	0.42	0.43	0.45
NC	6401	44242	40642			43222	46345	180852
SPD [m/s]	10.11	9.49	9.47			10.35	10.31	9.92
NBIAS (LOW LAYER)	-0.00	-0.04	-0.05			-0.03	-0.04	-0.04
NMVD (700-1000 hPa)	0.43	0.42	0.42			0.38	0.38	0.40
NRMSVD	0.51	0.50	0.50			0.45	0.45	0.48

*Table 10: Validation parameters for GEO-HRW-v50  
(Jul 2009-Jun 2010, MSG2 satellite, 12:00 UTC, European and Mediterranean area;  
Basic AMVs; Cross correlation tracking;  
Brightness temperature interpolation height assignment without Cloud products;  
No distinction between Cloudy and Clear air Water vapour AMVs due to the lack of Cloud products)*

### 2.3.2 High Resolution Winds Validation for GOES-N satellite series

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

Two different configurations are shown in the validation: the first one considering the conditions defined in the default \$SAFNWC/config/safnwc\_HRW.cfm.GOES15MIN configuration file, in which “CCC height assignment without Microphysics correction” is considered, and for which NWC/GEO CMA, CT and CTHH product outputs have to be available. The other one considers the running of GEO-HRW-v50 with the same configuration file, but without the provision of NWC/GEO Cloud product outputs, so considering “Brightness temperature interpolation height assignment without cloud products”.

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

Comparing with the equivalent statistics for MSG (shown in *Table 9* and *Table 10*), statistics for GOES-N AMVs (NBIAS, NMVD, NRMSVD) are very similar, and in some cases even slightly better. Considering the different channels (VIS07, WV065, IR107) there are no remarkable differences with the equivalent MSG channels.

GEO-HRW-v50 AMVs (Jul 2009-Jun 2010)	Cloudy VIS07	Cloudy WV65	Cloudy IR107	Clear Air	All AMVs
NC	5849	205757	208726	47253	467585
SPD [m/s]	22.34	24.46	22.98	15.31	23.00
NBIAS (ALL LAYERS)	+0.00	-0.03	-0.08	-0.00	-0.05
NMVD (100–1000 hPa)	0.25	0.27	0.29	0.35	0.28
NRMSVD	0.31	0.33	0.36	0.48	0.36
NC	4694	191878	173848	47253	417673
SPD [m/s]	24.71	24.68	24.33	15.31	23.47
NBIAS (HIGH LAYER)	+0.00	-0.03	-0.09	-0.00	-0.05
NMVD (100–400 hPa)	0.24	0.27	0.28	0.35	0.28
NRMSVD	0.29	0.33	0.35	0.47	0.36
NC	460	13879	25067		39406
SPD [m/s]	18.10	21.43	18.60		19.59
NBIAS (MEDIUM LAYER)	-0.03	-0.00	-0.06		-0.04
NMVD (400–700 hPa)	0.28	0.29	0.32		0.31
NRMSVD	0.36	0.36	0.40		0.38
NC	695		9811		10506
SPD [m/s]	9.17		10.24		10.17
NBIAS (LOW LAYER)	-0.06		-0.10		-0.10
NMVD (700–1000 hPa)	0.35		0.39		0.38
NRMSVD	0.43		0.48		0.48

*Table 11: Validation parameters for GEO-HRW-v50  
 (Jul 2010-Jun 2011, GOES13 satellite, 00/06/12/18:00 UTC, Continental United States area;  
 Basic AMVs; Cross correlation tracking; CCC height assignment without Microphysics correction)*

GEO-HRW-v50 AMVs				All
(Jul 2009-Jun 2010)	VIS07	WV65	IR107	AMVs
NC	8176	281224	77701	367101
SPD [m/s]	18.61	21.91	21.87	21.83
NBIAS (ALL LAYERS)	+0.05	-0.00	+0.02	+0.00
NMVD (100-1000 hPa)	0.30	0.29	0.29	0.29
NRMSVD	0.38	0.36	0.35	0.36
NC	3834	252275	36889	292998
SPD [m/s]	23.37	22.05	26.92	22.68
NBIAS (HIGH LAYER)	+0.06	+0.00	+0.00	+0.00
NMVD (100-400 hPa)	0.28	0.28	0.26	0.28
NRMSVD	0.35	0.35	0.32	0.35
NC	2530	28949	28624	60103
SPD [m/s]	17.94	20.65	19.91	20.18
NBIAS (MEDIUM LAYER)	+0.07	-0.07	+0.06	-0.00
NMVD (400-700 hPa)	0.32	0.32	0.32	0.32
NRMSVD	0.40	0.41	0.39	0.40
NC	1812		12188	14000
SPD [m/s]	9.49		11.19	10.97
NBIAS (LOW LAYER)	-0.02		-0.03	-0.03
NMVD (700-1000 hPa)	0.35		0.35	0.35
NRMSVD	0.44		0.42	0.42

*Table 12: Validation parameters for GEO-HRW-v50  
(Jul 2010-Jun 2011, GOES13 satellite, 00/06/12/18:00 UTC, Continental United States area;  
Basic AMVs; Cross correlation tracking;  
Brightness temperature interpolation height assignment without Cloud products;  
No distinction between Cloudy and Clear air Water vapour AMVs due to the lack of Cloud products)*

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

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

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

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

### 2.3.3 List of High Resolution Winds configurable parameters

A region configuration file (`file.cfg`), and a GEO-HRW model configuration file (`file.cfm`), with the parameters and options defined by the user for calculation, are needed in `$SAFNWC/config` directory for the running of GEO-HRW-v50 executable.

- Two model configuration files are suggested for MSG: `safnwc_HRW.cfm.MSG15MIN` and `safnwc_HRW.cfm.MSG05MIN` (respectively for ‘Nominal scan mode’ and ‘Rapid scan mode’, with calculation of AMVs respectively every 15 and 5 minutes).
- Two model configuration files are suggested for GOES-N: `safnwc_HRW.cfm.GOES15MIN` and `safnwc_HRW.cfm.GOES30MIN`. The first one can be used for example for calculation of AMVs every 15 minutes in the “Continental United States” region. The second one can be used for example for calculation of AMVs every 30 minutes in the “North America” region.

The complete list of configurable parameters included in these files, with their description and their corresponding default values, is available in Section 2.3.4 of this document. Some output examples of the running of GEO-HRW-v50 with these Model Configuration Files are shown in Section 2.3.6.

Besides, for every running slot, next input data are to be supplied. Of all these data, only MSG HRIT or GOES-N GVAR satellite data for the running slot and NWP temperature data for the running region are strictly needed for the running of GEO-HRW algorithm:

- Considering MSG satellite series: full resolution uncompressed HRIT data for the selected region, for the running slot and the previous slot, for all MSG/SEVIRI channels to be used for the AMV calculation in `$SAFNWC/import/Sat_data` directory. IR120 channel is additionally needed for the visible channel processing when “Brightness temperature interpolation height assignment” is to be used. IR108 and WV62 channels are additionally needed if the default configuration of the Quality control is kept (including the “Image correlation test”).
- Considering GOES-N satellite series: full resolution uncompressed GVAR data for the selected region, for the running slot and the previous slot. GOES-N GVAR data have first to be converted to NWC/GEO netCDF satellite input data format with the provided GOES2NC java tool (more information about this can be extracted from the document "User Manual of the GOES2NC tool" [AD.16]), and after this process included in `$SAFNWC/import/Sat_data` directory. IR107 channel is in any case needed for the visible channel processing when “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”).
- List of tracers, predecessor winds and trajectories calculated at the previous slot, if existing.
- NWP data: Fields of temperatures covering at least the selected region, with an horizontal resolution of 0.5° and a NWP time step of at most 6 hours, for a minimum of four and as a recommendation as many as possible of the following levels: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10 hPa, in `$SAFNWC/import/NWP_data` directory. The NWP fields of rectangular components of the wind (u,v) are also needed for the ‘Quality control forecast test’ or if the NWP wind guess has to be used for the definition of the ‘tracking area centre’. In case the “Orographic flag” is also calculated, NWP fields of geopotential heights are also required.
- NWC/GEO CT and CTTH output for the running region and slot in `$SAFNWC/export/CT` and `$SAFNWC/export/CTTH` directories, if “CCC height assignment method” is used.
- NWC/GEO CMIC output for the running region and slot in `$SAFNWC/export/CMIC` directory, if the Microphysics correction is used inside “CCC height assignment method”.
- NWC/GEO CT output for the running region and the previous slot in `$SAFNWC/export/CT` directory, if the NWP wind guess has to be used for the definition of the ‘tracking area centre’, or the “Brightness temperature interpolation height assignment with Cloud products” is used.

### 2.3.4 List of High Resolution Winds configurable parameters

The High Resolution Winds model configuration file holds the configurable parameters needed for the running of GEO-HRW-v50 executable. It must be located within \$SAFNWC/config directory. Four different reference Model Configuration Files have been included for the running of NWC/GEO-HRW-v5.0: two for their operational use with MSG/SEVIRI data every 15 minutes (safnwc\_HRW.cfm.MSG15MIN) and every 5 minutes (safnwc\_HRW.cfm.MESG05MIN); two for their operational use with GOES-N data every 15 minutes (safnwc\_HRW.cfm.GOES15MIN) and every 30 minutes (safnwc\_HRW.cfm.GOES30MIN). A brief description of the configurable parameters included in these files is shown in the next table.

<i>Keyword</i>	<i>Description</i>	<i>Type</i>	<i>Default Value(s)</i>
<b>Identification parameters</b>			
PGE_ID	PGE identification. This keyword is optional, but should not be changed by the user.	Chain of characters	GEO-HRW
SAT_BANDS	Satellite bands that can be used to run the PGE. This keyword is optional, but should not be changed. It defines the maximum value of bands for which AMVs can be calculated.	Chain of characters	HRVIS, VIS06, VIS08, WV62, WV73, IR108, IR120 (MSG)
WIND_CHANNEL	Satellite bands really used for AMV calculation. As possible values, it can include any of the bands shown by the previous parameter separated by commas (not by spaces).	Chain of characters	VIS07, WV65, IR107 (GOESN) HRVIS, VIS08, WV62, WV73, IR120 (MSG)
SLOT_GAP	Ordering number of the previous satellite slot, for which tracers are to be considered for the AMV processing. Possible values: 1: Nominal mode for MSG and GOES-N (15 min., previous slot) 2: Rapid scan mode for MSG (10 min, second previous slot)	Integer	1 (MSG 15 min. mode) 2 (MSG 05 min. mode) 1 (GOESN)
<b>Output parameters</b>			
BUFR_CENTRE_OR	Originating/generating centre of the BUFR file, as defined in WMO Common Code Table C-1. It is to be modified with the code related to the corresponding centre (e.g. 214 for Madrid). Output file format. Possible values: - NWC: AMV & Trajectories BUFR files, with the specific NWC SAF format. - EUM: AMV BUFR files, with the EUMETSAT/MPEF BUFR format. - NET: AMV netCDF files - ALL: All previous files together	Integer	214
OUTPUT_FORMAT	Quality Index threshold for the AMVs	Chain of characters	NWC
QI_THRESHOLD	Option to show if the Quality index threshold used in the wind output filtering includes the Quality forecast test	Integer	70
QI_THRESHOLD_USEFORECAST	Criterion for Best wind selection (Values: 0/1), as defined in the ATBD document.	Integer	1
QI_BEST_WIND_SELECTION	Flag to decide if Clear air AMVs calculated	Integer	1
CLEARAIRWINDS	Flag to decide if Trajectories calculated	Integer	1
CALCULATE_TRAJECTORIES	Flag for a final filtering of the AMVs based on: - Their Height level (when > 0), - Their Cloud type (when > 1), - Their Quality spatial test (1,2 as invalid values when > 2; 0,1,2 as invalid values when > 3).	Integer	2
FINALFILTERING	Flag for calculation of the Orographic flag (when > 0), and for its AMV filtering (when > 2)	Integer	2
USE_TOPO	Flag showing if the mean value of the latitude increment, longitude increment, speed, direction, temperature, pressure, pressure error and correlation related to an AMV and its predecessor (in case it exists) are used (when positive).	Integer	0
USE_MEANWIND	Maximum pressure error in the AMVs (hPa), when 'CCC height assignment method' used.	Integer	150
MAXPRESSUREERROR	Flag showing if very low infrared AMVs (below 900 hPa) are admitted in the AMV output file	Integer	0
VERYLOWINFRAREDAMVS	Flag to indicate if "Final Control Check" is used	Integer	1
FINALCONTROLCHECK			

<i>Keyword</i>	<i>Description</i>	<i>Type</i>	<i>Default Value(s)</i>
<b>Working area description parameters</b>			
LAT_MIN		Real	-75.0
LAT_MAX	Latitude and longitude borders (in degrees)	Real	75.0
LON_MIN	for the processing region (Basic AMVs)	Real	-179.0
LON_MAX		Real	179.0
LAT_MIN_DET		Real	-75.0
LAT_MAX_DET	Latitude and longitude borders (in degrees)	Real	75.0
LON_MIN_DET	for the processing region (Detailed AMVs)	Real	-179.0
LON_MAX_DET		Real	179.0
FRAC_DAY_SCENE	Minimum fraction of area illuminated by the sun needed to calculate the visible AMVs (HRVIS, VIS06, VIS08 channels)	Integer	8
ZEN_THRES	Sun zenith angle threshold (degrees)	Double	87.0
MSG_ZEN_THRES	Satellite zenith angle threshold (degrees)	Double	80.0
<b>Tracer parameters</b>			
MAX_TRACERS	Maximum number of tracers	Integer	120000
LSIZ_HRV	Basic tracer line/column dimension	Integer	24
ESIZ_HRV	(with MSG/HRVIS or GOES-N/VIS07 AMVs)	Integer	24
LSIZ_OTHER	Basic tracer line/column dimension	Integer	24
ESIZ_OTHER	(with all other AMVs)	Integer	24
MIN_BRIGHTNESS_VIS	Minimum acceptable 1 byte reflectance value in the search for targets (with visible AMVs)	Double	120.0
MIN_BRIGHTNESS_OTHER	Minimum acceptable 1 byte brightness temperature value in the search for targets (with infrared and water vapour AMVs).	Double	60.0
GVAL_VIS	Minimum acceptable 1 byte reflectance contrast in the pixels of a tracer (with visible AMVs)	Double	60.0
GVAL_OTHER	Minimum acceptable 1 byte brightness temperature contrast in the pixels of a tracer (with infrared and water vapour AMVs)	Double	48.0
TRACER_SEARCH_STEP_HRV	Minimum separation (in pixels) between tracers (for MSG/HRVIS or GOES-N/VIS07 AMVs)	Integer	24
TRACER_SEARCH_STEP_OTHER	Minimum separation (in pixels) between tracers (for all other AMVs)	Integer	6
<b>Tracking parameters</b>			
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 used by the old "Brightness temperature interpolation height assignment method" (when positive)	Integer	2
USE_MICROPHYSICS	Flag to decide if the Microphysics correction is to be calculated to "CCC height assignment" (when > 0), and if this Microphysics corrections is applied to the final AMV pressure (when > 1) (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1)	Integer	2 (MSG) 0 (GOESN)
WIND_GUESS	Flag to decide if the Wind guess is used for the definition of the Tracking area	Integer	0
MIN_CORRELATION	Minimum correlation acceptable in the Tracking process (if Cross correlation method used)	Double	80.0 (MSG) 50.0 (GOESN)
LLAG_HRV	Tracking line/column increment (with MSG/HRVIS or GOES-N/VIS07 AMVs) (this value is dependent of the time distance between satellite slots)	Integer	272 (30 min. mode) 136 (15 min. mode) 92 (05 min. mode)
ELAG_HRV		Integer	272 (30 min. mode) 136 (15 min. mode) 92 (05 min. mode) 68 (30 min. mode)
LLAG_OTHER	Tracking line/column increment (with all other AMVs) (this value is dependent of the time distance between satellite slots)	Integer	46 (MSG 15 min. mode) 34 (GOESN 15 min. mode) 32 (05 min. mode) 68 (30 min. mode)
ELAG_OTHER		Integer	46 (MSG 15 min. mode) 34 (GOESN 15 min. mode) 32 (05 min. mode)
USE_SUBPIXELTRACKING	Flag to decide if Subpixel tracking is to be used	Integer	1

<i>Keyword</i>	<i>Description</i>	<i>Type</i>	<i>Default Value(s)</i>
<b>Detailed tracer parameters</b>			
CDET	It defines if a detailed set of tracers is required. The range can be equal to the initial scale or only a subset of the initial region. When the range is smaller, the keywords LIN_D, NUML_D, ELE_D and NUME_D cannot be empty. Possible values: ALL: The range for the search of detailed tracers is the same as the basic scale. RANGE: Processes only a regional subset. <empty>: Detailed tracer search is not required.	Chain of characters	<empty>
LIN_D	Initial line/column of the region subset considered for detailed tracers. Possible values: - <empty> when CDET = ALL / empty	Integer	<empty>
ELE_D	- <A line/column number included in processing region> when CDET = RANGE	Integer	<empty>
NUML_D	Number of lines/columns of the region subset considered for detailed tracers. Possible values: - <empty> when CDET = ALL / empty	Integer	<empty>
NUME_D	- <A number of lines/columns included in processing region> when CDET = RANGE	Integer	<empty>
<b>NWP parameters</b>			
MIN_NWP_FOR_CALCULATION	Minimum number of NWP levels needed to calculate AMVs	Integer	4
NWP_PARAM	NWP parameters requested by GEO-HRW algorithm: * NWP_PT: Temperature at several levels (K)	Chain of characters	NWP_PT , 1 , NEIGHBOUR
NWP_PARAM	* NWP_UW: Wind velocity at several levels, u component (m/s)	Chain of characters	NWP_UW , 1 , NEIGHBOUR
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 , NEIGHBOUR
NWP_PARAM	Sampling rate used: 1 Interpolation method used: NEIGHBOUR	Chain of characters	NWP_GEOP , 1 , NEIGHBOUR

*Table 13: GEO-HRW Model Configuration File Description*

If the user has the need to reduce GEO-HRW running time, especially when working with a different slower platform, it is recommended to reduce the amount of channels for which AMVs should be calculated.

This issue applies specially when processing MSG data because of the larger amount of channels. Although it can be very useful to keep the calculation of AMV data with the seven different MSG/SEVIRI channels that are available (HRVIS,VIS06,VIS08,WV62,WV73,IR108,IR120, as seen in some examples in the “Validation report for GEO-HRW v3.2” [AD.12]), because of the general similarity that exists between AMVs extracted from IR108 and IR120 channel on one side, and VIS06 and VIS08 channel on the other side, the first recommendation to reduce GEO-HRW running time would be to keep five MSG/SEVIRI channels for the AMV calculation through WIND\_CHANNEL = HRVIS,VIS08,WV62,WV73,IR120 (which is the default configuration for GEO-HRW product). If further reductions in the amount of processed channels are needed, it would be recommended at least to keep next four channels: WIND\_CHANNEL = HRVIS,WV62,WV73,IR120 (as also seen in the “Validation report for HRW v3.2” [AD.12]).

In general, when using GOES-N satellite data it should always be possible to keep the AMV calculation for the three suggested channels: WIND\_CHANNEL = VIS07,WV65,IR107.

## 2.3.5 Description of High Resolution Winds output

Two different types of AMV outputs are possible for NWC/GEO High Resolution Winds.

On the one hand, BUFR output format, already used by SAFNWC/MSG v2013 software package and the previous ones, has been requested by the users working since long with this format, especially those related to the assimilation of the GEO-HRW Atmospheric Motion Vectors in NWP models.

On the other hand, netCDF output format has also been requested as an improvement 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) for the NWC/GEO software package, and has been approved by the EUM Format Advisory Group (See EUM/STG-OPSWG/30/11/VWG/15 presentation) for products delivered by the EUMETSAT Data Centre.

### 2.3.5.1 AMV BUFR bulletins

One file for the single AMV scale, or two different files for two different AMV scales (related each one of them to ‘Basic winds’ and ‘Detailed winds’, when so configured with configurable parameter CDET = ALL or RANGE), in form of BUFR bulletins are produced for each processed region for every running slot. If AMVs have been calculated for several channels, they are all included in the same BUFR bulletin. The BUFR bulletin can have two different formats, depending on the value of configurable parameter OUTPUT\_FORMAT.

#### 2.3.5.1.1 AMV BUFR bulletins with NWC SAF specific format

When OUTPUT\_FORMAT = NWC, an AMV BUFR bulletin with a specific NWC SAF format is written in \$SAFNWC/export/HRW directory for the single or basic scale under the name S\_NWC\_HRW-WIND\_<satid>\_<regionid>-BS\_YYYYMMDDThhmmssZ.bufr. For the detailed scale S\_NWC\_HRW-WIND\_<satid>\_<regionid>-DS\_YYYYMMDDThhmmssZ.bufr is the name used, where “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 processed slot for which the AMVs have been calculated.

To correctly define the BUFR bulletins, the user has additionally 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; the numeric codes for other locations are available at the WMO Common Code Table C-1 [RD.19]).

The BUFR table used for the writing of the AMVs in the BUFR output file considering this format (identified as \$SAFNWC/import/Aux\_data/HRW/B0000000000214012095.TXT) is shown in *Table 13*. It is based on BUFR Master Table number 0, Version number 12, although with some specific parameters for the NWC SAF BUFR output bulletins identified as 060xxx.

For all parameters in the table, the first column shows the “Parameter identification code”, the second column shows the “Parameter description”, the third column shows the “Unit used for the codification of the parameter (in some cases identified through a Code Table)”, the fourth column shows the “Number of decimals used in the codification of the parameter (where a value of 1 is used for a precision of one decimal place and a value of -1 is used for a precision only up to the tens)”, the fifth column shows the “Default value of the parameter” and 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 is  $2^7-1 = 127$ ).

Several different BUFR messages with AMVs calculated for only one channel, in each case with an only Subset of up to 1000 AMVs (winds), are included in this AMV BUFR output file.

001007	SATELLITE IDENTIFIER	CODE TABLE 001007	0	0	10
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	CODE TABLE 001031	0	0	16
001032	GENERATING APPLICATION (CODE TABLE 001032)	CODE TABLE 001032	0	0	8
002023	SATELLITE DERIVED WIND COMPUTATION METHOD	CODE TABLE 002023	0	0	4
002057	ORIGIN OF FIRST GUESS INFORMATION	CODE TABLE 002057	0	0	4
002152	SATELLITE INSTRUMENT USED IN DATA PROCESSING	CODE TABLE 002152	0	0	31
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz	-8	0	26
002154	SATELLITE CHANNEL BAND WIDTH	Hz	-8	0	26
004001	YEAR	YEAR	0	0	12
004002	MONTH	MONTH	0	0	4
004003	DAY	DAY	0	0	6
004004	HOUR	HOUR	0	0	5
004005	MINUTE	MINUTE	0	0	6
004025	TIME PERIOD OR DISPLACEMENT	MINUTE	0	-2048	12
005044	SATELLITE CYCLE NUMBER	NUMERIC	0	0	11
033035	MANUAL/AUTOMATIC QUALITY CONTROL	CODE TABLE 033035	0	0	4
060000	SEGMENT SIZE AT NADIR IN X DIRECTION (PIXELS)	PIX	0	0	7
060001	SEGMENT SIZE AT NADIR IN Y DIRECTION (PIXELS)	PIX	0	0	7
127000	REPLICATION OPERATOR	-	0	0	0
031002	EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR:WINDS	NUMERIC	0	0	16
060100	WIND SEQUENCE NUMBER	NUMERIC	0	0	24
060101	PRIOR WIND SEQUENCE NUMBER	NUMERIC	0	0	24
002028	SEGMENT SIZE AT NADIR IN X DIRECTION	M	-1	0	18
002029	SEGMENT SIZE AT NADIR IN Y DIRECTION	M	-1	0	18
002164	TRACER CORRELATION METHOD	CODE TABLE 002164	0	0	3
005001	LATITUDE (HIGH ACCURACY)	DEGREE	5	-9000000	25
006001	LONGITUDE (HIGH ACCURACY)	DEGREE	5	-18000000	26
005011	LATITUDE INCREMENT (HIGH ACCURACY)	DEGREE	5	-9000000	25
006011	LONGITUDE INCREMENT (HIGH ACCURACY)	DEGREE	5	-18000000	26
007004	PRESSURE	PA	-1	0	14
011001	WIND DIRECTION	DEGREE TRUE	0	0	9
011002	WIND SPEED	M/S	1	0	12
012001	TEMPERATURE	K	1	0	12
033007	PER CENT CONFIDENCE (WITH FORECAST TEST)	%	0	0	7
033007	PER CENT CONFIDENCE (WITHOUT FORECAST TEST)	%	0	0	7
060102	TRACER TYPE (CODE TABLE 060102)	CODE TABLE 060102	0	0	2
060103	HEIGHT ASSIGNMENT METHOD (CODE TABLE 060103)	CODE TABLE 060103	0	0	4
060200	NUMBER OF WINDS COMPUTED FOR THE TRACER	NUMERIC	0	0	3
060201	CORRELATION TEST (CODE TABLE 060201)	CODE TABLE 060201	0	0	3
060202	APPLIED QUALITY TESTS (CODE TABLE 060202)	CODE TABLE 060202	0	0	11
060203	NUMBER OF AVAILABLE NWP WIND GUESS LEVELS	NUMERIC	0	0	7
060204	NUMBER OF PREDECESSOR WINDS	NUMERIC	0	0	7
060205	OROGRAPHIC INDEX (CODE TABLE 060205)	CODE TABLE 060205	0	0	3
060206	CLOUD TYPE (NWC/GEO) (CODE TABLE 060206)	CODE TABLE 060206	0	0	5
060207	WIND CHANNEL (CHANNEL ID) (CODE TABLE 060207)	CODE TABLE 060207	0	0	5
060208	CORRELATION	%	0	0	7
060209	PRESSURE ERROR OR CORRECTION	PA	-1	-8000	14

*Table 14: BUFR table for AMV BUFR output files with NWC SAF specific BUFR format*

The Code Tables used for all parameters in this table except those characterized as 060xxx (which are specific parameters for NWC SAF BUFR output bulletins) are described in the BUFR Reference Manual [RD.20]. The Code Tables for the NWC SAF specific parameters are explained next:

- Code Table 060102, Tracer type:
  - 0 for 'Basic tracer'
  - 1 for 'Detailed tracer related to a Narrow basic tracer'
  - 2 for 'Detailed tracer related to a Wide basic tracer'
  - 3 for 'Detailed tracer unrelated to a Basic tracer'.

- Code Table 060103, Height assignment method:

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

- 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 low threshold and cold branch in Clear air AMV
- 5: CCC method using high threshold and cold branch in Clear air AMV
- 6: CCC method using low threshold and cold/bright branch in Cloudy AMV with undefined phase
- 7: CCC method using high threshold and cold/bright branch in Cloudy AMV with undefined phase
- 8: CCC method using low threshold and cold/bright branch in Cloudy AMV with liquid phase
- 9: CCC method using high threshold and cold/bright branch in Cloudy AMV with liquid phase
- 10: CCC method with microphysics correction using low threshold and cold/bright branch in Cloudy AMV with liquid phase
- 11: CCC method with microphysics correction using high threshold and cold/bright branch in Cloudy AMV with liquid phase
- 12: CCC method with low threshold and cold/bright branch in Cloudy AMV with ice phase
- 13: CCC method with high threshold and cold/bright branch in Cloudy AMV with ice phase
- 14: CCC method with microphysics correction using low threshold and cold/bright branch in Cloudy AMV with ice phase
- 15: CCC method with microphysics correction using high threshold and cold/bright branch in Cloudy AMV with ice phase.

- Code Table 060201, Correlation test:

- 0 for ‘Wind not selected as the Best wind for a tracer not having the Best correlation value’
- 1 for ‘Wind not selected as the Best wind for a tracer having the Best correlation value’
- 2 for ‘Wind selected as the Best wind for a tracer not having the Best correlation value’
- 3 for ‘Wind selected as the Best wind for a tracer having the Best correlation value’.

- Code Table 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:

- 0 for ‘Wind for which the corresponding quality test could not be calculated’
- 1 for ‘Wind whose corresponding quality test is at least a 21% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is at least two units lower than for the wind calculated for the same tracer with the best orographic flag)’
- 2 for ‘Wind whose corresponding quality test is up to a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the wind calculated for the same tracer with the best orographic flag)’
- 3 for ‘Wind with the best corresponding quality test among the winds calculated for a tracer’.

- Code Table 060205, Orographic flag:  
Values between 0 and 6, corresponding to those defined in Chapter 2.2.2.11 of this document.
- Code Table 060205, Cloud type:  
Values between 0 and 23, corresponding to those defined in *Table 5* of this document.
- Code Table 060207, Wind channel (Satellite channel used for the AMV/Trajectory calculation):  
MSG series values: 5 for ‘HRVIS’ 2 for ‘VIS06’ 3 for ‘VIS08’ 10 for ‘WV62’  
12 for ‘WV73’ 16 for ‘IR108’ 17 for ‘IR120’.  
GOES-N series values: 2 for ‘VIS07’ 10 for ‘WV65’ 16 for ‘IR107’.

### 2.3.5.1.2 AMV BUFR bulletins with EUMETSAT/MPEF format

When OUTPUT\_FORMAT = EUM, an AMV BUFR bulletin equivalent to those defined for the AMV extraction at the EUMETSAT Meteosat Product Extraction Facility is written under the name `S_NWC_HRW-WINDEUM_<satid>_<regionid>-BS_YYYYMMDDThhmmssZ.bufr` for the single or basic scale in `$/SAFNWC/export/HRW` directory. For the detailed scale, the name `S_NWC_HRW-WINDEUM_<satid>_<regionid>-DS_YYYYMMDDThhmmssZ.bufr` is used. 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.

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

The BUFR template used for the writing of the AMVs in the BUFR output file considering this format (which is similar to the ones described for the MPEF AMVs at EUMETSAT website at <http://www.eumetsat.int/website/home/Data/Products/Formats/index.html>), and which is based on BUFR Master Table number 0, Version number 12, is shown in *Table 15* (identified as `$/SAFNWC/import/Aux_data/HRW/B0000000000000012000.TXT`), with some explanation about the content of the different parameters when used by GEO-HRW algorithm underlined in italics.

Formally, the EUMETSAT/MPEF AMV BUFR format is a kind a blend of the NWC SAF AMV and Trajectory BUFR specific formats, because of including at the same time information related to the reference AMV to be used (which depending on the value of USE\_MEANWIND configurable parameter, can be related to the latest AMV in any GEO-HRW trajectory, or to the mean value of the latest two AMVs in the GEO-HRW trajectory), and information related to the up to four latest AMVs in any GEO-HRW trajectory (which is the information provided in the Trajectory BUFR files with the NWC SAF specific BUFR format, later explained later in Chapter 2.3.5.2). Considering this, when configurable parameter OUTPUT\_FORMAT = EUM is defined, only the AMV BUFR bulletin with the EUMETSAT/MPEF format is provided, and no Trajectory BUFR bulletins are provided.

In any case, it is only recommended to use the option to write GEO-HRW output with the EUMETSAT/MPEF format, when the main interest of the GEO-HRW AMV calculation is the assimilation of the AMVs in NWP models or other applications (possibly together with the EUMETSAT/MPEF AMVs). The main reason for this is that part of the information calculated with the AMVs cannot be included using this format because there is no place for it (like the “cloud type”, the “orographic flag” or the “correlation value”), and because of this, this additional information cannot be used operationally when this kind of AMV BUFR output is used. Moreover, the size of the AMV BUFR bulletins with the EUMETSAT/MPEF format is much larger, and can cause more important storage problems.

Several different BUFR messages with up to 100 Subsets with one AMV each, all of them related to the same channel, are included in this AMV BUFR output file.

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

011001 WIND DIRECTION (For the third latest AMV in the trajectory, when available)  
011002 WIND SPEED (For the third latest AMV in the trajectory, when available)  
008021 TIME SIGNIFICANCE (Starting time for the fourth latest AMV in the trajectory)  
004004 HOUR  
004005 MINUTE  
004006 SECOND  
008021 TIME SIGNIFICANCE (Ending time for the fourth latest AMV in the trajectory)  
004004 HOUR  
004005 MINUTE  
004006 SECOND  
011001 WIND DIRECTION (For the fourth latest AMV in the trajectory, when available)  
011002 WIND SPEED (For the fourth latest AMV in the trajectory, when available)  
---  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (Not used)  
012001 TEMPERATURE/DRY BULB TEMPERATURE (Not used)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (Not used)  
012001 TEMPERATURE/DRY BULB TEMPERATURE (Not used)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (Not used)  
012001 TEMPERATURE/DRY BULB TEMPERATURE (Not used)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (For the latest AMV in the trajectory)  
012001 TEMPERATURE For the latest AMV in the trajectory)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (Not used)  
012001 TEMPERATURE/DRY BULB TEMPERATURE (Not used)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (For the second latest AMV in the trajectory, when available)  
012001 TEMPERATURE For the second latest AMV in the trajectory, when available)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (Not used)  
012001 TEMPERATURE/DRY BULB TEMPERATURE (Not used)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (For the third latest AMV in the trajectory, when available)  
012001 TEMPERATURE For the third latest AMV in the trajectory, when available)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (Not used)  
012001 TEMPERATURE/DRY BULB TEMPERATURE (Not used)  
002163 HEIGHT ASSIGNMENT METHOD (Not used)  
007004 PRESSURE (For the fourth latest AMV in the trajectory, when available)  
012001 TEMPERATURE For the fourth latest AMV in the trajectory, when available)  
---  
222000 QUALITY INFORMATION FOLLOWS  
236000 DEFINE BIT-MAP  
031031 DATA PRESENT INDICATOR (Descriptor repeated 103 times, not used)  
---  
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE  
001032 GENERATING APPLICATION (Quality Control using forecast)  
033007 % CONFIDENCE (For the latest AMV in the trajectory)  
033007 % CONFIDENCE (For the second latest AMV in the trajectory, when available)  
033007 % CONFIDENCE (For the third latest AMV in the trajectory, when available)  
033007 % CONFIDENCE (For the fourth latest AMV in the trajectory, when available)  
222000 QUALITY INFORMATION FOLLOWS  
237000 REUSE PREVIOUSLY DEFINED BIT-MAP  
001031 IDENTIFICATION OF ORIGINATING/GENERATING CENTRE  
001032 GENERATING APPLICATION (Quality Control using forecast)  
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the latest AMV in the trajectory)  
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the second latest AMV in the trajectory)  
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the third latest AMV in the trajectory)  
033035 MANUAL-AUTOMATIC QUALITY CONTROL (For the fourth latest AMV in the trajectory)  
222000 QUALITY INFORMATION FOLLOWS  
237000 REUSE PREVIOUSLY DEFINED BIT-MAP

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

*Table 15: BUFR table for AMV BUFR output files with EUMETSAT/MPEF BUFR format*

### 2.3.5.2 Trajectory BUFR bulletins

If the calculation and writing of trajectories is activated for GEO-HRW algorithm with configurable parameters `CALCULATE_TRAJECTORIES = 1` and `OUTPUT_FORMAT = NWC` (which is the default option), one file for the trajectories related to the single AMV scale, or two different BUFR files for the trajectories related to the two different AMV scales ('Basic winds' and 'Detailed winds', when so configured with configurable parameter `CDET = ALL` or `RANGE`), are produced. If trajectories have been calculated for several channels, they are all included in the same BUFR bulletin. It is important here to remember that no Trajectory BUFR output file is produced if the EUMETSAT BUFR format is selected with configurable parameter `OUTPUT_FORMAT = EUM`.

The Trajectory BUFR bulletin is written in `$SAFNWC/export/HRW` directory under the name `S_NWC_HRW-TRAJ-<satid>-<regionid>-BS_YYYYMMDDThhmmssZ.bufr` for the basic scale. `S_NWC_HRW-TRAJ-<satid>-<regionid>-DS_YYYYMMDDThhmmssZ.bufr` is used for the detailed scale. 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 slot for which the trajectories have been calculated.

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

The BUFR specific table used for the writing of the Trajectories in the BUFR output file (identified as `$SAFNWC/import/Aux_data/HRW/B0000000000214012098.TXT`), and which is rather similar to the one used for the writing of the AMVs, is shown as *Table 16*. It is based on BUFR Master Table number 0, Version number 12, although with some specific parameters for the NWC SAF BUFR output bulletins identified as 060xxx. It behaves similarly as explained in Chapter 2.3.5.1.1 for the AMV BUFR bulletins using the NWC SAF specific format. The Code Tables used for the NWC SAF specific BUFR output parameters (also characterized as 060xxx), are exactly the same ones used in Chapter 2.3.5.1.1. All other Code Tables are similarly described in the BUFR Reference Manual [RD.20].

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

001007	SATELLITE IDENTIFIER	CODE TABLE	001007	0	0	10
001031	IDENTIFICATION OF ORIGINATING/GENERATING CENTRE	CODE TABLE	001031	0	0	16
001032	GENERATING APPLICATION (CODE TABLE 001032)	CODE TABLE	001032	0	0	8
002023	SATELLITE DERIVED WIND COMPUTATION METHOD	CODE TABLE	002023	0	0	4
002057	ORIGIN OF FIRST GUESS INFORMATION	CODE TABLE	002057	0	0	4
002152	SATELLITE INSTRUMENT USED IN DATA PROCESSING	CODE TABLE	002152	0	0	31
002153	SATELLITE CHANNEL CENTRE FREQUENCY	Hz		-8	0	26
002154	SATELLITE CHANNEL BAND WIDTH	Hz		-8	0	26
004001	YEAR	YEAR		0	0	12
004002	MONTH	MONTH		0	0	4
004003	DAY	DAY		0	0	6
004004	HOUR	HOUR		0	0	5
004005	MINUTE	MINUTE		0	0	6
004025	TIME PERIOD OR DISPLACEMENT	MINUTE		0	-2048	12
005044	SATELLITE CYCLE NUMBER	NUMERIC		0	0	11
033035	MANUAL/AUTOMATIC QUALITY CONTROL	CODE TABLE	033035	0	0	4
060000	SEGMENT SIZE AT NADIR IN X DIRECTION (PIXELS)	PIX		0	0	7
060001	SEGMENT SIZE AT NADIR IN Y DIRECTION (PIXELS)	PIX		0	0	7
060104	TRAJECTORY SEQUENCE NUMBER	NUMERIC		0	0	24
117000	REPLICATION OPERATOR	-		0	0	0
031002	EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR:WINDS	NUMERIC		0	0	16
002164	TRACER CORRELATION METHOD	CODE TABLE	002164	0	0	3
005001	LATITUDE (HIGH ACCURACY)	DEGREE		5	-9000000	25
006001	LONGITUDE (HIGH ACCURACY)	DEGREE		5	-18000000	26
005011	LATITUDE INCREMENT (HIGH ACCURACY)	DEGREE		5	-9000000	25
006011	LONGITUDE INCREMENT (HIGH ACCURACY)	DEGREE		5	-18000000	26
007004	PRESSURE	PA		-1	0	14
011001	WIND DIRECTION	DEGREE TRUE		0	0	9
011002	WIND SPEED	M/S		1	0	12
012001	TEMPERATURE	K		1	0	12
033007	PER CENT CONFIDENCE (WITH FORECAST TEST)	%		0	0	7
033007	PER CENT CONFIDENCE (WITHOUT FORECAST TEST)	%		0	0	7
060103	HEIGHT ASSIGNMENT METHOD (CODE TABLE 060103)	CODE TABLE	060103	0	0	4
060205	OROGRAPHIC INDEX (CODE TABLE 060205)	CODE TABLE	060205	0	0	3
060206	CLOUD TYPE (NWC/GEO) (CODE TABLE 060206)	CODE TABLE	060206	0	0	5
060207	WIND CHANNEL (CHANNEL ID) (CODE TABLE 060207)	CODE TABLE	060207	0	0	5
060208	CORRELATION	%		0	0	7
060209	PRESSURE ERROR OR CORRECTION	PA		-1	-8000	14

*Table 16: BUFR table for the Trajectory output file*

### 2.3.5.3 netCDF output files

One file for the single AMV scale, or two different files for two different AMV scales (related each one of them to ‘Basic winds’ and ‘Detailed winds’, when so configured with configurable parameter CDET = ALL or RANGE), in form of netCDF output files, are produced for each processed region for every running slot if configurable parameter OUTPUT\_PARAMETER = NET. If the AMVs have been calculated for several satellite channels, they are all included in the same file.

The netCDF file is written for the basic scale in \$SAFNWC/export/HRW directory under the name S\_NWC\_HRW-WIND\_<satid>\_<regionid>-BS\_YYYYMMDDThhmmssZ.nc. For the detailed scale the name S\_NWC\_HRW-WIND\_<satid>\_<regionid>-DS\_YYYYMMDDThhmmssZ.nc is used. “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 processed slot 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 17*. It will contain ‘n’ groups; each one containing the AMVs/Trajectories derived using a specific satellite channel (HRVIS, VIS06, VIS08, WV62, WV73, IR108, IR120 for MSG series and VIS07, WV65, IR107 for GOES-N series). Each one of these groups will contain ‘nb\_winds’ groups, each one containing the information related to a specific Atmospheric Motion Vector/Trajectory.

If additionally configurable parameter CALCULATE\_TRAJECTORIES = 1, the trajectories related to the ‘Basic winds scale’ and the ‘Detailed winds scale’ are also included in the corresponding netCDF output file. If trajectories have been calculated for several satellite channels, they are included in the same file. Each trajectory will finally contain ‘nb\_sect’ groups, containing the corresponding number of Trajectory sectors.

	Content
Dimensions:	
n	Number of Satellite channels used for AMV calculation
nb_winds	Number of AMVs for each Satellite channel
Types:	
compound Segment	// Structure to contain 1 Segment data
Segment(*) Trajectory	// Structure to contain nb_sect Segment data (1 Trajectory)
compound Wind	// Structure to contain 1 Wind Data (including Trajectory)
Variables	
Wind wind(nb_winds)	// Wind data
Attributes	

*Table 17: High Level specification of the GEO-HRW netCDF output*

The detailed structure of the netCDF output for the NWC/GEO High Resolution Winds Trajectories is shown in *Table 18*. The “BUFR Code Tables” defined in *Table 18* are described in the BUFR Reference Manual [RD.20], except those tables characterized as 060xxx, which are explained in Chapter 2.3.5.1.1 of this document. The list of common attributes described in Section 4.3 of the “Data Output Format for the NWC/GEO” document [AD.6] is also to be taken here into account.

	Content
<b>Dimensions:</b>	
n	Number of Satellite channels used for AMV calculation
nb_winds	Number of AMVs for each Satellite channel
<b>Types:</b>	
<b>compound Segment</b>	<b>// Structure to contain 1 Trajectory Segment</b>
int tracer_corr	// Tracer Correlation method (BUFR code table 002164)
float lat	// Latitude (degrees)
float lon	// Longitude (degrees)
float lat_inc	// Latitude increment (degrees)
float lon_inc	// Longitude increment (degrees)
float pressure	// Pressure (Pa)
float pressure_err	// Pressure Error or Correction (Pa)
float wind_speed	// Wind Speed (m/s)
float wind_direction	// Wind Direction (degree)
float temperature	// Temperature (K)
unsigned byte confidence_fore	// Per cent confidence with forecast test
unsigned byte confidence_no_fore	// Per cent confidence without forecast test
unsigned byte height_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte orography	// Orographic index (BUFR code table 06205)
unsigned byte cloud_type	// NWC/GEO Cloud Type (BUFR code table 06206)
unsigned byte correlation	// Correlation (% , [0,100])
<b>Segment(*) Trajectory</b>	<b>// Trajectory defined as a variable-length array of Segment structures</b>
<b>compound Wind</b>	<b>// Structure to contain Wind Data (1 data, including trajectory)</b>
unsigned int wind_id	// Wind sequence Number
unsigned int wind_prev_id	// Prior wind sequence number
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)
int tracer_corr	// Tracer Correlation method (BUFR code table 002164)
float lat	// Latitude (degrees)
float lon	// Longitude (degrees)
float lat_inc	// Latitude increment (degrees)
float lon_inc	// Longitude increment (degrees)
float pressure	// Pressure (Pa)
float pressure_err	// Pressure Error or Correction (Pa)
float wind_speed	// Wind Speed (m/s)
float wind_direction	// Wind Direction (degree)
float temperature	// Temperature (K)
unsigned byte confidence_fore	// Per cent confidence with forecast test
unsigned byte confidence_no_fore	// Per cent confidence without forecast test
unsigned byte tracer_type	// Tracer Type (BUFR code table 060102)
unsigned byte height_method	// Height Assignment Method (BUFR code table 060103)
unsigned byte n_winds	// Number of winds computed for the tracer
unsigned byte correlation_test	// Correlation test (BUFR code table 06201)
unsigned short quality_test	// Applied Quality tests (BUFR code table 06202)
unsigned byte nwp_wind_levels	// Number of available NWP wind guess levels
unsigned byte n_pred_winds	// Number of predecessor winds
unsigned byte orography	// Orographic index (BUFR code table 06205)
unsigned byte cloud_type	// NWC/GEO Cloud Type (BUFR code table 06206)
unsigned byte correlation	// Correlation (% , [0,100])
Trajectory trajectory	// Wind Trajectory (with variable number of Points)
<b>Variables:</b>	
<b>Wind wind(nb_winds)</b>	<b>// Wind data</b>
<b>Attributes</b>	
standard_name	horizontal_wind_vector
long_name	"NWC GEO High Resolution Winds"
wind_computation_method	// Satellite derived wind computation method (BUFR code table 002023)
first_guess	// Origin of the first guess (BUFR code table 025202)
channel_id	// Satellite channel id
channel_centre_frequency	// Satellite channel centre frequency (Hz)
channel_centre_width	// Satellite channel band width (Hz)
cycle	// Satellite cycle number
qi_control	// Manual/automatic quality control (BUFR code table 033035)
time_period	// Time period or displacement (minutes)

Table 18: Detailed specification of the GEO-HRW netCDF output

### 2.3.6 Visualisation examples of High Resolution Winds

Real time graphic displays of the NWC/GEO High Resolution Winds product, generated at the NWC/GEO Reference System, are to be available without any restriction in the website of the NWC SAF Help Desk (<http://www.nwcsaf.org>).

Next figures show typical displays of GEO-HRW product for AMVs and Trajectories considering the default configuration. First, with MSG2 satellite data in the European and Mediterranean region used for GEO-HRW-v50 validation (Figures 22 and 23). Later, with GOES13 satellite data in the Continental United States region also used for GEO-HRW-v50 validation (Figures 24 and 25). A colour coding based on the pressure level has been used.

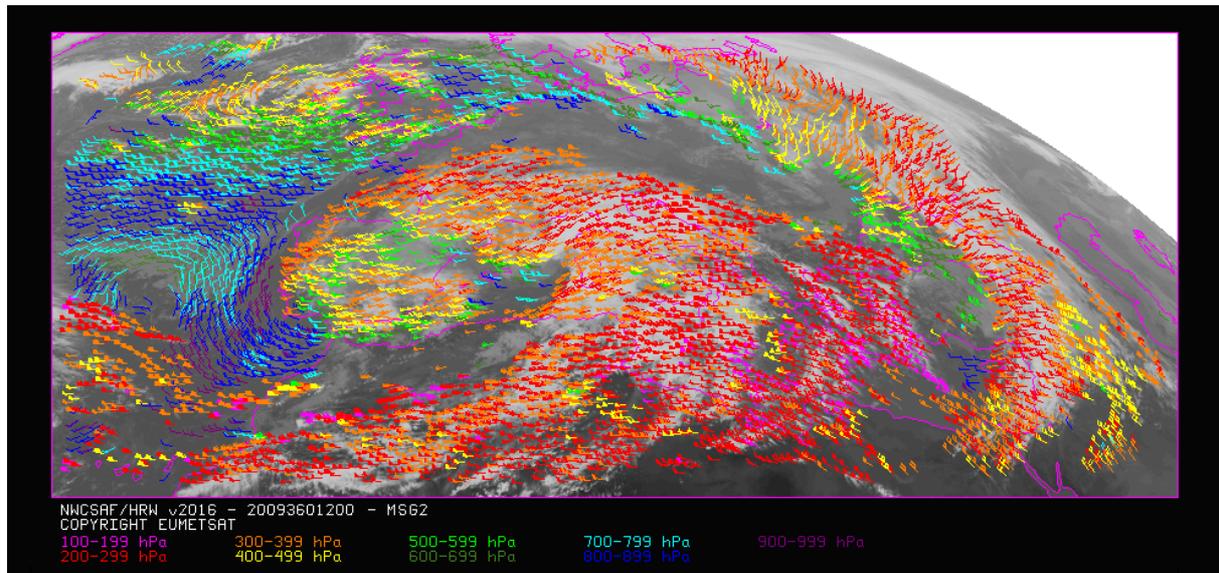


Figure 22: NWC/GEO-HRW v2016 AMV output in the European and Mediterranean region (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), considering the default conditions defined in \$SAFNWC/config/safnwc\_HRW.cfm.MSG15MIN model configuration file. Colour coding based on the AMV pressure level

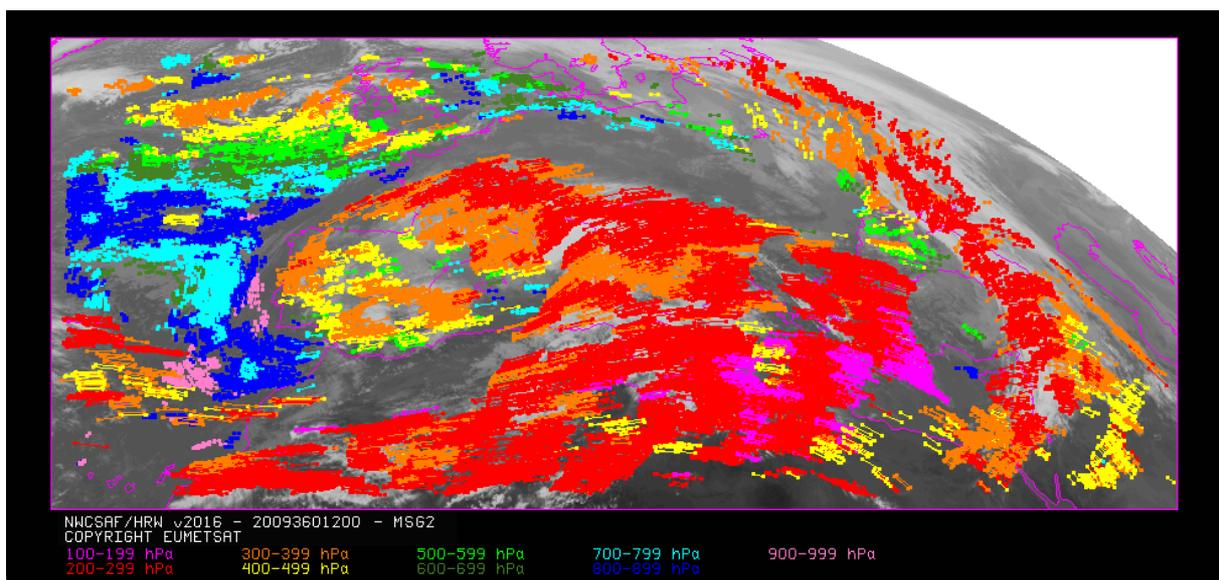


Figure 23: NWC/GEO-HRW v2016 Trajectory output in the European and Mediterranean region (trajectories lasting at least one hour, 26 December 2009 1200Z, Nominal scan mode, MSG2 satellite) considering the default conditions defined in \$SAFNWC/config/safnwc\_HRW.cfm.MSG15MIN model configuration file. Colour coding based on the AMV pressure level

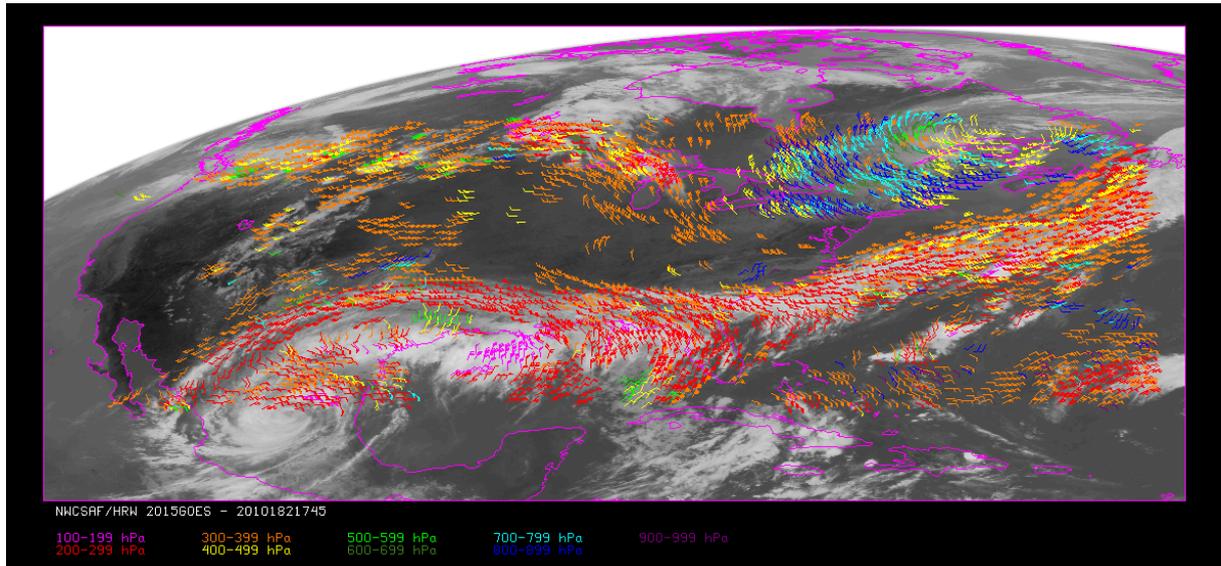


Figure 24: NWC/GEO-HRW v2016 AMV output in the Continental United States region (1 July 2010 1745Z, GOES13 satellite), considering the default conditions defined in \$SAFNWC/config/safnwc\_HRW.cfm.GOES15MIN model configuration file. Colour coding based on the AMV pressure level

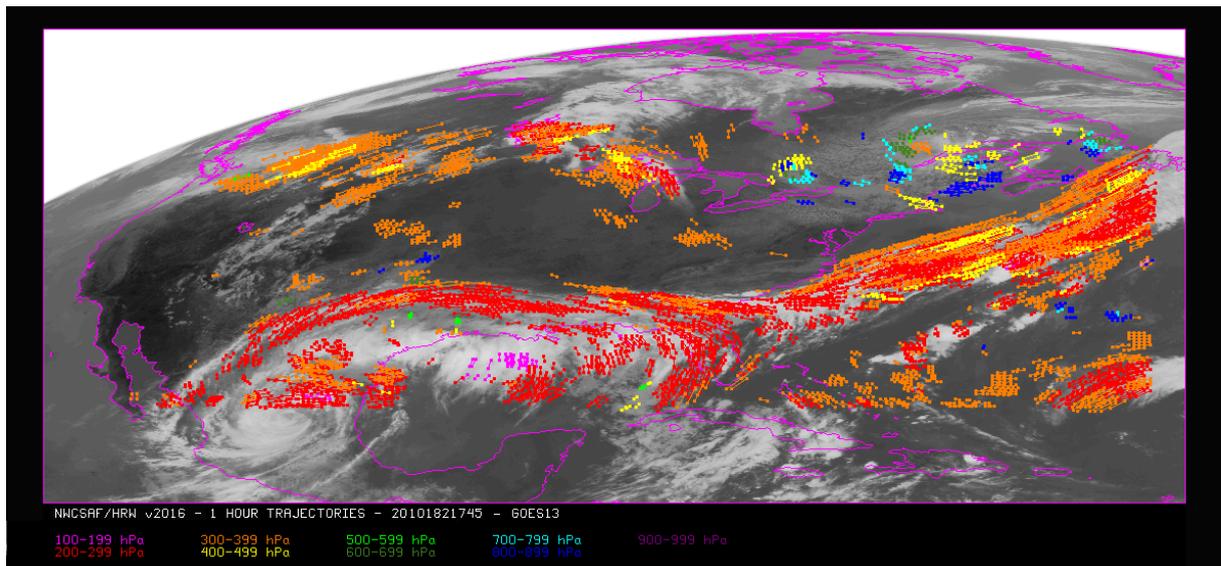


Figure 25: NWC/GEO-HRW v2016s Trajectory output in the Continental United States region (trajectories lasting at least one hour, 1 July 2010 1745Z, GOES 13 satellite), considering the default conditions defined in \$SAFNWC/config/safnwc\_HRW.cfm.GOES15MIN model configuration file. Colour coding based on the AMV pressure level

	Algorithm Theoretical Basis Document for the Wind product processors of the NWC/GEO	<b>Code:</b> NWC/CDOP2/GEO/AEMET/SCI/ATBD/Wind <b>Issue:</b> 1.1 <b>Date:</b> 15 October 2016 <b>File:</b> NWC-CDOP2-GEO-AEMET-SCI-ATBD-Wind_v1.1.doc <b>Page:</b> 68/81
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## 2.3.7 Implementation of High Resolution Winds

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

### 2.3.7.1 NWC/GEO software package installation and preparation step

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 the distribution file (a gzip compressed tar file) which successfully builds the executable (GEO-HRW-v50 executable file), to be stored into the \$SAFNWC/bin directory. The installation steps for NWC/GEO must follow the document “System Version Document for the NWC/GEO” [AD.7].

### 2.3.7.2 GEO-HRW execution step

The execution step is the processing of images with GEO-HRW-v50 algorithm in the region defined by the user. The running time scheduling relies on the Programmed Task Definition File. This process consists in the running of the command \$SAFNWC/bin/GEO-HRW-v50 along with the required parameters (slot, region file and model configuration file) by the Task manager. *Figures 26 to 28* in next pages summarise how the tasks to generate GEO-HRW-v50 output are performed by this executable.

The operational use of GEO-HRW-v50 executable requires the definition of the Region Configuration File \$SAFNWC/config/safnwc\_region.cfg (document [AD.5] must be verified about how the region can be defined).

The user has also to define the Model Configuration File to be used. Four different files are provided as default options with the software: \$SAFNWC/config/safnwc\_HRW.cfm.MSG15MIN and \$SAFNWC/config/safnwc\_HRW.cfm.MSG05MIN, for use every 15 minutes in ‘Nominal scan mode’ and every 5 minutes in ‘Rapid Scan mode’ with MSG series data, and for use with GOES-N series data every 15 and 30 minutes \$SAFNWC/config/safnwc\_HRW.cfm.GOES15MIN and \$SAFNWC/config/safnwc\_HRW.cfm.GOES30MIN.

The implementation of the running mode depends on the satellite configuration and the corresponding \$SAFNWC/config/sat\_conf\_file used. Each configuration file is an ASCII file, so further modifications can be easily performed with a text editor. The GEO-HRW model configuration file manages all variables in the executable file that are useful for the user.

To have NWC/GEO Cloud Type, Cloud Top Temperature and Pressure and/or Cloud Microphysics available for their use by GEO-HRW algorithm, it is needed to run GEO-CMA-v40, GEO-CT-v30, GEO-CTTH-v30 and GEO-CMIC-v10 executables before GEO-HRW-v50 for the same slot and region.

The ‘Rapid Scan mode’ in MSG data processing is only recommended to be used in relatively small areas (“National areas”), if all NWC/GEO products have to run together and a relatively small environment has been used for the installation of NWC/GEO software. With the five minute running constraint imposed by the MSG/SEVIRI ‘Rapid scan mode’, these circumstances permit the repeating of the process with all available satellite slots. 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 should be verified for more information on this.

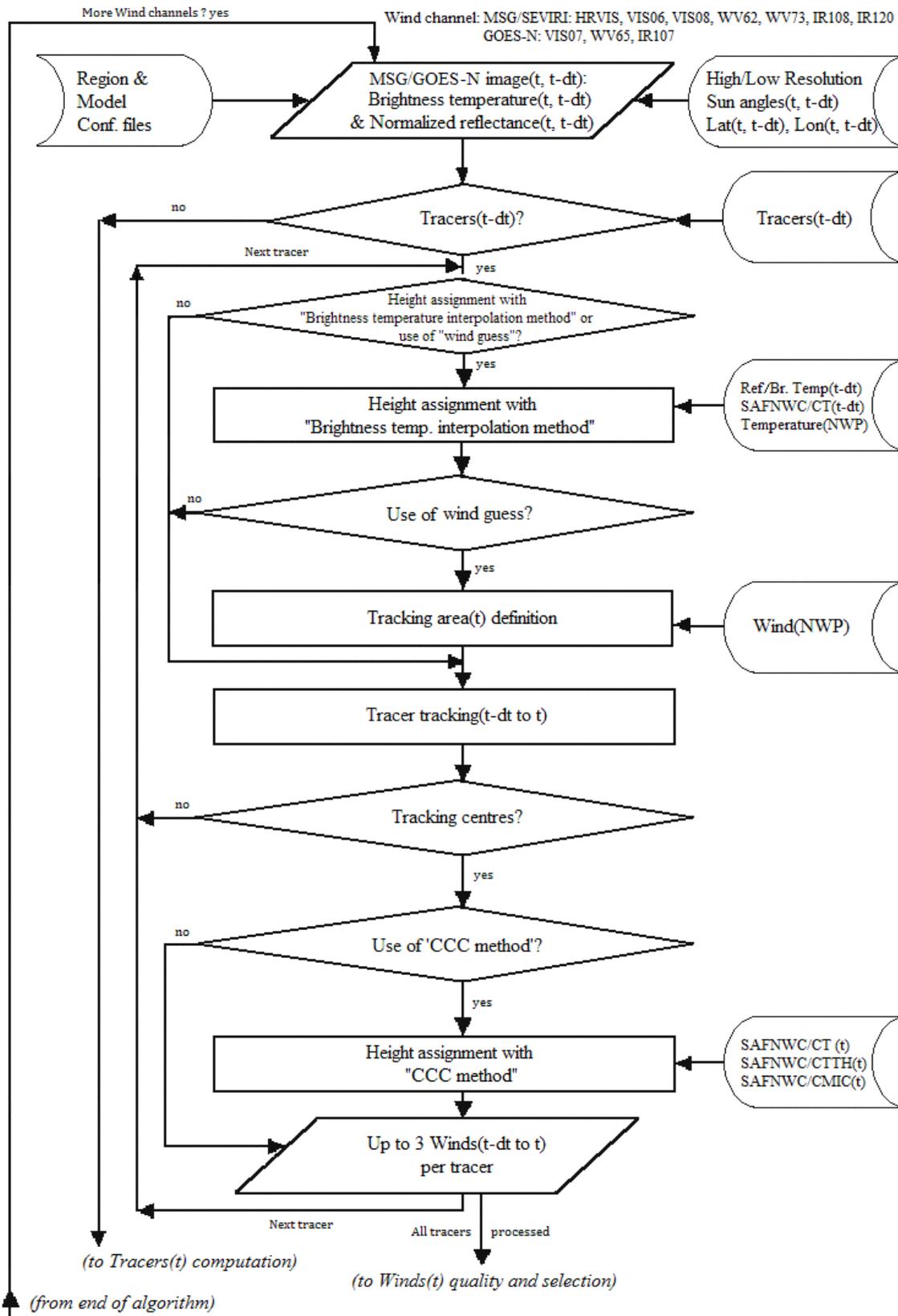


Figure 26: GEO-HRW implementation: Part 1, Preprocessing and AMV computation

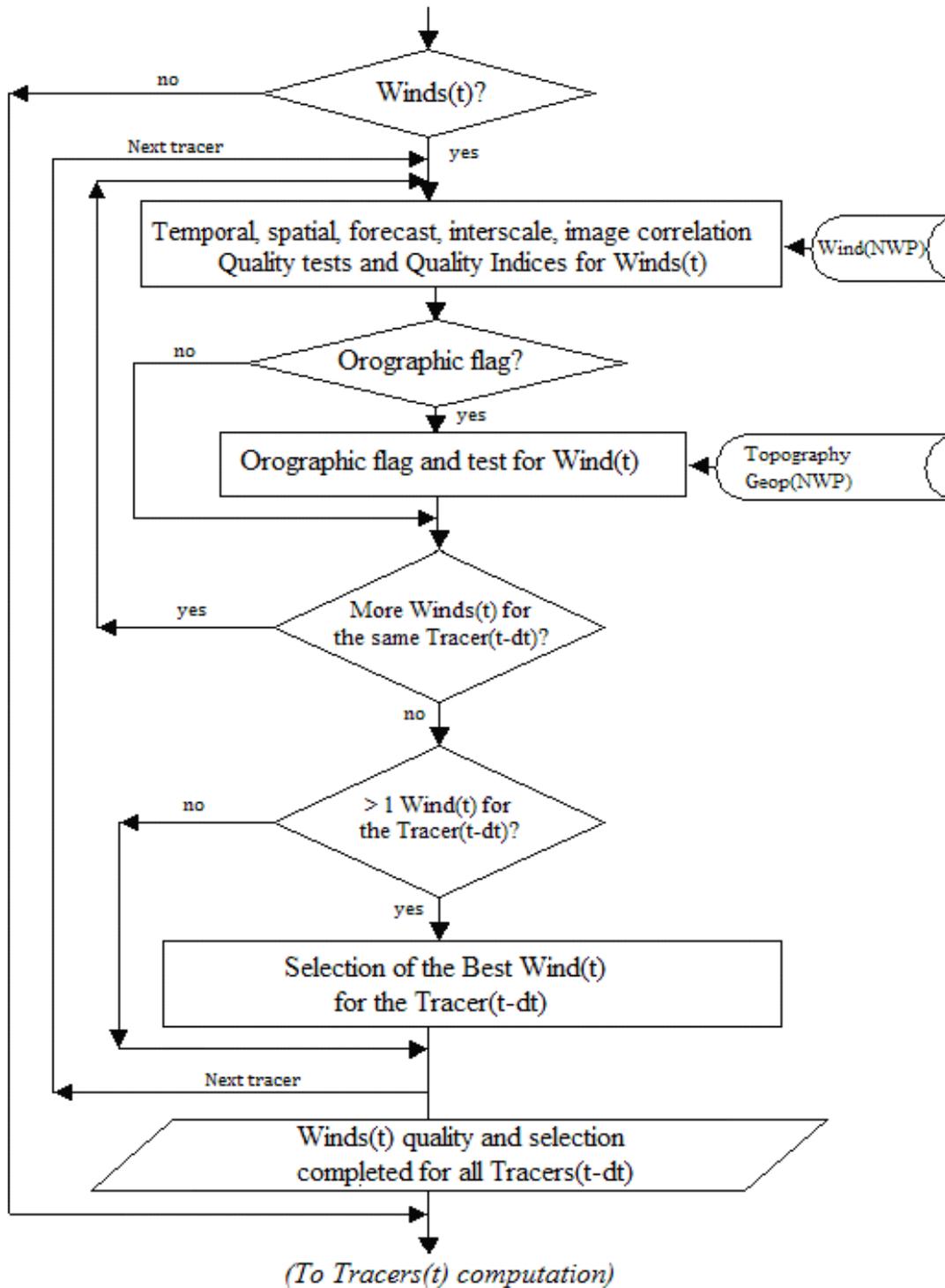


Figure 27: GEO-HRW implementation: Part 2, AMV quality and selection

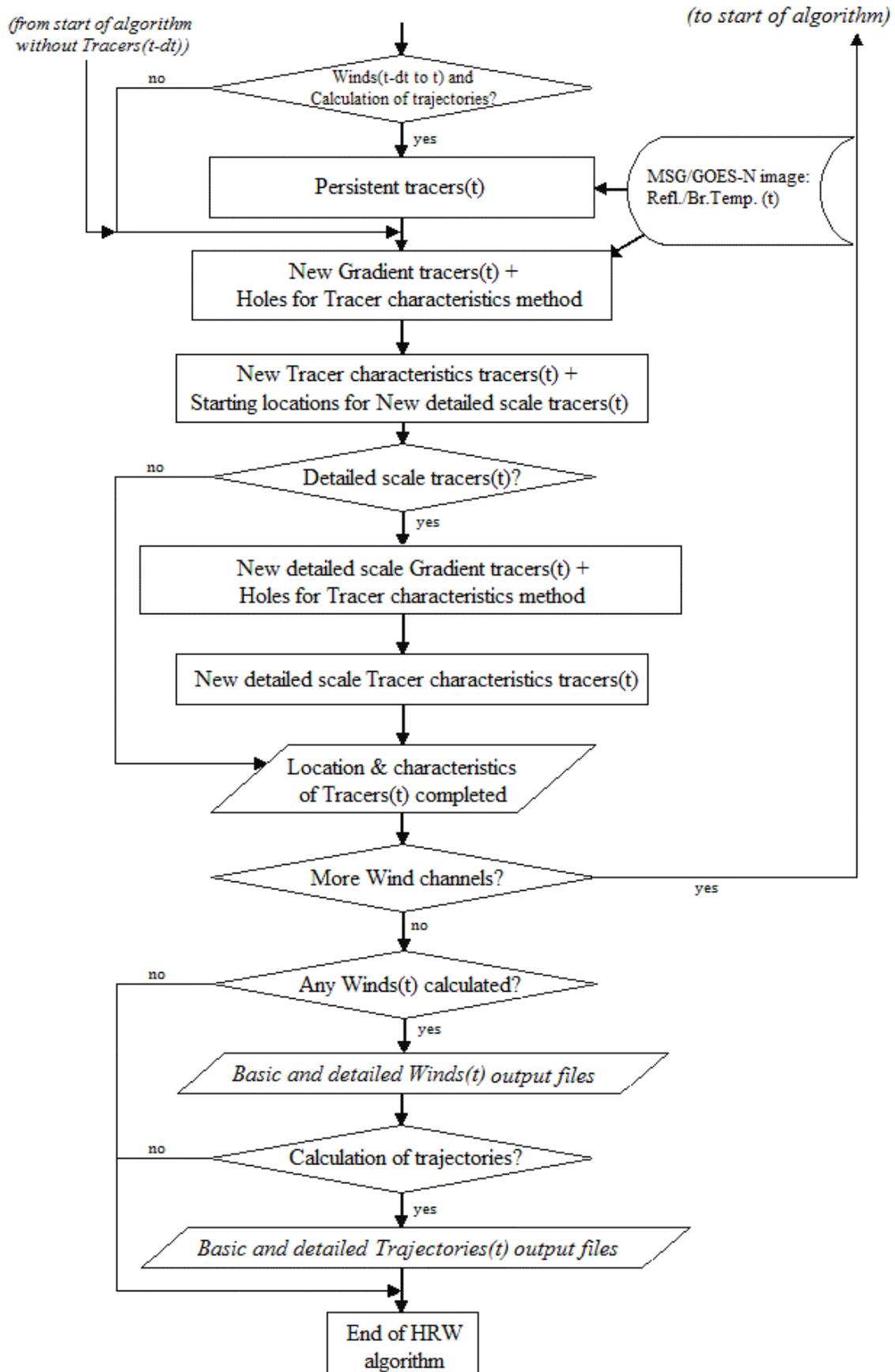


Figure 28: GEO-HRW implementation: Part 3, Tracer computation and writing of outputs

### **2.3.7.3 GEO-HRW documentation**

Since NWC/GEO v2016 software package, a detailed description of all algorithms, of the 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 GEO-HRW-v50 algorithm is in the file:

`NWC-CDOP2-GEO-AEMET-SW-ACDD-Wind_html_v1.0.zip`

To navigate throughout this documentation, decompress it and open following file in a web browser:

`NWC-CDOP2-GEO-AEMET-SW-ACDD-Wind_html_v1.1/HRW_html/index.html`

Additionally, every single step in the algorithm has been commented in detail throughout all functions of GEO-HRW-v50 code, so that all any AMV developer can very easily know 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 GEO-HRW-v5.0 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 19: Diagram Tree of GEO-HRW-v50 functions

HRW.c	=> Main GEO-HRW function, for the generation of the High Resolution Winds AMVs and Trajectories
*** hrw_ReadData	=> Reads the values of variables defined in the GEO-HRW Model configuration file
*** hrw_ReadSeviriData	=> Reads and initializes the MSG/GOES-N 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 the MSG/GOES-N 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 for the previous slot from a file located in \$SAFNWC/tmp directory
*** hrw_ReadPredWinds	=> Reads the Predecessor AMV data for the previous slot from a file located in \$SAFNWC/tmp directory
*** hrw_ReadTrajectories	=> Reads the Trajectory data for the previous slot from a file located in \$SAFNWC/tmp directory
*** hrw_GetWinds	=> Calculates the AMVs for the current slot considering the tracers from the previous slot
*** hrw_Alloc_Winds	=> Allocates memory for variables used in hrw_GetWinds module
*** hrw_TracerCharacteristics	=> Stores "tracer" variable information into the corresponding "tracer_wind" variable
*** hrw_CloudTypeCalculation	=> Calculates AMV Cloud type as defined in the "Brightness temperature height assignment"
*** hrw_SetModifTempGridValues	=> Fills "modiftempgrid" with IR/WV BT values for the "Brightness temperature height assignment"
*** hrw_GetCldhgt	=> Calculates Tracer Top temperature/pressure with "Brightness temperature height assignment"
*** hrw_NWPInvInterpolation	=> Converts the Tracer top Temperature to Pressure using NWP data
*** hrw_SetImageGridValues	=> Fills "imagegrid" with VIS Reflectances or IR/WV BT values in the tracer position
*** hrw_CalcTempCloudtype	=> Recalculates Tracer temperature mean/sigma with Cloud type info (for Tracer base temperature)
*** hrw_NWPInvInterpolation	=> Converts Tracer base Temperature to pressure using NWP data and modified mean/sigma values
*** hrw_TracerWindLevel	=> Defines the Tracer pressure level (with cloud top or cloud base) depending on its cloud type
*** hrw_WindGuess	=> Calculates the NWP wind guess at the tracer position
*** hrw_NWPDirInterpolation	=> Calculates the NWP wind at the tracer level considering the AMV pressure level calculated
*** hrw_WindModDir	=> Calculates the speed module and direction for the NWP wind guess at the tracer position

```

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

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*** hrw_WindGuess	=> Recalculates the wind guess at the tracer position considering the "CCC method" new pressure level
*** hrw_NWPDDirInterpolation	=> Calculates the NWP wind at the tracer level considering the new pressure level calculated
*** hrw_WindModDir	=> Calculates the speed module and direction for the NWP wind guess at the tracer position
*** hrw_Free_Winds	=> Deallocates memory for variables used in hrw_GetWinds module
*** hrw_Qc	=> Calculates the Quality indices and the Orographic flag for the calculated winds
*** hrw_QcAlloc_Short, _Float, _Parameters	=> Three functions allocating memory for variables in hrw_Qc module
*** hrw_QcSortLatitude	=> Sorts the current and predecessor AMV data considering their latitudes in their final positions
*** hrw_QcSort	=> Sorts an array of data considering one of its variables
*** hrw_QcPhase1	=> Calculates the individual (forecast/temporal/spatial) quality tests and total quality indices
*** hrw_QcPhase1_Alloc	=> Allocates memory for variables in hrw_QcPhase1 module
*** hrw_QcGetSpatialTest	=> Calculates the spatial quality test for a defined AMV
*** hrw_QcGetTemporalTest	=> Calculates the temporal quality test for a defined AMV
*** hrw_WindModDir	=> Calculates the speed and direction for the predecessor AMV data
*** hrw_QcPhase1_Free	=> Deallocates memory for variables in hrw_QcPhase1 module
*** hrw_IndTopoAssign	=> Calculates the Static orographic flag at the initial position of a current AMV
*** hrw_IndTopoReassign	=> Calculates the Dynamic orographic flag at the initial position of a current AMV
*** hrw_QcBestWindSelection	=> Selects the best wind for each tracer and calculates the quality flags
*** hrw_FinalControlCheck	=> Runs a Final speed and direction homogeneity check for the winds
*** 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 slot in \$SAFNWC/tmp directory
*** hrw_WriteTrajectories	=> Writes the Trajectory data file for the current slot in \$SAFNWC/tmp directory
*** hrw_GetTracers	=> Calculates the tracers for the current slot
*** hrw_Alloc_Tracers	=> Allocates memory for variables in hrw_GetTracers module
*** hrw_SetImageGridValues	=> Fills "imagegrid" with VIS Reflectances or IR/WV BTs in a tracer position for the tracer search
*** hrw_SearchTracerGradient	=> Looks for tracers considering the "Gradient method"
*** hrw_GradientMax	=> Calculates the tracer position considering the gradient maximum
*** hrw_SetImageGridValues	=> Fills "modifimagegrid" with VIS Reflectances or IR/WV BTs in the modified tracer position
*** hrw_Hisfron	=> Computes the VIS Reflectance or IR/WV BT histogram in the tracer area and its frontiers
*** hrw_SetTempGridValues	=> Fills "tempgrid" with IR/WV BT values in the modified tracer position
*** hrw_CalcTemp	=> Calculates the temperature mean/sigma in the modified tracer position

```

*** hrw_SearchTracerCharacteristics => Looks for tracers considering the "Tracer characteristics method"
  *** hrw_SetImageGridValues => Fills "imagegrid" with VIS Reflectances or IR/WV BTs in a tracer position for the tracer search
  *** hrw_Hisfron => Computes the VIS Reflectance or IR/WV BT histogram in the tracer area and its frontiers
  *** hrw_SetTempGridValues => Fills "tempgrid" with IR/WV BT values in the tracer position
  *** hrw_CalcTemp => Calculates the temperature mean/sigma in the tracer position
  *** hrw_TracerDiffSearch => "Big pixel brightness variability test", run here for "Tracer characteristics method" tracers
    *** hrw_TracerPixelCharacterization => Calculates the "Big pixel brightness values" in the tracer position
    *** hrw_TracerHorizontalDiff => Considers the Horizontal direction study in the "Big pixel variability test"
    *** hrw_TracerVerticalDiff => Considers the Vertical direction study in the "Big pixel variability test"
    *** hrw_TracerDescDiff => Considers the Descending direction study in the "Big pixel variability test"
    *** hrw_TracerAscDiff => Considers the Ascending direction study in the "Big pixel variability test"
  *** hrw_SetImageGridValues => Refills "imagegrid" with VIS Reflectances or IR/WV BTs if the previous candidate was not good
    *** hrw_TracerDiffSearch => "Big pixel brightness variability test", run here for "Tracer characteristics method" tracers
      *** hrw_TracerPixelCharacterization => Calculates the "Big pixel brightness values" in the modified tracer position
      *** hrw_TracerHorizontalDiff => Considers the Horizontal direction study in the "Big pixel variability test"
      *** hrw_TracerVerticalDiff => Considers the Vertical direction study in the "Big pixel variability test"
      *** hrw_TracerDescDiff => Considers the Descending direction study in the "Big pixel variability test"
      *** hrw_TracerAscDiff => Considers the Ascending direction study in the "Big pixel variability test"
  *** hrw_TracerDiffSearch => "Big pixel brightness variability test", run here for "Gradient method" tracers
    *** hrw_TracerPixelCharacterization => Calculates the "Big pixel brightness values" in the tracer position
    *** hrw_TracerHorizontalDiff => Considers the Horizontal direction study in the "Big pixel brightness variability test"
    *** hrw_TracerVerticalDiff => Considers the Vertical direction study in the "Big pixel brightness variability test"
    *** hrw_TracerDescDiff => Considers the Descending direction study in the "Big pixel brightness variability test"
    *** hrw_TracerAscDiff => Considers the Ascending direction study in the "Big pixel brightness variability test"
  *** hrw_TracersDetailedDiscrimination => Defines if a Basic tracer can also work as Detailed tracer
  *** hrw_Centile_Frontier => Defines the centile in the BT/Reflectance histogram considering a given frontier
  *** hrw_Free_Tracers => Deallocates memory for variables in hrw_GetTracers module
*** hrw_WriteTracers => Writes the Tracer data file for the current slot in $SAFNWC/tmp directory
*** hrw_Free_Satellite => Deallocates memory for MSG/GOES-N satellite data
*** hrw_Free_TWInd => Deallocates memory for "tracer wind" data
*** hrw_Free_Trajectories => Deallocates memory for "trajectory" data
*** hrw_Free_LevelsandGuesses => Deallocates memory for NWP data

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

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### 2.3.7.4 GEO-HRW running errors

The following table shows the whole list of errors and warnings that can appear during the running of 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, NWC SAF Helpdesk should be contacted.

Error (E) or Warning (W) Code	Message	Reason	Recovery action
E - 151	"Usage of HRW executable: GEO-HRW-v50 <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 related to the previous slot"	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 - 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
E - 166	"Error allocating memory for wind_channel_info struct"	Error after NwcSatfNit function	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.

Error (E) or Warning (W) Code	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	<p>All these errors are caused by the running of NWC/GEO-HRW product, and cannot be solved by the NWCSAF user.</p> <p>Nevertheless, as a whole, they should occur in less than a 0.5% of the cases.</p> <p>If the frequency is higher than that, please contact NWCSAF Helpdesk.</p>
E - 173	"Error reading satellite data for current 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 20: List of errors for GEO-HRW-v50 algorithm

## 2.4 HIGH RESOLUTION WINDS PRODUCT ASSUMPTIONS AND LIMITATIONS

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 in the working region of cloudy areas (or cloudless areas with humidity patterns in the water vapour images, if Clear air Water vapour Atmospheric Motion Vectors are considered).

Nevertheless, the situation has improved since version GEO-HRW-v3.2. Previously, the applicability of GEO-HRW algorithm was limited to cloudy areas because of considering HRVIS and IR108 channels only. The new AMVs at GEO-HRW-v3.2 related to humidity patterns in the water vapour channels (WV62, WV73) show for the first time wind vectors in clear air areas. Besides, the possibility to calculate AMVs with up to seven different channels with MSG/SEVIRI satellite (or up to three different visible, infrared and water vapour channels with GOES-N satellite), increases significantly the density of AMV data.

With all of this, the presence of geographical areas inside the working region where GEO-HRW algorithm does not find any wind vector is now smaller. Nevertheless, because the presence of humidity patterns in the clear air areas where tracers can adequately be defined and tracked is not guaranteed, and because in general clear air AMVs have worse validation statistics (causing the filtering of valid clear air AMVs to be more demanding than the filtering of cloudy AMVs), the presence of areas inside the working region where no AMVs are available and no information can be extracted is still possible. The users should evaluate, which implications this might have when using GEO-HRW algorithm.

About the calculated Atmospheric Motion Vectors, 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 vertical wind profile. 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 forecast winds can cause the AMVs to have a worse forecast QI than the one they should, and because of this some good winds might be rejected.

The first problem is solved not using the wind guess (with WIND\_GUESS = 0), which despite the increases in the running time of GEO-HRW algorithm it implies (because of using larger ‘tracking areas’), the optimizations included since GEO-HRW-v4.0 make this configuration fully operative as the default option for 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 GEO-HRW algorithm (implemented with QI\_THRESHOLD\_USEFORECAST = 0 since GEO-HRW-v4.0), which avoids the influence of the NWP model in the Quality of the AMVs. Nevertheless, this option has not been considered as the default one because the impact of the NWP model in the Quality of the AMVs is considered to be generally more positive than negative.

- In the height assignment (in general the main remaining challenge that scientists are currently facing with AMV extraction), if the ‘HRW Brightness temperature interpolation height assignment’ is used, small errors in the temperature profile can cause important errors in the heights assigned to the tracers. Besides, in this case 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 since GEO-HRW-v3.1 using the ‘CCC height assignment method’, where the ‘thermal inversion problem’ is solved using GEO-CTTH product output data).
- Considering all this, the use of the NWP model is nevertheless 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 method’). The quality of the height assignment inferred in previous versions of 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 skipped in GEO-HRW-v50 algorithm.

With all of this, the important improvements in the latest GEO-HRW versions (since v2.2 to v5.0) have reduced the limitations this algorithm previous had.

First of all, the use of NWC/GEO CT output helps to eliminate wrong ground tracers identified as clouds in the visible and infrared channels (related to “cloud free land or sea” or “land or sea contaminated with ice or snow”), and to verify the different behaviours of the AMVs considering the Cloud type they are related to. Secondly, the use of NWC/GEO CTTH output with ‘CCC method’ in the height assignment includes several new procedures (like the Radiance ratioing technique and the H20/IRW intercept method for the definition of the AMV height related to semitransparent clouds), which have improved the statistics of the AMVs related to the semitransparent cloud types respect to the previous versions of the algorithm. Finally, the inclusion of Microphysics data in GEO-HRW-v50 permit to take into account the Cloud depth for an improved AMV height assignment.

The adaptation of GEO-HRW algorithm to infrared and water vapour channels also helped to extend the AMV calculation to all hours of the day, and to both cloudy and clear air areas, following the necessities and suggestions of NWC SAF users. This eliminates the temporal limitation to daytime which GEO-HRW algorithm previously had. The extension to calculate winds in the ‘Rapid scan mode’ with MSG/SEVIRI satellite permits also to obtain new winds even every five minutes with every new slot, increasing the amount of available AMVs in a 15 minute time lapse by a factor of around 3 respect to the ‘Nominal scan mode’.

The default configuration not using the ‘wind guess’ in the definition of the ‘tracking area’ and the introduction of the ‘Quality index without forecast’ (reducing the influence of the NWP model in the calculation and definition of the quality of the AMVs) also contribute to improve the general quality of GEO-HRW AMVs.

Considering finally the calculation of trajectories through the successive tracking of the same tracer in consecutive slots, the most important limitation is the persistence in time of the tracers for the definition of the trajectories. To keep the quality of the corresponding AMVs, it has been considered necessary that the tracers should keep their characteristics (such as defined by ‘Gradient method’ or ‘Tracer characteristics method’) throughout the entire trajectory.

Because of the temporal evolution of the tracers, under these requirements after one hour only between 30% and 50% of the tracers persist; after three hours only between the 5% and 15% of the tracers persist. Additionally, the persistence is smaller due the smaller size of the tracers in the ‘Detailed scale’. Considering this, users of GEO-HRW product should be aware about the utility the trajectories provided to them under these conditions.

Additionally, the persistence of the tracers is 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 GEO-HRW algorithm.