User Manual for the Wind product processor of the NWC/GEO: Science Part

NWC/CDOP3/GEO/AEMET/SCI/UM/Wind, Issue 1, Rev. 0
21 January 2019

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

Prepared by Agencia Estatal de Meteorología (AEMET)
### REPORT SIGNATURE TABLE

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<thead>
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## DOCUMENT CHANGE RECORD

<table>
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<tr>
<td>1.0</td>
<td>21 January 2019</td>
<td>70</td>
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1. INTRODUCTION

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

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

1.1 SCOPE OF THE DOCUMENT

This document is the “User Manual (UM) for the Wind Product Processor of the NWC/GEO” software package (NWC/GEO-HRW, High Resolution Winds), which calculates Atmospheric Motion Vectors and Trajectories considering:

- Up to seven channels from MSG/SEVIRI imager: six 3 km low resolution visible, water vapour and infrared channels (VIS06 0.635 µm, VIS08 0.810 µm, WV62 6.250 µm, WV73 7.350 µm, IR108 10.800 µm and IR120 12.000 µm), and the 1 km high resolution visible channel (HRVIS 0.750 µm).
- Up to three channels from GOES-N/IMAGER: two 4 km low resolution water vapour and infrared channels (WV65 6.550 µm and IR107 10.700 µm), and the 1 km high resolution visible channel (VIS07 0.650 µm).
- Up to six channels from Himawari-8/9/AHI imager: four 2 km low resolution water vapour and infrared channels (WV62 6.250 µm, WV70 6.950 µm, WV73 7.350 µm and IR112 11.200 µm), one 1 km high resolution visible channel (VIS08 0.860 µm), and the 0.5 km very high resolution visible channel (VIS06 0.645 µm).

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

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

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

This document describes the algorithm implemented in the NWC/GEO-HRW v6.0 (Product Id NWC-038) of the NWC/GEO v2018 software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

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

#### 1.4.1. Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>4x4 big pixel matrix</td>
<td>4x4 big element matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_n)</td>
</tr>
<tr>
<td>Atmospheric Motion Vector (AMV)</td>
<td>Horizontal wind calculated through the horizontal displacement between two Earth positions in two different satellite images (defined as initial image and later image), of a square segment of n x n pixels called tracer</td>
</tr>
<tr>
<td>Basic dataset</td>
<td>Set of tracers or AMVs, calculated with the basic or wide tracer scale (with a default value of 24 x 24 pixels). Two kinds of Basic tracers are possible: wide basic tracers (with bright big pixels in the first and last big pixel row or column) and narrow basic tracers (occurring otherwise)</td>
</tr>
<tr>
<td>Bearing angle</td>
<td>Angle defined by the great circle connecting two locations on the Earth</td>
</tr>
<tr>
<td>Best fit pressure level</td>
<td>Pressure level which minimizes the vector difference between the AMV and a NWP reference wind, considering as reference wind the nearest NWP wind profile or nearest Radiosounding wind profile, with a linear variation of the wind components between profile levels</td>
</tr>
<tr>
<td>Big pixel</td>
<td>Each element of the 4x4 big pixel matrix, in which pixels of a tracer candidate are classified at reduced resolution, defining three different brightness classes (CLASS_0, CLASS_1, CLASS_2)</td>
</tr>
<tr>
<td>Bright big pixel</td>
<td>Big pixel inside a big pixel matrix, in which at least a 70% of its pixels is brighter than a given frontier (also called CLASS_2 big pixel)</td>
</tr>
<tr>
<td>Brightness value</td>
<td>Value for a given pixel of the N_Value matrices, characterized by the Normalized reflectance in the pixel for Visible channels and the Brightness temperature in the pixel in Infrared or Water vapour channel, and defined as an integer value ranging from 0 to 255</td>
</tr>
<tr>
<td>Clear air AMV</td>
<td>AMV defined through the horizontal displacement between two Earth positions in two different satellite images, of a tracer defined through a specific humidity feature in water vapour images</td>
</tr>
<tr>
<td>Closeness threshold</td>
<td>Minimum distance in lines and columns allowed between two tracer locations</td>
</tr>
<tr>
<td>Cloud type</td>
<td>Cloud type defined for each tracer or AMV with NWC/GEO-CT output data, used for example to define which of the two calculated height levels (cloud top, cloud base) is used in the “Brightness temperature interpolation height assignment process”</td>
</tr>
<tr>
<td>Cloudy AMV</td>
<td>AMV defined through the horizontal displacement between two Earth positions in two different satellite images, of a tracer defined through a specific cloudiness feature in visible, infrared or water vapour images</td>
</tr>
<tr>
<td>Common Quality Index</td>
<td>Quality parameter, calculated with a self-contained Fortran module defined by EUMETSAT and NOAA/NESDIS, to be included as such without modifications by all AMV algorithms, and useful for a common homogeneous use of AMVs calculated with different AMV algorithms.</td>
</tr>
<tr>
<td>Consistency</td>
<td>Difference between an AMV and some other expected wind, quantified in probabilistic terms for the Quality Index calculation</td>
</tr>
<tr>
<td>Coverage hole</td>
<td>Location in the initial image in which two consecutive failures in the definition of a tracer with Gradient method have occurred, so defining a location for the tracer search with the second method, Tracer characteristics method</td>
</tr>
<tr>
<td>-------------------------------</td>
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</tr>
<tr>
<td>Dark big pixel</td>
<td>Big pixel inside a big pixel matrix, in which less than a 30% of its pixels is brighter than a given frontier (also called CLASS_0 big pixel)</td>
</tr>
<tr>
<td>Detailed dataset</td>
<td>Set of tracers or AMVs, calculated with the detailed or narrow tracer scale (with a default value of 12 x 12 pixels). Three kinds of Detailed tracers are possible: unrelated to a basic tracer, related to a wide basic tracer, related to a narrow basic tracer</td>
</tr>
<tr>
<td>Distance factor</td>
<td>Formula used to define which AMVs contribute to the spatial and temporal consistency tests for a given AMV, and their corresponding contribution to the consistency test</td>
</tr>
<tr>
<td>Frontier</td>
<td>A significant minimum in the N_Value matrix histogram for a given tracer candidate</td>
</tr>
<tr>
<td>Great circle</td>
<td>Trajectory between two locations on the Earth surface, which relates them considering the smallest possible distance</td>
</tr>
<tr>
<td>Haversine formula</td>
<td>Formula used to compute the great circle distance between two locations on the Earth surface</td>
</tr>
<tr>
<td>IND_TOPO parameter</td>
<td>Value of the AMV Orographic flag parameter, calculated to detect land influence for a given Atmospheric Motion Vector</td>
</tr>
<tr>
<td>Initial image</td>
<td>Satellite image in which tracers are defined with any of the two tracer calculation methods (Gradient or Tracer characteristics), so defining the initial position in the AMV displacements</td>
</tr>
<tr>
<td>LAT_C, LON_C</td>
<td>Geographical coordinates of the tracking centre in the later image, considering a given AMV</td>
</tr>
<tr>
<td>LAT_T, LON_T</td>
<td>Geographical coordinates of the tracer centre in the initial image, considering a given AMV</td>
</tr>
<tr>
<td>Later image</td>
<td>Satellite image in which tracers defined previously are tracked with any of the two tracking methods (Euclidean distance or Cross correlation), defining the later positions in the AMV displacements</td>
</tr>
<tr>
<td>Main tracking centre</td>
<td>Tracking centre for a given tracer, which has the best possible Euclidean distance/Cross correlation values</td>
</tr>
<tr>
<td>Maximum brightness gradient</td>
<td>Location of the maximum brightness value gradient inside a tracer candidate, to be defined as a tracer location with Gradient method</td>
</tr>
<tr>
<td>Maximum optimisation distance</td>
<td>Maximum distance in lines or columns allowed between a coverage hole used in the search of tracers with Tracer characteristics method, and the corresponding tracer location</td>
</tr>
<tr>
<td>Mixed calculation method</td>
<td>Alternative method available for the calculation of AMVs and Trajectories with NWC/GEO-HRW algorithm, through which the tracer tracking is evaluated considering shorter time intervals, and the displacement is evaluated considering longer time intervals.</td>
</tr>
<tr>
<td>Neighbour AMV</td>
<td>AMV which is close enough to a given one in the current processing cycle, used in the Quality spatial correlation test</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>N_Value matrix</td>
<td>Normalized reflectances for Visible channels, or Brightness temperatures for Infrared or Water vapour channels, for a given image in the processing region, defined as integer values ranging from 0 to 255.</td>
</tr>
<tr>
<td>Orographic flag (dynamic)</td>
<td>Flag to show possible land influence in the previous positions of a given AMV. It is calculated after the static orographic flag procedure, and indicated through IND_TOPO values: 1,2,3,4,5,6.</td>
</tr>
<tr>
<td>Orographic flag (static)</td>
<td>Flag to show possible land influence in the position of a given AMV. Indicated through IND_TOPO values: 1,2,3,6.</td>
</tr>
<tr>
<td>Overall Quality Index</td>
<td>Final Quality Index, weighted sum of individual forecast, temporal and spatial consistency tests (not considering the interscale consistency test)</td>
</tr>
<tr>
<td>Parallax correction</td>
<td>Correction of the apparent horizontal displacement of a feature in a satellite image, due to its height over the Earth surface</td>
</tr>
<tr>
<td>Persistent tracer</td>
<td>Tracer related to AMVs calculated in the previous cycle, for which the tracer centre is the tracking centre of the AMV in the previous cycle</td>
</tr>
<tr>
<td>Pixel distance</td>
<td>Preliminary line and column separation in pixels between the tracer locations, before the readjustments made by the tracer selection methods</td>
</tr>
<tr>
<td>Pixel exclusion matrix</td>
<td>Ensemble of pixels inside the processing region in which additional tracers cannot be located</td>
</tr>
<tr>
<td>Predecessor AMV</td>
<td>AMV in the previous processing cycle, whose tracking centre is used as the tracer centre of a persistent tracer in the current processing cycle</td>
</tr>
<tr>
<td>Prior AMV</td>
<td>AMV in the previous processing cycle close enough to a given AMV in the current processing cycle, used in the Quality temporal correlation test</td>
</tr>
<tr>
<td>Quality index (QI)</td>
<td>Quality parameter used to define the quality of the generated AMVs and Trajectories. It is based on spatial, temporal and forecast consistency against reference AMVs or the NWP wind forecast. Two kinds of Quality indices are defined: with and without forecast (with and without the contribution of the consistency against the NWP wind forecast)</td>
</tr>
<tr>
<td>Quality index threshold</td>
<td>Minimum value of the Quality index (with/without forecast) so that the given AMV/Trajectory can be written in the output files</td>
</tr>
<tr>
<td>S (in CC computation)</td>
<td>Any pixel inside a tracking candidate</td>
</tr>
<tr>
<td>Secondary tracking centre</td>
<td>Tracking centre for a given tracer, which does not have the best Euclidean distance or Cross correlation</td>
</tr>
<tr>
<td>Segment of the image</td>
<td>A set of contiguous pixels in a satellite image, defined by its size and location</td>
</tr>
<tr>
<td>Single scale procedure</td>
<td>Tracer selection procedure, for which only one scale of tracers is calculated</td>
</tr>
<tr>
<td>Starting location</td>
<td>Each a priori location of tracers throughout the initial image, in principle uniformly covering the whole processing region</td>
</tr>
<tr>
<td>Subpixel tracking</td>
<td>Tracking processing, through which the tracking centres in the later image are located in a non-integer location of the tracking area, and which is calculated through second order interpolation of the Euclidean distance minima/Cross correlation maxima locations</td>
</tr>
<tr>
<td>T (in CC computation)</td>
<td>Any pixel inside a tracer</td>
</tr>
<tr>
<td>TESO parameter</td>
<td>Orographic test parameter, detailing if the orographic flag could be calculated for a given AMV, and the relative results in AMVs related to the same tracer, to be added to the Quality TEST indicator</td>
</tr>
<tr>
<td>----------------</td>
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</tr>
<tr>
<td>TEST parameter</td>
<td>Quality flag after the Quality control processing, detailing which quality consistency tests were applied for a given AMV, and the relative results of each quality consistency test for all AMVs related to the same tracer</td>
</tr>
<tr>
<td>Tracer</td>
<td>Square segment in the initial image with a fixed size (nxn pixels, called tracer size), identified by the location of its centre, and considered valid candidate for AMV calculation by any of the tracer calculation methods</td>
</tr>
<tr>
<td>Tracer candidate</td>
<td>Square segment in the initial image with a fixed size, where conditions for tracer search using “Tracer characteristics method” are evaluated</td>
</tr>
<tr>
<td>Tracer continuity</td>
<td>Processing option in which part of the set of tracers in the current processing cycle is defined through the tracking centres of AMVs in the previous processing cycle</td>
</tr>
<tr>
<td>Tracer location</td>
<td>Pixel coordinates of a tracer centre (line and column) in the initial image</td>
</tr>
<tr>
<td>Tracer selection procedure</td>
<td>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</td>
</tr>
<tr>
<td>Tracer size</td>
<td>Line/column dimension of a tracer. In NWC/GEO-HRW algorithm, both dimensions are similar defining square shaped tracers</td>
</tr>
<tr>
<td>Tracking</td>
<td>Determination of the best matching square segment for a given tracer in the initial image, with the same line and column dimension, inside the tracking area of a later image</td>
</tr>
<tr>
<td>Tracking area</td>
<td>Square segment in the later image containing the search area of a given tracer, in which all possible tracking candidates are located</td>
</tr>
<tr>
<td>Tracking candidate</td>
<td>Each square segment inside a tracking area of the later image, that is evaluated for the tracking of a given tracer</td>
</tr>
<tr>
<td>Tracking centre</td>
<td>Best matching square segment for a given tracer, with the same line and column dimension, inside the tracking area of a later image</td>
</tr>
<tr>
<td>Tracking centre location</td>
<td>For a tracking centre, pixel coordinates of its centre (line and column) in the later image</td>
</tr>
<tr>
<td>Trajectory</td>
<td>Path defining the displacement of a specific tracer throughout several satellite images</td>
</tr>
<tr>
<td>Two scale procedure</td>
<td>Tracer selection process considering tracers with two different tracer sizes (Basic dataset and Detailed dataset, being the line and column dimension of the second dataset half the dimension of the first dataset)</td>
</tr>
<tr>
<td>Weighted location</td>
<td>Location different that the centre of the tracer in the initial image or the tracking centre in the later image, relating best the displacement of the AMVs and Trajectories to the displacement of the part of the tracer with a largest contribution to the cross correlation.</td>
</tr>
<tr>
<td>Wind guess</td>
<td>NWP wind longitudinal and latitudinal components, through which the location of a smaller tracking area in the later image is defined for a quicker processing, although with a dependency on the NWP wind</td>
</tr>
</tbody>
</table>

**Table 1: List of Definitions**
### 1.4.2. Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMV</td>
<td>Atmospheric Motion Vector</td>
</tr>
<tr>
<td>BUFR</td>
<td>Binary Universal Form for the Representation of meteorological data</td>
</tr>
<tr>
<td>CDOP</td>
<td>NWC SAF Continuous Development and Operations Phase</td>
</tr>
<tr>
<td>CDOP2</td>
<td>NWC SAF Second Continuous Development and Operations Phase</td>
</tr>
<tr>
<td>CDOP3</td>
<td>NWC SAF Third Continuous Development and Operations Phase</td>
</tr>
<tr>
<td>CIMSS</td>
<td>NOAA/UW’s Cooperative Institute for Meteorological Satellite Studies</td>
</tr>
<tr>
<td>ECMWF</td>
<td>European Centre for Medium Range Weather Forecasts</td>
</tr>
<tr>
<td>EUMETSAT</td>
<td>European Organization for the Exploitation of Meteorological Satellites</td>
</tr>
<tr>
<td>GOES</td>
<td>NOAA’s Geostationary Operational Environmental Satellite series</td>
</tr>
<tr>
<td>HRVIS</td>
<td>MSG HRVIS High Resolution Visible channel</td>
</tr>
<tr>
<td>IOP</td>
<td>NWC SAF Initial Operations Phase</td>
</tr>
<tr>
<td>IR107, IR108, IR112, IR120</td>
<td>GOES-N 10.7µm - MSG 10.8µm - Himawari-8/9 11.2µm MSC 12.0µm Infrared channels</td>
</tr>
<tr>
<td>IWWG</td>
<td>International Winds Working Group</td>
</tr>
<tr>
<td>JMA</td>
<td>Japan Meteorological Agency</td>
</tr>
<tr>
<td>MSG</td>
<td>EUMETSAT’s Meteosat Second Generation Satellite series</td>
</tr>
<tr>
<td>NOAA</td>
<td>United States’ National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NWC/GEO</td>
<td>NWC SAF Software Package for Geostationary satellites</td>
</tr>
<tr>
<td>NWC/GEO-HRW</td>
<td>NWC SAF Product Generation Element for the High Resolution Winds</td>
</tr>
<tr>
<td>NWCLIB</td>
<td>NWC/GEO Common Software Library</td>
</tr>
<tr>
<td>NWC SAF</td>
<td>EUMETSAT’s Satellite Application Facility on support to Nowcasting and Very short range forecasting</td>
</tr>
<tr>
<td>NWP</td>
<td>Numerical Weather Prediction Model</td>
</tr>
<tr>
<td>SCI</td>
<td>NWC SAF Scientific Report</td>
</tr>
<tr>
<td>SMR</td>
<td>NWC SAF Software Modification Report</td>
</tr>
<tr>
<td>SPR</td>
<td>NWC SAF Software Problem Report</td>
</tr>
<tr>
<td>SW</td>
<td>Software</td>
</tr>
<tr>
<td>TM</td>
<td>NWC/GEO Task Manager</td>
</tr>
<tr>
<td>UW</td>
<td>United States’ University of Wisconsin/Madison</td>
</tr>
<tr>
<td>VIS06, VIS07, VIS08</td>
<td>MSG &amp; Himawari-8/9 0.6µm - GOES-N 0.7µm - MSG &amp; Himawari-8/9 0.8µm Visible channels</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
</tr>
<tr>
<td>WV62, WV65, WV70, WV73</td>
<td>MSG &amp; Himawari-8/9 6.2µm - GOES-N 6.5µm - Himawari-8/9 6.9µm - MSG &amp; Himawari-8/9 7.3µm Water vapour channels</td>
</tr>
</tbody>
</table>

*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.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Title</th>
<th>Code</th>
<th>Version</th>
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<tr>
<td>[AD.1]</td>
<td>Proposal for the Third Continuous Development and Operations Phase (CDOP3)</td>
<td>NWC/CDOP3/SAF/AEMET/MGT/PRO</td>
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<td>[AD.2]</td>
<td>Project Plan for the NWC SAF CDOP3 Phase</td>
<td>NWC/CDOP3/SAF/AEMET/MGT/PP</td>
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<tr>
<td>[AD.3]</td>
<td>Configuration Management Plan for the NWC SAF</td>
<td>NWC/CDOP3/SAF/AEMET/MGT/CMP</td>
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</tr>
<tr>
<td>[AD.5]</td>
<td>Interface Control Document for Internal and External Interfaces of the NWC/GEO</td>
<td>NWC/CDOP3/GEO/AEMET/SW/ICD/1</td>
<td>1.0</td>
</tr>
<tr>
<td>[AD.6]</td>
<td>Data Output Format for the NWC/GEO</td>
<td>NWC/CDOP3/GEO/AEMET/SW/DOF</td>
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<tr>
<td>[AD.7]</td>
<td>System and Component Requirements Document for the NWC/GEO</td>
<td>NWC/CDOP3/GEO/AEMET/SW/SCRD</td>
<td>2.1</td>
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<tr>
<td>[AD.8]</td>
<td>Estimation of computer environment needs to run NWC SAF products operatively in &quot;Rapid scan mode&quot;</td>
<td>NWC/CDOP/INM/SW/RP/01</td>
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<tr>
<td>[AD.9]</td>
<td>Validation Report for “High Resolution Winds” (HRW – PGE09 v2.2)</td>
<td>NWC/CDOP/INM/SCI/VR/05</td>
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</tr>
<tr>
<td>[AD.10]</td>
<td>Validation Report for “High Resolution Winds” (HRW – PGE09 v3.0)</td>
<td>NWC/CDOP/INM/SCI/VR/07</td>
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</tr>
<tr>
<td>[AD.11]</td>
<td>Validation Report for “High Resolution Winds” (HRW – PGE09 v3.1)</td>
<td>NWC/CDOP/INM/SCI/VR/09</td>
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</tr>
<tr>
<td>[AD.12]</td>
<td>Validation Report for “High Resolution Winds” (HRW – PGE09 v3.2)</td>
<td>NWC/CDOP/INM/SCI/VR/10</td>
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</tr>
<tr>
<td>[AD.13]</td>
<td>Validation Report for &quot;High Resolution Winds&quot; (HRW – PGE09 v4.0)</td>
<td>NWC/CDOP2/INM/SCI/VR/13</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Title</th>
</tr>
</thead>
</table>

Table 4: List of Reference Documents
2. **HIGH RESOLUTION WINDS (GEO-HRW) DESCRIPTION**

2.1 **GOAL OF HIGH RESOLUTION WINDS (GEO-HRW) PRODUCT**

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

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

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

- The high resolution visible channel (HRVIS),
- Two low resolution 0.6μm and 0.8μm visible channels (VIS06, VIS08),
- Two low resolution 10.8μm and 12.0μm infrared channels (IR108, IR120),
- Two low resolution 6.2μm and 7.3μm water vapour channels (WV62, WV73),

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

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

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

- The very high resolution 0.6μm visible channel (VIS06),
- One high resolution 0.8μm visible channel (VIS08),
- One low resolution 11.2μm infrared channel (IR112),
- Three low resolution 6.2μm, 6.9μm and 7.3μm water vapour channel (WV62, WV70, WV73).

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

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

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

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

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

2. **Processing:**
   - First, “tracers” are calculated in an “initial image” with two consecutive methods: Gradient and Tracer characteristics.
   - Later, these “tracers” are “tracked” in a “later image” through one of two different methods (Euclidean distance or Cross correlation), with the selection of up to three “tracking centres” for each “tracer”. “Atmospheric Motion Vectors (AMVs)” and “Trajectories” are then calculated, considering the displacement between the position of each “tracer” in the “initial image” and the position of the corresponding “tracking centres” in the “later image”.
   - The pressure level of the AMVs and Trajectories is defined through one of two different methods (“Brightness temperature interpolation method” or “Cross Correlation Contribution method”) for their vertical location in the atmosphere.

3. **Postprocessing:**
   - A Quality control with EUMETSAT “Quality Indicator” method is implemented, with the choice of the “Best AMV” considering the up to three AMVs calculated for each tracer, and a Final control check to eliminate wrong AMVs and Trajectories which are very different to those in their vicinity.
   - An “Orographic flag” can also be calculated, which incorporating topographic data detects those AMVs and Trajectories affected by land influence.

The code was progressively developed with GOES, MFG and MSG satellite data. Examples with MSG, GOES-N and Himawari-8/9 satellite series are presented throughout the description of the algorithm to illustrate the process.

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

In NWC/GEO-HRW v6.0, the default configuration implies the use of consecutive images (separated by 10 minutes with Himawari-8/9 series, by 15 minutes with MSG series, and by 15 or 30 minutes with GOES-N series) for the definition and tracking of the tracers, and so for the calculation of AMVs. An additional option for “Rapid scan mode” with MSG satellites is possible (with images separated by 5 minutes). No “Rapid scan mode” option has been defined for use with GOES-N or Himawari-8/9 satellite series for this release.
2.2.1 Preprocessing

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

1. Normalized reflectances for any MSG, GOES-N or Himawari-8/9 visible channel to be used; brightness temperatures for any MSG, GOES-N or Himawari-8/9 infrared or water vapour channel to be used; radiances for MSG/IR108 and WV62, GOES-N/IR107 and WV65, Himawari-8/9/IR112 and WV62 channels for the default configuration of the ‘Quality Control’.

2. Latitude and longitude, and solar and satellite zenith angle matrices for the satellite region to be used (which are calculated by NWC/GEO-NWCLIB library).

3. NWP temperature profiles. NWP wind component profiles can also be extracted for the ‘forecast consistency quality test’, for the definition of the tracking area in the later image, or for the calculation of validation statistics for the AMVs with NWC/GEO-HRW algorithm itself. NWP geopotential profiles can also be extracted if the ‘Parallax correction’ of the AMV location or the ‘Orographic flag’ are calculated. All of them are implemented in the default configuration.

4. NWC/GEO CT Cloud Type output for the previous slot and selected region, in case the ‘AMV Cloud type’ is calculated in the ‘Brightness temperature interpolation height assignment method’. NWC/GEO CT Cloud Type and CTTH Cloud Top Temperature and Pressure outputs for the current slot and selected region, in case ‘CCC height assignment method’ is used. NWC/GEO CMIC Cloud Phase, Liquid Water Path and Ice Water Path outputs for the current slot and selected region, in case the Microphysics correction is to be used inside ‘CCC height assignment method’. The three last ones are implemented in the default configuration.

Only the satellite data for the requested channels and the NWP temperature profiles are strictly needed for the calculation of AMVs and Trajectories. All other data contribute to a higher number of AMVs and Trajectories and a better quality of the output data.

2.2.2 Tracer calculation

Two tracer computation methods are applied: Gradient: Tracer characteristics. They are used one after the other in two different tracer selection strategies throughout the region: the ‘single scale procedure’ (when one scale of tracers is calculated), and the ‘two scale procedure’ (when two different scales of tracers are calculated: “basic” and “detailed”, being the line and element size of the “detailed tracers” half the size of the one for “basic tracers”).

Both methods calculate a tracer optimising its location around one of the ‘starting locations’ in the image. In NWC/GEO-HRW v6.0 default configuration, the distance between starting locations for tracers related to low and very low clouds is half the one for other cloud types to maximize the amount of AMVs related to these cloud types (configured with HIGHERDENSITY_LOWTRACERS = 1).

A resolution (“tracer size”) of 24 pixels is proposed as baseline for the ‘single scale procedure’ (used as default option with configurable parameter CDET=0) for all types of tracers. The latitude and longitude limits for calculation of AMVs and Trajectories can be specified with configurable parameters LAT_MAX, LAT_MIN, LON_MAX, LON_MIN. A resolution of 24 pixels for the ‘basic tracers’ and 12 pixels for the ‘detailed tracers’ is proposed for the ‘two scale procedure’ (when configurable parameter CDET=1). A smaller region can be defined for the detailed scale with configurable parameters LAT_MAX_DET, LAT_MIN_DET, LON_MAX_DET, LON_MIN_DET.

With the default configuration, configured with CALCULATE_TRAJECTORIES = 1, the definition of new “tracer locations” starts at the integer line/column location of all “tracking centres” related to valid AMVs in the previous round, when they are available. So, a set of “persistent tracers” is defined and tracked in several images, and the progressive locations of the tracer throughout the time define “Trajectories”. For this, it is necessary that the conditions implied by the "tracer method" used for the determination of the tracer in the “initial image”, keep on being valid throughout all the images.
### 2.2.3 Tracer tracking

The ‘tracking’ method seeks for the best ‘adjustment centre’ of a tracer computed in a previous image, over a larger portion on the following image (‘tracking area’), performing a pixel by pixel comparison inside a segment of the same size (‘tracking candidate’), repeatedly moving this segment over the tracking area until the best candidates are found. For this, one of next algorithms is used:

- **Euclidean distance** (configured with \( \text{TRACKING} = \text{LP} \)), where the sum \( \text{LP}_ij = \sum (T-S)^2 \) is calculated considering the visible normalized reflectances/infrared or water vapour brightness temperatures of all tracer (T) and tracking candidate (S) pixels at correlative locations. The best locations are defined through the minimum values of the sum \( \text{LP}_ij \).

- **Cross correlation** (configured with \( \text{TRACKING} = \text{CC} \), default value), that computes the correlation \( \text{CC}_ij = \text{Cov}(T,S)/\sigma_T \sigma_S \) where ‘\( \sigma \)’ is the standard deviation or root of the variance and ‘\( \text{Cov} \)’ is the covariance between the tracer and tracking candidate. The best locations are defined through the maximum values of the correlation \( \text{CC}_ij \).

To increase the speed of GEO-HRW algorithm, the ‘tracking area centre’ can be located at the position of the tracer which is forecast for the later image by the NWP wind, if so defined with configurable parameter \( \text{WIND\_GUESS} = 1 \). Nevertheless, NWC/GEO-HRW algorithm has been optimized not to use this as default option, to reduce the dependence of the algorithm from the NWP model used.

The line/column size in pixels of the “tracking area” is calculated so that it is able to detect displacements of the tracer of at least 272 km/h in any direction (value of configurable parameter \( \text{MIN\_SPEED\_DETECTION} \)), when the wind guess is not used in the definition of the tracking area. When the wind guess is used, this \( \text{MIN\_SPEED\_DETECTION} \) parameter is to be understood as the minimum difference in speed with respect to that of the NWP wind guess that the NWC/GEO-HRW algorithm is able to detect. Up to 3 ‘tracking centres’ are retained for both tracking methods: the absolute and 2 local best positions. The line/column and latitude/longitude location of the ‘tracking centres’ in the later image is refined as default option with second order interpolation with \( \text{USE\_SUBPIXEL\_TRACKING} = 1 \).

For this calculation, in NWC/GEO-HRW v6.0, a ‘parallax correction’ of the latitude and longitude values of the tracer and tracking centre is also used as default option through configurable parameter \( \text{USE\_PARALLAX\_CORRECTION} = 1 \). This ‘parallax correction’ corrects the horizontal deviation in the apparent position of the tracer/tracking centre due to its height over the Earth surface. The general effect of this is a very slight reduction in the AMV/Trajectory speed, more significant when at higher levels of the atmosphere and when nearer to the edge of the Earth disk. The calculation of the wind components considers the displacement along the corresponding “great circle” with the “haversine formula”. This procedure takes into account the real time each pixel was scanned, defined through the satellite input data files.

In NWC/GEO-HRW v6.0, a “mixed calculation method” considering short and long time intervals of images at the same time is also available for the first time with configurable parameter \( \text{MIXED\_SCANNING} = 1,2 \) (not used as default option), through which tracers are tracked considering the minimum time interval possible, but corresponding AMVs and Trajectories are calculated considering the displacements in longer time intervals (defined by parameter \( \text{SLOT\_GAP} = 2,3,4 \)). This “mixed calculation” is useful to increase the quality of the AMVs calculated with high resolution images, and to improve the quality of all AMVs. This is caused by the smaller changes in the features evaluating the tracking in shorter time intervals (and so the smaller possibilities for a wrong tracking), and the smaller problems with the spatial resolution evaluating displacements in longer time intervals.

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

Operatively, this method runs before the ‘tracer tracking’. This method was available in NWC/GEO-HRW algorithm in all versions up to now. Now it is only used when so specifically defined with configurable parameter DEFINEWITHCONTRIBUTIONS = 0, when the wind guess is used to define the tracking area in the later image with configurable parameter WIND_GUESS = 1, or when NWC/GEO-CT Cloud Type or NWC/GEO-CTTH Cloud Top Temperature and Pressure outputs are not available for the processing region for the image in which “tracers” are tracked.

This height assignment method is only available if a NWP temperature forecast with a minimum number of NWP levels is provided (configurable parameter MIN_NWP_FOR_CALCULATION, with a default value of 4). If the number of NWP temperature levels is smaller, the processing of NWC/GEO-HRW algorithm stops, without calculating any AMVs or Trajectories.

The input for the height assignment is the corresponding brightness temperature for each one of the infrared and water vapour channels; IR108 brightness temperature is used for the MSG visible channels, IR107 brightness temperature is used for the GOES-N visible channels, and IR112 brightness temperature is used for the Himawari-8/9 visible channels. A ‘base temperature’ and a ‘top temperature’ are so calculated with the corresponding brightness temperatures. A temperature to pressure conversion is then inferred with these two values and the NWP temperature forecast.

After this, with configurable parameter USE_CLOUDTYPE = 1,2, if NWC/GEO Cloud Type output is available for the processing region and image for which tracers were calculated, it is read to define which of the two calculated pressure values (‘base pressure’ or ‘top pressure’) represents better the displacement defined by the Atmospheric Motion Vector. The ‘AMV cloud type’ is calculated as the most common value of the NWC/GEO CT Cloud Type inside the tracer, if its presence is at least 3/2 times that of the second most common. If this condition is not fulfilled the values Cloud_type = 21 (multiple cloud types), = 22 (multiple clear air types), or = 23 (mixed cloudy/clear air types) are assigned.

Some tracers are the eliminated depending on this ‘AMV cloud type’ and the satellite channel they have been calculated with. These cases are identified inside a blue cell in Table 5, and are related to cloud free tracers in the visible and infrared channels, fractional clouds, and some cloud types for which the validation statistics are significantly worse.

In the rest of cases, the AMV pressure level is defined such as also shown in Table 5. If the ‘AMV cloud type’ has not been calculated, the ‘Base pressure’ is considered for all AMVs because most cloud types fit better with the ‘Base pressure’.
Table 5: AMV filtering related to the ‘AMV cloud type’ and each channel, and consideration of the ‘top pressure’ or ‘base pressure’ in the Brightness temperature interpolation height assignment method for the valid cases

<table>
<thead>
<tr>
<th>MSG channels</th>
<th>GOES-N channels</th>
<th>HRVIS</th>
<th>VIS06</th>
<th>VIS08</th>
<th>WV62</th>
<th>WV73</th>
<th>IR108</th>
<th>IR120</th>
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<tbody>
<tr>
<td>Himawari-8/9 channels</td>
<td>VIS06</td>
<td>VIS08</td>
<td>WV62</td>
<td>WV70</td>
<td>WV73</td>
<td>IR112</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Cloud free land</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>2 Cloud free sea</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>3 Land contaminated by snow/ice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>4 Sea contaminated by ice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>5 Very low cumulus/stratus</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>6 Low cumulus/stratus</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>7 Medium cumulus/stratus</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>8 High opaque cumulus/stratus</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>9 Very high opaque cumulus/stratus</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>10 Fractional clouds</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 High semitransp. thin clouds</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>12 High semitransp. meanly thick clouds</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>13 High semitransp. thick clouds</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>14 High semitransp. above other clouds</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>15 High semitransp. above snow/ice</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Top</td>
<td>Top</td>
<td>Top</td>
<td></td>
</tr>
<tr>
<td>21 Multiple cloud types</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
<tr>
<td>22 Multiple clear air types</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23 Mixed cloudy/clear air types</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td>Base</td>
<td></td>
</tr>
</tbody>
</table>
2.2.5 Height assignment with ‘CCC method’

‘CCC method - Cross Correlation Contribution method’ height assignment is implemented with configurable parameters TRACKING=CC and DEFINEWITHCONTRIBUTIONS=1. It is run after the “tracking” process, and it is the default option for all satellite series. The method was developed by Régis Borde and Ryo Oyama in 2008, and is fully documented in the paper “A direct link between feature tracking and height assignment of operational AMVs” [RD.17].

It requires the use of ‘Cross correlation’ as Tracking method, and the calculation of NWC/GEO CT Cloud type and CTTH Cloud Top Temperature and Pressure for the selected region and slot before the running of GEO-HRW product.

It has also the advantage of including in the height assignment all procedures included in NWC/GEO CTTH product for the Cloud pressure calculation, which are common methods used by other AMV producers, including:

- Opaque cloud top pressure retrieval from Window 10.8 µm and 12.0 µm brightness temperatures, with simulation of radiances with RTTOV, and ability of thermal inversion processing.
- Semitransparent cloud top pressure retrieval with Radiance ratioing technique and water vapour/infrared window intercept method, considering 6.2 µm, 7.3 µm and 13.4 µm channels.

It defines the ‘AMV pressure’ and ‘AMV temperature’, considering only the pressure and temperature of the pixels contributing most to the ‘Cross correlation’ between the ‘tracer’ in the “initial image” and the ‘tracking centre’ in the “final image”.

For this, the ‘partial contribution to the correlation’ (CCij) from each pixel inside the ‘tracer’ and the ‘tracking centre’ is defined with the following formula, in which respectively for the ‘tracer’ and the ‘tracking centre’ T(M)/S(M) are the ‘brightness values’ for each pixel, T(M)/S(M) are the mean values, σ(T)/σ(S) the standard deviations of the ‘brightness values’, and NUM is the total number of pixels inside the ‘tracer’ or ‘tracking centre’: C(CCC)i,j = (T(M) − T(S))/(S(M) − S(S)) / NUM·σ(T)/σ(S).

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

- In the ‘Cloudy AMVs’, a ‘CCC pressure P(CCC)’ value is calculated for each ‘tracking centre’, considering the partial contribution to the correlation (CCi,j) and the NWC/GEO CTTH Cloud top pressure (CTPij) with formula P(CCC)=Σ(CCCi,j·CTPij)/ΣCCi,j. For the calculation, only bright pixels (in visible cases) or cold pixels (in infrared cases) with valid CTPij values (corresponding to cloudy, non-fractional cloud types), and with CCi,j over a threshold (the mean correlation contribution or else zero) are considered. A similar calculation is done for the ‘CCC temperature T(CCC)’ and ‘CCC height H(CCC)’ values (this one in the case of use of the ‘parallax correction’). The ‘CCC cloud type Ct(CCC)’ value is calculated as the one with the highest total contribution to the correlation.

A ‘CCC pressure error ΔP(CCC)’ value is also calculated for each ‘tracking centre’ with the formula ΔP(CCC)=√(Σ(CCCi,j·CTPij/2)/ΣCCi,j – P(CCC)²), useful as a new Quality control parameter for the output AMVs. A maximum pressure error can be defined with configurable parameter MAXPRESSUREERROR (with default value 150 hPa).

Here it is clear that ‘CCC method’ offers a direct correspondence between the pressure levels given for GEO-HRW Cloudy AMVs and Trajectories, and those given to the Cloud tops by NWC/GEO CTTH product. It also defines a clear correspondence between the elements considered for the pressure level calculations, and the real cloud features observed in the satellite images.

Nevertheless, several studies in 2014 (Peter Lean et al. [RD.21], Á.Hernández-Carrascal & N.Bormann [RD.22], K.Salonen & N.Bormann [RD.23]), suggest that AMVs would better be
related to a pressure level lower than the Cloud top. An empirical relationship has been found to exist between the “difference between the AMV pressure level calculated with CCC method and the AMV best fit pressure level”, and the ‘CCC Liquid/Ice water path’ value, so that a correction for the ‘CCC pressure’ related to the Cloud depth can be defined.

So, with ‘CCC liquid/ice water path LWP/IWP$_{CCC}$’ values obtained with similar formulae to the previous ones for water/ice phase ‘tracking centres’, corrections in the ‘CCC pressure $P_{CCC}$’ values are obtained as functions of these parameters, considering a yearly tuning period between July 2010 and June 2011 in the European and Mediterranean region for MSG satellites, and a four-month tuning period between November 2017 and February 2018 in the China/Korea/Japan region for Himawari-8/9 satellites, using Radiosounding winds as reference for the best fit level. The correction tables are available in the “Algorithm Theoretical Basic Document for the Wind product processor of the NWC/GEO” [AD.14].

The corrections cause an improvement in all Validation parameters, and are implemented as default option with MSG and Himawari-8/9 satellites with configurable parameter $USE_{MICROPHYSICS} = 2$ (not with GOES-N satellite series because of the lack of NWC/CMIC product with this satellite series).

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

- In the ‘Water vapour clear air AMVs’, no CTP$_{ij}$ pressure values exist logically from NWC/GEO CTTH output for the clear air pixels. Because of this, the Brightness temperature from the corresponding channel (BT$_{ij}$) is used instead, considering only the pixels whose brightness temperature is colder than the threshold. 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: $\Delta T_{CCC} = \sqrt{\sum(CC_{ij} \cdot BT_{ij})^2/\sum CC_{ij} - T_{CCC}^2}$.

With these data, three different temperature values are defined by next formulas: $T_{CCC} + \Delta T_{CCC}$, $T_{CCC}$, $T_{CCC} - \Delta T_{CCC}$. For each one of these values, a temperature to pressure conversion is obtained through interpolation to the NWP temperature forecast, giving three pressure values: $P_{CCC_{\text{MAX}}}$ (related to $T_{CCC} + \Delta T_{CCC}$), $P_{CCC}$ (related to $T_{CCC}$) and $P_{CCC_{\text{MIN}}}$ (related to $T_{CCC} - \Delta T_{CCC}$). $P_{CCC}$ is defined as the ‘CCC Pressure value’ for the clear air AMVs. $\Delta P_{CCC} = |P_{CCC_{\text{MAX}}} - P_{CCC_{\text{MIN}}}|/2$ is defined as the ‘CCC Pressure error value’ for the clear air AMVs (only in cases for which a vertical continuous reduction or increase of temperature is found). In the cases where the ‘CCC Pressure value’ or the ‘CCC Pressure error value’ cannot be calculated, the AMVs are discarded.

With configurable parameter $DEF_{POS\_WITH\_CONTRIBUTIONS} = 1$ (which is the default option), the location of the AMV feature in both initial and final images is also 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): $X_{CCC} = \sum(CC_{ij} \cdot X_{ij})/\sum CC_{ij}$, $Y_{CCC} = \sum(CC_{ij} \cdot Y_{ij})/\sum CC_{ij}$.

With this relocation of the AMV, its position is related to the part of the AMV feature with largest contribution to the correlation. When trajectories are defined (with configurable parameter $CALCULATE\_TRAJECTORIES = 1$), tracking consecutively during several slots the same tracer, this relocation of the AMV position is only calculated for the first AMV in the trajectory and keeps the same value during all the time the trajectory is alive, to avoid discontinuities in its positioning.
2.2.6 Postprocessing: Quality control and Choice of the best wind

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

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

Several tests are applied (direction, speed and vector temporal consistency tests, vector spatial and forecast consistency tests) giving 5 different ‘individual QIs’; their weighted sum provides two ‘overall QIs’ (after two corrections affecting respectively winds with very low speed, and low winds with a low correlation between infrared and water vapour channels): the ‘Quality Index with forecast’ and the ‘Quality Index without forecast’. These “Quality index with forecast” or “Quality Index without forecast” are used for the filtering of the AMV and Trajectory data. The first one is used as default option, through configurable parameter QI_THRESHOLD_USEFORECAST = 1. The “Quality Index threshold” for the acceptance of an AMV or Trajectory as valid is defined by configurable parameter QI_THRESHOLD (with a default value of 70%, and a minimum value of 1%).

In spite of the common procedure in all AMV production centres, the experience in the “International Winds Workshops” has however shown that the configuration of the “Quality Indices” is very different for different AMV algorithms, and so a common homogeneous use for AMVs calculated with different algorithms was not possible up to now.

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

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

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

Despite the Quality control, it is detected sometimes that an AMV has a direction or speed completely different to the ones in its vicinity, without a clear justification. To eliminate these AMVs, which can be considered as errors, a function calculating the speed and direction histograms for all valid AMVs in small areas can be run: the ‘Final Control Check’ (activated as default option with configurable parameter FINALCONTROLCHECK = 1). When any of the columns of the speed or direction histograms has only one element, it is excluded: the lack in the same area of another AMV with relatively similar velocities or directions is enough to consider it an error.
2.2.7 Postprocessing: Orographic flag

Topographic information is finally incorporated to NWC/GEO-HRW algorithm, which in combination with NWP data, calculates an ‘Orographic flag’ to detect and reject those Atmospheric Motion Vectors affected by land influence. The reasons for this land influence can be: AMVs associated to land features incorrectly detected as cloud tracers; tracers blocked or whose flow is affected by mountain ranges; tracers associated to lee wave clouds, with atmospheric stability near mountain ranges.

The procedure reads two topographic matrices with representative “Minimum and Maximum Heights” (S_NWC_SFCMIN* and S_NWC_SFCMAX*, located in $SAFNWC/import/Aux_data/Common directory), which are then converted to the ‘Surface pressure levels corresponding to these Minimum and Maximum Heights’, considering NWP geopotential data. With these P_sfcmin/P_sfcmax values, the ‘Static orographic flag’ is calculated at the position of each tracer. Its possible values are:

- \textit{Ind\_topo=0}: The ‘Orographic flag’ could not be calculated.
- \textit{Ind\_topo=1}: AMV wrongly located below the lowest representative pressure level (mainly due to Microphysics corrections in the ‘AMV pressure’ value).
- \textit{Ind\_topo=2}: Very important orographic influence found in the current AMV position.
- \textit{Ind\_topo=3}: Important orographic influence found in the current AMV position.
- \textit{Ind\_topo=6}: No orographic influence found in the current AMV position.

The ‘Dynamic orographic flag’ is then calculated: values of ‘Ind\_topo’ are modified to verify the possibility of a previous in time orographic influence. This part only happens if Ind\_topo = 6 and the tracer is related to predecessor AMVs in previous slots. The value of Ind\_topo = 6 is then modified considering the next conditions:

- \textit{Ind\_topo = 0}: The ‘Orographic flag’ could not be calculated.
- \textit{Ind\_topo = 4}: Very important orographic influence found at a previous position of the AMV.
- \textit{Ind\_topo = 5}: Important orographic influence found at a previous position of the AMV.
- \textit{Ind\_topo = 6}: No orographic influence is found in any current/previous position of the AMV.

With configurable parameter USE\_TOPO = 1, the Orographic flag is calculated and incorporated to the output file, and AMVs with IND\_TOPO = 1 are eliminated. With USE\_TOPO = 2 (which is the default option), all AMVs and Trajectories with any Orographic influence (i.e. with Ind\_topo = 1 to 5) are eliminated from the output files.
2.2.8 Postprocessing: Autovalidation of NWC/GEO-HRW algorithm

Considering requests from NWC SAF users, NWC/GEO-HRW v6.0 calculates for the first time validation statistics for the AMVs with the algorithm itself (using as reference NWP analysis or forecast rectangular components of the wind, such as defined in Chapter 4.1 of this document, interpolated to the AMV final location and level).

This is implemented with configurable parameter NWPVAL_STATISTICS = 1,2,3,4. Depending on the values of this parameter, statistics for the different layers and satellite channels are provided separately or not. Please check Chapter 4.2 for more information on this parameter. The default option (NWPVAL_STATISTICS = 2) provides statistics for all layers together and the different satellite channels separately.

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

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

The following content is added to this file each time the validation statistics are run: several lines with the following format, showing the validation parameters mentioned in Chapter 5 of this document (NC, SPD, NBIAS, NMVD, NRMSVD) for the considered AMV scale “BBB” (defined as BAS,DET), AMV type “TTTTT” (defined as TOTAL,CLOUD,CLEAR), layer “LLL” (defined as ALL,HIG,MED,LOW) and satellite channel for which AMVs have been calculated “CCCCC” (defined as TOTAL,HRVIS,VIS06,VIS07,VIS08,IR107,IR108,IR112,WV062,WV069,WV073). The date and time of the NWC/GEO-HRW run, of the “model configuration file” used in the process, and if the validation statistics have been run against the NWP analysis or forecast winds (parameter “GGG”, defined as ANA, FOR) are also specified:

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The parameters shown here can be used by the NWC SAF user as an option for the quality monitoring of the calculated NWC/GEO-HRW data. Two additional elements are available in the validation process of NWC/GEO-HRW algorithm:

- The first one, activated with configurable parameter NWPVAL_NWPDIFFERENCE = 1 (implemented as default option) calculates also for each AMV the “Vector difference with the NWP reference wind”. This “Vector difference” can be used in Nowcasting tasks, so that the NWC SAF user is able to detect in which cases the AMV is very different to the NWP forecast wind, and may be aware for example if a warning is needed in some specific region or moment due to strong winds unforeseen by the NWP forecast.

- The second one, activated with configurable parameter NWPVAL_NWPBESTFITLEVEL = 1 (implemented also as default option) calculates also for each AMV the “NWP reference wind at the best fit pressure level” (defined by its speed, direction and pressure). This “NWP model wind at the best fit pressure level” can be used in verification tasks of the “AMV height assignment method”, to know in which cases there is more or less agreement between the AMV pressure level defined for the AMVs and Trajectories, and the one suggested by the NWP model reference.
The calculation of the “NWP reference wind at the best fit pressure level” consists of two steps: first, the model level with the smallest vector difference between the observation and the model background wind is to be found. Then, the minimum is calculated by using a parabolic fit to the vector difference for this model level and the two neighbouring levels.

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

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

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

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

2. OUTPUT_FORMAT = EUM: NWC/GEO-HRW output defined as one BUFR bulletin, whose format was defined several years ago by the “International Winds Working Group”, and which has been used for example for the EUMETSAT/MPEF (Meteosat Product Extraction Facility) AMVs. This option permits NWC SAF users to have a similar processing for the NWC/GEO-HRW outputs than for other AMV processing centres of the world.

3. OUTPUT_FORMAT = NET: NWC/GEO-HRW output defined as one netCDF bulletin. This option is available since NWC/GEO-HRW v5.0. It was requested during the “2010 Madrid Users' Workshop” and the “Consolidated Report on 2010 User Survey and Users’ Workshop” document (SAF/NWC/IOP/INM/MGT/2010-US+WS).

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

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

Considering this, for the moment, “BUFR sequence 310067” has been deactivated in NWC/GEO-HRW v2018 code and documentation. Once the situation becomes clear on this, NWC/GEO-HRW v2018 code will be properly updated in the Spring 2019 (together with the patch for GOES-R satellite series).
2.3.1. HRW output as BUFR bulletins with NWC SAF specific format (AMVs)

When OUTPUT_FORMAT = NWC, a BUFR bulletin related to the ones used as default option in all previous versions of NWC/GEO-HRW algorithm is written in $SAFNWC/export/HRW directory for the “Single/Basic AMV scale” with the name S_NWC_HRW-WIND_<satid>_WIND <regionid>_BS_YYYYMMDDThhmmssZ.bufr, or for the “Detailed AMV scale” with the name S_NWC_HRW-WIND <satid> <regionid>_DS_YYYYMMDDThhmmssZ.bufr, as AMV output file. Here, “satid” is the identifier of the satellite used, “regionid” is the identifier of the region used, and “YYYYMMDDThhmmssZ” is the date and time of the image used for the AMV calculation.

The BUFR variables used for the writing of the AMVs considering this format (identified in “BUFR local variable table” B00000214000000029096.TXT in $SAFNWC/import/Aux_data/HRW directory) are explained in Table 6.

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

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

An additional “BUFR local sequence table” (identified as D00000214000000029096.TXT file in $SAFNWY/import/Aux_data/HRW directory) is also requested for the generation of the BUFR files, but due to the fact that no specific sequences have been identified for the processing, this additional file is provided as an empty file.

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

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

- The first column shows the “Descriptor code”.
- The second column shows the “Descriptor Name”.
- The third column shows the “Unit used for the codification of the parameter” (in some cases identified through a Code Table).
- The fourth column shows the “Scale, the number of decimals used in the codification of the parameter” (where a value of 1 is used for a precision of one decimal place and a value of -1 is used for a precision only up to the tens).
- The fifth column shows the “Reference, the default value of the parameter”.
- The sixth column shows the “Number of bits used for the parameter codification”, and so, the maximum value the parameter can have (for example, for parameter 060203/Number of available wind guess levels, the maximum value of the parameter is $2^{7} - 1 = 127$).
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<tr>
<td>002023</td>
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<td>CODE TABLE 002023</td>
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<td>CODE TABLE 002057</td>
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</tr>
<tr>
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<td>FLAG TABLE 002152</td>
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<td>004001</td>
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<td>YEAR</td>
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<td>0</td>
<td>12</td>
</tr>
<tr>
<td>004002</td>
<td>MONTH</td>
<td>MONTH</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>004003</td>
<td>DAY</td>
<td>DAY</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>004004</td>
<td>HOUR</td>
<td>HOUR</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>004005</td>
<td>MINUTE</td>
<td>MINUTE</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>004025</td>
<td>TIME PERIOD OR DISPLACEMENT</td>
<td>MINUTE</td>
<td>0</td>
<td>-2048</td>
<td>12</td>
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<td>005044</td>
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<td>NUMERIC</td>
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<td>033035</td>
<td>MANUAL/AUTOMATIC QUALITY CONTROL</td>
<td>CODE TABLE 033035</td>
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<td>4</td>
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<tr>
<td>060000</td>
<td>SEGMENT SIZE AT NADIR IN X DIRECTION (FIXELS)</td>
<td>PIX</td>
<td>0</td>
<td>0</td>
<td>7</td>
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<tr>
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<td>SEGMENT SIZE AT NADIR IN Y DIRECTION (FIXELS)</td>
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<td>0</td>
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<td>-1</td>
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<td>TRACER CORRELATION METHOD</td>
<td>CODE TABLE 002164</td>
<td>0</td>
<td>0</td>
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<tr>
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<td>LATITUDE (HIGH ACCURACY)</td>
<td>DEGREE</td>
<td>5</td>
<td>-9000000</td>
<td>25</td>
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<tr>
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<td>LONGITUDE (HIGH ACCURACY)</td>
<td>DEGREE</td>
<td>5</td>
<td>-18000000</td>
<td>26</td>
</tr>
<tr>
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<td>LATITUDE INCREMENT (HIGH ACCURACY)</td>
<td>DEGREE</td>
<td>5</td>
<td>-9000000</td>
<td>25</td>
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<tr>
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<td>LONGITUDE INCREMENT (HIGH ACCURACY)</td>
<td>DEGREE</td>
<td>5</td>
<td>-18000000</td>
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<td>PA</td>
<td>-1</td>
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<tr>
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<td>011002</td>
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<td>0</td>
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<td>TEMPERATURE</td>
<td>K</td>
<td>1</td>
<td>0</td>
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<tr>
<td>033007</td>
<td>PER CENT CONFIDENCE (WITH FORECAST TEST)</td>
<td>%</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>033007</td>
<td>PER CENT CONFIDENCE (WITHOUT FORECAST TEST)</td>
<td>%</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
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<tr>
<td>060104</td>
<td>TRACER TYPE</td>
<td>CODE TABLE 060104</td>
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<tr>
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<td>HEIGHT ASSIGNMENT METHOD</td>
<td>CODE TABLE 060103</td>
<td>0</td>
<td>0</td>
<td>4</td>
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<tr>
<td>060200</td>
<td>NUMBER OF WINDS COMPUTED FOR THE TRACER</td>
<td>NUMERIC</td>
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<td>0</td>
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<tr>
<td>060201</td>
<td>CORRELATION TEST</td>
<td>CODE TABLE 060201</td>
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</tr>
<tr>
<td>060202</td>
<td>APPLIED QUALITY TESTS</td>
<td>CODE TABLE 060202</td>
<td>0</td>
<td>0</td>
<td>11</td>
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<tr>
<td>060203</td>
<td>NUMBER OF AVAILABLE NWP WIND GUESS LEVELS</td>
<td>NUMERIC</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>060204</td>
<td>NUMBER OF PREDECESSOR WINDS</td>
<td>NUMERIC</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>060205</td>
<td>OROGRAPHIC INDEX</td>
<td>CODE TABLE 060205</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>060206</td>
<td>CLOUD TYPE (NWCSAF/GEO)</td>
<td>CODE TABLE 060206</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>060207</td>
<td>AMV CHANNEL (NWCSAF/GEO)</td>
<td>CODE TABLE 060207</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>060208</td>
<td>CORRELATION</td>
<td>%</td>
<td>0</td>
<td>0</td>
<td>7</td>
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<tr>
<td>060209</td>
<td>PRESSURE ERROR</td>
<td>PA</td>
<td>-1</td>
<td>-8000</td>
<td>14</td>
</tr>
<tr>
<td>060210</td>
<td>PRESSURE CORRECTION</td>
<td>PA</td>
<td>-1</td>
<td>-8000</td>
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</tbody>
</table>
The “general common variables” in BUF Master Table number 0, Version number 29, are identified with codes smaller than 60000. Their explanation can be found in the “WMO FM94 BUFR Table B for Classification of elements and table”, available in document [RD.20].

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

### Table 6: Variables used for the AMV output with the NWC SAF specific BUFR format

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

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
</table>
| 060103     | Height assignment method  
Values 0 to 3 are related to ‘Brightness temperature interpolation height assignment method’.  
Values 4 to 15 are related to ‘CCC height assignment method’.  
Due to the actual implementation of HRW algorithm, Value 2 is never used.  
Possible values:  
0: ‘NWP interpolation using Top pressure in Clear air AMV’  
1: ‘NWP interpolation using Top pressure in Cloudy AMV’  
3: ‘NWP interpolation using Base pressure in Cloudy AMV’  
4: ‘CCC method using lower threshold and cold branch in a Clear air AMV’  
5: ‘CCC method using higher threshold and cold branch in a Clear air AMV’  
6: ‘CCC method using lower threshold and cold/bright branch in Cloudy AMV with undefined phase’  
7: ‘CCC method using higher threshold and cold/bright branch in Cloudy AMV with undefined phase’  
8: ‘CCC method using lower threshold and cold/bright branch in Cloudy AMV with liquid phase’  
9: ‘CCC method using higher threshold and cold/bright branch in Cloudy AMV with liquid phase’  
10: ‘CCC method with microphysics correction using lower threshold and cold/bright branch in Cloudy AMV with liquid phase’  
11: ‘CCC method with microphysics correction using higher threshold and cold/bright branch in Cloudy AMV with liquid phase’  
12: ‘CCC method using lower threshold and cold/bright branch in a Cloudy AMV with ice phase’  
13: ‘CCC method using higher threshold and cold/bright branch in a Cloudy AMV with ice phase’  
14: ‘CCC method with microphysics correction using lower threshold and cold/bright branch in Cloudy AMV with ice phase’  
15: ‘CCC method with microphysics correction using higher threshold and cold/bright branch in Cloudy AMV with ice phase’  |
| 060104     | Type of tracer  
Possible values:  
0: ‘Basic tracer’  
1: ‘Detailed tracer related to a Narrow basic tracer’  
2: ‘Detailed tracer related to a Wide basic tracer’  
3: ‘Detailed tracer unrelated to a Basic tracer’.  |
<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>060201</strong></td>
<td>Correlation test.&lt;br&gt;Possible values:&lt;br&gt;0: ‘Wind not selected as the Best wind for a tracer not having the Best correlation value’&lt;br&gt;1: ‘Wind not selected as the Best wind for a tracer having the Best correlation value’&lt;br&gt;2: ‘Wind selected as the Best wind for a tracer not having the Best correlation value’&lt;br&gt;3: ‘Wind selected as the Best wind for a tracer having the Best correlation value’.</td>
</tr>
<tr>
<td><strong>060202</strong></td>
<td>Applied Quality tests:&lt;br&gt;For each one the next Quality flags (Orographic flag, Forecast quality flag, Spatial quality flag, Temporal quality flag, Interscale quality flag), next possible values:&lt;br&gt;0: ‘Wind for which the corresponding quality test could not be calculated’&lt;br&gt;1: ‘Wind whose corresponding quality test is at least a 21% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is at least two units lower than for the wind calculated for the same tracer with the best orographic flag)’&lt;br&gt;2: ‘Wind whose corresponding quality test is up to a 20% worse than for the wind calculated for the same tracer with the best quality test (in the orographic test, the orographic flag value is one unit lower than for the wind calculated for the same tracer with the best orographic flag)’&lt;br&gt;3: ‘Wind with the best corresponding quality test among the winds calculated for a tracer’.</td>
</tr>
<tr>
<td><strong>060205</strong></td>
<td>Orographic index&lt;br&gt;Possible values:&lt;br&gt;The values of this parameter are between 0 and 6, corresponding to those defined for “Ind_topo” parameter in chapter 2.2.7 of this document.</td>
</tr>
<tr>
<td><strong>060206</strong></td>
<td>Cloud type associated to the tracer&lt;br&gt;Possible values:&lt;br&gt;The values of this parameter are between 0 and 23, corresponding to those defined in Table 5 of this document.</td>
</tr>
<tr>
<td><strong>060207</strong></td>
<td>Flag indicating the satellite channel used for the wind calculation&lt;br&gt;(Updated table for NWC/GEO-HRW v2018).&lt;br&gt;Possible values:&lt;br&gt;2: MSG/VIS06 or GOES-N/VIS07 or Himawari-8/9 VIS06&lt;br&gt;3: MSG/VIS08 or Himawari-8/9 VIS08&lt;br&gt;5: MSG/HRVIS&lt;br&gt;10: MSG/WV062 or GOES-N/WV065 or Himawari-8/9 WV062&lt;br&gt;11: Himawari-8/9 WV070&lt;br&gt;12: MSG/WV073 or Himawari-8/9 WV073&lt;br&gt;16: MSG/IR108 or GOES-N/IR107 or Himawari-8/9 IR112&lt;br&gt;17: MSG/IR120</td>
</tr>
<tr>
<td><strong>060220</strong></td>
<td>Validation against NWP analysis or forecast&lt;br&gt;Possible values:&lt;br&gt;0: GEO-HRW autovalidation statistics against “NWP model analysis”.&lt;br&gt;1: GEO-HRW autovalidation statistics against “NWP model forecast”.&lt;br&gt;3: GEO-HRW autovalidation statistics not calculated.</td>
</tr>
</tbody>
</table>

*Table 7: Description of “local specific variables” in the “local variable table”

$SAF_NWC/import/Aux_data/HRW/B000002140000029096.TXT*
2.3.2. HRW output as BUFR bulletins with NWC SAF specific format (Trajectories)

When OUTPUT_FORMAT = NWC, if the calculation of trajectories is activated with configurable parameter CALCULATE_TRAJECTORIES = 1 (which is the default option), a Trajectory BUFR bulletin related to the ones used in previous versions of NWC/GEO software package is written under the name S_NWC_HRW-TRAJ-_<satid>_ <regionid>-BS_YYYYMMDDThHmmssZ.bufr for the “Single or Basic scale”, or the name S_NWC_HRW-TRAJ_<satid>:_<regionid>-DS_YYYYMMDDThHmmssZ.bufr for the “Detailed scale” in $SAFNWC/export/HRW directory. Again, “satid” is the identifier of the satellite used, “regionid” is the identifier of the region used, and “YYYYMMDDYhhmmssZ” is the date and time of the image used for the Trajectory calculation.

The BUFR variables used for the writing of the Trajectories considering this are explained in Table 8. They are also based on the “BUFR local variable table” B0000021400000029096.TXT and the “BUFR local sequence table” B0000021400000029096.TXT used in the previous chapter for the AMV output.

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

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

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

The explanation of the “general common variables” and “local specific variables” used for the writing of the Trajectory BUFR output, is equivalent to that for the AMV BUFR output in the previous chapter.
<table>
<thead>
<tr>
<th>Descriptor</th>
<th>Name</th>
<th>Units</th>
<th>Scale</th>
<th>Reference</th>
<th>Number of bits</th>
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<td>CODE TABLE 02023</td>
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</tr>
<tr>
<td>060001</td>
<td>SEGMENT SIZE AT NADIR IN Y DIRECTION (PIXELS)</td>
<td>PIX</td>
<td>0</td>
<td>0</td>
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White entries: Fixed factors  
Grey entries: Replicated factors  

Table 8: Variables used for the Trajectory output with the NWC SAF specific BUFR format
2.3.3. HRW output as BUFR bulletins with the IWWG format (AMVs)

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

The BUFR variables used for the writing of the NWC/GEO-HRW AMVs considering this format, are explained in Table 9, with some explanations in red about how some variables are defined by NWC/GEO-HRW algorithm.

The variables are based on BUFR Master Table number 0, Version number 29 (identified in “variable table” B000000000000000029000.TXT and “sequence table” D000000000000000029000.TXT in $SAFNWC/import/Aux_data/HRW directory). The AMV output is very similar to the one defined for the previous version of NWC/GEO-HRW algorithm, with some small changes related to “mixed calculation” process.

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

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

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

It is recommended to use this option to write the NWC/GEO-HRW output only when the main interest is the assimilation of the AMVs in NWP models or other applications, together with other AMV outputs with an equivalent format (for example, EUMETSAT/MPEF AMVs). The main reason for this is that part of the information calculated with the AMVs cannot be included using this format (the “cloud type”, the “orographic flag”, the “correlation value”, or all new parameters included for the first time in NWC/GEO-HRW-v6.0 related to the NWP model at the AMV level or the best fit level), and so cannot be used operationally. For other uses, it is preferable to use any of the other available formats, which provide more information.
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<td>DAY (for the AMV to be used)</td>
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<tr>
<td>004005</td>
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### INFORMATION RELATED TO QUALITY CONTROL BIT MAP, DEFINING VARIABLES AFFECTED BY QUALITY CONTROL

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<td>-</td>
</tr>
<tr>
<td>010301</td>
<td>IDENTIFICATION OF ORIGINATING/GENERATING CENTRE</td>
<td>CODE TABLE 010301</td>
</tr>
<tr>
<td>010302</td>
<td>GENERATING APPLICATION (1 = QC USING FORECAST)</td>
<td>CODE TABLE 010302</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Wind direction of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Wind speed of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Pressure of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Temperature of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>Descriptor</td>
<td>Name</td>
<td>Units</td>
</tr>
<tr>
<td>------------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>222000</td>
<td>QUALITY INFORMATION FOLLOWS</td>
<td>-</td>
</tr>
<tr>
<td>237000</td>
<td>REUSE PREVIOUSLY DEFINED BIT-MAP</td>
<td>-</td>
</tr>
<tr>
<td>001031</td>
<td>IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)</td>
<td>CODE TABLE 01031</td>
</tr>
<tr>
<td>001032</td>
<td>GENERATING APPLICATION (2 = QC NOT USING FORECAST)</td>
<td>CODE TABLE 01032</td>
</tr>
<tr>
<td>033036</td>
<td>PERCENT CONFIDENCE (for Wind direction of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>PERCENT CONFIDENCE (for Wind speed of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>PERCENT CONFIDENCE (for Pressure of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>001031</td>
<td>IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)</td>
<td>CODE TABLE 01031</td>
</tr>
<tr>
<td>001032</td>
<td>GENERATING APPLICATION (2 = QC NOT USING FORECAST)</td>
<td>CODE TABLE 01032</td>
</tr>
<tr>
<td>033035</td>
<td>MANUAL-AUTOMATIC QUALITY CONTROL (for Wind direction of AMV to be used)</td>
<td>CODE TABLE 33035</td>
</tr>
<tr>
<td>033035</td>
<td>MANUAL-AUTOMATIC QUALITY CONTROL (for Wind speed of AMV to be used)</td>
<td>CODE TABLE 33035</td>
</tr>
<tr>
<td>033035</td>
<td>MANUAL-AUTOMATIC QUALITY CONTROL (for Pressure of AMV to be used)</td>
<td>CODE TABLE 33035</td>
</tr>
<tr>
<td>222000</td>
<td>QUALITY INFORMATION FOLLOWS</td>
<td>-</td>
</tr>
<tr>
<td>237000</td>
<td>REUSE PREVIOUSLY DEFINED BIT-MAP</td>
<td>-</td>
</tr>
<tr>
<td>001031</td>
<td>IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)</td>
<td>CODE TABLE 01031</td>
</tr>
<tr>
<td>001032</td>
<td>GENERATING APPLICATION (2 = QC NOT USING FORECAST)</td>
<td>CODE TABLE 01032</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Wind direction of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Wind speed of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Pressure of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>222000</td>
<td>QUALITY INFORMATION FOLLOWS</td>
<td>-</td>
</tr>
<tr>
<td>237000</td>
<td>REUSE PREVIOUSLY DEFINED BIT-MAP</td>
<td>-</td>
</tr>
<tr>
<td>001031</td>
<td>IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)</td>
<td>CODE TABLE 01031</td>
</tr>
<tr>
<td>001032</td>
<td>GENERATING APPLICATION (4 = QC USING COMMON IWWG QI)</td>
<td>CODE TABLE 01032</td>
</tr>
<tr>
<td>033036</td>
<td>PERCENT CONFIDENCE (for Wind direction of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>PERCENT CONFIDENCE (for Wind speed of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>PERCENT CONFIDENCE (for Pressure of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>222000</td>
<td>QUALITY INFORMATION FOLLOWS</td>
<td>-</td>
</tr>
<tr>
<td>237000</td>
<td>REUSE PREVIOUSLY DEFINED BIT-MAP</td>
<td>-</td>
</tr>
<tr>
<td>001031</td>
<td>IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)</td>
<td>CODE TABLE 01031</td>
</tr>
<tr>
<td>001032</td>
<td>GENERATING APPLICATION (4 = QC USING COMMON IWWG QI)</td>
<td>CODE TABLE 01032</td>
</tr>
<tr>
<td>033035</td>
<td>MANUAL-AUTOMATIC QUALITY CONTROL (for Wind direction of AMV to be used)</td>
<td>CODE TABLE 33035</td>
</tr>
<tr>
<td>033035</td>
<td>MANUAL-AUTOMATIC QUALITY CONTROL (for Wind speed of AMV to be used)</td>
<td>CODE TABLE 33035</td>
</tr>
<tr>
<td>033035</td>
<td>MANUAL-AUTOMATIC QUALITY CONTROL (for Pressure of AMV to be used)</td>
<td>CODE TABLE 33035</td>
</tr>
<tr>
<td>222000</td>
<td>QUALITY INFORMATION FOLLOWS</td>
<td>-</td>
</tr>
<tr>
<td>237000</td>
<td>REUSE PREVIOUSLY DEFINED BIT-MAP</td>
<td>-</td>
</tr>
<tr>
<td>001031</td>
<td>IDENTIFICATION OF ORIGINATING/GENERATING CENTRE (configurable parameter BUFR CENTRE OR)</td>
<td>CODE TABLE 01031</td>
</tr>
<tr>
<td>001032</td>
<td>GENERATING APPLICATION (4 = QC USING COMMON IWWG QI)</td>
<td>CODE TABLE 01032</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Wind direction of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Wind speed of AMV to be used)</td>
<td>%</td>
</tr>
<tr>
<td>033036</td>
<td>NOMINAL CONFIDENCE THRESHOLD (for Pressure of AMV to be used)</td>
<td>%</td>
</tr>
</tbody>
</table>

Table 9: Variables used for the AMV output with the IWWG BUFR format
2.3.4. HRW output as netCDF bulletins

When OUTPUT_FORMAT = NET, an AMV and Trajectory netCDF output bulletin is written under the name $S_{NWC}$HRW <satid>_<regionid>-BS/YYYYMMDDTthmmssZ.nc (for the “Single or Basic scale”), or $S_{NWC}$HRW <satid>_<regionid>-DS/YYYYMMDDTthmmssZ.nc (for the “Detailed scale”) in $SAFWNC/export/HRW$ directory. Again, “satid” is the identifier of satellite used, “regionid” is the identifier of the region used and “YYYYMMDDTthmmssZ” is the date and time for which the AMVs have been calculated.

The High level structure of the netCDF output for the NWC/GEO High Resolution Winds is shown in Table 10. It contains one series of data, containing all the AMVs/Trajectories derived for all satellite channels in the corresponding run of NWC/GEO-HRW algorithm. The dimension of the series of data is defined by “number_of_observations_XXXXX” parameter, which contains the amount of AMVs calculated for the given run of NWC/GEO-HRW algorithm for “XXXXX” satellite channel.

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

In Table 10, label “XXXX” is to be modified with the different satellite channels for which AMVs and Trajectories are calculated:

- “HRVIS”, “VIS06”, “VIS08”, “IR108”, “IR120”, “WV062” or “WV073” for MSG satellite series.
- “VIS06”, “IR107” or “WV065” for GOES-N satellite series.
- “VIS06”, “VIS08”, “IR112”, “WV062”, “WV069” or “WV073” for Himawari-8/9 satellite series.

<table>
<thead>
<tr>
<th>Types:</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>compound Segment</td>
<td>// Structure to contain 1 Segment data</td>
</tr>
<tr>
<td>Segment(*) Trajectory</td>
<td>// Structure to contain n Segment data (1 Trajectory)</td>
</tr>
<tr>
<td>compound Wind</td>
<td>// Structure to contain 1 Data (including AMV and Trajectory)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables:</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind wind XXXX(number_of_observations_XXXXX)</td>
<td>// Wind data for channel XXXX</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimensions:</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>number_of_observations_XXXXX</td>
<td>// Number of AMVs for channel XXXX</td>
</tr>
</tbody>
</table>

Table 10: High Level specification of the NWC/GEO-HRW netCDF output

The detailed structure of the netCDF output for the NWC/GEO High Resolution Winds and Trajectories is shown in Table 11. The “BUFR Code Tables” used are described in chapter 2.3.1 of this document. The list of “Common attributes” described in the “Data Output Format for the NWC/GEO” document [AD.6] is also to be taken here into account.

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

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

The “product_completeness” is the "percentage of AMVs” written in the netCDF output file, with respect to the theoretical value of AMVs defined by the algorithm at all preliminary locations. This parameter gives an idea of how many AMVs were successfully calculated, defined also as a percentage value (from 0% to 100%).
<table>
<thead>
<tr>
<th>Parameter types</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compound wind</strong></td>
<td>// Structure to contain 1 AMV data</td>
</tr>
<tr>
<td>// AMV sequence number</td>
<td>// Number of winds computed for the tracer</td>
</tr>
<tr>
<td>// AMV sequence number</td>
<td>// AMV sequence number</td>
</tr>
<tr>
<td><strong>Wind direction</strong></td>
<td>// Wind direction from which wind is blowing (º)</td>
</tr>
<tr>
<td>// Wind direction from which wind is blowing (º)</td>
<td>// Wind direction from which wind is blowing (º)</td>
</tr>
<tr>
<td>// Wind direction from which wind is blowing (º)</td>
<td>// Wind direction from which wind is blowing (º)</td>
</tr>
<tr>
<td>// Wind direction from which wind is blowing (º)</td>
<td>// Wind direction from which wind is blowing (º)</td>
</tr>
<tr>
<td>// Wind direction from which wind is blowing (º)</td>
<td>// Wind direction from which wind is blowing (º)</td>
</tr>
<tr>
<td><strong>Wind speed</strong></td>
<td>// Wind Speed (m/s)</td>
</tr>
<tr>
<td>// Wind Speed (m/s)</td>
<td>// Wind Speed (m/s)</td>
</tr>
<tr>
<td>// Wind Speed (m/s)</td>
<td>// Wind Speed (m/s)</td>
</tr>
<tr>
<td>// Wind Speed (m/s)</td>
<td>// Wind Speed (m/s)</td>
</tr>
<tr>
<td>// Wind Speed (m/s)</td>
<td>// Wind Speed (m/s)</td>
</tr>
<tr>
<td><strong>Air pressure</strong></td>
<td>// Air Pressure (Pa)</td>
</tr>
<tr>
<td>// Air Pressure (Pa)</td>
<td>// Air Pressure (Pa)</td>
</tr>
<tr>
<td>// Air Pressure (Pa)</td>
<td>// Air Pressure (Pa)</td>
</tr>
<tr>
<td>// Air Pressure (Pa)</td>
<td>// Air Pressure (Pa)</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>// Height Assignment Method (BUFR code table 060103)</td>
</tr>
<tr>
<td>// Height Assignment Method (BUFR code table 060103)</td>
<td>// Height Assignment Method (BUFR code table 060103)</td>
</tr>
<tr>
<td><strong>Trajectory</strong></td>
<td>// Trajectory defined as a variable length array of Segment structures</td>
</tr>
</tbody>
</table>

Table 1: Detailed specification of the NWC/GEO-HRW netCDF output
2.3.5. Output data filterings

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 configurable parameters are:

- **AMV_BANDS** (default value HRVIS, VIS06, WV62, WV73, IR108 for MSG satellite series; VIS07, WV65, IR107 for GOES-N satellite series; VIS06, WV62, WV70, WV73, IR112 for Himawari-8/9 satellite series), which defines the channels for which AMVs and Trajectories are calculated.

- **QI_THRESHOLD**: defines the “Quality index threshold” for the AMVs and Trajectories in the output files. Depending on configurable parameter QI_THRESHOLD_USEFORECAST, the “Quality index with forecast” (which is the default option) or the “Quality index without forecast” are respectively used for the AMV filtering).

- **CLEARAIRWINDS**: defines if the “Clear air water vapour AMVs” are to be included in the output files (in the default option they are included).

- **MAXPRESSUREERROR**: defines the maximum “AMV pressure error” (in hPa) allowed in the output AMVs and Trajectories, when “CCC height assignment method” has been used.

- **MIN_CORRELATION**: defines the minimum correlation (as a percentage value) in the output AMVs and Trajectories, when the “Cross Correlation tracking” has been used.

- **FINALFILTERING**: defines several filterings in the output AMVs and Trajectories, depending on its value:
  - With FINALFILTERING > 0, the “AMV pressure level” filtering defined in Table 12 is implemented (in which the blue layers for the different channels are eliminated; light blue layers are eliminated only for “Clear air AMVs and Trajectories”; very dark blue layers are only eliminated if configurable parameter VERYLOWINFRAREDAMVS = 1, which is not implemented as default option).
  - With FINALFILTERING > 1 (which is the default option), the “AMV cloud type” filtering defined in Table 6 is additionally implemented.

<table>
<thead>
<tr>
<th>MSG sat.</th>
<th>HRVIS</th>
<th>VIS06</th>
<th>VIS08</th>
<th>IR108</th>
<th>IR120</th>
<th>WV62</th>
<th>WV73</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOES-N sat.</td>
<td>VIS07</td>
<td>IR107</td>
<td>WV65</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Himawari-8/9 sat.</td>
<td>VIS06</td>
<td>VIS08</td>
<td>IR112</td>
<td>WV62</td>
<td>WV70</td>
<td>WV73</td>
<td></td>
</tr>
<tr>
<td>100-199 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200-299 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300-399 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400-499 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500-599 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600-699 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>700-799 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>800-899 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>900-999 hPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 12: AMV filtering related to the Height level and each satellite channel**
3. IMPLEMENTATION OF NWC/GEO-HRW PRODUCT

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

3.1 NWC/GEO SOFTWARE PACKAGE INSTALLATION AND PREPARATION

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

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

The execution step is the processing of satellite images with NWC/GEO-HRW-v60 algorithm, in the region defined by the user. The running scheduling relies on the Programmed Task Definition File. This process consists in the running of the command `$SAFNWC/bin/NWC/GEO-HRW-v60` along with the required parameters (required image time, Region configuration file and Model configuration file) by the Task manager, in the following way:

```
GEO-HRW-v60 YYYY-MM-DDTHH:MM:SSZ $SAFNWC/config/file.cfg $SAFNWC/config/file.cfm
```

1. Year (YYYY), month (MM), day (DD), hour (HH), minute (MM) and second (SS) parameters are to be provided for the definition of the image time to be processed.
2. `$SAFNWC/config/file.cfg` is the Region configuration file, to be defined such as shown in document [AD.5].
3. `$SAFNWC/config/file.cfm` is the Model configuration file, to be defined such as shown in chapter 4.2 of this document. Three different default Model configuration files are included in NWC/GEO software package for the running of GEO-HRW-v60 executable:
   - `safnwc_HRW_MSG.cfm`, to be used with MSG satellite series in “Nominal scan mode” and “Rapid Scan mode”.
   - `safnwc_HRW_GOESN.cfm`, to be used with GOES-N satellite data in “Nominal scan mode” in the Continental United States region and the North America region, with calculation of AMVs and Trajectories every 15 and 30 minutes respectively.
   - `safnwc_HRW_HIMA.cfm`, to be used with Himawari-8/9 satellite data in “Nominal scan mode”, with calculation of AMVs and Trajectories every 10 minutes respectively.

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

To have NWC/GEO-Cloud Type, Cloud Top Temperature and Pressure and Cloud Microphysics available for their use by NWC/GEO-HRW algorithm, it is also necessary to run GEO-CMA-v50, GEO-CT-v40, GEO-CTTH-v40 and GEO-CMIC-v20 executables before GEO-HRW-v60 executable for the same image and region.

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

*Figures 1 to 3 summarise how the tasks to generate the High Resolution Winds (NWC/GEO-HRW) are performed by the GEO-HRW-v60 executable:*
Figure 1: NWC/GEO-HRW implementation: Part 1, Preprocessing and AMV computation
Figure 2: NWC/GEO-HRW implementation: Part 2, AMV quality and selection
Figure 3: NWC/GEO-HRW implementation: Part 3, Tracer computation and writing of output files
3.3 NWC/GEO-HRW DOCUMENTATION

Since NWC/GEO v2016 software package, a detailed description of all algorithms, involved interfaces and data types, is provided in html format with the support of Doxygen tool, from comments included within the code of the products. Documentation for NWC/GEO-HRW v6.0 is provided in the zipped file:

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

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

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

Every single step throughout all functions of NWC/GEO-HRW-v60 algorithm has also been commented in detail, so that any AMV developer can know in detail all the process of the algorithm, having a look to the corresponding C/Fortran functions.

For a quicker reference, a Diagram tree of all functions of NWC/GEO-HRW v6.0 algorithm is also provided in the “Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO” document [AD.14]. This Diagram tree allows NWC/GEO users and developers to quickly know at a glance how it works.
### 3.4 NWC/GEO-HRW Running Errors

The following table shows the whole list of errors and warnings that can appear during the running of NWC/GEO-HRW 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.

<table>
<thead>
<tr>
<th>Error (E) or Warning (W)</th>
<th>Message</th>
<th>Reason</th>
<th>Recovery action</th>
</tr>
</thead>
<tbody>
<tr>
<td>E - 151</td>
<td>“Usage of HRW executable: HRW &lt;slot&gt; &lt;region_conf_file&gt; &lt;model_conf_file&gt;”</td>
<td>Input parameters are incorrect</td>
<td>Check instructions to start the run of NWC/GEO-HRW product</td>
</tr>
<tr>
<td>E - 152</td>
<td>&quot;Error allocating memory for tracers&quot;</td>
<td>Unable to allocate required memory for &quot;tracer&quot; struct</td>
<td>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</td>
</tr>
<tr>
<td>E - 153</td>
<td>&quot;Error allocating memory for tracer_wind struct, relating tracers and AMVs&quot;</td>
<td>Unable to allocate required memory for &quot;tracer_wind&quot; struct</td>
<td>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</td>
</tr>
<tr>
<td>E - 154</td>
<td>“Error allocating memory for structs related to a wind_channel_info struct”</td>
<td>Unable to allocate required memory for &quot;wind_channel_info&quot; struct</td>
<td>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</td>
</tr>
<tr>
<td>E - 155</td>
<td>&quot;Error allocating memory for the NWP grids for each variable&quot;</td>
<td>Unable to allocate required memory for NWP grids</td>
<td>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</td>
</tr>
<tr>
<td>E - 156</td>
<td>&quot;Satellite data for current slot are not valid&quot;</td>
<td>Satellite data are not valid</td>
<td>Verify if there is any problem with the satellite data used by NWC/GEO-HRW product</td>
</tr>
<tr>
<td>E - 157</td>
<td>“Error allocating memory for the Quality control Image correlation grid”</td>
<td>Unable to allocate required memory for Image Correlation Grid</td>
<td>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</td>
</tr>
<tr>
<td>E - 161</td>
<td>&quot;Error reading Parameters from Satellite configuration file&quot;</td>
<td>Error after NwcCFReadSat function</td>
<td>Verify that the $SAFNWC/config/sat_conf_file used for running NWC/GEO-HRW product is correct</td>
</tr>
<tr>
<td>E - 162</td>
<td>“Error in date format (%s). Required (YYYY-MM-DDThh:mm:ssZ)”</td>
<td>Error after NwcTimeSetStr function</td>
<td>Verify that the date format used for running NWC/GEO-HRW product is correct</td>
</tr>
<tr>
<td>E - 163</td>
<td>“Error setting Processing region”</td>
<td>Error after NwcRegionSet function</td>
<td>Verify that the $SAFNWC/config/region_conf_file used for running NWC/GEO-HRW product is correct</td>
</tr>
<tr>
<td>E - 164</td>
<td>&quot;Error reading Pressure levels from the Model configuration file&quot;</td>
<td>Error after NwcNwpReadPLevel function</td>
<td>Verify that the $SAFNWC/config/nwp_conf_file used for running NWC/GEO-HRW product is correct</td>
</tr>
<tr>
<td>E - 165</td>
<td>“Unable to initialize the NWP Temperature / Wind / Geopotential NWP profile”</td>
<td>Error after NwcNwpInitProfile function</td>
<td>Verify that the $SAFNWC/config/nwp_conf_file &amp; $SAFNWC/config/model_conf_file used for running NWC/GEO-HRW product are correct</td>
</tr>
<tr>
<td>Error (E) or Warning (W)</td>
<td>Message</td>
<td>Reason</td>
<td>Recovery action</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>E - 171</td>
<td>&quot;Error reading Parameters from the HRW configuration file&quot;</td>
<td>Error after hrw_ReadData function</td>
<td>Verify that the $SAFNWC/config/model_conf_file used for running NWC/GEO-HRW product is correct</td>
</tr>
<tr>
<td>E - 172</td>
<td>&quot;Error getting latitude / longitude / sun angles for the High resolution region&quot;</td>
<td>Error after hrw_GetAncillaryData function</td>
<td></td>
</tr>
<tr>
<td>E - 173</td>
<td>&quot;Error reading satellite data for current slot&quot;</td>
<td>Error after hrw_ReadSatelliteData function</td>
<td></td>
</tr>
<tr>
<td>E - 174</td>
<td>&quot;Error reading tracers from previous slot&quot;</td>
<td>Error after hrw_ReadTracers function</td>
<td></td>
</tr>
<tr>
<td>E - 175</td>
<td>&quot;Error reading Trajectories for the previous slot&quot;</td>
<td>Error after hrw_ReadTrajectories function</td>
<td></td>
</tr>
<tr>
<td>E - 176</td>
<td>&quot;Error during the AMV Tracking process&quot;</td>
<td>Error after hrw_GetWinds function</td>
<td></td>
</tr>
<tr>
<td>E - 177</td>
<td>&quot;Error during the AMV Quality Control&quot;</td>
<td>Error after hrw_Qc function</td>
<td>Nevertheless, as a whole, they should occur in less than a 0.5% of the cases. If the frequency is higher than that, please contact NWC SAF Helpdesk.</td>
</tr>
<tr>
<td>E - 178</td>
<td>&quot;Error writing Predecessor winds in SAFNWC/tmp directory&quot;</td>
<td>Error after hrw_WritePredWinds function</td>
<td></td>
</tr>
<tr>
<td>E - 179</td>
<td>&quot;Error writing Trajectories in SAFNWC/tmp directory&quot;</td>
<td>Error after hrw_WriteTrajectories function</td>
<td></td>
</tr>
<tr>
<td>E - 180</td>
<td>&quot;Error calculating tracers for current slot&quot;</td>
<td>Error after hrw_GetTracers function</td>
<td></td>
</tr>
<tr>
<td>E - 181</td>
<td>&quot;Error writing tracers in SAFNWC/tmp directory&quot;</td>
<td>Error after hrw_WriteTracers function</td>
<td></td>
</tr>
<tr>
<td>E - 182</td>
<td>&quot;Error writing the AMVs in the netCDF output file&quot;</td>
<td>Error after hrw_EncodeNetCDF function</td>
<td></td>
</tr>
<tr>
<td>E - 191</td>
<td>&quot;NWP temperature data are not available; Winds cannot be calculated&quot;</td>
<td>AMVs cannot be calculated because NWP data could not be read</td>
<td>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</td>
</tr>
</tbody>
</table>

Table 13: List of errors for NWC/GEO-HRW v6.0 algorithm
4. INPUTS AND CONFIGURABLE PARAMETERS

4.1 LIST OF INPUTS FOR HIGH RESOLUTION WINDS

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

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

- Considering GOES-N satellite series: full resolution uncompressed GVAR data for the processing region, for the images in which tracers are calculated and tracked. GOES-N GVAR data have first to be converted to NWC/GEO netCDF satellite input data format (with the provided SAT2NC java tool), and after this process included in $SAFNWC/import/Sat_data directory. IR107 channel is in any case needed for the visible channel processing when the old “Brightness temperature interpolation height assignment” is to be used. IR107 and WV65 channels are in any case needed if the default configuration of the Quality control is kept (including the “Image correlation test”).

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

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

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

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

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

Of all these data, only MSG/HRIT or GOES-N/GVAR or Himawari-8/9/HSD data and the NWP temperature profiles are strictly needed for the running of NWC/GEO-HRW algorithm.
4.2 **LIST OF HIGH RESOLUTION WINDS CONFIGURABLE PARAMETERS**

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

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

1. **MSG satellite series** (*safnwc_HRW_MSG.cfm*).
2. **GOES-N satellite series** (*safnwc_HRW_GOESN.cfm*).
3. **Himawari-8/9 satellite series** (*safnwc_HRW_HIMA.cfm*).

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

<table>
<thead>
<tr>
<th>Keyword</th>
<th>Description</th>
<th>Type</th>
<th>Default Value(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identification parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGE_ID</td>
<td>PGE identification. This keyword is optional, but should not be changed by the user.</td>
<td>Chain of characters</td>
<td>GEO-HRW</td>
</tr>
<tr>
<td>SAT_BANDS</td>
<td>A list of satellite bands that can be used to run for the calculation of AMVs and Trajectories with NWC/GEO-HRW algorithm. This keyword is optional, but should not be changed. It defines the maximum value of bands for which AMVs can be calculated. Values defined in a list separated by commas.</td>
<td>Chain of characters</td>
<td>HRVIS, VIS06, VIS08, IR108, IR120, WV062, WV073 (MSG)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>VIS07, IR07, WV065 (GOES-N)</td>
</tr>
<tr>
<td>AMV_BANDS</td>
<td>A list of satellite bands really used for the calculation of AMVs and Trajectories with NWC/GEO-HRW algorithm. As possible values, it can include any of the bands shown by the previous parameter, separated by commas.</td>
<td>Chain of characters</td>
<td>HRVIS, HRVIS06, HRVIS108, WV062, WV073 (MSG)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>VIS07, IR07, WV065 (GOES-N)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>VIS06, IR112, WV062, WV069, WV073 (HIMAWARI)</td>
</tr>
<tr>
<td>SLOT_GAP</td>
<td>Ordering number of the previous satellite image, for which tracers are to be considered for the AMV processing. The value for “Rapid scan mode” is one unit more than the value defined by the parameter.</td>
<td>Integer</td>
<td>1</td>
</tr>
<tr>
<td>MIXED_SCANNING</td>
<td>Flag to decide if the “Mixed method” is implemented for the processing of AMVs and Trajectories.</td>
<td>Integer</td>
<td>0</td>
</tr>
<tr>
<td>CDEF</td>
<td>Flag to define if Detailed AMVs and Trajectories calculated.</td>
<td>Integer</td>
<td>0</td>
</tr>
<tr>
<td><strong>Output parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BUFRCENTRE_OR</td>
<td>Originating centre of the BUFR file, as defined in WMO Common Code Table C-1 ([RD.19]). It is to be modified with the code related to the corresponding centre (e.g. the default value 214 means Madrid).</td>
<td>Integer</td>
<td>214</td>
</tr>
<tr>
<td>OUTPUT_FORMAT</td>
<td>A list of output file formats, with several options possible. Elements in the list are to be separated by commas: - NWC: AMV &amp; Trajectories BUFR files, using the specific NWC SAF format. - EUM: AMV BUFR files, using the IWG BUFR format. - NET: AMV netCDF files</td>
<td>Chain of characters</td>
<td>NWC</td>
</tr>
</tbody>
</table>
### Output filtering parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>QI_THRESHOLD</td>
<td>Quality Index threshold for the AMVs.</td>
<td>70</td>
</tr>
<tr>
<td>QI_THRESHOLD_USEFORECAST</td>
<td>Option to show if the Quality index threshold used in the wind output filtering includes the Quality forecast test.</td>
<td>1</td>
</tr>
<tr>
<td>QI_BEST_WIND_SELECTION</td>
<td>Criterion for Best wind selection (Values: 0/1, as defined in the ATBD document).</td>
<td>1</td>
</tr>
<tr>
<td>CLEARAIRWINDS</td>
<td>Flag to decide if Clear air AMVs calculated.</td>
<td>1</td>
</tr>
<tr>
<td>CALCULATE_TRAJECTORIES</td>
<td>Flag to decide if Trajectories calculated.</td>
<td>1</td>
</tr>
<tr>
<td>FINALFILTERING</td>
<td>Flag for a final filtering of AMVs based on: - Their Height level (if &gt; 0), - Their Cloud type (if &gt; 1), - Their Quality spatial test (1.2 as invalid values if &gt; 2; 0,1,2 as invalid values if &gt; 3).</td>
<td>2</td>
</tr>
<tr>
<td>USE_TOPO</td>
<td>Flag for calculation of Orographic flag (if positive), and for its AMV filtering (if = 2).</td>
<td>2</td>
</tr>
<tr>
<td>MAXPRESSUREERROR</td>
<td>Maximum pressure error in the AMVs (hPa), when 'CCC height assignment method' used.</td>
<td>150</td>
</tr>
<tr>
<td>VERYLOWINFRAREDAMVS</td>
<td>Flag showing if very low infrared AMVs (at levels lower than 900 hPa) are admitted in the AMV output files.</td>
<td>1</td>
</tr>
<tr>
<td>FINALCONTROLCHECK</td>
<td>Flag to decide the use of Final Control Check.</td>
<td>1</td>
</tr>
<tr>
<td>CORRELATIONMATRICES</td>
<td>This parameter is formally deactivated in the NWC/GEO-HRW v6.0 algorithm.</td>
<td>0</td>
</tr>
</tbody>
</table>

### Working area description parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAT_MIN</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Basic AMVs).</td>
<td>-75</td>
</tr>
<tr>
<td>LAT_MAX</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Basic AMVs).</td>
<td>75</td>
</tr>
<tr>
<td>LON_MIN</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Basic AMVs).</td>
<td>-180</td>
</tr>
<tr>
<td>LON_MAX</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Basic AMVs).</td>
<td>180</td>
</tr>
<tr>
<td>LAT_MIN_DET</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Detailed AMVs).</td>
<td>-75</td>
</tr>
<tr>
<td>LAT_MAX_DET</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Detailed AMVs).</td>
<td>75</td>
</tr>
<tr>
<td>LON_MIN_DET</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Detailed AMVs).</td>
<td>-180</td>
</tr>
<tr>
<td>LON_MAX_DET</td>
<td>Latitude and longitude borders (in degrees) for the processing region (Detailed AMVs).</td>
<td>180</td>
</tr>
<tr>
<td>FRAC_DAY_SCENE</td>
<td>Minimum fraction of area illuminated by the sun needed to calculate the visible AMVs (HRVIS, VIS06, VIS07, VIS08 channels).</td>
<td>8</td>
</tr>
<tr>
<td>SUN_ZEN_THRES</td>
<td>Sun zenith angle threshold (degrees).</td>
<td>87</td>
</tr>
<tr>
<td>SAT_ZEN_THRES</td>
<td>Satellite zenith angle threshold (degrees).</td>
<td>80</td>
</tr>
</tbody>
</table>

### Tracer parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX_TRACERS</td>
<td>Maximum number of tracers.</td>
<td>100000</td>
</tr>
<tr>
<td>TRACERSIZE_VERYHIGH</td>
<td>Tracer line and column dimension in pixels, when respectively using satellite images with very high, high and low resolution.</td>
<td>24</td>
</tr>
<tr>
<td>TRACERSIZE_HIGH</td>
<td>Tracer line and column dimension in pixels, when respectively using satellite images with very high, high and low resolution.</td>
<td>24</td>
</tr>
<tr>
<td>BRIGHTNESS_THR_VIS</td>
<td>1 byte reflectance threshold for visible tracers.</td>
<td>120</td>
</tr>
<tr>
<td>BRIGHTNESS_THR_OTHER</td>
<td>1 byte brightness temperature threshold for infrared and water vapour tracers.</td>
<td>60</td>
</tr>
<tr>
<td>GVAL_VIS</td>
<td>Minimum 1 byte reflectance contrast for visible tracers.</td>
<td>60</td>
</tr>
<tr>
<td>GVAL_OTHER</td>
<td>Minimum 1 byte brightness temperature contrast for infrared and water vapour tracers.</td>
<td>48</td>
</tr>
<tr>
<td>TRACERDISTANCE_VERYHIGH</td>
<td>Nominal separation in pixels between tracers, when respectively using satellite images with very high, high and low resolution.</td>
<td>24</td>
</tr>
<tr>
<td>TRACERDISTANCE_HIGH</td>
<td>Depending on value of HIGHERDENSITY_LOWTRACERS, this separation applies to all tracers (if = 0) or only to tracers related to very low and low clouds (if = 1).</td>
<td>12</td>
</tr>
<tr>
<td>TRACERDISTANCE_LOW</td>
<td>This separation applies to all tracers (if = 0) or only to tracers related to very low and low clouds (if = 1).</td>
<td>3 (GOES-N), 4 (MSG), 6 (HIMAWARI)</td>
</tr>
<tr>
<td>HIGHERDENSITY_LOWTRACERS</td>
<td>Option to decide if the nominal separation between tracers related to very low and low clouds is half the one between tracers related to other cloud types.</td>
<td>1</td>
</tr>
</tbody>
</table>
# Tracking parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRACING</td>
<td>Tracking method. Possible values: LP: Euclidean difference CC: Cross correlation.</td>
<td>Chain of characters CC</td>
</tr>
<tr>
<td>DEFINECONTRIBUTIONS</td>
<td>Flag to decide if “CCC height assignment” is to be used (requires also TRACKING=CC).</td>
<td>Integer 1</td>
</tr>
<tr>
<td>DEFPOSCONTRIBUTIONS</td>
<td>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).</td>
<td>Integer 1</td>
</tr>
<tr>
<td>USE_CLOUDTYPE</td>
<td>Flag to decide if - The Tracer cloud type is calculated by the old “Brightness temperature interpolation height assignment method&quot; (if positive), - And if the Tracer cloud type is taken into account for the calculation of the Tracer temperature (if = 2).</td>
<td>Integer 2</td>
</tr>
<tr>
<td>USE_MICROPHYSICS</td>
<td>Flag to decide if Microphysics correction is to be calculated to “CCC height assignment” (if positive), and if this Microphysics corrections is applied to the final AMV pressure (if = 2) (requires also TRACKING=CC and DEFINECONTRIBUTIONS=1).</td>
<td>Integer 2 (MSG &amp; HIMAWARI) 0 (GOES-N)</td>
</tr>
<tr>
<td>MIN_CORRELATION</td>
<td>Minimum correlation acceptable (if TRACKING=CC).</td>
<td>Integer 80 (MSG &amp; HIMAWARI) 50 (GOES-N)</td>
</tr>
<tr>
<td>WIND_GUESS</td>
<td>Flag to decide if the Wind guess is used for the definition of the Tracking area.</td>
<td>Integer 0</td>
</tr>
<tr>
<td>MINSPEED_DETECTION</td>
<td>When the wind guess is not used in the definition of the Tracking area, displacement in direction (in km/h) which the process is at least able to detect for AMVs/Trajectories.</td>
<td>Integer 272</td>
</tr>
<tr>
<td>USE_SUBPIXELTRACKING</td>
<td>Flag to decide if the subpixel tracking is used.</td>
<td>Integer 1</td>
</tr>
<tr>
<td>USE_PARALLAXCORRECTION</td>
<td>Flag to decide if the parallax correction is applied to the latitude/longitude of the tracer and tracking centre, for the calculation of the wind, considering the AMV height in metres.</td>
<td>Integer 1</td>
</tr>
</tbody>
</table>

# NWP validation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWPVAL_STATISTICS</td>
<td>Flag to decide if Validation statistics against NWP model winds are to be calculated. Possible values: - 1: Statistics provided for all layers and satellite channels together. - 2: Statistics provided for all layers together and each satellite channel separately. - 3: Statistics provided for each layer separately and all satellite channels together. - 4: Statistics provided for each layer and satellite channel separately.</td>
<td>Integer 2</td>
</tr>
<tr>
<td>NWPVAL_ANALYSIS</td>
<td>Flag to decide if the Validation statistics are to be computed against NWP analysis winds.</td>
<td>Integer 0</td>
</tr>
<tr>
<td>NWPVAL_NWPDIFFERENCE</td>
<td>Flag to decide if Vector difference between each AMV and the related NWP model wind is to be written in the output files.</td>
<td>Integer 1</td>
</tr>
<tr>
<td>NWPVAL_NWPBESTFITLEVEL</td>
<td>Flag to decide if the NWP model wind at the best fit pressure level for each AMV is to be written in the output files.</td>
<td>Integer 1</td>
</tr>
</tbody>
</table>
### NWP parameters

<table>
<thead>
<tr>
<th>MIN_NWP_FOR_CALCULATION</th>
<th>NWP parameters requested by NWC/GEO-HRW algorithm:</th>
<th>Chain of characters</th>
</tr>
</thead>
<tbody>
<tr>
<td>NWP_PARAM</td>
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<td>* NWP_UW: Wind velocity at several levels, u component (m/s)</td>
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<td>* NWP_GEOP: Geopotential height at several levels (m)</td>
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Table 14: NWC/GEO-HRW v6.0 Model Configuration File Description

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

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

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

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

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

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

The statistical parameters used in the process of validation are:

- **NC**: “Number of collocations” between NWC/GEO-HRW AMVs and the reference winds.
- **SPD**: “Mean speed of the reference winds in m/s”.
- **NBIAS**: “Normalized bias”.
- **NMVD**: “Normalized mean vector difference”.
- **NRMSVD**: “Normalized root mean square vector difference”.

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

The same dataset of AMVs is validated for all satellite series against both reference winds, to detect differences in the validation against these references.
5.1 NWC/GEO-HRW VALIDATION FOR MSG SATELLITE SERIES

For MSG satellite series, the Validation statistics correspond to the reference yearly period used since several years ago for NWC/GEO-HRW algorithm: July 2009–June 2010 at 12:00 UTC, with MSG2 satellite data, in a region covering Europe and the Mediterranean Sea, such as shown in Figure 4. Cloudy AMVs in the layer 100-1000 hPa and clear air AMVs in the layer 100-400 hPa with a Quality index with forecast ≥ 70%, are considered as valid for this validation.

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

Comparing the statistics against Radiosounding winds (in green colours) and ECMWF NWP analysis winds (in blue colours) in Table 15 (considering all layers together) and in Table 16 (considering the three layers separately), it can be seen that the NWP analysis wind mean speed is slightly smaller, and the NBIAS, NMVD and NRMSV are significantly smaller (around a 20% smaller). A conclusion can be taken here, that the general scale and behaviour of the AMV winds is more similar to that of NWP analysis winds than to that of Radiosounding winds.

Considering the different satellite channels, as for the previous version of NWC/GEO-HRW algorithm, the MVD and NRMSV seem very different considering all layers together, with changes larger than the 50% between the best case (Cloudy WV62 AMVs) and the worst case (Cloudy VIS08 AMVs). Nevertheless, this is only caused by the different proportion of AMVs in the different layers for each channel. Inside each one of the layers, differences of NMVD and NRMSV for the different channels are much smaller.

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

A quick comparison of the statistics against Radiosounding winds with those for the previous version of NWC/GEO-HRW algorithm (shown in white colours in Tables 16 and 17), the main element to be taken into account is that distribution of AMVs in the different layers has changed significantly, going from a value of 61%/25%/14% for the High/Medium/Low layer in the previous version, to a more homogeneous value in the new version of 52%/25%/23% (considering validated AMVs) and 45%/23%/32% (considering calculated AMVs). This helps to better characterize the behaviour of the wind in the different levels of the troposphere. The change is caused by the higher density of tracers related to low and very low clouds, with both an absolute and relative increase in the low level AMVs, such as requested by the NWC SAF users.

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

Comparing the validation parameters for the new and previous version of NWC/GEO-HRW, and considering all layers together in Table 15, there is a small increase of the NMVD and NRMSV values (up to a 10%), which is only caused by the larger proportion now of low layer AMVs, with worse validation parameters. Considering each layer separately in Table 16, the NMVD and NRMSV keep similar values in all of them, while the NBIAS reduces around a 20% with the new version in all layers.
### Table 15: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering all layers together against Radiosounding winds in light green; against ECMWF NWP analysis winds in light blue) and NWC/GEO-HRW v5.0 AMVs AMVs (against Radiosounding winds in white) (Jul 2009-Jun 2010 12:00 UTC, MSG2 satellite, European and Mediterranean region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction).

Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs.

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Table 16: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering three separate layers against Radiosounding winds in light green; against ECMWF NWP analysis winds in light blue) and NWC/GEO-HRW v5.0 AMVs AMVs (against Radiosounding winds in white)

(Jul 2009-Jun 2010 12:00 UTC, MSG2 satellite, European and Mediterranean region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction).

Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs.
5.2 NWC/GEO-HRW VALIDATION FOR GOES-N SATELLITE SERIES

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

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

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

Validation statistics against Radiosounding winds are considered in Table 17 (considering all layers together) and in Table 18 (considering the three layers separately). No validation statistics are provided against ECMWF NWP analysis winds this time, because no GOES13 images exist exactly at the NWP analysis hours.

Comparing with the equivalent statistics for MSG (shown in Table 15 and 16), validation statistics for GOES-N AMVs are similar (with differences up to a 15% in general); in many cases better. Considering the different GOES-N channels (VIS07, WV65, IR107) there are no remarkable differences with the equivalent MSG channels.

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

A quick comparison of the statistics against Radiosounding winds with those for the previous version of NWC/GEO-HRW algorithm (shown in white colours in Tables 17 and 18), the main elements to be taken into account are: on one side the larger population of AMVs, with increments between 20% and 25% in the High and Medium layer, and more significantly up to 380% in the Low layer (which is directly related to the “higher density for tracers related to low and very low clouds”). On the other side, because of these changes in the population of AMVs the distribution of AMVs in the different layers has also changed, going from a value of 89%/9%/12% for the High/Medium/Low layer in the previous version, to a more homogeneous value in the new version of 86%/7%/7% (considering validated AMVs) and 69%/12%/19% (considering calculated AMVs). The distribution between different layers has so improved, although this is less significant than in the MSG case.

Comparing validation parameters for the new and previous version of NWC/GEO-HRW, considering all layers together in Table 17, the validation statistics are exactly equivalent. So, the fact that more AMVs are calculated with similar statistics is a positive evolution of the GOES-N series AMVs with this version. Considering each layer separately in Table 18, the variations in NMVD and NRMSV parameters are smaller than a 10%, while the NBIAS reduces up to a 25%.
### Table 17: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering all layers together against Radiosounding winds in light green) and NWC/GEO-HRW v5.0 AMVs (against Radiosounding winds in white) (Jul 2010-Jun 2011, GOES13 satellite, 05:45/11:45/17:45/23:45 UTC, Continental United States region; Basic AMVs; Cross correlation; Higher density related to low and very low clouds; CCC height assignment without Microphysics).

Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs.

<table>
<thead>
<tr>
<th>NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Clear</th>
<th>All AMVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS07</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>IR107</td>
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<td>WV65</td>
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<td></td>
</tr>
<tr>
<td>Air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>22.34</td>
<td>21.82</td>
<td>25.22</td>
<td>14.64</td>
<td>22.43</td>
</tr>
<tr>
<td>SPD [m/s]</td>
<td>-0.01</td>
<td>-0.08</td>
<td>-0.04</td>
<td>+0.00</td>
<td>-0.05</td>
</tr>
<tr>
<td>NMVD (100-1000 hPa)</td>
<td>0.24</td>
<td>0.29</td>
<td>0.26</td>
<td>0.37</td>
<td>0.28</td>
</tr>
<tr>
<td>NRMSVD</td>
<td>0.31</td>
<td>0.37</td>
<td>0.33</td>
<td>0.49</td>
<td>0.36</td>
</tr>
</tbody>
</table>

| NC                                               | 5849   | 208726 | 205757 | 472533| 467585   |
| SPD [m/s]                                        | 22.34  | 22.98  | 24.46  | 15.31 | 23.00    |
| NMVD (100-1000 hPa)                              | 0.25   | 0.29   | 0.27   | 0.39  | 0.28     |
| NRMSVD                                          | 0.31   | 0.36   | 0.33   | 0.48  | 0.36     |

### Table 18: Validation parameters for NWC/GEO-HRW v6.0 AMVs (considering three separate layers against Radiosounding winds in light green) and NWC/GEO-HRW v5.0 AMVs (against Radiosounding winds in white) (Jul 2010-Jun 2011, GOES13 satellite, 05:45/11:45/17:45/23:45 UTC, Continental United States region; Basic AMVs; Cross correlation; Higher density related to low and very low clouds; CCC height assignment without Microphysics).

Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v5.0 Basic AMVs.

<table>
<thead>
<tr>
<th>NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Clear</th>
<th>All AMVs</th>
</tr>
</thead>
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<tr>
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<tr>
<td>IR107</td>
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<tr>
<td>Air</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>22.34</td>
<td>21.82</td>
<td>25.22</td>
<td>14.64</td>
<td>22.43</td>
</tr>
<tr>
<td>SPD [m/s]</td>
<td>-0.01</td>
<td>-0.08</td>
<td>-0.04</td>
<td>+0.00</td>
<td>-0.05</td>
</tr>
<tr>
<td>NMVD (100-400 hPa)</td>
<td>0.23</td>
<td>0.28</td>
<td>0.26</td>
<td>0.37</td>
<td>0.28</td>
</tr>
<tr>
<td>NRMSVD</td>
<td>0.28</td>
<td>0.35</td>
<td>0.33</td>
<td>0.49</td>
<td>0.35</td>
</tr>
</tbody>
</table>

| NC                                               | 18.29  | 17.04  | 20.84  | 18.03 |          |
| SPD [m/s]                                        | -0.01  | -0.09  | -0.04  | -0.00 | -0.05    |
| NMVD (400-700 hPa)                               | 0.35   | 0.37   | 0.29   | 0.33  |          |
| NRMSVD                                          | 0.35   | 0.43   | 0.37   | 0.41  |          |

| NC                                               | 4694   | 173848 | 191878 | 472533| 417673   |
| SPD [m/s]                                        | 24.71  | 24.33  | 24.68  | 15.31 | 23.47    |
| NMVD (700-1000 hPa)                              | 0.35   | 0.40   | 0.40   | 0.39  |          |
| NRMSVD                                          | 0.43   | 0.49   | 0.49   | 0.49  |          |

| NC                                               | 460    | 13879  | 191878 | 472533| 39406    |
| SPD [m/s]                                        | 18.10  | 18.60  | 21.43  | 19.59 |          |
| NMVD (400-700 hPa)                               | 0.28   | 0.28   | 0.27   | 0.35  | 0.28     |
| NRMSVD                                          | 0.29   | 0.35   | 0.33   | 0.47  | 0.36     |

| NC                                               | 695    | 9811   |        |       |          |
| SPD [m/s]                                        | 9.17   | 10.24  |        |       | 10.17    |
| NMVD (700-1000 hPa)                              | 0.35   | 0.39   |        |       | 0.38     |
| NRMSVD                                          | 0.43   | 0.48   |        |       | 0.48     |
5.3 **NWC/GEO-HRW VALIDATION FOR HIMAWARI-8/9 SATELLITE SERIES**

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

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

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis in Table 19 (considering all layers together) and in Table 20 (considering the three layers separately), the NBIAS, NMVD and NRMSVD parameters are once again around a 25% smaller against NWP analysis winds.

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

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

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

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

Comparatively, there is however room for improvement for the AMVs with Himawari, trying to reduce its errors in the Medium and Low layer, and trying to increase the proportion of AMVs in the Low layer for a better characterization of the wind throughout all the troposphere. As GOES-R and MTG-Imager satellite series are very similar to Himawari, any improvement in these aspects will be positive for the three new generation satellite series.
### Table 19: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering all layers against Radiosounding winds (in light green) and ECMWF NWP analysis winds (in light blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction)

<table>
<thead>
<tr>
<th>NWC/GEO-HRWv6.0 AMVs</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Clear</th>
<th>All</th>
<th>AMVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mar-Aug 2018, Himawari-8)</td>
<td>VIS06</td>
<td>VIS08</td>
<td>IR112</td>
<td>WV62</td>
<td>WV70</td>
<td>WV73</td>
<td>Air</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC</td>
<td>36841</td>
<td>71618</td>
<td>287147</td>
<td>189457</td>
<td>246356</td>
<td>280899</td>
<td>85148</td>
<td>1197466</td>
<td></td>
</tr>
<tr>
<td>SPD [m/s]</td>
<td>21.70</td>
<td>19.95</td>
<td>19.58</td>
<td>23.60</td>
<td>22.58</td>
<td>21.54</td>
<td>19.94</td>
<td>21.46</td>
<td></td>
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<tr>
<td>NBIAS (ALL LAYERS)</td>
<td>+0.00</td>
<td>-0.06</td>
<td>+0.04</td>
<td>+0.06</td>
<td>+0.06</td>
<td>+0.06</td>
<td>+0.06</td>
<td>+0.05</td>
<td></td>
</tr>
<tr>
<td>NMVD (100-1000 hPa)</td>
<td>0.24</td>
<td>0.26</td>
<td>0.27</td>
<td>0.26</td>
<td>0.27</td>
<td>0.26</td>
<td>0.30</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>NRMSEVD</td>
<td>0.29</td>
<td>0.31</td>
<td>0.35</td>
<td>0.32</td>
<td>0.33</td>
<td>0.33</td>
<td>0.38</td>
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<tr>
<td>NC</td>
<td>36841</td>
<td>71618</td>
<td>287147</td>
<td>189457</td>
<td>246356</td>
<td>280899</td>
<td>85148</td>
<td>1197466</td>
<td></td>
</tr>
<tr>
<td>NBIAS (ALL LAYERS)</td>
<td>-0.00</td>
<td>-0.06</td>
<td>+0.04</td>
<td>+0.06</td>
<td>+0.06</td>
<td>+0.06</td>
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<tr>
<td>NMVD (100-1000 hPa)</td>
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<td>0.20</td>
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<td></td>
</tr>
<tr>
<td>NRMSEVD</td>
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<td>0.25</td>
<td>0.24</td>
<td>0.25</td>
<td>0.25</td>
<td>0.30</td>
<td>0.26</td>
<td></td>
</tr>
</tbody>
</table>

### Table 20: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering three layers against Radiosounding winds (in light green) and ECMWF NWP analysis winds (in light blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation tracking; Higher density of tracers related to low and very low clouds; CCC height assignment with Microphysics correction)

<table>
<thead>
<tr>
<th>NWC/GEO-HRWv6.0 AMVs</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Cloudy</th>
<th>Clear</th>
<th>All</th>
<th>AMVs</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mar-Aug 2018, Himawari-8)</td>
<td>VIS06</td>
<td>VIS08</td>
<td>IR112</td>
<td>WV62</td>
<td>WV70</td>
<td>WV73</td>
<td>Air</td>
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<td>NC</td>
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<td>183124</td>
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<td>229291</td>
<td>85148</td>
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<tr>
<td>SPD [m/s]</td>
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<td>24.52</td>
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<td>19.32</td>
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<tr>
<td>NBIAS (HIGH LAYER)</td>
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<td>-0.01</td>
<td>+0.04</td>
<td>+0.06</td>
<td>+0.05</td>
<td>+0.03</td>
<td>+0.06</td>
<td>+0.04</td>
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</tr>
<tr>
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<td>0.23</td>
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<td>0.26</td>
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<td></td>
</tr>
<tr>
<td>NRMSEVD</td>
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<td>0.27</td>
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<td>0.31</td>
<td>0.31</td>
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<tr>
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<td>-0.01</td>
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<td>+0.05</td>
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<tr>
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<td>51608</td>
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<td>+0.07</td>
<td>+0.17</td>
<td>+0.22</td>
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<td>+0.12</td>
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<td>0.26</td>
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<tr>
<td>NRMSEVD</td>
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<td>0.36</td>
<td>0.39</td>
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6. **NWC/GEO-HRW 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 of cloudy areas or cloudless areas with humidity patterns in the working region. Nevertheless, the situation has improved with the progressive new versions of NWC/GEO-HRW algorithm:

- Initially, the applicability of NWC/GEO-HRW algorithm was limited to cloudy areas in European, African and Atlantic areas with MSG satellite data.
- Since the version of year 2011, AMVs related to humidity patterns in the MSG water vapour channels started to show wind vectors in clear air areas.
- Since the version of year 2012, the possibility to calculate AMVs with up to seven different MSG satellite channels increases significantly the density of possible AMV data throughout all the day. The additional option to calculate AMVs in “Rapid scan mode” with MSG satellite series also permits to obtain new AMVs in shorter time frames of five minutes with every new satellite image, increasing the amount of available AMVs by a factor of 3 respect to the MSG “Nominal scan mode”.
- Since the version of year 2018, the option exists to calculate AMVs and Trajectories in Asian and West Pacific areas with Himawari-8/9 satellite series. The planned extension to GOES-R satellite series in the year 2019 will finally allow for the operational calculation of AMVs and Trajectories with geostationary satellites covering all areas of the world with an only AMV algorithm, which will be an important milestone for NWC/GEO-HRW algorithm. The experience with these two new generation satellites (Himawari-8/9 now and GOES-R next year), will also be very useful for the development of the AMV algorithm for MTG-Imager satellite series, for which the main issues seem to be related to the density and quality of AMVs at low levels.

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

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

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

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

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

The first problem is solved not using the NWP wind guess (with WIND_GUESS = 0), which despite the increases in the running time of NWC/GEO-HRW algorithm it implies (because of using larger “tracking areas”), the optimizations included in the algorithm make this...
configuration fully operational as the default option for NWC/GEO-HRW algorithm. Users should keep this configuration, so reducing the dependence of the AMVs on the NWP model.

The second problem is solved using the “Quality index without forecast” in the operation of NWC/GEO-HRW algorithm (implemented with QI_THRESHOLD_USEFORECAST = 0), which avoids the influence of the NWP model in the Quality of the AMVs (nevertheless, this option has not been considered as the default one in NWC/GEO-HRW algorithm). Other option can be to use the “Common IWWG Quality index”, especially when AMV outputs from different algorithms are used, for which the use of this parameter has proved to be useful.

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

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

The quality of the height assignment inferred in previous versions of NWC/GEO-HRW algorithm without use of NWP data is considered not to be good enough to be used anymore, and so the option to calculate AMVs without NWP data has been eliminated in NWC/GEO-HRW algorithm.

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

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

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

First, with MSG2 satellite data in the European and Mediterranean region used for validation (Figures 4 and 5). Second, with GOES13 satellite data in the Continental United States region used for validation (Figures 6 and 7). Finally, with Himawari-8 satellite data in the China/Korea/Japan region used for validation (Figures 8 and 9).

Figure 4: NWC/GEO-HRW v6.0 “Basic AMV” output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_MSG.cfm model configuration file. Colour coding based on the AMV pressure level.

Figure 5: NWC/GEO-HRW v6.0 “Detailed AMV” output example in the European and Mediterranean region (14 May 2010 12:00 UTC, Nominal scan mode, MSG2 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_MSG.cfm model configuration file with parameter CDET=1. Colour coding based on the AMV pressure level.
Figure 6: NWC/GEO-HRW v6.0 “Basic AMV” output example in the Continental United States region (1 July 2010 17:45 UTC, GOES13 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_GOESN.cfm model configuration file. Colour coding based on the AMV pressure level.

Figure 7: NWC/GEO-HRW v6.0 “Detailed AMV” output example in the Continental United States region (1 July 2010 17:45 UTC, GOES13 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_GOESN.cfm model configuration file with parameter CDET=1. Colour coding based on the AMV pressure level.
Figure 8: NWC/GEO High Resolution Winds “Basic AMV” output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_HIMA.cfm model configuration file. Colour coding based on the AMV pressure level

Figure 9: NWC/GEO High Resolution Winds “Detailed AMV” output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering conditions defined in $SAFNWC/config/safnwc_HRW_HIMA.cfm model configuration file with configurable parameter CDET=1. Colour coding based on the AMV pressure level