



# Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)

SAF/NWC/CDOP2/INM/SCI/ATBD/09, Issue 4, Rev.0

*15 July 2013*

*Applicable to SAFNWC/MSG version 2013*

### REPORT SIGNATURE TABLE

Function	Name	Signature	Date
<b>Prepared by</b>	Javier García Pereda		<i>15 July 2013</i>
<b>Reviewed by</b>	Marcelino Manso Rejón SAFNWC/MSG DRR 2013		<i>15 July 2013</i>
<b>Authorised by</b>	Pilar Fernández Álvarez NWC SAF Project Manager		<i>15 July 2013</i>

## DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
2.2	15 February 2009	44	<p>Initial version, including all elements and changes in HRW v2.2. (Content derived from Software User Manual for HRW v2.1)</p> <p>Modifications related to DRI MSG 2009 Actions 17,18,19 have also been included.</p>
3.0	28 December 2009	45	<p>New version for HRW v3.0, with the modifications included:</p> <ul style="list-style-type: none"> <li>○ Adaptation and optimization of the algorithm code to calculate ‘Nominal scan mode’ IR108 winds.</li> <li>○ Adaptation and optimization of the algorithm code to calculate ‘Rapid Scan mode’ HRVIS and IR108 winds.</li> </ul> <p>Modifications related to DRI MSG 2010 have been included.</p>
3.1	1 April 2011	48	<p>New version for HRW v3.1, with the following modifications:</p> <ul style="list-style-type: none"> <li>○ The implementation of the new “CCC height assignment method” through collaboration with Régis Borde from EUMETSAT. This method defines the wind pressure with SAFNWC/MSG CTTH top pressure output, considering only the pixels contributing most to the image correlation, and offering a direct correspondence between the pressure values given by CTTH and HRW products.</li> <li>○ A new optimization of HRW code needed for the implementation of “CCC height assignment method”.</li> <li>○ An increase in the number of NWP levels that can be used by HRW product, defined by MAX_NWP_LEVELS parameter.</li> </ul>
3.2	15 February 2012	56	<p>New version for HRW v3.2, with the following modifications:</p> <ul style="list-style-type: none"> <li>○ The adaptation, tuning and optimization of HRW algorithm for the calculation of AMVs with images from five more SEVIRI channels: VIS06, VIS08, IR120, WV062, WV073 (including clear air AMVs from WV062 and WV073 channels), and for its easy extension to other SEVIRI channels in the near future.</li> <li>○ The simplification of several functions inside HRW algorithm for a more obvious correspondence between high and low resolution image matrices in the calculation of HRVIS winds. This procedure has been related to the analysis made on the implications of SPR-470 (Misalignment of HRVIS region), which nevertheless caused no visible impact on HRVIS AMV validation (as shown in the “Validation report for HRW v3.2” [AD.10]).</li> <li>○ Modifications in hrw_WindGuess.c, hrw_WindDisplace.c functions related to SPR-480 (Error in HRW Quality test against the forecast).</li> <li>○ Small modifications in the handling of NWP data for its easier configuration.</li> </ul> <p>Modifications related to DRI MSG 2012 have also been included.</p>

Version	Date	Pages	Changes
4.0	15 July 2013	78	<p>Main changes related to HRW v4.0</p> <ul style="list-style-type: none"> <li>○ Option to provide the HRW AMV BUFR output format as defined for the EUMETSAT/MPEF AMVs.</li> <li>○ Additional optimization of the HRW code to calculate the AMVs by default option without the use of the wind guess in the definition of the tracking area, so reducing the dependence of the AMVs from the NWP model data.</li> <li>○ Update of the Quality Control process, to include the additional elements currently activated in the EUMETSAT/MPEF AMV Quality Control. Considering this, a Quality index without use of forecast is additionally included in the BUFR output and can be used in the filtering of the valid AMVs.</li> <li>○ Calculation of trajectories through the successive tracking of the same tracer in consecutive slots (with a specific Trajectory BUFR format file).</li> <li>○ Update of the calculation of the Orographic flag, so that now it considers as previous positions of the AMV those defined in its corresponding trajectory (when they exist).</li> <li>○ Inclusion of the Subpixel tracking process, to avoid discontinuities in the field of wind speeds and directions caused by the resolution of the image pixels.</li> <li>○ Definition of the location of the AMV inside the tracer (in both initial and final image) not as the tracer centre but as the position of maximum correlation contribution defined by “CCC method”</li> <li>○ Formal recommending of all HRW code for a clearer understanding.</li> </ul>

## List of contents

<b>1. INTRODUCTION.....</b>	<b>9</b>
1.1 SCOPE OF THE DOCUMENT .....	9
1.2 SOFTWARE VERSION IDENTIFICATION .....	9
1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS .....	10
1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS .....	11
1.4.1. Definitions .....	11
1.4.2. Acronyms and Abbreviations.....	15
1.5 REFERENCES .....	16
1.5.1 Applicable Documents .....	16
1.5.2 Reference Documents .....	17
<b>2. HIGH RESOLUTION WINDS PRODUCT OVERVIEW .....</b>	<b>18</b>
<b>3. HIGH RESOLUTION WINDS ALGORITHM DESCRIPTION .....</b>	<b>19</b>
3.1 THEORETICAL DESCRIPTION.....	19
3.1.1 Physics of the problem.....	19
3.1.2 Mathematical Description of the algorithm .....	20
3.1.2.1 Algorithm outline .....	20
3.1.2.2 Algorithm detailed description .....	21
PRACTICAL CONSIDERATIONS .....	42
3.1.3 High Resolution Winds Validation .....	42
3.1.4 List of inputs for High Resolution Winds.....	45
3.1.5 List of High Resolution Winds configurable parameters.....	46
3.1.6 Description of High Resolution Winds output.....	49
3.1.6.1 AMV/Wind BUFR bulletins.....	49
3.1.6.2 Trajectory BUFR bulletin.....	64
3.1.7 Examples of High Resolution Winds visualisation .....	69
3.1.8 Implementation of High Resolution Winds .....	73
3.1.8.1 The HRW installation and preparation step .....	73
3.1.8.2 The HRW execution step.....	73
3.1.9 High Resolution Winds Product assumptions and limitations.....	77

## Lists of tables

Table 1: List of Definitions .....	14
Table 2: List of Acronyms and Abbreviations .....	15
Table 3: List of Applicable Documents.....	16
Table 4: List of Reference Documents .....	17
Table 5: Possible values of the Tracer cloud type parameter. ....	29
Table 6: Tracer/AMV filtering related to the ‘tracer cloud type’ and each SEVIRI channel, and consideration of the ‘top pressure’ or ‘base pressure’ in the Brightness temperature interpolation height assignment method for the valid cases.....	30
Table 7: AMV filtering related to the Height level and each SEVIRI channel.....	41
Table 8: Validation parameters for HRW v3.2; All layers considered together (Jul 2009-Jun 2010, European and Mediterranean area).....	42
Table 9: Validation parameters for HRW v4.0; All layers considered together (Jul 2009-Jun 2010, European and Mediterranean area).....	42
Table 10: Validation parameters for HRW v3.2; High, medium and low layers considered together (Jul 2009-Jun 2010, European and Mediterranean area).....	44
Table 11: Validation parameters for HRW v4.0; High, medium and low layers considered (Jul 2009-Jun 2010, European and Mediterranean area).....	44
Table 12: HRW Model Configuration File Description.....	48
Table 13: BUFR table for AMV BUFR output files with NWC SAF specific BUFR format .....	50
Table 14: Example of decoded AMV BUFR output file with NWC SAF specific BUFR format, with the first AMV in the output file.....	53
Table 15: BUFR table for AMV BUFR output files with Eumetsat/MPEF BUFR format.....	57
Table 16: Example of decoded AMV BUFR output file using the Eumetsat/MPEF BUFR format, with the first AMV in the output file (related to a trajectory with two elements).....	63
Table 17: BUFR table for the Trajectory output file.....	65
Table 18: Example of decoded Trajectory BUFR output file with one trajectory .....	68

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 7/78</p>
---	--	---

## Lists of figures

- Figure 1: Example of ‘N\_Value histogram’ (unsmoothed in violet and smoothed in pink) for a valid Low resolution visible tracer candidate. The minimum brightness threshold, the algorithm centiles and the defined frontier is also shown. .... 23
- Figure 2: Example of running of the Big pixel brightness variability test for a valid tracer candidate. 23
- Figure 3: ‘Basic scale AMVs’ (in red and yellow), and ‘Detailed scale AMVs’ (in green and blue), related to the Tracer calculation method used for their extraction, in the Two scale High resolution Winds example defined in Figures 13 to 16 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite) ..... 25
- Figure 4: ‘Basic scale AMVs’ (in red), and ‘Detailed scale AMVs’ (in yellow, green and blue, related to their relationship with the Basic scale AMVs), in the Two scale High resolution Winds example defined in Figures 13 to 16 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)..... 25
- Figure 5: A low resolution visible tracer case at 1145Z (O red mark), its position defined by the NWP wind guess at 1200Z (O yellow mark), and its true tracking position at 1200Z defined by HRW algorithm (O blue mark), for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009, Nominal scan mode, MSG2 satellite). The “yellow tracking area” (with its centre at the position defined by the NWP wind guess at 1200Z) corresponds to the option using the wind guess for the definition of the tracking area. The “green tracking area” (with its centre at the position of the tracer at 1145Z) corresponds to the option not using the wind guess for the definition of the tracking area. The larger size of the tracking area needed when the wind guess has not been used is to be noticed, which causes a longer time for the running of HRW algorithm, but at the same time reduces its dependence from the NWP model ..... 27
- Figures 6 and 7: Tracer cloud types values (as defined by “CCC height assignment method”) for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), compared with the PGE02 Cloud type output for the same moment..... 32
- Figures 8 and 9: Matrices and graphs used in the calculation of ‘CCC method height assignment’, for a VIS08 case using the bright branch of the Reflectance(Pixel correlation contribution) graph in the left side, and an IR108 case using the cold branch of the Brightness temperature(Pixel correlation contribution) graph in the right side, as explained in the text. The weighted position displacement of the AMV in the initial and later image, as defined with DEFPOSWITHCONTRIBUTIONS = 1, is also shown as a red cross in the images in the first row. .... 33
- Figure 10: Quality index including forecast for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)..... 37
- Figure 11: Quality index not including forecast for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)..... 37
- Figure 12: Pressure values in hPa for AMVs affected by orography (i.e. with Orographic flag values between 1 and 4) in a zoomed area around the Iberian Peninsula, during a 50 day interval of the Validation period (1 January to 19 February 2010 at 1200Z, Nominal scan mode, MSG2 satellite). A clear correlation between the mountain systems (Pyrenees, Iberian System, Central System, mountains around the Strait of Gibraltar and in the Balearic Islands) and very low AMVs (lower than 840 hPa) is seen ..... 39
- Figure 13: High Resolution Winds AMV output example in the European and Mediterranean Continental region (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), considering the default conditions defined in \$SAFNWC/config/safnwc\_pge09.cfm model configuration file. Colour coding based on the AMV pressure level..... 69



	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 9/78</p>
---	--	---

## 1. INTRODUCTION

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

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

This document is applicable to the NWC SAF processing package for Meteosat Second Generation satellites, SAFNWC/MSG.

### 1.1 SCOPE OF THE DOCUMENT

This document is the Algorithm Theoretical Basis Document for the HRW product: the component of the SAFNWC/MSG software package for the calculation of High Resolution Winds (HRW), using up to seven MSG/SEVIRI channels: HRVIS (High Resolution Visible), VIS06 and VIS08 (Visible 0.6  $\mu\text{m}$  and 0.8  $\mu\text{m}$ ), WV062 and WV073 (Water vapour 6.2  $\mu\text{m}$  and 7.3  $\mu\text{m}$ ), IR108 and IR120 (Infrared 10.8  $\mu\text{m}$  and 12.0  $\mu\text{m}$ ).

It describes the HRW product objectives, the scientific algorithm, the needed input data and the resulting output. It also provides basic information on the algorithm implementation.

### 1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithm implemented in the PGE09 version v4.0, included in the SAFNWC/MSG v2013 software package delivery.

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 10/78</p>
---	--	--

### 1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

The main improvements related to High Resolution Winds/HRW v4.0 (included in SAFNWC/MSG v2013 software package) are summarized next:

1. The option to provide the HRW AMV output as a BUFR output file whose format is similar to the one currently defined for the EUMETSAT/MPEF AMVs, for compatibility of use of both types of AMVs in NWP model assimilation.
2. The additional optimization of the HRW code to calculate the AMVs by default option without the use of the wind guess in the definition of the tracking area, so reducing the dependence of the AMVs from the NWP model data.
3. The update of the Quality Control process, to include the additional elements currently activated in the EUMETSAT/MPEF AMV Quality Control. Considering this, a Quality index without use of forecast is additionally included in the BUFR output and can be used in the filtering of the valid AMVs.
4. The calculation of trajectories through the successive tracking of the same tracer in consecutive slots. The output of these trajectories is defined through a different specific Trajectory BUFR format file.
5. The update of the calculation of the Orographic flag, so that now it considers as previous positions of the AMV those defined in its corresponding trajectory (when they exist).
6. The inclusion of the Subpixel tracking process, which permits to define the position of the tracer in the search area in the later image in a position different to the centre of a pixel, so avoiding discontinuities in the field of wind speeds and directions caused by the resolution of the image pixels.
7. The definition of the location of the AMV inside the tracer (in both initial and final image) not as the tracer centre but as the position of maximum correlation contribution defined by the “CCC height assignment method” (when it is used).
8. The formal review and recommending of all HRW code for a clearer understanding of it, for anyone who wants to read it and use it.

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 11/78</p>
---	--	--

## 1.4 DEFINITIONS, ACRONYMS AND ABBREVIATIONS

### 1.4.1. Definitions

4x4 array	Big array used in the Big pixel brightness variability test, defining a coarse structure in the tracer candidates
Adjustment centre	Local or absolute CC maximum or LP minimum in the tracking area
Basic dataset	Winds for the algorithm wide tracer scale
Big pixel	Each element of the 4x4 array classifying the tracer candidate at reduced resolution in the ‘Big pixel brightness variability’, defining three different brightness classes (CLASS_n)
Big pixel class difference	Sum of squared differences of big pixel classes, between the initial tracer location and a secondary adjustment centre
Bright big pixel	When its N_Value is equal or higher than a given frontier
CC	Cross correlation coefficient
CENT_N%	Brightness centile in the N_Value histogram
CLASS_n	Big pixel class, according to its population of bright pixels (three different classes with n values = 0,1,2)
Climatological profiles	A standard atmosphere coarsely described: alternative profile for wind level assignment when NWP data are not available
Closeness threshold	Minimum distance (line, element) allowed between tracer locations
Cloud type	Cloud type defined for each tracer with PGE02 output data, used for example to define which of the two calculated height levels (cloud top, cloud base) is used in the “Brightness temperature interpolation height assignment process”.
Coarse scale	Tracer size for the basic dataset in the two scale tracer selection option
Consistency	Wind difference compared to some expected wind, quantified in probabilistic terms for the Quality Index calculation
COV	Covariance
Deepest frontier	The frontier more largely exceeding the DEPTH_THRESHOLD
DEPTH_THRESHOLD	Threshold for histogram minima in the ‘Frontier definition in the N_Value histogram test’
Detailed dataset	Winds for the algorithm narrow tracer scale
DIF	Parameter difference or module of vector difference, in the Quality Index computation
Exclusion array	Places of the image which can not be tracer locations because of the failing closeness threshold
Fine/detailed scale	Tracer size for the detailed dataset in the two scale detailed tracer selection option (half the size of the coarse/basic scale)
First (tracking) candidate	Preferred tracking candidate for a tracer after the definition of the correlation centres, before the Quality Index calculation

FREQ(j )	Frequency in the histogram for summed classes j-1 to j+1
Frontier	A significant minimum in the N_Value histogram
GAP	Line and element distance separating tracking candidates in the gradual approach
Gradient method	First tracer computation method, see text
Gradual approach	Iterative approach to reduce the number of tracking candidates to be evaluated in the search area in the later image for a given tracer
Ind_topo	Value of the Algorithm Orographic flag parameter, calculated to detect land influence on the Atmospheric Motion Vectors
Interscale test (in the QI test)	Consistency of the detailed winds respect to the basic scale related winds
LAT_C, LON_C	Coordinates at correlation centre
LAT_T, LON_T	Coordinates at tracer centre
LP	Euclidean distance
Marked starting locations	Starting locations defined in the basic scale part for the detailed scale part, in the two scale procedure
Maximum optimisation distance	Maximum distance (line or element) allowed between the starting location and the final tracer location
Narrow basic tracer	A basic tracer where CLASS_2 values are not found in the left and right column neither in the upper and lower row, in the Big pixel structure in the ‘Big pixel brightness variability test’
Neighbour wind	Close enough wind to a given one
New tracers	Tracers unrelated to AMVs calculated in the previous cycle, in the tracer continuity option
Not closed adjustment centre	Adjustment centre in the border of the tracking area
NUM	Total of pixels in the tracer or in the tracking candidate
N_Value	Matrix used for the calculation of the tracers, defined as 1 byte Brightness temperature values in infrared and water vapour cases, and 1 byte Normalized Reflectance values in visible cases
Optimisation gap	Only tracer candidates nearer than that distance (line and element) are evaluated in the tracer characteristics method
Orographic flag (dynamic)	Flag to show possible land influence in the previous positions of the tracer. It is calculated after the static orographic flag procedure, and indicated through parameter Ind_topo (Values: 0,1,2,3,4,5,6)
Orographic flag (static)	Flag to show possible land influence in the tracer position. Indicated through parameter Ind_topo (Values 0,1,2,6)
Overall QI	Final Quality Index, weighted sum of QI of individual tests except the two scale test
Persistent tracers	Tracers related to AMVs calculated in the previous cycle, specific to the tracer continuity option

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

Tracer	Square segment of the image of fixed size (tracer size), identified by the location of its centre, and considered valid candidate for the AMV calculation by any of the two tracer calculation methods
Tracer candidate	Square segment in the image of fixed size, where conditions for tracer search using “Tracer characteristics method” are evaluated
Tracer continuity	Processing option where part of the set of tracers is defined through the final position of the AMVs in the previous cycle
Tracer characteristics method	Second tracer computation method, see text
Tracer location	Tracer image coordinates (line, element) of its centre.
Tracer selection procedure	Strategy to get a complete set of tracers throughout the desired region of the image. It consists of 2 iterations (2 methods) for the single scale procedure; 4 iterations (2 methods, 2 scales) for the two scale procedure
Tracer side/size	Line or element dimension of the tracer
Tracking	Determination of the best pixel adjustment inside the search area of a later image to a given tracer in a prior image
Tracking area	Square segment in the final image containing the search area for a given tracer, and where all tracking candidates are located
Tracking candidate	Each square segment in the final image that has to be evaluated for the tracking of a given tracer, and its centre
Two scale procedure	Tracer selection for tracers of two different tracer sizes (basic and detailed), being the size of the second one half of the first
Variability (of a tracer candidate)	Variation criteria in the Big pixel brightness variability test (based on 0 to 2 or 2 to 0 changes in CLASS <sub>n</sub> , along the linear arrays of Big pixels inside the tracer)
Wide basic tracer	A basic tracer where simultaneously CLASS <sub>2</sub> values are found in the left and right column and/or in the upper and lower row, in the Big pixel structure in the ‘Big pixel brightness variability test’
Z <sub>SUN</sub>	Sun zenith angle
$\sigma$	Standard deviation
$\sigma_{\text{Cloud}}$	Brightness temperature standard deviation for the pixels of the tracer

*Table 1: List of Definitions*

## 1.4.2. Acronyms and Abbreviations

AMV	Atmospheric Motion Vector
BUFR	Binary Universal Form for the Representation of meteorological data
CDOP	NWC SAF Continuous Development and Operations Phase
CDOP2	NWC SAF Second Continuous Development and Operations Phase
CIMSS	NOAA & UW’s Cooperative Institute for Meteorological Satellite Studies
EBBT	Equivalent Black Body Temperature
ECMWF	European Centre for Medium Range Weather Forecasts
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
GOES	NOAA’s Geostationary Operational Environmental Satellite
HRVIS	MSG/SEVIRI High Resolution Visible channel
HRW	SAFNWC/MSG High Resolution Winds Product
IOP	NWC SAF Initial Operations Phase
IR108, IR120	MSG/SEVIRI 10.8 $\mu$ m and 12.0 $\mu$ m infrared channels
MPEF	EUMETSAT Meteorological Product Extraction Facility
MSG	EUMETSAT’s Meteosat Second Generation Satellite
NOAA	United States National Oceanic and Atmospheric Administration
NWCLIB	SAFNWC/MSG Common Software Library
NWC SAF	Satellite Application Facility to Nowcasting and very short range forecasting
NWP	Numerical Weather Prediction Model
PGE	NWC SAF Product Generation Element
PGE09	NWC SAF Product Generation Element for the High Resolution Winds
RID	Review Item Discrepancy
SAFNWC/MSG	NWC SAF Software Package for MSG satellites
SCI	NWC SAF Scientific Report
SMR	NWC SAF Software Modification Report
SPR	NWC SAF Software Problem Report
SW	Software
TM	SAFNWC/MSG Task Manager
UW	University of Wisconsin/Madison
VIS06, VIS08	MSG/SEVIRI 0.6 $\mu$ m and 0.8 $\mu$ m visible channels
WMO	World Meteorological Organization
WV062, WV073	MSG/SEVIRI 6.2 $\mu$ m and 7.3 $\mu$ m water vapour channels

Table 2: List of Acronyms and Abbreviations

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 16/78</p>
---	--	--

## 1.5 REFERENCES

### 1.5.1 Applicable Documents

<i>Ref.</i>	<i>Title</i>	<i>Code</i>	<i>Version</i>
[AD.1]	Software User Manual for the SAFNWC/MSG Application: Software Part	SAF/NWC/CDOP2/INM/SW/SUM/2	7.0
[AD.2]	Product User Manual for “High Resolution Winds” (HRW – PGE09 v4.0)	SAF/NWC/CDOP2/INM/SCI/PUM/09	4.0
[AD.3]	Interface Control Document for the External and Internal Interfaces of the SAF NWC/MSG	SAF/NWC/CDOP2/INM/SW/ICD/1	7.0
[AD.4]	SAFNWC/MSG Output Products format definition	SAF/NWC/CDOP2/INM/SW/ICD/3	7.0
[AD.5]	Architectural Design Document for the INM related PGEs of the SAFNWC/MSG	SAF/NWC/CDOP2/INM/SW/AD/4	7.0
[AD.6]	Software Version Description Document for the SAFNWC/MSG Application	SAF/NWC/CDOP2/INM/SW/SVD/5	7.0
[AD.7]	Validation Report for “High Resolution Winds” (HRW – PGE09 v2.2)	SAF/NWC/CDOP/INM/SCI/VR/05	1.0
[AD.8]	Validation Report for “High Resolution Winds” (HRW – PGE09 v3.0)	SAF/NWC/CDOP/INM/SCI/VR/07	1.0
[AD.9]	Validation Report for “High Resolution Winds” (HRW – PGE09 v3.1)	SAF/NWC/CDOP/INM/SCI/VR/09	1.0
[AD.10]	Validation Report for “High Resolution Winds” (HRW – PGE09 v3.2)	SAF/NWC/CDOP/INM/SCI/VR/10	1.0
[AD.11]	NWC SAF Product Requirements Document	SAF/NWC/CDOP2/INM/MGT/PRD	1.2
[AD.12]	Estimation of computer environment needs to run NWC SAF products operatively in ‘Rapid scan mode’	SAF/NWC/CDOP/INM/SW/RP/01	1.0
[AD.13]	Validation Report for “High Resolution Winds” (HRW – PGE09 v4.0)	SAF/NWC/CDOP2/INM/SCI/VR/13	1.0

*Table 3: List of Applicable Documents*

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 17/78</p>
---	--	--

## 1.5.2 Reference Documents

Ref.	Title
[RD.1]	J.Schmetz, K.Holmlund, J.Hoffman, B.Strauss, B.Mason, V.Gärtner, A.Koch, L. van de Berg, 1993: Operational Cloud-Motion Winds from Meteosat Infrared Images (Journal of Applied Meteorology, Num. 32, pp. 1206-1225).
[RD.2]	S.Nieman, J.Schmetz, W.P.Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers (Journal of Applied Meteorology, Num. 32, pp. 1559-1568).
[RD.3]	C.M.Hayden & R.J.Purser, 1995: Recursive filter objective analysis of meteorological fields, and application to NESDIS operational processing (Journal of Applied Meteorology, Num. 34, pp. 3-15).
[RD.4]	K.Holmlund, 1998: The utilisation of statistical properties of satellite derived Atmospheric Motion Vectors to derive Quality Indicators (Weather and Forecasting, Num. 13, pp. 1093-1104).
[RD.5]	J.M.Fernández, 1998: A future product on HRVIS Winds from the Meteosat Second Generation for nowcasting and other applications. (Proceedings 4 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.24, pp.281-288).
[RD.6]	J.M.Fernández, 2000: Developments for a High Resolution Wind product from the HRVIS channel of the Meteosat Second Generation. (Proceedings 5 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.28, pp.209-214).
[RD.7]	J.M.Fernández, 2003: Enhancement of algorithms for satellite derived winds: the High Resolution and Quality Control aspects. (Proceedings 2003 Meteorological Satellite Conference, EUMETSAT Pub.39, pp.176-182).
[RD.8]	J.García-Pereda & J.M.Fernández, 2006: Description and validation results of High Resolution Winds product from HRVIS MSG channel at the EUMETSAT Nowcasting SAF (Proceedings 8 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.47).
[RD.9]	J.García-Pereda, 2008: Evolution of High Resolution Winds Product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 9 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.51).
[RD.10]	J.García-Pereda, 2010: New developments in the High Resolution Winds product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 10 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.56).
[RD.11]	C.M.Hayden & R.T.Merrill, 1988: Recent NESDIS research in wind estimation from geostationary satellite images (ECMWF Seminar Proceedings: Data assimilation and use of satellite data, Vol. II, pp.273-293).
[RD.12]	W.P.Menzel, 1996: Report on the Working Group on verification statistics. (Proceedings 3 <sup>rd</sup> International Wind Workshop, EUMETSAT Pub.18, pp.17-19).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3 <sup>rd</sup> international winds workshop, EUMETSAT Pub.18, pp.71-79).
[RD.14]	Xu J. & Zhang Q., 1996: Calculation of Cloud motion wind with GMS-5 images in China. (Proceedings 3 <sup>rd</sup> international winds workshop, EUMETSAT Pub.18, pp.45-52).
[RD.15]	K.Holmlund & C.S.Velden, 1998: Objective determination of the reliability of satellite derived Atmospheric Motion Vectors (Proceedings 4 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.24, pp.215-224).
[RD.16]	K.Holmlund, C.S.Velden & M.Rohn, 2000: Improved quality estimates of Atmospheric Motion Vectors utilising the EUMETSAT Quality Indicators and the UW/CIMSS Autoeditor (Proceedings 5 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.28, pp.72-80).
[RD.17]	R.Borde & R.Oyama, 2008: A direct link between feature tracking and height assignment of operational Atmospheric Motion Vectors (Proceedings 9 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.51).
[RD.18]	J.García-Pereda, R.Borde & R.Randriamampianina, 2012: Latest developments in “NWC SAF High Resolution Winds” product (Proceedings 11 <sup>th</sup> International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (WMO Publication, available at <a href="http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_v12/LatestVERSION/WMO306_v12_CommonTable_en.pdf">http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_v12/LatestVERSION/WMO306_v12_CommonTable_en.pdf</a> )
[RD.20]	M.Dragosavac, 2008: BUFR Reference Manual (ECMWF Operations Department Publication., available at <a href="http://www.ecmwf.int/products/data/software/bufr.html">http://www.ecmwf.int/products/data/software/bufr.html</a> )

Table 4: List of Reference Documents

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 18/78</p>
---	--	--

## 2. HIGH RESOLUTION WINDS PRODUCT OVERVIEW

The High Resolution Winds product aims to provide, for near real time meteorological applications, detailed sets of Atmospheric Motion Vectors (AMVs) from Meteosat Second Generation (MSG) satellite, considering up to seven MSG/SEVIRI channel data (HRVIS, VIS06, VIS08, WV062, WV073, IR108, IR120) throughout all hours of the day, as a dynamic information in the SAFNWC/MSG package. The product includes pressure level information, and a quality control flagging giving some indication of its error in probabilistic terms, with auxiliary indicators about how the product was determined. Since HRW v4.0 in the year 2013, HRW product provides also trajectories considering the successive tracking of the same tracers in consecutive images.

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

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

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 19/78</p>
---	--	--

## 3. HIGH RESOLUTION WINDS ALGORITHM DESCRIPTION

### 3.1 THEORETICAL DESCRIPTION

This section discusses the physics of deriving Atmospheric Motion Vectors (AMVs) from satellite imagery, and identifies some sources of error. In this section the theoretical basis and practical implementation of the corresponding algorithms are also described.

#### 3.1.1 Physics of the problem

In order to forecast the weather, conventional observations are sparse, whereas satellite based observations provide near global coverage at regular time intervals. The derivation of Atmospheric Motion Vectors (AMVs) from satellite images, where the winds correspond to the displacement of clouds or gradients in water vapour in consecutive satellite images, is an important source of global wind information, especially over the oceans and remote continental areas.

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

The Atmospheric Motion Vector calculation process is composed of several steps:

1. The reading and preprocessing of the satellite data.

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

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

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

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

Each selected feature in the initial image is then tracked in successive images in order to determine the displacement vector for the feature. Using images with an up to 30 minute interval, clouds can change shape or even disappear, but enough tracers survive to produce AMVs. With shorter time intervals up to 15 minutes, the problem is smaller and more vectors are produced.

4. The height assignment of the tracers.

The height of the feature must be determined to locate the AMVs in a tridimensional position. This is the step where errors can be more important throughout the AMV derivation. Several methods of height assignment are available: the comparison of the infrared brightness temperature of the tracer to a forecast temperature profile, radiance ratioing and H2O/IRW intercept techniques for the height assignment of semitransparent clouds, statistical assignment schemes,...

5. The calculation of the vectors.

Considering the geographical displacement of the tracers between both images.

6. A quality control.

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

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 20/78
---	--	--

## 3.1.2 Mathematical Description of the algorithm

### 3.1.2.1 Algorithm outline

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

#### 1. Preprocessing:

- The initialization of data: latitude/longitude/solar zenith angle matrices, NWP data, brightness temperature of the MSG/SEVIRI infrared and water vapour channels to be used and reflectances of the MSG/SEVIRI visible channels to be used. SAFNWC/MSG PGE02 Cloud Type and PGE03 Cloud Top Temperature and Pressure outputs also if needed.

#### 2. Processing:

- The tracer calculation with two consecutive methods: gradient, tracer characteristics.
- The tracer tracking through one of two different methods (Euclidean distance, Cross correlation), with the selection of up to three correlation centres.
- The height level assignment of the tracers through one of two different methods:
  - ‘Brightness temperature interpolation method’, which calculates the ‘top pressure’ and ‘base pressure’ related to the tracer, interpolating the Brightness temperature of the corresponding channel (or IR120 for the visible channels) to the NWP or Climatological vertical profiles, and defines the AMV height from these two possible levels considering the SAFNWC/MSG PGE02 Cloud type related to the tracer.
  - ‘Cross Correlation Contribution method (CCC method)’ (new method since PGE09 v3.1, available for Cross correlation tracking if SAFNWC/MSG PGE02 and PGE03 outputs were previously calculated), which defines the AMV height considering only the height of the pixels contributing most to the image correlation.
- The wind and trajectory calculation, considering the displacement between the position of the tracer and the correlation centres in successive images.

#### 3. Postprocessing:

- A Quality control with ‘EUMETSAT Quality Indicator’ method, with the choice of the ‘best wind’ considering the several winds calculated for each tracer, and a Final control check to eliminate wrong winds very different to those in their vicinity.
- The orographic flag calculation (if so configured), which incorporating topographic data detects those winds affected by land influence.

The code was progressively developed with GOES, Meteosat and MSG data. Examples with MSG data are presented throughout the description of the algorithm to illustrate it. The processing options and coefficients are also presented. Many of them are configurable: in that case, this circumstance is specifically indicated. Since PGE09 v3.2 it is possible to calculate AMVs with up to seven different MSG channels, following the requirements from NWC SAF users. The MSG channels with which winds are to be calculated are defined by configurable parameter ‘WIND\_CHANNEL’, where all SEVIRI channels for which AMVs are to be extracted are to be defined (for example, with value ‘HRVIS,VIS06,VIS08,WV062,WV073,IR108,IR120’, AMVs from all possible channels are extracted). The value ‘HRVIS,WV073,IR108’ calculates AMVs from only those three channels.

The AMVs can be calculated considering both ‘Nominal scan mode’ (with a repeating cycle of 15 minutes) and ‘Rapid scan mode’ (with a repeating cycle of 5 minutes). In the first case consecutive images (15 minutes apart, defined by configurable parameter SLOT\_GAP=1) are considered for the initial tracer calculation and their later tracking. In ‘Rapid scan mode’, images 10 minutes apart (defined by parameter SLOT\_GAP=2) are considered for the initial tracer calculation and their later tracking to maximize the amount of calculated winds with the best possible validation statistics.

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 21/78</p>
---	--	--

### **3.1.2.2 Algorithm detailed description**

#### **3.1.2.2.1 Preprocessing**

During the initialization process, next parameters are extracted for the selected region: latitude, longitude, solar and satellite zenith angle matrices, reflectances for any MSG/SEVIRI visible channel to be used, brightness temperatures for any MSG/SEVIRI infrared or water vapour channel to be used, NWP temperature and wind guess. NWP geopotential and surface temperature data are also extracted in case of calculation of the Orographic flag.

At this step, ‘N\_Value’ matrix containing the image data is defined for the calculation of tracers. In the visible channels (HRVIS, VIS06 or VIS08) reflectances are considered, normalized due to the variable illumination with the solar zenith angle with the formula:

$$\text{‘N\_Value’} = \text{Seviri\_Reflectances} / \cos(\text{Solar Zenith Angle}),$$

if the reflectance exists for each pixel. Otherwise, the pixel is considered invalid with N\_Value = 0.

In the infrared and water vapour channels (IR108, IR120, WV062, WV073), the brightness temperatures are used for the definition of ‘N\_Value’ matrix. When the brightness temperature value does not exist for a pixel, it is considered non valid with N\_Value = 0.

In both cases, data are considered as an integer variable with values ranging from 0 to 255 (8 bit data range). No reflectance/brightness temperature thresholds have been defined. Considering this, a final adjustment of data is done in both reflectance/brightness temperature matrices to assimilate the matrix minimum value throughout the whole image to 0 and the matrix maximum value to 255.

SAFNWC/MSG PGE02 Cloud Type and PGE03 Cloud Top Temperature and Height outputs are also read for the selected region and slot, in the case ‘CCC Method’ is to be used for the ‘AMV height assignment’ process. PGE02 Cloud Type for the previous slot (when tracers were calculated) is also read in case the tracer ‘Cloud type’ is used for the ‘Brightness temperature interpolation method’. Although these inputs are not necessary, they are recommended to be used for a better quality of the final AMV data.

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 22/78
---	--	--

### 3.1.2.2.2 Tracer calculation

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

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

The target scale defined as first option for the High Resolution Winds product is 24 pixels for the “single scale procedure” for all types of tracers. Nevertheless, different values can be defined for the High resolution channel (HRVIS) on one side through configurable parameters LSIZ\_HRV and ESIZ\_HRV, and the Low resolution channels (all others) on the other side through configurable parameters LSIZ\_OTHER and ESIZ\_OTHER.

A resolution of 24 pixels for the “basic tracers” and 12 pixels for the “detailed tracers” is proposed as baseline for the two scale procedure. These specific resolutions define different tracer scales between 72 km (“basic low resolution channel scale”) and 12 km (“detailed high resolution channel scale”), between the ‘mesoscale  $\beta$ ’ and the ‘mesoscale  $\gamma$ ’ dimensions. The nominal observation frequency of 15 minutes is enough to track the majority of objects with these sizes, although in some few cases like small cumulus over land related to the smallest size (“detailed HRVIS scale”), their lifecycle might be a bit short compared to the 15 minute nominal image frequency. The use of HRW product in the ‘Rapid scan mode’ configuration can be better to track tracers of this small size.

#### FIRST METHOD: GRADIENT

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

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

#### SECOND METHOD: TRACER CHARACTERISTICS

It is based on new development. It is useful fundamentally in the visible cases, where many potential tracers could present less sharp edges than in the infrared image because of cloudiness at different levels presenting a similar brightness.

It evaluates 'tracer candidates' located at increasing distances of the starting locations until a 'good tracer' is found inside a 'maximum optimisation distance'. Two series of tests: the 'Frontier definition in the N\_Value histogram' and the 'Big pixel brightness variability' are then applied in sequence:

##### 1. Test on ‘Frontier definition in the N\_Value Histogram’:

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

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

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

In the second part, one or more significant histogram minima or ‘frontiers’ are to be found in the ‘N Value histogram’ for the tracer candidate. The default running of HRW algorithm keeps only the most significant frontier in the processing, although the option exists to calculate more than one frontier. Each frontier defines then in the corresponding tracer a group of ‘bright pixels’ (defined as those pixels brighter than the given frontier) and a group of ‘dark pixels’ (defined as those pixels darker than the given frontier).

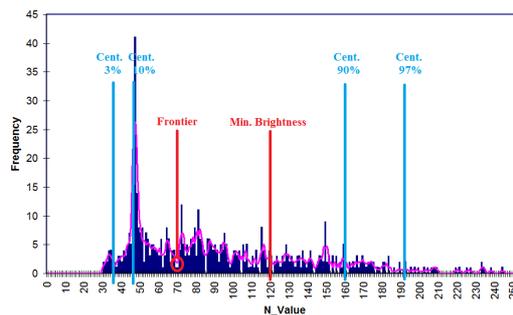


Figure 1: Example of ‘N Value histogram’ (unsmoothed in violet and smoothed in pink) for a valid Low resolution visible tracer candidate. The minimum brightness threshold, the algorithm centiles and the defined frontier is also shown.

## 2. Test on ‘Big pixel brightness variability’:

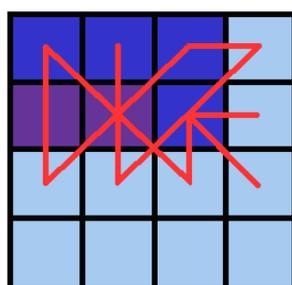
The ‘tracer candidate’ is then considered as a coarse structure of 4x4 pixel arrays (‘big pixels’), to be classified according to the brightness of its pixel population. Three classes are possible:

- CLASS\_0: ‘dark big pixel’, < 30% of its pixels are ‘bright pixels’;
- CLASS\_2: ‘bright big pixel’, > 70% of its pixels are ‘bright pixels’;
- CLASS\_1: ‘undefined big pixel’, intermediate case.

It is requested (to avoid ambiguous cases) that both CLASS\_0 and CLASS\_2 appear at least once in the 4x4 array, while occurrences of CLASS\_1 be less than twice the less frequent of the others.

The 4x4 array is then checked for ‘enough brightness variability’ in different directions: at least 2 transitions (CLASS\_0 to CLASS\_2 or CLASS\_2 to CLASS\_0) must exist along any linear array of the 4x4 array, considering each of the 4 main directions: rows, columns, ascending and descending diagonal directions (with all linear arrays checked for the row and column directions, and only the linear arrays with at least three elements for the diagonal directions).

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



- Example of tracer with its corresponding structure of ‘Big pixels’:
- Class 2 pixels in dark blue (bright pixels).
  - Class 1 pixels in violet.
  - Class 0 pixels in light blue (dark pixels).

The results of the ‘Big pixel Brightness variability test’ is also shown.

- ‘Good transitions’ shown in red.

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

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

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 24/78
---	--	--

## TRACER CLOSENESS CONDITION

No tracer is retained if it is found too close to a previously computed one (‘closeness threshold’). This condition is checked *a priori*, i.e. each time a tracer is computed, all pixels located nearer than the ‘closeness threshold’ to its centre are added to an ‘exclusion array’ and excluded as potential tracer locations. Considering this:

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

An additional condition is verified here, with which all pixels inside the tracer must have a satellite zenith angle and a solar zenith angle (in the case of using the visible channels HRVIS, VIS06 or VIS08) smaller than configurable parameters MSG\_ZEN\_THRES and ZEN\_THRES respectively (with default values 87° and 80°).

## SINGLE SCALE PROCEDURE

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

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

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

## TWO SCALE PROCEDURE

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

The ‘Basic scale’ works similarly to the procedure described for the single scale, and additionally defines ‘marked starting locations’ for the ‘Detailed scale’, when one of next three conditions are met:

- No ‘Basic tracer’ has been found, but at the starting location of the tracer candidate:
  1.  $CENT_{97\%} > 0.85 * MIN\_BRIGHTNESS$
  2.  $CENT_{97\%} < MAX\_BRIGHTNESS$

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

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

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

- A ‘Narrow basic tracer’ has been found, in which CLASS\_2 values do not appear in both first and last row, nor both first and last column, of the 4x4 ‘Big pixel brightness variability array’.  
In this case, only one starting location is defined for the ‘Detailed scale’, whose centre is defined by the weighted location of the ‘Big pixels’ in the 4x4 ‘Big pixel brightness variability array’.

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

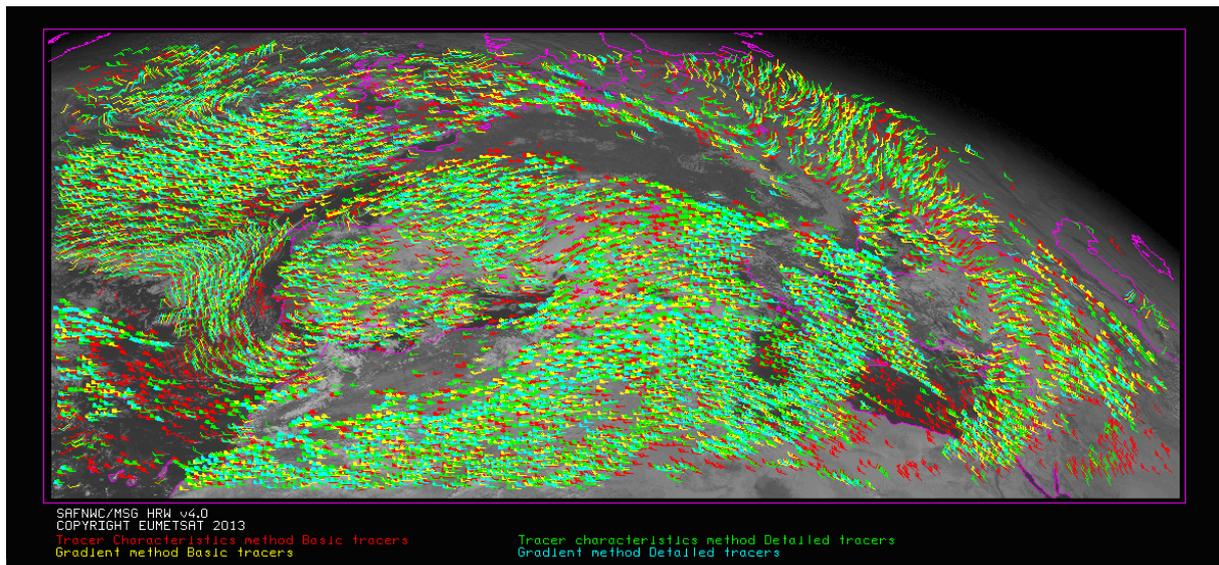


Figure 3: ‘Basic scale AMVs’ (in red and yellow), and ‘Detailed scale AMVs’ (in green and blue), related to the Tracer calculation method used for their extraction, in the Two scale High resolution Winds example defined in Figures 13 to 16 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

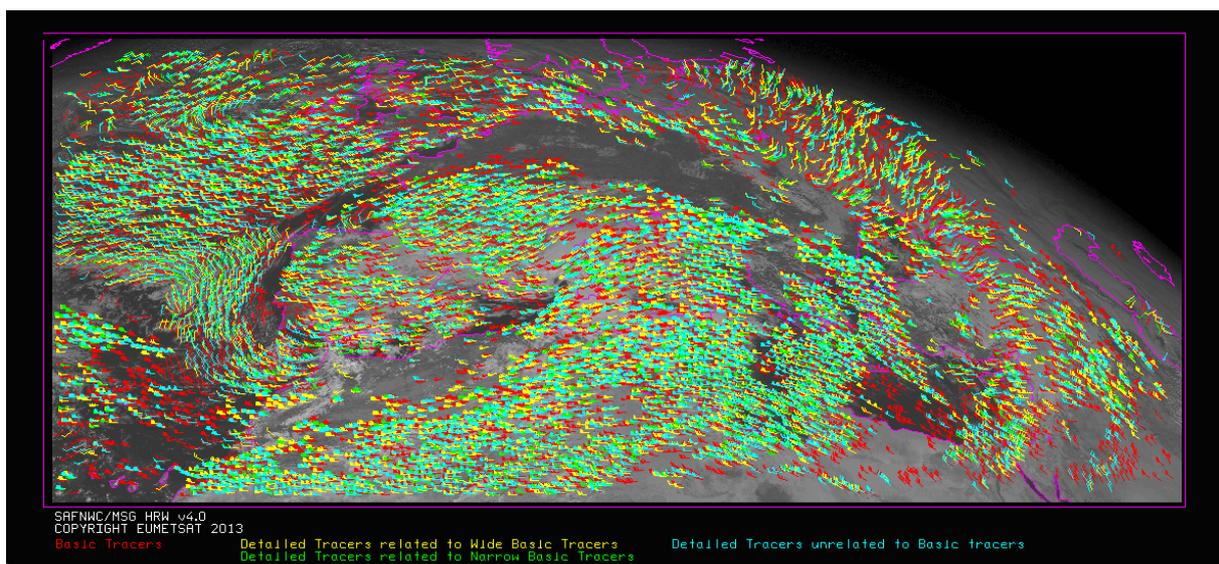


Figure 4: ‘Basic scale AMVs’ (in red), and ‘Detailed scale AMVs’ (in yellow, green and blue, related to their relationship with the Basic scale AMVs), in the Two scale High resolution Winds example defined in Figures 13 to 16 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 26/78
---	--	--

## CALCULATION OF TRAJECTORIES

With configurable parameter `CALCULATE_TRAJECTORIES = 1` (which is the default option), with the definition of new tracer centres starting at the integer final line/column position of all ‘adjustment centres’ calculated previously for valid winds at the same slot, when they are available, a set of ‘persistent tracers’ is successively tracked in consecutive images and the progressive positions of the tracer throughout the time are later written defining trajectories in a specific and different BUFR output file.

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

However, the ‘starting locations’ defined now for the new tracers are kept as such without the modifications in position which both ‘Gradient method’ and ‘Tracer Characteristics method’ define in other cases, to keep the continuity in the integer line/column positions of the ‘persistent tracers’, independently of being related to a tracer position in the previous slot or to an ‘adjustment centre’ in the following slot.

Only slight differences in the latitude/longitude position are possible comparing for a same trajectory the final position of the ‘tracer centre of the next wind’ (which must always be located in the centre of a pixel) and the ‘adjustment centre of the prior wind’ (in the case configurable parameter `USE_SUBPIXELTRACKING = 1` is used, with which it can be located in any position of the same pixel), but in all cases it is confirmed that the integer line/column position of both ‘tracer centre of the next wind’ and the ‘adjustment centre of the previous wind’ are always the same ones.

### 3.1.2.2.3 Tracer tracking

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

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

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

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

Nevertheless, since the year 2013 HRW algorithm has been optimized not to use the wind guess as default option, so reducing the dependence of the algorithm and the calculated AMVs from the NWP model used. Although the running time of HRW algorithm can still be around two to three times longer than using the wind guess, because of the previous reasons it is recommended to the users to keep operationally the configuration without use of the wind guess (with configurable parameter WIND\_GUESS = 0).

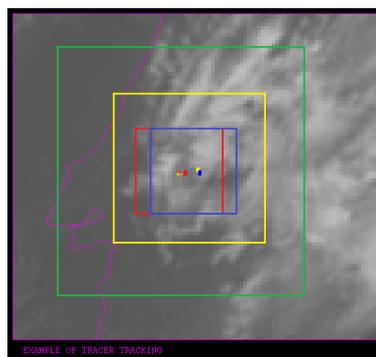


Figure 5: A low resolution visible tracer case at 1145Z (O red mark), its position defined by the NWP wind guess at 1200Z (O yellow mark), and its true tracking position at 1200Z defined by HRW algorithm (O blue mark), for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009, Nominal scan mode, MSG2 satellite). The “yellow tracking area” (with its centre at the position defined by the NWP wind guess at 1200Z) corresponds to the option using the wind guess for the definition of the tracking area. The “green tracking area” (with its centre at the position of the tracer at 1145Z) corresponds to the option not using the wind guess for the definition of the tracking area. The larger size of the tracking area needed when the wind guess has not been used is to be noticed, which causes a longer time for the running of HRW algorithm, but at the same time reduces its dependence from the NWP model

The ‘tracking area size’ is defined through configurable parameters LLAG\_HRV/ELAG\_HRV for the High resolution channel and LLAG\_OTHER/ELAG\_OTHER for the Low resolution channels. Default values are LLAG\_HRV=ELAG\_HRV=138 and LLAG\_OTHER=ELAG\_OTHER=46 in the ‘Nominal scan mode’, and LLAG\_HRV=ELAG\_HRV=92 and LLAG\_OTHER=ELAG\_OTHER=30 in the ‘Rapid scan mode’), which permits to detect displacements of at least 276 km/h in any direction, completely independently of the direction of the NWP wind guess.

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

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

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

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

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

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

For ‘Cross correlation method’ it is also requested that the correlation in the absolute maximum be greater than configurable parameter MIN\_CORRELATION (with a default value of 80%).

### TEST AND SELECTION OF CORRELATION CENTRES

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

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

If no secondary centre is complying, the procedure is still tried with temperature differences and class difference limits relaxed to the double.

### 3.1.2.2.4 Height assignment with ‘Brightness temperature interpolation method’

This method has been used by HRW algorithm in all versions up to now. Since HRW v4.0 it is only used when specifically defined with configurable parameter `DEFINewithCONTRIBUTIONS = 0`, or when the wind guess is used to define the tracking position in the later image with configurable parameter `WIND_GUESS = 1` (with none of these options used as default ones). It is additionally only available if a NWP temperature forecast has been provided, with a minimum number of NWP levels defined by the user through the configurable parameter `MIN_NWP_FOR_CALCULATION`, with a default value of 4).

The input for the height assignment is the corresponding brightness temperature for each one of the infrared and water vapour channels (IR108, IR120, WV062, WV073), and the IR120 brightness temperature for each one of the visible channels (HRVIS, VIS06, VIS08) . With these data:

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

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

After this, with configurable parameter `USE_CLOUDTYPE = 1`, the output of SAFNWC/MSG PGE02 Cloud Type product is read for the selected region and prior slot (when the tracers were calculated), to define which of the two calculated pressure values (‘base pressure’, ‘top pressure’) represents best the displacement defined by the AMV. Operatively, in this case it is necessary to run PGE01 and PGE02 executables before PGE09. The Tracer cloud type is defined for each tracer as the most common value of the PGE02 Cloud Type inside the tracer, if its presence is at least  $\frac{3}{2}$  times that of the second most common. If this condition is not fulfilled, the values Tracer cloud type = 21 (multiple cloudy types), = 22 (multiple clear air types), or = 23 (mixed cloudy/clear air types) are defined, when respectively the two most common cloud types inside the tracer are both cloudy types, both clear air types, or none of these two cases. In this case, a tracer is additionally only considered as valid in the visible and infrared cases when at least a 5% of its pixels are defined as cloudy pixels.

If SAFNWC/MSG PGE02 Cloud Type output is not available or `USE_CLOUDTYPE = 0`, the value Tracer cloud type = 0 (not processed) is given. All possible values are those shown in *Table 5*.

Possible values of the Tracer cloud type parameter	
0 Unprocessed cloud type	15 High semitransparent thin clouds
1 Cloud free land	16 High semitransparent meanly thick clouds
2 Cloud free sea	17 High semitransparent thick clouds
3 Land contaminated by snow/ice	18 High semitransparent above other clouds
4 Sea contaminated by ice	19 Fractional clouds
6 Very low cumulus/stratus	20 Undefined cloud type
8 Low cumulus/stratus	21 Multiple cloudy types
10 Medium cumulus/stratus	22 Multiple clear air types
12 High opaque cumulus/stratus	23 Mixed cloudy/clear air types
14 Very high opaque cumulus/stratus	

*Table 5: Possible values of the Tracer cloud type parameter.*

With all these data, considering the statistical study shown in the previous “Validation Report for High Resolution Winds (HRW – PGE09 v3.2), [AD.10]”, some tracers are eliminated depending on the tracer cloud type and the SEVIRI channel they have been calculated with. These cases are identified inside a dark cell in the next table and are related to cloud free tracers in the visible and infrared channels (not in the water vapour channels), fractional clouds in all cases (which in general show significantly worse validation statistics), and cloud types for which the Root mean square vector difference (RMSVD) is at least a 25% worse than for the channel with best statistics for that cloud type.

Considering the rest of cases, the height assignment is defined through the ‘top pressure’ in the Water vapour clear air tracers, in the tracers related to “High semitransparent thin clouds” and “High semitransparent meanly thick clouds”, and in the tracers related to “High semitransparent clouds above other clouds” in the infrared channels. All these cases are identified with ‘Top’ in the next table.

In all other cases the height assignment is defined through the ‘base pressure’. These cases are identified with ‘Base’ in the next table.

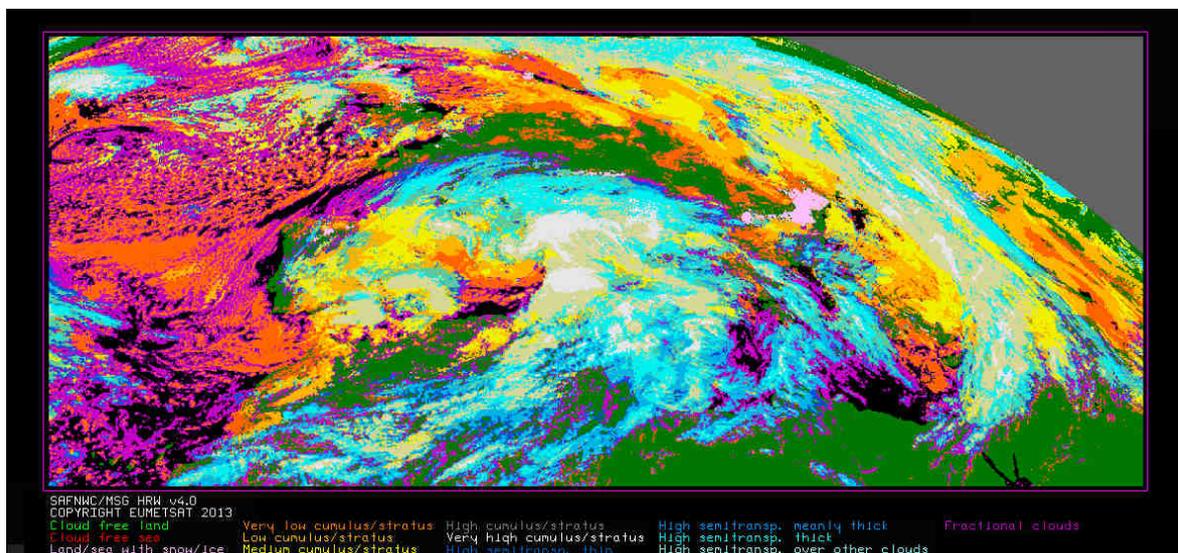
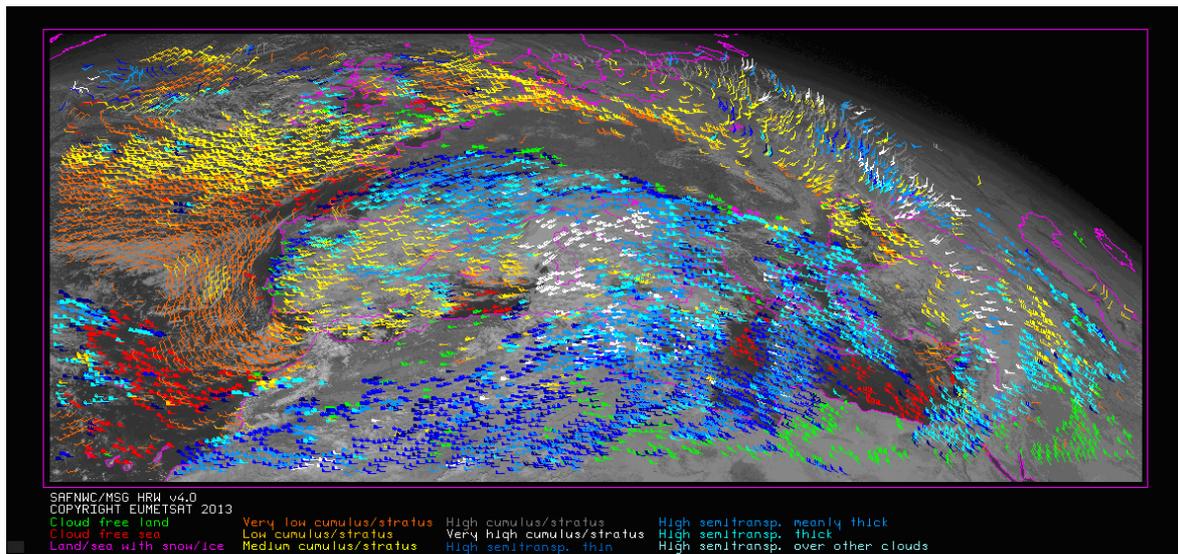
	HRVIS	VIS06	VIS08	WV062	WV073	IR108	IR120
1 Cloud free land				Top	Top		
2 Cloud free sea				Top	Top		
3 Land contaminated by snow/ice				Top	Top		
4 Sea contaminated by ice				Top	Top		
6 Very low cumulus/stratus	Base	Base	Base		Base	Base	Base
8 Low cumulus/stratus	Base	Base	Base		Base	Base	Base
10 Medium cumulus/stratus	Base	Base	Base		Base	Base	Base
12 High opaque cumulus/stratus	Base			Base	Base		
14 Very high opaque cumulus/stratus	Base			Base	Base		
15 High semitransp. thin clouds				Top	Top	Top	Top
16 High semitransp. meanly thick clouds	Top			Top	Top	Top	Top
17 High semitransp. thick clouds	Base			Base	Base	Base	Base
18 High semitransp. above other clouds				Base	Base	Top	Top
19 Fractional clouds							
21 Multiple cloud types	Base			Base	Base	Base	Base
22 Multiple clear air types				Top	Top		
23 Mixed cloudy/clear air types	Base			Base	Base	Base	Base

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

If USE\_CLOUDTYPE = 0 or the SAFNWC/MSG PGE02 Cloud Type output is not available, because most cloud types fit better with the ‘base pressure’, the ‘base pressure’ is considered for all tracers.

Operationally, this Height assignment method is run before the Tracer tracking. Because one of its outputs (the tracer pressure level) is needed for the calculation of the ‘tracking area centre’ (through the vertical interpolation of the NWP rectangular wind components) when the wind guess option is used, it is also run in the case of also using later the other Height assignment method (“CCC method”).

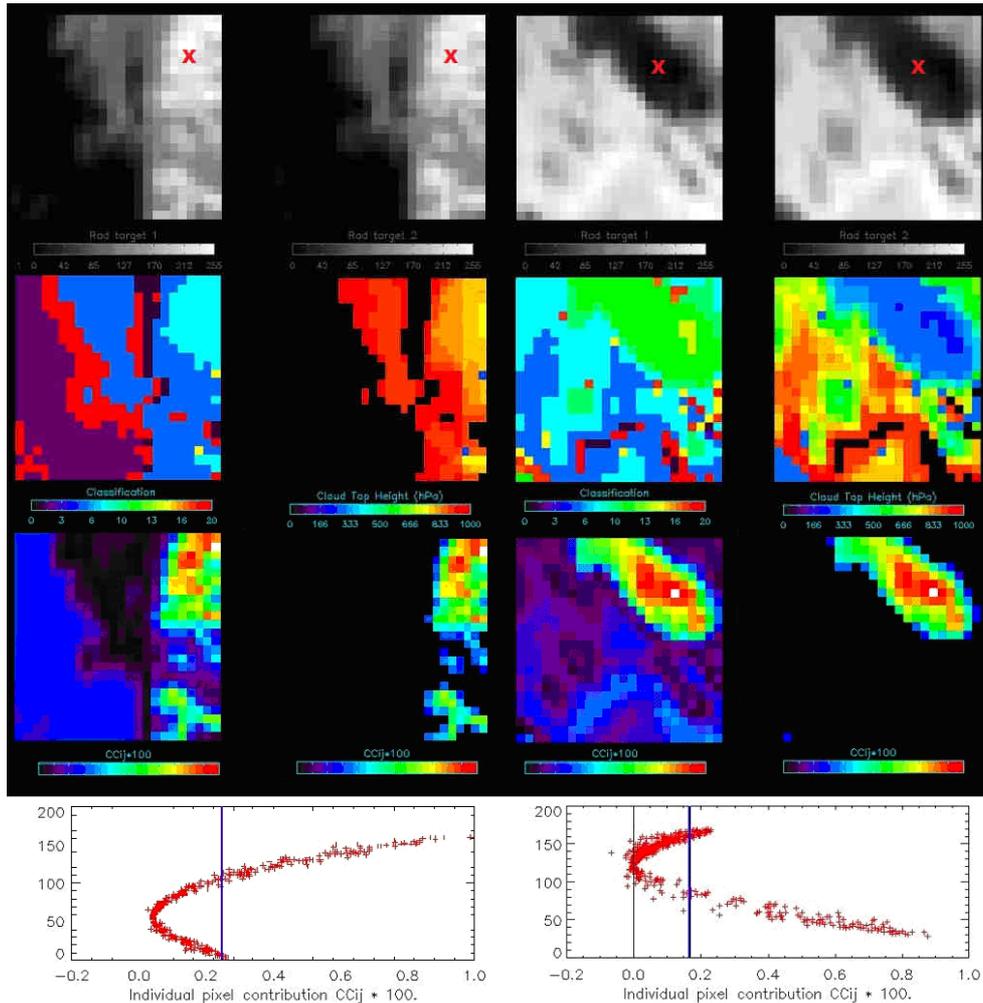




Figures 6 and 7: Tracer cloud types values (as defined by “CCC height assignment method”) for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), compared with the PGE02 Cloud type output for the same moment.

It has been checked that the optimum results are obtained using in the previous calculations only the pixels whose reflectance is higher than the threshold (“bright branch”) in the visible tracers, and the branch with largest ‘Correlation contribution sum’ (the largest branch in the ‘C shape’, which can be sometimes the “cold branch” and sometimes the “warm branch”) in the infrared and water vapour cloudy tracers.

Next images show two examples of the running of ‘CCC method’, for a VIS08 tracer on the left side (which uses as explained the pixels in the “bright branch”), and an IR108 tracer in the right side (which in this case uses as explained the “cold branch”, due to the larger correlation contribution sum of this branch). In the first row, the ‘N\_Value’ matrices for the initial image tracer and the second image ‘adjustment centre’ are shown. In the second row, the SAFNWC/MSG PGE02 Cloud type and PGE03 Cloud top pressure corresponding to the ‘adjustment centre’ are shown. In the third row, the ‘CCij matrix’ values (partial contributions to correlation from each pixel) are shown, in the left considering all pixels and in the right only those over the threshold (in these cases, the mean contribution to the correlation) in the correct branch considered by the method (the “bright branch” for the VIS08 tracer, and the “cold branch” for the IR108 tracer). As already explained, the lower graphs show respectively the Reflectance(Pixel correlation contribution) and the Brightness temperature(Pixel correlation contribution) for these cases, given by ‘N\_Values’ against ‘CCij values’, with the threshold considered by the method shown as a blue line.



Figures 8 and 9: Matrices and graphs used in the calculation of ‘CCC method height assignment’, for a VIS08 case using the bright branch of the Reflectance(Pixel correlation contribution) graph in the left side, and an IR108 case using the cold branch of the Brightness temperature(Pixel correlation contribution) graph in the right side, as explained in the text. The weighted position displacement of the AMV in the initial and later image, as defined with DEFPOSWITHCONTRIBUTIONS = 1, is also shown as a red cross in the images in the first row.

Only those pixels having both a value in the right middle and lower matrices of Figures 8 and 9 are used in the sums  $P_{CCC}$ ,  $T_{CCC}$ ,  $\Delta P_{CCC}$ . In the VIS08 example, these pixels corresponding only to the cloudy bright pixels on the right (cloud types = 6,8), are the ones contributing most to the correlation (values of  $P_{CCC}=834$  hPa and  $\Delta P_{CCC}=27$  hPa are given by the method). In the IR108 case, these pixels corresponding to the high level cloud on the right (cloud type=14), are the ones contributing most to the correlation (values of  $P_{CCC}=286$  hPa and  $\Delta P_{CCC}=24$  hPa are given by the method).

Additionally, since HRW v4.0 and with configurable option DEFPOSWITHCONTRIBUTIONS = 1 (which is the default option), the location of the AMV inside the tracer in both initial and final images is defined not as the tracer/tracking centre but as the weighted position displacement defined with the similar formulae (where  $X_{ij}$  and  $Y_{ij}$  correspond to the line and column position of each pixel):

$$X_{CCC}=\frac{\sum(CC_{ij}\cdot X_{ij})}{\sum CC_{ij}} \quad Y_{CCC}=\frac{\sum(CC_{ij}\cdot Y_{ij})}{\sum CC_{ij}}$$

With this relocation of the AMV, its position is correlated to the part of the tracer with largest contribution to the correlation. When trajectories are defined (as already told with configurable parameter CALCULATE\_TRAJECTORIES = 1), tracking consecutively during several slots the same tracer, this relocation of the AMV position is only calculated for the first AMV in the trajectory and keeps the same value during all the time the AMV is alive, to avoid discontinuities in the position of the AMV, when relating it to a tracer in the previous image or a tracking position in the next image.

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 34/78</p>
---	--	--

With these examples, it is clear that ‘CCC method’ offers a direct correspondence between the heights given for HRW winds and those given to the clouds by SAFNWC/MSG PGE03 product, eliminating any possible incongruence between both products. It also offers a clearer view of the cloud features considered in each case in the height assignment process, opening the field for new improvements in the height assignment process in the next years, because of the easy correspondence between the elements considered by ‘CCC method’ and real observable features.

### 3.1.2.2.6 Height assignment with ‘CCC method’ (Water vapour clear air cases)

An adaptation of ‘CCC method’ has been needed in HRW v3.2 for its use with the Water vapour clear air cases, because no pressure values can be extracted from PGE03 Cloud top pressure output in clear air pixels. First of all, this adaptation of the method is considered only in the WV062 and WV073 cases where the ‘Correlation contribution sum’ over the threshold is larger for the group of clear air pixels (Cloud type 1 to 4) than for the group of cloudy pixels (Cloud type 6 to 18), considering both branches of the Brightness temperature(Pixel correlation contribution) graph.

After this, the ‘CCC Cloud type’ and the ‘CCC Temperature,  $T_{CCC}$ ’ are calculated in a way similar to the one described in the previous chapter for the cloudy cases, although now the Brightness temperature from the corresponding channel for each pixel ( $BT_{ij062}$  or  $BT_{ij073}$ ) is used instead of the PGE03 Cloud Top Temperature, and only the pixels whose brightness temperature is colder than the threshold (“cold branch”) are considered. A ‘CCC temperature value error,  $\Delta T_{CCC}$ ’ is now also calculated considering a formula similar to the one used in the previous chapter for the pressure error:

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

Considering these data, three different temperature values are defined by next 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 then obtained through the interpolation to the NWP temperature forecast (or to a ‘Climatological temperature profile’ if it is missing, based on a quite simplified description of a standard atmosphere with 2 epochs of the year, 5 latitudes and 18 levels), giving three pressure values:  $P_{CCC_{MAX}}$  (related to  $T_{CCC} + \Delta T_{CCC}$ ),  $P_{CCC}$  (related to  $T_{CCC}$ ) and  $P_{CCC_{MIN}}$  (related to  $T_{CCC} - \Delta T_{CCC}$ ).

$P_{CCC}$  is defined as the ‘CCC Pressure value’ for the clear air AMVs.  $\Delta P_{CCC} = |P_{CCC_{MAX}} - P_{CCC_{MIN}}|/2$  is also defined as the ‘CCC Pressure error value’ for the clear air AMVs (in both cases where a vertical reduction or increase of temperature are found). In the case where a vertical inversion of temperature is found between  $P_{CCC_{MAX}}$  and  $P_{CCC}$ , but not between  $P_{CCC}$  in  $P_{CCC_{MIN}}$  or vice versa, a special value of 99 hPa is given to the ‘CCC Pressure error’.

### 3.1.2.2.7 Wind calculation

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

$$U = [(LON\_C - LON\_T) \times \cos((LAT\_C + LAT\_T)/2) \times CONVERT] / T\_INT;$$

$$V = [(LAT\_C - LAT\_T) \times CONVERT] / T\_INT;$$

where U, V are the west-to-east and south-to-north wind components (then easily converted to speed and direction); (LAT\_T, LON\_T), and (LAT\_C, LON\_C) are the coordinates at the tracer centre and the correlation centre; T\_INT is the time difference in hours between the initial tracer and the later tracking images (0.250 in the ‘MSG Nominal scan mode’ conditions; 0.167 in the default ‘MSG Rapid Scan mode’ conditions); the coefficient CONVERT converts °/hour to m/s.

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 35/78</p>
---	--	--

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

Basically, the Quality Indicator method developed by EUMETSAT and implemented for the Atmospheric Motion Vectors computed at the Meteosat Product Extraction Facility/MPEF (K.Holmlund, 1998) is used here. An update has additionally been included in the Quality Indicator method used by HRW v4.0, with some additional elements included at MPEF/AMV algorithm previously unused here.

This method assigns a quantitative flag to any Atmospheric Motion Vector: Quality Index (QI, ranging from 0 to 1). It is based on normalized functions, analytically fit to statistical properties in the behaviour of the winds. These properties relate to the expected change of the winds considering: temporal consistency (comparison to winds in the previous slot in the same location and level), spatial consistency (comparison to neighbour winds in the same slot in the same location and level), and consistency relative to a background (NWP forecast wind interpolated to the same slot, in the same location and level). In the two scale procedure, the HRW Quality Control is split in 2 different steps, representative of the ‘Basic scale’ and the ‘Detailed scale’.

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

- The QI (0 to 1) for the temporal direction consistency is given by:

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

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

- The 4 QI<sub>i</sub> (0 to 1) for the 4 other parameters (temporal speed consistency, temporal vector consistency, spatial vector consistency, forecast vector consistency) are:

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

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

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

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

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

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

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

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

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

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

ER = Earth radius in kilometres.

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

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 36/78
---	--	--

difference smaller than 1.35° (defined by parameters L\_CHECK\_LAT\_DIFF/T\_CHECK\_LAT\_DIFF) are valid. The reference winds with the smallest distance factor are considered for the Quality control.

The value of all these parameters is defined in `/include/PGE09/hrw_QualitySchema.h` file. Additionally, a weight on the different quality tests is defined through parameters W\_SPD/W\_SPD\_HRVIS (temporal speed consistency test weight, with default value 0), W\_DIR/W\_DIR\_HRVIS (temporal direction consistency test weight, with default value 0), W\_VEC/W\_VEC\_HRVIS (temporal vector consistency test weight, with default value 3), W\_LC (spatial vector consistency test weight, with default value 3), W\_FC (forecast vector consistency test weight, with default value 1) and W\_TC (interscale spatial vector consistency test, with default value 0). With all of this, only the temporal, spatial and forecast vector consistency tests are activated in the Quality control for HRW v4.0, which is the same situation than for the EUMETSAT/MPEF AMVs (although with different weights for the different quality tests; in the MPEF case the weight of the spatial and temporal vector consistency test is 2).

The user can nevertheless evaluate the impact of all these parameters in the HRW output changing their corresponding values and recompiling again PGE09 with `make clean` and `make all` at `$$SAFNWC/src/PGE09` directory. The weighted sum of the mentioned Quality tests defines the ‘Quality Index (QI)’ of the different winds, which is used for their filtering for their writing in the BUFR AMV and Trajectory output files. Two corrections are nevertheless included in this QI value before declaring it valid:

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

$$1 - [\tanh[(\max(A, \text{CORR}(\text{IR108}, \text{WV062}))/B)]]^C,$$

where CORR(IR108,WV062) is the correlation of IR108 and WV062 MSG/SEVIRI channels at the location of the ‘adjustment centre’ related to the evaluated wind, and the coefficients A, B, C are respectively 0, 0.2 and 200. This correction has the name of “Image correlation test”).

Two different Quality Indices are defined for each wind and written in the BUFR output files: one with contribution of the forecast consistency test (Quality index with forecast) and another one without contribution of the forecast consistency test (Quality index without forecast). The Quality Index threshold for the acceptance of an AMV as valid is defined by configurable parameter QI\_THRESHOLD (with a default value of 70 for HRW v4.0). The user can also decide if the Quality index with forecast or else without forecast is used for the AMV output filtering (with configurable parameter QI\_THRESHOLD\_USEFORECAST, with a default value of 1).

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

- Each ‘adjustment centre’ will be flagged at this stage (with up to 3 winds per tracer), and all winds available are considered valid for the spatial comparison disregarding their Quality Index.
- It is frequent that a quality test cannot be calculated (i.e. no wind was found for the comparison). The overall QI will thus include only the passed tests.
- Only one wind per tracer is selected for the BUFR AMV and Trajectory output. The suggested option (selected with configurable parameter BEST\_WIND\_SELECTION = 1) is: the best wind for the tracer for the most possible of next criteria: interscale spatial quality test, temporal quality test, spatial quality test, forecast quality test, correlation (with a triple contribution); if this is not definitive the best wind for the forecast quality test (significantly, with a difference of more than a 21%); if this is also not definitive the wind with the best correlation. In this case TEST output parameter will reflect, apart from the number of quality tests that each wind has passed, whether the wind has been the best (value = 3), slightly worse (value = 2, with a percentage difference larger than the 1%), or fairly worse (value = 1, with a percentage difference larger than the 21%)

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

- A different option defined with BEST\_WIND\_SELECTION = 0: the best wind for the tracer for the interscale QI; if this is not definitive the best for the temporal plus spatial QIs if it is larger than 85%; if this is also not definitive, the wind with the best overall QI.
- For the temporal consistency of successive winds related to a same trajectory, some limits are defined in the speed difference (MEANVEC\_SPEED\_DIF = 10 m/s), direction difference (MEANVEC\_DIR\_DIF = 20°) and the pressure level difference (MEANVEC\_PRESSURE\_DIF = 50 hPa) of two consecutive winds related to a same trajectory. These limits must be obeyed so that additional sectors can be added to the trajectory.
- With winds related to a ‘prior wind’, if configurable parameter USE\_MEANWIND = 1 is used, a correction of the HRW wind output for the current slot is done with the corresponding ‘prior wind’ for the same trajectory (when it exists), in which the mean value of speed, direction, correlation, quality, temperature, pressure and pressure error considering both winds is used in the HRW wind output. Nevertheless, this option is not used as the default one.

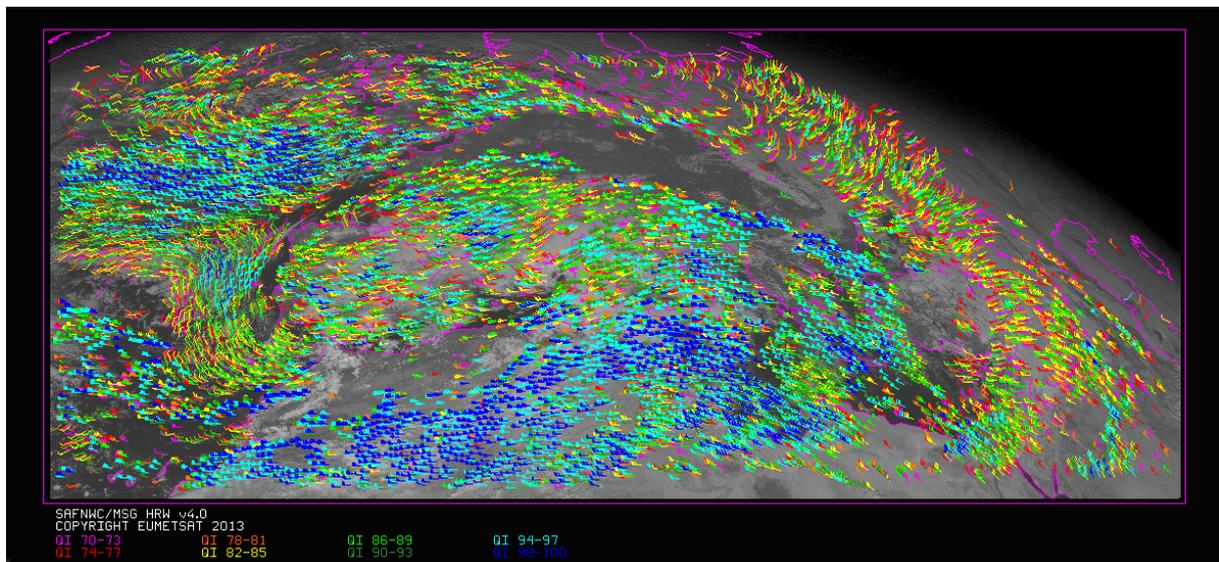


Figure 10: Quality index including forecast for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

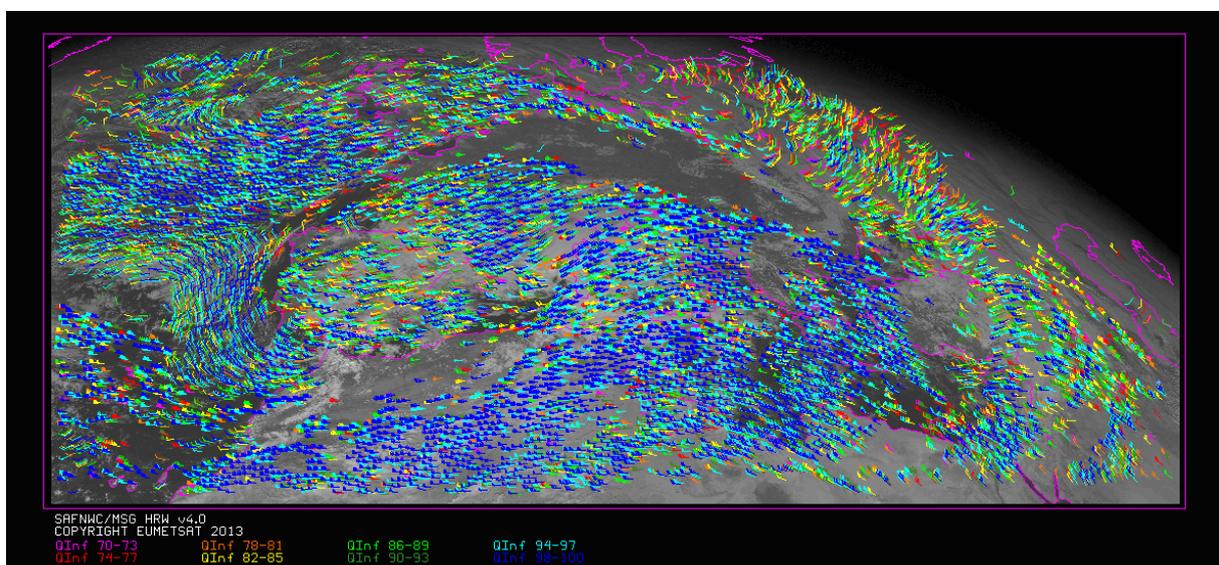


Figure 11: Quality index not including forecast for the High Resolution Winds example defined in Figures 13 and 14 (26 December 2009, 1200Z, Nominal scan mode, MSG2 satellite)

### 3.1.2.2.9 Orographic flag calculation

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

- AMVs associated to land features, incorrectly detected as cloud tracers.
- Tracers which are blocked or whose flow is affected by mountain ranges.
- Tracers associated to lee wave clouds, with atmospheric stability near mountain ranges.

The effect on these tracers is to present AMVs whose displacement does not correspond with the general atmospheric flow. Because of this, they should not be considered. In this part of the algorithm, with the configurable parameter USE\_TOPO = 1, an ‘orographic flag’ is calculated for each AMV with the intention of detecting this land influence.

The procedure starts defining a topography histogram for all locations, where data up to 1 degree away for each point are considered, and centiles 3% and 97% are calculated to define two matrices with representative Minimum and Maximum Heights around each location (H\_sfcmin & H\_sfcmax).

After this, these “Height matrices” are converted to two new ones representing the “Surface pressure matrices” corresponding to the Maximum and Minimum Heights (P\_sfcmax & P\_sfcmin), considering Geopotential and Temperature NWP data at different levels up to 500 hPa and the barometric formula:

$$P_{sfc} = P_{nnn} \exp[(2 * Go / Rd) * (Z_{nnn} - Z_{sfc}) / (T_{nnn} + T_{sfc})],$$

with Go=MEAN\_GRAVITY; Rd=DRY\_AIR\_GAS\_CONSTANT; sfc=surface; nnn=NWP level above surface level; T\_nnn and T\_sfc temperatures in Kelvin; Z geopotential heights in meters.

These "Surface Pressure levels" represent the lowest and highest surface pressure values in locations up to one degree away of each location of the image.

A ‘Normalized stability’ parameter is then calculated for each location of the geographical box. Considering the two pressure levels around P\_sfcmax:

$$E = [(T_{lower} - T_{upper}) / (Z_{upper} - Z_{lower})] / [Go / Cp],$$

with Cp=DRY\_AIR\_PRESSURE\_SPECIFIC\_HEAT. An atmosphere is then considered unstable if E>1; stable if E<1.

After this, the “Static orographic flag” (ind\_topo) is calculated at the initial position of each ‘correlation centre’. This is calculated with P\_sfcmin, P\_sfcmax and parameters TOPO\_PR\_DIFF = 1/2 (Representative pressure level of the location) and TOPO\_PR\_SUP = 25 hPa (Pressure margin over P\_sfcmax to avoid orographic influence). Possible values are:

- IND\_TOPO = 0: The Orographic flag could not be calculated.
- IND\_TOPO = 1:  $P_{traz} > P_{sfcmax} - TOPO\_PR\_DIFF * (P_{sfcmax} - P_{sfcmin})$   
Very important orographic influence found in the current tracer position.
- IND\_TOPO = 2:  $P_{traz} < P_{sfcmax} - TOPO\_PR\_DIFF * (P_{sfcmax} - P_{sfcmin})$   
and  $P_{traz} > P_{sfcmin} - TOPO\_PR\_SUP$   
Less important orographic influence found in the current tracer position.
- IND\_TOPO = 6:  $P_{traz} < P_{sfcmin} - TOPO\_PR\_SUP$   
No orographic influence found in the current tracer position: the tracer is over the level without orographic influence.

The “Dynamic orographic flag” is then calculated: values of ind\_topo are modified, to verify the possibility of a previous in time orographic influence. This part only happens if IND\_TOPO = 6 and the tracer is related to predecessor winds in the previous slots. The process cuts when ‘Static

orographic influence’ is found in any of the previous positions of the tracer, or a condition defined on the stability ( $\text{stability} < \text{STABILITY\_THRESHOLD} = 0.9$ ) disappears. The value of  $\text{IND\_TOPO} = 6$  is then modified considering the next conditions:

- *$\text{IND\_TOPO} = 0$ : The orographic flag could not be calculated.*
- *$\text{IND\_TOPO} = 3$ : Very important static orographic influence ( $\text{IND\_TOPO} = 1$ ) is found at any previous position of the tracer.*
- *$\text{IND\_TOPO} = 4$ : Less important static orographic influence ( $\text{IND\_TOPO} = 2$ ) is found at any previous position of the tracer.*
- *$\text{IND\_TOPO} = 5$ : No orographic influence is found in any current or previous position of the tracer, while the stability condition is kept.*
- *$\text{IND\_TOPO} = 6$ : No orographic influence is found in any current or previous position of the tracer, while the stability condition is not kept.*

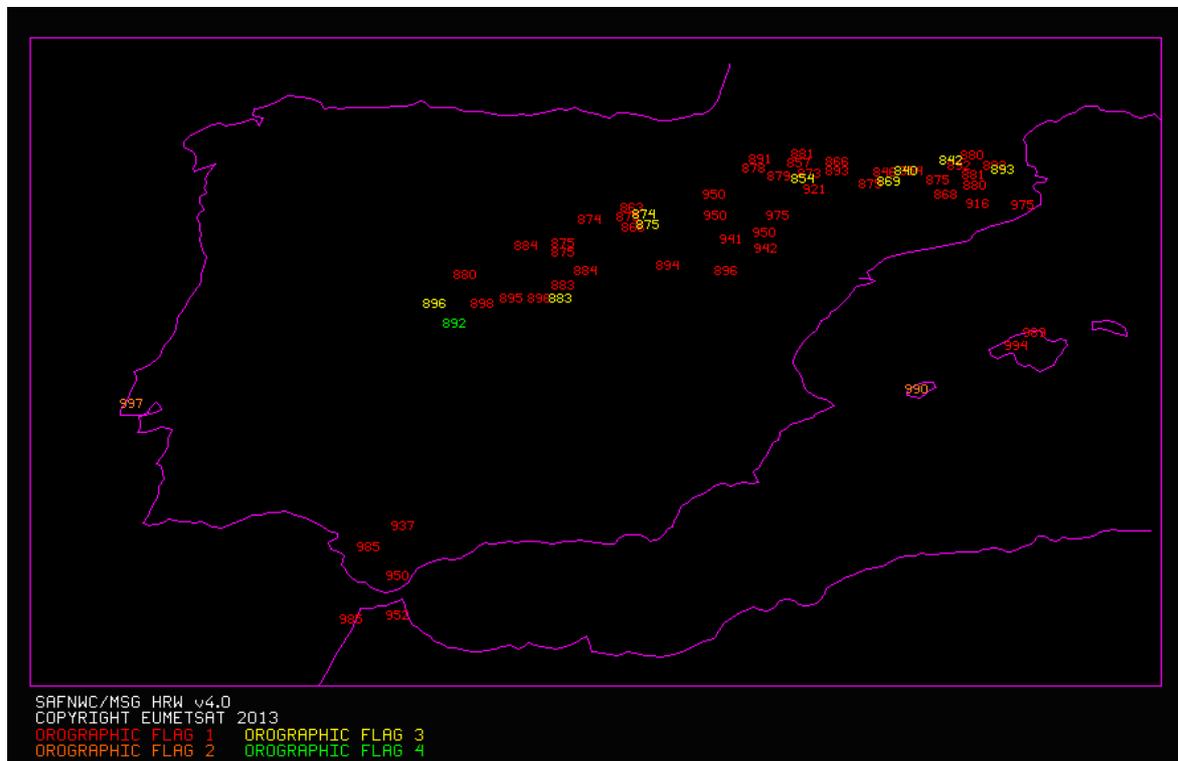


Figure 12: Pressure values in hPa for AMVs affected by orography (i.e. with Orographic flag values between 1 and 4) in a zoomed area around the Iberian Peninsula, during a 50 day interval of the Validation period (1 January to 19 February 2010 at 1200Z, Nominal scan mode, MSG2 satellite). A clear correlation between the mountain systems (Pyrenees, Iberian System, Central System, mountains around the Strait of Gibraltar and in the Balearic Islands) and very low AMVs (lower than 840 hPa) is seen.

Because of the different position the different ‘adjustment centres’ related to a same wind can be related to inside the tracer in the initial image, because of different values in the weighted position displacement defined by ‘CCC method’ with  $\text{DEFPOSWITHCONTRIBUTIONS} = 1$  configurable parameter, the up to three winds calculated for the same tracer can have since HRW v4.0 a different “Static orographic flag”, and because of this (in spite of being all these winds related to the same predecessor wind) also a different “Dynamic orographic flag”. On the contrary, all ‘adjustment centres’ related to a same wind have similar values in the “Static and dynamic orographic flag” in the case  $\text{DEFPOSWITHCONTRIBUTIONS} = 0$  is used).

Taking this into account, a comparison test similar to the ones in section 3.1.2.2.6 is calculated to compare the different winds for the same tracer related to orography. Possible values are:

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 40/78
---	--	--

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

As already seen, with configurable parameter USE\_TOPO = 1, IND\_TOPO and TESO variables are calculated and incorporated to the output file. When USE\_TOPO = 0, the “Orographic flag” is not calculated. Additionally, if configurable parameter FINAL\_FILTERING > 1 those AMVs with “Static orographic influence (IND\_TOPO = 1,2) are eliminated from the output file.

### 3.1.2.2.10 Final Control Check and Output data filtering

After the Quality control, sometimes it has been detected that an only Atmospheric Motion Vector has a direction or velocity completely different to the ones in its immediate vicinity. It has been seen that these AMVs make statistical results worse, without justifying clearly the reason for such big changes in direction or velocity. Because of this, they can be considered as errors. To eliminate these errors, a function called “Final Control Check” can be run after the Quality Control if using configurable parameter FINALCONTROLCHECK = 1 (which is the default option).

It calculates the velocity and direction histograms with all valid AMVs calculated with the same MSG/SEVIRI channel in relatively small areas inside the working region (square boxes of 5x5 degrees of latitude and longitude). When any of the columns of the velocity or direction histograms has only one element, it is excluded (amplitude of the columns defined by SPEED\_AMPLITUDE, DIRECTION\_AMPLITUDE parameters).

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

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

- WIND\_CHANNEL (default value HRVIS,VIS08,IR120,WV062,WV073), which defines the MSG/SEVIRI channels for which AMVs (and trajectories) are generated.
- QI\_THRESHOLD: defines the Quality index threshold for the AMVs in the BUFR output files. Depending on the value of QI\_THRESHOLD\_USEFORECAST (default value 1), the “Quality index with forecast” or the “Quality index without forecast” are used for the AMV filtering.
- CLEARAIRWINDS: defines if the Clear air water vapour AMVs are to be included in the BUFR output files (default option “yes”).
- MAXPRESSUREERROR: defines the maximum pressure error (in hPa) permitted in the output AMVs, when the “CCC height assignment method” has been used.
- MIN\_CORRELATION: defines the minimum correlation (as a %) in the output AMVs, when the “Cross Correlation tracking” has been used.
- FINALFILTERING: defines several filterings in the output AMVs, depending on its value.
  - With FINALFILTERING > 0, the AMV Height level filtering defined in next table is implemented (where dark blue layers for the different MSG/SEVIRI channels are eliminated; light blue layers are eliminated only for ‘Clear air AMVs’). In these cases the NRMSVD values are at least one sixth higher than for the MSG/SEVIRI with a minimum NRMSVD.

	HRVIS	VIS06	VIS08	IR108	IR120	WV062	WV073
100-199 hPa							
200-299 hPa							
300-399 hPa							
400-499 hPa							
500-599 hPa							
600-699 hPa							
700-799 hPa							
800-899 hPa							
900-999 hPa							

Table 7: AMV filtering related to the Height level and each SEVIRI channel

- With FINALFILTERING > 1 (which is the default option), the Cloud type filtering defined in Table 6 is implemented for the different MSG/SEVIRI channels. Additionally, AMVs with an “Orographic flag” = 1,2 are also eliminated.
- With FINALFILTERING > 2, AMVs with a “Spatial quality flag” = 1,2 are also eliminated.
- Finally, with FINALFILTERING = 4, AMVs with a “Spatial quality flag” = 0 are also eliminated.



	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 43/78</p>
---	--	--

channels except for the HRVIS AMVs (for which the density of data has significantly been reduced in HRW v4.0 to keep the HRW algorithm running time under limits, because of the higher relative time cost the calculation of AMVs has with this channel due to the larger tracking area it needs when the wind guess is not used) and also for the Clear air AMVs (where the amount of data reduces also slightly).

The reduction in the NMVD and NRMSVD occurs for all MSG/SEVIRI channels (especially for infrared and water vapour AMVs with a difference larger than the 10%). Finally, the behaviour of the NBIAS changes with each MSG/SEVIRI channel, with slight increases and decreases in the value depending on the specific case (except for Clear air AMVs, for which there is a significant decrease in the value).

Comparing the statistics for the different MSG/SEVIRI channels, the NRMSD seems again very different, with changes larger than the 50% between the best case (Cloudy WV062 AMVs, with 0.32) and the worst cases (Cloudy VIS06 and VIS08 AMVs, with 0.50). Nevertheless this is only caused by the different proportion of AMVs in the different pressure layers for each channel. As it can be seen in next two tables (where the validation statistics are extracted separately for the three different layers: High at 100-400 hPa, Medium at 400-700 hPa and Low at 700-1000 hPa), inside each one of the layers the differences of NMVD and NRMSVD for the different MSG/SEVIRI channels are relatively small.

Comparing additionally the statistics given for the three pressure layers for the current respect to the previous algorithm (HRW v4.0 and v3.2), increases in the amount of data over the 40%, 20% and 60% are observed respectively for the High, Medium and Low layer. Visible decreases in the NMVD and NRMSVD are additionally observed in the High and Medium layer for all cases (except Clear air AMVs in the medium layer). In the Low layer, small variations are seen in the NMVD and NRMSVD for the different channels which compensate considering all of them together to obtain similar mean values. Considering the NBIAS, there are small variations between HRW v4.0 and HRW v3.2 which are only significant at the Medium layer where a more negative value is generally seen (except in the Clear air AMVs).

With all of this, it can be seen that with HRW v4.0 smaller NMVD and NRMSVD values are got in all cases with a larger amount of AMVs (with unspecific changes considering the NBIAS). Considering additionally the conceptual differences between both HRW versions (specially the default configuration in HRW v4.0 not using the wind guess for the definition of the tracking area, which reduces the dependence of the calculated AMVs from the NWP model data, the inclusion of the Subpixel tracking in the calculation of the AMVs which avoids discontinuities in the field of wind speeds and directions caused by the resolution of the image pixels, and the additional information provided now in the Quality control with two different Quality Indices with and without forecast), it is formally recommended to NWC SAF users to update their HRW algorithm to HRW v4.0 included in SAFNWC/MSG v2013.

HRW v3.2 AMV Validation (Jul 2009-Jun 2010)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy WV062	Cloudy WV073	Cloudy IR108	Cloudy IR120	Clear Air	All AMVs
NC	74986			126993	141182	69778	73646	35489	522074
SPD [m/s]	23.49			23.89	23.35	23.12	23.05	17.34	23.02
NBIAS (HIGH LAYER)	-0.10			-0.06	-0.09	-0.12	-0.11	-0.04	-0.09
NMVD (100-400 hPa)	0.28			0.29	0.30	0.30	0.29	0.34	0.30
NRMSVD	0.35			0.36	0.37	0.37	0.37	0.42	0.37
NC	33356	41595	37728	6018	34416	32724	32364	12689	230890
SPD [m/s]	13.47	13.11	12.97	18.18	16.52	15.06	15.19	13.45	14.37
NBIAS (MEDIUM LAYER)	-0.12	-0.17	-0.17	+0.00	-0.03	-0.08	-0.06	-0.03	-0.10
NMVD (400-700 hPa)	0.38	0.42	0.42	0.38	0.39	0.39	0.39	0.39	0.40
NRMSVD	0.47	0.51	0.51	0.48	0.49	0.48	0.48	0.47	0.49
NC	30291	29618	26294		1050	10331	9161		106745
SPD [m/s]	9.52	9.84	9.89		13.13	11.10	11.09		10.02
NBIAS (LOW LAYER)	-0.09	-0.13	-0.14		-0.02	-0.09	-0.08		-0.11
NMVD (700-1000 hPa)	0.44	0.46	0.46		0.40	0.41	0.41		0.44
NRMSVD	0.52	0.54	0.54		0.48	0.49	0.48		0.52

*Table 10: Validation parameters for HRW v3.2 AMVs with the default configuration and High, Medium and Low layers considered separately (Jul 2009-Jun 2010, MSG2 satellite, European and Mediterranean area; Basic winds with Cross correlation tracking and CCC height assignment method; Pressure range [hPa]: [100-999) for Cloudy AMVs, [100-500) for Clear Air AMVs; Quality index with forecast:  $\geq 83$  for High and Medium layer;  $\geq 85$  for Low layer)*

HRW v4.0 AMV Validation (Jul 2009-Jun 2010)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy WV062	Cloudy WV073	Cloudy IR108	Cloudy IR120	Clear Air	All AMVs
NC	20317			181417	198792	167513	171248	37454	776741
SPD [m/s]	23.22			23.76	23.24	22.85	22.83	16.98	22.88
NBIAS (HIGH LAYER)	-0.10			-0.06	-0.09	-0.12	-0.11	-0.01	-0.09
NMVD (100-400 hPa)	0.26			0.25	0.26	0.27	0.27	0.32	0.27
NRMSVD	0.31			0.31	0.32	0.34	0.33	0.39	0.33
NC	12774	51714	48729	8387	57466	50698	49329	5550	284647
SPD [m/s]	12.84	12.68	12.54	17.96	15.62	15.27	15.34	13.45	14.35
NBIAS (MEDIUM LAYER)	-0.13	-0.20	-0.21	+0.00	-0.03	-0.11	-0.09	+0.10	-0.12
NMVD (400-700 hPa)	0.37	0.40	0.40	0.34	0.37	0.35	0.36	0.40	0.37
NRMSVD	0.45	0.47	0.48	0.42	0.45	0.43	0.44	0.47	0.45
NC	14189	49122	42948		6734	33313	30699		177005
SPD [m/s]	8.96	9.31	9.32		11.90	9.73	9.83		9.55
NBIAS (LOW LAYER)	-0.06	-0.13	-0.13		-0.03	-0.09	-0.10		-0.11
NMVD (700-1000 hPa)	0.46	0.45	0.46		0.42	0.42	0.42		0.44
NRMSVD	0.54	0.53	0.54		0.50	0.50	0.50		0.52

*Table 11: Validation parameters for HRW v4.0 with the default configuration and High, Medium and Low layers considered separately (Jul 2009-Jun 2010, MSG2 satellite, European and Mediterranean area; Basic winds with Cross correlation tracking and CCC height assignment method; Pressure range [hPa]: [100-999) for Cloudy AMVs, [100-425) for Clear Air AMVs; Quality index with forecast:  $\geq 70$  for High and Medium layer;  $\geq 75$  for Low layer)*

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 45/78</p>
---	--	--

### 3.2.2 List of inputs for High Resolution Winds

A region configuration file (`file.cfg`), and a HRW model configuration file (`file.cfm`, with the parameters and options that are indicated by the user for calculation) are needed in `$SAFNWC/config` directory.

- Two different model configuration files are suggested to the user, for their use with ‘MSG nominal scan mode’ (`safnwc_pge09.cfm`) and ‘MSG Rapid scan mode’ (`safnwc_pge09_nat_rss.cfm`). The complete list of configurable parameters to be included in this file, with a description of them and their corresponding default values, is available in Section 3.1.5. of this document. Some output examples of runnings of HRW product with these Model Configuration Files are shown in Section 3.1.6.

Besides, for every running slot next data need to be supplied:

- Full resolution data file for the selected region for all MSG/SEVIRI channels to be used for the AMV calculation, for the running slot and the previous slot: HRVIS, VIS06, VIS08, IR108, IR120, WV062 and WV073. IR120 channel is additionally needed in the visible cases when the old ‘Brightness temperature interpolation height assignment’ is to be used, and IR108 and WV062 channels are in all cases needed if the default configuration of the Quality control is kept (including the “Image correlation test”).
- List of tracers, predecessor winds and trajectories calculated at the previous slot, if existing.
- NWP data: Fields of temperatures and rectangular components of the wind (u,v), covering at least the selected region, for as many as possible of the following levels: 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 10 hPa. In case the “Orographic flag” should also be calculated, surface temperature fields and geopotential heights for levels 1000,925,850,700,500 hPa are also required. Forecast time closeness to data should be at least 3 hours, with MSG frequency as goal. Since HRW v3.1 the maximum value of NWP levels that can be used has been increased to 48 (value of `MAX_NWP_LEVELS` parameter).
- SAFNWC/MSG PGE02 and PGE03 output files for the running region and slot in the corresponding `/export/PGE02` and `/export/PGE03` directories, with configurable parameter `DEFINewithCONTRIBUTIONS = 1`.
- SAFNWC/MSG PGE02 output files for the running region and the previous slot in the corresponding `/export/PGE02` directory with configurable parameter `USE_CLOUDTYPE = 1`, in case `WIND_GUESS = 1` or `DEFINewithCONTRIBUTIONS = 0`.

With HRW v4.0, the provision of NWP data or SAFNWC/MSG PGE02 and PGE03 output files for the running region and slot are needed for the running of HRW algorithm. The Climatological profile used in previous versions of HRW algorithm when NWP data were not available for the ‘Height assignment of the cloudy AMVs’, is not used anymore because of the worse quality it inferred in the AMV output data. In case a user still wants to use HRW algorithm with a ‘Height assignment of Cloudy AMVs’ based on Climatological data, it is recommended to use the previous version of HRW algorithm (HRW v3.2, distributed with SAFNWC/MSG v2012).

In case NWP data are available for the HRW algorithm running, SAFNWC/MSG PGE02 and PGE03 output files are not mandatory but recommended for a better height assignment process and a better validation. To have these files available it is then necessary to run PGE01, PGE02 and PGE03 executables before PGE09 for the running slot and region.

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 46/78</p>
---	--	--

### 3.2.3 List of High Resolution Winds configurable parameters

The High Resolution Winds model configuration file holds the configurable parameters needed for the execution of PGE09. It must be located within \$SAFNWC/config directory. Two different reference Model Configuration Files have been included in the SAFNWC/MSG package, for their use with ‘Nominal scan mode’ (safnwc\_pge09.cfm) and with ‘Rapid scan mode’ (safnwc\_pge09\_rss.cfm).

A brief description and the possible values of the configurable parameters included in these files are shown in the next table. With these conditions, HRW algorithm running time is in the mean three and a half minutes for the MSG-N region in the current HRW development platform (an Intel/Linux Virtual server inside the NWC SAF BladeFrame BF400 S2, Xeon IA-32E 4-way 2400MHz with 8 GB RAM and Linux RHEL Server 5.3 Operative System).

<i>Keyword</i>	<i>Description</i>	<i>Type</i>	<i>Default Value(s)</i>
<b>Identification parameters</b>			
PGE_ID	PGE identification. This keyword is optional, but should not be changed by the user.	Chain of characters	PGE09
SEV_BANDS	SEVIRI bands that can be used to run the PGE. This keyword is optional, but should not be changed by the user. It defines the maximum value of SEVIRI bands for which AMVs can be calculated.	Chain of characters	HRVIS, VIS06, VIS08, WV062, WV073, IR108, IR120
WIND_CHANNEL	SEVIRI bands really used for AMV calculation. As possible values, it can include any of the next SEVIRI channels separated by commas (not by spaces): HRVIS, VIS06, VIS08, WV062, WV073, IR108, IR120.	Chain of characters	HRVIS, VIS08, WV062, WV073, IR120
SLOT_GAP	Ordering number of the previous SEVIRI slot, for which tracers are to be considered for AMV processing. Possible values: 1: Nominal mode (15 min., previous slot) 2: Rapid scan mode (10 min, 2 <sup>nd</sup> previous slot)	Integer	1 (Nominal mode) 2 (Rapid scan mode)
<b>Output parameters</b>			
BUFR_CENTRE_OR	Originating/generating centre of the BUFR file, as defined in WMO Common Code Table C-1. It is to be modified with the code related to the corresponding centre (e.g. 214 for Madrid).	Integer	214
BUFR_OUTPUT_FORMAT	BUFR output file format. Possible values: - NWC: two different BUFR files are generated (for AMVs & Trajectories) with the traditional SAFNWC/MSG PGE09 BUFR output format. - EUM: one BUFR file is generated (for AMVs) with the official EUMETSAT/MPEF AMV BUFR output format.	Chain of characters	NWC
QI_THRESHOLD	Quality Index threshold for the AMVs	Integer	70
QI_THRESHOLD_USEFORECAST	Option to show if the Quality index threshold used in the wind output filtering includes the Quality forecast test	Integer	1
QI_BEST_WIND_SELECTION	Criterion for Best wind selection (Values: 0/1), as defined in the ATBD document.	Integer	1
CLEARAIRWINDS	Flag to decide if Clear air AMVs are calculated (when positive).	Integer	1
CALCULATE_TRAJECTORIES	Flag to decide if Trajectories are calculated (when positive)	Integer	1
FINALFILTERING	Flag for a final filtering of the AMVs based on: - Their Height level (if > 0), - Their Cloud type (if > 1), - Their Quality spatial test (1,2 as invalid values if > 2; 0,1,2 as invalid values if > 3).	Integer	2
USE_TOPO	Flag for calculation of the orographic flag. (when positive).	Integer	1
USE_MEANWIND	Flag showing if the mean value of the latitude increment, longitude increment, speed, direction, temperature, pressure, pressure error and correlation related to an AMV and its predecessor (in case it exists) are provided (when positive).	Integer	0
MAXPRESSUREERROR	Maximum pressure error in the AMVs (hPa), when ‘CCC height assignment method’ is used.	Integer	150

<i>Keyword</i>	<i>Description</i>	<i>Type</i>	<i>Default Value(s)</i>
<b>Working area description parameters</b>			
LAT_MIN		Real	-75.0
LAT_MAX	Latitude and longitude borders (in degrees)	Real	75.0
LON_MIN	for the processing region (Basic AMVs)	Real	-179.0
LON_MAX		Real	179.0
LAT_MIN_DET		Real	-75.0
LAT_MAX_DET	Latitude and longitude borders (in degrees)	Real	75.0
LON_MIN_DET	for the processing region (Detailed AMVs)	Real	-179.0
LON_MAX_DET		Real	179.0
FRAC_DAY_SCENE	Minimum fraction of area illuminated by the sun needed to calculate the visible AMVs (HRVIS, VIS06, VIS08 channels)	Integer	8
ZEN_THRES	Sun zenith angle threshold (degrees)	Double	87.0
MSG_ZEN_THRES	Satellite zenith angle threshold (degrees)	Double	80.0
<b>Tracer parameters</b>			
MAX_TRACERS	Maximum number of tracers	Integer	120000
LSIZ_HRV	Basic tracer line/column dimension	Integer	24
ESIZ_HRV	(to be applied with HRVIS AMVs)	Integer	24
LSIZ_OTHER	Basic tracer line/column dimension	Integer	24
ESIZ_OTHER	(to be applied with all other AMVs)	Integer	24
MIN_BRIGHTNESS_VIS	Minimum acceptable 1 byte reflectance value in the search for targets (with visible AMVs)	Double	120.0
MIN_BRIGHTNESS_OTHER	Minimum acceptable 1 byte brightness temperature value in the search for targets (with infrared and water vapour AMVs).	Double	60.0
GVAL_VIS	Minimum acceptable 1 byte reflectance contrast in the pixels of a target (with visible AMVs)	Double	60.0
GVAL_OTHER	Minimum acceptable 1 byte brightness temperature contrast in the pixels of a target (with infrared and water vapour AMVs)	Double	48.0
TRACER_SEARCH_STEP_HRV	Minimum separation (in pixels) between tracers (for HRVIS AMVs)	Integer	24
TRACER_SEARCH_STEP_OTHER	Minimum separation (in pixels) between tracers (for all other AMVs)	Integer	6
<b>Tracking parameters</b>			
TRACKING	Tracking method. Possible values: LP: Euclidean difference CC: Cross correlation	Chain of characters	CC
DEFINECONTRIBUTIONS	Flag to decide if “CCC height assignment method” is to be used (when positive; this option requires also TRACKING=CC)	Integer	1
DEFPOSCONTRIBUTIONS	Flag to decide if the position of the AMV in the target is relocated to the position of maximum correlation contribution defined by “CCC height assignment method” (when positive; this requires also TRACKING=CC and DEFINECONTRIBUTIONS=1)	Integer	1
USE_CLOUDTYPE	Flag to decide if the Tracer cloud type is used by the old “Brightness temperature interpolation height assignment method” (when positive).	Integer	1
WIND_GUESS	Flag to decide if the Wind guess is used for the definition of the Tracking area (when positive)	Integer	0
MIN_CORRELATION	Minimum correlation acceptable in the Tracking process (if Cross correlation method used)	Double	80.0
LLAG_HRV	Tracking line/column increment (to be applied with HRVIS AMVs)	Integer	138(Nominal mode) 92(Rapid scan mode)
ELAG_HRV	(This value is dependent of the time distance between satellite slots)	Integer	138(Nominal mode) 92(Rapid scan mode)
LLAG_OTHER	Tracking line/column increment (to be applied with all other AMVs)	Integer	46(Nominal mode) 30(Rapid scan mode)
ELAG_OTHER	(This value is dependent of the time distance between satellite slots)	Integer	46(Nominal mode) 30(Rapid scan mode)
USE_SUBPIXELTRACKING	Flag to decide if Subpixel tracking is to be used (when positive)	Integer	1



	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 49/78</p>
---	--	--

## 3.2.4 Description of High Resolution Winds output

### 3.2.4.1 AMV/Wind BUFR bulletins

One file for the single AMV scale, or two different files for two different AMV scales (related each one of them to ‘Basic winds’ and ‘Detailed winds’, when so configured with configurable parameter CDET = ALL or RANGE), in form of BUFR bulletins are produced for each processed region for every running slot. If winds have been calculated for several MSG/SEVIRI channels, they are all included in the same BUFR bulletin. Additionally, the BUFR bulletin can have since HRW v4.0 two different formats, depending on the value of configurable parameter BUFR\_OUTPUT\_FORMAT.

#### 3.2.4.1.1 AMV/Wind BUFR bulletins with NWC SAF specific format

When BUFR\_OUTPUT\_FORMAT = NWC, an AMV BUFR bulletin equivalent to those defined in previous version of HRW product is written in \$SAFNWC/export/PGE09 directory under the name SAFNWC\_MSGx\_HRW\_yyyymmddhhmm\_rrrrrrrrrrrr\_B.buf (for the ‘single or basic AMV scale’), or the name SAFNWC\_MSGx\_HRW\_yyyymmddhhmm\_rrrrrrrrrrrr\_D.buf (for the ‘detailed AMV scale’), where “x” is the number of MSG satellite used, “yyymmddhhmm” is the date and time of the processed slot and “rrrrrrrrrr” is the region where the AMVs have been calculated.

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

The BUFR table used for the writing of the AMVs in the BUFR output file considering this format (identified as \$SAFNWC/import/Aux\_data/PGE09/B0000000000214012094.TXT) is shown in Table 13. It is based on BUFR Master Table number 0, Version number 12, although with some specific parameters for the NWC SAF BUFR output bulletins identified as 060xxx.

For all parameters in the table, the first column shows the “Parameter identification code”, the second column shows the “Parameter description”, the third column shows the “Unit used for the codification of the parameter (in some cases identified through a Code Table)”, the fourth column shows the “Number of decimals used in the codification of the parameter (where a value of 1 is used for a precision of one decimal place and a value of -1 is used for a precision only up to the tens)”, the fifth column shows the “Default value of the parameter” and the sixth column shows the “Number of bits used for the parameter codification and so the maximum value the parameter can have (for example, for parameter 060203/Number of available wind guess levels the maximum value of the parameter is  $2^7 = 128$ ).

Formally, several different BUFR messages with AMVs calculated for an only MSG/SEVIRI channel, in each case with an only Subset of up to 1000 AMVs (winds), are included in this AMV BUFR output file. An example of a decoded AMV BUFR file with one message with the first AMV is also shown in Table 14.

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

Table 13: BUFR table for AMV BUFR output files with NWC SAF specific BUFR format

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

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

- Code Table 060103, Height assignment method:

Values 0 to 3 are related to ‘Brightness temperature interpolation height assignment method’ and values 8 to 15 are related to ‘CCC height assignment method’. Although defined in this table, due to the actual implementation of HRW algorithm, values 2, 9, 11 are never used in reality.

- 0 for ‘NWP interpolation using Top pressure in a Clear air AMV’
- 1 for ‘NWP interpolation using Top pressure in a Cloudy AMV’
- 2 for ‘NWP interpolation using Base pressure in a Clear air AMV’
- 3 for ‘NWP interpolation using Base pressure in a Cloudy AMV’
- 8 for ‘CCC method using lower threshold and the cold branch in a Clear air AMV’
- 9 for ‘CCC method using lower threshold and the warm branch in a Clear air AMV’
- 10 for ‘CCC method using higher threshold and the cold branch in a Clear air AMV’
- 11 for ‘CCC method using higher threshold and the warm branch in a Clear air AMV’
- 12 for ‘CCC method using lower threshold and the cold/dark branch in a Cloudy AMV’
- 13 for ‘CCC method using lower threshold and the warm/bright branch in a Cloudy AMV’
- 14 for ‘CCC method using higher threshold and the cold/dark branch in a Cloudy AMV’
- 15 for ‘CCC method using higher threshold and the warm/bright branch in a Cloudy AMV’.

- Code Table 060201, Correlation test:

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

- Code Table 060202, Applied Quality tests:

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

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

- Code Table 060205, Orographic flag:

Values between 0 and 6, corresponding to those defined in Chapter 3.1.2.2.9 of this document.

- Code Table 060205, Cloud type:

Values between 0 and 23, corresponding to those defined in Chapter 3.1.2.2.4 of this document.

- Code Table 060207, Wind channel (MSG channel used for the wind calculation):

- 0 for ‘HRVIS’ 1 for ‘VIS06’ 2 for ‘VIS08’ 5 for ‘WV062’
- 6 for ‘WV073’ 9 for ‘IR108’ 10 for ‘IR120’.

```
:BUFR: # EDITION = 4
  0 # MBUFR Error code
:SEC1:
  0 # BUFR MASTER TABLE
214 # ORIGINATING CENTER: Madrid
  0 # ORIGINATING SUBCENTER
  0 # UPDATE SEQUENCE NUMBER
  5 # DATA CATEGORY: Single level upper-air data (satellite)
  0 # DATA SUBCATEGORY
  0 # LOCAL DATA SUBCATEGORY
 12 # BUFR MASTER TABLE VERSION NUMBER
 94 # LOCAL TABLE VERSION NUMBER
2009 # YEAR
  9 # MONTH
 20 # DAY
 12 # HOUR
  0 # MINUTE
:SEC3:
  1 # Num.subsets
 47 # Num.descriptors
  0 # Flag for Compressed data (1=compressed 0=uncompressed)
 001007
 001031
 001032
 002023
 002057
 002152
 002153
 002154
 004001
 004002
 004003
 004004
 004005
 004025
 005044
 033035
 060000
 060001
 127000
 031002
 060100
 060101
 002028
 002029
 002164
 005001
 006001
 005011
 006011
 007004
 011001
 011002
 012001
 033007
 033007
 060102
 060103
 060200
 060201
 060202
 060203
 060204
 060205
 060206
 060207
 060208
 060209
```

```

:SEC4:
21943 # N. VARIABLES !!!
:SUBSET 00001:
    56.00000 # 1) 001007-SATELLITE IDENTIFIER
    214.00000 # 2) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
    94.00000 # 3) 001032-GENERATING APPLICATION
    2.00000 # 4) 002023-SATELLITE DERIVED WIND COMPUTATION METHOD
    2.00000 # 5) 002057-ORIGIN OF FIRST GUESS INFORMATION
    9.00000 # 6) 002152-SATELLITE INSTRUMENT USED IN DATA PROCESSING
399699991330816.00000 # 7) 002153-SATELLITE CHANNEL CENTRE FREQUENCY (Hz)
749499978874880.00000 # 8) 002154-SATELLITE CHANNEL BAND WIDTH (Hz)
    2009.00000 # 9) 004001-YEAR (YEAR)
    9.00000 # 10) 004002-MONTH (MONTH)
    20.00000 # 11) 004003-DAY (DAY)
    12.00000 # 12) 004004-HOUR (HOUR)
    0.00000 # 13) 004005-MINUTE (MINUTE)
    15.00000 # 14) 004025-TIME PERIOD OR DISPLACEMENT (MINUTE)
    49.00000 # 15) 005044-SATELLITE CYCLE NUMBER (NUMERIC)
    0.00000 # 16) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
    24.00000 # 17) 060000-SEGMENT SIZE AT NADIR IN X DIRECTION (PIXELS) (PIX)
    24.00000 # 18) 060001-SEGMENT SIZE AT NADIR IN Y DIRECTION (PIXELS) (PIX)
    812.00000 # 19) 031002-EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR
    1.00000 # 20) 060100-WIND SEQUENCE NUMBER (NUMERIC)
    1.00000 # 21) 060101-PRIOR WIND SEQUENCE NUMBER (NUMERIC)
29480.00000 # 22) 002028-SEGMENT SIZE AT NADIR IN X DIRECTION (M)
76920.00000 # 23) 002029-SEGMENT SIZE AT NADIR IN Y DIRECTION (M)
    2.00000 # 24) 002164-TRACER CORRELATION METHOD
    60.29326 # 25) 005001-LATITUDE (HIGH ACCURACY) (DEGREE)
   -18.98530 # 26) 006001-LONGITUDE (HIGH ACCURACY) (DEGREE)
    0.13866 # 27) 005011-LATITUDE INCREMENT (HIGH ACCURACY) (DEGREE)
    0.36284 # 28) 006011-LONGITUDE INCREMENT (HIGH ACCURACY) (DEGREE)
39000.00000 # 29) 007004-PRESSURE (PA)
    232.00000 # 30) 011001-WIND DIRECTION (DEGREE TRUE)
    28.00000 # 31) 011002-WIND SPEED (M/S)
    243.50000 # 32) 012001-TEMPERATURE (K)
    85.00000 # 33) 033007-PER CENT CONFIDENCE (WITH FORECAST TEST) (%)
    88.00000 # 34) 033007-PER CENT CONFIDENCE (WITHOUT FORECAST TEST) (%)
    0.00000 # 35) 060102-TRACER TYPE
    15.00000 # 36) 060103-HEIGHT ASSIGNMENT METHOD
    3.00000 # 37) 060200-NUMBER OF WINDS COMPUTED FOR THE TRACER (NUMERIC)
    3.00000 # 38) 060201-CORRELATION TEST
    956.00000 # 39) 060202-APPLIED QUALITY TESTS
    15.00000 # 40) 060203-NUMBER OF AVAILABLE NWP WIND GUESS LEVELS (NUMERIC)
    1.00000 # 41) 060204-NUMBER OF PREDECESSOR WINDS (NUMERIC)
    5.00000 # 42) 060205-OROGRAPHIC INDEX
    12.00000 # 43) 060206-CLOUD TYPE (SAFNWC/MSG)
    0.00000 # 44) 060207-WIND CHANNEL (SEVIRI CHANNEL ID)
    90.00000 # 45) 060208-CORRELATION (%)
    3500.00000 # 46) 060209-PRESSURE ERROR (PA)

```

..., etc

*Table 14: Example of decoded AMV BUFR output file with NWC SAF specific BUFR format, with the first AMV in the output file.*

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 54/78
---	--	--

### 3.2.4.1.2 AMV/Wind BUFR bulletins with Eumetsat/MPEF format

When BUFR\_OUTPUT\_FORMAT = EUM, an AMV BUFR bulletin equivalent to those defined for the AMV extraction at the Meteosat Product Extraction Facility in Eumetsat is written under the name SAFNWC\_MSGx\_HRW\_yyyymmddhhmm\_rrrrrrrrrrrrr\_BEUM.buf (for the ‘single or basic AMV scale’), or the name SAFNWC\_MSGx\_HRW\_yyyymmddhhmm\_rrrrrrrrrrrrr\_DEUM.buf (for the ‘detailed AMV scale’) in \$SAFNWC/export/PGE09 directory, where “x” is the number of MSG satellite used, “yyymmddhhmm” is the date and time of the processed slot and “rrrrrrrrrrr” is the region where the AMVs have been calculated.

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

The BUFR template used for the writing of the AMVs in the BUFR output file considering this format (which is similar to the ones described for the MPEF AMVs at Eumetsat website at <http://www.eumetsat.int/Home/Main/DataProducts/Formats/index.htm>), and which is based on BUFR Master Table number 0, Version number 12 (identified by HRW algorithm as \$SAFNWC/import/Aux\_data/PGE09/B0000000000000012000.TXT), is shown in Table 15, with some explanation underlined and in italics of the content of the different parameters when used by HRW algorithm.

Formally, the Eumetsat/MPEF AMV BUFR format is a kind a blend of the NWC SAF AMV and Trajectory BUFR specific formats, because of including at the same time the information related to the reference AMV to be used (which depending on the value of USE\_MEANWIND configurable parameter can be similar to the latest AMV in any HRW trajectory, or the mean value of the latest two AMVs in the HRW trajectory, which is also the information provided in the AMV BUFR files with the NWC SAF specific BUFR format), and information related to the up to four latest AMVs in any HRW trajectory (which is the information provided in the Trajectory BUFR files with the NWC SAF specific BUFR format, which are explained later in Chapter 3.1.6.2.). Considering this, when configurable parameter BUFR\_OUTPUT\_FORMAT = EUM is defined, only the AMV BUFR bulletin with the Eumetsat/MPEF format is provided, and no Trajectories BUFR bulletins are provided.

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

Formally, several different BUFR messages with up to 100 Subsets with an only AMVs, all of them related to the same MSG/SEVIRI channel, are included in this AMV BUFR output file. An example of a decoded AMV BUFR file with one Subset with the first AMV (related to a trajectory including two elements) is also shown in Table 16.

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

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

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

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

```
:BUFR: # EDITION = 4
      0 # MBUFR Error code
:SECL:
      0 # BUFR MASTER TABLE
    214 # ORIGINATING CENTER: Madrid
      0 # ORIGINATING SUBCENTER
      3 # UPDATE SEQUENCE NUMBER
      5 # DATA CATEGORY: Single level upper-air data (satellite)
      0 # DATA SUBCATEGORY
      0 # LOCAL DATA SUBCATEGORY
     11 # BUFR MASTER TABLE VERSION NUMBER
      1 # LOCAL TABLE VERSION NUMBER
    2009 # YEAR
      9 # MONTH
     20 # DAY
     12 # HOUR
      0 # MINUTE
:SEC3:
    100 # Num.subsets
    278 # Num.descriptors
      0 # Flag for Compressed data (1=compressed 0=uncompressed)
    001007
    001031
    002020
    002028
    002029
    004001
    004002
    004003
    004004
    004005
    004006
    005001
    006001
    002152
    002023
    007004
    011001
    011002
    002153
    002154
    012071
    002163
    002164
    008012
    007024
    002057
    008021
    004001
    004002
    004003
    004004
    008021
    004024
    008021
    004004
    004005
    004006
    008021
    004004
    004005
```



```
012001
222000
236000
031031 (Descriptor repeated 103 times)
001031
001032
033007 (Descriptor repeated 4 times)
222000
237000
001031
001032
033035 (Descriptor repeated 4 times)
222000
237000
001031
001032
033036 (Descriptor repeated 4 times)
222000
237000
001031
001032
033007 (Descriptor repeated 4 times)
222000
237000
001031
001032
033035 (Descriptor repeated 4 times)
222000
237000
001031
001032
033036 (Descriptor repeated 4 times)
222000
237000
001031
001032
033007 (Descriptor repeated 4 times)
222000
237000
001031
001032
033035 (Descriptor repeated 4 times)
222000
237000
001031
001032
033036 (Descriptor repeated 4 times)
222000
237000
001031
001032
033007 (Descriptor repeated 4 times)
222000
237000
001031
001032
033035 (Descriptor repeated 4 times)
222000
237000
001031
001032
033036 (Descriptor repeated 4 times)
:SEC4:
278 # N. VARIABLES !!!
:SUBSET 00001:
    56.00000 # 1) 001007-SATELLITE IDENTIFIER
   214.00000 # 2) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
   333.00000 # 3) 002020-SATELLITE CLASSIFICATION
      Null # 4) 002028-SEGMENT SIZE AT NADIR IN X DIRECTION (M)
      Null # 5) 002029-SEGMENT SIZE AT NADIR IN Y DIRECTION (M)
  2009.00000 # 6) 004001-YEAR (YEAR)
     9.00000 # 7) 004002-MONTH (MONTH)
    20.00000 # 8) 004003-DAY (DAY)
    12.00000 # 9) 004004-HOUR (HOUR)
     0.00000 # 10) 004005-MINUTE (MINUTE)
     0.00000 # 11) 004006-SECOND (SECOND)
    60.29326 # 12) 005001-LATITUDE/HIGH ACCURACY (DEGREE)
```

-18.98530 #	13) 006001-LONGITUDE/HIGH ACCURACY (DEGREE)
9.00000 #	14) 002152-SATELLITE INSTRUMENT USED IN DATA PROCESSING
2.00000 #	15) 002023-SATELLITE DERIVED WIND COMPUTATION METHOD
39000.00000 #	16) 007004-PRESSURE (PA)
232.00000 #	17) 011001-WIND DIRECTION (DEGREE TRUE)
28.00000 #	18) 011002-WIND SPEED (M/S)
399699991330816.00000 #	19) 002153-SATELLITE CHANNEL CENTRE FREQUENCY (Hz)
749499978874880.00000 #	20) 002154-SATELLITE CHANNEL BAND WIDTH (Hz)
Null #	21) 012071-COLDEST CLUSTER TEMPERATURE (K)
14.00000 #	22) 002163-HEIGHT ASSIGNMENT METHOD
2.00000 #	23) 002164-TRACER CORRELATION METHOD
Null #	24) 008012-LAND/SEA QUALIFIER
70.22000 #	25) 007024-SATELLITE ZENITH ANGLE (DEGREE)
2.00000 #	26) 002057-ORIGIN OF FIRST GUESS INFORMATION
Null #	27) 008021-TIME SIGNIFICANCE
Null #	28) 004001-YEAR (YEAR)
Null #	29) 004002-MONTH (MONTH)
Null #	30) 004003-DAY (DAY)
Null #	31) 004004-HOUR (HOUR)
1.00000 #	32) 008021-TIME SIGNIFICANCE
15.00000 #	33) 004024-TIME PERIOD OR DISPLACEMENT
28.00000 #	34) 008021-TIME SIGNIFICANCE
11.00000 #	35) 004004-HOUR (HOUR)
45.00000 #	36) 004005-MINUTE (MINUTE)
0.00000 #	37) 004006-SECOND (SECOND)
29.00000 #	38) 008021-TIME SIGNIFICANCE
12.00000 #	39) 004004-HOUR (HOUR)
0.00000 #	40) 004005-MINUTE (MINUTE)
0.00000 #	41) 004006-SECOND (SECOND)
232.00000 #	42) 011001-WIND DIRECTION (DEGREE TRUE)
28.00000 #	43) 011002-WIND SPEED (M/S)
28.00000 #	44) 008021-TIME SIGNIFICANCE
11.00000 #	45) 004004-HOUR (HOUR)
30.00000 #	46) 004005-MINUTE (MINUTE)
0.00000 #	47) 004006-SECOND (SECOND)
29.00000 #	48) 008021-TIME SIGNIFICANCE
11.00000 #	49) 004004-HOUR (HOUR)
45.00000 #	50) 004005-MINUTE (MINUTE)
0.00000 #	51) 004006-SECOND (SECOND)
232.00000 #	52) 011001-WIND DIRECTION (DEGREE TRUE)
27.90000 #	53) 011002-WIND SPEED (M/S)
Null #	54) 008021-TIME SIGNIFICANCE
Null #	55) 004004-HOUR (HOUR)
Null #	56) 004005-MINUTE (MINUTE)
Null #	57) 004006-SECOND (SECOND)
Null #	58) 008021-TIME SIGNIFICANCE
Null #	59) 004004-HOUR (HOUR)
Null #	60) 004005-MINUTE (MINUTE)
Null #	61) 004006-SECOND (SECOND)
Null #	62) 011001-WIND DIRECTION (DEGREE TRUE)
Null #	63) 011002-WIND SPEED (M/S)
Null #	64) 008021-TIME SIGNIFICANCE
Null #	65) 004004-HOUR (HOUR)
Null #	66) 004005-MINUTE (MINUTE)
Null #	67) 004006-SECOND (SECOND)
Null #	68) 008021-TIME SIGNIFICANCE
Null #	69) 004004-HOUR (HOUR)
Null #	70) 004005-MINUTE (MINUTE)
Null #	71) 004006-SECOND (SECOND)
Null #	72) 011001-WIND DIRECTION (DEGREE TRUE)
Null #	73) 011002-WIND SPEED (M/S)

Null #	74)	002163-HEIGHT ASSIGNMENT METHOD
Null #	75)	007004-PRESSURE (PA)
Null #	76)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	77)	002163-HEIGHT ASSIGNMENT METHOD
Null #	78)	007004-PRESSURE (PA)
Null #	79)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	80)	002163-HEIGHT ASSIGNMENT METHOD
Null #	81)	007004-PRESSURE (PA)
Null #	82)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	83)	002163-HEIGHT ASSIGNMENT METHOD
39000.00000 #	84)	007004-PRESSURE (PA)
243.50000 #	85)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	86)	002163-HEIGHT ASSIGNMENT METHOD
Null #	87)	007004-PRESSURE (PA)
Null #	88)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	89)	002163-HEIGHT ASSIGNMENT METHOD
37700.00000 #	90)	007004-PRESSURE (PA)
242.10001 #	91)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	92)	002163-HEIGHT ASSIGNMENT METHOD
Null #	93)	007004-PRESSURE (PA)
Null #	94)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	95)	002163-HEIGHT ASSIGNMENT METHOD
Null #	96)	007004-PRESSURE (PA)
Null #	97)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	98)	002163-HEIGHT ASSIGNMENT METHOD
Null #	99)	007004-PRESSURE (PA)
Null #	100)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
Null #	101)	002163-HEIGHT ASSIGNMENT METHOD
Null #	102)	007004-PRESSURE (PA)
Null #	103)	012001-TEMPERATURE/DRY-BULB TEMPERATURE (K)
0.00000 #	104)	222000-
0.00000 #	105)	236000-
Null #	106)	031031-DATA PRESENT INDICATOR Repeated 103 times up to
Null #	208)	031031-DATA PRESENT INDICATOR
214.00000 #	209)	001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
1.00000 #	210)	001032-GENERATING APPLICATION
85.00000 #	211)	033007-PER CENT CONFIDENCE (%)
78.00000 #	212)	033007-PER CENT CONFIDENCE (%)
Null #	213)	033007-PER CENT CONFIDENCE (%)
Null #	214)	033007-PER CENT CONFIDENCE (%)
0.00000 #	215)	222000-
0.00000 #	216)	237000-
214.00000 #	217)	001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
1.00000 #	218)	001032-GENERATING APPLICATION
0.00000 #	219)	033035-MANUAL/AUTOMATIC QUALITY CONTROL
0.00000 #	220)	033035-MANUAL/AUTOMATIC QUALITY CONTROL
Null #	221)	033035-MANUAL/AUTOMATIC QUALITY CONTROL
Null #	222)	033035-MANUAL/AUTOMATIC QUALITY CONTROL
0.00000 #	223)	222000-
0.00000 #	224)	237000-
214.00000 #	225)	001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
1.00000 #	226)	001032-GENERATING APPLICATION
70.00000 #	227)	033036-NOMINAL CONFIDENCE THRESHOLD (%)
70.00000 #	228)	033036-NOMINAL CONFIDENCE THRESHOLD (%)
Null #	229)	033036-NOMINAL CONFIDENCE THRESHOLD (%)
Null #	230)	033036-NOMINAL CONFIDENCE THRESHOLD (%)
0.00000 #	231)	222000-
0.00000 #	232)	237000-

```

214.00000 # 233) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
  2.00000 # 234) 001032-GENERATING APPLICATION
88.00000 # 235) 033007-PER CENT CONFIDENCE (%)
85.00000 # 236) 033007-PER CENT CONFIDENCE (%)
  Null # 237) 033007-PER CENT CONFIDENCE (%)
  Null # 238) 033007-PER CENT CONFIDENCE (%)
  0.00000 # 239) 222000-
  0.00000 # 240) 237000-
214.00000 # 241) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
  2.00000 # 242) 001032-GENERATING APPLICATION
  0.00000 # 243) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  0.00000 # 244) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  Null # 245) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  Null # 246) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  0.00000 # 247) 222000-
  0.00000 # 248) 237000-
214.00000 # 249) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
  2.00000 # 250) 001032-GENERATING APPLICATION
  Null # 251) 033036-NOMINAL CONFIDENCE THRESHOLD (%)
  Null # 252) 033036-NOMINAL CONFIDENCE THRESHOLD (%)
  Null # 253) 033036-NOMINAL CONFIDENCE THRESHOLD (%)
  Null # 254) 033036-NOMINAL CONFIDENCE THRESHOLD (%)
  0.00000 # 255) 222000-
  0.00000 # 256) 237000-
214.00000 # 257) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
  3.00000 # 258) 001032-GENERATING APPLICATION
63.00000 # 259) 033007-PER CENT CONFIDENCE (%)
58.00000 # 260) 033007-PER CENT CONFIDENCE (%)
  Null # 261) 033007-PER CENT CONFIDENCE (%)
  Null # 262) 033007-PER CENT CONFIDENCE (%)
  0.00000 # 263) 222000-
  0.00000 # 264) 237000-
214.00000 # 265) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
  3.00000 # 266) 001032-GENERATING APPLICATION
  0.00000 # 267) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  0.00000 # 268) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  Null # 269) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  Null # 270) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
  0.00000 # 271) 222000-
  0.00000 # 272) 237000-
214.00000 # 273) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
  3.00000 # 274) 001032-GENERATING APPLICATION
  14.00000 # 275) 033036-NOMINAL CONFIDENCE THRESHOLD (%)
  14.00000 # 276) 033036-NOMINAL CONFIDENCE THRESHOLD (%)
  Null # 277) 033036-NOMINAL CONFIDENCE THRESHOLD (%)
  Null # 278) 033036-NOMINAL CONFIDENCE THRESHOLD (%)

```

..., etc

*Table 16: Example of decoded AMV BUFR output file using the Eumetsat/MPEF BUFR format, with the first AMV in the output file (related to a trajectory with two elements)*

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 64/78
---	--	--

### 3.2.4.2 Trajectory BUFR bulletin

If the calculation and writing of trajectories is activated inside HRW algorithm with configurable parameters `CALCULATE_TRAJECTORIES = 1` and `BUFR_OUTPUT_FORMAT = NWC` (which is the default option in HRW v4.0 algorithm), one file for the trajectories related to the single AMV scale, or two different files for the trajectories related to the two different AMV scales (‘Basic winds’ and ‘Detailed winds’, when so configured with configurable parameter `CDET = ALL` or `RANGE`), in form of BUFR bulletins are produced for each processed region for every running slot. If trajectories have been calculated for several MSG/SEVIRI channels, they are all included in the same BUFR bulletin. It is important here to remember that no Trajectory BUFR output file if the Eumetsat BUFR format is selected with configurable parameter `BUFR_OUTPUT_FORMAT = EUM`.

The Trajectory BUFR bulletin is written in `SSAFNWC/export/PGE09` directory under the name `SAFNWC_MSGx_HRW_yyyymmddhhmm_rrrrrrrrrrrrr_BTRAJ.buf` (for the ‘single or basic AMV scale’), or the name `SAFNWC_MSGx_HRW_yyyymmddhhmm_rrrrrrrrrrrrr_DTRAJ.buf` (for the ‘detailed AMV scale’), where “x” is the number of MSG satellite used, “yyymmddhhmm” is the date and time of the processed slot and “rrrrrrrrrrr” is the region where the AMVs have been calculated.

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

The BUFR specific table used for the writing of the Trajectories in the BUFR output file (identified as `SSAFNWC/import/Aux_data/PGE09/B0000000000214012097.TXT`), which is rather similar to the one used for the writing of the AMVs, is shown as Table 17. It is based on BUFR Master Table number 0, Version number 12, although with some specific parameters for the NWC SAF BUFR output bulletins identified as 060xxx. It behaves similarly as explained in Chapter 3.1.6.1.1 for the AMV BUFR bulletins using the NWC SAF specific format. The Code Tables used for the NWC SAF specific BUFR output parameters (also characterized as 060xxx), are exactly the same ones used in Chapter 3.1.6.1.1. All other Code Tables are similarly described in the BUFR Reference Manual [RD.20].

Formally, different BUFR messages with an only Subset with one Trajectory each (with up to 24 AMVs in the trajectory), are included in this Trajectory BUFR output file. An example of a decoded Trajectory BUFR file with one message with a trajectory is shown as Table 18.

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

Table 17: BUFR table for the Trajectory output file

```
:BUFR: # EDITION = 4
      0 # MBUFR Error code
:SEC1:
      0 # BUFR MASTER TABLE
    214 # ORIGINATING CENTER: Madrid
      0 # ORIGINATING SUBCENTER
      0 # UPDATE SEQUENCE NUMBER
      5 # DATA CATEGORY: Single level upper-air data (satellite)
      0 # DATA SUBCATEGORY
      0 # LOCAL DATA SUBCATEGORY
     12 # BUFR MASTER TABLE VERSION NUMBER
     97 # LOCAL TABLE VERSION NUMBER
    2009 # YEAR
       9 # MONTH
      20 # DAY
      12 # HOUR
       0 # MINUTE
:SEC3:
      1 # Num.subsets
     38 # Num.descriptors
      0 # Flag for Compressed data (1=compressed 0=uncompressed)
    001007
    001031
    001032
    002023
    002057
    002152
    002153
    002154
    004001
    004002
    004003
    004004
    004005
    004025
    005044
    033035
    060000
    060001
    060102
    117000
    031002
    002164
    005001
    006001
    005011
    006011
```

007004  
011001  
011002  
012001  
033007  
033007  
060103  
060205  
060206  
060207  
060208  
060209

:SEC4:

54 # N. VARIABLES !!!

:SUBSET 00001:

56.00000 #	1) 001007-SATELLITE IDENTIFIER
214.00000 #	2) 001031-IDENTIFICATION OF ORIGINATING/GENERATING CENTRE
97.00000 #	3) 001032-GENERATING APPLICATION
2.00000 #	4) 002023-SATELLITE DERIVED WIND COMPUTATION METHOD
2.00000 #	5) 002057-ORIGIN OF FIRST GUESS INFORMATION
9.00000 #	6) 002152-SATELLITE INSTRUMENT USED IN DATA PROCESSING
399699991330816.00000 #	7) 002153-SATELLITE CHANNEL CENTRE FREQUENCY (Hz)
749499978874880.00000 #	8) 002154-SATELLITE CHANNEL BAND WIDTH (Hz)
2009.00000 #	9) 004001-YEAR (YEAR)
9.00000 #	10) 004002-MONTH (MONTH)
20.00000 #	11) 004003-DAY (DAY)
12.00000 #	12) 004004-HOUR (HOUR)
0.00000 #	13) 004005-MINUTE (MINUTE)
15.00000 #	14) 004025-TIME PERIOD OR DISPLACEMENT (MINUTE)
49.00000 #	15) 005044-SATELLITE CYCLE NUMBER (NUMERIC)
0.00000 #	16) 033035-MANUAL/AUTOMATIC QUALITY CONTROL
24.00000 #	17) 060000-SEGMENT SIZE AT NADIR IN X DIRECTION (PIXELS) (PIX)
24.00000 #	18) 060001-SEGMENT SIZE AT NADIR IN Y DIRECTION (PIXELS) (PIX)
1.00000 #	19) 060104-TRAJECTORY SEQUENCE NUMBER (NUMERIC)
2.00000 #	20) 031002-EXTENDED DELAYED DESCRIPTOR REPLICATION FACTOR
2.00000 #	21) 002164-TRACER CORRELATION METHOD
60.29326 #	22) 005001-LATITUDE (HIGH ACCURACY) (DEGREE)
-18.98530 #	23) 006001-LONGITUDE (HIGH ACCURACY) (DEGREE)
0.13866 #	24) 005011-LATITUDE INCREMENT (HIGH ACCURACY) (DEGREE)
0.36284 #	25) 006011-LONGITUDE INCREMENT (HIGH ACCURACY) (DEGREE)
39000.00000 #	26) 007004-PRESSURE (PA)
232.00000 #	27) 011001-WIND DIRECTION (DEGREE TRUE)
28.00000 #	28) 011002-WIND SPEED (M/S)
243.50000 #	29) 012001-TEMPERATURE (K)
85.00000 #	30) 033007-PER CENT CONFIDENCE (WITH FORECAST TEST) (%)
88.00000 #	31) 033007-PER CENT CONFIDENCE (WITHOUT FORECAST TEST) (%)
1.00000 #	32) 060103-HEIGHT ASSIGNMENT METHOD

```

5.00000 # 33) 060205-OROGRAPHIC INDEX
12.00000 # 34) 060206-CLOUD TYPE (SAFNWC/MSG)
0.00000 # 35) 060207-WIND CHANNEL (SEVIRI CHANNEL ID)
90.00000 # 36) 060208-CORRELATION (%)
3500.00000 # 37) 060209-PRESSURE ERROR (PA)
2.00000 # 38) 002164-TRACER CORRELATION METHOD
60.15894 # 39) 005001-LATITUDE (HIGH ACCURACY) (DEGREE)
-19.34028 # 40) 006001-LONGITUDE (HIGH ACCURACY) (DEGREE)
0.13753 # 41) 005011-LATITUDE INCREMENT (HIGH ACCURACY) (DEGREE)
0.36005 # 42) 006011-LONGITUDE INCREMENT (HIGH ACCURACY) (DEGREE)
37700.00000 # 43) 007004-PRESSURE (PA)
232.00000 # 44) 011001-WIND DIRECTION (DEGREE TRUE)
27.90000 # 45) 011002-WIND SPEED (M/S)
242.10001 # 46) 012001-TEMPERATURE (K)
78.00000 # 47) 033007-PER CENT CONFIDENCE (WITH FORECAST TEST) (%)
85.00000 # 48) 033007-PER CENT CONFIDENCE (WITHOUT FORECAST TEST) (%)
1.00000 # 49) 060103-HEIGHT ASSIGNMENT METHOD
6.00000 # 50) 060205-OROGRAPHIC INDEX
12.00000 # 51) 060206-CLOUD TYPE (SAFNWC/MSG)
0.00000 # 52) 060207-WIND CHANNEL (SEVIRI CHANNEL ID)
91.00000 # 53) 060208-CORRELATION (%)
3300.00000 # 54) 060209-PRESSURE ERROR (PA)

```

:7777:

*Table 18: Example of decoded Trajectory BUFR output file with one trajectory*

### 3.2.5 Examples of High Resolution Winds visualisation

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

Next figures show typical displays of HRW product for AMVs and Trajectories considering “Nominal scan mode” in a Continental area (a 772x1856 VIS\_IR pixel region over Europe and the Mediterranean Sea), for both “Basic scale” (which is the default option) and “Detailed scale” of winds. In the AMV display, two different colour codings based on the AMV pressure level and the MSG/SEVIRI channel used for the calculation, have been used.

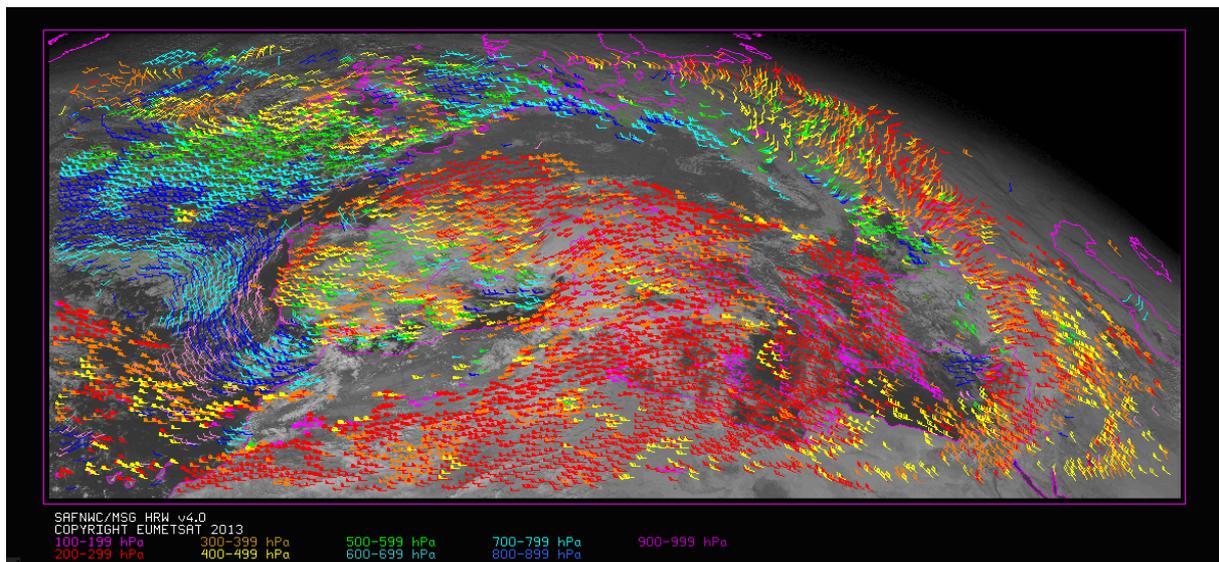


Figure 13: High Resolution Winds AMV output example in the European and Mediterranean Continental region (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), considering the default conditions defined in \$SAFNWC/config/safnwc\_pge09.cfm model configuration file. Colour coding based on the AMV pressure level

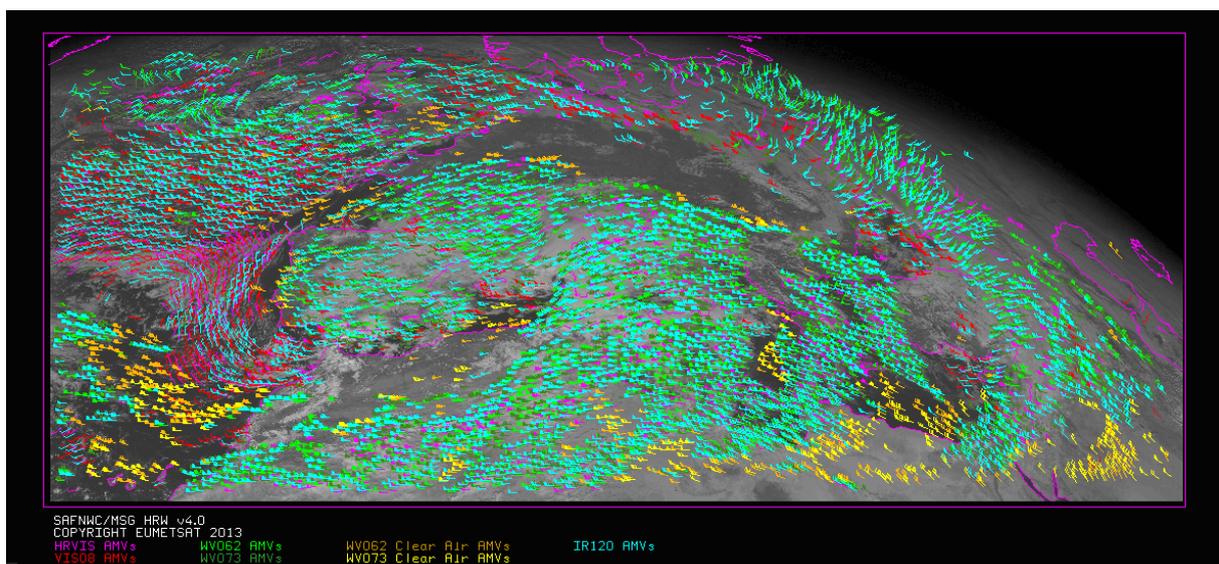


Figure 14: High Resolution Winds AMV output example in the European and Mediterranean Continental region (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), considering the default conditions defined in \$SAFNWC/config/safnwc\_pge09.cfm model configuration file. Colour coding based on the SEVIRI channel used in the AMV calculation

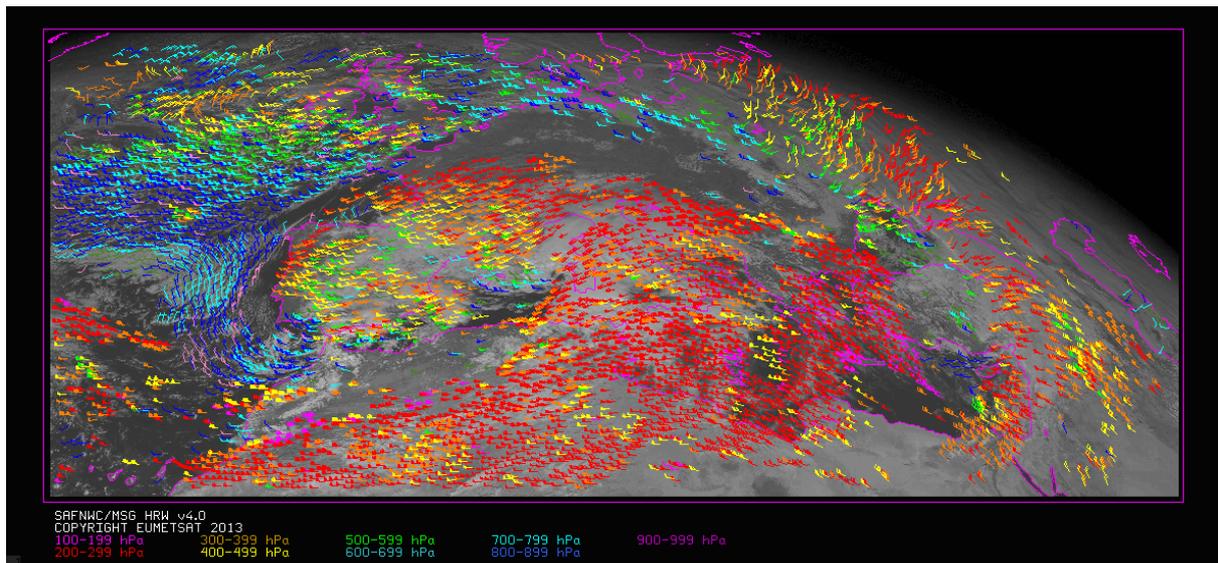


Figure 15: High Resolution Winds AMV output example in the European and Mediterranean Continental region (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), for the Detailed scale when the Two Scale configuration (with Basic and Detailed Winds) has been used (for this option, the model configuration file \$SAFNWC/config/safnwc\_pge09.cfm is modified with CDET=ALL). Colour coding based on the AMV pressure level

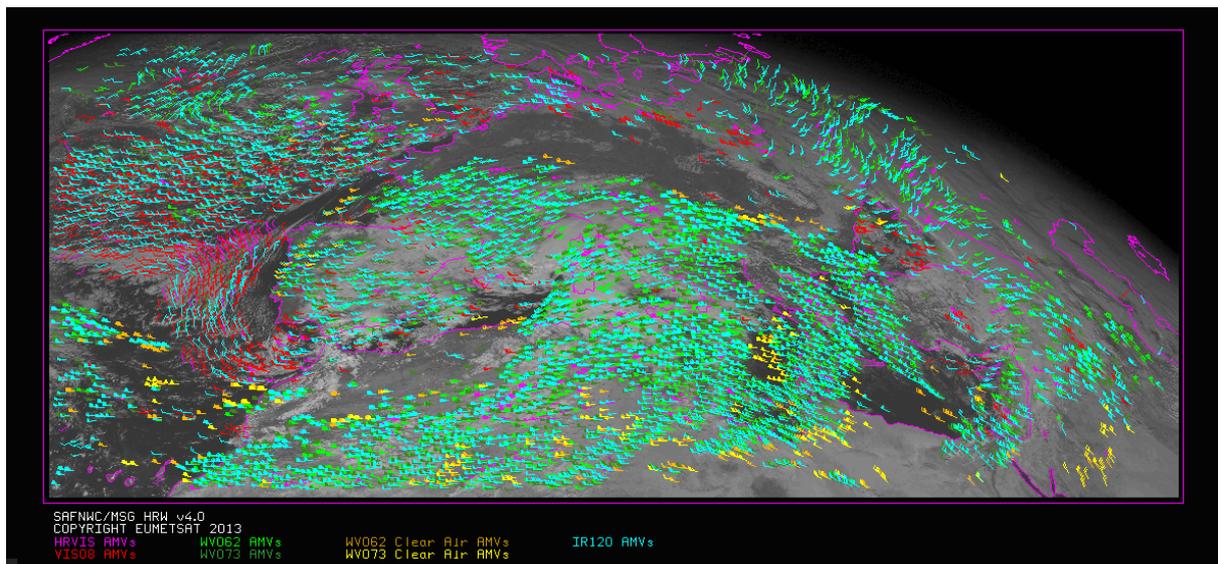


Figure 16: High Resolution Winds AMV output example in the European and Mediterranean Continental region (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite), for the Detailed scale when the Two Scale configuration (with Basic and Detailed Winds) has been used (for this option, the model configuration file \$SAFNWC/config/safnwc\_pge09.cfm is modified with CDET=ALL). Colour coding based on the SEVIRI channel used in the AMV calculation.

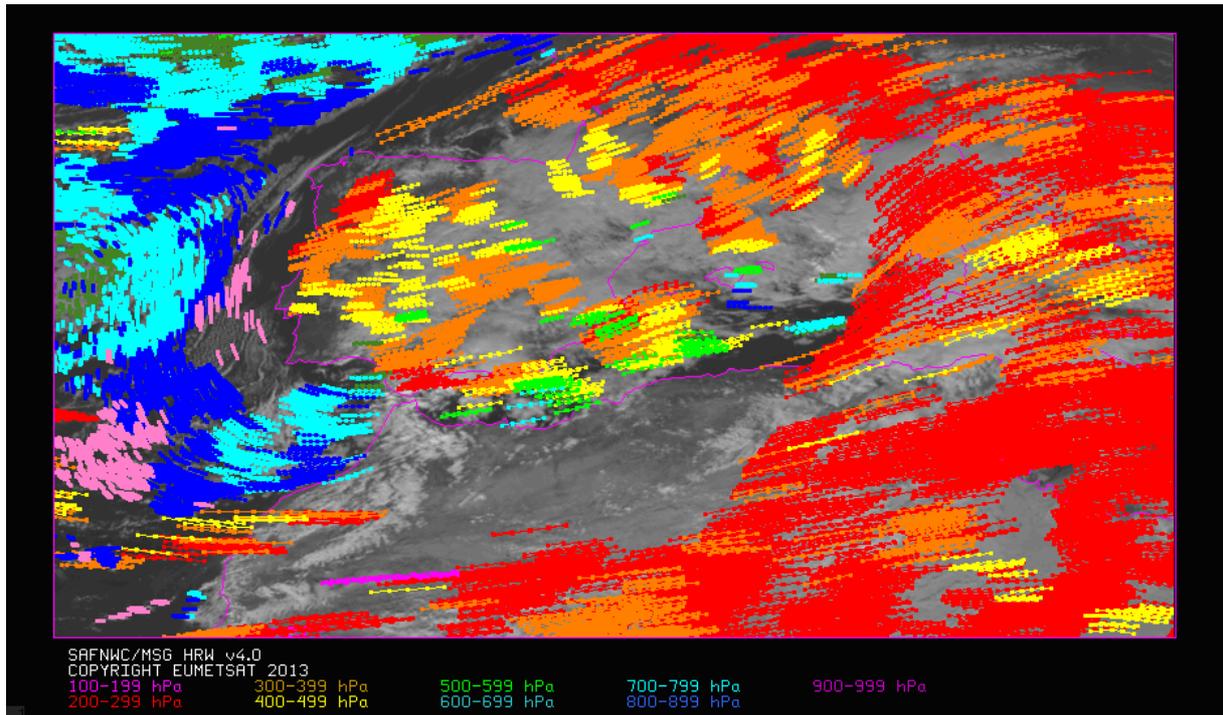


Figure 17: High Resolution Winds Trajectory output example (for trajectories lasting at least one hour up to 1200Z) in a zoomed area around the Iberian Peninsula, in the example defined in Figures 13 and 14 (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)

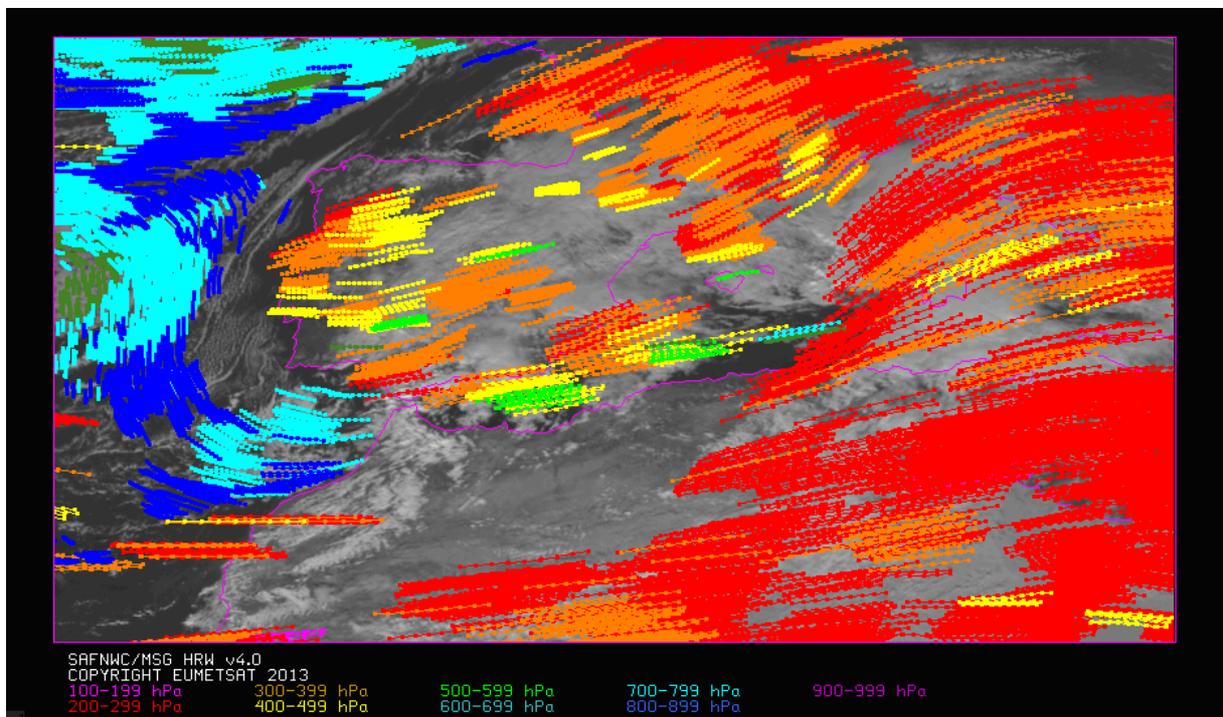


Figure 18: High Resolution Winds Trajectory output example (for trajectories lasting at least three hours up to 1200Z) in a zoomed area around the Iberian Peninsula, in the example defined in Figures 13 and 14 (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)

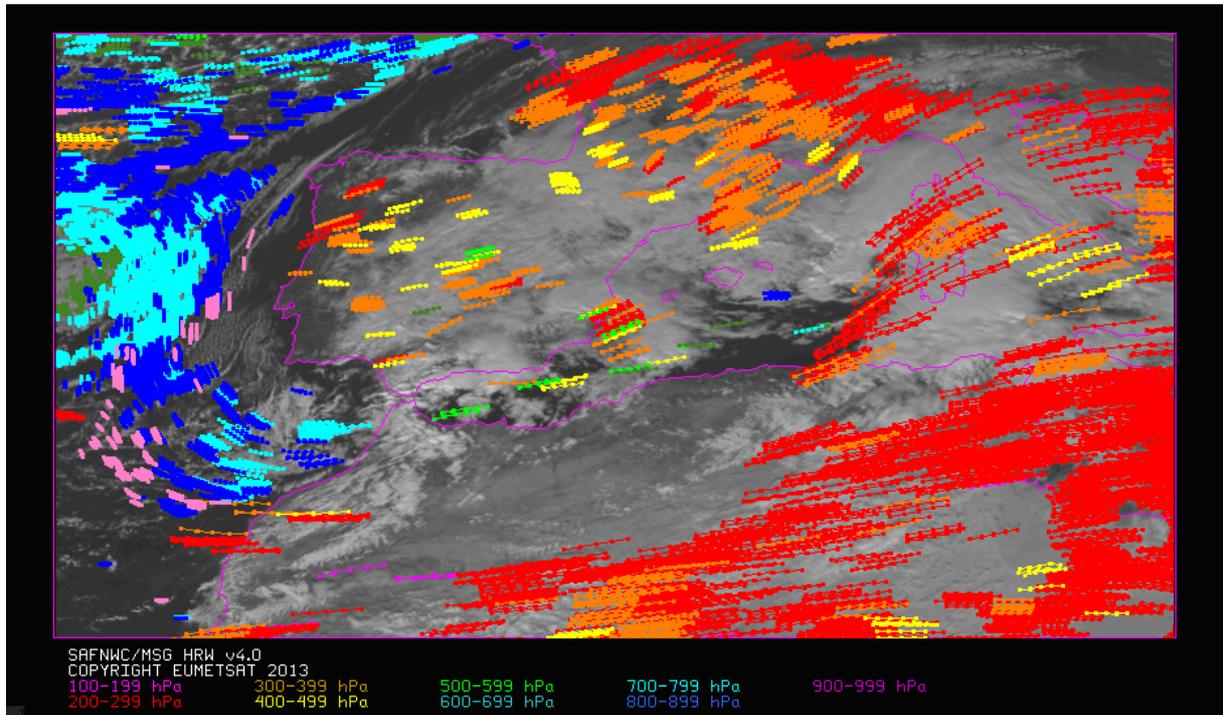


Figure 19: High Resolution Winds Trajectory output example for the Detailed scale (for trajectories lasting at least one hour up to 1200Z) in a zoomed area around the Iberian Peninsula, in the example defined in Figures 15 and 16 (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)

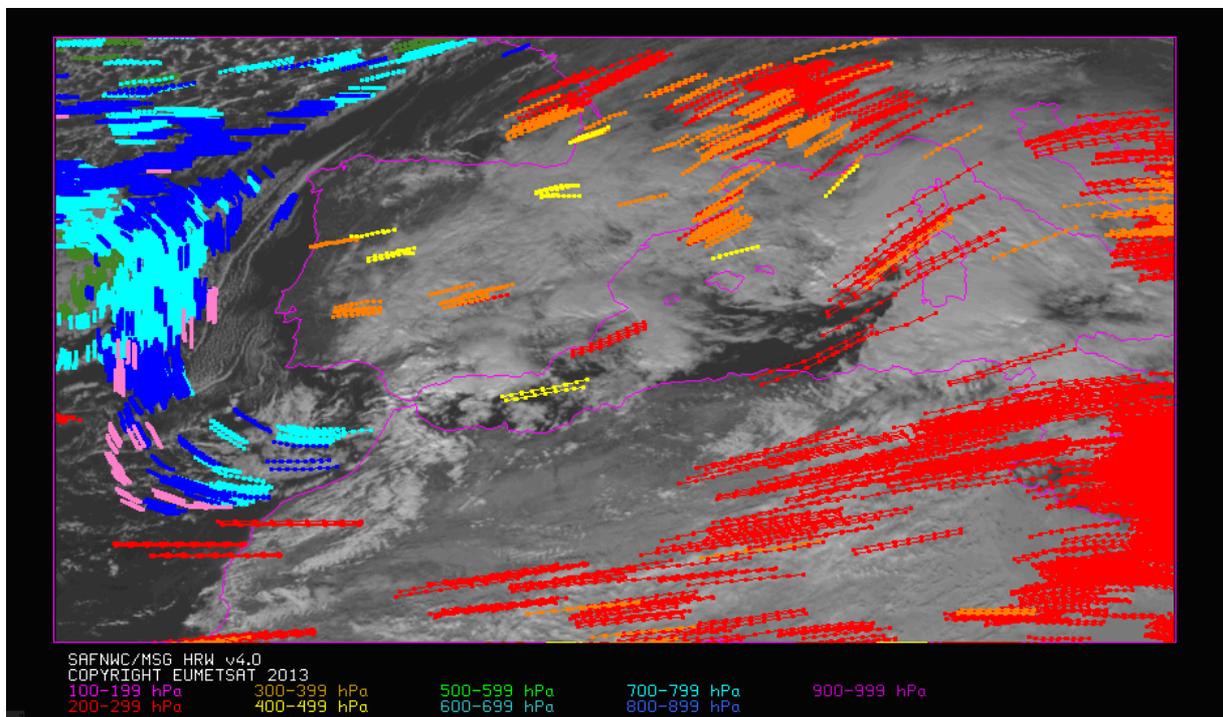


Figure 20: High Resolution Winds Trajectory output example for the Detailed scale (for trajectories lasting at least three hours up to 1200Z) in a zoomed area around the Iberian Peninsula, in the example defined in Figures 15 and 16 (26 December 2009 1200Z, Nominal scan mode, MSG2 satellite)

	Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)	<b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 73/78
---	--	--

### 3.2.6 Implementation of High Resolution Winds

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

#### 3.2.6.1 The HRW installation and preparation step

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

Once the user has obtained the necessary permissions to download the software package, the software installation procedure does not require special resources. It is restricted to decompress the distribution file (a gzip compressed tar file) and to successfully build the executable (PGE09 file), to be stored into the \$SAFNWC/bin directory. The installation steps for HRW must follow the “Software Version Description Document” [AD.6].

#### 3.2.6.2 The HRW execution step

The execution step is the processing of SEVIRI images with HRW algorithm in the region defined by the user. The HRW running time scheduling relies on the Programmed Task Definition File. This process consists in the running of the command HRW along with the required parameters (slot, region file and model configuration file) by the Task manager. The next 3 figures summarise how the tasks to generate the High Resolution Winds, described in the algorithm section 3.1.2.2, are then performed by the PGE09 executable.

The operational use of SAFNWC/MSG software requires the definition of the Region Configuration File `config/safnwc_region.cfg` (document [AD.3] must be verified about how the region can be defined).

The user has also to define the Model Configuration File to be used. Two different files are provided with the software: `config/safnwc_pge09.cfm` and `config/safnwc_pge09_rss.cfm`, to be used respectively with ‘Nominal scan mode’ and ‘Rapid Scan mode’. The implementation of the running mode depends on the satellite configuration and the corresponding `config/sat_conf_file` used.

The Rapid Scan mode is only recommended to be used in relatively small areas (“National areas”), if all SAFNWC/MSG products have to run together and a relatively small environment has been used for the installation of SAFNWC/MSG software. With the five minute running constraint imposed by the ‘Rapid scan mode’, this permits the repeating of the process with all available satellite slots. In a “Continental area” it is generally not possible to run all SAFNWC/MSG products operatively in ‘Rapid scan mode’. [AD.12] document should be verified for more information on this.

Each configuration file is an ASCII file, so further modifications can be easily performed with a text editor. The HRW model configuration file manages all variables in the executable file that are useful for the user.

It is important to remind the usefulness of the SAFNWC/MSG PGE02 and PGE03 output data for a better height assignment process and a better validation. To have this file available it is then necessary to run PGE01, PGE02 and PGE03 executables before PGE09 for the same slot and region.

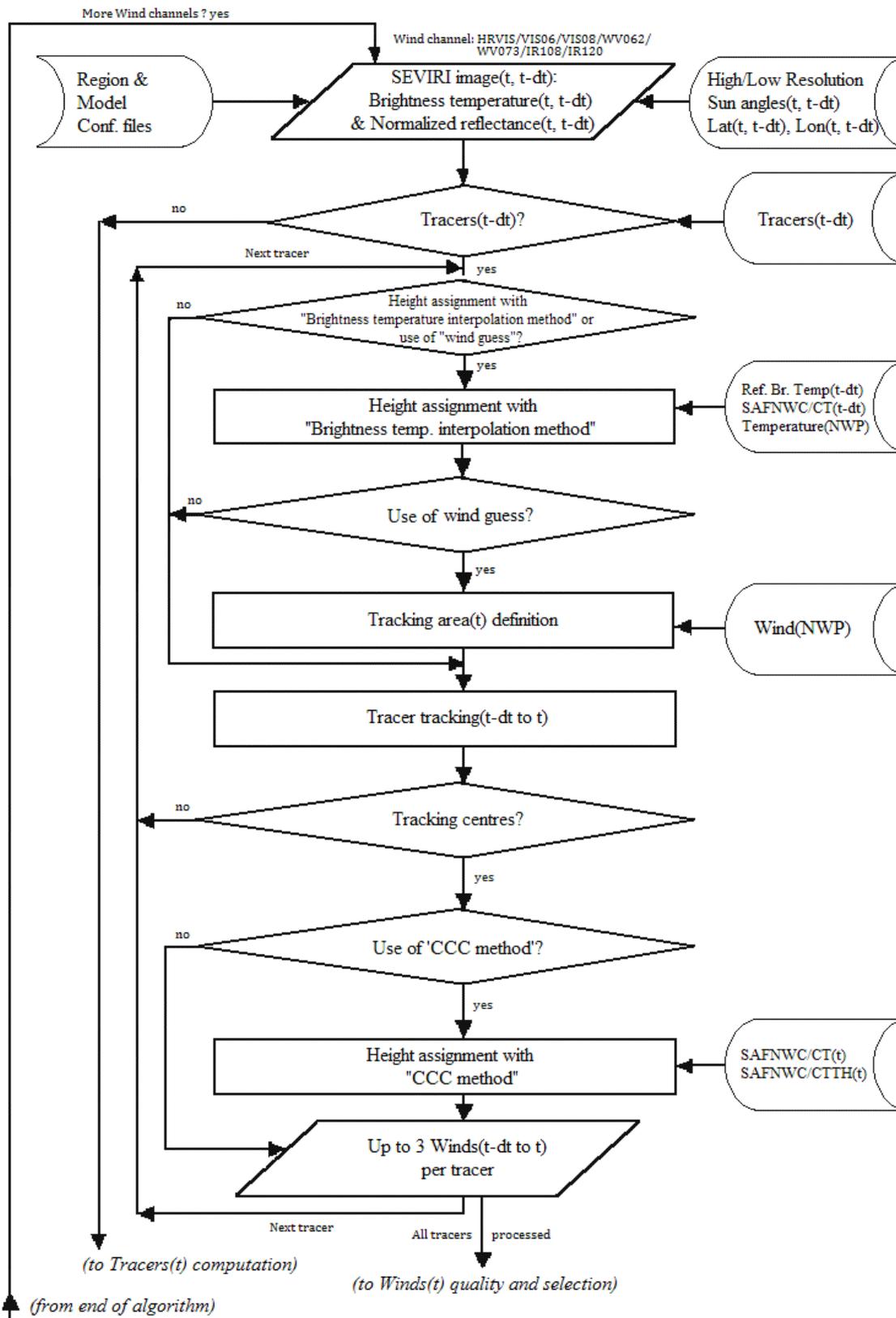


Figure 21: HRW implementation: Part 1, Preprocessing and wind computation.

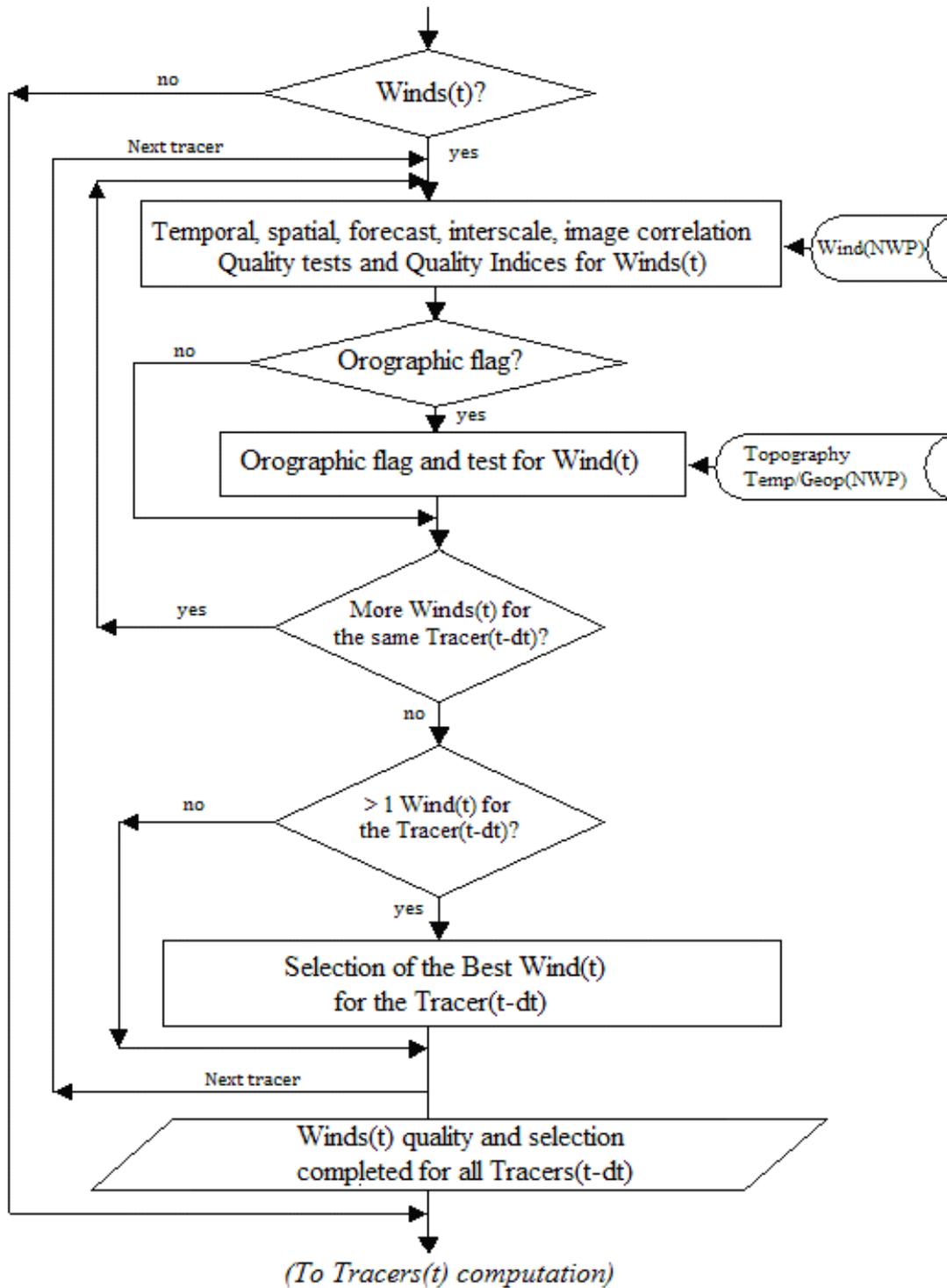


Figure 22: HRW implementation: Part 2, Wind quality and selection.

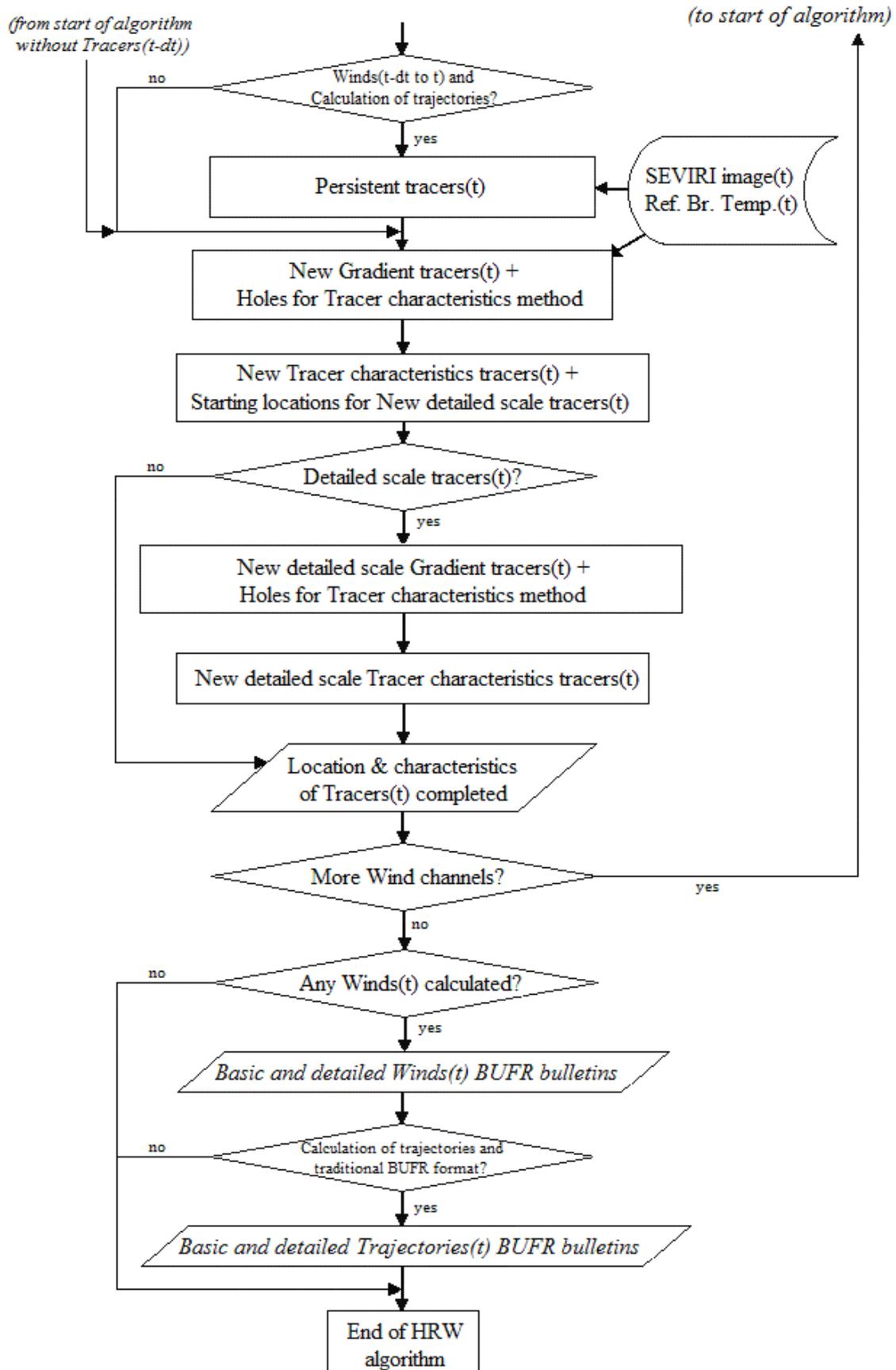


Figure 23: HRW implementation: Part 3, Tracer computation and writing of BUFR output.

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 77/78</p>
---	--	--

### 3.2.7 High Resolution Winds Product assumptions and limitations

The main circumstance that has to be taken into account when using the High Resolution Winds product is the variability with time of the amount of available data, related to the evolution with time in the working region of cloudy areas (or cloudless areas with humidity patterns in the water vapour images, if clear air water vapour Atmospheric Motion Vectors are considered).

Nevertheless, the situation has improved since version HRW v3.2. Previously, the applicability of HRW algorithm was limited to cloudy areas because of considering HRVIS and IR108 channels only. The new AMVs at HRW v3.2 related to humidity patterns in the water vapour channels (WV062, WV073) show for the first time wind vectors in clear air areas. Besides, the possibility to calculate AMVs with up to seven different SEVIRI channels increases significantly the density of AMV data.

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

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

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

The first problem is solved not using the wind guess (with WIND\_GUESS = 0), which despite the increases in the running time of HRW algorithm it implies (because of using a larger ‘tracking area’), the latest optimizations included in HRW v4.0 make this configuration fully operative as the default option in HRW algorithm. Considering this, users should keep this configuration in their use of HRW algorithm, so reducing the dependence of their AMVs on the NWP model.

The second problem is solved using the “Quality index without forecast” in the operation of HRW algorithm (implemented in HRW v4.0 with QI\_THRESHOLD\_USEFORECAST = 0), which avoids the influence of the NWP model in the Quality of the AMVs. Nevertheless, this option has not been considered as the default one because the impact of the NWP model in the Quality of the AMVs is considered to be generally more positive than negative.

- In the height assignment (in general the main remaining challenge that scientists are currently facing with AMV extraction), if the ‘HRW old method’ is used small errors in the temperature profile can cause important errors in the heights assigned to the tracers. Besides, in this case the assumption is taken that the temperature is supposed to diminish constantly with higher levels throughout the atmosphere. Due to this, problems in the level assignment appear when a temperature inversion is present. (This problem is solved since HRW v3.1 using the ‘CCC height assignment method’, where the ‘thermal inversion problem’ is solved using the PGE03 product output data).
- Considering all this, the use of the NWP model is nevertheless considered to be mandatory for the AMV height assignment in HRW v4.0 (directly through the ‘Brightness temperature interpolation height assignment, or indirectly through ‘CCC height assignment method’ related to SAFNWC/PGE03 Cloud top pressure output). The quality of the height assignment inferred in previous versions of HRW algorithm is considered not to be good enough to be used anymore, comparing with the general improvements in the Quality of the AMVs when the default configuration with NWP model is used).

	<p>Algorithm Theoretical Basis Document for “High Resolution Winds” (HRW - PGE09 v4.0)</p>	<p><b>Code:</b> SAF/NWC/CDOP2/INM/SCI/ATBD/09 <b>Issue:</b> 4.0 <b>Date:</b> 15 July 2013 <b>File:</b> SAF-NWC-CDOP2-INM-SCI-ATBD-09_v4.0.doc <b>Page:</b> 78/78</p>
---	--	--

With all of this, the important improvements in HRW versions v2.2, v3.0, v3.1, v3.2 and v4.0 have reduced the limitations HRW algorithm previous had.

First of all, the use of SAFNWC/MSG PGE02 output helps to eliminate wrong ground tracers identified as clouds in the visible and infrared channels (related to “cloud free land or sea” or “land or sea contaminated with ice or snow”), and to verify the different behaviours of the AMVs considering the Cloud type they are related to. Secondly, the use of SAFNWC/MSG PGE03 output with ‘CCC method’ in the height assignment includes several new procedures in the HRW algorithm (like the Radiance ratioing technique and the H2O/IRW intercept method for the definition of the AMV height related to semitransparent clouds), which have improved the statistics of the AMVs related to the semitransparent cloud types respect to the previous versions of the algorithm.

The adaptation of HRW algorithm in versions v3.0 and v3.2 to up to seven SEVIRI channels (HRVIS, VIS06, VIS08, WV062, WV073, IR108, IR120) has also helped to extend the AMV calculation to all hours of the day, and to both cloudy and clear air areas, following the necessities and suggestions of NWC SAF users. This eliminates the temporal limitation to daytime that HRW algorithm previously had. The extension in this version to calculate winds in the Rapid scan mode, permits also to obtain new winds every five minutes with every new MSG Rapid scan slot, increasing the amount of available AMVs in a 15 minute time lapse by a factor of around 3 respect to ‘Nominal scan mode’.

The default configuration not using the ‘wind guess’ in the definition of the ‘tracking area’ and the introduction of the ‘Quality index without forecast’ in HRW v4.0 (reducing the influence of the NWP model in the calculation and definition of the quality of the AMVs) also contribute to improve the general quality of HRW AMVs.

Considering finally the most important new element included in HRW algorithm v4.0, the calculation of trajectories through the successive tracking of the same tracer in consecutive slots, the most important limitation is the persistence in time of the tracers for the definition of the trajectories. To keep the quality of the corresponding AMVs, it has been considered necessary that the tracers should keep their characteristics (such as defined by ‘Gradient method’ or ‘Tracer characteristics method’) throughout the entire trajectory.

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

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