EUMETSAT NWC SAF

SUPPORT TO NOWCASTING AND VERY SHORT RANGE FORECASTING

Scientific and Validation Report for the Wind product processor of the NWC/GEO

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Applicable to GEO-HRW-v6.2 (NWC-086)

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DOCUMENT CHANGE RECORD

Version	Date	Pages	Changes
1.0	*21 January 2019*	46	Version for NWC/GEO-HRW v6.0 in NWC/GEO v2018, including changes proposed by the Developer and the Reviewers at the NWC/GEO v2018 DRR.
1.1	*18 December 2019*	54	Updated version for NWC/GEO-HRW v6.1 in NWC/GEO v2018.1.
2.0	*10 January 2022*	63	Updated version for NWC/GEO-HRW v6.2 in NWC/GEO v2021.
2.0.1	*28 February 2022*	63	Updated version for NWC/GEO-HRW v6.2 in NWC/GEO v2021, including changes proposed by the Developer and the Reviewers at the NWC/GEO v2021 DRR.

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1. INTRODUCTION

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

The main objective of the NWC SAF is to provide, develop and maintain software packages to be used with operational meteorological satellite data for Nowcasting applications. More information about the project can be found at the NWC SAF webpage, https://nwc-saf.eumetsat.int.

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

1.1 SCOPE OF THE DOCUMENT

This document is the "Scientific and Validation Report for the Wind Product Processor of the NWC/GEO" software package (GEO-HRW, High Resolution Winds), which calculates Atmospheric Motion Vectors (AMVs) and Trajectories considering:

- Up to seven channels from MSG/SEVIRI imager: six 3 km low resolution visible, water vapour and infrared channels (VIS06 0.635 μm, VIS08 0.810 μm, WV062 6.250 μm, WV073 7.350 μm, IR108 10.800 μm and IR120 12.000 μm), and the 1 km high resolution visible channel (HRVIS 0.750 μm).
- Up to three channels from GOES-N/IMAGER: two 4 km low resolution water vapour and infrared channels (WV065 6.550 μm and IR107 10.700 μm), and the 1 km high resolution visible channel (VIS07 0.650 μm).
- Up to six channels from Himawari-8/9/AHI imager: four 2 km low resolution water vapour and infrared channels (WV062 6.250 μm, WV069 6.950 μm, WV073 7.350 μm and IR112 11.200 μm), one 1 km high resolution visible channel (VIS08 0.860 μm), and the 0.5 km very high resolution visible channel (VIS06 0.645 μm).
- Up to six channels from GOES-R/ABI imager: four 2 km low resolution water vapour and infrared channels (WV062 6.150 μm, WV070 7.000 μm, WV074 7.400 μm and IR112 11.200 μm), one 1 km high resolution visible channel (VIS08 0.860 μm), and the 0.5 km very high resolution visible channel (VIS06 0.640 μm).

The adaptation for GOES-R satellite series has been extended in this version to GOES-17 satellite with some limitations: AMVs and Trajectories are calculated by NWC/GEO-HRW in the default mode for GOES-16 and GOES-17, only when Full Disk images in "Mode 6" are provided (with images every 10 minutes), for areas in the image where NWC/GEO-Cloud products could be calculated and the quality flag for the satellite channel used for AMV calculation is zero (optimal) for all pixels implied in the AMV calculation. This way, the quality of the AMVs and Trajectories is guaranteed, and the problems related to the cooling issue in the GOES-17 ABI imager are avoided, although this also implies that NWC/GEO-HRW output is not available 24 hours per day all days of the year.

With all this, NWC/GEO-HRW v6.2 is able to cover with five different simultaneous geostationary satellites the whole Earth, and AMVs and Trajectories can be calculated simultaneously throughout the whole planet, except in the moments around the Equinoxes in which GOES-17 cannot be processed.

There is a commitment so that the adaptation of NWC/GEO-HRW product to all these geostationary satellite series (MSG, GOES-N, Himawari-8/9 and GOES-R) is fully validated. The validation results for NWC/GEO-HRW v6.2 (calculated for MSG, GOES-13, Himawari-8, GOES-16 and GOES-17) and the conclusions related to the update to NWC/GEO-HRW v6.2, are available in this document.

As in previous versions of NWC/GEO-HRW, the validation has been based on the comparison of the NWC/GEO-HRW v6.2 AMVs with winds obtained from Radiosounding bulletins available from the GTS. The statistical indicators established in the "Report from the Working Group on Verification Statistics of the 3rd International Winds Workshop" [RD.12], with some amendments in the "Report from the Working Group on Verification & Quality Indices of the 4th International Winds Workshop" [RD.15]), are calculated to achieve this. These indicators have been thoroughly used throughout the

world for the Validation of Satellite winds through the comparison with Radiosounding winds. Since NWC/GEO-HRW v6.0 in NWC/GEO v2018, AMVs are also validated using ECMWF model analysis winds as additional reference. This permits to evaluate differences in behaviour and scale of NWC/GEO-HRW AMVs with respect to both reference winds used.

A comparison with the default configuration of NWC/GEO-HRW v6.0 in NWC/GEO v2018 software package (for AMVs related to MSG, GOES-N and Himawari-8/9 satellite series), and with the default configuration of NWC/GEO-HRW v6.1 in NWC/GEO-v2018.1 software package (for AMVs related to GOES-16 satellite), are also verified to show the improvements of NWC/GEO-HRW product since these versions. (NWC/GEO-HRW v6.1 was basically an extension of v6.0 to GOES-16 satellite). The similarities and differences found in the validation of NWC/GEO-HRW AMVs for the four different satellite series for which the algorithm is available (MSG, GOES-N, Himawari-8/9 and GOES-R), are also evaluated in this document.

1.2 SOFTWARE VERSION IDENTIFICATION

This document describes the algorithm implemented in NWC/GEO-HRW v6.2, Product Id NWC-086, of the NWC/GEO v2021 software package release.

1.3 IMPROVEMENTS FROM PREVIOUS VERSIONS

The main improvements related to NWC/GEO-HRW v6.2 are the following ones:

1. The extension of NWC/GEO-HRW algorithm to Himawari-9 and GOES-17 satellites, as for all other NWC/GEO products. Considering GOES-17 satellite, a specific adaptation of NWC/GEO-HRW code has been done to cope with the "cooling issues" in the GOES-17/ABI radiometer.

2. Optimisation of the running time of NWC/GEO-HRW product. With MSG, Himawari-8/9 and GOES-R satellites, a similar number of AMVs is calculated now in the default configurations with an up to 30% reduction in the running time with respect to NWC/GEO-HRW v6.1.
    - This has been done with the use of more effective operations and functions in the code (for example, avoiding multiplications and divisions by variable parameters when their value is one, using more effective operations and functions like the change of divisions and power operations for multiplications when possible, avoiding the repetitive use of the same costly operation more than once, etc.).
    - The optimisation has also been reached using equivalent but more effective processes in the parts of the code that were more time consuming (for example, making the “tracking” faster by defining the “tracking area” with the real dimensions of corresponding pixels).

3. Better distribution of AMVs in High/medium/low levels. For all satellites the proportion of medium and low level AMVs has increased at least a 9%, and for MSG satellites an optimal distribution of high/medium/low level AMVs of 35%/32%33% has been reached. This is useful for a better characterization of all levels of the troposphere in which AMVs are calculated (approximately between 140 and 1000 hPa).

4. The update of six SPRs occurring since the release of the previous NWC/GEO-HRW v6.1 version:
    - SPR-696 (Issue occurring in around 1% of cases).
    - SPR-697 (NWP management with missing levels).
    - SPR-706 (Option so that the satellite visible channels can be received in any resolution).
    - SPR-712 (Update of some HRW files so that the running keeps equivalent to previous versions under similar input data conditions).
    - SPR-717 (Error occurring when HRW is run in night conditions, related to updates included in HRW v6.2 and HRW vMTG).
    - SPR-721 (Small update of HRW height assignment for AMVs between 0-230 hPa, related to a study by the Hungarian Meteorological Service (OMSZ) in January 2021).

Comparing with NWC/GEO-HRW vMTG day-1, which will be the following version to be released, both codes are exactly equivalent with only the following seven differences:

1. Logically, NWC/GEO-HRW vMTG day-1 will be the first version supporting MTG-I satellite series, while NWC-GEO v6.2 still does not support it.
2. NWC/GEO-HRW v6.2 is the last version in which GOES-N satellite series is supported. In NWC/GEO-HRW vMTG day-1, processing in the Americas and Eastern Pacific will only be provided through GOES-R satellite series.
3. NWC/GEO-HRW v6.2 is the last version providing as output the BUFR bulletin based on the "previous International Winds Working Group (IWWG)" format. This format is being replaced by the BUFR bulletin based on the "2018 IWWG format". The IWWG gave AMV producers and users the recommendation in its 2018 Workshop to adopt this new AMV BUFR template (through action IWW14 – WG1 – Action 6) within one year after the definition of this new format, and in 2021 all AMV users should already be used to the new format.
4. In NWC/GEO-HRW v6.2 GRIB-API library is used for the encoding of the HRW BUFR bulletins. In NWC/GEO-HRW vMTG day-1, ECCODES library is used for the encoding of the HRW BUFR bulletins.
5. The structure of the NWC/GEO-HRW netCDF output changes between these two versions. In NWC/GEO-HRW vMTG day-1, the structure of this netCDF output will be CF compliant and easier to process (following recommendations from NWCSAF users).
6. The definition of the Earth ellipsoid changes for different satellites in NWC/GEO-HRW vMTG day-1, being defined as configurable parameters in different configuration files. In NWC/GEO-HRW v6.2, these parameters are similar for all satellites, so causing some small differences in the satellite navigation. This change affects all NWC/GEO products.
7. The structure of $SAFNWC temporal directory changes a bit between versions. This change affects all NWC/GEO products.

1.4 REFERENCES

1.4.1 Applicable Documents

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

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

Current documentation can be found at the NWC SAF Helpdesk web: http://nwc-saf.eumetsat.int.

Ref.	*Title*	*Code*	*Ver.*
[AD.1]	Proposal for the Third Continuous Development and Operations Phase (CDOP3)	NWC/CDOP3/SAF/AEMET/MGT/PRO	1.0
[AD.2]	Project Plan for the NWCSAF CDOP3 Phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.6
[AD.3]	Configuration Management Plan for the NWCSAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.1
[AD.4]	NWCSAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.5
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/1	2.0.1
[AD.6]	Data Output Format for the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/DOF	2.0.1
[AD.7]	Algorithm Theoretical Basis Document for the Wind product processor of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/ATBD/Wind	1.0.1
[AD.8]	User Manual for the Wind product processor of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/UM/Wind	2.0

Table 1. List of Applicable Documents

1.4.2 Reference Documents

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

Ref.	Title
[RD.1]	J.Schmetz, K.Holmlund, J.Hoffman, B.Strauss, B.Mason, V.Gärtner, A.Koch, L. van de Berg, 1993: Operational Cloud Motion Winds from Meteosat Infrared Images (Journal of Applied Meteorology, Num. 32, pp. 1206-1225).
[RD.2]	S.Nieman, J.Schmetz, W.P.Menzel, 1993: A comparison of several techniques to assign heights to cloud tracers (Journal of Applied Meteorology, Num. 32, pp. 1559-1568).
[RD.3]	C.M.Hayden & R.J.Purser, 1995: Recursive filter objective analysis of meteorological fields, and application to NESDIS operational processing (Journal of Applied Meteorology, Num. 34, pp. 3-15).
[RD.4]	K.Holmlund, 1998: The utilisation of statistical properties of satellite derived Atmospheric Motion Vectors to derive Quality Indicators (Weather and Forecasting, Num. 13, pp. 1093-1104).
[RD.5]	J.M.Fernández, 1998: A future product on HRVIS Winds from the Meteosat Second Generation for nowcasting and other applications. (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.6]	J.M.Fernández, 2000: Developments for a High Resolution Wind product from the HRVIS channel of the Meteosat Second Generation. (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.7]	J.M.Fernández, 2003: Enhancement of algorithms for satellite derived winds: the High Resolution and Quality Control aspects. (Proceedings 2003 Meteorological Satellite Conference, EUMETSAT Pub.39).
[RD.8]	J.García-Pereda & J.M.Fernández, 2006: Description and validation results of High Resolution Winds product from HRVIS MSG channel at the EUMETSAT Nowcasting SAF (Proceedings 8th International Wind Workshop, EUMETSAT Pub.47).
[RD.9]	J.García-Pereda, 2008: Evolution of High Resolution Winds Product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.10]	J.García-Pereda, 2010: New developments in the High Resolution Winds product (HRW), at the Satellite Application Facility on support to Nowcasting and Very short range forecasting (Proceedings 10th International Wind Workshop, EUMETSAT Pub.56).
[RD.11]	C.M.Hayden & R.T.Merrill, 1988: Recent NESDIS research in wind estimation from geostationary satellite images (ECMWF Seminar Proceedings: Data assimilation and use of satellite data, Vol. II, pp.273-293).
[RD.12]	W.P.Menzel, 1996: Report on the Working Group on verification statistics. (Proceedings 3rd International Wind Workshop, EUMETSAT Pub.18).
[RD.13]	J.Schmetz, K.Holmlund, A.Ottenbacher, 1996: Low level winds from high resolution visible imagery. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.14]	Xu J. & Zhang Q., 1996: Calculation of Cloud motion wind with GMS-5 images in China. (Proceedings 3rd international winds workshop, EUMETSAT Pub.18).
[RD.15]	K.Holmlund & C.S.Velden, 1998: Objective determination of the reliability of satellite derived Atmospheric Motion Vectors (Proceedings 4th International Wind Workshop, EUMETSAT Pub.24).
[RD.16]	K.Holmlund, C.S.Velden & M.Rohn, 2000: Improved quality estimates of Atmospheric Motion Vectors utilising the EUMETSAT Quality Indicators and the UW/CIMSS Autoeditor (Proceedings 5th International Wind Workshop, EUMETSAT Pub.28).
[RD.17]	R.Borde & R.Oyama, 2008: A direct link between feature tracking and height assignment of operational Atmospheric Motion Vectors (Proceedings 9th International Wind Workshop, EUMETSAT Pub.51).
[RD.18]	J.García-Pereda, R.Borde & R.Randriamampianina, 2012: Latest developments in "NWC SAF High Resolution Winds" product (Proceedings 11th International Wind Workshop, EUMETSAT Pub.60).
[RD.19]	WMO Common Code Table C-1 (WMO Publication, available at https://library.wmo.int/doc_num.php?explnum_id=10722#page=956)
[RD.20]	WMO Code Tables and Flag Tables associated with BUFR/CREX table B, version 31 (WMO Publication, available at https://library.wmo.int/doc_num.php?explnum_id=10722#page=252)
[RD.21]	P.Lean, G.Kelly & S.Migliorini, 2014: Characterizing AMV height assignment errors in a simulation study (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.22]	Á.Hernández-Carrascal & N.Bormann, 2014: Cloud top, Cloud centre, Cloud layer – Where to place AMVs? (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.23]	K.Salonen & N.Bormann, 2014: Investigations of alternative interpretations of AMVs (Proceedings 12th International Wind Workshop, EUMETSAT Pub.63).
[RD.24]	D.Santek, J.García-Pereda, C.Velden, I.Genkova, S.Wanzong, D.Stettner & M.Mindock, 2014: 2014 AMV Intercomparison Study Report - Comparison of NWC SAF/HRW AMVs with AMVs from other producers (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/225)
[RD.25]	D.Santek, R.Dworak, S.Wanzong, K.Winiecki, S.Nebuda, J.García-Pereda, R.Borde & M.Carranza, 2018: 2018 AMV Intercomparison Study Report (available at http://www.nwcsaf.org/aemetRest/downloadAttachment/5092)
[RD.26]	K.Salonen, J.Cotton, N.Bormann & M.Forsythe, 2015: Characterizing AMV height-assignment error by comparing best-fit pressure statistics from the Met Office and ECMWF data assimilation systems (Journal of Applied Meteorology and Climatology, Vol.54, Num.1).

Table 2. List of Reference Documents

2. DESCRIPTION OF THE VALIDATION PROCEDURE

2.1 VALIDATION PROCEDURE

The validation process for NWC/GEO-HRW v6.2 incorporates for each validated AMV both reference winds used in the validation: Radiosounding winds and ECMWF model analysis winds. To do this, relevant data for the validation (AMVs and NWP analysis reference winds from NWC/GEO-HRW AMV "NWC" BUFR output on one side, and the corresponding Radiosounding reference wind for each AMV extracted from Radiosounding wind profiles obtained from the GTS on the other side), are converted into McIDAS MD files following a scheme called WDMR.

The NWP analysis reference winds have been extracted by the autovalidation process included in NWC/GEO-HRW algorithm; the Radiosounding wind profiles are obtained through an intermediate McIDAS process.

The structure of data in this WDMR scheme is shown in the following table. The NWC/GEO-HRW validation process selects AMV data from the WDMR McIDAS MD file, considering the value of some specific parameters, and calculates the corresponding validation statistics. For validation against Radiosounding winds, elements in green in the table are used. For validation against NWP analysis winds, elements in blue in the table are used.

ROW/COLUMN ELEMENT	"NWC" BUFR DESCRIPTOR	PARAMETER MD ID.	WDMR SCHEME DESCRIPTION
Row 01	001007	SS	Satellite Identifier
Column 01	004001/002/003	DAY	Date
Column 02	004004/005	TIME	Time
Column 03	004025	INTT	Temporal interval (tracer to tracking centre)
Column 04	031002	CMAX	Number of NWC/GEO-HRW AMVs per Slot
Column 05	060000	TRAX	Segment size of tracer in X direction in pixels
Column 06	060001	TRAY	Segment size of tracer in Y direction in pixels
Column 07	060100	IDN	AMV sequence number inside the Slot
Column 08	060104	TYPE	Characterization as Basic or Detailed tracer, and Type of Detailed tracer
Column 09	002028	SIZX	Segment size of tracer in X direction in m
Column 10	002029	SIZY	Segment size of tracer in Y direction in m
Column 11	060103	TYPL	Characterization as Cloudy or Clear air wind, and Height assignment method used
Column 12	002164	TYPT	Euclidean Distance or Cross Correlation tracking
Column 13	005001	LAT	Initial latitude
Column 14	006001	LON	Initial longitude
Column 15	005011	DLAT	Latitude increment
Column 16	006011	DLON	Longitude increment
Column 17	012001	T	AMV Temperature
Column 18	007004	P	AMV Pressure
Column 19	011001	DIR	AMV Wind Direction
Column 20	011002	SPD	AMV Wind Speed
Column 21	033007	QI	AMV Quality index using forecast
Column 22	033007	QINF	AMV Quality index not using forecast
Column 23	033007	QIWG	AMV IWWG Common Quality index

ROW/COLUMN ELEMENT	"NWC" BUFR DESCRIPTOR	PARAMETER MD ID.	WDMR SCHEME DESCRIPTION
Column 24		QT	AMV Quality index threshold using forecast
Column 25		QTNF	AMV Quality index threshold not using forecast
Column 26		QTWG	AMV IWWG Common Quality index threshold
Column 27	060202	TES2	Two scale quality test flag
Column 28	060202	TEST	Temporal quality test flag
Column 29	060202	TESE	Spatial quality test flag
Column 30	060202	TESG	Forecast quality test flag
Column 31	060201	TESA	Correlation test flag
Column 32	060203	AVNW	Number of NWP levels used in HRW calculation
Column 33	060204	WPRE	Number of Predecessor AMVs in the trajectory
Column 34	060200	WREP	Number of Computed AMVs for the tracer
Column 35	060101	IDN0	Number of Predecessor AMV in the previous slot
Column 36	060205	FLAI	Orographic flag
Column 37	060202	TESI	Orographic test flag
Column 38	060206	CT	AMV NWC/GEO Cloud type
Column 39	060207	WCH	AMV NWC/GEO Satellite channel
Column 40	060208	CORR	Correlation between tracer and tracking centre
Column 41	060209	PERR	AMV Pressure error
Column 42	060210	PCORR	AMV Pressure correction (by Cloud Microphysics)
Column 43	060211	DIRN	NWP wind direction at AMV level
Column 44	060212	SPDN	NWP wind speed at AMV level
Column 45	060216	DIFN	Difference with NWP wind at AMV level
Column 46	060213	DRNB	NWP wind direction at AMV best fit level
Column 47	060214	SPNB	NWP wind speed at AMV best fit level
Column 48	060217	DFNB	Difference with NWP wind at AMV best fit level
Column 49	060215	PWNB	NWP pressure at AMV best fit level
Column 50		IDR	Radiosounding identifier
Column 51		LATR	Radiosounding latitude
Column 52		LONR	Radiosounding longitude
Column 53		DIRR	Radiosounding wind direction at AMV near level
Column 54		SPDR	Radiosounding wind speed at AMV near level
Column 55		DIFR	Difference with Radiosounding wind
Column 56		PWR	Radiosounding pressure at AMV near level
Column 57		DRRN	Radiosounding wind direction at AMV best fit
Column 58		SPRB	Radiosounding wind speed at AMV best fit level
Column 59		DFRB	Difference with Radiosounding wind
Column 60		PWRB	Radiosounding pressure at AMV best fit level

Table 3. Description of McIDAS WDMR Scheme and Correspondence with NWC/GEO-HRW "NWC" BUFR output

2.2 STATISTICAL PARAMETERS

The statistical parameters for the validation of NWC/GEO-HRW Atmospheric Motion Vectors (AMVs) are the ones proposed at the Third International Winds Workshop (Ascona, Switzerland, 1996), afterwards recommended by the Coordination Group for Meteorological Satellites (CGMS) for the international comparison of satellite winds.

A description of these statistical parameters is shown here:

1. NC: Number of collocations between the reference wind vectors (Radiosounding winds or NWP analysis winds) [Ur,Vr] and the NWC/GEO-HRW AMV wind vectors [Ui,Vi].
2. SPD: Mean horizontal wind speed in m/s for the reference winds (Radiosounding winds or NWP analysis winds).
3. BIAS: Difference between the mean horizontal wind speed of the reference winds (Radiosounding winds or NWP analysis winds), and the collocated NWC/GEO-HRW AMVs winds:

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}\left(\sqrt{U_i^2 + V_i^2} - \sqrt{U_r^2 + V_r^2}\right)$$

   It shows an estimation of the systematic error related to the calculation of the wind speed modulus (over- or underestimation of the mean AMV wind speed with respect to the mean reference wind speed). The index "i" here denotes each collocation and runs from 1 to the total number of collocations N.

4. MVD: Mean vector difference between the reference winds (Radiosounding winds or NWP analysis winds) and the collocated NWC/GEO-HRW AMV wind speeds:

$$MVD = \frac{1}{N}\sum_{i=1}^{N} VD_i$$

   It shows an estimation of the systematic error related to the calculation of vectors, for which:

$$VD_i = \sqrt{(U_i - U_r)^2 + (V_i - V_r)^2}$$

5. RMSVD: Root mean square vector difference:

$$RMSVD = \sqrt{(MVD)^2 + (SD)^2}$$

   It shows an estimation of the systematic and random error related to the calculation of the wind vectors. It is calculated through the Mean vector difference (MVD), and the Standard deviation (SD) of each vector difference with respect to the mean, for which:

$$SD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(VD_i - MVD)^2}$$

Due to the variable magnitude the defined statistical parameters can have in different samples, the mean horizontal wind speed for the reference winds (SPD, parameter 2) is used for normalization. So, the relative parameters related to the ones before:

3a. NBIAS = BIAS / SPD,

4a. NMVD = MVD / SPD,

5a. NRMSVD = RMSVD / SPD,

which are independent of the magnitude of the winds and can more easily be compared in different samples of data, are going to be used and presented throughout this Validation Report.

Considering the validation against Radiosounding winds, AMVs are compared to the nearest Radiosounding wind, with a maximum distance of 150 km and a maximum pressure difference of 25 hPa (standard limits defined for the comparison of AMVs with Radiosounding winds). This way, only a part of the AMVs can be validated against Radiosounding winds.

Considering the validation against NWP analysis winds, the interpolation of the NWP wind to the AMV location and level is used. This way, formally all AMVs can be validated against NWP analysis winds.

To ease the comparison of the validation of AMVs against both reference datasets (Radiosounding winds and NWP analysis winds), throughout this Validation report only AMVs which could be validated against both reference datasets are considered. Although the size of the AMV sample is so smaller, the number of AMV data validated against both datasets is exactly the same in all cases, and differences in the validation can be better extracted because of using exactly the same AMVs for each case.

3. VALIDATION OF HRW V6.2 AMVS WITH MSG SATELLITES

3.1 VALIDATION FOR BASIC AMVS WITH DEFAULT CONFIGURATION

The validation of NWC/GEO-HRW v6.2 algorithm for MSG satellite series is considered first. It is based on the validation of AMVs calculated during 354 days of the yearly period July 2009 – June 2010 at 12:00 UTC, with MSG-2 satellite images, in an area covering Europe and the Mediterranean Sea. This area is shown in *Figure 1*.

The default conditions for NWC/GEO-HRW v6.2 for MSG satellites, considering "Nominal scan satellite mode", "Basic scale AMVs", "Cross correlation tracking", "CCC height assignment method with Microphysics correction", and a "higher density for tracers related to medium and low level clouds", are considered first. These conditions are specified in the default model configuration files for MSG satellites `$SAFNWC/config/MSG*/safnwc_HRW.cfm`, but with validation of all possible satellite channels. Cloudy AMVs in the layer 100-1000 hPa and clear air AMVs in the layer 100-400 hPa, with a Quality index with forecast ≥ 75%, are considered for the validation. NWC/GEO-Cloud product outputs (CMA, CT, CTTH and CMIC) in the processing region have to be available so that NWC/GEO-HRW can fully process the conditions defined in the model configuration file. The running of three consecutive slots for all Cloud and HRW products every day during the reference validation period (11:30 UTC, 11:45 UTC and 12:00 UTC), is needed for the validation. An example of NWC/GEO-HRW output with this configuration is shown in *Figure 1*.

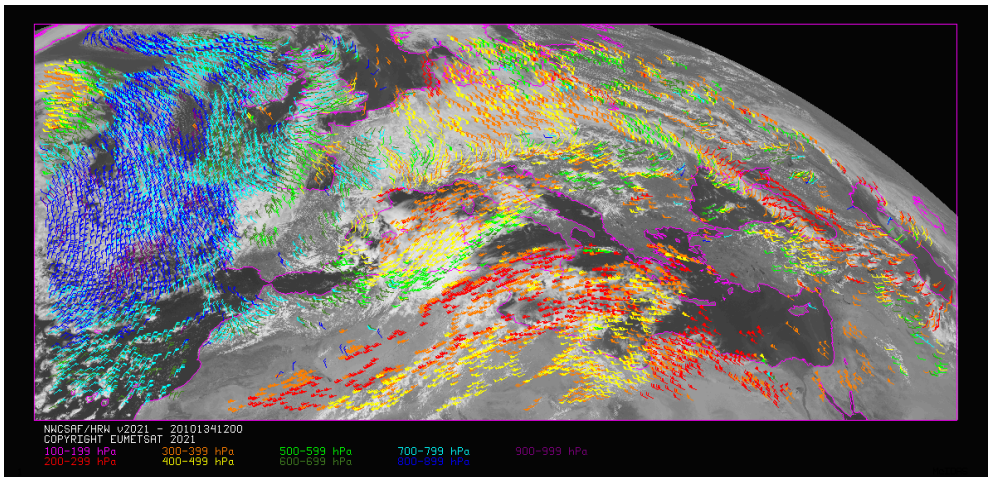


Figure 1: NWC/GEO-HRW v6.2 "Basic AMV" output example in the European and Mediterranean region (14 May 2010 12:00 UTC, MSG-2 satellite), considering default conditions defined in `$SAFNWC/config/MSG*/safnwc_HRW.cfm` model configuration files. Colour coding based on the AMV pressure level

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis in *Table 4* (considering all layers together) and in *Table 5* (considering the three layers separately), the NBIAS, NMVD and NRMSVD parameters are significantly smaller (around a 30% smaller) against NWP analysis winds. A conclusion can be taken here, that the general scale and behaviour of AMV winds is more similar to the one of NWP analysis winds than to the one of Radiosounding winds.

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

Considering the different layers, NWC/GEO-HRW Product Requirement Table "Optimal accuracy" (NRMSVD ≤ 0.35 against Radiosounding winds) is reached in the high layer, and the NWC/GEO-HRW Product Requirement Table "Target accuracy" (NRMSVD ≤ 0.50 and 0.56 respectively against Radiosounding winds) is reached in the medium and low layer.

NWC/GEO-HRWv6.2 AMVs (Jul 2009-Jun 2010, MSG-2	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC	87205	153088	138941	223076	225536	106108	210943	19460	1164357
SPD [m/s]	11.03	10.26	10.28	16.18	16.48	22.77	19.17	18.01	15.54
NBIAS (ALL LAYERS)	-0.05	-0.12	-0.13	-0.08	-0.07	-0.01	-0.03	+0.00	-0.07
NMVD (100-1000 hPa)	0.39	0.41	0.41	0.31	0.31	0.26	0.30	0.30	0.33
NRMSVD	0.46	0.48	0.49	0.38	0.38	0.32	0.37	0.37	0.40
NC	87205	153088	138941	223076	225536	106108	210943	19460	1164357
SPD [m/s]	10.80	9.95	9.99	15.89	16.20	22.40	18.83	17.98	15.24
NBIAS (ALL LAYERS)	-0.03	-0.10	-0.10	-0.06	-0.05	-0.00	-0.01	+0.00	-0.05
NMVD (100-1000 hPa)	0.25	0.28	0.29	0.21	0.21	0.17	0.20	0.23	0.22
NRMSVD	0.31	0.34	0.35	0.26	0.26	0.21	0.25	0.29	0.27

Table 4: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Basic AMVs

NWC/GEO-HRWv6.2 AMVs (Jul 2009-Jun 2010, MSG-2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC (35%)	7221			82709	88198	93040	116780	19460	407408
SPD [m/s]	22.17			21.86	21.83	23.48	22.68	18.01	22.28
NBIAS (HIGH LAYER)	-0.02			-0.06	-0.05	-0.02	-0.04	+0.00	-0.04
NMVD (100-400 hPa)	0.23			0.26	0.26	0.25	0.26	0.30	0.26
NRMSVD	0.28			0.31	0.31	0.31	0.32	0.37	0.32
NC (32%)	24251	44481	42496	85498	84967	13068	82282		377043
SPD [m/s]	12.05	11.79	11.73	14.36	14.61	17.73	15.30		13.99
NBIAS (MEDIUM LAYER)	-0.08	-0.14	-0.15	-0.08	-0.07	+0.04	-0.01		-0.07
NMVD (400-700 hPa)	0.37	0.37	0.38	0.35	0.35	0.36	0.37		0.36
NRMSVD	0.44	0.45	0.45	0.43	0.43	0.44	0.45		0.44
NC (33%)	55733	108607	96445	54869	52371		11881		379906
SPD [m/s]	9.14	9.63	9.65	10.43	10.51		11.50		9.86
NBIAS (LOW LAYER)	-0.05	-0.11	-0.12	-0.12	-0.11		-0.00		-0.10
NMVD (700-1000 hPa)	0.46	0.43	0.43	0.39	0.38		0.39		0.42
NRMSVD	0.54	0.50	0.51	0.46	0.46		0.47		0.49
NC (35%)	7221			82709	88198	93040	116780	19460	407408
SPD [m/s]	21.90			21.61	21.58	23.10	22.31	17.98	21.98
NBIAS (HIGH LAYER)	-0.01			-0.05	-0.04	-0.00	-0.03	+0.00	-0.03
NMVD (100-400 hPa)	0.14			0.16	0.16	0.16	0.16	0.23	0.16
NRMSVD	0.17			0.21	0.20	0.19	0.20	0.29	0.20
NC (32%)	24251	44481	42496	85498	84967	13068	82282		377043
SPD [m/s]	11.76	11.40	11.34	14.04	14.30	17.39	14.99		13.66
NBIAS (MEDIUM LAYER)	-0.06	-0.11	-0.12	-0.06	-0.05	+0.06	+0.01		-0.05
NMVD (400-700 hPa)	0.26	0.27	0.27	0.25	0.25	0.25	0.28		0.26
NRMSVD	0.32	0.34	0.33	0.31	0.31	0.31	0.35		0.33
NC (33%)	55733	108607	96445	54869	52371		11881		379906
SPD [m/s]	8.94	9.36	9.39	10.13	10.20		11.21		9.59
NBIAS (LOW LAYER)	-0.03	-0.09	-0.10	-0.09	-0.09		+0.02		-0.08
NMVD (700-1000 hPa)	0.29	0.29	0.29	0.26	0.26		0.31		0.28
NRMSVD	0.35	0.34	0.35	0.32	0.32		0.38		0.34

Table 5: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Basic AMVs

3.2 COMPARISON WITH HRW V6.0 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 default configuration for MSG satellite series with those for NWC/GEO-HRW v6.0 default configuration in *Tables 6 and 7* is considered here (NWC/GEO-HRW v6.1 was basically an extension of v6.0 to GOES-16 satellite).

The main element is that the distribution of AMVs in the different layers has changed significantly, going from a value of 52%/25%/23% for the High/Medium/Low layer in the previous version, to a much more homogeneous value in the new version of 35%/32%/33% (considering validated AMVs). This was a main objective of NWC/GEO-HRW v6.2, helping to better characterize the behaviour of the wind in the different levels of the troposphere.

The change is caused by the higher density of tracers related to medium and low level clouds, with both a relative and absolute increase of AMVs in the medium and low layer (with 38% more AMVs in the medium layer and 49% more AMVs in the low layer). Considering the high layer there is however a relative and absolute reduction in the number of AMVs (with 28% less AMVs in the high layer). Considering all layers together, there is nevertheless a 6% small increase in the total number of AMVs.

Comparing the validation parameters for NWC/GEO-HRW v6.2 with those for v6.0, considering all layers together the values are basically equivalent, with only a very slight 3% increase of the NMVD and NRMSVD values against Radiosoundings, which is only caused by the larger proportion now of medium and low layer AMVs, with higher validation parameters. Considering the different satellite channels, some of them improve their NBIAS while some other worsens it, all of them compensating without changes when considering all the AMVs together.

Considering each layer separately, the NMVD and NRMSVD keep similar values in v6.0 and v6.2 versions in the three layers, while the NBIAS shows in general against both Radiosoundings and NWP analysis winds up to 25% reductions in the high and medium layer, and up to 15% increases in the low layer, which compensate each other when considering all AMVs together.

With all this, a much better distribution of AMVs in the different vertical levels is reached with very similar validation statistics, and this can be considered a positive evolution of the AMVs for MSG satellite series with the new NWC/GEO-HRW version.

NWC/GEO-HRWv6.0 AMVs (Jul 2009-Jun 2010, MSG-2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC	67288	98861	90082	226314	228664	139042	227273	20383	1097907
SPD [m/s]	12.87	10.28	10.25	17.50	17.72	22.78	20.14	17.42	17.23
NBIAS (ALL LAYERS)	-0.03	-0.13	-0.13	-0.08	-0.07	-0.02	-0.05	+0.01	-0.07
NMVD (100-1000 hPa)	0.35	0.41	0.42	0.30	0.30	0.26	0.29	0.30	0.32
NRMSVD	0.42	0.49	0.49	0.37	0.37	0.32	0.36	0.37	0.39
NC	67288	98861	90082	226314	228664	139042	227273	20383	1097907
SPD [m/s]	12.72	9.99	9.98	17.19	17.41	22.37	19.76	17.23	16.91
NBIAS (ALL LAYERS)	-0.02	-0.10	-0.11	-0.07	-0.06	-0.01	-0.03	+0.02	-0.05
NMVD (100-1000 hPa)	0.22	0.28	0.29	0.20	0.20	0.17	0.19	0.22	0.22
NRMSVD	0.28	0.35	0.35	0.25	0.25	0.21	0.24	0.28	0.27

Table 6: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering all layers together against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.0 AMVs (Jul 2009-Jun 2010, MSG-2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC (52%)	15919			119091	124905	128731	157689	20383	566718
SPD [m/s]	21.13			21.85	21.81	23.23	22.63	17.42	22.19
NBIAS (HIGH LAYER)	-0.03			-0.07	-0.06	-0.03	-0.06	+0.01	-0.05
NMVD (100-400 hPa)	0.25			0.26	0.26	0.26	0.26	0.30	0.26
NRMSVD	0.30			0.32	0.32	0.32	0.32	0.37	0.32
NC (25%)	15447	31346	29700	65544	64179	10311	60432		276959
SPD [m/s]	12.88	11.72	11.49	14.29	14.44	17.13	14.95		13.91
NBIAS (MEDIUM LAYER)	-0.05	-0.15	-0.16	-0.09	-0.08	+0.04	-0.02		-0.08
NMVD (400-700 hPa)	0.35	0.38	0.38	0.35	0.35	0.36	0.37		0.36
NRMSVD	0.42	0.45	0.46	0.43	0.43	0.44	0.46		0.44
NC (23%)	35922	67515	60382	41679	39580		9152		254230
SPD [m/s]	9.21	9.61	9.63	10.11	10.14		11.51		9.79
NBIAS (LOW LAYER)	-0.02	-0.11	-0.11	-0.11	-0.10		-0.02		-0.09
NMVD (700-1000 hPa)	0.45	0.43	0.44	0.40	0.40		0.41		0.42
NRMSVD	0.53	0.51	0.51	0.48	0.47		0.48		0.50
NC (52%)	15919			119091	124905	128731	157689	20383	566718
SPD [m/s]	20.87			21.54	21.50	22.81	22.22	17.23	21.83
NBIAS (HIGH LAYER)	-0.01			-0.06	-0.05	-0.01	-0.04	+0.02	-0.04
NMVD (100-400 hPa)	0.16			0.17	0.17	0.16	0.17	0.22	0.17
NRMSVD	0.19			0.22	0.21	0.20	0.21	0.28	0.21
NC (25%)	15447	31346	29700	65544	64179	10311	60432		276959
SPD [m/s]	12.58	11.33	11.11	13.95	14.09	16.83	14.65		13.56
NBIAS (MEDIUM LAYER)	-0.03	-0.12	-0.13	-0.07	-0.06	+0.06	-0.00		-0.05
NMVD (400-700 hPa)	0.25	0.28	0.28	0.25	0.25	0.26	0.28		0.26
NRMSVD	0.31	0.34	0.34	0.31	0.31	0.32	0.35		0.33
NC (23%)	35922	67515	60382	41679	39580		9152		254230
SPD [m/s]	9.17	9.37	9.42	9.86	9.91		11.21		9.58
NBIAS (LOW LAYER)	-0.01	-0.09	-0.10	-0.09	-0.08		+0.00		-0.07
NMVD (700-1000 hPa)	0.28	0.28	0.29	0.27	0.27		0.31		0.28
NRMSVD	0.34	0.35	0.35	0.33	0.33		0.38		0.34

Table 7 Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering three separate layers against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

3.3 VALIDATION FOR DETAILED AMVS WITH DEFAULT CONFIGURATION

The validation of "Detailed AMVs" (with a default tracer size of 12x12 pixels instead of the 24x24 pixels considered by the "Basic AMVs") for MSG satellite series is considered now. The calculation of "Detailed AMVs" is activated changing configurable parameter CDET = 1 in the default model configuration file. These are provided as an additional dataset of AMVs together with the "Basic AMVs", which are always calculated.

The conditions for the validation of "Detailed AMVs" are exactly equivalent to those shown in chapter 3.1 for the MSG "Basic AMVs". An example of this configuration is shown in *Figure 2*. The validation statistics are presented in *Table 8* considering all layers together, and *Table 9* considering the three layers separately for the same validation period.

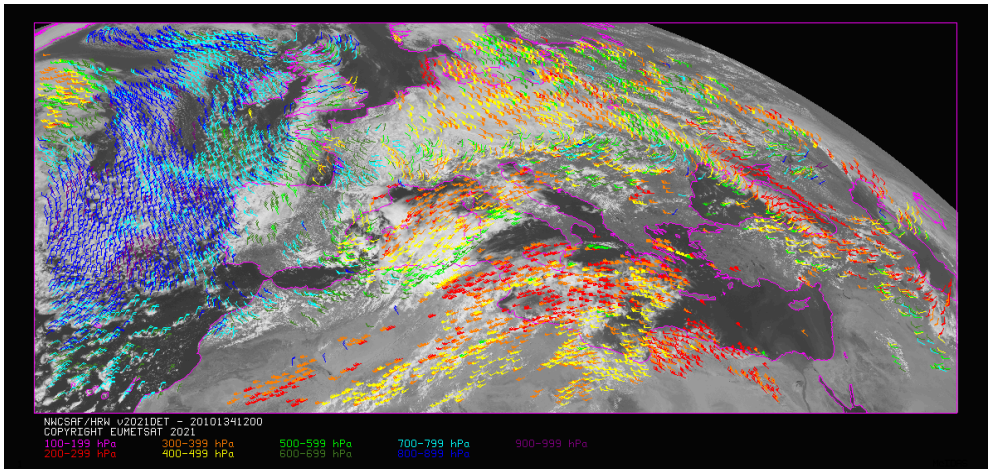


Figure 2: NWC/GEO-HRW v6.2 "Detailed AMV" output example in the European and Mediterranean region (14 May 2010 12:00 UTC, MSG-2 satellite), considering default conditions defined in `$SAFNWC/config/MSG*/safnwc_HRW.cfm` model configuration files but with configurable parameter CDET = 1. Colour coding based on the AMV pressure level

Comparing with the "Basic AMVs", a small 5% reduction in the total number of "Detailed AMVs" can be seen, although with NWC/GEO-HRW v6.2 version the difference in the amount of AMVs has reduced a lot with respect to previous versions. The distribution of validated AMVs in the different layers has a value of 38%/30%/32% for the High/Medium/Low layer, which is basically equivalent to the one for "Basic AMVs", so also helping to better characterize the behaviour of the wind in the different levels of the troposphere. Considering the validation parameters for all layers together, the NMVD and NRMSVD are slightly better than for the "Basic AMVs", with small reductions up to a 5%, while the NBIAS shows general reductions up to a 40% in the "Detailed AMVs".

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis winds, all validation parameters are again significantly smaller (around a 35% smaller) against NWP analysis winds. Considering the different layers, NWC/GEO-HRW Product Requirement Table "Optimal accuracy" is reached in the high layer, and the NWC/GEO-HRW Product Requirement Table "Target accuracy" is reached in the medium and low layer.

In short, the behaviour of "Detailed AMVs" is very similar to the one of "Basic AMVs", with slightly better statistics, and so both datasets can be used together for the characterization of the wind in the different layers of the troposphere.

NWC/GEO-HRWv6.2 AMVs (Jul 2009-Jun 2010, MSG-2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC	53617	180846	176311	204845	203347	55037	172627	1602	1048232
SPD [m/s]	11.44	10.71	10.52	18.29	18.67	24.71	21.90	19.22	16.33
NBIAS (ALL LAYERS)	-0.04	-0.09	-0.09	-0.04	-0.03	-0.02	-0.02	-0.06	-0.05
NMVD (100-1000 hPa)	0.38	0.40	0.40	0.28	0.28	0.25	0.27	0.35	0.32
NRMSVD	0.46	0.47	0.48	0.34	0.34	0.30	0.33	0.45	0.38
NC	53617	180846	176311	204845	203347	55037	172627	1602	1048232
SPD [m/s]	11.16	10.45	10.28	18.00	18.40	24.20	21.55	19.45	16.03
NBIAS (ALL LAYERS)	-0.02	-0.07	-0.07	-0.02	-0.01	-0.00	-0.00	+0.05	-0.03
NMVD (100-1000 hPa)	0.25	0.27	0.27	0.18	0.18	0.15	0.17	0.24	0.21
NRMSVD	0.31	0.33	0.33	0.23	0.23	0.19	0.22	0.31	0.26

Table 8: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Detailed AMVs

NWC/GEO-HRWv6.2 AMVs (Jul 2009-Jun 2010, MSG-2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC (38%)	4580			100763	106483	52735	131005	1602	397168
SPD [m/s]	23.14			22.83	22.73	24.97	23.61	19.22	23.33
NBIAS (HIGH LAYER)	-0.01			-0.04	-0.03	-0.02	-0.03	-0.06	-0.03
NMVD (100-400 hPa)	0.24			0.24	0.25	0.24	0.25	0.35	0.25
NRMSVD	0.29			0.30	0.30	0.29	0.30	0.45	0.30
NC (30%)	13305	56514	55125	74901	72237	2302	40173		314557
SPD [m/s]	12.63	11.95	11.78	15.07	15.30	18.80	16.63		14.11
NBIAS (MEDIUM LAYER)	-0.07	-0.11	-0.10	-0.03	-0.02	+0.06	+0.05		-0.04
NMVD (400-700 hPa)	0.36	0.37	0.38	0.33	0.33	0.36	0.36		0.35
NRMSVD	0.43	0.44	0.45	0.40	0.41	0.45	0.45		0.43
NC (32%)	35732	124332	121186	29181	24627		1449		336507
SPD [m/s]	9.49	10.14	9.95	10.89	10.98		13.22		10.14
NBIAS (LOW LAYER)	-0.04	-0.08	-0.08	-0.08	-0.07		+0.07		-0.08
NMVD (700-1000 hPa)	0.44	0.41	0.42	0.35	0.35		0.40		0.41
NRMSVD	0.52	0.48	0.49	0.43	0.43		0.48		0.48
NC (38%)	4580			100763	106483	52735	131005	1602	397168
SPD [m/s]	22.81			22.53	22.46	24.43	23.23	19.45	22.99
NBIAS (HIGH LAYER)	-0.00			-0.02	-0.02	-0.00	-0.02	+0.05	-0.01
NMVD (100-400 hPa)	0.15			0.15	0.15	0.15	0.15	0.24	0.15
NRMSVD	0.18			0.19	0.19	0.18	0.19	0.31	0.19
NC (30%)	13305	56514	55125	74901	72237	2302	40173		314557
SPD [m/s]	12.30	11.60	11.45	14.77	15.02	18.81	16.39		13.81
NBIAS (MEDIUM LAYER)	-0.04	-0.08	-0.08	-0.01	-0.00	+0.06	+0.06		-0.02
NMVD (400-700 hPa)	0.26	0.27	0.27	0.23	0.23	0.24	0.26		0.25
NRMSVD	0.32	0.33	0.33	0.28	0.29	0.29	0.32		0.31
NC (32%)	35732	124332	121186	29181	24627		1449		336507
SPD [m/s]	9.24	9.93	9.75	10.62	10.76		13.09		9.93
NBIAS (LOW LAYER)	-0.02	-0.06	-0.07	-0.06	-0.06		+0.08		-0.06
NMVD (700-1000 hPa)	0.27	0.27	0.28	0.24	0.24		0.30		0.27
NRMSVD	0.33	0.32	0.33	0.29	0.29		0.38		0.32

Table 9: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Detailed AMVs

3.4 COMPARISON WITH HRW V6.0 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 "Detailed AMVs" with those for NWC/GEO-HRW v6.0 in *Tables 10 and 11* is considered here.

As for the "Basic AMVs", the main element is that the distribution of AMVs in the different layers has changed significantly from a value of 51%/23%/26% for the High/Medium/Low layer in the previous version, to a much more homogeneous value of 38%/30%/32% in the new version (considering validated AMVs). As for the "Basic AMVs", this was a main objective of NWC/GEO-HRW v6.2, helping to better characterize the behaviour of the wind in the different levels of the troposphere.

There is again a relative and absolute increase of AMVs in the medium and low layer (with 62% more AMVs in the medium layer and 56% more AMVs in the low layer). Considering the high layer there is a relative and absolute reduction in the number of AMVs (with 5% less AMVs in the high layer). Considering all layers together, there is a 27% significant increase in the total number of AMVs, which makes very similar the total number of "Basic AMVs" and "Detailed AMVs".

Comparing the validation parameters for NWC/GEO-HRW v6.2 "Detailed AMVs" with those for v6.0, considering all layers together the values are exactly equivalent. Considering the different satellite channels, some of them improve again their NBIAS while some other worsens it, all of them compensating without changes when considering all the AMVs together.

Considering each layer separately, there are slight improvements against both Radiosounding winds and NWP analysis winds in the NMVD and NRMSVD parameters up to a 6%. The NBIAS shows up to 50% reductions in the high and medium layer, and up to 17% increases in the low layer, which compensate each other when considering all AMVs together.

NWC/GEO-HRWv6.0 AMVs (Jul 2009-Jun 2010, MSG-2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC	28829	102806	97852	180541	179209	73681	162405	2868	828191
SPD [m/s]	11.78	10.24	10.11	18.12	18.57	24.56	21.92	17.80	17.39
NBIAS (ALL LAYERS)	-0.01	-0.09	-0.10	-0.05	-0.04	-0.02	-0.03	+0.08	-0.05
NMVD (100-1000 hPa)	0.37	0.41	0.41	0.28	0.28	0.25	0.27	0.31	0.32
NRMSVD	0.44	0.48	0.49	0.35	0.34	0.31	0.33	0.39	0.38
NC	28829	102806	97852	180541	179209	73681	162405	2868	828191
SPD [m/s]	11.69	10.00	9.89	17.81	18.26	24.02	21.52	17.89	17.07
NBIAS (ALL LAYERS)	-0.00	-0.07	-0.08	-0.04	-0.03	-0.00	-0.01	+0.07	-0.03
NMVD (100-1000 hPa)	0.24	0.27	0.28	0.18	0.18	0.16	0.17	0.23	0.21
NRMSVD	0.30	0.33	0.34	0.23	0.22	0.20	0.22	0.29	0.26

Table 10: Validation parameters for NWC/GEO-HRW v6.0 Detailed AMVs considering all layers together against Radiosounding winds (green) and ECMWF NWP analysis winds (blue) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.0 AMVs (Jul 2009-Jun 2010, MSG-2)	Cloudy HRVIS	Cloudy VIS06	Cloudy VIS08	Cloudy IR108	Cloudy IR120	Cloudy WV62	Cloudy WV73	Clear Air	All AMVs
NC (51%)	4750			101623	106457	71134	131661	2868	418493
SPD [m/s]	22.08			22.39	22.44	24.78	23.46	17.80	23.11
NBIAS (HIGH LAYER)	-0.02			-0.05	-0.04	-0.02	-0.04	+0.08	-0.04
NMVD (100-400 hPa)	0.25			0.25	0.25	0.25	0.25	0.31	0.25
NRMSVD	0.30			0.31	0.30	0.31	0.31	0.39	0.31
NC (23%)	4985	31548	30370	49089	46966	2547	28748		194253
SPD [m/s]	12.60	11.23	11.09	14.05	14.32	18.23	15.55		13.43
NBIAS (MEDIUM LAYER)	-0.04	-0.13	-0.13	-0.06	-0.05	+0.06	+0.01		-0.06
NMVD (400-700 hPa)	0.36	0.39	0.39	0.34	0.34	0.37	0.36		0.36
NRMSVD	0.44	0.46	0.47	0.42	0.41	0.45	0.45		0.44
NC (26%)	19094	71258	67482	29829	25786		1996		215445
SPD [m/s]	9.00	9.80	9.66	10.28	10.31		12.18		9.84
NBIAS (LOW LAYER)	+0.00	-0.08	-0.08	-0.08	-0.07		-0.02		-0.07
NMVD (700-1000 hPa)	0.44	0.42	0.43	0.38	0.37		0.38		0.41
NRMSVD	0.52	0.49	0.50	0.45	0.45		0.45		0.48
NC (51%)	4750			101623	106457	71134	131661	2868	418493
SPD [m/s]	21.77			22.06	22.12	24.24	23.04	17.89	22.72
NBIAS (HIGH LAYER)	-0.01			-0.03	-0.02	-0.00	-0.02	+0.07	-0.02
NMVD (100-400 hPa)	0.16			0.16	0.16	0.16	0.16	0.23	0.16
NRMSVD	0.20			0.20	0.20	0.19	0.20	0.29	0.20
NC (23%)	4985	31548	30370	49089	46966	2547	28748		194253
SPD [m/s]	12.42	10.85	10.71	13.72	13.97	18.06	15.21		13.09
NBIAS (MEDIUM LAYER)	-0.02	-0.10	-0.10	-0.03	-0.02	+0.07	+0.03		-0.03
NMVD (400-700 hPa)	0.27	0.28	0.28	0.23	0.23	0.25	0.26		0.25
NRMSVD	0.33	0.35	0.35	0.29	0.29	0.31	0.32		0.32
NC (26%)	19094	71258	67482	29829	25786		1996		215445
SPD [m/s]	8.99	9.63	9.52	10.07	10.16		11.80		9.68
NBIAS (LOW LAYER)	+0.00	-0.06	-0.06	-0.06	-0.06		+0.01		-0.05
NMVD (700-1000 hPa)	0.27	0.27	0.27	0.24	0.24		0.27		0.26
NRMSVD	0.33	0.32	0.33	0.29	0.29		0.34		0.32

Table 11: Validation parameters for NWC/GEO-HRW v6.0 Detailed AMVs considering three separate layers against Radiosounding winds (green) and ECMWF NWP analysis winds (blue) (Jul 2009-Jun 2010 12:00 UTC, MSG-2 satellite, Nominal scan, European and Mediterranean region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

4. VALIDATION OF HRW V6.2 AMVS WITH GOESN SATELLITES

4.1 VALIDATION FOR BASIC AMVS WITH DEFAULT CONFIGURATION

The validation of NWC/GEO-HRW v6.2 algorithm for GOES-N satellite series is considered now. It is based on the validation of NWC/GEO-HRW AMVs calculated during the whole year July 2010 – June 2011 with GOES-13 satellite images, extracted every 15 minutes in an area covering the Continental United States. Next triplets of images for NWC/GEO-HRW algorithm processing, and next Radiosounding data have been considered for this GOES-N validation:

- Images at 23:15, 23:30, 23:45 UTC; 23:45 UTC AMVs validated against 00:00 UTC Radiosounding winds.
- Images at 05:15, 05:30, 05:45 UTC; 05:45 UTC AMVs validated against 06:00 UTC Radiosounding winds.
- Images at 11:15, 11:30, 11:45 UTC; 11:45 UTC AMVs validated against 12:00 UTC Radiosounding winds.
- Images at 17:15, 17:30, 17:45 UTC; 17:45 UTC AMVs validated against 18:00 UTC Radiosounding winds.

No AMVs could be processed at 00:00, 06:00, 12:00 and 18:00 UTC because GOES-13 images are not available at these main synoptic hours.

This process every six hours has been used in the statistics to increase the amount of comparisons, especially for visible AMVs. Dawn or dusk occurs at the main synoptic hours 00:00 and 12:00 UTC, because of which the number of visible AMVs in these moments is small. The number of Radiosounding observations available at midday time, i.e. around 18:00 UTC, is however also very limited. Because of all this, the number of collocations for visible AMVs keeps on being small.

Statistics against NWP analysis winds are not provided for this satellite series (in contrast to all other satellite series), due to the lack of ECMWF analysis at 06:00 and 18:00 UTC, which would reduce to a half the number of processed slots in this validation process.

The validation takes into account the default conditions for NWC/GEO-HRW v6.2 for GOES-N satellites, considering "Basic scale AMVs" with "Cross correlation tracking" and "CCC method height assignment without microphysics correction". Comparing with MSG satellite series, no microphysics correction is implemented in the height assignment due to the lack of NWC/GEO-CMIC product with this satellite series. An example of NWC/GEO-HRW with this configuration is shown in *Figure 3*.

These conditions are specified in `$SAFNWC/config/GOES[13-15]*/safnwc_HRW.cfm` model configuration files, with all satellite channels being validated. Cloudy AMVs in the layer 100-1000 hPa and clear air AMVs in the layer 100-400 hPa, with a Quality index with forecast ≥ 75% are considered for this validation. NWC/GEO-Cloud product outputs for GOES-N (CMA, CT and CTTH) have to be available so that NWC/GEO-HRW v6.2 can fully process the conditions defined in the defined model configuration files.

The validation statistics are presented in *Table 12* (considering all layers together) and *Table 13* (considering the three layers separately). All moments of the day have been considered together.

Considering the different satellite channels, the main difference is related to the Clear air AMVs, for which MVD and NRMSVD parameters are around a 25% larger. However, their contribution to the characterization of the wind in cloudless areas is important to keep them inside the processing.

Considering the different layers, as in MSG case, NMVD and NRMSVD parameters are progressively larger for the high, medium and low layer. NWC/GEO-HRW Product Requirement Table "Optimal accuracy" is reached in the high and medium layers (with NRMSVD ≤ 0.35 and ≤ 0.40 respectively against Radiosounding winds), and the NWC/GEO-HRW Product Requirement Table "Target accuracy" (NRMSVD ≤ 0.56 against Radiosounding winds) is also reached in the low layer.

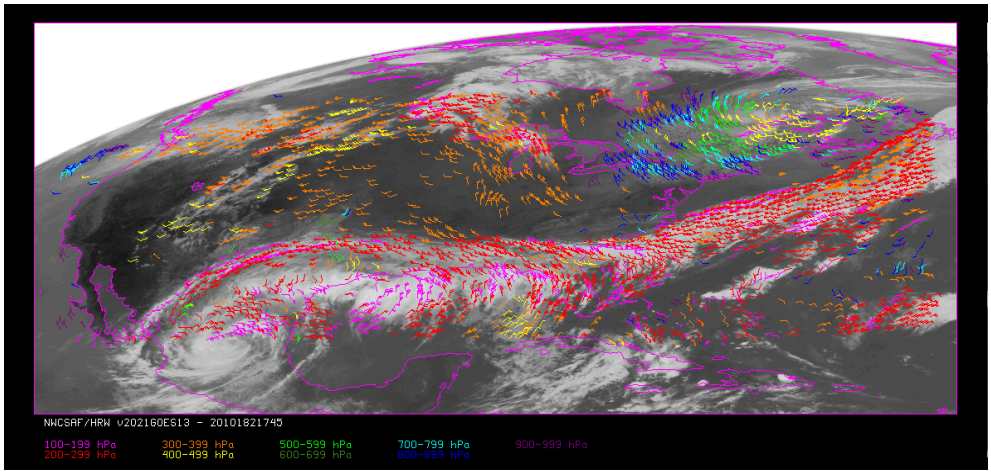


Figure 3: NWC/GEO-HRW v6.2 "Basic AMV" output example in the Continental United States region (1 July 2010 17:45 UTC, GOES-13 satellite), considering default conditions in `$SAFNWC/config/GOES[13-15]*/safnwc_HRW.cfm` model configuration files. Colour coding based on the AMV pressure level

NWC/GEO-HRWv6.2 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC	57968	294137	195334	84335	633574
SPD [m/s]	19.81	19.65	24.36	14.90	20.48
NBIAS (ALL LAYERS)	-0.02	-0.06	-0.02	+0.03	-0.03
NMVD (100-1000 hPa)	0.27	0.30	0.26	0.37	0.29
NRMSVD	0.34	0.38	0.33	0.46	0.37

Table 12: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering all layers together against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Basic AMVs

NWC/GEO-HRWv6.2 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC (75%)	36581	176295	178420	84335	475631
SPD [m/s]	24.99	23.49	24.58	14.90	22.49
NBIAS (HIGH LAYER)	-0.01	-0.07	-0.02	+0.03	-0.03
NMVD (100-400 hPa)	0.24	0.28	0.26	0.37	0.28
NRMSVD	0.29	0.35	0.33	0.46	0.35
NC (13%)	2987	61794	16914		81695
SPD [m/s]	18.01	17.61	22.01		18.53
NBIAS (MEDIUM LAYER)	-0.10	-0.04	+0.00		-0.03
NMVD (400-700 hPa)	0.37	0.33	0.28		0.32
NRMSVD	0.48	0.41	0.35		0.40
NC (12%)	20200	56048			76248
SPD [m/s]	10.70	9.79			10.03
NBIAS (LOW LAYER)	-0.02	-0.08			-0.06
NMVD (700-1000 hPa)	0.39	0.40			0.40
NRMSVD	0.48	0.49			0.49

Table 13: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering three separate layers against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Basic AMVs

4.2 COMPARISON WITH HRW V6.0 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 "Basic AMVs" for GOES-N satellite series against Radiosounding winds with those for NWC/GEO-HRW v6.0 default configuration in *Tables 14 and 15* is considered here. (NWC/GEO-HRW v6.1 was basically an extension of v6.0 to GOES-16 satellite).

NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC	9282	287572	247350	64486	608690
SPD [m/s]	21.33	21.82	25.22	14.64	22.43
NBIAS (ALL LAYERS)	-0.01	-0.08	-0.04	+0.04	-0.05
NMVD (100-1000 hPa)	0.24	0.29	0.26	0.37	0.28
NRMSVD	0.31	0.37	0.33	0.49	0.36

Table 14: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering all layers together against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics)

NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC (86%)	6828	215848	235439	64486	522601
SPD [m/s]	25.28	24.74	25.44	14.64	23.82
NBIAS (HIGH LAYER)	-0.01	-0.09	-0.04	+0.04	-0.05
NMVD (100-400 hPa)	0.23	0.28	0.26	0.37	0.28
NRMSVD	0.28	0.35	0.33	0.49	0.35
NC (7%)	243	33933	11911		46087
SPD [m/s]	18.29	17.04	20.84		18.03
NBIAS (MEDIUM LAYER)	-0.11	-0.05	+0.00		-0.03
NMVD (400-700 hPa)	0.34	0.35	0.29		0.33
NRMSVD	0.45	0.43	0.37		0.41
NC (7%)	2211	37791			40002
SPD [m/s]	9.46	9.44			9.44
NBIAS (LOW LAYER)	-0.02	-0.09			-0.09
NMVD (700-1000 hPa)	0.35	0.40			0.39
NRMSVD	0.43	0.49			0.49

Table 15: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering three separate layers against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics)

The main element to be taken into account is the larger population of medium and low level AMVs, with increments of 77% for medium level AMVs and 90% for low level AMVs (which is directly related to the "higher density for tracers related to medium and low level clouds"). Considering the high layer there is a small 10% reduction in the number of AMVs, and considering all AMVs altogether there is a small 4% increase.

Because of these changes in the population of AMVs the distribution of AMVs in the different layers has also changed, going from a value of 86%/7%/7% for the High/Medium/Low layer in the previous version, to 75%/13%/12% in the new version (considering validated AMVs). The distribution between different layers has improved, although less significantly than in the MSG case.

Comparing validation parameters for the new and previous version of NWC/GEO-HRW, considering all layers together in *Tables 12 and 14*, and the three layers separately in *Tables 13 and 15*, there are reductions up to 40% in the NBIAS and small changes up to 4% in the NMVD and NRMSVD against Radiosounding winds. So, a better distribution of AMVs in the different vertical levels is reached with similar statistics, and this can be considered a positive evolution of the AMVs for GOES-N satellite series with the new NWC/GEO-HRW v6.2 version.

4.3 VALIDATION FOR DETAILED AMVS WITH DEFAULT CONFIGURATION

The validation of "Detailed AMVs" (with a default tracer size of 12x12 pixels instead of the 24x24 pixels considered by the Basic AMVs) for GOES-N satellite series is considered now. The calculation of "Detailed AMVs" is activated changing configurable parameter CDET = 1 in the default model configuration files. These AMVs are provided as an additional dataset of AMVs together with the "Basic AMVs", which are always calculated.

The conditions for the validation of "Detailed AMVs" are exactly equivalent to those shown in chapter 4.1 for the GOES-N "Basic AMVs". An example of this configuration is shown in *Figure 4*. The validation statistics are presented in *Table 16* (considering all layers together) and *Table 17* (considering the three layers separately) for the same validation period.

Comparing with the "Basic AMVs", a 42% reduction in the number of AMVs is seen for the "Detailed AMVs". This result can be explained through the smaller size of the tracers (affecting especially the water vapour channel, for which the image features are generally larger), the smaller persistence in time of the finest image features (affecting especially the VIS07 AMVs, for which the size of the "Detailed tracers" is the smallest of all: up to 12x12 km), and especially the smaller contrast in the features using smaller tracer sizes. The distribution of validated AMVs in the different layers has a value of 78%/13%/9% for the High/Medium/Low layer, concentrating the AMVs in the high layer slightly more than for the "Basic scale".

Considering the validation parameters for the whole dataset of AMVs and the different layers, the NMVD and NRMSVD are up to a 10% better than for the "Basic AMVs", while the NBIAS shows better approximations to 0. Considering the different layers, NWC/GEO-HRW Product Requirement Table "Optimal accuracy" is also reached in the high and medium layers, and the NWC/GEO-HRW Product Requirement Table "Target accuracy" is also reached in the low layer.

In short, the behaviour of "Detailed AMVs" is similar or slightly better than the one of "Basic AMVs", and so both datasets can be used together for the characterization of the wind in the different layers of the troposphere.

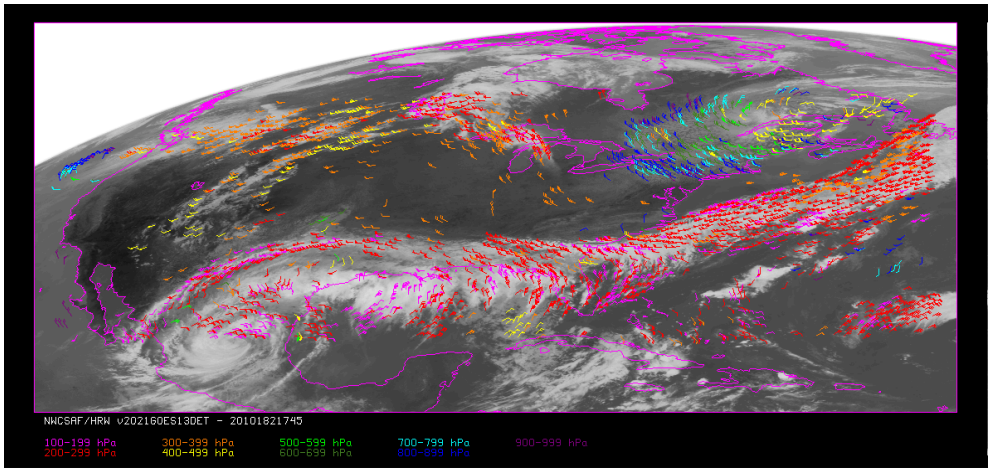


Figure 4: NWC/GEO-HRW v6.2 "Detailed AMV" output example in the Continental United States region (1 July 2010 17:45 UTC, GOES-13 satellite), considering default conditions in `$SAFNWC/config/GOES[13-15]*/safnwc_HRW.cfm` model configuration files but with configurable parameter CDET = 1. Colour coding based on the AMV pressure level

NWC/GEO-HRWv6.2 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC	19920	183844	126797	24772	355333
SPD [m/s]	20.89	21.50	25.72	15.28	22.54
NBIAS (ALL LAYERS)	+0.00	-0.02	-0.00	+0.08	-0.00
NMVD (100-1000 hPa)	0.27	0.28	0.25	0.37	0.27
NRMSVD	0.34	0.35	0.31	0.46	0.34

Table 16: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering all layers together against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Detailed AMVs

NWC/GEO-HRWv6.2 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC (78%)	11645	120253	119076	24772	275746
SPD [m/s]	27.25	24.80	25.91	15.28	24.53
NBIAS (HIGH LAYER)	-0.00	-0.03	-0.00	+0.08	-0.01
NMVD (100-400 hPa)	0.23	0.26	0.25	0.37	0.26
NRMSVD	0.29	0.32	0.31	0.46	0.32
NC (13%)	997	39039	7721		47757
SPD [m/s]	18.43	18.55	22.82		19.24
NBIAS (MEDIUM LAYER)	-0.02	+0.01	+0.05		+0.01
NMVD (400-700 hPa)	0.38	0.32	0.30		0.32
NRMSVD	0.49	0.40	0.37		0.40
NC (9%)	7278	24552			31830
SPD [m/s]	11.03	10.02			10.25
NBIAS (LOW LAYER)	+0.03	-0.02			-0.00
NMVD (700-1000 hPa)	0.41	0.39			0.39
NRMSVD	0.50	0.48			0.48

Table 17: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering three separate layers against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Detailed AMVs

4.4 COMPARISON WITH HRW V6.0 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 "Detailed AMVs" for GOES-N satellite series with those for NWC/GEO-HRW v6.0 in *Tables 18 and 19* is considered here.

NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC	1533	205435	191379	7341	405688
SPD [m/s]	23.59	24.69	26.52	16.23	25.40
NBIAS (ALL LAYERS)	+0.00	-0.04	-0.02	+0.09	-0.03
NMVD (100-1000 hPa)	0.23	0.26	0.24	0.35	0.25
NRMSVD	0.30	0.32	0.30	0.44	0.31

Table 18: Validation parameters for NWC/GEO-HRW v6.0 Detailed AMVs considering all layers together against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics)

NWC/GEO-HRWv6.0 AMVs (Jul 2010-Jun 2011, GOES13)	Cloudy VIS07	Cloudy IR107	Cloudy WV65	Clear Air	All AMVs
NC (93%)	1174	179457	186679	7341	374651
SPD [m/s]	27.57	25.83	26.62	16.23	26.04
NBIAS (HIGH LAYER)	+0.00	-0.05	-0.02	+0.09	-0.03
NMVD (100-400 hPa)	0.22	0.25	0.24	0.35	0.25
NRMSVD	0.27	0.31	0.30	0.44	0.31
NC (6%)	29	20920	4700		25649
SPD [m/s]	17.17	18.45	22.54		19.20
NBIAS (MEDIUM LAYER)	-0.09	+0.04	+0.04		+0.01
NMVD (400-700 hPa)	0.44	0.32	0.30		0.32
NRMSVD	0.56	0.40	0.37		0.40
NC (1%)	330	5058			5388
SPD [m/s]	10.01	10.19			10.18
NBIAS (LOW LAYER)	-0.04	-0.05			-0.05
NMVD (700-1000 hPa)	0.36	0.39			0.39
NRMSVD	0.44	0.49			0.48

Table 19: Validation parameters for NWC/GEO-HRW v6.0 Detailed AMVs considering three separate layers against Radiosounding winds (Jul 2010-Jun 2011 05:45/11:45/17:45/23:45 UTC, GOES-13 satellite, Continental United States; Basic AMVs; Cross correlation; CCC height assignment without Microphysics)

The main element to be taken into account again is the larger population of medium and low level AMVs, with increments of 86% for medium level AMVs and 491% for low level AMVs (which is directly related to the higher density for tracers related to medium and low level clouds). Considering the high layer AMVs and all AMVs altogether there is a 26% reduction and a 12% reduction respectively in the number of AMVs.

However, because of these changes the distribution of AMVs in the different layers has also changed, going from a value of 93%/6%/1% for the High/Medium/Low layer in the previous version, to 78%/13%/9% in the new version (considering validated AMVs). The distribution between different layers has improved, so showing a better characterization of the wind in the different layers of the troposphere.

Comparing validation parameters for the new and previous version of NWC/GEO-HRW, considering all layers together in *Tables 16 and 18*, and the three layers separately in *Tables 17 and 19*, there are reductions up to 100% in the NBIAS and small changes up to 10% in the NMVD and NRMSVD against Radiosounding winds. So, a better distribution of AMVs in the different vertical levels is reached with basically similar statistics, and this can be considered a positive evolution of the AMVs for GOES-N satellite series "Detailed AMVs" with this NWC/GEO-HRW v6.2 version.

4.5 COMPARISON WITH MSG SATELLITE SERIES

The comparison of the statistics of NWC/GEO-HRW v6.2 default configuration for GOES-N satellite series with the one for MSG satellites series is considered here. Comparing with the equivalent statistics for MSG (shown in *Tables 4 and 5*), validation for GOES-N is in general better (with reductions in the NBIAS between 25% and 60%, and in the NMVD and NRSMVD up to 12%). Only in the high layer, NMVD and NRMSVD show better values for MSG than for GOES-N.

Considering the different GOES-N channels, the statistics for GOES-N/VIS07 AMVs are better than for the equivalent MSG/HRVIS channel (although this can be caused by the larger proportion of high layer AMVs for the GOES-N/VIS07 AMV validation). For the rest of equivalent channels statistics are much more similar.

The main difference between both satellite series is related to the distribution of AMVs in the different layers, with a much higher proportion of high layer AMVs for GOES-N satellite series. The result can be related to the facts that the only GOES-N visible channel is a high resolution one (for which the number of AMVs tends to be smaller), and that only one infrared channel is used for the GOES-N AMV validation. Additionally, the validation region used for GOES-N is much more continental than the one used for MSG (Continental United States versus Europe and the Mediterranean Sea), which also reduces the number of available low level AMVs.

5. VALIDATION OF HRW V6.2 AMVS WITH HIMAWARI-8/9 SATELLITES

5.1 VALIDATION FOR BASIC AMVS WITH DEFAULT CONFIGURATION

The validation of NWC/GEO-HRW-v6.2 algorithm for Himawari-8/9 satellite series is based on the validation of AMVs calculated during 164 days of the half-yearly period March – August 2018 at 00:00 UTC, with Himawari-8 satellite images, in a region covering China, Korea, Japan and the adjacent parts of the Pacific Ocean. This region is shown in the example in *Figure 5*.

The default conditions for NWC/GEO-HRW v6.2 for Himawari-8/9 satellites, considering "Nominal scan satellite mode", "Basic scale AMVs", "Cross correlation tracking", "CCC height assignment method with Microphysics correction", and a "higher density for tracers related to medium and low level clouds", are considered for the validation. These conditions are specified in the default model configuration files `$SAFNWC/config/HIMA*/safnwc_HRW.cfm`, but with validation of all possible satellite channels. Cloudy AMVs in the layer 100-1000 hPa and water vapour clear air AMVs in the layer 100-400 hPa, with a Quality index with forecast ≥ 75%, are considered for the validation.

NWC/GEO-Cloud product outputs (CMA, CT, CTTH and CMIC) in the processing region have to be available so that NWC/GEO-HRW can fully process the conditions defined in the model configuration file. The running of three consecutive slots for all Cloud and HRW products every day during the reference validation period (23:40 UTC, 23:50 UTC and 00:00 UTC), is needed for the validation.

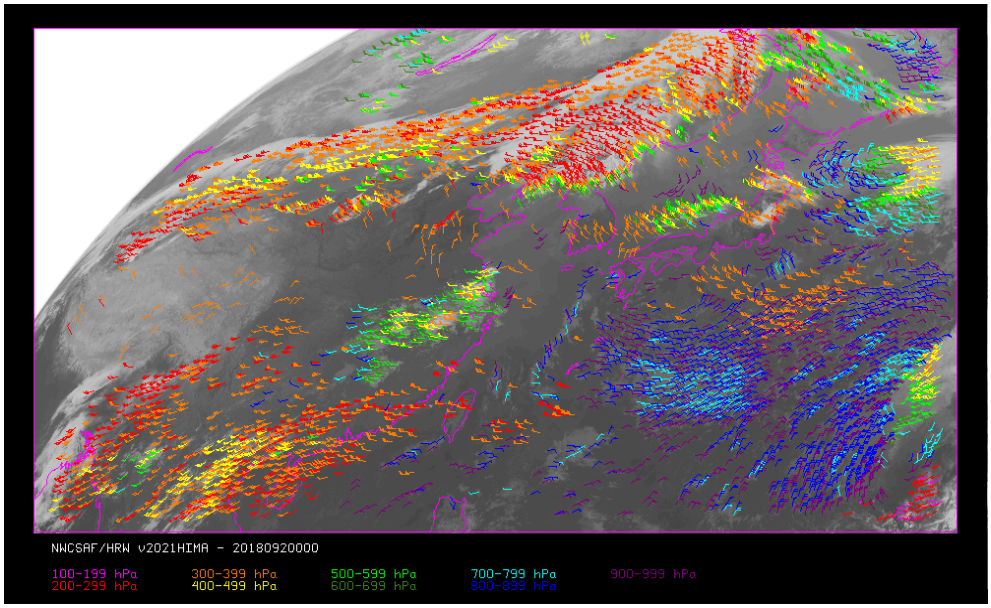


Figure 5: NWC/GEO-HRW v6.2 "Basic AMV" output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering default conditions defined in `$SAFNWC/config/HIMA*/safnwc_HRW.cfm` model configuration files. Colour coding based on the AMV pressure level

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis in *Table 20* (considering all layers together) and in *Table 21* (considering the three layers separately), the NBIAS, NMVD and NRMSVD parameters are once again around a 25% smaller against NWP analysis winds, and up to a 33% smaller in the low layer.

Considering the different layers, as in previous cases the validation parameters are progressively larger for the high layer, medium layer and low layer. The NWC/GEO-HRW Product Requirement Table "Optimal accuracy" (NRMSVD ≤ 0.35 against Radiosounding winds) is reached in the high layer, and the NWC/GEO-HRW Product Requirement Table "Target accuracy" (NRMSVD ≤ 0.50 and 0.56 respectively against Radiosounding winds) is reached in the medium and low layer.

NWC/GEO-HRWv6.2 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC	29665	59599	331845	185496	279045	332266	146493	1364409
SPD [m/s]	17.86	16.09	18.31	23.22	21.61	20.62	20.37	20.32
NBIAS (ALL LAYERS)	+0.02	+0.02	+0.05	+0.08	+0.09	+0.07	+0.04	+0.06
NMVD (100-1000 hPa)	0.27	0.29	0.29	0.27	0.30	0.29	0.29	0.29
NRMSVD	0.33	0.36	0.37	0.33	0.36	0.35	0.37	0.36
NC	29665	59599	331845	185496	279045	332266	146493	1364409
SPD [m/s]	17.90	16.14	18.30	23.30	21.65	20.64	20.56	20.37
NBIAS (ALL LAYERS)	+0.01	+0.02	+0.05	+0.08	+0.09	+0.07	+0.03	+0.06
NMVD (100-1000 hPa)	0.18	0.20	0.22	0.20	0.23	0.22	0.23	0.21
NRMSVD	0.23	0.25	0.28	0.25	0.28	0.27	0.29	0.27

Table 20: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to equivalent NWC/GEO-HRW v6.0 Basic AMVs

NWC/GEO-HRWv6.2 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC (73%)	14137	24302	183797	174321	214796	231462	146493	989308
SPD [m/s]	25.74	24.62	22.16	23.43	22.97	22.56	20.37	22.49
NBIAS (HIGH LAYER)	-0.00	-0.00	+0.06	+0.08	+0.07	+0.06	+0.04	+0.06
NMVD (100-400 hPa)	0.21	0.22	0.26	0.27	0.27	0.26	0.29	0.26
NRMSVD	0.25	0.26	0.32	0.32	0.33	0.32	0.37	0.32
NC (23%)	7912	16309	116810	11175	64249	100804		317259
SPD [m/s]	13.65	13.27	14.88	20.05	17.08	16.18		15.81
NBIAS (MEDIUM LAYER)	+0.09	+0.09	+0.05	+0.16	+0.17	+0.10		+0.10
NMVD (400-700 hPa)	0.34	0.35	0.35	0.36	0.42	0.37		0.37
NRMSVD	0.44	0.45	0.45	0.43	0.51	0.47		0.47
NC (4%)	7616	18988	31238					57842
SPD [m/s]	7.62	7.60	8.51					8.10
NBIAS (LOW LAYER)	+0.05	+0.04	-0.00					+0.02
NMVD (700-1000 hPa)	0.47	0.50	0.44					0.46
NRMSVD	0.58	0.61	0.53					0.56
NC (73%)	14137	24302	183797	174321	214796	231462	146493	989308
SPD [m/s]	25.71	24.62	22.31	23.50	23.08	22.70	20.56	22.62
NBIAS (HIGH LAYER)	-0.00	-0.00	+0.05	+0.08	+0.07	+0.05	+0.03	+0.05
NMVD (100-400 hPa)	0.15	0.16	0.19	0.20	0.20	0.19	0.23	0.19
NRMSVD	0.18	0.19	0.24	0.25	0.25	0.24	0.29	0.24
NC (23%)	7912	16309	116810	11175	64249	100804		317259
SPD [m/s]	13.70	13.27	14.62	20.16	16.85	15.92		15.59
NBIAS (MEDIUM LAYER)	+0.08	+0.09	+0.07	+0.15	+0.19	+0.12		+0.12
NMVD (400-700 hPa)	0.24	0.25	0.26	0.29	0.35	0.30		0.29
NRMSVD	0.31	0.32	0.34	0.35	0.43	0.37		0.37
NC (4%)	7616	18988	31238					57842
SPD [m/s]	7.77	7.75	8.45					8.13
NBIAS (LOW LAYER)	+0.03	+0.02	+0.00					+0.01
NMVD (700-1000 hPa)	0.28	0.30	0.31					0.31
NRMSVD	0.35	0.38	0.39					0.38

Table 21: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to equivalent NWC/GEO-HRW v6.0 Basic AMVs

5.2 COMPARISON WITH HRW V6.0 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 "Basic AMVs" for Himawari-8/9 satellite series, with those for NWC/GEO-HRW v6.0 in *Tables 22 and 23,* is considered here (NWC/GEO-HRW v6.1 was basically an extension of v6.0 to GOES-16 satellite).

The main element is that the distribution of AMVs in the different layers has improved, going from a value of 82%/14%/4% for the High/Medium/Low layer in the previous version, to a better value in the new version of 73%/23%/4%. The change is caused by the higher density of tracers related to medium and low level clouds, with an absolute increase in the number of AMVs in the medium and low layer (with 88% more AMVs in the medium layer and 29% more AMVs in the low layer). Considering the high layer there is a similar number of AMVs than in the previous version. Considering all layers together, there is a 14% increase in the total number of AMVs.

Comparing the validation parameters for NWC/GEO-HRW v6.2 with those for v6.0, considering all layers together the values are basically equivalent, with only minimum increases up to 4% in the NMVD and NRMSVD values against Radiosounding winds and NWP analysis winds, which are only caused by the larger proportion now of medium and low layer AMVs with higher validation parameters. Considering the NBIAS, there is also a minimum increase in its value against both references. Considering the different satellite channels, some of them show increases of more than 10% in several validation parameters (red figures in *Table 20*), but this is only caused again by the higher proportion of medium and low layer AMVs with higher validation parameters.

Considering each layer separately, the NMVD and NRMSVD keep basically similar values in v6.0 and v6.2 versions in the three layers for all satellite channels except VIS06 channel, for which the NMVD and NRSMVD degrades more than 10% in two cases (red figures in *Table 21*). Considering all channels together, the variations in the NMVD and NRMSVD in the three layers are smaller than a 7%. Considering each layer separately, the NBIAS shows increases for some channels and decreases for other ones; however, putting all channels together for each layer, a small increase in the high and low layer NBIAS still occurs.

With all this, a better distribution of AMVs in the different vertical levels is reached with very similar statistics, and this can be considered a positive evolution of the AMVs for Himawari-8/9 satellite series with the new NWC/GEO-HRW version.

NWC/GEO-HRWv6.0 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC	36841	71618	287147	189457	246356	280899	85148	1197466
SPD [m/s]	21.70	19.95	19.58	23.60	22.58	21.94	19.32	21.46
NBIAS (ALL LAYERS)	+0.00	-0.00	+0.04	+0.06	+0.06	+0.04	+0.06	+0.05
NMVD (100-1000 hPa)	0.24	0.26	0.27	0.26	0.27	0.26	0.30	0.28
NRMSVD	0.29	0.31	0.35	0.32	0.33	0.33	0.38	0.35
NC	36841	71618	287147	189457	246356	280899	85148	1197466
SPD [m/s]	21.72	19.97	19.60	23.65	22.62	21.96	19.56	21.50
NBIAS (ALL LAYERS)	-0.00	-0.00	+0.04	+0.06	+0.06	+0.04	+0.05	+0.05
NMVD (100-1000 hPa)	0.17	0.18	0.20	0.19	0.21	0.20	0.23	0.21
NRMSVD	0.21	0.23	0.25	0.24	0.25	0.25	0.30	0.26

Table 22: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering all layers together against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.0 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC (82%)	26769	48276	196718	183124	214714	229291	85148	984040
SPD [m/s]	25.83	24.52	22.61	23.73	23.44	23.31	19.32	23.06
NBIAS (HIGH LAYER)	-0.01	-0.01	+0.04	+0.06	+0.05	+0.03	+0.06	+0.04
NMVD (100-400 hPa)	0.22	0.23	0.25	0.26	0.26	0.25	0.30	0.25
NRMSVD	0.26	0.27	0.31	0.31	0.31	0.30	0.38	0.31
NC (14%)	4200	9507	65466	6333	31642	51608		168756
SPD [m/s]	14.67	14.18	14.68	20.08	16.72	15.85		15.60
NBIAS (MEDIUM LAYER)	+0.10	+0.09	+0.05	+0.17	+0.21	+0.11		+0.11
NMVD (400-700 hPa)	0.32	0.33	0.35	0.36	0.43	0.38		0.37
NRMSVD	0.40	0.42	0.49	0.47	0.54	0.50		0.50
NC (4%)	5872	13835	24963					44670
SPD [m/s]	7.90	7.97	8.53					8.27
NBIAS (LOW LAYER)	-0.03	+0.03	-0.01					+0.00
NMVD (700-1000 hPa)	0.44	0.47	0.43					0.45
NRMSVD	0.54	0.58	0.53					0.55
NC (82%)	26769	48276	196718	183124	214714	229291	85148	984040
SPD [m/s]	25.81	24.51	22.73	23.77	23.51	23.39	19.56	23.14
NBIAS (HIGH LAYER)	-0.01	-0.01	+0.04	+0.06	+0.05	+0.03	+0.05	+0.04
NMVD (100-400 hPa)	0.16	0.16	0.18	0.19	0.19	0.18	0.23	0.19
NRMSVD	0.19	0.20	0.23	0.24	0.23	0.22	0.30	0.23
NC (14%)	4200	9507	65466	6333	31642	51608		168756
SPD [m/s]	14.75	14.15	14.44	20.11	16.57	15.60		15.40
NBIAS (MEDIUM LAYER)	+0.09	+0.09	+0.07	+0.17	+0.22	+0.13		+0.12
NMVD (400-700 hPa)	0.23	0.24	0.26	0.29	0.36	0.30		0.29
NRMSVD	0.30	0.31	0.33	0.36	0.44	0.38		0.38
NC (4%)	5872	13835	24963					44670
SPD [m/s]	8.08	8.13	8.48					8.32
NBIAS (LOW LAYER)	+0.01	+0.01	-0.00					+0.00
NMVD (700-1000 hPa)	0.25	0.29	0.30					0.29
NRMSVD	0.33	0.36	0.39					0.37

Table 23: Validation parameters for NWC/GEO-HRW v6.0 Basic AMVs considering three separate layers against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

5.3 VALIDATION FOR DETAILED AMVS WITH DEFAULT CONFIGURATION

The validation of "Detailed AMVs" (with a default tracer size of 12x12 pixels instead of the 24x24 pixels considered by the "Basic AMVs") for Himawari-8/9 satellite series is considered now. The calculation of "Detailed AMVs" is activated again changing configurable parameter CDET = 1 in the default model configuration files. These are provided as an additional dataset of AMVs together with the "Basic AMVs", which are always calculated.

The conditions for the validation of "Detailed AMVs" are exactly equivalent to those shown in chapter 5.1 for the Himawari-8/9 "Basic AMVs". An example of this configuration is shown in *Figure 6*. The validation statistics are presented in *Table 24* (considering all layers together) and *Table 25* (considering the three layers separately) for the same validation period.

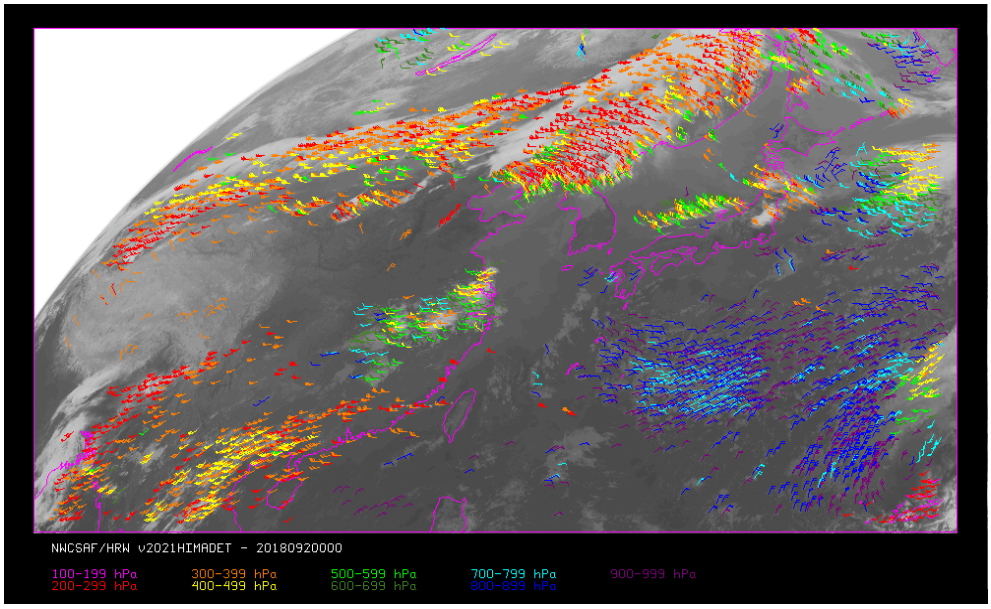


Figure 6: NWC/GEO-HRW v6.2 "Detailed AMV" output example in the China/Korea/Japan region (2 April 2018 00:00 UTC, Himawari-8 satellite), considering default conditions defined in `$SAFNWC/config/HIMA*/safnwc_HRW.cfm` model configuration files with configurable parameter CDET = 1. Colour coding based on the AMV pressure level

Comparing with the "Basic AMVs", a 44% reduction in the number of AMVs is seen for the "Detailed AMVs". This is similar to the behaviour seen with GOES-N satellites series. Again, this can be explained through the smaller size and persistence of the detailed tracers, and especially the smaller contrast in the features using smaller tracer sizes.

The distribution of validated AMVs in the different layers has a value of 76%/21%/3% for the High/Medium/Low layer, slightly concentrating more the AMVs in the high layer with respect to what was observed with the "Basic AMVs". The smaller number of low level "Detailed AMVs" is also to be taken into account in operational use.

Considering the validation, NMVD and NRMSVD parameters are in general up to a 10% smaller than for the "Basic AMVs", while the NBIAS shows in contrast some increments. Considering the accuracies of the NWC/GEO-HRW Product Requirement Table, the situation is similar for the "Basic AMVs" and "Detailed AMVs". With all of this, the behaviour of "Detailed AMVs" is similar to the one of "Basic AMVs", and so both datasets can be used together operationally.

NWC/GEO-HRWv6.2 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC	6389	44174	230532	88513	152291	213109	32673	767681
SPD [m/s]	14.61	18.19	20.47	24.63	23.74	22.89	22.12	22.15
NBIAS (ALL LAYERS)	+0.04	+0.02	+0.07	+0.07	+0.08	+0.07	+0.10	+0.07
NMVD (100-1000 hPa)	0.31	0.27	0.28	0.25	0.27	0.27	0.30	0.28
NRMSVD	0.39	0.33	0.35	0.31	0.32	0.33	0.38	0.34
NC	6389	44174	230532	88513	152291	213109	32673	767681
SPD [m/s]	14.71	18.23	20.51	24.70	23.82	22.93	22.36	22.22
NBIAS (ALL LAYERS)	+0.04	+0.02	+0.07	+0.06	+0.07	+0.07	+0.09	+0.07
NMVD (100-1000 hPa)	0.20	0.18	0.21	0.19	0.20	0.20	0.24	0.20
NRMSVD	0.26	0.23	0.26	0.23	0.25	0.25	0.30	0.26

Table 24: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Detailed AMVs

NWC/GEO-HRWv6.2 AMVs (Mar-Aug 2018, Himwari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC (76%)	1614	21565	144550	85778	130582	167453	32673	584215
SPD [m/s]	25.29	25.55	23.57	24.73	24.71	24.37	22.12	24.22
NBIAS (HIGH LAYER)	-0.00	+0.00	+0.07	+0.07	+0.06	+0.06	+0.10	+0.06
NMVD (100-400 hPa)	0.21	0.22	0.25	0.25	0.25	0.24	0.30	0.25
NRMSVD	0.26	0.26	0.30	0.30	0.30	0.30	0.38	0.30
NC (21%)	2403	11626	77000	2735	21709	45656		161129
SPD [m/s]	14.28	14.11	15.88	21.45	17.89	17.44		16.54
NBIAS (MEDIUM LAYER)	+0.09	+0.09	+0.10	+0.16	+0.21	+0.15		+0.13
NMVD (400-700 hPa)	0.34	0.34	0.35	0.35	0.43	0.39		0.38
NRMSVD	0.44	0.44	0.45	0.43	0.52	0.48		0.47
NC (3%)	2372	10953	8982					22337
SPD [m/s]	7.69	8.07	9.82					8.73
NBIAS (LOW LAYER)	+0.07	+0.05	+0.03					+0.04
NMVD (700-1000 hPa)	0.47	0.47	0.41					0.44
NRMSVD	0.58	0.57	0.49					0.54
NC (76%)	1614	21565	144550	85778	130582	167453	32673	584215
SPD [m/s]	25.12	25.55	23.73	24.80	24.81	24.48	22.36	24.34
NBIAS (HIGH LAYER)	-0.00	+0.00	+0.06	+0.06	+0.06	+0.05	+0.09	+0.06
NMVD (100-400 hPa)	0.15	0.15	0.19	0.19	0.18	0.18	0.24	0.18
NRMSVD	0.19	0.18	0.23	0.23	0.23	0.22	0.30	0.23
NC (21%)	2403	11626	77000	2735	21709	45656		161129
SPD [m/s]	14.42	14.11	15.72	21.65	17.83	17.25		16.40
NBIAS (MEDIUM LAYER)	+0.08	+0.09	+0.11	+0.15	+0.21	+0.17		+0.14
NMVD (400-700 hPa)	0.23	0.24	0.27	0.28	0.36	0.31		0.29
NRMSVD	0.30	0.30	0.34	0.35	0.43	0.39		0.37
NC (3%)	2372	10983	8982					22337
SPD [m/s]	7.94	8.21	9.85					8.84
NBIAS (LOW LAYER)	+0.03	+0.03	+0.03					+0.03
NMVD (700-1000 hPa)	0.25	0.28	0.28					0.28
NRMSVD	0.31	0.36	0.36					0.36

Table 25: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.0 Detailed AMVs

5.4 COMPARISON WITH HRW V6.0 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 "Detailed AMVs" for Himawari-8/9 satellite series, with those for NWC/GEO-HRW v6.0 in *Tables 26 and 27* is considered here.

The main element is that the distribution of AMVs in the different layers has improved, going from a value of 88%/10%/2% for the High/Medium/Low layer in the previous version, to a better value in the new version of 76%/21%/3%. The change is again caused by the higher density of tracers related to medium and low level clouds, with an absolute increase in the number of AMVs in the medium and low layer (with 123% more AMVs in the medium layer and 41% more AMVs in the low layer). Considering the high layer there is a small 6% decrease in the number of AMVs with respect to the previous version, and considering all layers together there is a small 8% increase in the total number of AMVs.

Comparing the validation parameters for NWC/GEO-HRW v6.2 with those for v6.0, considering all layers together the values are more different than those for "Basic AMVs", with increments up to 13% in the NMVD and the NRMSVD, and increments up to +0.07 value in the NBIAS against both Radiosounding winds and NWP analysis winds However, these are again caused by the larger proportion now of medium and low layer AMVs with higher validation parameters. Considering the different satellite channels, cloudy AMVs show in general increments in the validation parameters (red figures in *Table 24*), while the Clear air AMVs show reductions in them (green figures in *Table 24*).

Considering each layer separately, the NMVD and NRMSVD values are more similar to those for v6.0 in the three layers for all satellite channels, with only variations in the NMVD and NRMSVD larger than 10% in some cases related to visible channels, with reductions for VIS06 channel (green figures in *Table 25*) and increases for VIS08 channel (red figures in *Table 25*). The NBIAS shows larger variations, in general with reductions in the medium layer and with increases in the high and low layer. Considering all channels together, only small increments in the NBIAS are seen in the high and low layer.

With all this, a better distribution of AMVs in the different vertical levels is again reached with basically similar statistics, and this can be considered a positive evolution of the "Detailed AMVs" for Himawari-8/9 satellite series with the new NWC/GEO-HRW version.

NWC/GEO-HRWv6.0 AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC	6002	37393	207718	96056	151000	198745	13567	710481
SPD [m/s]	20.64	22.10	21.50	24.53	24.26	23.72	21.44	23.14
NBIAS (ALL LAYERS)	+0.01	+0.00	+0.05	+0.05	+0.05	+0.04	+0.13	+0.05
NMVD (100-1000 hPa)	0.25	0.24	0.26	0.25	0.25	0.25	0.31	0.25
NRMSVD	0.31	0.29	0.32	0.30	0.30	0.30	0.39	0.31
NC	6002	37393	207718	96056	151000	198745	13567	710481
SPD [m/s]	20.71	22.12	21.55	24.54	24.31	23.75	21.72	23.18
NBIAS (ALL LAYERS)	+0.00	+0.00	+0.05	+0.05	+0.05	+0.04	+0.11	+0.04
NMVD (100-1000 hPa)	0.17	0.17	0.19	0.18	0.18	0.18	0.24	0.18
NRMSVD	0.22	0.21	0.23	0.22	0.23	0.22	0.31	0.23

Table 26: Validation parameters for NWC/GEO-HRW v6.0 Detailed AMVs considering all layers together against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.0AMVs (Mar-Aug 2018, Himawari-8)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV69	Cloudy WV73	Clear Air	All AMVs
NC (88%)	3772	26678	161951	94839	142229	179612	13567	622648
SPD [m/s]	27.18	26.45	23.41	24.55	24.64	24.39	21.44	24.26
NBIAS (HIGH LAYER)	-0.00	-0.00	+0.05	+0.05	+0.04	+0.03	+0.13	+0.04
NMVD (100-400 hPa)	0.21	0.22	0.24	0.25	0.24	0.24	0.31	0.24
NRMSVD	0.26	0.26	0.29	0.30	0.29	0.29	0.39	0.29
NC (10%)	643	3750	38462	1217	8771	19133		71976
SPD [m/s]	13.58	15.60	15.62	22.67	18.10	17.46		16.51
NBIAS (MEDIUM LAYER)	+0.16	+0.10	+0.09	+0.18	+0.23	+0.17		+0.13
NMVD (400-700 hPa)	0.36	0.32	0.34	0.36	0.45	0.38		0.37
NRMSVD	0.45	0.40	0.48	0.44	0.51	0.48		0.48
NC (2%)	1587	6965	7305					15857
SPD [m/s]	7.94	8.95	9.96					9.32
NBIAS (LOW LAYER)	+0.05	+0.03	-0.02					+0.00
NMVD (700-1000 hPa)	0.48	0.44	0.39					0.42
NRMSVD	0.58	0.52	0.47					0.50
NC (88%)	3772	26678	161951	94839	142229	179612	13567	622648
SPD [m/s]	27.15	26.42	23.50	24.56	24.69	24.42	21.72	24.31
NBIAS (HIGH LAYER)	-0.00	-0.00	+0.04	+0.04	+0.04	+0.03	+0.11	+0.04
NMVD (100-400 hPa)	0.15	0.16	0.18	0.18	0.18	0.17	0.24	0.18
NRMSVD	0.19	0.19	0.22	0.22	0.22	0.21	0.31	0.22
NC (10%)	643	3750	38462	1217	8771	19133		71976
SPD [m/s]	13.95	15.55	15.52	22.69	18.07	17.40		16.44
NBIAS (MEDIUM LAYER)	+0.13	+0.10	+0.10	+0.18	+0.23	+0.17		+0.14
NMVD (400-700 hPa)	0.26	0.23	0.26	0.29	0.36	0.31		0.28
NRMSVD	0.34	0.30	0.33	0.36	0.44	0.39		0.37
NC (2%)	1587	6965	7305					15857
SPD [m/s]	8.12	9.18	9.92					9.41
NBIAS (LOW LAYER)	+0.03	+0.01	-0.02					-0.00
NMVD (700-1000 hPa)	0.26	0.25	0.27					0.26
NRMSVD	0.34	0.32	0.34					0.34

Table 27: Validation parameters for NWC/GEO-HRW v6.0 Detailed AMVs considering three separate layers against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (Mar-Aug 2018 00:00 UTC, Himawari-8 satellite, China/Korea/Japan region; Basic AMVs; Cross correlation; CCC height assignment with Microphysics)

5.5 COMPARISON WITH MSG SATELLITE SERIES

Comparing the statistics of NWC/GEO-HRW v6.2 default configuration for Himawari-8/9 satellites with those for MSG satellites, the number of AMVs calculated for Himawari-8/9 is two and a half times considering regions of similar sizes and an equivalent number of satellite slots. A positive effect is so clearly seen for the calculation of AMVs with the better spatial and temporal resolution of the new generation of satellites. The calculation of AMVs every 10 minutes instead of every 15 minutes is also to be noticed.

Considering the distribution of AMVs in the different layers, for Himawari-8/9 satellites it has a value of 73%/23%/4% for the High/Medium/Low layer, while for MSG satellites it has a value of 35%/32%/33% (considering validated AMVs). The much higher concentration of AMVs in the High layer for Himawari-8/9 satellites is caused by two main reasons:

- On one side, the China/Korea/Japan region used for the validation with Himawari-8/9, with less maritime areas and large high altitude and desert areas, and so with less frequent low clouds. Something similar occurred with GOES-N satellites in the Continental United States region used for its validation.
- On the other side, the different lineup of satellite channels used in the corresponding AMV processing. For MSG there are three visible, two infrared and two water vapour channels, while for Himawari-8/9 there are two visible, one infrared and three water vapour channels. The ones for MSG distribute better the AMVs in the high, medium and low layer, while the Himawari-8/9 ones tend to concentrate more the AMVs in the high layer. An option for this could be then to use in future versions of Himawari-8/9 algorithm more visible or infrared channels in the AMV processing.

Comparing the validation parameters for both satellites, considering all layers together Himawari-8/9 satellite series shows better NMVD and NRMSVD values (up to a 12% smaller), which is only caused by its larger proportion of high layer AMVs, with better validation parameters. It is remarkable to see that NBIAS parameter shows similar values but with an opposite sign.

Considering each layer separately, validation parameters are more or less similar for MSG and Himawari-8/9 satellites in the high layer. NMVD and NRMSVD parameters are however up to a 15% worse in the medium and low layer for Himawari-8/9. NBIAS parameter is larger in the high and medium layer and smaller in the low layer for Himawari-8/9.

In spite of the differences, the operability of NWC/GEO-HRW algorithm for both satellite series is equivalent. As already said, for both satellites the “Optimal accuracy” is reached in the high layer, and the “Target accuracy” is reached in the medium and low layer.

6. VALIDATION OF HRW V6.2 AMVS WITH GOES-16 SATELLITE

6.1 VALIDATION FOR BASIC AMVS WITH DEFAULT CONFIGURATION

The validation of NWC/GEO-HRW-v6.2 algorithm for GOES-R satellite series is based on the validation of "Basic AMVs" calculated with GOES-16 satellite images, in the region covering the Continental United States shown in *Figure 7*, and which is equivalent to the one used for GOES-N satellite series. AMVs calculated during 89 days of the quarterly period May – July 2019, at 00:00 UTC and 12:00 UTC, are considered for this validation. The results are provided in *Tables 28 and 29*.

The default conditions for NWC/GEO-HRW v6.2 for GOES-R satellites, considering "Mode 6 scanning with images every 10 minutes" (operational for GOES-16 since April 2019), "Basic scale AMVs", "Cross correlation tracking", "CCC height assignment method with Microphysics correction", and a "higher density for tracers related to medium and low level clouds", are defined for the validation. These conditions are specified in the default model configuration files `$SAFNWC/config/GOES[16-17]*/safnwc_HRW.cfm`, but with validation of all possible satellite channels. Cloudy AMVs in the layer 100-1000 hPa and water vapour clear air AMVs in the layer 100-400 hPa, with a Quality index with forecast ≥ 75%, are included in this validation.

NWC/GEO-Cloud product outputs (CMA, CT, CTTH and CMIC) in the processing region have to be available so that NWC/GEO-HRW can fully process the conditions defined in the model configuration file. The running of three consecutive slots for all Cloud and HRW products for the validation moments (23:40 UTC, 23:50 UTC and 00:00 UTC on one side, and 11:40 UTC, 11:50 UTC and 12:00 UTC on the other side), are needed. This configuration is equivalent to the one used for Himawari-8/9, and permits very easily a comparison in the results for both satellite series.

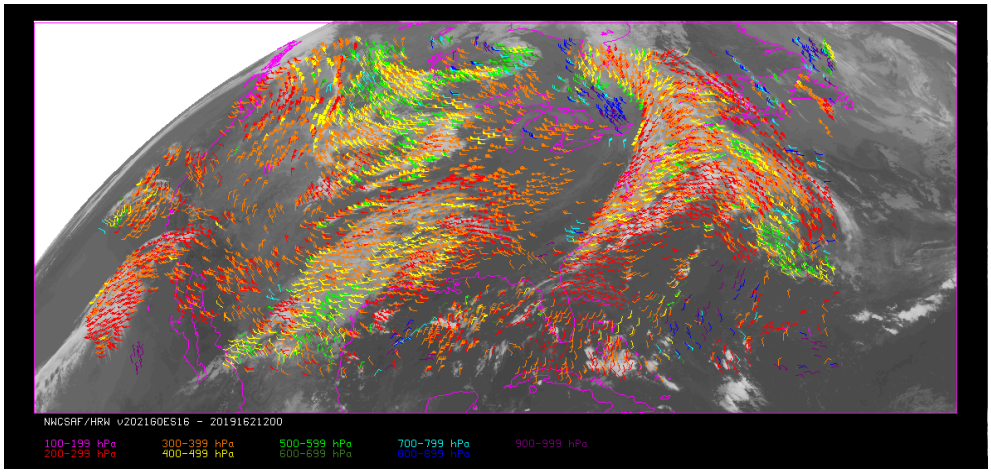


Figure 7: NWC/GEO-HRW v6.2 "Basic AMV" output example in the Continental United States region (11 June 2019 12:00, GOES-16 satellite, "Mode 6"), considering the default conditions in `$SAFNWC/config/GOES[16-17]*/safnwc_HRW.cfm` model configuration files. Colour coding based on the AMV pressure level

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis in *Tables 28 and 29*, the NBIAS, NMVD and NRMSVD are once again between a 20% and a 35% smaller against NWP analysis winds. Considering the different layers, as in previous cases, the validation parameters are progressively larger for the high layer, medium layer and low layer.

The distribution of AMVs in the High/Medium/Low layer considering validated AMVs has a value of 77%/18%/5%, which is rather similar to the value obtained with Himawari-8/9. As for all previous satellites series, the NWC/GEO-HRW "Optimal accuracy" (NRMSVD ≤ 0.35 against Radiosounding winds) is reached in the high layer, and the "Target accuracy" (NRMSVD ≤ 0.50 and 0.56 respectively against Radiosounding winds) is reached in the medium and low layer.

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC	13356	39108	321491	194908	262606	304891	214706	1351066
SPD [m/s]	17.68	16.24	18.63	23.22	22.15	21.41	17.89	20.41
NBIAS (ALL LAYERS)	+0.04	+0.04	+0.05	+0.07	+0.08	+0.06	+0.05	+0.05
NMVD (100-1000 hPa)	0.27	0.28	0.29	0.27	0.28	0.27	0.31	0.28
NRMSVD	0.33	0.35	0.36	0.33	0.35	0.34	0.39	0.36
NC	13356	39108	321491	194908	262606	304891	214706	1351066
SPD [m/s]	17.98	16.39	18.66	23.16	22.13	21.39	18.02	20.42
NBIAS (ALL LAYERS)	+0.02	+0.03	+0.05	+0.08	+0.08	+0.06	+0.04	+0.05
NMVD (100-1000 hPa)	0.16	0.18	0.21	0.19	0.20	0.19	0.24	0.21
NRMSVD	0.20	0.23	0.26	0.24	0.26	0.25	0.31	0.26

Table 28: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.1 Basic AMVs

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC (77%)	6695	16042	181833	184702	210957	224909	214706	1039844
SPD [m/s]	24.49	23.49	21.92	23.45	23.18	22.91	17.89	21.87
NBIAS (HIGH LAYER)	+0.01	+0.01	+0.05	+0.07	+0.06	+0.04	+0.05	+0.05
NMVD (100-400 hPa)	0.21	0.22	0.27	0.26	0.26	0.25	0.31	0.26
NRMSVD	0.25	0.27	0.33	0.32	0.32	0.31	0.39	0.33
NC (18%)	2705	10194	93729	10206	51649	79982		248465
SPD [m/s]	15.71	14.70	16.53	19.19	17.97	17.20		17.07
NBIAS (MEDIUM LAYER)	+0.08	+0.06	+0.03	+0.17	+0.18	+0.11		+0.10
NMVD (400-700 hPa)	0.29	0.30	0.32	0.39	0.41	0.36		0.35
NRMSVD	0.36	0.37	0.40	0.50	0.51	0.45		0.45
NC (5%)	3956	12872	45929					62757
SPD [m/s]	7.49	8.41	9.92					9.46
NBIAS (LOW LAYER)	+0.17	+0.11	+0.03					+0.05
NMVD (700-1000 hPa)	0.56	0.47	0.38					0.41
NRMSVD	0.69	0.59	0.47					0.50
NC (77%)	6695	16042	181833	184702	210957	224909	214706	1039844
SPD [m/s]	24.42	23.32	21.91	23.37	23.13	22.85	18.02	21.85
NBIAS (HIGH LAYER)	+0.01	+0.02	+0.05	+0.07	+0.06	+0.05	+0.04	+0.05
NMVD (100-400 hPa)	0.13	0.14	0.19	0.18	0.18	0.17	0.24	0.19
NRMSVD	0.16	0.18	0.24	0.23	0.22	0.21	0.31	0.24
NC (18%)	2705	10194	93729	10206	51649	79982		248465
SPD [m/s]	15.90	14.82	16.59	19.37	18.04	17.28		17.15
NBIAS (MEDIUM LAYER)	+0.06	+0.05	+0.03	+0.16	+0.17	+0.10		+0.09
NMVD (400-700 hPa)	0.19	0.20	0.24	0.31	0.34	0.29		0.28
NRMSVD	0.25	0.26	0.31	0.38	0.42	0.37		0.36
NC (5%)	3956	12872	45929					62757
SPD [m/s]	8.52	8.98	10.01					9.70
NBIAS (LOW LAYER)	+0.03	+0.04	+0.02					+0.03
NMVD (700-1000 hPa)	0.25	0.27	0.27					0.27
NRMSVD	0.32	0.34	0.34					0.34

Table 29: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; Higher density related to medium and low level clouds;CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.1 Basic AMVs

6.2 COMPARISON WITH HRW V6.1 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 "Basic AMVs" for GOES-16 satellite with those for NWC/GEO-HRW v6.1 in *Tables 30 and 31,* is considered here.

The main element is that the distribution of AMVs in the different layers has improved, going from a value of 86%/11%/3% for the High/Medium/Low layer in the previous version, to a better value in the new version of 77%/18%/5%. The change is caused by the higher density of tracers related to medium and low level clouds, with an absolute increase in the number of AMVs in the medium and low layer (with 78% more AMVs in the medium layer and 47% more AMVs in the low layer). Considering the high layer there is a 6% reduction in the number of AMVs. Considering all layers together, there is a 5% increase in the total number of AMVs.

Comparing the validation parameters for NWC/GEO-HRW v6.2 with those for v6.1, considering all layers together the values are basically equivalent, with only some increases up to 11% in the NMVD and NRMSVD values against Radiosounding winds and NWP analysis winds, which are only caused by the larger proportion now of medium and low layer AMVs with higher validation parameters. Considering the NBIAS, the values are exactly the same in both versions against both references. Considering the different satellite channels, the NMVD and NRMSVD only has increases of more than 10% in the VIS06 channel (red figures in *Table 28*), but this is only caused again by the higher proportion of medium and low layer AMVs with higher validation parameters. The NBIAS shows some increases in the Cloudy AMVs and some reductions in the Clear air AMVs, which cancel when added considering all AMVs together.

Considering each layer separately, the NMVD and NRMSVD keep basically similar values in v6.1 and v6.2 versions in the three layers for all satellite channels, except for VIS06 channel which shows some reductions in the high layer and some increases in the low layer, and for VIS08 channel which shows some reductions in the high layer (green and red figures respectively in *Table 29*). Considering all channels together, the variations in the NMVD and NRMSVD in the three layers are smaller than a 6%. Considering each layer separately, the NBIAS shows some increases, in general in the high layer and the low layer, and some reductions, in general in the medium layer.

With all this, a better distribution of AMVs in the different vertical levels is reached with very similar statistics, and this can be considered a positive evolution of the AMVs for GOES-16 satellite with the new NWC/GEO-HRW v6.2 version.

NWC/GEO-HRWv6.1 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC	18100	46595	309601	224150	269282	302135	113820	1283683
SPD [m/s]	21.12	19.46	18.70	22.29	21.72	21.20	17.44	20.49
NBIAS (ALL LAYERS)	+0.02	+0.02	+0.05	+0.06	+0.06	+0.04	+0.07	+0.05
NMVD (100-1000 hPa)	0.24	0.26	0.29	0.27	0.28	0.27	0.32	0.28
NRMSVD	0.30	0.33	0.36	0.33	0.34	0.33	0.40	0.34
NC	18100	46595	309601	224150	269282	302135	113820	1283683
SPD [m/s]	21.07	19.33	18.66	22.06	21.53	21.03	17.57	20.37
NBIAS (ALL LAYERS)	+0.02	+0.03	+0.05	+0.07	+0.07	+0.05	+0.07	+0.05
NMVD (100-1000 hPa)	0.15	0.17	0.20	0.19	0.19	0.19	0.25	0.19
NRMSVD	0.19	0.22	0.26	0.24	0.25	0.24	0.32	0.25

Table 30: Validation parameters for NWC/GEO-HRW v6.1 Basic AMVs considering all layers together against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.1 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC (86%)	14118	33407	218923	218055	243720	259050	113820	1101093
SPD [m/s]	23.92	22.61	20.94	22.40	22.21	22.02	17.44	21.49
NBIAS (HIGH LAYER)	+0.01	+0.01	+0.05	+0.06	+0.05	+0.03	+0.07	+0.04
NMVD (100-400 hPa)	0.22	0.24	0.27	0.27	0.27	0.26	0.32	0.27
NRMSVD	0.27	0.30	0.34	0.33	0.33	0.32	0.40	0.33
NC (11%)	1564	6160	57312	6095	25562	43085		139778
SPD [m/s]	16.32	14.85	15.50	18.30	17.09	16.29		16.14
NBIAS (MEDIUM LAYER)	+0.09	+0.07	+0.04	+0.20	+0.20	+0.11		+0.10
NMVD (400-700 hPa)	0.29	0.30	0.32	0.40	0.42	0.37		0.36
NRMSVD	0.37	0.38	0.40	0.49	0.51	0.46		0.45
NC (3%)	2418	7028	33366					42812
SPD [m/s]	7.88	8.57	9.50					9.26
NBIAS (LOW LAYER)	+0.11	+0.10	+0.02					+0.04
NMVD (700-1000 hPa)	0.50	0.44	0.39					0.40
NRMSVD	0.63	0.58	0.50					0.52
NC (86%)	14118	33407	218923	218055	243720	259050	113820	1101093
SPD [m/s]	23.73	22.32	20.86	22.16	21.99	21.81	17.57	21.33
NBIAS (HIGH LAYER)	+0.02	+0.02	+0.06	+0.07	+0.06	+0.04	+0.07	+0.05
NMVD (100-400 hPa)	0.14	0.16	0.19	0.19	0.18	0.17	0.25	0.18
NRMSVD	0.18	0.20	0.24	0.24	0.23	0.22	0.32	0.23
NC (11%)	1564	6160	57312	6095	25562	43085		139778
SPD [m/s]	16.37	14.87	15.52	18.37	17.18	16.35		16.18
NBIAS (MEDIUM LAYER)	+0.08	+0.06	+0.04	+0.20	+0.19	+0.11		+0.10
NMVD (400-700 hPa)	0.20	0.21	0.24	0.34	0.35	0.29		0.28
NRMSVD	0.27	0.27	0.31	0.41	0.43	0.37		0.36
NC (3%)	2418	7028	33366					42812
SPD [m/s]	8.63	9.01	9.60					9.45
NBIAS (LOW LAYER)	+0.01	+0.04	+0.01					+0.02
NMVD (700-1000 hPa)	0.25	0.27	0.27					0.27
NRMSVD	0.31	0.34	0.34					0.34

Table 31: Validation parameters for NWC/GEO-HRW v6.1 Basic AMVs considering three separate layers against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; CCC height assignment with Microphysics)

6.3 VALIDATION FOR DETAILED AMVS WITH DEFAULT CONFIGURATION

The validation of "Detailed AMVs" (with a default tracer size of 12x12 pixels instead of the 24x24 pixels considered by the "Basic AMVs") for GOES-16 satellite is considered now. The calculation of "Detailed AMVs" is activated again changing configurable parameter CDET = 1 in the default model configuration files. These AMVs are provided as an additional dataset of AMVs together with the "Basic AMVs", which are always calculated. An example of this configuration is shown in *Figure 8*.

The conditions for the validation of "Detailed AMVs" are exactly equivalent to those shown in chapter 6.1 for the GOES-16 "Basic AMVs". The validation statistics are presented in *Table 32* (considering all layers together) and *Table 33* (considering the three layers separately) for the same validation period.

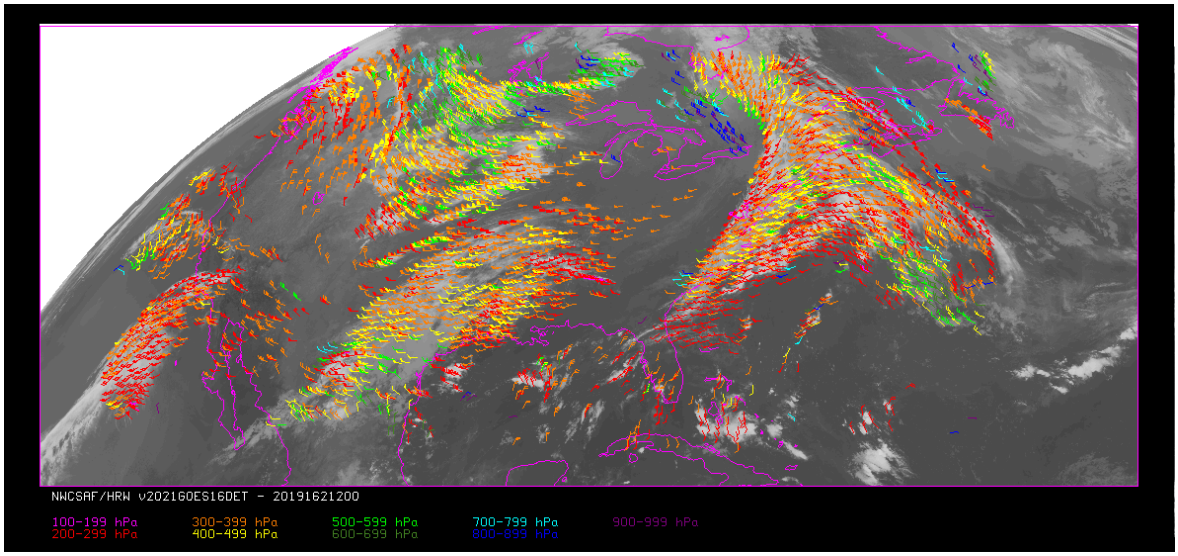


Figure 8: NWC/GEO-HRW v6.2 "Detailed AMV" output example in the Continental United States region (11 June 2019 12:00, GOES-16 satellite, "Mode 6"), considering the default conditions in `$SAFNWC/config/GOES[16-17]*/safnwc_HRW.cfm` model configuration files with configurable parameter CDET = 1. Colour coding based on the AMV pressure level

Comparing with the "Basic AMVs", a reduction in the number of AMVs of about a 42% is seen for the "Detailed AMVs". This is similar to the behaviour seen in GOES-N and Himawari-8/9 satellites series. Again, this can be explained through the smaller size and persistence of the detailed tracers, and especially the smaller contrast in the features using smaller tracer sizes.

The distribution of validated AMVs in the different layers has a value of 79%/18%/3% for the High/Medium/Low layer, slightly concentrating more the AMVs in the High layer with respect to what was observed with the "Basic AMVs". The smaller number of low level "Detailed AMVs" is also to be taken into account in operational use. Considering the validation, NMVD and NRMSVD parameters have small variations up to 10% with respect to those for the "Basic AMVs", while the NBIAS tends to be slightly more positive.

With this, the behaviour of "Detailed AMVs" is very similar to that of "Basic AMVs", and so both datasets can be used together operationally. However, the smaller number of low level "Detailed AMVs" is also to be taken into account for operational use. This result is equivalent to the one found for Himawari-8/9 AMVs.

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC	3552	27221	225762	107240	162988	210986	49955	787704
SPD [m/s]	12.50	17.24	20.01	24.28	23.34	22.55	18.83	21.75
NBIAS (ALL LAYERS)	+0.12	+0.05	+0.07	+0.06	+0.08	+0.07	+0.10	+0.07
NMVD (100-1000 hPa)	0.38	0.27	0.28	0.25	0.26	0.27	0.32	0.27
NRMSVD	0.46	0.34	0.35	0.31	0.33	0.33	0.39	0.34
NC	3552	27221	225762	107240	162988	210986	49955	787704
SPD [m/s]	13.66	17.51	20.02	24.19	23.30	22.51	19.05	21.75
NBIAS (ALL LAYERS)	+0.02	+0.03	+0.07	+0.07	+0.08	+0.07	+0.09	+0.07
NMVD (100-1000 hPa)	0.18	0.17	0.20	0.17	0.18	0.19	0.25	0.19
NRMSVD	0.23	0.21	0.25	0.21	0.23	0.24	0.32	0.25

Table 32: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.1 Detailed AMVs

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC (79%)	733	11914	140876	104753	141721	168940	49955	618892
SPD [m/s]	24.81	24.46	22.62	24.38	24.02	23.67	18.83	23.26
NBIAS (HIGH LAYER)	+0.01	+0.07	+0.07	+0.06	+0.06	+0.05	0.10	+0.06
NMVD (100-400 hPa)	0.21	0.22	0.26	0.25	0.25	0.24	0.32	0.25
NRMSVD	0.25	0.27	0.32	0.30	0.30	0.30	0.39	0.31
NC (18%)	859	6520	69111	2487	21267	42046		142290
SPD [m/s]	17.30	15.74	16.81	20.10	18.84	18.06		17.49
NBIAS (MEDIUM LAYER)	+0.09	+0.08	+0.07	+0.20	+0.22	+0.17		+0.13
NMVD (400-700 hPa)	0.29	0.29	0.33	0.39	0.42	0.39		0.36
NRMSVD	0.35	0.36	0.41	0.48	0.51	0.48		0.46
NC (3%)	1960	8787	15775					26522
SPD [m/s]	5.80	8.58	10.72					9.64
NBIAS (LOW LAYER)	+0.35	+0.15	+0.05					+0.10
NMVD (700-1000 hPa)	0.80	0.47	0.38					0.42
NRMSVD	0.95	0.60	0.46					0.52
NC (79%)	733	11914	140876	104753	141721	168940	49955	618892
SPD [m/s]	24.79	24.34	22.61	24.28	23.95	23.61	19.05	23.22
NBIAS (HIGH LAYER)	+0.01	+0.02	+0.07	+0.07	+0.06	+0.05	+0.09	+0.06
NMVD (100-400 hPa)	0.12	0.14	0.18	0.16	0.16	0.16	0.25	0.17
NRMSVD	0.15	0.17	0.22	0.21	0.20	0.20	0.32	0.22
NC (18%)	859	6520	69111	2487	21267	42046		142290
SPD [m/s]	17.74	15.98	16.84	20.53	18.96	18.11		17.57
NBIAS (MEDIUM LAYER)	+0.06	+0.05	+0.07	+0.17	+0.21	+0.16		+0.12
NMVD (400-700 hPa)	0.18	0.19	0.25	0.30	0.36	0.32		0.29
NRMSVD	0.23	0.24	0.32	0.37	0.43	0.40		0.37
NC (3%)	1960	8787	15775					26522
SPD [m/s]	7.71	9.38	10.86					10.14
NBIAS (LOW LAYER)	+0.01	+0.05	+0.04					+0.04
NMVD (700-1000 hPa)	0.25	0.25	0.26					0.25
NRMSVD	0.33	0.32	0.32					0.32

Table 33: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics) Green figures show improvements of at least 10%, and red figures show worsenings of at least 10%, with respect to NWC/GEO-HRW v6.1 Detailed AMVs

6.4 COMPARISON WITH HRW V6.1 DEFAULT CONFIGURATION

The comparison of the statistics of NWC/GEO-HRW v6.2 "Detailed AMVs" for GOES-16 satellite, with those for NWC/GEO-HRW v6.1 in *Tables 34 and 35* is considered here.

The main element is that the distribution of AMVs in the different layers has improved, going from a value of 89%/9%/2% for the High/Medium/Low layer in the previous version, to a better value in the new version of 79%/18%/3%. The change is again caused by the higher density of tracers related to medium and low level clouds, with an absolute increase in the number of AMVs in the medium and low layer (with 106% more AMVs in the medium layer and 91% more AMVs in the low layer). Considering the high layer there is a small 13% decrease in the number of AMVs with respect to the previous version, and considering all layers together the total number of AMVs is very similar.

Comparing the validation parameters for NWC/GEO-HRW v6.2 with those for v6.1, considering all layers together the values are more different than those for "Basic AMVs", with increments up to 14% in the NMVD and the NRMSVD, and increments up to +0.07 value in the NBIAS against both Radiosounding winds and NWP analysis winds However, these are again caused by the larger proportion now of medium and low layer AMVs with higher validation parameters. Considering the different satellite channels, Cloudy AMVs show some increments in the validation parameters (red figures in *Table 32*), while Clear air AMVs show reductions in them (green figures in *Table 32*).

Considering each layer separately, the NMVD and NRMSVD values are more similar to those for v6.1 in the three layers for all satellite channels, with only variations in the NMVD and NRMSVD larger than 10% related to the visible channels, with reductions in the medium layer for VIS06 channel (green figures in *Table 33*) and increases in the low layer for VIS06 and VIS08 channels (red figures in *Table 33*). The NBIAS shows larger variations, in general with reductions in the medium layer and with increases in the high and low layer. Considering all channels together, only small increments in the NBIAS are seen in the high and low layer.

With all this, a better distribution of AMVs in the different vertical levels is again reached with basically similar statistics, and this can be considered a positive evolution of the "Detailed AMVs" for GOES-16 satellite with the new NWC/GEO-HRW version.

NWC/GEO-HRWv6.1 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC	2652	18481	221512	129480	178937	221402	20584	793048
SPD [m/s]	19.52	20.69	19.92	22.90	22.59	22.04	18.35	21.57
NBIAS (ALL LAYERS)	+0.04	+0.02	+0.06	+0.05	+0.05	+0.05	+0.13	+0.05
NMVD (100-1000 hPa)	0.25	0.25	0.28	0.26	0.26	0.26	0.32	0.26
NRMSVD	0.31	0.31	0.34	0.32	0.32	0.32	0.40	0.32
NC	2652	18481	221512	129480	178937	221402	20584	793048
SPD [m/s]	19.86	20.56	19.87	22.64	22.40	21.89	18.51	21.43
NBIAS (ALL LAYERS)	+0.02	+0.02	+0.07	+0.07	+0.06	+0.06	+0.12	+0.06
NMVD (100-1000 hPa)	0.15	0.16	0.19	0.18	0.18	0.17	0.25	0.18
NRMSVD	0.19	0.20	0.24	0.22	0.22	0.22	0.32	0.22

Table 34: Validation parameters for NWC/GEO-HRW v6.1 Detailed AMVs considering all layers together against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.1 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC (89%)	1670	13409	172684	128279	170405	203035	20584	710066
SPD [m/s]	25.26	23.79	21.40	22.93	22.81	22.48	18.35	22.29
NBIAS (HIGH LAYER)	+0.02	+0.00	+0.06	+0.05	+0.05	+0.04	+0.13	+0.05
NMVD (100-400 hPa)	0.21	0.23	0.27	0.26	0.26	0.25	0.32	0.26
NRMSVD	0.26	0.29	0.33	0.32	0.31	0.31	0.40	0.32
NC (9%)	258	2183	38537	1201	8532	18367		69078
SPD [m/s]	15.40	16.16	15.93	19.40	18.14	17.21		16.61
NBIAS (MEDIUM LAYER)	+0.14	+0.08	+0.06	+0.22	+0.24	+0.16		+0.12
NMVD (400-700 hPa)	0.33	0.29	0.32	0.39	0.43	0.38		0.35
NRMSVD	0.42	0.36	0.41	0.48	0.51	0.46		0.44
NC (2%)	724	2889	10291					13904
SPD [m/s]	7.75	9.69	10.03					9.84
NBIAS (LOW LAYER)	+0.15	+0.10	+0.04					+0.05
NMVD (700-1000 hPa)	0.53	0.41	0.38					0.39
NRMSVD	0.66	0.50	0.46					0.48
NC (89%)	1670	13409	172684	128279	170405	203035	20584	710066
SPD [m/s]	25.32	23.46	21.33	22.67	22.61	22.30	18.51	22.12
NBIAS (HIGH LAYER)	+0.01	+0.02	+0.07	+0.07	+0.06	+0.05	+0.12	+0.06
NMVD (100-400 hPa)	0.12	0.15	0.18	0.17	0.17	0.16	0.25	0.17
NRMSVD	0.15	0.19	0.23	0.22	0.21	0.21	0.32	0.22
NC (9%)	258	2183	38537	1201	8532	18367		69078
SPD [m/s]	15.81	16.36	15.92	19.64	18.31	17.27		16.65
NBIAS (MEDIUM LAYER)	+0.11	+0.07	+0.06	+0.21	+0.23	+0.16		+0.12
NMVD (400-700 hPa)	0.24	0.20	0.24	0.32	0.36	0.31		0.28
NRMSVD	0.32	0.25	0.31	0.40	0.44	0.39		0.36
NC (2%)	724	2889	10291					13904
SPD [m/s]	8.71	10.26	10.23					10.15
NBIAS (LOW LAYER)	+0.02	+0.04	+0.02					+0.02
NMVD (700-1000 hPa)	0.27	0.25	0.25					0.25
NRMSVD	0.34	0.31	0.31					0.31

Table 35: Validation parameters for NWC/GEO-HRW v6.1 Detailed AMVs considering three separate layers against Radiosounding winds (in green) and ECMWF NWP analysis winds (in blue) (May-Jul 2019 00:00 & 12:00 UTC; GOES-16 satellite; "Mode 6"; Continental United States region; Cross correlation; CCC height assignment with Microphysics)

6.5 COMPARISON WITH MSG, GOES-N & HIMAWARI-8/9 SATELLITE SERIES

Comparing the statistics of NWC/GEO-HRW v6.2 default configuration for GOES-16 satellite with those for Himawari-8/9 satellites, a very similar number of AMVs is obtained considering regions of similar sizes and an equivalent number of satellite slots. This vertical distribution of AMVs is also rather equivalent for both satellites in general, due to the similarities between ABI and AHI imagers and the satellite channels used for the AMV calculation.

Comparing the statistics for GOES-16 satellite with those for MSG satellites, the number of AMVs calculated for GOES-16 is two and a half times considering regions of similar sizes and an equivalent number of satellite slots, such as occurred with Himawari-8/9. A positive effect is so clearly seen for the calculation of AMVs with the better spatial and temporal resolution of the new generation of satellites. The calculation of AMVs every 10 minutes instead of every 15 minutes is also to be noticed.

Comparing the number of AMVs for GOES-16 with those for GOES-N, a significant increase in the number of AMVs is also obtained per slot. This way, a positive effect is clearly seen again for the calculation of AMVs with the better spatial resolution of the new generation of satellites, and the wider spectrum of satellite channels available for the AMV calculation with respect to those used with GOES-N. Additionally, the AMV calculation with GOES-N satellites was limited in NWC/GEO-HRW product to the "Continental United States region" every 15 minutes, and the "Extended North America region" every 30 minutes. A more frequent AMV calculation every 10 minutes is so available in North and Central America, and AMVs can now also be calculated every 10 minutes in South America and oceanic areas inside the GOES-16 full disk, which is a significant change for related NWC/GEO users.

Considering the distribution of AMVs in the different layers, for GOES-16 satellite it has a value of 77%/18%/5% for the High/Medium/Low layer, which is very similar to those found for Himawari-8/9 and GOES-N satellites series. Comparing with MSG satellites, with a value of 35%/32%/33%, the much higher concentration of AMVs in the High layer is caused as in the Himawari-8/9 case by two main reasons:

- On one side, the Continental United States region used for the validation with GOES-16, with less maritime areas and some high altitude and desert areas, and so with less frequent low clouds.
- On the other side, the different lineup of satellite channels used in the corresponding AMV processing. For MSG there are three visible, two infrared and two water vapour channels, while for GOES-16 there are two visible, one infrared and three water vapour channels. The ones for MSG distribute better the AMVs in the high, medium and low layer, while the GOES-16 ones tend to concentrate more the AMVs in the high layer. An option for this could be then to use in future versions of GOES-R algorithms more visible or infrared channels in the AMV processing.

Comparing the validation parameters for all satellites, GOES-16 satellite shows slightly better values than MSG (which is only caused by its larger proportion of high layer AMVs) and similar values to GOES-N and Himawari-8/9. Here it is remarkable to see that NBIAS parameter shows positive values for GOES-16 and Himawari-8/9, while it has negative values for MSG and GOES-N.

Considering each layer separately, validation parameters are more or less similar for MSG, GOES-N and GOES-16, while those for Himawari-8/9 are slightly higher (possible caused by the region used for validation with Himawari-8/9).

With all this, the operability of NWC/GEO-HRW algorithm is equivalent for the four satellite series. As already said, in all of them the "Optimal accuracy" is reached in the high layer, and the "Target accuracy" is reached in the medium and low layer. Comparatively, there is however room for improvement for AMVs with Himawari-8/9 and GOES-R satellite series, trying to reduce the errors and to increase the proportion of AMVs in the medium and low layer for a better characterization of the wind throughout all the troposphere. As MTG-I satellite series will be very similar to these ones, any improvement will be positive for all these new generation satellite series.

7. VALIDATION OF HRW V6.2 AMVS WITH GOES-17 SATELLITE

7.1 VALIDATION PROCESS FOR GOES-17 SATELLITE

A specific validation has been defined for GOES-17 due to the cooling issues in the corresponding GOES-17/ABI radiometer, which occur around the spring and autumn equinoxes around 13:00 UTC time. Following figures provided by NOAA show respectively the intensity of this cooling issue throughout the year 2021 (*Figure 9*) and throughout the day for different dates and satellite channels (*Figure 10*). A very similar behaviour is expected for different years.

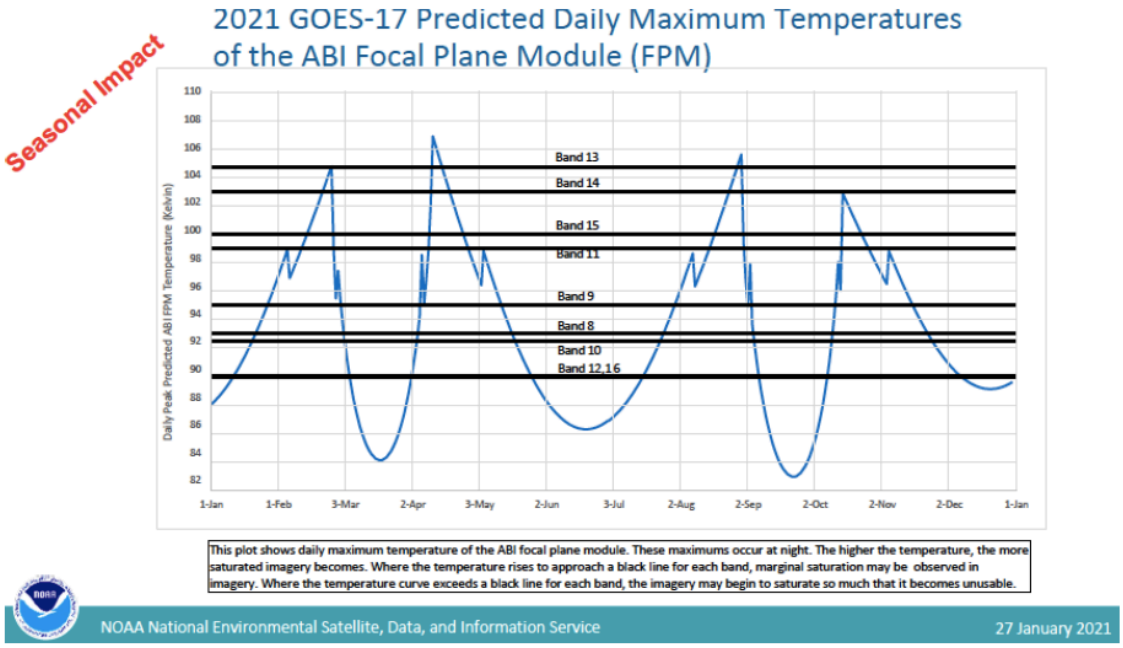


Figure 9: Intensity of the cooling issue in GOES-17/ABI radiometer throughout the year for the different satellite channels

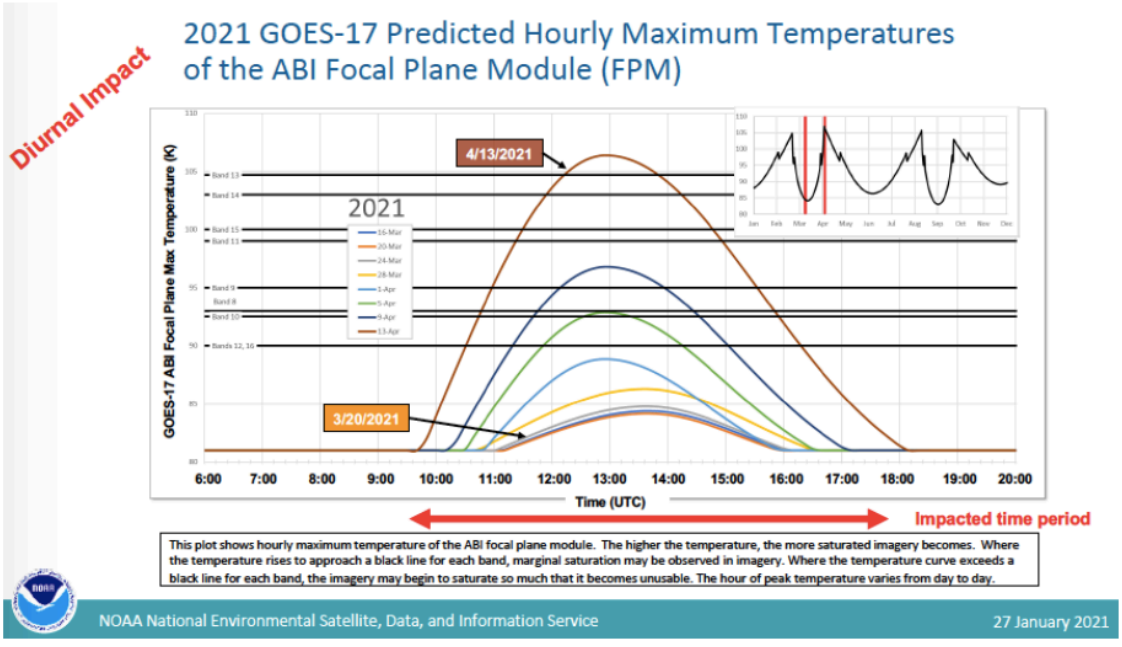


Figure 10: Intensity of the cooling issue in GOES-17/ABI radiometer throughout the day for different satellite channels and dates

Considering this, the validation of NWC/GEO-HRW v6.2 algorithm for GOES-17 satellite is based on the validation of "Basic AMVs" and "Detailed AMVs" in a region covering the Northeastern Pacific region (shown in *Figures 11 and 12*), considering two different processes:

- On one side, the validation of AMVs calculated during 86 days of the quarterly period February – April 2021 at 00:00 UTC. The results are provided in *Tables 36 and 37* for "Basic AMVs" and *Tables 38 and 39* for "Detailed AMVs". Although this quarterly period occurs around the spring equinox, AMVs at this moment are not affected by the cooling issue, and so the behaviour of the ABI radiometer is optimal. The running of three consecutive slots for all Cloud and HRW products for the validation moment (23:40 UTC, 23:50 UTC and 00:00 UTC) is needed. This configuration is equivalent to the one used for GOES-16, and permits very easily a comparison in the results for both satellites, both working in optimal conditions. The results of this are presented in Chapters 7.2, 7.3 and 7.4.
- On the other side, the validation of AMVs calculated throughout the complete day, considering two different dates: 22 June 2020 (unaffected by the cooling issue) and 24 February 2021 (affected by the cooling issue). Comparing both results, it can be seen if the cooling issue has some impact in the AMVs calculated throughout one day. The results of this are presented in Chapter 7.5.

The default conditions for NWC/GEO-HRW v6.2 for GOES-R satellites, considering "Cross correlation tracking", "CCC height assignment method with Microphysics correction", and a "higher density for tracers related to medium and low level clouds", are defined for the validation. These conditions are specified in the default model configuration files `$SAFNWC/config/GOES[16-17]*/safnwc_HRW.cfm`, which are also the ones used for GOES-16, with validation of all possible satellite channels. Cloudy AMVs in the layer 100-1000 hPa and water vapour clear air AMVs in the layer 100-400 hPa, with a Quality index with forecast ≥ 75%, are included in this validation.

As for all previous satellite series, both "Basic scale AMVs" and "Detailed scale AMVs" are validated. And as for all other cases, NWC/GEO-Cloud product outputs (CMA, CT, CTTH and CMIC) in the processing region have to be available so that NWC/GEO-HRW can fully process the conditions defined in the model configuration file.

7.2 VALIDATION FOR BASIC AMVS WITH DEFAULT CONFIGURATION

As already said, the first part of the validation of NWC/GEO-HRW-v6.2 product for GOES-17 satellite is based on the validation of "Basic AMVs" calculated in the Northeastern Pacific region shown in *Figure 11*. AMVs calculated during 86 days of the quarterly period February – April 2021 at 00:00 UTC are considered for this validation. The results are provided in *Tables 36 and 37*.

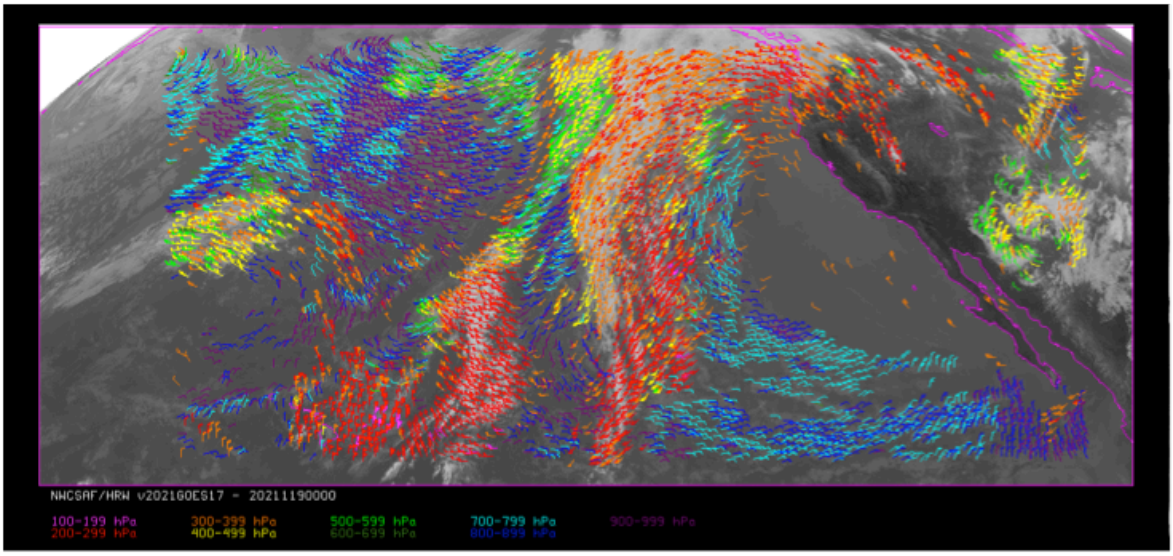


Figure 11: NWC/GEO-HRW v6.2 "Basic AMV" output example in the Eastern Pacific Ocean region (29 April 2021 00:00, GOES-17 satellite, "Mode 6"), considering the default conditions defined in `$SAFNWC/config/GOES[16-17]*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

Comparing the statistics against Radiosounding winds and ECMWF NWP analysis in *Tables 36 and 37,* considering respectively all layers together and the three layers separately, the NMVD and NRMSVD are once again between a 25% and a 45% smaller against NWP analysis winds. Considering the different layers, as in previous cases, the validation parameters are progressively larger for the high layer, medium layer and low layer against Radiosounding winds, although not against NWP analysis winds, for which validation parameters are similar in the medium and low layer.

The distribution of AMVs in the High/Medium/Low layer has a value of 57%/33%/10% considering validated AMVs. The smaller concentration of AMVs in the high layer with respect to GOES-N, Himawari-8/9 and GOES-16 is related to the region used for the validation, which is largely oceanic and due to this with more frequent low clouds.

As for all previous satellites series, the NWC/GEO-HRW "Optimal accuracy" (with NRMSVD ≤ 0.35 against Radiosounding winds) is reached in the high layer, and the "Target accuracy" (with NRMSVD ≤ 0.50 and 0.56 respectively against Radiosounding winds) is reached in the medium and low layer.

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC	1752	3913	14559	8834	14236	15519	2314	61127
SPD [m/s]	17.40	16.89	20.68	28.31	25.76	24.79	21.81	23.71
NBIAS (ALL LAYERS)	+0.04	+0.03	+0.00	+0.04	+0.02	-0.00	+0.17	+0.02
NMVD (100-1000 hPa)	0.29	0.29	0.26	0.24	0.26	0.25	0.34	0.26
NRMSVD	0.36	0.36	0.34	0.32	0.33	0.34	0.42	0.34
NC	1752	3913	14559	8834	14236	15519	2314	61127
SPD [m/s]	18.22	17.65	21.11	28.20	25.72	24.72	22.20	23.86
NBIAS (ALL LAYERS)	-0.00	-0.01	-0.01	+0.04	+0.03	-0.00	+0.15	+0.01
NMVD (100-1000 hPa)	0.16	0.17	0.17	0.16	0.18	0.17	0.26	0.18
NRMSVD	0.22	0.24	0.23	0.21	0.23	0.23	0.33	0.23

Table 36: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Feb-Apr 2021 00:00 UTC; GOES-17 satellite; "Mode 6"; Eastern Pacific Ocean region; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC (57%)	602	1317	6123	7106	8535	8463	2314	34460
SPD [m/s]	30.56	29.41	29.59	30.37	30.45	30.31	21.81	29.63
NBIAS (HIGH LAYER)	+0.00	-0.00	+0.01	+0.03	+0.02	-0.00	+0.17	+0.02
NMVD (100-400 hPa)	0.21	0.20	0.21	0.22	0.21	0.21	0.34	0.22
NRMSVD	0.26	0.24	0.26	0.28	0.27	0.27	0.42	0.28
NC (33%)	280	798	4801	1728	5701	7056		20364
SPD [m/s]	16.65	14.56	18.04	19.85	18.74	18.17		18.28
NBIAS (MEDIUM LAYER)	+0.07	+0.02	-0.03	+0.06	+0.04	-0.01		+0.00
NMVD (400-700 hPa)	0.28	0.34	0.31	0.38	0.37	0.35		0.35
NRMSVD	0.32	0.45	0.42	0.55	0.48	0.48		0.47
NC (10%)	870	1798	3635					6303
SPD [m/s]	8.53	8.76	9.15					8.95
NBIAS (LOW LAYER)	+0.12	+0.12	+0.03					+0.07
NMVD (700-1000 hPa)	0.50	0.45	0.39					0.42
NRMSVD	0.59	0.53	0.47					0.50
NC (57%)	602	1317	6123	7106	8535	8463	2314	34460
SPD [m/s]	30.53	29.38	29.64	30.24	30.32	30.22	22.20	29.58
NBIAS (HIGH LAYER)	+0.00	-0.00	+0.01	+0.04	+0.02	+0.00	+0.15	+0.02
NMVD (100-400 hPa)	0.12	0.13	0.13	0.14	0.14	0.13	0.26	0.14
NRMSVD	0.16	0.16	0.17	0.19	0.18	0.17	0.33	0.18
NC (33%)	280	798	4801	1728	5701	7056		20364
SPD [m/s]	17.36	15.24	18.29	19.84	18.84	18.13		18.39
NBIAS (MEDIUM LAYER)	+0.02	-0.02	-0.04	+0.06	+0.03	-0.00		+0.00
NMVD (400-700 hPa)	0.17	0.23	0.23	0.26	0.28	0.26		0.26
NRMSVD	0.21	0.33	0.30	0.35	0.36	0.34		0.34
NC (10%)	870	1798	3635					6303
SPD [m/s]	9.97	10.14	10.44					10.29
NBIAS (LOW LAYER)	-0.03	-0.02	-0.09					-0.06
NMVD (700-1000 hPa)	0.24	0.24	0.24					0.24
NRMSVD	0.34	0.32	0.34					0.33

Table 37: Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Feb-Apr 2021 00:00 UTC; GOES-17 satellite; "Mode 6"; Eastern Pacific Ocean region; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics)

7.3 VALIDATION FOR DETAILED AMVS WITH DEFAULT CONFIGURATION

The validation of "Detailed AMVs" (with a default tracer size of 12x12 pixels instead of the 24x24 pixels considered by the "Basic AMVs") for GOES-17 satellite is considered now. The calculation of "Detailed AMVs" is activated again changing configurable parameter CDET = 1 in the default model configuration file. These AMVs are provided as an additional dataset of AMVs together with the "Basic AMVs", which are always calculated. An example of this configuration is shown in *Figure 12*.

The conditions for the validation of "Detailed AMVs" are exactly equivalent to those shown in chapter 7.2 for the GOES-17 "Basic AMVs". The validation statistics are presented in *Table 38* (considering all layers together) and *Table 39* (considering the three layers separately) for the same validation period.

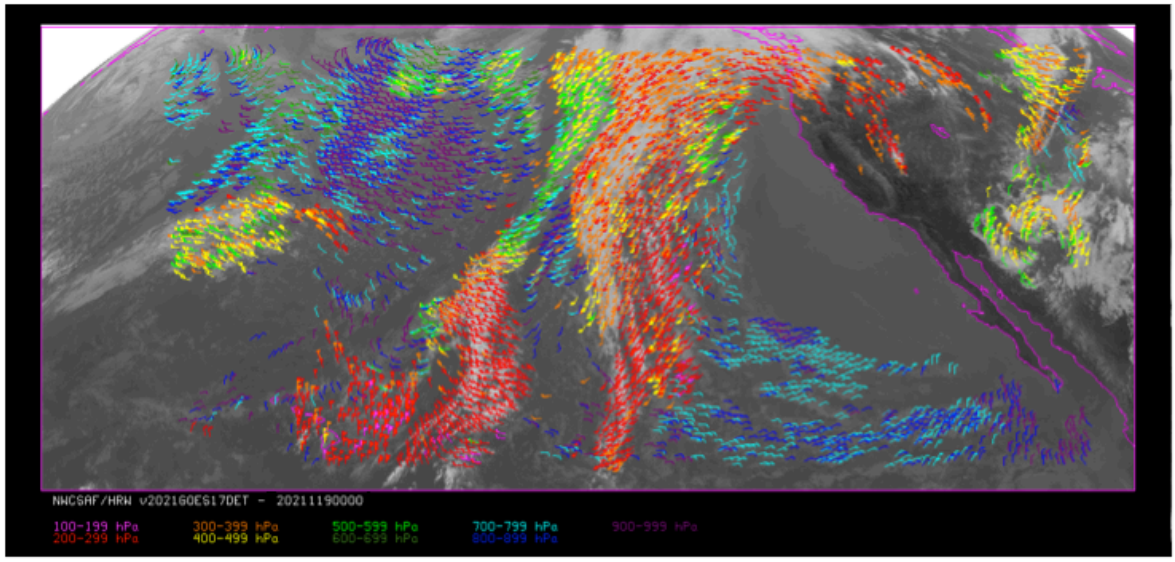


Figure 12: NWC/GEO-HRW v6.2 "Detailed AMV" output example in the Eastern Pacific Ocean region (29 April 2021 00:00, GOES-17 satellite, "Mode 6"), considering the default conditions defined in `$SAFNWC/config/GOES[16-17]*/safnwc_HRW.cfm` model configuration file. Colour coding based on the AMV pressure level

Comparing with the "Basic AMVs", a reduction in the number of AMVs of about a 35% is seen for the "Detailed AMVs". This is similar to the behaviour seen in GOES-N, Himawari-8/9 and GOES-16 satellites. Again, this can be explained through the smaller size and persistence of the detailed tracers, and especially the smaller contrast in the features using smaller tracer sizes.

The distribution of validated AMVs in the different layers has a value of 65%/28%/7% for the High/Medium/Low layer, slightly concentrating more the AMVs in the high layer with respect to what was observed with the "Basic AMVs", as for all the previously mentioned satellite series. Considering the validation, NMVD and NRMSVD parameters have general reductions up to 20% with respect to those for the "Basic AMVs", while the NBIAS tends to be slightly more positive.

With this, the behaviour of "Detailed AMVs" is very similar to that of "Basic AMVs", and so both datasets can be used together operationally.

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC	473	3066	11038	4387	8466	11747	819	39976
SPD [m/s]	14.15	20.21	22.94	29.34	27.79	26.59	22.33	25.41
NBIAS (ALL LAYERS)	+0.08	+0.03	+0.02	+0.03	+0.02	+0.00	+0.21	+0.02
NMVD (100-1000 hPa)	0.36	0.25	0.25	0.22	0.23	0.24	0.36	0.24
NRMSVD	0.43	0.31	0.32	0.29	0.30	0.31	0.46	0.31
NC	473	3066	11038	4387	8466	11747	819	39976
SPD [m/s]	15.39	20.78	23.37	29.44	27.81	26.48	22.64	25.58
NBIAS (ALL LAYERS)	-0.00	+0.00	+0.00	+0.03	+0.02	+0.00	+0.19	0.01
NMVD (100-1000 hPa)	0.19	0.15	0.16	0.13	0.15	0.15	0.27	0.15
NRMSVD	0.26	0.20	0.20	0.17	0.19	0.20	0.33	0.20

Table 38: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering all layers together against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Feb-Apr 2021 00:00 UTC; GOES-17 satellite; "Mode 6"; Eastern Pacific Ocean region; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics)

NWC/GEO-HRWv6.2 AMVs (May-Jul 2019, GOES-16 M6)	Cloudy VIS06	Cloudy VIS08	Cloudy IR112	Cloudy WV62	Cloudy WV70	Cloudy WV74	Clear Air	All AMVs
NC (65%)	69	1391	5687	4064	6473	7663	819	26166
SPD [m/s]	31.40	30.07	29.52	30.11	30.29	30.52	22.33	29.91
NBIAS (HIGH LAYER)	-0.02	+0.01	+0.03	+0.02	+0.01	+0.00	+0.21	+0.02
NMVD (100-400 hPa)	0.19	0.20	0.21	0.22	0.21	0.21	0.36	0.21
NRMSVD	0.23	0.24	0.26	0.28	0.27	0.26	0.46	0.27
NC (28%)	96	709	3840	323	1973	4084		11025
SPD [m/s]	18.10	16.39	18.29	19.65	19.56	19.22		18.78
NBIAS (MEDIUM LAYER)	+0.10	+0.03	+0.00	+0.15	+0.05	-0.00		+0.02
NMVD (400-700 hPa)	0.32	0.29	0.31	0.37	0.35	0.33		0.33
NRMSVD	0.36	0.36	0.41	0.48	0.47	0.46		0.44
NC (7%)	308	966	1511					2785
SPD [m/s]	9.06	8.79	10.01					9.48
NBIAS (LOW LAYER)	+0.14	+0.12	+0.07					+0.09
NMVD (700-1000 hPa)	0.51	0.43	0.37					0.41
NRMSVD	0.61	0.52	0.45					0.49
NC (65%)	69	1391	5687	4064	6473	7663	819	26166
SPD [m/s]	30.43	30.23	29.73	30.16	30.32	30.45	22.64	29.96
NBIAS (HIGH LAYER)	+0.00	+0.01	+0.02	+0.02	+0.01	+0.01	+0.19	+0.02
NMVD (100-400 hPa)	0.11	0.12	0.13	0.12	0.13	0.12	0.27	0.13
NRMSVD	0.13	0.16	0.16	0.16	0.16	0.16	0.33	0.17
NC (28%)	96	709	3840	323	1973	4084		11025
SPD [m/s]	18.74	16.92	18.53	20.30	19.56	19.04		18.85
NBIAS (MEDIUM LAYER)	+0.06	-0.00	-0.00	+0.12	+0.05	+0.00		+0.01
NMVD (400-700 hPa)	0.24	0.20	0.21	0.26	0.24	0.24		0.23
NRMSVD	0.27	0.26	0.28	0.34	0.31	0.30		0.29
NC (7%)	308	966	1511					2785
SPD [m/s]	10.97	10.00	11.75					11.06
NBIAS (LOW LAYER)	-0.05	-0.01	-0.08					-0.05
NMVD (700-1000 hPa)	0.21	0.23	0.22					0.22
NRMSVD	0.32	0.30	0.29					0.30

Table 39: Validation parameters for NWC/GEO-HRW v6.2 Detailed AMVs considering three separate layers against Radiosounding winds (in white) and ECMWF NWP analysis winds (in yellow) (Feb-Apr 2021 00:00 UTC; GOES-17 satellite; "Mode 6"; Eastern Pacific Ocean region; Cross correlation; Higher density related to medium and low level clouds; CCC height assignment with Microphysics)

7.4 COMPARISON WITH GOES-16 SATELLITE

Comparing the statistics of NWC/GEO-HRW v6.2 for GOES-17 satellite with those for GOES-16 satellites, there are some differences:

- On one side, in spite of using a similar amount of validation slots, the number of AMVs validated for GOES-17 is significantly smaller. This is only caused by the fact that the region used for validation of GOES-17 is basically oceanic, with a smaller number of Radiosounding stations, which define the reference wind data for all AMVs.
- On the other side, the proportion of High/Medium/Low level AMVs is 57%/33%/10% for GOES-17, while it was 77%/18%/5% for GOES-16, with a much higher proportion of high level AMVs. As already mentioned, this is also caused by the region used in the validation of GOES-17 which is largely oceanic and due to this with more frequent low clouds.

Comparing the validation parameters, considering all layers together and the three layers separately, GOES-17 satellite shows better values of NMVD and NRMSVD parameters (with reductions in a pair of cases up to 35%), and the NBIAS shows also significantly smaller values. This is most possibly related to the type of AMVs included in the GOES-17 validation, which are in a larger part maritime AMVs, and through the validation they show to have better validation statistics.

7.5 VALIDATION THROUGHOUT A FULL DAY OF BASIC AND DETAILED AMVS

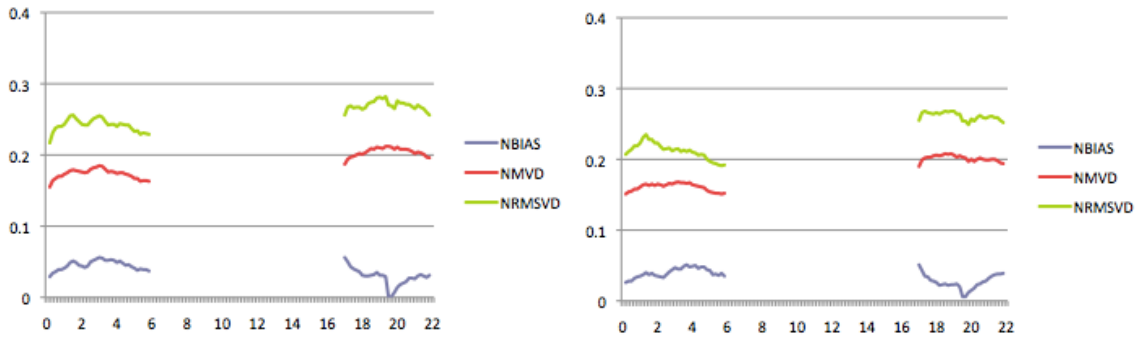
The validation parameters of "Basic AMVs" and "Detailed AMVs" calculated throughout the whole day for 24 February 2021, affected by the GOES-17/ABI cooling issue, is presented in following *Figures 13 and 14*.

The restrictions of NWC/GEO-HRW software for the calculation in default mode of AMVs and Trajectories with GOES-17 satellite have to be remembered here: only when Full Disk images in "Mode 6" are provided, with images every 10 minutes, for areas in the image where NWC/GEO-Cloud products could be calculated, and the quality flag for the satellite channel used for AMV calculation is zero/optimal for all pixels implied in the AMV calculation.

As the figures show this guarantees the quality of AMVs and Trajectories, because validation parameters do not degrade approaching the moment in which the cooling issue of GOES-17/ABI radiometer occurs (around 13:00 UTC). Actually, validation parameters are rather constant throughout the whole day for this date (for the moments in which NWC/GEO-HRW is available).

However, this restriction also implies that NWC/GEO-HRW can be unavailable for a long period of up to ten/twelve consecutive hours in dates like this. NWC/GEO-HRW users need to take this into account, and evaluate the implications of this lack of NWC/GEO-HRW GOES-17 outputs in their processing (occurring in four 50-day periods per year around the equinoxes).

In large part of the period of unavailability, the lack of NWC/GEO-HRW is caused by the lack of NWC/GEO-Cloud outputs. A simple way of providing a longer period of NWC/GEO-HRW outputs is to change configurable parameter KEEPDEFAULTPROCEDURE = 0 in the `safnwc_HRW.cfm` model configuration file so that AMVs can be calculated even when some NWC/GEO-Cloud outputs are not available. However, this also implies that the AMV calculation process and corresponding validation are somewhat different. The user should evaluate the advantages and disadvantages of doing this change.



Figures 13 and 14: Evolution throughout the day for Validation parameters for NWC/GEO-HRW v6.2 Basic AMVs (left) and Detailed AMVs (right), for a day with impact from the GOES-17/ABI cooling issue: 24 February 2021.

8. CONCLUSIONS

Some conclusions can be extracted from this "Validation report" for NWC/GEO-HRW v6.2. NWC/GEO-HRW product has been validated against both Radiosounding winds and NWP model analysis winds. In general, as in previous versions, it has been seen that NBIAS, NMVD and NRMSVD validation parameters are significantly smaller (around a 30% smaller) against NWP analysis winds, and the general scale and behaviour of AMV winds is more similar to the one of NWP analysis winds than to the one of Radiosounding winds.

In the comparison with previous versions (in *Table 40*), the validation is very similar. However, there is a better distribution of AMVs in the different layers for all satellite series, contributing to a better characterization of the winds in all tropospheric levels (for all of them the percentage of medium and low layer AMVs is at least a 9% larger, and for MSG satellites an optimal distribution of AMVs of 35%/32%/33% in the High/Medium/Low layer is even reached).

Evolution of the Validation statistics between HRW versions, related to the Operative thresholds defined in the HRW Product Requirement Table (against Radiosounding winds)	**High Layer NRMSVD/ Percentage of AMVs**	**Medium Layer NRMSVD/ Percentage of AMVs**	**Low Layer NRMSVD/ Percentage of AMVs**
NWC/GEO-HRW v6.0, Default configuration, MSG	**0.32 / 52%**	**0.44 / 25%**	**0.50 / 23%**
NWC/GEO-HRW v6.0, Default configuration, GOES-N	**0.35 / 86%**	**0.41 / 07%**	**0.49 / 07%**
NWC/GEO-HRW v6.0, Default configuration, Himawari-8/9	**0.31 / 82%**	**0.50 / 14%**	**0.55 / 04%**
NWC/GEO-HRW v6.1, Default configuration, GOES-16	**0.33 / 86%**	**0.45 / 11%**	**0.52 / 03%**
NWC/GEO-HRW v6.2, Default configuration, MSG (With a 6% increase in the total amount of AMVs)	**0.32 / 35%**	**0.44 / 32%**	**0.49 / 33%**
NWC/GEO-HRW v6.2, Default configuration, GOES-N (With a 4% increase in the total amount of AMVs)	**0.35 / 75%**	**0.40 / 13%**	**0.49 / 12%**
NWC/GEO-HRW v6.2, Default configuration, Himawari-8/9 (With a 14% increase in the total amount of AMVs)	**0.32 / 73%**	**0.47 / 23%**	**0.56 / 04%**
NWC/GEO-HRW v6.2, Default configuration, GOES-16 (With a 5% increase in the total amount of AMVs)	**0.33 / 77%**	**0.45 / 18%**	**0.50 / 05%**
NWC/GEO-HRW v6.2, Default configuration, GOES-17	**0.28 / 57%**	**0.47 / 33%**	**0.50 / 10%**
NWC/GEO-HRW Product Requirement Table Optimal Accuracy	**0.35**	**0.40**	**0.45**
NWC/GEO-HRW Product Requirement Table Target Accuracy	**0.44**	**0.50**	**0.56**
NWC/GEO-HRW Product Requirement Table Threshold Accuracy	**0.53**	**0.60**	**0.67**

Table 40: Evolution of Validation statistics between NWC/GEO-HRW v6.0/v6.1 and v6.2 versions related to the Operative thresholds defined in the NWC/GEO-HRW Product Requirement Table

Together with this there is a small increase in the total amount of AMVs, and the running time of the product has also been reduced: NWC/GEO-HRW v6.2 is up to 30% quicker for MSG, Himawari-8/9 and GOES-R satellites using the default configurations for a similar number of AMVs. All these changes, which have been a frequent request from NWC/GEO users, are considered sufficient to justify that NWC/GEO users update to NWC/GEO-HRW v6.2 version.

For all applicable satellite series (all of them validated: MSG, GOES-N, Himawari-8/9, GOES-R), the "Optimal accuracy" defined by the NWC/GEO-HRW Product Requirement Table is reached for the high layer AMVs, and the "Target accuracy" is reached for the medium and low layer AMVs. This way, NWC/GEO-HRW v6.2 can be used operationally with equivalent options for the four satellite series: MSG, GOES-N, Himawari-8/9 and GOES-R.

Considering GOES-17 satellite, validation parameters have similar quality than those for GOES-16 in the moments for which NWC/GEO-HRW output is available, so not having any degradation caused by the GOES-17/ABI cooling issue. However, the restrictions defined to cope with the problem in this radiometer imply that NWC/GEO-HRW outputs can be unavailable throughout a range of several consecutive hours around 13:00 UTC, in four 50-day periods per year around the equinoxes. NWC/GEO-HRW users with GOES-17 need to take this into account.

Finally, considering the validation for Himawari-8/9 and GOES-R satellite series, there is still room for improvement trying to reduce the errors in the medium and low layer, and still trying to increase more the proportion of AMVs in the low layer. As MTG-I satellite series will also be very similar to these ones, any improvement in these aspects will be positive for the three new generation satellite series.