

Atmospheric Motion Vectors IODC Release 1 Validation Report

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1 INTRODUCTION

Since EUMETSAT operates the first generation of geostationary satellites, it uses its own capability to derive Atmospheric Motion Vectors (AMVs) providing speed and direction, as well as altitude.

The EUMETSAT algorithm (EUMETSAT, 2015), optimised for time series processing of both Meteosat First (MFG) and Second Generation (MSG), has been used to derive the Climate Data Record (CDR) of geostationary AMVs. It is the first IODC AMV CDR based on cross-

calibrated geostationary radiances covering a period of 21 years (1998-2019), using data from three geostationary satellites: Meteosat-5, Meteosat-7 and Meteosat-8 operated over the Indian Ocean (Indian Ocean Data Coverage (IODC)). This CDR complements the data record generated using the imagers from Meteosat satellites located at 0-degrees¹ extending the overall spatial coverage.

AMVs are derived from satellite measurements by tracking the movement of clouds and water vapour structures in successive satellite images. Wind speeds and directions are estimated and an altitude is assigned. The main application is data assimilation in numerical weather prediction models to constrain the model with observations, which improves weather forecasting and reanalysis in otherwise data-poor regions.

This CDR of AMVs will be used as an input into reanalysis systems (Hersbach et al., 2019), such as the 6th European reanalysis, ERA6, which will provide a physically consistent description of the atmosphere for about a century.

AMVs are also a source of information for climate studies, and several applications can be envisaged, e.g., an analysis of the winter weather extremes in Europe largely depending on the location of the jet stream, a belt of fast winds located high in the atmosphere. This CDR, together with the corresponding 0-degree GEO AMV Release 2² (EUMETSAT, 2021a), is suited to analyse the temporal changes and variability of the jet stream (Lattanzio et al., 2019). Coverage of the Indian Ocean may benefit studies of the Indian Summer Monsoon (ISM), e.g. by contributing to an improved understanding of the dynamical features of the monsoon.

Essential funding for this development from the ERA-CLIM2 EU Research Project and the Copernicus Climate Change Service (C3S) is acknowledged.

1.1 Purpose and Scope

This report provides the results of the validation of the AMV IODC CDR Release 1 (R1). The objective of this document is to provide detailed information on the quality of the derived AMV time series from comparison to other data sets and statistical analysis.

1.2 Reference Documents

Borde, R., Doutriaux-Boucher, M., Dew, G., and Carranza, M.: A Direct Link between Feature Tracking and Height Assignment of Operational EUMETSAT Atmospheric Motion Vectors, *Journal of Atmospheric and Oceanic Technology*, 31, 33–46, <https://doi.org/10.1175/JTECH-D-13-00126.1>, 2014.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., Berg, L. van de, Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., Rosnay, P. de, Tavolato, C., Thépaut, J.-N., and Vitart, F.: The ERA-Interim reanalysis: configuration and

¹ DOI: http://doi.org/10.15770/EUM_SEC_CLM_0020

² http://doi.org/10.15770/EUM_SEC_CLM_0020

performance of the data assimilation system, Quarterly Journal of the Royal Meteorological Society, 137, 553–597, <https://doi.org/10.1002/qj.828>, 2011.

EUMETSAT: MSG Meteorological Products Extraction Facility Algorithm Specification Document, 2015.

EUMETSAT: Report on quality analysis of comparison data for AMV evaluation , C3S_311b T5.3 M05, 2018.

EUMETSAT: Atmospheric Motion Vectors Release 2 Validation Report - EUM/OPS/REP/20/1177583, 2020.

EUMETSAT: AMVR20000Atmospheric Motion Vectors Climate Data Record Release 2 - MFG and MSG - 0 degree (2), https://doi.org/10.15770/EUM_SEC_CLM_0020, 2021a.

EUMETSAT: Atmospheric Motion Vectors Release 2 Product Users Guide - EUM/OPS/REP/20/1191306, 2021b.

García-Pereda, J. and Borde, R.: The Impact of the Tracer Size and the Temporal Gap between Images in the Extraction of Atmospheric Motion Vectors, J. Atmos. Oceanic Technol., 31, 1761–1770, <https://doi.org/10.1175/JTECH-D-13-00235.1>, 2014.

GCOS (WMO), (UNESCO) United Nations Educational, S. and C. O., Programme, (UNEP) United Nations Environment, Science, (ICSU) International Council for, and World Meteorological Organization (WMO): GCOS, 154. Systematic Observation Requirements for Satellite-based Products for Climate Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC : 2011 update, WMO, Geneva, 138 p. pp., 2011.

Haimberger, L.: Homogenization of Radiosonde Temperature Time Series Using Innovation Statistics, Journal of Climate, 20, 1377–1403, <https://doi.org/10.1175/JCLI4050.1>, 2007.

Hersbach, H., Bell, W., Berrisford, P., Horányi, A., J., M.-S., Nicolas, J., Radu, R., Schepers, D., Simmons, A., Soci, C., and Dee, D.: Global reanalysis: goodbye ERA-Interim, hello ERA5, <https://doi.org/10.21957/VF291HEHD7>, 2019.

Holmlund, K.: The Utilization of Statistical Properties of Satellite-Derived Atmospheric Motion Vectors to Derive Quality Indicators, Wea. Forecasting, 13, 1093–1104, [https://doi.org/10.1175/1520-0434\(1998\)013<1093:TUOSPO>2.0.CO;2](https://doi.org/10.1175/1520-0434(1998)013<1093:TUOSPO>2.0.CO;2), 1998.

John, V. O., Tabata, T., Rüthrich, F., Roebeling, R., Hewison, T., Stöckli, R., and Schulz, J.: On the Methods for Recalibrating Geostationary Longwave Channels Using Polar Orbiting Infrared Sounders, Remote Sensing, 11, 1171, <https://doi.org/10.3390/rs11101171>, 2019.

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Sèze, G. and Pawlowska, H.: Cloud cover analysis with METEOSAT-5 during INDOEX, J. Geophys. Res., 106, 28415–28426, <https://doi.org/10.1029/2001JD900097>, 2001.

Zhang, Z., Chan, J. C. L., and Ding, Y.: Characteristics, evolution and mechanisms of the summer monsoon onset over Southeast Asia, *Int. J. Climatol.*, 24, 1461–1482, <https://doi.org/10.1002/joc.1082>, 2004.

1.3 Acronyms

AMV		Atmospheric Motion Vector
ATBD		Algorithm Theoretical Basis Document
C3S		Climate Change Service
CCC		Cross Correlation Contribution
CDR		Climate Data Record
CFC		Cloud Fractional Cover
CLM		CLOUD Mask
CLA		CLOUD Analysis
CSDP		Climate Service Development Plan
CTH		Cloud Top Height
DJF		December January February
DOI		Digital Object Identifier
EBBT		Equivalent Black Body Temperature
ECMWF		European Centre for Medium-Range Weather Forecasts
ELW		Expanded Low-resolution cloud motion Wind
ERA		European ReAnalysis
EUMETSAT		European Organisation for the Exploitation of Meteorological Satellites
GCOS		Global Climate Observing System
IODC		Indian Ocean Data Coverage
IR		InfraRed
ISM		Indian Summer Monsoon
ITCZ		Intertropical Convergence Zone
JJA		June July August
MFG		Meteosat First Generation
MPEF		Meteosat Product Extraction Facility
MSG		Meteosat Second Generation
MVIRI		Meteosat Visible and Infrared Imager
NRMSE		Normalised Root Mean Square Error
NRT		Near Real Time
NWP		Numerical Weather Prediction
OPE		Operational

QI		Quality indicator
RAOBCORE		RADiosonde OBservation COrection using Reanalyses
R1		Release 1
RMSE		Root Mean Square Error
SAF		Satellite Application Facility
SEVIRI		Spinning Enhanced Visible and InfraRed Imager
SSP		Sub Satellite Point
SSR		Sensor Spectral Response
TCDR		Thematical Climate Data Record
WV		WaterVapor

2 DATA RECORD GENERATION SUMMARY

The AMV product provides information on speed (m/s), direction ($^{\circ}$), and height (given in pressure units hPa) of vectors (as shown in Figure 1) which are derived by tracking clouds structures between two adjacent images in time.

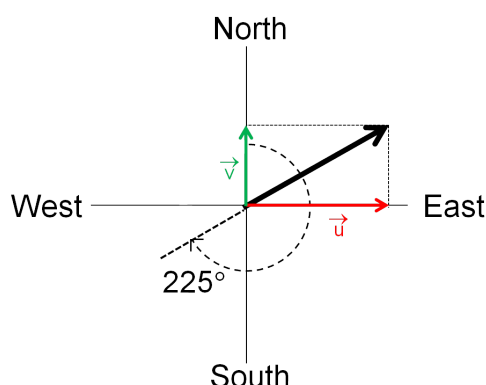


Figure 1: Wind direction measured in degrees in clockwise direction starting from the north. For example, a direction of 225° represents a wind blowing from the southwest. The altitude of the wind is expressed in hPa.

The final hourly/two hourly wind product is an average of the three intermediate products derived every 15/30 minutes using images from the SEVIRI/MVIRI instrument. Each wind vector is accompanied by a Quality Index (QI). The quality index takes into account the consistency between the three intermediate vectors (temporal QI) and the consistency with the surrounding vectors (spatial QI) and with the corresponding forecast wind (forecast QI). The final QI is derived from the temporal, spatial and forecast QIs (Holmlund, 1998).

Atmospheric Motion Vectors are wind vectors retrieved at all heights below the tropopause, derived from two MVIRI/SEVIRI channels: the Water Vapour (WV) around $6.2 \mu\text{m}$ and the Infrared (IR) around $10.8 \mu\text{m}$, all combined into one product. In both channels, winds are retrieved by tracking cloud features.

In the wind field, the meteorological convention is used:

- 0° : Winds blowing from North
- 90° : Winds blowing from East
- 180°: Winds blowing from South
- 270°: Winds blowing from West

Details about the input data and the processing can be found in the Product User Guide (EUMETSAT, 2021b).

2.1 Spatial and temporal coverage

The amount of generated AMV products is around 94% for Meteosat First Generation and close to 95% for Meteosat Second Generation of all theoretically expected. The main reason for missing AMV product is the non-availability of the corresponding input images (either for all or some channels). Further sporadic gaps for MFG are due to the non-availability of the ancillary external calibration coefficient (John et al., 2019). The amount of missing data is higher compared to the 0° because there is no backup satellite for the IODC mission during maintenance or unexpected issues. In addition, a few (about 0.01%) AMV products do not contain wind vectors. This is caused by the data processing system but the exact reason is still under investigation.

The temporal coverage for each platform is given in Table 1, the spatial coverage for the IODC missions is shown in Figure 2. The only portion sensed for the whole period is the one labelled as “COMMON”. The validation has been performed over the complete areas of all platforms, not limiting to the common area. An investigation to assess if this has an impact on the outcome has been performed and showed that the results do not change according to the area considered.

Table 1: Satellite, instrument, nominal orbit for the period 1998-2019. The period includes Meteosat 5, 7 (MFG) and Meteosat 8 (MSG).

Satellite	Instrument	Mission (SSP)	Start Date	End Date
Meteosat-5	MVIRI	0630DEG (63°)	1998-07-01	2007-04-16
Meteosat-7	MVIRI	0570DEG (57°)	2006-11-28	2017-03-31
Meteosat-8	SEVIRI	0415DEG (41.5°)	2017-02-01	2019-08-31

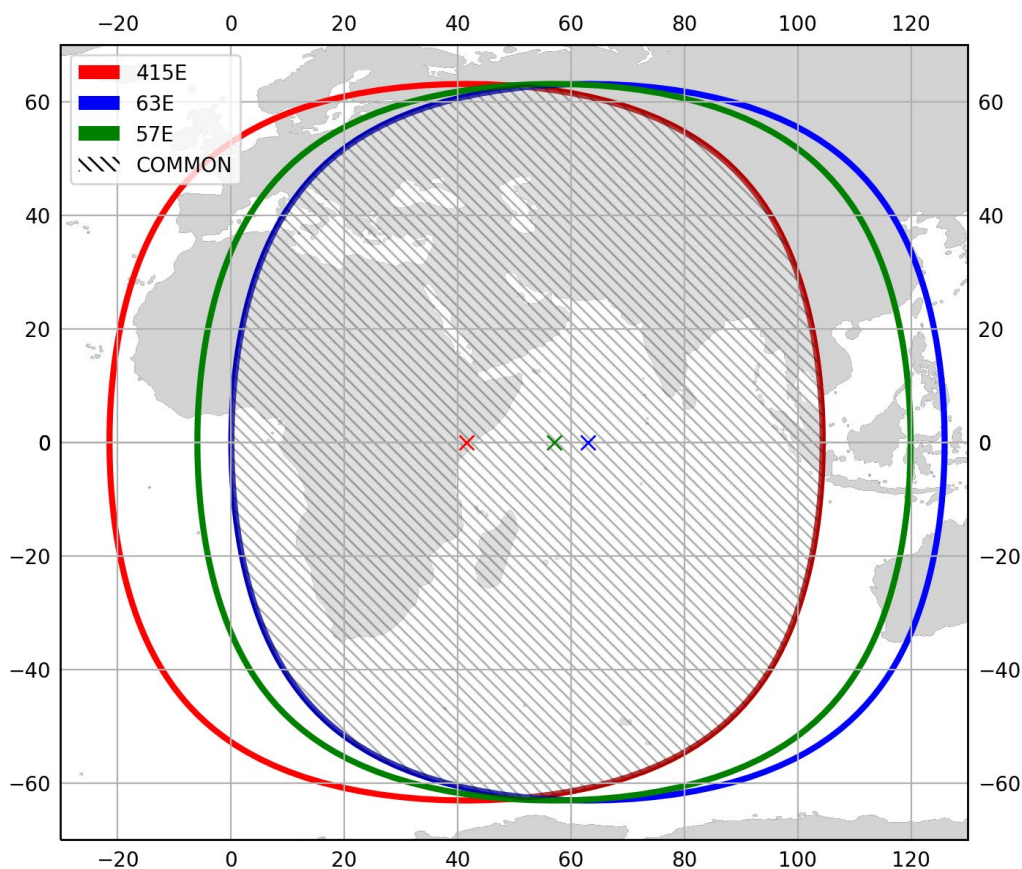


Figure 2: Spatial coverage exploited for AMVs up to 65 degrees for all three-sub satellite points covering the whole IODC mission and the common area sensed over the complete time period.

2.2 Satellite position

The Meteosat satellites used for the IODC missions are all close to their end of operative life, with fuel tanks for orbital manoeuvres practically empty. Because of this, the orbit of the satellites cannot actively be kept stable and the platforms increasingly drift over time without any possible correction (see Figure 3 to Figure 5). Even if the level 1.5 images used for the generation of level 2 products are rectified to the nominal position, the portion of Earth sensed and the acquisition time of each line is affected by such an orbital drift. The amplitude of the drift with respect to latitude and less in longitude is also increasing over time, making the effect more relevant the longer the satellite is used (see for an example Figure 6).

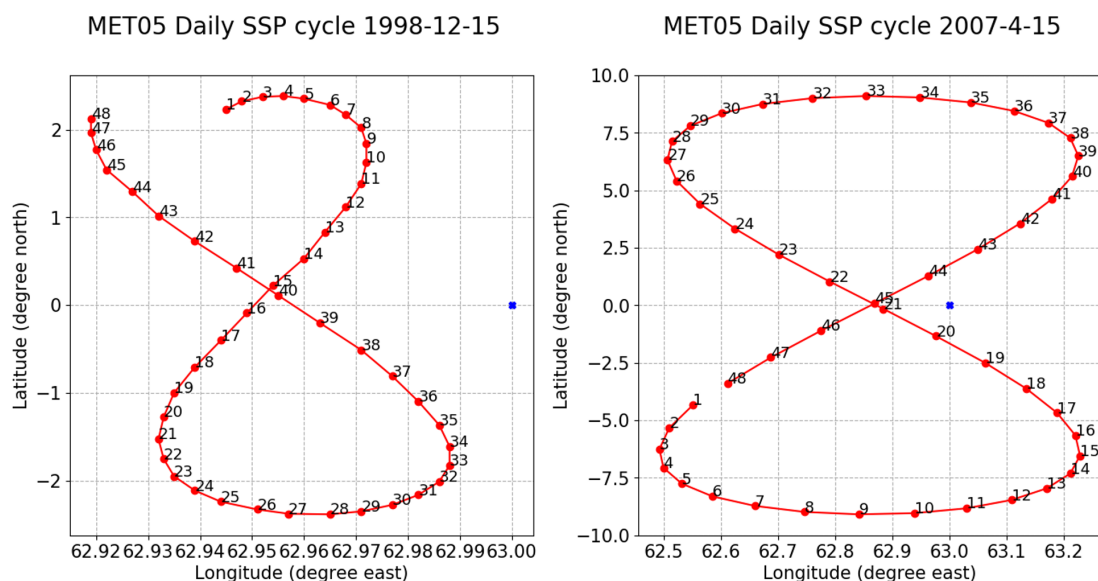


Figure 3: Sub satellite point position: diurnal cycle for Meteosat-5 at the beginning of the IODC period (left panel) and close to the end (right panel). The different values are the slot numbers from 1 to 48 (one slot every 30 minutes), being for instance slot 24 the 12:00 UTC time.

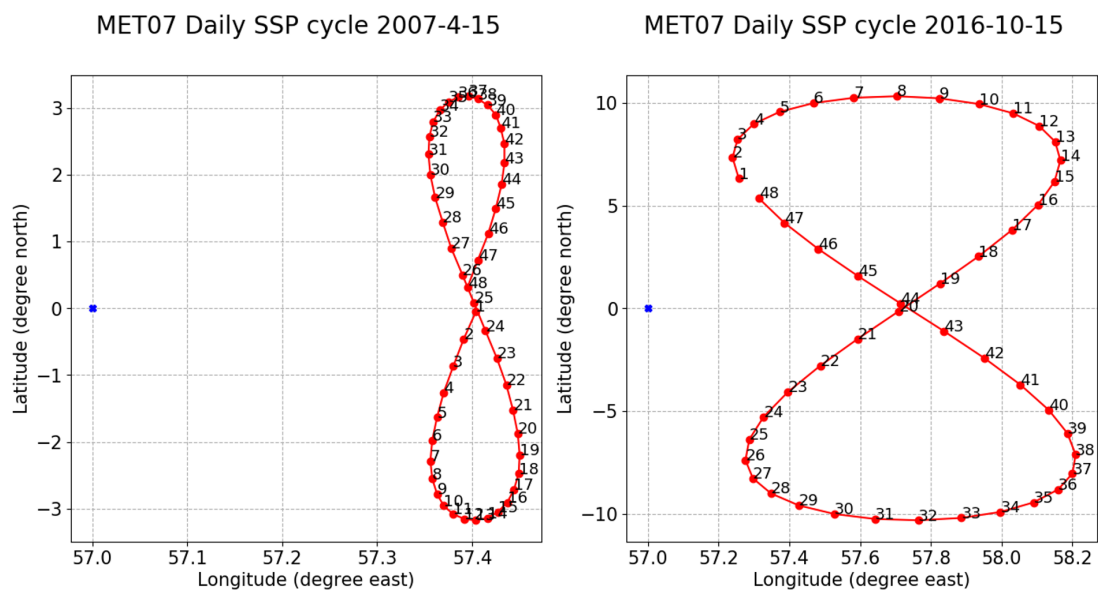


Figure 4: Sub satellite point position: diurnal cycle for Meteosat-7 at the beginning of the IODC period (left panel) and close to the end (right panel). The different values are the slot number from 1 to 48 (one slot every 30 minutes), being for instance slot 24 the 12:00 UTC time.

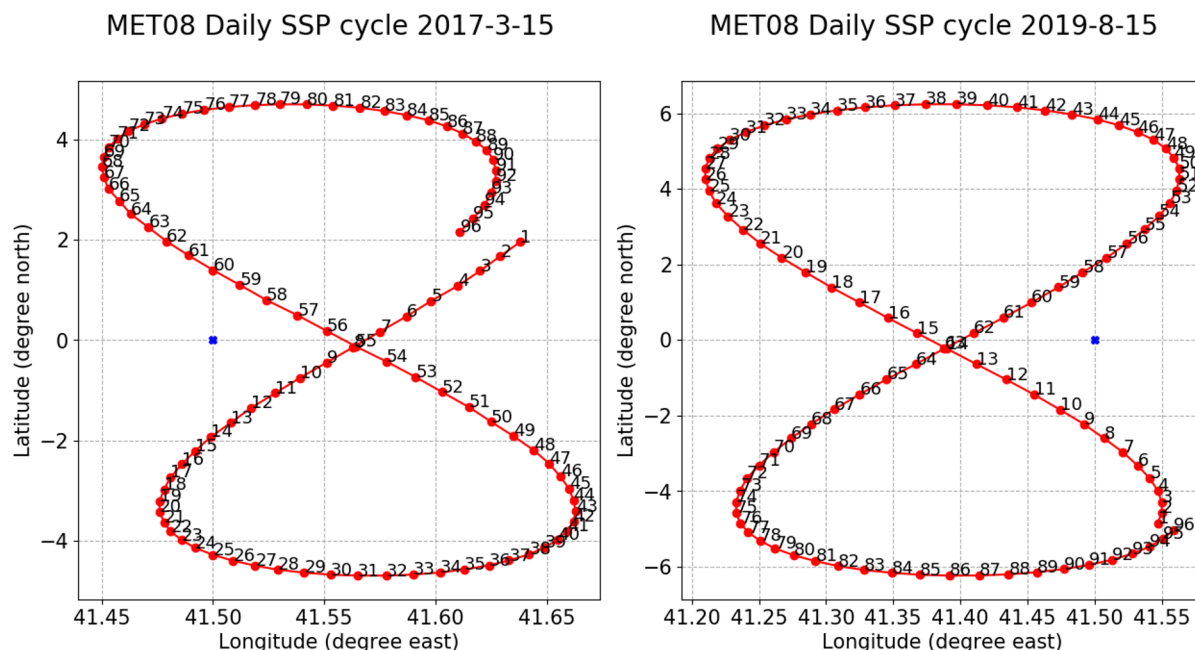


Figure 5: Sub satellite point position: diurnal cycle for Meteosat-8 at the beginning of the IODC period (left panel) and close to the end (right panel). The different values are the slot number from 1 to 96 (one slot every 15 minutes), being for instance slot 48 the 12:00 UTC time.

MET05 Full period SSP cycle

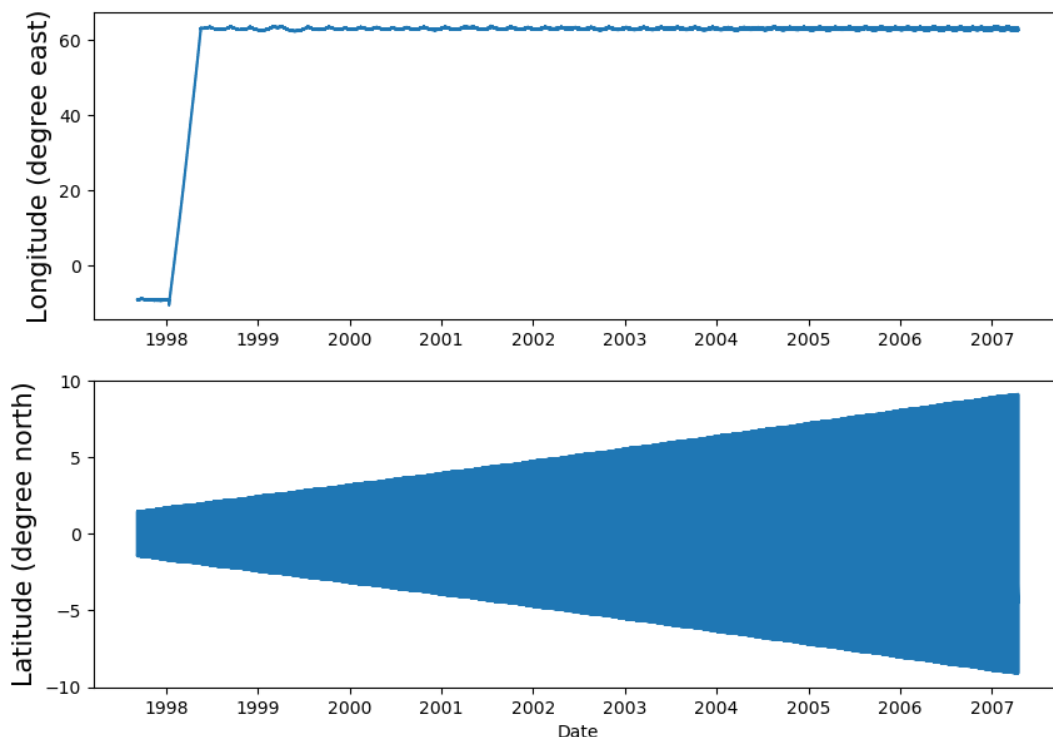


Figure 6: Full SSP variation for Meteosat-5, longitude (upper plot) and latitude (bottom plot). It shows the time of the orbital manoeuvre to bring the satellite to the new position in 1998 (upper diagram) and the latitude range covered during the period (lower diagram).

It is very difficult to quantify the impact of this orbital drift on the generation of AMVs. However it is important to mention it, as it clearly differs from the stable position of the Meteosat located at 0° used to derive the complementary CDR AMV³. We could not identify any specific issue of the CDR related to the orbit drift. The time series, validated in this document, appears stable and homogeneous.

3 VALIDATION DATA

AMVs are compared to Near Real Time (NRT) AMVs from the EUMETSAT ground segment for one year of Meteosat-8 data. It shows differences between the latest NRT AMV retrieval and the adapted algorithm used for the CDR and working consistently for both generations of Meteosat instruments MVIRI and SEVIRI.

For validation purposes, AMVs are compared against independent wind datasets such as radiosondes and model reanalysis. Because reanalyses data are always available, the comparison against the reanalysis forecast is done over the full disk or at least a big portion of it. The comparison against radiosondes depends on the number of observations for the locations where radiosonde data is available (see section 3.2). The two analysis (using radiosonde and reanalysis) have a different objective and are complementary. The comparison against model reanalysis focuses mainly on global geographical statistical analysis, while the comparison to radiosondes aims to a more local but absolute comparison.

Table 2 presents the reference data used for this validation, described in the following subsections.

Table 2: Reference data used for the AMV validation.

Instrument/Data Source	Description	Temporal Coverage
Operational near real time SEVIRI AMVs	EUMETSAT operational NRT product	2018 (MSG only)
RAOBCORE	Homogenized Radiosonde data	1998 – 2019
ERA-Interim	Model forecast data	1998 – 2019

3.1 Operational Near Real Time SEVIRI AMVs

EUMETSAT produces AMVs from SEVIRI measurements in real time (Borde et al., 2014; EUMETSAT, 2015) that are routinely assimilated by Numerical Weather Prediction (NWP) forecasting centres (Dee et al., 2011). Those AMVs are compared with the reprocessed AMVs using only SEVIRI NRT AMVs as they are easily accessible from the EUMETSAT archive. The tracking is done in the same way for both NRT and reprocessed AMVs. The difference between CDR and NRT algorithms comes mainly from the different cloud mask, the vector height assignment and the auxiliary model forecast input data used. NRT vector height assignment uses all available MSG channels while the CDR uses only two channels to ensure homogeneity with estimates from the Meteosat first generation imager. In NRT, the new cross-correlation contribution (CCC) method (Borde et al. 2013) was used. From 2017, the same approach is used also for the operational IODC AMVs.

³ http://doi.org/10.15770/EUM_SEC_CLM_0020

3.2 Radiosonde data

A radiosonde is an instrument that is carried into the atmosphere by a balloon to send back information on vertical profiles of meteorological atmospheric variables such as temperature, pressure, humidity, and winds by means of a small radio transmitter. Radiosonde data are one of the rare means of independent reference data for the validation of reprocessed satellite AMVs. Validation of an AMV climate data record needs temporally stable and high quality datasets covering the period. In that respect, the Radiosonde OBservation COREction using reanalyses dataset is ideal (Haimberger, 2007) (RAOBCORE, <https://www.univie.ac.at/theoret-met/research/raobcore/>). RAOBCORE has also been used as an independent source of validation data within the ERA-CLIM and ERA-CLIM2 projects. The data are homogenised and are thus suitable for climate analyses. From 1979 onwards, the homogenisation involved the detection and removal of time series discontinuities in the temperature through comparison with the ERA-Interim data (Dee et al., 2011). There are 2283 radiosonde stations over the globe (Figure 7). The RAOBCORE data coverage is dominated by the Northern Hemisphere. Radiosondes are launched at most twice a day, which restricts the validation to two times a day at most.

An AMV derived from geostationary data is co-located to the radiosonde measurement if the spatial distance to the launch site is less than 100 km and if temporal difference is less than 90 minutes. The temporal difference is relative to the time of the radiosonde launch that is the only time reported in the radiosonde dataset. A wind measurement from a radiosonde does not necessarily represent the same wind as the one derived from satellite data, as the radiosonde-wind could be sensitive to smaller scale and more local winds, for example. A complete quality analysis of radiosonde data currently used at EUMETSAT to validate AMVs can be found in (EUMETSAT, 2018).

Co-locations have been produced over the different periods and regions according to the satellite data coverage as listed in Table 1. The criteria to co-locate radiosondes and AMV are listed in Section 5.3. The location and the total number of the available radiosondes are shown in Figure 7.

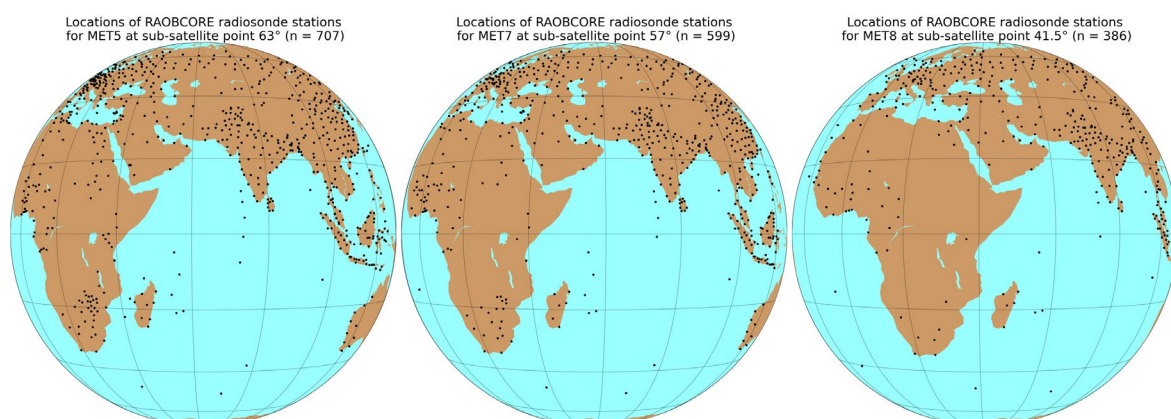


Figure 7: Locations of RAOBCORE radiosonde stations. All stations with corrupt or missing data are excluded. Stations available for (a) Meteosat-5, (b) Meteosat-7 and (c) Meteosat-8 during the time range of each data record.

Figure 8 shows that co-locations are mostly found over land, most of the co-locations are located over Europe, Africa and Asia. No or very few co-locations with radiosondes are found

over some portions of the central and eastern part of Africa. The choice of the co-location criteria influences somehow the statistics but do not affect the conclusion.

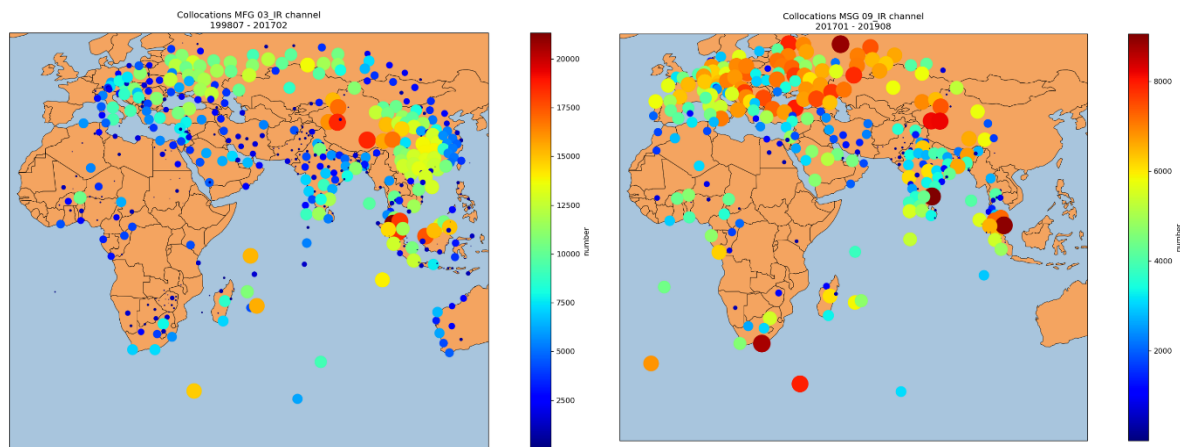


Figure 8: Number of co-locations at given radiosonde station between Meteosat AMVs and a radiosonde within 90 minutes and 100 km, left MFG (1998 – 2017) and right MSG (2017 – 2019).

3.3 Reanalysis data

Comparison against model data is a common measure used among AMV producers and users to evaluate AMV quality. We are using the ERA-Interim forecast data (Dee et al., 2011) and not the latest ERA5 (Hersbach et al. 2020) to evaluate our reprocessed AMVs in order to be consistent with what has been done for the 0-degree GEO AMV CDR Release 2 (EUMETSAT, 2020) of Meteosat located at zero. We use the 60 model levels⁴ of ERA-interim forecast data at 0, 6, 12, 18 UTC at one degree latitude/longitude resolution. Each valid AMV is compared with its corresponding model vector. No interpolation is done and each wind vector is compared with the closest model data in time and space.

4 GENERAL EVALUATION

In this section, the AMV CDR is analysed in terms of its internal consistency. Time series covering the key retrieval variables are shown for the complete spatial and temporal coverage.

For the analysis, the data record is divided into four classes of retrieved wind vectors depending on their assigned height as described in Table 3. In addition, two geographical regions are considered in some part of the validation as shown in

Table 4. For the IODC region, the tropics are the location of the most relevant atmospheric dynamic events.

Table 3: AMV height (pressure in hPa) classes used for the validation

CLASS	Description
ALL	All vectors are considered for calculating the statistics
HIGH	Only vectors with a height < 400 hPa are considered for calculating the statistics
MID	Only vectors with $400 \leq \text{height} \leq 700$ hPa are considered for calculating the statistics
LOW	Only vectors with a height > 700 hPa are considered for calculating the statistics

⁴ <https://www.ecmwf.int/en/forecasts/documentation-and-support/60-model-levels>

Table 4: *Geographical regions used for the validation*

REGION	Description
FD	Full Meteosat Disk
TR	Tropics: $-23^{\circ} < \text{latitude} < 23^{\circ}$

4.1 Temporal analysis

To check the temporal homogeneity of the data record the daily global means of the speed and the number of AMVs is computed throughout the period for each operational satellite located at 63° , 57° , or 41.5° (see Figure 2).

Note that the average calculation is done using winds from the entire Meteosat even if the SSP of each satellite differs. As shown in Figure 2, the bulk of the processed area is seen by all three platforms, but the outer parts are not the same due to the different SSPs. However, as shown in Table 5 and Table 6, similar results are observed if the mean is calculated using only AMV retrieved in the common area (Figure 2). This is explained as the large scale middle and high level winds are mainly zonal (west-east component).

4.1.1 IR AMVs

Table 5 and Figure 9 show the average daily total number of infrared wind vectors and their associated average speed, split by atmospheric levels.

Table 5: *Mean of the daily averaged infrared AMVs: number and speed as retrieved using imagers on board Meteosat first (Meteosat-5 and Meteosat-7) and second generation (Meteosat-8) satellites. The global daily average is computed for AMV with a speed $\geq 5\text{ m/s}$ and $QI > 60$ over the common area between the 3 satellites and over the entire disk. The number of AMVs for the full disk is also given per level (high/mid/low).*

Satellite	Area used	Total AMV number	Speed (m/s)		
			High level	Mid level	Low level
MET05	Common area	38127	20.1	16.9	10.8
	Entire disk	43939 24185 / 7468 / 12286	19.7	16.9	10.8
MET07	Common area	44952	19.3	15.4	10.4
	Entire disk	50663 29146 / 9918 / 11598	18.9	15.3	10.3
MET08	Common area	128474	19.4	15.8	10.4
	Entire disk	149153 73923 / 33319 / 41909	19.6	15.7	10.1

The number of AMV retrieved by Meteosat-7 is about 15% higher than by Meteosat-5 (44952 vs 38127). As expected, the number of AMVs increases drastically when moving to the second Meteosat generation, from 48.000 to 150.000 daily vectors, because of the increased spatial resolution and doubled temporal resolution (García-Pereda and Borde, 2014). The high level AMVs represents half of the total number of AMVs for all satellites. The low level AMVs and mid level are the other half where the low level AMVs are the majority.

The average speed estimate is consistent and very stable over the entire period for both generations of satellites. As the influence of the surface friction is reduced, the speed increases with the altitude. It ranges from 10.5 m/s for low level AMVs to 19.6 m/s for high level AMVs.

The speed of MVIRI data derived AMVs is on average 0.4 m/s faster than those derived from SEVIRI. This difference is not significant and probably due to the smaller set of vectors used to compute the daily mean for MVIRI compared with SEVIRI.

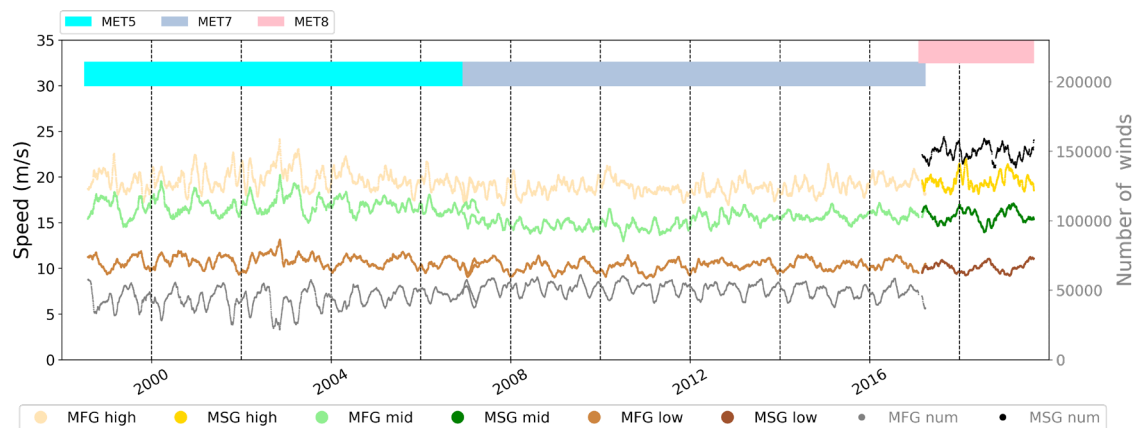


Figure 9: 30-days running mean of daily averaged infrared AMVs: number and speed as retrieved using imagers on board Meteosat first (Meteosat-5 and Meteosat-7) and second generation (Meteosat-8) satellites. Global daily average is computed for AMV with a speed ≥ 5 m/s and $QI > 60$.

4.1.2 WV AMVs

In the WV channel, only high and mid-level AMVs can be derived because the signal only comes from the upper levels of the troposphere.

Table 6: Mean of the daily averaged cloudy WV AMVs: number and speed as retrieved using imagers on board Meteosat first (Meteosat-5 and Meteosat-7) and second generation (Meteosat-8) satellites. Global daily average is computed for AMV with a speed ≥ 5 m/s and $QI > 60$ over the common area between the 3 satellites and over the entire disk. The number of AMVs for the full disk is also given per level (high/mid).

Satellite	Area used	Num. AMV	Speed (m/s)		
			High level	Mid level	Low level
MET5	Common	25103	20.7	22.5	N/A
	Disk	29786 total 28380 / 1406 high/mid	20.4	22.6	N/A
MET7	Common	29711	19.8	22.1	N/A
	Disk	34039 total 32827 / 121 high/mid	19.5	22.1	N/A
MET8	Common	77261	20.8	23.6	N/A
	Disk	87111 total 82856 / 4255 high/mid	21.0	23.7	N/A

The WV AMVs can be retrieved tracking cloudy (Figure 10) water vapour features. About 88000 cloudy AMVs per day are retrieved using SEVIRI images on average. The WV winds are mostly high level AMVs they represent more than 95% of the total cloudy WV AMVs (see Table 6). From MVIRI images only about 30000 cloudy AMVs per day are retrieved on average. For both, MVIRI and SEVIRI, the mid-level AMVs are slightly faster than the high-level AMVs (23 vs. 21 m/s). This comes from the fact that, over a day, very few winds are retrieved at mid-level. Those winds are located only between 400 and 450 hPa. Their average

speed is higher than the high level winds because of the sampling: there is a quite numerous amount of high level AMVs, located for example over the ocean and Southern Africa, that are not very fast (below 12m/s), bringing the averaged speed down.

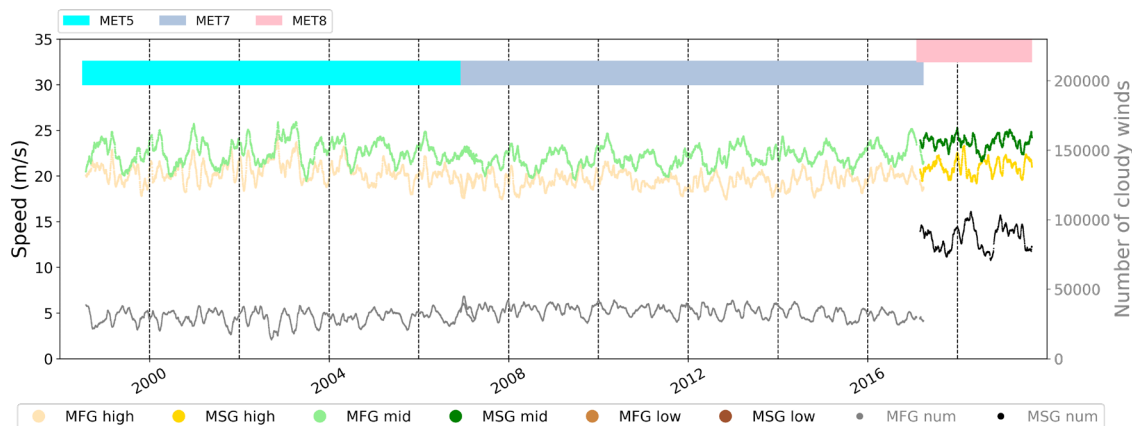


Figure 10: same as Figure 9 but for the cloudy WV ($6.2\mu\text{m}$) channel. The winds are retrieved using clouds as target features in the atmosphere.

4.2 Spatial distribution

The spatial distribution of the AMV during the entire period covered by the CDR is shown as the hourly (1 hour for MSG and 2 hours for MFG) zonal average number of AMVs in one-degree latitude boxes displayed as Hovmoeller plots in the four panels of Figure 11. The plots start in 1998 with Meteosat-5 and reach until August 2019 with Meteosat-8. The figures split according to the different atmospheric levels, starting with the entire atmosphere in panel (a) and then going down through the three different atmospheric height, high level (b), middle level (c) to end with the lowest atmospheric level closer to the surface in panel (d). The existing processing overlapping period between Meteosat-5 and Meteosat-7 is clearly visible between the end of 2006 and the beginning of 2007 where the amount of AMVs is higher. The very positive aspect is that such overlapping does not have any impact on the average speed (see Figure 12). In addition, the change from MFG to MSG in 2017 clearly shows, as expected, an increase in number of winds retrieved but a stability in the average speed (Figure 12) with the only exception of the low-level vectors gaining a few m/s. The reason for this is not easy to establish but it could be linked to the higher temporal sampling (4 images/hour instead of 2 images/hour) of MSG compared to MFG able to catch faster cloud movements and also to the different geographical area covered by Met-7 and Met-8.

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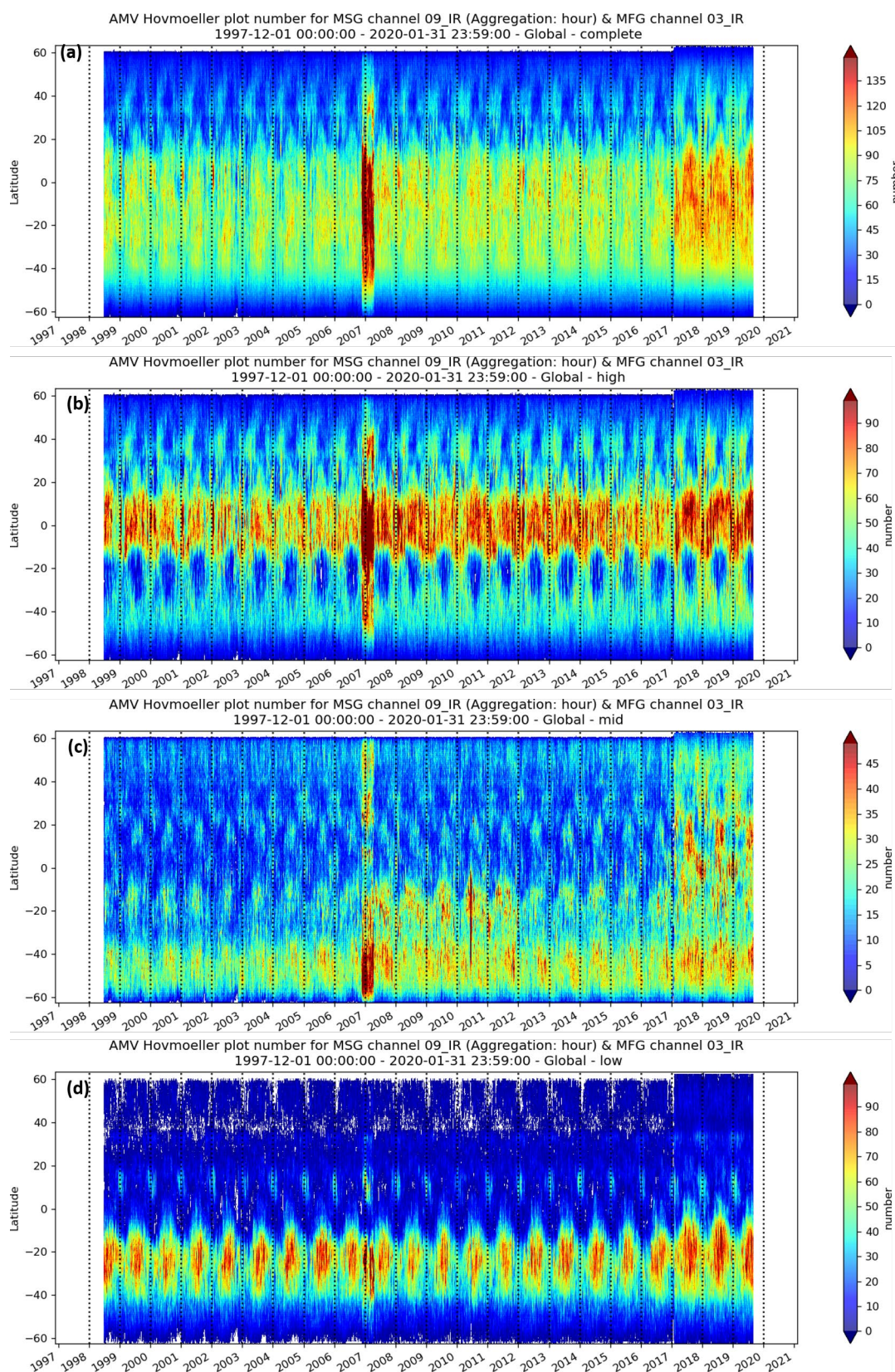


Figure 11: Hovmoeller plot of zonal hourly average of the number of MFG and MSG IR AMVs at one-degree for all atmospheric heights. Only AMVs with speed >5m/s and QI>60 are used. (a) All levels together, (b) high level (height<400 hPa), (c) mid level (400 hPa height<700 hPa), (d) low level (height > 700 hPa).

In the tropics, we have the highest number of AMVs when looking at the complete atmosphere or at the high-level winds and partially to the middle level, driven mostly by the change in position of the ITCZ during the year. Low-level peak in the region of Tropic of Capricorn (latitude 30 degrees south). These features are shown also by Sèze and Pawlowska who performed an interesting study about the cloud coverage over the IODC region (Sèze and Pawlowska, 2001). The retrieval for MFG has a latitude limit in the Northern Hemisphere of 60 degrees. The same limit is not present for the Southern Hemisphere or for MSG. It is due to an issue in the processor that will be addressed for the next release.

The wind speed varies seasonally as it is shown in Figure 12. The highest wind speeds can be found in the sub-tropical and polar jet. Their variation during the year in this portion of the Earth is directly linked with the onset and strength of the ISM (Zhang et al., 2004).

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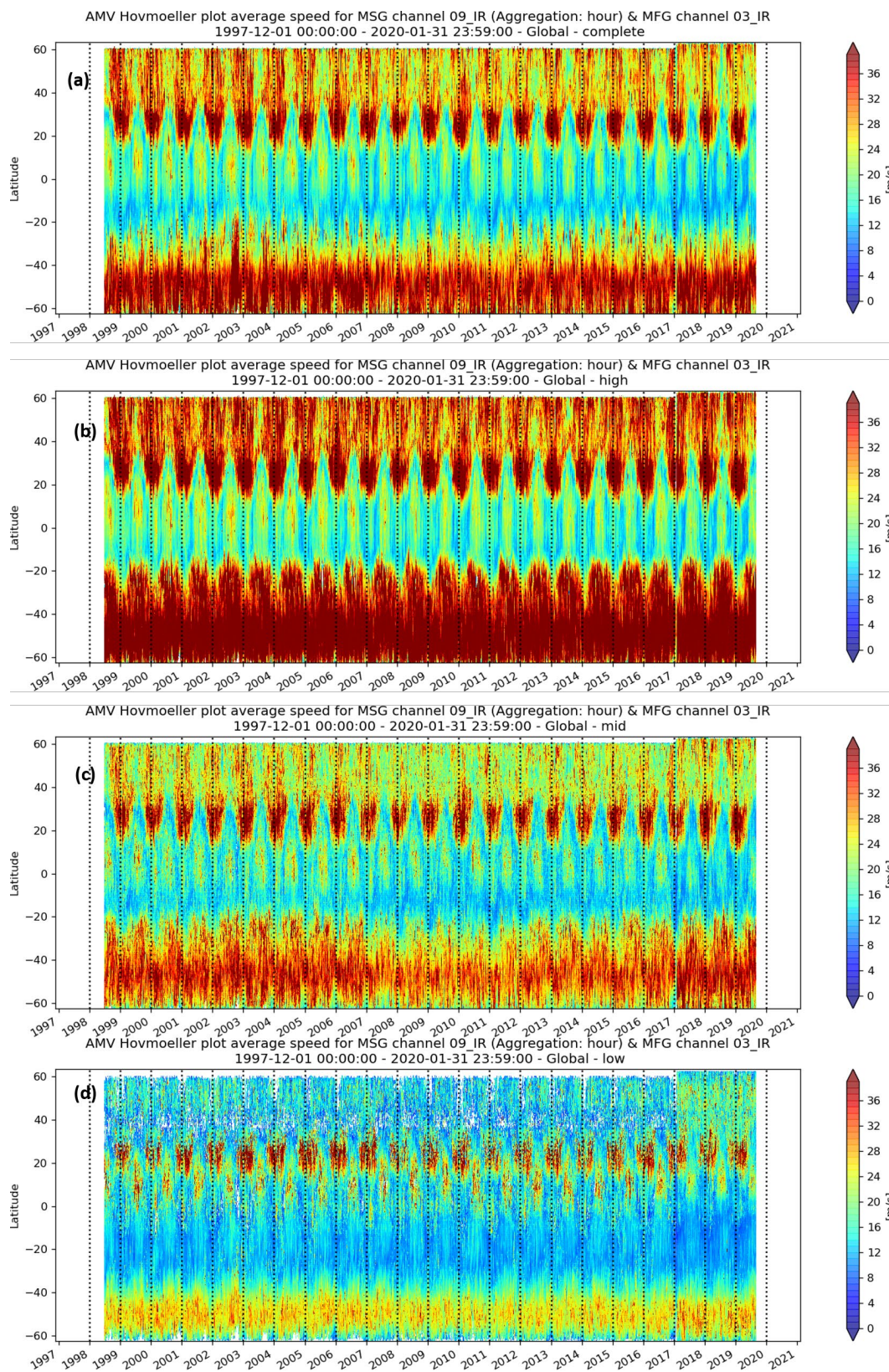


Figure 12: Hovmoeller plot of zonal hourly average of the speed in m/s of MFG and MSG IR AMVs at one-degree resolution for all atmospheric heights. Only AMVs with speed >5m/s and $QI > 60$ are used. (a) All levels together, (b) high level (height < 400 hPa), (c) mid level (400 hPa height < 700 hPa), (d) low level (height > 700 hPa).

The analysis for the WV channel shows very similar pattern as for the IR channel.

We generated temporally and spatially averaged maps of some key quantities for assessing some known atmospheric circulation patterns such as the Indian Summer Monsoon (ISM). The little analysis focused on the winter monsoon season (DJF: December, January, and February) and on the summer monsoon season (JJA: June, July, and August). In the summer season, winds blowing from southwest bring strong precipitation over India and other countries of the Indian ocean such as the republic of Maldives. In winter, the nominal wind direction is opposite.

The spatial averaging is done at 1-degree resolution. Only IR vectors with a QI higher than 60 and a speed higher than 5m/s have been considered for this analysis.

In Figure 13 and Figure 14, we show a climatology for wind vectors located at low level (1000-700 hPa) and high level (400-0 hPa) of the atmosphere their respective zonal (positive from west to east), and meridional (positive south to north) components as well as their height averaged over the whole period (1998-2019) for two seasons JJA and DJF.

On these two atmospheric levels (see Figure 13), we can appreciate some of the wind features linked with the onset and strength of the summer monsoon (Zhang et al., 2004) compared with the pattern during boreal winter (see Figure 14).

During the JJA period we can identify some major dynamic modes:

- The Somali jet (low-level jet off the coast of the Arabic peninsula),
- The shift north and weakens of the high level westerly (compared to DJF),
- The shift north over India of the high level Easterly (compared to DJF).

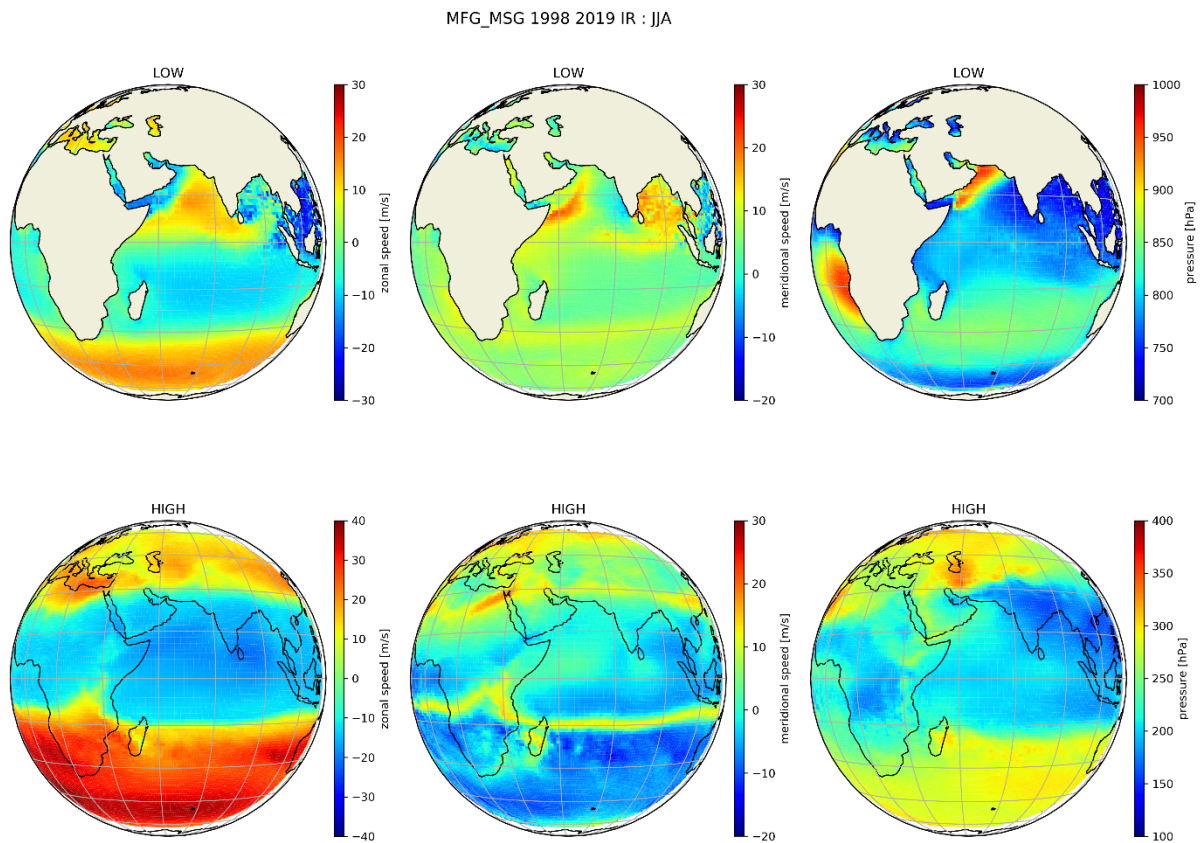


Figure 13: Winds parameter averages over the period 1998-2019 for low level (upper panel) over ocean and high level (lower panel). From left to right: zonal component (positive from west to east), meridional speed component (positive from south to north) and wind height.

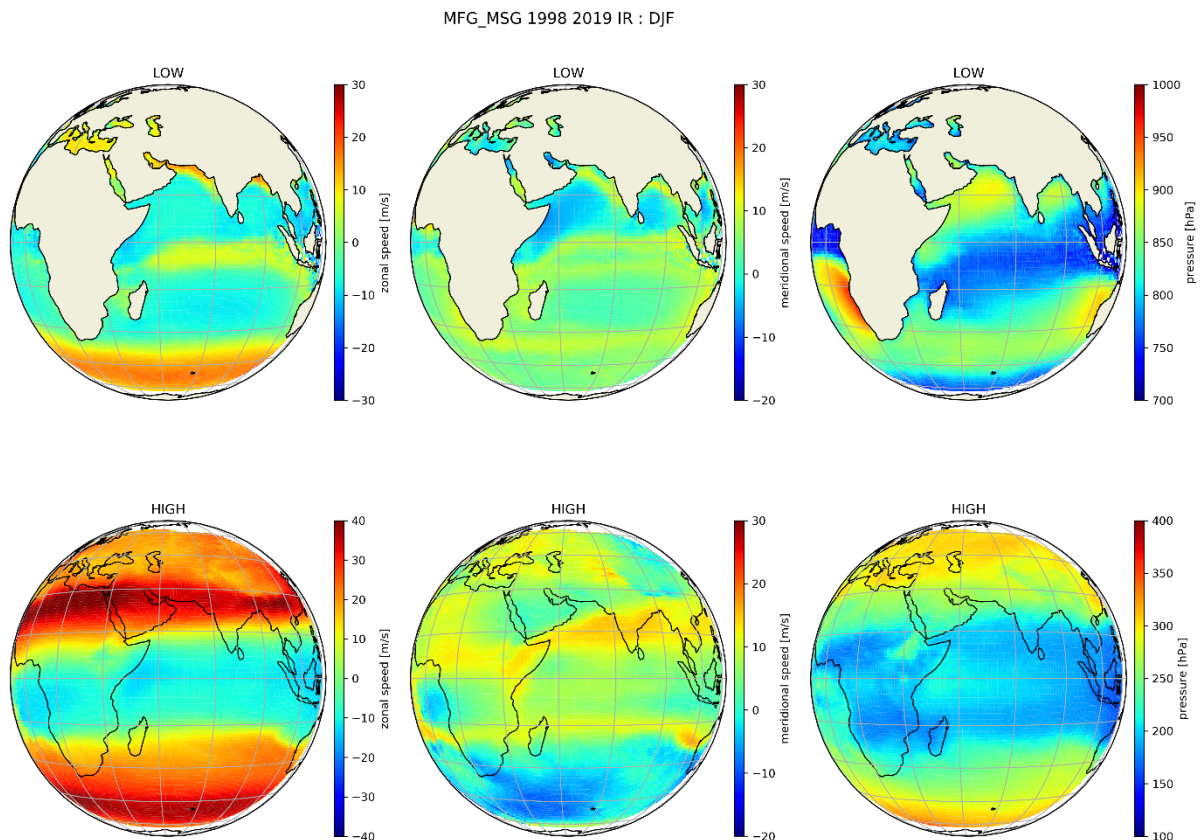


Figure 14: Same as Figure 13 for the winter season (December, January, and February).

In conclusion, because of the higher temporal and spatial resolution of the Meteosat second generation, there is more AMV retrieved using MSG than MFG. However, the IODC AMV CDR time series obtained is homogeneous and stable over the entire period. The CDR AMVs exhibit geographical and seasonal features in line with well-known atmospheric circulation patterns such as the Indian summer monsoon.

5 COMPARISON AGAINST REFERENCE DATA

The Global Climate Observing System (GCOS) requirements for upper-air winds retrieval are 2 m/s and 20 degrees, with 100 hPa accuracy in height assignment (GCOS (WMO) et al., 2011). Those requirements are mentioned as reference but there is no commitments to completely fulfil them. Assuming that the radiosondes are the closest measurement to the truth, in order to assess if, at least for the speed, the CDR AMVs match this requirement one can check the bias between the CDR AMV and the radiosondes. In section 5.3, the fulfilment of the requirements are analysed.

5.1 MSG NRT operational product comparison

In this section, a comparison between the reprocessed (CDR) and the NRT operational MSG AMVs is discussed. The comparison is done on MSG only because there is no corresponding NRT products available for MFG⁵. Due to the huge amount of data needed, the comparison is limited to the year 2018. The main difference between NRT and CDR is the usage of an other method for height assignment. For the CDR we used only the 2 channels available on both

⁵ MFG IODC NRT (ELW) have been derived not using the CCC method

MFG and MSG (IR 10.8 + WV 6.2) to have an homogeneous series. The input forecast data used for height assignment also differs between NRT (using NWP forecast) and CDR (using ERAinterim forecast).

5.1.1 Single product comparison

This comparison aims to check if any difference in the geographical distribution over the disk or if any major mismatch in the height assignment is present. The comparison is done for AMV retrieved using the IR channel and using cloudy target WV channel. The following plots include a barbs map with underneath normalized histograms of speed (m/s) and height (hPa). The histograms are normalised such as the whole area (not the sum of the frequencies) is equals to one.

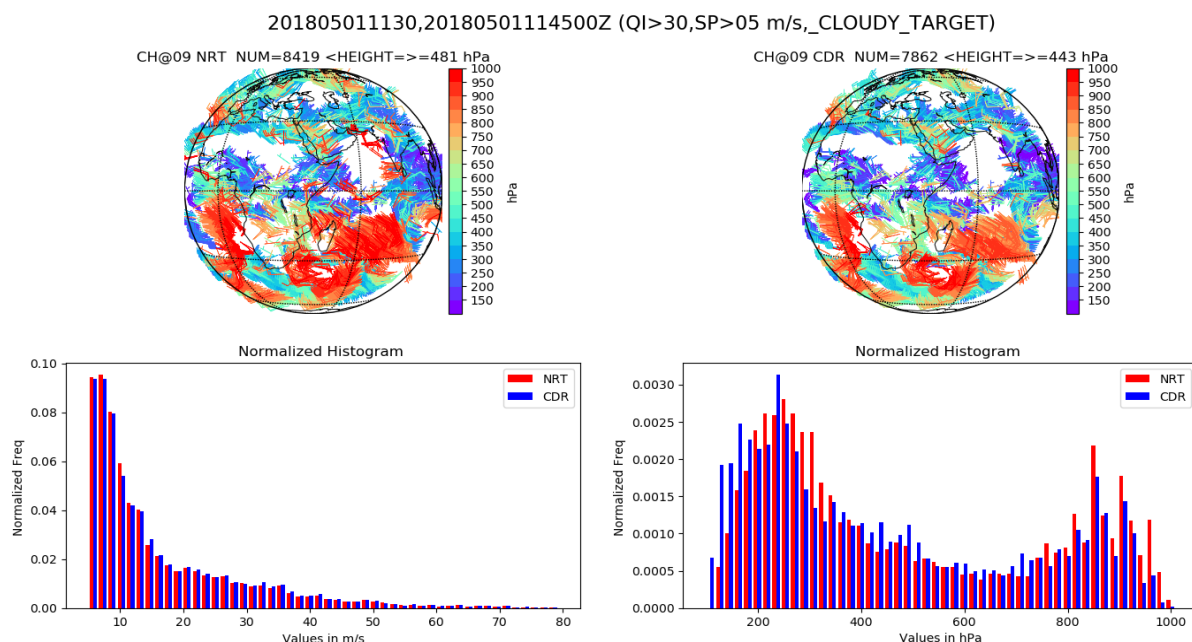


Figure 15: Comparison between the same IR AMV product generated for the 1st of May 2018 at 12:00 from the NRT level 2 processing framework (left/red) and the CDR reprocessing facility (right/blue). Only vectors with a QI>30 and a speed >5 m/s have been considered. The histograms show speed in m/s (bottom left) and height (bottom right).

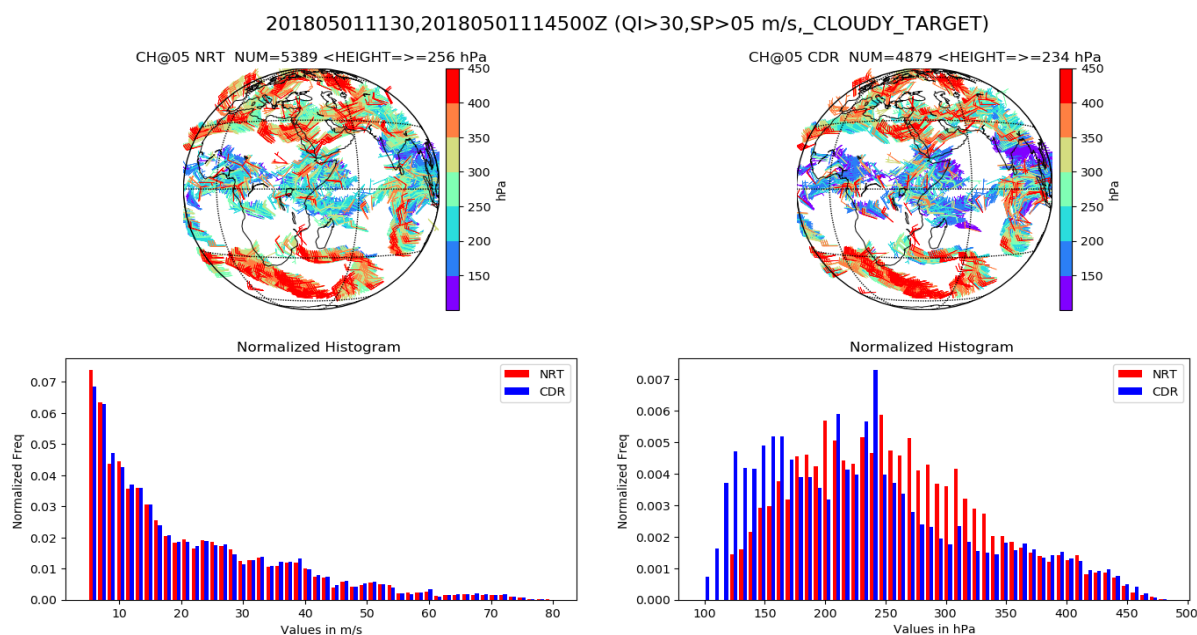


Figure 16: Same as Figure 15 for the WV cloudy target case.

The comparison shows a good agreement for the speed in all three cases. When looking at the winds height, the comparison shows a rather good agreement for the IR channel. However for the WV channel CDR AMV and NRT AMVs the heights differ. The NRT AMVs are located lower in the atmosphere than the CDR AMVs. The cloudy AMV CDR height's distribution is clearly shifted toward the higher part of the atmosphere (about 50 hPa) with regards to the NRT one. Thanks to the similar speed distribution, the cloudy WV AMVs map reveals very similar wind fields patterns. The height distribution changes is most probably due to the usage of a different cloud mask and cloud height assignments algorithms used throughout the period for NRT and CDR. It is possible that the cloud masking difference will have less impact on cloudy cases because the same cloud pattern must be present in two consecutive images. For the cloudy case, using only two channels in CDR makes much more challenging a robust detection of multi-layer or thin clouds and to assign the correct height to the wind vectors derived from tracking such clouds.

5.1.2 Full disk average

Figure 17 presents the hourly (daily running mean) AMVs over the full disk of the number (bottom panel) of IR AMV and their associated speed (middle panel) and height (upper panel). The AMVs are split by the three atmospheric levels to check the pressure consistency. The number of high level AMVs is very similar for NRT and CDR. The number of mid and low level differs. The number of low level IR AMV is higher in summer (JJA) while the number of high level winds is higher in winter for both NRT and CDR. However, there is always more low level NRT AMVs on average. Even if of course the number of winds retrieved are not the same, as already noted in Section 5.1.1, the speed and the height are in good agreement. There is only a small bias of about 10-20 hPa where the high level NRT are slightly lower. From this comparison, for the IR channel, the fact that a different cloud mask and cloud height assignments algorithms are used throughout the period between NRT and CDR does not seem to generate relevant differences.

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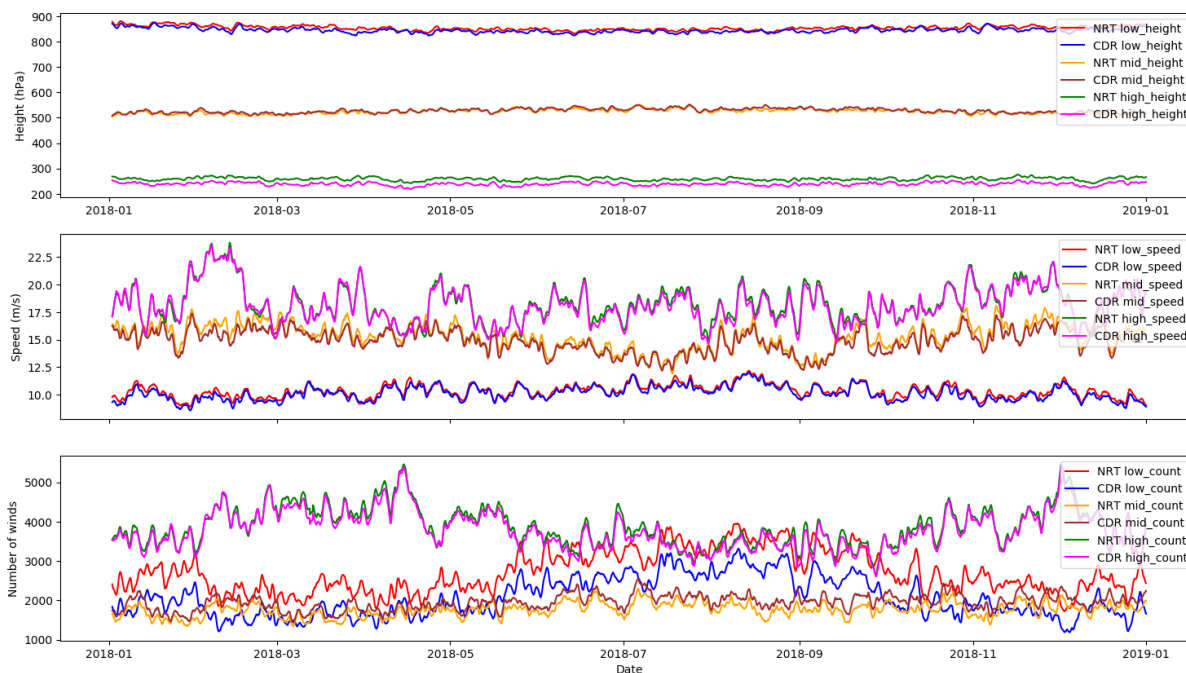


Figure 17: Time series of the hourly AMVs (daily running mean) for the IR channel derived AMVs reprocessed (CDR) versus near real time operational (NRT) for the complete 2018 year. From top to bottom: height (hPa), speed (m/s) and number of winds. The comparison is done for all vectors with a $QI > 30$ and speed > 5 m/s.

Figure 18 shows the hourly (daily running mean) of the number of WV (cloudy target case) AMVs and the associated speed and height. For the WV no low-level information is available because the contribution from lower level of the atmosphere is negligible in the WV channel. The number, speed and height for the middle layer look consistent, while the high-level winds show a little bias in the number and a more robust one in the height (less high level CDR AMV but higher in the atmosphere) with a stable speed of around 25-30 m/s. This result is in line with what already presented in Section 5.1.1.

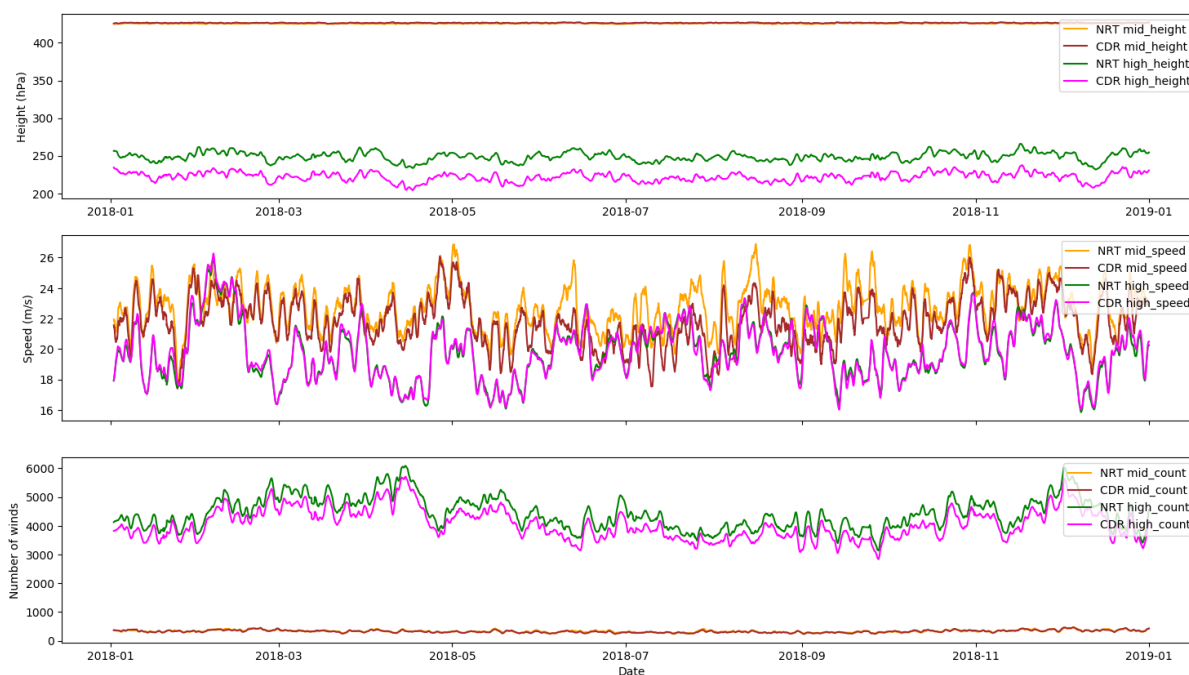


Figure 18: Same as Figure 17 for the case WV cloudy targets.

5.2 Reanalysis and radiosonde comparison method

Comparison of the retrieved satellite winds to reference data is performed following standards outlined in the CGMS guidelines for quality evaluation of Atmospheric Motion Vectors (Holmlund, 1998). Bias and Root Mean Square Error (RMSE) are computed for the retrieved wind vectors versus model or radiosonde data (see Appendix A). The analysis of the full time series is divided into four geographical (full disk, northern hemisphere, southern hemisphere and tropics) and four altitude layers (all, high, middle, low) as defined in

Table 4.

A correct height assignment for this comparison is the most important because a negative speed bias is most likely due to a wind vector that was assigned too high in the atmosphere whereas a positive bias might be explained by a wind being assigned too low (Figure 19). The bias could also be due to other factors such as an error in the tracking or in the reference data but the height assignment is the most relevant one. While the analysis against forecast is performed over the full disk, the comparison against radiosondes depends on the number of observations for the locations where radiosonde data is available (see Figure 7 and Figure 8). The two analysis have then a different objective. The first one focuses mainly on an average but global geographical analysis, while the second aims to a more local but absolute comparison.

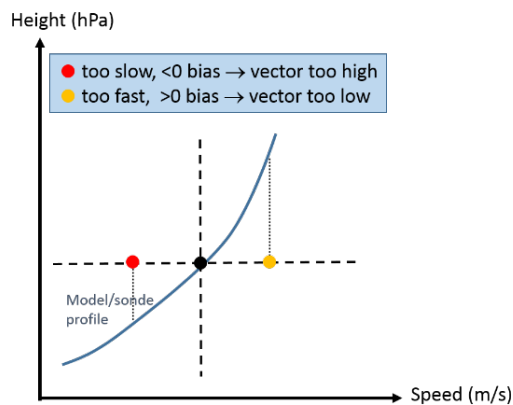


Figure 19: Graphical definition for the bias between observed and reference speeds.

This comparison was performed using both model data (section 5.4) and radiosondes (section 5.3) as reference. Model data, are derived also assimilating satellite and ground-based observations, are a good reference because they are available everywhere at every time. Radiosondes are real in-situ measurements, done generally only twice a day at 00 and 12 UTC. The co-locations are based only on the launch time and location of the radiosonde, this can introduce errors as the radiosonde needs time for its ascend (up to two hours) and can drift considerably during this time (up to 200 km).

The speed bias (in m/s) in the following sections is given by AMV from satellite minus reference (radiosonde or model). More details on the calculation of the bias are given in Appendix A.

5.3 Comparison with radiosondes observations

Radiosondes observations, even considering all potential sources of uncertainty, provide the best validation reference for satellite retrieved AMVs (EUMETSAT, 2018). Compared to model data, however, they are not globally available. This can lead to different statistics compared to NWP comparisons or to full disk averages, as certain regions are dominating and some regions are not represented at all, due to the lack of operational radiosonde stations.

The co-location criteria are:

- Time difference < 90 minutes
- Spatial distance < 100 km
- AMV QI > 60
- Speed > 5 m/s

The resulting spatial distribution of the co-locations, i.e. radiosonde stations used can be seen in section 3.2. The validation against radiosondes is split up into AMVs from MVIRI and SEVIRI as well as a combined analysis involving both.

5.3.1 Co-location

Figure 20 shows the daily number of co-locations for the MVIRI and SEVIRI time series for both IR and WV channels. In order to avoid noise on the plots, a running mean of 30 days has been applied. We clearly see a quite stable number of daily Meteosat and radiosonde co-locations for MVIRI both IR and WV, even if the number slightly increase when moving from

Meteosat-5 to Meteosat-7. This can be due to the a little increase number of AMVs retrieved from Meteosat-7 compared to Meteosat-5 (Figure 9). The number of course increases drastically when moving to SEVIRI because the higher spatial and temporal resolution of the images. More colocations are found for high level winds because there is much more high levels AMVs (see Table 5 and Table 6) on average. A seasonal variation is also present especially for high level AMVs where there is on average more colocations in summer (JJA) than in winter (DJF) for all 2 channels (IR, WV).

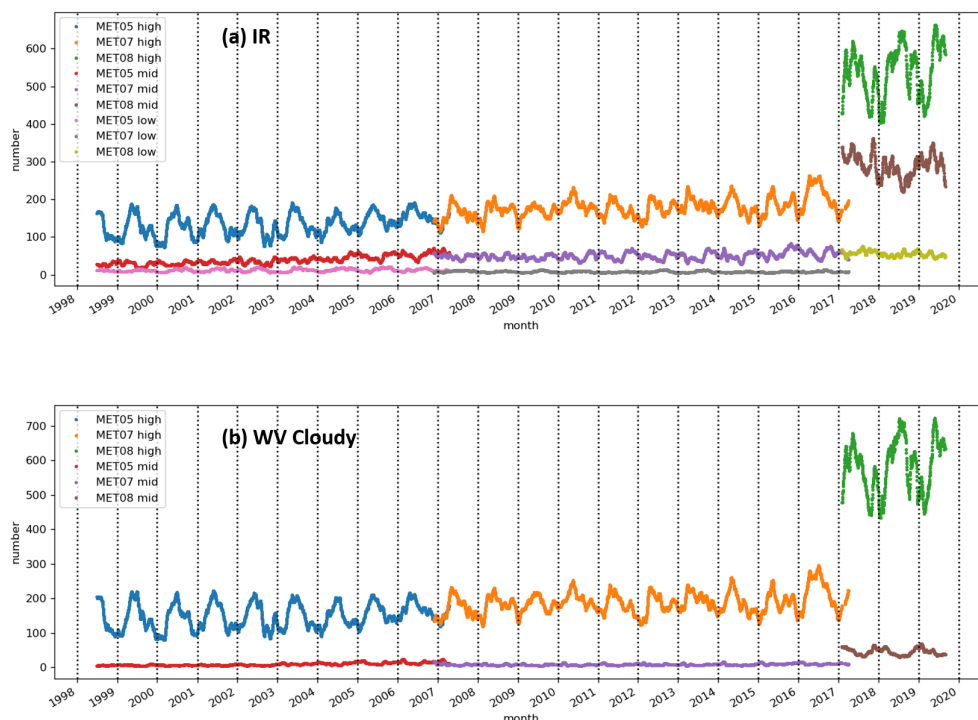


Figure 20: Time series showing the 30 days running mean number of co-locations per day for the full disk MVIRI/SEVIRI IR (a), WV cloudy target (b) AMVs and the radiosondes. The different colors distinguish among height levels and satellites.

5.3.2 Speed bias

In this section, we show the speed bias in m/s between the AMVs and the co-located radiosondes for the IR and WV channels. All three atmospheric levels are shown in Figure 22. The seasonal variation in the bias comes directly from the change in average speed during the year (see Figure 21). This is a known feature. It can be due to wrong height assignment (the effect is slightly lower for higher QI threshold) but also to natural events. For instance, the jet stream are stronger in the boreal winter than in summer. In the tropical belt over the IODC region, the dominant wind patterns are due the monsoon. Here the strongest winds are generally in the Boreal summer, the low level Somali jet for instance as it can appreciated in Figure 13 and Figure 23.

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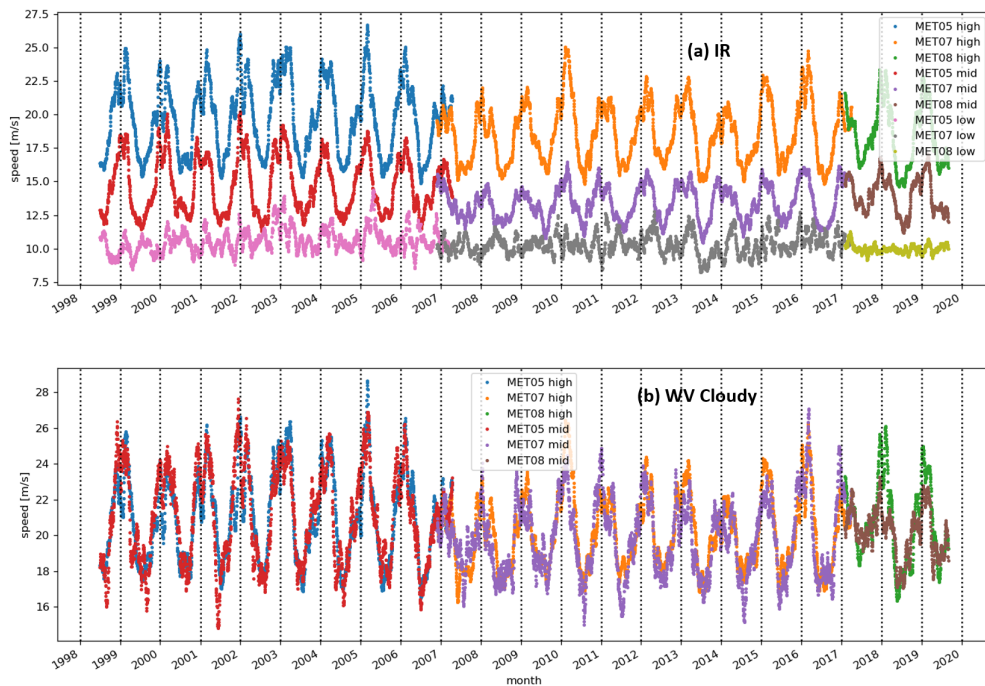


Figure 21: Time series showing the 30 days running mean speed per day for the full disk MVIRI/SEVIRI IR (a), WV cloudy target (b) AMVs for the collocated winds. The different colors distinguish among height levels and satellites.

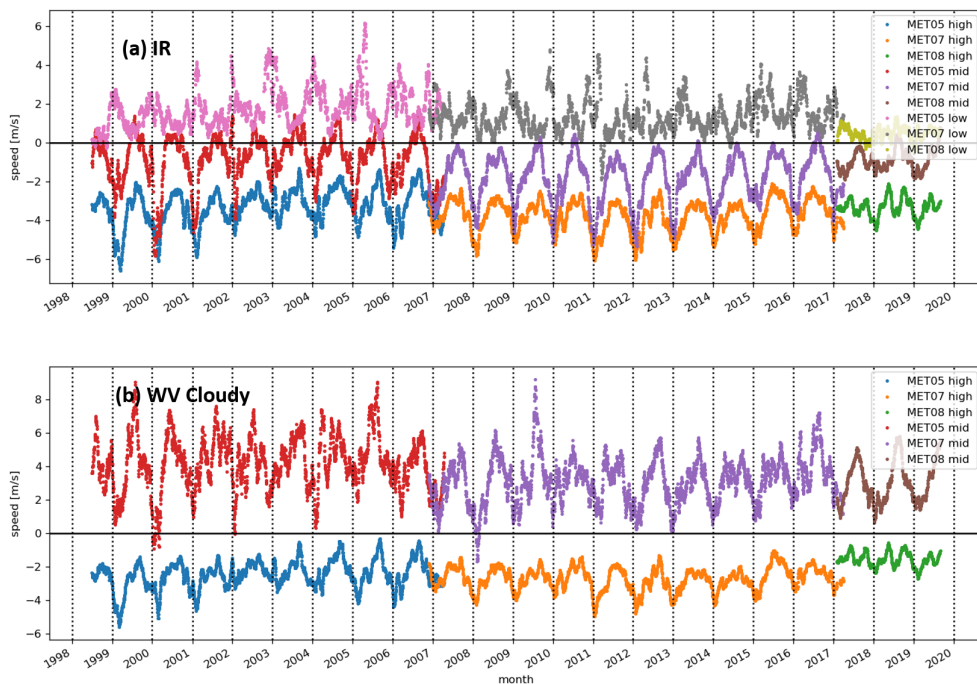


Figure 22: Time series showing the 30 days running mean speed bias (obs – radiosonde) per day for the full disk MVIRI/SEVIRI IR (a), WV cloudy target (b) AMVs and the radiosondes. The different colors distinguish among height levels and satellites.

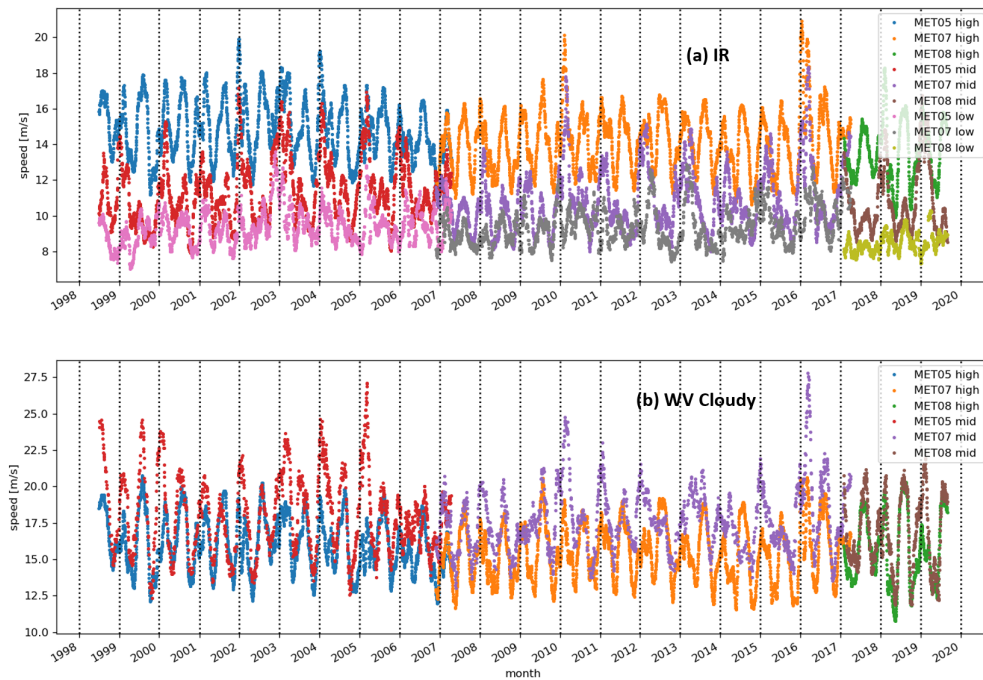


Figure 23: Same as Figure 21 but for the tropics (TR) region.

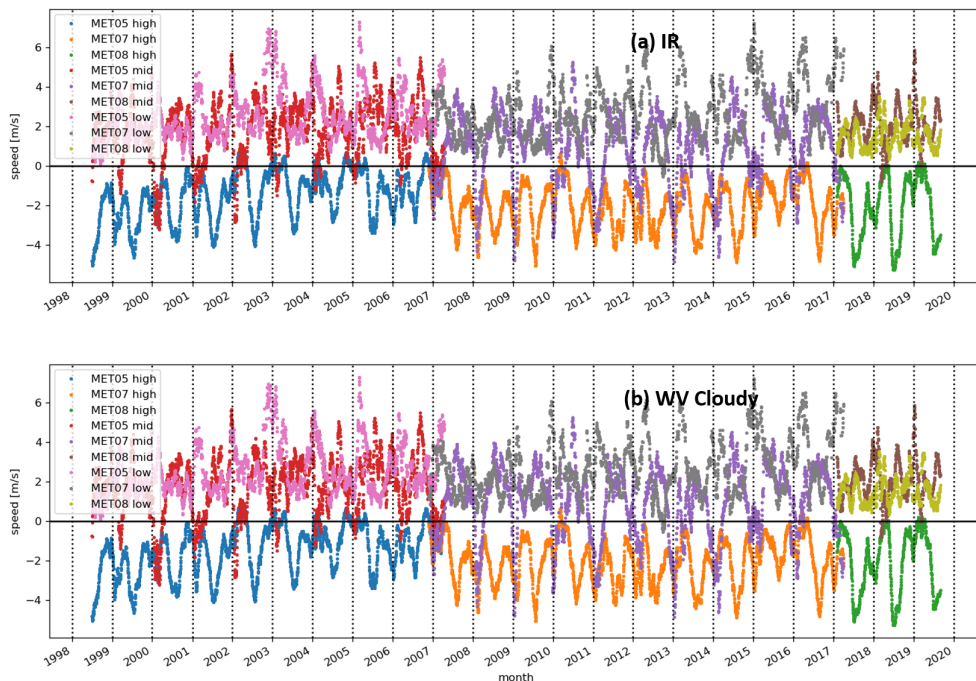


Figure 24: Same as Figure 22 but for the tropics (TR) region.

The per-level bias sign is constant over the whole MFG and MSG period for IR and WV cloudy target. There is a positive speed bias for the low level IR AMVs indicating that the vectors are located too low in the atmosphere. There a negative speed bias for the high level AMV indicating that the vector are located too high in the atmosphere. This seems to indicate that

the height of the NRT high level winds which are on averaged lower (Figure 17 and Figure 18) should be more realistic. The speed bias definitely reducing (getting closer to zero) when passing from MFG to MSG: reducing by about 2 m/s from roughly ± 4 m/s for the IR channel and ± 6 m/s for the WV case.

The bias for the Tropics (TR) region (see Figure 24) is similar to the Full Disk (FD) case for the IR channel. The WV cloudy bias is smaller compared to FD. Unlike for the full disk, over the tropics, the bias is not reduced when passing from MFG to MSG. The not stable satellite position might have a small impact in the co-location and relative speed bias estimation. The 0-degree CDR, generated by platforms with a stable orbital position, in fact exhibits a lower speed bias (EUMETSAT, 2020).

5.4 Comparison with reanalysis model data

Model data are available globally and provide a robust and statistically representative reference data. Each AMV speed is compared with the closest model vector at this height. The statistical variables are defined in Appendix A. The analysis for both the monthly maps and the time series has been performed for AMVs with a $QI > 80$ and a speed > 5 m/s in order to limit the inclusion in the comparison of unrealistic low quality vectors. The QI used includes the consistency with the forecast. The comparison is then not completely independent and this could increase the agreement (lower speed bias) between the model and the observations.

5.4.1 Time Series

The temporal evolution of the bias and Normalised Root Mean Square Error (NRMSE) provides an indication of the temporal stability of the retrieved winds. For high and midlevel AMVs there is a negative speed bias for the IR window channel that varies over the whole Meteosat disk by less than 1.5 m/s (see Figure 25). This indicates that the high and mid level AMVs are too high in the atmosphere (see Figure 19). The bias for low-level winds is positive (winds are located too low with respects to the model data) and less than 0.5 m/s. The analysis also reveals a step for mid-levels winds changing from negative to positive from first to second generation of Meteosat. However the number of mid level AMV is very small compared to the high level ones. The reason for the step change in mid level bias is still not clear. There is also a step of 0.5 m/s in the mid-level winds around the time of the transition between Meteosat-5 and Meteosat-7 at the end of 2006. The same step is not present when focusing on the tropical belt (Figure 25, panel C). The reason for this change in the extra tropics is unclear. The NRMSE is around 0.225 for low-level winds and a bit higher (~ 0.275 - 0.350) for middle and high level vectors. No evident change is present moving from first to MSG.

If only the tropical belt is considered, the negative bias of the FD winds become slightly positive within 1 m/s for high-level winds. This seems to indicate that it is mainly the extra tropical winds that are slightly too high in the atmosphere. For the TR low level AMVs, the bias remains positive at about 0.5 m/s. The NRMSE does not show major changes if compared with the full disk case.

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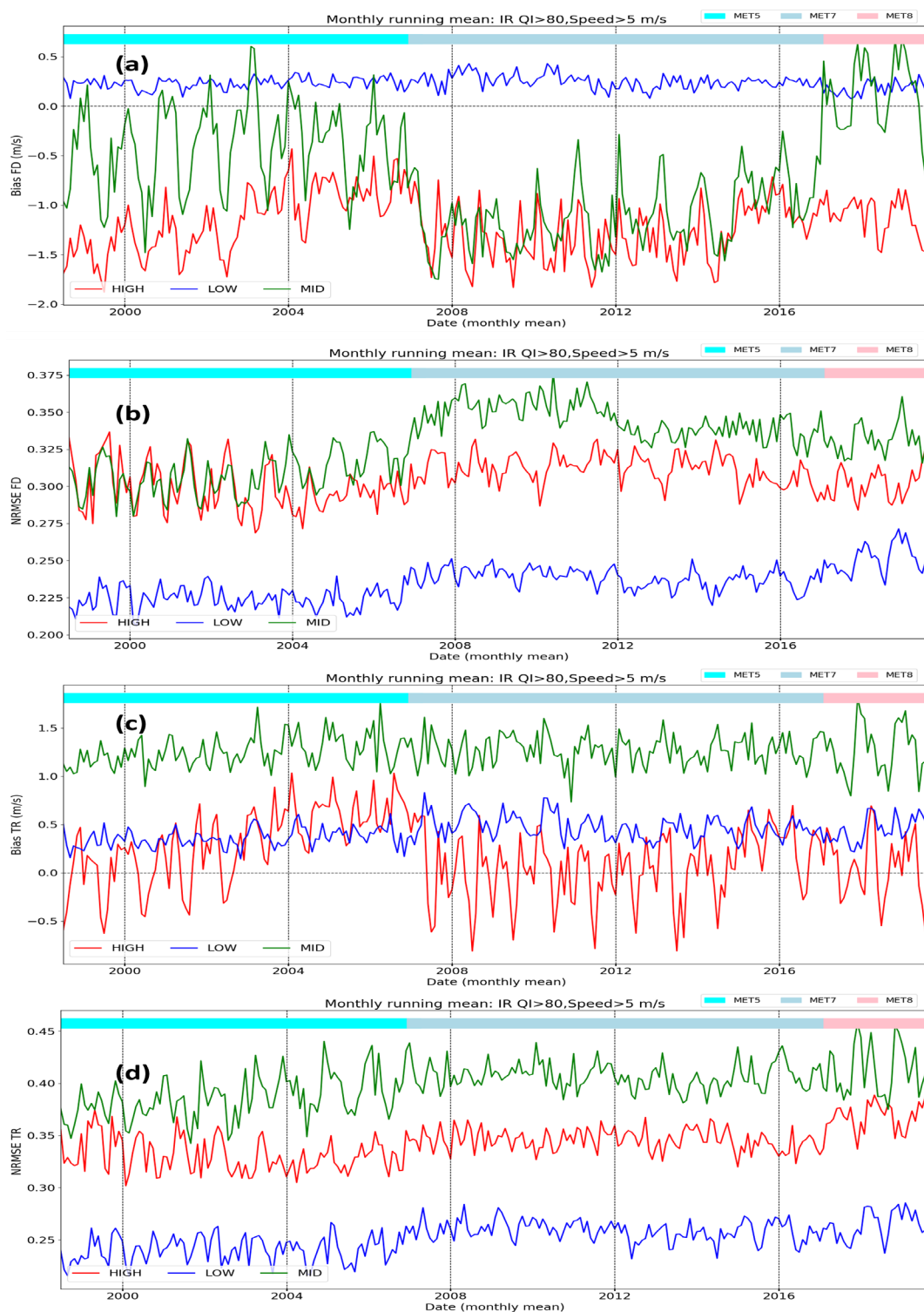


Figure 25: Monthly full disk (a), Tropics (c) bias in m/s and normalised RMSE full disk (b) and Tropics (d) for the three atmospheric level: IR ($10.8\ \mu\text{m}$) high (red), middle (green), low (blue). Only vectors with a QI >80 and a speed $>5\ \text{m/s}$ are considered.

The full disk speed bias (Figure 26) for WV cloudy target is negative within 1 m/s for high-level winds and positive between 2 and 5 m/s for middle layer winds. The NRMSE is comparable for both layers and around 0.3. When looking at the tropic belt only, the bias pattern are similar to the full disk case but the high-level vectors present a value bouncing above and

below zero. The NRMSE is ~25% bigger for the middle layer winds than the high level vectors. No clear changes is present moving from MFG to MSG.

Like for the IR AMVs this analyses indicates that the high level winds are too high compared to the model AMVs.

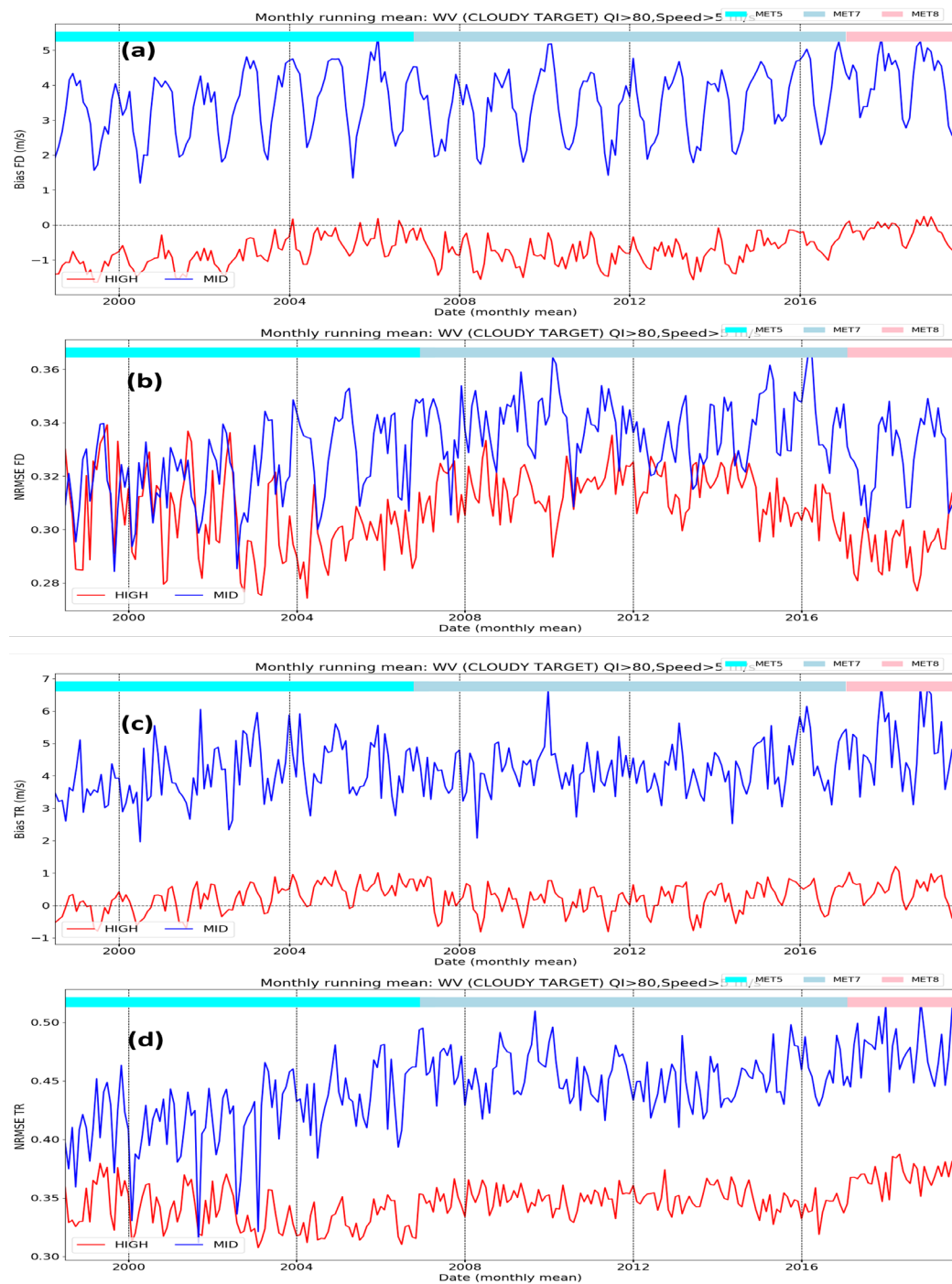


Figure 26: Monthly full disk (a), Tropics (c) bias in m/s and normalised RMSE full disk (b) and Tropics (d) for the three atmospheric level: WV (6.2 μ m) cloud target high (red), middle (blue). Only vectors with a QI > 80 and a speed > 5 m/s are considered.

In conclusion, the speed bias against ECMWF reanalysis is on average relatively small with values around 1-1.5 m/s. The comparison indicated that the high level IR and WV cloudy winds are located slightly too high in the atmosphere. The low level AMV are slightly too low in the atmosphere. For middle layer AMVs from WV channel cloudy-sky targets the bias is positive between 3 and 5 m/s. This speed bias value is constant along time, meaning that the retrieval uncertainty is not depending on the radiometric quality of a single instrument.

5.4.2 Monthly average comparison

In order to check the presence of a speed bias in relation of the geographical position, AMVs and model data have been compared on monthly averaged maps at 1° latitude and longitude resolution for a few months. The comparison is done for wind vectors retrieved for the IR channel with a $QI > 80$ and a minimum speed of 5 m/s. No constraints are set for the allowed difference in height and direction between the measured vectors and the reference model data.

For the month of July 2001, Meteosat-5 IR AMVs, number of winds, speed biases, and its RMSE are shown in Figure 27. The comparison of the averaged speeds (Meteosat5 observation versus model reference) shows an overall agreement in the sense that the same spatial speed structures appear in both maps. The bias is mainly in the range 4 m/s with a normalized RMSE around 0.4 m/s (meaning that the RMSE is 40% of the speed value). The bias is overall negative. The main differences appear for the area in south of the extra tropic where the negative speed bias implies that the winds in that area are too high in the atmosphere.

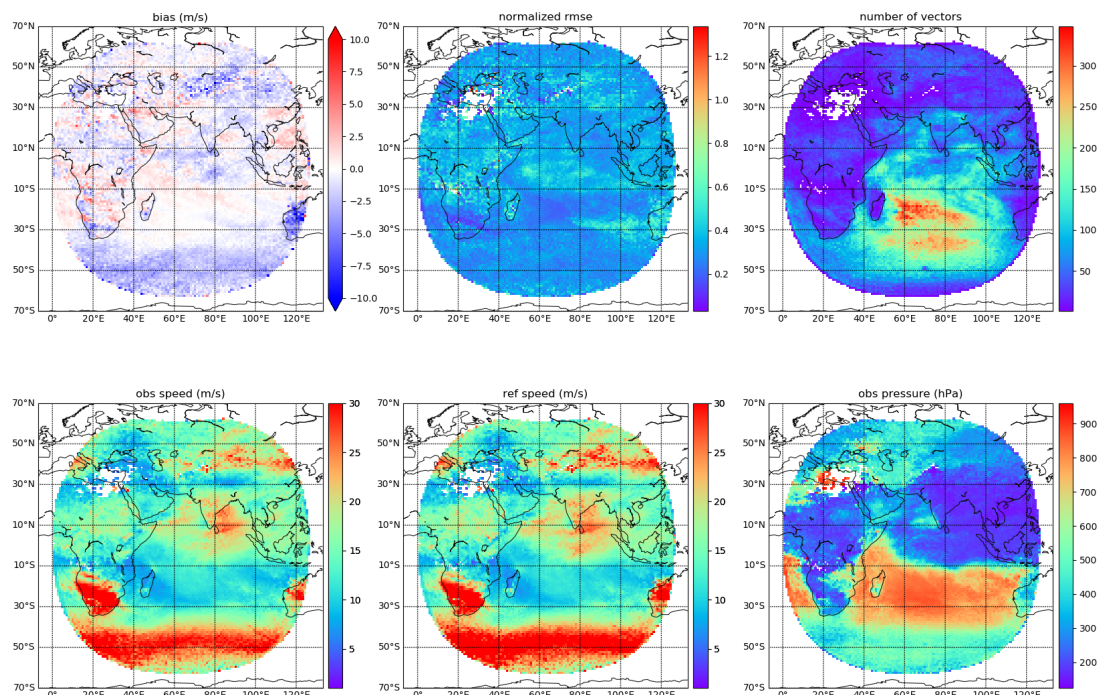


Figure 27: Monthly 1-degree mean maps of Bias, NRMSE and number of vectors (top row) and satellite derived speed, reanalysis speed and observation height (bottom row) for July 2001 (Meteosat-5). All IR levels together. Only vectors with a $QI > 80$ and a speed > 5 m/s are considered. Bias is estimated as Observation – Reference (model).

The comparison of Meteosat-7 (Figure 28) shows similar patterns and figures as in the case of Meteosat-5 with a little increase of the negative bias in the tropical Indian ocean. Meteosat-8

(Figure 29) also compares similarly but the bias in the south hemisphere extra tropics is reduced. Unlike for the MFG satellites, a small positive bias in the tropics (below the Arabian Peninsula) appeared. The maps for Meteosat-8 result in sharper figures because of the higher number of retrievals compared to MFG. This is an expected feature due to the different temporal and spatial resolution (García-Pereda and Borde, 2014).

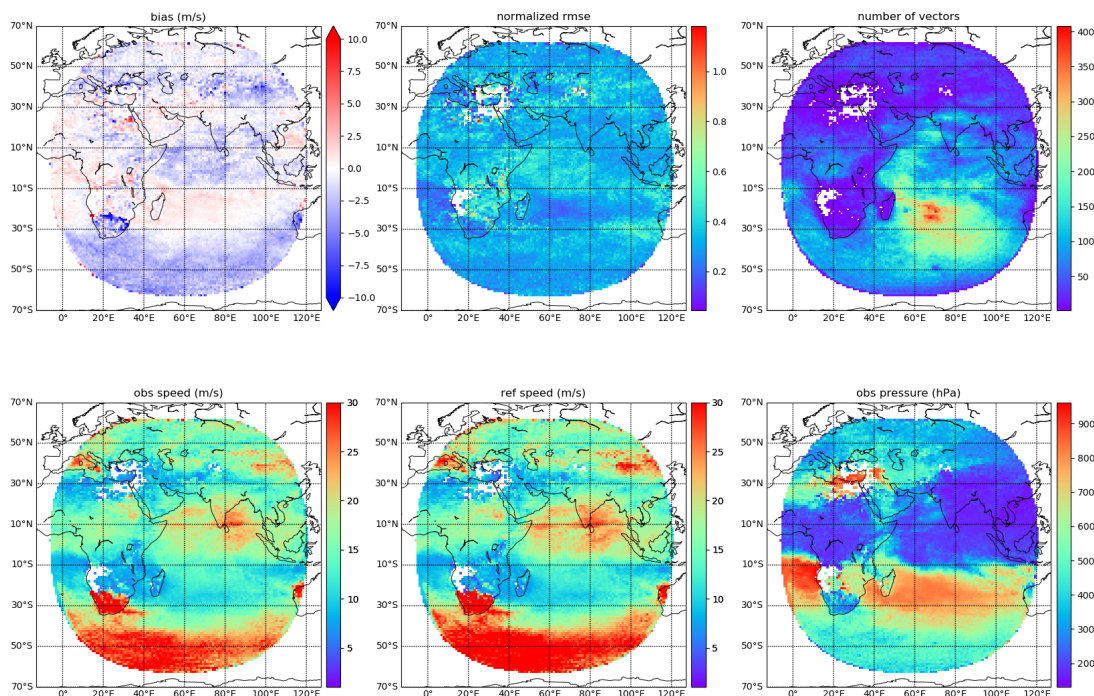


Figure 28: Same as Figure 27 for July 2008 (Meteosat-7).

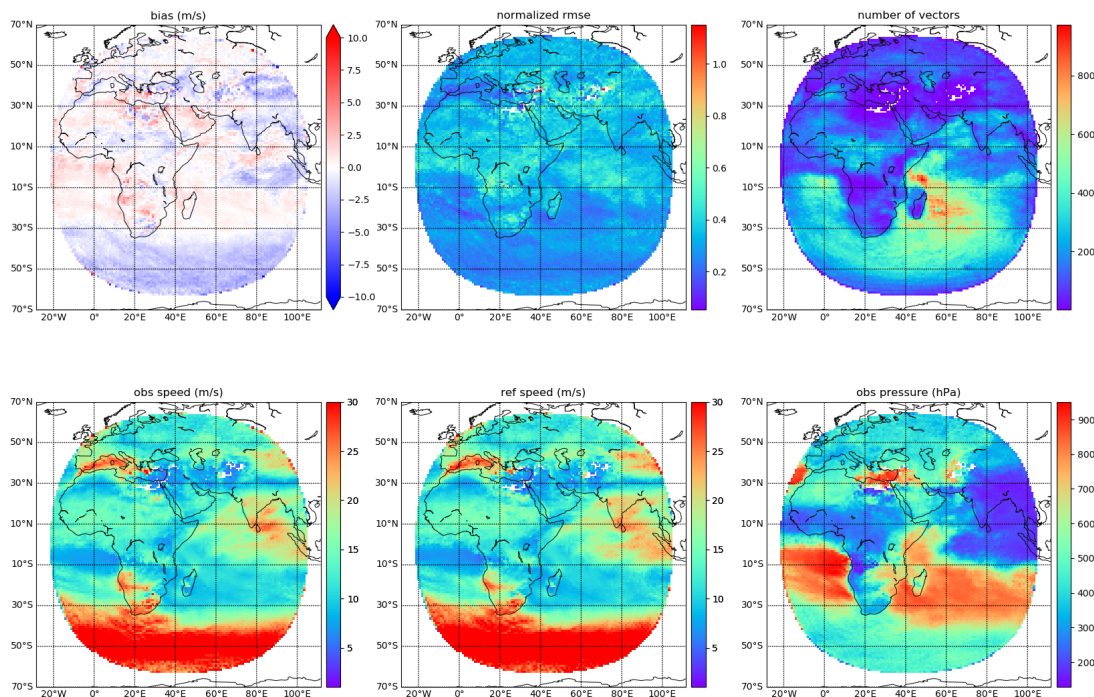


Figure 29: Same as Figure 27 for July 2018 (Meteosat-8).

6 SUMMARY

The GEO IODC AMV release 1 is 21 years long (from 1998 until 2019) in a region of approximately 60° latitude and longitude around the equator at the three different SSPs (41.5, 57, and 63° (Figure 2) east longitude. AMVs are derived using images from MVIRI (one image every 30 minutes) and SEVIRI (one image every 15 minutes) instruments on board first and second generation of Meteosat, the EUMETSAT geostationary satellite series. The same retrieval scheme is used for both. Hourly (24 products per days) and bi-hourly (12 products per day) products are generated respectively for SEVIRI and MVIRI. The wind height (or pressure) is derived using only the two channels present in both generations of instruments: the CDR contains then vectors derived from the IR (around 10.8 μm) and from the WV (around 6.2 μm) images.

The main conclusions of the validation are:

- The winds vectors can be categorised in three atmospheric layers: low (pressure > 700hPa), mid (400<pressure<700 hPa) and high (pressure < 400 hPa) levels. The AMV speed is homogeneous and stable (± 0.5 m/s) over the period, even if the area covered is a bit different for the three satellites.
- On average, the number of daily SEVIRI IR and WV AMVs retrieved is 60% more than from MVIRI measurements. This is due to the higher temporal and spatial resolution of SEVIRI measurements. On average, ~67% more IR than WV AMVs are retrieved. There are no low level WV AMVs as expected and almost 95% of all cloudy WV winds are retrieved as high atmospheric level.
- As expected, there are almost no differences (< 0.4%) between the MSG NRT and the CDR AMV averaged speed because the tracking is done in the exact same way and using the same input images. The differences between NRT and CDR mainly comes from the vectors vertical distribution in the atmosphere. These differences in height are due to the different height assignment methods and the number of channels used (two channels for CDR versus 12 channels for NRT) for the retrieval. Some difference is also due to the different cloud mask. Wrongly or differently assesses clouds can of course mean different corresponding assigned heights. The difference mainly impacts the high level AMVs that are higher on averaged than the NRT, while it is not relevant for middle and low level winds.
- The retrieved AMVs have been co-located with RAOBCORE radiosondes. The comparison shows that the number of co-locations is stable, exhibiting an annual cycle and depends on the number of AMVs. In the infrared, high-level winds exhibit a negative average speed bias of about -4 m/s and middle level a negative average speed bias of about 1.5 m/s. Low level IR AMVs show a slight positive speed bias of about 1.5 m/s. In the water vapour, we can observe a negative speed bias in the high-level cloudy winds at about -2.5 m/s. The middle level cloudy winds have a bias of about +3 m/s.
- Comparison against ERA interim reanalysis data over the full disk area shows a relatively small average speed bias for IR, between -1.5 and +0.5 m/s, and a normalised RMSE is

stable between 0.2 and 0.4. The WV cloudy-sky targets AMV speed bias instead spans between -1 and +3.5 m/s with a normalised RMSE between 0.28 and 0.35. This speed bias value is constant along time (± 0.2 m/s), meaning that the retrieval uncertainty is not depending on the radiometric quality of a single instrument.

In conclusion, the first release of the IODC atmospheric motion vectors from Meteosat first and second generation satellites provides overall a robust and reliable time series spanning over 21 years. The results show that this CDR is in overall good agreement with the GCOS requirements. This release complements the 0° AMV CDR⁶ previously published.

7 LIMITATIONS AND POTENTIAL FURTHER IMPROVEMENTS

In the current release, the following limitations should be considered by the users:

- Current cloud top height retrieval is only using the two IR (10.8 μ m) and WV (6.2 μ m) channels. This approach was followed to provide a time series that is homogeneous from 1998-2019 suitable for climate analysis covering both first and second Meteosat generation. The SEVIRI IR and WV cloudy AMVs slightly differ compared to the operational NRT EUMETSAT AMVs.
- Currently the forecast data are not temporally interpolated but the field closest in time is used in radiative transfer and for AMV QI computation. This might have some impact on the quality of the cloud analysis and, as a consequence, affecting the height assignment for the AMVs.
- For only 0.01% of the available images no wind vectors were produced. The reason is not completely clear and still under investigation.
- The WV cloudy middle layer vectors show an anomalous fast bias versus re-analysis of around 5 m/s. This could be due to an erroneous height assignment for this pressure range. Vectors retrieved for high layer behave as expected. This issue will be analysed for a future release.
- The retrieval for MFG has a latitude limit in the Northern Hemisphere of 60 degrees. The same limit is not present for the Southern Hemisphere or for MSG. It is due to an issue in the processor that will be addressed for the next release

⁶ http://doi.org/10.15770/EUM_SEC_CLM_0020

APPENDIX A DEFINITIONS OF STATISTICAL MEASURES

The statistical parameters used in classical validation procedure to assess the quality for the AMV products, are BIAS and RMSE:

The BIAS is the mean difference between the satellite wind speed and the reference speed;

$$BIAS = \frac{1}{NC} \sum_{i=1}^{NC} \left(\left(\sqrt{u_i^2 + v_i^2} \right) - \left(\sqrt{u_{r,i}^2 + v_{r,i}^2} \right) \right)$$

Where NC is the number of collocations between reference observation vectors [ur,vr] and the corresponding vectors [u,v] derived from a satellite observation

The RMSE is the root-mean-square error (RMSE) traditionally reported as the square root of the sum of the squares of the mean vector difference (MVD) and the standard deviation about the mean vector difference (SD)

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

Where:

MVD is the mean vector difference:

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

With:

$$VD_i = \sqrt{(u_i - u_{r,i})^2 + (v_i - v_{r,i})^2}$$

And:

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

The normalised RMSE (NRMSE) is defined as:

$$NRMSE = \frac{RMSE}{\frac{1}{NC} \sum_{i=1}^{NC} \left(\sqrt{u_i^2 + v_i^2} \right)}$$

APPENDIX B ADDITIONAL PLOTS

In this section, we included some additional plots to provide more details for the interested user. Hovmoeller plots

In the following Figure 30 and Figure 31, one can see the plots for the number of retrieved AMVs and speed in m/s for the WV channel, for cloudy targets.

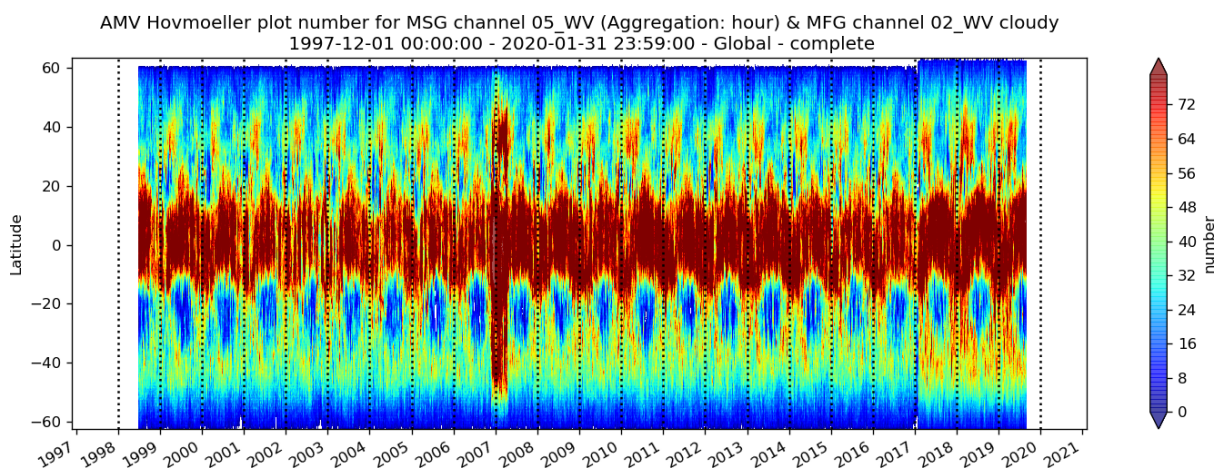


Figure 30: Hovmoeller plot of zonal hourly average of the number of MFG and MSG WV cloudy AMVs at one-degree resolution for all atmospheric heights. Only AMVs with speed $>5\text{m/s}$ and $QI>60$ are used.

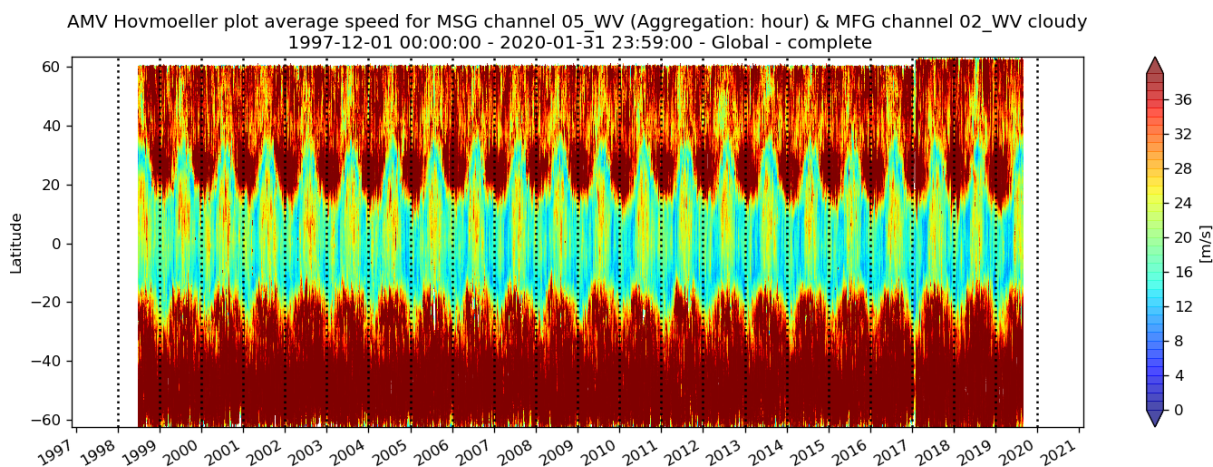


Figure 31: Hovmoeller plot of zonal hourly average of the averaged speed in m/s of MFG and MSG WV cloudy AMVs at one-degree resolution for all atmospheric heights. Only AMVs with speed $>5\text{m/s}$ and $QI>60$ are used.