Atmospheric Motion Vectors Release 2 Product Users Guide

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1 INTRODUCTION

1.1 Purpose and Scope

This document describes the Meteosat Atmospheric Motion Vector (AMV) TCDR Release 2 and provides information needed to order, download, decode, and use the data. In addition, it provides summary information on the validation, including facts limiting the use of the data.

1.2 Reference Documents

Borde, R., De Smet, A., and Arriaga, A.: Height assignment of atmospheric motion vectors with Meteosat 8, Remote Sensing, Proc. SPIE 5571, Remote Sensing of Clouds and the Atmosphere IX, 217, https://doi.org/10.1117/12.565207, 2004.

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, 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 performance of the data assimilation system, 137, 553–597, https://doi.org/10.1002/qj.828, 2011.

MSG Meteorological Products Extraction Facility Algorithm Specification Document - EUM/MSG/SPE/022 v7B:

EUMETSAT: NetCDF Creation Guidelines; Best Practises, Conventions and Applicable Standards - EUM/OPS/STD/11/3120, 2017.

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

Hocking, J., Rayer, P., Rundle, D., and Saunders, R.: RTTOV v11 Users Guide, https://nwpsaf.eu/site/download/documentation/rtm/docs_rttov11/users_guide_11_v1.4.pdf, 2015.

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, 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, 11, 1171, https://doi.org/10.3390/rs11101171, 2019.

Schmetz, J., Holmlund, K., Hoffman, J., Strauss, B., Mason, B., Gaertner, V., Koch, A., and Berg, L. V. D.: Operational Cloud-Motion Winds from Meteosat Infrared Images, 32, 1206–1225, https://doi.org/10.1175/1520-0450(1993)032<1206:OCMWFM>2.0.CO;2, 1993.

Stöckli, R., Duguay–Tetzlaff, A., Jedrzej, B., Hollmann, R., Fuchs, P., and Werscheck, M.: CM SAF ClOud Fractional Cover dataset from METeosat First and Second Generation - Edition 1 (COMET Ed. 1), https://doi.org/10.5676/EUM_SAF_CM/CFC_METEOSAT/V001, 2017.

1.3 Acronyms and abbreviations

AIRS	Atmospheric Infrared Sounder
AMV	Atmospheric Motion Vector
ATBD	Algorithm Theoretical Basis Document
CDR	Climate Data Record
CFC	Cloud Fractional Cover
CLA	Cloud Analysis
CLM	CLoud Mask
CSDP	Climate Service Development Plan
CTH	Cloud Top Height
EBBT	Equivalent Black Body Temperature
ECMWF	European Centre for Medium-range Weather Forecasts
FCDR	Fundamental Climate Data Record
HIRS	High-Resolution Infrared Radiation Sounder
IASI	Infrared Atmospheric Sounding Interferometer
MPEF	Meteorological Product Extraction Facility
MFG	Meteosat First Generation
MSG	Meteosat Second Generation
MVIRI	Meteosat Visible and Infrared Imager
NRT	Near Real Time
OPA	Opaque
RAOBCORE	RAdiosone OBservation COrrection using REanalyses
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SBAF	Spectral Band Adjustment Factors
SSR	Sensor Spectral Response
TCDR	Thematic Climate Data Record
VIS	Visible
WV	Water Vapour

2 BACKGROUND

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

This product is a unique Climate Data Record (CDR) of geostationary AMV using the operational EUMETSAT algorithm adapted for time series processing. This is the first AMV CDR based on cross-calibrated geostationary radiances covering a period of more than 38 years (1981-2019), using data from nine geostationary satellites: Meteosat-2 to Meteosat-11.

AMVs are derived from satellite data by tracking the movement of clouds and water vapour structures in successive satellite images. AMVs are used daily in numerical weather prediction models to improve weather forecasts. This AMV CDR can be used for as an input observation into a modern numerical weather prediction system, which provides a physically consistent description of the Earth system for almost the last century, as for example the planned European Re-Analysis-6 (ERA6).

AMVs are also an important 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 is suited to analyse the temporal changes and variability of the jet stream throughout the last 38years.

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

3 DATA RECORD OVERVIEW

General	Data record name	Atmospheric Motion Vectors Release 2
	Data record digital identifier	DOI: 10.15770/EUM_SEC_CLM_0020 (0-degree)
	Data record short description	Reprocessed Atmospheric Motion Vector (AMV) time series derived from data of the Meteosat first and second generation satellites. AMVs provide wind speed (m/s), wind direction (degree) and altitude in the atmosphere (hPa).
	Record type	Thematic Climate Data Record
	Content	Meteosat level-2 atmospheric motion vectors (TCDR)
Coverage	Spatial	• Meteosat disk • each pixel (IFOV) ground resolution of 2.5 km (3.0 km) for MVIRI (SEVIRI) at sub-satellite point.
	Time period	16 August 1981 – 31 August 2019
	Temporal frequency	• MSG/SEVIRI hourly • MFG/MVIRI bihourly
Instrument	Instruments names	Meteosat Visible and Infrared Imager (MVIRI) Spinning Enhanced Visible and Infrared Imager (SEVIRI)
	Instruments descriptions	• **MVIRI** is a passive imaging radiometer, the optical system consists of a scanning Ritchey-Chretien telescope with a primary aperture of 400 mm diameter (140 mm secondary aperture) and focal lengths of 3650 mm for VIS (resolution 2.5 km) and 535 mm for WV and IR ranges (resolution 5 km). • **SEVIRI** is a compact telescope and scan assembly, allowing the implementation of a large passive cooler which improves IR detector performances by lowering their operating temperature. The imaging SEVIRI radiometer is equipped with a patented three-mirror (3M) telescope of compact design (focal length of 5367 mm) which allows the insertion of a small black body for full-pupil calibration. It has 12 spectral channels, 11 provide measurements with a resolution of 3 km at the sub-satellite point. The twelfth, so-called HRV (High Resolution Visible) channel of SEVIRI (Spinning Enhanced Visible and Infrared Imager), provides measurements with a resolution of 1 km.
Instrument Data	Input data	• MVIRI level-1.5 IR and WV channel • SEVIRI level-1.5 IR10.8 and WV6.2 • ERA-Interim forecast • Cloud top height at pixel resolution
	Output data	Geostationary atmospheric motion vector retrieved using the EUMETSAT algorithm
	Format	The products are provided in NetCDF4 format
Access	EUMETSAT Data Centre	The data set is available from EUMETSAT Data Centre (https://eoportal.eumetsat.int/)
	Delivery	• ftp push • online pull

4 DATA RECORD DEFINITION

4.1 Product generated

This is the second release of the geostationary Atmospheric Motion Vectors (AMV) using an adapted version of the latest EUMETSAT algorithm allowing to retrieve AMVs from recalibrated image data acquired by Meteosat Visible and Infrared Imager (MVIRI) and Spinning Enhanced Visible and Infrared Imager (SEVIRI) radiometers aboard Meteosat first and second generation.

The AMV product provides information on speed (m/s), direction (°), and height (given in pressure units hPa) of vectors which are derived by tracking clouds or water vapour structures between two adjacent images in time.

The final hourly/two hourly wind product is an average of the three intermediate products (Figure 1) derived every 15/30 minutes using the SEVIRI/MVIRI instrument.

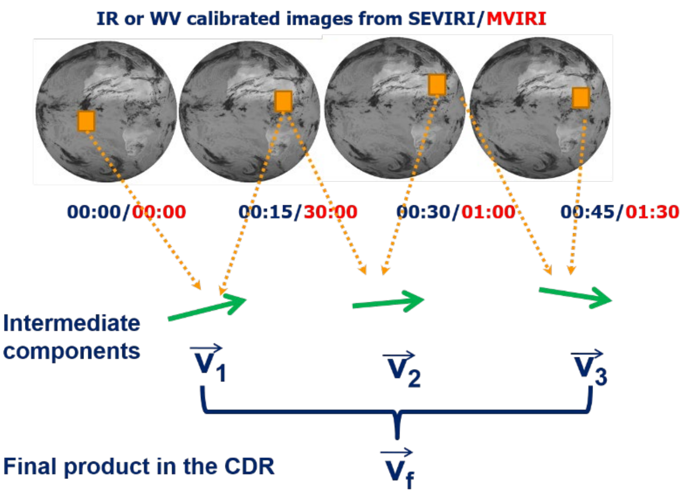

Figure 1: *Principle of hourly/two hourly AMV derivation using four individual images from SEVIRI/MVIRI radiometers. The AMV vector is an average of three individual components (from the three intermediate products).*

Each wind vector is accompanied by a Quality Index (QI). The quality index (see section 7.1) 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 QI. QI are described in (Holmlund, 1998).

Atmospheric Motion Vectors are wind vectors retrieved at all heights below the tropopause, derived from two MVIRI/SEVIRI channels (Water Vapour (WV) channel around 6.2 µm and InfraRed (IR) channel around 10.8 µm), all combined into one product. In the IR channel winds are retrieved by tracking cloud features in the IR channel. Both cloud and clear-sky features can be tracked in the water vapour images.

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

The horizontal and vertical components of the wind (u and v) can be computed for the speed and direction using the following formulae:

$$\vec{u} = \text{speed } \cos(270 - direction) = -\text{ speed} \sin(direction)$$

$$\vec{v} = \text{speed } \sin(270 - direction) = -\text{ speed} \cos(direction)$$

An example for MFG and MSG is given in *Figure 3*.

4.2 Temporal coverage

AMV are derived using images acquired from the Meteosat Visible and Infrared Imager (MVIRI) on board Meteosat First Generation (MFG) and the Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard Meteosat Second Generation (MSG). A complete temporal coverage for each Meteosat is provided in Table 1.

Table 1: *Satellite, instrument, mission, nominal orbit position and services for the period 1981-2019. The period includes Meteosat 2-7 (MFG) and Meteosat 8-11 (MSG).*

Satellite	Instrument	Mission (SSP)	Start Date	End Date
Meteosat-2	MVIRI/VIS	0DEG (0°)	1981-08-16	1988-08-11
Meteosat-3	MVIRI/VIS	0DEG (0°)	1988-08-11	1991-01-25
Meteosat-4	MVIRI/VIS	0DEG (0°)	1989-06-19	1994-02-04
Meteosat-5	MVIRI/VIS	0DEG (0°)	1991-05-02	1997-02-13
Meteosat-6	MVIRI/VIS	0DEG (0°)	1996-10-21	2000-01-20
Meteosat-7	MVIRI/VIS	0DEG (0°)	1998-06-03	2006-07-19
Meteosat-8	SEVIRI/HRV	0DEG (0°)	2004-02-21	2007-05-31
Meteosat-9	SEVIRI/HRV	0DEG (0°)	2007-05-01	2013-04-30
Meteosat-10	SEVIRI/HRV	0DEG (0°)	2013-04-01	2018-02-20
Meteosat-11	SEVIRI/HRV	0DEG (0°)	2018-02-18	2019-08-31

The temporal coverage of the data record is more than 36 years for the Prime mission at 0° longitude (see *Figure 2*).

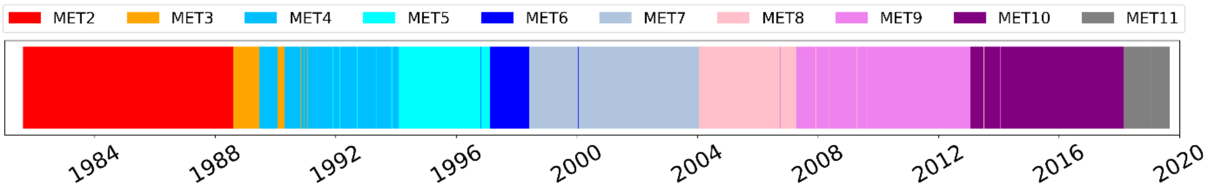

Figure 2: *Operational Meteosat prime satellite over the period for satellites located at 0°.*

4.3 Spatial coverage

This release provides hourly and bihourly products derived over the full disk, with maximum extents of 60°N − 60°S and 60°W − 60°E around the nominal Sub-Satellite Point (SSP) (see Figure 4)

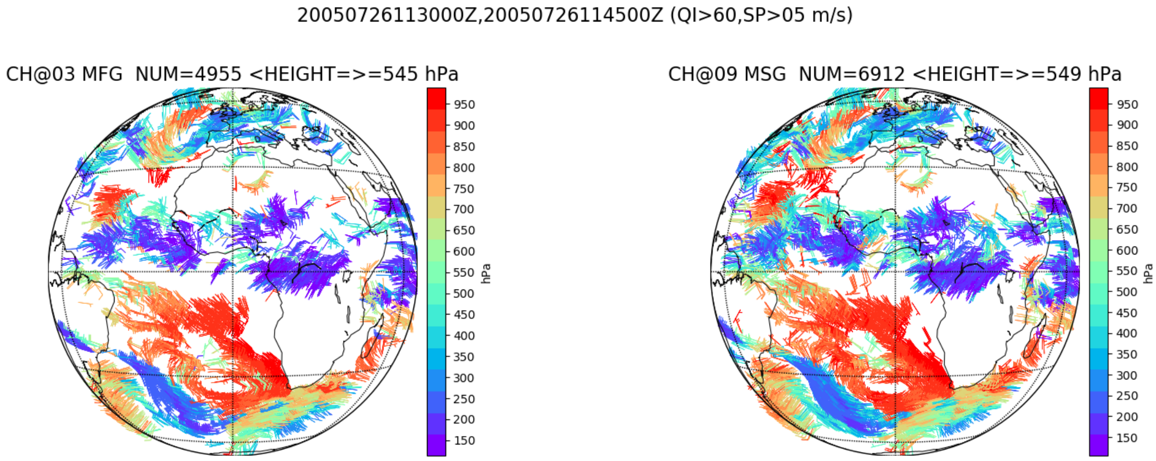

Figure 3: *Example product of MFG (left) and MSG (right) for the same date and time 26/07/2005@11:30. Only vectors with a QI>60 and a speed higher than 5 m/s have been considered.*

Figure 4: *0DEG spatial coverage exploited for AMVs up to 60 degrees.*

5 DATA RECORD GENERATION SUMMARY

5.1 Major steps of the retrieval

This processor is a standalone version of the operational software used for SEVIRI in the EUMETSAT operational Level 2 Meteosat Product Extraction Facility (MPEF) and it is fully described in (MSG Meteorological Products Extraction Facility Algorithm Specification Document - EUM/MSG/SPE/022 v7B).

The processing is divided into four basic steps (Figure 5): (1) Re-formatting the ERA-Interim data (from 60 to 24 levels) and estimation of clear sky radiances/temperatures using the RTTOV[1] V11 radiative transfer model (Hocking et al., 2015), (2) generation of cloud mask at pixel level and (3) derivation of a corresponding cloud top height, (4) retrieval of AMV.

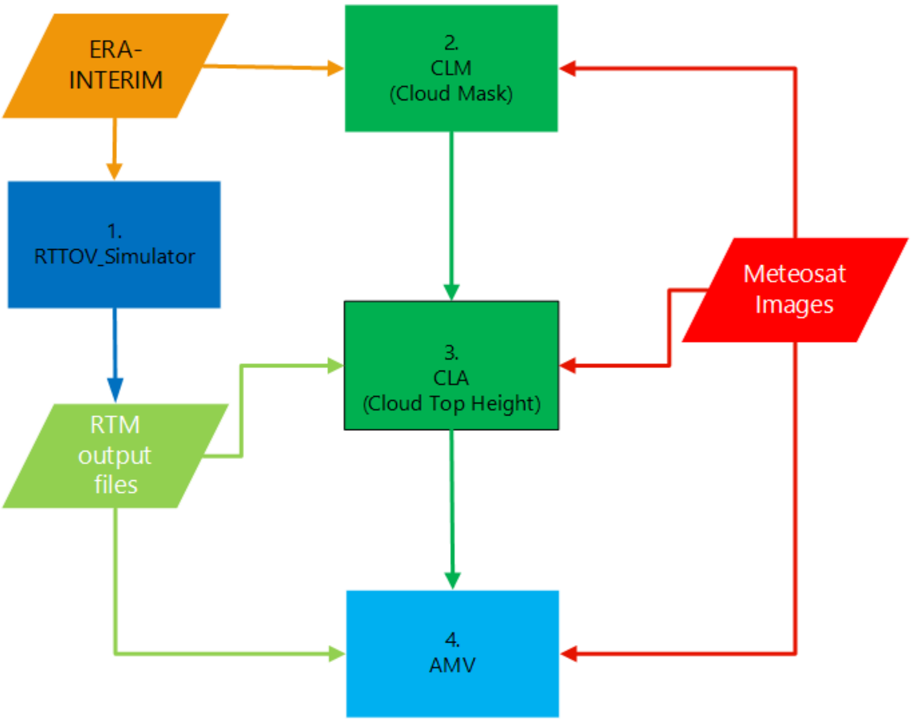

Figure 5: *Processing steps for the generation of AMVs.*

5.2 Input data

5.2.1 Meteosat imagery

AMV products are derived using imagery acquired by both MFG/MVIRI and MFG/SEVIRI instruments. For the first generation of Meteosat satellites, MVIRI FCDR (doi:10.15770/EUM_SEC_CLM_0009) containing recalibrated IR and WV radiances have been used. The recalibration method, described in detail in John et al., 2019, relies on data of the Infrared Atmospheric Sounding Interferometer (IASI), Atmospheric Infrared Sounder (AIRS), and High-Resolution Infrared Radiation Sounder (HIRS/2) on-board polar orbiting satellites. IASI hyperspectral measurements are used to determine Spectral Band Adjustment Factors (SBAF) that account for spectral differences between the geostationary and polar orbiting satellite measurements. A new approach to handle the spectral gaps of AIRS measurements using IASI

[1] Link valid 20/05/2020 https://www.nwpsaf.eu/site/software/rttov

spectra was developed and used. The recalibration coefficients computed based on this method can be directly applied to the lowest level of MVIRI measurements available, i.e., digital counts, to obtain recalibrated radiances. The recalibrated radiances were validated against MSG SEVIRI radiances during overlapping periods. Significant reduction in biases have been observed for both IR and WV channels, 4% and 10%, respectively compared to the operational radiances.

Note that all MFG satellite images have been acquired in a similar way using the same encoding format except for the two pre-operational satellites Meteosat-2 and -3. For those two, only three detector (instead of four) were available and only three channels of image data could be received in a given time slot. In general, the reception alternated between two VIS channels and IR on one time slot and one VIS channel, infrared (IR) and water vapour (WV) on the next time slot. For the pre-operational satellites, the IR detector channel data consisted of 8-bit data, whereas the other two detector channels consisted of 6-bit data (EUMETSAT 2017). For all later satellites, data of all four channels consisted of 8-bits. From the official EUMETSAT documentation[2]: the Meteosat-2 WV detector was switched off on odd-numbered time slots from slot 13 to slot 35 from 15 December 1982 until the end of its lifetime and for the whole lifetime of Meteosat-3.

With these settings, WV channel AMV retrieval are not possible. During the daytime images are available only hourly making it difficult to track fast winds. At night-time, the images are available every 30 minutes but are encoded on 6-bits making them too blurred to allow the current tracking mechanism to work (Figure 6).

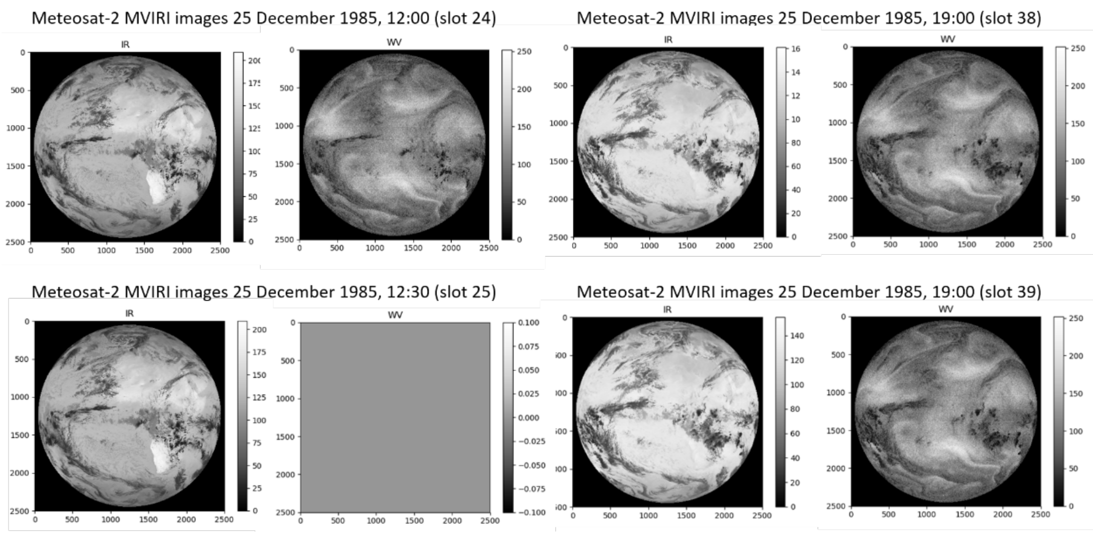

Figure 6: *Example of Meteosat-2 MVIRI IR and WV images for the 25th December 1985. Note that during daytime between 6:30 and 17:30 (odd slots 13-35) WV images are not available and that WV images are encoded on 6-bits instead of 8-bits for IR leading to more blurry images.*

The combination of these two problems did not allow a robust and reliable WV winds retrieval. The WV Meteosat-2,-3 AMVs are not included in this CDR release.

5.2.2 Reanalysis model data

The reanalysis data are only used to compute the altitude of each wind vector and its quality indicator, but not for the tracking of the wind. Reanalysis outputs from ECMWF ERA-Interim (Dee et al., 2011) forecast data are used as input for the reprocessing. We use the 6 and 12 hour reanalysis

[2] Link valid 19/11/2020 https://www.eumetsat.int/meteosat-first-generation-gain-settings

forecast from the 0 and 12 UTC base times, leading to 4 forecast files per day (0, 6, 12 and 18 UTC). The forecast grid is 1°x1°. The parameters used for the processing are listed in Table 2. More details on the ERA-Interim re-analysis data can be found on the ECMWF web site[3].

Table 2: *ERA-Interim data fields used for AMV processing.*

Model Layers (1 -60)	**Surface**
Temperature	Geopotential
u-component	Surface pressure
v-component	2m temperature
Specific humidity	2m dew point temperature
Ozone	surface skin temperature

Figure 7 shows example maps for temperature and specific humidity at a height of around 200 hPa.

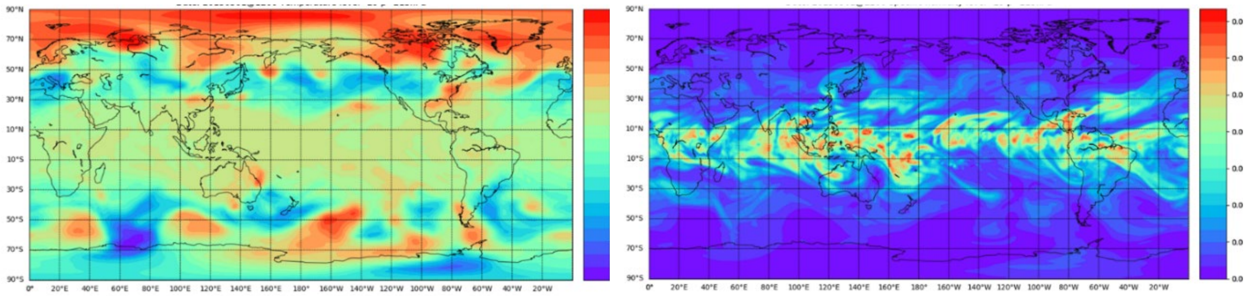

Figure 7: *ERA-INTERIM forecast data: example of temperature (left panel) in Kelvin and specific humidity (right panel) in kg.kg^{-1} @213hPa for the 1st of January 2015.*

5.2.3 RTTOV simulation

Reanalysis output data (see section 5.2.2) are used to feed a radiative transfer model, the Radiative Transfer for TOVS (RTTOV version 11.2) (Hocking et al., 2015) in order to generate the atmospheric state data required for the estimation of the cloud top height (see section 5.4) and wind vectors (Section 5.5). The 60 model levels are interpolated onto 40 levels as describe in Figure 8.

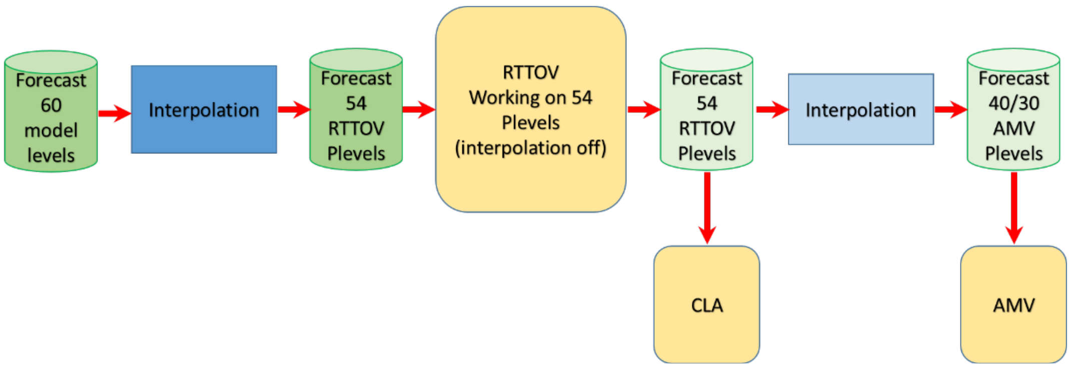

Figure 8: *Preparation of input data for CLA and AMV retrieval modules using forecast data from ECMWF reanalysis.*

[3] Link valid 14/09/2020 https://www.ecmwf.int/en/forecasts/datasets/archive-datasets/reanalysis-datasets/era-interim

5.3 Cloud mask

The CLoud Mask (CLM) is retrieved for both MVIRI and SEVIRI using the same algorithm developed at MeteoSwiss within the Climate Monitoring SAF (Stöckli et al., 2017). The implemented scheme is based on a Bayesian approach applied to a set of scores calculated exploiting only the two visible SEVIRI channels (one single visible channel for MVIRI) and the thermal IR channel around 10.8 µm. The algorithm also builds up a daily background reflectance map to assess potential clouds with higher reliability. The mask is provided as a Cloud Fractional Cover (CFC) in eight fixed steps ranging from 0 to 100%.

5.4 Cloud top height

The cloud top height is estimated only exploiting the WV and IR channels present in both MVIRI and SEVIRI according to the method described in Borde et al., 2004. The height assignment is performed to all pixels flagged as cloudy in the cloud mask. A pixel is considered as cloudy if its CFC is larger than a certain threshold. For this release the CFC threshold for is set to 50%.

The cloud top height is derived for each cloudy pixel using a very robust basic retrieval technique because only two channels (IR and WV) are used. The first and always attempted Cloud Top Height (CTH) estimation is the Equivalent Black Body Temperature (EBBT) or “opaque cloud” method. The level of best agreement between the measured radiances in the IR channel around 10.8 µm and the calculated radiances from the RTTOV simulator (ref RTTOV 11.2) using ERA-interim data as input is determined (low-level inversion in the profile is taken into consideration in the retrieval). The pressure of that level is considered to be the cloud top pressure of an opaque cloud. If a pixel has been flagged as semi-transparent or partly cloudy, the WV/IR rationing method (Schmetz et al., 1993) is applied. More details about this in Appendix A.

In the AMV processor, the vector height assignment is obtained by using the most likely tracked cloudy pixel using the Cross-Correlation Contribution (CCC) method (Borde et al., 2014).

5.5 Wind vector derivation

Wind vectors are retrieved by tracking the motion of clouds and patterns of other atmospheric constituents such as water vapour in between two images. The first step of the AMV extraction scheme is to find a target (a high contrast feature in the image) at a selected grid point. The size of the target is 72km (24x3) for SEVIRI and 80km (16x5) for MVIRI[4]. A search area of 48x48 pixels for SEVIRI and 32x32 pixels for MVIRI centred on the grid point is used (see Figure 9). For each possible location of the target box in the search area, a measure of contrast is calculated using two methods the Local Standard Deviation (LSD) of 3x3 pixels computed at the centre (contrast), and the number of pixels (NLSD) within the target box with an LSD larger than a configurable value. The target location is selected to be the 24x24 (16x16 for MVIRI IR and 12x12 for the WV MVIRI) pixel target box, which has maximum contrast and with NLSD larger than a configurable number. The target selected in the first image is then located in the second image: having located the target in this first image, a search for its corresponding position, 15 minutes (30 min for MVIRI) later, in a second image is made. The search is carried out in an 80×80 pixels (54x54 for MVIRI) box

[4] In this release MVIRI IR and WV target size differ: IR target is 80km (16 pixels x 5km) while WV target size is 60 km (12 pixels x 5km)

centered on the target location in the first image. A cross-correlation method is used for the matching.

An atmospheric motion vector (AMV) is derived from the spatial displacement of the target over the time between the two images. The height assignment (pressure) assigned to the AMV is calculated as a weighted average of the individual pixel's cloud-top height (see section 5.4) estimated for each cloudy pixel, calculated using the CCC function method to determine the pixels that contribute the most to the vectors (Borde et al., 2014).

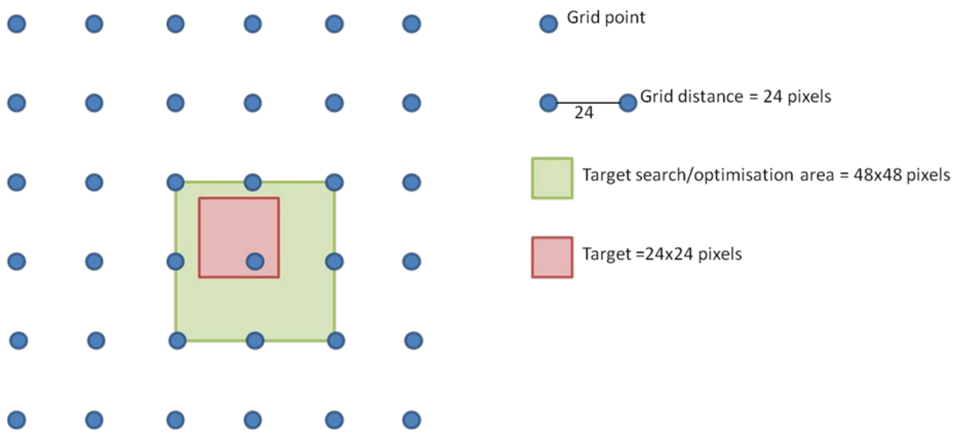

Figure 9: *Target selection for AMV tracking for SEVIRI.*

6 VALIDATION SUMMARY

The 38 years AMVs time series (from 1981 until 2019) has been comprehensively validated (EUMETSAT, 2020). For the validation, the AMV CDR R2 has been compared against the corresponding products from the near real time (NRT) stream, against ERA-INTERIM data and against radiosondes measurements and the main conclusions of the validation are:

- WV AMVs are available for Meteosat-4 to Meteosat-11 only. For Meteosat-2 and Meteosat-3 there is no WV AMVs due to the poor quality of images in this channel.

- About 20% of the retrieved MFG WV AMVs are duplicated[5]. This is due to the processing setup and does not affect the quality of the CDR. The issue will be fixed in a future release.

- The CDR is homogeneous and stable over the complete period. The reprocessed winds exhibit geographical and seasonal features in line with well-known atmospheric circulation patterns. Recurring inter-annual variability in average speed distribution is clearly visible in the northern subtropics. Constantly high wind speeds (> 25 m/s) occur over the southern oceans (the so-called "Roaring Forties").

- On average, the number of daily IR MSG AMVs retrieved is three times more than from MFG. The number of daily MSG WV AMVs retrieved is twice the number of MFG AMVs. This is due to the higher temporal and spatial resolution of MSG. On average, twice as many IR as WV AMVs are retrieved. There are no low level WV AMVs as expected and almost 80% of all WV winds are retrieved at high atmospheric level.

- Between February 2004 and July 2006 Meteosat-7 (first generation) and Meteosat-8 (second generation) images were both rectified to the same 0° longitude orbit position. AMVs from both generations of satellites have been compared in this overlap period. MFG retrieves more high level IR AMVs leading to globally faster winds. The cloudy water vapour AMVs give a similar picture with more Meteosat-7 AMVs at higher altitudes compared to Meteosat-8 and hence a distribution towards faster speeds for the MFG winds.

- As expected there are almost no differences (< 0.4%) between the near real time and the CDR MSG AMV averaged speed, considering that the tracking is done in the exact same way in the CDR and in NRT on the same input images. In addition, the tracking method did not change throughout the MSG history in operations. Differences between NRT and CDR mainly comes from the vertical distribution of the vectors in the atmosphere. These differences in height are most likely due to the different height assignment methods used.

- The retrieved AMVs have been co-located with the RAdiosone OBservation COrrection using REanalyses (RAOBCORE) radiosondes. The bias and the RSME do not change in the series. The comparison shows that the number of collocations is stable, including some annual cycles and merrily depends on the number of AMVs. In the infrared, high and mid level winds exhibit a negative speed bias of 1-3m/s. Low level IR AMVs show a slight positive speed bias of about 0.5m/s. For the water vapour winds, we can observe a negative speed bias in the high level cloudy winds at about -1.0m/s. The mid level cloudy winds have a bias of about 3m/s. Cloud

[5] Unique vectors can be identified for instance using the "unique" function included in the "numpy" python package.

free water vapour AMVs shows a trend in the bias which goes from a slightly positive value (approx. 1m/s) to -3m/s.

- Comparison against ERA interim reanalysis data shows a relatively small average speed bias (between -1.5 and 0.5 m/s) with the only exception of the WV cloudy targets where the bias is about 4.5 m/s most likely due to a wrong height assignment. For the IR a step is present moving from first to second meteosat generation, increasing from negative to positive for middle-level winds and from positive to slightly negative for low-level winds. There is an overall positive speed bias in the tropics and a negative speed bias in the jet area. This feature being common among all AMV retrieval methods. The normalised RMSE is stable between 0.2 and 0.4.

In conclusion, the second release of the atmospheric motion vectors from Meteosat first and second generation satellites provides overall a robust and reliable time series spanning over 38 years for assimilation in numerical weather prediction models and for climate monitoring studies. Improvements of some of the found limitations will be addressed in the next release and the CDR will be further extended in space to cover the Indian Ocean Data Coverage (IODC) region and in time.

7 PRODUCT FORMAT DESCRIPTION

The dataset are available in the EUMETSAT NetCDF format. MSG/MFG AMVs consists of a maximum of 24/12 daily products in the two channels IR and WV.

7.1 NetCDF product description

Native final AMV products are converted into NetCDF4. There are 49 global attributes listed in Table 3. There are 33 variables (Table 4), variable names follow when possible the CF-convention[6]. The *u* and *v* components of the winds have been computed using the equation described in the section 4.1 and added to the product.

Table 3: *Example for the list of global attributes for a file containing AMVs derived from the Meteosat-10 infrared window channel (Channel 9) 00:45 UTC on the 12 June 2015.*

Variable	Content
description	Reprocessed Atmospheric Motion Vector (AMV) time series derived from data of the Meteosat first and second-generation satellite. AMVs provide wind speed (m/s), wind direction (degree) and altitude in the atmosphere (hPa). This file contains infrared window channel AMVs from SEVIRI on board Meteosat10.
creation_time	2020-12-07T11:03:37Z
creator_name	USC Climate Team, EUMETSAT
creator_email	ops@eumetsat.int
creator_url	https://www.eumetsat.int
id	DOI: 10.15770/EUM_SEC_CLM_0020
title	Meteosat Atmospheric Motion Vector data record
institution	EUMETSAT
licence	EUMETSAT data policy https://www.eumetsat.int/legal-framework/data-policy
source	Reprocessed operational satellite radiance observations (infrared channel 09 SEVIRI), cloud top height of each satellite pixel and reanalyses (ERA-interim).
history	07/12/20 11:03:37Z - netCDF generated from original data using software version 1.0 from AMVFinalProductChan@09_20150612094500Z_00.gz
references	Schmetz, J., Holmlund, K., Hoffman, J., Strauss, B., Mason, B., Gaertner, V., Koch, A., and Berg, L. V. D.: Operational Cloud-Motion Winds from Meteosat Infrared Images, 32, 1206-1225, https://doi.org/10.1175/1520-0450(1993)032<1206:OCMWFM>2.0.CO;2, 1993. 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, 1998 Borde, R., De Smet, A., and Arriaga, A.: Height assignment of atmospheric motion vectors with Meteosat 8, Remote Sensing, Proc. SPIE 5571, Remote Sensing of Clouds and the Atmosphere IX, 217, https://doi.org/10.1117/12.565207, 2004. 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, 31, 33–46, https://doi.org/10.1175/JTECH-D-13-00126.1, 2014.
summary	This file is part of the second release of AMVs derived from Meteosat data. This data record was processed using the operational EUMETSAT MPEF algorithm adapted for the reprocessing. Each file contains all AMVs for a certain spectral channel from a specific instrument on a specific satellite. AMVs are computed from three intermediate components, using 4 consecutive Meteosat images. The product is generated averaging the three intermediate components. The CDR time series covers 16 August 1981 – 31 August 2019.
comments	The employed processing chain only uses 2 channels IR and WV to estimate the pixel cloud top height exploited to derive the altitude of the wind vector. This is done in the same way for both M

[6] http://cfconventions.org/Data/cf-standard-names/75/build/cf-standard-name-table.html

	eteosat first and second generation to keep temporal consistency .
instrument	SEVIRI
platform_long_name	Meteosat-10
platform	MET10
keywords	Geostationary, AMV, wind, atmospheric motion vector, speed, direction, height, level2, Meteosat, MVIRI, SEVIRI
processing_centre	EUMETSAT Headquarter
processing_level	2
processing_algorithm_version	5
product_version	Release 2
time	2015-06-12T00:45:00Z
sensing_start_time	2015-06-12T00:00:00Z
sensing_stop_time	2015-06-12T01:00:00Z
cdr_platform_start_time	2013-01-31T00:45:00Z
cdr_platform_end_time	2017-12-31T23:45:00Z
processing_mode	R
processing_type	O
data_format_type	NetCDF Classic format
disposition_mode	O
number_of_images	4
channel_id	09
channel_frequency_center	27758564000000.0
channel_bandwidth	149896250000000.0
procesing_segment_width	24
procesing_segment_height	24
segment_width	72000
segment_height	72000
number_of_winds	11510
number_of_winds_qi_30	6594
number_of_repeat_cycles	4
start_time_comp_1	2015-06-12T00:00:00Z
start_time_comp_2	2015-06-12T:00:15:00Z
start_time_comp_3	2015-06-12T:00:30:00Z
end_time_comp_1	2015-06-12T00:30:00Z
end_time_comp_2	2015-06-12T:00:45:00Z
end_time_comp_3	2015-06-12T:01:00:00Z
geospatial_lat_max	70.0
geospatial_lon_max	70.0
geospatial_lat_min	-70.0
geospatial_lon_min	-70.0
Conventions	CF-1.7

Table 4: *Content of one NetCDF4 file*

Number	Name	Standard name	Long name	Description	Unit	Valid minimum	Valid Maximum	Type
1	latitude	latitude	latitude north positive	Latitude of the vector	degrees_north	-70.0	70.0	float32
2	longitude	longitude	longitude west negative	Longitude of the vector	degrees_east	-70.0	70.0	float32
3	sat_zen	platform_zenith_angle	platform zenith angle	Satellite zenith angle	degrees	0.0	90.0	float32
4	tar_type	status_flag	target type clear or cloudy	Target type used for the tracking. 0 is cloudy 1 is clear	none	0.0	1.0	float32
5	wind_meth	status_flag	wind method used for AMV derivation	Method used for AMV derivation. 3 cloudy 5 clear 1 other	none	0.0	5.0	float32
6	lf	land_area_fraction	land fraction	Land fraction at the vector location	percent	0.0	100.0	float32
7	lsm	land_binary_mask	land sea mask	Land sea flag; 0: land; 1: sea; 2: coast	none	0.0	2.0	float32
8	speed	wind_speed	final wind vector speed	This is the final AMV speed obtained by averaging 3 intermediate components	m/s	0.0	500.0	float32
9	u	eastward_wind	u component of the final wind speed	This is the u, or zonal, component of the final AMV speed	m/s	-200.0	200.0	float32
10	v	northward_wind	v component of the final wind speed	This is the v, or meridional, component of the final AMV speed	m/s	-200.0	200.0	float32
11	dir	wind_from_direction	final wind vector direction	This is the final AMV direction obtained by averaging 3 intermediate components	degrees	0.0	360.0	float32
12	height	air_pressure	final wind vector height	This is the final AMV pressure (using CCC method) obtained by averaging 3 intermediate components	hPa	0.0	1200.0	float32
13	bt	brightness_temperature_at_cloud_top	final wind brightness temperature	Brightness temperature corresponding to the vector height	K	100.0	400.0	float32
14	heightstd	air_pressure standard_error	final vector height standard deviation	This is the std dev of the AMV pressure calculated using CCC	Pa	0.0	1000.0	float32
15	qi	quality_flag	final wind vector quality index	Final wind quality index of the vector excluding forecast	percent	0.0	100.0	float32
16	qi_exc	quality_flag	Final wind vector quality inde	Final quality index of the vector including forecast	percent	0.0	100.0	float32

			x excluding forecast					
17	qi_fcst	quality_flag	qi forecast consistency	QI of forecast consistency	percent	0.0	100.0	float32
18	tvec	quality flag	qi temporal vector consistency	QI of temporal vector consistency	percent	0.0	100.0	float32
19	qi_spd	quality_flag	qi speed consistency	QI of speed consistency	percent	0.0	100.0	float32
20	qi_dir	quality_flag	qi direction consistency	QI of direction consistency	percent	0.0	100.0	float32
21	svec	quality_flag	qi spatial vector consistency	QI of spatial vector consistency	percent	0.0	100.0	float32
22	qi_s_height	quality_flag	qi spatial height consistency	QI of spatial height consistency	percent	0.0	100.0	float32
23	qi_chan	quality_flag	qi channel consistency	QI inter-channel consistency	percent	0.0	100.0	float32
24	qi_height	quality_flag	qi height consistency	QI of height consistency	percent	0.0	100.0	float32
25	qi_t_height	quality_flag	qi temporal height consistency	QI of temporal height consistency	percent	0.0	100.0	float32
26	dir1	wind_from_direction	wind direction of first component	This is the direction of the first intermediate component	degrees	0.0	360.0	float32
27	dir2	wind_from_direction	wind direction of second component	This is the direction of the 2nd intermediate component	degrees	0.0	360.0	float32
28	dir3	wind_from_direction	wind direction of third component	This is the direction of the 3rd intermediate component	degrees	0.0	360.0	float32
29	speed1	wind_speed	wind speed of first component	This is the speed of the first intermediate component	m/s	0.0	500.0	float32
30	speed2	wind_speed	wind speed of second component	This is the speed of the 2nd intermediate component	m/s	0.0	500.0	float32
31	speed3	wind_speed	wind speed of third component	This is the speed of the 3rd intermediate component	m/s	0.0	500.0	float32

7.2 Naming convention

The product filename follows the WMO convention adopted in EUMETSAT for NetCDF files (EUMETSAT, 2017).

Table 5: *Description of the NetCDF filename for the CDR.*

Filename convention for reprocessed netCDF Meteosat geostationary AMVs	
W_XX-EUMETSAT-Darmstadt,<CHANNEL>+ATMOSPHERE+AMV,<SATID>+<INSTRUMENT>+_C_<ORIGINATOR>_<START_DATE>_<END_DATE>_1_OR_FES_<SSP>_<MAJOR_RELEASE_VERSION>_<MINOR_RELEASE_VERSION>.nc	
Example of a filename for WV AMV retrieved using images from SEVIRI on-board the MSG Meteosat 11 satellite	
W_XX-EUMETSAT-Darmstadt,WV+ATMOSPHERE+AMV,MSG4+SEVIRI+_C_EUMG_20190501050000Z_20190501060000Z_1_OR_FES_E0000_0200.nc	
Example of a filename for IR AMV retrieved using images from MVIRI on-board the MFG Meteosat 7 satellite	
W_XX-EUMETSAT-Darmstadt,IR+ATMOSPHERE+AMV,MET7+MVIRI+_C_EUMS_20010111160000Z_20010111180000Z_1_OR_FES_E0000_0200.nc	
Description	
<CHANNEL>	Channel used to derive AMV in the file (IR or WV)
<SATID>	Satellite used. Note that for MSG: MET08 to MET11 MSG1 to MSG4 are used
<INSTRUMENT>	MVIRI or SEVIRI
<ORIGINATOR>	EUMG or EUMS
<START_DATE>	Date of the first image used (yyyyMMddhhmmss)
<END_DATE>	Date of the last image used (yyyyMMddhhmmss)
<SSP>	Sub satellite point: 0°
< MAJOR_RELEASE_VERSION >	Release major version
< MINOR_RELEASE_VERSION >	Release minor version

8 PRODUCT ORDERING

The data are accessible via the EUMETSAT Data Centre. To access the data from EUMETSAT, you need to register with the EUMETSAT Data Centre. When registered, you can order the data through a written request send to EUMETSAT's helpdesk.

8.1 Register with EUMETSAT Data Centre

Do this to register with the EUMETSAT Data Centre:

1. Register in the EUMETSAT EO-Portal (https://eoportal.eumetsat.int/) by clicking on the New User – Create New Account tab;
2. After finalisation of the registration process, an e-mail is sent to the e-mail address entered in the registration. Click the confirmation link in the e-mail to activate your account;
3. Login and subscribe to the Data Centre Service by going to the Service Subscription Tab and selecting Data Centre Service. Follow instructions issued from the web page to add needed information.

8.2 Order data

The data record described in this product user guide can also be ordered via the EUMETSAT User Service Helpdesk in Darmstadt, Germany. Please send a written request to this helpdesk, email ops@eumetsat.int, indicating the data record that you want to order including its Digital Object Identifier (DOI) number.

9 PRODUCT SUPPORT AND FEEDBACK

For enquiries about the CDR described in this product user guide, please contact the EUMETSAT User Service Helpdesk by email: *ops@eumetsat.int.*

10 PRODUCT REFERENCING

The data record described in this product user guide has a unique DOI that should be used for referencing. The product's filename provides a unique identifier for each product.

11 ACKNOWLEDGEMENTS

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APPENDIX A CLOUD TOP HEIGHT ESTIMATION

This section describes in details the scheme used to retrieve the cloud pixel height used by the AMV algorithm to assign a height to each pixel. The height of those cloudy pixels is then used by the CCC method in the AMV algorithm to assign a pressure to each wind vector. For consistency between Meteosat first and second generation imagers only two SEVIRI channels are used (IR10.8 and WV6.2). At first, three cloud top height estimations are done: (a) EBBT opaque cloud (IR), (b) semi-transparent correction (STC) (IR/WV method) and (c) low level inversion using the IR channel. For those height estimations, the input from the radiative transfer model RTTOV calculations (derived from ERA-Interim model data) is a paramount. Note that this usage of model information that could be older up to 6 hours than the observation could have an impact on the quality and reliability of the retrieved cloud top height. The final height assignment for a cloudy pixel is coming from one the three heights.

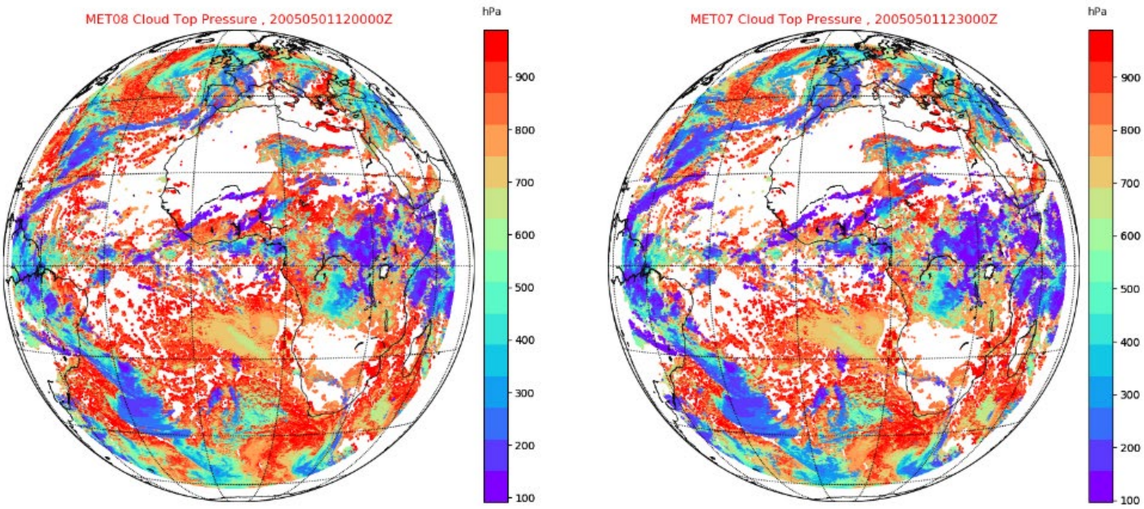

Figure 10: *Example of cloud top height for one image: Left panel SEVIRI (pixel 3km, scan time 12 minutes) and on the right panel MVIRI (pixel 2.5km, scan time 25 minutes).*

The core of the CLA algorithm has been provided by Lutz from EUMETSAT (personal communication). It is illustrates in Figure 11. The following sections describe the three height estimations.

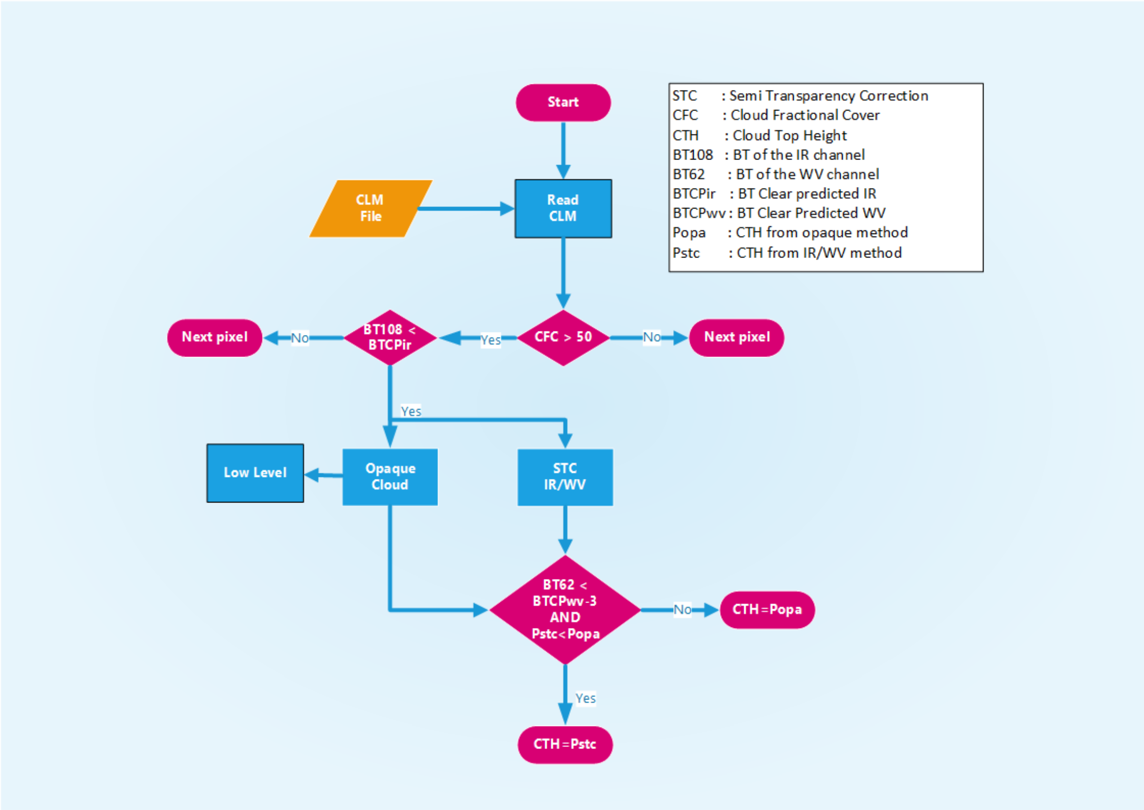

Figure 11: *Flow chart showing the current CTH retrieval for both MVIRI and SEVIRI. Image reading is not shown for sake of simplicity. In this sketch, the reading and handling of images is not represented.*

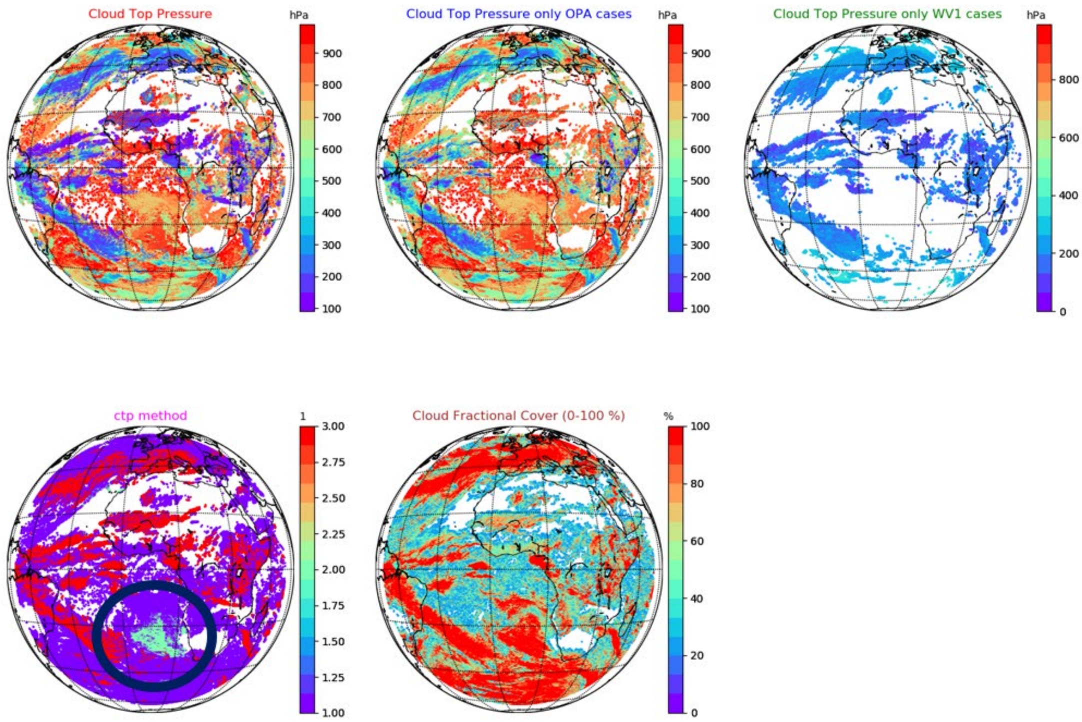

Figure 12: *Example of CLA retrieval for MET10 on the 01/05/2015 at 12:30 UTC. The final cloud top pressure (top left), Opaque method only (top middle), IR/WV ratio (top right). The method used (magenta: OPA, red: IR/WV, aquamarine: low level) is in the bottom left. Bottom right indicates the corresponding cloud mask.*

A.1 Opaque cloud (EBBT method) and low level inversion

The first and always attempted height estimation is the OPAque cloud method (OPA). This method tries to find a match between the pixel temperature and the position of a cloud on the vertical profile generated with the RTTOV simulator (EBBT). In the "nominal" case (see Figure 13) the temperature is expected to monotonically increase for increasing pressure (getting closer to the surface) below the tropopause.

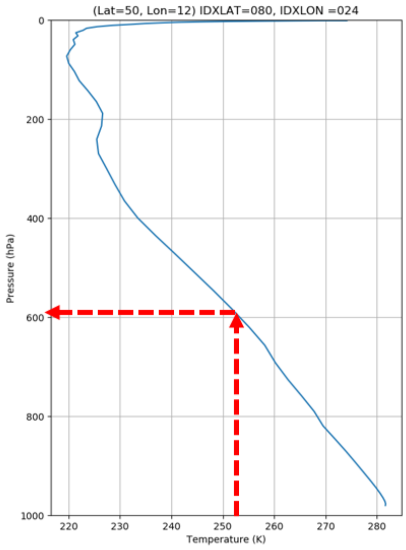

Figure 13: *EBBT method to retrieve the altitude (pressure in hPa) of an opaque cloudy pixel having with a BT=251K. The RTTOV model output at the pixel location is represented in blue.*

There are locations where the vertical atmospheric temperature profile present an inversion lower in the atmosphere. In those situations, the cloud altitude could be set at several locations as shown in the Figure 14. The current approach is attempting to retrieve the cloud pixel height (CTH) for the two situations (with and without inversions) using one unique strategy. The retrieval is done in six steps:

1- The test for the altitude corresponding to a certain observed radiance is done using the RTTOV profile. To avoid levels below the surface the first effective pressure level (*klev_eff*) is looked for (see Figure 15).
2- Compute the level of the troposphere (*lev_tropo*).
3- The search for EBBT is performed from *klev_eff* to *lev_tropo*, looping for the top to the surface.
4- An array of the differences (*Array_diff_BT*) between the current pixel IR BT (*Pixel_IR_BT*) and the profile temperature for the layer among *klev_eff* and *lev_tropo* is calculated.
5- The first two minima of *Array_diff_BT* are considered. If the two profile temperature corresponding to the two minima have pressure difference higher than 200 hPa they cannot correspond to the "Nominal" case and the "Low level inversion" case will be applied.
6- Once that the profile level corresponding to *Pixel_IR_BT* has been found, the final height is calculated using a linear interpolation with the following profile level. The definition of the two profile levels for the interpolation is mathematically slightly different between the "Nominal" and "Low level inversion" cases but conceptually identical.

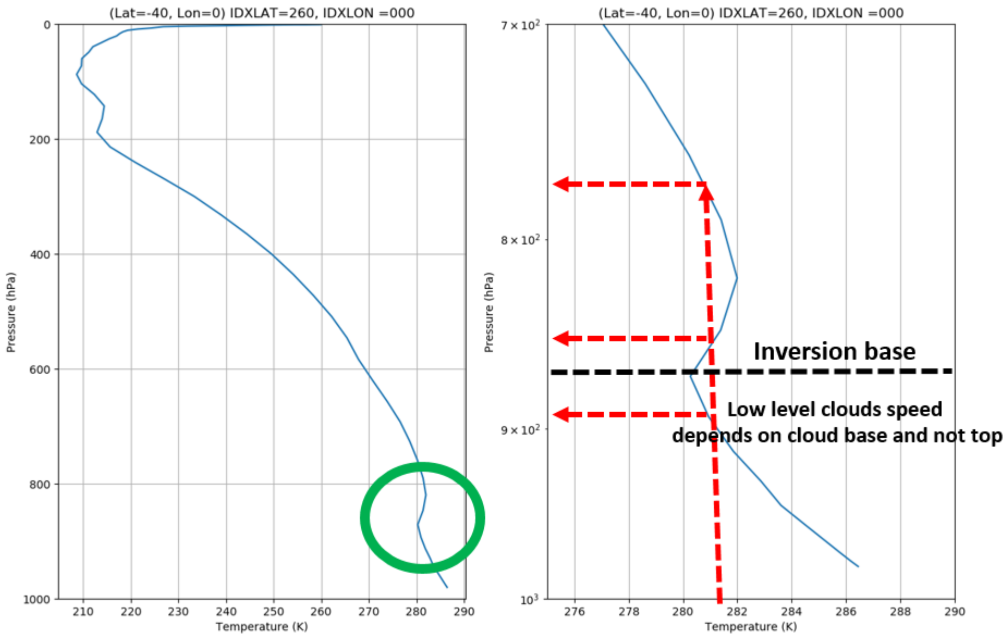

Figure 14: *Example of a low-level inversion. The plot on the right is a zoom of the left plot around the inversion.For a cloudy pixel with a BT=281.5K several altitudes could be infer from the RTTOV simulation.*

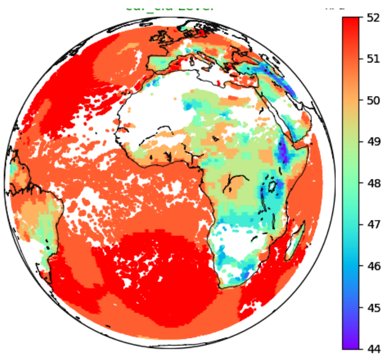

Figure 15*: geographical distribution of klev_eff, RTTOV effective model level (first RTTOV model level that correspond the pixel surface pressure). The example is for the 01 May 2005 at 11UTC.*

A.2 IR/WV ratio correction

If the cloud is not opaque but semi-transparent, the EBBT method is not accurate. It could bring to a wrong estimation of the cloud height. As only two channels are available for the retrieval, the only easiest solution to assess the height is to use an infrared/water-vapour method shown in Appendix A.2. The OPA method (only exploiting the IR10.8 µm) will assess the cloud height at around 336 hPa (interpolation of points along the red line corresponding at the measured IR value, left panel Figure 16). The application of the semi-transparent correction (IR/WV ration) will set the cloud where the red line crosses the dashed line at 272 hPa (pressure value corresponding to the green diamond on both panels of Figure 16). This method is described with more details in Schmetz et al., 1993.

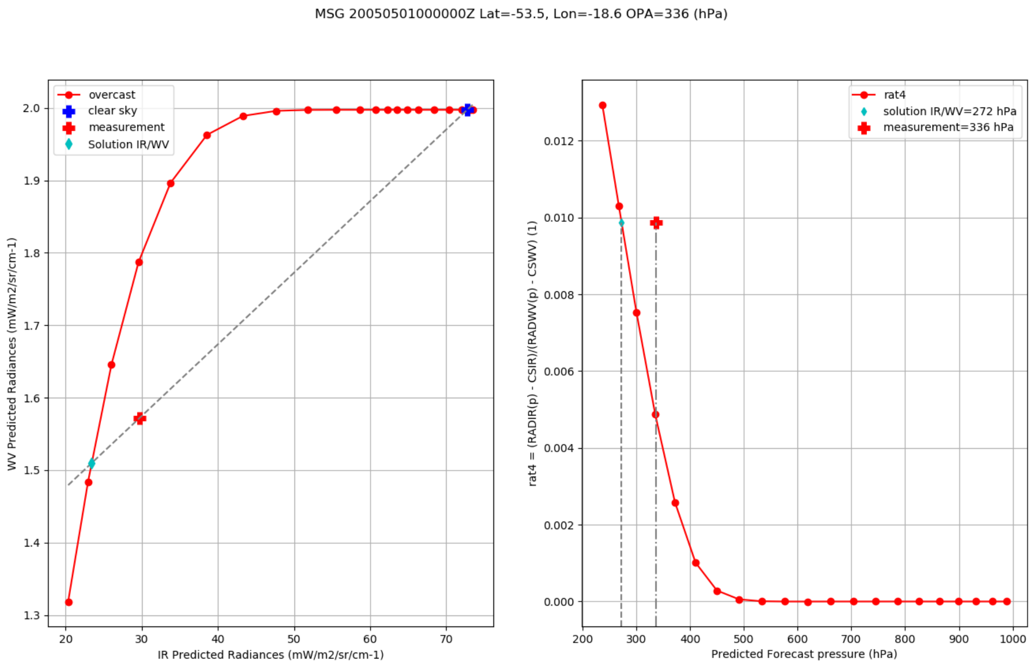

Figure 16: *Example of semi-transparent real scene. Meteosat-8 01/05/2005@0000Z (Latitude: -53.5, Longitude -18.6) The OPA estimated height is 336 hPa (red cross). The applied correction moves it up to 272 hPa (green diamond). The relation between IR/WV and the pressure profile is on the left panel. On the right panel, it is shown the relation between the pressure profile and a function (Rat4) depending on the measured IR/WV radiance and the clear sky background radiance from ERA-INTERIM.*