AMV EXTRACTION SCHEME FOR MTG-FCI AT EUMETSAT

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Abstract
Atmospheric Motion Vectors (AMVs) have been derived from Meteosat satellites since the late seventies at the European Space Operations Centre (ESOC) then at EUMETSAT. The extraction technique has been regularly improved over the last decades, resulting from new capabilities offered by the Meteosat Second Generation (MSG) SEVIRI instrument and from constantly increasing computing capabilities. AMVs are currently derived hourly from Visible (VIS08), Water vapour (WV62 and WV73) and infrared (IR108) channels of SEVIRI. They currently constitute an important part of the observation data provided to Numerical Weather Prediction models for assimilation.

The AMV extraction scheme developed in preparation for Meteosat Third Generation Flexible Combined Imager (MTG-FCI) retrieves the AMVs in a generally similar fashion to the present operational extraction scheme used at EUMETSAT for MSG. The image data preparation, target selection, tracking and AMV quality control steps remain unchanged from the MSG AMV extraction scheme. However, several changes are proposed which should make the retrieval more accurate and the algorithm more flexible and better maintainable. This paper presents the AMV extraction scheme in preparation for MTG-FCI and discusses the main changes from the current MSG AMV algorithm.

INTRODUCTION
The AMV extraction scheme developed in preparation for Meteosat Third Generation (MTG) retrieves the AMVs in a generally similar fashion to the present operational extraction scheme used at EUMETSAT for Meteosat Second Generation (MSG) (Schmetz et al., 1993; Holmlund, 2000). The image data preparation, target selection, tracking and AMV quality control steps remain unchanged from the MSG AMV extraction scheme. A complete and detailed description of these steps can be found in the EUM.MSG.SPE.022 document (ASD; ‘MSG Meteorological Products Extraction Facility Algorithm Specification Document’). However, several changes are proposed for MTG which will make the algorithm more flexible and better maintainable. These differences are:

- Use of a triplet of MTG repeat cycles (currently 4 MSG repeat cycles are used for an hourly AMV product)
- No image enhancement process for the IR10.5 channel
- A new height assignment scheme: CCC (Borde and Oyama, 2008)
- Use of a cloud top height product to set the AMV height
- Calculation of AMV height standard deviation and possibly height error estimate
- Setting the final AMV speed and direction to the speed and direction of the last intermediate component
- Setting the final AMV coordinates to the position of the tracked feature

AMVs will be extracted from the VIS 0.8, IR 3.8 (night only), IR 10.5, WV 6.3 and WV 7.3 channels. However it is unclear at this point whether the winds extracted from the IR 3.8 channel will provide additional information when compared to the IR 10.5 AMVs.
Figure 1: AMV Processing
Motion vectors will be extracted between each pair of consecutive repeat cycles, leading to two intermediate AMV products for an image triplet. The final product will be then derived from these two intermediate products.

The steps performed in order to derive one single displacement vector for one channel for the intermediate AMV product are illustrated in Figure 1:

1. Target selection
2. Derivation of target displacement
3. Height assignment, including the pixel selection scheme
4. Automatic quality control

In step (1), all possible targets are extracted for a given image. A first guess target position is at the location of the end position of the successfully tracked targets from the previous cycle. The target position is optimised within the target search area to gain maximum contrast within the target area.

Step (2) tries to find the position of the same targets in the following image.

In step (3), the extracted vector is assigned a height: Vectors successfully extracted with cloud targets are assigned a height corresponding to the temperature at which the cloud is radiating. Vectors extracted with water vapour targets are assigned a height related to a representative layer of the displacement.

Finally all vectors are subjected to an Automatic Quality Control in step (4) for both the intermediate and final products.

With this described setup the AMV product would be generated every 30 minutes.

**MAIN IMPORTANT CHANGES FROM MSG AMV ALGORITHM**

**CCC method for pixel selection**

Borde and Oyama (2008) showed the importance of the process applied to select the pixels used to set the AMV altitude. They described a new method that keeps a closer link between the tracking and the height assignment step in the AMV extraction algorithm. They proposed using the individual pixel contribution to the cross correlation coefficient, $CC_{ij}$, defined by Büche et al. (2006), to select the pixels that contribute the most to the tracking, thus defining a suitable subset of image pixels for the height assignment. The AMV pressure $P$ is calculated as the average Cloud Top Height (CTH) pressure of the selected pixels, weighted by their individual contribution to correlation coefficient $CC_{fi}$:

$$P = \frac{\sum_{cold\_branch} CC_{i,j} \cdot CTH_{i,j} \cdot CC_{ij} > CC_{ij\_thr}}{\sum_{cold\_branch} CC_{i,j} \cdot CC_{ij} > CC_{ij\_thr}}$$

(1)

For AMVs derived using infrared channels only, the pixels that get a successful CTH value and that have a radiance smaller than the average radiance within the target area and that have $CC_{ij}$ greater than $CC_{ij\_thres}$ threshold are selected to calculate the pressure. $CC_{ij\_thres}$ is dynamically set to the average $CC_{fi}$ $<CC_{fi}>$ calculated using the pixels present within the target area. However when the target areas contain very large and homogeneous cloudy layer it can happen that no coldest pixels have $CC_{ij}$ greater than the average $CC_{fi}$ $<CC_{fi}>$. In such a case, all the pixels that have a radiance smaller than the average radiance within the target area and that have $CC_{ij}$ greater than 0 are used to calculate the pressure.
The CTH information could be provided by the standard scene and cloud analysis (SCE-CLA) product or by the Optimal Cloud Analysis (OCA) product. The AMV algorithm will be flexible and will allow a final selection of the underlying height assignment product. This allows the use of the latest and best validated scientific improvements in cloud height assignment.

A weighted pressure standard deviation is calculated accordingly, and associated to the pressure P, using the same set of pixels. This standard deviation gives information on the variability which is present within the target box. It is expressed in hPa.

In the visible part of the spectra the scattering of the photons on cloud particles dominates the radiative transfer processes. Therefore the cloud tops which correspond to pixels having the smaller radiance in the IR channel now correspond to the pixels which have the larger reflectance in Visible channels. For AMVs derived using VIS 0.8 channel only the pixels that get a successful CTH value, that have a reflectance larger than the average reflectance within the target area and that have \( CC_{ij} > CC_{ij, \text{thres}} \) are selected to calculate the pressure. The rest of the pressure and pressure standard deviation calculation processes remains identical to the one described above for the IR channel.

**Use of OCA product**

The AMV pressure shall be calculated using, OCA cloud top heights. The OCA algorithm is based on optimal estimation method. It retrieves cloud micro-physical and bulk properties from SEVIRI observations: optical thickness, effective particle radius, cloud top temperature, cloud top pressure, and cloud phase. It differs in substance from the standard EUMETSAT method in using visible channels (daytime only) and all infrared channels simultaneously, giving an overconstrained system which allows detection of difficult scenes (e.g. multi-layer cloud) which can then be eliminated or potentially treated more appropriately (Watts et al. 2011). It is hoped that the OCA pixel based CTH with its robust quality control information might improve the reliability of the AMV height assignment.

Figure 2 illustrates the differences between the CTH calculated by the standard algorithm, upper left pictures, and the OCA product upper right picture, for a scene taken the 10th august 2006 at 12:00 UTC. The two last pictures on the bottom represent the OCA product filtered by the quality factor JM < 80 and JM < 20 respectively. JM represents the quality of fit to the measurements achieved by the retrieval process.

The OCA product appears generally less patchy than standard CLA product, especially at low and mid levels. This is due to low level temperature inversion method used in the OCA algorithm, which sets the first guess cloud top height under the temperature inversion when this has been detected in the forecast profiles. At high levels the CO2 slicing method used in the standard CLA algorithm tend to set the cloud top heights slightly higher in the troposphere than OCA algorithm.

The JM quality control factor associated to OCA product can be used to select the pixels for which the retrieval is reliable. Cloud edges or multilayer situations are generally associated to high solution cost, then associated to poor quality control, and can be easily removed or flagged for further use in AMV height assignment process. However, filtering the pixels for which the JM quality control is less than a predefined threshold may reduce significantly the number of pixels available to set the AMV altitude, as is shown on the bottom right picture of the Figure 2. Operational use of such filtering process will be fine tuned to find a good balance between the amount of pixels available to set the AMV HA and the expected quality of the CTH.

Watts et al., (2011) proposed a method to derive two-layer cloud properties from concurrent visible, near- infrared, and infrared observations. It is a modification of a single-layer scheme and is applied to Spinning Enhanced Visible Infrared Imager (SEVIRI) observations and validated against coincident A-Train data. This method has been implemented recently in the OCA algorithm and is applied to the pixels that have high solution costs. Results show that upper layer CTHs are of comparable accuracy.
to the single-layer cases, lower-layer CTHs show some useful accuracy. This last improvement of OCA product is expected to be very useful for future AMV HA applications.

Set final AMV location to the feature tracked location.

The final AMV position is actually set to the center of the target box. However, since the CCC method clearly identifies the feature tracked during the tracking step, the final AMV position can be moved from the center of the target box to the more appropriate position of the tracked feature. Figure 3 shows the histograms of the distance to the center of the target box for the geographical position of various percentages of the coldest pixels within the target box (colored lines), and for the weighted position of the coldest pixels that have $CC_j$ larger than $<CC_j>$ (solid line) and $CC_j$ larger than 0.
(dashed line). The distance to the center of the target box is given in pixels. Using 24x24 target boxes, the largest possible distance to target center is nearly 17 pixels. The peak of the histogram is around 10 pixels for black solid line, which represents 30 km at nadir. Setting the final AMV position to the location of the feature tracked is important for comparisons and validation of the AMV product against forecast fields and radiosonde observations, but also when AMVs are assimilated in NWP models.

Figure 3: Histogram of the distance of various percentages of coldest pixels to the center of the target box. Black lines correspond to the distance of the cold branch positions; considering pixels that have $\text{CC}_i$ larger than $< \text{CC}_i >$ (solid line) and larger than 0 (dashed line). (1\textsuperscript{st} December 2006 at 2:00 and 2:15 UTC).

PRELIMINARY RESULTS

The impact of using OCA product instead of the standard CLA cloud top height to set the AMV altitude has been tested for the whole month of August 2008 using triplets of Metosat-8 images around 12:00 UTC (11:45, 12:00 and 12:15 UTC). Three different HA configurations have been tested: 1) using the standard CLA CTH product selected by CCC method, 2) using all the OCA pixels selected by CCC method, 3) using only the OCA pixels selected by CCC method that have a quality control JM smaller than 80. Only the AMVs extracted using the infrared 10.8 $\mu$m channel and having a final quality index larger than 0.8 in a range between 0 and 1 have been considered in the following.

Figure 4 shows AMV pressure histograms for the three configurations. The use of standard CLA CTH product is plotted in red, the use of OCA product without and with filtering are plotted in blue and green respectively. The blue and green curves are very close together, showing that the use of JM factor does not impact too much the final AMV altitude except at high levels. Differences between CLA and OCA at low levels are explained by the use of low level inversion method in the OCA algorithm. This method has not been applied using the standard CLA CTH, which end to set the cloud tops slightly higher in the troposphere. The use of OCA retrieval at high levels tends to set the cloud tops lower in the troposphere. The CO2 slicing method used to correct the semi-transparency effect in the standard CLA algorithm is known to slightly underestimate the cloud top pressure (Borde and Dubuisson, 2008). Setting the cloud tops lower in the troposphere at high levels appears then as an expected result that must improve the general AMVs statistics.
Figure 4: histograms of the pressure associated to the AMVs for the three HA configurations.

Figure 5 shows the histograms of the number of pixels used to estimate the AMV altitude. The lines related to standard CLA CTH and OCA ALL are very similar, peaking around 100 pixels, which represents nearly 17% of pixels in the 24x24 target box. The number of pixels used to calculate the AMV altitude is greatly reduced when considering only the OCA pixels that have JM quality factor smaller than 80. As shown on the Figure 3, this slightly impacts the AMV pressures only at high levels for which the altitude estimated using OCA is supposed to be more reliable.

Figure 5: histograms of the amount of pixels selected by CCC method to estimate the AMV altitude.

Figure 6 presents histograms of the pressure standard deviation associated with the AMV altitude. This is calculated on the exactly same set of pixels used to estimate the AMV pressure, and it is expressed in hPa. It gives information on the variability of the pixels used to set the AMV altitude. Just as the selection of the pixels used to set the altitude is done by CCC method based on their individual contribution to the correlation, so the same set of pixels is finally used for the three HA configurations of the same AMV. Consequently the various pressure standard deviation histograms of the Figure 6 are very similar, peaking around 15 hPa. However, the pressure standard deviations calculated using
the OCA product filtered by the JM factor lesser than 80 tend to be more frequently smaller. This can be explained by a more homogeneous and reliable estimation of the CTH. A large amount of AMVs have pressure standard deviation larger than 50 hPa, going up to more than 150 hPa even for altitudes estimated using OCA product. This information indicates a large variability of the pixels used to set the altitude, even if their individual pixel based CTH retrieval is reliable. This information should be very useful in assimilation for NWP applications.

![Figure 6. histograms of the pressure standard deviation associated top the AMV altitude.](image)

Figure 7 shows speed biases against collocated forecast fields for high level (100–400 hPa), mid level (400 – 700 hPa) and low level (> 700 hPa) AMVs respectively. The red line corresponds to results of AMVs for where altitudes have been calculated using standard CLA CTH and the green where the altitudes have been calculated using OCA product. The x-axis represents the julian days for the whole month of August 2006. Setting the cloud tops slightly lower in the troposphere, the use of OCA product reduces the well known slow speed bias at high levels. The results are more mitigated at mid levels where AMVs extracted using OCA product present a slightly fast bias. However, few AMVs are extracted at mid levels as shown on the AMV pressure histograms of the Figure 4, and some of them correspond to multilayer situations for which the altitude is very difficult to estimate precisely. Actual cloud top height methods retrieve the CTH somewhere between the two layers depending on the cloud microphysics, optical thickness and the respective altitude of the two layers, (Borde and Dubuisson, 2010, Watts et al., 2011). The latest version of OCA algorithm is able to derive two-layer cloud properties from concurrent visible, near-infrared, and infrared observations (Watts et al, 2011). This last improvement in the OCA product has not been used in the present study, but it is hoped to improve again the performance of the AMV HA process in the future.
DISCUSSION

This paper presents the AMV extraction scheme in preparation for MTG-FCI and details the two main changes from the current MSG AMV extraction algorithm. The technique tested above (Borde and Oyama, 2008) uses the existing CLA-CTH parameter in conjunction with CC[i,j] information to set AMV height. This technique should improve the overall consistency of the AMV algorithms, preserving the essential link between altitude estimation and feature tracked. It uses the pixel based CLA cloud product to estimate the AMV altitude. This also ensures a close agreement between the AMV altitude and the cloud top pressures extracted at the same location.

The CTHs retrieved by OCA algorithm may be used to set the AMV altitude. This product is based on an optimal estimation technique which has the advantage of providing a cost estimate that can be used as a quality indicator of the reliability of the retrieval. Preliminary results comparing the use of OCA product instead of the standard CLA product to set the AMV altitude are very encouraging, especially at high levels where the known slow speed bias seems to be reduced. However additional tests need to be done operationally to confirm these first results. The high flexibility of the proposed algorithm will it to benefit easily from the latest improvements in cloud top height retrieval. It is also hoped to better treat multilayer situations in the future using the latest developments of the OCA algorithm.

*Figure 7. Speed biases against collocated forecast fields for high, mid and low levels respectively.*
REFERENCES

ASD; ‘MSG Meteorological Products Extraction Facility Algorithm Specification Document’ edited by EUMETSAT. Reference: EUM.MSG.SPE.022


