IMPROVED EXTRACTION OF LOW-LEVEL ATMOSPHERIC MOTION VECTORS OVER WEST-AFRICA FROM MSG IMAGES

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Abstract

Determining reliable low-level atmospheric motion vectors (AMVs) remains a difficult task, especially over land. In this presentation, a method for the tracking of low-level clouds over West-Africa initially developed at the LMD on Meteosat first-generation images, in order to determine in particular African monsoon winds, has been adapted to MSG images and improved. Specific adaptations of existing AMV calculation methods include the use of smaller target and search windows. A height based on the pressure of the dominant cloud class (from the Nowcasting SAF cloud classification) is associated to each motion vector. Comparisons of this height to lidar heights derived from the CALIOP instrument onboard the CALIPSO satellite indicate that very thin clouds are not detected in the cloud classification, thus the height assignment of some AMVs may be incorrect.

In the examples shown, atmospheric motion winds have been calculated during the West-African rainy season (summer) 2006. They occurred during the intensive observing periods of the AMMA (African Monsoon Multidisciplinary Analyses) experiment.

1. INTRODUCTION

Currently a small number of radiosondes and surface stations measure the wind over West-Africa. Atmospheric motion vectors (AMVs) derived from MSG (currently Meteosat-9) images complete these measurements over this area and the surrounding oceanic region. The resulting weather forecasts over this continental area are of poor quality, due to the limited number of available measurements, and to the exclusion of low-level AMVs over land from assimilation due to their insufficient reliability.
The insufficient understanding of the meteorology in this geographical area was at the origin of the AMMA campaign (African Monsoon Multidisciplinary Analyses). In this study, we present the first steps, elements and limitations for the development of an AMV product specifically devoted to West-Africa. Complementary data, including supplementary radiosondes, dropsondes and pressurised balloons, gathered during to the AMMA experiment may help for to validate this new product in a near future. On the other hand these AMVs might be useful for other participants of this campaign, e.g. for initialising mesoscale circulation models.

In the next section we present the method developed at the Laboratoire de Météorologie Dynamique (LMD) for the calculation of AMVs. In the following section specific characteristics for an extraction of low-level winds over land are detailed. A height assignment method, based on cloud classification data, and its limitations complete this presentation of the AMV product.

Measurements realised from the CALIPSO (Cloud-Aerosol Lidar and Infared Pathfinder Satellite Observation) satellite have also been used to estimate the height of the observed clouds. CALIPSO is one member of the A-train, a constellation of quasi-collocated satellites on a sun-synchronous orbit. It carries three instruments, the most useful of them for estimating the height of clouds is the CALIOP lidar (Cloud-Aerosol Lidar with Orthogonal Polarization) which operates at two wavelengths, 0.532 and 1.64 μm (Winker et al., 2007). In the last section of this study before the conclusion, cloud heights derived from the CALIOP lidar are compared to heights derived from a cloud classification and the differences are interpreted.

2. DATA AND AMV DETERMINATION METHODOLOGY

Due to time limitation, this study has been limited to two cases during the rainy season over West-Africa, namely 5 and 26 July 2006, during daytime. The studied area covers the tropical eastern Atlantic and West-Africa, i.e. between 40°W and 20°E, and from 0° to 20°N approximately. Specific features on 5 July are the presence of a limited number of mesoscale convective cloud systems (MCSs) over land, a relatively large coverage by medium-level clouds over the Gulf of Guinea (between the equator and the African coast or south of 7°N). For the 26 July case, the presence of numerous low-level clouds related to the monsoon flow and few MCSs led to a good coverage by low-level AMVs over the continent.

2.1 LMD atmospheric motion vector calculation method

AMV are calculated with a software developed at the LMD, according to the following methodology :

- Two AMV fields are calculated from a triplet of images (at 11:45 - 12:00 and 12:15 UTC). Vectors are calculated with the Euclidean distance method.
- Target and search windows used for vector calculation have a basic size of 12 x 12 pixels (36 x 36 km at subsatellite point), and 28 x 28 pixels (84 x 84 km) respectively. These windows cover a smaller area than their counterparts extracted operationally : for example, target windows of 24 x 24 pixels are used by EUMETSAT to extract their AMV product from MSG images.
- A regular grid with 12 pixels (36 km) between neighbouring gridpoints. As a consequence, target windows do not overlap.
- A series of quality tests extract reliable vectors. These tests remove too small vectors and very large vectors. Temporal and spatial consistency checks are then applied on vector speed and direction.
- At this stage, no height is determined or assigned to AMVs. As a consequence, the complete extraction and selection procedure of AMVs is less severe than normal procedures used in operational conditions. Nevertheless, a vast majority of AMVs obtained from our methodology forms large groups of consistent vectors.

The retained AMVs (after these quality tests) are compared to the corresponding ECMWF analysed winds (at 12:00 UTC). The pressure level (of analysed winds) where the absolute value of the amplitude of the vector difference between an AMV and the collocated analysed wind is minimal defines the best-fit level of this AMV. This best-fit level is used as a verification parameter and is not a height derived directly from the image data.

One should notice that AMVs are extracted at smaller scales and on a denser grid than those produced by most other extraction centres.

2.2 Choice of MSG channel

Previous studies starting with Meteosat first generation images have shown that low-level clouds could be tracked more easily over the African continent in the visible channels (Desalmand et al., 1999). The most attracting channel from MSG for such a task seems a priori to be the HRV channel with its 1 km resolution at subsatellite point. Unfortunately the West-African area between 40°W and 0°E is only covered after 14:00 UTC by the moving extraction window of the observation instrument. This limits the period for AMV extraction to 3 hours approximately, the other limitation of this channel (and all other visible channels) being the illumination of the Earth during daytime only. (Before the 31 August 2005, the HRV extraction windows were almost fixed and no extraction at all was possible over this area.) On the other hand, the extraction of HRV AMVs over the African area around the Gulf of Guinea (between 0°E and 20°E) is possible over a longer period, starting earlier. In order to have longer series of low-level AMVs covering the whole West-African area at the best, we preferred to use the VIS 0.8 channel, although this choice limits the extraction of AMVs to daytime only. For the same extraction parameters (target and search window sizes, thresholds of quality tests), the IR 10.8 channel, which generally enables the extraction of a larger number of vectors at all levels, is less adapted for extracting winds at low levels than MSG's VIS channels (Szantai and Désalmand, 2003). Figure 1 shows the AMV field in the VIS 0.8 channel on 26 July 2006 at 12:00 UTC, with an important coverage of the African continent by low-level winds between 12°W and 10°E, and also a coverage of the ocean by trade and monsoon winds north and south of the intertropical convergence zone, located approximately at 8°N.

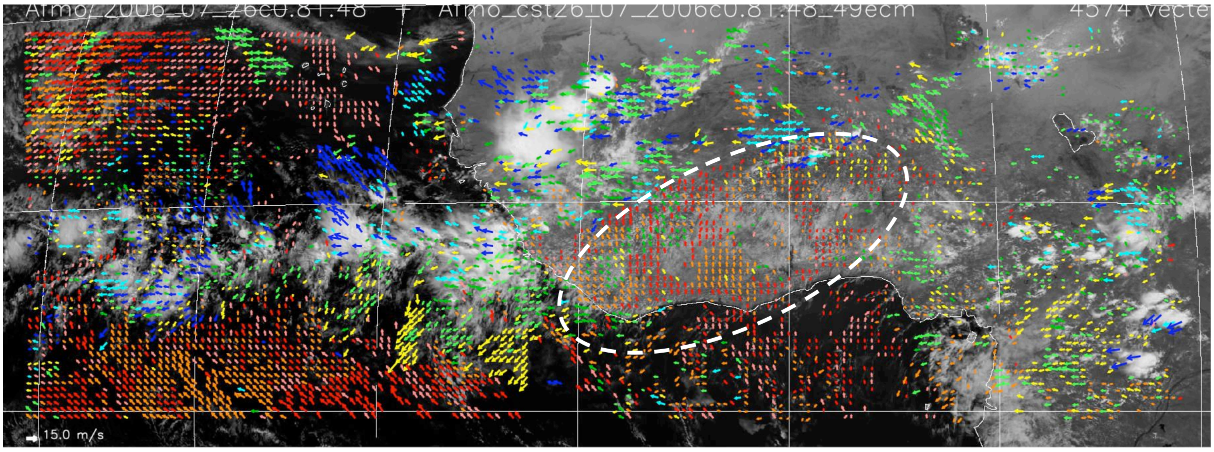

Figure 1 : atmospheric motion vectors in the VIS 0.8 channel, 26 July 2006, 11:45 – 12:00 UTC. Colors correspond to the levels of best-fit with ECMWF analyses : 1000 hPa (pink), 925 (red), 850 (orange), 700 (yellow), 500 (light green), 400 (darker green), 300 (light blue), 250 and 200 hPa (dark blue). The dashes indicate the area of monsoon winds over land.

2.3 Influence of the maximal displacement

The maximal possible displacement D_{maxth} in pixels is derived form the sizes of the target and search window used for AMV calculation by the following relation :

$$\mathbf{D_{maxth} = (L_s - L_t) / 2} \qquad (1)$$

with L_s and L_t : size of the search window, resp. the target window.
Once the size of the target window has been fixed, in order to extract motion vectors of a chosen spatial scale, the search window size is generally determined in order to extract all motion corresponding to realistic winds, including large motions associated to the strongest possible winds. In this study, the basic sizes of target and search windows are 12 and 28 pixels, enabling a maximal possible displacement of 8 pixels, corresponding to a wind speed of 27 m/s. This speed corresponds to almost all observable winds in this tropical area, except possibly stronger gusts of winds observable at small scale in convective systems.

	Lt (pixels)	Ls (pixels)	Dmaxth (pixels)	Vmaxth (m/s)	NV vectors
Standard search window	12	**28**	8	27	2785
Reduced search window	12	**20**	4	13	2685
Common parameters	12				2518

Table 1 : different parameters and number of vectors for a standard and a reduced search window. The theoretical maximal wind speed (V_{maxth}) is valid at subsatellite point.

In order to extract more small, low-level motion vectors associated to the monsoon flow, we have reduced the size of the search window from 28 to 20 pixels (Table 1). For the 5 July case, the vectors calculated with both search window sizes are superimposed on figure 2. A vast majority of vectors, in yellow on the figure, is identical for both sizes. Although the total number of extracted AMVs does not change much for this case, the density of low-level winds is increased over land with the small search window (red vectors). The density of AMVs at all levels is also locally increased over the ocean. On the other hand, larger groups of strong winds are extracted only with the large search window (in green). Thus the use of a smaller search window (with adapted thresholds for the quality tests) appears to be better adapted to the extraction of slow winds, in particular African monsoon winds.

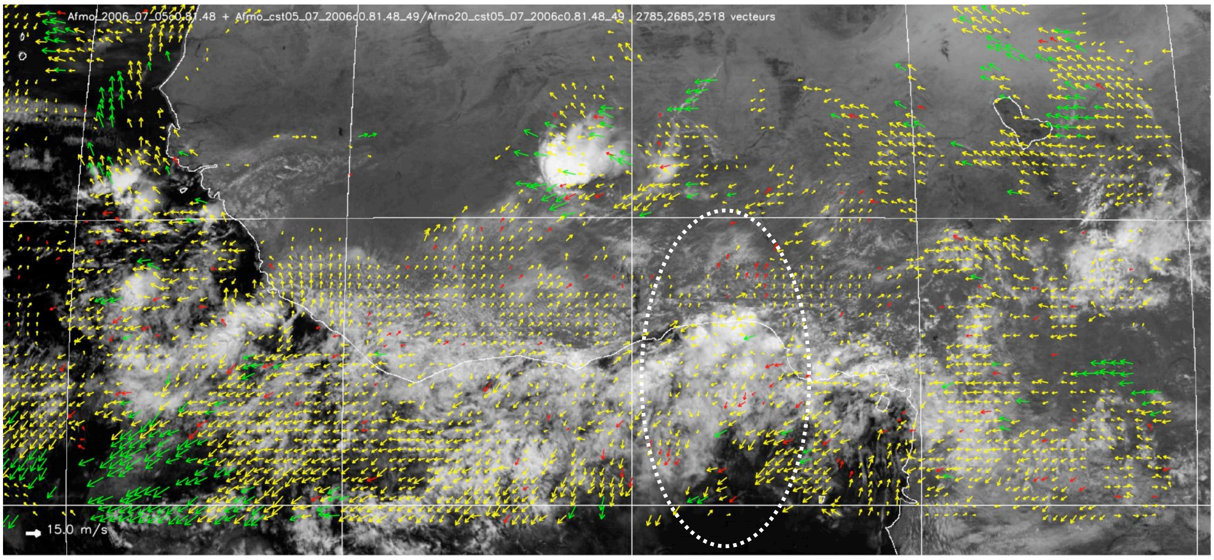

Figure 2 : Atmospheric motion vectors (5 July 2006, 11:45 – 12:00 UTC, VIS 0.8 channel), calculated with a standard (large) search window (in green and yellow), and with a small search window (in red and yellow). Vectors obtained with both window sizes are in yellow. Larger groups of strong AMVs are present at the lower left, and around the large convective system at upper centre. An increased concentration of slow winds is indicated by the dashed ellipse.

3. CLOUD CLASSIFICATION-BASED HEIGHT ASSIGNMENT OF AMVS

3.1 Definition of the cloud-classification based pressure for AMVs

Cloud classification images can be extracted from different channels of the original images. Figure 3a shows the cloud classification constructed with the method developed by the Nowcasting SAF (Derrien and Le Gléau, 2005). Cloudy pixels are grouped into very low-, low-, medium- and high-level opaque clouds, high-level semi-transparent clouds and pixels with partial cloud coverage. According to this classification, low-level clouds dominate over the western part of the land area (west of 5°W), whereas semi-transparent and opaque high-level clouds are predominant over the eastern part.

For each cloudy pixel, the pressure is deduced from the EBBT derived mainly from the IR 10.8 channel pixel value, also from pixel values in the WV and CO_2 absorption channels for semi-transparent clouds, and with the help of temperature profiles obtained from other measurements (analyses or short-term forecasts).

When clouds are present inside a correlation window used for AMV calculation, a cloud class (or type) is always dominant. The pressure associated to this AMV is defined by the *average pressure of the pixels from the dominant cloud class* (P_{acb} : averaged, classification-based pressure).

This definition has some structural limitations :

- in some areas, no cloudy pixels are detected but an AMV is calculated. Example : on figure 3a and b over the Sahara, (upper-right part of the images), AMVs indicate a motion at a high level, according to the best-fit level of the large group of vectors in this area.
- no pressure is extracted for some of the partial cloud coverage pixel.

Other definitions are potential candidates for a definition of an AMV pressure but could not be investigated due to a lack of time :

- the pressure of the coldest pixel or of a chosen percentage of the coldest pixels of the target window (the temperature of the cloud top is also derived for each pixel with the cloud classification). This definition seems well adapted for high-level clouds.
- the pressure of the warmest cloud pixel or of a percentage of the warmest pixels of the target window. This definition seems well adapted for low-level clouds.

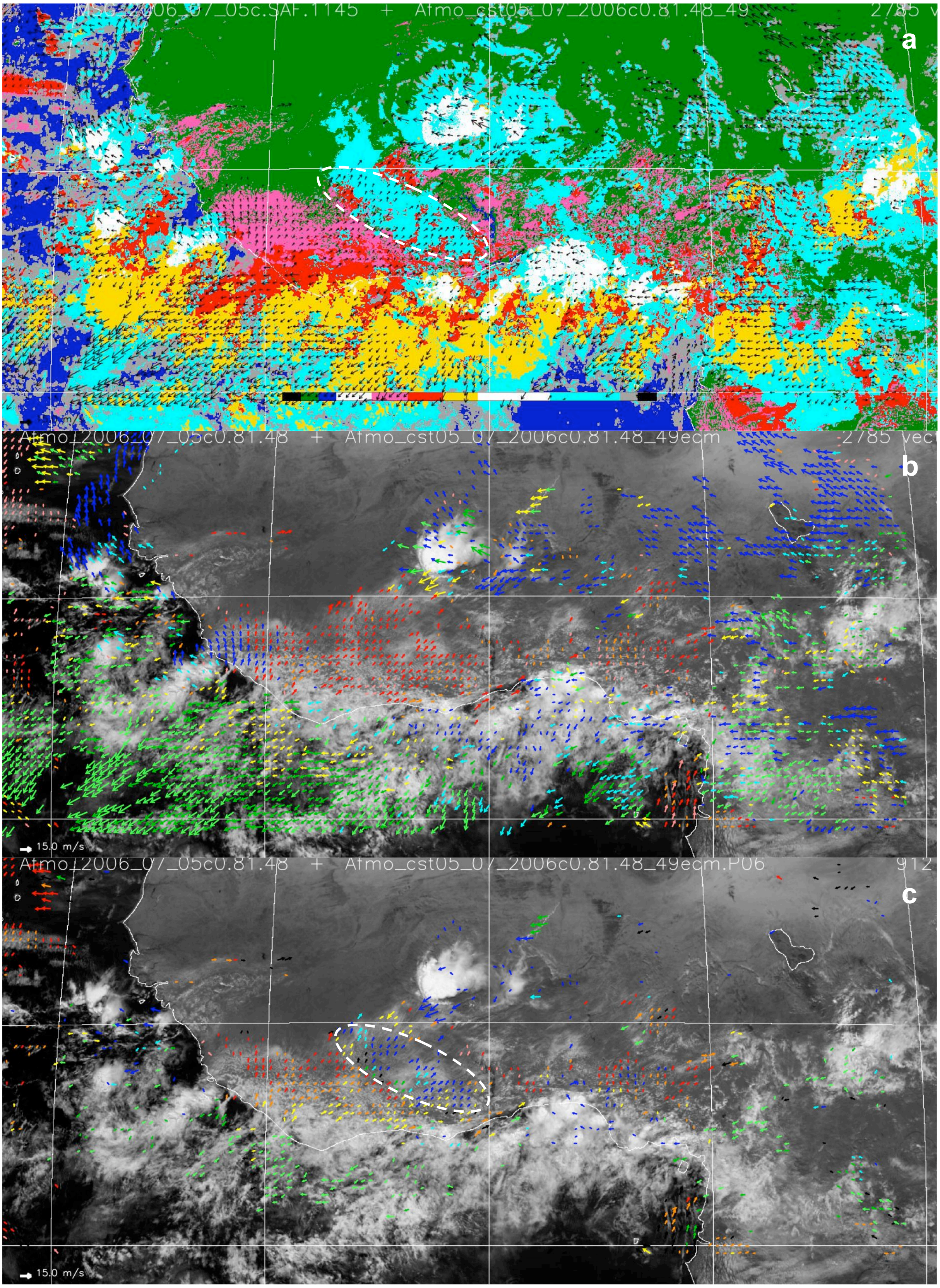

Figure 3 : (a, top) : cloud classification image with AMVs (5 July 2006, 12:00 UTC). Cloudless areas : ocean or lake (dark blue) ; land (green). Clouds : low (pink and red) ; medium-level (yellow) ; high-level thick (white) ; high-level semi-transparent (light blue) ; partial pixel coverage (grey). (b, middle) : AMVs with best-fit level : 1000 hPa (pink) ; 925 (red) ; 850 (orange) ; 700 (yellow) ; 500 and 400 (green) ; 300 (light blue) ; 250 and 200 hPa (dark blue). (c, bottom) : selection of low-level AMVs (filtered with Pbfl >= 700 hPa), with the average pressure of the dominant cloud class (same colour code as previous figure).

3.2 Differences between best-fit level and classification-based pressure

The averaged, classification-based pressure is compared to the best-fit level pressure (figure 3b and c). On figure 3c, the best-fit level information (considered as the reference) has been used to select low-level AMVs (i.e. with P_{bfl} >= 700 hPa). The remaining filtered AMVs have then been coloured as a function of their average pressure of the dominant cloud class. As expected, averaged, classification-based pressures are dominant over land, but a large group of low pressures, corresponding to high semi-transparent clouds, stands out. In this area (centre left of images), the dominant high-level cloud class does not correspond to the dominant low-level motion revealed by the AMVs.

3.3 Inconsistent determination of the best-fit level

As mentioned, the best-fit level with ECMWF analyses is used as a verification parameter in order to check if an AMV is consistent with cloud types observed on satellite images. It consists in calculating the amplitude of the vector difference ΔV defined by the following function :

$$\Delta V(P) = \left| \overrightarrow{V_{sat}} - \overrightarrow{V_{ECMWF}(P)} \right| \qquad (2)$$

and determining its minimal value ΔV_{min} , which corresponds to a pressure, the best-fit level P_{bfl}. A potential error in this determination may occur when the vector difference function has two local minima with very close values. In order to detect this risk, the following ratio is derived from the vector differences at the best-fit level and at the pressure level where the second minimum is observed :

$$R_{\Delta V} = \frac{\Delta V(P_{bfl})}{\Delta V(P_{2nd\_minimum})} \qquad (3)$$

When this ratio is close to 1, the risk of selecting a wrong best-fit level is high. Figure 4 shows that for a vast majority of AMVs, the ratio $R_{\Delta V}$ is very small (<< 1) or only one minimum value is observed for ΔV. But in some cases, individual or groups of AMVs with two close minimal values of ΔV are observed, i.e. with a $R_{\Delta V}$ close to 1. Two groups of such AMVs can be observed at the centre, and bottom centre of figure 4. These cases correspond to situations where the analysed winds at two non-neighbouring levels are relatively close to each other, in comparison to analysed winds at all other levels. This limited risk of false assignment of the best-fit pressure level validates the use of this parameter as a relatively reliable height indicator for AMVs, at least for the examined cases in the tropics. This limitation of the best-fit level determination must been kept in mind whenever the best-fit level is used, in particular for height comparisons.

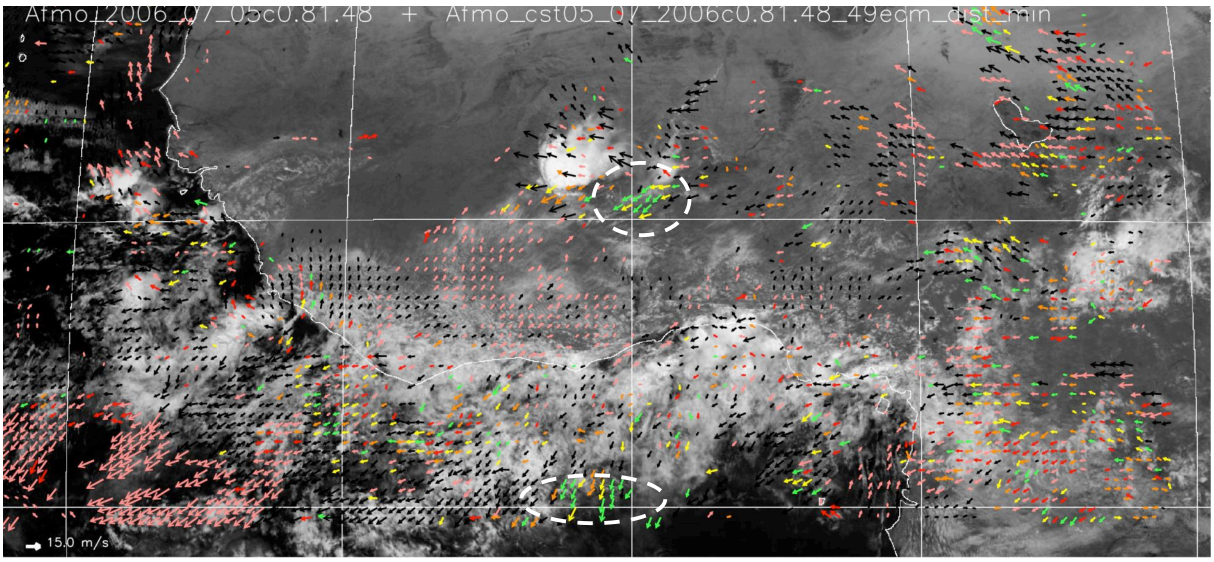

Figure 4 : Atmospheric motion vectors (5 July 2006, 11:45 – 12:00 UTC, VIS 0.8 channel), with a colour corresponding to $R_{\Delta V}$: (pink) 0 – 0.2 ; (red) 0.2 – 0.4 ; (orange) 0.4 – 0.6 ; (yellow) 0.6 – 0.8 ; (green) 0.8 – 1. Vectors in black correspond to one local minimum of the ΔV function. Dashes indicate higher concentrations of vectors with a high $R_{\Delta V}$ (> 0.8).

4. COMPARISON OF CALIOP LIDAR HEIGHT AND CLASSIFICATION-BASED HEIGHT

In this section, cloud top heights measured by the CALIOP lidar have been compared qualitatively to the corresponding heights derived from the SAF classification over the West-African area. Complete comparisons and statistics covering a longer period (3 weeks in February-March 2007) have been presented in a more general presentation during this workshop (Sèze et al., 2008). CALIOP data was provided by the ICARE data centre in Lille (*http://www.icare.univ-lille.fr*).

Along its trajectory, the CALIPSO satellite flies above the Earth's surface at 1 h 30 local time. This corresponds to two (or in some cases, three) passes during daytime above the area of this study, (i.e. West-Africa and the neighbouring equatorial Atlantic Ocean) and to two (or three) MSG slots. Although the lidar swath is very narrow (70 m across-track) in comparison to the MSG pixel size (3 km width), we could compare the lidar height to the collocated cloud classification-based height. Lidar measurements will allow the access to a representative vertical structure except in situations when opaque cloud layers prevent lower cloud observations (optical thickness above 3). This implies no porosity is observed, which is mostly the case in convective structures. Figure 5 presents a composite image of the SAF classification-based pressure corresponding to image slots 55 (13:30 UTC, right swath) and 62 (15:15 UTC, left swath) on 5 July 2006. The broad swaths with the pressure information correspond approximately to the area covered by the PARASOL radiometer onboard CALIPSO, each of them being centred on the narrow lidar swath, which gives the height of the uppermost cloud layer top.

For both lidar swaths, clouds are located approximately at the same height as indicated by the cloud classification, or above that height. The lidar is able to detect layers of thin clouds, which are not taken into account by the cloud classification. On the upper profile, a thin cloud layer (above 15 km) can be identified above the main (thicker) cloud around 10 km corresponds to the high clouds detected on classification images. Similarly, on the lower profiles, very high thin clouds (above 15 km) are detected by the lidar only, whereas the main medium-level cloud visible on the image classification data (above 5 km) is also present as a thicker layer of clouds on the profile.

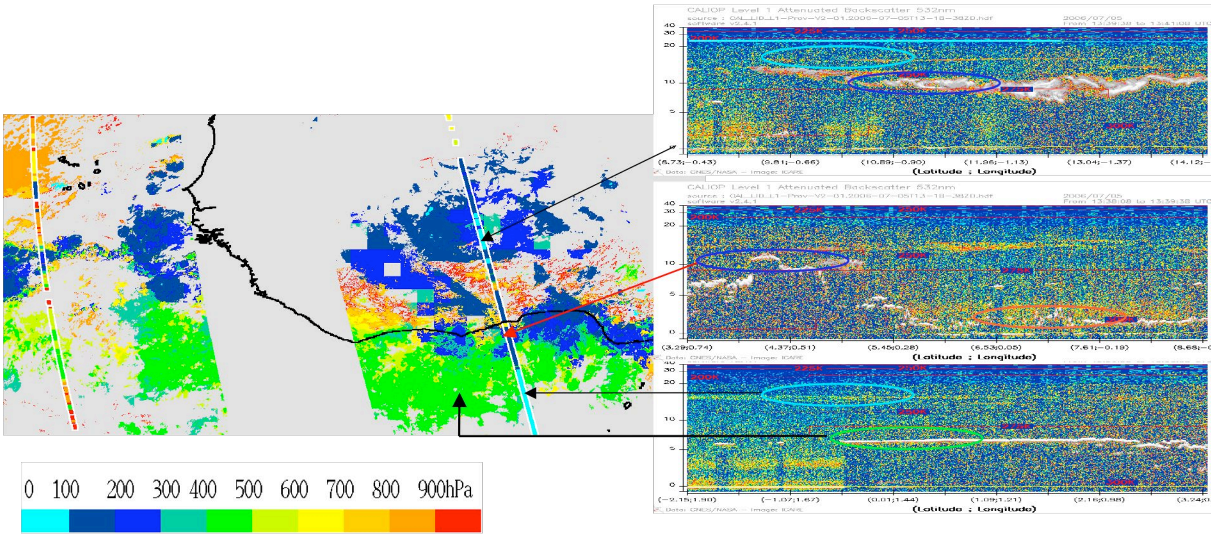

Figure 5 : (left) SAF classification-based pressure image on 5 July 2006, image 62 (left swath) and 55 (right swath). (Right) lidar backscattered profiles along the trajectory of CALIPSO (corresponding to image 55, at 13:30 UTC), from south (left) to north (right).

The CALIOP lidar appears to be able to detect the top of very thin clouds, which pass above the main thicker clouds otherwise well determined in the classification. The main advantage of the lidar is its ability to detect multiple cloud layers, provided that the upper layer is not too thick and enables the transmission of the laser light to the lower layer(s). In the case of multiple cloud layers, a precise relation between an AMV and a cloud layer and its properties has yet to be determined.

5. CONCLUSIONS AND PROSPECTS

In this presentation, we have defined several characteristics and limits of an atmospheric motion vector product under development at the LMD specifically devoted to the West-African area, covering also the neighbouring tropical Atlantic Ocean.

For a continuous production of AMVs during daytime, the VIS 0.8 channel is better adapted for the extraction of low-level winds, in particular over the continent. Images in the HRV channel can provide AMVs at a smaller scale due to its improved spatial resolution, unfortunately they cover the West-African area at best during a short period of daytime (typically 3 hours).

With a smaller search window than the one currently used, the number of small AMVs increases. Thus we suggest the use of a small search window in order to improve the extraction of slow winds such as monsoon winds, especially over the continent. With a small search window, the possible displacements are limited, thus the risk of tracking the wrong cloud structures is reduced, especially in the case of textured cloud fields (typically fields of cumulus clouds in the monsoon flow). In order to extract the greatest number of AMVs, we suggest to merge two vector fields calculated with the same correlation window and search windows of different size. Thus more slow winds are retained with the small search window, and strong winds are only extracted with the large search window, a large majority vectors being extracted in both cases.

For each pixel, a cloud classification gives only the class (and indirectly in most cases the height of the top) of the uppermost cloud, when this cloud is thick enough to be detected. The CALIOP lidar with its limited coverage confirms the presence of multiple cloud layers, when classified pixels of different cloud classes are present in a small neighbourhood. It also detects very thin clouds not present at all in the cloud classification, which may correspond to AMVs in apparently cloudless areas.

A height determination of an AMV based on the pressure of the most frequent cloud type is not well adapted when clouds of two classes / at different levels are present. Therefore we plan make future tests with heights for AMVs based on the lowest pressure of the high cloud class, and on the highest pressure of the low cloud class. Alternatives consist in using average pressure values of a given percentage of a cloud class.

A bad determination of the pressure at the best-fit level with analysed winds can be a limiting factor for the validation of AMVs with a pressure level determined by another method. But in this case study, the areas and the number of AMVs with and incorrect determination of the best-fit level (due to multiple close minima of the vector difference function) is small.

In a near future we plan to extract AMVs over the West-African area over a long period (July 2006, or possibly the whole summer 2006), with heights derived from the cloud classification pressure and based on different definitions. CALIOP lidar heights will also be compared to classification-based heights over this period in order to extract statistics. Comparisons of AMVs with other data gathered during the AMMA campaign, in particular radiosondes and dropsondes, are also planned, they may indicate if a suspected slow bias is present. Otherwise, the AMV extraction method developed by the Nowcasting SAF (from EUMETSAT) potentially could provide another AMV dataset for comparisons.

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