COMPARISON OF ATMOSPHERIC MOTION VECTORS AND DENSE VECTOR FIELDS CALCULATED FROM MSG IMAGES

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Abstract

A method based on optical flow techniques has been developed at IRISA to compute dense motion vector fields from images [Corpetti et al., 2002]. This method has been applied on consecutive MSG images in the thermal infrared (IR 10.8 μm) channel. Adaptations of the method consist in using a cloud classification to calculate "locally dense" vector fields for the different cloud types.

Dense vector fields corresponding to different ranges of height (low, medium and high) or resulting from a combination of parts of vector fields at different cloud heights have been extracted. They are compared to atmospheric motion vector fields calculated with a "classical", Euclidean distance-based method, and then validated with ECMWF analysed winds. Vectors calculated with both methods show in general similar directions, but the speed of dense vectors is smaller than their "classical" counterparts (when present). Among the factors that may influence the representativity of dense vector fields are the quality of the cloud classification used as a mask and the coverage of the image by clouds of a specific type / at a specific (group of) level(s).

1. INTRODUCTION

During the last decade, the number and quality of atmospheric motion vectors (AMVs) extracted from satellite images has dramatically increased. This is due mainly to the arrival of a new generation of geostationary meteorological satellites. Their imagers produce images of a higher quality, with a better spatial resolution and at a higher frequency, from a larger number of channels (e.g. 10 bits per pixel value, 3 km per pixel at subsatellite point, 15 min standard time interval, 12 channels for MSG satellites). The progress on tracking methods and height assignment of tracers, mainly clouds, had also a positive but less important impact on the quantity and quality of the extracted motion vectors.

To further increase the number of extracted motion vectors (or winds), other image-processing techniques producing vector fields with (at least locally) a denser coverage are taken in consideration. A series of methods have been developed since the 1980’s, initially for the tracking of solid objects from a pair of images : optical flow estimation methods. Basically, most of these methods are capable of estimating the motion of every pixel of an image. The estimation of the motion of fluids gives less reliable methods than widely used template-matching methods ; optical-flow-based methods generally underestimate the speed of extracted wind vectors. In this study, an optical flow method has been developed and adapted specifically to the estimation of the motion of a fluid, in this case the atmosphere. IRISA had already extracted dense vector fields from Meteosat-7 images with a primitive, less sophisticated version of this method (Szantai et al., 2000).

In the next session, the data (images) used to generate dense vector and (standard) AMV fields will be briefly presented, as well as the different wind datasets used for comparison and verification. Section 3 describes the optical flow calculation algorithm. Section 4 first presents comparisons of dense vector fields on cloudy areas delimited by a cloud classification with “classical” cloud motion vectors (CMVs). In the following subsection, the optical flow algorithm is modified : it uses a cloud classification to extract dense vectors in a limited height domain and CMVs are used to initialise the calculation of the dense vector field. Finally section 5 concludes this study by showing the advantages and some limits of this new dense vector estimation method.

2. DATA

In this case study, we used Meteosat-8 (MSG-1) images from 5-June-2004, around 12:00 UTC. Vector fields were derived mainly from the 10.8 μm thermal infrared channel (IR 10.8) over two limited areas (North Atlantic/ Western Europe : 512 x 512 pixels area, and West Africa / Gulf of Guinea : 1024 x 1024 pixels area). Other channels were used for visual comparison (including movie loops) and verification of the results.

2.1 Motion vector fields and winds

To fulfil the main goal of this study, the validation of dense motion vectors, these are compared to 3 other motion vector/wind fields :

- Cloud motion vectors calculated at the LMD (LMD-CMVs) :

These vectors are calculated on a regular pixel-grid, undergo a series of quality tests : removal of too large / too small vectors, spatial and temporal consistency checks (Szantai and Désalmand, 2004). No height assignment is undertaken. 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.

- Atmospheric motion vectors calculated by EUMETSAT (AMVs) :

These vectors are calculated with a more complete procedure. The vector calculation is regular-grid based (the final position of the vector is associated to the cloud or atmospheric structure which is supposedly tracked). Vectors have a complete height assignment procedure based on the IR 10.8 brightness temperatures and possibly also on other channels (IR 13.4 or WV 6.2), and on other meteorological data not produced by satellite. In this study, AMVs are mainly used for visual verification of dense vector (and LMD-CMV) fields.

- ECMWF analysed winds :

The used dataset has been regridded on a regular longitude-latitude grid. Winds are available on 9 pressure levels between 1000 and 200 hPa, corresponding approximately to the levels where clouds are expected to move. ECMWF winds are used mainly for the determination of the best-fit level of vectors, i.e. the pressure level where the vector difference between a dense vector or an LMD-CMV, and a collocated (after interpolation) analysed wind is minimal.

3. DENSE VECTOR FIELD CALCULATION METHOD

3.1 Basic optical flow calculation method

In the original formulation (Horn and Schunck, 1981), a vector field representing the motion of objects on an image can be extracted if two assumptions are satisfied :
- the luminance (brightness) of a pixel does not change during the motion ;
- neighbouring pixels should represent the same or a close motion.

These assumptions are generally verified for most pixels of moving objects and their background. Practically the calculation method consists in minimising a functional H over the whole image. This cost function is composed of two terms : the data term, representing spatial and temporal variations of the luminance (H_1) and a regularisation term (smoothness constraint H_2), representing local variations of the motion vector.

$$H = H_1 + \alpha H_2$$

This cost function is minimised by an iterative process. The coefficient α is tuned to increase or decrease the influence of the smoothness constraint on the vector calculation.

3.2 Specific adaptation to fluid motion

Numerous variations of this principle and adaptations to various types of images have been developed in the last 25 years, mainly to determine the motion of solid objects. For fluid motion, Corpetti et al. (2002) have modified the original relation :
- based on the continuity equation instead of the conservation of luminance, the data term H_1 has been modified. It now involves the divergence of the (horizontal) motion vector.
- the regularisation term H_2 now involves the divergence and curl (rotational) of the motion vector instead of the horizontal components (u, v) of the motion vector.
- a multiresolution procedure is applied (calculation of motion at different scales), in order to enable the determination of large vectors.

3.3 Improved initialization method

To handle large displacements of fine atmospheric structures based on the previously described method, a correlation - optical flow collaborative initialisation scheme is introduced. Dense motion vectors fields are initialised by the minimisation of a energy function. Practically the energy function to be minimised includes a term constraining the solution to be close to CMVs, which results in an interpolation of CMVs preserving a divergence and curl spatial smoothness. With this constraint, large motions can be handled. Thus the multiresolution processing is no longer needed and can be removed.

3.4 Use of a cloud mask

As mentioned in the previous section, the previous estimated vector field is used as an initial solution for the fluid dedicated optical-flow calculation method described in section 3.2. Furthermore, in order to estimate independently motion related to different layers, a cloud classification is introduced. The latter differentiates clouds of a specific type, at a specific height (or atmospheric pressure) range. Thus, data belonging to the other atmospheric layers can be discarded in the optical flow estimation process. Therefore motion vector calculation is extended over the whole image, over cloudless areas and areas covered by clouds of other types (Heas et al., 2006).

The EUMETSAT intermediate cloud classification product (CLA) contains for each pixel a code associated to a cloud (or surface) type. Practically, the 10 cloud classes have been regrouped into 3 major super-classes of low, medium and high clouds (fig. 1, for the West-Africa area). From these super-classes, 3 dense vector fields are then calculated at low, medium and high level. For all vector fields, the cloud classification also helps to check that the height of the vectors determined directly (for AMVs) or by determination of the best-fit level with ECMWF analyses (for LMD-CMVs) is consistent.

4. COMPARISON WITH LMD-CMVS

4.1 Comparison over the cloudy area

LMD vector fields have been calculated over the West-Africa area (fig. 2a). Although important parts of the image are considered as non-cloudy (mainly ocean and desert) according to the classification, an important proportion of the vectors on the original grid have been retained (3507 among 7396). Comparison with analysed winds indicates that low-level winds (1000 to 850 Hpa) dominate in the southern Atlantic (lower part of the image) even in areas classified as non-cloudy, whereas medium and high-level (pressures between 700 and 200 hPa) winds are dominant closer to the African coast and over the African continent (upper part of the image).

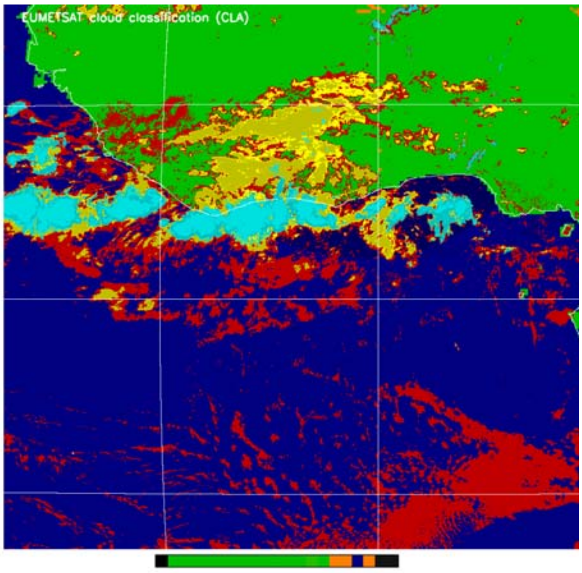

Figure 1: **EUMETSAT cloud classification (CLA) over the West-Africa / Gulf of Guinea area. Colour code of the classes : Vegetation desert sea sunglint (over the sea). Low medium high clouds.**

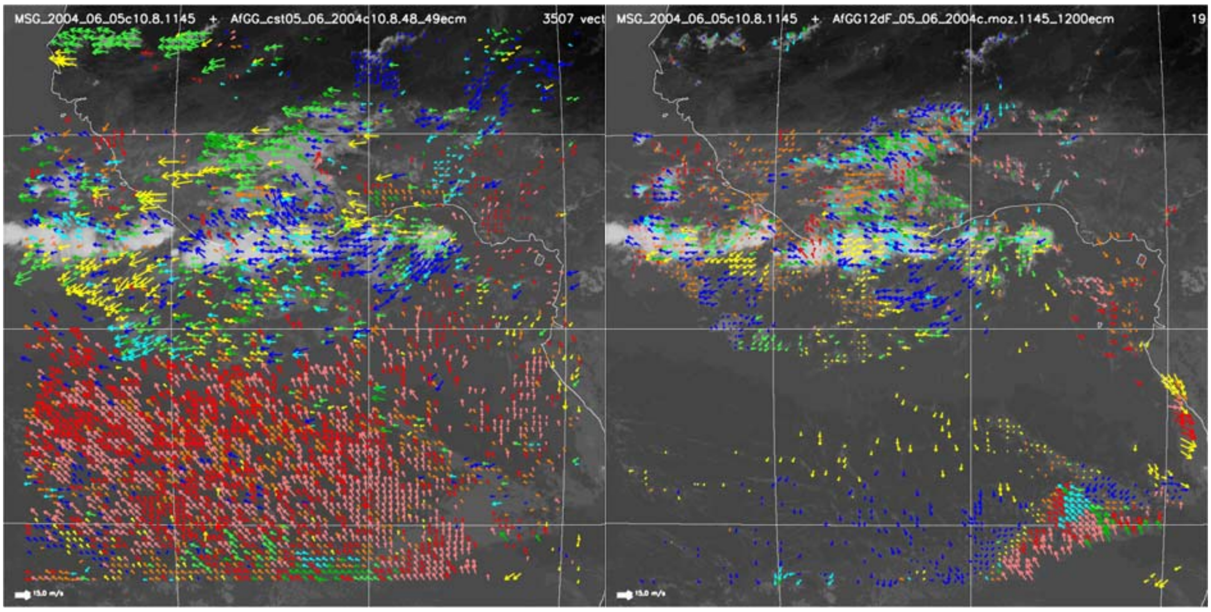

Figure 2: **(a) LMD-CMVs, 3507 vectors (without classification-based selection). (b) Dense vector field with vectors only on cloud covered areas according to the classification (1916 vectors). The colour of a vector represents its best-fit pressure level : (low altitude) 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa (high altitude).**

A composite 'dense' vector field has been constructed from the 3 original dense vector fields calculated at low, medium and high levels and sampled on the same regular grid as the LMD-CMVs. For each of these fields, only the vectors originating on pixels of the corresponding super-class are extracted (i.e. vectors from the low-level field are extracted if their origin corresponds to a pixel of the low-level super-class, etc…) and then associated to form a new, composite vector field (fig. 2b). This vector field appears visually less dense than the corresponding LMD-CMV field (1916, i.e. 26 % of the original grid, vs. 3507 vectors). This is partly due to the sampling (grid-points may fall between small or thin cloud structures) and to misclassified pixels, especially in the South Atlantic area, where the coverage by low clouds is underestimated.

The best-fit (pressure) level of 1128 collocated vectors on the LMD-CMV and composite dense vector field is different in some parts of the image labelled as cloudy. Over a part of the South Atlantic area, dense vectors (with a dominant north / north-westerly direction) are found at a higher altitude (700 hPa) than LMD-CMVs (1000 – 925 hPa, vectors have a south-easterly direction), which also corresponds to the best-fit level observed on CMVs in the WV 7.3 channel. The histogram of best-fit levels of collocated vectors (fig. 3) confirms the differences between both vector fields : dense vectors are the most numerous at 700 hPa (vs. 500 hPa for CMVs), and also have a higher second maximum at 200 hPa. Statistics on common vectors confirm that the speed of LMD-CMVs is higher (average of 8.3 m/s, bias of -2.9 m/s).

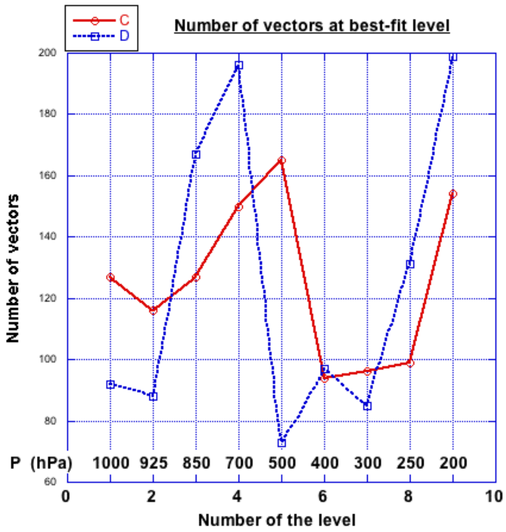

Figure 3 : **Repartition of the 1128 collocated vectors (on cloud-labelled areas) at the different best-fit pressure levels. C: LMD cloud motion vectors. D : dense vectors.**

4.2 Comparison at specific pressure levels with improved dense vector calculation method

In this section, for each level (low, medium and high), the dense vector field calculation is initialised with LMD-CMVs when available in the corresponding cloud class. This mainly oceanic area is dominated by low-level clouds, with few high-level clouds mainly located on the left (western) and lower right (south-eastern) parts of the image (fig. 4).

In a first step, LMD-CMVs are visually compared to corresponding (EUMETSAT) AMVs in the IR 10.8 channel (fig. 5a and b) to assess their quality. Both fields show the same general motion. AMVs are less dense. In particular, they are more limited to cloud edges when clouds are homogeneous (this the case for low-level clouds off the Iberian peninsula). In some strong wind areas (jet-stream west of Ireland), LMD-CMVs have a best-fit level at a higher altitude (250 or 200 hPa) than AMVs (which have their own height determination) in the same area. Thus high-level AMVs are proportionally less numerous than LMD-CMVs. Both vector fields have heights generally consistent with the cloud classification (fig. 4).

Dense vector fields are extracted at low (fig. 6a), medium and high levels (fig. 6b). One would expect that the dense vector field based on low-level (respectively medium-, high-level) clouds would exhibit best-fit levels mainly at low level (respectively medium, high level). This is partly verified. The main high-level wind areas (lower left, lower centre and lower right part of fig. 6) are logically present on the high-level dense field (fig. 6b), but also more unexpectedly on the low-level dense field (fig. 6a). Similarly, vectors with a best-fit at low-level are present on the low-level field (upper part, centre of fig. 6a), but also on the high-level field (fig. 6b).

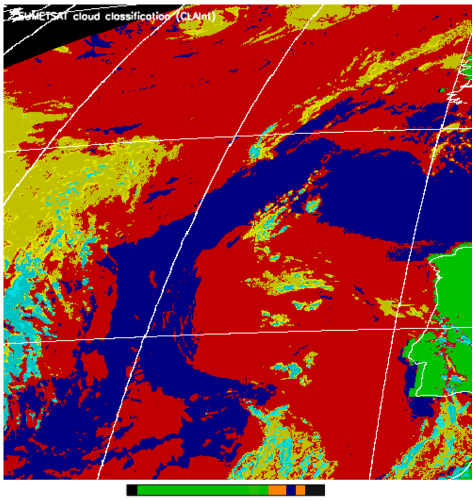

Figure 4: **EUMETSAT cloud classification over the North Atlantic area (includes Portugal on the lower right). Colour code of the classes : Unclassified vegetated land sea . Low medium high clouds.**

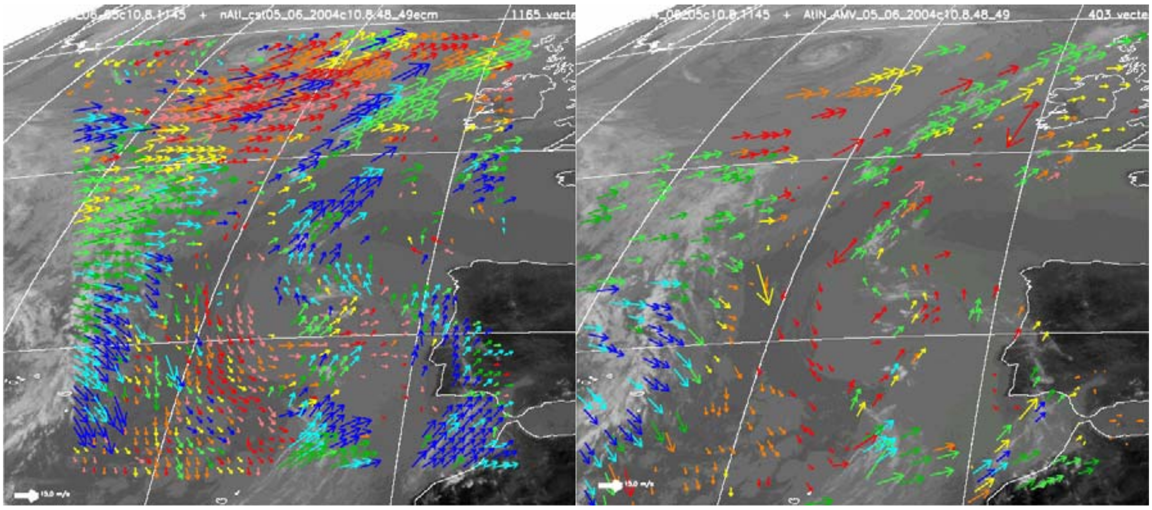

Figure 5: **(a) LMD-CMVs over the North Atlantic area. (b) EUMETSAT AMVs (from the IR 10.8 channel only) over the same area. LMD-CMVs are colour-coded as a function of their best-fit level, AMVs as a function of their own pressure level : (low altitude) 1000, 925, 850, 700, 500, 400, 300, 250 and 200 hPa (high altitude).**

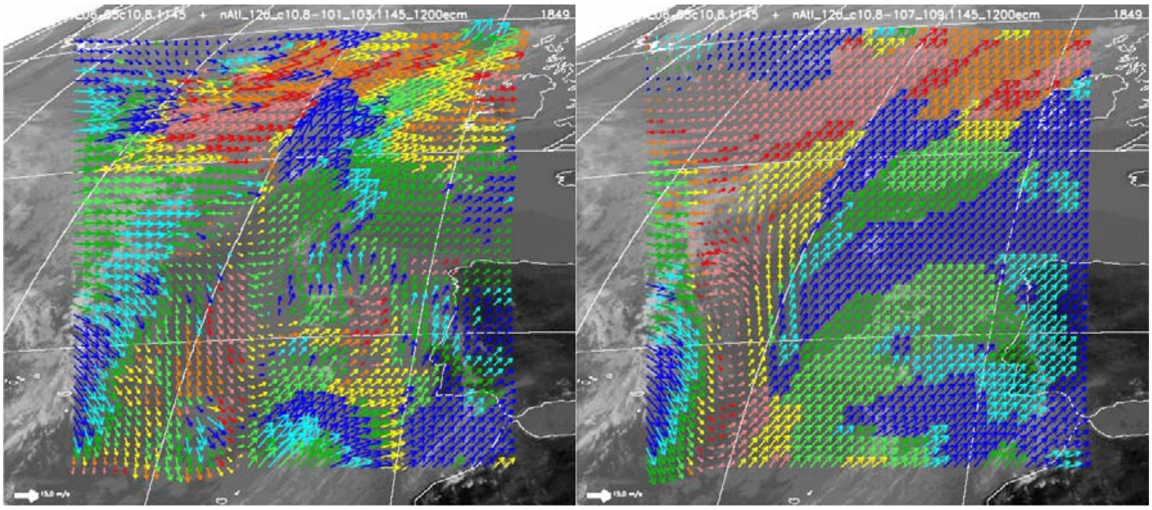

Figure 6: **(a) Dense vectors at low level. (b) at high level. Same colour-code for best-fit level as fig. 5.**

On the other hand, some areas not covered by LMD-CMVs are covered by consistent vectors (i.e. at an expected level) on the dense vector fields. In particular, two areas covered by low clouds identified on the classification (west of the Straits of Gibraltar, lower right of fig. 6a, and west of Ireland, upper right) have consistent vectors at 700 hPa. Whether these vectors represent a real motion has to be investigated.

5. CONCLUSIONS AND PROSPECTS

This case study confirms that optical flow-based dense vector fields show motion basically consistent with traditional cloud / atmospheric motion vector calculation methods. They can also provide motion information in some areas not covered by ‘traditional’ vectors. Differences are observed more specifically in areas of strong winds (such as jet-streams), where the optical-flow method tends to underestimate the strength of the wind.

For a better separation of motions at different levels, the EUMETSAT cloud classification has been used to initiate the calculation of the motion at each level. For each classification-based vector field, we expected to find an overall motion with the same group of best-fit levels, compatible with the cloud classes used. This is verified only for a part of the field, even when the dense vector calculation is initialised by cloud motion vectors selected with the help of the classification. In this configuration, part of the height information contained in a CMV used for initialisation seems to contaminate dense vectors at other levels. Reasons of this unexpected behaviour of the optical flow method has to be investigated further.

Improvements in the quality of results can also be expected from the use of a more representative cloud classification. The newer version of the EUMETSAT classification method (made available after the studied period – June 2004) should give more realistic results. The classification produced by the Nowcasting SAF (Derrien and Le Gléau, 2005), which better extracts clouds with partial pixel coverage and better discriminates high-level thin clouds, is also expected to enable a more representative dense vector field extraction. Another limiting factor has been identified : the limited coverage of clouds at a specific level. In the case of dense vector fields covering the whole image (as in section 4.2), vectors located far away from the clouds originally associated to the level are less reliable than those located under or in the vicinity of these clouds.

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