DISPLACEMENT VECTORS FROM METEOSAT-WV-IMAGES USING A NEW EXTRACTION TECHNIQUE

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ABSTRACT

The application of the cross correlation method to original water vapour images is becoming a standard technique in the evaluation of wind vectors for the middle troposphere. Nevertheless, the method fails in quite a lot of cases because of the smooth and shallow character of the grey value surface. It is shown that the results from correlation of original images can be approved and completed if pictures representing the derivatives like main curvatures or gradients of the originals are evaluated as well. As a consequence the number of acceptable displacement vectors can be increased by about 50 % if a small decrease of accuracy with respect to length and angle is tolerable.

INTRODUCTION

It has been shown by Kästner et al. (1980) and Eigenwillig and Fischer (1982) that water vapour images can be investigated sucessfully to evaluate wind vectors for the middle and upper troposphere. In the meantime the evaluation of water vapour wind vectors by application of the cross correlation method is becoming a standard technique. Details of this technique were published by Laurent et al. (1990) and Büche et al. (1990), where extended reference lists are given. Image sequences from the operational METEOSAT-4 are of clear nature and WV structures can be tracked immediately without preceeding image restoration. The method is compensated for the smooth and shallow character of WV structures by using a greater segment size of e.g. 48 x 48 pixels in the correlation technique compared to 32 x 32 pixels typically in operational cloud tracking from infrared image sequences (see Schmetz et al. 1987). Nevertheless the correlation technique fails in a lot of cases, where the grey value surface approaches the shape of a cylinder or even worse a plane resulting in unclear displacement signals at least in one coordinate direction.

The present paper concentrates on the evaluation of displacement vectors and shows that filter techniques can be advantageously used to increase the number of acceptable vectors. The scene of June 21, 1989, slots 23, 24 and 25 around 12 hours UTC has been selected by EUMETSAT for intercomparison purposes within the scope of a wind campaign. Corresponding segments of 1024 x 1024 pixels out of the WV image sequence are chosen for the analysis (Fig. 1). They cover South Europe and mainly West Africa and contain wide areas with pure water vapour emission as well as others where signals con-
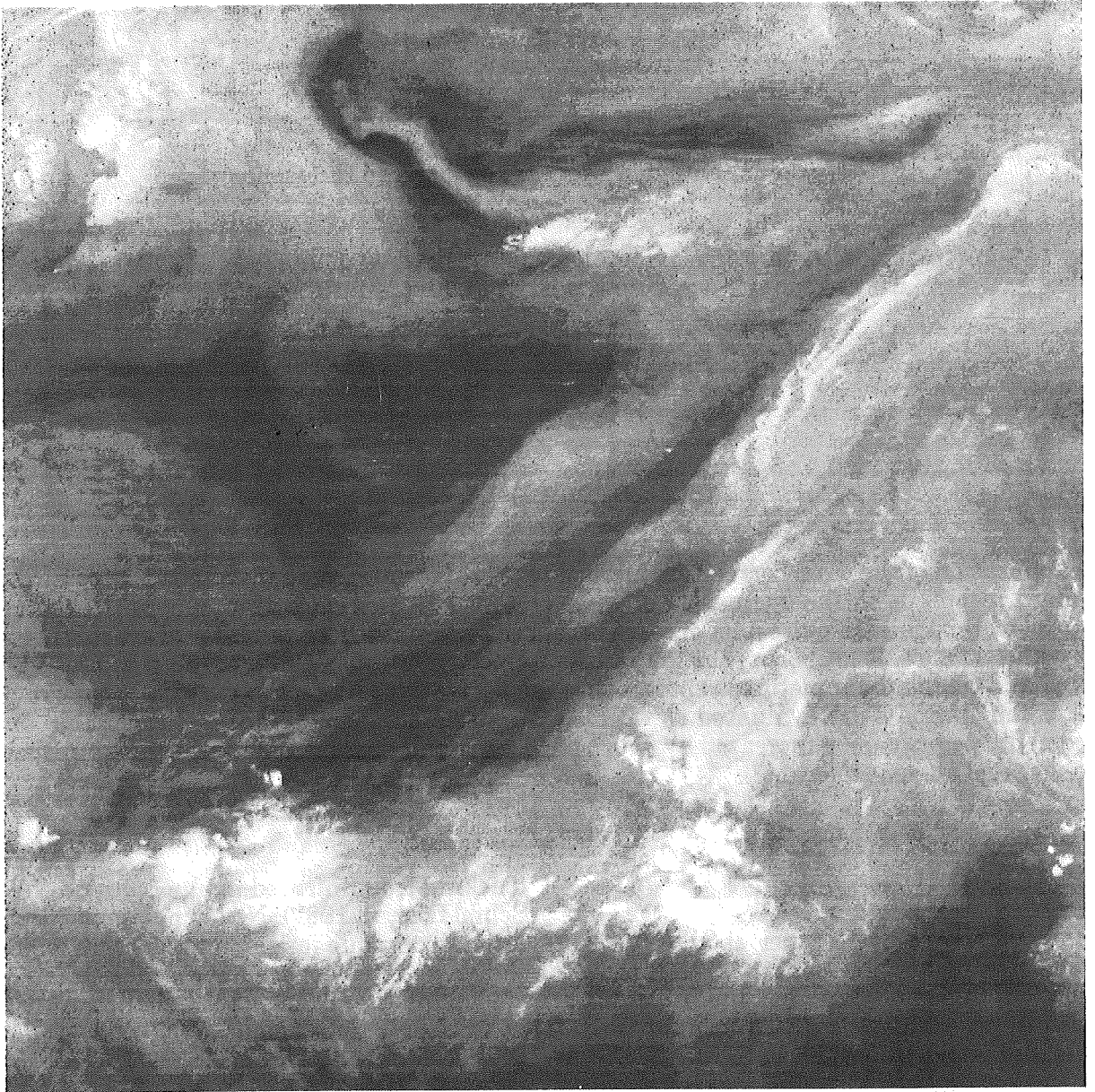
Fig.1   Water vapour channel scene taken by METEOSAT-4 on 21 June 1989 over West Africa and South Europe.

tain information from clouds. The main features are the inner tropical convergence zone in the lower part of the image, a jet stream flowing from the Gulf of Guinea to Libya (approximately the diagonal from lower left to upper right) and cloud fields from the Azores to Europe (upper left part).

METHOD

Reference set of displacement vectors

Throughout this work the conventional cross correlation method is applied using a segment size of $N^2 = 48 \times 48$ pixels. This number is taken over from our earlier work as a good compromise both with respect to stabil-

ity and uniqueness of the method as well as computer time needed for the evaluation. The step size between neighbouring segments is taken equal to N in order to guarantee that resulting displacement vectors are really independent and free of interpolation effects. Then twice a total of 19 x 19 displacement vectors results from a time sequence of 3 images A, B and C using the given numbers for the sizes of images, segments and steps.

In order to evaluate a figure of merit for displacement vectors from filtered images a representative set of vector pairs from original images is needed. First the lenghts of vectors evaluated from images A and B are compared to those obtained from B and C. From Fig. 2 it is evident that a relative difference of length

$$|\Delta L| = 2 \cdot \frac{||B\,C| - |A\,B||}{|B\,C| + |A\,B|} \qquad (1)$$

smaller or equal to 40 % excludes cases where one of the vectors approaches zero length or is unreasonably long. From Fig. 3 it is concluded that angles between corre-
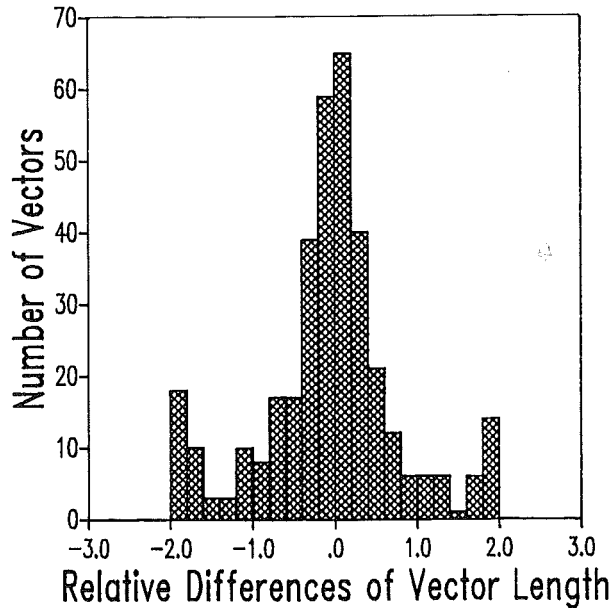
sponding vectors should not exceed 30 degrees. In addition to that, all lengths should
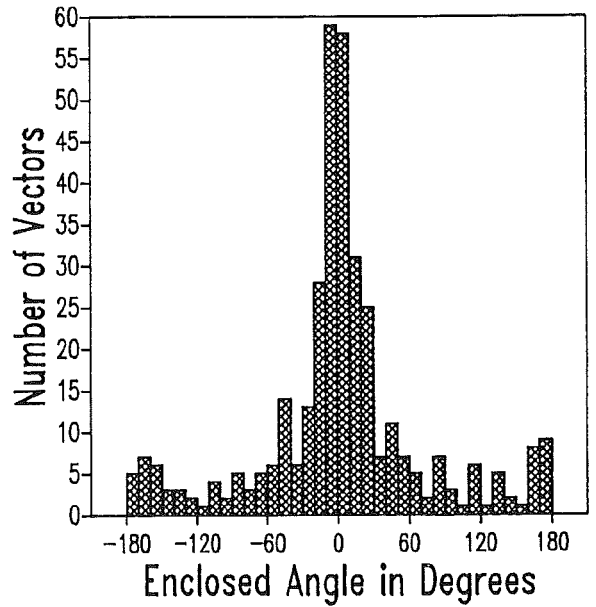

Fig.3   The number of displacement vector pairs as a function of enclosed angle.

be greater than zero. The set of remaining vector pairs is defined to be a "good" one, i.e. it guarantees that grey value structures within segments are clearly shaped and do not change too much in time. The number of pairs found is 152 (out of 361), their root mean square (r.m.s.) deviation of vector length is ± 19 % (compared to ±83 % for all pairs) and the r.m.s. deviation of angle is ± 14° (± 71° for all). In both cases the mean values are very close to zero. These numbers cannot be lowered essentially and should be taken as inherently connected with the selected scenes.

Effect of median filters

To show the effect of filters on the number of good vectors a series of homogeneous median filters is applied to original images with n times n elements as a parameter. The values of the standard deviations for length difference and enclosed angle between vectors from filtered (AB_F; BC_F) and corresponding original images ($AB_{Orig.}$; $BC_{Orig.}$) are plotted in Fig. 4. Both become greater with in-

Fig.2   The number of displacement vector pairs evaluated from 3 original images plotted over their relative differences of the length ΔL.
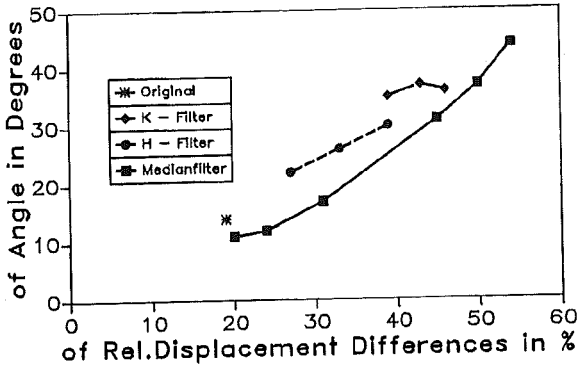
Standard Deviations

Fig. 4 Standard deviations of relative displacement vector differences and enclosed angle for results from filtered images compared to those from the originals. The numbers are a function of the filter size n and are to be added quadratically to those inherent to the original images.

creasing n and show the loss of information introduced by the averaging process. After an initial increase the number of "good" vectors (as defined above) that are obtained from filtered images decreases as expected. But the number of additional good vectors, i.e. results from filtered images at places where no acceptable result exists from the original remains almost constant (see Fig. 5). Consequently, the application of a small filter mask results in roughly 33 % more good displacement vectors but on the cost of a reduced accuracy in length ($\geq$ 20 %) and angle ($\geq$ 12°).
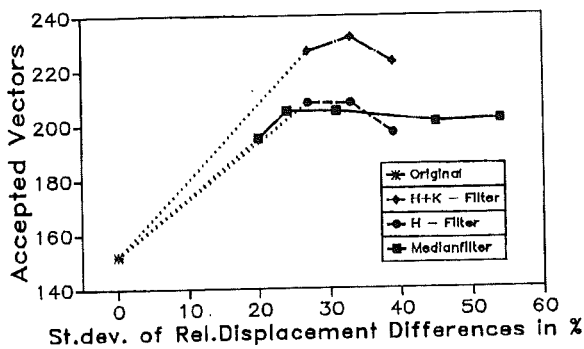

Fig. 5 The number of good vector pairs if those from filtered images are accepted at places where no good results from original images exist.

The filters to be discussed in this chapter are essentially of different kind and can be applied in pairs. They estimate the first and second order derivatives of the grey values surface and combine them in specific ways. The information content of the original image is split into two linearly independent subsets which allow for reconstruction of the original up to the first or second order, respectively. A certain smoothing effect is included in the transformation process. The free parameters are: the grid size n for the estimation of derivatives using the method of differences; the grid size and the parameter σ when Gaussian differential operators are applied.

The pair of filters H and K calculates pixel by pixel the main curvatures κ_1 and κ_2 of the surface from the surroundings and combines them to the average (H = (κ_1 + κ_2) /2) and Gaussian (K = $\kappa_1 \cdot \kappa_2$) curvatures. The resulting two images look quite different from the original but their structures show equivalent displacements (Büche et al. 1990). The standard deviations for the relative differences of vector lengths and for the angles between the vectors obtained from corresponding sites within transformed and original images are plotted in Fig. 4 as well. The uncertainty introduced from H-filtering is not too far off from the effect of homogeneous median filters using the same grid size. But the K -transformation is more sensitive to variations of grey values resulting in somewhat increased length and angle uncertainties. However, their main advantage is linear independence and the results can be combined. The number of good vector pairs from the originals is increased by about 37 % if those from H-transformed ones are included. This number even rises to 53 % if good results from K-transformed images are added as well after the inclusion of those from H-transformed ones (see Fig. 5).

During the application of the following pair of filters the absolute value and angle of the gradient (hereafter called G and P, respectively) are calculated from the surroundings of each pixel (Korn, 1988). Like H the trans-

formation G has a certain smoothing effect. But the direction P of the gradient is even more sensitive to variations of grey values than the Gaussian curvature K. The related numbers for the uncertainties of displacement vector length and enclosed angle are given in Fig. 6 where results from Gaussian
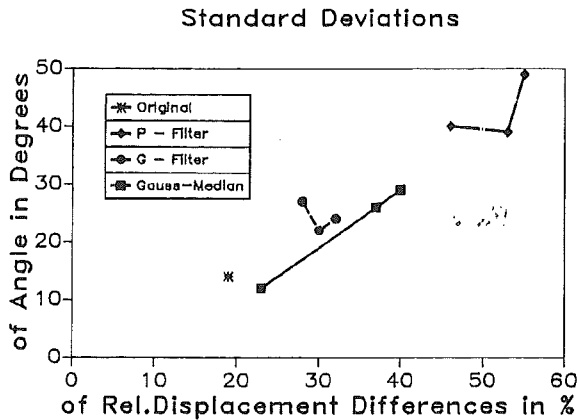
Standard Deviations

Fig. 6 Standard deviations of relative displacement vector differences and enclosed angle for results from filtered images compared to those from the originals.

median filtering with the corresponding parameters are included. The curves for G and P show greater mutual distance than those found from H and K-transformations. The corresponding numbers for the additional good vector pairs are 35 % (for G) and 48 % (for G and then P, successively; see Fig. 7).
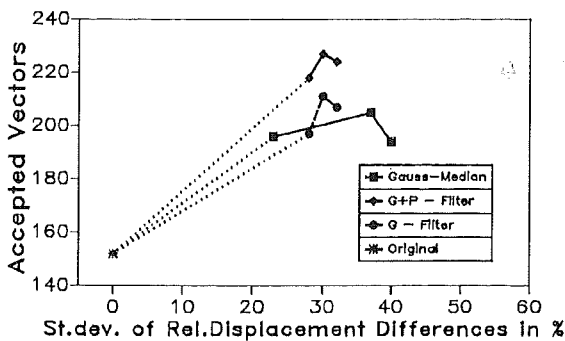
Fig. 7 The number of good vector pairs if those from filtered images are accepted at places where no good results from original images exist.

CONCLUSIONS

It is shown that filters can successfully be used to increase the number of acceptable vector pairs from structure tracking within water vapour images. For all cases considered in this paper the filtering process conserves the length and direction of displacement vectors on average, but the related standard deviations increase with increasing information loss. Even weak median filtering with homogeneous weights increases the number of acceptable displacement vectors considerably. However, this gain is still enhanced by the application of filter pairs. The results can be added in successive order according to the levels of uncertainty in length and angle (Fig. 8). Finally, the number of accepted vectors is increased by about 50 % on the cost of an additional uncertainty which does not go far beyond that one inherently connected with the imaging and evaluation techniques. Many of these additional vector pairs are found close to or within smooth regions of the grey values surface which appeared to be problematic for structure tracking from originals.
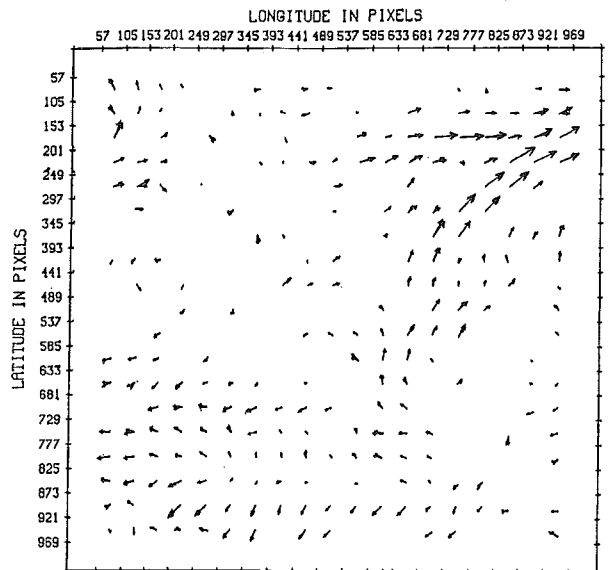
Fig. 8 Field of displacement vectors deduced from a sequence of 3 water vapour images as shown in Fig 1. Results from H- and K-transformed images are included.

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