EXPERIENCE IN THE HEIGHT ATTRIBUTION OF PURE WATER VAPOUR STRUCTURE DISPLACEMENT VECTORS

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ABSTRACT

The aim is pursued to find a consistent interpretation of displacement vectors evaluated from pure water vapour structures in a series of METEOSAT scenes. Three different ways to define a representative height for structure displacements are tested. The results are compared to the wind vectors taken from profiles measured by radiosonde ascents on one hand and from an ECMWF model analysis on the other. From a series of three consecutive images taken on June 21, 1989, around 12 hours UTC no decision could be made on the height assignment appropriate for uses of displacement vectors in the sense of single level winds. Even the interpretation of the displacements in kind of effective wind vectors calculated from multilayer contributions did not lead to higher accuracy. Various arguments for this situation are discussed.

1. INTRODUCTION

In their basic work Fischer et al. (1981) used their radiative transfer model especially adapted to the characteristics of the water vapour (WV) channel to calculate the contribution function. The height related to the maximum of this function is assigned to the displacement vector. The model of the European Space Operations Center (ESOC) which is still under development is based on the effective brightness temperature (Holmlund, 1993). This model uses a fixed but small number of the coldest pixels from a segment to define the effective brightness temperature. This temperature is converted into a height using the atmospheric temperature profile. The beginning of a systematic study of the height assignment process for water vapour structure displacements was presented in a recent contribution by Büche et al. (1994).

The present paper continues their work and reports on a broader evaluation in which many parameters like segment size, levels which define cloud free segments etc. are varied while the use of more refined definitions for relevant site or representative radiance of the tracked structures are postponed. In addition to the use of atmospheric profiles from the model analysis of the European Center for Medium Range Weather Forecast (ECMWF) data from radiosonde ascents are included as well. The radiative transfer calculations are done using the programme LOWTRAN7 (Kneizys et al., 1988).

2. METHODOLOGY

A series of 3 consecutive water vapour images taken by METEOSAT-4 on June 21, 1989, 12 hours UTC is scanned using a regular grid with segments of 48 x 48 or 32 x 32 pixels, respectively. The water vapour structures contained within non-overlapping segments of the intermediate scene are tracked within the preceeding as well as in the fol1owing one using the cross correlation method. The resulting 2 displacement vectors $\vec{d}_1$ and $\vec{d}_2$ for the advancement of a WV structure from the first over the second to the third scene are accepted if they fulfill the following conditions: The difference in their lengths $|\vec{d}_1| - |\vec{d}_2|$ related to their average length $(|\vec{d}_1| + |\vec{d}_2|)/2$ should not exceed 40 %; the included angle should be less than or equal to 30 degrees. Alternatively, the deviations in length or angle are taken into account more symmetrically by the condition, that the vectors difference $|\vec{d}_1 - \vec{d}_2|$ related to their average vector $|\vec{d}_1 + \vec{d}_2|/2$ should not exceed e.g. 60 %. To keep the interpretation of the results as elementary as possible no use is made from results of preprocessed images as is reported in our previous work [Büche et al., 1991; 1992].

Since pure water vapour structures are to be evaluated the segments should be free from clouds in the intermediate and upper troposphere. To fulfill this condition two different criteria are applied alternatively. The first one orders a great amount (e.g. 87,5 %) of all infrared (IR) pixels to be within a small radiance bin of 0.757 Watt m^{-2} sr^{-1}. This degree of homogeneity is a very restrictive condition (hereafter called HOMIR) and concentrates the evaluation on regions of clear atmosphere and low level cloud cover. Almost all of these cases are included if a different level is applied to separate cloudy segments: Since temperature in the atmosphere decreases with increasing height, a useful condition is given by all infrared pixels within a segment ought to have an effective IR brightness temperature greater than minus 10 centigrades (called TIRM10).

As shown in a recent contribution [Büche et al. 1994] the height assignment to the tracked water vapour structures can be done in three different ways at least. The first two start from a selection of a relevant site for the structure (e.g. the center of a segment, which is used throughout this paper) and interpolate the atmospheric profiles for temperature and humidity. After a radiative transfer calculation resulting in the so-called contribution function CNTRBF (Z) the two heights $Z_{1,2}$ can be defined:

$$Z_1 \equiv \text{ZMAX} = \text{Z(CNTRBF} = \text{Max!)}$$

$$Z_2 \equiv \text{ZCNT} = \frac{1}{\text{Norm}} \cdot \int_0^\infty \text{Z.CNTRBF(Z,}\ldots\text{)dZ}$$

where Z_l represents the height of the maximum value of the contribution function. The height Z_2 is an effective one where the weights are taken by the contribution function as well. For Z_l and Z_2 the humidity profile of the atmosphere must be known. The third way of defining a height makes use of the representative radiance of a tracked structure, calculates the effective water vapour brightness temperature T_{eff}^{wv} and interpolates the height in the corresponding temperature profile:

$$Z_3 \equiv \text{ZTEF} = T_{\text{Prof}}^{-1}(T_{\text{eff}}^{\text{WV}}) \, .$$

This way has the advantage of not using the humidity profile in addition to image data.

3. VALIDATION OF WV-DISPLACEMENT VECTORS

3.1 Use of ECMWF Data

In a first approach to validate displacement vectors these are compared to the wind vectors taken from data which were received from an analysis within the scope of the ECMWF model. A time series of rectangular scenes from the northern hemisphere together with the equatorial zone (hereafter called scene A) is scanned with segments of 48 x 48 pixels. The atmospheric profile is interpolated to the center of the segments. The comparison between wind ($\vec{w}$) and displacement ($\vec{d}$) vectors is given in three numbers:

The relative difference between the lengths	$\text{WVEL} = 2.\frac{\lvert\vec{w}\rvert - \lvert\vec{d}\rvert}{\lvert\vec{w}\rvert + \lvert\vec{d}\rvert}$
The angle included by the vectors	$\text{WDIR} = \measuredangle\,(\vec{w},\ \vec{d})$
The relative difference of vectors $\vec{w}$ and $\vec{d}$	$\text{WDIF} = \frac{\lvert\vec{w} - \vec{d}\rvert}{\lvert\vec{w}\rvert}$

where two out of these numbers are statistically independent. The selection of cloud free segments as well as the different ways of attributing a single level height to the displacements are executed as described in Chapter 2. The results in respect of average numbers and scatterings are given in Table la. Neither segments containing homogeneous infrared scenes nor those with warm pixels only show a qualitative advantage of one method of height assignment over the others. The heights ZCNT (ZTEF) attributed to the displacements are found to be about 700 meters (250 meters) on average higher than the maximum ZMAX in the contribution function. If one method would be better than another, the standard deviations are expected to be remarkably lower than for the other results.

	ZMAX	ZCNT	ZTEF	Kind of segments
Cases	18	18	18 from	55 HOMIR
WVEL	8,33 ± 36,4 %	17,2 ± 36,1 %	11,1 ± 33,8 %	
WDIR	+4,45 ± 36,7°	+ 3,89 ± 34,5°	+ 6,7 ± 36,7°	
WDIF	0,544 ± 0,276	0,494 ± 0,267	0,528 ± 0,314	
Cases	54	54	54 from	201 TIRM10
WVEL	8,0 ± 49,0 %	14,4 ± 47,8 %	6,8 ± 50,4%	
WDIR	-1,1 ± 34,5°	-2,2 ± 34,3°	0,4 ± 34,0°	
WDIF	0,614 ± 0,399	0,596 ± 0,389	0,587 ± 0,346	

Tab. 1a: Displacement vectors $\vec{d}$ from WV scene A of 21 June 1989 12 hours UTC compared to wind vectors $\vec{w}$ from the corresponding ECMWF analysis and for three different height assignments. Cloudy segments are separated by two different conditions: 87.5 % of all pixels have IR radiances within a bin of 0.757 W m^{-2} sr^{-1} (=HOMIR); the effective IR brightness temperatures are warmer than -10ºC (=TIRM10).

	ZMAX	ZCNT	ZTEF	Kind of segments
Cases	21	20	20 from	187 HOMIR
WVEL	2,6 ± 35,2 %	7,0 ± 41,6 %	2,5 ± 37,5 %	
WDIR	-2,6 ± 33,7 °	3,0 ± 29,3°	1,5 ± 30,1°	
WDIF	0,555 ± 0,395	0,615 ± 0,420	0,580 ± 0,457	
Cases	86	88	85 from	534 TIRM10
WVEL	-3,8 ± 38,6 %	-3,5 ± 41,4 %	-4,8 ± 37,2%	
WDIR	-2,3 ± 27,4°	-0,6 ± 27,1°	0,4 ± 27,2°	
WDIF	0,564 ± 0,386	0,583 ± 0,396	0,569 ± 0,356	

Tab. 1b: Same scene as in Table la, but a different evaluation of displacement vectors and other levels for the condition of good vectors are used. The comparison is restricted to -1 ≤ WVEL ≤ 1 and -90° ≤ WDIR ≤ + 90° in order to prevent a few very bad cases to force the result unrealistically.

In a second step scene A is scanned once more, but almost all parameters and levels are varied. The size of the segments was changed to 32 x 32 pixels. Length and direction of displacement vectors are taken into account with equal weights using the condition $2|\vec{d}_{12} - \vec{d}_{23}| / (|\vec{d}_{12}| + |\vec{d}_{23}|) \leq 0.6$ for the definition of good vectors. To avoid forcing of the standard deviations by a few (even one only!) cases of unrealistic displacement vectors the comparison is restricted to

$$-1 \leq WVEL \leq +1 \quad \text{and} \quad -90^{o} \leq WDIR \leq +90^{o}$$

The remaining cases are listed in Table 1b. First of all the number of good pairs of displacement vectors and cloud free segments is increased. Nevertheless the sites are distributed mainly over the same regions of the scene as before. Again no hint for the better method can be found from the comparisons neither for homogeneous IR-scenes nor for the segments containing warm pixels only.

As a side product during this study it is found that the field of displacement vectors obtained from inclusion of results from filtered images [Büche et al. 1991; 1992; not shown in this context] have two advantages which go beyond the situation reported in this chapter. While the height assignment leads to almost the same situation as reported in this context, the resulting number of good displacement vectors is increased as well, but - first of all - many of them are situated in regions of the scene, which remain empty after a search using simply a smaller segment's size.

3.2 Use of Radiosonde Data

A closer approach to the height assignment problem can be expected from a comparison of displacement vectors to measured winds from radiosonde profiles. The sites of radiosonde ascents and good displacement vectors within the full scene are given in Figure 1. Their geographical coordinates are confined to within a distance of 62.5 degrees from the subsatellite point on a great circle arc. To search for WV structure displacements segments of 48 x 48 pixels are centered to these sites. Sonde profiles for the height assignment are selected and must be complete up to at least one pressure level beyond the heights Z. For the sake of completeness up to 100 hPa humidity values are linearly extrapolated according to the last dew point temperatures. The temperatures themselves are linearly extrapolated as well until to the tropopause. Beyond it temperature is kept constant.

Table 2 shows the results from the comparison of WV structure displacements to radiosonde winds and the three given height definitions. Again there is a remarkable reduction of the standard deviations for all three kinds of height assignment after the separation of cloudy cases. But there is no clear signal that one of these ways is most suited for the solution of the single level height assignment task. The numbers for the relative vector difference WDIF (lines 4, 6, 7 of Table 2) are comparable to those for the ECMWF data in Table 1a (line 4) and cloud free IR segments HOMIR, but significantly smaller than for the pixels warmer than -10°C (line 8 of Table 1a). While the differences of the wind vectors in length and direction tend to be centered around zero, a deviation of the vector difference from zero of almost 2 standard deviations is noticeable.

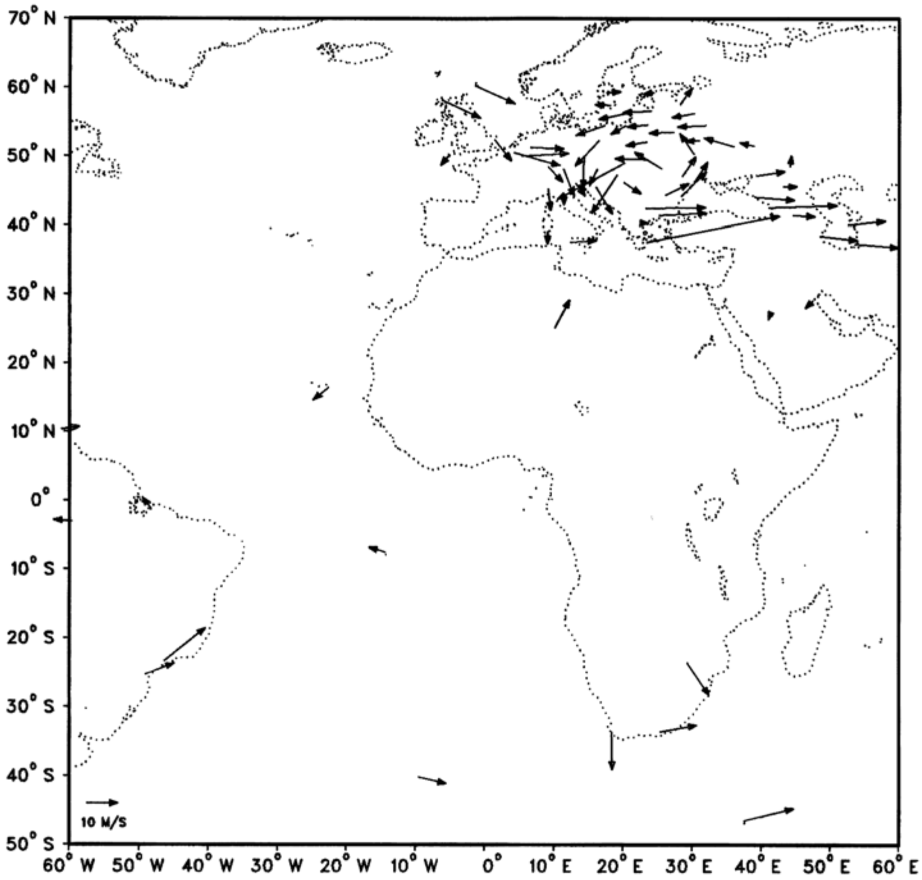

Fig. 1: Displacement vector field of water vapour structures at sites of radiosonde ascents from METEOSAT on June 21, 1989, 12 hours UTC.

	All segments	Cloud free segments HOMIR	Cloud free segments TIRM10	Height Assignment
Cases	45	13	26	
WVEL	16 ± 46 %	24 ± 35 %	25 ± 31 %	ZMAX
WDIR	5,2 ± 30,0 °	7,1 ± 26,2°	7,4 ± 22,2°	ZMAX
WDIF	0,57 ± 0,45	0,50 ± 0,24	0,47 ± 0,22	ZMAX
$WDIF_{Min}$	0,26 ± 0,22	0,22 ± 0,18	0,23 ± 0,15	Minimum difference within profile
WDIF	0,60 ± 0,42	0,57 ± 0,28	0,55 ± 0,24	ZCNT
WDIF	0,57 ± 0,45	0,50 ± 0,28	0,47 ± 0,25	ZTEF

Tab. 2: Comparison of WV displacement vectors from the full scene at sites of radiosonde ascents within 62,5° around the subsatellite point to the wind velocities taken from measured profiles using three different height assignment methods.

Up to this point the height assignment method and/or the basic data seem to be of low sensitivity to finding a single level wind vector from the WV images. This may initiate a look for the degree of matching between radiosonde winds and displacements by varying the height freely within the troposphere. Line 5 of Table 2 reproduces the minimum differences from the winds in the atmospheric profile. The standard deviations of these differences are less than but close to the standard deviations in lines 4, 6 and 7 for cloud free segments. Even a tendency to a small offset from zero is noticed. Or, to be close to the minimum differences from the wind vectors means the method should not expected to be sensitive to a variation in a single level height.

3.3 Radiosonde versus ECMWF wind field

In absence of a qualitative difference in the comparisons of displacement vectors to radiosonde data on one hand and to ECMWF data on the other it is presumed that the data themselves deviate from each other. For pressure levels from 500 up to 250 hPa differences between the velocities $(w_{RS} - w_{EC})/w_{RS}$ are found around (0 ± 45) %; the directions of wind velocities deviate by (-2 ± 22)°, and the vector differences by about 0.32± 0.48. With reference to the corresponding numbers in Tables 1 and 2 it is surprising that the two sets of reference data show a higher mutual scattering. Wind vectors measured by radiosonde ascents are of primary character. They are of local nature in space as well as in time. This is partially in contradiction to how displacement vectors are generated. These average the weather conditions over the segment's extensions of 240 x 240 km^2 in the subsatellite point as well as over at least 1 hour of time during the procedure of taking 3 consecutive images. In contrast to this vectors from the ECMWF wind field are model data that result from an assimilation procedure excluding apparent contradictions and aiming for consistency of the wind field. This way these data reproduce mainly an average behaviour of the atmosphere.

3.4 Effective wind vectors

So far the three ways of defining heights have not led to a decision on how to define a single level wind vector from the displacements of tracked water vapour structures. Therefore a change of philosophy is to use an effective wind velocity for the comparisons. A displacement vector of radiance structures can be understood as the sum of motions of WV amounts, the WV itself being distributed not only over the segment's lateral dimensions, but in the vertical dimension as well. This view may be important mainly in cases where the existence of wind shear is expected. The definition of an average wind is done in analogy to the definition of the effective height (cf. Ch. 2) by integration of the wind profile multiplied by the contribution function.

The comparison of the displacement vectors to the average wind vectors shows almost the same situation as is given in Table 2. Again no clear signal can be seen whether the effective wind vectors are matching to the displacement vectors better than the so-called single level wind.

	All segments	Cloud free segments HOMIR	Cloud free segments TIRM10	Height Assignment
Cases	44	13	26	
WVEL	6 ± 57 %	12 ± 43 %	16 ± 36 %	none
WDIR	2,9 ± 29,9 °	3,6 ± 30,5°	7,1 ± 21,9°	(equivalent to
WDIF	0,59 ± 0,57	0,55 ± 0,31	0,46 ± 0,26	ZCNT)

Tab. 3: Comparison of WV displacement vectors at sites of radiosonde ascents to effective wind vectors calculated from the measured profiles.

4. CONCLUSIONS

Displacement vectors evaluated by tracking pure water vapour structures in three consecutive METEOSAT images are compared to the wind fields from two different sources: from the ECMWF model analysis and from radiosonde ascents. Three different ways of defining an effective height which in turn is attributed to the related displacement vector are tested. Two ways are using profiles of temperature and humidity from the data and get their results from a radiative transfer calculation. The third way calculates the effective brightness temperature by inversion of the Planck function and interpolates the effective height without using humidity data. The degree of matching between wind vectors and displacement vectors is estimated from the standard deviation of expressions formed during the comparisons. Surprisingly neither one of the height definitions nor the use of radiosonde data in contrast to model data led to a remarkably low scattering of these expressions. It seems that all cases taken into account are close to the minimum scatter of deviations which is obtained from an unrestricted variation of height. Even a change in the interpretation from single level height attribution to a multilayer effective wind vector has not led to a clear decision between the methods. Therefore it is presumed that cases with low and high wind shear should be studied separately in the future.

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