FURTHER IMPROVEMENTS OF CLOUD MOTION WIND EXTRACTION TECHNIQUES

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ABSTRACT

The displacements of clouds in successive satellite images reflects atmospheric motions at various scales. The main application of the satellite derived cloud motion vectors at a scale of about 100 - 200 km, is their use as winds in the data analysis for numerical weather prediction.

This paper focusses on improvements to existing techniques for deriving cloud motion winds (CMW) from the present generation of satellites. Taking recent improvements of the operational CMWs from METEOSAT as an example, the impact of different changes on the quality will be discussed. It is shown that better height assignment of a wind vector and radiance filtering techniques preceding the cloud tracking have ameliorated the errors in METEOSAT winds significantly.

For the foreseeable future CMWs will be used as single level winds in the data assimilation schemes and improvements to existing CMW retrieval techniques have to be made accordingly. Areas for improvement are seen in the height assignment, automatic quality control, and quality flags that would allow a more effective use of CMWs in the data assimilation.

1. INTRODUCTION

Global observations of atmospheric wind fields are potentially the most important data in the analysis for numerical weather forecast. There are two reasons why accurate wind observations are generally preferable to mass observations (Baker, 1991): firstly, a numerical forecast model accepts winds more readily than mass data for the relatively small scales that are observed, as small-scale mass variability is dispersed as gravity waves and does not lead to wind field changes. Secondly, winds are derived from the mass field via differentiation which enhances the noise of the observations. Direct wind observations are indispensible at low latitudes where winds cannot be inferred from the mass field and upper air soundings from the conventional network are scarce.

The global network of geostationary satellites provides the basis for the derivation of cloud motion winds (CMW) from successive and carefully aligned satellite images. The operational derivation of CMWs from satellite images started in the mid-seventies (Smith, 1985). Initial impact studies of this new data source on weather forecast revealed a positive impact (Kallberg et al., 1982). The last decade has seen a substantial progress in data assimilation and numerical weather prediction, whereas little development work on cloud motion winds was conducted until a few years ago. Logically the more recent studies on the impact of CMWs on the forecast quality have been less convincing (Kelly and Pailleux, 1989). The primary criticism of CMWs arose from the underestimation of wind speed especially in and near jet streams. It is intriguing that the most recent impact studies (see contributions in these proceedings) show again a more positive result.

CMWs are not a direct measurement of the wind field and, therefore, may possess properties that compromise their use as single level observations of the wind field. Specifically, clouds are are not always passive tracers nor is the location of cloud occurrance representative for the wind field. Cloud motion may also represent a layer-mean flow rather than a wind vector at a specific level. However, it has to be accepted, for the foreseeable future, that the use of

CMWs in NWP will be as a single level vector. Consequently improvements should principally enhance the usefulness of CMWs as single wind data.

2. CLOUD MOTION WINDS FROM METEOSAT IMAGES

The early cloud tracking method used at ESOC has been described by Morgan (1979). A detailed description of the current system is given by Schmetz et al. (1991); here only a brief summary is presented.

In the present version of the cloud tracking software the image data are preprocessed before the tracking commences. The image preprocessing makes use of the spatial coherence method (Hoffman, 1990; Coakley and Bretherton, 1982); that is, a transformed image is constructed such that fully cloudy pixels of the highest cloud layer obtain a high weight while contaminated cloud pixels and the background get decreasingly lower weights.

The automatic cloud tracking employs cross-correlation, and three successive IR images are used to determine a displacement vector. A segment of 32x32 IR pixels of an image at the time h forms the target area, which is correlated at times $h + 30$ min and $h - 30$ min with areas equivalent to the size of a segment. The search area consists of 3x3 segments, which yields 65x65 possible displacements to be correlated. Since computer time is prohibitive to compute full correlation surfaces, the search for a peak in the correlation surface starts at a displacement suggested by a wind forecast from the European Centre for Medium Range Weather Forecast (Nuret and Schmetz, 1988). The search is confined to an area of 35 by 35 pixels, which is large enough to limit the dependance of the result on the forecast (a displacement of 35 pixels in 30 minutes corresponds to a speed of about 100 m/s).

The use of three successive images enables a symmetry check of the two corresponding vectors, where the two vectors must agree within certain limits with respect to speed and direction (Schmetz and Nuret, 1987).

The height attribution of a wind vector is based on the IR cluster brightness temperature as determined from the histogram analysis and forecast temperature profiles are used as correlative data. Semi-transparent clouds undergo a height correction making use of simultaneous IR and WV measurements (Bowen and Saunders, 1984; Szejwach, 1982).

The cloud motion winds are subject to an automatic quality control followed by a manual editing. The automatic quality control consists of a rough check against the ECMWF forecast, where CMWs in vast disagreement with the forecast are flagged. The flagged CMWs can be reinstated at the manual control.

3. IMPROVEMENTS TO THE CMW RETRIEVAL

a. Chronicle of changes

The improvements made previously to the METEOSAT CMW retrieval consisted of four major changes (see Schmetz, 1991 and references therein), the significance of which can be described as follows:

- March 1987: The radiance slicing technique for high level clouds was introduced in order to alleviate the problem of tracking a mixture of clouds and background. Tracking unsliced images potentially introduces a slow bias since lower clouds/backgrounds move at a slower speed or not at all. The radiance slicing extracted high level cloud pixels as obtained from the multispectral image analysis.
- September 1987: The new calibration of the Meteosat water vapour channel based on radiative transfer calculations gave considerably higher calibration coefficients. This in turn has lead to a better height assignment of semitransparent clouds, which form a major part (some 50%) of high level cloud tracers.
- March 1989: The cloud tracking was modified such that the cross-correlation is calculated for an area of 35 x 35 pixels around a displacement suggested by a wind forecast. This guided tracking replaced a search 'strategy' which started at 'zero'-displacement and stopped at the first peak found in the correlation surface. Since correlation surfaces are generally multi-peaked there was a potential for a slow bias and rogue winds in the old search method.
- March 1990: The simple radiance slicing has been replaced by a preprocessing which extracts pixels of the highest cloud layer using a spatial coherence method. Its main advantage over the previous slicing is the better enhancement of the cloud layer to be tracked with a gradual screening of warmer pixel values.

b. Impact of changes

The impact of a change is monitored by routine comparison with collocated radiosondes, where the collocation area extends over 2°x2° and is within a time interval of one hour. Poleward of 25° the longitude interval of a collocation box is increased to 3°.

Two quantities are considered to illustrate the improvements: The monthly mean speed bias is defined as the difference between monthly average CMW speed minus radiosonde speed. The second quantity is the monthly mean of the RMS vector difference of the collocation values.

A careful assessment of the impact of changes requires some processing of the monthly mean collocation values, since both the speed bias and the RMS vector difference increase with wind speed. Therefore a normalization has been computed in the following way: a linear regression is calculated for the speed bias and the RMS vector difference versus the monthly mean radiosonde speed for the time intervals between changes.

The regression lines are then used to compute the speed bias and the RMS vector difference at a mean radiosonde speed of 10 m/s for low level CMWs and at 24 m/s for high level. Results for the time periods before and after the four changes are shown in Figure 1a and 1b, respectively. In addition the RMS error of the CMWs has been estimated by subtracting the variances due to time and distance separation between sonde and CMW from the measured variance of the vector differences. The variances due to time and space separation were taken from Kitchen (1989).

While the first change (radiance slicing) brought about a significant improvement to low level CMWs (Figure 1a) the latter three changes had a rather neutral effect. This may indicate that low level CMWs with an estimated vector error of 2.5 m/s (at 10 m/s wind speed) are as good as they can be, although Hasler et al. (1979) achieved errors as low as 0.9 - 1.7 m/s in comparison to aircraft wind measurements.

For high level winds (Figure 1b) the three more recent changes all gave a significant improvement, reducing the speed bias (at a mean radiosonde speed of 24 m/s) from about 4 m/s to 1.5 m/s.

4. FURTHER IMPROVEMENTS

a. Height assigment

Three out of the four changes described above affected the height attribution of a cloud motion vector in one way or another. This clearly illustrates the potential for improvements inherent of the height assignment methods. We do not think that this potential is exhausted yet: Figure 2 illustrates the semi-transparency correction as it is used at ESOC. Specific points that need consideration are:

i) what is the effect of an inconsistency between radiative forward calculations and the observed radiances (counts); for instance the observed clear-sky background rarely lies on the computed curve.

ii) the concept illustrated in Figure 2 is strictly applicable only to opaque broken cloud

iii) small particles may increase the emissivity in the IR channel by a larger amount than in the WV, which is presently not considered in the radiative forward calculations

iv) it may also be useful to apply empirical altitude corrections (to somewhat lower levels) in cirrus areas with strong vertical wind shear (see discussion in Schmetz and Holmlund, 1991).

b. Exploit other imaging channels

It has been advocated for more than a decade that motion tracking in water vapour images (or more generally in absorption channel images) naturally complements CMWs from IR window channels. A recent study by Laurent (1991), that ultimately aims at the operational implementation of water vapour winds within the Meteosat system, has brought about a somewhat different perspective: It appears that the major advantage of WV images rests upon the superior tracking of high level clouds. The advantage is twofold: first, tenuous cirri and the associated moisture field are easier to detect in the WV channel. A second point is that the use of an absorption channel implicitly provides a radiance slicing (Menzel et al., 1983), thus alleviating the height assignment problem of thin or broken cloud occuring in the IR window channel. Conceptually this points at new satellite technology that provides information on narrow vertical layers for the tracking of atmospheric features (Smith, 1989).

The original idea that tracking pure WV features would provide winds complementary to the cloud tracking is not substantiated by Laurent's (1991) results; mid-tropospheric single level WV winds appear to be inferior to the IR cloud winds, presumably due to the deep layer integration of the WV channel in clear air.

The use of visible channels shows promise for low level cloud. Advantages are seen in the higher spatial resolution of the visible images from geosynchronous satellites that could provide more accurate results (Shenk, 1991; Lunnon, 1991).

c. Shorter time intervals

Previous studies (e.g. Shenk, 1991 and references therein) have demonstrated the value of high temporal resolution for correctly identifying cloud tracers. Cumulus clouds may require repeat cycles for the images as low as a few minutes, which is is substantially different from the typical 30 min repeat cycle of scanning at most operational centers. This point deserves further research, that ultimately should envisage an automated tracking of small scales in the short-interval images.

Along with the above, goes a need for increased accuracy of image navigation, since the image navigation error will become increasingly important for wind vectors from shorter image intervals.

d. Quality control

Further research on quality control is warranted for two reasons: First, for the purpose of improved quality control at production going beyond the present symmetry or acceleration check. Ongoing work (see Holmlund, 1991) exploiting correlative information on the vertical and horizontal wind shear from a forecast proves already useful for stratifying the CMWs in terms of quality. Future work, solely based on image data, will encompass checks for consistency of winds in both space and time; where the latter implies a quasi-continuous production of winds from image sequences. Cloud pattern and texture analysis could be useful for delineating poor tracers; this will necessitate extensive training data sets for establishing the parameters with classification skill.

The second reason for classifying winds in terms of quality or characteristics rests upon the potential use in the data assimilation. If we were able to tag a quality label to each wind vector the data could be used more effectively for numerical weather prediction and with a larger impact. It may also be interesting to introduce 'character flags' indicating whether an CMW represents a single level wind or rather an average over deep layer mean (as it appears to be the case for pure WV winds). Possibly the two types can be used in the data assimilation with different vertical correlation functions.

e. Use of forecast in motion tracking ?

The present Meteosat system uses the ECMWF forecast as the starting point for the feature tracking via cross-correlation. As shown above the use of the forecast improved the comparison versus independent radiosondes. Principally the forecast acts as a filter reducing the number of rogue winds produced in the previous system, which used a search strategy starting at zero-displacement.. If sufficient computing power was available, one could compute full correlation surfaces and avoid the use of a forecast at the production.

A separate topic is the use of a forecast for automatic quality control.

f. Working environment

Based on the experience with the development and operational extraction of cloud motion winds we see clear advantages in a close cooperation between applied research and operations. Our present way of working considers the initial basic research, the development of prototype software and its quasi-operational running in a parallel operational software suite as one single evolutionary process, that is reiterated until it provides satisfactory results. The asset of the approach is the immediate feedback from operations to the basic ideas.

However the system has its weak points as it appears that often the development cycle become driven by the quasi-operational performance of the prototype software. This can enforce adhoc changes rather than truly conceptual changes. Therefore independent research will always be indispensible for further improvements.

The computer environment should be powerful enough to allow for a sufficient amount of quasi-operational work for development purposes. Modern hardware design and fast specialised tools (parallel processing etc.) have to be considered for future operational systems, however one should not forget that the software and running cost will sum up to the lion's share of a system. That is to say, a fair investment in flexibility will pay off at a later stage.

g. Better use of CMWs in NWP

Finally it is fair to mention that the use of CMWs as single level winds is not really just. It is appreciated that alternatives are are difficult to come by, however, it may already be useful to reconsider the spreading of the single level information via vertical structure functions and make it even dependent on the synoptic situation.

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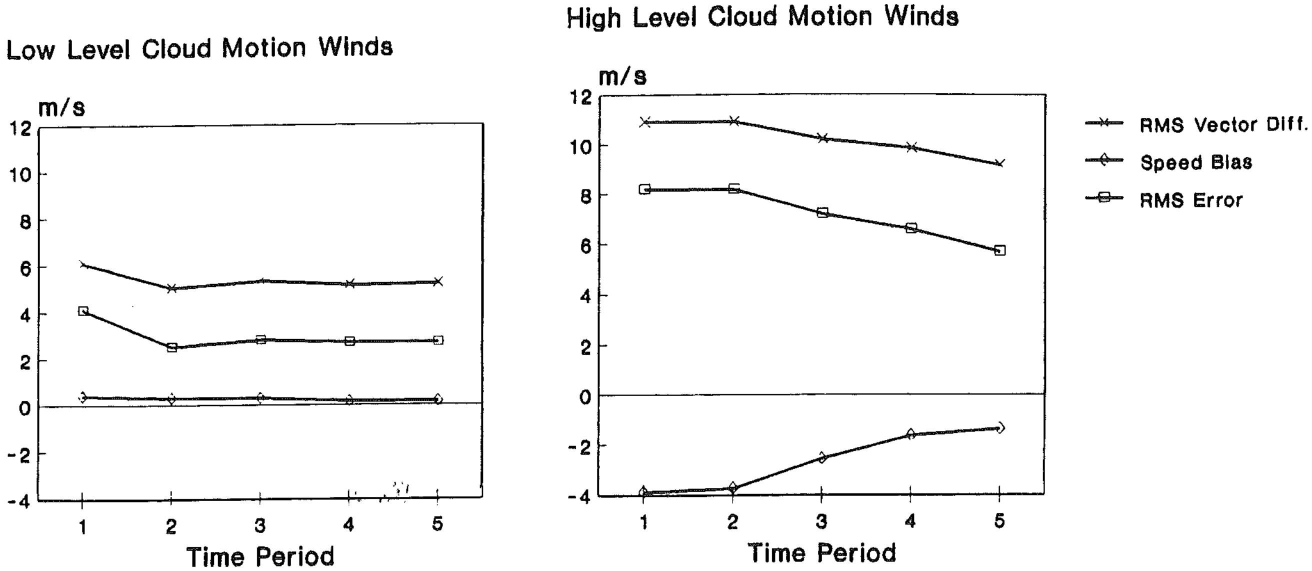

Figure 1: Evolution of monthly averages of the speed bias (CMW minus R/S), RMS vector difference and the estimated vector error of cloud motion winds from METEOSAT. Periods refer to the five time intervals separated by the four changes discussed in section 3.
Left figure shows low level CMWs (> 700 hPa) and the figure to the right high level CMWs (< 400 hPa).

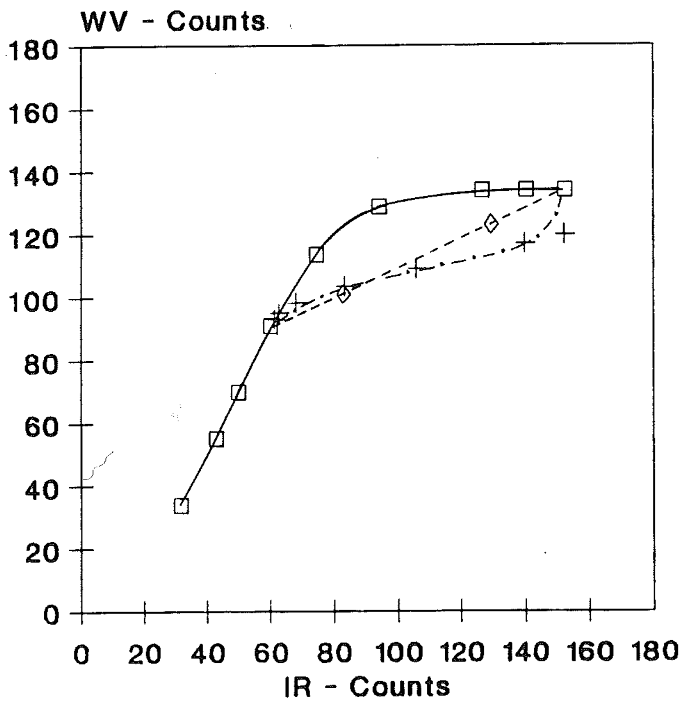

Figure 2: The bispectral height correction of semi-transparent clouds operationally in use at ESOC. The solid curve corresponds to model calculations of the satellite observed counts for opaque clouds; squares along the curve pertain to clear sky and clouds at 1.6, 3.2, 6, 8, 9.6, 11, 12 and 14 km altitude, respectively, in a tropical atmosphere and nadir view.
The straight line (dashed) corresponds to an opaque cloud with variable fractional cloud cover (satellite observations are assumed to be along that line). The intersection of the straight line with the curve provides the estimate of the corrected IR cloud brightness temparature or height.
The dash-dotted line corresponds to the trace that a plane-parallel cloud (at 9.6 km) would leave in the IR/WV count domain if the optical depth was changed. The rapid decrease of WV counts on the right hand side (clear sky) is due to the increase of atmospheric humidity at cloud level which has little effect on the IR radiance. For emissivities close to 1, the dash-dotted curve is above the straight line since at shorter wavelengths the Planck function is more sensitive to the increased brightness temperature.