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Correlation of vorticity advection values and grey shade values in infra-red satellite images

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A statistical analysis of the correlation between vorticity advection values and grey shade values in infra-red satellite images is presented. Average correlation coefficients for six-month data set in all four chosen levels were found positive. This means that higher vorticity advection values result in brighter grey shades in satellite images. The best correlation was found for vorticity advection in 500 and 300 hPa levels. Absolute values of average coefficients are below 0.2 meaning that correlation is not good in all synoptic situations. The results were significantly improved when only those images were considered in which comma cloud structures, enhanced cumuli clouds or frontal intensifications were found. Statistics for the 16 selected cases indicated satisfactory correlation between vorticity advection and pixel values. This enables forecasting of cloud paths and development by following the vorticity advection maxima related to the mentioned cloud structures.

Povezanost vrijednosti advekcije vrtložnosti s vrijednostima sivih nijansi na infracrvenoj satelitskoj slici

Provedena je statistička analiza korelacije advekcije vrtložnosti i vrijednosti sivih nijansi na infracrvenoj satelitskoj slici. Prosječni koeficijenti korelacije za šest-mjesečni niz podataka na sva četiri odabrana izobarna nivoa su pozitivni. To znači da veća vrijednost advekcije vrtložnosti rezultira višim signalom na IR satelitskoj slici. Najboljom se pokazala korelacija za advekciju vrtložnosti na izobarnim plohama 500 i 300 hPa. Apsolutne vrijednosti koeficijenata korelacije su niže od 0.2, što znači da povezanost nije dobra u svim sinoptičkim situacijama. Rezultati su značajno poboljšani kad su za statističku obradu uzete samo one satelitske slike na kojima su pronađene oblačne strukture oblika zareza, pojačani cumulus oblaci ili intenzivirana naoblaka na fronti. Statistička analiza za 16 odabranih slučajeva pokazuje da se korelacija između advekcije vrtložnosti i vrijednosti sivih nijansi može u tim situacijama smatrati zadovoljavajućom. To ujedno pruža i mogućnost prognoziranja razvoja i kretanja oblačnih struktura praćenjem pripadnih maksimuma advekcije vrtložnosti.

1. Introduction

Satellite images, which are nowadays incorporated into weather analysis and synoptic research in all weather services, can be used in two ways. The first one is the diagnosis of cloud configurations in the image in respect to the physical state or process that led to the particular cloud system. This type of analysis is mostly subjective but can also include objectively derived fields of meteorological parameters on isobaric or isentropic surfaces, providing more precise diagnosis of involved physical processes. An example of such analysis is given in Zwatz-Meise et al. (1994a, b). The other approach is the quantitative evaluation of the grey shade values from the image. The extracted grey shade values can be used, for example, as input values for numerical prediction models (Allam et al. 1992) or for precipitation estimation (Aulamo and Pylkkö, 1992). Previous work in this field showed that for precipitation evaluation the best results are obtained by combining infra-red (IR) and visible (VIS) images. However, since VIS images are not available during the night some evaluations have been made using other parameter fields in place of VIS images (Zwatz-Meise, 1992; Zwatz-Meise and Stockinger, 1992). One of the parameters that were used for those evaluations was vorticity advection. The results in these papers, as well as in Zwatz-Meise and Bendl (1992), showed that positive vorticity advection (PVA) maxima are usually accompanied by higher grey shade values in satellite images. An example of such correlation is shown in Fig. 1. It is obvious that PVA maxima spatially correspond to brighter IR signal. Theoretical view into the relation between vorticity advection and rising motion, causing cloud development, is given in the Appendix.

The main aim of the work presented here was to find out whether a statistical correlation between grey shade values in satellite images and vorticity advection values exists in general. The presence of such correlation would mean that, for example, high positive vorticity advection values are related to low temperatures of cloud tops, which could be used in predicting the development of certain cloud structures using prognostic vorticity advection values.

2. Materials and method

The input data for the statistics performed here were IR METEOSAT images and analysis vorticity advection values at 850, 700, 500 and 300 hPa levels in grid-points of the European Centre for Medium Range Weather Forecast model. Each satellite image consists of pixels which can have one of 256 grey shade values, from 0 to 255. Those values are inversely proportional to the temperature of the radiating surface so that high pixel value means lower surface temperature, or, in case of clouds, higher cloud tops. The data set consists of values for six months (September 1994 to February 1995),

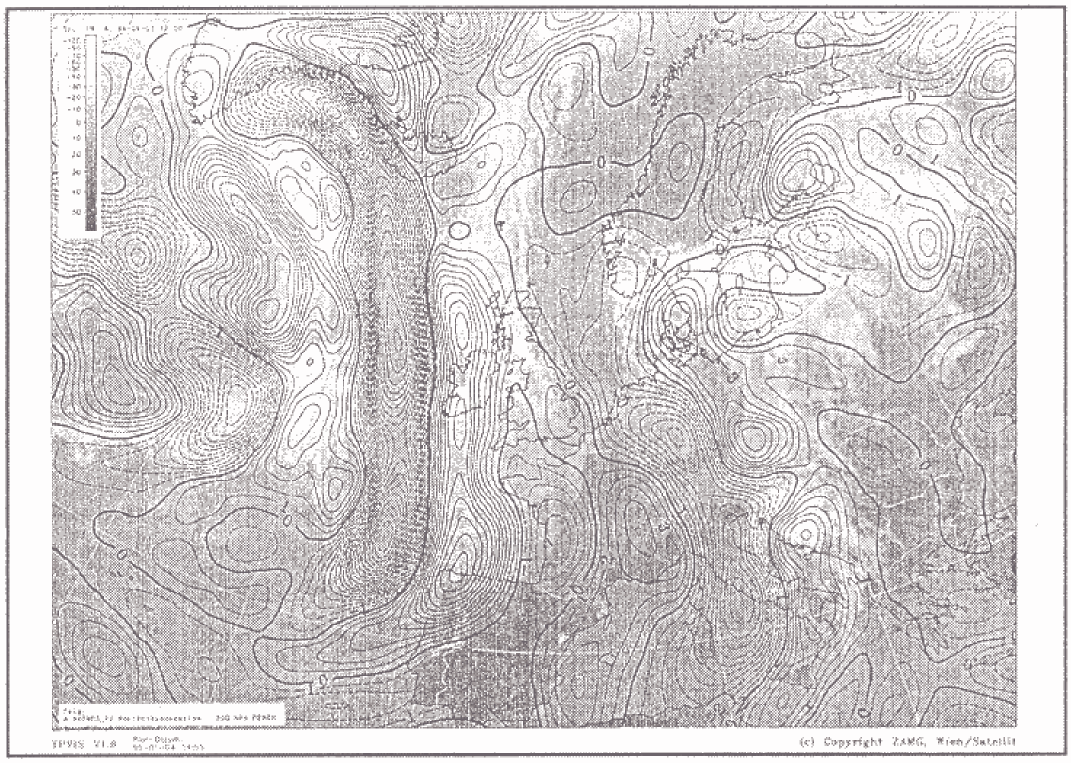

Figure 1. An example of spatial correspondence between infra-red satellite image and vorticity advection at 300 hPa level. (METEOSAT image and ECMWF analysis vorticity advection field on 03 Sept. 1994, 12 UTC). Positive vorticity advection is shown by solid lines and negative by dashed lines.

measured twice a day (00 and 12 UTC). The grey shade levels were divided into 19 intervals in order to simplify the calculation and the presentation of the results. The pixel value of 169 was taken as a threshold value for clouds. In other words, all values above 169 represent the radiation from cloud tops.

3. Results of general statistics

Average correlation coefficients (Fig. 2) show that the best correlation of IR pixel values and positive vorticity advection (PVA) is found at 500 and 300 hPa levels. Further analysis will therefore be performed only for those isobaric levels. All coefficients are positive indicating that stronger PVA generally results in higher IR pixel value. The absolute values of correlation coefficients are relatively low, below 0.2. However, since the coefficients are positive it means that greater vorticity advection is correlated to higher grey shade values.

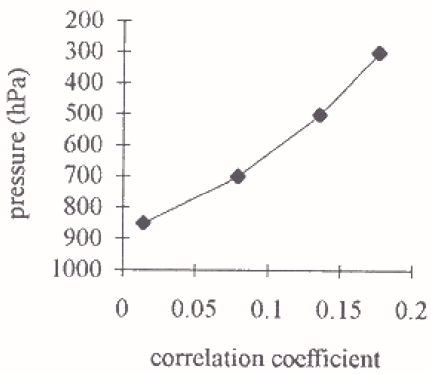

Figure 2. Average correlation coefficients for the correlation between vorticity advection values and grey shade values in IR satellite image for 6-month data set.

Relative frequencies of points with PVA within each grey shade value interval show that for IR pixel values higher than 169 in both 300 (Fig. 3) and 500 hPa (Fig. 4), more than 50% of corresponding points have positive vortic-

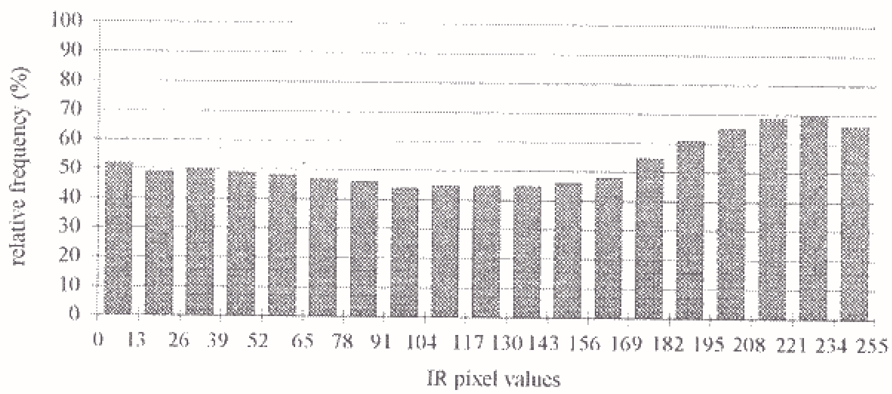

Figure 3. Relative frequencies of points with positive vorticity advection at 300 hPa level within each IR pixel value interval.

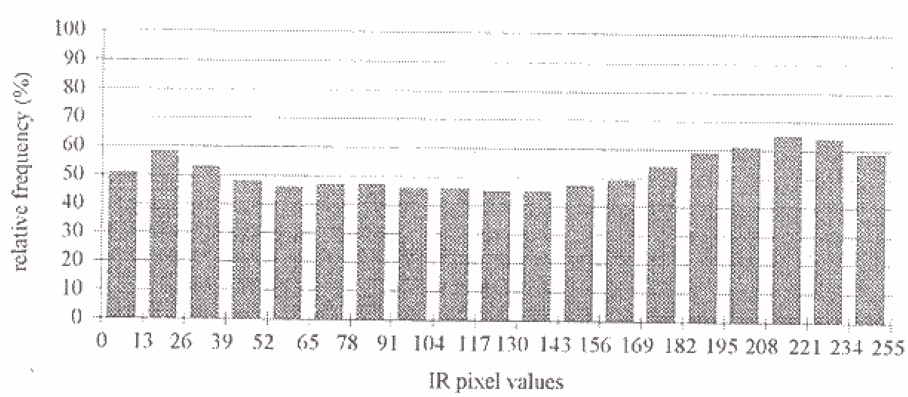

Figure 4. Relative frequencies of points with positive vorticity advection at 500 hPa level within each IR pixel value interval.

ity advection. Nevertheless, there is still a great number of pixels (from 35 to 46 % in 500 hPa and from 30 to 45 % in 300 hPa) with grey shade values greater than 169 having negative vorticity advection. It can also be noticed that for IR signal below 39 corresponding vorticity advection at 500 hPa (Fig. 4) is positive with more than 50% probability. That indicates the fact that the correlation of vorticity advection and IR pixel values is not good in all synoptic situations. Since vorticity advection is just one of four quasigeostrophic forcing functions causing the rising motion, there are cases when other three processes annul the effects of vorticity advection. For example, a strong warm air advection can cause ascending motion, regardless of vorticity advection and in such case clouds with high tops can appear also in regions with anticyclonic vorticity advection. In Fig. 1. there is a small part of a warm front, in the upper right corner, where vorticity advection values are negative, while the IR grey shades are bright, indicating cold cloud tops. Since general statistics include the whole images, similar cases are often found, making correlation coefficients rather low, because in those parts of the images the correlation is negative.

4. Statistics of special cases

From subjective analysis of satellite images combined with vorticity advection fields and from some previous works (Zwatz-Meise and Mahringer, 1990: Zwatz-Meise and Bendl, 1992) it was concluded that there are some typical cloud configurations that are usually related to maxima of cyclonic vorticity advection. For example, enhanced cumulus clouds as well as cloud structures that form the shape of a comma, both of which usually develop in cold air behind a cold front, show very good spatial correspondence to PVA maxima. Besides those, in the regions where intensification of cloudiness on a cold front caused by jet streaks or waves is observed in the satellite image, parameter analyses usually show that cyclonic vorticity advection maxima are also present.

Considering these facts it was of great interest to perform an additional statistical evaluation, taking only those cases in which mentioned cloud structures were found in the satellite image. Therefore 16 cases of comma structures, enhanced cumulus clouds and frontal intensification were selected. The difference in results is obvious for IR pixel values greater than 169. Instead of 55 to 70% of grey shade values above 169, which corresponded to positive vorticity advection at 300 hPa for the whole 6-month period, in selected cases 60 to 90% of pixels have PVA (Fig. 5). If vorticity advection intervals are taken separately, for all six months 30 to 50% of pixel values above 169 correspond to VA values above $10 \cdot 10^{-9}$ s^{-2}, while for selected cases percentage is 50 to 70% (Fig. 6). This clearly shows that the correlation of grey shade values and vorticity advection is much better for those special cases. Since the number of

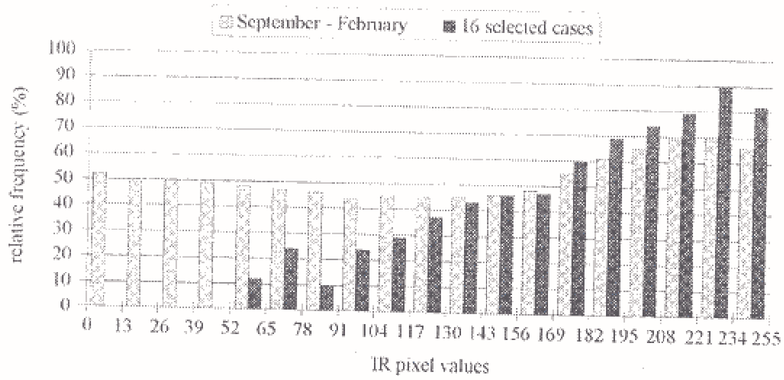

Figure 5. Relative frequencies of points with positive vorticity advection at 300 hPa for all six-months data (grey) and for 16 selected cases (black).

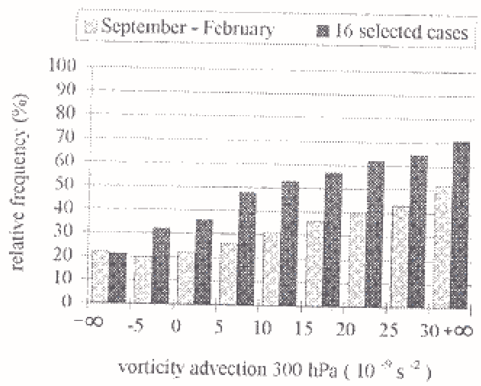

Figure 6. Relative frequencies of pixels in IR image with grey shade values greater than 169 for all six-months data (grey) and 16 selected cases (black).

special cases that were taken is very small compared to the number of data taken for general statistics, it can be presumed that greater number of selected cases would give even better results.

5. Conclusions

The results of general statistics showed that all average correlation coefficients between vorticity advection values and pixel values in IR satellite image are positive, indicating that greater vorticity advection results in brighter grey shade levels. The best correlation is found for 300 and 500 hPa levels. Although the general correlation is not very good, there are cases where this correlation is significant. A comparison between statistics of all six months data and the one for selected cases showed that relative frequencies of pixel values above 169 for PVA greater than $10 \cdot 10^{-9}$ s^{-2} rise by about 20% when only comma structures, enhanced cumuli and frontal intensifications are selected. The analyses pointed out that in those cases correlation can be considered as satisfactory. The result would probably improve if more cases were used.

This also means that in the case of mentioned special cloud structures prognostic vorticity advection data alone can be used for forecasting of cloud development. Once a structure in the satellite image is recognised as one of the mentioned cloud structures, its further path and development can be forecasted by following the corresponding vorticity advection maximum and its change in prognostic charts. However, the fact that one should first recognise a cloud structure in the image and relate it to one particular maximum, means that prognostic vorticity advection values can only be used in combination with satellite images. Whether this prediction can be done numerically on basis of the statistic results presented here is still left to be shown. Furthermore, since vorticity advection is only one of the forcing functions causing the rising motion, the other processes should also be included into a general method for cloud forecasting.

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Appendix

In order to develop a method for objective satellite image interpretation or the one that could be used for cloud forecasting, several dynamical processes have to be considered. It is assumed that rising motion is a prerequisite for the development of most of the cloud types. Therefore processes related to upward motion have to be discussed. There are four quasigeostrophic forcing functions associated with the rising motion:

1. Vorticity advection becoming more cyclonic with height, or with respect to $-p$ (p – pressure).
2. A local maximum of temperature advection
3. The vertical component of the curl of the frictional force becoming more cyclonic with height
4. A local maximum in diabatic heating.

Each forcing function is dependent on others and the nett effect of all forcing functions is additive. Nevertheless, the effects of each function can be discussed as if it operated alone. This work discusses only the effects of differential vorticity advection.

Those effects can be presented on the example of a typical wavetrain in the baroclinic westerlies in middle troposphere (Fig. 7). There is a cyclonic (positive) vorticity advection downstream from the maxima in absolute vorticity, which are located along the trough axes. The magnitude of vorticity advection is usually larger in upper levels than it is at the surface when pressure systems tend to be circular. Therefore cyclonic vorticity advection gets more cyclonic with height which causes upper level divergence and rising motion in middle troposphere downstream from the upper-level troughs. Practical work showed that if the wind speed is assumed to be increasing with height, then instead of using vertical increase of PVA, pronounced maxima of cyclonic vorticity advection at one upper-tropospheric level can be taken as an

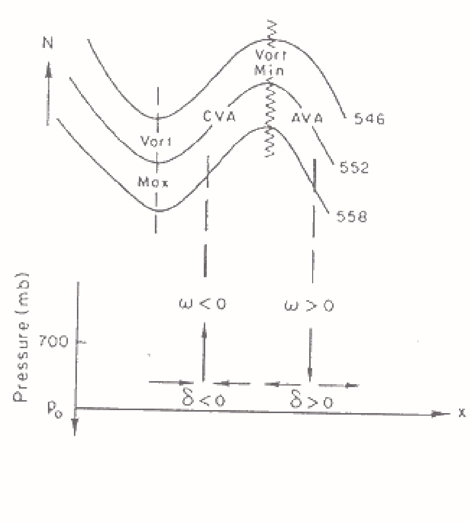

Figure 7. The effects, according to quasigeostrophic theory, of differential vorticity advection in a typical wavetrain in the baroclinic westerlies. Height contours at 500 hPa in dam (solid lines); CVA (cyclonic vorticity advection) and AVA (anticyclonic vorticity advection). The corresponding vertical velocity (ω) and horizontal divergence (δ) patterns are given below. (From Bluestein, 1993).

indication of ascending motion (Zwatz-Meise and Bendl, 1992). It should, however, be emphasised that vorticity advection in middle and upper troposphere does not cause the development of high-level (cirrus) clouds. The clouds that are expected to develop due to differential vorticity advection are mostly convective or cumulus clouds with cold cloud tops, which make them appear very bright in the IR satellite images.

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