Search of potential vorticity anomalies through dry intrusions detection on water vapour images

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Abstract: - The relation between potential vorticity anomalies and occurrence of intensive convection could be investigated through detection of warm areas on satellite WV pictures in the spectral channel of 6.2 µm. Unlike other articles dependence was not tested on selected situations but on a common four-month series of data. Within processing eleven variants of detection were checked.

Key-words: - Potential vorticity anomaly, WV satellite imagery, dry intrusion

1 Introduction
In terms of cyclonegenesis, a knowledge of potential vorticity distribution is a quite useful tool. Although favorable conditions of the existence of convection are often first of all subject to processes of large scale, the smaller surface formations and effects tending to be the initiating mechanism, are usually insufficiently recorded by the model and thus also formable. A convection which is the result of dynamic processes at upper troposphere layers, whether on a synoptic or a mesosynoptic scale, is reflected in a higher degree of its organization and consequently in a better predictability [3], [9].

Formations such phenomena tend to be well-distinguishable in WV pictures. Such places manifested by tropopause lowering and areas of dry or descending air appear as small dark patches, points or belts. The mentioned anomalies of tropopause height (potential vorticity anomalies) are an important factor in the development of dynamically induced convection. In these places the stratospheric air with low θw (wet bulb potential temperature) moving over the low-laid layer of warm air with high θw generates an area of potential instability at middle levels [2],[5].

If as one of the basic assumption, the existence of connection between potential vorticity structure, dry intrusions, dry bands, tropopause height and warm dark areas distribution on water vapour images (WV images) is considered, it is possible to set up method of detecting potential vorticity anomalies on searching areas with higher brightness temperature compared to the surrounding environment.

2 Used data
As a basic source of processed data were used satellite images taken by Meteosat 8 in the spectral channel 6.2 µm. The temporal resolution of the sequence was 15 minutes, spatial resolution 3 x 3 km at nadir (approximately 4 x 6 km in the Central Europe) [8]. Images were stored in original geostationary projection and in the archival format XPIF.

As data proving strong convection occurrence were used radar images from Czech radar network CZRAD with the spatial resolution 1 x 1 km [8], [4] and time step 10 minutes. Images were converted to the two-dimensional matrixes of echo intensity values then adjusted by using georeference and calibration. In next stages of processing, only matrix elements corresponding to radar echo intensity being equal or more than 52dBZ were considered. Period under study covered time from 1 May 2006 00: UTC till 21 Sept. 2006 23:45 UTC. Approximately 2% of data could not be included in the processing due to poor quality.

3 Processing Methodology
As an initial ideological point was used ISIS method (Instrument de Suivi dans l’Imagerie satellitaire) [6] originally developed for detection of cold cloud tops in Metéor France. Subsequently this method was modified by Michel a Bouttier for usage on WV images [1]. Some of the used criteria and parameters were chosen with reference to the results published in the above-mentioned publications.
3.1 Detection of warm areas

The way of detection of warm areas was generally based on application of spatial determination through temperature criteria. Depending on assessment of characteristics of the whole images: minimum temperature $T_{\text{min}}$, maximum temperature $T_{\text{max}}$ and range of temperature $\Delta T$, the values of parameters used in the examined variants of detection methods were set up.

Three ways of determination (detection) of warm areas divided into eleven variations were tested. All of variants used three common basic initial parameters in terms of detected areas: required minimum temperature $T_{\text{min}}$, required minimum area $S_{\text{min}}$, and required minimum range of temperature $\Delta T_d$. A detailed survey of variants and corresponding parameters are available in the table 1 and [7].

**Detection method 1** was only based on application of three basic parameters $T_{\text{min}}$, $S_{\text{min}}$ and $\Delta T_d$. The variants of this method are simple analogies to horizontal sectional views of spatial distribution of brightness temperature.

**Detection method 2** considered besides three basic parameters, another parameter - required minimum temperature difference between border pixels falling into the detected warm area and neighboring pixels extrinsic to the detected area: $\Delta T_h$ (see Fig.1). Temperature difference value was set up $\Delta T_h \geq 0.3^\circ\text{C}$.

![Fig.1 Scheme of the 2nd method of warm areas detection (horizontal projection). Empty points represent pixels falling into the detected area, full points extrinsic to the area. Temperature difference between them represents $\Delta T_h \geq 0.3$ K.](image1)

**Detection method 3** included mentioned three basic parameters plus criterion of continual decrease or at least constancy of brightness temperature values from pixel with maximal temperature of detected area $T_{\text{max area}}$ towards to the edges of detected warm area (determined by border pixels brightness temperature), then $T_{\text{max area}} - T_{\text{i}} = \Delta T_d$ (Fig.2). Temperature values were rounded off by 0.3°C, 0.6°C, 1.0°C for the rest of tested variants.

![Fig.2 Scheme of the 3th method of detection. $T_{\text{min}}$ is required minimum temperature, $T_{\text{i}}$ is rounded off temperature, $\Delta T$ represents value of rounding $T_{\text{n}}, \Delta T$ difference between $T_{\text{max area}}$ and $T_{\text{min area}}, \Delta T_d$ required minimum range of temperature of detected area, $S_{\text{min}}$ required minimum area. Modified, see [9].](image2)

3.2. Comparison of occurrence of detected warm areas and radar echos

In the next phases of processing, position data and time of occurrence of detected warm areas were compared with occurrence of deep convection (chosen radar echo intensity equal to or higher than 52dBZ). The evaluation was done under the simplified presumption that deep convection clouds develop only in conjunction with the presence of the upper temperature anomaly (detected warm areas on WV images in this case). Two approaches were used for data processing. In both of them, the occurrence of detected warm areas was searched in the time interval up to 24 hours prior to radar echo registration.

In the 1st approach, presence of detected warm area in the neighborhood of fixed defined area (determined area within 256 km from both Czech radars) was tested. Warm anomalies were searched in predefined distances: up to 0 km (detected warm area occurred inside radar range coverage), 100, 200, 300, and 400 km behind the edge of the coverage by Czech radar network. Subsequently, these data were compared with a number of radar echo pixels from cumulative intervals: > 100, > 200, > 300, > 500, > 1000, > 1500 pixels. The terms with lower numbers of pixels were also taken into consideration.

In the 2nd approach a relative position of deep convection cores (pixels with the intensity equal or higher than 52 dBZ) were investigated. For each radar echo larger than 9 pixels, the centre of gravity...
was defined. Then searching through the area determined by intervals: 0 to 50 km; 51 to 100 km; 101 to 200 km; 201 to 300 km; 301 to 400 km from centre of gravity was inspected. Results of the 2nd approach were evaluated by an occurrence frequency whilst the 1st approach by standard statistical characteristics POD, FAR, EQS.

3 Results
In evaluation of all methods, the following characteristics were investigated first: number of detected areas, size of detected areas, minimum and maximum temperature as well as range of temperatures of detected areas.

3.1. Temperature characteristics derived from the whole images
Total distribution of all brightness temperature values corresponded well to the normal distribution. Maximum frequency of values was observed around 231K. Values $T_{\text{min}}$ were chosen on the basis of data assessment. The following cumulative frequencies of occurrence corresponded to the chosen brightness temperature values:

- $225.15 \text{ K (-48°C)}$ 8%
- $230.15 \text{ K (-43°C)}$ 40%
- $231.15 \text{ K (-42°C)}$ 48%
- $235.15 \text{ K (-38°C)}$ 78%
- $238.15 \text{ K (-35°C)}$ 91%
- $240.15 \text{ K (-33°C)}$ 96%

3.2. Assessment of characteristics of detected area
Data on values of temperature range within detected areas showed to be very interesting. In principle, these data illustrated how and which method and variant detects „deep” area. The greatest temperature range was recorded by detection method 1 and 2. The lowest temperature range was found by detection method 3. Data revealed a difference between individual months.

From the results came out that the structures of both the whole images and detected warm areas were not homogenous, but rather relatively ragged. However, detection method 3 consisting in smoothing by means of temperature value rounding off in order to eliminate an impact of small fluctuations in the field of temperature, did not prove itself as being suitable. Higher values rounding off being used by this method brought about a relatively rapid increase of number of detected pixels per image. Thus, it can be assumed that at certain value of rounding off, the resulting value of surface of detected area $S_{\text{area}}$ would approach to detection method 1. That is why, in further processing, attention was focused on the detection methods 1 and 2.

3.3. Comparison of occurrence of detected areas with radar
The results showed that the most often (in 25 to 30% cases) positions $T_{\text{max area}}$ of detected areas were located in the distance of 100 - 200 km from registered radar echoes. In terms of time, warm areas occurred mostly approximately 5 - 10 hours before the first registration of intensive convection. The same variant for an interval of 200 - 300 km was characterized by the little bit lower frequency. Frequencies of occurrence of detected warm areas through variant var_2 for all distance intervals were relatively low, and mostly, there were not more than 5%. It can be explained so that only a small number of these warm (i.e. deep) temperature (tropopause height) anomalies gets near to the Czech Republic territory. Other maximum frequencies in the time period of 20 hours and more were not apparently connected with the influence of detected warm areas, but they had been probably caused by a convection in the instable air after passage of a cold front.

However, it should be noted that the disadvantage of the selected method is the fact that a mutual position and direction of movement of detected warm areas and radar echoes was not taken into consideration. A high percentage of FAR was probably due to the fact that the number of detected areas also included latent dry bands, being characterized by only weak or no descending motions. Therefore they did not induce more intensive PV anomalies and i.e. convection. No doubt that results were also influenced by a selection of relatively high values of reflective capability (52 dBZ) corresponding only to very intensive convection. If the values were lower, the results would be probably more favourable.

3.4. Evaluation of geographic occurrence of detected areas
For the evaluation of geographic occurrence, one variant from detection method 2 and 3 and both variants of detection method 1 were chosen to illustrate the frequency distribution.
Visualized results of variant var_10 of the detection method 3 (Fig.3) in principle revealed the uniform frequency distribution occurrence within geographic region under study. Even though clusters did not directly indicate a character of paths of detected warm areas or dry intrusions, it is evident from the figure that the occurrence of areas detected by this variant in the North was concentrated into a smaller number of areas compared to the South. Using detection method 2, represented by variant var_5, the maximum number of detected pixels was higher in comparison with method 3, though also here, the frequency of distribution of pixels on the greater part of studied area was not more than 1% (Fig.4). Results for variants var_1 and var_2 of detection method 1 confirmed the zone character of distribution of detected pixels (Fig.5, Fig.6).

Results show that very deep, and thus intensive intrusions, occurred more in the West than in the East and rather above sea than above land. Such finding can be interpreted as a partial conclusion saying that probability that moving cold front will be accompanied by a dry intrusion, being able to release an instability of the part of troposphere and consequently to generate an intensive convection, is higher above Western Europe than above Central Europe. A low percentage of occurrences detected by method 3 evidences a low detection capability. That was why, all variants of the 3rd method were excluded from further processing.

4 Conclusion
The aim of chosen detection method of warm areas was to verify a validity of dependence of development of deep convective clouds on the occurrence of the temperature (potential vorticity) anomalies for the Central Europe region. Data
analysis revealed a rather rugged structure of the whole images, including detected warm areas. However, solution using the detection method 3 consisting in smoothing out by means of rounding off temperature values in order to eliminate an influence of small fluctuations in the field of temperature, did not provide satisfactory results. That was the reason why attention was then focused on detection method 1 and 2.

Further potential improvement lie in elimination of the cases of detection of areas being not evidently connected with the anomalies of potential vorticity. This issue could be solved either by filtering off based on geographic determination or by connecting a detection of warm areas to the rear side of the cold fronts or jet streams. This could increase probability of detection of only dry intrusions or dry dynamic bands being associated with the presence of PV anomalies.

The proposed algorithm of the detection method 1 is implemented to the diagnostic-analytical application in testing mode use at the Department of Military Geography and Meteorology Department of University of Defence in Brno.

References:


Table 1: Summary of methods, variants and their parameters

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- **T**: 
  - 225.15 K
  - 230.15 K
  - 231.15 K
  - 235.15 K
  - 238.15 K
  - 240.15 K

- **S**: 
  - 9 pixels

- **round off**: 
  - 0.3
  - 0.3
  - 0.6
  - 1.0
  - 0.3

- **AT**: 
  - 15 K
  - 22 K

- **T_h**: 
  - 0.3 K

- **∆T**: 
  - 2.2 K
  - 1.5 K

- **9 pixels**: 
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- **var_1**
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- **var_3**
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- **var_4**
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- **var_5**
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