CHARACTERISTICS OF EMBEDDED WARM AREAS AND SURROUNDING COLD RINGS AND COLD-US

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Abstract

The paper addresses convective storms that exhibit cold ring or cold-U/V features surrounding embedded warm areas at their cloud tops, as observed in color enhanced infrared window satellite imagery. One of the main motivations of our work is the need to study mentioned features in an objective way. We propose an automatic method for determination of spatial properties of embedded warm areas and surrounding cold features. The algorithm was tested on several cases and first results indicate that it is possible to use ellipse for description of cold ring and cold-U/V features, i.e., that ellipse parameters can serve as characterization of spatial properties of the features. Examples of time evolution of the parameters are shown indicating time stability of the algorithm.

1 INTRODUCTION

Cold rings and cold-U/Vs surrounding distinct warm areas are observed in color enhanced infrared (IR) window brightness temperature (BT) satellite imagery of some convective storms (e.g. Setvák et al., 2010). The warm area inside the cold ring is called central warm spot (CWS), the warm area inside the cold-U/V in the vicinity of its apex is called close-in warm area (CWA). Both of them constitute general category called embedded warm areas (EWAs; Setvák et al., 2010). Typically, one more warm area (distant warm area, DWA), which is more transient, occurs further downwind between the remote parts of the cold-U/V arms (Heymsfield and Blackmer, 1988; Heymsfield et al., 1991). Plenty of studies were published concerning these features, first of them in the early 1980's (Adler et al., 1981; Fujita, 1982; Heymsfield et al., 1983a; Heymsfield et al., 1983b; McCann, 1983; Negri, 1982). Nevertheless, no quantitative definitions of these features exist so far. Sometimes the duration of more than approximately 30 – 40 minutes is required for referring the features as cold-U and CWA or cold ring and CWS (e.g. Setvák et al., 2010).

Several explanations of formation of these features were suggested including microphysical properties of cloud top particles, wake effects, plume masking mechanism and other processes (e.g. Heymsfield and Blackmer, 1988; Heymsfield et al., 1991; McCann, 1983; Setvák et al., 2010). However, origin and dynamics of these features have not been fully explained yet, although naturally a lot of helpful results has been already obtained. Studies based on observations as well as modeling exist which imply that thermal inversion above tropopause and upper-level wind shear are probably the key factors for formation of cold rings and cold-U/Vs (e.g. Setvák et al. 2008; Setvák et al., 2010). Setvák et al. (2008) and simulations made by Wang (2009) also indicate that occurrence of cold rings is associated with weak upper-level wind shear whereas cold-U/Vs are associated with stronger wind shear. Nevertheless, the difference in conditions leading to evolution of cold rings and cold-U/Vs is not exactly understood yet. Usually, either cold rings or cold-Us occur on storm cloud tops in given situation, however, sometimes both features are observed simultaneously on cloud tops of two nearby storms, i.e., in the same or very similar environmental conditions. Sometimes even transformation between CWS and CWA occurs (Setvák et al., 2008; typically a cold-ring-shaped storm transforms into a cold-U/V-shaped one), which suggest existence of some relationship between these two features.

One of the latest studies (Homeyer, 2013) indicates that presence of above-anvil stratospheric cirrus clouds is the most likely explanation of CWAs enclosed by cold-U/V features. The work is based mainly on high-resolution three-dimensional radar observations and the explanation of CWA by presence of stratospheric cirrus is justified by excluding other possible explanations. Homeyer, however, mentions also some uncertainties in used techniques and notes that further studies are required to examine the proposed explanation.

Usually, well pronounced overshooting top (OT) is observed at the apex of the cold part of the feature, at least at some stage of storm evolution. In some cases (not often, usually in a later stage of the storm evolution), however, the overshooting top evolves inside the EWA without disturbing its existence (as shown e.g. in Fig. 2a). Such evolution has not been unambiguously explained yet.

In addition to mentioned investigation of origin and evolution of embedded warm areas surrounded by cold features also first research on their objective detection has been already done. Different methods are described in Vaníčková (2007), Brunner et al. (2007), Bedka et al. (2011) and Iršič Žibert and Žibert (2013).

Main aim of our current study is to explore feasibility of automatic evaluation of spatial and temporal parameters of cold-Us with CWAs and cold rings with CWSs. Our research is motivated by mentioned uncertainties in origin and dynamics of these features together with their observed association with occurrence of severe weather (e.g. Adler et al., 1985; McCann, 1983). In section 2 we propose and describe an automatic method for fitting cold features surrounding embedded warm areas by rotated ellipses with the aim of automatic objective determination of spatial properties of the features. Section 3 shows examples of automatically fitted ellipses for several different cases including an example of their time evolution. Moreover, time evolution of output parameters describing spatial properties of embedded warm areas and surrounding cold features is provided. Section 4 summarizes the results.

2 METHODOLOGY

As was already mentioned in the introduction, one of our goals is a development of automatic method for determination of spatial properties of embedded warm areas and surrounding cold features. In this section we propose first version of such method. Our algorithm was developed and tested on pre-selected set of cold-ring and cold-U/V-shaped storms. MSG SEVIRI IR10.8 band data are used as the primary inputs to the algorithm. Reasonably smooth and stable time evolution of the algorithm output (spatial characteristics of the feature in consequent times) is required.

Our aim is to describe spatial properties of the studied features by some parametrized geometrical shape. On the basis of subjective observations of the cold rings and cold-Us in satellite imagery, rotated ellipse was chosen as the best candidate. The rightness of the choice was verified by manual fitting and also a posteriori by first results of the fitting algorithm (shown in section 3).

By the nature of the cold rings and cold-U/Vs, there exists a “BT trough” (a curve of local brightness temperature minima) around local temperature maximum (or maxima) of the feature. The algorithm is based on detection of such BT troughs, their fitting by rotated ellipses and determination of their spatial properties using five parameters of the ellipse (center coordinates, half axes, orientation). Alternatively, one could describe spatial properties of a cold feature by the ellipse that has minimal average temperature along its curve. However, during our testing usage of this alternative definition was unstable in some situations, typically in the later stages of storm evolution where the temperature profile of the cold feature and its close surrounding is often very flat.

Particular steps of the procedure are illustrated in Fig. 1. At first the algorithm finds local mimima and maxima in IR BT field inside storm cloud top (area with IR10.8 BT less than 240 K; see Fig. 1a). For each relevant local maximum (corresponding to the embedded warm area) several nearby local minima with the largest BT gradients relative to the maximum are selected (Fig. 1b). Further in the text we call each such pair of maximum and assigned minimum as a “couplet”. Taking into account more couplets for the same feature increases probability of successful BT trough detection in more complex situations, e.g., in a case of an overshooting top occurring inside a CWS (an example shown in Fig. 2a). Therefore, all the following steps are done simultaneously for all the couplets with the same local temperature maximum. In the second step the algorithm detects "skeleton" of the feature, i.e., continuous area colder than couplet's maximum at least by ΔT_{Sk} ~ 2K which contains couplet's minimum (Fig. 1c). Subsequently, "contour points" of the feature (continuous BT trough located inside the skeleton surrounding couplet's maximum) are detected (Fig. 1d). The BT trough is considered continuous if the distance of neighboring points is smaller than ad hoc chosen value Δ. Sensitivity of the results on the value of Δ will be tested in the future. Contours that do not surround the warm spot at least in the angle 216° are rejected at this point. Approach of the contour finding was partially inspired by Bedka et al. (2011) and Iršič Žibert and Žibert (2013). In the last step of the algorithm the contour points are fitted by an ellipse (Fig. 1e, 1f) such that parameters of the ellipse (center coordinates, half axes, orientation) are determined to minimize average distance between the ellipse and the contour points. The fitting is performed only for range of angles corresponding to the detected contour points which enables to cover also cold-U/V cases where the contour is unclosed by the nature of the feature (see Fig. 3). For cases with more complex BT field, where ellipses found for different couplets with the same local maximum are not identical, the ellipse with the lowest average temperature along its curve is selected.

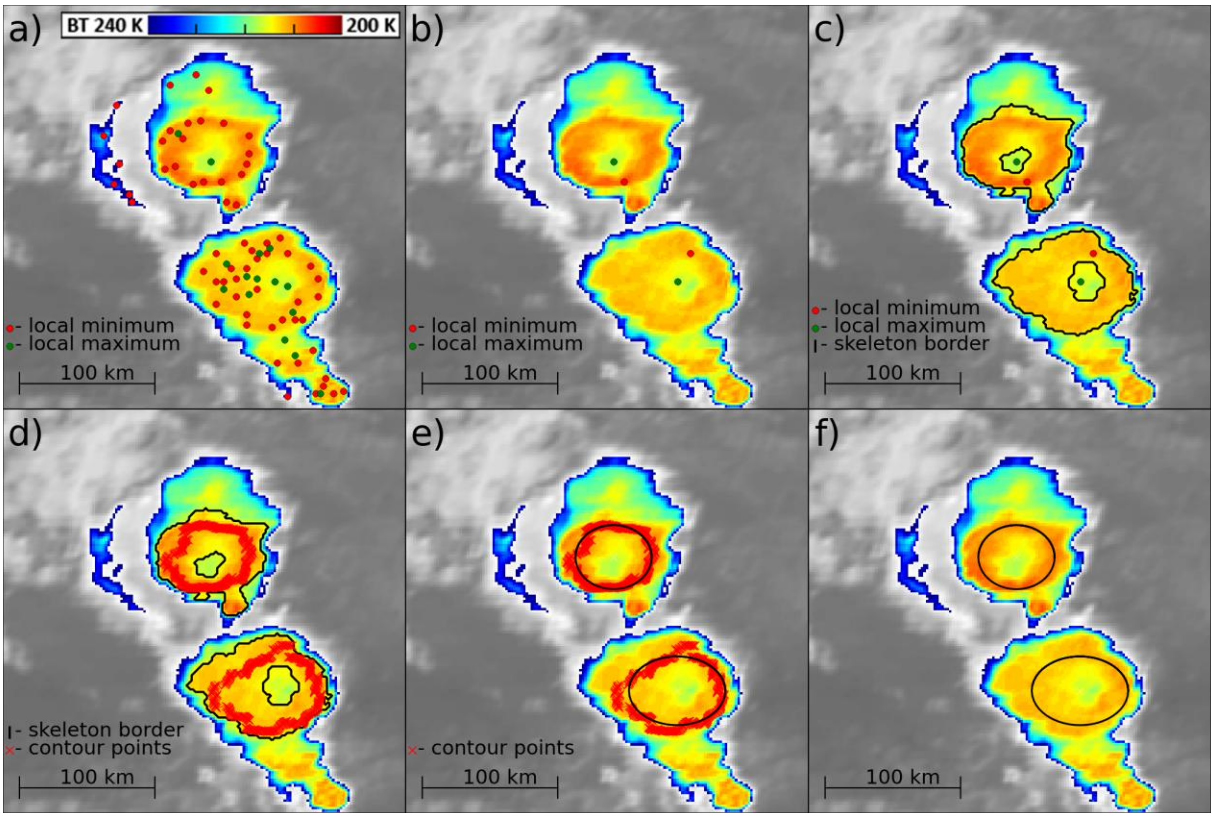

Figure 1: **Illustration of individual steps of automatic procedure for fitting of cold feature by ellipse showed on storms above the Czech Republic and Austria on 25 June 2006 13:45 UTC. a) detection of local minima and maxima; b) couplet detection; c) detection of skeleton; d) detection of contour points (BT trough); e)-f) fitting of contour points by ellipse. For simplicity, steps b)-f) are shown only for a single couplet for each feature.**

3 EXAMPLES OF ALGORITHM OUTPUTS

In this section we show examples of results obtained by the fitting algorithm for several different cases. Results of the fitting for two storms with well pronounced CWSs and cold rings were already shown in Fig. 1. As was already mentioned in the introduction, sometimes (not often, usually in a later stage of the storm evolution) an overshooting top evolves inside EWA without disturbing its existence. Fig. 2a documents that the automatic procedure is suitable also for such cases. We note that success of the algorithm in such situations, where isolated local temperature minima are located next to the cold part of the feature (both, outwards or inwards), is largely enhanced by taking into consideration several candidate couplets for each local temperature maximum as described in the previous section. Another example (Fig. 2b) illustrates that the algorithm also works well for relatively small storms. So far we have shown only results for cold-ring-shaped storms. However, as the procedure also enables to fit only a part of ellipse (unclosed contours), it is suitable also for cold-U/V features (see Fig. 3).

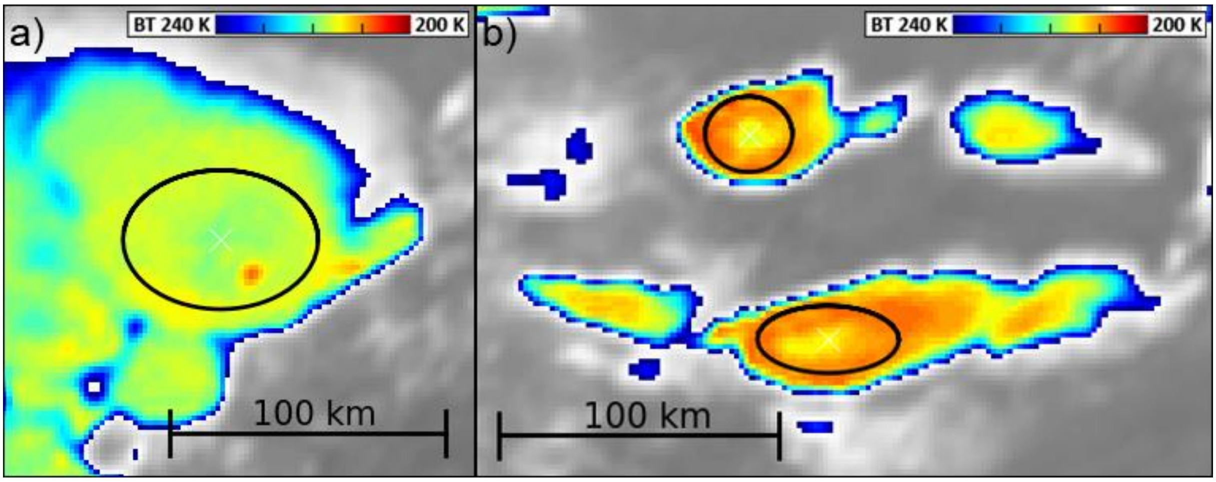

Figure 2: **Examples of ellipses fitted by the automatic procedure for a) cold-ring-shaped storm with cold overshooting top inside the CWS on 5 July 2012 at 13:25 UTC above Germany; b) two relatively small cold-ring-shaped storms on 11 May 2009 at 16:35 UTC above Austria. For time evolution of parameters of these two ellipses see Fig. 5 and 6.**

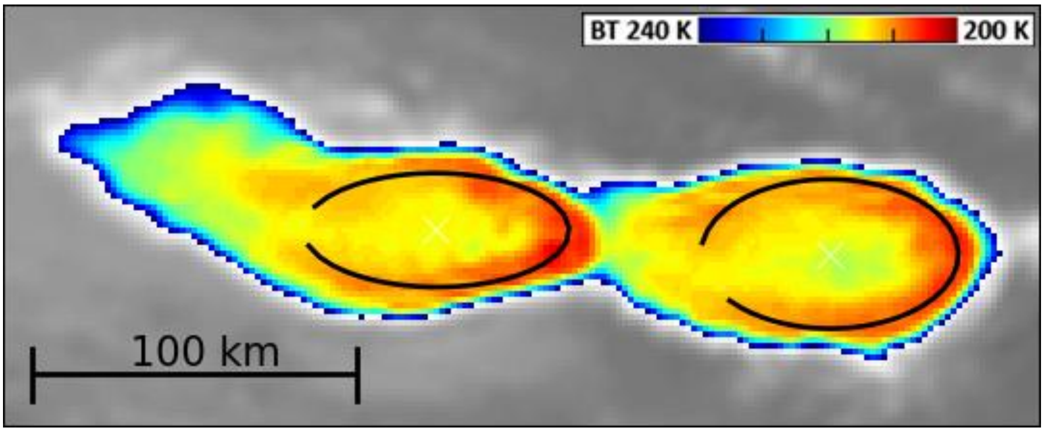

Figure 3: **Example of parts of ellipses fitted by the automatic procedure illustrating the suitability of the algorithm also for cold-U/V storms. Shown on storms on 31 May 2008 at 13:45 UTC above Germany. For time evolution of parameters of these ellipses see Fig. 4.**

Our first results show that the algorithm is stable in time in the sense that it provides reasonably continuous time evolution of the output parameters for most of the tested cases. Hence, the obtained results are sufficient for determination of trends in evolution of parameters (for examples see Fig. 4 and 5). An example of time evolution of fitted ellipses is shown in Fig. 6. We note here that in our current study we focus mainly on the increasing and mature phase of isolated storm cells which do not undergo merging or splitting. Merging of more cells, cell splitting as well as decay of the storm anvil in later phase of its evolution lead to more complicated structure of BT field and adjustment of the algorithm for such behavior is planned in future.

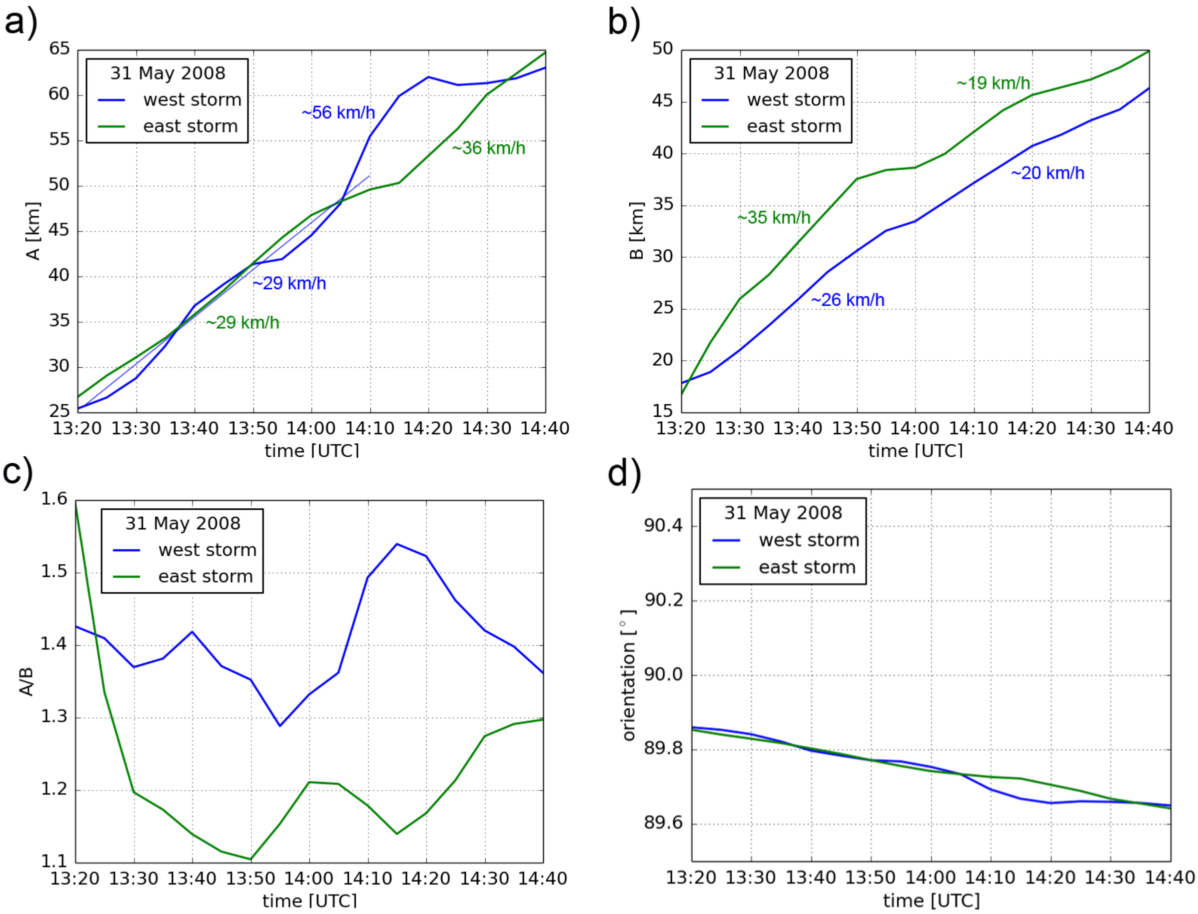

Figure 4: **Evolution of ellipse parameters slightly smoothed for better visibility of the trends: a) half axis A, b) half axis B, c) ratio A/B, d) orientation of the ellipse (Westward = 90°, Northward = 180°) for the cold-U storms on 31 May 2008 above Germany (see Fig. 3).**

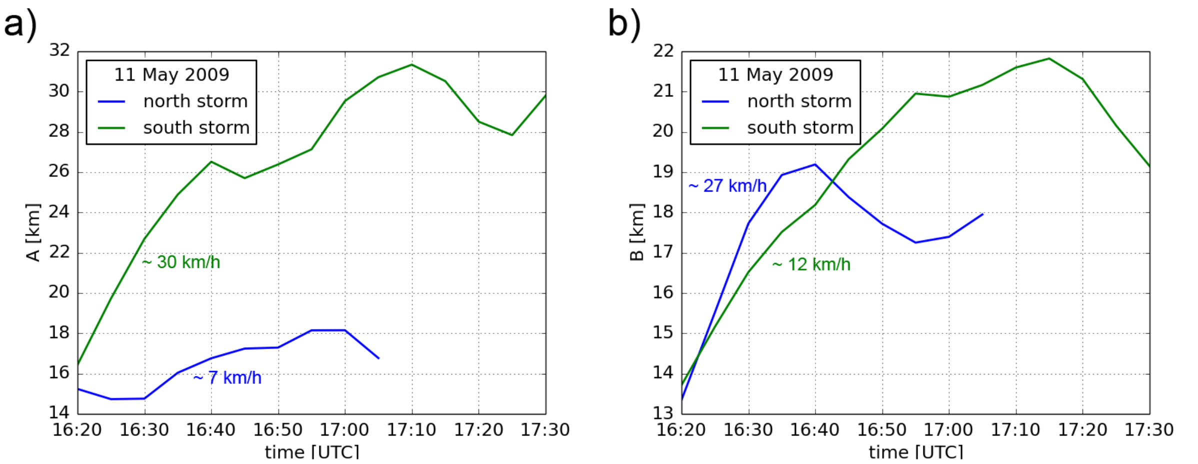

Figure 5: **Evolution of ellipse parameters slightly smoothed for better visibility of the trends: a) half axis A, b) half axis B for the storms on 11 May 2009 above Austria (see Fig. 2b and 6).**

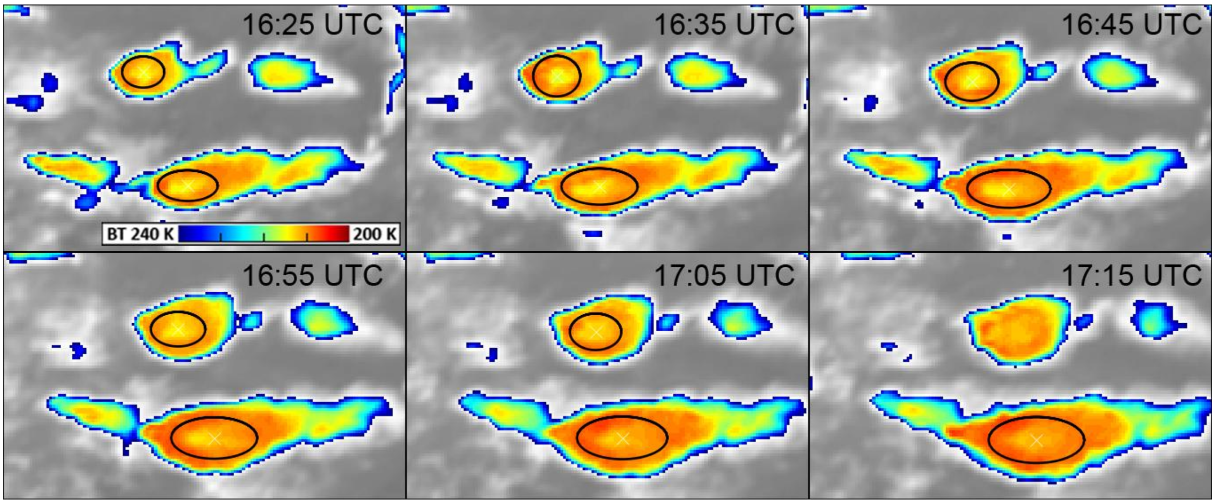

Figure 6: **Example of time evolution of fitted ellipses shown on storms on 11 May 2009 above Austria. For time evolution of parameters of these ellipses see Fig. 5. In the last frame (17:15 UTC) the north ellipse is not detected any more as the temperature difference between the embedded warm area and cold part of the feature is too small.**

4 CONCLUSIONS

In our study, we proposed an automatic method for objective determination of spatial properties of embedded warm areas and surrounding cold features and performed first tests of the method. First results indicate that it is possible to describe cold ring and cold-U/V features by rotated ellipse and that ellipse parameters can serve for description of spatial properties of the features. Change of parameters in time can provide valuable information about rates of processes taking place in upper parts of storm clouds. Automatic determination of spatial properties should enable and/or simplify quantitative comparison of observations based on satellite data with other meteorological variables as well as model results (e.g. Wang, 2007). The results show that the proposed algorithm is stable in time for most of tested cases.

Some improvements of the algorithm are, however, still planned. E.g., values of several parameters of the algorithm, such as definition of BT trough continuity, were chosen ad hoc and we expect that their adjustment made in conjunction with more thorough statistical evaluation of the algorithm output will improve its detection and fitting capability. In the current version, the algorithm cannot be used for automatic detection of the studied features as the false alarm ratio is too high. Therefore, we also plan to adjust couplet detection by incorporating OT detection algorithm (e.g. Bedka, 2011) and interconnect the method with an automatic algorithm detecting cold rings and cold-U/Vs previously studied by Vaníčková (2007), Brunner et al. (2007), Bedka et al. (2011) and Iršič Žibert and Žibert (2013).

Our future work will focus on application of the method on larger data set and on statistical evaluation of obtained results. One example of planned processing is comparison of feature orientation with upper-level wind directions.

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