# Identification and Tracking of Convective Modes based on Radar Data 

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## I. INTRODUCTION

Significant research has been done over the past decades on the topic of convective systems, and numerous case studies have led to a greater understanding of the variety of different convective modes. Despite the existance of many case studies, only a few studies have attempted to gain a first impression of the overall properties of every convective mode; for instance, Gallus et al. (2008) and Duda and Gallus (2010) did an analysis of severe weather reports as a function of convective modes during spring and summer in the United States. In both papers, gridded radar reflectivity data were used to distinguish between different convective storm types. Duda and Gallus (2010) also used the output of the NSSL MDA (cf. Stumpf et al. (1998)). Here we present a first attempt to identify convective modes using solely radar reflectivity and velocity volume data; we focus on case studies for verification of the detection and characterization algorithm, before it will be used for a long-term, statistical study.

## II. DATA AND METHODOLOGY

Radar data from the IMK C band Doppler radar are used to identify convective storms and to determine the convective mode. All datasets used in this work have 14 elevations from $0.5^{\circ}$ to $30^{\circ}, 360$ azimuthal intervals of $1^{\circ}$ beam width, and 240 radial intervals of 500 m length. Reflectivity volume data are available every 5 minutes, while dual PRF velocity data are obtained every 10 minutes. To determine the mode of convection, a time step of 10 minutes is used in order to guarantee availability of velocity data to check for deep organised rotation.

The identification and tracking routine TRACE3D, developed by Handwerker (2002), is used in this work. Some preprocessing is necessary to eliminate spurious data which could negatively impact the subsequent routines. Especially noise within the velocity dataset is a problem, since the correlation and regression analysis, which is performed to find the centers of deep organised rotation associated with a reflectivity core (RC), is very sensitive to noise. Ground clutter and second trip echoes also have to be removed whenever possible, using the routine RMSTE (cf. Bückle (2010)).

To separate isolated cells from multicells, the number of reflectivity cores within a contiguous region of precipitation (ROP, $Z \geq 25 \mathrm{dBZ}$ ) is counted. A region of precipitation with two or more RCs is therefore classified as a multicell cluster. Some isolated cells may be embedded in a large region of stratiform precipitation and for this purpose, the ratio of the RC area and the ROP area is checked. A principal component
analysis is performed to distinguish between convective systems which are approximately elliptically shaped and others which have a more linear shape. An axis ratio of 3 or more indicates that a storm is likely to be a line. Isolated cells are only checked for a linear or elliptic shape if their first principal axis has a length of at least 10 km . Clusters which have a first principal axis of 50 km or more or a diagonal length of at least 100 km with a first principal axis of at least 25 km are considered to be an MCS.
Supercells are the most difficult convective mode to determine as the noise filter applied to the velocity dataset is by far not perfect. Another problem is detection and tracking of the strongest vortex center which is obtained by a correlation analysis of the radial velocity in the vicinity of an RC, and the vortex core of a simulated, idealized mesocyclone with a known radius $r_{m}$ and angular velocity $\omega_{m}$, transformed into radar coordinates and reduced to the radial component which can be measured by the radar. For the calculation of the vortex core, solid body rotation with a constant angular velocity $\omega_{m}$ inside and zero velocity outside is assumed. The data is discarded for any dataset for a specific radial and azimuthal position which turns out to have data available either only on one side of the velocity dipole, or for less than five entries, or for less than one third of the maximum available number of data points.

To be classified as a deep organised vortex signature, there has to be a vertical column at one radial and azimuthal position where both fields are strongly correlated, i.e. $\left|\rho\left(v_{a}, v_{m}\right)\right|>0.8$ and an angular velocity $\omega \geq \frac{1}{r_{\text {meso }}} \cdot 5 \mathrm{~ms}^{-1}$ is reached over at least two elevations. It is possible to detect both cyclonic and anticyclonic rotation with this method, which is shown in two case studies (see Sec. III).

A supercell has to have a vortex signature with a mean tangential velocity $\overline{v_{t}}=r_{\text {meso }} \overline{\omega(r, \varphi, \epsilon)}$ at the vortex edge at or above $v_{t, \text { min }}=5 \mathrm{~m} \mathrm{~s}^{-1}$ over all elevations with nonzero angular velocity. The direction of rotation has to stay constant in the whole vertical column, which is confined to a height between 1 km and 6 km AGL to exclude most of the outflow dynamics in the upper part of a convective storm and most of the boundary layer turbulence effects. This signature has to be observed over at least three subsequent dual PRF scans ( 30 minutes). During one scan, the vortex signature must at least be strong, which means a maximum tangential velocity above $10 \mathrm{~m} / \mathrm{s}$. The current version of the algorithm does not distinguish between different severity levels, rather it marks every RC which has a cyclonic or anticyclonic vortex signature. The cell tracking is done using the ASSIGN routine of TRACE3D and connecting the assignment with the convective mode stored at one single time step.

## III. PRELIMINARY RESULTS

## Improvements in TRACE3D

A new method is introduced to find a reasonable cut-off reflectivity $Z_{\text {min }}$ when performing the RC search. Instead of $Z_{\max }-10 \mathrm{dBZ}$, a histogram is computed for each ROP and the cut-off reflectivity $Z_{\min }$ is defined as the reflectivity of the 85 th percentile. Fig. 1 shows the accumulated relative frequency as a function of reflectivity. The cut-off reflectivity of the new method is marked with a red line, the blue lines show the maximum reflectivity and $Z_{\min }$ as used in the old method.


FIG. 1: Relative frequency of pixels from the ROP 5 on June 7, 1998 at 12:00 UTC as a function of reflectivity. Using the old method to determine $Z_{\min }$ in TRACE3D will result in less than $0.5 \%$ of all pixels within ROP 5 to form RCs. Some small structures are lost as the new method shows a lot more merging events, and therefore large RCs, but for identification of convective modes, a high detection efficiency is more crucial than a large number of RCs.

In this case, the old method missed a lot of RCs within the squall line, while the new method found most of the individual RCs within the squall line. The reflectivity cores within ROP 5 represent most parts of the squall line. A comparison of both methods at one single time step is shown in Fig. 2.

## Case Study I: Cyclonic Supercell on June 9, 2010

A supercell with cyclonic rotation developed over eastern France and entered the observation area around 15:30 UTC. At this time, this convective cell had a distance of more than 100 km to the radar site and no vortex signature could be observed. After 18:30 UTC, this storm was merged with another storm which had its origin over the Black Forest and moved to the NNW, whereas the cyclonic supercell moved from SW to NE. $X$ and $Y$ are Cartesian coordinates which are calculated w.r.t. the radar site (centered at $(0,0)$ ) and represent the x and $y$ distance of the strongest vortex signature from the radar (which is not necessarily the centre of the mesocyclone). Fig.


FIG. 2: Top: RC output of TRACE3D at 12:00 UTC on June 7, 1998 using the old method to determine $Z_{\text {min }}$.
Bottom: RC output of TRACE3D at the same time but using the new method for $Z_{\text {min }}$.

3 shows the track of the supercell and the properties $X, Y$, $Z_{\max }, \omega$ and $r_{m}$ are listed in Tab. I.

## Anticyclonic Supercell on July 12, 2011

In the afternoon of July 12, 2011, a severe supercell storm formed SW of Heilbronn and produced hail up to 4 cm in diameter. This storm is first detected in the data at 15:25 UTC and leaves the observation area after 18:10 UTC. A time series similar to Tab. I is shown in Tab. II. The vortex signature disappeared after 17:40 UTC due to a large radial distance and strong attenuation. Fig. 4 shows the track of the RC associated with the supercell storm.

## IV. CONCLUSIONS AND OUTLOOK

It could be shown that the new algorithm performed well in finding the RCs within a squall line and tracking two example supercells, one cyclonic and the other anticyclonic. Other case studies are planned to ensure that the good performance here is not coincidental. Especially the angular velocity thresholds have to be checked for optimum values to distinguish between


FIG. 3: Track of the severe supercell storm on June 9, 2010 from 15:25 UTC until 19:00 UTC.

| $t$ (UTC) | $X(\mathrm{~km})$ | $Y(\mathrm{~km})$ | $Z_{\max }$ | $\omega\left(10^{-3} \mathrm{~s}^{-1}\right)$ | $r_{m}(\mathrm{~m})$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $15: 50$ | -89.7 | -56.0 | 67.6 | 1.73 | 4000 |
| $16: 00$ | -88.1 | -48.8 | 67.4 | 2.56 | 4000 |
| $16: 10$ | -84.4 | -43.0 | 65.2 | 3.40 | 4000 |
| $16: 20$ | -74.2 | -37.8 | 66.5 | 8.06 | 3000 |
| $16: 30$ | -70.3 | -34.3 | 67.8 | 6.82 | 3000 |
| $16: 40$ | -67.5 | -25.9 | 69.7 | 7.67 | 4000 |
| $16: 50$ | -57.3 | -25.5 | 69.0 | 12.6 | 2000 |
| $17: 00$ | -42.7 | -24.6 | 65.3 | 6.99 | 2000 |
| $17: 10$ | -41.8 | -26.1 | 64.2 | 11.8 | 2000 |
| $17: 20$ | -34.5 | -14.0 | 64.5 | 3.00 | 5000 |
| $17: 30$ | -44.8 | -6.3 | 64.9 | 5.10 | 3000 |
| $17: 40$ | -41.2 | 0.7 | 65.4 | 3.56 | 5000 |
| $17: 50$ | -29.2 | 0.5 | 66.8 | 4.94 | 3000 |
| $18: 00$ | -23.4 | 4.1 | 65.7 | 4.18 | 4000 |
| $18: 10$ | -25.8 | 20.2 | 69.0 | 10.5 | 2000 |
| $18: 20$ | -24.0 | 13.9 | 68.0 | 6.60 | 3000 |
| $18: 30$ | -9.2 | 10.9 | 65.0 | 2.65 | 5000 |

TABLE I: Time series of the cyclonic supercell on June 9, 2010

| Time (UTC) | $\mathrm{X}(\mathrm{km})$ | $\mathrm{Y}(\mathrm{km})$ | $Z_{\max }$ | $\omega_{\max }\left(10^{-3} \mathrm{~s}^{-1}\right)$ | $r_{\text {meso }}(\mathrm{m})$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $15: 30$ | 4.8 | -30.3 | 56.7 | -1.81 | 5000 |
| $15: 40$ | 7.8 | -24.0 | 64.1 | -2.51 | 5000 |
| 15:50 | 11.6 | -16.6 | 68.1 | -2.71 | 5000 |
| $16: 00$ | 24.0 | -16.8 | 67.1 | -4.92 | 3000 |
| $16: 10$ | 28.7 | -1.5 | 69.7 | -5.27 | 3000 |
| $16: 20$ | 31.4 | -4.4 | 67.3 | -4.46 | 4000 |
| $16: 30$ | 45.0 | -4.7 | 68.4 | -4.44 | 4000 |
| $16: 40$ | 53.2 | 0.9 | 69.0 | -8.36 | 2000 |
| $16: 50$ | 51.6 | -4.5 | 70.1 | -21.29 | 2000 |
| $17: 00$ | 61.3 | -7.5 | 66.3 | -11.8 | 2000 |
| $17: 10$ | 56.3 | -6.9 | 65.2 | -2.68 | 5000 |
| $17: 20$ | 67.4 | -10.7 | 67.8 | -2.52 | 5000 |
| $17: 30$ | 73.2 | -1.3 | 67.9 | -1.36 | 5000 |
| $17: 40$ | 80.6 | -4.2 | 63.2 | -1.17 | 5000 |

TABLE II: Time series of the anticyclonic supercell on July 12, 2011


FIG. 4: Track of the anticyclonic supercell storm on July 12, 2011 from 15:25 UTC until 18:10 UTC. The mean storm motion was from WSW to ENE.
storms with marginal, short-term rotation and supercells with deep and strong rotation over a long period of time. After further development and evaluation, this algorithm is intended to be used for climatological purposes, e.g. to obtain the mean properties of supercells in SW Germany.

## V. REFERENCES

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