The Mesocyclone Detection Algorithm of DWD

Thomas Hengstebeck¹, Dirk Heizenreder², Paul Joe³, Peter Lang⁴
¹Deutscher Wetterdienst (DWD), Offenbach, Germany, thomas.hengstebeck@dwd.de
²Deutscher Wetterdienst (DWD), Offenbach, Germany, dirk.heizenreder@dwd.de
³Environment Canada, Toronto, Ontario, Canada, paul.joe@ec.gc.ca
⁴Deutscher Wetterdienst (DWD), Hohenpeissenberg, Germany, peter.lang@dwd.de


Dr. Thomas Hengstebeck, Deutscher Wetterdienst, FEZE-C
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Definition Mesocyclone*: A cyclonically rotating vortex, around 2-10 km in diameter, in a convective storm. Mesocyclones are frequently found in conjunction with updrafts in supercells.

*see AMS Glossary of Meteorology

Mesocyclones often occur in connection with severe weather events:

- Heavy rain
- Hail
- Strong winds
- Tornados

Structure of a typical supercell storm (adapted from Wallace, Hobbs, *Atmospheric Science*, 2006)

Automated Meso-Warnings can give valuable hints to meteorologists in the warning service (who usually cannot analyze all available data in real time).
MDA – Principle
Rankine Combined Vortex

Vortex wind field

Shear $s = \frac{dv}{dr}$

Rigid Rotation in inner region ($r \leq R$) → const. shear

Mathematical Model

$$v_{doppler} = v_0 \cdot \begin{cases} 
\frac{r}{R}, & r \leq R \\
\frac{R}{r}, & r > R 
\end{cases}$$

Figure adapted from S. V. Vasiloff: Improving Tornado Warnings with the Federal Aviation Administration’s Terminal Doppler Weather Radar Bull. Amer. Meteor. Soc., 82, 861–874, 2001

Adapted from http://www.nssl.noaa.gov/papers/dopplerguide/chapter4.html
**Appearance in radar (example)** Tornadic Supercell Großenhain, May 24, 2010 13:45 UTC reference time, Tornado rated F3

Doppler wind corrected data

Azimuthal profile

RC – vortex signature clearly visible
Doppler Data Preprocessing

- Correction of Doppler wind for DualPRF unfolding errors (Laplacian operator*)
- Calculation of azimuthal shear correcting aliasing

Combine long range and large measurement interval of Doppler velocities by means of DualPRF mode

For DWD Doppler scan (1200/800Hz):
- \( V_{\text{ext. Nyquist}} = 32 \text{ m/s} \)
- \( \text{Range}_{\text{max}} = 124 \text{ km} \)

ERROR if \( v_1 \neq v_2 \) (tolerance of 5.3 m/s exceeded)

**Assumption:** \( V_1 = V_2 \)

\[ \begin{align*}
    \rightarrow & \text{ derive } V_e \\
    \rightarrow & \text{ replace } V_2 \\
    \text{by } V_{2,e} = V_2 + n V_{2n}
\end{align*} \]

Simulated Data: Meso Vortex superimposed on unidirectional wind field, Gaussian noise added, DualPRF 1200/800Hz

*Laplacian Filter*

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\( V_1 \approx V_2 \) → derive \( V_e \) → replace \( V_2 \) by \( V_{2,e} = V_2 + n V_{2n} \)

ERROR if \( v_1 \neq v_2 \) (tolerance of 5.3 m/s exceeded)

\[ \text{Simulated Data: } \]

Meso Vortex superimposed on uni-directional wind field, Gaussian noise added, DualPRF 1200/800Hz

**MDA – Processing**

**Doppler Data Preproc. and Program Flow**

**Doppler Data Preprocessing**

- Correction of Doppler wind for DualPRF unfolding errors (Laplacian operator)
- Calculation of **azimuthal shear** correcting aliasing

**MDA**

- Search for pattern vectors, i.e. sequences of significant, positive azimuthal shear
- Filter pattern vectors (momentum and shear thresholds)

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*basic algorithm described in:

D.S. Zrnic, D.W. Burgess and L.D. Hennington

*Automatic Detection of Mesocyclonic Shear with Doppler Radar*

Doppler Data Preprocessing

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- Filter pattern vectors (momentum and shear thresholds)
- Group pattern vectors to features
- Filter features (no. of pattern vectors, symmetry criteria)

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**MDA**

- Search for pattern vectors, i.e. sequences of significant, positive azimuthal shear
- Filter pattern vectors (momentum and shear thresholds)
- Group pattern vectors to features
- Filter features (no. of pattern vectors, symmetry criteria)
- Group features to meso-objects
- Estimate Severity of meso-objects
### MDA – Processing
#### Severity Calculation

<table>
<thead>
<tr>
<th>Severity-Level</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. reflectivity [dBZ]</td>
<td>≥ 10</td>
<td>30</td>
<td>40</td>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Avg. Reflectivity [dBZ]</td>
<td>≥ 10</td>
<td>20</td>
<td>25</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Height above ground [km]</td>
<td>≤ 5</td>
<td>3</td>
<td>2.5</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Meso-Height [km]</td>
<td>&gt; 0</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>VIL [kg m(^{-2})]</td>
<td>&gt; 2</td>
<td>2</td>
<td>5</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Echo top height [km]</td>
<td>&gt; 1</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>VIL density* [g cm(^{-3})]</td>
<td>&gt; 0</td>
<td>1</td>
<td>1.5</td>
<td>2.</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Quality of Detection / severity level**

Severity 1 detections are connected with very low thresholds and rather serve for development/tuning purposes.

* VIL density = VIL / Echo top height

**Tuning still in progress!** Later MDA-version will contain additional thresholds for shear and momentum for levels 4 + 5
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All Doppler wind plots in this section show data with applied dualPRF unfolding error correction
Supercell Großenhain
Tornado rated F3, May 24, 2010

80-100 km long track of damage mainly between Mühlberg in Brandenburg and Großhartau in Saxony

12:15 UTC

Well developed Hook Echo

13:30 UTC

No detection just 2 PV

14:45 UTC

Severity Level Color-Coding:
- Level 1
- Level 2
- Level 3
- Level 4
- Level 5
Supercell Großenhain
Tornado rated F3, May 24, 2010

Mesocyclonic signatures detected in 12 sweeps (Elevations 1.5°, 2.5°, 4.5-11°, 15-19°)

Aliasing corrected during azim. shear calc.
Mesocyclonic signatures detected in 12 sweeps (Elevations 1.5°, 2.5°, 4.5-11°,15-19°)

Supercell Großenhain
Tornado rated F3, May 24, 2010
Supercell Sautorn, Bavaria
Tornado rated F2, July 13, 2011

Meso-Detections, Severity-Level 5, 13.07.2011, 15:30 UTC - 16:15 UTC

based on: information from an eye-witness report, photograph(s) and/or video footage of the inflicted damage, a report on a website, a damage survey by a severe weather expert, an eyewitness report of the damage occurring over: land

land use where event was first observed: land

intensity: F2

the intensity rating was based on a damage survey by a severe weather expert, photograph(s) and/or video footage of the inflicted damage, an eyewitness report of the damage.

path length: 1 km

tornado caused damages in Sautorn village: brick-barn downed / destroyed; roofs blown away; lorry blown off;

source: TORNADOLISTE; http://www.tornadoliste.de/110713sautorn.htm

report status: report confirmed (QC1)
contact: Thilo Kühne (ESWD management) [e-mail]

6th European Conference on Severe Storms (ECSS 2011), 3 - 7 October 2011, Palma de Mallorca, Balearic Islands, Spain
Supercell Sautorn, Bavaria
Tornado rated F2, July 13, 2011

Radar Munich, 2011-07-13 16:15 UTC, Elevation 0.5°
Radar Munich, 2011-07-13 16:15 UTC, Elevation 0.5°

Supercell Sautorn, Bavaria
Tornado rated F2, July 13, 2011
<table>
<thead>
<tr>
<th>#</th>
<th>date</th>
<th>Region</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2011-05-31</td>
<td>Brandenburg</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>2</td>
<td>2011-06-06</td>
<td>Allgäu, Nordeifel</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>3</td>
<td>2011-06-16</td>
<td>Central Franconia, Passau</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>4</td>
<td>2011-06-22</td>
<td>Alps (Rosenheim)</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>5</td>
<td>2011-07-12</td>
<td>Baden-Württemberg</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>6</td>
<td>2011-07-13</td>
<td>East from Munich to Bavarian Forest</td>
<td>Supercell mesocyclone, F2 tornado at Sautorn</td>
</tr>
<tr>
<td>7</td>
<td>2011-07-19</td>
<td>Munich</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>8</td>
<td>2011-08-14</td>
<td>Bavaria, Danube</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>9</td>
<td>2011-08-18</td>
<td>North Rhine-Westphalia</td>
<td>Mesocyclone at southern end of squall line</td>
</tr>
<tr>
<td>10</td>
<td>2011-08-24</td>
<td>Central Hesse, Berlin</td>
<td>Supercell in Hesse (hail ⌀ 4cm), splitting supercell close to Berlin</td>
</tr>
<tr>
<td>11</td>
<td>2011-09-02</td>
<td>South of Stuttgart</td>
<td>Supercell mesocyclone</td>
</tr>
<tr>
<td>12</td>
<td>2011-09-04</td>
<td>Ravensburg</td>
<td>HP-supercell (hail ⌀ 4 cm, 100 mm precipitation)</td>
</tr>
<tr>
<td>13</td>
<td>2011-09-11</td>
<td>Harz Mountains (Elsnigk, Bernburg), Würzburg, Kassel, Eberswalde</td>
<td>Several supercells, F2 tornado at Bernburg</td>
</tr>
</tbody>
</table>
## Outlook

**RADSYS-E** (exchange of DWD radar network 2010-14: modern dual-polarized C-band Doppler radars, 17 operational systems)

- Better quality of Doppler data from new radar systems expected (less noise)
- Usage of new products for better severity estimation (e.g. hydrometeor classification → identification of hail core)

### Change of scan-strategy

- Higher temporal and range resolution (→ better tracking)
- Use *unfiltered* data and supply threshold parameters (e.g. SQI) for special application based settings instead of using filtered data (→ avoid "filter holes")

### Further development

- Extension of KONRAD (SCIT ) to KONRAD3D, linking of MDA to cell detection
- Consideration of near Storm environment (shear, CAPE from model)
- Calculation of Rotation tracks (see NSSL*) as further tool to judge plausability of mesocyclone detections

* T. M. Smith, K. L. Elmore: The Use of Radial Velocity Derivatives to Diagnose Rotation and Divergence, 11th Conference on Aviation, Range, and Aerospace Meteorology

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Outlook


ID / Time: VOL_10488_17_20100524_1215

Maximum shear in column

Reflectivity [dBZ], elevation 0.5°

max shear in column [m/s/km]

max. shear accumulated over 2.5 h

Thank you for your attention!