SEVERE HAIL SIZE DISCRIMINATION USING DUAL-POLARIZED WEATHER RADAR DATA.
A DUAL-WAVELENGTH COMPARISON BETWEEN “C“ AND “S” BAND.

6th European Conference on Severe Storms (ECSS 2011)
3 - 7 October 2011, Palma de Mallorca, Balearic Islands, Spain

Rudolf Kaltenboeck, Alexander Ryzhkov
Outline

- Motivation
- Data
- Methodology
- Results
  - hail backscattering effects
  - average profiles within hail bearing storm
- Attenuation – differential phase
- Conclusion - Outlook
Motivation

aviation

weather radar

hail
Motivation

- new installed dual polarized weather radars (C-band) in Austria
Motivation

Operational European Weather Radars

OPERA database:

Dec. 2010
Motivation
Operational European Weather Radars
OPERA database:
Dec. 2010
Aim

Large Hail D > 2.5 cm
Giant Hail D > 5 cm
Data
SPC hail reports for Oklahoma, 2/2009-4/2011
Data: OU-PRIME C-band

- different scan strategies e.g.:
  - range bin: 125 m
  - range: 125 km
  - elevation: 0.25-9/19 (8)
  - bw: 0.5°
Data: KOUN S-band

- polarimetric prototype of the WSR-88D
- range bin: 250 m
- range: 300 km
- elevation: 0.5-19.5° (#14)
- bw: 1°

- distance: 6.8 km
Data: Dual Polarized Moments used in this study

- Differential Reflectivity \( Z_{\text{DR}} \)
  - depends on the particle size, shape, orientation, density, and water content

- Cross-Correlation coefficient \( \rho_{hv} \)
  - correlation between horizontally and vertically polarized weather signals
  - decrease indicate variety of HM, tumbling, mixture water / ice, irregular shape, resonance size, rapid shape deformation, large hail

- Differential Phase as quality parameter
  - specific (propagation) + backscatter diff. phase

- Simultaneous mode: no LDR
Maximum Hail Size: Single Pol

- Max-Reflectivity or VIL in relation to freezing level height
- Echo-Top
- Probability of hail ... maximal expected hail size (severe hail index – depends on temperature-height weighting function and kinetic energy of hail)

(e.g. Waldvogel, 1979; Donavan and Jungbluth, 2007; Edwards and Thompson, 1998; Witt et al., 1998)
Maximum Hail Size: Dual Pol

- polarimetric characteristics of hailstones depend on their size, shape, falling behavior, and are strongly affected by the degree of melting and the probing radar wavelength.

- better quality of hail detection (FAR reduced)

- location of hail in the storm
  - including its height above ground

- S-band
  - hail differential reflectivity HDR (e.g. Aydin et al., 1986, Depue et al., 2007)
  - HCA (e.g. Park et al. 2009) - no hail size

- S/C/(X)-band:
  - melting hail – polarimetric characteristics of large hail
    (e.g. Ryzhkov et al., 2009, Borowska et al., 2010; Kumjian et al., 2010, Picca and Ryzhkov, 2011, Tabery et al., 2009)
**Data:** Dual Polarized Moments

C-band: resonance effects

Strong attenuation and differential attenuation in hail at C band further complicates the issue of hail detection / sizing
Data: Dual Polarized Moments

C-band: resonance effects

- Strong attenuation and differential attenuation in hail at C band further complicates the issue of hail detection / sizing

[Graph showing Z_{DR} for hailstones at 0°C]
Data: Dual Polarized Moments

C-band: resonance effects

- Strong attenuation and differential attenuation in hail at C band further complicates the issue of hail detection / sizing
Data: Dual Polarized Moments

C-band: resonance effects

C-Band: ZDR-Rho HV (Hailsize in cm)

10 cm slight lower rho, Lower ZDR

2.5 cm
Hail-diameter: 10cm

**S-band** – wet hail below freezing level

- **S-band**: large hail is characterized by high $Z$, low $Z_{\text{DR}}$, and low $\rho_{hv}$
- **C-band**: large hail is characterized by high $Z$, high $Z_{\text{DR}}$, and very low $\rho_{hv}$
- all radar frequencies: smaller wet hail has high $Z_{\text{DR}}$
**Hail-diameter: 10cm**

**C-band** – wet hail below freezing level

- S-band: large hail is characterized by high $Z$, low $Z_{DR}$, and low $\rho_{hv}$
- **C-band**: large hail is characterized by high $Z$, high $Z_{DR}$, and very low $\rho_{hv}$
- **all radar frequencies**: smaller wet hail has high $Z_{DR}$
Hail-diameter: 10cm
C-band – dry hail aloft
Hail-diameter: 10cm
S-band – dry hail aloft

Radar reflectivity (dBZ)

Differential reflectivity (dB)

Differential phase (deg)

Cross-correlation coefficient

CAPPI 5.5km
$<0.9$
Cross section
hail size 2.5 cm

- C-band
- S-band

<table>
<thead>
<tr>
<th>Z</th>
<th>ZDR</th>
<th>Z</th>
<th>ZDR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10km
Weak Convection – thermal plumes
C-band

0°C
Dry hail aloft
HAIL BACKSCATTERING EFFECTS WHICH AFFECT DUAL POL MOMENTS AND CORRESPONDING VERTICAL STRUCTURE
TBSS C-band
three scatter signature signal
LOW RhoHV due to ZDR gradient, SNR C-band
ZDR Column + Side-lobe effects

C-band

-20°C

High ZDR, Low RhoHV due to Resonance + melting hail

ZDR column updraft
vertical profile: hail: 2 - 10cm
$Z \geq 55\text{dBZ}$
vertical profile: hail: 2 - 10cm
\( Z \geq 55\text{dBZ} \)

**S-band:**
- \( Z = 60 \)
- \( Z_{\text{DR}} \)
- \( \rho_{\text{hv}} = 0.95 \)

**C-band:**
- \( Z = 2 \)
- \( Z_{\text{DR}} = 5 \)
- \( \rho_{\text{hv}} = 0.85 \)
$\Phi_{DP}$ hail size dependence for C-band
nonmonotonic radial dependencies of $\Phi_{DP}$

- below freezing level
$\Phi_{DP}$ hail size dependence for C-band

S-band, PPI 0.5°
Hail-size: 10.8cm

monotonic radial increase of $\Phi_{DP}$
$\Phi_{DP}$ hail size dependence for C-band

C-band, PPI 0.25°
Hail-size: 10.8cm

monotonic radial increase of $\Phi_{DP}$ hysteresis
Φ_{DP} hail size dependence for C-band

nonmonotonic radial dependencies of Φ_{DP}
$\Phi_{DP}$ hail size dependence for C-band

nonmonotonic radial dependencies of $\Phi_{DP}$
**Φ\(_{DP}\) hail size dependence for C-band**

nonmonotonic radial dependencies of Φ\(_{DP}\)

associated with large raindrops originated from melting hail
Φ_{DP} hail size dependence for C-band

nonmonotonic radial dependencies of Φ_{DP}

K_{DP} for melting hailstones at 26°C

Graph showing K_{DP} / N (deg/km) vs. Particle diameter (cm) for different bands: S-band (blue), C-band (red), X-band (green).
Comparison of \( Z_{DR} \) and \( \rho_{hv} \) changes below wet bulb freezing level height for two hail classes:

<table>
<thead>
<tr>
<th></th>
<th>MEDIAN</th>
<th>Standard-Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large hail</td>
<td>Giant hail</td>
</tr>
<tr>
<td>( Z_{DR} )</td>
<td>C band</td>
<td>+4dBZ</td>
</tr>
<tr>
<td>( Z_{DR} )</td>
<td>S band</td>
<td>+1dBZ</td>
</tr>
<tr>
<td>( \rho_{hv} ) C band</td>
<td>0.91</td>
<td>0.84</td>
</tr>
<tr>
<td>( \rho_{hv} ) S band</td>
<td>0.94</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Comparison of \( \rho_{hv} \) at -10°C wet bulb temperature height for two hail classes:

<table>
<thead>
<tr>
<th>( \rho_{hv} )</th>
<th>MEDIAN</th>
<th>Standard-Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Large hail</td>
<td>Giant hail</td>
</tr>
<tr>
<td>C band</td>
<td>0.95</td>
<td>0.82</td>
</tr>
<tr>
<td>S band</td>
<td>0.94</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Conclusion

- location of hail within the storm
- vertical profiles of polarisation moments efficiently utilized for hail size discrimination
- C-band hail features are much more pronounced
- below freezing level:
  - strong increase in $Z_{\text{DR}}$
  - strong decrease in $\rho_{\text{hv}}$
- hail generation at -10 °C
  - strong decrease in $\rho_{\text{hv}}$
Ongoing Work

- extend dataset

- hail cases from Austria
  - C-band
  - additional small hail reports (D < 2cm)

- verification

- attenuation C band + nonmonotonic radial dependencies of $\Phi_{DP}$

- trend analyses -> Nowcasting
Thank you for your attention!

rudolf.kaltenboeck@austrocontrol.at