Thunderstorm Development over the North Alpine Foreland: Microphysical and Wind Field Radar Retrievals from the VERTIKATOR Campaign in July 2002

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ABSTRACT

A convective event observed on 9 July 2002, during the VERTIKATOR campaign, is presented to highlight the capabilities of the bistatic network around the POLDIRAD system used in Oberpfaffenhofen. The dual polarization and Doppler abilities of POLDIRAD combined with bistatic antennas allow simultaneous retrievals of microphysical properties and wind fields. A classification scheme based on differential reflectivity and linear depolarization ratio is used to distinguish various types of hydrometeors present in the convective cells. The processing of Doppler data obtained with the bistatic network was upgraded to yield automatically dealiased 2-D horizontal wind-fields.

1. Introduction

While the 'wet part' of MAP focussed on the Alpine south side in autumn the field campaign of project VERTIKATOR concentrated on the initiation and development phase of strong summer thunderstorms as an important means for effective vertical transports. The area of interest consisted of the north Alpine region to the east of the Rhine valley at the French-German border. During July 2002 an operation centre was active at Oberpfaffenhofen which coordinated numerous measuring facilities in the area.

This presentation focusses on the afternoon of 9 July 2002 when a strong multicell thunderstorm complex developed rapidly above the Alpine rim (between the Allgäu and the Wetterstein massif) and moved in a northeasterly direction across the polarimetric radar POLDIRAD at the operation centre.

We first present the meteorological situation using data from the Meteorological Application and Presentation system (MAP) of Deutscher Wetterdienst. Then we provide results of the application of a classification scheme on polarimetric data. Finally we focus on the wind field retrieval by a bistatic network.

2. Synoptic- and meso-scale situations on 9 July 2002

The 500 hPa analysis of the German global model (GME) at 12 UTC shows a depression centered to the north of Ireland, which entails a cyclonic flow on the western part of Europe (Fig. 1). A long cold front extends from Scotland across the Netherlands to northern Spain. The GME analysis shows an intrusion of stratospheric air at the rear of the cold front: the potential vorticity at 320 K is higher in this area. The radio sounding at 12 UTC in Munich (Fig. 2) shows a CAPE equal to 1005 $J \cdot kg^{-1}$, which denotes instability. The amount of precipitable water is 21 mm. The storm develops in the warm sector air mass ahead of the cold front. The ground observations at 12 UTC show that temperatures are very high where convection appears later, whereas the relative humidity does not attain significant values.

3. Description of the convective event

At 12 UTC, convection has just begun over the southern Alps at the border between Switzerland and Italy, and the first lightning bolts impacts are recorded in this area. In the VERTIKATOR region, convection begins at around 1330 UTC over Tyrol. The first RHI available, at 1348 UTC, points towards 192° and shows two cells developing in the region of Garmisch-Partenkirchen. These cells are advected by the synoptic-scale wind to the north-east, while others are developing in the same area.

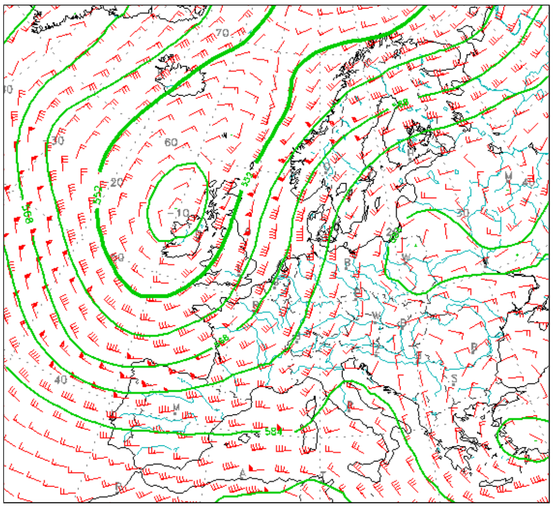


Figure 1: Geopotential and horizontal wind (standard barbs in kn) at 500 hPa on Europe on 9 July 2002, 12 UTC (GME analysis).

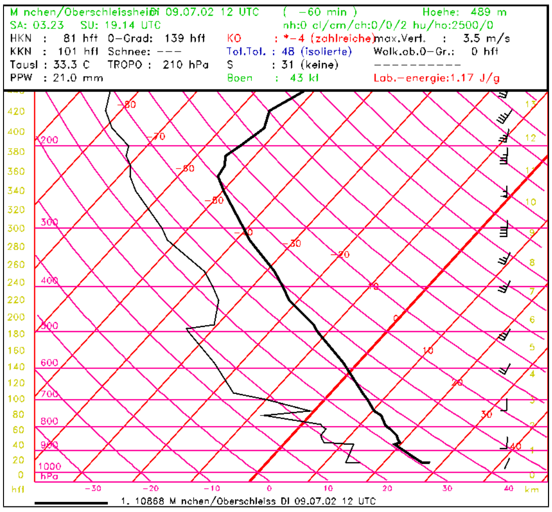


Figure 2: Radiosounding in München-Oberschleißheim (Munich) on 9 July 2002, 12 UTC.

The first flash impact is recorded in this region at 1450 UTC. It comes from the cell scanned on the RHI at 1448 UTC. The cells grow and merge while being advected and form a meso-scale convective system(MCS). At 1730 UTC, the cells cannot be distinguished from each other and the resulting MCS crosses Munich at around 1800 UTC, then moves northeastwards. The maximum height observed on RHI scans (about 12–13 km) is reached at 1448 UTC.

4. Polarimetric measurements

POLDIRAD is able to transmit and receive horizontally and vertically polarized radiation at C-band (5.5 GHz; 5.5 cm wavelength). This feature allows for deriving various polarimetric parameters such as differential reflectivity, linear depolarization ratio. These quantities are very useful to infer the micro-physical properties of hydrometeors because they are mainly influenced by the shape, falling behaviour and phase of the particles. Thus, a proper combination of polarimetric parameters can provide a good way of classifying hydrometeors. Such a classification can be used to improve our knowledge of storms structures. It can also assist nowcasting purposes for forecasting severe events. Initialization procedures of high-resolution models may furthermore be taken into account to adjust the contents of microphysical variables. The classification could also be utilized for assimilation in numerical weather prediction models (NWP). The contents of the different types of hydrometeors can be infered by using Z–R relationships adapted for each class (see for instance Höller, 1995).

Here we use the classification of Höller *et al.* (1994), which is based on differential reflectivity and linear depolarization ratio and contains ten classes. Differential reflectivity is defined as $Z_{\mathrm{DR}} = 10 \log \frac{z_{\mathrm{HH}}}{z_{\mathrm{VV}}}$ (in dB; see Seliga and Bringi, 1976), and linear depolarization ratio as $\mathrm{LDR} = 10 \log \frac{z_{\mathrm{HV}}}{z_{\mathrm{HH}}}$ (in dB; see Bringi *et al.*, 1986), where z_{XY} denotes the reflectivity factor for horizontally ($X = H$) or vertically ($X = V$) emitted, and received (respectively $Y = H$ or $Y = V$) waves. Differential reflectivity depends on the shape and orientation of hydrometeors. It is therefore positive for oblate (*i.e.* large) raindrops, and close to zero or negative for hail, graupel and snow. Linear depolarization ratio depends on the presence and disposition of ice and water which hydrometeors are made of. It is low (negative) for raindrops and can reach 0 dB for melting ice particles. Regions affected by 3-body scattering effects are not taken into consideration in the classification scheme because they are not reliable enough to provide a correct result.

The classification scheme of Höller *et al.* (1994) allows us to obtain the microphysical structure of the storm for every RHI or PPI scan operated in a dual polarization mode. Along with this, dual polarization PPI scans also provide 2-D horizontal wind fields obtained with the bistatic Doppler network associated to POLDIRAD.

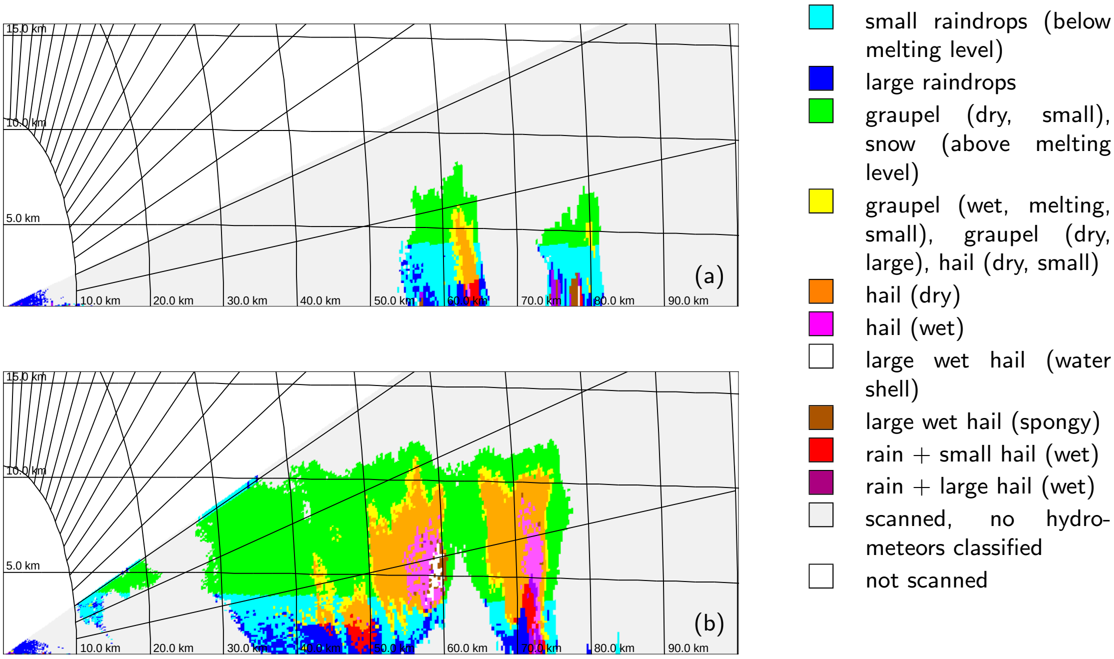


Figure 3: Hydrometeor classification on RHI scans: (a) developing cell at 1348 UTC, 192°, (b) four cells during the vigourous phase at 1521 UTC, 215°.

Figure 3 shows the result of the classification scheme on two RHI scans at different stages of the convective event. The same pattern can be observed on each RHI: each cell has a core composed of large wet hail — if sufficiently developed —, surrounded by wet hail, then successively by hail and graupel. This core is enveloped by snow above the melting level, at about 4 km MSL, and by small raindrops below the melting level, eventually becoming larger as they approach the ground. The base of the core is made of large raindrops mixed with some hailstones. Within an hour the cloud tops rose by 5 km to a height of more than 12 km.

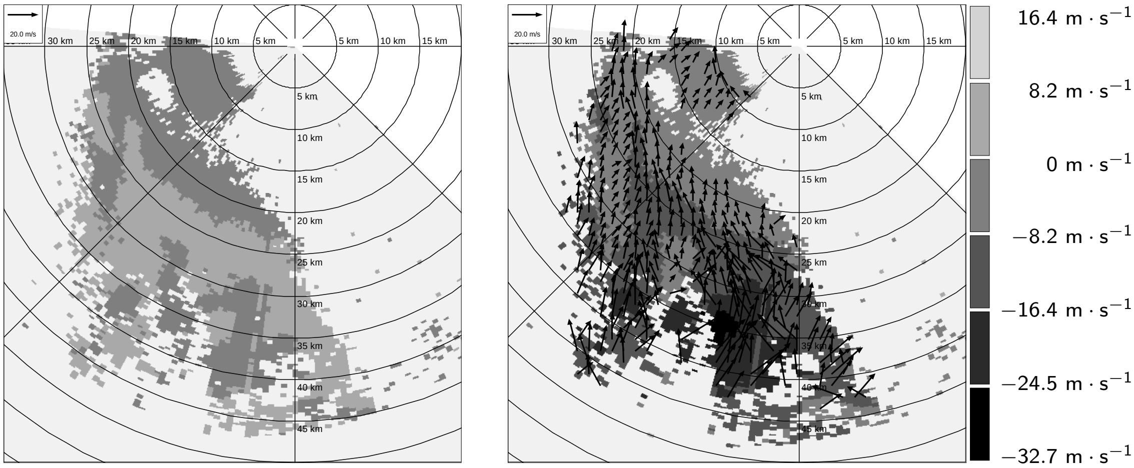
5. Doppler measurements

POLDIRAD has the capability of measuring Doppler velocities within precipitation areas. These measurements alone only provide radial velocities. In order to derive full two-dimensional wind fields, at least one other radar or one other bistatic antenna is required at a different location. The latter alternative provides reliable results and is much cheaper than the former one. Therefore it was decided to install three remote bistatic antennas in the region up to 35 km to the west of Oberpfaffenhofen (Friedrich *et al.*, 2000).

Doppler measurements do not directly provide physical values because the velocities are aliased: due to sampling, measured speeds cannot exceed a certain value, called the Nyquist velocity and denoted as V_n, which depends on the radar parameters: $V_n = \lambda \cdot f_{\mathrm{PR}}/4$, where λ denotes the wavelength, and f_{PR} the pulse repetition frequency of the emitted radiation. In our single polarization mode, the Nyquist velocity amounts to 16.35 $\mathrm{m \cdot s^{-1}}$.

Therefore, the velocities have to be dealiased. This issue has been tackled for monostatic radars since the 1970's, but not yet for bistatic receivers. Here we use an algorithm based on the one developed by James and Houze (2001) for the monostatic data of the Monte Lema radar during the MAP campaign. Once dealiased, bistatic and monostatic velocity fields can be combined and provide a full two-dimensional horizontal wind field.

In order to retrieve microphysical properties at the same time, we have to use the dual polarization mode, which corresponds to a low Nyquist velocity of 8.175 $\mathrm{m \cdot s^{-1}}$. The raw Doppler velocity field has therefore only a low dynamic range and is not easy to dealias. A special filter is applied which prevents the algorithm from taking into account obviously wrong values and speeds up the dealiasing process at



(a) (b)

Figure 4: PPI obtained with the bistatic receiver in Ried at 1602 UTC, 11° elevation angle: (a) aliased, (b) dealiased bistatic wind component and derived horizontal wind vectors.

the same time.

A sounding in Munich at 15 UTC indicates that the synoptic-scale wind between 600 and 350 hPa (*i.e.* between 4 and 8 km height or between 30 and 55 km away from the radar on Fig. 4) is northeastbound with a mean speed of about 13 $m \cdot s^{-1}$. The cells themselves move at about 6 $m \cdot s^{-1}$, which means that they are not simply advected by the synoptic-scale wind. The raw Doppler velocities obtained at 1602 UTC with a bistatic antenna are shown on Fig. 4a, while Fig. 4b depicts the corresponding dealiased velocity field along with the wind vectors obtained as a combination of the monostatic and bistatic dealiased wind fields. High and low speeds in adjacent areas show the presence of rotation within the convective cells. The highest speeds on Fig. 4b amount to 33 $m \cdot s^{-1}$. In relation to the numbers above this reveals the strength of the internal storm circulation.

6. Conclusion

Dual polarization and Doppler measurements combined provide a reliable way of obtaining important information about precipitation areas, such as microphysical properties and wind fields. This information altogether is liable to be used in nowcasting, assimilated in NWP models, and is valuable for the initialization or validation of high-resolution models. Furthermore these techniques allow to fully document the convective event over Bavaria on 9 July 2002, making the case a good reference for future comparisons with high-resolution simulations.

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