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Wind-field observations with the operational Doppler radar network in Germany

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Abstract. Doppler velocity measurements from Doppler weather radars can be used to estimate the horizontal wind field. In the past several techniques were developed for this purpose to be used during field campaigns. But only a few weather services retrieve operational the horizontal wind vector from their Doppler radars. In this paper we show that it is possible to apply successfully the known methods to the Doppler velocity measurements performed by operational Doppler radars of the Deutscher Wetterdienst. Both, single and dual Doppler techniques were applied to ensure a large area where the horizontal wind field can be estimated.

1 Introduction

Doppler weather radars have been available for several decades. While reflectivity measurements are routinely used for forecasting purposes and national or international composites are generated by the operators, only a few weather services make full use of the Doppler velocity like retrieving the horizontal wind field. However, there is a strong interest in the knowledge of the three-dimensional distribution of the horizontal wind vector. The wind field could be used for short term nowcasting, like in the vicinity of an airport. Doppler weather radars cannot directly provide the wind vector, they only measure the radial component of the wind vector. The manual interpretation of the radial Doppler velocity requires training and is prone to misinterpretation in certain situations. Therefore, several methods have been developed in the past to estimate the horizontal wind field from Doppler velocity measurements.

In this paper we will show how the Doppler velocity measured by the radars of the Deutscher Wetterdienst (DWD) can be used to estimate the horizontal wind field over wide areas within Germany. Most of the 17 weather radars operated by the Deutscher Wetterdienst are presently Dopplerised. The maximum range for Doppler measurements is 120 km. In several regions two or more observation areas of the Doppler radars overlap. In this regions the horizontal wind field can be retrieved using a dual or multiple Doppler radar analysis. In the remaining regions of the Doppler coverage single-radar wind field retrievals have to be applied. Figure 1 shows the location of the Doppler radars and the regions where single and multiple Doppler techniques can be performed.

The retrieval of the horizontal wind vector is applied to radar measurements from the radars at Türkheim and Hohenpeißenberg in southern Germany. In Sect. 2 single and multiple Doppler techniques are reviewed. Section 3 shows how data have to be prepared for the analysis and in Sect. 4 results for selected weather situations are presented.

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2 Wind field estimation using Doppler radar

2.1 Single Doppler techniques

Several techniques exist to estimate the wind vector from the Doppler data of a single weather radar. In the following the techniques which are used in this project are shortly reviewed.

2.1.1 Velocity Azimuth Display (VAD)

The VAD is the classical application to estimate the wind vector with a single radar. As described in detail by Lhermitte and Atlas (1961) or Browning and Wexler (1968) this technique is used to accurately estimate the horizontal wind vector and its horizontal gradients above the radar as an average across the circle at constant range of a conical PPI scan, i.e. at an elevation of about 20°. For this technique it is assumed that the wind field is homogeneous within this circle. As long as this assumption is not violated, the estimated horizontal wind vector is highly accurate and within the standard deviation of the Doppler velocity (assumed to be 1 m/s). The VAD technique will be used to retrieve the wind vector above the radar location.

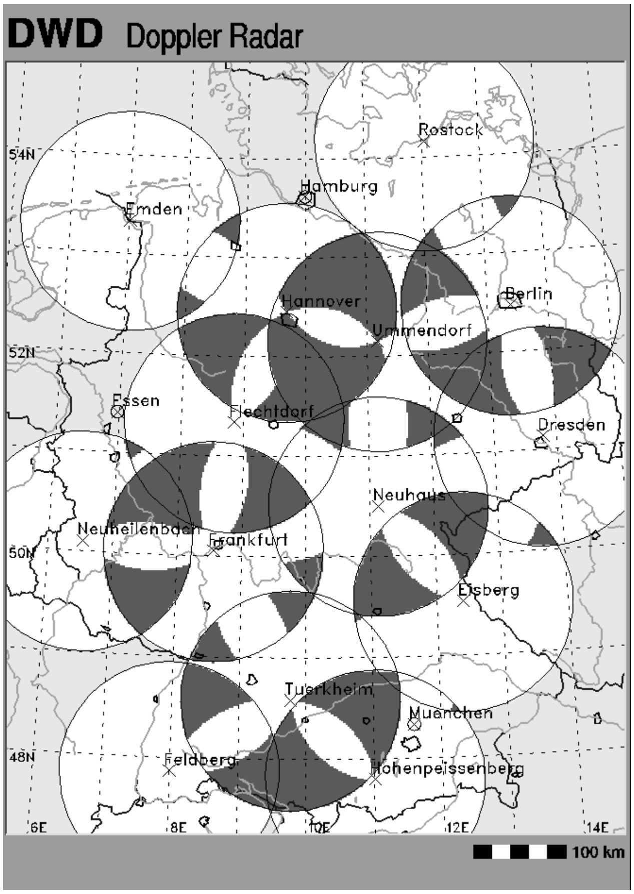

Fig. 1. Map of the Doppler weather radars of the Deutscher Wetterdienst in Germany. The white areas indicate the coverage within the 120 km range, the dark gray areas indicate the dual-Doppler areas. The radars at Hamburg, Essen and München are presently not Dopplerised.

In addition to the VAD technique, the VVP technique (VVP: velocity volume processing; Waldteufel and Corbin, 1979; Koscielny et al., 1982) is frequently used for the same purpose. VVP gives further information on the vertical gradient of the horizontal wind vector and on the vertical wind. However this additional information is achieved with a reduction of the overall accuracy of the retrieved wind components and its derivatives.

2.1.2 Uniform Wind Technique (UW)

The UW technique was first introduced by Persson and Andersson (1987). It is a simplification of the VAD technique. For the retrieval of the horizontal wind components u_0 and v_0 it is sufficient to solve

$$v_r(i) = u_0 \cos\theta \sin\phi(i) + v_0 \cos\theta \cos\phi(i) \quad (1)$$

for radial velocity measurements $v_r(i)$ along a circle. ϕ is the azimuth angle, θ is the elevation angle. The unknown horizontal tangential velocity component is defined by

$$v_t = -u_0 \cos\theta \cos\phi + v_0 \cos\theta \sin\phi \quad (2)$$

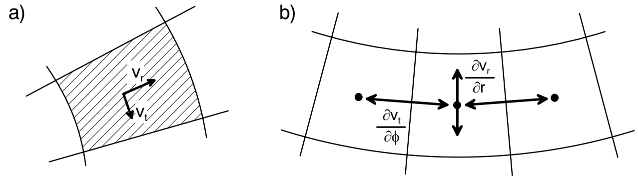

Fig. 2. (a) Sector element of the Uniform Wind technique for the estimation of the radial v_r and tangential wind component v_t. (b) Adjustment of tangential wind component v_t using v_r and ∂v_r.

which is identical to

$$v_t = -\partial v_r / \partial \phi \quad (3)$$

This allows estimation of the unknown tangential component from radial velocity along an arc instead of a complete circle since only $\partial v_r / \partial \phi$ has to be estimated. Typically the data of several range rings are averaged to estimate v_t. Then the sector element will have a typical size of 15° in width and 15 km in depth (cf. Fig. 2a). The larger the selected sector element will be, the higher the accuracy of the retrieved wind vector. On the other hand, it is more likely that for large sector elements the assumption of a uniform wind field in this sector element is violated, e.g. within convective cells or frontal zones.

The UW technique was later improved by the ECUW technique (ECUW = combination of Equation of Continuity with the Uniform Wind technique; Hagen, 1989). Here the UW technique is combined with the 2-dimensional equation of continuity which is in polar co-ordinates

$$v_r + r\,\partial v_r / \partial r = \partial v_t / \partial \phi \quad (4)$$

where r is the range. With the equation of continuity a relation can be set up between the tangential gradient of the tangential velocity ($\partial v_t / \partial \phi$) and the radial gradient of the radial velocity ($\partial v_r / \partial r$; cf. Fig. 2b). Assuming no large-scale convergence this relation can be used to iteratively adjust the retrieved tangential wind component (v_t) until the equation of continuity is satisfied or a minimum error is reached.

Due to the averaging of several measurements across the sector element, the accuracy of the retrieved horizontal wind vector is high; even better than the standard deviation of the radial Doppler measurement. However this is only valid, if the wind field is constant across the sector element. If there are perturbations in this sector element the accuracy can dramatically drop.

2.2 Multiple Doppler technique

If two or more Doppler radars observe the same location from different directions the horizontal components can be estimated directly. For research purposes multiple Doppler techniques are frequently used. In these networks the distance between the Doppler radars are in the range of 30 to 60 km. This is much shorter than the typical distance between radars in an operation network of an weather service. An

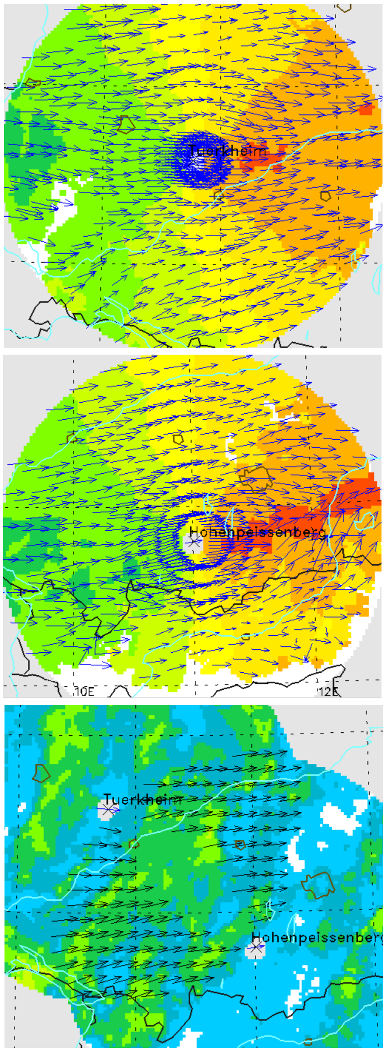

Fig. 3. Horizontal wind vector field at 3 km MSL on 2 June 2001 at 1156 UTC. a) radar Türkheim using the ECUW technique, underlay field is Doppler velocity, b) same as a) but for radar Hohenpeißenberg, c) retrieved dual-Doppler wind field underlaid with reflectivity, only every 5th wind vector is plotted.

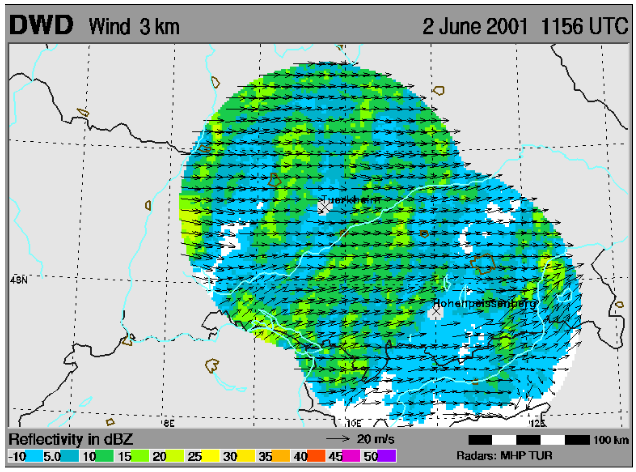

Fig. 4. As Fig. 3. Merged wind vector field using dual-Doppler and ECUW wind field estimation.

economic alternative to the use of several Doppler radars is the usage of a bistatic Doppler radar network (Wurman et al., 1993; Friedrich et al., 2000) together with a Doppler radar. An overview of the techniques and their application can be found in the summary of the "Multiple Doppler Workshop" by Carbone et al. (1979). The spatial resolution of the estimated horizontal wind vector is in the same order as the resolution of the radar measurements, i.e. 1 to 2 km.

Highest accuracy of the retrieved horizontal wind vector in a dual-Doppler installation can be achieved at locations where the intersection angle between the two Doppler velocities is 90°. Here the standard deviation of the horizontal wind vector is $\sqrt{2}$ times the standard deviation of the radial Doppler velocity measurement (assumed to be 1 m/s). For other intersection angles the accuracy decreases. For the further analysis the retrieval of the wind vector using dual-Doppler is limited to the area where the standard deviation is below 4 m/s. This corresponds to an intersection angle of 40° and 140°, respectively.

Horizontal wind fields retrieved from dual-Doppler measurements can be assumed to be reliable, as long as the measurements are performed within a few minutes. Larger time differences can give erroneous wind field estimations since the measurements at the same location but different time may correspond to a different weather situation. This can be the case during fast convective development or strong advection.

3 Data preparation and quality assurance

The quality of Doppler data has to be assured for the retrieval of the wind vector. This requires proper dealiasing of folded Doppler velocities, removal of spurious echoes and of ground clutter. The DWD uses a dual-PRF algorithm to increase the Nyquist interval up to ±32 m/s. Higher Doppler velocities will be folded and cannot be used for further processing. Ground clutter is mostly removed by the radar data processor. The data from radar Hohenpeißenberg are partly contaminated by ground clutter of the Alps, here a further processing was necessary. This is done by using the clutter power provided with the raw data. If the clutter power is high and the Doppler velocity below ±2 m/s the data in the respective range bin are cancelled.

The radars of the DWD perform volume scans every 15 minutes with 18 elevations from 37° down to 0.5°. For the VAD analysis an elevation of 20° is selected, the ECUW technique is applied to data from elevations below 16°. The single Doppler analysis using VAD and ECUW are performed with the Doppler velocity data having a resolution of 1° by 1 km in spherical co-ordinates. The analysis are done independently for each radar.

Next, the corrected radial velocities and the horizontal wind vector as estimated from the ECUW technique are in-

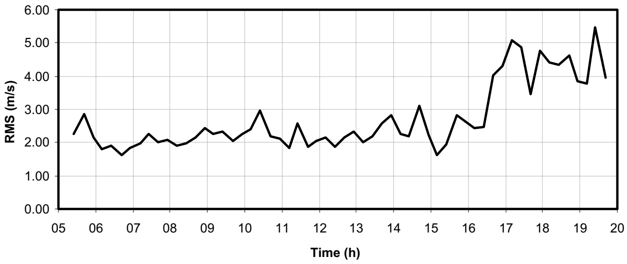

Fig. 5. Root mean square error (RMS) of the difference between dual-Doppler wind vector estimation and ECUW wind vector estimation in the dual-Doppler area on 2 June 2001. The mean RMS from the height levels between 2 and 8 km MSL is shown.

terpolated onto a common Cartesian grid with a horizontal resolution of $2 \times 2\,\text{km}^2$ and a vertical resolution of 1 km. The maximum height is 8 km MSL. The interpolation also considers the different heights of the radars of the DWD (between 35 and 1506 m MSL; Türkheim at 731 m MSL, Hohenpeißenberg at 1005 m MSL).

The gridded radial Doppler velocities of all radars are used for a dual-Doppler analysis in regions where data from more than one radar are available.

In a final step the estimated horizontal wind field from the dual-Doppler analysis and the ECUW technique are merged to give a single horizontal wind field estimate. Dual-Doppler winds are assumed to be of higher accuracy than the ECUW winds, therefore the dual-Doppler winds are used for the overlapping region and only in the remaining areas ECUW winds are used.

4 Wind field observations

As an example the horizontal wind field estimation using the radars Türkheim and Hohenpeißenberg will be presented. Figure 3 shows the horizontal wind vectors as estimated by the radars on 2 June 2001 at 12:00 UTC at 3 km MSL. In Fig. 3a and b the wind vectors as estimated by the ECUW technique are presented. The vectors are underlaid with the measured Doppler velocity. The weather situation is dominated by wide spread precipitation during the passage of a cold front. Both radars show a prevailing westerly and southwesterly flow. In Fig. 3c the dual-Doppler wind vectors underlaid with the reflectivity factor are shown. In Fig. 4 the wind field merged from the ECUW and dual-Doppler technique is shown.

As stated in Sect. 2 and 3 the wind fields estimated by the dual Doppler technique are assumed to be of higher accuracy than wind fields estimated by the ECUW technique. Since there are no further upper-air wind measurements in the dual-Doppler area available, no independent validation of the retrieved wind field is possible.

As a measure of the quality of the retrieved ECUW wind fields the root mean square error (RMS) between the ECUW and dual-Doppler winds in the dual-Doppler area is computed for each of the 8 vertical level. RMS for the wind field shown in Figs. 3 and 4 is about 1.8 m/s. Note, that the estimated standard deviation of the dual Doppler wind fields was estimated to be between 1.4 and 4 m/s (c.f. Sect. 2.2). Figure 5 shows the mean RMS for all wind field estimations at the different height levels on 2 June 2001 between 05:20 and 20:00 UTC. It can be seen that for the morning and noon hours the range of RMS is between 2 and 3 m/s. Only in the afternoon when the situation was dominated by convective rainshowers and RMS increased. Here the assumptions for the ECUW technique were not fulfilled completely. In general the high values occurred at higher height levels. Here the data density is lower because of the upper height of precipitation.

5 Conclusions

Doppler weather radars operated by the DWD cover almost the complete area of Germany. The estimation of the horizontal wind field is possible within this network of Doppler radars. In regions were more than one radar observe the same location, dual Doppler techniques can be used for the estimation of the horizontal wind field. The dual Doppler technique retrieves the horizontal wind field with high spatial resolution and an accuracy of 1.4 to 4 m/s. However, the area in which dual Doppler techniques can be applied are small because of the large distance between the radars. Therefore additional techniques were necessary to enlarge the area for retrieval of the horizontal wind field. A single Doppler technique, the ECUW technique, was applied to the remaining area of Doppler velocity coverage of the radar. Compared to the dual Doppler wind fields, the wind fields retrieved with the ECUW technique are of lower accuracy much coarser spatial resolution.

Even though the differences between the horizontal wind fields estimated by ECUW and dual Doppler are small for the presented case study, it can not concluded that the ECUW technique always gives reliable estimates of the horizontal wind. Other single Doppler techniques have to assessed. It is also possible to use wind profiles as estimated by wind profilers as an additional information for the single Doppler estimation. The retrieved horizontal wind fields have to be compared to independent Doppler estimates of the horizontal wind field. Additionally, bistatic Doppler radar measurements can be used for validation of the retrieved wind fields. Further quality and consistent checks similar to the ones used for the DLR bistatic radar network (Friedrich and Hagen, 2002) have to be developed to improve the reliability of the estimated wind fields and to remove non-realistic wind vectors.

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