P4.10 WIND VECTOR FIELD DETERMINATION WITH BISTATIC MULTIPLE-DOPPLER RADAR NETWORK

Katja Friedrich * and Martin Hagen

DLR–Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany

1. INTRODUCTION

The knowledge of the three-dimensional wind field is of great importance for practical usage, e.g. for nowcasting applications and for research.
After developing and building of a Doppler capable bistatic receiver for meteorological applications by Wurman et al. (1993), bistatic multiple-Doppler radar is developing to an easily implemented addition and an inexpensive alternative to monostatic multiple-Doppler radars.
A bistatic multiple-Doppler radar network includes one transmitting Doppler radar and several non-transmitting Doppler receivers at remote sites. Simultaneous measurements of several components of wind fields are one advantage of a bistatic Doppler radar network because there is just one source of illumination. Therefore, time-space interpolation are not necessary for creating a horizontal wind field. High spatial mobility (location, angle of view) as well as compatibility to other monostatic Doppler radars is an other benefit of bistatic radar. Transmit and receive systems can be differently optimised and independently implemented for different meteorological applications.
Investigations on measurement characteristics within a bistatic Doppler radar and wind vector field analysis are already initiated (Wurman et al., 1993; Protat and Zawadzki, 1999; de Elia, 2000; Friedrich et al., 2000).

2. NETWORK SETUP

The separation of transmitter and receiver leads to a variation of the geometry dependable radar characteristics (Tab. 1). Contrary to monostatic radar where properties change with distance r'_T the radar characteristics in a bistatic network vary with distance and scattering angle (Tab. 1).
Due to the distribution of the $\cos(\frac{\gamma}{2})$ (Fig. 1), the domain can be classified into 3 characteristical areas:
(1) *Area near transmitter-receiver-baseline* (hatched): In the forward scattering area Doppler measurements are not possible because of signal interferences. Close to the baseline the length of the resolution is very high and accuracy low.

* Corresponding author address: Katja Friedrich, DLR–Institut für Physik der Atmosphäre, Oberpfaffenhofen, 82234 Wessling, Germany; E–Mail: katja.friedrich@dlr.de.

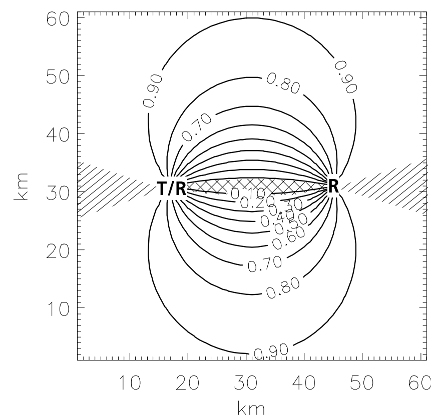

Fig. 1: Spatial distribution of the cosine of scattering angle $\gamma/2$.

Tab. 1: Comparison of radar characteristics for a monostatic and bistatic Doppler radar. Note that all bistatic radar characteristics vary with the scattering angle γ.

	MONOSTATIC	BISTATIC
Lines of constant delay	circles	ellipses
Scattering angle	$\gamma = 0°$	$0° \leq \gamma \leq 180°$
Resolution-volumelength	$a = \frac{c\tau}{2}$	$a = \frac{c\tau}{2\cos^2(\frac{\gamma}{2})}$
Velocity component	$\vec{v}_r \perp$ circle	$\vec{v}_e \perp$ ellipse
Nyquist-interval	$v_N = \pm\frac{\lambda}{4T_S}$	$v_N = \pm\frac{\lambda}{8T_S\cos(\frac{\gamma}{2})}$
Received power	$P_b \sim \frac{\sum\sigma}{r_T'^2}$	$P_b \sim \frac{\sum\sigma(I_v+I_h)}{r_R'^2\cos^2(\frac{\gamma}{2})}$
Polarisation (Rayleigh-scattering)	$I \sim I_0$	$I_v(\chi) \sim \sin^2(\chi)$ $I_h(\chi) \sim \cos^2(\chi)\cos^2(\delta)$

(2) *Quasi-monostatic area* (lined): Here, the electromagnetic wave is scatter mainly backwards. The intersection angle between the radial velocity $|\vec{v}_r|$ and the bistatic velocity $|\vec{v}_e|$ is smaller than $10°$ which makes an dual-Doppler wind composition impossible.
(3) *Quasi-bistatic area*: In this area qualitatively high measurements of Doppler velocity with a reasonable size of the resolution volume ($160\ m$ - $900\ m$), high accuracy of the horizontal wind field and a sufficient intersection angle is achieved.

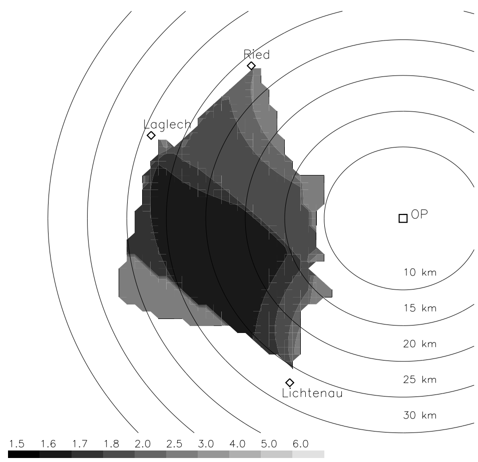

Fig. 2: Spatial distribution of the standard deviation [ms^{-1}] of the horizontal wind field induced by geometry as a multiple of $\sigma_{|\vec{v}_r|}$ within the network (Fig. 3) for a clear-air situation.

Furthermore, an improvement in accuracy up to 40% can be achieved for a triple-Doppler instead of dual-Doppler processing due to over-determined areas (Fig. 2, Fig. 3).
For measurements within low elevations and at weather situation with weak scatterers the monostatic Doppler radar should transmit the electro-magnetic wave with vertical polarisation while the bistatic antenna receives vertically (Wurman et al. (1993); de Elia (2000)). For higher elevation (e.g. 25°) linear 45°- or 135°- polarisation is more appropriate.

3. WIND VECTOR FIELD

The bistatic Doppler radar network at the DLR in Oberpfaffenhofen consists of one monostatic polarisation Doppler radar POLDIRAD and three bistatic radar systems at remote sites containing an antenna and a receiver system (Fig. 3). The network covers an area of 40 km x 40 km. The horizontal opening angle of the bistatic antenna is 60° while the vertical opening angle is 8°.

3.1 Quality Improvement Procedure

A procedure on behalf of defined quality criteria is created weighting each data point for further data processing.
In the first step, two quality criteria are proposed. The first criteria considers only wind velocity measurements within the *quasi-bistatic area* (Fig. 1, Sec. 2) where the scattering angle limit is between 40° and 140° (Satoh and Wurman, 1999). This criteria can be expanded depending on the main focus reaching from a strong constraint using only data within this region or a weak constraint, where all data is used and weighted according to the scattering angle ($W = \sin(\gamma - 10°)$).
As second criteria, a signal quality index (SQI) is defined by

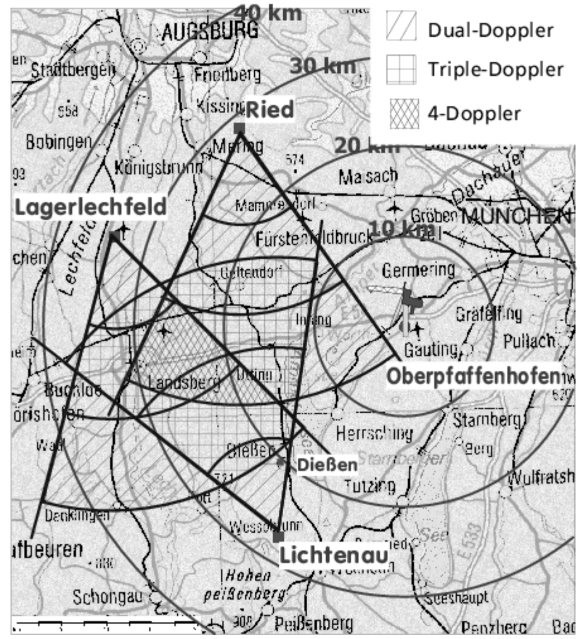

Fig. 3: Map of the bistatic multiple-Doppler radar network at DLR in Oberpfaffenhofen.

setting the NCP threshold (Normalised Coherent Power - index related inversely to the spectral width ranging from 0 to 1) to 0.3 (Satoh and Wurman, 1999) when the reflectivity does not exceed the average horizontal reflectivity by 5 dBZ.

3.2 Variational Method

Due to low elevation angle of the bistatic antennas (8°) mainly horizontal component of the wind field can be measured. To achieve a 3D wind field additional measurments are necessary or a variational method can be used.
Protat and Zawadzki (1999) created a variational analyse method for 3D wind field retrieval that fulfils the continuity equation and is adjusted to the measured horizontal wind vectors. The vertical wind component is calculated on behalf of the equation of continuity and an upward/downward integration. Afterwards, the measured wind field is adjusted to a synthetic wind field over a cost function. This model is exactly determined with just one bistatic receiver and over-determined with an additional one.

4. STRATIFORM PRECIPITATION

4.1 Meteorological Situation & Model Setup

A cold front approaching from NW was investigated on 2 February 2000. During the whole day a dominant high pressure zone over the Alps caused mainly SW flow with maximum values around 15 ms^{-1}. Shortly before the front arrived, wind changed to W and after the passage

to NW increasing up to 20 ms^{-1}. Referring to three meteorological surface observation station, the front passed the investigation area between 1630-1830 UTC from NW to SE. Unfortunately, before the cold front reached the investigation area, the cold front started to dissolve and spread widely.
Monostatic and bistatic velocities were used as input data for the variational analysis method to retrieve a full three dimensional wind field. All formulations described in Protat and Zawadzki (1999). The retrieval was performed with 'quality proved' data (Sec. 3.1). The horizontal resolution is $500\ m$ and a vertical resolution is set to $750\ m$ starting the first level at $850\ m\ MSL$.

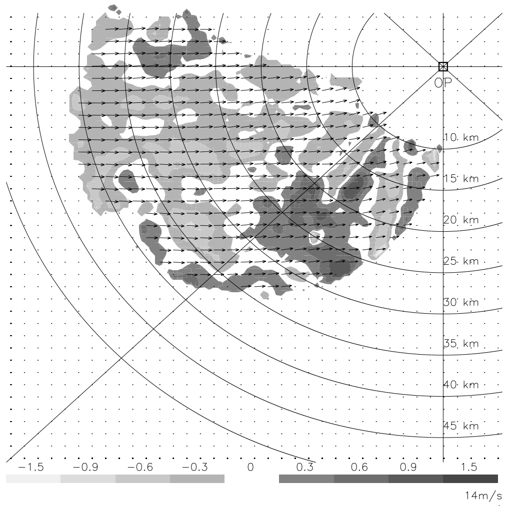

Fig. 4: Retrieved 3D wind field [ms^{-1}] between 1703 UTC at $1.6\ km\ MSL$ on 2 February 2000. Horizontal wind field is indicated by arrows and underlayed by vertical velocity.

4.2 Assessment and Validation

During the whole investigation period up- and downwinds up to $1.5\ ms^{-1}$ were observed. Pre-frontal (1200-1643 UTC) the vertical motion was dominated by upwinds of about $0.6\ ms^{-1}$ while shortly after the front had reached the retrieval area, it was dominated by downward motion. In the vertical wind field (Fig. 4) between 1703-1713 UTC the front lay around $190° - 250°$ SW of Oberpfaffenhofen. Here, the pre-frontal area was indicated by up-winds while after the passage downwind was dominant.
During the complete investigation period clear meteorological structures were visible within the observation area. Although, small spatial areas existed which do not correlate to the reflectivity data, the structure according to a front passage can be verified. Unfortunately, there was no validation to other vertical velocity measurements. Validation with reflectivity data turned out to be complicated because the front was widely spread and reflectivity was contaminated by the bright band at $1.6\ km$.

5. CONCLUSIONS

Simultaneous measurements at each receiver and high mobility are the advantage of the bistatic Doppler radar. Therefore, it represents a good alternative to monostatic dual-Doppler measurements and is a good addition to the monostatic Doppler radar. The main differences between monostatic and bistatic Doppler radar are shortly pointed out in Table 1.
Finding an optimal location for the bistatic receiver systems requires the consideration of the bistatic radar characteristics (Tab. 1) within the *quasi-bistatic area* and the investigations on the accuracy (Fig. 2, Sec. 3) of horizontal wind field according to the main focus of the investigation. The horizontal wind field can be derived with an accuracy influenced by geometry of $1 - 2\ ms^{-1}$ over the whole bistatic network in Oberpfaffenhofen (Fig. 4). Here, the accuracy increases up to 40% because 4-/triple-Doppler processing is done instead of dual-Doppler.
For a stratiform precipitation case on 2 February 2000 the quality criteria as well as the variational method was applied. Although a quantitatively analysis of the vertical velocity can not be made, the vertical motion field fits reasonable into the weather situation with areas of updraft before the frontal passage and down-draft after the passage.

ACKNOWLEDGEMENTS

We thank all people who supported us by installation and operational usage and the radar team at McGill University Montreal for introducing me to the retrieval program.

REFERENCES

de Elia, R.: 2000, *Performance study of a bistatic radar network*, PhD thesis, Dep. of Atmospheric and Oceanic Sciences, McGill University, Montreal.

Friedrich, K., Hagen, M. and Meischner, P.: 2000, Vector wind field determination by bistatic multiple-Doppler radar, *Phys. Chem. Earth (B)* **25**, 1205–1208.

Protat, A. and Zawadzki, I.: 1999, A variational method for real-time retrieval of three-dimensional wind field from multiple-Doppler bistatic radar network data, *J. Atmos. Oceanic. Technol.* **16**, 432–449.

Satoh, S. and Wurman, J.: 1999, Accuracy of composite wind fields derived from a bistatic multiple-Doppler radar network, *Proc. 29th Radar Meteorology Conf., Montreal*, Amer. Meteor. Soc., pp. 221–224.

Wurman, J., Heckman, S. and Boccippio, D.: 1993, A bistatic multiple-Doppler radar network, *J. Appl. Meteor.* **32**, 1802–1814.