Wind Profiling by Doppler Weather Radar

Iwan Holleman (holleman@knmi.nl)
Royal Netherlands Meteorological Institute (KNMI), The Netherlands

ABSTRACT

Doppler weather radars can be employed to determine wind profiles at a high temporal resolution. Several algorithms and quality ensuring procedures for the extraction of wind profiles from radar volume data have been published. A comparison and verification of the extracted wind profiles is being performed at KNMI. Preliminary results indicate that weather radars can provide high-quality wind profiles.

Keywords: Doppler Weather Radar, Radiosonde, NWP, Wind profiles, Verification

1. INTRODUCTION

Weather radars are well known for their ability to detect precipitation at a high spatial and temporal resolution. Precipitation data deduced from reflectivity measurements by weather radars are extensively used for monitoring of (severe) weather and are increasingly used for hydrological applications. The majority of the operational weather radars in Europe is capable of performing Doppler measurements. Using the Doppler technique, the environmental wind can be extracted from the motion of the precipitation. The wavelength of weather radars is optimized for detection of precipitation and is typically 5 or 10 cm. In clear air, therefore, no return signal and thus no wind information is expected, but often (weak) signal is received from the boundary layer, moisture gradients, or large cloud particles. KNMI operates two C-band Doppler weather radars from Gematronik which are amongst others used for obtaining wind profiles.

A Doppler radar only measures the component of the velocity vector in the line of sight, the so-called radial velocity. Radial velocity data is not straightforward to interpret, some further processing is required before it can be presented to users or assimilated into numerical weather prediction (NWP) models. Under the assumption of a linear wind field within the analyzed volume, profiles of the wind speed and direction, vertical velocity, and divergence can be extracted from radial velocity data. Several algorithms for the extraction of wind profiles have been developed, most notably Velocity Azimuth Display (VAD)[1,2] and Volume Velocity Processing (VVP).[3]

Currently, the potential of Doppler radar wind profiles for application in nowcasting, aviation meteorology, and assimilation in NWP models is being assessed at KNMI. This work is part of the COST-717 action on "Use of radar observations in hydrological and NWP models".[4] In this study different algorithms for the extraction of wind profiles and different quality control procedures are being compared and verified. It is planned to collect about a year of three-dimensional reflectivity, velocity, and spectral width data from the Doppler radars. Radar wind profiles at De Bilt will be verified against data from the collocated radiosonde site, and those at De Bilt and Den Helder will be compared quantitatively to profiles of the HIRLAM NWP model. Preliminary verification results are presented in this article, and they indicate that the quality of wind profiles extracted using the Gematronik VVP implementation is generally good. Care has to be taken, however, to avoid loss of quality due to ground clutter and variability of the fall speed of the precipitation. Bird migration can lead to (unexpected) major errors.

2. WIND PROFILING

A Doppler radar uses electromagnetic waves to investigate atmospheric properties: the amplitude of waves is used to estimate the reflectivity and the phase of the waves is used to estimate the radial velocity. The radial velocity of scattering particles is determined from the observed phase jumps between successive transmitted pulses. Doppler radars are recording volume data, i.e., reflectivity, velocity, and spectral width information as a function of range, azimuth, and elevation. The radar geometry used to obtain wind profiles is shown

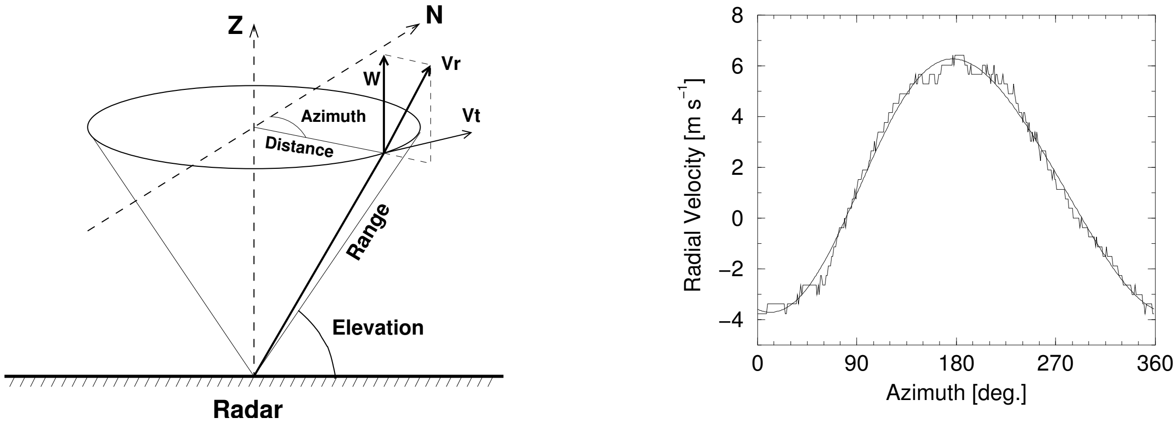

Figure 1. Schematic overview of the radar geometry used to measure Doppler wind profiles is given in left part of the figure. An example of a VAD extracted from radial velocity data is shown together with a fitted sine on the right.

schematically in Figure 1. The radial, tangential, and vertical velocity components have been indicated in this figure.

Wind profiles can be obtained from single-site radial velocity data under the assumption of a linear wind model. In this model, the wind field in the vicinity of the radar is approximated by:

$$U(x,y,z) = u_0 + x\frac{\partial u}{\partial x} + y\frac{\partial u}{\partial y} + (z-z_0)\frac{\partial u}{\partial z} \quad (1)$$

$$V(x,y,z) = v_0 + x\frac{\partial v}{\partial x} + y\frac{\partial v}{\partial y} + (z-z_0)\frac{\partial v}{\partial z} \quad (2)$$

$$W(x,y,z) = w_0 + (z-z_0)\frac{\partial w}{\partial z} \quad (3)$$

The derivatives of the vertical velocity W in x- and y-directions can be neglected with respect to the derivatives of U and V in z-direction.[3] In addition to the movement due to the wind, the hydrometeors have a fall velocity ($W_f < 0$). Using this linear wind field and fall velocity, the radial wind can be calculated as a function of distance (ρ), azimuth (ϕ), and elevation/height (θ/z):

$$V_{radial} = (w_0 + W_f)\sin\theta + \frac{DIV}{2}\rho\cos\theta + u_0\cos\theta\sin\phi + v_0\cos\theta\cos\phi \quad (4)$$

$$+ \frac{SHR}{2}\rho\cos\theta\sin 2\phi + \frac{STR}{2}\rho\cos\theta\cos 2\phi \quad (5)$$

$$+ \frac{\partial w}{\partial z}(z-z_0)\sin\theta + \frac{\partial u}{\partial z}(z-z_0)\sin\theta\sin\phi + \frac{\partial v}{\partial z}(z-z_0)\sin\theta\cos\phi \quad (6)$$

where DIV is the horizontal divergence, SHR and STR are the shearing and stretching deformations of the horizontal wind field.[2] The height around which the analyzed volume is centered is denoted z_0. When Doppler radar data is displayed at constant distance (ρ) and elevation (θ), the radial velocity as a function of azimuth (ϕ) will have the form of a sine, see Figure 1. The wind speed and direction can be determined from the amplitude and the phase of the sine, respectively. This technique is called Velocity-Azimuth Display (VAD).[1,2] Instead of processing a single VAD, one can also process all available velocity volume data within a certain height layer at once. The parameters of the linear wind field can then be extracted using a multi-dimensional and multi-parameter linear fit. This so-called Volume Velocity Processing technique (VVP) has been introduced by

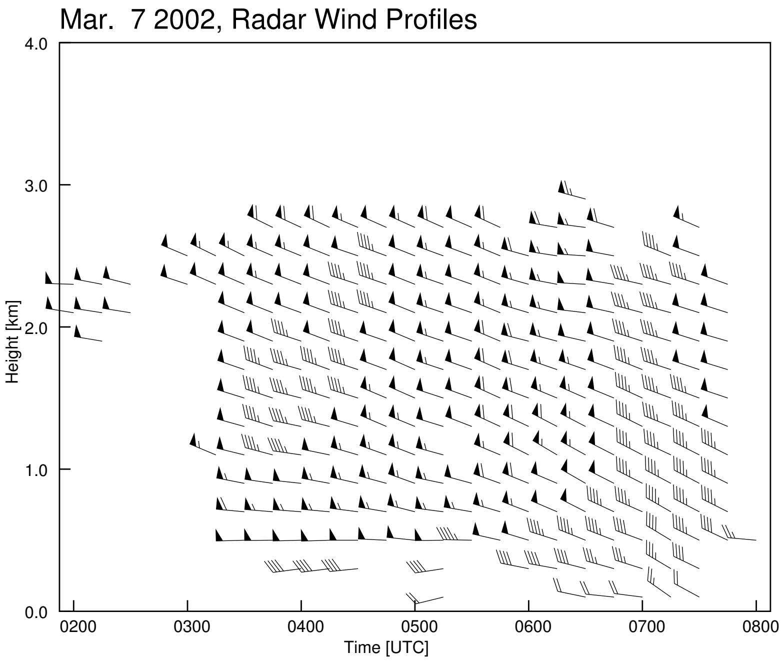

Figure 2. Example of a time-height plot of 6 hours of VVP wind profiles for 7 March 2002. A radar wind profile is available every 15 minutes and wind information is available at 200 m height intervals. Wind speed and direction are indicated by wind vanes. Each full barb represents a wind speed of 5 m/s and each triangle a wind speed of 25 m/s.

Waldteufel and Corbin.[3] The complexity of the fit model can be increased by stepwise addition of equations 5 and 6 to the base radial velocity formula (Eq. 4).

An example of a time-height plot of radar wind profiles extracted using the Gematronik VVP algorithm is shown in Figure 2. The wind profiles are extracted from Doppler volume scans consisting of ten elevations which are recorded four times per hour. These plots contain valuable information on wind signatures of (passing) meteorological phenomena for operational nowcasters and aviation meteorologists.

3. QUALITY OF WIND PROFILES

The quality of radial velocity data and thus of wind profiles can be heavily affected by variability of the precipitation fall velocity, interfering ground clutter, and migrating birds. The variability of the fall velocity of the hydrometeors, maximum 4 m/s for rain and 1 m/s for snow,[2] can hamper the extraction of horizontal winds. This interference becomes more pronounced for higher elevations and thus results in a maximum elevation of roughly 9° in rain and 27° in snow. Ground clutter from sidelobes or nearby obstacles can be suppressed to a large extent by reducing the echo power around zero radial velocity using discrete filtering techniques. For extraction of wind profiles, it is also recommended to reject all remaining points with radial velocities close to zero.

Non-hydrometeor targets such as insects and birds are detected by Doppler radar as well. While some insects can provide a help in defining the boundary layer wind,[5] birds and actively flying insects area a real problem for velocity retrieving algorithms.[6] Erroneous wind data due to birds can be recognized by inconsistency of the wind data or by deviation from reference wind profiles. There is no definitive answer to the bird migration interference problem yet.

Preliminary results of the verification of the wind profiles at De Bilt extracted using the Gematronik VVP algorithm against data from the collocated radiosonde site are available. In Figure 3 a scatter plot of the wind speeds from the radar and from the radiosonde is depicted. Only data from 12UTC is plotted in this figure.

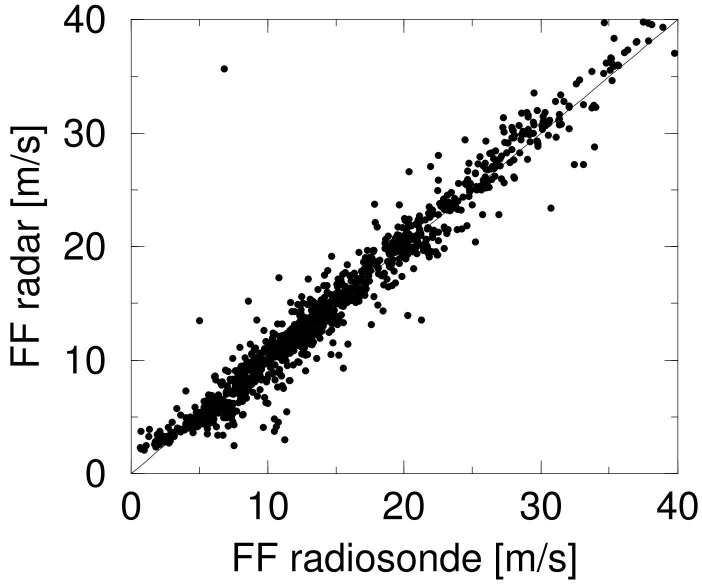

Figure 3. Scatter plot of radar wind speeds at De Bilt from Gematronik VVP algorithm and wind speeds from the collocated radiosonde site. Only data from 12UTC is plotted in figure. The line $y = x$ is indicated in the figure as well.

The matched wind speed pairs are nicely distributed along the $y = x$ line. A fit of all matched wind speed pairs, where obvious outliers have been removed, reveals an almost exact correspondence between the two detection systems: a slope of 1.002(2) and an offset of 0.07(3). In addition, the difference between wind directions and the length of the difference vectors have been analyzed for the matched pairs. No significant bias in wind direction and an average difference vector length of 2.0 m/s were found. This result compares favorably to the average length of about 3 m/s found in verification of Swedish VAD winds against radiosonde data.[7]

4. CONCLUSIONS

In many meteorological circumstances, a Doppler weather radar can provide wind profiles at a high temporal resolution. A long-term verification of the radar wind profiles at De Bilt against data from the collocated radiosonde site is being performed. Preliminary results indicate that the quality of the wind profiles is good, but care has to be taken because of sensitivity to bird migration.

REFERENCES

1. R. M. Lhermitte and D. Atlas, "Precipitation motion by pulse doppler radar," in *9th conference on Radar Meteorology*, pp. 218–223, AMS, 1961.
2. K. A. Browning and R. Wexler, "The determination of kinematic properties of a wind field using doppler radar," *J. Appl. Meteor.* **7**, pp. 105–113, 1968.
3. P. Waldteufel and H. Corbin, "On the analysis of single doppler radar data," *J. Appl. Meteor.* **18**, pp. 532–542, 1979.
4. A. M. Rossa, "The cost 717 action: use of radar observations in hydrological and nwp models," *Phys. Chem. Earth (B)* **25**, pp. 1221–1224, 2000.
5. J. R. Riley, "Radar returns from insects: Implications for meteorological radars," in *29th conference on Radar Meteorology*, pp. 390–393, AMS, 1999.
6. J. Koistinen, "Bird migration patterns on weather radars," *Phys. Chem. Earth (B)* **25**, pp. 1185–1194, 2000.
7. T. Andersson, "Vad winds from c band ericsson doppler weather radars," *Meteor. Zeitschrift* **7**, pp. 309–319, 1998.