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Impact of a novel de-aliasing strategy on the quality of Doppler radar wind profiles and super-observations used for data assimilation

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1 Introduction

Currently, radar data quality issues are lively discussed in the Nordic Weather Radar Network (NORDRAD), the BALTEX Radar Network (BALTRAD), and the COST 717 communities (e.g. Saltikoff et al., 2004; Alberoni et al., 2003). Detailed information can be found on the respective websites http://nordrad.fmi.fi/methods/ and http://www.smhi.se/cost717/.

The aliasing problem is well-known and has been addressed by many authors during the last decades. There exist two main approaches to tackling this issue: one is based on improving the measurement technique of the radar system. For example, velocity aliasing can be reduced significantly by measuring radial winds with alternating sets of pulses using high and low PRFs (Doviak and Zrnić, 1993). The dual-PRF method has the disadvantage that measurements performed at slightly different times or locations are combined which can lead to representativeness errors.

The other approach focuses on post-processing methods. The basic assumption for most of them is that the true wind field is sufficiently smooth and regular; this is true for the greater part of the weather situations with the exception of mesocyclones, tornado vortices or highly sheared environments. The elementary de-aliasing techniques are based on local statistics (Ray and Ziegler, 1977; Bargen and Brown, 1980; Leise, 1981; Mohr and Miller, 1983; Miller et al., 1986) or on local continuity (Eilts and Smith, 1990; Liang et al., 1997). Both methods need a starting point; therefore, they are not capable of de-aliasing isolated areas of radar data without additional information on the environmental wind. This information could be provided as a profile from a nearby sounding (e.g. radiosonde or wind profiler) or from a numerical weather prediction (NWP) model. Defolding of radar winds can also be accomplished in a straightforward manner by always taking the Nyquist number that results in the smallest deviation from a given wind profile (Doviak and Zrnić, 1993). More sophisticated de-aliasing techniques based on, for instance, two or more-dimensional variational methods have been developed during the last two decades (Merritt, 1984; Boren et al., 1986; Bergen and Albers, 1988; Desrochers, 1989; Jing and Wiener, 1993; Wüest et al., 2000). They try to identify regions with the same Nyquist number. Then adjacent regions are compared to detect and correct folded data.

Siggia and Holmes (1991) proposed a variation of the VVP (volume velocity processing; Waldteufel and Corbin, 1979) algorithm, in which de-aliasing is built into the procedure itself, rather than being done as a separate pass. Unlike the methods mentioned above, they do not need independent wind information. Their technique achieves a de-folding factor of three by running 22 VVPs simultaneously on the same input data set. Each VVP assumes a different trial wind field, and the one which yields the best fit (lowest variance) is adopted as the correct solution.

2 De-aliasing method

Based on the idea of Siggia and Holmes (1991) to combine VVP and de-folding, a new de-aliasing algorithm has been developed at SMHI. The innovation of the new method is that it maps the measurements onto the surface of a torus. Unlike many other concepts, it does not depend on wind information from a nearby sounding (e.g. radiosonde or wind profiler) or from an NWP model.

The new method is based on a linear wind model V_m, in which the radial wind velocity in a specified height interval can be expressed as a function of azimuth (Φ) and elevation angle (Θ):

$$V_m(u, v) = (u \sin \Phi + v \cos \Phi) \cos \Theta \,. \quad (1)$$

It should be mentioned that the zonal (u) and meridional wind speeds (v) are assumed to be proportional to the horizontal transport of precipitation. For the sake of simplification, the vertical velocity of hydrometeors is neglected.

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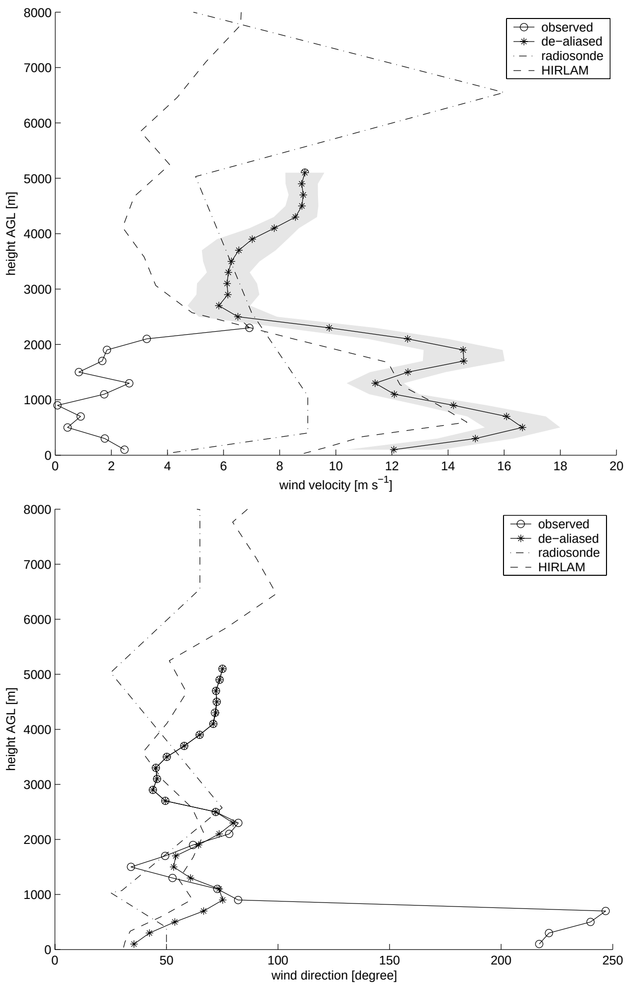

Fig. 1. Vertical profiles of wind velocity (top) and direction (bottom) derived from observed and de-aliased radial wind velocities for Vantaa radar on 4 December 1999 at 12:00 UTC. The gray-shaded area indicates the one-σ-deviation of the de-aliased velocity observations from the VVP solution. Additionally, wind profiles from a six hour HIRLAM forecast for the closest grid point to Vantaa and a radiosonde sounding for Tallinn are shown.

Assuming that the elevation angle and the distance to the radar are constant, each observation at a given azimuth angle is assigned a radial velocity. Unfortunately, the resulting curve could have discontinuities due to aliasing difficulties. To avoid this problem, we map the measurements onto the surface of a torus and yield a continuous parametric curve

$$F(\Phi) = \underbrace{\sin\Phi\left[R + \frac{V_a}{\pi}\sin\left(V_o\frac{\pi}{V_a}\right)\right]}_{F_1}\mathbf{e}_1 + \underbrace{\cos\Phi\left[R + \frac{V_a}{\pi}\sin\left(V_o\frac{\pi}{V_a}\right)\right]}_{F_2}\mathbf{e}_2 + \underbrace{\frac{V_a}{\pi}\cos\left(V_o\frac{\pi}{V_a}\right)}_{F_3}\mathbf{e}_3\,, \qquad (2)$$

where V_o is the observed radial wind velocity and V_a is the Nyquist velocity. The unit vectors $\mathbf{e}_1$, $\mathbf{e}_2$ and $\mathbf{e}_3$ describe the geometry of the new system. The choice of the torus radius R is arbitrary as long as $R > \frac{V_a}{\pi}$. A complete derivation of the novel de-aliasing strategy has been published by Haase et al. (2003).

In order to make a validation of the algorithm as realistic as possible, we decided to apply it on Doppler data from an existing radar network. Variations in real measurements are a priori more natural than in a synthetically generated wind field. Following this concept, Swedish Doppler radar observations were artificially aliased using a reduced Nyquist velocity. Afterwards, the method's capability to reconstruct the original wind field was examined. We performed several case studies covering different weather situations. Almost all aliased velocities were de-folded correctly. However, the performance for stratiform situations was slightly better. An update of the new de-aliasing technique including its validation will be available soon (Haase and Landelius, 2004).

3 Results

NORDRAD is a cooperation project between Finland, Norway, Sweden, and Estonia. Since radial winds from Finnish radars are strongly affected by aliasing problems, we applied the proposed de-folding algorithm to Doppler winds measured with the Vantaa radar (60.27° N, 24.87° E) during the winter storm of December 4, 1999.

3.1 Wind profiles

We generated wind profiles based on the VVP method using radial wind observations within a radius of 40 km. The VVP technique is typically applied to thin layers of data at successive heights. In this case study the vertical resolution is 200 m. Wind speed and direction can be extracted via a multi-dimensional and multi-parameter linear fit of all observations in a certain height interval. If the azimuthal data coverage is less than 1/3 the wind retrieval is rejected at this height level.

Figure 1 shows vertical profiles of wind velocity and direction derived from observed and de-aliased radial wind velocities for Vantaa radar on 4 December 1999 at 12:00 UTC. Aliasing effects are clearly visible up to 2500 m AGL. This is due to the fact that for the lowest four elevation angles (0.4°, 1.3°, 2.3°, 3.3°) only single-PRF data is available. The corresponding Nyquist velocity is 7.55 m s^{-1}. The gray-shaded area indicates the one-σ-deviation of the de-aliased velocity observations from the VVP solution. Its narrow shape is an evidence that the de-folding method is quite stable in this case study.

Unfortunately, there is no radiosonde sounding available for the radar location in Vantaa. Instead, the radiosonde observation for Tallinn (59.38° N, 24.58° E), Estonia, is shown in Fig. 1 (approximately 100 km distance from Vantaa). Although the vertical resolution is much lower than for the radar measurements, structures in the wind speed and direction profiles are similar. The HIRLAM (High Resolution Limited Area Model; Undén et al., 2002) forecast (22 km grid point spacing, no assimilation of radar winds in 1999) reveals the same trend as the de-aliased wind profiles, however not as detailed.

3.2 Super–observations

A super-observation is an intelligently generalized observation created through horizontal smoothing in polar space, based on high resolution data. It includes also a number of derived variables which collectively serve to describe the characteristics of a given observation (Michelson, 2003). A method for generation of radial wind super-observations is already implemented at SMHI.

An example how radial wind super-observations benefit from the new de-aliasing technique is illustrated in Fig. 2. The generalized treatment of the original high resolution polar data can be clearly discerned, as can the preservation of the polar nature of the derived super-observation product (4° azimuthal and 5 km radial resolution). In the output bins with only few high resolution input bins, the super-observation generator has the effect of filling in gaps which leads to more complete and smoothed results.

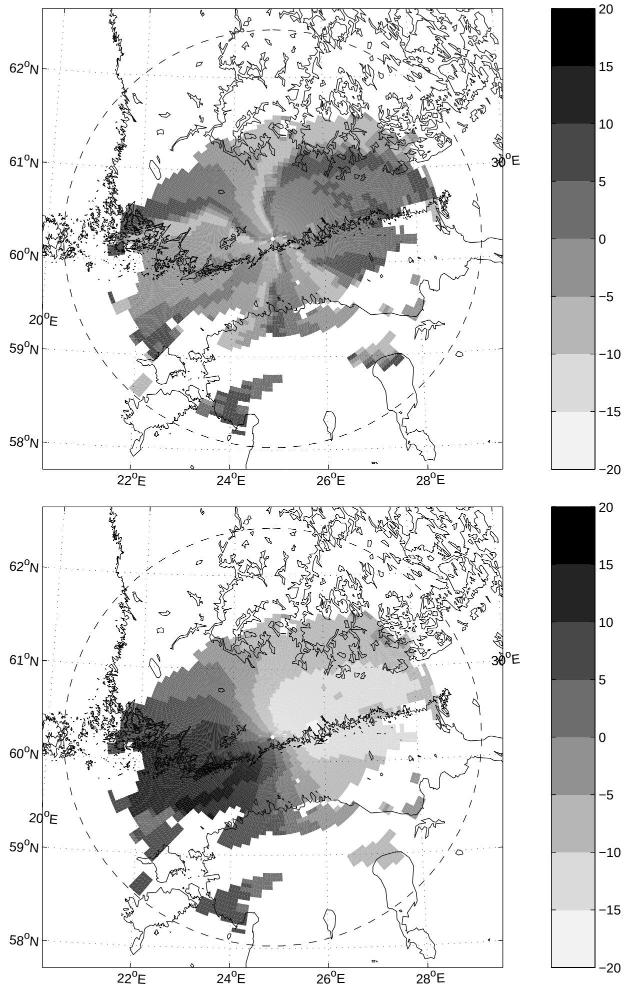

Fig. 2. Super-observation of observed (top) and de-aliased Doppler winds (bottom) in m s^{-1} for Vantaa radar on 4 December 1999 at 12:00 UTC (0.4° elevation angle). Negative values refer to radial winds towards the radar. The dashed line indicates the 250 km range ring.

4 Data assimilation

An important goal of the new de-aliasing algorithm is to improve the quality of Doppler radar wind profiles and super-observations (Sect. 3) used for data assimilation into NWP models.

At SMHI, VAD (vertical azimuth display; Andersson, 1998) profiles are assimilated operationally into HIRLAM aiming to complement the radiosonde soundings in time and space. Alternatively, polar volume radar data can be used in variational assimilation schemes models through the generation of super-observations. An appropriate observation operator for radial winds has been developed for HIRLAM (Lindskog et al., 2000). The use of super-observations instead of high resolution data has three major benefits: i) higher representativeness in respect of the NWP model resolution, ii) lower correlation of the observation errors, and iii) lower computational costs during the assimilation cycle. Additionally, a radial wind super-observation provides more spatial information compared to the corresponding VAD and VVP profile, respectively. Currently, no de-folding routine is applied operationally at SMHI.

5 Conclusions

A novel de-aliasing algorithm for Doppler radar velocity data has been developed at SMHI. It is an accurate and robust tool based on a linear wind model and designed to eliminate multiple folding. The innovation of the new technique is that it maps the measurements onto the surface of a torus. Unlike many other concepts, it does not depend on wind information from a nearby sounding (e.g. radiosonde or wind profiler) or from an NWP model.

The case study presented in Sect. 3 reveals that the quality of the wind profiles and super-observations benefits from the proposed de-aliasing method. This applies for stratiform and convective weather situations (not shown).

In order to evaluate the new technique on a more statistical basis, we are currently preparing a de-aliasing experiment for a representative summer and winter period including all Finnish radars. The de-folded polar volume radar data will be applied to the HIRLAM variational assimilation scheme through the generation of wind profiles and super-observations. Their use is expected to improve substantially with the introduction of the proposed de-aliasing method.

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