4A.2 AN APPLICATION OF THE DOPPLER RADAR RADIAL WIND BIAS ESTIMATION METHOD

K. Salonen*, H. Järvinen, S. Järvenoja, R. Eresmaa and S. Niemelä
Finnish Meteorological Institute

1. INTRODUCTION

Variational data assimilation enables exploitation of indirect observations of the numerical weather prediction (NWP) model variables, such as Doppler radar radial winds. The observed quantity is expressed in terms of the model variables through observation modelling. The tools developed for data assimilation of indirect observations can be used to exploit the observations also for other purposes, like NWP model validation.

This article summarises a bias estimation method for Doppler radar radial wind observations introduced in Salonen et al. (2007). The reliable bias estimation method and the huge amount of available radar radial wind observations make them attractive to be used in NWP model validation. The potential of radar wind observations as an independent data source for model validation is demonstrated by comparing two high resolution limited area model (HIRLAM; Unden et al. 2002) versions, which differ only in the formulation of the surface stress direction.

The article is organized as follows. Section 2 summarises the bias estimation method for radar radial winds. Section 3 demonstrates how radar wind observations can be used in NWP model validation, and a short summary is presented in section 4.

2. BIAS ESTIMATION METHOD

Doppler radar measures the radial wind component around the radar by azimuthal scanning of 360° at several antenna elevation angles. In case of a uniform wind field, the radial wind component has a cosine form as a function of azimuth angle at a given elevation and range. The amplitude of the cosine function determines the wind speed and its phase determines the wind direction (Sauvageot, 1992). Aggregating the observation minus model background (OmB) values for different azimuth directions in the bias calculation can result in a near-zero bias even in the presence of systematic differences in the observed and modelled wind speed and direction. This is illustrated in the next example.

Upper panel of Fig. 1 shows a scatterplot of radial wind observations and their model counterparts from radar Arlanda, Sweden, 12th June 1999 06 UTC, at elevation angle 0.5° and measurement range 45 km. The scatterplot has an abnormal elliptic form, which indicates that there is some systematic error present. Lower panel of Fig. 1 shows the observations (black dots) and model counterparts (blue dots) as a function of azimuth angle. There is some difference in the amplitudes, and a significant phase difference between the observed radial wind and the model counterpart. The phase difference indicates that there is approximately 30° difference in the observed and modelled wind direction. If the radial wind bias is calculated by summing up the individual OmB values, the result is 0.6 m/s. Without seeing Fig. 1 it would be impossible to notice that the data is extremely biased.

The misinterpretations in the bias estimation can be avoided by applying the bias estimation method introduced in Salonen et al. (2007). It enables estimation of the bias in wind speed and direction for Doppler radar radial wind observations. The method, in short, is as follows: in the case of radar radial wind observations there is no unique reference such as u- and v-components in the conventional wind observations. Thus $at first$, an arbitrary reference direction is chosen to make the observations comparable with each other. $Second$, a rotation angle $\Delta\phi$ is determined. In data assimilation system, each radial wind observation has a model counterpart and the model wind direction at the observation location is known exactly. $\Delta\phi$ is determined as a difference between the reference wind direction and the model wind direction. The azimuth angle corresponding to the observation is rotated by adding $\Delta\phi$ to it. With this rotation the nominal wind direction is the same for all observations. $Third$, after the rotation, an azimuth bin average is calculated. By fitting the radial wind equation $v_r = v_h \cos(\delta - \phi)$ to the bin averaged observations, estimates for horizontal wind speed v_h and direction $\delta + \pi$ are obtained. The same procedure is applied also to the model counterparts. The differences in the amplitude and phase of the fitted v_r curves indicate biases in the wind speed and direction, respectively.

By applying the bias estimation method to the data shown in Fig. 1 the obtained bias in wind speed is 1

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[*] *Corresponding author address*: Kirsti Salonen, Finnish Meteorological Institute, P.O.BOX 503, FIN-00101 Helsinki, Finland; e-mail: kirsti.salonen@fmi.fi

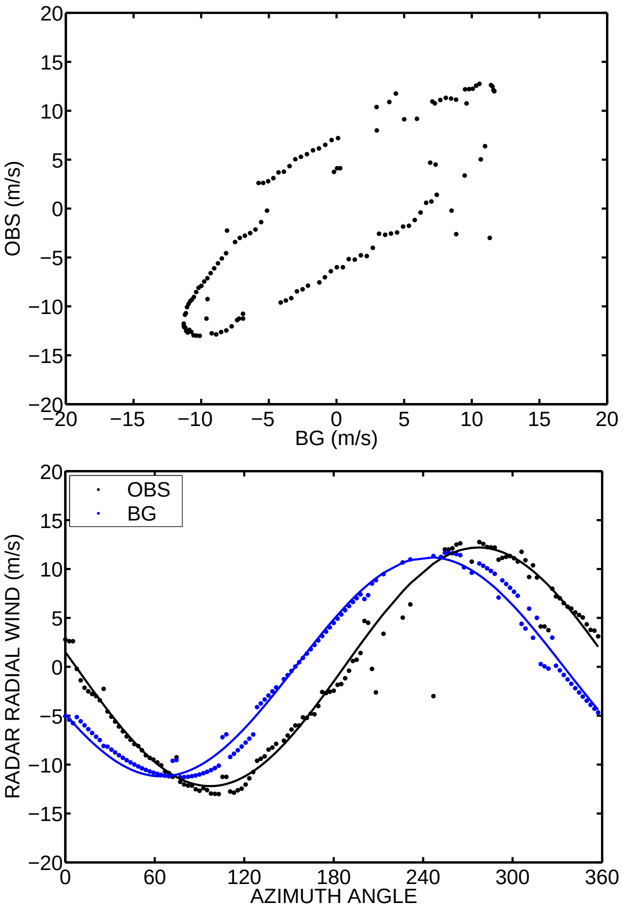

Figure 1: Scatterplot of radar radial wind observations as a function of model counterpart (upper panel). The bin-averaged observed radial wind speed (black dots) and model counterparts (blue dots) as a function of azimuth angle (lower panel). The fitted cosine curve for observations (black line) $v_r = 12.2m/s \cdot \cos(\delta - 277.1^\circ)$ and for model counterparts (blue line) $v_r = 11.2m/s \cdot \cos(\delta - 244.4^\circ)$.

m/s and in wind direction 32.7°. These values give much more realistic impression of the systematic errors in the data, compared to the bias estimate obtained directly from the radial wind OmB values.

3. EXPLOITATION OF THE BIAS ESTIMATION METHOD AS A VALIDATION TOOL

The number of available radar wind observations is enormous compared to the number of available conventional wind observations, like radiosounding and aircraft observations. This fact, together with the presented bias estimation method, makes radar wind data very attractive to be used in NWP model validation.

The HIRLAM forecast model has suffered from too deep low pressure systems due to insufficient filling of the cyclones. The process of filling surface lows depends on the turbulence parametrization in combination with the model dynamics. Tijm (2003) has suggested that cyclone decaying can be improved by modifying the formulation of the surface stress direction. The surface stress is turned clockwise (northern hemisphere) by a fixed amount instead of assuming that the surface stress is parallel to the lowest model level wind direction. Results presented by Järvenoja (2004) and Sass and Nielsen (2004) indicate that the modified surface stress reduces bias in surface pressure and 10-metre winds, but upper air winds become slightly more biased when introducing the surface stress modifications. This kind of modification in the model gives an interesting framework to study the usability of radar wind data in model validation.

Two one-month (January 2002) model experiments have been made with HIRLAM version 7.1alpha3. The experiment setups differ only in the formulation of the surface stress direction. In the experiment 'NO ROT' the surface stress is parallel to the lowest model level wind direction, and in the experiment 'ROT' the surface stress has been rotated according to Tijm (2003). The model versions are validated against radar wind observations from Swedish radars at Arlanda (59.66°N, 17.95°E), Karlskrona (56.30°N, 15.61°E), Leksand (60.72°N, 14.88°E) and Vilebo (58.11°N, 15.94°E). The model counterparts for the radar observations are calculated from model background, which is a 6 h forecast, with the radar radial wind observation operator (Lindskog et al., 2004; Salonen et al., 2003). For comparison the validation is done also against radiosounding wind observations from the model integration area. 95% confidence intervals for the bias statistics are calculated by using the bootstrap method (Efron, 1982; Efron and Gong, 1983). Bootstrap method is based on sampling with replacement. The sample size is the same as the size of the original data set. In these experiments the sampling has been repeated 10 000 times.

Figure 2 shows the vector wind bias calculated against radar wind observations. Near the ground the vector wind bias is over 1 m/s. At low levels the quality of the radar observations can be degraded by ground clutter and other non-meteorological echoes. However, despite the relatively large bias near the ground, it is evident that the bias is significantly larger for the experiment ROT than for the experiment NO ROT below the 2 km altitude.

Upper panel of Fig. 3 shows the vector wind bias calculated against radiosounding observations from the

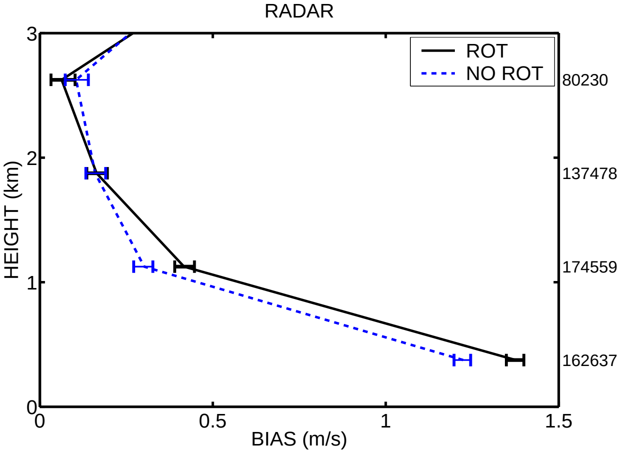

Figure 2: The vector wind bias as a function of height for radar wind observations. Black solid line indicates experiment with rotated surface stress and blue dashed line indicates experiment without the rotation. Black and blue bars show the 95% confidence intervals. The number of observations is shown on the right side of the figure.

model integration area. The magnitude of the vector wind bias is notably smaller for the radiosounding observations than for the radar wind observations. Validation against radiosounding wind observations indicates also that the bias is smaller for the NO ROT experiment than for the ROT experiment. However, the 95% confidence intervals overlap at all altitudes, especially above the 1 km altitude, and the conclusion that the results are statistically significant cannot be made. For comparison, lower panel of Fig. 3 shows the vector wind bias calculated against radiosounding observations from the three Swedish radiosounding stations. The 95% confidence intervals are wide and mainly overlapping. No conclusions at all can be made about the statistical significance of the differences between the experiments.

The model validation results shown here support the earlier results, and indicate that the radar wind data is very useful in NWP model validation. The number of available radar observations is enormous compared to the available radiosounding observations. In this study the radar data set (650 050 observations) was more than 5 times larger than the radiosounding data set (124 220 observatios). The large number of radar observations results in narrow confidence intervals and allows one to draw statistically significant conclusions.

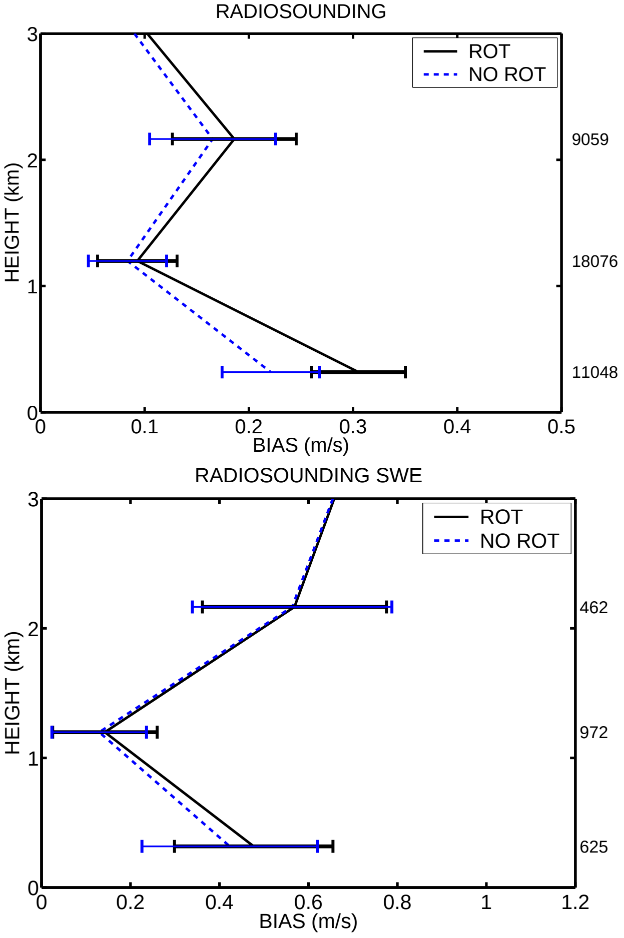

Figure 3: The same as Fig. 2 but for radiosoundings from the model integration area (upper panel) and radiosoundings from Sweden (lower panel).

4. SUMMARY

The presented bias estimation method enables defining the bias in wind speed and direction for Doppler radar radial wind observations. The obtained bias values are straightforward to interpret, unlike the bias values obtained directly from the radial wind OmB values.

A highly potential application for the radar radial wind observations and the bias estimation method is to use them in NWP model validation. The usefulness of the radar wind data in model validation has been demonstrated succesfully by comparing two HIRLAM model versions which differ only in the formulation of the surface stress. The considered bias values contain both the systematic errors in the observations and in the model. The bias calculated against radar wind observations is larger in magnitude than the bias calculated against radiosonde wind observations. However, the model validation benefits from the large amount of radar observations and statistically significant conclusions can be made.

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