Application of radar wind observations for wind atlas validation

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Date: June 18, 2010

1. Introduction

Many countries focus on developing strategies to replace and complement traditional energy sources, such as fossil fuels and nuclear energy, with renewable non-polluting energy sources. Wind power is one alternative and its use is growing rapidly. Knowledge about local wind conditions is essential in order to build wind power plants to reasonable locations.

Wind atlas is a tool which provides detailed information on wind strengths and directions in terms of annual and monthly averages. Finnish Meteorological Institute (FMI) has produced a new numerical weather prediction (NWP) model based wind atlas of Finland (http://www.windatlas.fi/en/index.html). AROME (Applications of Research to Operations at Mesoscale; Bouttier, 2009) NWP model and WASP (the Wind Atlas Analysis and Application Program; Mortensen et al., 1993) statistical model have been applied in the wind atlas production. Wind conditions are given with 2.5 km horizontal resolution. Along coasts and in other windy areas information is even more detailed, having horizontal resolution of 250 m.

In order to confirm the realism of the wind atlas, wind forecasts used in the wind atlas production need to be validated against reliable observations. Traditionally, the quality of NWP model based wind forecasts is studied by comparing the forecasts to mast wind observations below ∼300 m height, and to radiosounding wind observations in the upper atmosphere. Radiosounding wind observations are considered to be of high quality but the spatial and temporal resolution of the observations is poor.

Doppler weather radars provide wind information with high spatial and temporal resolution and their applicability to NWP model validation have been successfully demonstrated (Salonen et al., 2008). For example, a Doppler radar scanning with 2° elevation angle up to 150 km range with a 1 km resolution in range can provide wind information up to 6.5 km height with a nominal resolution of 35 m. In practice, the height resolution is degraded because of the increasing measurement volume with increasing measurement range. In this study, radar data from the FMI radar network have been utilized in wind forecast validation. The FMI radar network consists of eight Doppler weather radars which are able to cover most of the country. During the wind atlas production, AROME 6- and 12-hour wind forecasts have been compared to the radar wind observations, as well as to radiosounding observations. The comparison has been done according to seasons.

The article is organized as follows. Section 2 shortly describes the Finnish Wind Atlas and how it has been produced. Section 3 discusses the model data and observations used in the wind atlas validation, and Section 4 shows the validation results. Finally, a short summary is given in Section 5.

2. Finnish Wind Atlas

The new wind atlas of Finland provides information about the wind conditions in terms of monthly and seasonal averages (http://www.windatlas.fi/en/index.html). The simulation consists of 72 months of data from the period 1989-2007. 48 months of the simulation represent the average wind conditions in Finland during the considered 18-year period. The remaining 24 months represent the year with the strongest winds, and the year with the weakest winds.

The simulations are based on the joint use of the AROME NWP model and the WASP statistical model which is widely used in wind atlas applications. The non-hydrostatic AROME model is run with 2.5 km horizontal
resolution and 40 levels in vertical. The model setup is similar than the setup used for operational daily forecast runs. AROME 6-hour forecasts have been used in the wind atlas production. WASP model have been used at coastal and other windy regions to provide wind information with 250 m horizontal resolution. In the final products, wind information is given for seven altitudes: 50 m, 75 m, 100 m, 125 m, 150 m, 200 m, and 400 m. Figure 1 shows the average wind speed at 200 m height with 2.5 km horizontal resolution for January, as an example of the results.

3. Data sets used in the validation

AROME model has been run operationally at FMI over a domain covering the whole Finland since July 2008. To confirm the realism of the wind forecasts used in the wind atlas production, operational AROME 6- and 12-hour forecasts have been validated for the period of July 2008 - May 2009. The period is divided into four subperiods according to seasons. Validation has been done against radar radial wind observations, as well as against conventional radiosounding observations, as a comparison. The following subsections give more details on the data sets used in the validation.

3.1 Radar observations

A measurement task designed especially for high quality wind measurements is operated at FMI radars every 15 minutes (Saltikoff et al., 2010). The measurement task consists of three low elevation scans, $2^\circ$, $4^\circ$ and $6^\circ$. Dual-PRF technique is applied to alleviate the ambiguity problems. The resulting unambiguous velocity interval in the measurement task is $\pm 35.9 \text{ ms}^{-1}$, and the unambiguous range is 150 km. The spatial resolution of the observations is 1 km. In total, the data set for July 2008 - May 2009 consists of over 26 000 000 observations from the eight radars.

Figure 2 sketches the resolution of the radial wind observations. The left panel of Fig. 2 shows the observation heights as a function of measurement range for elevation angles $2^\circ$, $4^\circ$ and $6^\circ$. The right panel of Fig. 2 gives a view on the vertical resolution. The nominal vertical resolutions for elevation angles $2^\circ$, $4^\circ$, and $6^\circ$ are 35, 70 and, 105 m, respectively. However, in reality the radar wind measurement is a weighted average from the radar measurement volume which is the larger the longer the measurement range. Thus, the actual vertical resolution is somewhat degraded.

In this article, validation results are shown for radar wind observations only from elevation angle $2^\circ$. Measurements are considered up to 80 km measurement range. This corresponds approximately to 3.2 km height. This elevation angle is chosen because it gives the most detailed observations from the lower levels. Measurements from the first 10 km from the radar are excluded to minimize the impact of observations contaminated by ground clutter.

3.2 Radiosounding observations

There are three radiosounding stations in Finland providing observations on daily basis. Observing times for Jokioinen and Sodankylä stations are 00 and 12 UTC, and for Jyväskylä station 06 and 18 UTC. In this study, 06 and 12 UTC observations are utilized, as the initial time for the operational AROME runs is 00 UTC. The radiosounding data set consists of circa 6000 observations.

3.3 Model data

The Finnish Wind Atlas is based on 6-hour AROME forecasts. In the validation also 12-hour forecasts have been considered in addition to the 6-hour forecasts because there are more radiosounding observations available at 12 UTC.

Model counterparts for the wind observations are produced with the so called observation operators from the forecast fields. In case of the radiosounding wind observations, the observation operator simply interpolates the horizontal model wind components $u$ and $v$ to the observation location.

The observation operator for radar radial wind observations also interpolates the model wind field to the observation location (Salonen et al., 2003; Järvinen et al. 2009). Bi-linear interpolation is used in the
horizontal interpolation and a Gaussian averaging kernel in the vertical interpolation. Gaussian averaging kernel takes into account the broadening of the radar pulse volume as a function of measurement range. The interpolated wind components are then projected on the horizontal plane towards the radar and on the vertical plane to the slanted direction towards the radar. The applied observation operator takes into account also the pulse path bending.

4. Validation results

In the following, the validation results are considered in terms of observation minus model counterpart wind speed and direction bias and standard deviation. Bias gives information about the systematic modelling and/or observation errors, while standard deviation describes the magnitude of random errors. Details about the special aspects of radar radial wind bias estimation can be found from Salonen et al. (2007). In the case of radar winds, standard deviation of the radial wind component is studied directly.

4.1 Comparison to radar observations

Figure 3 shows the wind speed bias as a function of height for 6-hour AROME forecasts calculated against wind observations from Vimpeli radar for all four considered seasons. The wind speed bias varies mainly between $\pm 0.5$ ms$^{-1}$. Thus, the bias is relatively small. Scatterplots (not shown) reveal that occasionally the dual-PRF technique systematically fails to resolve the correct radial wind speed. This is due to the fact that the short and long PRFs are used in adjacent azimuth angles and the azimuthal resolution may not always be sufficient to resolve the correct wind speed. This can happen if there is a strong gradient in the radial wind speed, e.g. due to mesocyclone, or close zero velocity when there is naturally strong gradient in the radial wind speed (Nevvonen and Saltikoff, 2010).

Figure 4 is similar to Fig. 3 but for the wind direction bias. The bias varies between $\pm 5^\circ$. For autumn and spring seasons the bias is actually very close to zero above 1 km height. It can be concluded that in terms of the wind direction bias the quality of both the AROME wind forecasts and the radar wind observations is very good.

Finally, Fig. 5 shows the standard deviation for the radial wind component as a function of height. It varies between 2–3.5 ms$^{-1}$. The occasional failure of the dual-PRF technique, discussed in the context of bias, contributes also to the magnitude of the random error. Other sources of random observation errors are e.g. exceeding of the unambiguous velocity interval, and remaining non-meteorological echoes, such as ground clutter, which are not detected and removed by the radar data preprocessing.

Validation of AROME 6-hour forecasts against wind observations from the other radars gives very similar results, excluding radar Luosto. This will be discussed more in Section 4.3. Validation of the 12-hour forecasts gives also similar results and is not discussed further in this article.

4.2 Comparison to radiosounding observations

Radiosounding wind observations are considered to be of very high quality. The drawback is that their spatial and temporal resolution is low. In this study AROME wind forecasts have been compared to radiosounding observations to gain knowledge is the quality of radar wind observations sufficient for this kind of model validation purposes.

Figure 6 shows the wind speed bias (upper left panel), wind direction bias (upper right panel) and the wind speed standard deviation (lower panel) for AROME 6-hour wind forecasts calculated against radiosounding observations from Jyväskylä for the period September - November 2008. The dashed line in the figures indicate the approximate height up to which radar observations are available. The wind speed bias varies between -0.5 – 0.2 ms$^{-1}$, the wind direction bias between $-5^\circ$ – $1^\circ$, and the standard deviation $2 – 3.8$ ms$^{-1}$. Thus, the magnitude of the biases and the standard deviation are of the same order than when calculated against radar wind observations. Results are similar for other considered periods as well. Thus, it can be concluded that radar observations are extremely valuable supplement to the observations used for model validation purposes.
4.3 Mutual benefits

Monitoring the quality of model forecasts against observations gives important information about the observation quality as well. A good example of this mutual benefit is radar Luosto which was included in the validation study.

The validation results against wind observations from Luosto are rather similar to other results during July -August 2008 (not shown). However, in the autumn period the wind direction bias increases substantially, and receives values as high as 150° (left panel of Fig. 7). Typically the radial wind measurements are interpreted such that negative values are towards the radar and positive values are away from the radar. This is defined in the radar software. Due to a human error, the positive and negative values were interpreted conversely for some time, and this caused the large wind direction biases in the validation. The error was fixed and the validation results returned back to the same level as for the other radars (right panel of Fig. 7).

This example demonstrates clearly how comparison against model data can reveal flaws in the observations which in the worst case could remain unnoticed for a very long time.

5. Summary

Finnish Meteorological Institute has produced a new NWP model based wind atlas of Finland. The wind atlas is based on AROME NWP model and WaSP statistical model. In order to confirm the realism of the wind forecasts used in the wind atlas production, AROME 6- and 12-hour wind forecasts have been validated against radar radial wind observations and radiosounding wind observations. The results indicate that the systematic and random errors are relatively small, and of the same order of magnitude independent of the validating observation type. The validation benefits from the large number of radar observations. Radar observations have significantly higher resolution both in space and in time. There are more than 4000 times more radar observations than radiosounding observations available for the considered period of July 2008 -May 2009.

References


Figure 1: Mean windspeed at 200 m height for January. (Original figure available at http://www.windatlas.fi)

Figure 2: Observation heights as a function of measurement range (left panel) and the vertical resolution of the observations (right panel) for elevation angles 2°, 4° and 6°.
Figure 3: Wind speed bias as a function of height for 6-hour AROME forecasts calculated against wind observations from Vimpeli radar. Considered periods are Jun - Aug 2008 (upper left panel), Sep - Nov 2008 (upper right panel), Dec 2008 - Feb 2009 (lower left panel) and Mar - May 2009 (lower right panel).

Figure 4: Same as Fig. 3 but for the wind direction bias.
Figure 5: Same as Fig. 3 but for the radial wind standard deviation.

Figure 6: Wind speed bias (upper left panel), wind direction bias (upper right panel), and wind speed standard deviation (lower panel) as a function of height (pressure) calculated against wind observations from Jyväskylä sounding station. Considered period is Sep - Nov 2008. The dashed line in the figures indicate the height up to which radar observations are available.
Figure 7: Wind direction bias as a function of height calculated against wind observations from Luosto radar. Considered periods are Sep - Nov 2008 (left panel) and Mar - May 2009 (right panel).