Sensitivity of simulated winds upstream of mountains to horizontal resolution

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Abstract: A severe windstorm in the complex terrain of NW-Iceland on 1-2 February 2002 has been simulated. The windstorm is characterized by large horizontal variability in wind speed and vertically propagating gravity waves that break below 500 hPa. Mesoscale phenomena such as downslope windstorms are generally well simulated but winds immediately upstream of steep mountains are however relatively poorly reproduced. Here, the windstorm is simulated with horizontal resolution up to 330 m and the simulated wind speed upstream of a mountain is compared to observations. The greater the resolution is, the steeper is the topography and the simulated winds are closer to observed winds. At a horizontal resolution of 330 m, the simulated winds are however still stronger than the observed winds.

Keywords *- Complex terrain, local windstorms, terrain sensitivity upstream of mountains*

1. INTRODUCTION

A strong northeasterly windstorm hit Iceland on the evening of 1 February 2002. The highest wind speeds were observed in the mountainous terrain of Northwest-Iceland. Here the storm was also characterized by a large mesoscale variability in the observed winds. While the maximum observed mean winds and gusts exceeded 32 m/s and 44 m/s at Æðey, the mean wind and gusts reached only 16 m/s and 28 m/s at Bíldudalur (Fig. 1). Analysis of numerical simulations, satellite imagery, as well as available ground based observations, indicate that

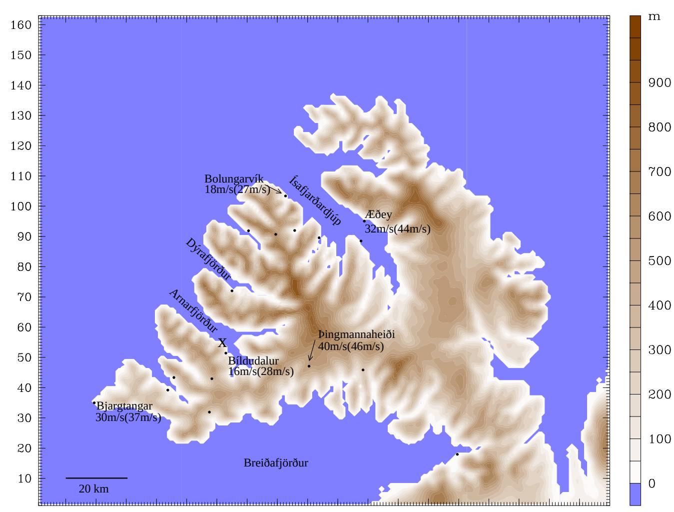

Figure 1. Terrain height [m] in Northwest-Iceland. Numbers show maximum 10 minute mean winds and gusts [m/s] observed during the storm at chosen weather stations.

local windstorms were related to vertically propagating gravity waves above the mountains of Northwest-Iceland (Ágústsson 2004, Ágústsson and Ólafsson 2004). These waves were found to break below 500 hPa, presumably causing the strong and gusty winds observed at the surface below the waves.

Experiments have previously been performed on the sensitivity of the gravity waves to the orography (Ólafsson and Ágústsson 2004). In one experiment, the width of the largest fjord, Ísafjarðardjúp, was reduced. In a numerical simulation with the modified orography, the breaking waves aloft were considarbly steeper and surface winds slightly weaker than in a control run with unmodified orography. In this paper, we describe a different sensitivity test on simulated surface winds. Previous studies of the storm showed that simulated surface winds were on average significantly overestimating the observed winds at locations immediately upstream of steep mountains. This is most likely related to a poorly represented deceleration of the upstream flow by the mountains. Here we do a series of numerical simulations with increasing horizontal resolution and investigate how the upstream windfield near the mountains varies with an improved representation of the topography, in particular the terrain slope.

The second section of this paper discusses shortly the methodology used in the study. In section 3, some of the results of the sensitivity studies are discussed and compared to available observational and geographical data. Section 4 gives the most significant results of the study.

2. METHODOLOGY

The storm of 1-2 February 2002 is simulated with the MM5 numerical model (Grell et al. 1995). The model is run in a nested configuration at four different resolutions, 9 km, 3 km, 1 km and 330 m. Forty vertical levels are used. Boundaries of the atmospheric model are forced with analysis from the ECMWF.

The storm has previously been successfully simulated with the same atmospheric model and the results verified with observations from approx. 15 different automatic stations in Northwest-Iceland. In this study, the simulations are verified with observations of the 10 minute mean wind at 10 m above ground level at the automatic station at Bíldudalur (Fig.1). The station belongs to Veðurstofa Íslands (The Icelandic Meteorological Office) and is located in the small settlement of Bíldudalur, under a relatively steep mountain which faces east and northeast (Fig. 2).

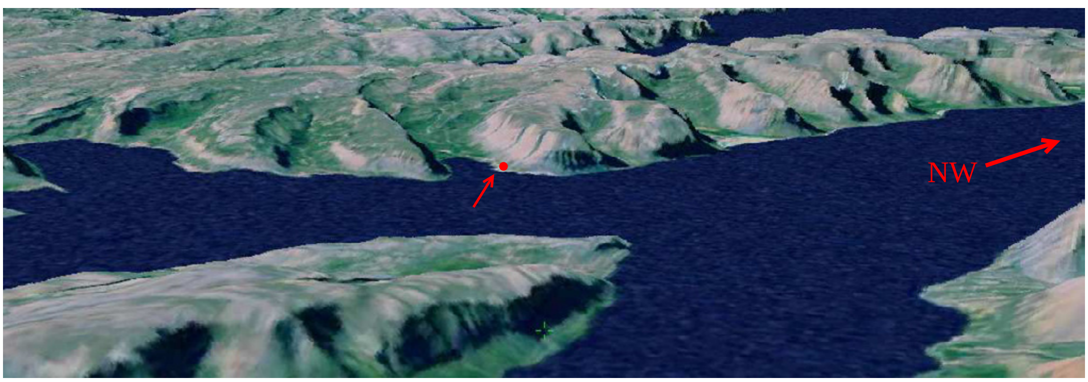

Figure 2. Aerial view over the fjord Arnarfjörður, looking in a westerly direction towards Bíldudalur, which is marked with a red arrow and a dot. Data from Landmælingar Íslands (The Icelandic Geosurvey).

3. RESULTS

The simulated windfield near Bíldudalur varies greatly with the horizontal resolution of the simulations. At a grid size of 9 km, no details can be seen in the small scale flow, but the large scale flow is however well reproduced (not shown here) as has been verified in previous studies (e.g. Ágústsson 2004).

With a grid size of 3 km (Fig. 3) there are some details seen in the structure of the flow. However, a comparison with the simulation with a grid size of 1 km (Fig. 3) shows that the simulated wind field is unrealistic for a resolution lower than 1 km. This is not surprising as the most important features in the topography, e.g. the fjords, have a characteristic width on the order of 10 km or less. With a resolution of 3 km or lower, the terrain can not be correctly represented.

At a horizontal resolution of 1 km, the representation of the terrain improves dramatically compared to a resolution of 3 km (cf. Figs. 2 and 3). The surface wind field is more detailed with a high wind speed region, indicative of a downslope windstorm, appearing in the fjord Arnarfjörður (Fig. 1). Areas of lee-side sheltering and upstream deceleration of the airflow in Arnarfjörður and near Bíldudalur can also be seen.

There is a big difference between the details seen in the flow at a resolution of 3 km and 1 km. When the resolution is increased again (Fig. 4), there is not as dramatic increase in the details of the surface windfield as seen before. However, the representation of the topography improves and the greatest difference is observed in the steepness of the mountain slopes (Figs. 2–5). Consequently, there are also some significant differences in the simulated windfield. Lee-side sheltering is better defined than with a grid size of 1 km, e.g. on the northern side of

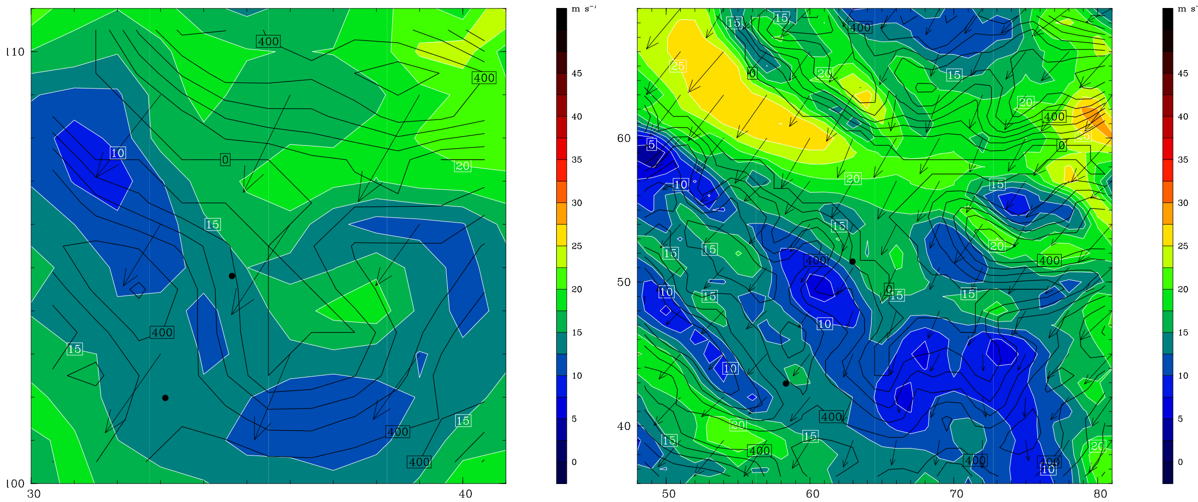

Figure 3. Simulated surface wind [m/s] and topography [m] at a horizontal resolution of 3 km (left) and 1 km (right) at 00 UTC 2 February 2004. The black dot near the centre marks the location of Bíldudalur.

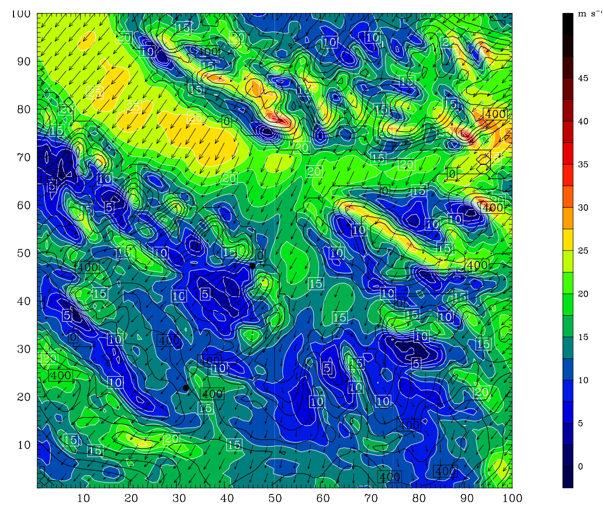

Figure 4. Simulated surface wind [m/s] and topography [m] at a horizontal resolution of 330 m at 00 UTC 2 February 2004. The black dot near the centre marks the location of Bíldudalur.

Arnarfjörður. Also evident is the decrease in wind speed immediately upstream of the mountains on the southern side of the fjord. The simulated surface winds are weaker everywhere along the southern coast of the fjord and especially near the location of Bíldudalur. This decrease is also well seen at other times (Fig. 6). From 22 UTC on 1 February 2002 to 03 UTC on 2 February, the wind at Bíldudalur is on average 2.5 m/s weaker with a resolution of 330 m as opposed to 1 km. The weaker winds are more consistent with observations at Bíldudalur.

The weaker winds upstream of the mountains are presumably related to an improved representation of the topography, in particular an increased steepness of the mountains, which were to sloping at a resolution lower than 330 m (Fig. 5). The steeper mountains are expected to give a stronger deceleration of the impinging airflow.

4. CONCLUSIONS

In this paper, we have described a sensitivity study on the effect of variable horizontal resolution on the simulated surface wind field upstream of a mountain in a severe windstorm in Northwest-Iceland.

While the surface wind is on average well simulated at most locations during the storm, the observed wind is generally overestimated upstream of steep mountains. Although there is not a big change in the storm’s magnitude, the simulated wind speeds at Bíldudalur agree better with observations when the resolution is increased from 1 km to 330 m.

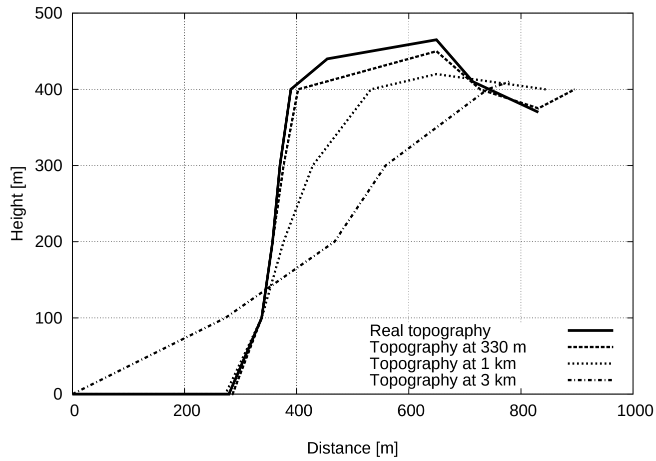

Figure 5. Real and simulated terrain slopes in the direction of the wind at the location marked X in Fig. 1.

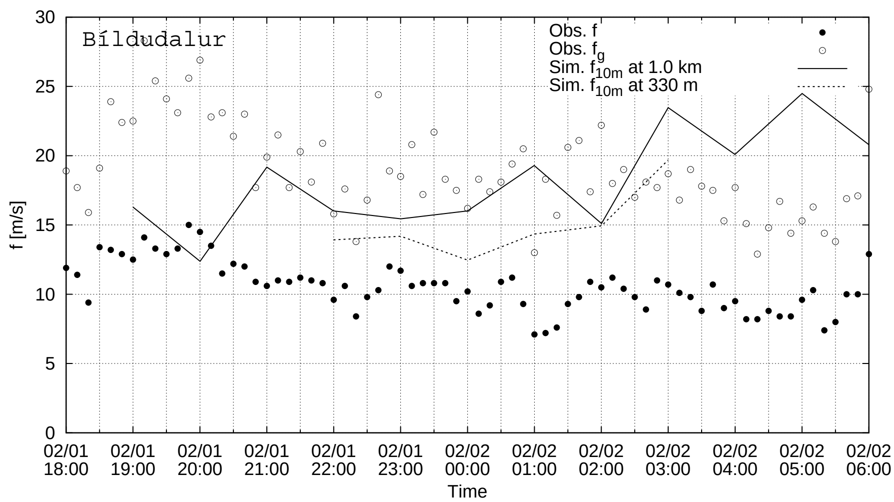

Figure 6. Observations of 10 minute mean winds and gusts [m/s], as well as simulated surface winds [m/s] at a resolution of 1 km and 330 m at Bíldudalur.

The improvement in the simulated surface winds is related to an improvement of the representation of the topography, especially the steepness of the terrain which reflects on how strongly the impinging airflow is decelerated by the upstream mountains.

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