P1.7

OBSERVATIONS AND SIMULATION OF DOWNSLOPE WINDSTORMS AND GRAVITY WAVES OVER NORTHWEST-ICELAND

Haraldur Ólafsson and Hálfdán Ágústsson*
Veðurstofa Íslands and Háskóli Íslands**

1. INTRODUCTION

On 1 February 2002, a strong windstorm hit Northwest-Iceland. The storm lasted for approximately two days, and disrupted transport on ground and in the air, caused damage to structures and led to several avalanches.

In this study, the storm is analyzed using conventional observations of wind at the ground, numerical simulation and satellite images. The storm is of particular interest because of the large mesoscale variability in the observed wind speed.

2. THE STORM OF 1–2 FEBRUARY 2002

Figure 1 shows the mean sea level pressure at 00 UTC on 2 February 2002. There is a deep low at the south coast of Iceland and a high over Greenland. Consequently, there is a large pressure gradient over Iceland and the Denmark strait, and a strong northeasterly windstorm over Northwest-Iceland.

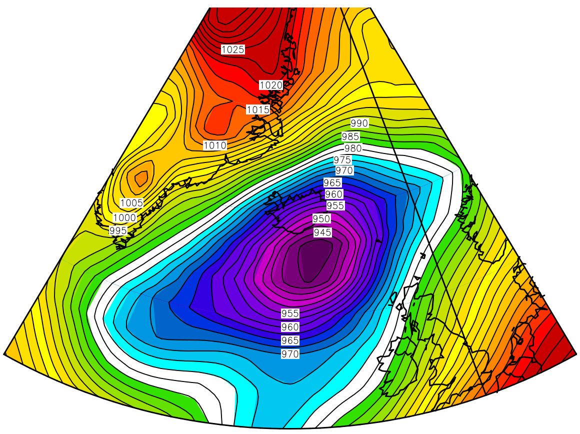

Figure 1: The mean sea level pressure [hPa] at 00 UTC on 2 February 2002. Based on data from NCEP, acquired through NOAA/CDC.

As in many other storms in mountainous terrain, there was large spatial variability in the wind speed. At Æðey (Fig. 4), the 10 minute mean wind speed exceeded 32 m/s and the maximum gust was 44 m/s, while in Bíldudalur (Fig. 4), the mean wind reached only 16 m/s and the maximum gust was 28 m/s.

3. SATELLITE OBSERVATIONS

Figure 2 shows satellite images of Northwest-Iceland, taken during the windstorm. In the images, there are

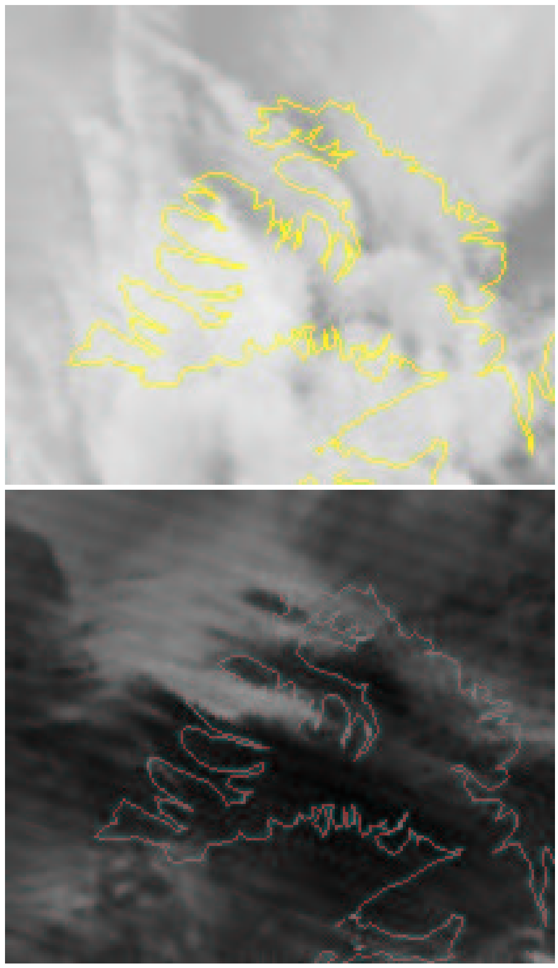

Figure 2: Satellite images (IR) valid at 03:52 UTC (upper panel) and 13:30 UTC (lower panel) on 2 February 2002. The images are from the NOAA satellites, and were aquired through the Satellite Receiving Station of Dundee University in Scotland.

*Corresponding author: Veðurstofa Íslands, Bústaðavegi 9, IS 150 Reykjavík, ICELAND, e-mail: halfdan@vedur.is.
**Icelandic Meteorologic Office and University of Iceland.

cloud bands running perpendicular to the wind direction, indicating gravity waves aloft. The waves signature is particularly clear in the vicinity of Æðey. It should be noted that the waves extend far to the west, to an area where there are no mountains below.

4. SIMULATION OF THE STORM

The storm is simulated with the numerical model MM5 (Dudhia et al. 2002), with a horizontal resolution of 9, 3 and 1 km, and 40 vertical layers. The numerical domains, D1, D2 and D3, are shown in Fig. 3. The initial data and boundary values are from the European Centre for Medium-range Weather Forecasts (ECMWF). For further information on the simulation of the storm, the reader is referred to Ágústsson and Ólafsson (2004) or Ágústsson (2004).

Figures 3 and 4 show the simulated surface wind speed at a resolution of 9 and 1 km, respectively. Several areas with locally enhanced wind speeds appear in the simulation at a horizontal resolution of 1 km. Where observations are available (e.g. Æðey and Þingmannaheiði, Fig. 5), they confirm the strong winds. At a resolution lower than 1 km, the complex topography in Northwest-Iceland is poorly resolved, and there is little detail in the simulated surface wind field. At a resolution of 9 km, there are however regions of slightly enhanced wind speeds near Æðey and Þingmannaheiði.

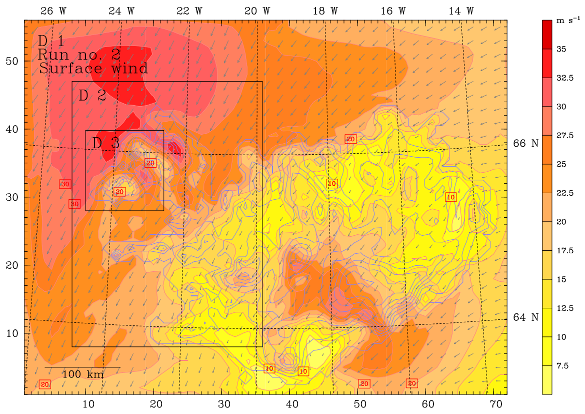

Figure 3: Simulated surface wind at low horizontal resolution (9 km) at 00 UTC on 2 February 2002. Terrain contours with a 200 m inteval. The delineated domain marked D1 is enclosed by Fig. 4.

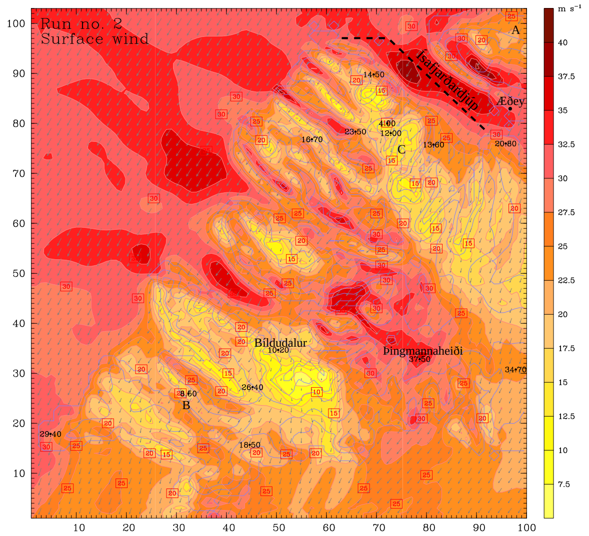

Figure 4: Simulated surface wind at high horizontal resolution (1 km) at 00 UTC on 2 February 2002. Terrain contours with a 200 m inteval. Shown are 10 minute mean wind speed observations (numbers) at 10 m a.g.l., at selected weather stations.

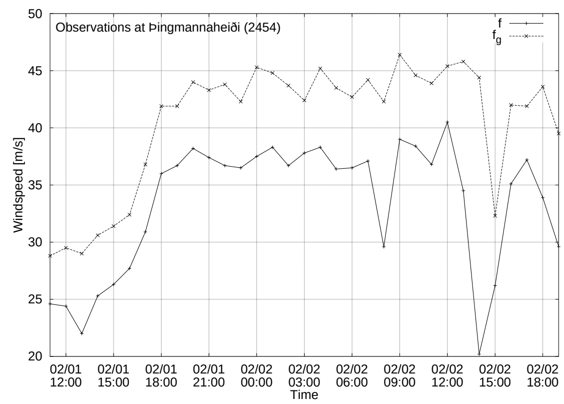

Figure 5: Observed 10 minute mean wind, f, and 3 second wind gusts, f_g, at 10 m a.g.l., at Þingmannaheiði in Northwest-Iceland.

5. BREAKING WAVES

Figure 6 shows a northeast-southwest oriented cross-section through domain D3 in Fig. 4. The figure reveals large amplitude oscillations over the mountains. In these waves, the maximum wind speed is found where the air is descending, while in the ascending part of the wave, the wind is much weaker. Æðey is below the descending part of the steepest wave, while Bíldudalur is below the ascending part of another wave, further

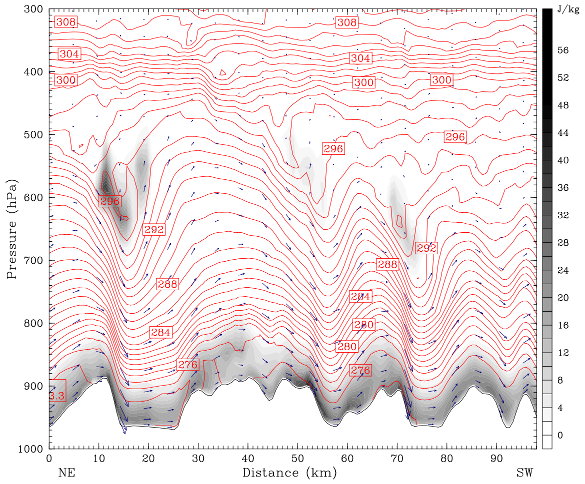

Figure 6: Along-wind cross-section from A to B in Fig. 4, at 00 UTC on 2 February 2002. Shown are wind vectors, potential temperature [K] and turbulent kinetic energy (shaded regions).

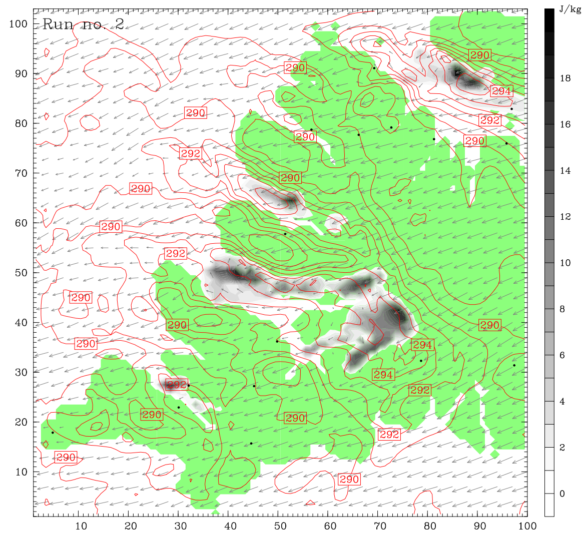

Figure 7: Wind vectors, potential temperature [K] and turbulent kinetic energy (shaded) at 550 hPa on 2 February 2002 at 00 UTC.

downstream.

Figure 6 shows that the waves break in a region of reverse vertical wind shear in the ambient flow close to 600 hPa. There is statically unstable air and strong turbulence where the waves break.

The distribution of turbulence kinetic energy, shown in Figures 7 and 8, indicates breaking gravity waves in several areas in the region. Strong winds are indeed observed in Æðey and at Þingmannaheiði (Fig. 5), which is close to the eastern limits of the southernmost wave breaking region, but observations at the ground are not available from elsewhere below breaking waves.

The potential temperature field and the wind field in Figures 7 and 8 show that the model reproduces the transport of energy to the northwest, away from the mountains and perpendicular to the flow direction.

6. Modified orography

The sensitivity of the gravity waves to the orography was investigated. A sensitivity simulation was performed, where the width of the fjord Ísafjarðardjúp (Fig. 4) was reduced by extending the mountains on the southern side into the middle of the fjord (dotted line in Fig. 4). In Figures 9 and 10, the results of the sensitivity simulation are compared to the results of a simulation which uses unmodifed orography.

The breaking wave over Ísafjarðardjúp is considerably steeper when the width of the fjord has been reduced, than with the actual orography. The maximum wind speeds in the wave are slightly greater, and found

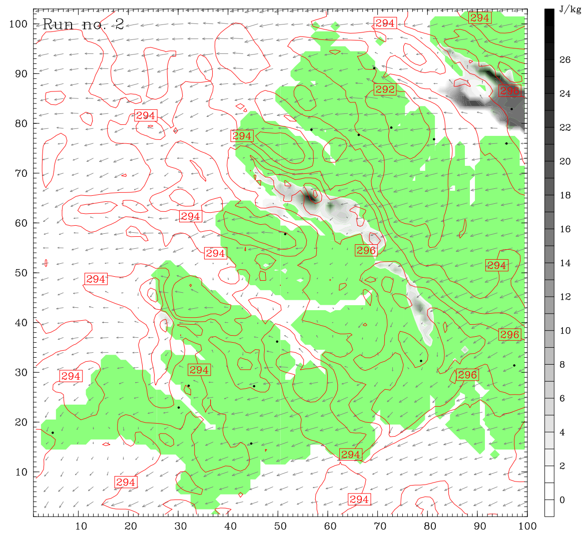

Figure 8: Wind vectors, potential temperature [K] and turbulent kinetic energy (shaded) at 650 hPa on 2 February 2002 at 00 UTC.

at a slightly lower altitude in the simulation which uses unmodified orography than in the sensitivity run. The largest difference in wind speeds is found at the surface. In the sensitivity run, the maximum surface wind speeds do not exceed 33 m/s, while with unmodified orography, the maximum wind speeds at the surface are approx. 37 m/s.

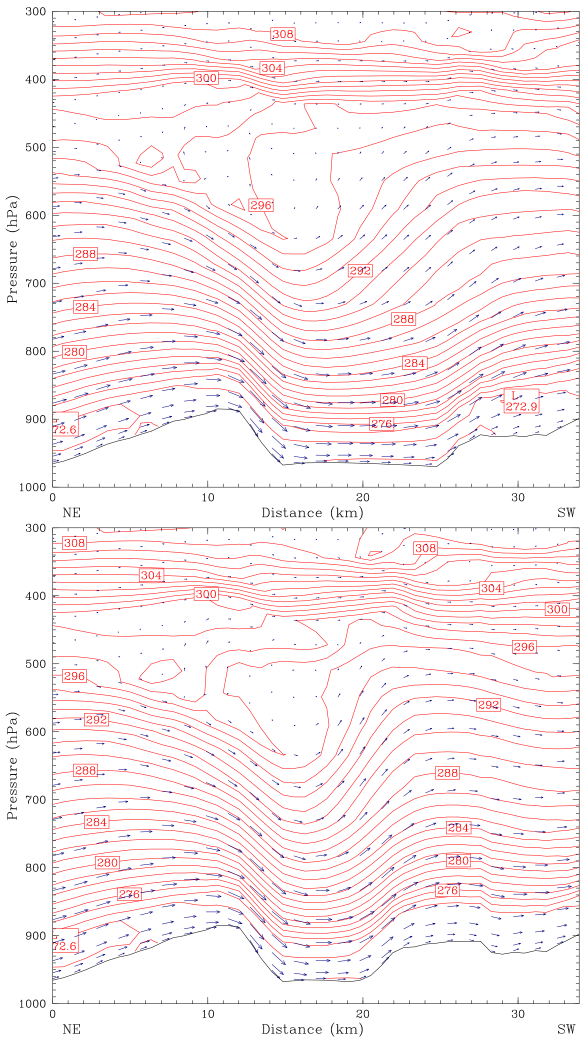

Figure 9: Along-wind cross-section from A to C in Fig. 4, at 00 UTC on 2 February 2002. Upper panel uses the actual orography while lower panel uses the modified orography. Shown are wind vectors and potential temperature [K] isolines.

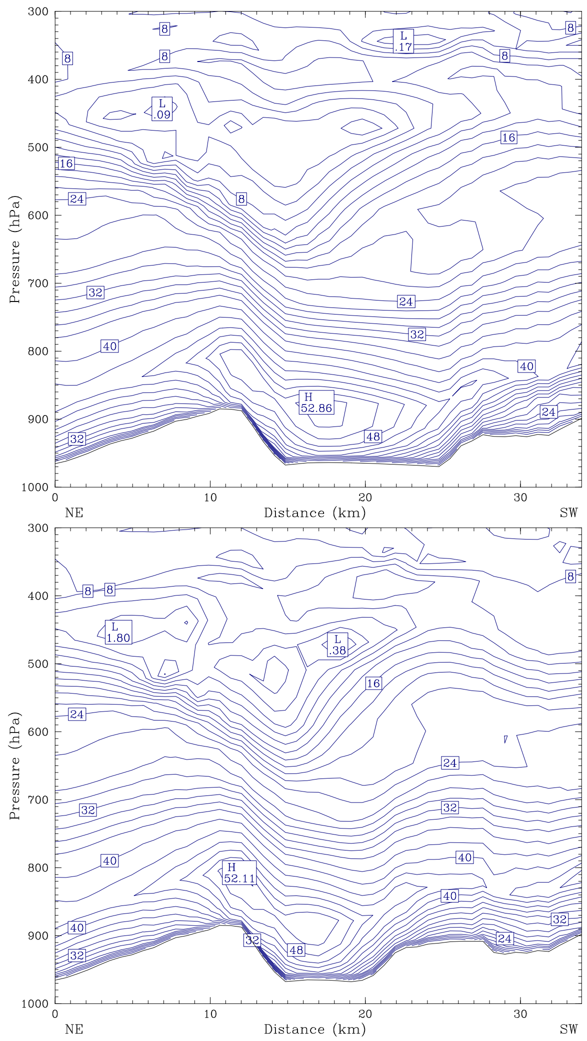

Figure 10: Along-wind cross-section from A to C in Fig. 4, at 00 UTC on 2 February 2002. Upper panel uses the actual orography while lower panel uses the modified orography. Shown are wind speed isolines [m/s].

7. CONCLUSIONS

Local intensification of a windstorm in Northwest-Iceland appears to be associated with gravity waves aloft. A numerical simulation reproduces the waves and indicates that they break close to 600 hPa, where they meet a reverse vertical wind shear in the background flow. This is reminiscent of the model of a downslope windstorm proposed by Smith (1985). The wave energy is partly transported away from the mountains in a direction perpendicular to the flow.

The gravity wave activity appears to be dependent on the width of the fjords. In a simulation with a more narrow fjord, the waves are steeper, but there is less wind speed at the surface.

The results are promising for the use of high-resolution simulations for forecasting the local structure of windstorms in complex terrain, and even for predicting atmospheric turbulence.

8. ACKNOWLEDGEMENT

The study was supported by Veðurstofa Íslands (The Icelandic Meteorological Office), Rannsóknastofa í veðurfræði (The Institute for Meteorological

Research) and Rannsóknanámssjóður Rannsóknaráðs Íslands (The Icelandic Research Fund for Graduate Students).

REFERENCES

Ágústsson, H.: 2004, *High-resolution numerical simulations of windstorms in the complex terrain of Iceland*. Háskóli Íslands (University of Iceland).

Ágústsson, H. and Ólafsson, H.: 2004, High-resolution simulations of windstorms in the complex terrain of Iceland, 16.4, *11th conference on mountain meteorology and the Annual Mesoscale Alpine Program (MAP)*. Available at http://ams.confex.com/ams/11Mountain/techprogram/meeting_11Mountain.htm (May 2004).

Dudhia, J., Gill, D., Guo, Y., Manning, K., Bourgeois, A., Wang, W., Bruyere, C., Wilson, J. and Kelly, S.: 2002, *PSU/NCAR Mesocale Modeling System Tutorial Class Notes and User's Guide: MM5 Modeling System Version 3*, Mesoscale and Microscale Meteorology Division, National Center for Atmospheric Research. Available at http://www.mmm.ucar.edu/mm5/documents/tutorial-v3-notes.html (July 2003).

Smith, R. B.: 1985, On severe downslope winds, *J. Atmos. Sci.* **42**(23), 2597 – 2603.