16.3 Observations and numerical simulations of a wake and corner winds in a strong windstorm over Iceland

Haraldur Ólafsson[a,1] and Melvyn A. Shapiro[b]

[a)]University of Iceland, Icelandic Meteorological Office and Institute for Meteorological Research, Reykjavík, Iceland
[b)]NOAA/Environmental Technology Laboratory, Boulder CO, USA

1. INTRODUCTION

The reduction of wind speed downstream of mountains has gained interest in recent years with the availability of satellite-based observations of the wind field over water surfaces and increased computer power for high-resolution numerical simulations. Traditionally, wakes have been considered as a characteristic of blocked flow. If the low-level flow is blocked and diverted around the mountain, there is a permanent descent of warm air and there is an extended low pressure area at low levels in the lee of the mountain. For flow at intermediate values of the Rossby number (~1), the wind reduction downstream of the mountain can be explained by the lee low reducing the horizontal pressure gradient behind the mountain top and in the left lee. On the right hand side in the lee, the pressure graident is enhanced and there is acceleration in the flow (Ólafsson, 2000). The right hand acceleration (tip jet) is found in several places on the earth and is for example a very characteristic feature of westerly flow past Southern Greenland as described by Doyle and Shapiro (1999). The wind reduction in the wake has been related to energy dissipation in breaking mountain waves or in a hydraulic jump in the stratified flow (Schär and Smith, 1993). Simulations have shown air descent, wave breaking, hydraulic jumps and potential vorticity (PV) creation over mountains generating wakes that have been observed in real flow (Smith, 1997; Pan and Smith, 1999) . Surface friction has also been shown to impact the stability of the wake (Grubisic et al., 1995).

2. THE GREAT SALTSTORM 9-10 NOVEMBER 2001

On 9-10 November 2001 a violent storm hit Iceland. The observed 10 min wind speed came close to 40 ms^{-1} at the north coast of the island and exceeded 50 ms^{-1} in the mountains. The airmass was exceptionally dry and depositions of sea salt were recorded several hundreds of km away from the coast. There was some damage on low quality constructions.

The storm was caused by a cyclone that deepened very rapidly as it moved to the northeast along the east coast of Greenland. The cyclone was associated with an upper level PV anomaly that intensified significantly when passing over S-Greenland (Shapiro et al. 2002). This cyclone was intimately linked to the Greenland topography and is greatly reduced in a simulation where the topography of Greenland has been lowered down to sea level.

The windstorm over East Iceland was at its maximum during the morning of 10 November. At that time, satellite-based wind observations (QuikSCAT, Fig. 1) show a well defined region of reduced wind speed downstream of Iceland. This wake was bounded by strong winds to the north that are a continuation of the windstorm that blows along the north coast of Iceland. To the south of the wake, there is a well defined tip jet with a maximum a short distance off Southeast Iceland.

[1] E-mail: haraldur@vedur.is, web: http://www.vedur.is/~haraldur

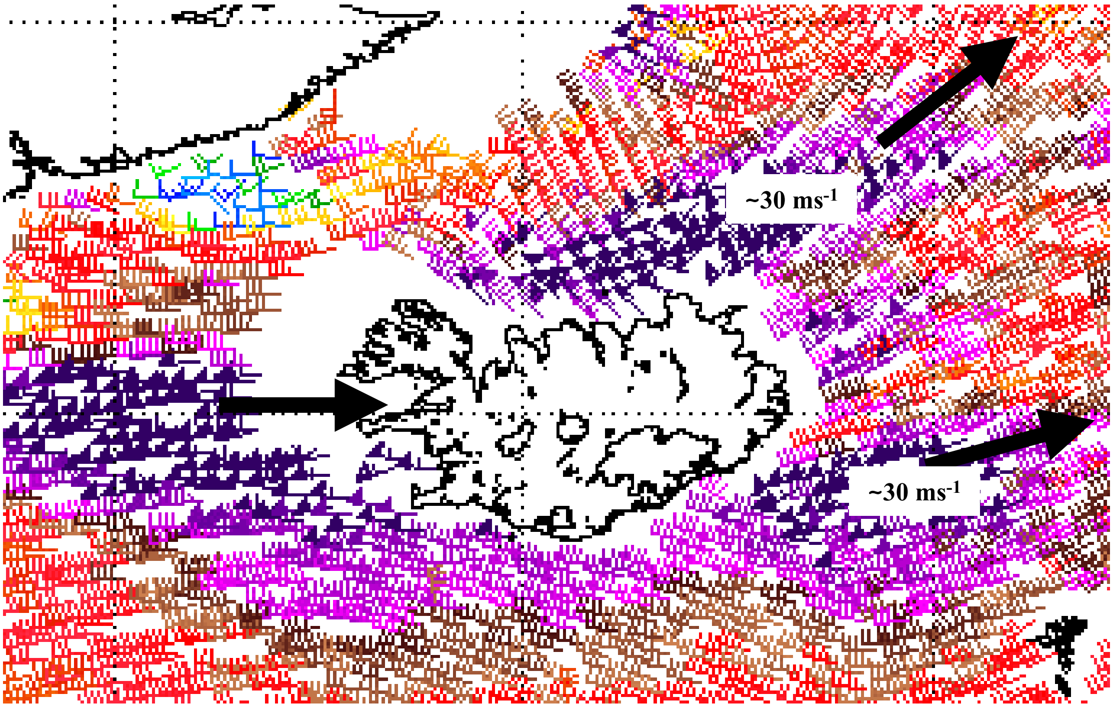

Fig. 1. QuikSCAT 10-m wind speeds early morning on 10 November 2001.

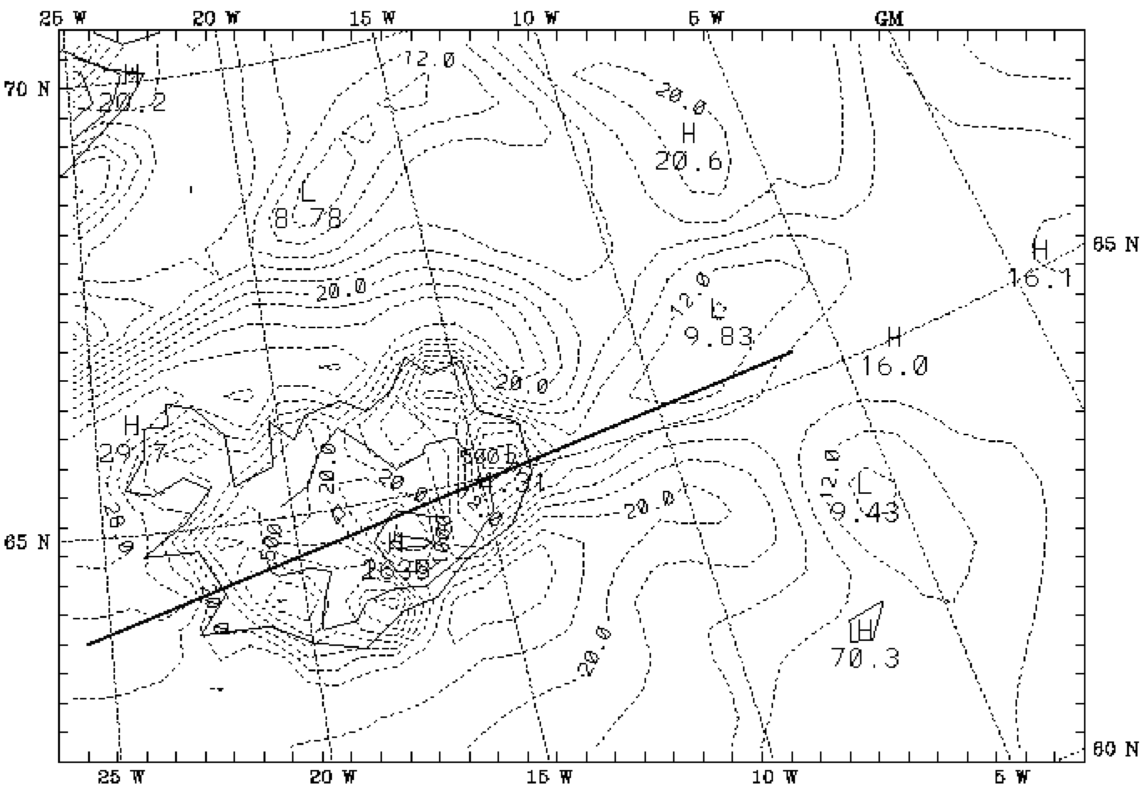

Fig. 2. Simulated 10-m wind (ms^{-1}) and the topography of Iceland in the outer domain (horizontal resolution 36 km) at 6 UTC on 10 November 2001.

3. NUMERICAL SIMULATIONS

The windstorm was simulated with the MM5 simulation system (Grell et al., 1995). The simulation had a horizontal resolution of 36 km in a large domain that extends across the North Atlantic and an inner domain covering South Greenland and Iceland with a horizontal resolution of 12 km. There were 40 vertical levels. A few simulations with different topography and different values of the surface roughness were run only in the large domain.

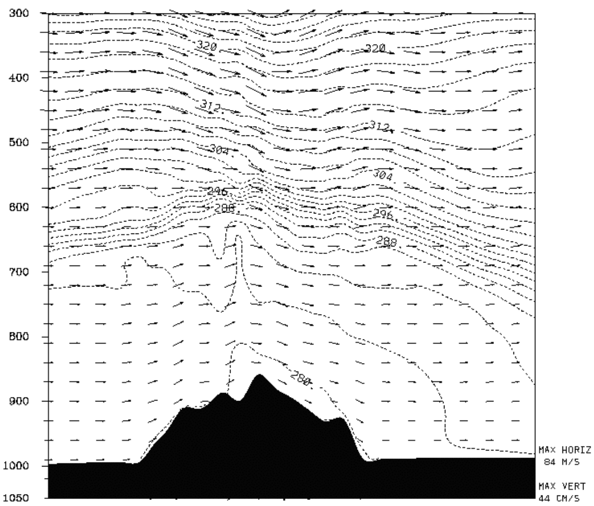

Fig 3. A cross section from the outer domain showing simulated wind vectors and potential temperature (K) at 6 UTC on 10 Nov. 2001 The position of the cross section is shown in Fig. 2.

The 12 km-simulation reproduces the wake and an associated PV streamer. The simulated wake is associated with warm air that has descended from above. The wake was also simulated at 36 km-resolution (Fig. 2), allowing for some sensitivity tests to be run only at that resolution. The tip jet is reproduced in Fig. 2, and the location of the wind maximum close to the southeast coast of Iceland is in agreement with the QuikSCAT data (Fig. 1). In the wake as well as in the jets on both sides of it, the simulation underestimates the wind speed of about 5 ms^{-1}. A cross section along the flow over Iceland and into the wake is shown in Figure 3. Below 700 hPa the airmass is almost neutral, while above 700 hPa it is very stable. This stable layer slopes downward to the east where it appears as a cold front that has passed over Iceland, moving rapidly eastwards. There is rising motion everywhere on the windward side, and in the lee there is regular descent. The low-level flow follows the topography quite closely. There are some signs of gravity

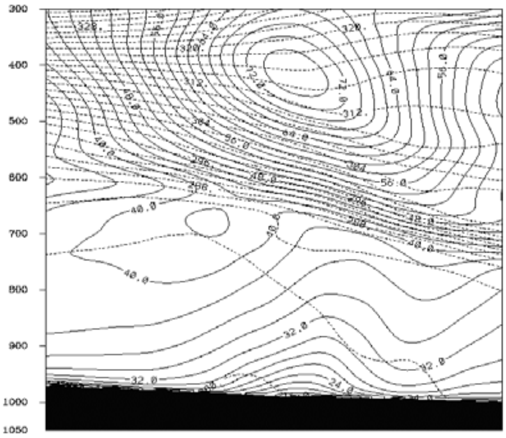

Fig. 4. Simulated wind and potential temperature at 6 UTC on 10 Nov 2001 in a cross section from north to south across the wake about 50 km east (downwind) of Iceland.

waves in the stable air above, but in the near-neutral layer below there are hardly any gravity waves. At 12-km resolution there were somewhat stronger waves over the lee slopes. Figure 4 shows a cross section across the wake from north to south about 50 km east of Iceland. The figure shows that the tip jet and the wake reach up to the frontal zone at 700 hPa, which is about twice the height of the mountains in the model. The wake is associated with a weak warm anomaly.

To get insight into the role of friction in creating the wake, the storm has been simulated with the roughness coefficient (z_o) reduced to 0.1 mm. The flow has also been simulated with the same reference roughness, but no topography in Iceland. At low roughness, the overall structure of the downstream flow remains similar to the

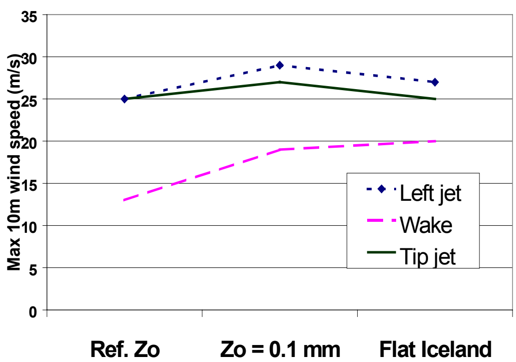

Figure 5. Maximum wind speed in the left jet, in the wake and in the rigth hand jet (tip jet) in simulations with reference surface roughness, with z_o=0.1 mm and with reference roughness on a flat Iceland

reference roughness simulation. There is however stronger wind in the wake and also in the jets on each side of it (Fig. 5), bringing the low-roughness simulation closer to the QuikSCAT observations. The maximum wind to the left and the right of the wake and the wind speed in the central part of the wake 100 km downstream of the coast are given in Fig. 5. Apparently, surface friction acts to amplify the absolute and relative wind deficit in the wake. The simulation with reference surface roughness on a flat Iceland also produces a wake, but that wake extends a much shorter distance downstream.

4. DISCUSSION

A large, extended wake has been observed during the Great Saltstorm over Iceland on 10 November 2001. The wake is reproduced in a numerical simulation that reveals neither upstream blocking, nor wave breaking. In fact, there is very little wave activity simulated at low levels over Iceland. The absence of blocking and wave breaking is not surprising, since the non-dimensional mountain height (Nh/U) is only about 0.25, which is much less than generally needed for the flow to enter into these regimes. Dissipation is however needed to produce the wake and the associated PV, but it appears to have other sources than breaking waves. Surface friction is indeed responsible for dissipation and the simulated sensitivity to the roughness over land suggests that dissipation due to surface friction may be important for the wake. For the case of flat ground and consequently no general lee-side subsidence, there is a significant, but only a short wake. The mountains of Iceland are therefore certainly needed for the wake to extend as far as it does.

In operational NWP models, the surface friction over Iceland is generally overestimated. This study suggests that such an overestimation may lead to an underestimation of the forecast wind speed, not only over land, but also downstream of Iceland.

ACKNOWLEDGEMENT

M. A. Shapiro´s research was partially supported by ONR grant 0602435N and the NASA/Office of Earth Science.

REFERENCES

Doyle, J. and M. A. Shapiro, 1999: Flow response to large-scale topography: the Greenland tip jet. Tellus, 51A(5), 728-748.

Grell, G. A., J. Dudhia and D. R . Stauffer, 1995: A description of the fifth-generation Penn State/NCAR mesoscale model (MM5). NCAR Tech. Note, NCAR, NCAR/TN-398+STR.

Grubisic, V., R. B. Smith and C. Schär, 1995: The effect of bottom friction on shallow-water flow past an isolated obstacle. J. Atmos. Sci., v.50, 1985-2005.

Ólafsson, H, 2000: The impact of flow regimes on asymmetry of orographic drag at moderate and low Rossby numbers. Tellus, 52A, 365-379.

Pan, F., and R. B. Smith, 1999: Gap winds and wakes: SAR observations and numerical simulations. J. Atmos. Sci., v.56, 905-923.

Shapiro, M. A., S. Low-Nam, H. Ólafsson, J. Doyle and P. K. Smolarkiewicz, 2002: Large-amplitude gravity-wave breaking over the Greenland lee and the subsequent formation of downstream synoptic-scale traupopause folding and stratospheric-tropospheric exchange. 10th Conf. on Mountain Meteorology, Salt Lake City, Utah, USA.

Schär, C. and R. B. Smith, 1993: Shallow water flow past isolated topography. Part I: vorticity productcion and wake formation. J. Atmos. Sci., v.50, 1373-1400.

Smith, R. B., A. C. Gleason and P. A. Gluhosky, 1997: The wake of St. Wincent. J. Atmos. Sci., v.54, 606-623.