P2.24

IDEALIZED SIMULATIONS OF KATABATIC FLOWS IN ICELAND: KATABATIC WINDS OR LAND BREEZE?

Hálfdán Ágústsson* and Haraldur Ólafsson
Institute for Meteorological Research, University of Iceland, Icelandic Meteorological Office and the Bergen School of Meteorology.

1. INTRODUCTION

Local thermal flows may be organized where there is a local horizontal pressure gradient due to differential surface heating or cooling.

According to a simple conceptual model of katabatic flows (e.g. Egger 1990), they develop in sloping topography where the air at the surface cools relative to the air aloft, e.g. due to radiative cooling on clear nights. The cold and heavy air flows downslope in a relatively shallow layer due to its negative buoyancy while the flow is dampened due to the turbulent drag or other more complex dynamics (e.g. Mahrt 1982). Thermal flows may also be generated on level ground and a typical example is the land breeze i.e. the cold surface flow from cooler land surfaces over warmer water bodies. During the night the ground may cool faster than the sea and consequently the surface pressure increases on land and the surface air flows towards the sea where it rises. Aloft, the pressure increases over the water and a return flow is setup towards the weaker pressure above land. Similar flows may also occur across other surfaces boundaries provided that the temperature or its development is different across it, e.g. at the edge of sea ice.

In Iceland the studies of thermal flows have mostly been limited to studies of katabatic winds on the Breiðamerkurjökull outlet glacier of Vatnajökull (e.g. Van der Avoird and Duynkerke 1999) which are mostyly based on the observations described in Oerlemans et al. (1999). Another study used a numerical model to explore the local and regional katabatic flows organized by the complex topography in Iceland (Ágústsson et al. 2007) during an event with weak synoptic forcing and strong radiative surface cooling. There are several other studies that indicate that katabatic flows are of importance in Iceland (e.g. Bromwich et al. 2005). However, the authors are not aware of other extensive studies of thermal flows in Iceland or their interaction with the complex topography

Here we use a mesocale model to numerically simulate the atmosphere from a state of rest with a realistic wintertime cooling as during a day with clear skies. Idealized simulations with and without the orography or the sea allow for an analysis of the different contributions of the katabatic winds and land breeze to the total thermal flows.

*Corresponding author: Reiknistofa í veðurfræði, Grensásvegi 9, IS 150 Reykjavík, ICELAND; e-mail: halfdana@hi.is.

2. THE MESOSCALE MODEL

The simulations are performed with the nonhydrostatic mesoscale model, MM5 (Grell et al. 1995). The model is run on two nested domains with a resolution of 9 and 3 km with 40 σ-layers in the vertical and including the full physics. Initially the atmosphere is at a complete rest with clear skies. The model is run for up to 48 hours with the solar heating as on winter solstice, i.e. 21 December. Only the results of the 3 km domain are used.

Several experiments are performed with different topography, both with an idealized mountainous island as well as with the true topography of Iceland (cf. Figs. 1 and 2). A control run includes both the mountains and the sea while sensitivity tests are performed with no orography and no sea. The idealized mountain is circular with a ridge on its southern side. The slope is constant with the mountain plateu height equal to 500 m while the ridge crest is at 300 m.

3. THERMAL FLOWS ON AN IDEALIZED ISLAND

The simulated surface flow on an idealized mountainous island (Fig. 1) shows several interesting features, some of which were not expected a priori.

There is a strong land breeze at the coast which penetrates further out over the sea with time. Inland, there is a somewhat weaker katabatic flow that is mostly limited to the slopes of the mountain. There is a very weak divergent flow at the mountain plateu. Both the land breeze and the katabatic winds turn clockwise due to the Coriolis-forcing. The most interesting features are observed around the peninsula on the southern end of the island. At the tip of the ridge there is a jet where the land breeze and katabatic winds of the ridge merge and are accelerated around the tip. There is also some topographic channeling of the katabatic flow where the flow from the main mountain joins the flow from the

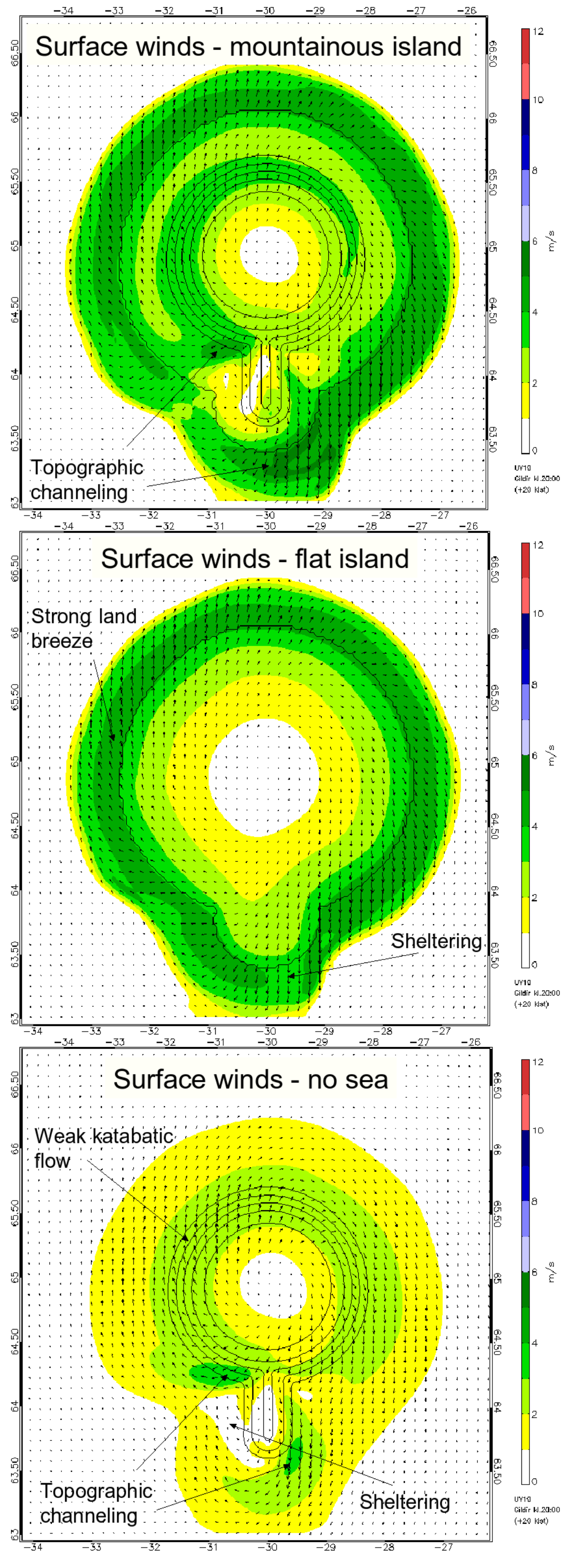

Figure 1: Simulated surface winds [m/s] on an island with an idealized mountain (above), no topography (middle) and no sea (below). Terrain contours with a 100 m interval.

left side of the ridge. There is also sheltering from the flow on both side of the ridge but significantly stronger and more extensive on the left side of the ridge.

Simulating without the sea, thus removing the land breeze, reveals that the sheltering on both sides of the ridge is purely a topographic feature and is not related to the land breeze. On the right side of the ridge the weak winds are caused by the katabatic winds from the mountain and the ridge being decelerated by each other. The strong sheltering on the left side is a result of the adverse effect of the ridge on the flow. However, the katabatic winds weaken without the land breeze as they depend on the land breeze to constantly remove the stagnant cold air from the lowlands.

Removing the mountain from the island reveals that the land breeze is mostly unaffected by the katabatic winds. However, the land breeze is weaker where the topographic channeling is now missing, i.e. at the tip of the peninsula, as well as where the now missing katabatic winds would catch up with the breeze.

We will term the effect of the mountain ridge or peninsula on the thermal flows as the "peninsula"-effect.

4. Thermal flows in the true icelandic topography

Figure 2 shows the 2-metre temperature after 24 hours of radiative surface cooling through the long arctic night in Iceland. The highlands and glaciers have cooled more than the lower lying areas and the air at the surface of the ocean is near 0°C with colder air being advected over it from the land.

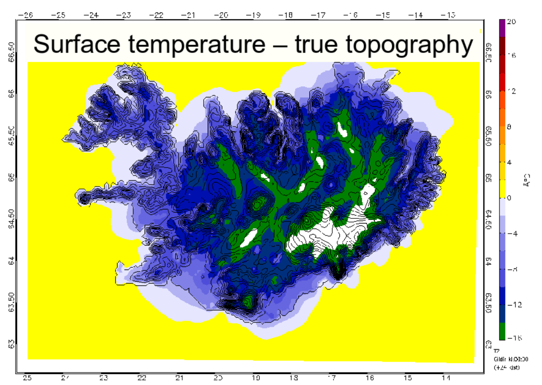

Figure 2: Simulated 2-metre temperature [°C] in the true icelandic topography at hour 24. Terrain contours with a 100 m interval.

The simulated thermal flows in the true icelandic topography occur at many different spatial scales and flow speeds (Fig. 3). A comparison with the simulated flow without the topography reveals what part of the coastal flows are in fact the land breeze (Fig. 3). It also shows locations where the land breeze is being enhanced when katabatic flows merge with it or where the breeze is being reduced or eliminated by the topography. The "peninsula"-effect discussed above

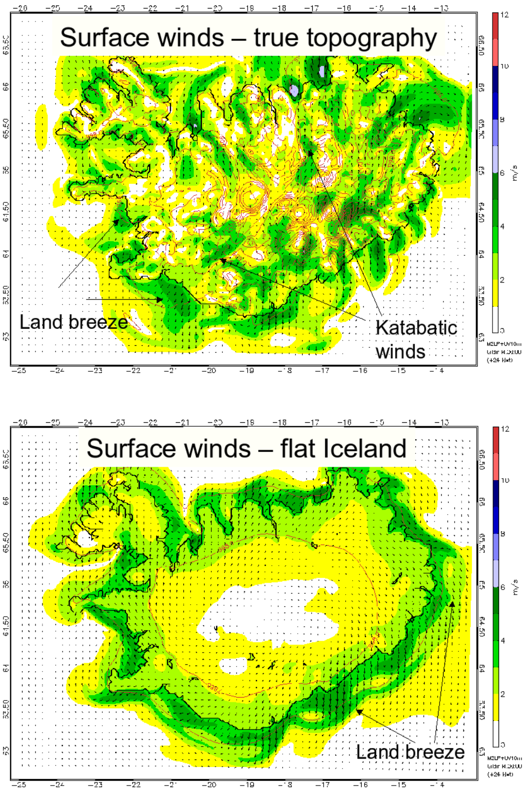

Figure 3: Simulated surface winds [m/s] in the true icelandic topography (above) and with the topography removed (below). Terrain contours with a 100 m interval.

in the context of the idealized simulations is observed at several locations around the coastline, e.g. in central north. There is a strong channeling of the land breeze in several of the fjords and the katabatic flows are also being enhanced inland by the topography with several well pronounced currents entering the northern and southern lowlands. In Southwest-Iceland there is a weak impact of the large peninsula on the flow, presumably because the peninsula is at least partly flat.

Looking at the flow aloft (Fig. 4) a strong cyclonic flow is revealed. The flow is mostly confined to a band above the coastline but is wider or faster in some places while it is slower in others due to the underlying topography. The depth of the flow varies greatly and the strongest flow is approx. 600 m above the ground but the flow aloft is far thicker than the land breeze and the even thinner katabatic winds. The cyclonic flow is a

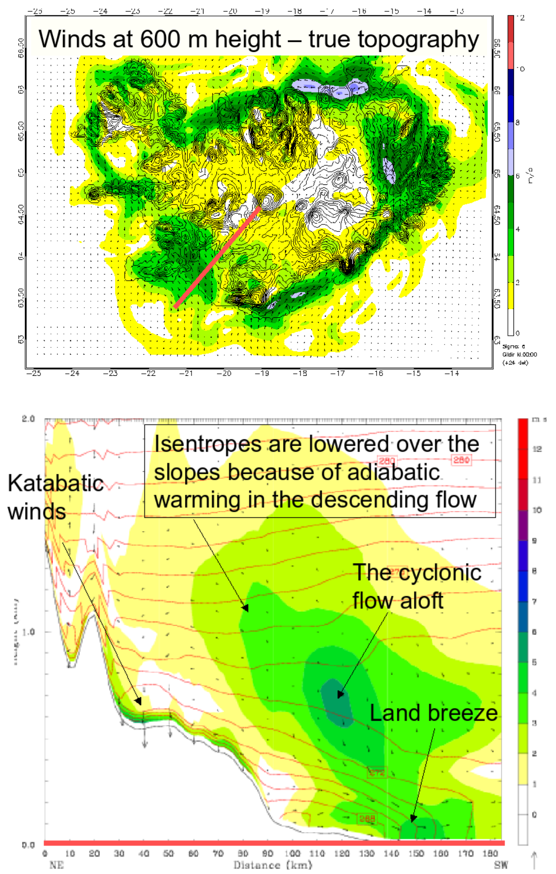

Figure 4: Simulated winds [m/s] at approx 600 m above Iceland. True topography is shown with 100 m contours (above). A section from N to S along the red line shows the topography, isentropes, wind vectors and wind speed [m/s] (below).

result of the thermal low aloft which is generated by adiabatic warming in the descending flow above the slopes. At the surface there is divergence and high pressure due to the cold air at the lowest levels.

5. Some concluding remarks

The present study describes simulations of thermal flows in Iceland during a day of strong radiative surface cooling. The thermal flows are organized by the topography as well as the differential cooling of the land and the sea.

The idealized simulations reveal that there is strong land breeze at the coast. Apparently the land breeze has previously been referred to as "katabatic winds" which are in many cases considerably weaker than the land breeze and are created in the sloping topography. The topography:

- gives rise to the katabatic winds which sometimes merge with the land breeze.
- reduces or eliminates the land breeze in many coastal regions
- contributes to channeling of the winds and a stronger ageostrophic component of the coastal winds.
- gives rise to strong cyclonic flow aloft through a deformation of the temperature field (adiabatic warming) over the mountains. This flow is as much as ten times deeper than the katabatic winds and the land breeze at the surface.

However, the katabatic winds weaken and cease to exist if the land breeze, or possibly other background flows, do not constantly remove the stagnant cold air at lower levels. When the cold pool deepens the driving force behind the katabatic flows weakens, i.e. the horizontal temperature gradient above the mountain slopes.

The "peninsula"-effect contributes to a sheltering on the left hand hand side of peninsulas and an acceleration of the flow on the right hand side when looking from the sea towards land. This reflects the analogous results of a similar study of thermal winds in Iceland during a day of strong surface heating (Ólafsson and Ágústsson 2008).

The setup of the simulations performed here are nearly identical to the setup of the current HRAS-system (Ólafsson et al. 2006) which is used in operational weather forecasting in Iceland. In this context the results of this study may be of importance for the operational forecasting of thermal winds and the interpretation of numerical forecasts during periods of weak synoptic pressure gradients. Katabatic winds are presumably strongest in Iceland during winter and in anticyclonic situations with a strong radiative surface cooling. They may be of importance during cold spells when minimum surface temperature records are set (Jónsson 2003). These generally occur in relatively flat and shallow basins where there is very weak or no inflow and outflow of air. If katabatic winds arrive in such basins they may mix the airmass vertically or cause a subsidence of warmer air from aloft which hinders a further cooling of the surface air.

However, before further conclusions can be drawn, the present results have to be validated with a thorough comparison with the observational data available. In that sense more observations aloft in Iceland would in fact be beneficial. Automatic surface observations of wind and temperature are performed at a high temporal and spatial resolution in many regions of Iceland and allow for a reasonable verification of the surface flows.

Acknowledgements

This study is carried out in connection with the RÁV project which is supported by the Icelandic research fund (RANNÍS).

References

Ágústsson, H., Cuxart, J., Mira, A. and Ólafsson, H.: 2007, Observations and simulation of katabatic flows during a heatwave in iceland, *Meteorol. Z.* **16**(1), 99–110.

Bromwich, D. H., Bai, L. and Bjarnason, G. G.: 2005, High-resolution regional climate simulations over Iceland using polar MM5, *Mon. Weather Rev.* **133**, 3527 – 3547.

Egger, J.: 1990, Thermally forced flows: Theory, *in* W. Blumen (ed.), *Atmospheric processes over complex terrain*, American Meteorological Society Monographs **45**, pp. 43 – 57.

Grell, G. A., Dudhia, J. and Stauffer, D. R.: 1995, A Description of the Fifth-Generation PennState/NCAR Mesoscale Model (MM5), *Technical Report NCAR/TN-398+STR*, National center for atmospheric research. Available at http://www.mmm.ucar.edu/mm5/doc1.html (May 2004).

Jónsson, T.: 2003, Langtímasveiflur VI; Kuldaköst og kaldir dagar, *Scientific Report 03033*, Veðurstofa Íslands, Reykjavík. Available at http://www.vedur.is/utgafa/greinargerdir/ (March 2006).

Mahrt, L.: 1982, Momentum balance of gravity flows, *J. Atmos. Sci.* **39**, 2701 – 2711.

Oerlemans, J., Björnsson, H., Kuhn, M., Obleitner, F., Pálsson, F., Smeets, C. J. P. P., Vugts, H. F. and Wolde, J. D.: 1999, Glacio-meteorological investigations on Vatnajökull, Iceland, summer 1998: An overview, *Boundary-Layer Meteorol.* **92**, 3 – 26.

Ólafsson, H. and Ágústsson, H.: 2008, Summertime thermal winds over iceland, *Proc. of the 13th conference on mountain meteorology*.

Ólafsson, H., Jónasson, N. and Karlsdóttir, S.: 2006, Háupplausnar reikningar til almennrar spágerðar (HRAS), lokaskýrsla, *Technical Report 06011*, Veðurstofa Íslands, Reykjavík. Available at http://www.vedur.is/utgafa/greinargerdir/ (March 2006).

Van der Avoird, E. and Duynkerke, P. G.: 1999, Turbulence in a katabatic flow. Does it resemble turbulence in stable boundary layers over flat surfaces?, *Boundary-Layer Meteorol.* **92**, 39 – 66.