OBSERVATIONS AND SIMULATIONS OF KATABATIC FLOWS DURING A HEATWAVE IN ICELAND

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Abstract: Katabatic flows during the night of 11–12 August 2004 in Iceland are studied using observations and a numerical weather prediction model. During this period, there was a heatwave in Iceland. In relation with the very high daytime temperatures, weak synoptic winds and clear skies, a radiative surface cooling in excess of 10–15°C was observed during the night at many locations throughout Iceland. The situation has been simulated with the Meso-NH model. The results indicate that katabatic winds develop in the stable nocturnal boundary layer when the cold and heavy air descends from the highlands and mountains down to lower lying areas. The simulations are made at a high horizontal and vertical resolution, forced with boundaries and initial conditions from the ECMWF. The simulations and initial conditions are compared to available ground based observations and satellite images showing the surface radiative temperature. The simulations seem to reproduce well most of the observed winds, including patterns where weak synoptic winds or katabatic flow interact with orography. The simulations also give valuable indications of locations of relatively strong katabatic winds, where no observations are currently available. A similar simulation has been performed with the MM5 atmospheric model and an intercomparison is under way.

***Keywords** - Katabatic winds, stable boundary layer, Iceland*

1. INTRODUCTION

Katabatic winds may develop in sloping topography and in stable boundary layers. As the air at the surface of the earth cools, e.g. due to radiative cooling during clear nights, a vertical density gradient develops in response to the limited turbulent exchange with the air aloft. The cold and heavy air then flows downslope under the influence of gravity, namely due to the buyoancy effect. Katabatic winds are observed throughout the world and are generally of relatively weak magnitude, i.e. approx. 1–4 m/s, and limited vertical and horizontal extent. Due to the weak nature of katabatic winds, they are frequently masked by the background flow and are therefore generally best observed under calm and clear sky conditions when there is a strong radiative surface cooling.

Such a situation was observed in Iceland during a record breaking heatwave on 9–14 August 2004. The official temperature record in Reykjavík was broken shortly before noon on 11 August when the 2 metre thermometer at Veðurstofa Íslands (The Icelandic Meteorological Office) showed 24.8°C. In spite of the relatively short night (approx. 7 hours), the temperature in Reykjavík had fallen approx. 10°C by the next morning. The diurnal temperature difference exceeded 15°C in other parts of Iceland. The skies were generally clear throughout the night and synoptic winds very weak (not shown here). An analysis of the dimensionless mountain height indicates that the weak north- and easterly low-level airflow impinging on North-Iceland is in fact blocked and diverted around Iceland.

In this study we investigate the observations and simulation of katabatic winds in Southwest-Iceland during the night of 12 August 2004. The procedure is inspired by similar studies of nocturnal circulations on the island of Mallorca (Cuxart and Jiménez 2004, Mira et al. 2004). In Iceland, the region of interest (Fig. 1) is a relatively flat area with an approximate N-S and E-W extent of 75 km. The region is surrounded by relatively steep mountains and complex terrain to the east and west, while to the north there is a more gentle slope towards the central highlands of Iceland. Towards the south, the region extends out to the open sea. Outside the glaciers, the central highlands reach approx. 800 m above mean sea level, while the glaciers rise more than 1500 m a.m.s.l. Katabatic winds may be expected to enter the region of interest from all directions except from the south.

The second section of this paper discusses shortly the available observational data. The setup of the simulation is explained in section 3. The results of the simulation are discussed and compared to observations in section 4, while section 5 gives a summary of the study and the most significant results.

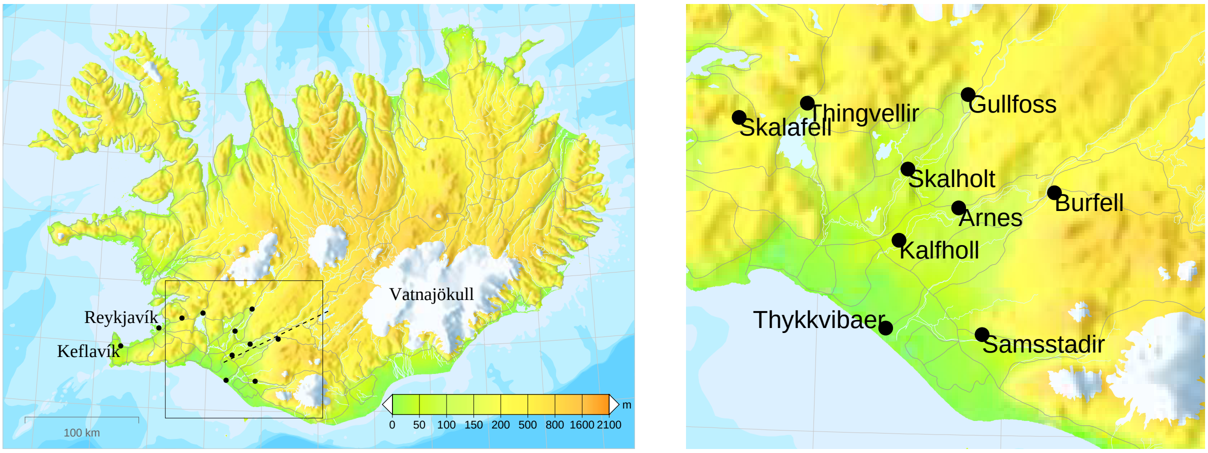

Figure 1. Topography of Iceland with the region of interest to the right (delineated). Also shown are the locations of a vertical cross-section and chosen weather stations.

2. OBSERVATIONAL DATA

In the main region of interest, i.e. Southwest-Iceland, there are number of automatic weather stations with observations readily available (Fig. 1). Most of the stations belong to Veðurstofa Íslands while the two stations at Skálholt and Gullfoss belong to Vegagerðin (The Public Roads Administration). The station at Skálafell is located at the top of a mountain and other stations are located at low altitudes and in relatively flat terrain. The station at Keflavík is an upper-air station. Observations of the 10 minute mean wind speed, wind direction and temperature are available at 10 minute intervals from most of the stations. The temperature is observed at 2 metres above ground level while the wind is either observed at 10 m or at the top of a 6 m mast raised approx. 1 m above its immidiate surroundings (Gullfoss and Skálholt).

In stable boundary layers, the surface radiative temperature predicts the evolution of the air temperature in the surface layer and is a key parameter affecting the development of katabatic winds. Images showing the surface radiative temperature of land surfaces are therefore prepared from images from the NOAA-satellites and used for comparison with the simulated surface radiative temperature field.

3. SETUP OF THE SIMULATION

The chosen atmospheric situation is simulated with the Meso-NH atmospheric model of the French research community (Lafore et al. 1998). The model is run on one domain with a horizontal grid size of 4 km and 160 x 120 gridpoints. There are 85 levels in the vertical with a resolution of 3 m at the surface and gradually decreasing towards the model top at approx. 300 hPa. The high vertical resolution is needed as the vertical extent of katabatic currents may be on the order of 10–50 m and with a resolution of similar or lower magnitude, the model may not capture the katabatic winds.

Analysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) are used as initial conditions and to force the model at its boundaries. The simulation is initiated at 12:00 UTC on 11 August 2004 while the period of main interest is from 18:00 UTC to approx. 06:00 UTC the next morning.

4. RESULTS

The observed surface radiative temperature at 23:34 UTC on 11 August (Fig. 2) shows the strong cooling of the surface in the beginning of the night. The red spots corresponding to high surface temperatures are presumably erroneous as they might be related to inflow of moist or cloudy air, or to the surface temperature of water bodies. The simulated surface radiative temperatures in Fig. 2 appear to be in reasonable agreement with the observations. The purple areas of highest simulated temperature are related to water bodies and are therefore not applicable for comparison with observations. The greatest difference is in the central highlands near Vatnajökull where the simulation appears approx. 4°C colder than the observations.

Katabatic winds are evident late in the night (Fig. 3). The strongest currents in Southwest-Iceland are northeasterly and arrive from the central highlands near the stations at Árnes and Gullfoss. There is relatively good

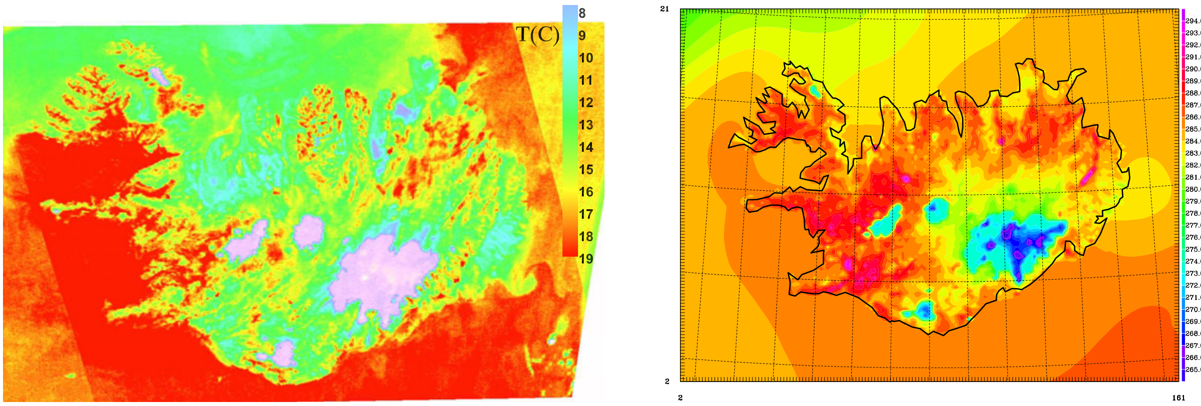

Figure 2. Observed [°C] (left) and simulated surface radiative temperature [K] (right) at, respectively, 23:34 UTC and 23:00 UTC, on 11 August 2004. Note the different colour scales, the yellow colour in the left panel corresponds to the red colour in the panel to the right.

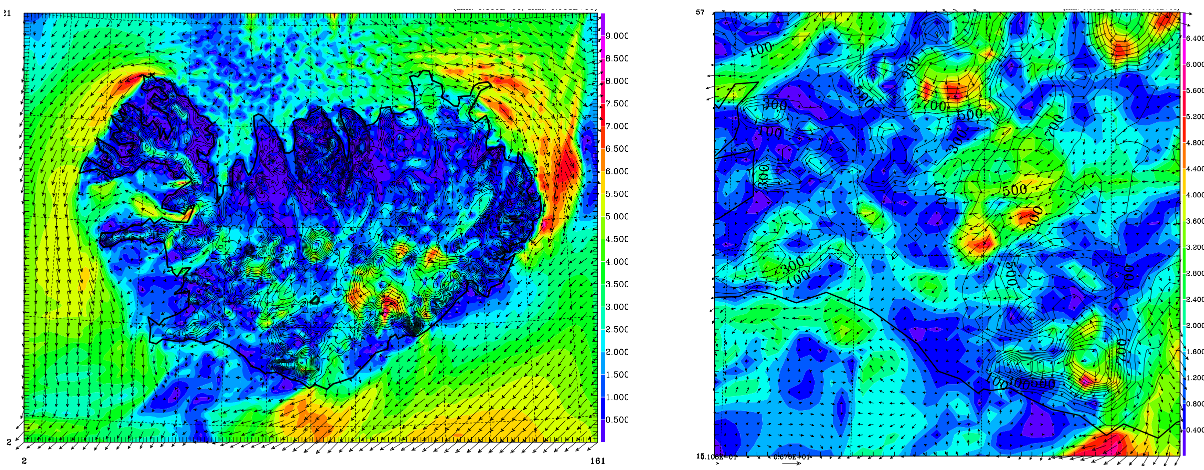

Figure 3. Topography [m] and simulated surface wind [m/s] at 05:00 UTC on 12 August 2004. The region of interest is shown to the right (delineated in Fig. 1).

agreement between the temporal behaviour of the simulated and observed winds at the stations at Árnes and Kálfhóll (Fig. 4). At both stations, a veering of the wind from southerly directions to northeasterly is observed and well simulated. The northerly winds are presumably related to katabatic currents, as seen in Fig. 3. A reversal of the wind direction is observed in the early morning, but it is only captured at Kálfhóll. The observed winds are weak throughout the evening and the night but are in general well captured by the model.

Vertical sections (Fig. 5) along the NE-SW oriented line in Fig. 1 show the vertical structure of the atmosphere and the katabatic winds. The low-level jet in Fig. 5 is oriented along the cross-section and the air is flowing downhill from the highlands. This katabatic flow is detached from the flow above and has a maximum velocity of approx. 10 m/s at ca. 100 m a.m.s.l. near Árnes. Towards the centre of the section, the jet has a vertical extent similar to the depth of the stable boundary layer while further downwind, the katabatic flow appears thinner and it is at a more elevated altitude, perhaps as it flows over cold and stagnant air in the lowlands.

5. CONCLUSIONS

In this study, katabatic flows during an heatwave in Iceland have been studied and simulated with the Meso-NH model. At the current resolution, the katabatic winds are reasonably well reproduced. This has some application in the context of real-time simulations for forecasting purposes.

Although the land is relatively flat in Southwest-Iceland, some of the errors in the simulated wind may be accounted for by sub-grid orography. An increased horizontal resolution can therefore be expected to have an positive impact on the simulations.

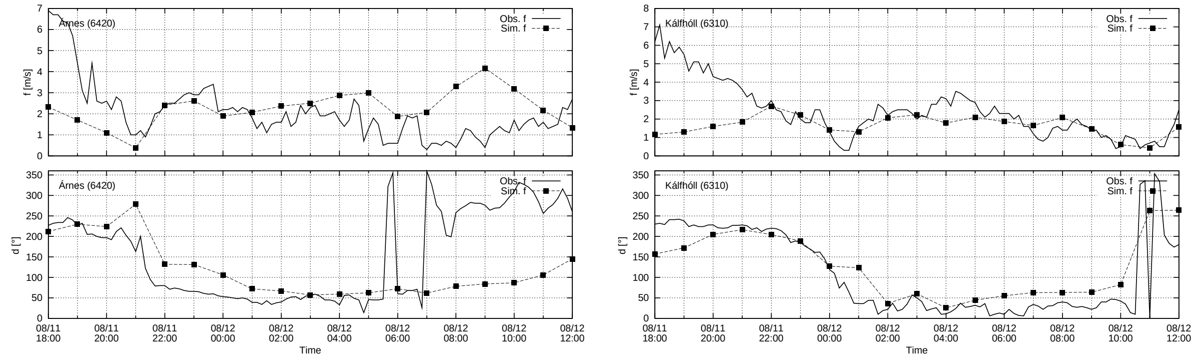

Figure 4. Observed and simulated wind speed, f [m/s], and direction, d [°], at Árnes and Kálfhóll.

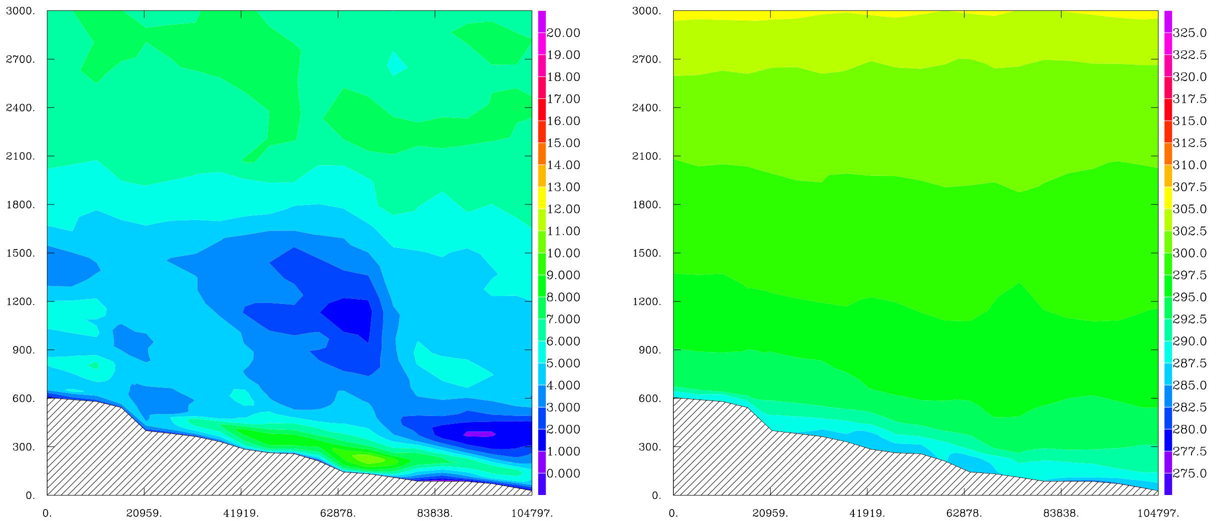

Figure 5. Cross-section along the dotted line in Fig. 1. Simulated windspeed [m/s] (left) and potential temp. [K] (right) at 05:00 UTC on 12 August 2004. The axis show the distance [m] above sea level and along the section.

The authors are not aware of another study that describes katabatic flow over Iceland, apart from several studies conducted on Vatnajökull, mainly on the Breiðamerkurjökull outlet glacier. The simulation supports the idea of persistent and relatively stong katabatic winds on the Icelandic glaciers, in particular the big outlet glaciers of Vatnajökull (Parmhed et al. 2004).

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REFERENCES

Cuxart, J. and Jiménez, M. A.: 2004, Nocturnal circulations under weak pressure gradients in the island of Mallorca, *16th Symposium on Boundary Layers and Turbulence (AMS)*.

Lafore, J. P., Stein, J., Asencio, N., Bougeault, P., Ducrocq, V., Duron, J., Fischer, C., Hereil, P., Mascart, P., Pinty, J. P., Redelsperger, J. L., Richard, E. and de Arellano, J. V.-G.: 1998, The Meso-NH Atmospheric Simulation System. Part I: Adiabatic formulation and control simulations, *Ann. Geophys.* **16**, 90 – 109.

Mira, A., Cuxart, J., Jiménez, M. A. and Guijarro, J.: 2004, Verification of high-resolution simulations for the Majorca island using satellite images, *EMS annual meeting abstracts*, Vol. 1.

Parmhed, O., Oerlemans, J. and Grisogono, B.: 2004, Describing surface fluxes in katabatic flow on Breiðamerkurjökull, Iceland, *Quart. J. Roy. Meteor. Soc.* **130**, 1137 – 1151.