

# DOWNSLOPE WINDSTORM IN ICELAND – WRF/MM5 MODEL COMPARISON

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**Abstract:** A severe windstorm downstream of Mnt. Öräfajökull in Southeast Iceland is simulated on a grid of 1 km horizontal resolution by using the PSU/NCAR MM5 model and the Advanced Research WRF model. Initial and boundary conditions for the simulations are derived from the European Centre for Medium range Weather Forecasts (ECMWF) analysis. The MM5 model is first run on 9 and 3 km resolution using two–way nesting. Then, the output from the 3 km MM5 domain are used to initialise and drive both the 1 km MM5 and WRF simulations. Both models capture gravity–wave breaking over Mnt. Öräfajökull, while the vertical structure of the lee wave differs between the two simulations. The WRF simulated downslope winds are in good agreement with the strength of the observed downslope windstorm, with the maximum wind speed as great as  $30 \text{ ms}^{-1}$ , whilst the winds in the MM5 simulation only reach about  $20 \text{ ms}^{-1}$ . The simulated surface temperature in the WRF simulation is also closer to the observations than the MM5 simulation.

**Keywords:** *Model comparison, MM5, WRF, Iceland, downslope windstorm.*

## 1. INTRODUCTION

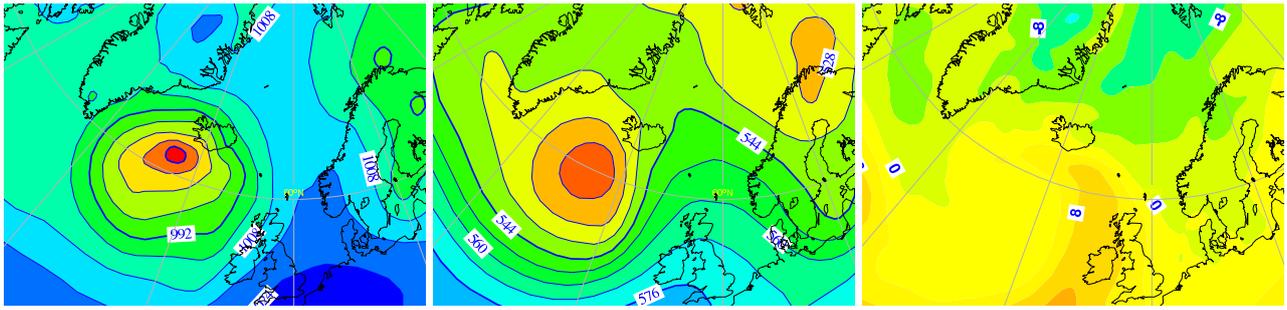
The climate and weather of Iceland are largely governed by the interaction of orography and extra–tropical cyclones because Iceland is located in the North Atlantic storm track. As a result of this interaction, downslope windstorms are quite common. Research on Icelandic downslope windstorms was very limited until a recent study by Ólafsson and Ágústsson (2007) (hereafter ÓÁ–07), in which a severe downslope windstorm that hit Freysnes, Southeast Iceland, in the morning of 16 September 2004 was investigated by utilizing a numerical weather prediction model. In this study, two simulations are carried out and compared for the same event as studied in ÓÁ–07 by using two mesoscale models: V3–7–3 of MM5 (Grell et al. , 1994) and the Advanced Research WRF model (Skamarock et al. , 2005). The output from the 3 km domain of the simulation presented in ÓÁ–07 is used to initialise and drive the two models on a grid of 1 km horizontal resolution and 39 vertical layers with the model top at 100 hPa. Both the MM5 and WRF models are configured in as similar way as possible. The objective of this study is to investigate the differences in the simulated dynamics of the downslope windstorm that are caused by the differences in the numerics of the two models. Comparisons of the two simulations are made using observed surface winds, temperature and precipitation.

This paper is structured as follows: In the next section we describe the synoptic overview and list the available observational data in the area. The results are presented in section 3, followed by concluding remarks.

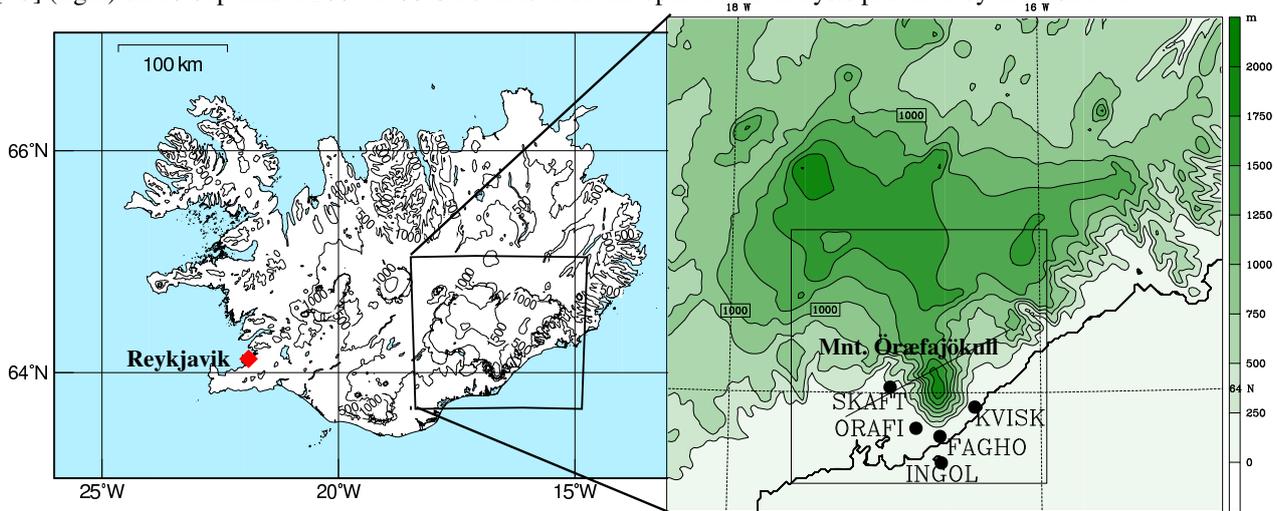
## 2. SYNOPTIC OVERVIEW AND AVAILABLE OBSERVATIONAL DATA

Figure 1 shows the mean sea level pressure, the geopotential height at 500 hPa and the temperature at 850 hPa at the time when windgusts greater than  $50 \text{ ms}^{-1}$  were observed at the Skaftafell and Öräfi weather stations (see Fig. 2 for location of the stations). At the surface, the geostrophic winds are from the ESE, while over land the surface winds are from the ENE or NE. At 500 hPa, the flow is relatively weak ( $20\text{--}25 \text{ ms}^{-1}$ ) and the wind direction is from the SSE. There is a sector of warm air at 850 hPa stretching from Ireland towards S–Iceland. In the early morning of 16 September, the observed 2 meter temperature at Skaftafell exceeds  $15^\circ\text{C}$  which is about  $7^\circ\text{C}$  above the seasonal average. The geostrophic wind at the surface is greater than  $30 \text{ ms}^{-1}$  and there is a directional and a reverse (negative) vertical wind shear in the lower part of the troposphere.

Figure 2 shows the domain setup of the MM5 and WRF simulations as well as the location of automatic meteorological stations. These are Skaftafell (SKAFT), Öräfi (ORAFI), Ingólfshöfði (INGOL), Fagurhólsmýri



**Figure 1:** Mean sea level pressure [hPa] (left), geopotential height at 500 hPa [m] (middle) and temperature at 850 hPa [°C] (right) on 16 September 2004 at 06 UTC. Based on the operational analysis provided by the ECMWF.



**Figure 2:** Domain setup and location of observational sites. The box on the right hand side shows the region of interest around Mnt. Öraefajökull.

(FAGHO) and Kvísker (KVISK). Surface wind speed and direction, gusts and temperature are all measured at these stations. At stations SKAFT, FAGHO and KVISK, accumulated precipitation is measured once to twice daily. The straight line crossing Mnt. Öraefajökull shows the location of the cross sections shown in Fig. 5.

### 3. RESULTS

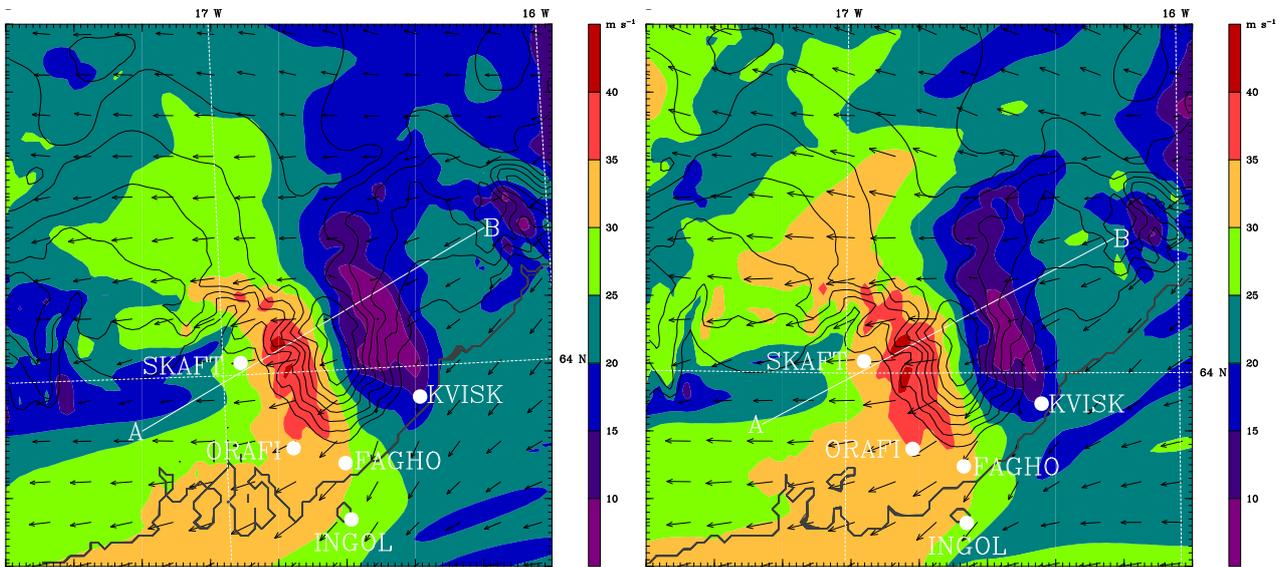
Both MM5 and WRF simulations capture strong winds over the Vatnajökull ice cap (Fig. 3) as well as over the lowlands. In both simulations the flow is decelerated upstream of Mnt. Öraefajökull. The simulated near surface wind speed has a maximum immediately downstream of the highest mountain (Mnt. Öraefajökull). This maximum does not extend far downstream. There is also a secondary maximum of wind speed emanating from the edge of the same mountain. This secondary maximum extends far downstream. Accumulated precipitation measured at Skaftafell (SKAFT), Fagurhólmseyri (FAGHO) and Kvísker (KVISK) is compared with simulated precipitation in Table 1. Both models correctly simulate the dry area downstream of Mnt. Öraefajökull but tend to overestimate the precipitation on the windward side. This overestimation can, to some extent, be explained by undercatchment of the rain gauges due to strong winds. The precipitation gradient in the WRF simulation (i.e. more precipitation at KVISK than at FAGHO) is in better agreement

Precip	Observed	Sim-MM5	Sim-WRF
SKAFT	0.0	0.0	0.8
FAGHO	42.4	49.8	74.8
KVISK	59	55.5	97.6

**Table 1:** Observed and simulated accumulated (between 15 September, 18 UTC and 16 September, 09 UTC) precipitation [mm] at stations Skaftafell (SKAFT), Fagurhólmseyri (FAGHO) and Kvísker (KVISK).

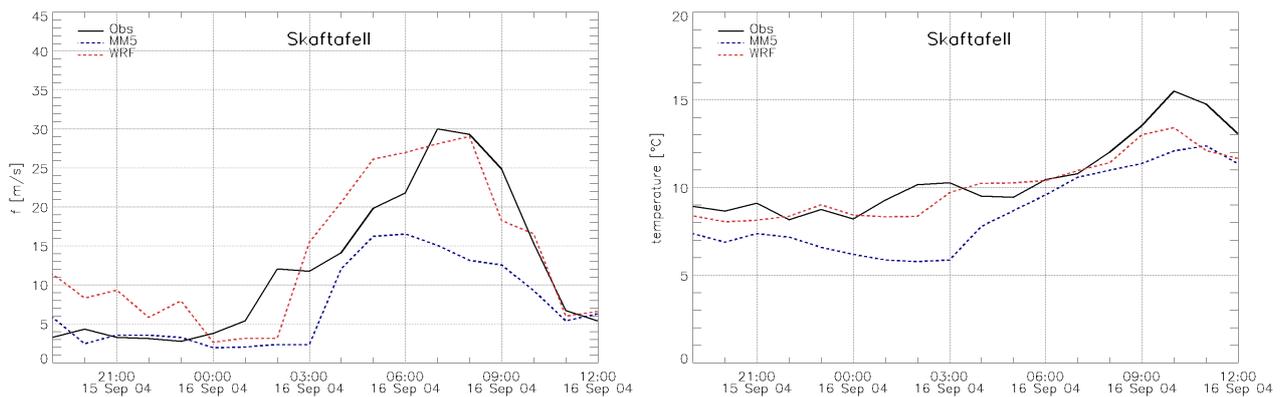
with observed gradient than is the MM5 simulation, although the precipitation amount in the MM5 simulation is closer to observed values.

With regard to wind speed, there exists a noticeable quantitative difference between the two models. Figure 4 shows observed and simulated surface wind speed and temperature at Skaftafell (SKAFT). The WRF



**Figure 3:** Simulated near surface wind speed [m/s] by MM5 (left) and WRF (right) at 16 September 2004, 06 UTC.

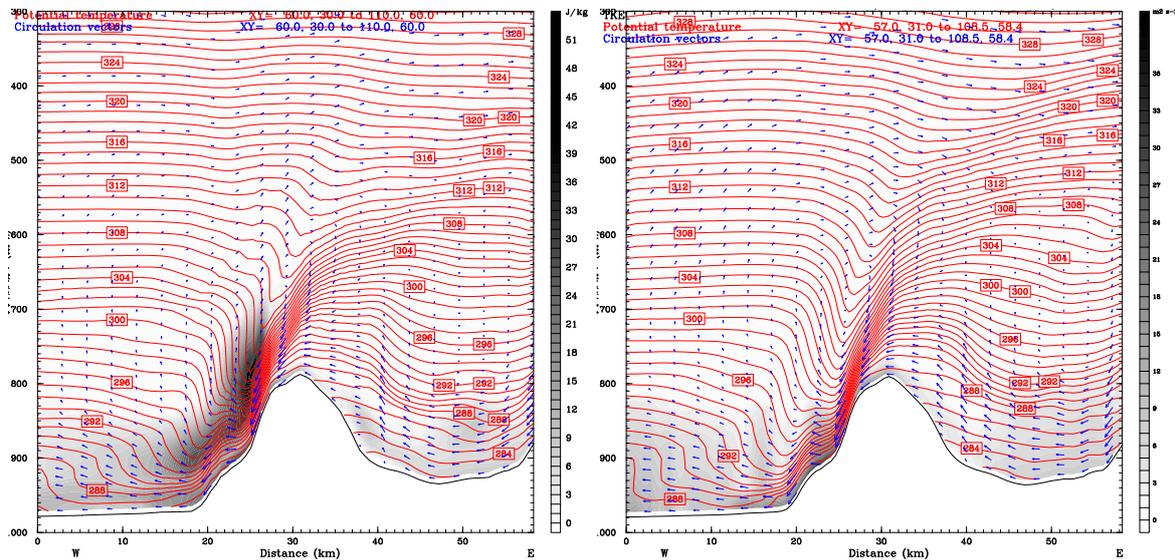
model captures the full strength of the windstorm ( $30 \text{ ms}^{-1}$ ) whilst simulated wind speed in MM5 only reached about  $20 \text{ ms}^{-1}$ . Further, the 2 meter temperature is captured considerably better by the WRF model than by MM5. On average, the MM5 simulated 2 meter temperature is  $2\text{--}3^\circ\text{C}$  colder than measured while the 2 meter temperature in WRF is very close to the observed surface temperature. However, at other stations (ORAFI, KVISK, FAGHO and INGOL) away from the wind maximum, the difference between simulated temperature and wind direction between the two models are small (not shown). At station Örafi (ORAFI) the WRF model overestimates the mean wind by approximately  $5 \text{ ms}^{-1}$  while MM5 captures the wind field correctly.



**Figure 4:** Observed (solid black) and simulated (red dash – WRF, blue dash – MM5) 10 meter wind speed [m/s](left) and 2 meter temperature [ $^\circ\text{C}$ ] (right) at station Skaftafell (WMO# 4172 – SKAFT) in the lee of Mnt. Örafajökull.

At Kvísker (KVISK) both models perform similarly, the MM5 underestimates the winds slightly while WRF slightly overestimates them. At station Fagurhólmýri (FAGHO) the MM5 consistently underestimates the corner wind and fails to capture the maximum wind strength by  $8 \text{ ms}^{-1}$ . WRF fares considerably better, but still underestimates the observed maximum winds ( $30 \text{ ms}^{-1}$ ) by  $4 \text{ ms}^{-1}$ . With the current model configuration, station Ingólfshöfði (INGOL) is off-shore in both models. Hence, observed and simulated fields can not be compared in a logical manner.

Figure 5 shows a cross section along line AB in Fig. 3 from the two simulations. In the MM5 simulation, the distribution of turbulence kinetic energy (TKE) shows that there is very strong mountain wave breaking between approximately 800 and 600 hPa and very little wave activity above 500 hPa. There is intense turbulence below 700 hPa associated with the wave breaking. At the surface, there is also a layer of high TKE. The wave breaking, simulated by the WRF model, on other hand, differs from the wave breaking simulated by MM5. Particularly, the WRF simulated wave breaking is much weaker than that in the MM5 simulation. Interestingly, there is high TKE production at the surface in the WRF simulation as in the MM5 simulation.



**Figure 5:** Cross section along line AB (cf. Fig. 3) showing potential temperature (red lines) [K], wind along the cross section (blue arrows) [m/s] and turbulent kinetic energy (TKE) [J/kg] for MM5 (left) and WRF (right) at 16 September 2004, 06 UTC.

#### 4. DISCUSSION AND CONCLUSIONS

The major difference between the MM5 and WRF simulations is in the wave breaking. In the MM5 simulation, there is greater dissipation in the downslope wind associated with greater TKE production below 600 hPa at all times than there is in WRF. In the WRF simulation, the dissipation mainly takes place between 950 and 700 hPa. After 03 UTC, 16 September, it is confined between surface and 800 hPa. The difference in the intensity of the simulated downslope winds can be explained by less dissipation associated with turbulence in the WRF simulation than the MM5 simulation. Since upper air observations are not available to verify the simulated wave breaking, the accuracy of the simulated surface winds and temperature is the only measurable performance of both the MM5 and WRF models for this windstorm event.

Given the lack of upper air observations for this downslope windstorm event and the limitation of a single-case study, the results from this study are far from being conclusive. Further studies are needed to address the question as to whether or not the advanced numerics in the WRF model makes it better suitable than the MM5 model for high resolution simulations/forecasts of downslope windstorms in Iceland.

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