DOWNSLOPE WINDSTORM IN ICELAND – WRF/MM5 MODEL COMPARISON-I

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Abstract: A severe windstorm downstream of Mnt. Öræfajökull 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. Both models are run with a new, two equation planetary boundary layer (PBL) scheme as well as the ETA/MYJ PBL schemes. 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. Öræfajökull, while the vertical structure of the lee wave differs between the two models and the two PBL schemes. The WRF simulated downslope winds, using the MYJ PBL scheme, are in good agreement with the strength of the observed downslope windstorm, with the maximum wind speed as great as 30 ms^{-1}, whilst using the new two equation scheme surface winds only reach about 20 ms^{-1}. On the contrary, the MM5 simulated surface winds, with the new two equation model, are in better agreement to observations than when using the ETA scheme. Surface winds reach 22 ms^{-1} when using the two equation model whilst the winds in the ETA simulation only reach about 17 ms^{-1}. The simulated surface temperature in the WRF simulations is also closer to the observations than the MM5 simulations.

Keywords *- Model comparison, PBL scheme comparison, MM5, AR–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 Hálfdán 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, four 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) and two different PBL schemes, the current ETA/MYJ planetary boundary layer model and a new two equation model (Bao et al. 2007, NCAR Tech. Note, in print). 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 four simulations are made using observed surface winds, temperature and precipitation. This paper is structured as follows: In the next section we descripe 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 ms^{-1} were observed at the Skaftafell and Öræfi 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 (20–25 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°C which is about 7°C above the seasonal average. The geostrophic wind at the surface is greater than 30 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.

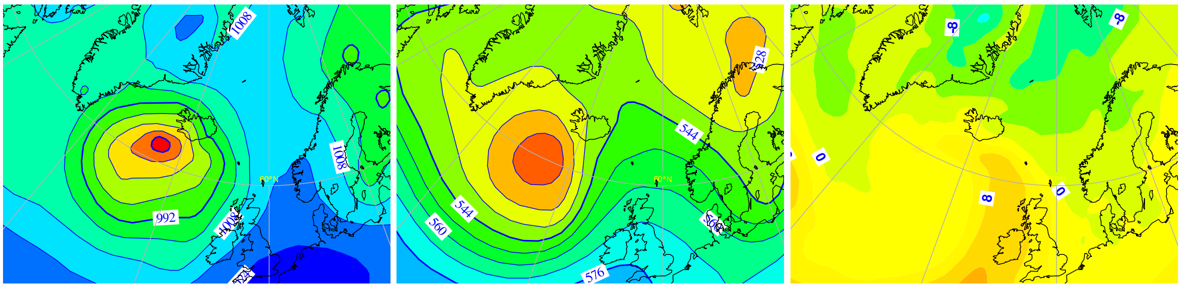

Figure 1: Mean sea level pressure [hPa] (left), geopotential height at 500 hPa [m] (middle) and temperature at 850 hPa [°C] (right) on 16 September 2004 at 06 UTC. Based on the operational analysis provided by the ECMWF.

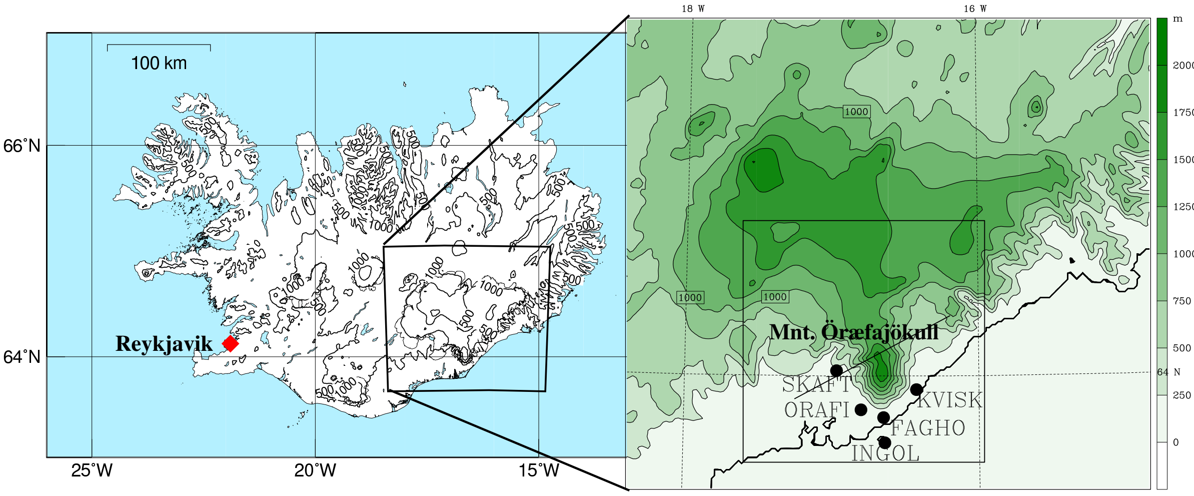

Figure 2: Domain setup and location of observational sites. The box on the right hand side shows the region of interest around Mnt. Öræfajökull.

These are Skaftafell (SKAFT), Öræfi (ORAFI), Ingólfshöfði (INGOL), Fagurhólsmýri (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. Öræfajökull shows the location of the cross sections shown in Fig. 6.

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

Precip	Observed	MM5		AR–WRF	
		ETA	2–eq	MYJ	2–eq
SKAFT	0.0	0.0	0.0	0.8	1.2
FAGHO	42.4	49.8	47.6	74.8	36.0
KVISK	59	55.5	45.9	95.0	71.2

3. RESULTS

Both MM5 and WRF simulations capture strong winds over the Vatnajökull ice cap (Fig. 3) as well as over the lowlands. In all simulations the flow is decelerated upstream of Mnt. Öræfajökull. The simulated near surface wind speed has a maximum immediately downstream of the highest mountain (Mnt. Öræfajökull). 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), Fagurhólsmýri (FAGHO) and Kvísker (KVISK) is compared with simulated precipitation in Table 1. Both models correctly simulate the dry area downstream of Mnt. Öræfajökull but tend to overestimate the precipitation on the windward side with the exception of WRF/2eq (named WRF Bao in Fig. 4). This overestimation can, to some extent, be explained by undercatchment of the rain gauges due to strong winds. The precipitation gradient in the WRF simulations (i.e., more precipitation at KVISK than at FAGHO) is in better agreement with observed gradient than is the MM5

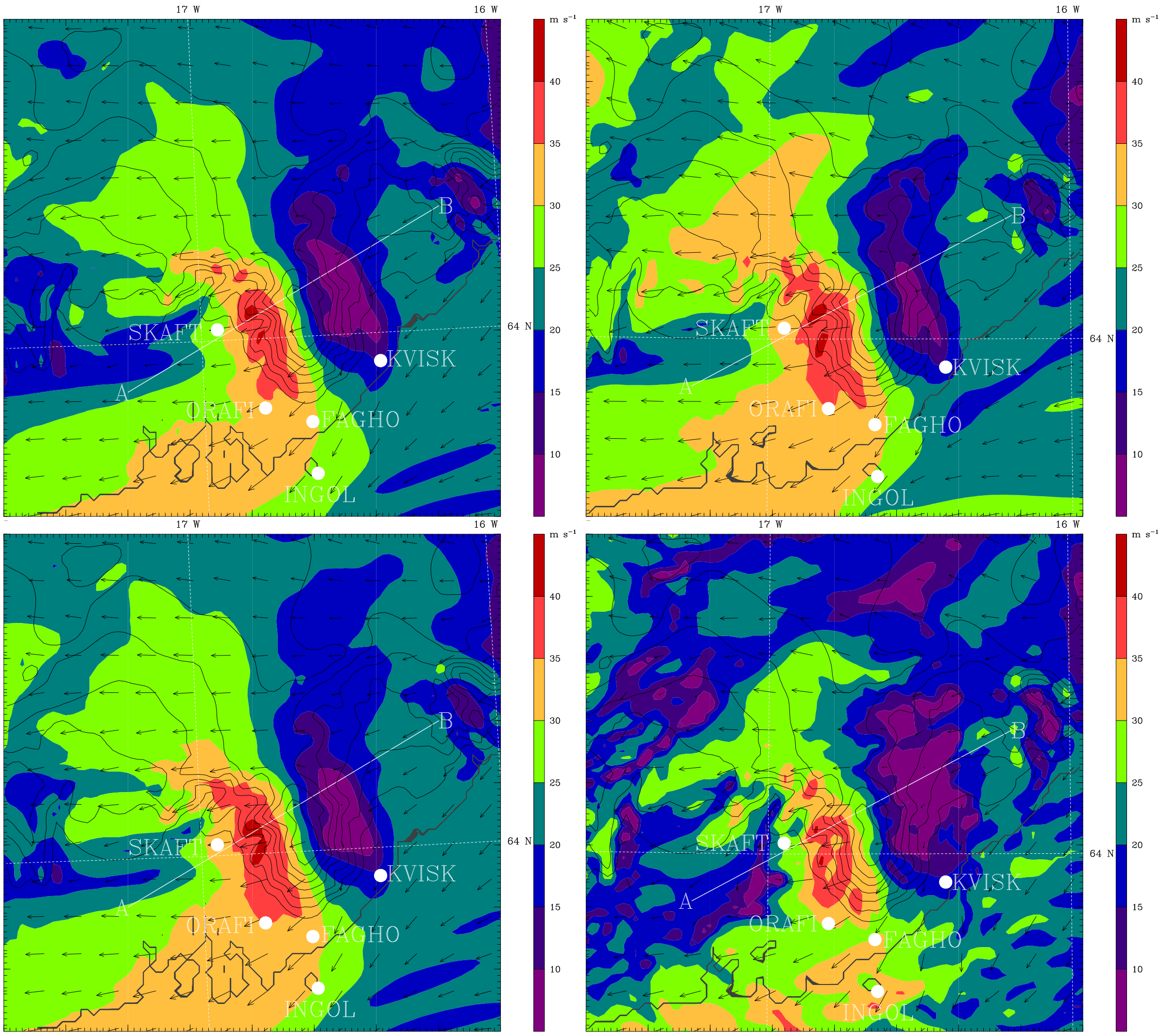

Figure 3: Simulated near surface wind speed [m/s] by MM5 (left panels) and WRF (right panels) at 16 September 2004, 06 UTC. Top panels show results from the ETA and MYJ boundary layer schemes and the bottom panel shows results using the new two equation PBL model.

simulation, although the precipitation amount in the MM5 simulation is closer to the observed values. In the WRF/2eq simulation the upstream blocking extends closer to location FAGHO than it does in the WRF/MYJ simulation. As heavy precipitation is often accosiated with strong winds this could to some extend explain the difference in simulated precipitation between the two WRF simulations upstream and at the tip of the mountain (stations KVISK and FAGHO). With regard to wind speed, there exists a noticeable quantitative difference between the four simulations. Figure 4 shows observed and simulated surface wind speed and temperature at Skaftafell (SKAFT). The WRF simulated downslope winds, using the MYJ PBL scheme, are in good agreement with the strength of the observed downslope windstorm, with the maximum wind speed as great as 29 ms^{-1}, whilst using the new two equation scheme surface winds only reach about 22 ms^{-1}. On the contrary, the MM5 simulated surface winds, with the new two equation model, are in better agreement to observations than when using the ETA scheme. Surface winds reach 22 ms^{-1} when using the two equation model whilst the winds in the MM5/ETA simulation only reach about 17 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 2–3°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 in temperature and wind direction between the four simulations are small (not shown). At

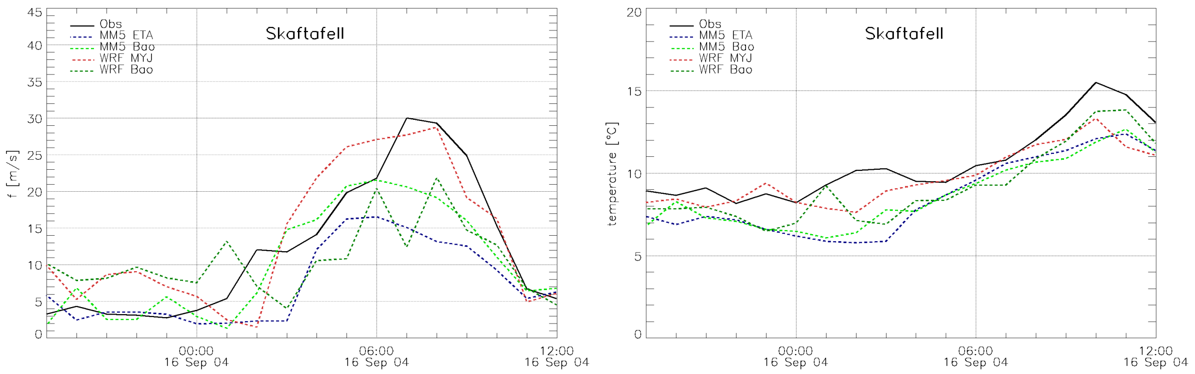

Figure 4: Observed (solid black) and simulated (blue dash – MM5/ETA, light green dash – MM5/2eq, red dash – WRF/MYJ, dark green dash – WRF/2eq) 10 meter wind speed [m/s] (left) and 2–meter temperature [°C] (right) at station Skaftafell (WMO# 4172 – SKAFT) in the lee of Mnt. Öræfajökull.

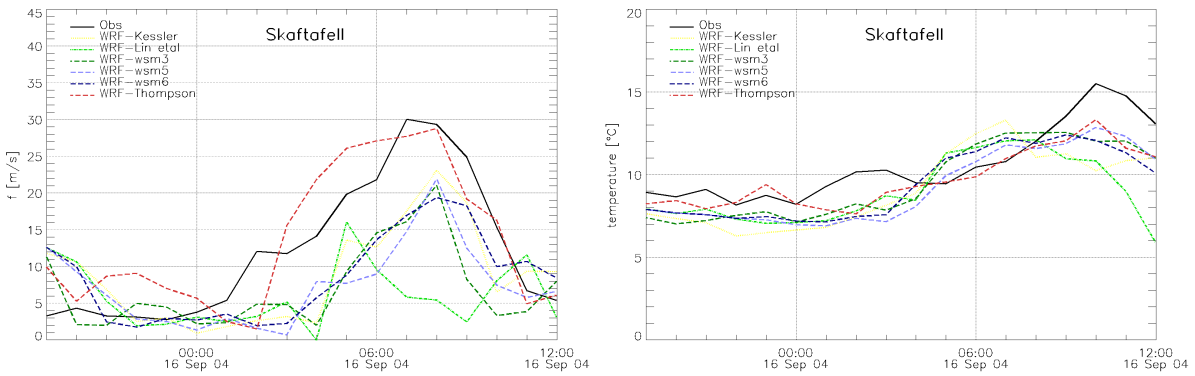

Figure 5: Observed (solid black) and simulated (dashed) 10 meter wind speed [m/s](left) and 2–meter temperature [°C] (right) at station Skaftafell (WMO# 4172 – SKAFT) in the lee of Mnt. Öræfajökull. Various colors represent various micro physic parameterizations within the AR–WRF model: Yellow – Kessler, light green – Lin et al., dark green – WSM3, ligth blue – WSM5, dark blue – WSM6 and red – Thompson scheme.

station Öræfi (ORAFI) the WRF/MYJ model overestimates the mean wind by approximately 5 ms^{-1} while MM5/ETA captures the wind field correctly. Both two equation simulations (MM5/2eq and WRF/2eq) show similar results, the wind speed being 2–3 ms^{-1} greater than observed values. At Kvísker (KVISK) both models perform similarly, the MM5 underestimates the winds slightly while WRF slightly overestimates them. At station Fagurhólsmýri (FAGHO) the MM5 simulations are very similar, both simulations consistently underestimate the corner wind and faile to capture the maximum wind strength by 7–8 ms^{-1}.

The WRF models fare considerably better, but still underestimates the observed maximum winds (30 ms^{-1}) by 4 ms^{-1}. With the current modelconfiguration, station Ingólfshöfði (INGOL) is off–shore in both models. Hence, observed and simulated fields can not be compared in a logical manner. The intensity of the simulated downslope windstorm is not only sensitive to the PBL schemes but also to the cloud microphysics schemes.

Figure 5 shows the variation of the AR–WRF simulated surface wind speed (left) and temperature (right) at Skaftafell that is caused by using various options of the cloud microphysics schemes. It is seen that there is a significant variation in the simulated maximum surface wind speed corresponding the different cloud microphysics schemes, and the Thompson scheme appears to produce the result in the best agreement with the observation. The surface temperature is also best simulated with the Thompsons scheme, being very close to observed temperature during the peak of the storm (04UTC to 08UTC on 16 September). During this period the AR–WRF model, using other micro physic parameterizations, overestimates the surface temperature at Skaftafell by 1–3 °C. However, the model does not capture the observed temperature maximum (15.5 °C) at 10UTC, but the Thompson scheme produces results that are closest to the observed values.

The sensitivity to cloud micro physics scheme can be explained by the fact that various schemes produce

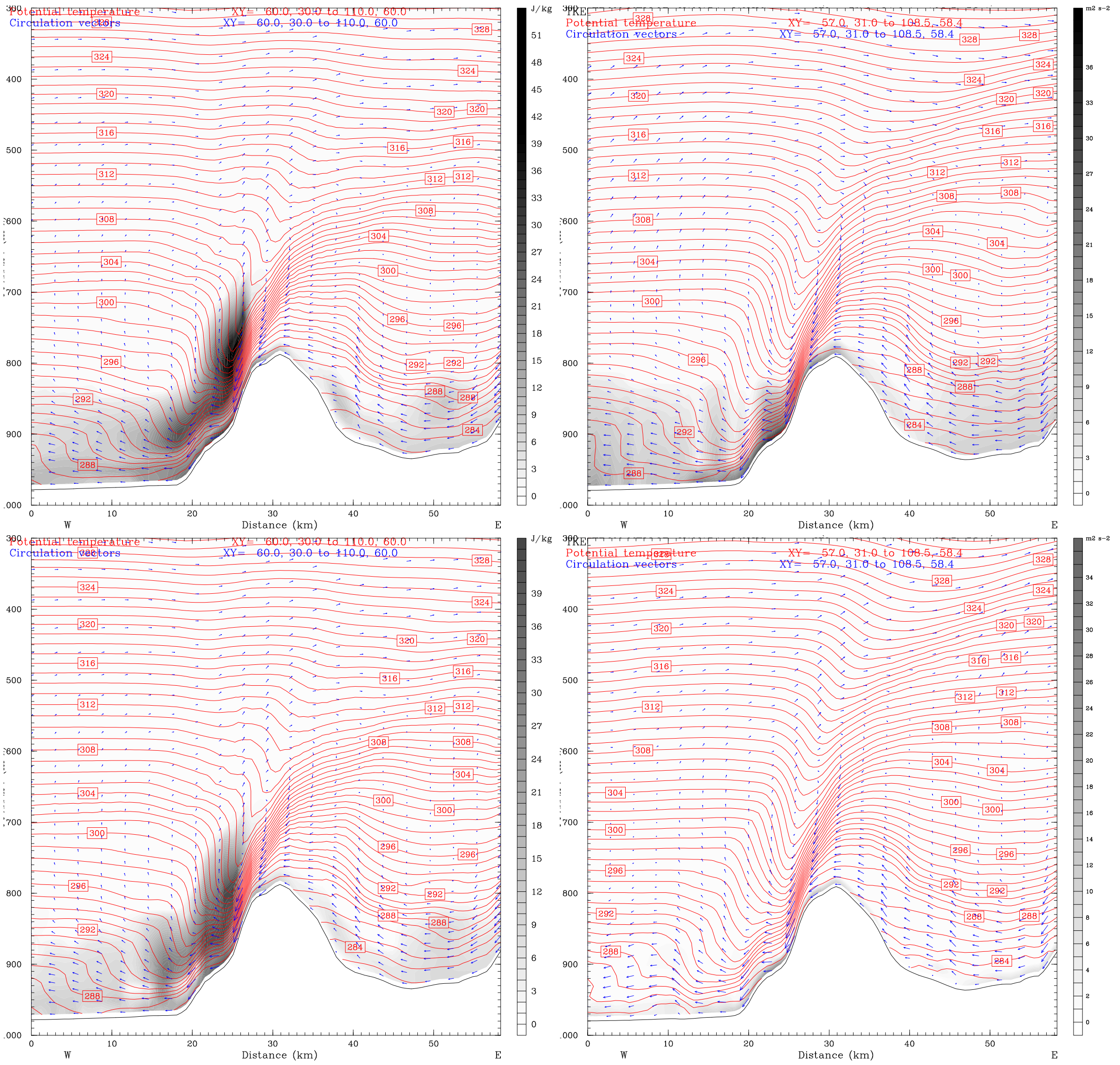

Figure 6: Cross section along line AB (cf. Fig. 3) showing potential temperature (red lines) [K], wind along the cross section (blue arrows) [m/s] and turbulent kinetic energy (TKE) [J/kg] for MM5 (left panels) and WRF (right panels) at 16 September 2004, 06 UTC. Top panels show results from the ETA and MYJ boundary layer schemes and the bottom panel shows results using the new two equation PBL model.

different upslope distributions of precipitation and hydrometeors, resulting in variation in the upslope static stability. Since the intensity of downslope wind is directly related to the intensity of the downslope gravity-wave breaking that is strongly dependent on the upslope static stability, this sensitivity is the manifestation of the great impact of the upslope precipitation on the downslope wind speed.

Figure 6 shows a cross section along line AB in Fig. 3 from the four simulations. In both the MM5 simulations, the distribution of turbulence kinetic energy (TKE) shows that there is very strong mountain wave breaking between approximately 800 and 650 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. In spite of common features the MM5/ETA and MM5/2eq simulations reveal important differences in the wave and TKE structure. Between 18UTC and 00UTC on 15 September, there is stronger TKE between 900 and 700 hPa in the MM5/ETA simulation downslope of the mountain. The wavestructure is however very similiar. Few hours later, between 01UTC and 03UTC on 16 September, the wave penetrates considerably deeper in the ETA/2eq simulation. Surface wind speed at Skaftafell increase sharply from 3 ms^{-1} to

15 ms^{-1} whilst staying calm in the MM5/ETA simulation. The TKE is confined below the T_{pot}=286 K isoline in the MM5/2eq simulation but below the T_{pot}=289 K isoline in the MM5/ETA simulation. During the peak of the windstorm, between 06UTC and 09UTC on 16 September, there is stronger TKE aloft in the lee of the mountain in the MM5/2eq simulation but the wavestructure is now very similar. After 09UTC there is very little difference between the two MM5 simulations.

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. The cross–sections reveal greater differences between the two WRF simulations (WRF/MYJ and WRF/2eq) than there appear to be between the two MM5 simulations. Firstly, there is very little TKE aloft (900–700 hPa) in the WRF/2eq simulation between 21UTC and 03UTC on 15–16 September. Both simulations show similar characteristics between 03UTC and 06UTC on 16 September but after that, between 07UTC and 10UTC there is considerably greater TKE aloft in the lee of the mountain in the WRF/2eq simulation.

4. DISCUSSION AND CONCLUSIONS

The major difference between the MM5 and WRF simulations is in the wave breaking. In the MM5 simulations, there is greater dissipation in the downslope wind associated with greater TKE production below 600 hPa at all times than there is in WRF/MYJ. In the WRF/MYJ 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/MYJ simulation than in the WRF/2eq and the MM5 simulations. 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.

Another major difference between the MM5 and WRF models is the different characteristics revealed when using the two equation PBL model. In WRF surface wind speed, in the lee of the mountain, is greatly reduced compared to the MYJ boundary layer scheme. This is in the opposite compared to the MM5 simulation, there the two equation model gives rise to greater surface winds that are closer to observed values.

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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