DOWNSLOPE WINDSTORMS IN ICELAND – WRF/MM5 MODEL COMPARISON - II

Hálfdán Ágústsson[12], Jian-Wen Bao[3], Ólafur Rögnvaldsson[14] and Haraldur Ólafsson[124]
[1] Institute for Meteorological Research, Reykjavík, Iceland
[2] University of Iceland, Reykjavík, Iceland
[3] NOAA/ESRL, Boulder, USA
[4] University of Bergen, Norway
E-mail: Hálfdán Ágústsson - halfdana@hi.is

Abstract: This study is focused on the sensitivity of simulated severe windstorms downstream of the Snæfellsnes mountain range in West-Iceland to various choices of the planetary boundary layer (PBL) and cloud parameterizations that are available in the PSU/NCAR MM5 model and the Advanced Research WRF model. Both MM5 and AR-WRF are run on a 1 km horizontal grid with two different PBL schemes, the classical ETA/MYJ scheme and a modified version of it (a 2-equation scheme), along with all the available microphysical schemes in AR-WRF. The results from the study show that the simulated surface wind speed downstream of the mountain range and close to the mountain foot (location Bláfeldur), is greater in AR-WRF than in MM5 and in better agreement with observations, regardless what combination of PBL and cloud parameterizations is used. The simulated surface winds using the 2-equation PBL scheme are slightly greater than those simulated using the ETA/MYJ scheme. The simulated winds show little sensitivity to the choice of microphysical scheme. The simulated near surface temperature is similar in all the model simulations with the difference being less than 1°C in general.

Keywords *- Model comparison, MM5, AR-WRF, Iceland, downslope windstorms*

1. INTRODUCTION

Downslope windstorms are relatively common in the Snæfellsnes peninsula in West-Iceland and have been observed both in northerly and southerly flows (e.g. Ólafsson et al. 2002). Apart from the recent study of Ólafsson and Ágústsson (2007), which analysed a severe downslope windstorm in Southeast-Iceland, the downslope windstorms in Iceland have not been extensively documented in the scientific literature so far. They have however previously been related to extreme weather events (e.g. Ágústsson and Ólafsson 2007).

Here, we study recent downslope windstorms in the Snæfellsnes peninsula. The storms are simulated with the MM5 (Grell et al. 1994) as well as the AR-WRF (Skamarock et al. 2005) numerical models. The models are initiated with two different data sets and the sensitivity of the simulated fields and dynamics to different microphysics and parameterization of turbulent mixing in the PBL is tested. Also, the ETA boundary layer scheme is compared to a new 2-equation version of the same scheme[1]. Ground observations of temperature and wind from automatic weather stations are used for verification.

The following section gives a brief overview of the synoptic situation while sec. 3 describes the available observations. The results are presented in sec. 4 and the concluding remarks are in the last section.

2. SYNOPTIC OVERVIEW

Two northerly windstorms hit the Snæfellsnes peninsula in West-Iceland on 5–6 March 2007. Very weak winds were observed for approx. 12 hours between the storms, even though the synoptic situation only changed slightly. Mean surface winds exceeded 30 m/s in the late evening of 5 March with somewhat weaker winds in the early evening of 6 March. Wind gusts exceeded 40 m/s throughout both storms with gusts as great as 50 m/s observed on the lee-side of the peninsula. Far weaker winds were observed on the windward side.

There was a surface low over Iceland (Fig. 1, left), shifting its centre and shape slightly throughout both days. The storms are related to a strong E-W oriented pressure gradient across West-Iceland while the gradient was more zonal and slightly weaker during the weak wind period. Northwest of Iceland, the surface flow is further enhanced as the Greenland orography forces the airflow through Denmark strait. Aloft, there was a relatively flat and broad depression centred over Iceland (Fig. 1, right). The strongest gradients aloft, both in pressure and temperature, were far south of Iceland. Consequently, there was relatively little veering of the wind with height while there was significant reverse wind shear with the strongest winds at or just above mountain level.

3. OBSERVATIONAL DATA

The simulated flow is compared to surface observations of wind and temperature from the automatic

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[1] Bao et al.: 2007, NCAR Tech. Note, (in print)

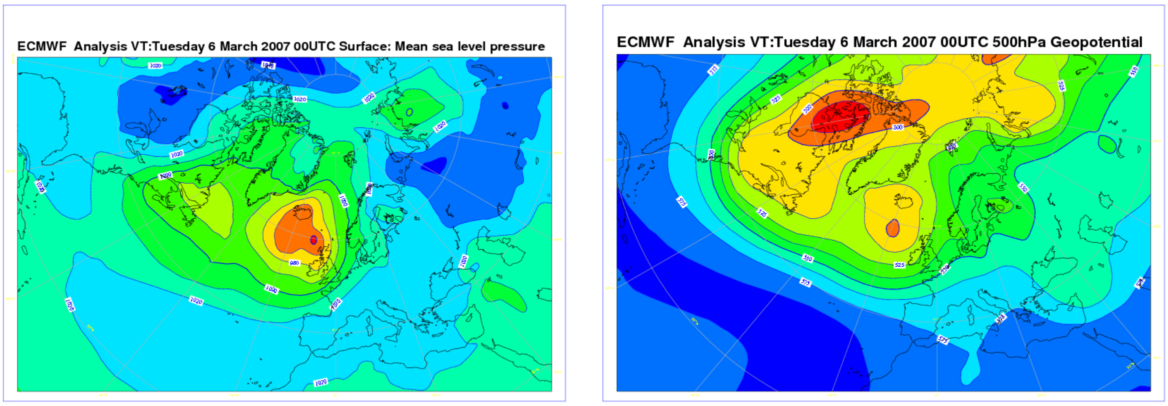

Figure 1: The mean sea level pressure [hPa] (left) and the geopotential height [m] at 500 hPa (right) at 00 UTC on 6 March 2007, according to the ECMWF-analysis.

weather stations at: Gufuskálar, Ólafsvík, Bláfeldur, Grundarfjörður, Hraunsmúli, Fróðárheiði, Kolgrafarfjörður, Vatnaleið and Stykkishólmur (Fig. 2). Most of the stations belong to Veðurstofa Íslands (IMO, The Icelandic Meteorological Office) while a few belong to Vegagerðin (The Public Road Administration). Observations of 10-minute mean temperature and wind speed, as well as 3-second maximum wind gust are available at 10-minute intervals from most of the stations. The wind is observed at 10 m or at the top of a 6 m mast raised approx. 1 m above its immidiate surroundings. The temperature is observed at 2 m. All data is stored and checked for errors at IMO.

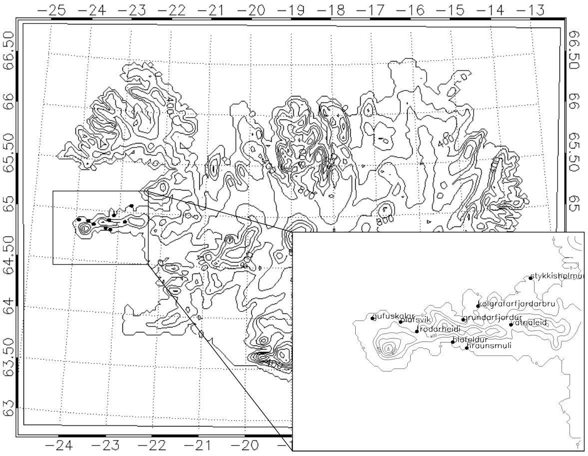

Figure 2: Topography of Iceland and location of observation sites. Terrain contours every 200 m. Also shown are the numerical domains with a resolution of 3 and 1 km.

4. RESULTS

The storms of 5–6 March 2007 are simulated using V3-7 of MM5 and V2.2 of AR-WRF. The setup of the models is similar, 39 vertical layers with the model top at 100 hPa and 3 identical domains with a resolution of 9, 3 and 1 km. The MM5-model is initialized and forced with operational analysis from the European Centre for Medium-Range Weather Forecasts (ECMWF) while the WRF-model is also forced with operational GFS-analysis (Global Forecasting System). When forced with ECMWF data, the AR-WRF is only run on the 1 km domain and forced with data from the 3 km MM5-domain. In this way, the same data is used to initialize the 1 km domains for both models which simplifies considerably the comparison of the simulation results.

Model sensitivity to initial data

There is a relatively large difference between the simulated surface field when different initial data is used. The surface wind field is realistically simulated with both GFS- and ECMWF-data (Fig. 3). There is a more localized deceleration of the impinging flow and leeside-speedup with the AR-WRF and GFS-data, while the MM5- and AR-WRF give somewhat smoother simulated windfields with ECMWF-data.

When compared to observations from automatic weather stations (e.g. Figs. 4 and 5) the AR-WRF with GFS-data is found to perform best. There is less difference between the simulated wind upstream than downslope. Upstream, e.g. at Kolgrafarfjarðarbrú, the AR-WRF does slightly better in capturing the wind maxima during both storms while both models overestimate sligthly the strength and duration of the minimum between the storms. At the downslope location of Hraunsmúli, the AR-WRF with GFS-data captures

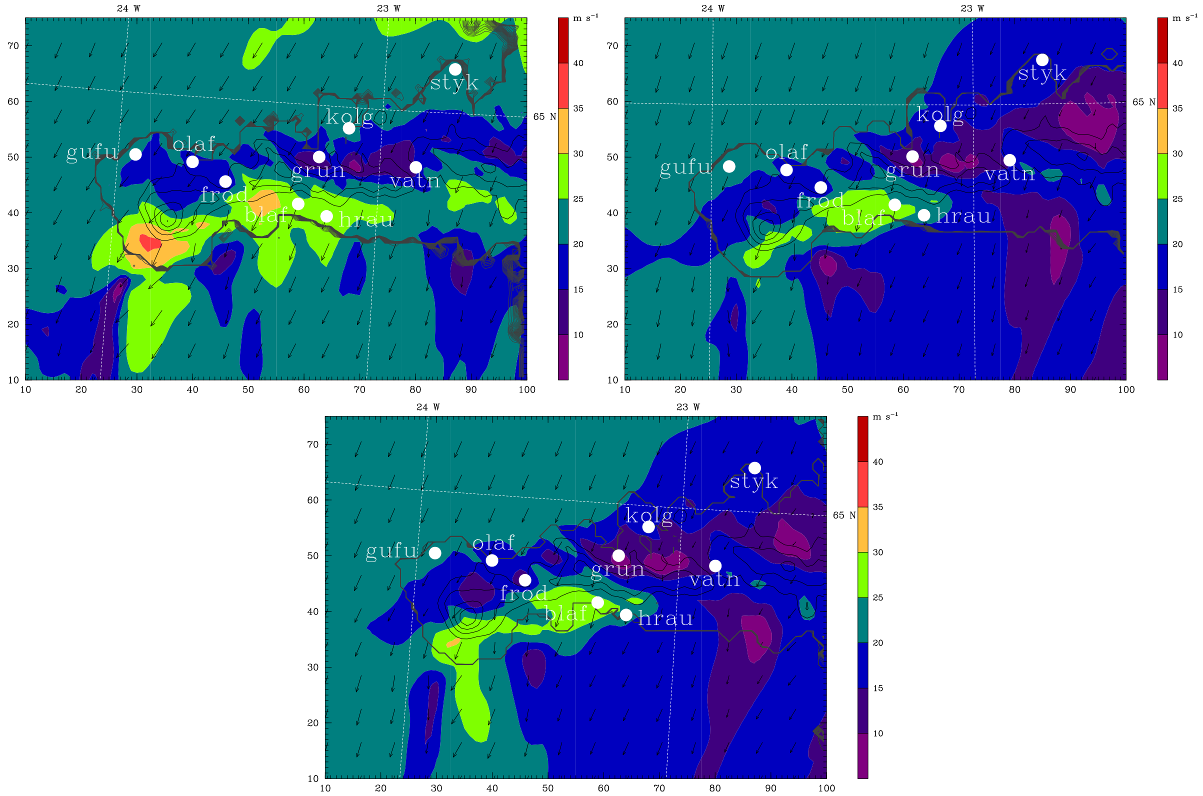

Figure 3: The simulated surface wind field [m/s] at horizontal resolution of 1 km at 00 UTC on 6 March, with the ETA-scheme, in AR-WRF with GFS-analysis (left) and ECMWF-analysis (right), as well as in MM5 with ECMWF-analysis (below). Also shown are station locations.

correctly the wind maxima while they are strongly underestimated in the other simulations. However, the AR-WRF fares slightly worse when capturing the duration of the weak wind situation while both models and types of initial data capture the wind strength correctly. The far stronger and gustier downstream winds are found to be related to gravity wave activity aloft. A NS-oriented section (not shown) across the peninsula, reveals a breaking gravity wave and significant turbulence near the station of Hraunsmúli, a location known for severe weather and gusty winds in northerly flow. The weaker upstream winds are due to the decelarating effect of the topography on the impinging flow.

The MM5-model overestimates the temperature by approx. 3°C during the storms and comes closest to capturing correctly the maximum around noon on 6 March. On average, the AR-WRF with GFS-data fares considerably better while it underestimates the downstream maximum slightly. Both models and types of initial data show an error in the timing of maximum upstream temperature, while the observed maximum lags about 5 hours.

The difference in simulated fields is presumably partly related to the difference in the accuracy of the upstream condition from the analysis, as well as different model numerics. A preliminary study of a sounding from the recent GFDex-project[2] indicates that the conditions upstream of Northwest-Iceland are more accurate in the GFS-analysis (not shown). However, more observations aloft are needed for verification, but e.g. differences in upstream moisture content and atmospheric stability will affect the conditions for the generation of gravity waves over the peninsula and the decelerating effect of the topography on the impinging flow.

Sensitivity to parameterization of turbulent mixing

The MM5 performs nearly identically with the two different boundary layers schemes, with the 2-equation version of the ETA-scheme (referenced as BAO in the figures) outperforming the original ETA-scheme slightly (Figs. 4 and 5). The schemes give similar results with the WRF-model using GFS-data, with stronger oscillations in the wind speed on the upwind site with the 2-equation scheme.

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[2] http://lgmacweb.env.uea.ac.uk/e046/research/gfdex/

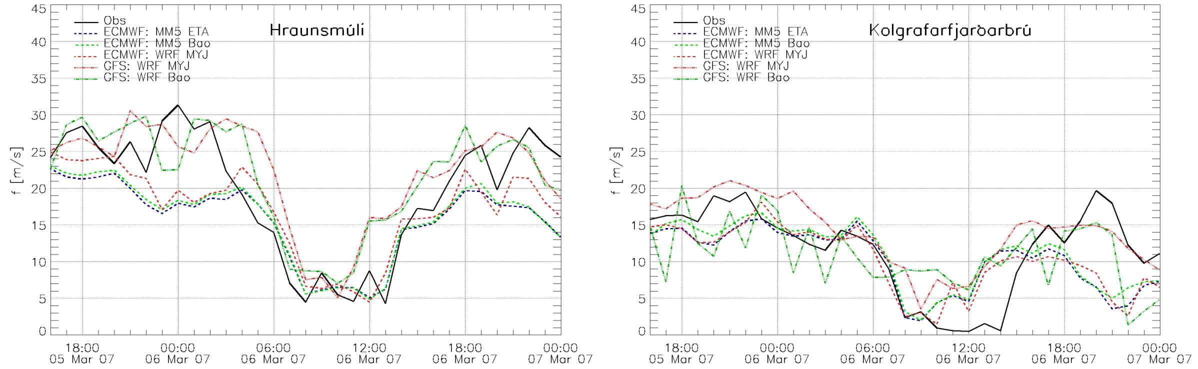

Figure 4: The simulated surface wind field [m/s] at horizontal resolution of 1 km with different setup of model. At Hraunsmúli (left) and at Kolgrafarfjarðarbrú (right).

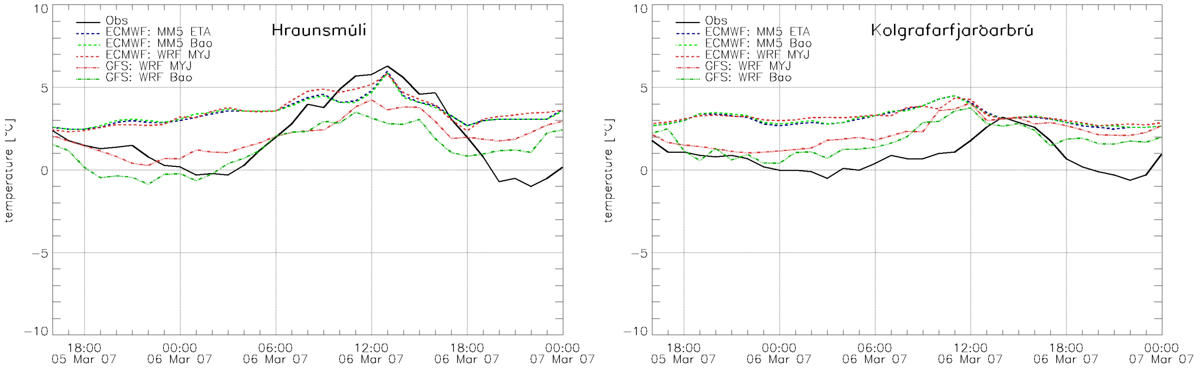

Figure 5: The simulated temperature [°C] at horizontal resolution of 1 km with different setup of model. At Hraunsmúli (left) and at Kolgrafarfjarðarbrú (right).

Sensitivity to microphysical parameterization

There are relatively small differences in the simulated surface flow when the choice of microphysical scheme in AR-WRF is varied (Fig. 6, left). All the different microphysics parameterizations give similar results and capture the surface wind reasonably, except during the first storm's maximum. The greatest difference is found when turbulent mixing in the PBL is neglected (noPBL). This is contrary to the results of the recent study of Rögnvaldsson et al. (2007, Fig. 5), where a strong dependance on the microphysics is observed during a downslope windstorm in Southeast-Iceland (Fig. 6, right), where the "Thompson"-scheme is found to perform best. In the case of Rögnvaldsson et al. (2007), the upstream mountain rises at least 1000 m higher than the Snæfellsnes peninsula. There may therefore be a greater orographic lifting of the airmass which explains to some degree the different results for the two studies. It may also be partly related to the upstream conditions which are presumably less sensitive to the choice of microphysics in the current case. Atmospheric stability will for example be affected by the moisture content of the impinging flow and certain hydrometeor species are only parameterized in some of the microphysical schemes.

5. CONCLUSIONS AND DISCUSSIONS

Here we have successfully simulated downslope windstorms in Iceland using two mesoscale models. As upper air observations are not available for verification, ground observations are the only means to verify and compare the performance of both models. The WRF-model is in general more accurate during the windstorm, especially when forced with GFS-analysis. However, this study is not conclusive and observations aloft would be beneficial.

Contrary to a recent study (Rögnvaldsson et al. 2007) of a downslope windstorm in Iceland, there is surprisingly little difference in the simulated surface winds and temperature when different microphysics schemes are applied in the WRF-model. This may be partly related to the size of the upstream mountain, which is far smaller in the current case, or the upstream conditions,

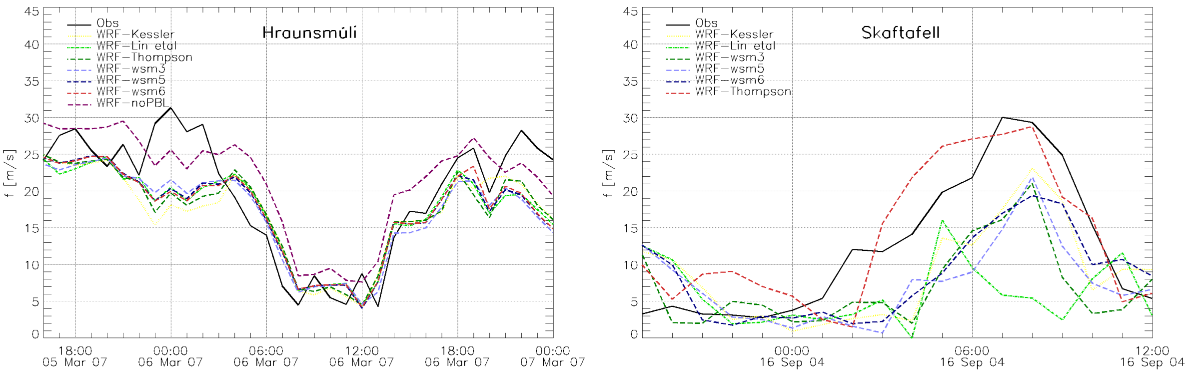

Figure 6: The simulated surface wind field [m/s] at horizontal resolution of 1 km with WRF and various moisture-schemes. At Hraunsmúli (left) and at Skaftafell in Southeast-Iceland (right, Rögnvaldsson et al. (2007).)

e.g. atmospheric stability and hydrometeor species.

The strong dependance of the downslope windstorms on the accuracy of the initial and forcing data is evident. The far better performance with the operational GFS-analysis is presumably related to the greater vertical resolution, i.e. greater number of pressure levels, than in the operational analysis from the EMCWF. A preliminary study does indeed indicate that the upstream conditions are more accurate in the GFS-analysis.

There is greater dependence on the choice of PBL-scheme in the WRF-model than in MM5, with more fluctuations in the surface fields in the 2-equation PBL-scheme in WRF. However, the schemes perform similarily in both models which is indicative that the 2-equation scheme is a valid method for the parameterization of the TKE. Further tests and simulations are needed and will be addressed in the coming studies.

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