WIND GUST FORECASTING IN MM5

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Wind gusts are calculated using a method based on considerations of turbulence and atmospheric stability in the planetary boundary layer. This method was recently introduced by Brasseur and has already been successfully applied to various atmospheric situations, amongst those several in the complex terrain in Iceland. Here, the method is applied to simulations of flow over Iceland. The atmospheric data is generated with the MM5 model at a high horizontal resolution and using boundary conditions from the ECMWF. The gust prediction method is implemented as post-processing within the IDL environment, into which the simulated MM5-data is imported using the MM5IDL-package. The performance of the method is validated by comparison with gust observations from a collection of automatic weather stations spread throughout flat and mountainous terrain in Iceland. The accuracy of the method is strongly dependent on the accuracy of the simulated atmospheric fields. Generally, a well captured mean wind speed is needed for correctly reproducing the wind gusts. However, in the wake of mountains in Southwest-Iceland gusts appear to be systematically overestimated.

Keywords *- Wind gust forecasting, MM5, complex terrain, severe winds, Iceland*

1. INTRODUCTION

The strongest winds observed in windstorms are related to fluctuations in the wind speed at periods as short as a few seconds. These fluctuations are known as wind gusts and are frequently the cause of the greatest damage in windstorms as their strength may easily exceed twice the mean wind speed (see e.g. Durran 1990). A correct description of the surface gusts is therefore of importance for operational forecasting and when estimating the local wind climate.

Most numerical atmospheric models, such as the MM5 modeling system (Grell et al. 1995), give wind-information that can be interpreted as a mean wind, averaged over a few minutes, while estimates of wind gusts are not readily available. The models do however contain information that may theoretically be used to estimate the surface gusts, i.e. the surface type, the topography and the vertical structure of wind, turbulence and stability in the planetary boundary layer (PBL). Here, wind gusts are estimated in simulated flow over Iceland, using a method which is based on considerations of turbulence and atmospheric stability in the PBL (Brasseur 2001). The atmospheric data is generated with the MM5 model while the gust prediction method is implemented as post-processing within the IDL environment, into which the simulated MM5-data is imported using the MM5IDL-package (Rögnvaldsson and Rögnvaldsson 2004).

The following section discusses the methodology while in section 3, predicted gusts in a chosen windstorm are compared to observational data. The ultimate section is a short discussion of the performance of the method and the necessary next steps.

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2. METHODOLOGY

Brasseur (2001) proposes that strong surface gusts may be produced when turbulent eddies deflect air parcels flowing high in the boundary layer down to the surface. As the wind speed generally increases with height in the PBL, the deflected air parcels will be observed as a gusty wind at the surface. This intuitive idea emphasizes the importance of turbulent kinetic energy (TKE) for the creation of wind gusts. In a stable boundary layer, the buoyancy forces oppose the vertical deflection of air parcels and for an air parcel to reach the surface, the TKE has to be great enough to counter the buoyancy forces. On the other hand, in an unstable layer the buoyancy forces enhance vertical transport and increase the turbulence. The method is mathematically expressed as

$$\frac{1}{z_p}\int_0^{z_p} E(z)\,\mathrm{d}z \geq \int_0^{z_p} g\frac{\Delta\theta_v(z)}{\Theta_v(z)}\,\mathrm{d}z, \qquad (1)$$

where z_p, $E(z)$, Θ_v and $\Delta\theta_v$ are respectively the height of the parcel, the TKE, the virtual potential temperature and its variation for the parcel when deflected to the surface. The estimated wind gust, f_g, is chosen as the maximum wind speed for all parcels which satisfy (1) in the boundary layer. The method also gives a bounding interval for the estimated gust strength. The upper bound, $f_{g,max}$, is taken as the maximum wind speed in the PBL and the lower bound, $f_{g,min}$ is determined by using the vertical component of the local turbulence, as opposed to the mean TKE in the left hand side of (1). For a more thorough explanation of the method, the reader is refered to Brasseur (2001).

The method of Brasseur (2001) has been coded using the MM5IDL package (Rögnvaldsson and Rögnvaldsson 2004) which allows for the gust prediction to be applied as postprocessing on the atmospheric data, which is created with the MM5 numerical model (Grell et al. 1995). The model is run at a high resolution, 9, 3 and 1 km in the horizontal and 40 vertical levels. Boundaries of the atmospheric model are forced with data from the ECMWF. Currently, all simulations have been performed with the ETA PBL scheme. A large number of simulations have been performed, representing very different atmospheric conditions over Iceland. A substantial part of the data is created as a part of the HRAS-project[1] which is used in operational weather forecasting in Iceland.

The predicted gusts are compared to observations at chosen automatic observation sites in Iceland (Fig. 1). Most of the available weather stations belong to

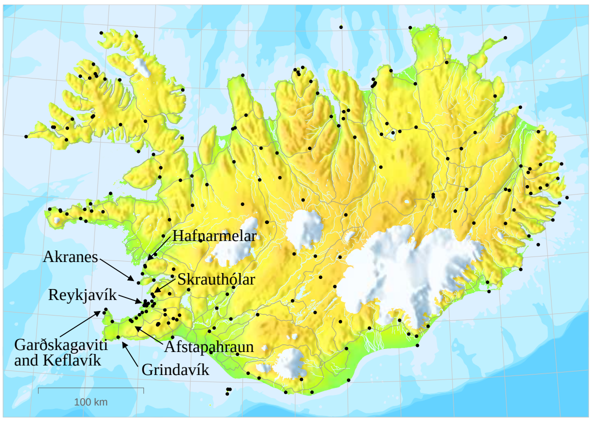

Figure 1: Topography of Iceland and locations of automatic weather stations with wind observations available. Arrows mark stations refered to in this paper.

Veðurstofa Íslands (The Icelandic Meteorological Office) while other belong to various Icelandic institutes or companies. The stations are located in different terrain, both coastal and inland, as well as in relatively flat and mountainous terrain. Obervations of the 10 minute mean wind speed and 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. Due to the non-local nature of wind gusts, the difference in observation heights is presumably of little importance for the observed gust strength.

3. RESULTS

In this paper we choose to show and discuss results of the gust prediction for an easterly windstorm. On the evening of 13 January 2005, a cyclone of approx. 980 hPa was located southwest of Iceland (not shown here), causing easterly and southeasterly flow over Iceland. The storm was strongest in the southwest of Iceland where the observed surface winds and gusts were as strong as 30 and 45 m/s, respectively.

As can be expected in complex terrain, there was a large spatial variability in the observed surface winds (cf. Figs. 1 and 3). This variability is reasonable reproduced in the model at a resolution of 3 km (not shown here) and 1 km (Figs. 2 and 3). Throughout the whole

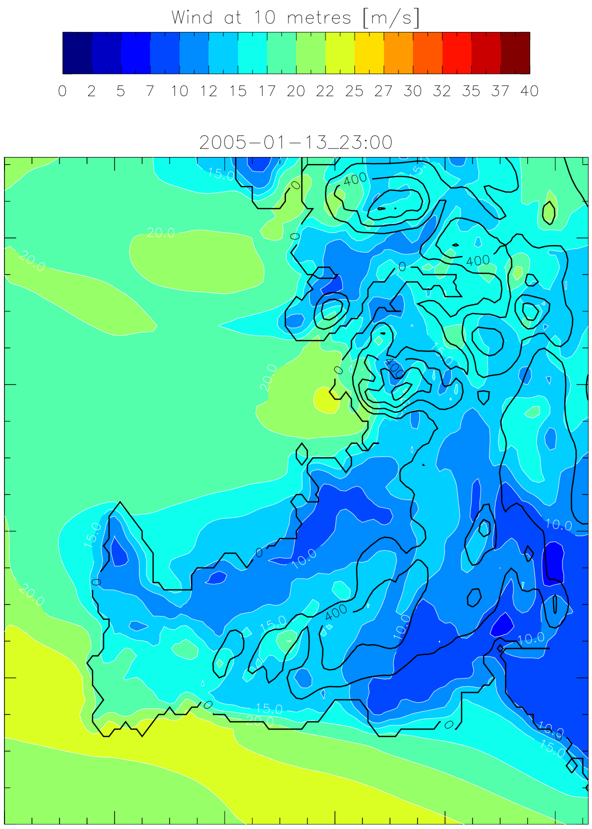

Figure 2: Simulated surface wind in Southwest-Iceland at 23 UTC on 13 January 2005. Also shown is the topography of Iceland [m].

storm, the surface wind is best captured at the stations at Garðskagaviti, Reykjavík and Skrauthólar while the worst performance of the model is on average at Afstapahraun The greatest difference between observed and simulated surface winds is approx. 10 m/s at Grindavík, Akranes and Hafnarmelar (cf. Fig. 3).

There is a somewhat greater variability in the simulated gusts as opposed to the mean wind (Fig. 4). Comparison with the gustfactor (gust/mean wind) of the simulated wind (Fig. 5) indicates that that the gust strength is systematically overestimated in the lee of the mountains of the Reykjanes peninsula, i.e. near Afstapahraun and reaching towards Garðskagaviti and Reykjavík. This is confirmed by the observed gust at Afstapahraun which are on average 10-20 m/s weaker than

[1]URL:http:www.os.is/ or/vedurspa/

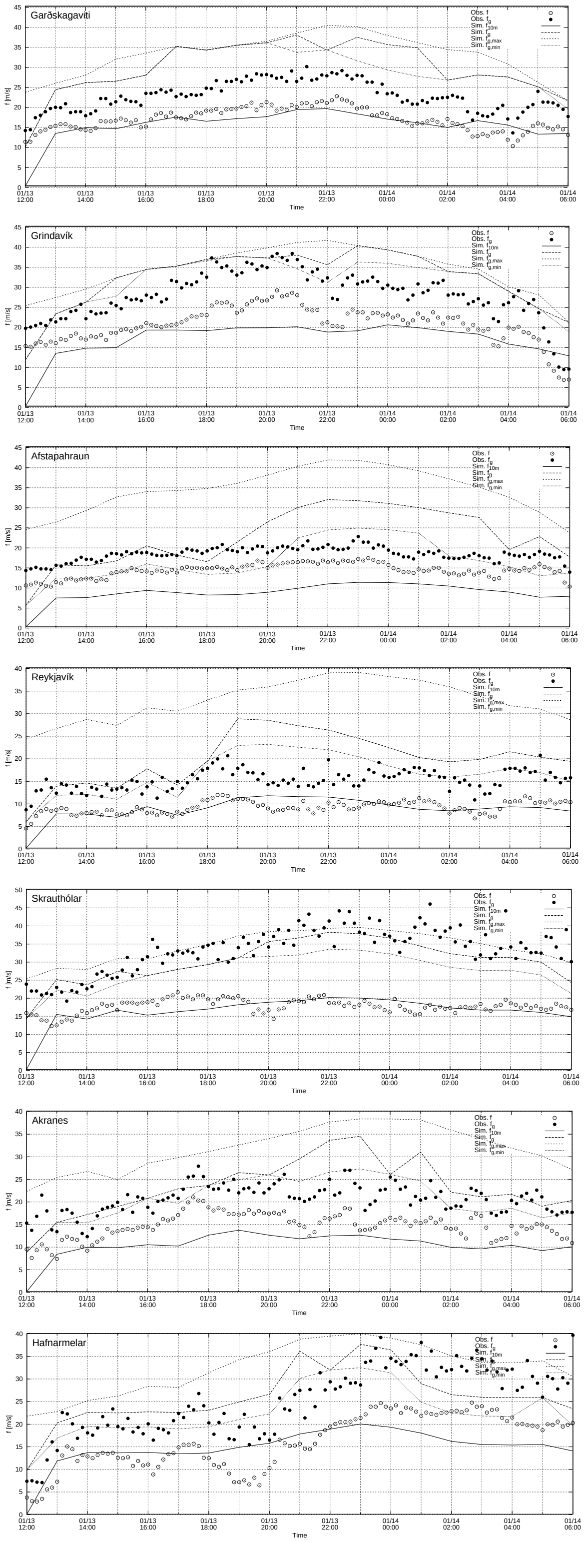

Figure 3: Observed and simulated surface winds and gusts at selected stations.

the simulated gusts (Fig. 3) when the storm is strongest. Somewhat similar results are seen at Garðskagaviti, and

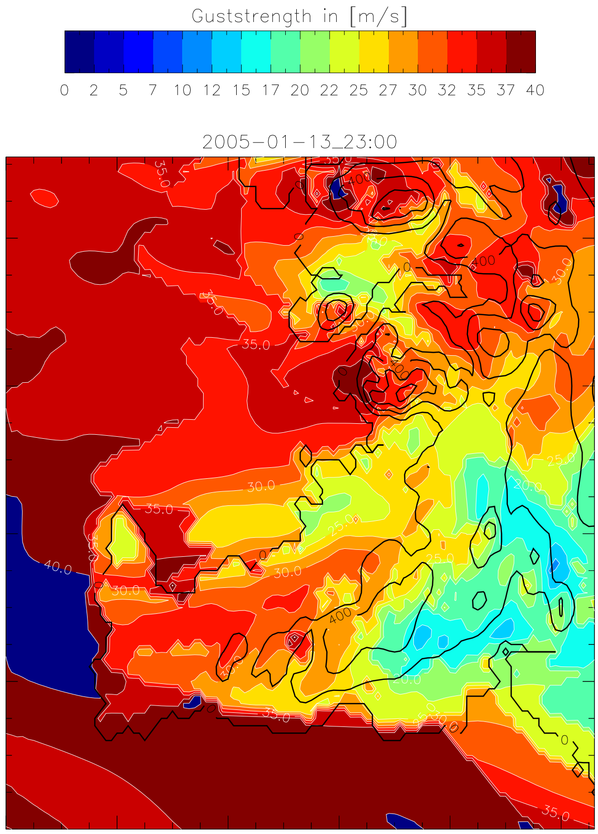

Figure 4: Simulated gust strength in Southwest-Iceland at 23 UTC on 13 January 2005. Also shown is the topography of Iceland [m]. Note that the scale saturates at 40 m/s.

to a lesser extent at Reykjavík and Akranes, where gusts are overestimated by approx. 10 m/s.

Although the maximum gusts are underestimated by approx. 10 m/s at Skrauthólar, the gust prediction method appears to perform best at the station. The station is located under a steep mountain rising more than 700 m above the station. The station at Hafnarmelar is similarily located and also at that station the gust prediction method is found to perform reasonably well.

The method also performs reasonably at Grindavík which has only the ocean and no mountains on its upwind side.

4. CONCLUSIONS AND DISCUSSIONS

We have used the method of Brasseur to parameterize wind gusts in atmospheric simulations of flow over Iceland with the MM5 model.

As in previous studies (e.g. Goyette et al. 2003, Ágústsson 2004, Belǔsić and Klaić 2004) we find that the performance of the gust parameterization is strongly correlated with the ability of the model to correctly sim-

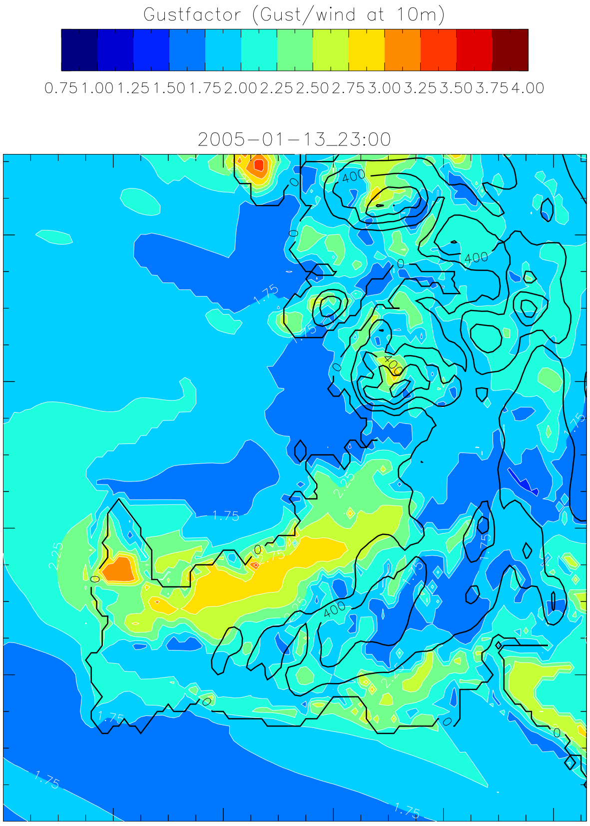

Figure 5: Gust factor (gusts/mean wind) of simulated wind in Southwest-Iceland at 23 UTC on 13 January 2005. Also shown is the topography of Iceland [m].

ulate the atmospheric fields in the boundary layer. However, although a correct estimate of the mean wind is generally necessary to reproduce the gusts acceptably, we find a systematic error in the wake of the mountains in Southwest-Iceland where the gust strength is overestimated. Upper-air observations from the station at Keflavík show strong winds at low-levels in the PBL and upwards (not shown here) in the region. The overestimated gusts therefore indicate that the method is systematically deflecting air from excessively high altitudes down to the surface, or in other words, there is presumably to strong turbulence in the model.

Work is currently under way to implement the method as part of the PBL-scheme of the atmospheric model, which will then give a continous gust-estimate during each simulation, as opposed to an estimate at individual output times. However, further testing of the method is needed, in particular with respect to the impact of the PBL scheme and, horizontal and vertical, resolution on the performance of the gust prediction.

Nevertheless, the study indicates that the gust prediction method can be used for predicting gusts in complex terrain in Iceland. This is of special interest in the context of operational weather forecasting where gust forecasts may give valueable information, for example regarding road safety and possible damage to structures in severe windstorm events.

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