WIND GUST FORECASTING IN ICELAND WITH THE METHOD OF BRASSEUR

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Abstract: Wind gusts are parameterized in a numerical weather prediction model using a new 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. In this study, the method is applied to a large collection of simulations of flow over Iceland. The simulated data is generated with the MM5 numerical model at a high horizontal resolution and using boundary conditions from the ECMWF. The performance of the method is validated by comparison with wind 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 and for locations where the mean wind speed is well simulated, the predicted wind gusts are found to be in general in acceptable agreement with the observations.

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

1. INTRODUCTION

The strongest winds are related to fluctuations in the wind speed at periods as short as a few seconds. These are known as wind gusts and are a manifestation of atmospheric turbulence. The turbulence is primarily found in the atmospheric boundary layer, where high vertical wind shear and low static stability give rise to turbulent motion. Turbulence may also be found aloft, e.g. due to Kelvin-Helmholtz dynamical instability in regions of high wind shear near upper level jets or in relation with local convective instability in regions where gravity (buyoancy) waves break. There is in fact strong evidence in the relevant literature, indicating that major gust events may be related to turbulence created aloft in connection with gravity wave activity over complex terrain. The relative strength of the gusts is frequently described by the gust factor which is the ratio of the instantaneous wind speed to the 10 minute mean. Values of 1.2–1.6 are typically observed in "normal" weather conditions at 10 metres above ground level while the ratio may easily exceed 2 in extreme weather events. Consequently, the greatest damage and danger in severe windstorms is frequently related to wind gusts.

Due to the threat of strong wind gusts, several different gust prediction methods have been devised. Brasseur (2001) has developed a new gust prediction method thad differs from most other methods as it is fully based on physical considerations, as opposed to statistical systems or similarity theory. The method has been shown to be on par with other gust forecasting systems, but also offers some important advantages. It is easily applied to results from most numerical atmospheric models and therefore well suited for operational gust forecasting. Also, as the method is fully based on physical considerations, it has the potential to improve the understanding of the relation of wind gusts with turbulence. The method has previously been applied to two severe windstorm events in complex terrain in Iceland (Ágústsson 2004) where the method was found to perform well. Similar results were found by Goyette et al. (2003), Belŭsić and Klaić (2004) in continental Europe.

In this study, the method of Brasseur (2001) is applied to a collection of simulations of atmospheric flow over Iceland. The results are compared with wind gust observations from a set of automatic observation stations spread throughout both relatively flat and mountainous terrain in Iceland.

The second section of this paper discusses shortly the methodology applied in the study, while in section 3 some of the results of the gust prediction are discussed and compared to available observational data. Section 4 is a short summary of the study and the most significant results.

2. METHODOLOGY

It is proposed (Brasseur 2001) 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 boundary layer, the deflected air parcels will be observed as a gusty wind at the surface. This idea emphasizes the importance of turbulent kinetic energy (TKE) for the creation of wind gusts, but the TKE can be obtained from a numerical model of the atmosphere. 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. 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. The upper bound, $f_{g,max}$, is taken as the maximum wind speed in the PBL. As turbulence is generally weak outside the boundary layer, air parcels originating there are not expected to be able to reach the surface of the earth. 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 gust prediction method is applied to atmospheric data created with the MM5 numerical model (Grell et al. 1995). The model is run at a high resolution, 9 km or greater in the horizontal and 40 vertical levels. A large number of simulations have been performed, representing very different atmospheric conditions over Iceland. A major part of the data is created as a part of the HRAS-project (High Resolution Atmospheric Simulations) which is used in operational weather forecasting in Iceland. Boundaries of the atmospheric model are forced with data from the ECMWF. In the study, the gust prediction method is applied to the numerical data after each simulation. The method has been coded using the MM5IDL package (http://www.os.is/∼or/rev/mm5idl/) which allows for easy manipulation of large amounts of MM5-output. Work is currently under way to code 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.

The results of the gust prediction method are compared to gust observations at chosen automatic observation sites in Iceland (Fig. 1). Most of the available weather stations belong to Veðurstofa Íslands (The Icelandic

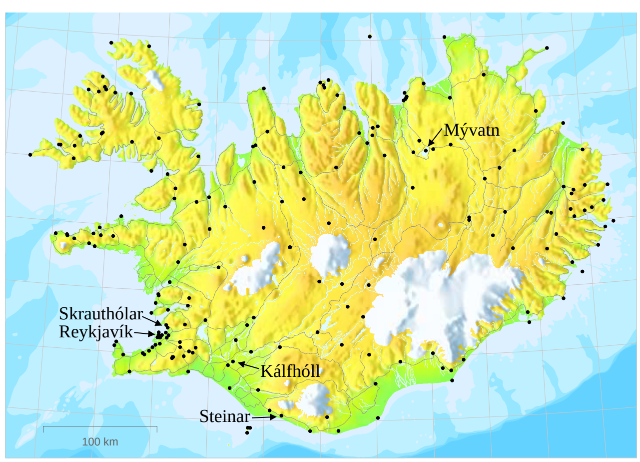

Figure 1. Topography of Iceland and locations of automatic weather stations with wind observations available. Arrows mark stations refered to in this paper.

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 no importance for the observed gust strength.

3. RESULTS

The gust prediction method has been applied to a large number of different atmospheric flows over Iceland. In this paper, we choose to show and discuss results from a recent period, i.e. 21-26 March 2005. The period has been simulated with a horizontal grid size of 3 km. Surface winds were generally weak during the period and on average near 10 m/s. Two short periods of stronger and gustier winds are however observed in the afternoon of 23 March and the night of 26 March (cf. Fig.2).

During the morning of 23 March 2005, a relatively shallow cyclone of approx. 980 hPa moved northward to a location just southwest of Iceland (not shown here). The cyclone remained at that location from 18 UTC, causing easterly and southeasterly flow over Iceland. During the afternoon, the strongest winds observed at Veðurstofa Íslands in Reykjavík were approx. 13 m/s with gusts of nearly 19 m/s. At the nearby station of Skrauthólar, the strongest mean wind was 16.7 m/s while the gusts exceeded 35 m/s (Fig. 2). Skrauthólar is located directly under a steep mountain rising more than 700 m above the stations altitude of 20 m.

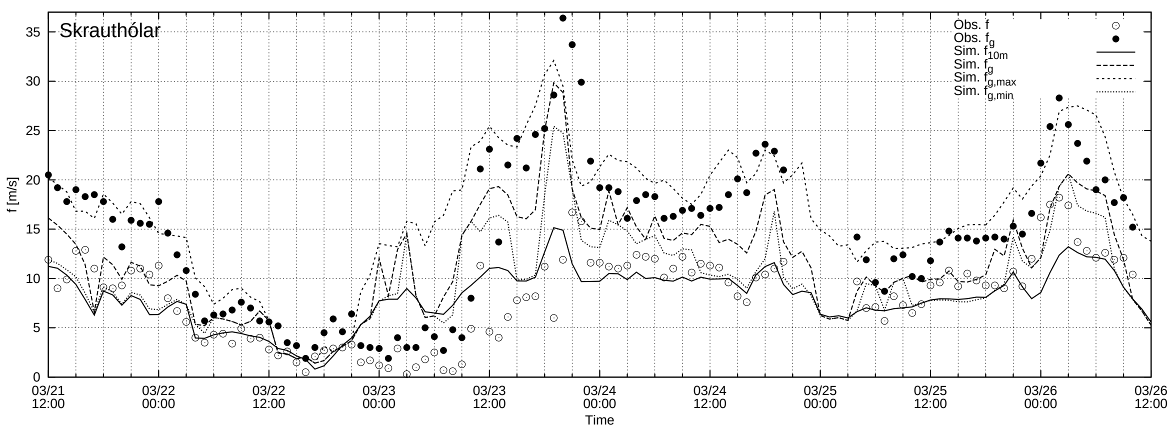

Figure 2. Timeseries at Skrauthólar of observed mean wind speed, f, and wind gusts f_g, simulated wind at 10 m, f_{10m}, gusts, f_g, and gust bounds, $f_{g,min}$ and $f_{g,max}$.

The atmospheric model captures well the mean wind at Skrauthólar during the whole storm, although there is an error in excess of 5 m/s when very weak winds are observed during the night of 23 March (Fig. 2). The performance of the model is similar at nearby Reykjavík (not shown here). Wind gusts are also in general well predicted throughout the period and observed gusts are mostly within or very near the bounds of the predicted gusts. The maximum gust strength is slightly underestimated but the temporal behaviour of the observed gust is well captured, except during the already mentioned period of very weak surface winds. The gust prediction method is in fact not excepted to perform well for winds weaker than approx. 10 m/s (Brasseur 2001). The errors in simulated mean wind speed and predicted gust strength appear to be correlated.

Fig. 3 shows the simulated surface wind and gust strength for the whole of the simulation domain at 15 UTC on 23 March. The simulated surface wind is on average 10–15 m/s but stronger in the high mountains. The simulated wind speeds agree well with the 10.6 m/s, 18.9 m/s and 5.60 m/s mean winds observed, respectively, at the stations of Kálfhóll and Steinar in Southwest-Iceland and at Mývatn in the north (Fig. 1). The variability is on the other hand much greater in the predicted gust strength than in the wind speed. The gusts are far stronger in the southwest than in the rest of Iceland. The gusts are especially strong on and near the southern glaciers and highlands, where the predicted gusts exceed 40 m/s. This is presumably due to the interaction of the flow with the orography. Comparison with the observed gusts at Steinar (29.90 m/s), Kálfhóll (15.40 m/s) and Mývatn (7.50 m/s) indicates that the predicted gust pattern is in reasonable agreement with the observations.

4. CONCLUSIONS

Wind gusts have been parameterized in a collection of atmospheric simulations of flow over Iceland. The results of this study on the quality of the Brasseur method are consistent with previous studies, e.g. Goyette et al.

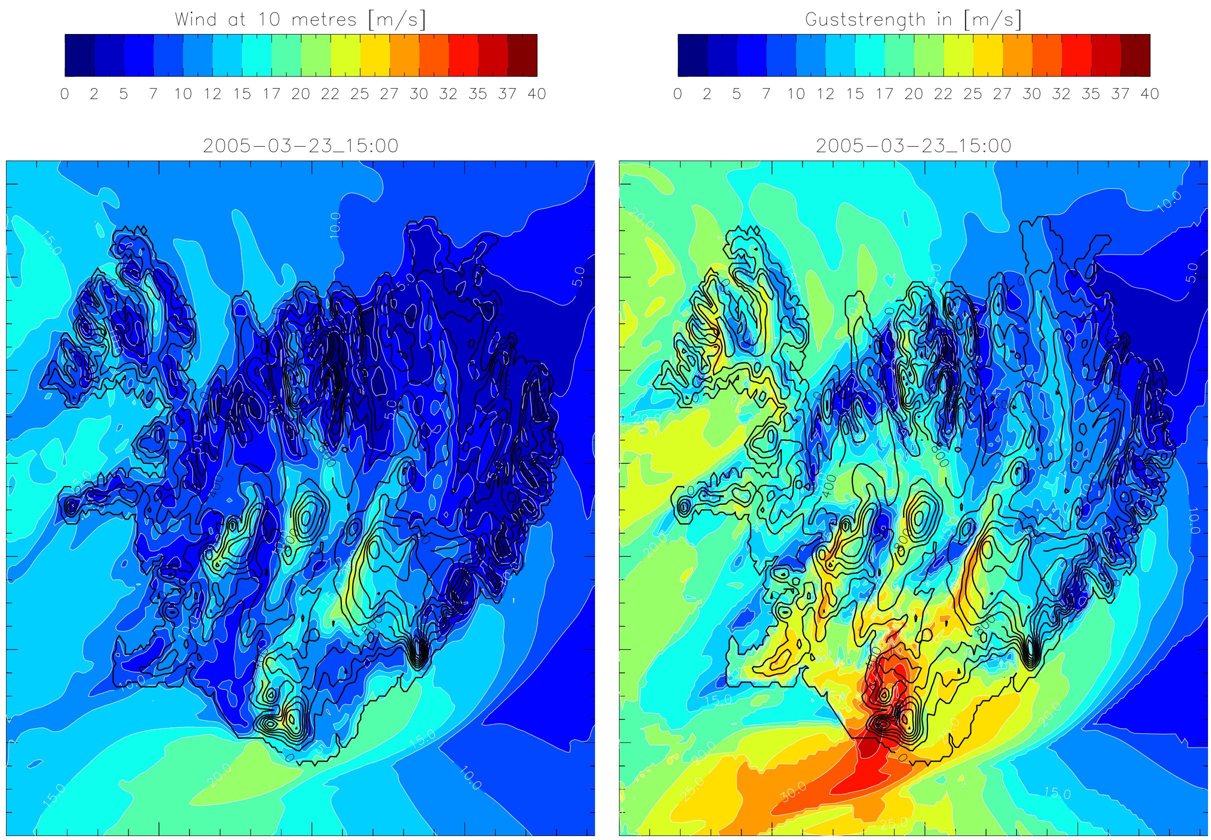

Figure 3. Simulated wind at 10 m (left) and gusts (right) at 15 UTC on 23 March 2005. Also shown is the topography of Iceland [m].

(2003), Ágústsson (2004), Belůsić and Klaić (2004). The performance of the gust parameterization is strongly correlated with the ability of the model to correctly simulate the atmospheric fields in the boundary layer. Where the mean surface wind is correctly captured, the predicted gusts are generally also in reasonable agreement with the observations.

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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