FORECASTING WIND GUSTS IN COMPLEX TERRAIN

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Abstract: Wind gusts are calculated in a large collection of simulated atmospheric flows in complex terrain in Iceland. The gust method is based on a comparison of atmosperic stability and turbulent kinetic energy in the planetary boundary layer. The atmospheric data is a part of realtime numerical simulations used in forecasting in Iceland and is generated with the MM5 model at a horizontal resolution of 9 and 3 km, and in some cases 1 km. Initial and boundary conditions are 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 calculated gust strength is compared with wind gust observations from numerous automatic weather stations. The estimated gusts are strongly dependent on the quality of the simulated flow and are on average well captured when the mean winds are correctly simulated. Maximum gusts in downslope windstorms are however frequently underestimated. The error is presumably related to an inadequate simulation of the downstream surface winds which are also strongly underestimated in the windstorms. The method has previously been found to perform well in a corner wind, while here, wind gusts are successully reproduced upstream of mountains as well as in the mountains.

Keywords - *Gust forecasting, windstorms, complex terrain, Iceland*

1. INTRODUCTION

The greatest winds 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 may easily exceed twice the mean wind speed in extreme weather events. The gusts are a manifestation of atmospheric turbulence which is primarily found in the atmospheric boundary layer (BL), but may also be found aloft, e.g. near upper level jets where it may be a danger to aviation. The turbulent motion is driven by high vertical wind shear and/or low static stability. Of importance for this study is the turbulence created in atmospheric flow in and above complex terrain. There is in fact strong evidence in the relevant literature, indicating that major gust events may be related to turbulence aloft, created by local convective instability in regions where gravity (buyoancy) waves break.

The strong gusts are one of the main causes of damage to structures and vegetation in extreme weather events. Several different systems to predict gusts have therefore been devised. Some are based on statistical methods, e.g. using empirical gust factors or an inspection of the vertical wind and stability profiles. Other methods are based on the parameterization of turbulence in numerical weather prediction models, such as the method of Brasseur (2001) which is employed here. The method is fully based on physical considerations and has been proven successful, both in studies in continental Europe as in Belŭsić and Klaić (2004) as well as during windstorms in Iceland (e.g. Ólafsson and Ágústsson 2007).

Wind gusts have been predicted in a large collection of simulations of atmospheric flow over Iceland. Here we focus on predicted gusts during a chosen period in a region in West-Iceland. Wind gust observations from numerous automatic weather stations in complex terrain, are compared with the predicted gusts. The next section discusses the methodology applied in the study, while in section 3 some the results of the gust prediction are discussed and compared to the available observational data. Section 4 summarized the most significant results.

2. METHODOLOGY

Brasseur (2001) proposes that strong surface gusts may be created by turbulent eddies that deflect air parcels flowing aloft in the boundary layer down to the surface (Fig. 1). Due to the general increase of wind speed with height and the short time span surface friction acts to decelerate the air parcels, they will be observed as a gusty wind at the surface. Here, the turbulent kinetic energy (TKE) is of primary importance for the creation of wind gusts and may be obtained from

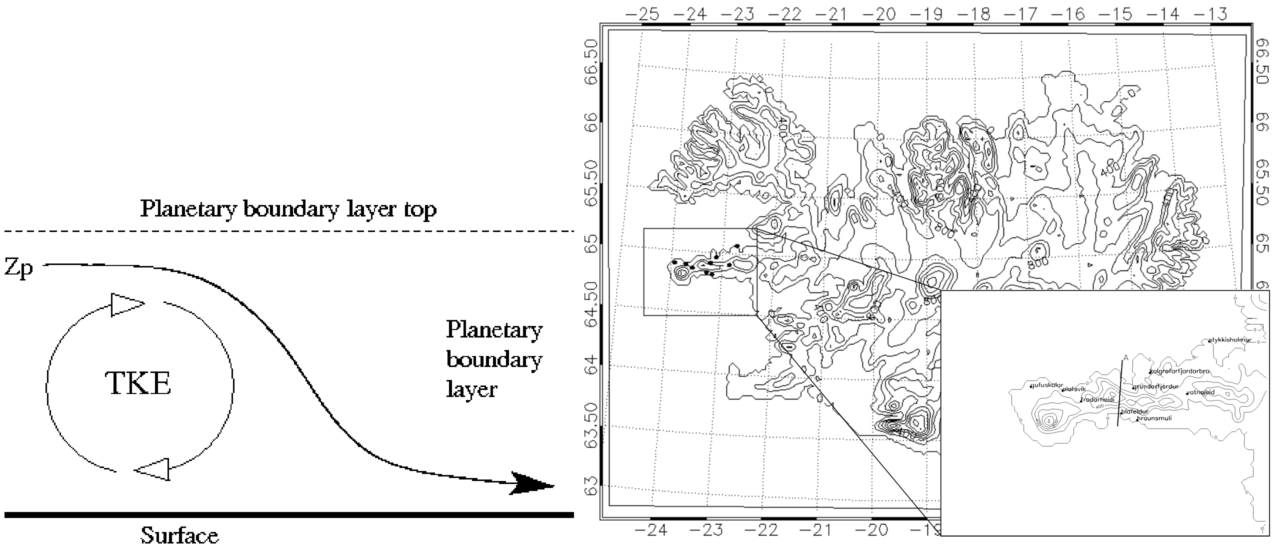

Figure 1. Left: The predicted gusts are created by turbulent eddies that deflect air from aloft to the surface. Right: The numerical domains with a horizontal resolution of 3 and 1 km as well as locations of chosen weather stations in the Snæfellsnes peninsula.

numerical models. In stable boundary layers, the atmospheric stability (buoyancy forces) oppose the vertical deflection of air parcels, while in unstable layers it enhances the turbulence. The method is mathematically expressed as

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

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 but since turbulence is generally weak above the boundary layer, air parcels originating there are not expected to be able to reach the surface of the earth.

In addition to the estimated gust strength, the method gives a bounding interval for the estimated gusts. The upper bound, $f_{g,max}$, is taken as the maximum wind speed in the PBL. The lower bound, $f_{g,min}$ is found by using the vertical component of the local turbulence, as opposed to the mean TKE in the left hand side of (1). An in depth explanation of the method is given by Brasseur (2001).

The wind gusts are predicted in atmospheric data which is a part of realtime numerical simulations used in forecasting in Iceland, e.g. at the Icelandic Meteorological Office. The data includes a large number of different flow regimes and here we choose to present results for a period of approx. 1 month, starting on 14 February 2007, from the Snæfellsnes peninsula in West-Iceland. The data is generated with the MM5 model (Grell et al. 1994), with 40 levels in the vertical and a horizontal resolution of 9 and 3 km, and in some cases 1 km (Fig. 1). The high resolution is necessary to reproduce the flow in complex terrain, e.g. gravity wave activity and mechanically induced turbulence where the flow interacts with the topography. Initial and boundary conditions are 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 (http://www.os.is/∼or/rev/mm5idl/).

The calculated gust strength is compared with wind gust observations from numerous automatic weather stations in complex terrain in Iceland (see Fig. 1 for station locations). The weather stations belong to Veðurstofa Íslands (The Icelandic Meteorological Office) and Vegagerðin (The Public Roads Authority). Observations include the 10 minute mean wind and 3 second maximum wind gusts. The wind is observed at either 10 m or approx. 7 m above the ground. The difference in observation heights is expected to be irrelevant due to the non-local nature of the wind gusts.

3. RESULTS

The period from approx. 14 February to 14 March 2007 is characterized by several northerly windstorms in the Snæfellsnes peninsula, with observed mean winds exceeding 30 m/s and gusts as great as 50 m/s. In between the windstorms are periods of far weaker winds which are often south- or easterly. The data presented in Fig. 2 includes observations from the Bláfeldur automatic station on the southern side of the Snæfellsnes peninsula and predicted gusts at the 21 and 24 hour forecast time. The horizontal grid of the numerical domain is of 3 km. It is apparent that on average, the predicted gusts

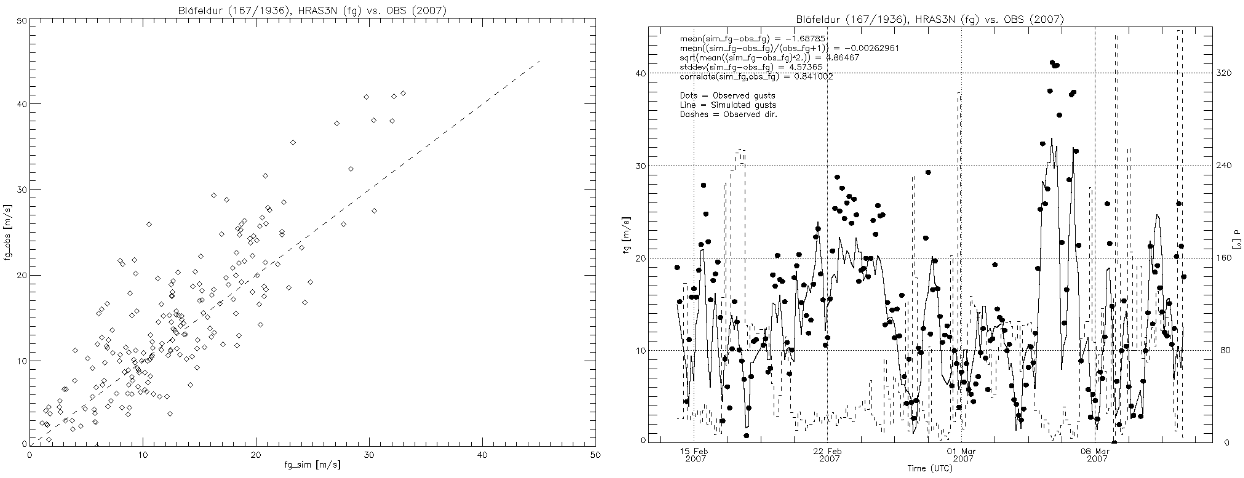

Figure 2. Observed and simulated wind gusts f_g, in a 3 km grid, at the Bláfeldur station from 14 February to 14 March 2007.

correlate well with the observed gusts at Bláfeldur and the temporal behaviour is well captured. The greatest errors are in northerly winds, when the flow is nearly perpendicular to the peninsula and has to pass over it. At these time, the winds are on average strong and gusty. The strongest winds are observed on 5–6 March, during severe northerly windstorms, when an accurate gust estimate is in fact most important. Somewhat similar results are seen at other stations in the peninsula, although the northerly windstorms and the associated errors are far less prominent in stations located on the northern side of the peninsula.

On the evening of 5 March, a surface low was located southeast of Iceland, with the centre near the Faroe Islands. There was a high over Greenland and relatively high pressure gradients over western Iceland and the Denmark strait, causing the strong northeasterly winds. Fig. 3 shows the predicted gust strength in the Snæfellsnes peninsula at 22 UTC on the evening of 5 March. The horizontal resolution is 1 km. The predicted gusts are strongest, as expected, everywhere on the southern side of the peninsula with a maximum near the locations of Bláfeldur and Hraunsmúli. Much weaker winds and gusts are predicted in the upstream decelerated flow. The surface winds are on average reasonably simulated on the northern side, e.g. at Stykkishólmur, Kolgrafarfjarðarbrú and Grundarfjörður (Tab. 1). The observed gusts are mostly within or very near the bounds of the predicted gusts and the temporal behaviour of the observed gusts is well captured. However, the atmospheric model only manages to capture the mean winds correctly on the southern side during the lull in the storm between 5 and 6 March. During the maximum of the windstorms, the mean winds are greatly underestimated at several stations, e.g. at the downstream stations of Bláfeldur and Hraunsmúli, while there are however stations where the performance is much better, e.g. at the Vatnaleið station in the centre of the eastern part of the peninsula (Tab. 1). The observed gusts are greatly underestimated during the storms, which is as expected since the gust prediction method is strongly dependent on the simulated mean winds which are strongly underestimated.

Table 1: Observed and simulated (with a horizontal resolution of 1 km) mean winds and gusts [m/s] at chosen stations at 22 UTC on 5 March 2007.

Station	$f_{10,obs}$	$f_{10,sim}$	$f_{g,obs}$	$f_{g,sim}$
Grundarfjörður	13.2	8.8	21.5	27.2
Kolgrafarfjarðarbrú	15.9	16.3	25.8	24.8
Stykkishólmur	10.2	12.9	18.7	20.7
Bláfeldur	32.1	19.6	40.8	34.1
Hraunsmúli	29.2	17.9	49.5	30.8
Vatnaleið	16.9	12.1	28.8	24.2

A more in depth study of the windstorms on 5 and 6 March reveals breaking waves above the Snæfellsnes peninsula during the northerly windstorms (Fig. 3). The conditions for wave breaking are favourable, strong winds at mountain top level and a reverse wind shear with a minimum in wind speed above 500 hPa. There is a large concentration of TKE in the region of the breaking waves and accelerated flow below the breaking waves and above the leeside slopes of the peninsula, presumably causing the observed downslope windstorms, e.g. at the Bláfeldur and Hraunsmúli stations.

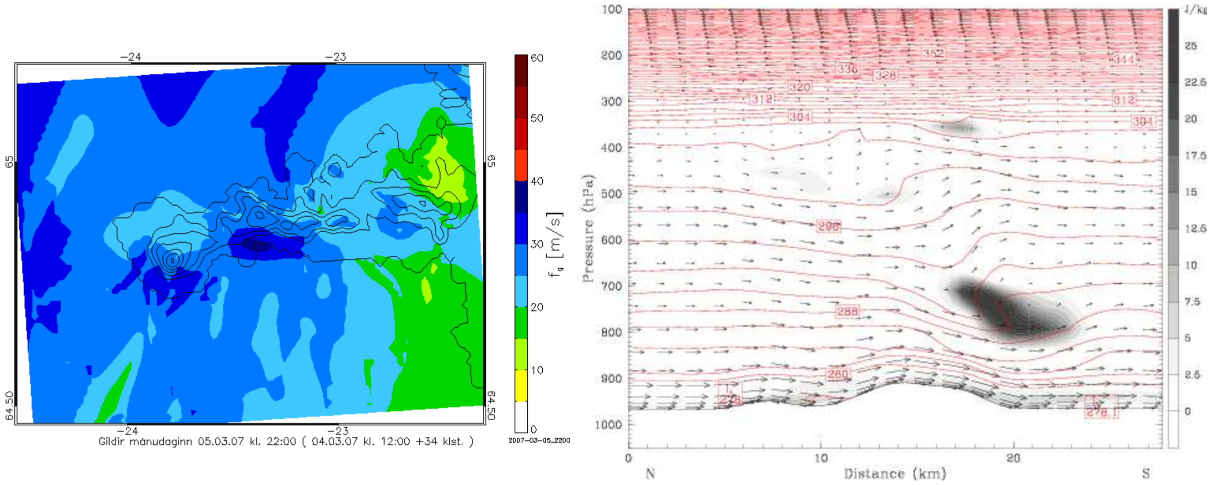

Figure 3. Left: Simulated wind gusts f_g on the Snæfellsnes peninsula. Right: Section A (see location in Fig. 1) from north to south across the Snæfellsnes peninsula. Shown are isolines of potential temperature, wind speed vectors and turbulent kinetic energy. Both panels are valid at 22 UTC on 5 March 2007 with a horizontal resolution of 1 km.

4. CONCLUSIONS

Wind gusts have been parameterized in a collection of atmospheric simulations of flow over Iceland. Here we discuss the predicted gusts during a period of one month, which includes severe windstorms, in the Snæfellsnes peninsula in West-Iceland.

The results of this study are consistent with previous studies on the use of the gust prediction method, e.g. Ólafsson and Ágústsson (2007). The quality of the predicted gusts is strongly correlated with the ability of the model to correctly simulate the mean surface winds. Where the mean surface winds are correctly captured, the predicted gusts are on average in reasonable agreement with the observations. The greatest errors in the gust prediction include the underestimation of the predicted gusts during severe downslope windstorms. This is presumably to related to the inadequate simulation of the downstream surface winds by the atmospheric model and the BL scheme. We feel that further tests with different BL schemes and atmospheric models, e.g. the WRF-model, are needed. Furthermore, observations of the key atmospheric fields in the BL, including the turbulence, would be invaluable.

However, the results are of the study indicate that gusts can be successfully predicted in the 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 during severe windstorms.

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