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Parametrization of convective gusts

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Gusts are defined as wind extremes and constitute an important forecast parameter in particular for air, ship and road traffic guidance, and warnings concerning environmental damage. The latter is related to the force the wind exerts on an obstacle which is proportional to the square of the wind speed. Therefore it is not only necessary to know the mean wind speed, in general the near-surface 10-metre wind speed is used as the relevant quantity, but also the wind extremes.

Until recently the gust formulation has been based on an assessment of the turbulent gustiness in the boundary layer. However, this takes no account of gustiness associated with convective situations. A new formulation has been developed which overcomes this limitation.

Representation of gusts

Practically, gusts are defined as extreme winds observed by anemometer. A 3-second running average is applied to the data. The reporting practice is such that gusts are reported as extremes over the preceding 3 or 6 hours. Until IFS cycle 33r1 (Cy33r1) the ECMWF model wind gusts have been parametrized as the sum of the instantaneous 10-metre wind speed and a turbulent gustiness depending on the static stability of the boundary layer:

$$U_{10\ \mathrm{gust}} = U_{10} + 7.71 u_*[1 + f(z/L)]$$

where u_* is the friction velocity, itself a function of the 10-metre wind speed, z is the height, and L is the Monin-Obukhov length-scale. This is an empirical relation based on observed turbulence spectra. Post-processing is applied to the model data in accordance with the reporting practice.

This formulation has proven quite successful when compared to standard SYNOP, METAR and Buoy reports. However, it cannot represent gusts that are generated in deep convective situations either through organized downdraughts in a sheared environment or evaporatively driven downdraughts. Following reports from Deutsche Wetterdienst (DWD) and other meteorological centres about the underestimation of wind gusts over land, the introduction of a convective contribution to the wind gusts was put forward for implementation in Cy35r1 (30 September 2008). Indeed, this seemed feasible as since Cy32r3 (7 November 2007) the model deep convection has a reasonably smooth spatial structure and a decent diurnal cycle in the extra-tropics.

The convective gusts are simply estimated as proportional to the low-level wind shear:

$$\mathrm{U}_{10\ \mathrm{gust,\,conv}} = \alpha \max\,(0, \mathrm{U}_{850} - \mathrm{U}_{950})$$

with $\alpha = 0.6$ a tunable 'mixing' parameter and $\mathrm{U}_{850} - \mathrm{U}_{950}$ the difference between the 850 hPa and 950 hPa wind speeds, representing the low-level wind shear. The total gustiness is simply given as the sum of the turbulent gustiness and the convective gustiness, the latter being only computed in regions where deep convection is active as identified by the model's convection scheme. This formulation is close to the forecasters' practice which is to estimate in extreme conditions the near-surface gusts from the 850 hPa wind speed. It also has the advantage that its contribution is only significant in situations with strong wind shear as, for example, in frontal systems and long-lived organized mesoscale convective systems. We also experimented with other parametrizations of convective gusts (depending, for example, on the downdraught vertical velocity close to the surface to represent outflow gustiness in squall-lines), but the spatial structure and amplitude produced by these formulations were unsatisfactory.

A summer and wintertime case

The impact of the convective gust parametrization is best illustrated by case studies such as that illustrated in Figure 1. Figure 1a shows the infrared satellite signature of an intense synoptic system at 18 UTC on 22 February 2008 over the Baltic Sea that produced heavy gusts of up to 35 m s^{-1} between 18 and 21 UTC within a narrow cold frontal band over Denmark, North Germany and the Baltic coast as assessed from available SYNOP and METAR reports (Figure 1b). This case was brought to our attention by the Deutsche Wetterdienst as the operational 21-hour gust forecast (Figure 1c) generally reproduced the observations but underestimated by up to 10 m s^{-1} the maxima over land close to the Baltic coast and over Denmark.

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However, Figure 1d shows that the diagnostic convective gust parametrization is able to produce additional gustiness of around 5–8 m s^{-1} in the desired regions, namely mainly over land along the frontal system, and to the rear of the cyclone over sea.

In Figure 2 a recent case of continental summertime convection is illustrated. Football fans might still remember this day as it was actually this convective event that led to the interruption of the transmission of the Euro 2008 match on 25 June between Turkey and Germany because of thunderstorms in Vienna. The satellite image for 12 UTC on 25 June (Figure 2a) indicates an extended mesoscale convective system over Central Europe and deep convection over parts of Russia. Observations for Central Europe (Figure 2b) reveal wind gusts of 20–25 m s^{-1} between 12 and 15 UTC in the vicinity of the convective system. The operational forecast from 00 UTC on 25 June (Figure 2c) was able to produce maximum winds approximately in the right location, but underestimated the maxima by about 5–10 m s^{-1}. The convective gust parametrization (Figure 2d) is able to locally increase wind speeds by roughly 4 m s^{-1} in the convective areas.

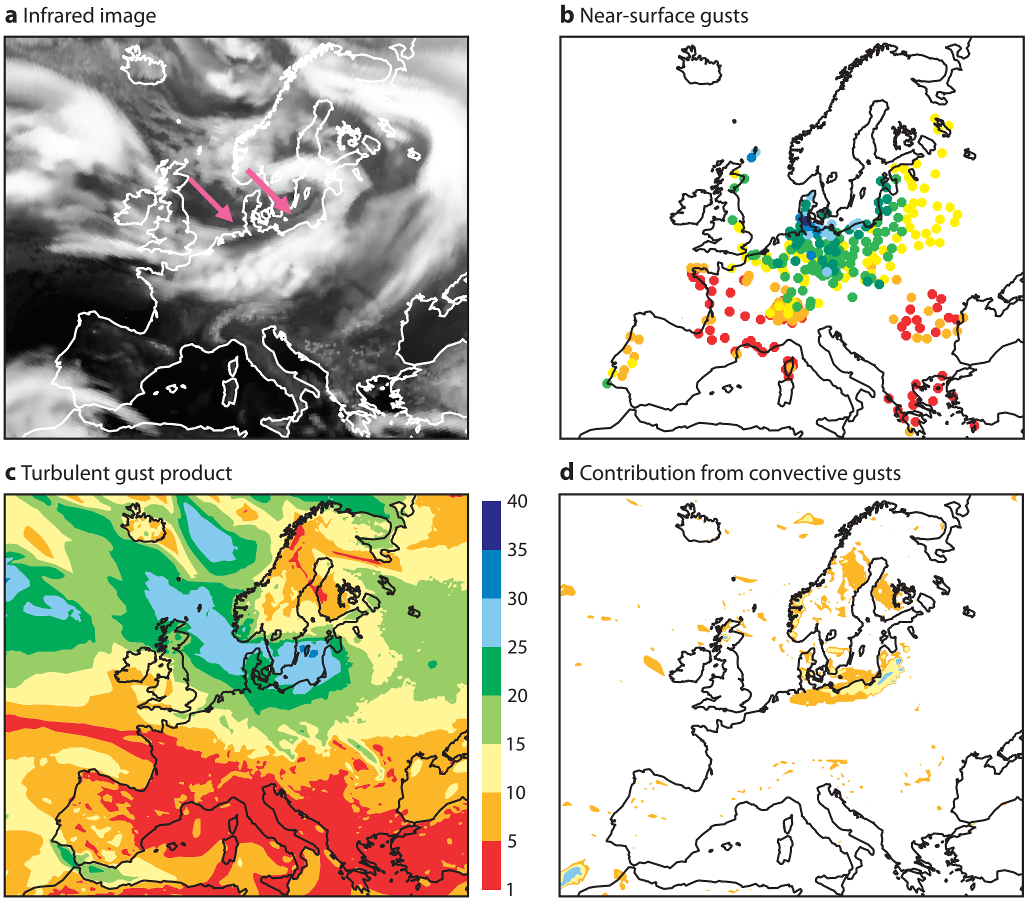

Figure 1 (a) ECMWF forecast infrared satellite image for 18 UTC on 22 February 2008 with the gust front marked by the arrows, (b) near-surface wind gusts (m s^{-1}) for 21 UTC on 22 February 2008 from SYNOP and METAR reports, (c) 21-hour operational forecast with Cy33r1 using the 'turbulent' gust product, and (d) the additional contribution from the convective gusts. A different colour scale is used in (d) compared to (b) and (c). Note that the reporting practice, including the minimum wind speed to be considered as a gust, varies widely between countries.

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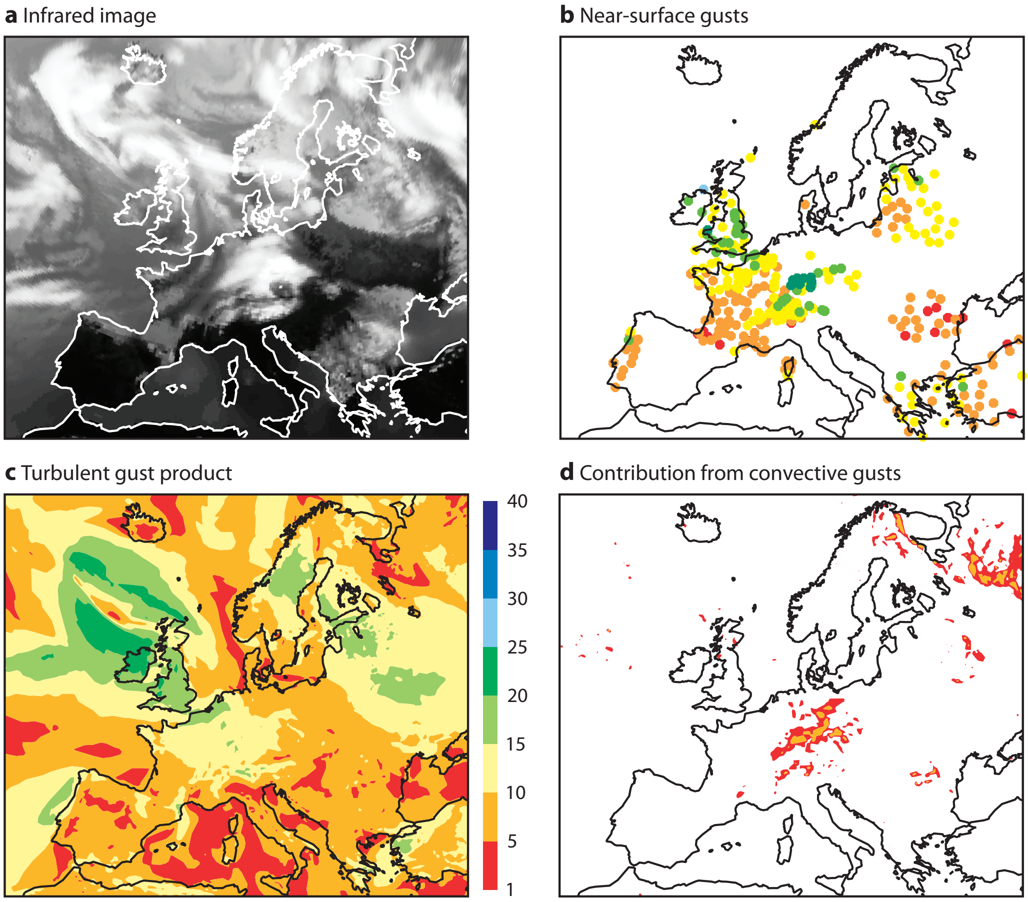

Figure 2 Same as Figure 1, but with the satellite image for 12 UTC on 25 June 2008, and the gusts observed and modelled between 12 and 15 UTC.

Time evolution

The north of the Iberian peninsula and the south of France were hit by an intense cyclone on 24 January 2009, during which record wind speeds of 191 km h^{-1} (~53 m s^{-1}, Galicia) and 184 km h^{-1} (~51 m s^{-1}, Perpignan) have been registered. We were lucky to obtain half-hourly observations of mean winds and gusts from our colleagues Jean-Luc Attié and Pierre Durand from Laboratoire d'Aérologie/Université Paul Sabatier Toulouse who maintain a meteorological station on the roof of a building: (http://ufrpca-phy.ups-tlse.fr/meteo/).

The wind measurements where derived from 35 kHz sonic anemometer data, with the anemometer being at an absolute height of around 25 metres above ground.

In Figure 3 we compare the observed evolution of the mean wind and wind gusts for 24 January 2009 to the 3-hourly model output for the instantaneous wind, and the model wind gusts from the operational deterministic forecast from 12 UTC on 23 January 2009 using Cy35r1. There is a very good agreement between the forecast and the observations both in terms of time evolution and magnitude of the mean wind speeds and gustiness, with the observed gusts attaining speeds of 100–144 km h^{-1} (~28–40 m s^{-1}) between 06 and 18 UTC, whereas the model gusts attain speeds of around 120 km h^{-1} (~33 m s^{-1}). Note that the mean wind speed is considerably lower than the gusts during that period with values of around 45 km h^{-1} (~12 m s^{-1}) in the observations and 50 km h^{-1} (~14 m s^{-1}) in the model. We have also displayed the convective contribution to the forecast gusts. The convective contribution is moderate but significant before the onset of the main storm, and overall leads to a better fit to the observations.

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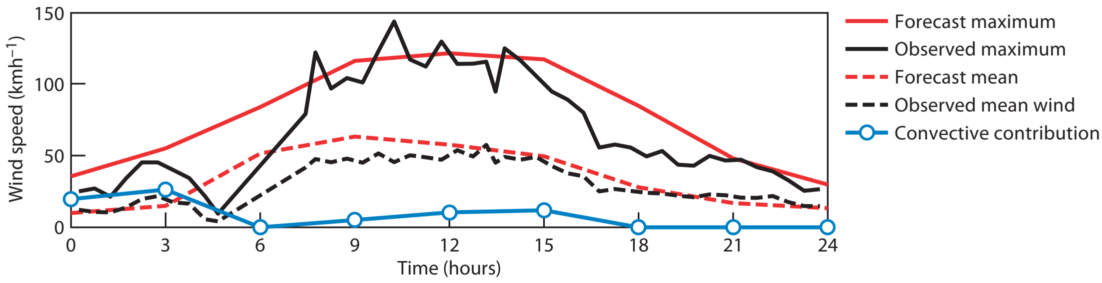

Figure 3 Observed mean wind speed (dashed black line) and maximum wind speed (solid black line) for 24 January 2009 at a meteorological station at Toulouse University, France at 43.82°N/1.2°E (courtesy Jean-Luc Attié and Pierre Durand), together with corresponding 3-hourly forecast values (red lines) from the operational deterministic forecast from 12 UTC on 23 January. The blue line denotes the convective contribution to the gusts.

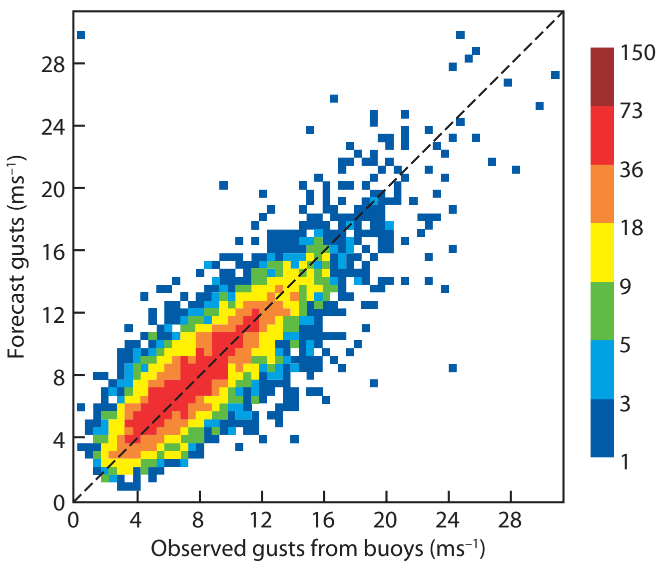

Figure 4 Scatter diagram of 24-hour forecast wind gusts (m s^{-1}) over sea obtained from pre-operational test runs with Cy35r1 versus buoy observations for the period July to August 2008. Colours denote data entries in each bin; the total number of observations is 8251.

Concluding remarks

The very simple convective addition to the model gusts is able to enhance the gustiness in convective frontal situations and when mesoscale organized convection with shear is present. This is desirable over land where use of only the turbulent gust formulation prior to Cy35r1 probably underestimates the extremes. We think it is important to represent an estimation of these extremes if possible, as these extremes produce the most (or all) damage. The danger of such a parametrization is, however, that it might introduce a bias in the representation of gusts. This is, however, not the case as is shown in Figure 4, where the new model wind gusts (turbulent + convective) from 24-hour forecasts with Cy35r1 have been evaluated against all available buoy observations for the period July to August 2008. The rms error is just below 2 m s^{-1} and is therefore slightly better than for the previous gust product (turbulent gust only), in spite of a bias that is slightly increased from near zero in the previous product to a value of 0.05 m s^{-1}. Remaining errors in the ECMWF gust product, such as errors in the diurnal cycle or specific errors over land, are likely due to forecast errors in the mean 10-metre wind.

The convective contribution was added to the wind gusts in post-processing with the implementation of Cy35r1 on 30 September 2008.

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