Improved Diagnosis of Convective and Turbulent Gusts: Test Results of new Gust Parameterizations (Interim Report on Work Package 3.10.2.)

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1 Introduction

In the former operational version of LM, gusts were diagnosed by increasing the wind in the lowest model layer depending on stability. In general forecasters complained about seriously underestimated gusts in convective situations and overestimated gusts in non-convective situations. In a first attempt to improve the gust parameterisation, convective gusts were considered in addition to the operational gust determination. The kinetic energy of convective downdrafts was computed depending on the vertical integral of their negative buoyancy. The square root of kinetic energy, multiplied by a tuning parameter to account for the horizontal distribution of the downward directed kinetic energy, was considered to be the convective gust. The results were not completely satisfactory as convective gusts still seemed to be underestimated. In a new approach described here, the water loading effect was included in the parameterisation of convective gusts. Additionally, a parameterisation of gusts after Brasseur (2001) was introduced to improve the results in non-convective situations.

2 Theory

In the following the parameterisations of convective and turbulent gusts are shortly described.

Convective gusts

The parameterisation of convective gusts is based on Nakamura et al. (1996), who proposed to use the downdraft kinetic energy produced by the negative buoyancy and the direct transport of momentum from higher layers to the surface:

$$V_{gust,con0} = \sqrt{\alpha \int_0^H 2g \left(\frac{\Delta\theta}{\theta} + \gamma q_r \right) dz + \beta V(H)^2}\ , \tag{1}$$

where H is the height of the downdraft generation, $\Delta\theta$ is the difference of the potential temperatures of downdraft and environment, and q_r is the mixing ratio of precipitation. The factor α accounts for the distribution of kinetic energy to different directions.

First operational tests showed significant problems with the direct momentum transport term. In cases of rather light but penetrative convection connected to the polar front, this term is able to transport momentum from the layer of the jet-stream down to the surface, producing unrealistically high gusts. Therefore the last term in (1) is neglected in the following ($\beta = 0$). Operationally also the effect of water loading is neglected ($\gamma = 0$) and we use $\alpha = 0.2$. This configuration is used in the reference simulations. In the test simulations we increase the tuning parameter for the horizontal distribution of kinetic energy to $\alpha = 1/\pi$ and we include the water loading effect by $\gamma = 1$.

An additional problem of the parameterisation of convective gusts is the case of small or even vanishing (due to evaporation below cloud base) convective precipitation. Although also in reality convective gusts may occur without convective precipitation, this situation seemed to be overpredicted both with respect to the frequency of occurence and with respect to the windspeed of the gusts. Therefore, the gusts parameterised by (1) with the parameters as given above are suppressed, if the convective precipitation rate at the surface falls below $0.015\,mm/h$. This threshold value is chosen in accordance with the interpretation of model results, where showers or thunderstorms are diagnosed only if this value is exceeded. Therefore, the final convective gust in the test simulation is determined by

$$\begin{array}{lcll} V_{gust,con} = & V_{gust,con0} & \text{if} & rr_{con} > 0.015 mm/h \\ V_{gust,con} = & 0.0 & \text{if} & rr_{con} \leq 0.015 mm/h \quad , \end{array} \tag{2}$$

where rr_{con} is the convective precipitation rate. This reduction in case of low convective precipitation is not used in the reference experiment, here $V_{gust,con} = V_{gust,con0}$.

Turbulent gusts

The present operational method for the determination of turbulent gusts relies on the windspeed in the lowest model level and a stability dependent increase of the wind speed:

$$V_{gust,turb} = |V_{ke}| + 7.2 \cdot u_* \quad , \tag{3}$$

where V_{ke} is the wind speed in the lowest model level, and u_* is the friction velocity.

The formulation (3) makes the gust determination dependent on the height of the lowest model level. Additionally, the formulation is not really physically based but rather a product of a limited amount of tuning. Therefore it seemed to be appropriate to change to the method proposed by Brasseur (2001). He based his approach on the consideration of turbulent and buoyant energies. Brasseur's (2001) basic assumption is that turbulent motions are able to transport momentum downward from a height z_p to the surface as long as the energy of large turbulent eddies averaged from the surface to the height z_p is larger than the buoyant energy between the surface and z_p:

$$\frac{1}{z_p} \int_0^{z_p} 0.5\; q^2(z) dz \geq \int_0^{z_p} g \frac{\Delta\theta_v(z)}{\theta_v(z)} dz \tag{4}$$

Here $0.5\; q^2$ is the turbulent kinetic energy (in J/kg), $\Delta\theta_v$ is the difference of the virtual potential temperatures between the environment and a rising parcel. The integration starts from the surface, which is assumed at $z = 0$, and is continued as long as the inequation holds. Then the largest value of the grid-scale momentum $V(z)$ between $z = 0$ and $z = z_p$ is assumed to be the maximum gust at the surface:

$$V_{gust,turb0} = Max[V(z), z = 0...z_p] \tag{5}$$

Clearly, this approach is more or less independent of the layer structure of the model. But tests revealed that situations exist with significantly too low diagnosed gusts using this method. To overcome this problem, a contribution of the turbulent kinetic energy at the surface $E_{z=0}$ is added to yield the final value of the turbulent gust:

$$V_{gust,turb} = \sqrt{V^2_{gust,turb0} + 0.5 q^2_{z=0}} \tag{6}$$

In convective situations this parameterisation might experience the same problems as were noted in the first attempt to parameterise convective gusts ($\beta \neq 0$, see above). In such

	turbulent	**convective**	
reference run	eq. (3)	eq. (1)	$\alpha = 0.2$ $\beta = 0.0$ $\gamma = 0.0$
experiment	eqs. (4)-(6)	eqs. (1),(2)	$\alpha = 1/\pi$ $\beta = 0.0$ $\gamma = 1.0$

Table 1: Setup of operational and modified runs

situations the difference in virtual temperature might become negative over a large height interval, making the inequation being valid up to very large heights. Therefore, this parameterisation is strictly confined to turbulent gusts of the lower troposphere by defining an upper limit for the integration: $z_{p,max} = 2000m$. Tests in non convective situations with an increased value of this limit (4000 m) did not show any change in the resulting gusts.

Equations and parameters used in the reference runs and in the experiments

Table 1 compiles the equations and parameters used for the reference runs and for the experiments.

3 Single test cases

Predominantly convective situations

In the following examples it would be somewhat difficult to see the effect of the convective gusts, because normally also turbulent gusts play a role. Therefore, additional runs have been made with the turbulent gusts switched off, in order to see the changes in the convective gusts more clearly. The respective results are shown here.

July 10, 2002

One of the most important test cases for convective gusts is the Berlin storm of 10 July 2002, where in the late afternoon and in the evening a cold front and a prefrontal mesoscale convective complex (MCC) caused violent gusts of up to 42 m/s in Berlin and in the surrounding area (Gatzen, 2004). Gusts of this force were not predicted by the operational models. A convergence line, which in reality was transformed into the MCC, was simulated far to the east of the cold front. There was no convective rain predicted at the convergence line, but moderate gusts were diagnosed here. The cold front and the associated convective rain were simulated rather well, but also only moderate gusts were diagnosed here. This was in accordance with the observations, which showed the intensity of the cold front to weaken rapidly and the MCC becoming the main feature. In fact, this situation turned out to be a very difficult task for model prediction. One reason might have been the very special synoptic situation of a derecho-development (Gatzen, 2004) in connection with the MCC. Nearly all of the most violent gusts (> 34 m/s) were observed in the region of the derecho.

From the viewpoint of gust diagnosis the most serious problem appeared to be the determination of the level of free sink. In terms of convection parameterisation here the downdrafts originate and the integration in (1) ends. The level of free sink was diagnosed at rather low altitudes in some areas of heavy convective rain in the region of the cold front. This led to much too low values of the convective gusts. This problem could not yet be solved.

The distribution of convective precipitation from 9 UTC to 12 UTC is shown in Fig. 1. The approaching cold front can be seen over northern Germany, whereas the convergence line

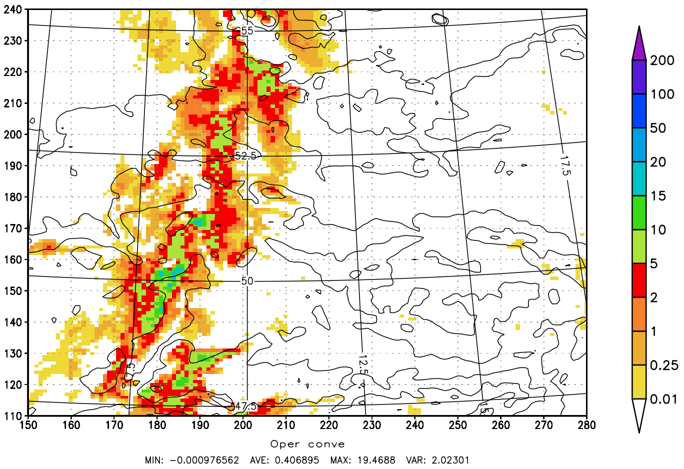

Figure 1: Distribution of convective precipitation [mm] from 09 UTC to 12 UTC on 10 July 2002

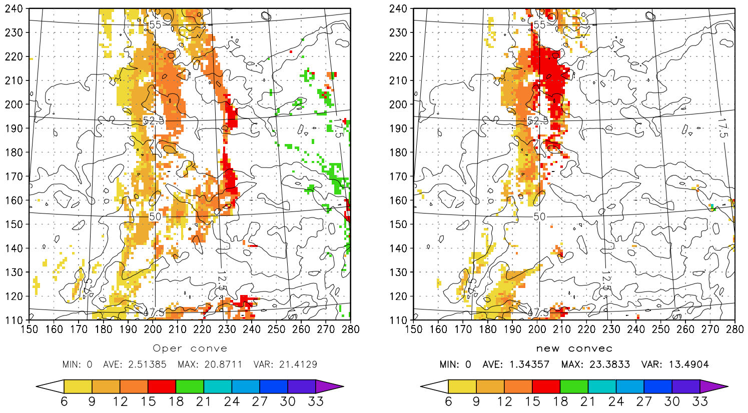

Figure 2: Distribution of the maximum convective gusts [m/s] from 09 UTC to 12 UTC on 10 July 2002. Left hand part: operational version of the gust diagnosis, right hand part: modified diagnosis

does not show up in the precipitation distribution. But the distribution of convective gusts in the operational version clearly shows the convergence line (left part of Fig. 2). In the modified version (right part of Fig. 2) all gusts in areas without convective precipitation are suppressed. In the region of the cold front, the gusts are higher than before because of the consideration of the effect of water loading and because of the new value for α. These effects are more pronounced in the evening, see Fig. 3. Maximum gusts are higher bei nearly 5 m/s, although still far from reaching the observed values. It should be mentioned that the area averaged value of the convective gusts is lower in the modified version of gust diagnosis than in the operational version because gusts connected to low precipitation rates are suppressed.

August 12, 2004

In the afternoon of August 12 a very narrow low pressure trough crossed the southwestern and southern parts of Germany with rather high convective precipitation rates and strong gusts. The observed precipitation for 06 UTC to 12 UTC (Fig. 4) shows a band of high precipitation stretching from Switzerland/northeastern France to the Netherlands, which is clearly separated from the dry area to the east. The LM simulation (Fig. 5) is partly successful. The trough is well positioned, but LM erroneously predicts moderate convective

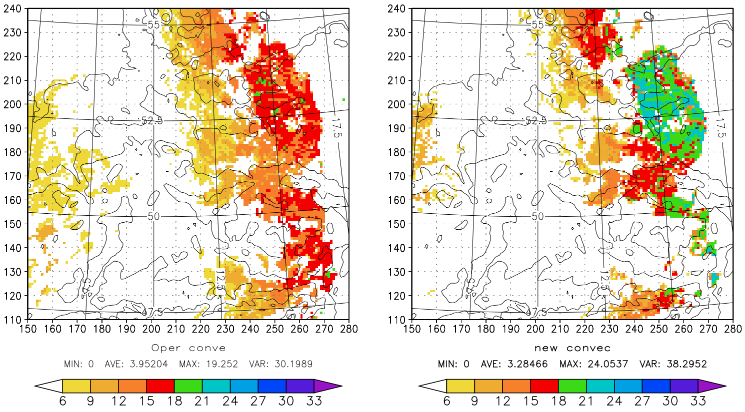

Figure 3: Distribution of the maximum convective gusts [m/s] from 18 UTC to 21 UTC on 10 July 2002. Left hand part: operational version of the gust diagnosis, right hand part: modified diagnosis.

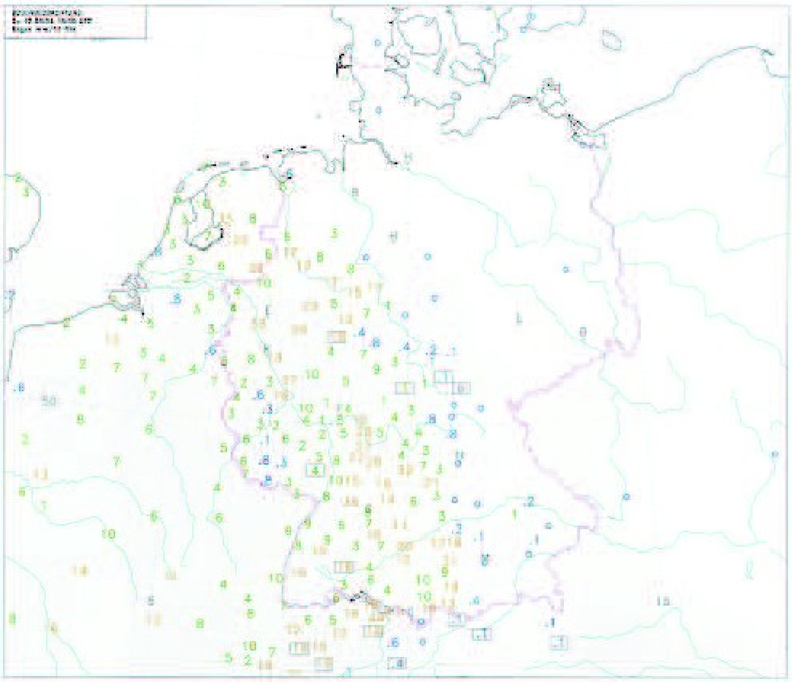

Figure 4: Distribution of observed precipitation [mm/12h] from 06 UTC to 18 UTC on 12 August 2004.

activity in Northeastern Germany, the Czech Republic and in Slovakia. In southwestern and southern Germany the precipitation amount predicted, with values up to some 50 mm/12h, is slightly larger than observed. In contrast, in the Benelux countries predicted precipitation amounts are somewhat too low.

The distribution of observed gusts (Fig. 6) for the period 15 to 18 UTC shows highest values in the easternmost part of the trough. Here values up to 70 knots are reported. Values in the western part of the trough are lower with the exception of reports from high level stations (indicated by a square around the value). The general structure is very well simulated by LM (Fig. 7). But in the operational version (left hand part of the figure) the predicted gusts are much too low (note the dimension m/s in Fig. 7 instead of knots in Fig. 6). The new version

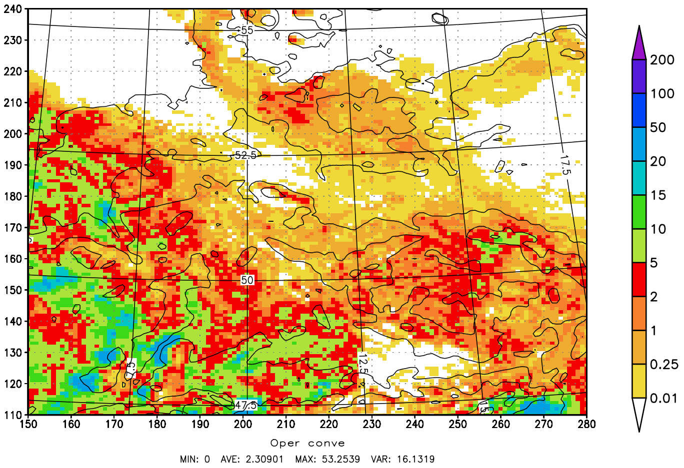

Figure 5: Distribution of predicted precipitation [mm/12h] from 06 UTC to 18 UTC on 12 August 2004.

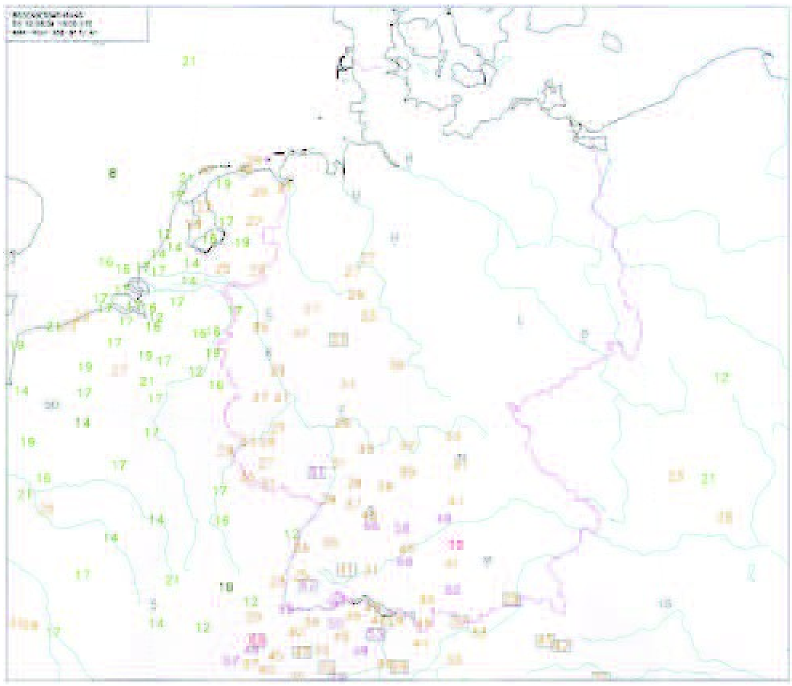

Figure 6: Distribution of observed gusts [knots] from 15 UTC to 18 UTC on 12 August 2004.

of the gust parameterisation (right hand part of Fig. 7) shows a significant improvement, although still the values are too low. Because of the erroneous prediction of convection east of the trough region also gusts are predicted here. And inevitably these gusts are higher in the modified version of the gust parameterisation. Nevertheless, as in the case of 10 June 2002 the area averaged value is lower for the modified version.

A situation with low values of gusts: April 07, 2004

This day was simulated in order to test the behaviour of both the new gust parameterisations in a situation of no significant gusts. There was no need for warning of gusts. On April 07, 2004, widespread showers occured over Germany. In central and in southern Germany gusts

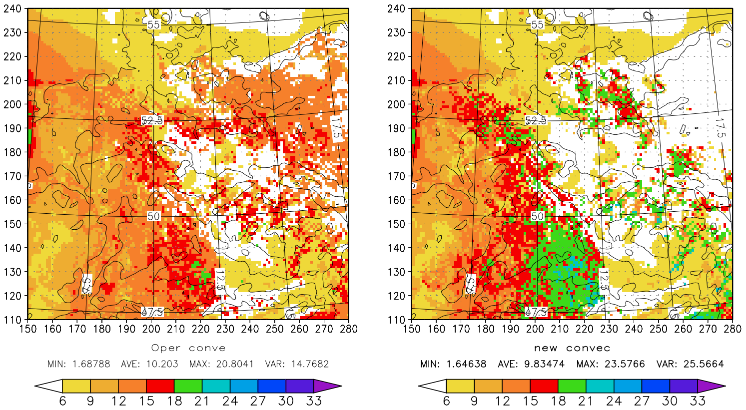

Figure 7: Distribution of the maximum convective gusts [m/s] from 15 UTC to 18 UTC on 12 August 2004. Left hand part: operational version of the gust diagnosis, right hand part: modified version of the gusts diagnosis.

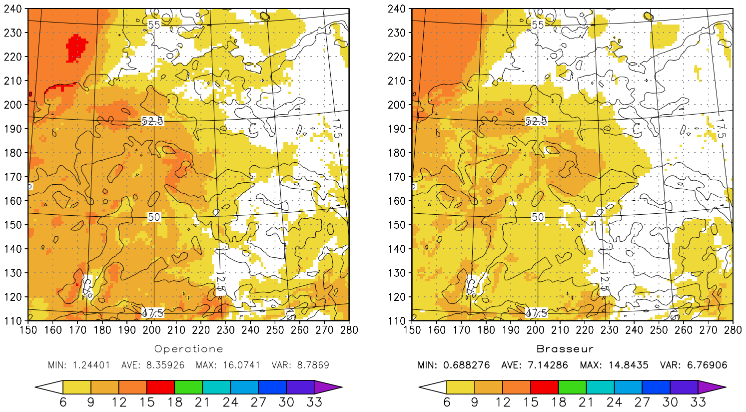

Figure 8: Distribution of predicted gusts [m/s] from 06 UTC to 09 UTC on 07 April 2004. Left hand part: Operational version of gust diagnosis, right hand part: modified diagnosis of convective and turbulent gusts.

of up to 12 m/s were reported. Occasionally somewhat higher values occured at higher level stations. Only over the German Bay values up to 15 m/s were observed. In this case the maximum of convective and turbulent gusts is shown. The operational prediction was rather successful with perhaps slightly too high values (Fig. 8, left hand part). The modified parameterisations (Fig. 8, right hand part; both the convective and the turbulent parts use the new versions of the gusts parameterisation) show a small reduction of the values, which might even better fit to the observations.

Predominantly turbulent situations

In this section some cases with turbulence dominated gusts are investigated. In all these cases convection does not play a significant role. Therefore, no separation between the different origins of the gusts is made, the maximum gusts are shown.

May 13, 2004

This situation is characterised by very low gusts over most of the LM-area. Exceptions are the Rhone valley and the Golfe du Lion. In these regions a strong Mistral is blowing. Gusts of 27 m/s are reported in Orange in the Rhone valley and 30 m/s at Cape Bear (southeast of Perpignan). The results of the simulations are shown in Fig. 9 for the whole model area,

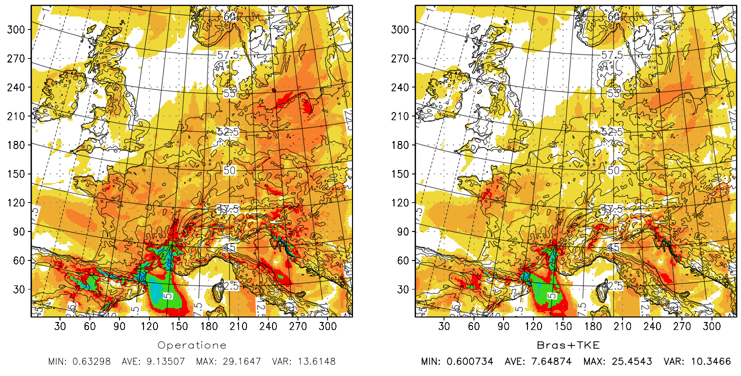

Figure 9: Distribution of predicted gusts [m/s] from 09 UTC to 12 UTC on 13 May 2004. Left hand part: Operational version of gust diagnosis, right hand part: modified diagnosis of gusts after Brasseur.

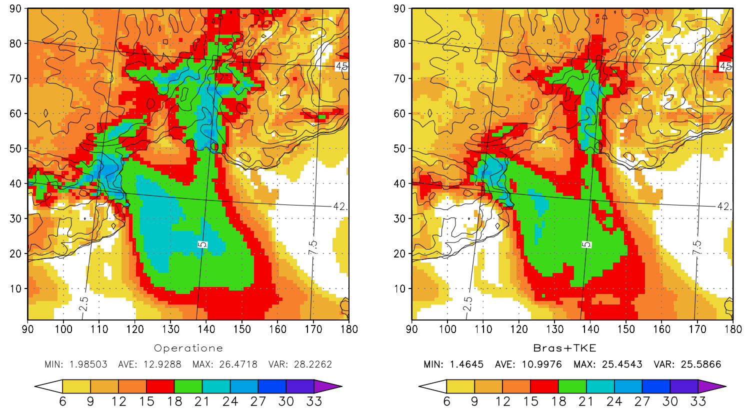

Figure 10: Distribution of predicted gusts [m/s] from 09 UTC to 12 UTC on 13 May 2004 for the Rhone valley and the Golfe du Lion. Left hand part: Operational version of gust diagnosis, right hand part: modified diagnosis of gusts after Brasseur.

and in Fig. 10 for the region of the Rhone valley and the Golfe du Lion. Observations are not shown here. Over most of the LM-area the operational version overestimates the gusts. Either no gusts are reported, or the reported values are around 8 to 10 m/s. Only at the coast of the Baltic Sea and in Brittany values of up to 12 m/s are reported. Here the values are captured quite well by the predictions of the operational model. The Brasseur gusts are lower on average by 1.5 m/s. These lower values better fit to the observations than the higher values in the operational model. E.g., in the region of the Thuringian Forest, the Ore Mountains, the Bavarian Forest, the Czech Republic and Slovakia no gusts are reported, but the operational model simulates values around 15 m/s. Only at the coast of the Baltic Sea the Brasseur gusts might be slightly too low. In the region of the Rhone valley the Brasseur method restricts the highest gusts to the inner part of the valley. This seems to better reproduce the few observations available. But the highest values observed here are not met by both the model predictions.

Nov 18/19, 2004

Two intensive depressions crossed Germany in November 2004. The first one on November 18, 2004 caused gale-force winds in northern Germany, whereas the second one on November 19, 2004 mainly hit southern Germany. For the first situation Fig. 11 shows the distribution

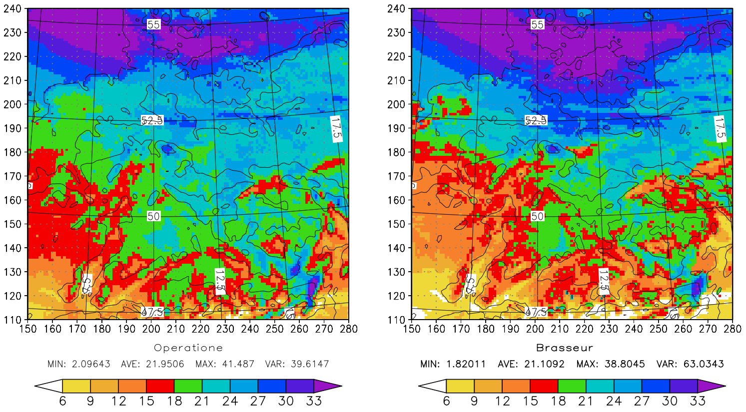

Figure 11: Distribution of predicted gusts [m/s] from 03 UTC to 06 UTC on 18 November 2004 for Germany. Left hand part: Operational version of gust diagnosis, right hand part: modified diagnosis of gusts after Brasseur.

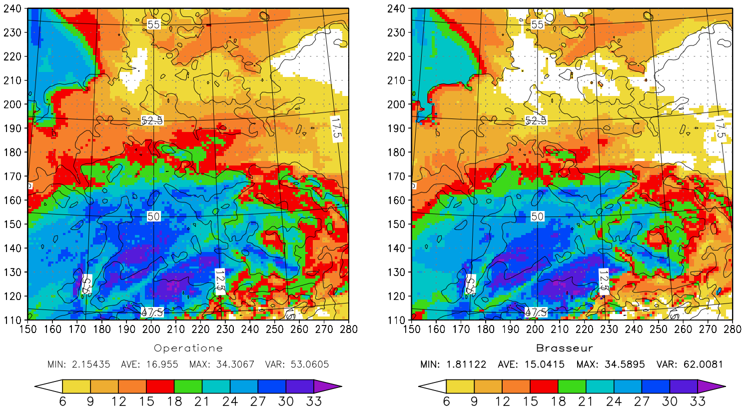

Figure 12: Distribution of predicted gusts [m/s] from 03 UTC to 06 UTC on 19 November 2004 for Germany. Left hand part: Operational version of gust diagnosis, right hand part: modified diagnosis of gusts after Brasseur.

of gusts in Germany. Compared to the operational version the area of high wind speeds is somewhat more extended using the Brasseur version. But the maximum and the average values are slightly reduced. Especially in southern Germany the gusts are less pronounced with the Brasseur version. The somewhat lower values in northern Germany are closer to the observations. The results are similar for the second case on 19 November (Fig. 12). There is a slight reduction of both the average and the maximum values. A more drastic reduction with the Brasseur method occurs in the region of Corsica (Fig. 13). The maximum value is reduced from 46 to 36.5 m/s. The latter value seems to be more likely, but no observations are available to verify the results of one or the other method.

4 Parallel experiments

The parameterisations as described above have to be tested in parallel experiments in order to judge their overall performance with respect to the operational verification. The period 01 July 2004 to 31 August 2004 was chosen to represent mainly convective gusts, whereas for turbulent gusts the period was 01 November 2004 to 31 December 2004. For the summer period the operational determination of turbulent gusts is used in combination with the

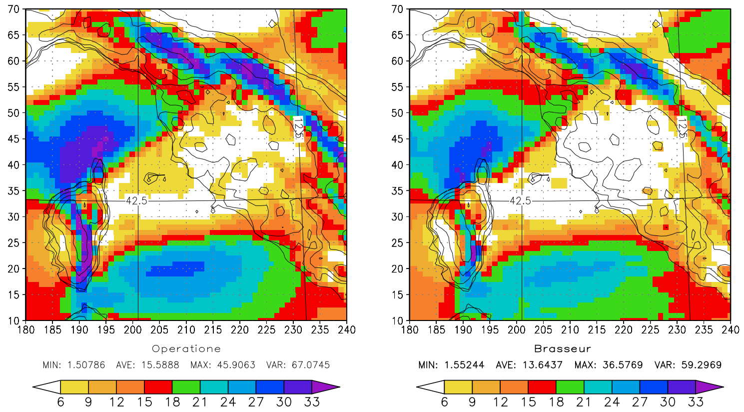

Figure 13: Distribution of predicted gusts [m/s] from 03 UTC to 06 UTC on 19 November 2004 for the regions of Corsica and part of Italy. Left hand part: Operational version of gust diagnosis, right hand part: modified diagnosis of gusts after Brasseur.

		convective gusts	**turbulent gusts**
summer	**reference runs**	operational	operational
	experiments	modified	operational
winter	**reference runs**	operational	operational
	experiments	operational	modified

Table 2: Determination of gusts in the reference runs and in the experiments

modified version of convective gusts. For the autumn/winter period the operational diagnosis of convective gusts is combined with the modified version for turbulent gusts. Table 2 shows the usage of the different variants of gust diagnosis according to Table 1.

For each of the periods a reference run was performed. Reference run and experiment for the turbulent gusts use LM Version 3.15, and the reference run and the experiment for the convective gusts are based on LM Version 3.16.

Convective gusts

At present no objective verification results are available, because reference run and experiment were not identical in all results but gusts. Therefore both runs had to be repeated.

Turbulent gusts

Reference run and experiment were finished successfully, including the operational verification of the results. Table 3 shows mean verification results for the three months for all significant gusts (> 12 m/s) and for severe gusts (> 20 m/s). The evaluation is for all stations. The statistical measures are: equitable threat score (ETS), frequency bias (FBI), probability of detection (POD), and false alarm rate (FAR). Optimum values are 100 (%) for ETS and POD, 1 for FBI, and 0 (%) for FAR. If the change from the reference run to the experiment is larger than 5 %, the numbers are color-coded: green for improvement and red for deterioration.

In general the results in Table 3 are dissapointing. Just counting the coloured numbers: there are only 7 in green but 13 in red. Looking at all gusts (> 12 m/s) the decrease of the absolute number of simulated gusts compared to observed gusts (FBI) and the reduction of the false alarm rate are positive. But there is a significant decrease in the probability of

	ETS		FBI		POD		FAR	
	ref	exp	ref	exp	ref	exp	ref	exp
> **12 m/s**								
October	25.9	24.7	1.7	1.2	66.1	53.8	59.6	55.0
November	34.5	34.5	1.6	1.4	77.7	70.2	51.1	47.4
December	34.2	33.6	1.7	1.3	84.6	74.1	50.4	47.4
> **20 m/s**								
October	16.0	9.5	0.7	0.4	25.7	13.3	63.4	67.8
November	27.3	23.3	1.1	1.3	46.9	64.7	58.4	65.4
December	20.2	18.0	1.2	1.4	38.3	38.6	64.8	70.6

Table 3: Verification of the results of the reference run (ref) and of the experiment using the modified diagnosis of turbulent gusts (exp). See text for details.

		> **12 m/s**		> **20 m/s**	
		ref	exp	ref	exp
ETS	stable	32	31	22	17
	unstable	31	34	28	21
FBI	stable	1.9	1.6	1.2	1.3
	unstable	1.8	1.4	1.1	1.0
POD	stable	80	71	41	37
	unstable	82	71	46	41
FAR	stable	56	52	63	70
	unstable	53	45	57	59

Table 4: Verification of the results of the reference run (ref) and of the experiment (exp), for stable and unstable conditions. See text for details.

detection of gusts. A major positive outcome is the considerable increase in the probability of detection for severe gusts in November and the slight improvement in December. But for severe gusts also the false alarm ratio increases considerably in all three months. Also, for severe gusts the equitable threat score is reduced to much lower values in the experiment compared to the reference run.

The operational verification provides estimates of the diurnal cycle of the different scores. Here some indication on a dependence on stability appeared. Therefore, all scores were determined separately i) for 12 UTC (on average unstable stratification) and ii) for 06 and 18 UTC (on average stable stratification). The results for the three months were averaged for this evaluation. Looking at the statistical measures depending on stability in Table 4, it can be observed that indeed with only one exception the scores are better in unstable than in stable situations. But with respect to this behaviour there is no significant difference between reference run and experiment.

5 Continuation of the workpackage during the next one year phase

It is suggested to continue the work during the next phase. The work will comprise the following aspects.

- Evaluation of the results of the reruns of reference run and experiment using the modified diagnosis of convective gusts.

- If necessary, retuning of the parameter α in (1) and conducting a shorter experiment.
- In depth evaluation of the results of reference run and experiment using the Brasseur-method for turbulent gusts.
- Retuning of the Brassuer-method if possible.
- Rerun of reference run and experiment for turbulent gusts, evaluation of the results.

References

Brasseur, O., 2001: Development and application of a physical approach to estimating wind gusts. *Mon. Weath. Rev.*, 129, pp. 5-25

Gatzen, Chr., 2004: A Derecho in Europe: Berlin, 10 July 2002. *Weather and Forecasting*, 19, pp. 639-645

Nakamura, K., R. Kershaw, and N. Gait, 1996: Prediction of near-surface gusts by deep convection. *Meteorol. Appl.*, 3, pp. 157-167