Validation of Boundary Layer Clouds: Test Results with the Minimum Vertical Diffusion Coefficient set equal to Zero in LM (Interim Report on Work Package 3.5.1.)

E. Heise

Deutscher Wetterdienst, Offenbach a.M., Germany

1 Introduction

There is a long lasting problem of LM to rapidly dissolve low stratus/stratocumulus over land in late autumn and in winter. This results in extremely high errors of near surface temperatures. Some earlier tests performed by D. Mironov suggested the prescribed minimum value of the vertical diffusion coefficient to be the reason for this behaviour. The minimum value of $1\,m/s^2$ was introduced because of problems over the North Sea. In the early stage of the operational LM the North Sea appeared to be completely covered by low level clouds most of the time. The introduction of the minimum vertical diffusion coefficient solved this problem. Meanwhile it became obvious that the evaporation rate from water surfaces was too high in LM, contributing to an overdevelopment of depressions over water. A considerable reduction of the evaporation rate by increasing the laminar resistance for scalar fluxes over water by a factor of 10 was introduced operationally in April 2004. This reduced the problem of overdevelopment. At the same time this action should reduce an overprediction of low clouds by reducing the available moisture in the lower layers of the model atmosphere. Therefore it seems to be logically to set back the minimum value of the vertical diffusion coefficient to zero. In a long parallel experiment the consequences of this change are tested. The following questions have to be answered by evaluating the simulations:

1. Is the tendency of LM to dissolve too rapidly low level clouds over land reduced to a tolerable amount?
2. Is the temperature prediction improved?
3. Does LM simulate again a more or less completely cloud covered North Sea?
4. Are there detrimental effects to other results?

A positive outcome of the experiment would result in the answer 'Yes' for the first two questions and in 'No' for the next two questions.

2 Parallel experiments

Two parallel experiments were conducted for the period 01 October 2004 to 31 December 2004. The reference run uses LM Version 3.15 without changes [this is the first version with the so-called aerosol-bug corrected]. In the experiment there is only one change compared to the reference run: the minimum vertical diffusion coefficient is set to zero. Objective verification of the simulation results will be used to assess the overall quality of both the reference run and of the experiment. In addition to the objective verification, a visual inspection of the cloud cover over the North Sea is conducted in order to exclude (hopefully) the occurrence of unrealistic overcast situations.

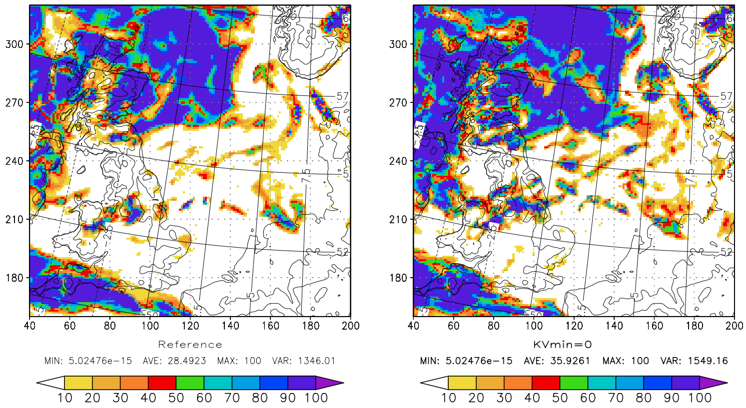

Figure 1: Distribution of low clouds (%) for 10 October 2004, 12 UTC. Left part: reference run, right part: experiment.

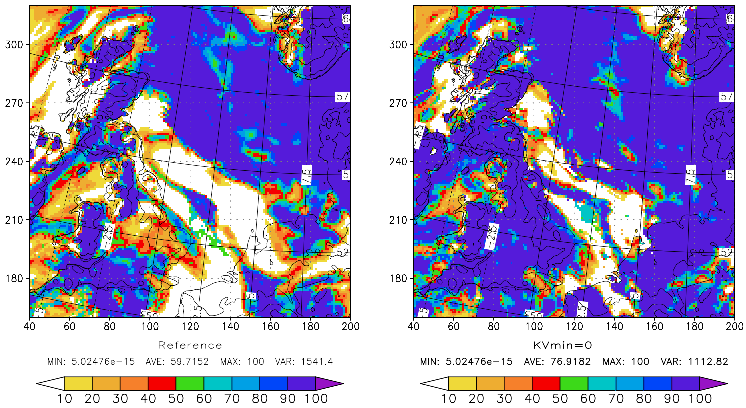

Figure 2: Distribution of low clouds (%) for 30 October 2004, 00 UTC, 24 hours prediction time. Left part: reference run, right part: experiment.

October 2004

In general October is not the month where extremely large errors in the prediction of low stratus clouds are anticipated. Although the domination of convection is not as present as in the summer months, solar insolation is still strong enough to quickly dissolve low level stratus clouds developing during night in stable high pressure systems. But sea surface temperatures are rather warm and could perhaps cause excessive low cloud cover over the large water areas.

As a first example Fig. 1 shows the distribution of low clouds over the North Sea and over adjacent areas for 10 October 2004 after 12 hours prediction time. Both over land and over sea cloud cover is larger in the experiment with the minimum vertical diffusion coefficient set to zero than in the reference run. But there is no indication of an excessive increase over sea. Satellite pictures (not shown here) indicate an overcast situation with low clouds over the northern part of the North Sea with the exception of the area close to the Norwegian coast. The model results are in reasonably good agreement with the satellite pictures.

A second example is presented in Fig. 2. A large increase in the mean cloud cover in the experiment compared to the reference run is ovious (from 59.7 % to 76.3 %). But the increase is rather similar both over the sea and over land areas. Especially the cloudless area off the coast of the British Isles is conserved in the experiment, although it is a bit reduced in size. This area can also be seen in the respective satellite picture (not shown here).

October 2004	**Reference**	**Experiment**
frequency bias		
total cloud cover (0-2/8)	1.26	1.04
total cloud cover (7-8/8)	1.08	1.22
low level cloud cover (0-2/8)	1.09	0.92
low level cloud cover (7-8/8)	0.91	1.23
percent correct		
total cloud cover	60.9	62.1
low level cloud cover	60.5	58.9
mid level cloud cover	60.4	58.4
high level cloud cover	55.9	55.5
2m temperature	73.9	75.1
2m dew point	69.9	71.5
root mean square error (K)		
2m temperature	1.93	1.89
2m dew point	2.36	2.27
true skill statistics		
precipitation > 0.1 mm/6h	49.2	46.3
precipitation > 2.0 mm/6h	38.5	38.5
precipitation > 10.0 mm/6h	22.0	23.2
equitable threat score		
gusts > 12 m/s	25.86	27.52
gusts > 15 m/s	24.12	23.56
gusts > 20 m/s	15.98	12.12
gusts > 25 m/s	3.00	3.80

Table 1: Mean values of verification scores for October 2004 for the reference run and for the experiment. The verification is performed for all observing stations available in the model area.

The objective verification provides mean values over all forecast times for statistical measures. Some of them are shown in Table 1. The frequency bias for small ($\leq 2/8$) and large ($\geq 7/8$) values of cloud amount shows the anticipated result of reducing low and increasing high cloud amounts. But in total this effect seems to be too large in this month. This is also reflected in the percent correct values, which show a minor improvement for total cloud cover only. According to the percent correct values and to the root mean square error, the temperatur and dew point predictions improved a little. There is a mixed signal for precipitation, where the prediction of high values is slightly improved. But the success for precipitation yes/no (> 0.1 mm/6h) is decreased considerably. The bias of 2m temperature and dew point (not shown in the table) is on average reduced, especially the warm temperature bias at noon is reduced from 0.78 K to 0.48 K. But the cold bias at 6.00 p.m. increased from -0.20 K to -0.38 K. The positive bias of dew point prediction at noon is reduced from 1.55 K to 1.25 K, and at 6.00 p.m. from 0.45 to 0.20 K. There are only small changes of temperature and dew point biases for the other verification times. There are moderate and not expected changes in the verification of gusts. On average the gusts verification for the experiment is worse compared to the reference run, especially for higher values of the gusts.

November 2004

In November there was especially one case where the synoptic meteorologists vehemently complained about the cloud cover forecast. This was the situation of November 11. The

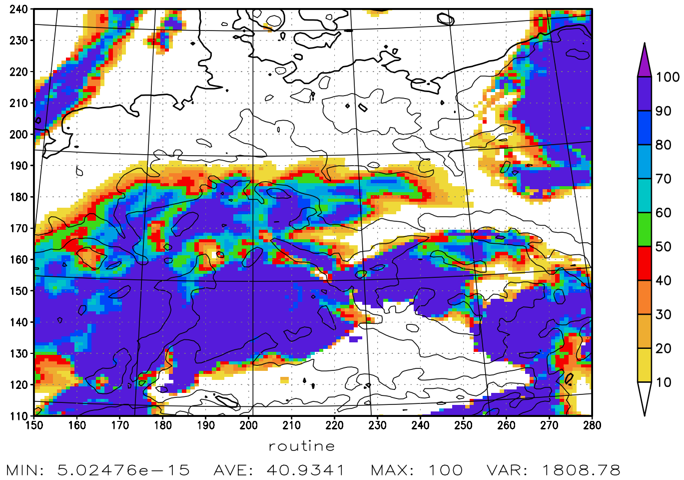

Figure 3: Distribution of low clouds (%) in the routine run of 10 November 2004, 12 UTC, 24 hours prediction time. Validation time 11 November 2004, 12 UTC.

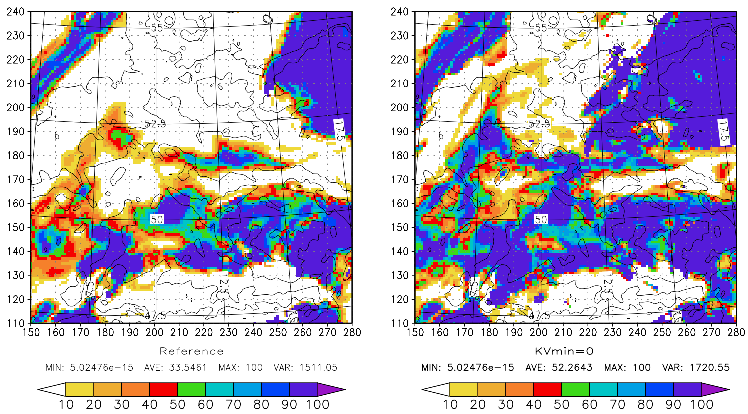

Figure 4: Distribution of low clouds (%) for 11 November 2004, 12 UTC, 12 hours prediction time. Left part: reference run, right part: minimum vertical diffusion coefficient set to zero.

central and the southern parts of Germany were under the very weak influence of a cyclone over Sardinia, whereas there was a ridge of comparably high pressure over northern Germany. In general the surface pressure gradient was small over Germany. According to the satellite pictures, a mainly cloudless band was stretching from the area of Aachen (ca. 51^oN, 6^oE) to the isle of Gotland. Even in this band occasionally low clouds were present. Also the foothills of the Alps and a small band parallel to the Ore Mountains were mainly free of clouds. The other parts of Germany as well as the Czech Republic were covered by low clouds.

The operational LM-forecast of 12 UTC on November 10 in Fig. 3 (this was the forecast which led to the complaints) shows large areas free of clouds in northern Germany, whereas southern Germany and the Czech Republic are covered with clouds. As in the observations, the foothills of the Alps and the band parallel to the Ore Mountains are cloudless, but the north-south extension of these areas is too large, especially in southeastern Bavaria.

Because in the parallel experiments forecasts were run only at 00 UTC (over a period of 24 hours), a direct comparison with the operational forecast is not possible. Therefore, we have to rely on the 00 UTC forecast of November 11. Fig. 4 shows a comparison of the prediction of low clouds for the reference run and for the experiment. Apparently, the reference run (left hand part of Fig. 4) underestimates the cloud cover even more than the operational forcast

November 2004	Reference	Experiment
frequency bias		
total cloud cover (0-2/8)	1.47	0.95
total cloud cover (7-8/8)	0.94	1.12
low level cloud cover (0-2/8)	1.22	0.87
low level cloud cover (7-8/8)	0.83	1.10
percent correct		
total cloud cover	63.9	67.9
low level cloud cover	55.6	59.0
mid level cloud cover	61.3	58.0
high level cloud cover	65.7	64.4
2m temperature	70.8	71.7
2m dew point	78.8	79.4
root mean square error (K)		
2m temperature	2.17	2.15
2m dew point	2.43	2.42
true skill statistics		
precip > 0.1 mm/6h	53.4	43.2
precip > 2.0 mm/6h	56.0	56.6
precip > 10.0 mm/6h	47.7	49.6
equitable threat score		
gusts > 12 m/s	34.52	37.86
gusts > 15 m/s	32.46	33.28
gusts > 20 m/s	27.26	21.66
gusts > 25 m/s	14.68	14.00

Table 2: Mean values of verification scores for November 2004 for the reference run and the experiment. The verification is performed for all observing stations available in the model area.

in Fig. 3. But the forecast is significantly improved in the experiment (right hand part of Fig. 4). One can just make out the mainly cloudless band from Aachen to the isle of Gotland (this island is not shown in the figure). The extension of the cloudless bands adjacent to the Alps and to the Ore Mountains is reduced, there are some clouds in northwestern Germany, and eastern Germany is mainly covered by clouds.
The objective verification scores are shown in Table 2. In the reference run a significant overprediction of low cloud cover values of both total and low level cloud cover is diagnosed by the frequency bias. And simultaneously high cloud cover values are underpredicted. The situation changes in the experiment, on average the values of the frequency bias are now closer to one, with the exception of high values of total cloud cover. The percent correct values of total cloud cover and low level cloud cover increase in the experiment compared to the reference run, but mid and high level cloud prediction is better in the reference run. There are only negligible changes in the scores for 2m temperature and dew point. As for the October verification there is a mixed signal for precipitation verification with a small improvement for high values but a large worsening of the prediction of low precipitation rates. There is some improvement of the verification of low gust values, but a significant worsening for high values.

December 2004

From 6 to 09 December 2004 there was a period of significant underestimation of low cloud

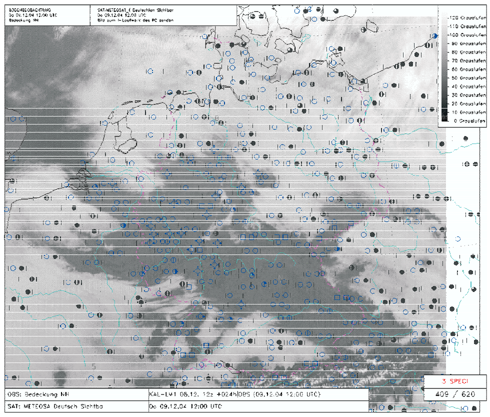

Figure 5: Satellite distribution of cloud cover for 09 December 2004, 12 UTC. Clear sky is shown by dark areas. The station symbols show surface observations (to the left of the vertical bar) and LM-predictions (to the right of the vertical bar).

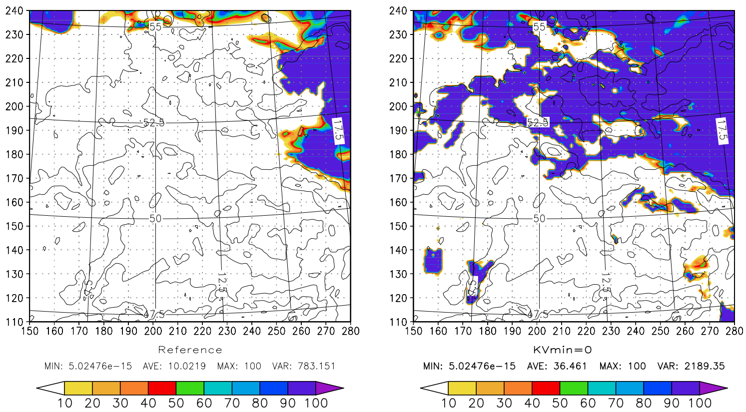

Figure 6: Distribution of low clouds (%) for 09 December 2004, 00 UTC, 12 hours prediction time. Left part: reference run, right part: experiment.

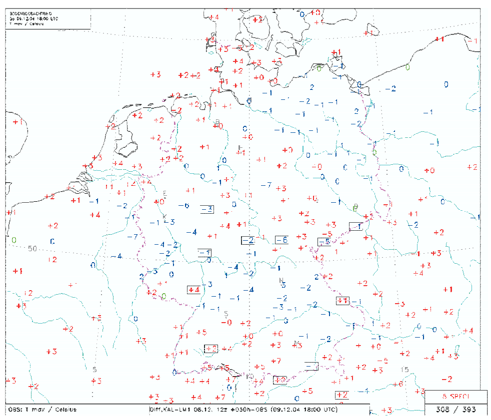

Figure 7: Difference of predicted minus observed 2m maximum temperatures on 09 December 2004.

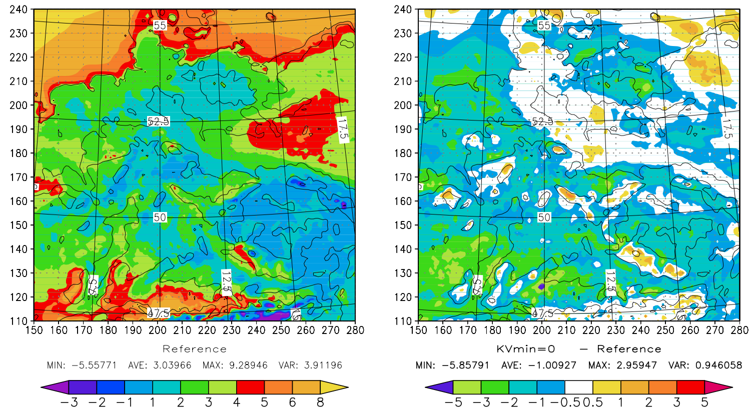

Figure 8: Predicted maximum 2m temperatures in the reference run (left part), and difference experiment minus reference run (right part) on 09 December 2004.

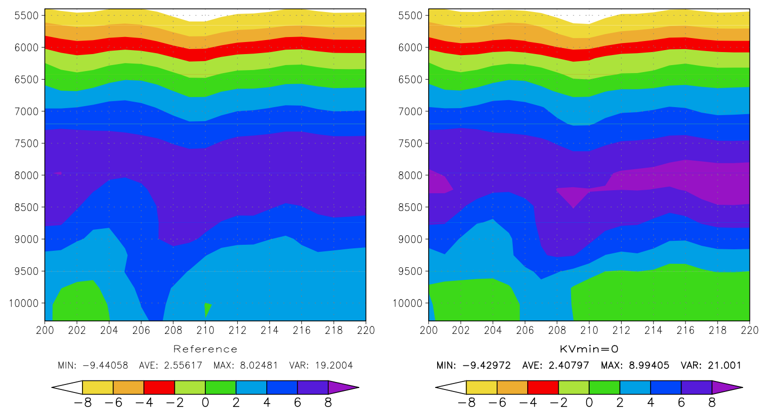

Figure 9: Cross section of temperature in the lowest 20 layers of LM on 09 December 2004. The cross section runs in zonal direction through the northern part of the Thuringian Forest on model row 163 from model column 200 to 220.

cover in LM over Germany. The case of 09 December is used here for demonstration. The satellite picture in Fig. 5 shows large parts of Germany and the surroundig area cloud covered with the exception of a northwest/southeast oriented band in central and southern Germany, which is mainly cloudfree. Looking at the reference run in Fig. 6, only part of Poland is cloud covered in the LM simulation. In the experiment the simulation is improved, northern Germany is mainly covered by clouds, but still southern Germany and northeastern France are nearly completely free of clouds. In the operational model, which is nearly identical to the reference run, the large errors in cloud cover led to large errors in the predicted 2m maximum temperatures (Fig. 7). In southern Germany predicted temperatures are too warm by up to 7 K (synoptic station Altenstadt), whereas in the areas, which are cloudfree in the observations, predicted temperatures are too low.

On average, the 2m temperature maxima are lower in the experiment by 1 K (Fig. 8). The largest temperature reduction occurs in southwestern Germany, but there is also a reduction of temperatures in northeastern Germany, where the operationally predicted temperatures are too cold already. A significant warming takes place at mountain tops of the Thuringian Forest, the Ore Mountains and the Bavarian Forest, where the operational forecast at some stations showed significantly too cold temperatures. No change in the cloud cover prediction occured here. The reason for this significant temperature increase is explained in Fig. 9. In the reference run the strong temperature inversion in the lower atmosphere is smoothed considerably compared to the experiment. Clearly this is due to the prescribed minimum vertical diffusion coefficient in the reference run.

December 2004	**Reference**	**Experiment**
frequency bias		
total cloud cover (0-2/8)	1.64	1.12
total cloud cover (7-8/8)	0.82	1.01
low level cloud cover (0-2/8)	1.31	0.93
low level cloud cover (7-8/8)	0.75	1.05
percent correct		
total cloud cover	63.0	71.0
low level cloud cover	58.7	65.4
mid level cloud cover	68.6	67.2
high level cloud cover	77.7	77.0
2m temperature	63.9	64.2
2m dew point	76.4	78.0
root mean square error (K)		
2m temperature	2.67	2.70
2m dew point	2.89	2.85
true skill statistics		
precip > 0.1 mm/6h	60.7	47.0
precip > 2.0 mm/6h	63.9	63.9
precip > 10.0 mm/6h	44.6	42.7
equitable threat score		
gusts > 12 m/s	34.18	35.54
gusts > 15 m/s	29.76	29.84
gusts > 20 m/s	20.18	16.30
gusts > 25 m/s	8.68	4.17

Table 3: Mean values of verification scores for December 2004 for the reference run and for the experiment. The verification is performed for all observing stations available in the model area.

The results of objective verification are presented in Table 3. According to frequency bias and percent correct the cloud cover forecast was improved significantly in the experiment compared to the reference run. On average there is no significant change of temperature and dew point forecasts. Again, there is a large degradation of precipitation forecast, and also a degradation of the prediction of high gust values.

3 Summary and discussion

The LM tends to rapidly dissolve low stratus in late autumn and in winter. This leads to cloudfree situations in the model in contrast to overcast situations in reality and to associated temperature errors. This problem was suspected to be caused by the introduction of a minimum vertical diffusion coefficient of 1 m/s^2 some years ago. The reason for using the minimum vertical diffusion coefficient were problems with cloud cover over water areas. Here cloud cover tended to be much too high. As last year evaporation over water surfaces was reduced considerably, the minimum vertical diffusion coefficient might turn out to be dispensable.

A couple of single test cases with the minimum vertical diffusion coefficient set to zero showed improvements in the cloud cover prediction. Therefore, the period 1 October 2004 to 31 December 2004 was simulated with a reference run and an experiment. The aim of the experiment was to quantify the effect of this reduction on the simulation of low clouds in autumn and winter.

The objective verification showed a mixed signal. On the one hand cloud cover prediction was improved, but on the other hand there were detrimental effects on precipitation and gusts. The questions at the end of the introduction gain the following answers:

1. Is the tendency of LM to dissolve too rapidly low level clouds over land reduced to a tolerable amount? **Yes**

2. Is the temperature prediction improved? **There was only a marginal improvement**

3. Does LM simulate again a more or less completely cloud covered North Sea? **No evaluation has been done so far**

4. Are there detrimental effects to other results? **Yes**

These results cannot be considered as satisfying. A rigorous investigation of the results is necessary to find out the reasons for the failure of the experiment.