THE INFLUENCE OF MM5 NUDGING SCHEMES ON CMAQ SIMULATIONS OF BENZO(A)PYRENE CONCENTRATIONS AND DEPOSITIONS IN EUROPE

Volker Matthias*, Markus Quante and Armin Aulinger
GKSS Research Center, Institute for Coastal Research, Geesthacht, Germany

1. INTRODUCTION

Three dimensional Eulerian chemistry transport models (CTMs) like CMAQ need highly resolved meteorological fields as input data. These fields can be a source of significant errors which contribute to uncertainties in simulations of the atmospheric distribution of chemical species and aerosols. Therefore, the evaluation of the quality of meteorological simulations used for chemistry transport studies is indispensable.

At GKSS, the 5th generation NCAR/Penn State University mesoscale meteorological model (MM5) is used as meteorological preprocessor for CMAQ. MM5 can be used with different nudging options to assure a close connection between the simulated fields and the driving global reanalysis data. In this paper we investigate the influence of different nudging options on the results of a long term CMAQ model run for persistent pollutants, in this case benzo(a)pyrene.

2. MODEL

CMAQ has been expanded at GKSS to study the trans-boundary transport of polycyclic aromatic hydrocarbons (PAHs; i.e. benzo(a)pyrene) and their deposition within coastal regions of Europe (Aulinger et al., 2007). The goal of our studies are multi-year runs of MM5-CMAQ for the assessment of past trends in PAHs concentrations and deposition. The model is set up on a 54 x 54 km² grid for Europe and on a nested smaller domain with a 18 x 18 km² grid for the North Sea region.

MM5 is operated with the more sophisticated parameterizations for cloud micro physics (Reisner2, Reisner et al., 1998), the planetary boundary layer (MRF, Hong and Pan, 1996), and the subscale cumulus convection (Kain Fritsch 2, Kain, 2004). The Noah land surface module (LSM, Chen and Dudhia, 2001) is used and the model is driven by ERA40 reanalysis data (1 x 1 degree, 6 hourly atmospheric fields, surface and soil data). Four dimensional data assimilation (FDDA) is used in different configurations to nudge the model results with the ERA40 gridded data.

3. MEASUREMENT DATA

Our modeling of persistent pollutants, that are only present in very low concentrations in the atmosphere, aims at long times series of several years. Therefore the meteorological fields were tested for systematic deviations from long term observations. Because the long range transport of atmospheric pollutants is closely connected to its vertical transport, it is important to compare the model results to data that contains also vertical information and not only ground data.

Radiosoundings that are routinely performed by the European Weather Services and that can be publicly accessed are well suited for this purpose. The data comprises regular observations (usually twice a day) of temperature, wind, and humidity up to the tropopause. One disadvantage is of course that the data is already assimilated in the driving reanalysis fields. However there is no real alternative to the data if a homogeneous data set covering whole Europe is needed. Nevertheless, we used also wind profiler data to check wind speed and wind direction at three stations in Central Europe.

All radiosoundings used in this study were extracted from the IGRA data set (Durre et al., 2006), that contains data from more than 1000 stations world wide in a common format. Figure 1 shows the locations of 88 stations in Europe that were selected for our tests.

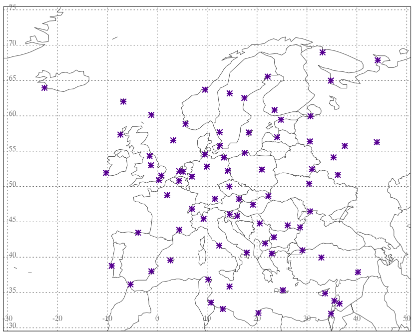

Fig.1 : Map of the selected radiosonde stations

**Corresponding author:* Volker Matthias, GKSS Research Center, Institute for Coastal Research, Environmental Chemistry Department, Max-Planck-Strasse 1, 21502 Geesthacht, Germany; e-mail: volker.matthias@gkss.de

4. RESULTS

4.1 Nudging schemes

To test the different nudging schemes, several runs with different options were performed for April 2000 and the results were compared to the measurements at 19 selected stations. Afterwards the whole year 2000 was modeled with the optimal nudging options and these results were compared to the radiosonde data from 88 stations and to the wind profilers.

Nine different model setups were chosen for the initial tests:

1. No nudging
2. Periodic restart every 96 hours
3. Wind (U,V) nudging
4. U,V and temp. (T) nudging
5. U,V,T and rel. hum.(RH) nudging
6. U,V,T,RH nudging, no LSM
7. U,V,T,RH nudging, daily var. SST
8. U,V,T,RH nudging, only 9 vert. lay.
9. U,V,T,RH nudging, only 12 vert. lay.

All runs except case 2 were performed for 34 days (from 28 March 2000 to 30 April 2000) without restart. The results from 1 April to 30 April were then used for the comparisons (resulting in a spin up time of 4 days). Only for the periodic restart, the model was run for 11 periods of 4 days each, using only the last 3 days for the comparisons. Temperature and Humidity were only nudged above the PBL. The sea surface temperature is usually initialized at the beginning of a MM5 run and then kept constant over the whole run. In one setup, the SST was daily adapted to the SST given in the reanalysis data.

At each station, the mean difference and the root mean square (rms-)error were calculated for each profile and then averaged for the whole month. The results for temperature and relative humidity are displayed in Figures 2 and 3.

It can be clearly seen that nudging of the temperature leads to a significantly lower rms-error and to a very small mean difference between model and observations. This is also connected to the number of vertical layers that was used in MM5. The simulations with 9 and 12 vertical layers showed the largest rms-errors and on average 1 K too high temperatures. If no nudging was applied, temperatures were underestimated by the model. The effect was less severe when the model was restarted every 4 days, but the results were still significantly worse than for the nudging cases.

The picture is slightly different for the relative humidity. Again, highest deviations from the observations were detected for the cases without

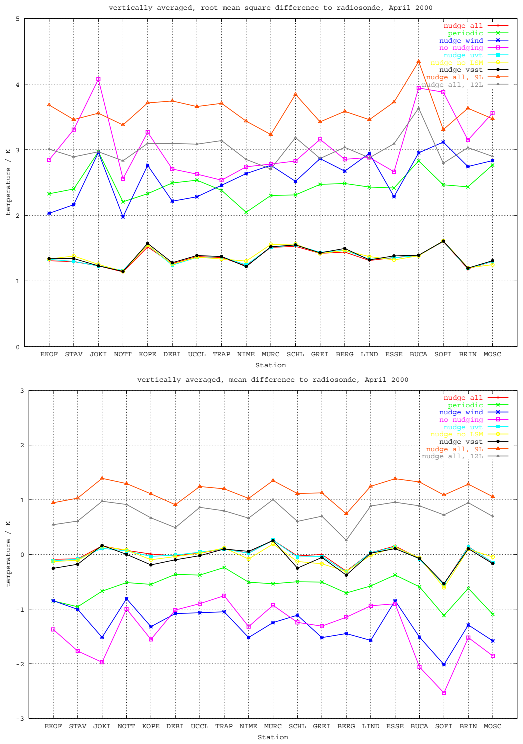

Fig. 2: Mean rms error (top) and mean deviation (bottom) of the modeled temperature compared to radiosoundings at 19 selected stations in Europe in April 2000.

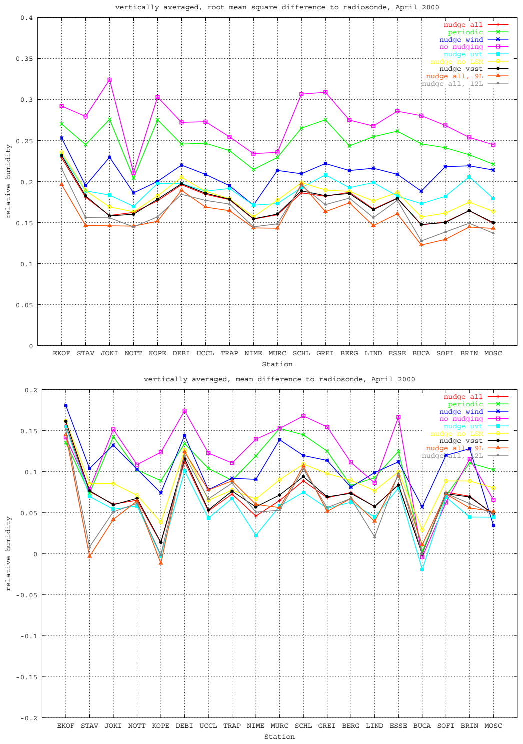

Fig.3: Same as Fig. 2 but for relative humidity

nudging. All other results were quite close together and even if only the wind components u and v were nudged, the rms-error and the mean deviation were much lower than for the cases without nudging. The use of a land surface model slightly improved the results. However, at all stations the modeled values of the relative humidity were higher than the observations.

For wind direction and wind speed, the two runs without nudging also showed much higher rms-errors than all other runs. In contrast, the mean deviations of wind speed and wind direction were similar for all runs.

4.2 Seasonal and regional dependence

Additional to the dependence on the nudging scheme, which was tested only for April 2000, the model results might also depend on season and on location. Therefore annual runs were performed with complete nudging of u, v, T and RH, the use of the Noah LSM and monthly varying SST. Each month was modeled separately with a spin up time of 4 days. It was tested before that this time is sufficient to achieve results that are independent from the initial conditions.

The results are displayed in color code in Figures 4 – 7.The x-axis shows the temporal variation and the y-axis shows the stations which were sorted from west (No.1) to east (No.88). Here, only the bias in temperature, rel. humidity, u-wind and v-wind are given. Black colors denote not enough data.

Some scatter in the results for the temperature can be seen in Fig. 4, but no systematic effects were present. Some stations (in particular Reykjavik, the most westerly station in the model domain) show large discrepancies between model and observations but mostly the bias is below 0.5 K.

Some seasonal and regional effects were found for the relative humidity. While in winter and spring, RH is mostly overestimated (as it has already been seen for the April results), some underestimations are also observed in summer and fall at the more easterly stations. Nevertheless, the results give a quite uniform picture.

The wind components are more variable and they show some systematic effects. The u-wind component is mostly underestimated, in particular in winter when the average wind speed is higher than in summer. The v-wind component shows a clear geographical dependence with too low values in the western part of Europe and too high values in the eastern part. Again, the situation is more pronounced in winter than in summer.

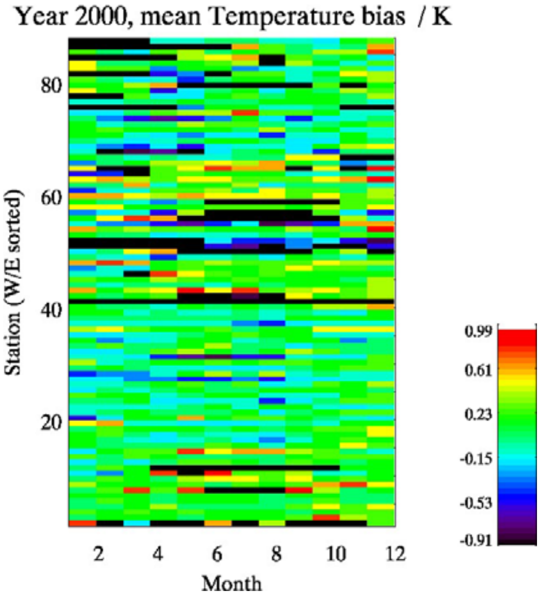

Fig. 4: Monthly comparison of the mean deviation of temperature from radiosonde profiles at 88 European stations and MM5 model results calculated with complete nudging.

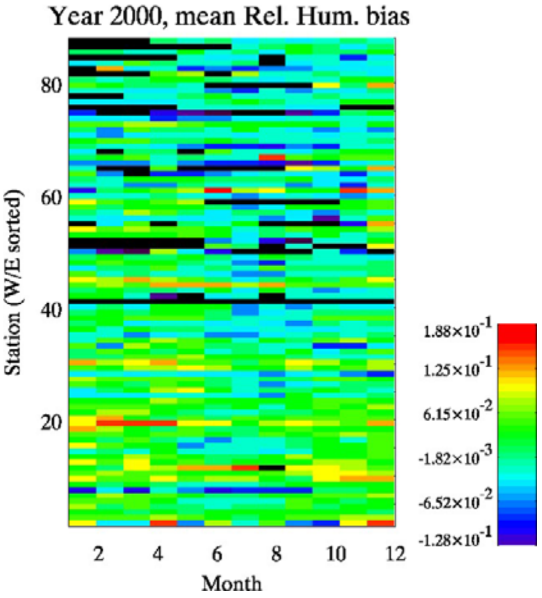

Fig. 5: Same as Fig. 4 but for RH.

To investigate the effect further, the modeled wind data was also compared to hourly wind profiler data at three European stations: Pendine/UK, Cabauw, The Netherlands and Lindenberg/Germany. In this case, the annual time series at all model levels where profiler data was

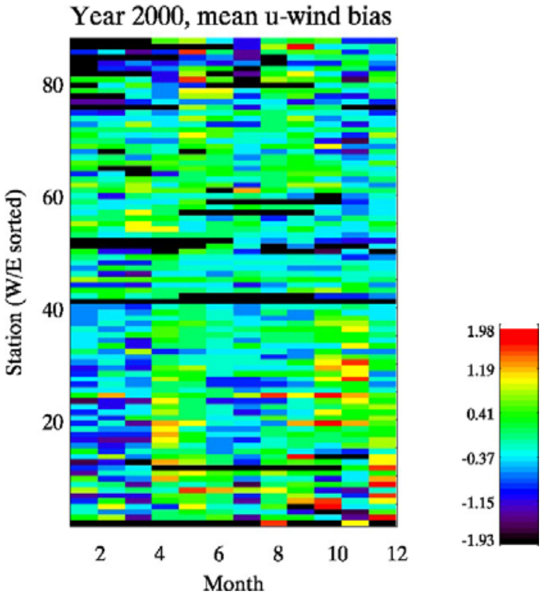

Fig.6: Same as Fig. 4 but for the u-wind (in m/s).

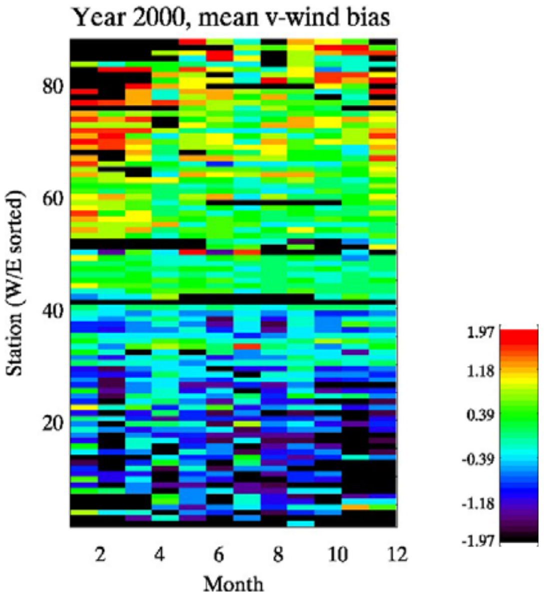

Fig. 7: Same as Fig. 4 but for the v-wind (in m/s).

available were investigated. At Pendine, the negative v-wind bias was also observed, the u-wind bias was slightly positive over the whole year. The absolute deviations increase with wind speed and therefore with altitude. The temporal correlation of the time series is larger than 0.9 in all heights. The bias is smaller at Cabauw, but here v is also underestimated while u is overestimated. The temporal correlations are not as high as at Pendine, they vary between 0.8 and 0.9. Closest agreement was achieved at

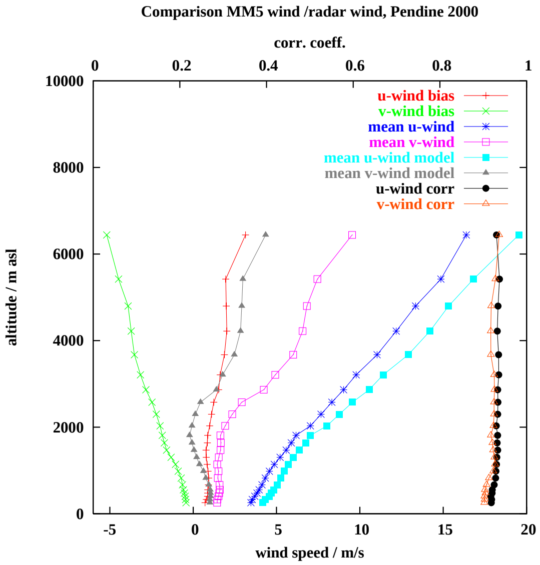

Fig. 8: Comparison of u- und v-wind components calculated with MM5 for 2000 with hourly wind profiler data at Pendine/UK.

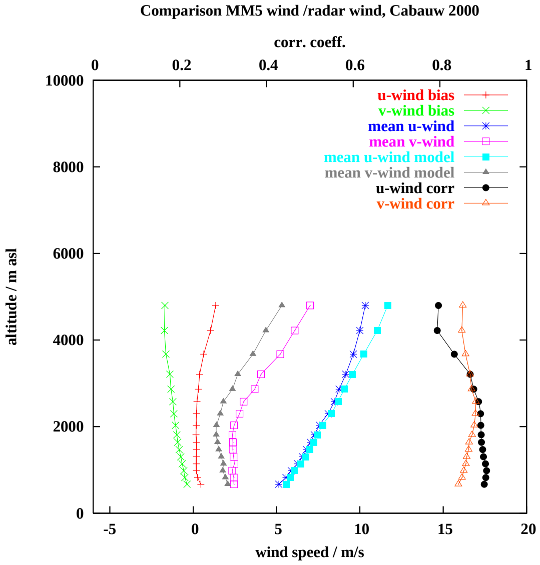

Fig. 9: Same as Fig.8, but at Cabauw, The Netherlands.

Lindenberg, where the bias is almost zero and the correlations are around 0.95.
Although wind profiler data was available only at a few stations, the results of the comparisons between model simulations and radiosondes could be confirmed. Up to now an explanation for this effect could not be found.

4.2 Influence on B(a)P distributions

The influence of the different model setups on the B(a)P concentrations was investigated for two of the nine different cases described in section 4.1.

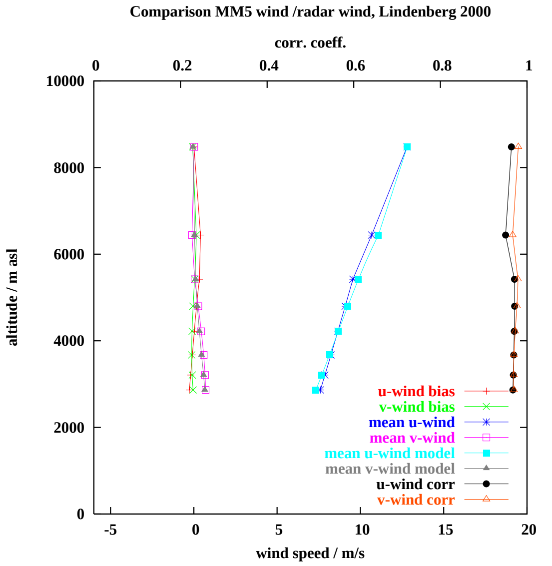

Fig. 10: Same as Fig.8, but at Lindenberg, Germany.

The reference run was performed with complete nudging and it was compared to the case when the model was periodically restarted but none of the variables was nudged. The results are shown in Fig. 11 for the mean concentration at ground level in April 2000 and in Figure 12 for the mean wet deposition.

In the simulation with periodic restart, lower concentrations were modeled in some regions (like the Po basin in north Italy and around Moscow). Here, higher wet depositions occur which leads to the conclusion that changes in the hydrological cycle might cause the differences in the concentrations.

6. CONCLUSIONS

The influence of different nudging options in the mesoscale meteorological model MM5 on the B(a)P concentrations and depositions in April 2000 was investigated. Significant differences, particularly in regions with high B(a)P concentrations were observed. Because in regions with lower B(a)P concentrations, enhanced wet deposition was modeled, it is likely that the hydrological cycle is significantly different in the two simulations.

Out of the nine investigated cases, the meteorological fields calculated with complete nudging of T, RH, u and v showed the lowest deviations from regular radiosonde observations. Nevertheless, some systematic deviations from the measured wind components, particularly the v-wind component exist. The v-wind component is underestimated in western Europe while it is overestimated in eastern Europe. This result was confirmed when selected wind profiler time series were compared to the modeled wind field. However, an explanation could not be found up to now.

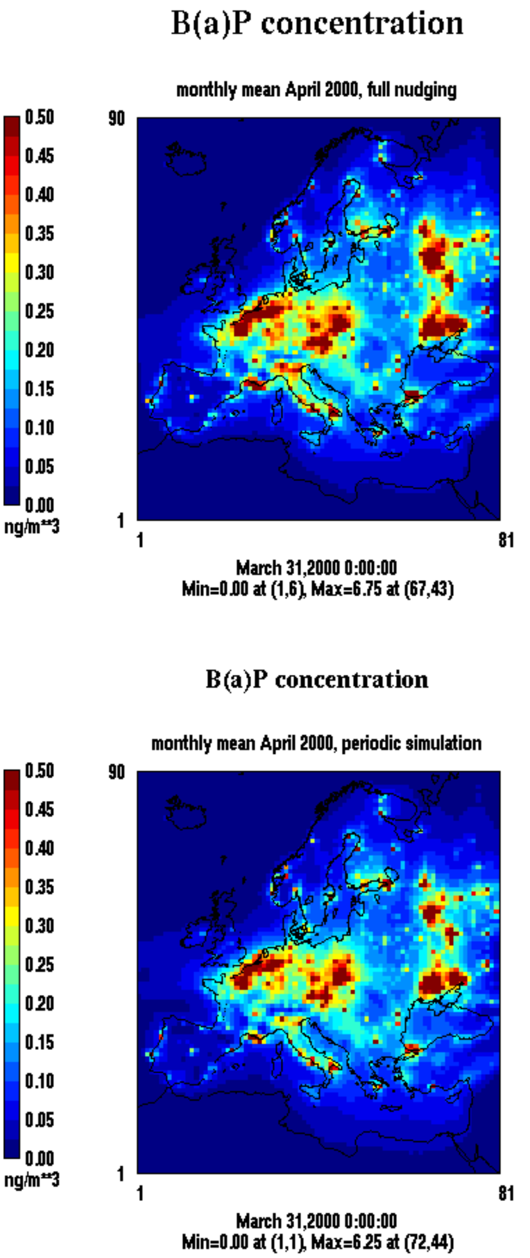

Fig. 11: Modeled B(a)P concentrations in Europe in April 2000 calculated with different meteorological input fields. Top: with full nudging of T,RH, u and v. Bottom: without nudging but with a periodic restart of the model every 4 days.

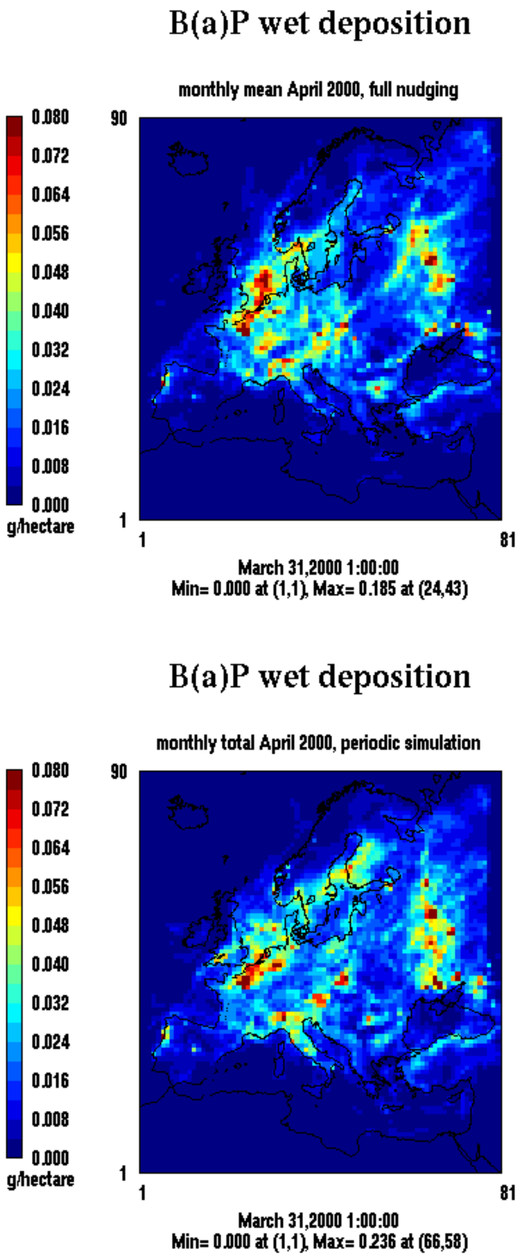

Fig. 12: Same as Fig. 11 but for wet deposition.

Acknowledgements

The authors are grateful to NCAR and Penn State University for the use of MM5 and to US EPA for the use of CMAQ. We thank Myles Turp (UK Met office) for providing wind profiler data from the CWINDE project.

References

Aulinger, A., Matthias, V., Quante, M., 2007: Introducing a partitioning mechanism for PAHs into the Community Multiscale Air Quality modelling system and its application to simulating the transport of benzo(a)pyrene over Europe. *Journal of Applied Meteorology*, accepted

Byun, D.W., Ching, J.K.S., 1999: *Science Algorithms of the EPA Models-3 Community Multiscale Air Quality Modeling System. EPA/600/R-99/030*, US Environmental Protection Agency, Office of Research and Development, Washington DC.

Chen, F. and Dudhia, J., 2001: Coupling an advanced land-surface/hydrology model with the Penn State/NCAR MM5 modeling system. Part I: Model implementation and sensitivity. *Monthly Weather Review,* **129**, 569-585.

Durre, I., Vose, R.S., and Wurtz, D.B., 2006: Overview of the Integrated Global Radiosonde Archive. *Journal of Climate,* **19**, 53-68.

Grell, G., Dudhia, J., and Stauffer, D.R., 1995: *A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5).* NCAR Technical Note 398, NCAR, Boulder, Colorado, USA.

Hong, S.Y., Pan, H.L., 1996: Nonlocal boundary layer vertical diffusion in a Medium-Range Forecast Model. *Monthly Weather Review,* **124**, 2322.

Kain, J., 2004: The Kain Fritsch Convective Parameterization: An Update. *Journal of Applied Meteorology*, **43**, 170-181.

Reisner, J., Rasmussen, R. J., Bruintjes, R. T., 1998: Explicit forecasting of supercooled liquid water in winter storms using the MM5 mesoscale model, *QJRMS*, **124B**, 1071.