Development and evaluation of a Zooming air pollution model for European Urban Studies (ZEUS)

A contribution to subproject SATURN

P. Louka[1], I. Douros[1], C. Simonidis[2], A. Arvanitis[1] and N. Moussiopoulos[1]

[1] Laboratory of Heat Transfer and Environmental Engineering, Aristotle University Thessaloniki, 54006 Thessaloniki, Greece
[2] Institute of Technical Thermodynamics, University of Karlsruhe, 76128 Karlsruhe, Germany

Summary

Multiscale model systems, capable of prescribing refined boundary conditions to the next smaller scale and incorporating accurate fluxes to the larger scales, will enable the establishment of more accurate source-receptor relationships. The multiscale model ZEUS (Zooming model for European Urban air pollution Studies) is under development, based on three-dimensional prognostic models. Within the year 2001, specific tests dealt with further evaluation of the core model of ZEUS, namely the prognostic, non-hydrostatic mesoscale model MEMO (Moussiopoulos, 1994, 1995; Kunz and Moussiopoulos, 1995). The further evaluation of MEMO is important as the wind fields predicted by the model are used as input to subsequent air pollutant dispersion and transformation simulations. For this purpose, the selected study case was based on the detailed ESCOMPTE pre-campaign experimental results to predict the mesoscale wind flow patterns in the complex area of Marseilles.

Aim of the research

This contribution is related to SATURN's urban cluster. It aims at developing and evaluating the Zooming model for European Urban air pollution Studies (ZEUS). Partial goals are the development of (i) a canopy scale model, (ii) a method for the coupled treatment of wind flow and pollutant dispersion, (iii) a "top-down/bottom-up" model cascade strategy including advanced turbulence models and (iv) appropriate modules for the description of condensation and heterogeneous chemistry in ZEUS.

The scientific objectives of this year concentrate on a further evaluation of the mesoscale model MEMO in order to assess the model's ability to predict the mesoscale wind flow patterns over complex terrains as well as its inter-comparison with other mesoscale models.

Activities during the year

MEMO was applied to the Greater Marseille area (GMA) in order to simulate airflow patterns observed during the ESCOMPTE pre-campaign period. The main objective was the evaluation of the mesoscale model MEMO as until now a correlation between the modelled and measured variables for the particular area has not been examined. At the same time the output of MEMO is compared with the output of other mesoscale models (cf. Galmarini & Peuch, 2002) in the frame of an intercomparison exercise. The selected case-study was the period between 29/6/2000 and 1/7/2000, i.e. a summer period for which, depending on the meteorological conditions, the formation of photochemical smog may be favoured. The numerical grids used for the simulations covered an area of 648×324 km^2. In order to assess the sensitivity of the model results to the grid resolution two

different cell sizes were used, namely 4×4 km^2 and 2×2 km^2. In all cases 25 vertical layers were assumed allowing for the finer resolution at lower altitudes. The depth of the lowermost (shallowest) layer was set to 20m, while model top was fixed at 6 km above the sea level. Soundings performed during the pre-campaign period were used for deriving the initial and boundary conditions of MEMO simulations.

The weather situation during the selected period was characterised by relatively light winds. As stability is concerned, the conditions of the atmosphere over the GMA could be characterised as unstable.

Principal results

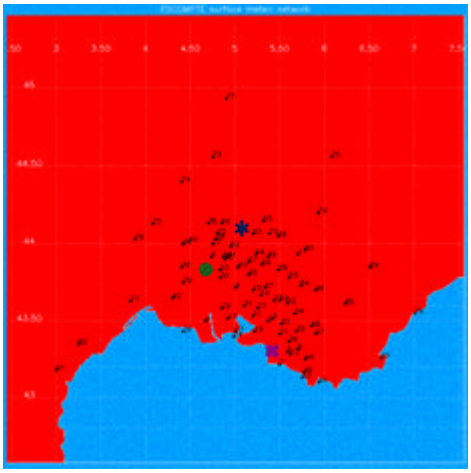

Figure 1. Location of the three chosen stations; ✖ for Marseille, ● for Tarascon, and ✱ Carpendras.

The adjacent map illustrates the area of South France and the location of all stations where measurements were obtained during the ESCOMPTE pre-campaign together with 15 more fictive stations for which model intercomparison is also performed (cf. Galmarini & Peuch, 2001). Three of the measured stations were chosen to be presented in this report at locations where different local meteorology was expected, namely a location by the sea (i.e., Marseille showed as ✖ in Figure 1), at a location further inland (i.e., Tarascon showed as ● in Figure 1), and a location far from the sea (i.e., Carpendras showed as ✱ in Figure 1).

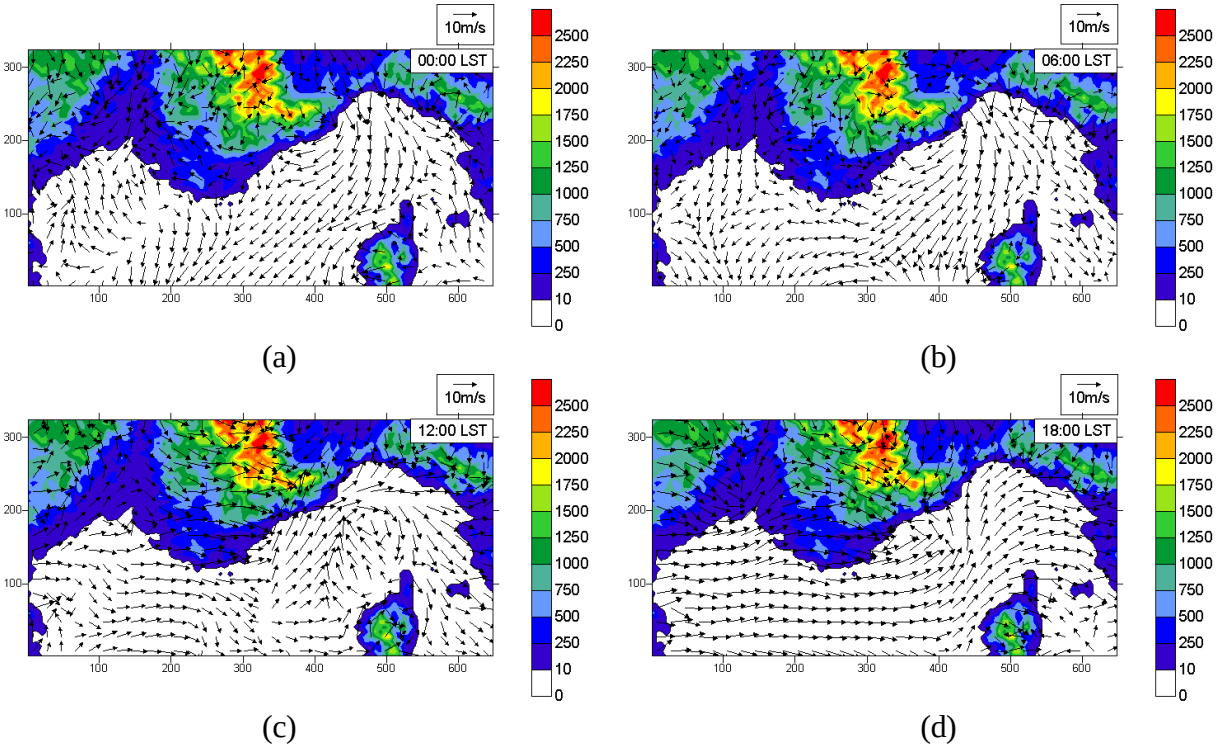

Figure 2. Example of the simulated wind field with resolution 2×2 km^2 on the 30th of June 2000 at (a) 00:00 LST, (b) 06:00 LST, (c) 12:00 LST, and (d) 18:00 LST. The colour scale corresponds to the orography of the region.

Figure 2 shows the simulated wind field with resolution 2×2 km^2 on the 30th of June 2000 at four times during the day. The predicted flow is generally characterised by north winds turning into northeasterlies over the sea at 00:00 and 06:00 LST, while katabatic winds may also be observed, the appearance of local circulations at noon due to convection, and finally the presence of local sea breeze at 18:00 LST.

Model evaluation

Figures 3 to 5 illustrate the time series for the simulated (with both resolutions) and measured wind speed, wind direction and air temperature, respectively for the three selected stations. In general, the simulated values for both resolutions are comparable, with those of highest resolution capturing more details as expected. Taking a closer look at each selected station, it is shown that for the station of Marseille located by the sea the correlation with measurements is better for the MEMO run with the highest resolution. Especially for velocity and temperature the simulated values with the highest resolution are very close to the measurements. For the stations of Tarascon and Carpendras located further inland, the performance of the model is also good with both MEMO runs being comparable and similar with the measurements. The model performance for temperature is found to be better for Marseille and Tarascon, while correlation is considerably higher for the daytime values than for night-time values for the station of Carpendras, for which night-time temperature is overpredicted.

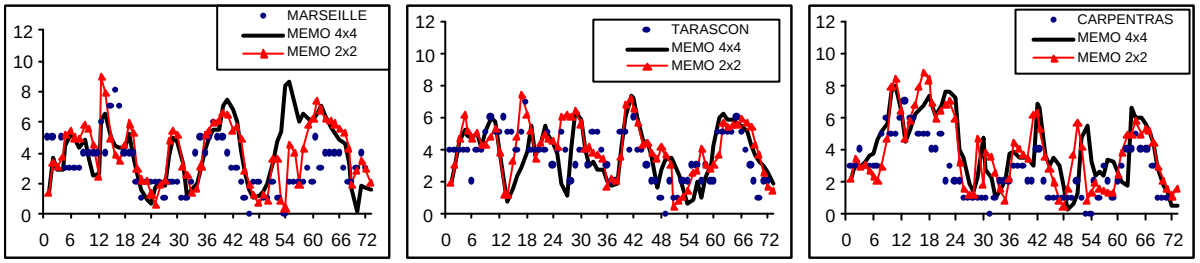

Figure 3. Wind speed at 10m over the ground for the three chosen locations

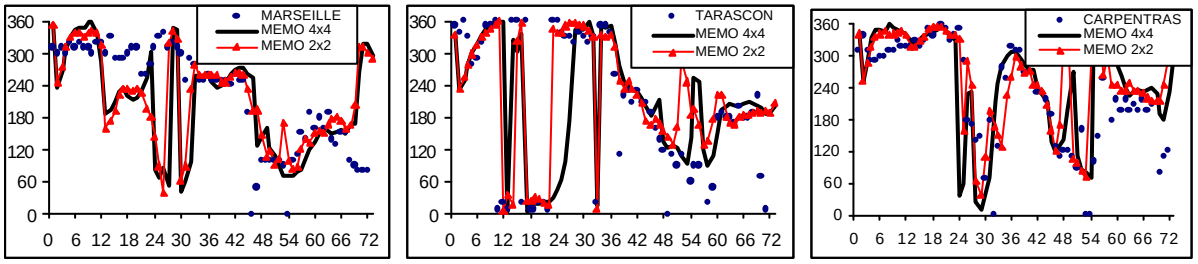

Figure 4. Wind direction at 10m over the ground for the three chosen locations

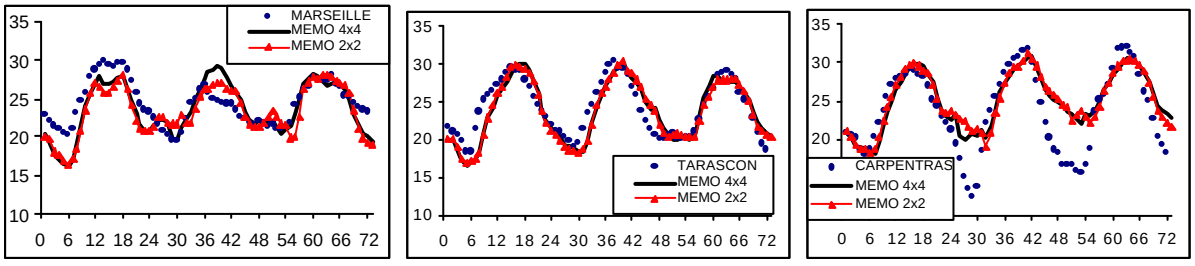

Figure 5. Air temperature at 10m over the ground for the three chosen locations

The results reflect the fact that physical mechanisms and processes governing the mesoscale wind flow in areas far inland are well predicted by the model with both resolutions used being similar. Closer to the sea for which local circulations are present and therefore flow is more complex, the highest-resolution simulation performs better as it captures more details of the local flow. It is suggested that the overprediction of the night-time temperature for the station of Carpendras located at a mountain's slope is possibly due to an underestimation of the radiative heat flux from the ground associated with the land-use categorisation implemented in the model. Overprediction of the night-time temperature is generally observed at all mountainous stations of similar positions. Considering the complexity of the subject, model performance can be assessed as good for surface wind speeds and temperatures.

Main conclusions

The non-hydrostatic mesoscale model MEMO has been applied to the meteorologically complex area of South France. Comparison with available measurements revealed that the model is capable of successfully reproducing the wind flow patterns with the performance being better for the highest resolution simulations especially for areas close to the sea.

Aims for the coming year

The focus for the coming year will be the development and testing of an integrated multi-scale model system capable of simulating the multi-scale transport and transformation of particulate matter (PM).

The coupling approach adopts one-way nesting at the local-to-regional scale: nested simulations of the mesoscale model considering both the dispersion and interaction of primarily emitted particles and the secondary formation of particles provide meteorological and pollutant concentration data to a series of domains. The microscale domain - resolving the geometrical details of a part of the city - is then allocated within the finest mesoscale domain as the lower end of the multi-scale model cascade. As a specialty of this approach, the microscale model results are used to improve the description of the boundary layer vertical structure in the mesoscale simulations. Quasi-steady microscale model computations then provide hourly averaged wind and near source pollutant concentration fields allowing investigation of the initial dilution phase in short distances from the exhaust. Henceforth, the obtained microscale model results are fed back to the mesoscale model thus improving the parameterisations of the canopy-atmosphere exchanges and vertical fluxes by taking into account microscale effects.

A generic aerosol chemistry submodel on the basis of an available concept (Arvanitis et al., 2001) will address specifically (i) the dilution phase and transformations in the first meters from traffic emissions; (ii) gas-aerosol interaction through evaporation and condensation; (iii) sea salt chemistry; (iv) transformations involving the crustal elements; (v) heterogeneous transformations involving organics; (vi) transformation and deposition of resuspended particulates. Upon its completion, the generic aerosol chemistry submodel will be appropriately optimised in order to provide to the various ZEUS constituents a working module for easy integration.

References

Arvanitis A., Moussiopoulos N. and Kephalopoulos S. (2001) Development and testing of an aerosol module for regional/urban scales. Proceedings of the 2nd International Conference on Air Pollution Modelling and Simulation, April 9-13, 2001, Paris.
Galmarini, S. and Peuch, V-H. (2002) Evaluation and Inter-comparison of mesoscale models on the ESCOMPTE pre-campaign (Summer 2000): Atmospheric flow simulation and passive tracer dispersion. SATURN Annual report 2001.

Kunz, R., Moussiopoulos N. (1995) Simulation of the wind field in Athens using refined boundary conditions. Atmos. Environ. 29, 3575-3591.

Moussiopoulos, N. (ed.) (1994) The EUMAC Zooming model: model structure and applications. Garmish-Partenkirchen: EUROTRAC Special Publication, ISS, 266 pp.

Moussiopoulos, N. (1995) The EUMAC Zooming model, a tool for local-to-regional air quality studies. Meteorol. Atmos.Phys. 57, 115-133.