Transactions on Ecology and the Environment vol 3, © 1994 WIT Press, www.witpress.com, ISSN 1743-3541

Nested wind flow simulation over the Lisbon region

M. Coutinho[a], R. Kunz[b], C. Borrego[a],
N. Moussiopoulos[c]
[a] *Department of Environment and Planning, University of Aveiro, P-3800 Aveiro, Portugal*
[b] *Institute of Technical Thermodynamics, University of Karlsruhe, D-76128 Karlsruhe, Germany*
[c] *Laboratory of Heat Transfer and Environmental Engineering, Aristotle University Thessaloniki, GR-54006 Thessaloniki, Greece*

Abstract

A nested version of the mesoscale meteorological model MEMO is applied to the Greater Lisbon Area. The simulation comprises three nested domains of resolutions 5 x 5 km^2, 2 x 2 km^2 and 1 x 1 km^2 centered over the city of Lisbon. This paper includes a description of the wind fields calculated for the medium and fine grid as well as vertical cross sections of the medium grid. Results enhance the importance of using fine simulations to depict the characteristics of the flow field in a area of such complexity.

1 Introduction

The Greater Lisbon Area (GLA), with a total population of 3.5 million inhabitants. was chosen for this study taking into account the geographical distribution of the main industrial sources and of the most important urban centers. Lisbon is built in a very complex topographic region, dominated by a 320 km^2 large estuary and multiple hills, surrounded by small mountain ranges reaching heights over 400 m above sea level (Figure 1).

The wind flow in the Lisbon region is influenced by several phenomena belonging to different mesoscale subscales. For prognostic wind flow simulations it is therefore necessary to model the different scale influences by adequate spacial and temporal resolutions. One possibility to achieve a higher resolution in parts of the model domain is to perform a nested grid simulation.

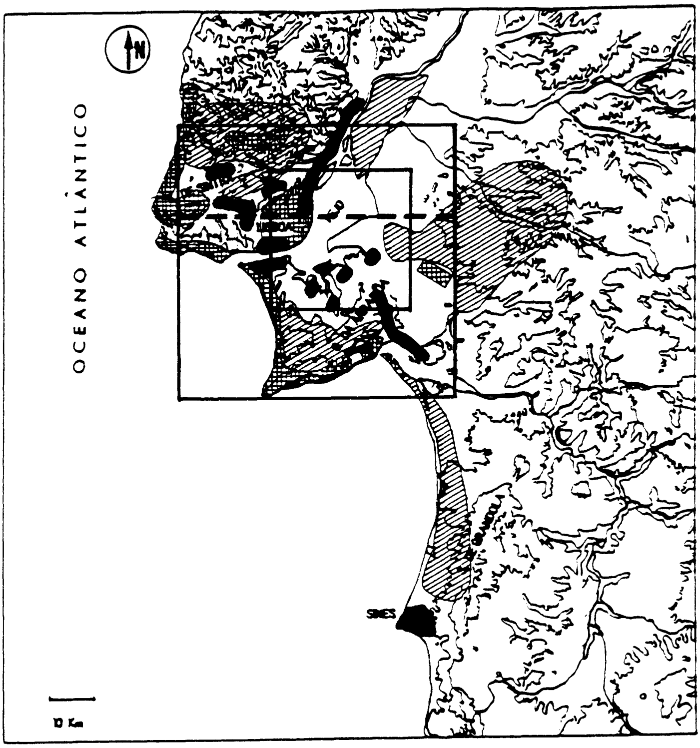

Figure 1: Location of the coarse, medium and fine grids. The location of the vertical cross section is given by the dashed line. Residential areas are squared, industrial areas are solid and forest and agricultural areas area marked with diagonals.

The mesoscale model MEMO is a non-hydrostatic prognostic model developed to simulate wind flow over complex terrain. The model MEMO is one of the core models of the EUMAC Zooming Model (EZM). It was developed at the University of Karlsruhe and is currently applied at several international research institutions. A description of the model MEMO is given in Flassak [1] and Moussiopoulos et al. [2].

Within the model MEMO the conservation equations for mass, momentum and scalar quantities like energy, humidity or pollutant concentrations are solved numerically. Due to the mathematical structure of the conservation equations both, an initial state and boundary conditions have to be specified. The initial state is derived using a diagnostic model based on measured data. Boundary conditions at the lower boundary are calculated taking into account solar radiation and heat fluxes at the ground. To determine the quantities at the lateral boundaries the solution of the model domain itself as well as the tendencies of quantities due to the large scale model environment have to be taken into account. In principle, large scale tendencies can be derived from measurements. As measurements are usually given at a rather poor spatial and temporal resolution a nesting facility was developped for the model MEMO to numerically generate lateral boundary values at a higher resolution in time and space. Furthermore, with the aid of a nesting technique it is possible to increase the resolution in parts of the modelling domain and thereby focus on special local effects.

The nesting technique which is used in MEMO is based on the expanded radiation boundary condition prosed by Carpenter [3]. It is a one-way interactive nesting scheme. So, the nested simulations need not be computed simultaneously. Hence, the requirement of main storage does allow to perform the nested simulations not only on a mainframe computer but also on a smaller computer like a workstation.

2 Case specification

The presented wind flow simulation comprises three nested model domains which coincide with three numerical grids: the coarse grid domain (CG) has an extension of 150 x 150 km^2 at a horizontal resolution of 5 x 5 km^2. The 60 x 60 km^2 medium grid domain (MG) is given at 2 x 2 km^2 resolution whereas the fine grid domain (FG) spreads over 30 x 30 km^2 at a resolution of 1 x 1 km^2. The location of the numerical grids are shown in Fig. 1. The height of each domain is equal and is set to 6000 m. Each numerical grid has a non-equidistant vertical gridspacing increasing with height and a minimum value of 20 m at the bottom. The landuse of the land surface in each model domain is uniform representing farmland.

The meteorological situation analyzed represents the most frequent meteorological type during summer in the Iberian peninsula [4]. A thermal low is created at the high and arid central plateau of the peninsula, producing a relatively strong (3-4 $m.s^{-1}$) N-NE wind over Portugal. Strong insolation promotes the formation of mesoscale circulations. The lower tropospheric pressure field for the 4th of August 1992 was selected because it is an example of a typical summer situation. An extension of the Azores anticyclone extended over the northern part of the Iberian peninsula and a low pressure system was located to the west of the British islands.

Meteorological data from vertical soundings were used to initialize the model and to determine the large scale part of the boundary conditions of the outermost nested model simulation. The time of simulation was 24 hours starting at 0.00 Local Standard Time (LST). The calculations were done on the vector processor SNI600/20 of the University of Karlsruhe. Each grid consisted of 30 x 30 grid meshes in the horizontal directions and 35 vertical layers.

3 Results

3.1 Wind fields

In this section results of the MG and the FG wind flow simulation are presented. Results of the CG simulation are only used to obtain the large scale part of the lateral boundary values for the MG simulation. The CG results are very similar to those presented by Coutinho et al. [4] and therefore are not presented in this paper. Figs. 2 and 3 show prognostic wind flow results of the MG and FG model domain, respectively. For reasons of clarity only one fourth of all wind vectors is plotted. The topography is plotted at intervals of 100 m.

The nocturnal flow pattern (400 LST) is dominated by north-easterly winds and the land breeze which develops nearly all along the coastline. Katabatic winds occur on the southern slopes of the Sintra and Arrabida mountains.On the northern slopes downslope winds are nearly completely suppressed by the synoptic forcing. Wind patterns calculated by the MG and FG simulation are rather similar with a slight reduction of wind speed in the FG results.

In the flow field at 800 LST there is no substantial change in neither the MG nor in the FG model results. At 1200 LST the land breeze offshore the Tejo Valley starts to deform. South of Mount Sintra and above the Atlantic Ocean the sea breeze was already established. As a consequence of the sea breeze, which develops west of the MG model domain, air flow above and north of Mount Sintra is directed onshore. When focussing on the FG model results at 1200 LST it can be observed that northerly winds south-east of Lisbon and above the estuary are still governed by the synoptic winds. Nevertheless, a lake breeze starts to form at the south-western coast of the estuary.

At 1600 LST the flow in the MG model domain is marked by a clear sea breeze front developing on the north-south direction following the coastline. In the range of the estuary local influences are dominant. Details of the flow above the estuary can be seen in the FG model results. Lisbon is now under the influence of the lake breeze which has reached an extension of about three km west of the estuary. North of Lisbon, air masses which are driven from the Atlantic Ocean towards the Iberian Penninsula are counteracting the lake breeze.

In the evening (2000 LST) the northernmost sea breeze has reached the area of the estuary. As a consequence, at this time the lake breeze is completely suppressed. At midnight the sea breeze has nearly stopped. Synoptic scale pressure gradients induce northerly winds in the northeastern part of the model domain and above the sea surface. Katabatic winds are enhanced on the southern slopes of Mt. Sintra and Mt. Arrábida. The flow pattern found in the

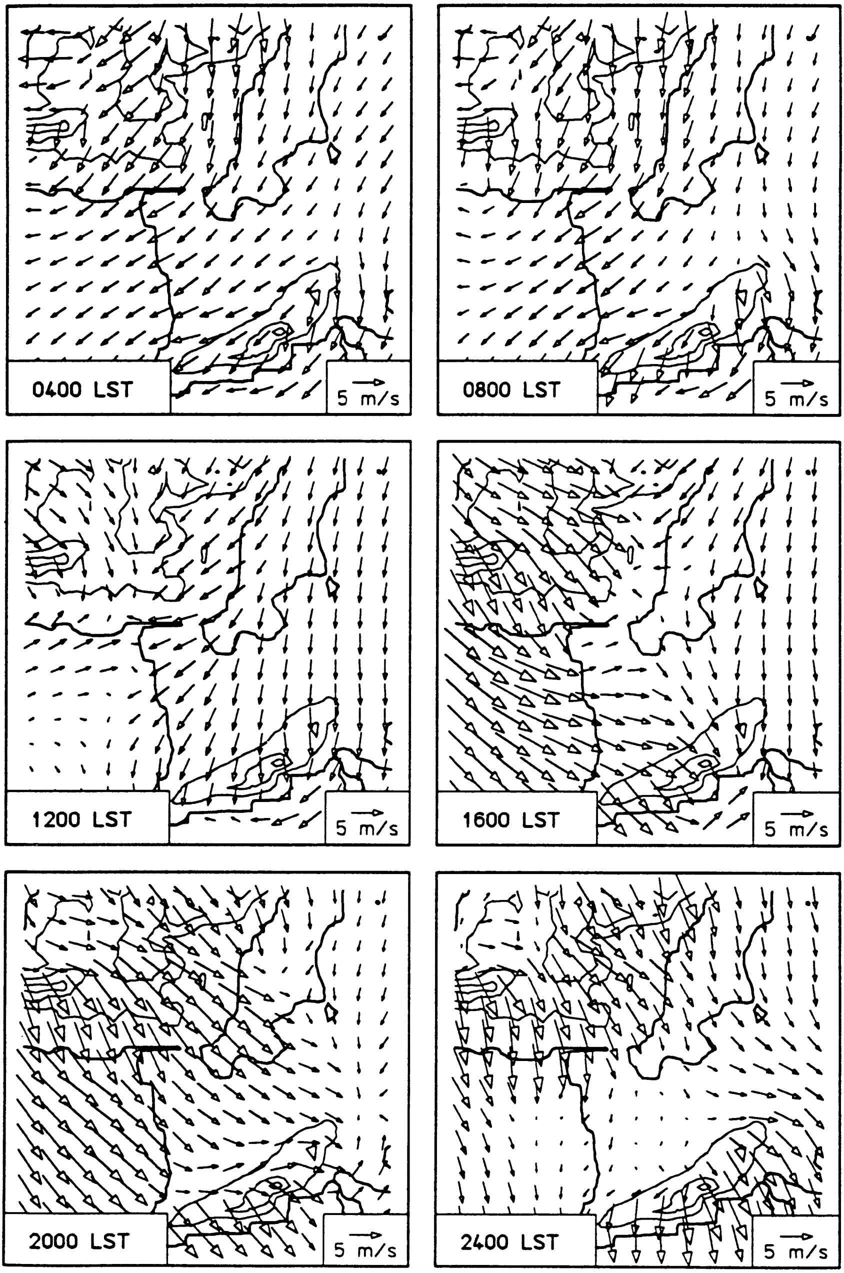

Figure 2: Wind field at approximately 10 m above ground level calculated with MEMO on the medium grid at 400, 800, 1200, 1600, 2000 and 2400 LST of August 4, 1992.

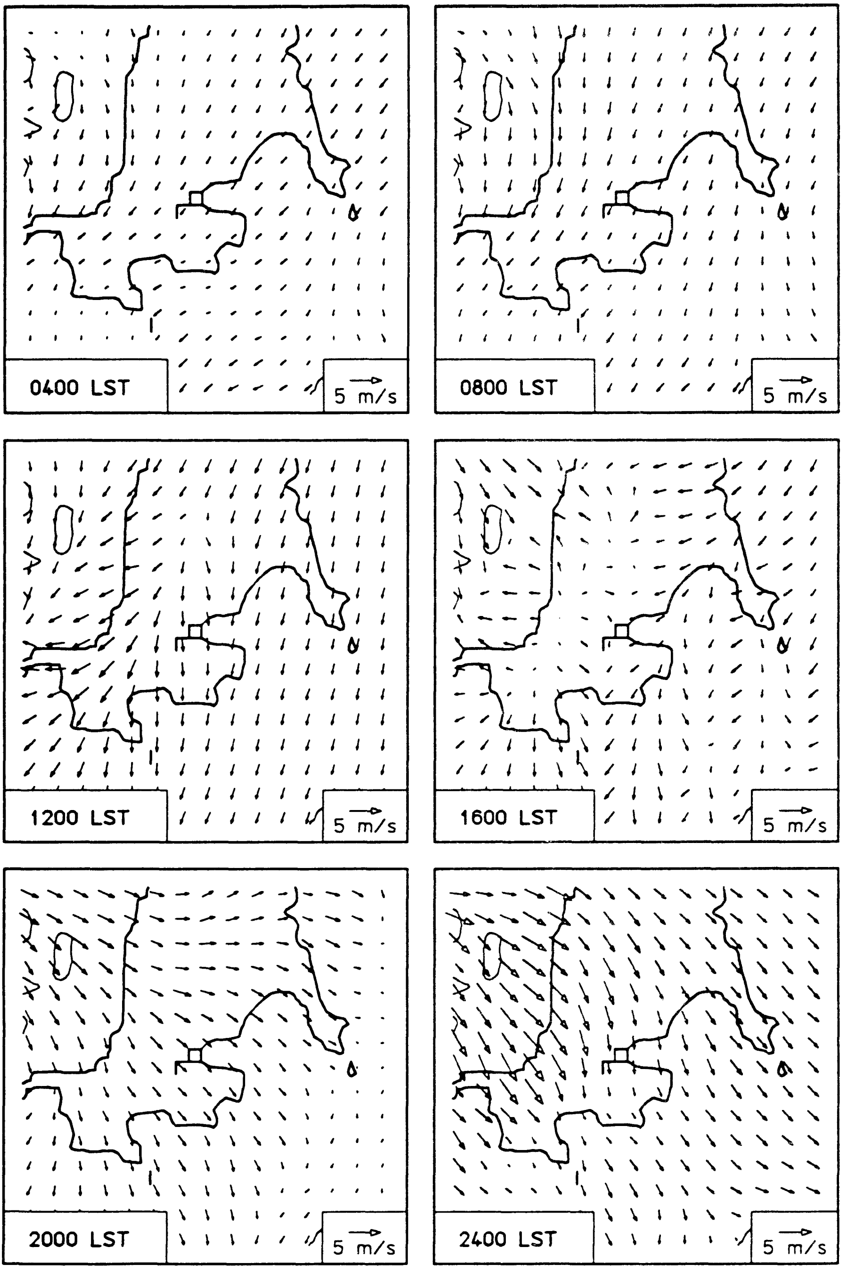

Figure 3: Wind field at approximately 10 m above ground level calculated with MEMO on the fine grid at 400, 800, 1200, 1600, 2000 and 2400 LST of August 4, 1992.

Transactions on Ecology and the Environment vol 3, © 1994 WIT Press, www.witpress.com, ISSN 1743-3541

MG model results is confirmed by the high resolution FG simulation.

3.2 Vertical cross sections

To illustrate the vertical structure of the flow field vertical cross sections of the prognostic MG flow field are shown in fig. 4. The cross sections reach up to a height of 2000 m above sea level (ASL). Vertical and horizontal components of the wind vectors are plotted using different scaling factors. So, the angles of the vectors do not correspond to reality. The site of the cross section is very close to the city of Lisbon. Its location is given in fig. 1.

In the morning (400 LST and 800 LST) the flow field shows a strong influence of the synoptic forcing as can be observed in the surface wind field. Winds are coming mainly from northern directions. In the vicinity of the mountains the winds are deflected towards north-easterly directions due to the influence of the topography. At 1200 LST east of Lisbon and above the estuary there are still northerly to north-easterly winds. In the mountaineous region near the coast, however, air masses are driven towards easterly directions by the influence of the sea breeze. As a result, a convergence zone forms west of the city where air is lifted up to higher altitudes.

In the afternoon (1600 LST) the convergence of air masses has moved to the centre of the city. The uplift is enforced due to the increased impact of the sea breeze and the development of the lake breeze in the afternoon. Air masses once being raised subside in the surroundings of the city and form vertical eddy structures.

At 2000 LST as the lake breeze has stopped and the convergence zone has moved to the estuary. In the western part of the modelling domain a reverse flow between 700 m and 1500 m ASL induced by the large scale forcing has started. As a consequence, air masses being lifted near the centre of the city are driven back to the sea. At the end of the simulation period (2400 LST) the elevation of air calms down. The reverse flow has expanded to the eastern boundary of the modelling domain.

4 Conclusions

A nested grid wind flow simulation was perfomed for the GLA using the non-hydrostatic model MEMO. Results show that the wind flow in the GLA, which decisively affects the dispersion of pollutants, is influenced by phenomena from different scales.

First there is the synoptic forcing by a large scale pressure gradient. As the characteristic time scale of synoptic processes is rather large compared to the mesoscale their influence on the atmospheric flow in the modelling domains nearly constant during the simulated period. An additional influence on the flow

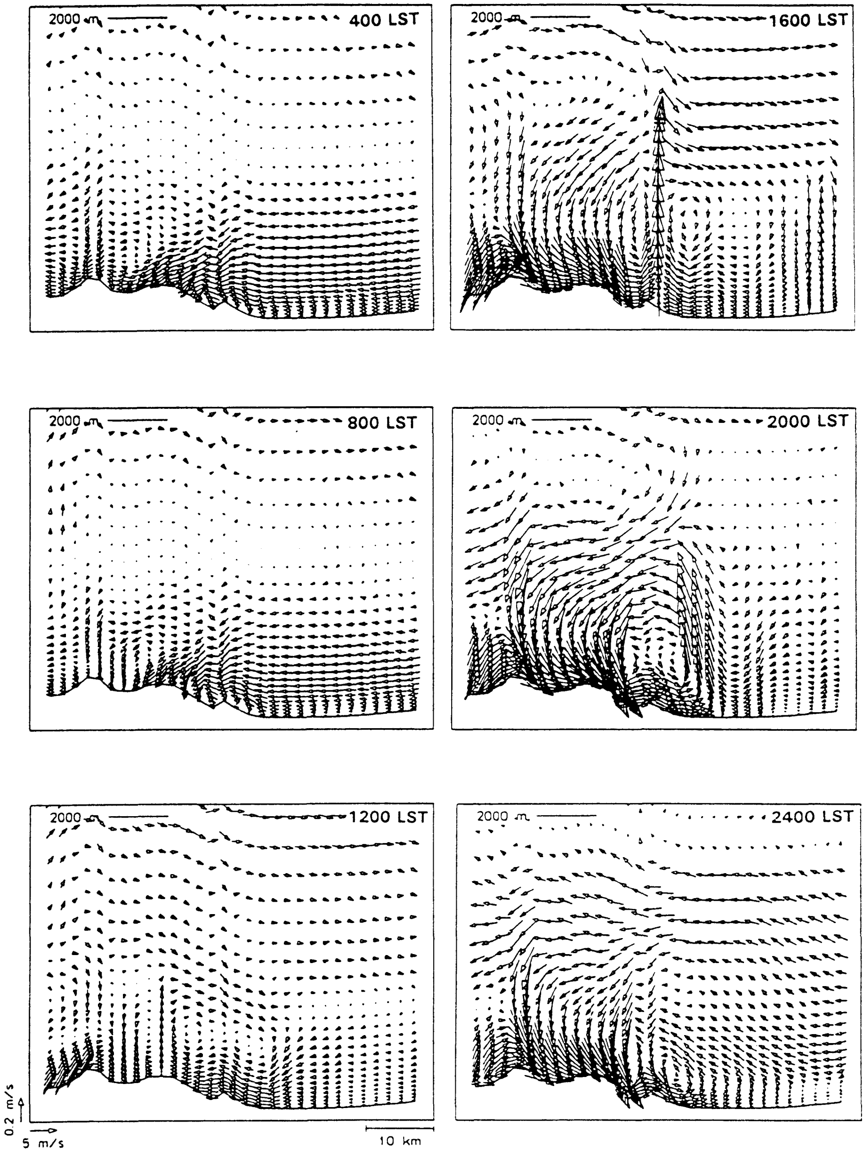

Figure 4: Wind field calculated with MEMO on a W-E vertical cross section over Lisbon at 400, 800, 1200, 1600, 2000, 2400 LST on August 4, 1992. The position of the cross section is marked in Figure 1.

pattern is due to the land/sea breeze circulation near the Atlantic coast. Both, the land-sea breeze circulation and slope winds induced by the complex terrain are properly resolved in the MG simulation. Furthermore, there is a local lakebreeze circulation which is caused by the estuary. The influence of the lake breeze on the wind flow in the Lisbon region is well described by the FG simulation. The model results predict that air being lifted to higher altitudes near the centre of Lisbon is driven out to the sea in the evening whereas during the day it is partly remixed to lower altitudes close to the city.

In the near future, results of the three grids will be compared with meteorological measurements. Further investigations shall be made using a more realistic landuse.

The nesting technique applied on this work represents a very powerful tool to analyse the most detailed features of the atmospheric flow that occur in complex topographic regions.

Acknowledgments

This work was prepared under the framework of the Luso-German Scientific Integated Actions.

References

1. Flassak, Th. *Ein nichthydrostatisches mesoskaliges Modell der planetaren Grenzschicht*, Fortschr.-Ber. 1990. VDI, Reihe 15, Nr. 74, 203 Seiten.
2. Moussiopoulos, N., Flassak, Th., Berlowitz, D., Sahm, P. Simulations of the Wind Field in Athens With the Nonhydrostatic Mesoscale Model MEMO, *Environmental Software*, 1993, **8**, 29-42.
3. Carpenter, K. M. Note on the paper 'Radiational condition for the lateral boundaries of limited-area numerical models' by Miller, M.J. and Thorpe, A.J. (Q.J. 107, 615-628), *Quart. J. R. Met. Soc.*, 1982, **108**, 717-719.
4. Coutinho, M., Rocha, A., Borrego, C. Numerical Simulation of Meso-Meteorological Circulations in the Lisbon Region, *Proceedings of the 20th International Meeting on Air Pollution Modelling and its Application*, in print, 1994.