5.19 NUMERICAL MODELLING OF FLOW AND DISPERSION IN ROME AREA

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INTRODUCTION

Air-quality problems affect almost all cities in the world. More worry scenarios take place in large cities where vehicular, industrial and domestic emissions of pollutants are increasing. Large urban areas often lie in the vicinity of the sea. In Mediterranean basin their climate are dominated by breeze regimes. Some observational and numerical studies have been realized for the breeze circulation in Athens (*Melas, D. et al.*, 1995 and 1998) and in Rome (*Mastrantonio, G. et al.*, 1994; *Leuzzi, G. and P. Monti*, 1997; *Caballero, R. and A. Lavagnini*, 2002). The city of Rome has about 3,5 million inhabitants and is located in a relatively flat area, about 25 km inland from the shoreline. Previous works showed that, in the case of light synoptic winds, the atmospheric circulation in that region is strongly influenced by local effects. In particular, daily and long term observations showed that, during the summer period, nights and days are generally characterised by land and sea breeze events, respectively (*Leuzzi, G. and P. Monti*, 1997). Furthermore, Rome is liable to the presence of slope winds originating at neighbouring mountainous areas (Central Appennines). The simultaneous presence of this large variety of flow patterns makes the analysis of the meteorological field very attractive in that coupling of so different structures are expected to give rise complicated wind fields and, consequently, very complex dispersion phenomena. Despite the frequent overcoming of concentration safety thresholds, numerical studies of Rome air quality are rather rare.

The aim of this work is to investigate the transport and the concentration of pollutants emitted by vehicular traffic in the urban atmospheric boundary layer associated to the city of Rome over a diurnal cycle. The wind and turbulence fields were evaluated by using a three dimensional meteorological model (CSUMM), while a Lagrangian stochastic model developed by the authors was utilised to calculate the dispersion of pollutants.

THE METEOROLOGICAL MODEL, THE DOMAIN AND THE INPUT DATA

The Colorado State University Mesoscale Model (CSUMM, version 2.0, developed originally by Pielke, R.A., 1974) was used for the evaluation of the wind velocity, temperature and specific humidity in a gridded domain. The performances of this model have been recently investigated by Monti, P. and G. Leuzzi (1999). CSUMM is a hydrostatic, incompressible, prognostic model able to predict the evolution of the atmosphere by the space-time integration of the budget equation of mass, momentum, heat and moisture. At the ground surface the temperature is evaluated from a heat balance, while moisture flux is proportional to an assigned "moisture availability parameter". The modelling domain (200x200 km^2) is nearly centred on the city of Rome. The model grid contains 201×201 horizontal grid points with a constant grid size of 1×1 km^2 and 18 grid points along the vertical. The lower 11 levels are z=10, 20, 44, 100, 300, 500, 700, 900, 1200, 1500 and 2000 m, the other 7 levels are equally spaced up to 9000 m with a grid size of 1000 m.

The model requires the knowledge of soil parameters as density, specific heat, thermal diffusivity, moisture availability, roughness length and albedo. The available CSUMM code did not permit the setting of these parameters at each grid point. As a consequence, in order to differentiate the soil parameters of the rural areas from those of the Rome urban area, the numerical code has been suitably modified. The simulation is referred to 21, 22 and 23

August 1994. During this period a high-pressure system with low pressure gradient was present over Italy, and the solar radiation was strong during the daytime. Therefore, the situation considered in the present study is appropriate for the development of thermally-induced flows like sea and land breeze, slope flows and urban heat islands. CSUMM requires the knowledge of the large scale geostrophic wind and the initial profiles of temperature and specific humidity. These data have been taken from Pratica di Mare radiosonde station (ITAV, Meteorological Service), located near the shore line (41°39'N, 12°26E) 24 km south of the centre of Rome, at an altitude of 12 m above MSL. Since in the lower layers winds recorded by the radiosonde are generally representative of local mesoscale circulation, rather than by large scale flow as required to initialise the numerical model, in the height range $0 < z < 100\,\mathrm{m}$ the wind data have been derived from a spatial averaging of CDC (Climate Data Center) data set. The temperature of the sea-surface is set to 300.5 K.

THE LAGRANGIAN STOCHATIC MODEL

A three-dimensional Lagrangian stochastic model based on *Thomson, D.J.* (1987) algorithm was used to evaluate the dispersion of the CO emitted by an inhomogeneous area source, simulating the emissions from vehicular traffic within the city of Rome. Data of CO emissions for a typical ferial day have been taken by STA (Mobility Agency for the City of Rome) report (*STA*, 2001). The Lagrangian model has been developed by *Monti, P. and G. Leuzzi* (1996) and *Leuzzi, G. and P. Monti* (1998) and in the present paper has been used a new version able to take into account unsteadiness of the flow field. Hourly output from CSUMM is used as input for the Lagrangian model. In particular, the three mean velocity components are directly available from the meteorological model, while the three velocity variances and the Lagrangian time scale have been derived from the computed friction velocity, turbulent kinetic energy and turbulent diffusivity.

RESULTS

Meteorological results

The meteorological simulation covers a period of 72 h. It starts at 0000 LST of 21 August and stops at 2400 LST of 23 August 1994. Figures 1 and 2 show the predicted wind fields at 10 m AGL at 0400 and 1500 LST of 23 August. The square indicates the Rome area, where the results corresponding to the simulation of dispersion will be shown.

At 0400 (Figure 1) drainage winds coming from the main mountain system are established. The land breeze is present all over the shore line, but two strengthening originate from drainage winds. In Figure 2 the horizontal wind field predicted at 1500 LST is shown. The sea breeze reaches its maximum intensity and merges with all the anabatic winds. The wind velocity above the Rome area is almost homogeneous. At night time land breeze and mountain winds are restoring. The first land breeze system forms in the southern coast, where mountains are located in the neighbourhood of the shore line.

Dispersion results

In this subsection the time evolution of the concentration field associated to the CO emission from vehicular traffic is investigated. Particle release starts at 0000 LST of 21 August and ends at 2400 LST of 23 August 1994, but only the results of the last day will be shown. The analysis is conducted by considering the concentration maps in the low layer (0÷10 m) associated to the flow field discussed in the previous subparagraph.

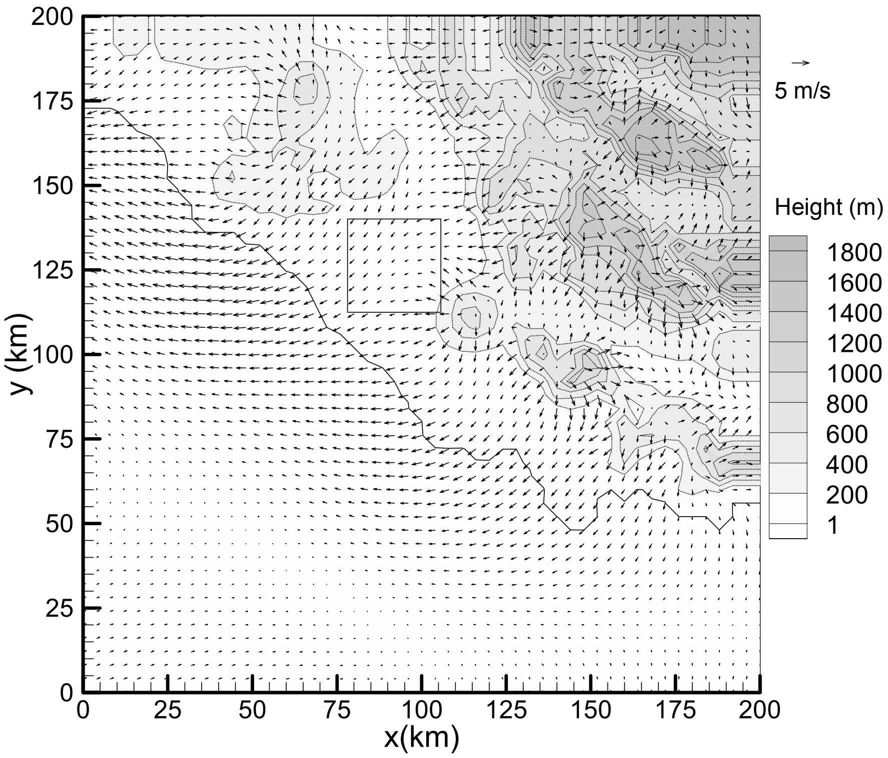

Figure 1. Horizontal wind vectors at ~10 m above the ground at 0400 LST 23 August 1994.

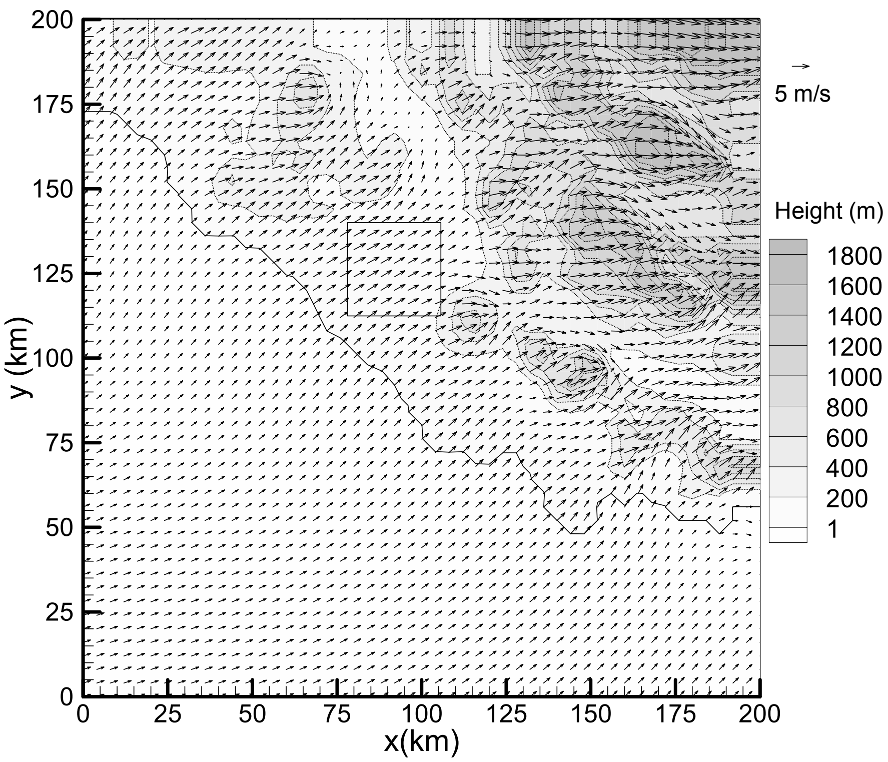

Figure 2. Horizontal wind vectors at ~10 m above the ground at 1500 LST 23 August 1994.

At 0900 LST the land breeze drops and the vehicular emission reaches the highest values of the day. Most of the polluted cloud is confined near the sources (Figure 3a) with a slow movement toward west. During the successive hours the sea breeze grows up. The pollutant particles are rapidly dispersed by a south-westerly wind, decreasing concentration levels. In the evening, after a clockwise rotation, the sea breeze gradually falls. Later, the pollutant tends to accumulate, giving rise to high levels of concentration downwind of the sources (Figure 3b). These effect are amplified by the strong thermal stratification that inhibits turbulence diffusion processes along the vertical direction. Suburban zones located downwind of the city may be subject to strong increasing of concentration levels. In Figure 4 the time history of CO concentration is plotted. CO computed levels are averaged in all the cells where a monitoring urban station is present. In order to consider the effect of the urban heat island (UHI) two simulations have been performed. In the first one the UHI has been simulated by assuming that soil parameters within Rome area have the typical values of urban soils. In the second run the urban soil parameters have been set equal to those of the rural areas; in doing so, UHI effects have been removed. CO peaks for the UHI case are quite lower, in particular for the early morning peak. This behaviour can be explained considering the more rapid erosion from below of the nocturnal boundary layer. Although CO concentrations are averaged in a large area, they show the same magnitude of the concentration typically measured by street side stations. This confirms the importance to simulate pollutant dispersion for a city as a whole, in that concentrations associated to local emissions are small compared to background concentrations.

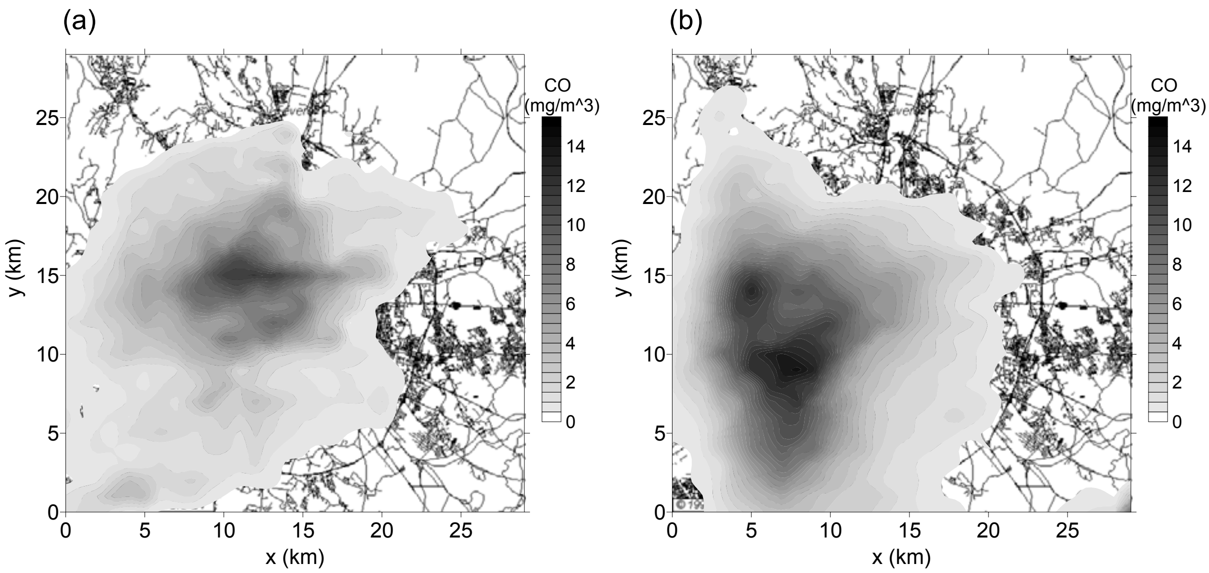

Figure 3. Concentration at the ground level at 0900 LST (a) and 2400 LST (b).

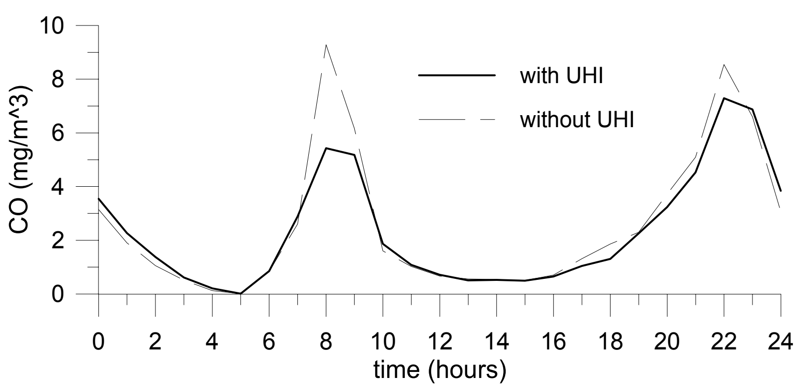

Figure 4. The time series of ground level CO with and without UHI.

CONCLUSIONS

This paper describes some preliminary results concerning the numerical simulation of wind and concentration fields performed in correspondence of the Rome area. A modified version of CSUMM (Colorado State University Mesoscale Model) and a stochastic Lagrangian particle model developed by the authors have been used for the analysis.
The salient findings of the present study can be summarised as follows:

- The urban boundary layer of the Rome area is strongly influenced by the land and sea breeze regimes. Both these winds interact with slope winds originating at neighbouring mountainous areas giving rise to complicated flow patterns.
- Early morning and late afternoon emission peaks correspond to wind drops due to the alternate switching between land and sea breeze. This fact increases the concentration peaks, in particular the second one which is preceded from an extended emission.
- In the night, a high level concentration cloud is advected by the land breeze toward the west suburbs. Critical pollution levels persist due to the strong atmospheric stratification characterising the land breeze.
- The UHI lowers both the concentration peaks, in particular the early morning one is reduced by a factor of two.

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