A modelling system for air quality estimates in coastal areas


Abstract

A combined modelling system consisting of a mesoscale meteorological model (Regional Atmospheric Modelling System/Colorado State University), a 3D diagnostic model (CALMET) and a Lagrangian puff dispersion model (CALPUFF) has been implemented to simulate air pollutant transport and dispersion in a coastal area influenced by mesoscale circulations. As preliminary test, the procedure has been applied over a coastal area in the South East Italy, whose geographic position and topography make simplified models unable to take into account most of needed details. Simulations were performed using EMCWF data in two real typical meteorological scenarios, with an hypothetical emission scenario. Results indicate that the system can be considered a useful tool to support decisions in evaluating air quality and the impact produced by a number of pollution sources.

1 Introduction

Mesoscale circulations together local effects caused by coastlines exert a significant influence on the atmospheric dispersion of pollutants, which can rarely be described by simplified models. Flow complexity becomes a crucial point in planing an air quality monitoring network. Most regulatory dispersion models are based on the steady-state Gaussian plume approach which assumes that flow is stationary and homogeneous. These hypotheses are no longer valid in presence of complex circulations. In such cases the ground-level impact of plumes is often determined by non-stationary 3 dimensional trajectories, which should be computed and used to drive pollutant transport and dispersion calculations. A combined approach to air pollution modelling is here presented which is able to reproduce the spatial variability of the wind field in complex coastal terrain,
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A combined approach to air pollution modelling is here presented which is able to reproduce the spatial variability of the wind field in complex coastal terrain, and in mesoscale studies involved domains of tens of kilometers. The system couples RAMS, a mesoscale meteorological model, and CALMET, a 3D diagnostic model in order to provide a realistic three-dimensional wind and temperature fields, and two-dimensional fields of boundary layer parameters to be used by the Lagrangian puff dispersion model, CALPUFF.

As a test of the procedure, the modelling system has been applied to the Salento Peninsula within a project concerning the realisation of an air quality monitoring network.

2 Description of the modelling system components

The Regional Atmospheric Modelling System (RAMS) is a highly versatile system developed at Colorado State University for simulating and forecasting weather systems, spanning in scale from an hemisphere down to the planetary boundary layer. Its major components are an atmospheric model, which performs the actual simulation and a data analysis package, which prepares initial data for the atmospheric model from observed meteorological data. The atmospheric model is constructed around the full set of primitive dynamical equations, which govern atmospheric motions; these equations are supplemented with optional parameterisations for turbulent diffusion, solar and terrestrial radiation, sensible and latent heat, exchange between the atmosphere, kinematics effects of terrain. The equation system is solved on a rectangular grid using terrain following co-ordinates. The most important features of RAMS are summarised in [1].

CALMET (CALifornian METeorological model) [2] is a meteorological model which includes a diagnostic wind field generator and a micrometeorological model for overland and overwater boundary layers. Here, it is used in the option which allows to consider as input the wind field produced by the prognostic model. CALPUFF (CALifornian PUFF model) [3] is a non-steady-state Gaussian puff model containing modules for complex terrain effects, overwater transport, coastal interactive effects, building downwash, dry and wet pollutant removal, and simple chemical transformation. It is designed to use the three dimensional meteorological fields provided by CALMET.

3 Description of the area

Salento Peninsula is located in the south-eastern corner of Italy (figure 1). The topography is quite flat along the coasts with small surveys, less than 200m high, along the central axis of the southern part.

The longitudinal axis of Salento is about 100 km long in NW-SE direction, the transversal one is in average 30-40 km wide. The area is surrounded by two different seas (the Southern Adriatic and the Northern Ionian Sea), connected by the Otranto Strait, having different values of salinity and temperature, and a
relatively small depth. Therefore, the area is subject in all its coastal perimeter (about 200 km) to complex sea-land-sea breeze systems. The presence of relatively close mountains, especially Balkans, far no more than 200 km, influences weather in a strong way, allowing the persistence of frontal systems for many days. The particular geographic position and topography of the peninsula makes the flow structure over it quite complex. All the $SO_2$ industrial emissions distributed over the area were considered in the dispersion simulations. The largest emissions are located along the right and left coastlines, in the Brindisi and Taranto area. The emission inventories are mean values for the whole year and therefore they can not represent the emission specific characteristics for each day and hour.

Figure 1: Salento Peninsula. Circles indicate emission points.

4 Meteorological scenarios

On the basis of the analysis of the weather maps (DWD) relative to the year 1998, two typical meteorological situations were individuated and selected: one in winter from 17 to 19 January 1998, the other one in summer from 24 to 27 July 1998.

In the first, the passing of a typical cold frontal system shows an interesting evolution of wind field. At the beginning, the upper map evidences the presence of a deep trough in all the domain with its centre between Sicily and Tunisia (500/1000 hPa chart 00:00 UTC 17 January 98). Therefore, a cyclonic circulation affects all the regions of central Mediterranean Sea. The southern part of an extensive frontal system extends from the north-western Italy to Sardinia, and moves toward the south-east. (Surface chart 00 UTC 17 January 98). After 24 hours, near the ground two centres of low pressure can be distinguished: one is located between Calabria and Sicily, the other one, corresponding to the passage of the frontal system, moves toward the south-east, crossing Puglia in all
its length (Surface chart 00 UTC 18 January 98). The eastern part of a ridge extends its effects on central and northern Tyrrhenian sea, pushing the upper level minimum across Sicily, toward the south-east (500/1000 hPa chart 00:00 UTC 19 January 98). At the end of the period considered, the front has passed across Italy and a new upper low is approaching the northern Italy from the north.

In the summer scenario, the synoptic situation remains almost constant for all the period. By the analysis of the weather maps it is evident that Italy is under the effect of the eastern side of a wide ridge and a moderate north-western circulation affects all the domain. At the ground, a levelled pressure field is present over Italy, with a northern circulation in Puglia near the ground. The north-western wind is the dominant climatological component over Salento in that period of the year, and its persistence may extend for one or more weeks consecutively.

5 Simulations results

5.1 Flow simulation

The RAMS model was initialised and driven using the ECMWF data, updating fields every six hours. Two nested grids were selected for the meteorological situations. The outer grid had a mesh of 26 x 36 points and 22.5 km horizontal grid increment, while the inner grid had a mesh of 35x35 points and 7.5 km horizontal grid increment, centred over Salento Peninsula (40.8° N 18.0°E). Twenty one terrain following vertical levels were used in both grids, having 100 m vertical spacing near the ground, stretching with a fixed ratio of 1.2 up the 13 level, 1000 m for higher levels.

From figures it is evident that a moderate upper south-westerly flow affects all the domain. The evolution of the flow near the ground reflects the movement of the frontal system. In particular, along the Otranto channel, ahead of the front, the low level flow is approximately southerly. After 24 hours, the rotation of the upper wind interests in particular the southern Tyrrhenian sea, where it rotates about 180 degrees counterclockwise. At 00 UTC of the 19 January, the upper flow is north-northwesterly in all the domain. Close the ground the pattern is more complex, with westerly winds over Tyrrhenian and south-southwesterly in the central Adriatic sea. At the end of the period, the flow is westerly over the whole domain, with a light southerly component near the ground.

Summer simulation started at 00:00 24 July 1998 and lasted 4 days ending at 24:00 27 July 1998. Figure 3 shows only some of the RAMS outputs, i.e., for the 24 July 1998 at four different times. The wind near the ground has got the same flow features in each day. The breeze results very intense only in the Ionian Calabria and Basilicata, in the south-western corner of the domain, where in the warmest hours the wind rotates from west-north-west to east (locally south-east).
Figure 2. RAMS simulations. Wind fields near the ground at 00:00 (a), 06:00 (b), 12:00 (c), 18:00 (d) of 17 January 1998

These regions are situated downstream the main flow, and therefore the intensity of the northern wind is reduced there. An apparent rotation from north-west to north-east appears also near Bari (in the central Puglia). Over Salento the effect is smaller and it appears just as a 30 degrees rotation from north to north-north-east.

Results obtained are in good agreement with the synoptic situation illustrated by weather maps, suggesting good model capabilities to reproduce the main features of the atmospheric flow.

5.2 Dispersion simulation

The wind fields produced by RAMS were used as input to CALMET model. This procedure has permitted the prognostic model to be run with a significantly larger horizontal grid spacing and different vertical grid resolution than that used
in the diagnostic model. CALMET also provides all boundary layer parameters necessary to run the dispersion model CALPUFF.

The winter dispersion simulation started at the same initial time of the flow simulation, i.e, 00:00 h 17 January 1998 and lasted for three days, ending at 23:00 h 19 January 1998. The summer simulation started 00:00 24 July 1998 and lasted for 4 days ending at 24:00 27 July 1998.

![Figure 3. RAMS simulations. Wind fields near the ground at 00:00 (a), 06:00 (b), 12:00 (c), 18:00 (d) of 24 July 1998.](image)

Figure 4 shows the ground level concentration fields for 17 January at different times. It is evident that plumes, following the flow at the different heights they are, disperse over the whole area. In one day the plumes rotate of 360°. As consequence, due to the winter weather instability, the pollution level is quite
Figure 4. CALPUFF simulations. Ground level concentration (mg/m³) at 03:00 (a), 09:00 (b), 15:00 (c), 21:00 (d) of 17 January 1998, at 00:00 18 January 1998 (e), 03:00 18 January 1998 (f) [→→ wind fields at 2500 m. →→ wind fields at ground level]
Figure 5. CALPUFF simulations. Ground level concentration fields (mg/m³) at 00:00 24 July 1998 (a), 06:00 24 July 1998 (b), 00:00 25 July 1998 (c), 06:00 25 July 1998 (d), 00:00 26 July 1998 (e), 06:00 26 July 1998 (f) [→→ wind fields at 2500 m. →→ wind fields at ground level]
low with $SO_2$ maximum ground level concentration localised around the largest industrial emissions. Different results are obtained in the summer simulated scenario. Figure 5 shows the ground level concentration fields at different times during the simulation period. Here, due to the wind direction persistence, the pollution level is quite high and concentrated in the same area downwind the largest emissions.

6 Conclusions

The RAMS-CALMET-CALPUFF modelling system has been implemented to investigate the capability of such a system to represent and reproduce mesoscale circulations and their effect on the transport and dispersion of air pollutants. Simulations were performed over the Salento Peninsula in two real typical meteorological conditions, one in winter and one in summer. Results obtained with CALMET combined with RAMS are in good agreement with those obtained with RAMS alone, and with weather maps. The mean flow has been then used to simulate the dispersion of pollutant in the area. The system appears to be a necessary tool to investigate the impact produced by a number of pollution sources in complex terrain, and to support decisions in planning air quality monitoring network.

References

