

Model simulations of industrial plumes over the Apulia-Region

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1 Introduction

Planning an air quality network to control ground level impact of industrial emissions distributed over an area of domains of tens of kilometers requires a detailed reconstruction of the emission, meteorological and dispersion scenarios. Mathematical models represent the only practical tool that can allow to individuate the best allocations for the future measurement points, and to integrate them for comprehension and forecasting of the pollutant dispersion phenomena. Most regulatory dispersion models are based on the steady-state Gaussian plume approach which assumes that the flow is stationary and homogeneous, but these hypotheses are no longer valid in presence of complex circulations.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. During the last years there have been important developments in mesoscale prognostic and dispersion modelling in parallel with increasingly affordable and accessible high performance computing and effective visualization of model output. The computational power offered by a common workstation allows to use of mesoscale prognostic models to drive dispersion codes. Aim of this work is to present a combined approach to air pollution modelling with a preliminary wind model evaluation. The system couples in cascade the mesoscale meteorological model RAMS, the 3D diagnostic model CALMET and the Lagrangian puff dispersion model, CALPUFF. The dispersion system has been applied to the Apulia region (South- Eastern Italy) within a project concerning the realisation of an atmospheric pollution network for industrial emissions.

2 Dispersion modelling system

RAMS (Pielke et al.1992) is a three dimensional, primitive equation atmospheric mesoscale model that uses a terrain following coordinate system. RAMS model was initialised and driven using the data from the European Centre for Medium-Range Weather Forecasts, updating fields every six hours. CALMET (Scire et al., 1990a) is a 3-D meteorological model which includes a diagnostic wind field generator and a micrometeorological model for overland and overwater boundary layers. CALPUFF (CALifornian PUFF model) (Scire et al. 1990b) 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. The models cascade allows the prognostic model to be run with different vertical grid resolution and a significantly larger horizontal grid spacing than the one used in the diagnostic model. CALMET also provides all boundary layer parameters necessary to run the dispersion model.

3 Description of the area

The model was applied to the Apulia region, located in the south-eastern corner of Italy. The area, surrounded by two different seas (the southern Adriatic and the northern Ionian Sea), is subject in all its coastal perimeter to complex sea-land-sea breeze systems, and has orographic reliefs up to 1000 m in the northern part (Gargano area).

Figura 1 shows the area with the position of industrial emissions and meteorological stations from the Italian Military Meteorological Service (Aeronautica Militare) which are used to evaluate the wind model performance.

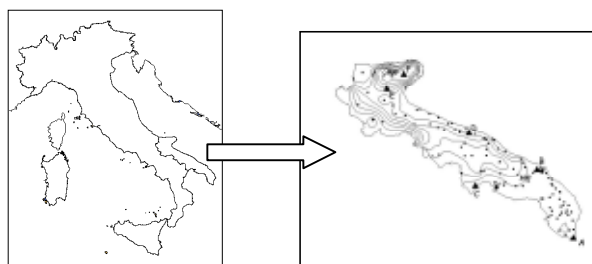


Figure 1 Area investigated. Letters indicate meteorological stations. Points indicate industrial emissions. Bigger points indicate the larger industrial emissions.

The meteorological measurements were taken at ground and stored at intervals of three hours. General information regarding the location of the meteorological stations are summarised in Table 1.

Table 1 Location of the meteorological stations *h* is the height relative to sea level.

STATION	lat.	long.	h (m)	STATION	Lat.	long.	h
			(m)				(m)
A	39°49'	18°21'	112	D	41°07'	16°54'	12
B	40°39'	17°57'	10	E	41°31'	15°42'	60
C	40°25'	16°58'	5	F	41°42'	15°57'	843

4 Simulations

4.1 RAMS simulations

Three meteorological situations were simulated. The first (Case 1) from 17th to 19th January 1998, is typical winter scenario, characterised by the passing of a cold frontal system which shows a rotation of an interesting evolution of wind field. The second (Case 2) from 24th to 27th July 1998 is typical summer scenario with the synoptic situation almost constant for all the period. The area 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 the Apulia near the ground. The north-western wind is the dominant climatological component over Apulia in that period of the year, and its persistence may extend for one or more weeks consecutively. The third (Case 3) 28th July 1999 was a typical sea-breeze situation. 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 32x32 points and 11.25 km horizontal grid increment, centred over Murge (40.8° N 16.9°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. Figure 2 shows the comparison between the predicted wind speed extrapolated at the surface and the measured surface data for case 1 and case 3, respectively. Figure 3 shows the temporal evolution of the wind speed at the 6 meteorological stations for case 2.

Two statistical quantities were computed from the all model results: the normalized mean square error, *nmse*, (characterising the amount of the deviation between predictions and observations), and the fractional bias, *fb*, (showing the tendency and the sign of the deviation):

$$nmse = \frac{(\overline{C_o} - \overline{C_p})^2}{\overline{C_o} \overline{C_p}} \quad fb \text{ (fractional bias)} = \frac{(\overline{C_o} - \overline{C_p})}{(0.5(\overline{C_o} + \overline{C_p}))}$$

where subscripts *o* and *p* refer to observed and predicted quantities, and an overbar indicates an ensemble average.

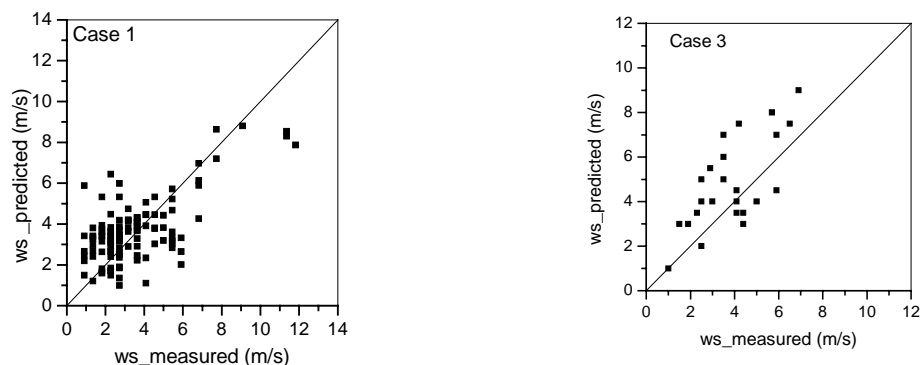


Figure 2 Scatter plot between measured surface wind speed and predicted for the 6 meteorological stations.

As the wind direction is measured with mechanical instruments, the reliability of these observations increases with increasing wind speeds. To avoid the statistical analysis of wind direction is falsified by the natural variability linked to low wind speed, wind direction values are only taken in account, if the corresponding wind speed exceed 1m/s. It is evident from figures and also confirmed by the statistical indices summarised in Table II that the prognostic model can reproduce in a realistic way the wind field in the cases considered.

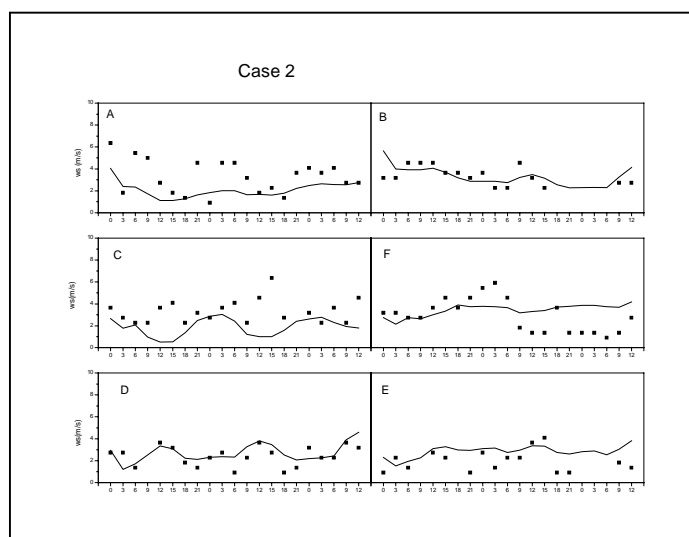


Figure 3 Time series of the observed and simulated wind speed at the 6 meteorological stations. Points indicates measurements. Continuous lines indicate the model.

Table 2 Global analysis results.

	Wind speed (m/s)		Wind direction (deg)	
	Nmse	fb	Nmse	fb
All cases	0.26	-0.05	1.1	-0.31

4.2 Rams –Calmet-Calpuff simulations

Dispersion simulations were performed considering the main industrial emissions distributed over all the area investigated. Figure 4 shows an example of the ground level concentration fields for 17-18 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°. Thus, the pollution level, due to the winter weather instability, is quite low with SO₂ maximum ground level concentration localised around the largest industrial emissions.

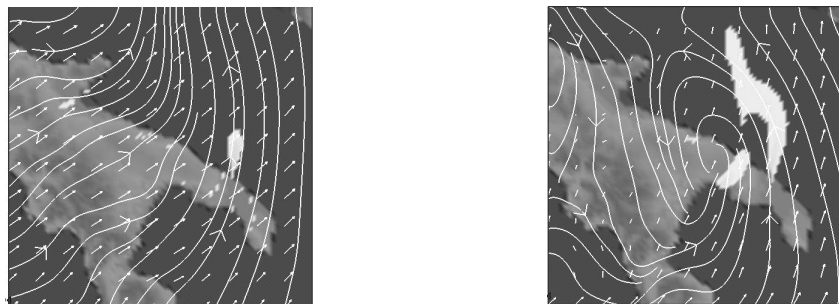


Figure 4 CALPUFF simulations. Ground level concentration at 03:00 (a) 15:00 (b) 17 January 1998 [→→→ wind fields at 2500 m. →→→ wind fields at ground level].

Figure 5 shows the ground level concentration fields for Case 2 at different times. Here, due to the wind direction persistence, the pollution level is quite high and concentrated in the area downwind the largest emissions.

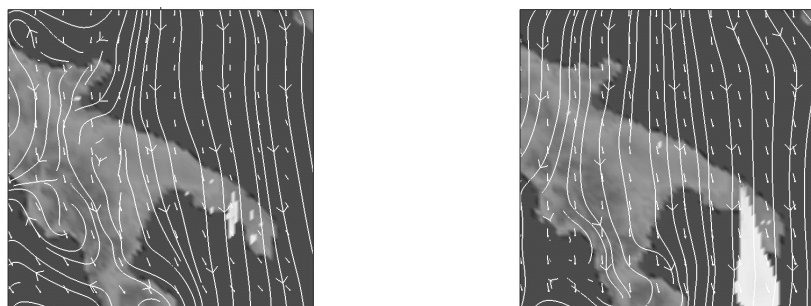


Figure 5 CALPUFF simulations. Ground level concentration fields at 03:00 (a), 15:00 (b) 24 July 1998 [→→→ wind fields at 2500 m. →→→ wind fields at ground level].

5 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 Apulia region in some real typical meteorological conditions. Comparison between RAMS predictions and measured shows that the model can simulate the general mean wind field over a complex area in a realistic way. Despite a good overall agreement, there are some discrepancies in some stations. This could be due to the insufficient spatial representation of topography that does not allow the resolution of the local terrain effect. It has been noted that measurements are taken at a discrete location while calculated values are representative for a grid cell of 11200x11200m.

The mean flow has been then used to simulate the dispersion of pollutant in the area. The global 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

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