A Comparison of Different Modelling Techniques to Evaluate Atmospheric Dispersion of Pollutants in Complex Coastal Sites

A contribution to subproject CAPMAN

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Summary

The performances of the Lagrangian particle model SPRAY (Tinarelli et al., 1994) and the US EPA regulatory model ISC3ST (US) have been intercompared in two applications dealing with industrial emissions at coastal sites. The two considered models have been applied to reconstruct climatological ground level concentrations around the thermal power plants of Fusina, nearby Venice, and Vado Ligure. The former site is characterised by flat terrain and shows the climatological features of the north-western Adriatic Sea coasts, with local scale circulations like sea/land breezes having a limited statistical frequency. The latter site is located on the Ligurian coast and it is characterised by very complex terrain and a climatology dominated by the superposition of land/sea breezes and slope flows. In Venice, the two models give similar results for both long term average concentrations and daily average percentiles. Relevant differences have been observed only for very high (over 98^{th}) hourly average percentiles and maximum values. On the contrary, at the more complex Vado Ligure site the two modelling systems produced different results that are hardly comparable. The reliability of the downscaling of synoptic weather data to the local scale to drive air pollutant dispersion models in complex coastal conditions, has been evaluated through the application of a mesoscale prognostic model. Grid nesting technique has been used to enhance space resolution from the meteorological analysis grid size (0.5 deg.) to the target resolution of 1 km. The prognostic non-hydrostatic model RAMS (Pielke et al., 1992) has been used as the meteorological driver for the Lagrangian particle model SPRAY. The results of earlier modelling applications on the site of Vado Ligure offered the possibility to compare diagnostic and prognostic meteorological codes. This comparison has been extended to the pollutant concentration produced by the same dispersion model driven by the two different meteorological approach. The overall results obtained by the two modelling systems seem to be comparable.

Aim of the research

In this phase of the project we wish to compare the results obtained through the application of a modelling system made by a mass-consistent diagnostic meteorological model coupled with a Lagrangian particle model and a steady state Gaussian model. Even if it is well known that steady state models are not suited to reproduce dispersion phenomena in complex terrain, they are still frequently employed in the frame of air quality impact assessment studies. It is therefore relevant to compare the concentration fields obtained by the different modelling techniques in such a complex condition. A different item of our project regarded the possibility to reconstruct local flow fields directly from large scale meteorological information. This potentiality is very interesting for practical applications because the diagnostic reconstruction of local scale flow needs to be based on local meteorological measurements (ground stations and vertical profiles) that are normally hardly available, and the execution of very expensive and time consuming field campaigns. The comparison of

diagnostic and prognostic meteorological model results can set in evidence the advantages and limitations of the two modelling approaches.

Activities during the year

The performances of the Gaussian model ISC3ST and of the modelling system composed by the mass-consistent meteorological model MINERVE (Aria Tech., 1995) and by the Lagrangian particle model SPRAY have been compared in two practical applications concerning industrial emissions at coastal sites. The first test case regarded the site of Fusina. The place is characterised by flat terrain and local wind measurements that generally show a limited horizontal variation and vertical shear of the winds. The two models have been applied to compute ground level concentrations due to the emissions of two thermal power plants located a few kilometers apart. The simulations covered a period of one year. Hourly average concentrations have been post-processed to compute long term statistics. The concentration fields corresponding to the Italian and European standards and guidelines have been intercompared. The second test case concerned the reconstruction of ground level concentrations due to the emissions of a thermal power plant sited in Vado Ligure. On site field campaigns provided a relevant amount of data for model evaluation. During a previous study, short term episodes have been reconstructed through the application of the cited MINERVE+SPRAY modelling system. Hourly ground level concentration fields have been then used to build seasonal and yearly averages, applying a method based on the statistic of the weather type associated to each episode. These results have been used as a basis to compare concentrations obtained by the Gaussian model ISC3ST, that has been applied to simulate the whole year that includes the previously analysed episodes. In order to verify the possibility to reconstruct local flow directly from large scale meteorological information, a selected summer episode (23-25/07/1997) has been simulated applying the non-hydrostatic prognostic model RAMS. A two way nesting technique has been employed to describe both the synoptic driving flow and local scale phenomena. Three nested grids have been defined, with horizontal resolution of 16, 4 and 1 km respectively, for a total space extension of about 1100, 200 and 53 km. RAMS has been initialised using the ECMWF 0.5 degrees resolution analysis fields, synoptic and local observations. ECMWF analyses have been used to drive boundary conditions with a 6 hour time resolution. The Lagrangian particle model SPRAY has been driven by the mean wind fields generated by both MINERVE and RAMS meteorological processors. Diagnostically simulated turbulence fields have been defined using a built-in parameterisation scheme based on the Monin-Obukhov similarity theory and the evaluation of the surface energy budget. In the prognostic case, turbulence fields have been generated by the interface code MIRS (Trini Castelli and Anfossi, 1997), that uses the information given by the closure parameterisation scheme employed by RAMS. In particular the velocity variances $\sigma_i^2 \, (i = 1,2,3)$ were computed either from Hanna (HS) scheme (1982) or from RAMS according to the Mellor and Yamada (MY) closure scheme (1982).

Principal results

In the coastal site of Fusina, characterised by a rather simple wind climatology, the results of MINERVE+SPRAY and ISC3 models are comparable, at least for the more relevant features of the concentration fields. Important differences are observed only for hourly percentiles higher that 98th. A quite different result is obtained for the site of Vado Ligure, where terrain and flow complexity originated large differences in the concentration fields produced by the models. For seasonal and yearly average (*Figure 1*) concentrations the two models indicated areas of impact located over different portions of the computational domain. Moreover the average concentration fields produced by ISC3 do not reproduce the wind rose characteristics. ISC3 showed a tendency to overestimate concentrations, producing maximum values that are

not observed by any station of the air quality control network. Concerning the evaluation of the possibility to downscale synoptic weather information to the local scale, RAMS correctly reproduces the breeze cycle features close to the ground, with a general tendency to overestimate wind speeds near the surface. There are instead some problems to reproduce all the spatial and temporal details shown by the measurements. The main discrepancies are located in the layer between 750 m and 1500 m. Figure 2 shows horizontal wind cross-sections produced by MINERVE and RAMS in the layer closer to the surface during nocturnal land breeze conditions. The wind pattern is similar in the region around the power plant location, while in the northern, western and south-western part of the domain the two wind fields substantially differ. With regard to dispersion simulations, the two modelling systems show results of comparable quality. The RAMS+SPRAY modelling system seems to be more reliable than the diagnostic modelling system in regions not covered by meteorological measurements, far from the emission. As an example, *Figure 3* depicts the SO_2 g.l.c. trends recorded at the Bocca d'Orso chemical station, located 8.7 km to the north-west of the emission site, at a height of 530 m asl.

Main conclusions

The evaluation of the impact on air quality of industrial emissions has to verify the attainment of air quality standards that usually state limits on yearly and seasonal statistics of pollutant. In coastal areas, where non-stationary meteorological conditions can be frequent, different modelling tools can give very different results, influencing the compliance with air quality standards. Steady state and 3D modelling techniques give similar results only in places characterised by "simple" wind climatology, e.g. sites characterised by weak space variations of wind speed and direction. In complex coastal sites 3D models are needed to correctly reproduce at least the major features of pollutant dispersion. The comparison of diagnostic and prognostic meteorological models used as a driver to Lagrangian particle dispersion models showed results of comparable quality. These results confirmed the possibility to use meteorological fields obtained from the prognostic downscaling of large scale weather data to reconstruct the local scale flow where extensive observations are not available. This approach can be an alternative to the use of diagnostic models based on an expensive measuring network.

Aim for the coming year

The activities concerning the coastal sites of Fusina and Vado Ligure and financed by ENEL have been completed during the last year. The possibility to start a new project concerning photochemical pollution in southern Italy coastal sites is being discussed.

References

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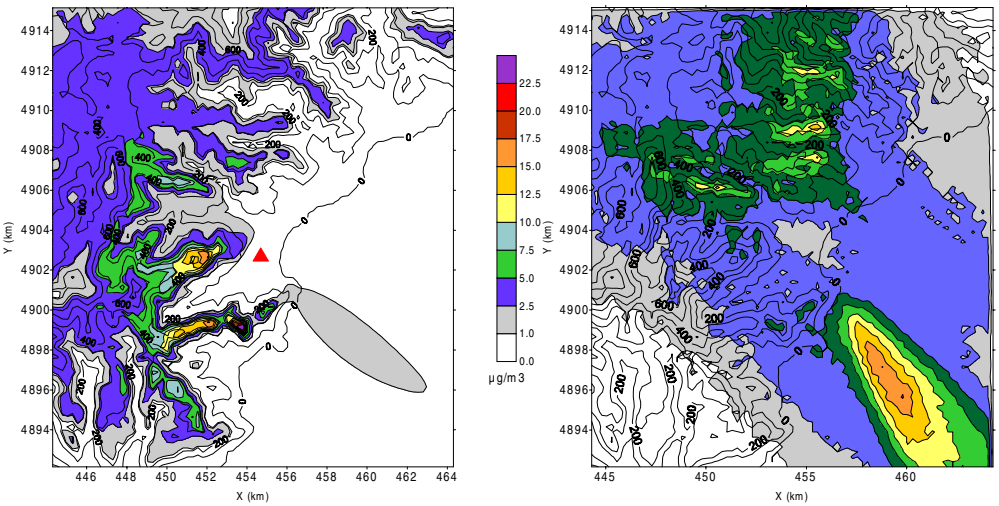

Figure 1. Ground level yearly average concentration of SO_2 (µg/m^3): (left) ISC3ST, (right) SPRAY driven by MINERVE. The red triangle indicates the emission location.

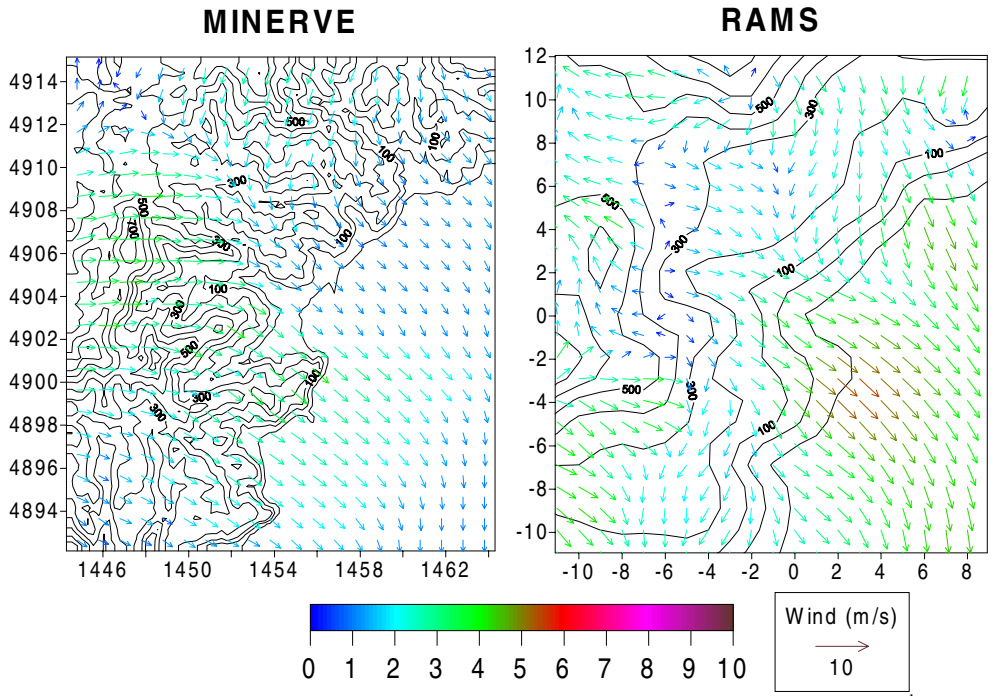

Figure 2. Near ground wind field computed by MINERVE (left) and RAMS (right). July 23rd 1997 23:00 lst.

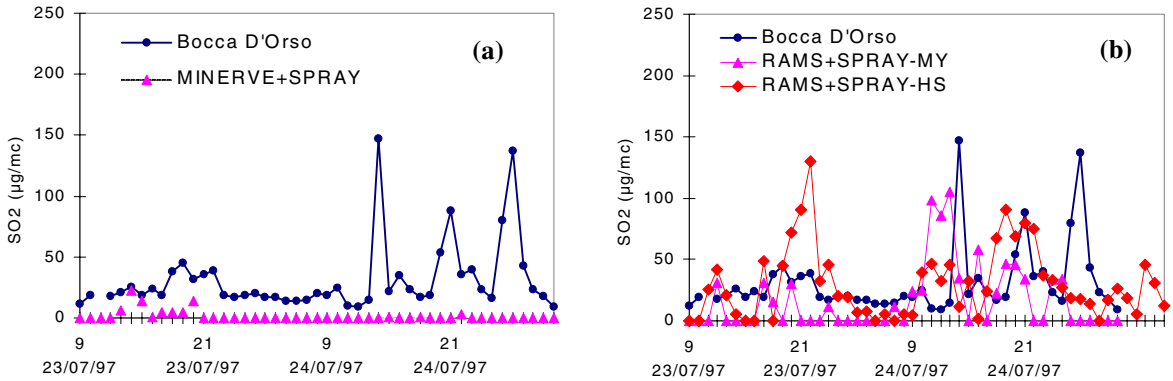

Figure 3. Comparison between computed and measured g.l.c. time series at the Bocca d'Orso station. a) MINERVE+SPRAY b) RAMS+SPRAY