EVALUATION OF REAL-TIME MODELLING SYSTEMS FOR POLLUTANT DISPERSION IN CASE OF INDUSTRIAL ACCIDENTS

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INTRODUCTION

In the case of accidents involving the emission of pollutants in the atmosphere, health authorities and local administrators often need to know what areas could be affected by dangerously high pollutant concentrations. Reliable modelling tools are necessary in order to provide real-time risk evaluation and management.

The goal of the project described in this paper is to evaluate a ready-to-use and semi-qualitative modelling system, including a meteorological processor and a dispersion model, flexible and reliable enough to be used for such real-time evaluations. The different types of emissions involved, such as the release of toxic substances or of smoke from fires, require, in principle, different approaches (e.g. depending on type of pollutants, emission rate, temperature and velocity). Of these parameters, emission rates are important for a quantitative estimate of pollutant concentrations, but the qualitative description of the dispersion and time evolution of a plume doesn't require a good estimate of source strength. Temperature and emission velocity, on the other hand, affect plume rise and dispersion, and therefore the spatial distribution of the smoke.

Even though steady-state gaussian models are still often used (mainly because of their simplicity) for emergency situations, it is well known that they are not suited to describe events on a short time scale. For the modelling of such an episode, with different possible emissions characteristics and variable meteorological conditions, a three-dimensional, non steady-state air quality model was considered necessary. The lagrangian model SPRAY (*Brusasca, G. et al.*, 1998; *ETC/AAC*, 2003) and the gaussian puff model CALPUFF (*Scire, J.S. et al.*, 2000) have therefore been tested. They were applied to the fire of a waste storage plant. The dispersion models were tested first by generating meteorological inputs with appropriate diagnostic models, CALMET (*J. S. Scire et al*, 2000) and MINERVE (*Aria Technologies*, 2001), starting from real-time meteorological data from standard instruments and local radio-soundings. In order to evaluate the possibility of using the modelling system to predict the evolution of the smoke plume, the second application involved the use of forecast meteorological fields provided by a non-hydrostatic prognostic model, the limited area model LAMI (*COSMO*, 2005).

DESCRIPTION OF THE EVENT

The case study under analysis was that of the fire of a waste storage plant in Baranzate, near Milan. The fire lasted for about 5 hours (from 6 to 11 a.m. on July 30, 2004), causing interventions of administrative authorities, such as the closure of the Milan-Varese motorway. A large smoke plume invested the Milan urban area and was observed by MSG1 (*fig. 1*), a geostationary satellite launched by EUMETSAT in 2002 with enhanced space-time resolution and increased number of channels compared to the previous Meteosat7. The satellite photos, with a time step of 15-minutes, are available from the High Resolution Visible Radiometer (see www.eumetsat.int); they show the initial widening of the plume in the western part of the metropolitan area and then its transport and further dispersion to the south-east, up to the borders of Lombardy.

Fig. 1: Photos of the plume taken presumably at 7a.m. (left) and 8 a.m. (centre). On the right, an example of a satellite image: the white spot is Milano city, while the not-so-easily discernible dark area below is the smoke front at 8 a.m.

These images were used as a tracer for the fire plume, but it must be stressed that only the southeastern displacement during the central and final part of the event is clearly depicted. Other characteristics of the plume were obtained from photos from the ground and technical reports. All these documentation has been used to derive information about the evolution of the event and to perform a qualitative comparison with the model predictions.

EVENT METEOROLOGY

A 3-D non stationary meteorological description was necessary in order to run the dispersion models so that essential features such as wind shear, variable emission rates and a buoyant area source could be treated on a short time scale. During the event, on a synoptic scale, Northern Italy was under the influence of an anticyclonic ridge whose Southwest-to-Northeast axis was situated over the Iberian Peninsula. This produced a Northwesterly dry flow with fair weather and typical summer temperatures (minimum of 20 °C, maximum of 30-32 °C), clear sky conditions with haze in the lower layers. At 500 hPa there was a moderate Northwestern wind (3-7 m/s), whereas between 850 and 700 hPa the moderate winds (3-10 m/s) had changeable directions around North. In the early morning a weak low-level jet blew over the plain from East at a height of 200-400 meters. At the ground level winds were mainly due to a breeze circulation: very weak from the North up to 7 a.m., then weak with moderate gusts from the South.

For the reconstruction of the 3-D fields, a 66 x 62 Km² horizontal domain with a 1 x 1 Km² grid was adopted, with 12 vertical layers for CALMET, and 20 for MINERVE, with the top layer at 5000 m. The domain covered the relatively flat area around Milan, with ground elevation ranging from 50 to 390 m asl. The meteorological fields for the first phase were produced from analysis and interpolation of measured data from the surface station network (27 sites) and a radio sounding from Milan Linate. A Rass-Sodar station close to the source was used to evaluate the representativeness of the radio sounding for the lower levels in the area around the fire. Both CALMET and MINERVE produce a good reconstruction of the wind field and of the mixing height, but for MINERVE the free atmosphere is less influenced by the growth of the mixing layer (smaller eddies during the warmest hours) resulting in a more laminar upper flow; MINERVE also creates a more realistic vertical velocity pattern. Further analysis on this is under way.

The second phase involved the forecast fields produced by LAMI, routinely supplied on a daily basis to the ARPA Met Service. The dataset is tailored for mesoscale weather forecast (3-hourly data only on standard isobaric surfaces) but, on demand, it is possible to receive the fields on all the 35 levels of the model and for every hour; 90 LAMI grid points were considered (grid step of about 7 Km) over the domain. The forecast fields were then reduced to the 1km-grid using CALMET and MINERVE. Standard control options for both diagnostic models were used: future developments of the work should involve the optimisation of these parameters, in order to improve the final output fields.

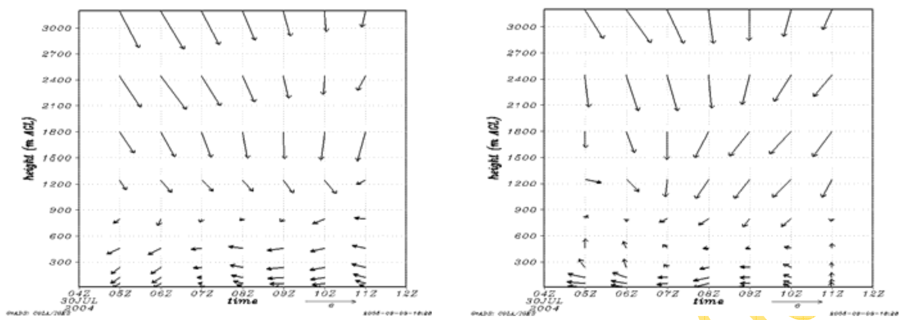

Fig. 2: Time evolution of the wind vertical profile at the source grid point for CALMET with measured data (left) and CALMET with LAMI data (right)

LAMI wind fields were introduced into CALMET both as a first guess for the complete diagnostic wind module and as the input for the objective analysis alone; measured data were assimilated on a different run only for comparison. The results correctly describe some features of the measured fields (change of direction in the lower layers in time, and upper level winds), while they show less realistic patterns for the vertical velocity. In all cases the original fields proved to be a poor forecast for the middle-low troposphere (between 925 and 850 hPa), because of a forecast Northeastern wind instead of the Northwestern wind actually present. (*fig. 2*). This single case study is obviously not enough to evaluate the forecast model but it highlights the general need for a real time and semi-automatic verification of forecast fields.

MODELLING RESULTS

CALPUFF and SPRAY are non-steady state models that can account for 3-dimensional variable trajectories. The domain adopted was the same used for the meteorological diagnostic models. A buoyant area source of 25 x 18 m² was simulated, for which CALPUFF uses a numerical algorithm to compute plume rise; SPRAY behaves similarly by assuming a 10 m high buoyant source box elevated by 10 m over terrain level. The range of fume temperatures during the event was estimated from literature to be between 200 and 1000°C, and the emission velocity between 2.5 and 5 m/s. Variable hourly emission rates were used for both models and mean 1-hour concentrations were calculated. For these preliminary applications, with the goal of a qualitative comparison between models and with the observed spatial distribution, accurate source strength estimation was not essential. For the comparison, output concentration fields were normalized to their maximum value for each vertical level and then plotted to show the outline of the farthest reach of the plume. Analysis of Linate temperature and wind profiles, of pictures taken during the fire and of satellite images suggested that the plume may have reached a height of about 500-600 m during the first phases (*fig.1*), and then risen to about 1000-1200 m, where the wind direction turned steadily from North North-West, thus transporting the plume to the South and South-East.

Figure 3 shows some qualitative results obtained from the two dispersion models in tracing the extent of the area reached by the smoke plume at 7, 9, and 11 a.m. The distributions at 600 m show a reasonable agreement with the situation observed in the satellite images during the first two hours. The plume moves towards the South-West in both cases, heading towards the North-West only later (09:00-11:00 AM). Also for the upper level, wind direction is almost steadily from the North and North-West for the entire time, and the plume moves accordingly. It is interesting to note that the lagrangian model isolines tend to be more irregular than the ones obtained with the puff model. This is due to the nature of lagrangian particles; these results are consistent with the satellite images, where the fire plume is irregular and seems to fray and separate around 9 a.m. The lagrangian plume also travels further than the puffs towards both the South-South-East and, to a lesser extent, towards the North-West. Both models predict the maximum concentration values within a short distance from the source. While the agreement between modelled concentrations and satellite images of fire plume is reasonable for the first few hours, towards the end of the event the satellite images show that the plume reaches farther to the South-East than the simulated maps. This could be due to the fact that the actual plume rises to 1000 m and above sooner than the simulations predict.

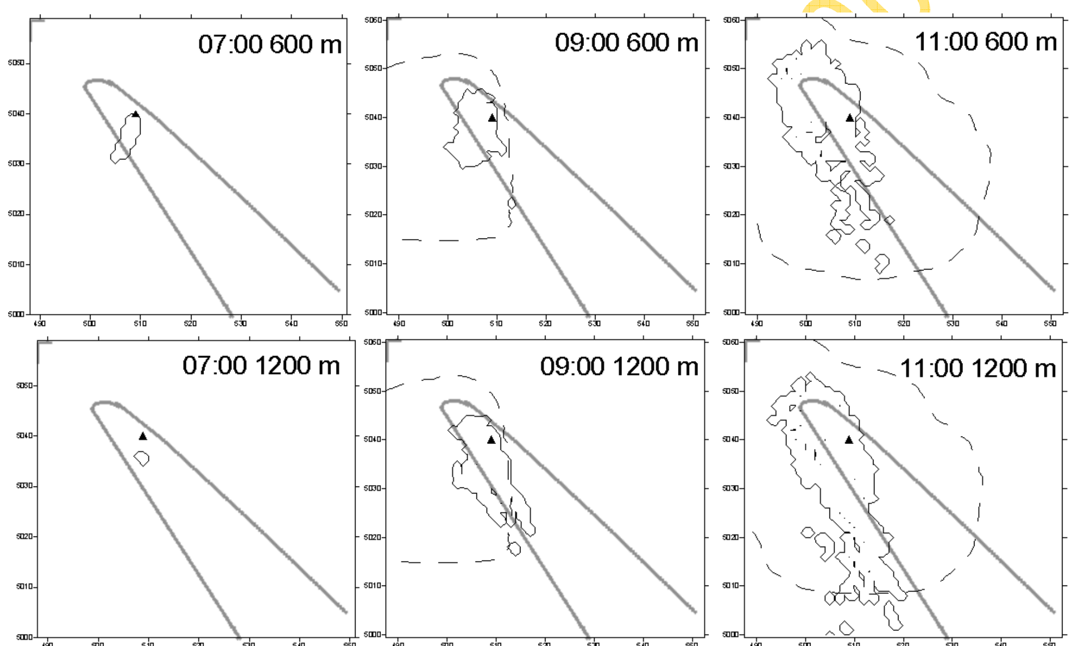

Fig. 3: Relative concentration maps at different hours. The triangle indicates the source; the lines show the maximum extension of the plume (the thick solid line is the observed trajectory, thin line is the prediction from SPRAY and the dotted line that from CALPUFF).

A second run of the models was therefore carried on with higher temperature (1000°C) and emission velocity (5 m/s) for the whole simulation. In this case, the puff model results change considerably, while the lagrangian model gives results similar to the previous ones, though spreading the plume on a larger area, probably because a significant plume rise had been obtained even with the lower temperatures (see *fig. 4*). With the temperature increase, CALPUFF results reproduce quite well the actual flow of the smoke plume. One additional difference between the models, which is currently under investigation, is that while SPRAY keeps track of all particles emitted since the start of the simulation, CALPUFF does not compute concentrations produced by puffs above the mixing layer (see *fig. 2* at 7 a.m.).

In the simulations carried out with the forecast meteorological fields, the direction of the plume is inconsistent with the actual situation, for the reasons discussed previously. However, the work done helped in pointing out the critical aspects of the real time modelling system to be created: minimum required dataset, grid settings, file format conversions, choice of control parameters, computational time, skill of forecast fields, and real time evaluation of the quality of the final output.

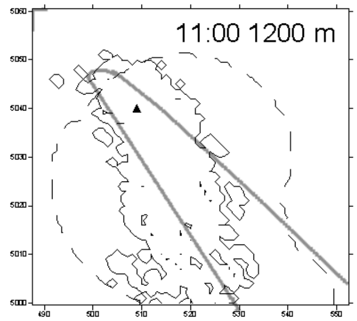

Fig. 4: Relative concentration plots at 11a.m. under the assumptions of an increased fume temperature and speed for all simulation time. Symbols are the same used in figure 3.

CONCLUSIONS

The project was started with the goal of developing a real-time modelling system to predict the time and space distribution of pollutants emitted during an accidental release. The preliminary results presented in this paper, based on the study of the transport and dispersion of a smoke plume released during a fire, show that at least a qualitative description of the event is possible using meteorological diagnostic processors and three-dimensional non steady-state dispersion models, while the use of forecast meteorological fields still requires a careful critical evaluation of the reliability of the forecast.

The lagrangian model could be tested with a shorter time step and be better tuned for fire event treatment. The puff model, on the other hand, provides a buoyant area source option specifically developed for describing emissions from fires, though it is necessary to include in it contributions of the puffs emitted when the mixing height is low. In all cases, the choice of some source parameters has proven critical. This shows a critical need for a good understanding of the specific characteristics of the event to be described. In the future, the possibility of using existing models specifically developed to estimate emission strength and temperatures in the case of fires will be examined. In addition, it will be necessary to test the modelling systems on other case studies, to verify their performance under different conditions.

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