7.01 OPERATIONAL ON-LINE MODELLING TOOL: EVALUATION OF THE THREE MOST COMMON TECHNIQUES (GAUSSIAN PUFF, EULERIAN AND LAGRANGIAN). APPLICATION ON FOS-BERRE DATA.

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INTRODUCTION

In many industrial areas, SO_2 pollution episodes remain an important issue. Local authorities are looking for solutions to enforce Air Quality standards without harming the industrial activity, and they sometimes prefer to apply constraints on few selected plants, basing their action on ground level concentrations and not only on total emissions. Since ambient air monitoring is inevitably limited and sparse, it has to be complemented by a mapping on the whole area, which may be performed with dispersion modelling, rather than with simple interpolation techniques.

In order to define such on-line systems for quasi-real-time response, we compare in this paper the three most common dispersion techniques (Gaussian, Eulerian and Lagrangian), as implemented in the ARIA Industry Software:

TRAMES is a Lagrangian Puff Model with Gaussian Puffs, where elliptical puff centrelines follow 3D trajectories

HERMES is a Eulerian Gridded dispersion model using 3D turbulent diffusivities (Kz) derived from simple turbulence closures (O'Brien, Louis)

SPRAY is a Lagrangian Particle Dispersion model using a Monte-Carlo scheme (Thompson)

These modules are run on high SO_2 pollution episodes for the FOS-BERRE industrial area (close to MARSEILLES, along the French Mediterranean coast). The input uses exactly the same 3D meteorological fields computed by MINERVE (3D meteorological diagnostic model) and exactly the same emissions dataset, limited to the main Large Point Sources (LPS) taken from the regional emission inventory.

SYSTEM CONFIGURATION

The idea is to be able to run a dispersion model and deliver results on-line for an industrial area including a few dozens LPS. In term of CPU time, this constraint is not very strong, since ten minutes of CPU time to compute 24 hours of real time would be more than acceptable : this means that such systems should not be restricted to simple straight-line Gaussian modelling techniques, as is often the case for impact evaluation packages. The wind and other meteorological fields (temperature, humidity, turbulent diffusivities) are computed using all meteorological data available in the area, and provided to the three dispersion models (Puff, Eulerian and Lagrangian).

3D DIAGNOSTIC WIND FIELD MODEL

MINERVE is a three-dimensional regional scale diagnostic meteorological model (Perdriel. 1995). The model starts from an arbitrary number of meteorological data (ground stations, profiles, large scale Numerical Weather Prediction models output), and uses a detailed description of topography (Digital Terrain Model, Land Use) to construct a sequence of refined 3D meteorological fields, including wind, temperature and turbulence. Meteorological fields result from an optimal interpolation of the available data, under the constraints of mass conservation (continuity) and control of vertical velocities by atmospheric stability (temperature gradients). The model also diagnoses the boundary layer evolution, computes turbulence using diagnostic formulations (O'Brien, Louis), producing both Kz and turbulent kinetic energy. It runs in a terrain-following 3D coordinate system and is very quick (a few minutes for 24 hrs simulations) because the diagnostic approach does not include complex time integrations, so that its use is recommended for emergency response purposes, and for routine regular operation in forecast systems (Cox and al. , 1998)

GAUSSIAN PUFF MODEL

The current version incorporates a Gaussian Puff Model called TRAMES, developed by EDF and ARIA Technologies. The advantages of TRAMES are that it has shorter run times than Eulerian or Lagrangian Particle models. The use of a Gaussian Puff approach rather than a straight-line Gaussian formulation allows to take into account the time dependency of the release rate and of the background concentration fields into account, but another key advantage is the ability of Puff models to handle spatially varying wind fields and multiple meteorological observations. Coupled TRAMES and MINERVE provide increased accuracy for modelling in areas where terrain-steering effects need to be incorporated.

EULERIAN MODEL

HERMES is a three-dimensional regional scale eulerian (gridded) transport and dispersion model (*Perdriel* 1990). The model starts either from a large scale NWP output (Numerical Weather Prediction in the form of GRIB files), either from the MINERVE output as initial conditions and boundary conditions, because of a nesting capability, which allows to simulate a smaller inner domain located inside a larger one. When the model is coupled with the MINERVE Flow outputs, it uses the meteorological fields (wind, temperature, water content, turbulence) to compute the time sequence of 3D distribution of pollutants emitted by arbitrary sources. Emissions may include an arbitrary number of substances in parallel, including several particle classes, with different diameters. Point sources, line sources and area sources are considered. Several plume rise formulations are available. Both dry and wet depositions are considered. When the code is used after MINERVE, the 2D precipitation rate (cell by cell) may be used to determine wet deposition to the ground. Since dispersion computations only are much quicker than the flow computations, HERMES / MINERVE may also be used for real-time computations.

LAGRANGIAN PARTICLE MODEL

SPRAY (*Tinarelli G, 2000)* is a three dimensional Lagrangian dispersion model designed to simulate the airborne pollutant dispersion, able to take into account the spatial and temporal in homogeneities of both the mean flow and turbulence. Concentration fields generated by point, area or volume sources can be easily simulated by this model. The behaviour of the airborne pollutant is simulated through “virtual particles” whose mean movement is defined by the local wind and the dispersion is determined by velocities obtained as solution of Lagrangian stochastic differential equations, able to reproduce the statistical characteristics of the turbulent flow. Different portions of the emitted plumes can therefore experience different atmospheric conditions, allowing more realistic reproductions of complex phenomena (low wind speed conditions, strong temperature inversions, flow over topography, presence of terrain discontinuities such as land-sea or urban-rural), hard to simulate with more traditional approaches like the Gaussian one.

APPLICATION ON THE FOS-BERRE INDUSTRIAL AREA

Figure 1(a) presents the industrial site. It is located at the south of France around the FOS-BERRE bay. The complexity of the topography, the presence of the bay and the vicinity of the Mediterranean Sea make the atmospheric flow sometimes very complex. SO_2 data are collected in routine by the Association in charge of the air quality monitoring (AIRFOBEP). The SO_2 is the pollutant which is the historically the most frequently measured (see Figure 1(b) for the spatial distribution of sensors)

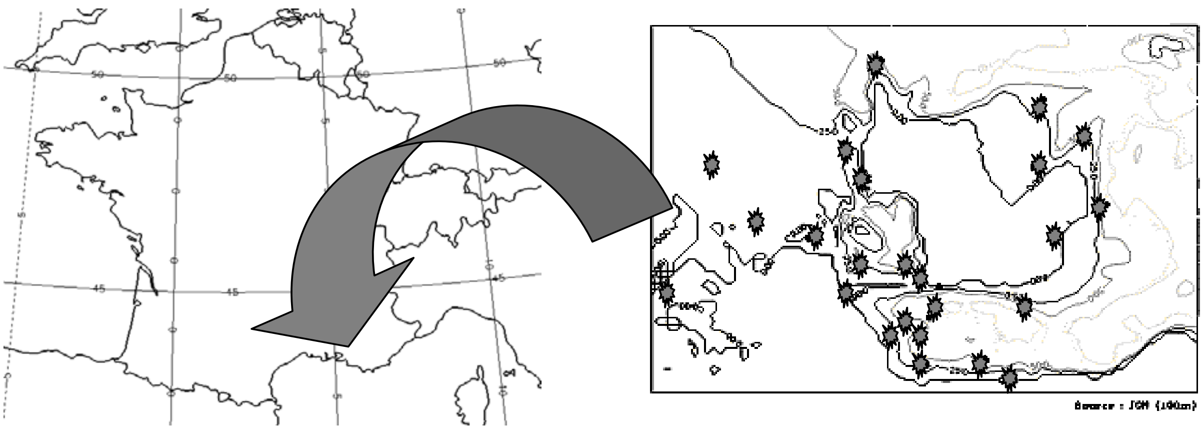

Figure 1. (a) left : the industrial Site in France (b) right: location of the air quality stations around the Fos-Berre Lake (AIRFOBEB monitoring air quality network)

SO_2 is mostly emitted by industrial plants. In the present tests, we only consider the main industrial emitters: no SO_2 due to traffic. Every LPS (figure 2(a)) is described by the position, the height and diameter of the stack, temperature and speed at the outlet. To save CPU time, merging of emissions was done every time that was possible.

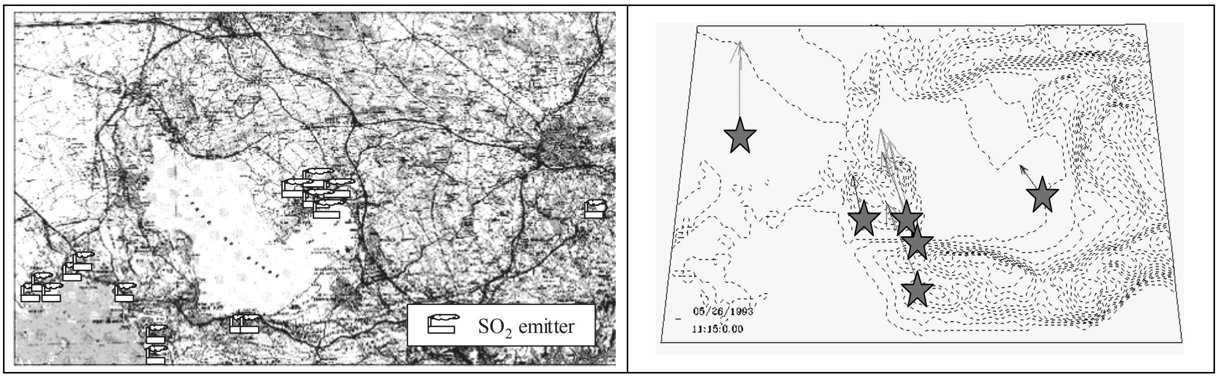

Figure 2. (a) left : Location of the main SO_2 emitters (b) right: location of ground the meteorological stations

The 3D meteorological fields are computed using all the available meteorological data. In our case, we used six ground stations from the METEO-FRANCE network. Note that the same computation can be done using other meteorological model output (forecast or enhanced 4D assimilation techniques) if needed. In the present episode modelling, using this 6 station data turned out to be enough. The meteorological conditions of this 24 hours sequence (May, 26^{th} 1993) indicate a 180 rotation from southern winds to northern winds during the day.

Although each module can use is own grid, we decided to use the same "light" 1km resolution grid for all modules, with a 44 x 31 km domain in the horizontal and 21 stretched levels on the vertical. Minimum thickness of the horizontal layers was 15 meters close to the ground.

MAIN RESULTS OVER AN EPISODE

The model result evaluation is not an easy task mainly because we have to compare 2D/3D fields with a set of discrete observation points. We used a variant of the “nearest neighbour” method, by selecting the grid value from the nine nearest grid points giving the best agreement with the sensor value (Figure 3). This method bypasses the question of the interpolation method inside the mesh. This method is also more tolerant to wind direction errors and more adapted to appreciate the capability of the models to find same order of magnitude within a “reasonable“ localisation error of two grid steps (2*ΔX).

Time series

The time series computed using the method described before clearly show that the wind field is satisfactorily reproduced since the time dependency is correct: the SO_2 peak arrival time agrees with the measurement for both northern and southern stations. Moreover, the “dynamic” of the peaks is respected: shorter peak (one hour around 6UT) for the northern stations, more spread in the afternoon for the southern ones.

- The Lagrangian method (SPRAY) gives the best agreement with the measurements in all the measurement sites even in the worst (Figure 4).
- The Puff model (TRAMES) gives the fastest response but results are generally significantly worse than SPRAY
- The Eulerian method (HERMES) gives the worst score among the three methods.

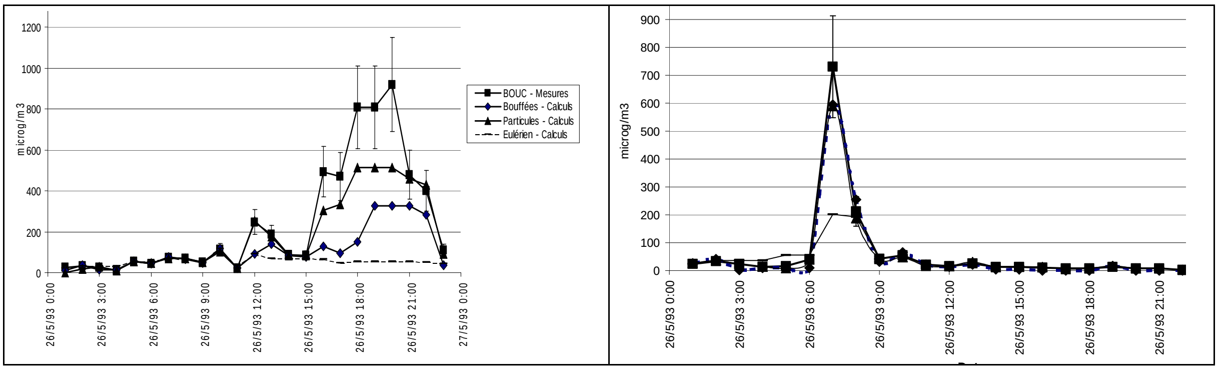

Figure 4. Time series comparison: Squares represents the measurements inside its 25% error bar, triangles the Lagrangian results (SPRAY), Diamonds the puff model results (TRAMES) and the dash line the Eulerian code. Left : Worst score “BOUC” station (south of BERRE lake). Right : Best score BERRE Station (North of the BERRE lake).

General score

The three methods give reasonable scores especially during the morning peak (more stable atmosphere). The afternoon peak is more complex due to unstable atmosphere.

Lagrangian model presents the best score with 40% of significant data within an interval of +/- 5% and more than 75% of these data are retrieved by SPRAY within an interval of +/- 25%.(see figure 5) SPRAY turbulence (not Fickian) is also better than the other modules for convective situation. These good results confirm previous results giving better scores to Lagrangian approaches (*Brusasca G, 1989)*

The worst score in this comparison is obtained by HERMES (Eulerian). The main reason is the fact that the grid step is way too coarse (1km) to treat the narrow plumes generated by industrial sources with an Eulerian approach. Much better results have been obtained with the same model using higher spatial resolutions (200m grid step), but with higher computational constraints.

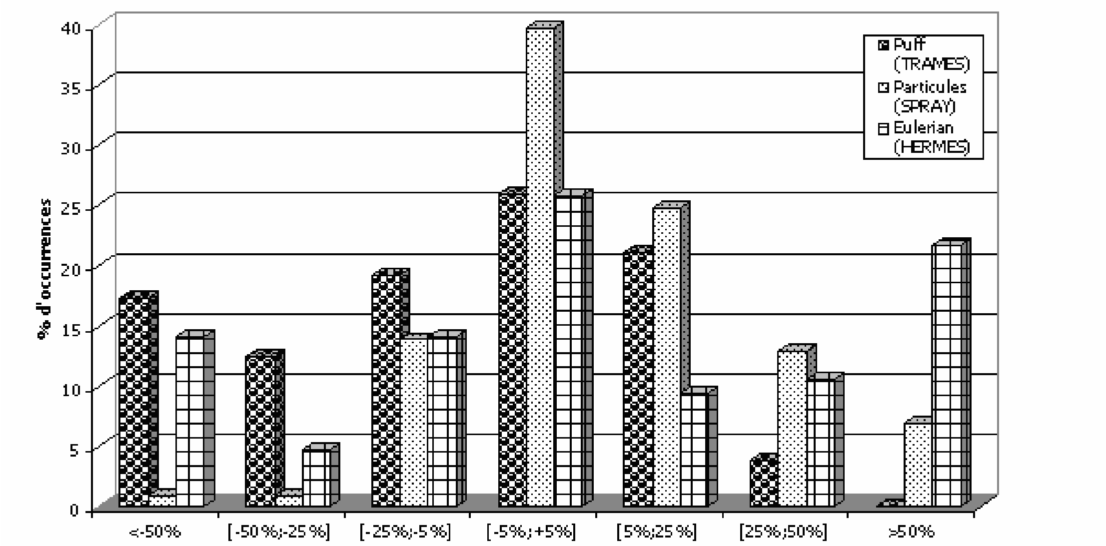

Figure 5. General score (all data) for this episode (bubbles: TRAMES puff model; dots : SPRAY Lagrangian model; grid: HERMES Eulerian model). Along X : error range class, along Y : percentage of pair of computed and measured values falling in the range for each model.

CONCLUSION

The CPU time for the three methods is acceptable. The Eulerian approach is the most time consuming, with 20 times the Puff model CPU time. The lagrangian approach is only three times the Puff model CPU time, and confirms the interest of a Lagrangian Particle approach for operational on-line systems applied to industrial sites, where Large Point Sources dominate. Note that these computations took a limited number of industrial sources only : a Eulerian approach might still be preferred if the number of sources becomes higher and if one needs to consider lines (traffic) or area (diffuse) sources.

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