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PERFORMANCE OF DIFFERENT MODELS TO EVALUATE ATMOSPHERIC DISPERSION IN CALM WIND CONDITIONS

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ABSTRACT

This study investigates the performance of different air pollution dispersion models in wind calm conditions. The models have been applied to two case studies: the cities of Modena and Reggio Emilia, both placed in the Po river valley (Northern Italy), an area characterized by prevailing weak winds conditions. The emission sources are the municipal waste incinerator of Modena and the Turbo Gas plant of Reggio Emilia. Total suspended particulate (TSP) concentration levels are estimated by three models: the Gaussian Industrial Source Complex (ISC3) and WinDimula 3.0 models, and the langrangian particle model SPRAY. The performances of the models have been compared.

DISPERSION MODELS

SPRAY (Tinarelli, G. et al., 1998) is a 3D lagrangian stochastic particle dispersion model able to simulate air pollution dispersion and deposition-decay phenomena in non homogenous, non stationary conditions and over complex topography (Thomson, D.J., 1987).

The model WinDimula 3.0 (Cagnetti, P. and M.C. Cirillo, 1982; Cirillo, M.C. et al., 1986) is an atmospheric multisource Gaussian steady-state dispersion model of non reagent pollutants generated by point, line and area sources.

The dispersion model ISC3 is a steady-state Gaussian model allowing to assess pollutant concentrations from point, area and volume sources.

CASE STUDIES

The cities of Modena and Reggio Emilia are located in the central part of the Po river valley (Northern Italy), an area characterized by flat topography and prevailing conditions of weak winds, often occurring in autumn and winter seasons. Wind calm conditions (i.e. wind speed lower than 2 m/s) occurred for about 78% of the simulation time in Reggio Emilia and about 30% in Modena site (Database CALMET-SIM).

Modena

The model domain is 15x15 km^2, with resolution of 100 m; the center of the domain is in the emission source. The domain origin (S-W corner) is located at cartographic coordinates (646613; 4942233)m (UTM33-WGS84). The simulation period spans over one year from October 1st, 2006 to September 30th, 2007.

Reggio Emilia

The computational domain is 20x20 km^2, with a resolution of 500 m. The S-W corner is located at cartographic coordinates (617777; 4942835)m (UTM32-ED50), with the emission source in the domain center. The simulation period is from September 1st, 2004 to August 31st, 2005.

The simulations were performed using meteorological data acquired by Osservatorio Geofisico of the University of Modena and Reggio Emilia (Modena, Italy) and meteorological data simulated by CALMET model provided by the Emilia-Romagna Meteorological Service.

RESULTS

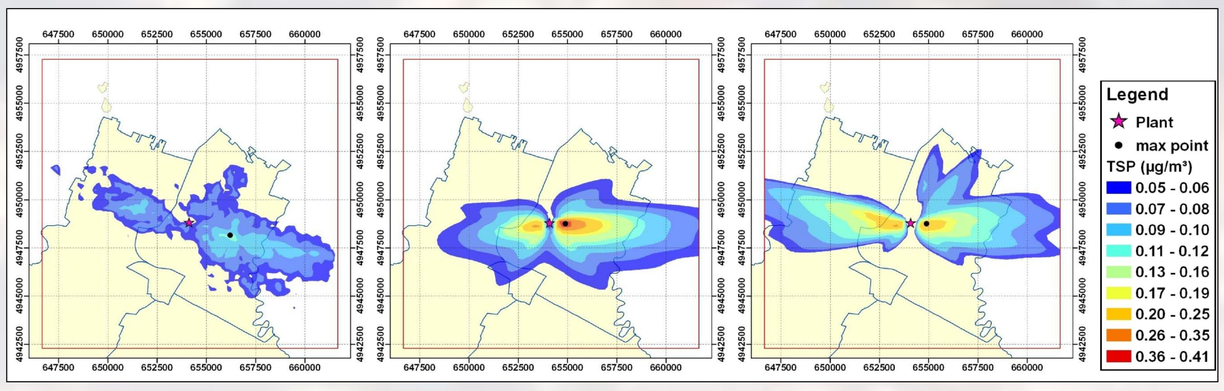
The average concentration levels and concentration maps at the ground obtained from one-year-long simulation runs resulted very similar for the three models, for this reason the subsequent analysis involved the simulation results for a shorter time length.

Modena

1) Autumn simulation: from Oct. 01 to 27, 2005 (poor dispersion conditions);

2) Summer simulation: from June 01 to July 20, 2006 (meteorological conditions favorable to pollutant dispersion).

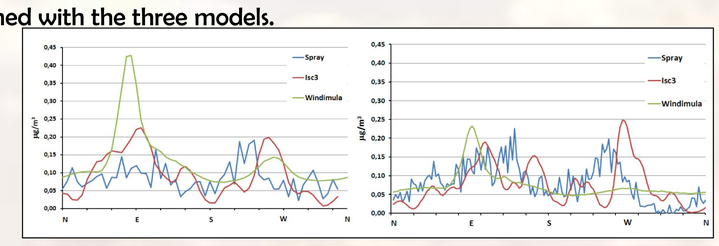
1) The simulations show relevant differences in the spatial distribution patterns of the TSP plumes and in the maximum concentration levels, whereas the difference in average TSP concentration at ground level for the whole period resulted below 10%. The figure shows the TSP concentration plumes at the ground from the simulations performed with SPRAY (left), WinDimula (centre) and ISC3 (right).



For all three models the plume shape is stretched along the main axis of the Po valley (approximately from West to East). The lagrangian plume boundaries spread irregularly, due to the stochastic motion component that well simulates turbulent dispersion, whereas the less realistic Gaussian plumes are excessively stretched windward by weak winds (speed < 1 m/s). The concentration maxima calculated by the gaussian models fall approximately in the same point (black dots), close to the source; the SPRAY maximum is placed about 1500 m from them, farther from the source, and its concentration value is lower. WinDimula describes better than ISC3 the upwind zone closest to the source, even if the concentration values obtained by the Cirillo-Poli algorithm (Cirillo, M.C. and A.A. Poli, 1992) may be overestimated (wind speed < 1 m/s events uniformly assigned to the first upper wind speed class direction).

The figure below shows the concentration values at the ground from 4 consecutive days of wind calm along a circumference centered at the source with 1 km radius (left) and along a circumference with a 2.5 km radius (right), from the simulations performed with the three models.

SPRAY simulation is more reliable, with a quasi random variability of concentration values around the source. The Gaussian models encounter major difficulties in the simulation near the source, while they perform better far from it.



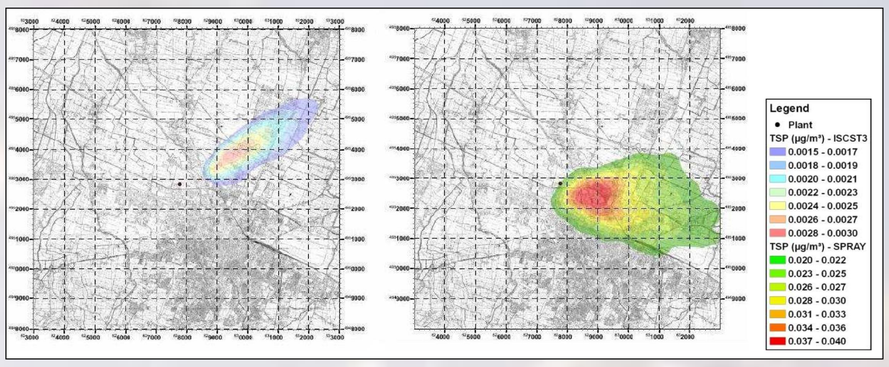
2) The more relevant role of wind transport in pollutant dispersion determines similar concentration distribution patterns for the three models and lower plume surfaces at ground level.

Reggio Emilia

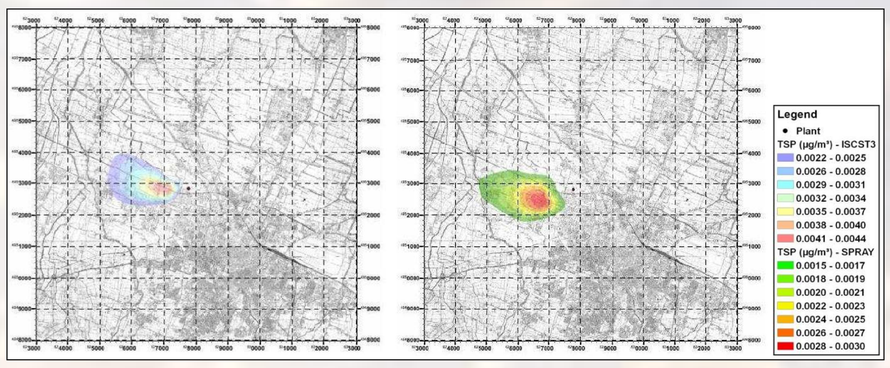
1) Autumn-winter simulation: from Nov. 27 to Dec. 24, 2004 (critical meteo conditions);

2) Summer simulation: from May 09 to June 21, 2005 (favorable to pollutant dispersion).

1) The prevalent and very weak wind component blew from West (91% wind calm). The situation is well simulated by SPRAY (right), whose concentration map shows a plume enlarged by turbulence, slightly driven eastward of the source.
The ISC3 simulation (left) defines a not reliable plume stretched at NE of the plant.



The ISC3 concentration level results one order of magnitude lower than in the SPRAY simulation and the source point is not included the plume (R=0.36).



2) The plume shape and spatial distribution are similar and concentration values are comparable, even if they result higher for ISC3 respect to SPRAY evaluation (R=0.53).

CONCLUSIONS

In wind calm conditions the advective transport is reduced and the pollutants are homogeneously distributed over the whole mixed layer depth, where they accumulate also very close to the source. The lagrangian simulation describes more satisfactorily this situation: the size and the shape of the plume are mainly determined by the turbulent mixing and the concentration field at ground level is more uniform. The area covered by the lagrangian plume at ground level is lower than the Gaussian plume surfaces and also the maximum concentration values calculated by SPRAY are lower. These results confirm that ISC3 and WinDimula are mainly suitable for climatologic application over long time period; ISC3 has not to be applied during wind calm conditions, WinDimula performs better than ISC3, while SPRAY gives the most reliable simulation of the air quality deterioration due to pollutant emission in wind calm conditions.

Reference

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