



An integrated approach to the pollution hazard analysis and management

V. Ferrara¹, C. Gariazzo², C.M. Ottavi¹, U. Poli²

¹Department of Electronic Engineering, University of Rome "La Sapienza", Italy.

²National Institute for Occupational Safety and Prevention, Environmental Department, Rome, Italy.

Abstract

The risk analysis includes the detection of hazards, the assessment of risks and their management. These three main aspects of environmental risk study are strictly linked together in order to archive an effective mitigation of hazards and to minimize consequences. In this work an integrated approach to the study of the environmental system is presented to allow an effective management of risk and the mitigation of possible hazards and a decision support to operators and authorities. The aim of this paper is to present our approach to the study of atmospheric pollution by using the environmental management platform Terrapack® [4]. An application to the simulation of an air pollution episode due to a smoke-stack placed in the neighbourhood of the city of Florence (Italy) is shown. The analysis includes vector, raster and alpha-numeric data: ground-based meteorological and pollutants concentration measurements from on-site monitoring network, digital map of complex terrain, emission census, and modelling data base which includes our dispersion code to simulate the air pollution episode. In the simulation system, both the common used air pollution models based on the Gaussian plume equation [1] and the mixed method [2] describing the plume time evolution by means of elements, either segments or puffs are included. The latter model being used in the calm or low-wind situations and in both nonstationary and nonhomogeneous conditions. The time evolution of the 2-3D pollutant (SO₂) concentration maps will be shown. Results of our simulation code have been compared to results of MODIA code, a simulation software program validate from U.S. EPA [3].



1 Introduction

In the field of environmental phenomena studies and particularly in the field of risk analysis, researcher must resolve frequently many problems regarding: detection and measurement of parameters, organisation of data archives, connection of workstations, archive data to results intersection, efficient visualisation of results, etc.. At the same way, the best supervision of environmental scenery and critical parameters must be guaranteed to operator that deals with emergency. We have investigated and designed a system that is oriented to environmental simulations and can solve many of the previous problems. Particularly we have improved existing systems with the inclusion of external tools (software codes of environmental simulations) which, making access to data, make their elaboration easier. To demonstrate methodology effectiveness we have created a new tool to analyse the air pollution problem and we have simulated an episode due to a smoke-stack. In this case we have used meteorological data and pollutant concentration that have been collected during a measurements campaign (1997). In this paper, we introduce first basic criteria of our system structure, then we examine the air pollution models and finally we describe the simulation example based on effective data.

2 Structure of the system

The hazard analysis and management of pollution problem can be in a easier manner by using a specific system architecture.

Two different solutions have been proposed: creation of general purpose interfaces oriented to connect remote structures [4], design of dedicated system oriented to environmental simulations [6]. We have developed the last one and built the environmental management platform Terrapack[®] [4], able to use more recent technologies in communication and software fields

Complex environmental management systems are organised by means of distributed structure, including specialised elaboration institutes of archives, communication, real-time measures, etc.. Data are commonly available in the communication network and the structure can be distributed by modulus. Management of system configuration and resources location becomes the core of structure design. Special care must be taken in connecting transmission lines, distinguishing between fast and slow lines. Preferably, dynamical data are transmitted and static data are stored in local.

To allow an effective management of risk and the mitigation of possible hazards and a decision support to operators and authorities, system must warrant: effective scenarios visualisation, real-time data update, fast predictive simulations of environmental phenomena, correlation with different data (e.g. social data). Principally the system must define an interactive work area where the scenery is a friendly elaboration of numerical data. There are different types of static and dynamic data: those required to solve environmental problem analysis and those used to develop intervention activities.

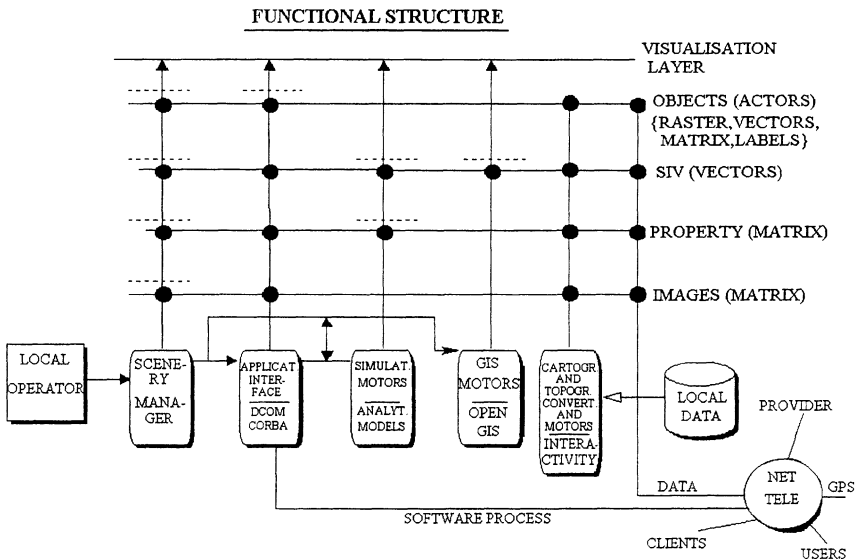


Figure 1: Main scheme of our environmental management platform Terrapack®. Objects, map-oriented and map-object vectors (SIV) and images concur to construction of the visualisation layer.

In the work area more data and objects could be presented and managed: geo-referenced images or raster cartography in matrix format, map-oriented and objected-oriented vectors (SIV) including information data, actors (symbols, multimedia objects, etc.) connected to other functionality of the system. Figure 1 shows the main scheme of the environmental management platform Terrapack®. This platform distinguishes itself from standard GIS systems using essentially:

- a programmable simulation motor, to incorporate models and algorithms from different sources and to assess many environmental phenomena,
- a scenery manager, to organise in a consistent work-area vectors, matrix, information layers in vector format, images (matrix), query results, calculation results, dynamical data coming from communication network, etc.,
- input and output interfaces, oriented to external process.
- a processor, to create new dynamical information layers by means of queries, GIS and software simulation results.

Figure 2 shows an example of superimposed data-base visualisation and management. This figure represents management of : background cartography (matrix), characteristics of territorial points (e.g. altitude), vector data together with their query (data census of Italian Communes, by National Statistical Institute ISTAT 1991), vector processing of simulations (broadcast simulation from UHF transmitter), specific tools able to put in evidence characteristics of simulation fields (visualisation of contour lines by means of a cursor).

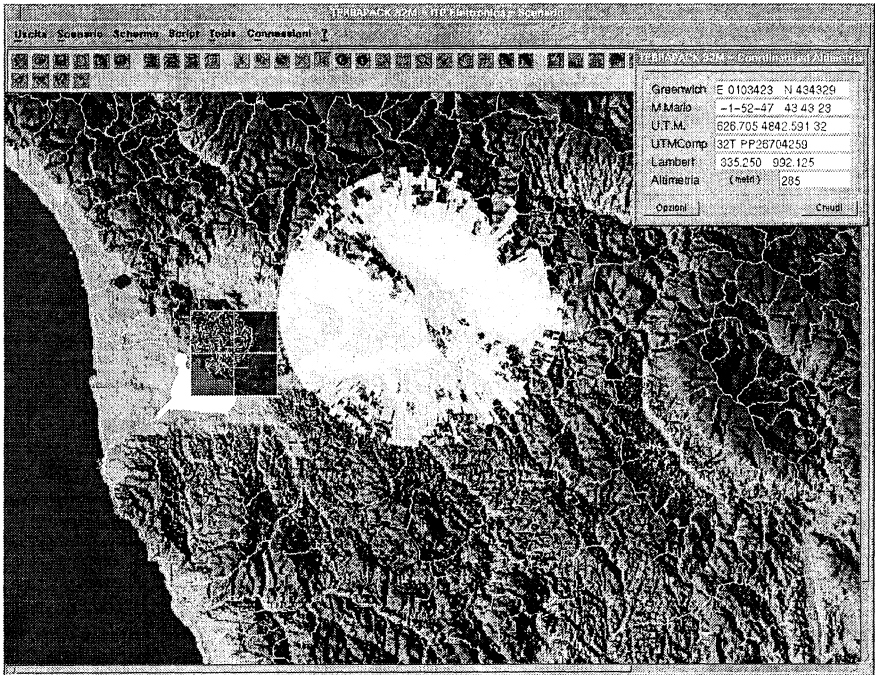


Figure 2: Example of visualisation and management from the platform Terrapack®. The area of the Italian region Toscana is shown together with some superimposed objects and simulation outputs.

3 Predictive models

To verify the performance of our system, we have produced a software program based on air pollution predictive models. This new code profitably uses libraries supplied from the platform and becomes a special tool of the same Terrapack®. Therefore, classic Gaussian plume equation [1] and an air pollution model based on more accurate numerical mixed method [2] have been inserted.

We have adopted the following simplest form of the Gaussian equation that describes the average steady-state concentration c of the pollutant at the receptor (x_r, y_r, z_r) by a single elevated point source $(0, 0, z_s)$

$$c(x_r, y_r, z_r) = \frac{Q}{2 \pi \sigma_h \sigma_z u} \cdot \exp \left[-\frac{1}{2} \left(\frac{y_r}{\sigma_h} \right)^2 \right] \cdot \exp \left[-\frac{1}{2} \left(\frac{z_s + |h - z_r|}{\sigma_z} \right)^2 \right] \quad (1)$$

where Q is the pollutant emission rate, σ_h and σ_z are the plume standard deviation on horizontal and vertical planes at the downwind distance x_r , u is the average wind speed at z_s . This steady-state concentration is valid only in stationary and homogeneous conditions.

The mixed method describes the plume time evolution by means of elements either segments or puffs and it can be used in both non-stationary and non-homogeneous conditions. Segmented plume model describes the pollutant concentration during transport conditions when average wind speed is $u \geq 1$ m/s, whereas puff model is applicable during calm or low-wind conditions. Each single puff contributes to increase pollutant concentration by means of equation (2)

$$\Delta c = \frac{\Delta M}{(2\pi)^{3/2} \sigma_h^2 \sigma_z} \cdot \exp \left[-\frac{1}{2} \left(\frac{x_p - x_r}{\sigma_h} \right)^2 \right] \cdot \exp \left[-\frac{1}{2} \left(\frac{y_p - y_r}{\sigma_h} \right)^2 \right] \cdot \exp \left[-\frac{1}{2} \left(\frac{z_p - z_r}{\sigma_z} \right)^2 \right] \quad (2)$$

where ΔM is the mass increment of pollutant of the puff, whose centre is located at (x_p, y_p, z_p) . Moreover, mixed method allows to extend predictive simulation from flat to complex terrain.

We have adopted criteria and formulas in literature: Gaussian equation (segments are sections of Gaussian plume), basic formula of single puff contribution, Turner routine of plume rise, Pasquill stability class method, linear chemistry, dry/wet deposition patterns, etc.. Depending from altitude (DTM data base), we have developed algorithms to calculate effects of ground reflection on pollutant concentration. Moreover, we have implemented routines to calculate horizontal projection of wind speed and directions (in each point of area calculation domain): ground-based meteorological measurements from on-site monitoring network, semi-empiric formula to assess the value of the friction velocity and Monin-Obulkhov length. The computation of the vertical wind component is according to Salerno method [7] and utilizes: atmospheric stability, roughness parameters, wind profiles, geostrophic winds. In our method we have adopted the following equations for vertical velocity computation, for transport (3) and low-wind conditions (4):

$$w(z) = M \cdot \sqrt{u_x^2 + u_y^2} \cdot \sin \left[\arctg \left(\frac{\Delta z}{\Delta h} \right) \right] \quad (3)$$

$$w(z) = c \cdot \mu \cdot \sqrt{u_x^2 + u_y^2} \cdot \sin \left[\arctg \left(\frac{\Delta z}{\Delta h} \right) \right] \quad (4)$$

where M , c , μ , u_x and u_y are the same as in the Salerno method, Δz is the obstacle height and Δh is the distance from obstacle top.

3.1 Software program test

Standard tests on flat terrain, assuming constant stability class and constant speed wind have been carried out and results have been compared to results of



MODIA code, a simulation software program validated from U.S. EPA (Environment Policy Agency) based on Gaussian equation.

Table 1: Input data set for test

Input data	Value
$\Delta x \times \Delta y$ (area)	10000x10000 m ²
Δt (time step)	0.5 min
average wind speed	2 m/s
stack height	50 m
stack diameter	2 m
smoke	12 m/s
smoke temperature	373.15°K
primary pollutant	SO ₂
primary pollutant flow	0.5 Kg/s
air temperature	285.15°K
average height of surrounding buildings	10 m

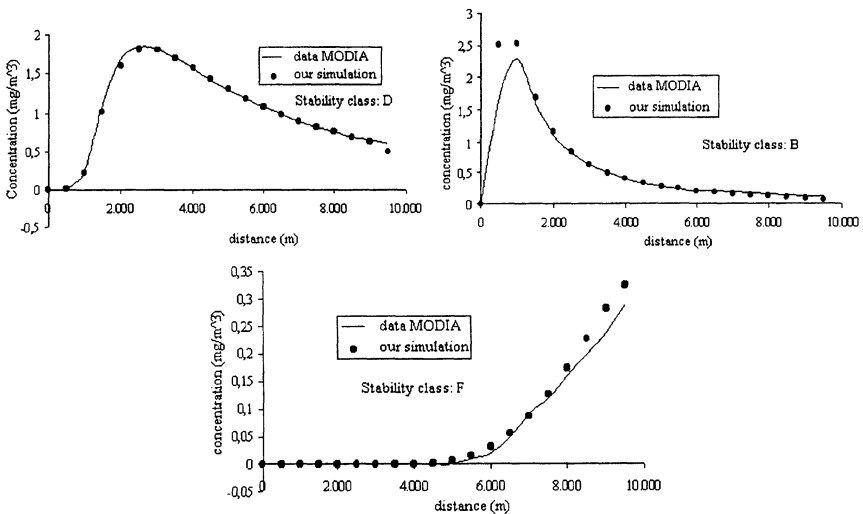


Figure 3: Comparison between MODIA and our code results by using the input data set from Table 1.

First, we have calibrated the parameters of our model, e.g. σ_h , σ_{z1} and σ_{z2} , by using stability class D and input data of simulation test shown in Table 1. In Figure 3 a comparison between MODIA and our code results is presented by using three different stability classes. The test has shown little differences,

particularly when stability class is B and at short distance from smoke-stack location.

4 Case-study

Simulations of atmospheric pollution episodes due to smoke-stack release placed in the neighbour of the city of Florence (Italy) have been carried out. The aim of this case-study is to evaluate the efficacy of the integrated tools included in a management system when environmental risk activities of analysis, control and supervision are performed.

4.1 Meteorological and pollution campaign

We have simulated pollution episodes in a flat area (Campi Bisenzio) that extends from Florence to Pistoia. Calvana Mountains (615 m) north-westerly, Mount Morello (934 m) northward and Mount Albano at south-westerly are natural boundaries of this area. For our simulation we availed ourselves of ground-based meteorological and pollutants concentration measurements from on-site monitoring network. ISPESL together with ARPAT [8] conducted a pollution monitoring campaign from June to July 1997. Meteorological data have been measured in six stations located at: Mount Morello (934 m), Settignano (185 m), Florence-S. Lorenzo square (near to Ximeniano, 48 m), Florence-CNR-IATA station (45 m), Pozzolatico (ISPESL, 165 m), San Martino alla Palma (ISPESL, 190 m). Ground-based pollutant data have been measured in nine different stations (Boboli, Novoli, Scandicci, Bassi, Ponte alle Mosse, Settignano, Mount Morello, Cathedral square, Pozzolatico).

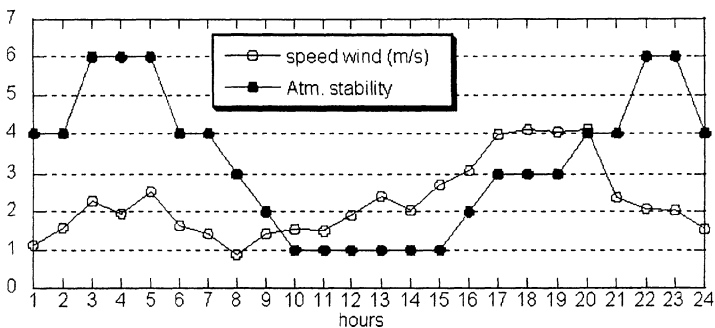


Figure 4: Wind speed and atmospheric stability measured at the meteo station located at Xeminiano on July 21st, 1997.

Meteorological data have been processed to analyse situation on July 21st, 1997: wind field and atmospheric stability. ISPESL has utilized the 3D meteorological model: *HERMES*® to determine the reference wind field.

Figure 4 shows the atmospheric stability, carried out by using Pasquill [9] and Turner [1] methods, together with wind speed measured at Florence-S. Lorenzo square. We have evaluated the vertical thermal gradient by means of temperature measurements at two different heights measured at Pozzolatice meteo station (Figure 5) and, by using Monin-Obukhov length, we have verified the previous atmospheric stability.

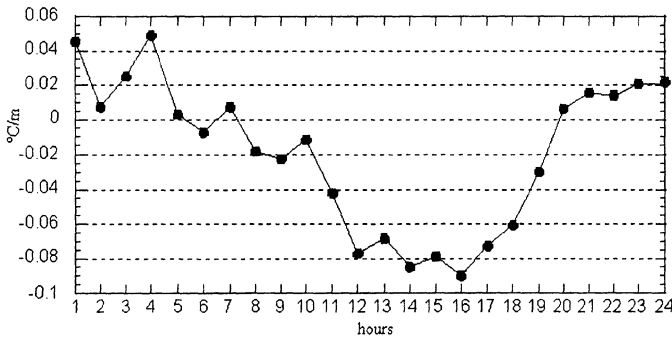


Figure 5: Evolution of thermal gradient measured at the meteo station located at Pozzolatice on July 21st, 1997.

4.2 Pollution simulation

The pollutant concentrations measured in the ground stations in absence of smoke-stack emissions have been assumed as background concentration evolution. Therefore the system allows to represent the evolution of pollutant concentration, superimposed to the cartographic map. The supervision of environmental conditions is guaranteed. Moreover a specialised tool of the integrated system is able to predict the increase of pollutant concentration related to the emission of the supposed smoke-stack placed in the area. The software tool allows us to vary predicted atmospheric scenarios and to check new risk condition. Moreover, it is possible to check continuously vulnerable areas (e.g. highly populated zone) and to give decision making support to operators and authorities.

Table 2: Geometrical characteristic of smoke-stack and pollutant emission data

Data	Value
smoke-stack height (m)	80
output stack-diameter (m)	2
effluent flow (mass unit /s)	100
smoke temperature (°K)	393
smoke speed (m/s)	15

In this paper we have simulated an air pollution episode due to a smoke-stack located at Campi Bisenzio and we have supposed a realistic pollutant emission as listed in Table 2. In particular, we have examined the SO_2 pollutant increase one in different meteorological conditions (Table 3).

Figure 6 shows an example of the perspective map of pollutant concentration scenery in unstable atmospheric conditions. Extension of area is $10 \times 10 \text{ Km}^2$.

Table 3: Characteristic data of simulation scenery

Atmospheric stability	hour	Air Temperature ($^{\circ}\text{C}$)	Solar radiation	H_{mix} (m)
F	03:00	18.5	absent	550
A	11:00	25.3	bright	300
D	20:00	26.8	feeble	600

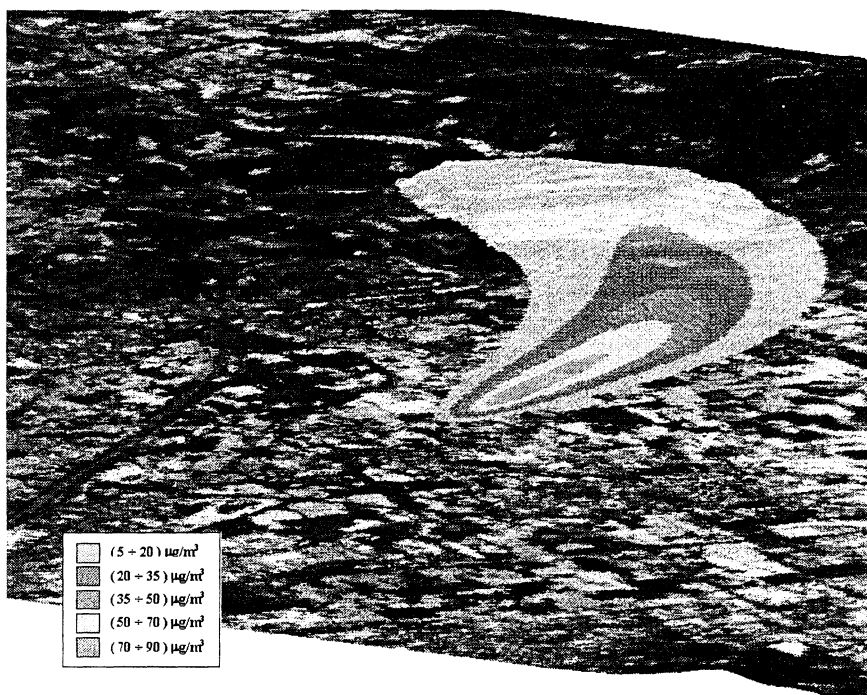


Figure 6: Perspective of area under examination. Texture of map has been obtained by superimposing SPOT image and calculated concentration of SO_2 pollutant.

For this case-study we have used two computers to simulate a typical hardware structure, including one local user station (IBM compatible PC-Pentium II) connected to a remote HP workstation. The simulation software code resides in



PC computer. This one manages local scenarios maps and static data (i.e. altitude data, 20 m resolution in area) and receives dynamical data as wind speeds and directions from HP workstation. The last one is able to manage dynamical data, to elaborate more complex graphic visualisation (3D) and to manage alarm signal sorting.

5 Conclusions

An integrated approach to analysis, control and supervision of environmental risk has been presented. We have taken special care of process and visualisation interactivity. In order to test facilities of system we have included our simulation code of prediction air pollution as a new tool. Then, by using the last one, we have presented a case-study based on real atmospheric data. The integrated system has allowed to reduce the development time of tool simulation code, by using specialised software libraries, and calculation duration.

References

- [1] Turner, D.B., *Workbook of atmospheric dispersion estimates*, US EPA, Office of Air Programs, Research Triangle Park, North Carolina, (1970)
- [2] Zanetti, P. A new mixed segment-puff approach for dispersion modelling, *Atmospheric Environment*, **20(6)**, pp. 1121-1130, (1986)
- [3] Snyder, W.H., *The EPA meteorological wind tunnel: its design, construction and operating characteristics*, U.S. EPA, Rpt. No. EPA-600/4-79-051. Research Triangle Park, North Carolina, (1979)
- [4] Ottavi, C.M., Ferrara, & V. Guerriero, M. TERRAPACK: uno strumento matriciale per la trattazione dei problemi territoriali, *Proc. of 3th Nat. Conf. on GIS AM-FM*: Rome, pp. 527 – 539, 1991.
- [5] Jaber, A., Guarnieri, F., & Wybo, J.L. A System of Intelligent Software Agents to Favour the Cooperation between Emergency Decision Support Systems, *Proc. of The International Emergency Management Society Conference. Disaster and Emergency Management: International Challenges for next Decade*: Washington DC, pp 515-525, 1998.
- [6] Ottavi, C.M. La Simulazione del Territorio per le Valutazioni e la Gestione del Rischio Ambientale, *Proc. of 1st Conf. MondoGIS: Dalla tecnologia alle applicazioni*, Rome, 1999
- [7] Salerno R., Licitra G., & Pisani B. *A wind Model for an Italian Coastal Area Based on Meteorological Data Available from the On-site Monitoring Network*, Computational Mechanics Publications: Southampton Boston, pp. 31-44, 1992.
- [8] Lepore, L., Poli, U., & Valeri, V. Smog fotochimico – Risultati della campagna estiva 1997, *Atti della Giornata di studio su: La qualità dell'aria a Firenze e nell'aria fiorentina*: Florence, 1998.
- [9] Pasquill, F. (eds). *Atmospheric Diffusion*, Von Nostrand, 1962.