Transport and dispersion from cooling towers in the complex topography of the Tuscany geothermal areas

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ABSTRACT

A transport-dispersion model has been applied for a geothermal region in Tuscany, with various typical meteorological situations. The wind fields ate given by a model developed for complex orography. The pollutant sources are given by some cooling towers placed in the area. The simulations have shown the importance of the knowledge of the air flow in such a region. It can be shown that the plumes can be transported quite far from the area or concentrates themselves along a slope depending on the meteorological conditions and the topography The latter feature is able to strongly influence the plume, whose trajectory is also dependent on the source characteristics.

INTRODUCTION

The geothermal areas in Tuscany are placed in a complex topography region, with hills and mountains of different heights In these regions it is important to describe the correct patterns of air flow in order to have an accurate representation of transport and dispersion of pollutants. To reach this aim it is necessary to use a mathematical model for circulation in connection with a dispersion model, because common dispersion operational models for flat areas, like the gaussian ones for example, cannot attain the desired objective of estimating dispersion accurately.

The studied area includes a large part of the geothermal areas in Tuscany, where there are many potential sources of pollutants and many of them are cooling towers. Due to the characteristics of the topography and these sources, the pollutant can be transported quite far from the area, when certain meteorological conditions prevail. It should be pointed out that the chemical and physical proprieties of the emitted gases contribute to modify the plume characteristics and the atmospheric dilution of the plume is influenced also by the source structure.

A wind field model has been applied to this area to reconstruct the air flow Over this region. After this, a dispersion model has been used to represent the transport and diffusion from some selected point in this area, where geothermal plants are located.

USED MODELS

The model WINDY (Salerno, 1993a) describer three-dimensional wind fields over an area. It was initially developed by different authors (Clerici *et al.*, 1988) and subsequently modified, improved and adapted to the regional scale (Salerno, 1992; 1993a). It takes into account orography, temperature gradients, friction, land-sea interface and stability, which are inserted into the balance equation, i.e. the continuity equation. First an initial temperature field and a coarse representation of the horizontal wind are obtained in each cell of the grid by an orography-consideringinterpolation.

After this, the next step is the computation of vertical velocities. They are due to mechanical effects (the deflection of the horizontal flow by a barrier). and thermal effects (Salerno and Meneguzzo, 1992). For high wind speeds and neutral or unstable conditions, the collision between the air mass and the barrier can be considered roughly elastic and the vertical velocity due to orography, w_{or}, is given by the vertical component of the deflected velocity ofthe air mass. For low wind speeds and stable conditions. the flow energy may not be large enough for the air mass to climb over the barrier. The Froude number has been used to take into account these effects; t is substantially a combination or obstacle height h, flow speed U and stratification (represented hy Brunt-Väisälä frequency, N).

The model takes into account the thermal gradients near the surface, the friction, the valley-mountains breezes and the land-sea breezes. For a complete description, see Salerno (1993a).

The propagation of the vertical speeds to the upper layer is linked to the Richardson number, Ri. The propagation to the uppcr layers of vertical speed is dumped (in stable conditions), by using a formulation based on Ri (Salerno, 1992). In unstable conditions a nearly stable atmosphere is anyway considered to prevent a too high step of vertical speeds approaching the top of the model domain, whcre it should vanish

The vertical wind field has *to be* corrected to minimize the global mass flux through the external boundary of the considered region. The correction depends nn orography of the considered region. The bigger is the region depth, the larger is the outgoing mass and, consequently, the correction The final horizontal wind field is computed solving the following approximation of the steady-state continuity equation, written as Poisson's equation:

$$\nabla^2\Phi = -\frac{\partial w}{\partial z} - \frac{w}{z}\frac{\partial \rho}{\partial z} \qquad (1)$$

whcre

$$u = \frac{\partial\Phi}{\partial x} \quad \text{and} \quad v = \frac{\partial\Phi}{\partial y} \qquad (2)$$

with the suitable boundary conditions (Salerno, 1993a)

The concentration field has been simulated solving the advection-diffusion equation. Using the hypothesis of incompressibility, the advection-diffusion equation may be written in its pseudo-velocity form (Salerno, 1992; Vignati, 1994)

$$\frac{\partial\chi}{\partial t} + \nabla\cdot\left(\chi \mathbf{U}_P\right) = S \qquad (3)$$

where χ is a scalar concentration, Up includes two terms: the advection field, U_A, and a diffusivity velocity $-(K/\chi)\nabla\chi$, S is the emission term. IC chemical reactions arc taken into account, an additional term must be added ai the nght side of Equation *(3)*

The equation is solved using the following boundary conditions (Salemo, 1992):

$$\chi' \mathbf{U}_P \cdot \mathbf{n} = 0 \qquad (4)$$

where $\chi' = \chi - \chi_b$, χ_b is the background concentration in the horizontal flow, which is the result of the sources outside the domain, and n is the outer unit vector The idca of dry deposition velocity is used to calculate the deposition flux to the ground (Wesely and Hicks, 1977; Karamchandani *et al.*, 1990).

Other simulations have been performed by the trajectory-puff model PALADIM (Salerno, 1993b). All results have been compared to those obtained by a standard gaussian model

THE CASE STUDY

The case study area is represented in the figure 1. It has a dimension of 123×75 km in the horizontal and it presents different surface characteristics, like the presence of both the sen and the land, hills, mountains, valleys, The highest mountain of the area is the Mount Amiata, at 1713 m a s l.

The climate on the synoptic scale is the typical one of the western Mediterranean sea area. From Autumn to Spring the highest frequency nf surface cyclones per unit area of the entire Northern hemisphere occurs, while *the* zonal circulation is rare (Castro, 1988).

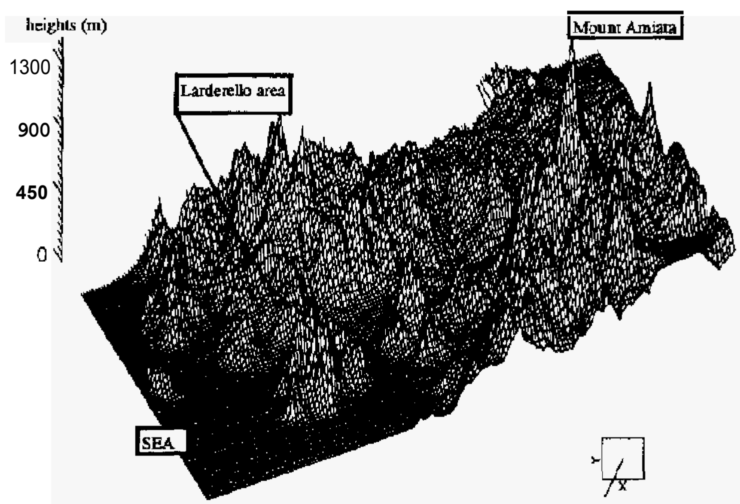


Figure 1. Three-dimensional representation of the considcred arca

This is due to the thermal contrast between sea and land or to the invasion of cold air masses from higher latitudes. During the Summer, cyclones are rare and the land is warmer than the sea; there are many *clear sky* situations interrupted only by local storms.

The presence of hills and mountains throughout the area influences the air masses, blocking and deflecting the flux. Winds mainly come from E, NE, SW or W. Due *to* the prevailing western winds the mean value of temperatwe is 24.4 °C in Summer and 7 5 °C in Winter.

To study the influence of the topographic and surface characteristics of this area on the circulation and dispersion, different simulations have been performed using various wind and temperature profiles, considering the typical meteorological situations. Here it is shown the case from a westerly flux which impinges on the west side of the considered domain at the midday of a summertime day. In connection some pollutant sources are taken *into* account. One is located in the Larderello area, three others are at S. Fiora, Piancastagnaio and Abbadia S Salvatore, near Mount Amiata All sources have the same physical characteristics.

A grid of 180x107 points in the horizontal has been used for both models; 16 layers of different depths have been used in the vertical for the wind model, from the sea level up to 2000 m.

For the transport-diffusion model an additional level near the ground ha5 been considered to obtain the concentration at 2 m above terrain

RESULTS

In the figure 2 the plotting shows the wind field at 25 m a.s l. to see the combination of the sea breeze with the coastal conformation and the orographic feature. The maximum depth of the diurnal breeze is *550* m.

The figures evidences the influence of the different elements characterizing the studied area During daytime heating, upslope

Figure 2. Wind field at *25* m a.s.l.

Figure 3. Trajectories of plumes from cooling *towers* at Larderello, S. Fiora, Piancastagnaio and Abbadia S. Salvatore. For reference the trajectories from an hypothetical source at Piombino and Grosseto are reported, to evidence the effects of the surface characteristics

winds develop in the mountain areas. Inward fluxes. inducted by the upslope *winds*, are present in the valleys. Along the sea-shore, the sea breeze is dominant with a weak synoptic circulation. The depth of the sea breeze varies. but in summer it can reach some hundreds of meters. It interacts with the topographical features of the terrain near the coastline where the presence of the barriers *can* deflect the flux (figure 2).

This short illustration of the flux characteristic in this area gives an idea of the multiple interaction in such a complex topography. All effects can influence the plume trajectories and, hence, the concentration of pollutant. In the figure 3 some plume trajectories are shown for the cage study situation of a westerly flux coming from the sea. In this case the considered sources *are* coaling towers with a height of 18.55 m. The plume rise has been computed using the classical expressions of Briggs. Isolated sources have been considered; hence no enhancement factors are added to plume *rise* evaluation.

For the represented situation, the maximum steady value of concentration, for an emission of 1 g/s of a generic gaseous pollutant, was of 50 $\mu g/m^3$ at a distance of 500 m (PALADIM results for the source sited at Piancastagnaio). A secondary maximum appeared at 1000 m from the source. It must be pointed out thar the corresponding value far a gaussian standard model was less than 30 $\mu g/m^3$. Sub-gnd concentration computed *with* the eulerian model showed a maximum steady value of 40 $\mu g/m^3$ for this source in Piancastagnaio(figure 4).

Lower concentration values arose from the other sources using the non-gaussian models *Thesc* values somewhat differ from those computed by the gaussian model. These differences are probably due to topographical features.

CONCLUSIONS

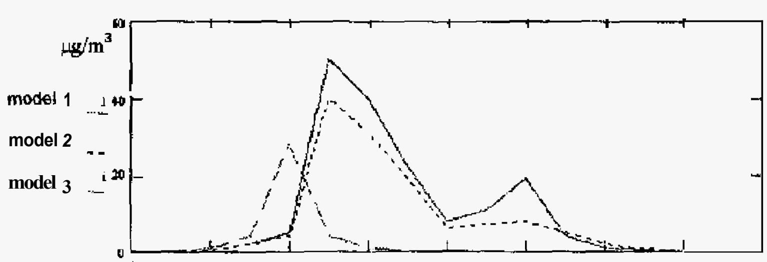
The application of a steady wind model and a transport-diffusion model on A Tuscany *area* have been performed, The area is relevant for the geothermal applications. Some cooling towers have been placed in different sites to see the multiple interactions on plume trajectories and on its dispersion.

The complexity of the orography greatly influences the concentrationfield. The computations made with an Eulerian model and a puff-trajectory model have shown that the concentration values differs from those calculable with a standard gaussian model, which cannot take into account plume trajectories and. generally, the effects of the topography and surface characteristics.

The analyses of the concentrations have shown that there is an increase of dispersion along wind direction (a typical feature of the complex topography regions) and the possibility of the impingement of the plume on a slope during stable conditions, with the accumulation of pollutants at the ground. A secondary maximum fur the concentrations is often found,

Moreover the *emitted* aerosol may be heavier than the air. This modifies the plume trajectories, enhancing the concentration near the source and reducing the windward extension of the pollution. This can also depends on the droplets radii.

It must be considered that this is only a very partial analyses, since other source *effects* and plume characteristics must be taken into account In fact, the presence of watcr vapour modifies the plume characteristics and, hence, the concentration and the deposition depending on the pollutant considered. A cloud model, adapted for this problem, should be used in connection with the transport and dispersion of the cloud itself to take intu account the effects of condensation and evaporation. This is currently under



(model 3) to gaussian model.

development

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This paper is in memory of G.C. Clerici, who prematurely died during its development

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