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Plume dispersion modelling during a sea-breeze event

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Abstract

The Lagrangian Adaptative Volume Plume Model (AVP) was used to simulate the dynamics of a power plant plume during a typical sea breeze period at the east coast of Spain. Data collected during the MECAPIP project around a power plant were used to reproduce the shapes and general behavior of plumes observed by an instrumented aircraft. Results from these simulations show that the model can predict the temporal plume pathway and plume shapes that are frequently observed during sea-breeze events. Concentration patterns were well simulated during fumigation conditions.

1 Introduction

Several summer measurement campaigns were launched in the surroundings of the Castellón oil-fired power plant, as part of the **MECAPIP and RECAPMA** projects, sponsored by the EC, Millán et al.,[1]. The objective of these exercises was to characterize the dynamics of the polluted airmasses and, in particular of the power plant plume at this coastal site.

In this paper, data collected during the 1989 summer campaign of the MECAPIP project was used to analyze the ability of the Lagrangian Adaptative Volume Plume Model (AVP), described in Ludwig et al.,[2], to simulate the dynamics of the power plant plume during a sea breeze period, during which strong vertical gradient of atmospheric stability and wind were observed. Previous application of the model showed that it can reproduce the shapes, slopes, and general dimensions of plume vertical cross-sections observed by airborne lidar at Kincaid, Illinois. This model was also modified to establish a 3D sub-grid around the plume in which concentrations are computed, when the plumes are considered to be imbedded in 3D Eulerian dispersion models, Bornstein et al., [3]

2 Description of the Site.

The main airshed considered for the study, covering 50 by 46 Km, is a flood plain that ends after approximately 30 Km in a range of mountains which converge inland toward a narrow river valley (Figure 1). The Castellón power plant, within an industrial area, is located on the shoreline of the Spanish east coast. It is oil-fired and has two 540 MW units each feeding a 150 m stack. During the period presented here, only one unit was operating.

Data analyses of summer campaigns show that the plume undergoes a diurnal cycle associated with the evolution of the prevailing atmospheric circulation, Millán, et al. [4]. At about sunrise, the plume is transported approximately parallel to the coast in a SW direction, on a neutral to stable layer between 100-150 to 450-700 m decoupled from the surface layer. The onset of the sea breeze is early in the morning and the inland turning of the wind direction occurs progressively, from ground upwards, and is completed by early noon. At about midday (11:00-13:00 UTC) when the Thermal Internal Boundary Layer (TIBL) builds-up to plume height, the effluent suddenly fumigates downward toward the ground. During the late afternoon two plume behaviors have been observed, they may be related to the formation and location of the Iberian Thermal Low. The plume either rotates counterclockwise toward a SW direction or rotates clockwise to end-up in a N-NEN direction.

3 Application of the AVP model during a sea-breeze event.

The MECAPIP summer campaign of 1989 was launched at a peninsular level. For this study, data collected on 27 July 1989 was selected to simulate sulfur dioxide concentration patterns in the surroundings of the plant. T-sondes were launched near the plant from early morning (04:00 TC) to late afternoon (18:00 UTC). An instrumented aircraft measured meteorological and air pollution parameters. The flight route was a horizontal fan pattern shown in figure 1. A tracers experiment was also conducted and a mobile laboratory recorded SO_2 concentration every 10 minutes (CS-SUR in figure 1).

The synoptic condition for 27 of July 1989 shows the Azores anticyclone centered over the Southwest of Ireland, with an associated ridge aligned NW-SE between the Gulf of Biscay and the east coast. The Iberian Thermal Low (ITL) was located over the southern half of the peninsula. On the 500 Hpa weather map a divergence associated with the ITL was observed. High resolution pressure maps showed that the formation of the thermal low produces a significant pressure gradient over the northern coast to the center of the peninsula. Except for this gradient, the horizontal pressure gradient was weak over the peninsula.

4 Analysis of the Input Data.

The meteorological data that the model used were obtained by objective analysis of the wind and temperature vertical profiles recorded by the T-sonde. Vertical air temperature gradient was used to calculate atmospheric stability following Ludwig et al.,[5]. First, the meteorological variables were calculated in 20 levels in the vertical using a weight interpolation scheme, and then they were interpolated linearly in time, giving values every hour. Each hour the meteorological values were updated assuming that during this period the values are uniform. They were modelled for 14 hours from 04:00 to 17:00 UTC.

In this simulation, two assumptions were made: a vertical wind equals zero and a horizontal uniform wind field. The analyzed wind field showed that from 7:00 to 13:00 UTC a progressive increase in wind speed was observed, associated with sea-breeze/up-slope winds (figure 2). During these hours, the growth of the TIBL, indicated by a higher wind speed, increased very rapidly during the morning and decreased slowly during late afternoon. During the sea-breeze period, the wind shifted in a clockwise direction, attributed primarily to the Coriolis force action on the sea-breeze. After 16:00 UTC, light wind return flows were observed above 400 m. For successive hours, the return flow layers became deeper as a consequence of persistence of large scale subsidence over the cold sea.

The analyzed temperature and wind profiles showed that early in the morning atmospheric stratification presented several elevated inversions, which could be attributed to the different time arrival and heights of the sea-breeze/up-slope return flow layers of the previous days. At 12:00 UTC, an unstable surface layer and strong wind shear were observed along with return flow around 800 m to the top. A weak subsidence inversion was observed throughout all the soundings which sunk progressively toward the ground along the evening with a change in height; this subsidence sank abruptly around 17:00, when its base was detected at around 200 m .

Source emission parameters, such as emission rate, exit temperature and velocity of the gas SO_2 were given by the utility staff. In this study, it was considered a buoyant plume. Some modifications in the plume rise parameterization of the original version of the model were made to account for the atmospheric stratification observed on this day. Effective plume height was between 300-400 meter, except for the last two simulated hours,16:00-17:00, when the effective height reached up to 600 m due to the light wind at the stack height.

5 Results and Discussion.

Under the meteorological conditions presented above, the simulated plume evolution was as follows: early in the morning the plume was transported decoupled from the ground, with northeasterly wind, parallel to the coast. For successive hours, the plume rotated clockwise channeled along the river valley and produced a rotating fumigation from ~7 km west of the plant to 32 Km, until 16:00 UTC (Figure 4). Anticyclonic turning of the plume continued during the whole simulated period. It ended up almost decoupled from the ground in a northerly direction at 17:00 UTC (see figure 5).

Significant concentration levels, at 10 meters, were not predicted until 10:00 UTC, when the onset of fumigation occurred (figure 4). By 13:00 UTC, concentration distribution showed a multiple peak pattern. Maximum concentration values of 72 ppb were predicted around 10 km west of the plant and a second peak of 62 ppb around 17 km west from the plant. By 16:00 UTC some surface concentration was predicted, but by 17:00 most of the material was aloft (Figure 5). Modeled concentration patterns only reached the ground-base monitoring station, CS-SUR, at 13:00 UTC (predicting 62 ppb) while the observed concentration peak was around 12:00 UTC (measuring 234 ppb). This could be attributed to overprediction of plume rise, to inaccuracy of the wind field or to measurement of concentrations from other sources downwind. Observed concentration decreased slowly until 17:00 UTC.

Isopleths of the concentration cross-section were plotted in perpendicular planes to the plume centerline (figure 5). At 07:00 UTC the plume was mostly confined to 200-450 meters, between the two inversion detected during morning (figure 3). Some evidence of turbulent mixing was predicted in lower levels. By 10:00 UTC wind shear was reflected in the concentration pattern cross-section, showing a slanted shape and two maxima at different levels, due to higher wind speed at the lower levels while plume rotates northward. By 12:00 UTC the plume was fumigating down to the ground. At 17:00 UTC plume was decoupled from the ground and had a ">" shape showing the effect of wind shear. Material was mostly over the 200 m inversion, at 19 km away from the plant.

SO_2 concentrations were measured by the aircraft at 500 points at different height from the m.a.s.l. at nearly constant height following the terrain (figure 6).Maximum concentrations were observed close to the source. The general plume shape was well reproduce by the model and multiple maximum zones were well predicted, although modeling results failed to simulate the maxima near the source. This may have been caused by inaccurate calculation of the terrain height over the flight route. In the future those height would be digitalized precisely. Concentration values calculated by the model were, in general, overpredicted.

6 Conclusion

These preliminary simulations show that the model can reproduce the temporal plume evolution. The model predicted rotating fumigation of pollutants around midday according to experimental observations. In the future, the model will be applied with data collected during the RECAPMA project, during which experimental measurements of plume rise and dispersion parameters of the plume were conducted Alonso et al., [6]. Comparison with this data will permit adjustment of plume rise and diffusion parameterization. It will also be using outputs generated by a PBL model to provide a more

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accurate meteorological parameters.

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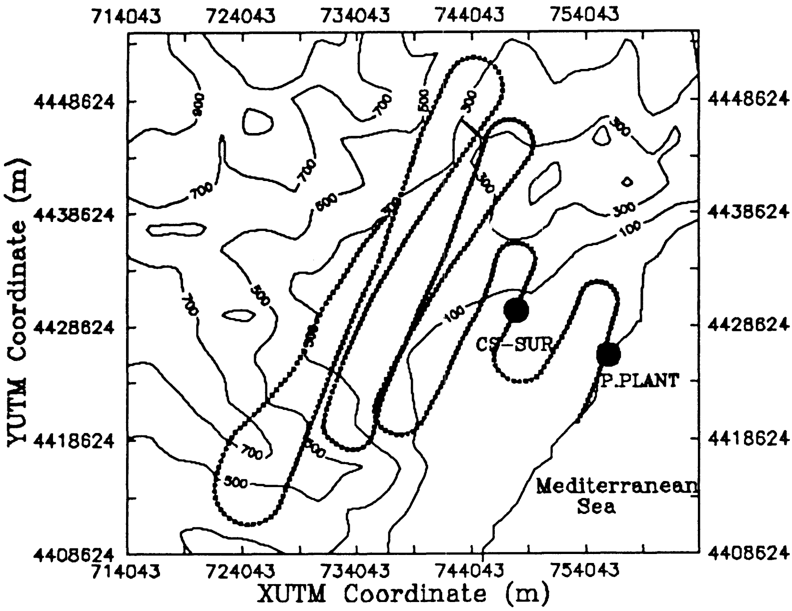

Figure 1. Map of the site showing main topographical features, ground-base monitoring station (CS-SUR), location of the power plant and tethered-sonde (P. Plant). Dotted line is aircraft flight route.

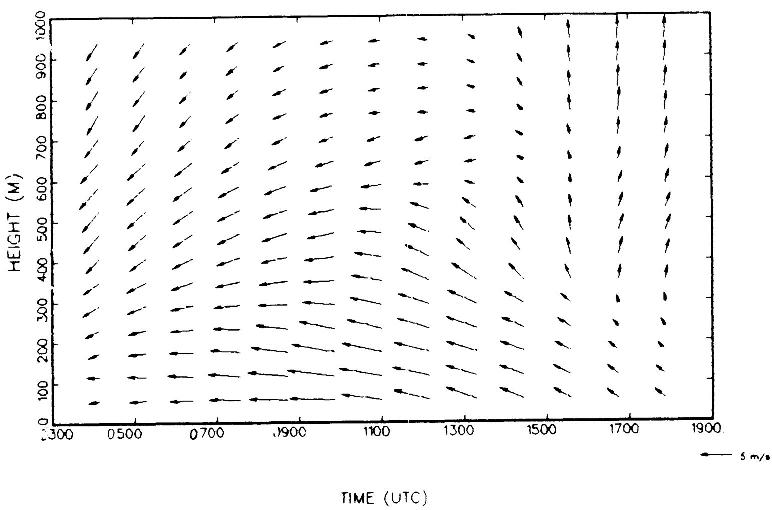

Figure 2. Analyzed wind profiles for 27 July 1989 obtained at fixed heights, from soundings near the power plant.

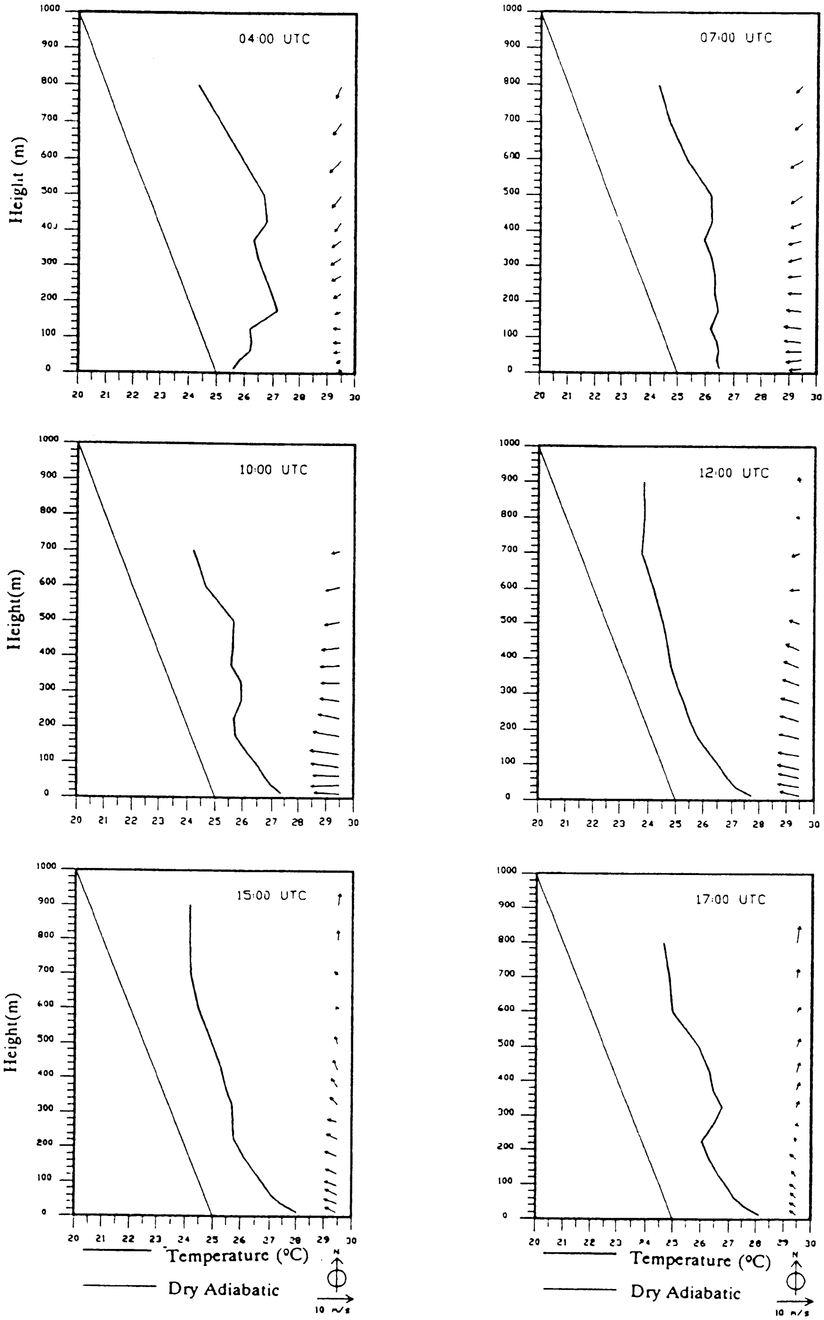

Figure 3. Analyzed temperature and associated wind profiles for 27 July 1989 obtained at fixed height from the soundings. Dry adiabatic has been plot for reference.

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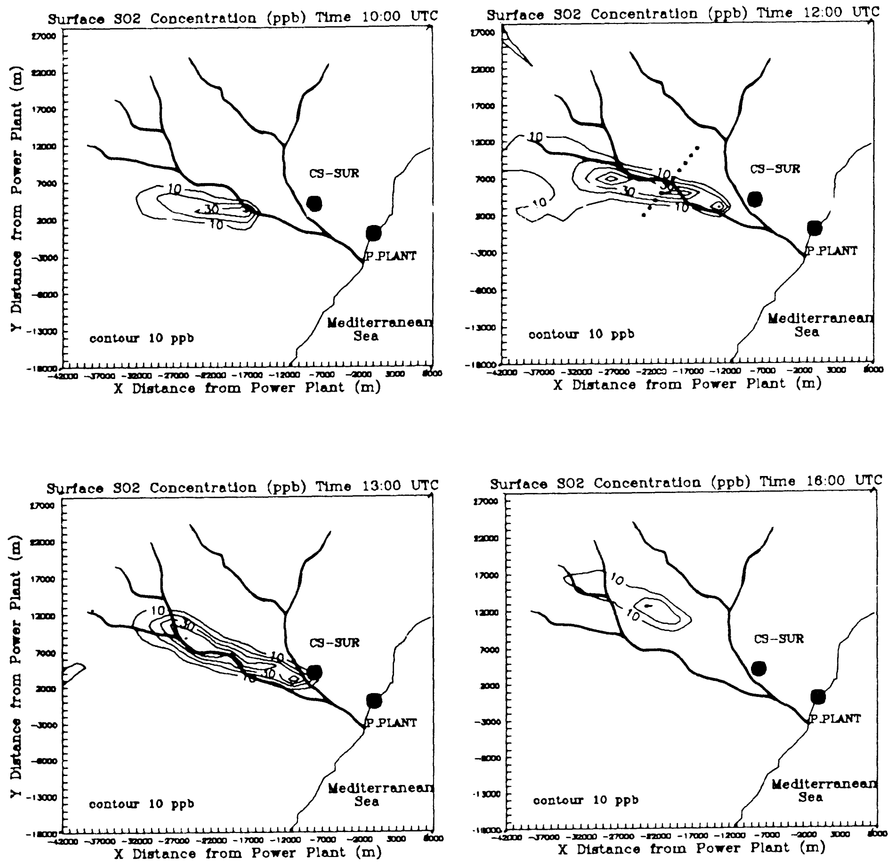

Figure 4. Calculated sulfur dioxide concentrations pattern for 27 July 1989 at 10 meter above the suface, for some hours with significant level of sulfur dioxide concentration. Dotted line refers to cross-section of figure 5.

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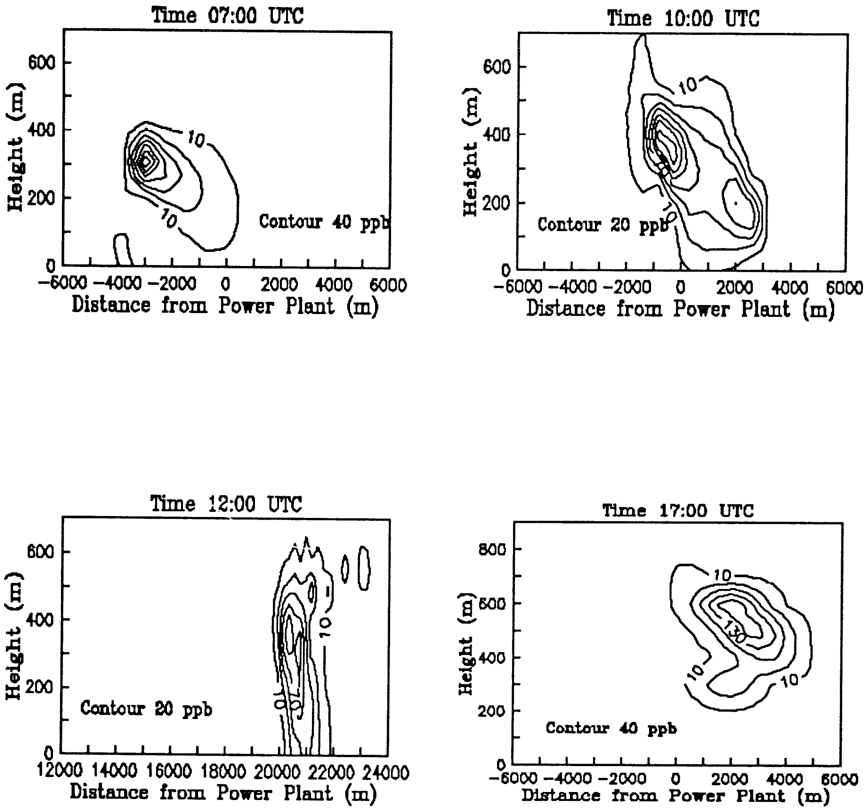
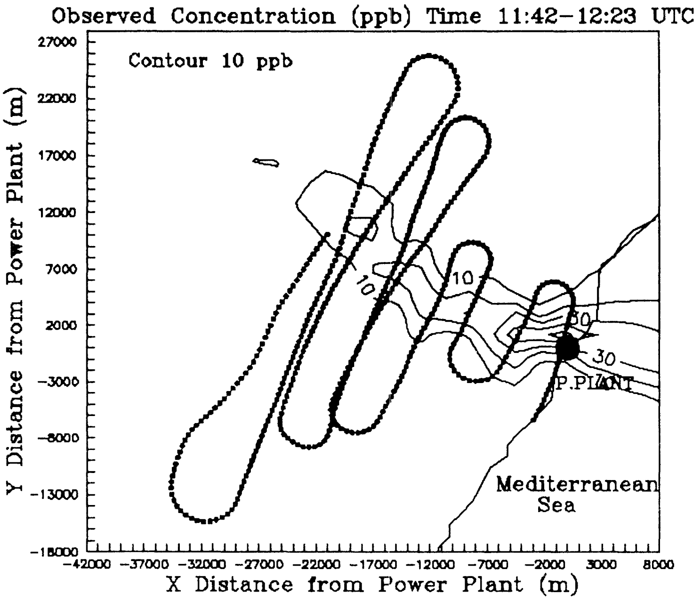


Figure 5. Calculated sulfur dioxide concentration pattern for 27 July 1989 in a N-S plane, about 16 Km W of the source at 07:00 and 10:00 UTC, in a NE-SW plane about 17 Km NW of the source for 12:00 UTC, and in a W-E plane 19 km N of the source for 17:00 UTC.



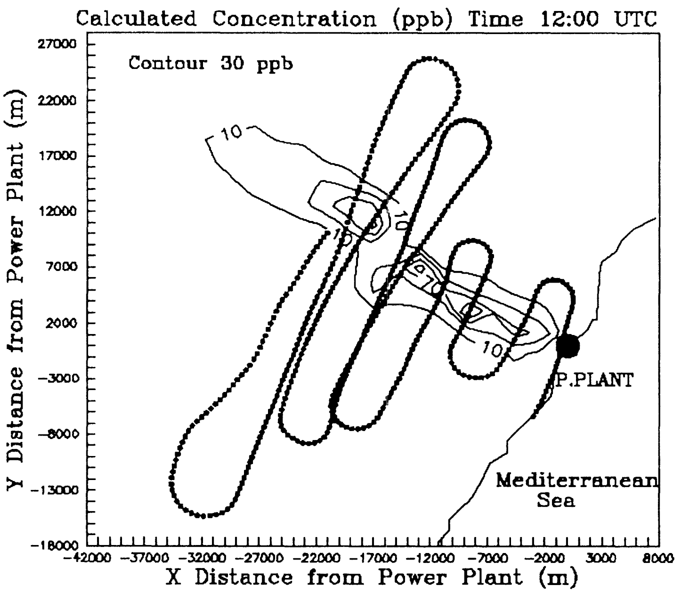


Figure 6. Comparison between aircraft observation and calculated sulfur dioxide concentration pattern in a approximated constant height following terrain.