Modeling of SO_2 Emissions from Yatağan Power Plant

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The meteorological model, CALMET, and its plume dispersion model, CALPUFF, were used in order to simulate the dispersion of SO_2 emitted from Yatağan Power Plant and its effect on Yatağan district in the episodic event on December 2 and 3, 2000. It is found that south westerly and light winds and the nighttime surface inversion layers lead to accumulation of pollutants over Yatağan district. The results are compared with the measurements done by Local Environmental Authorities of Muğla. The simulation results indicate that the maximum ground level concentrations were found northeast from the source, which agrees with experimental measurement. On the other hand, the magnitude of results obtained with the model shows some differences compared with experimental measurements.

Key words : SO_2 pollution, Air quality modeling, Power Plant Plumes, CALPUFF Modeling System, Yatağan

1. Introduction

This paper presents a dispersion and monitoring study of the SO_2 pollution emitted by the Yatağan Power Plant (YPP), which is located in the south – western region of Turkey. This study was carried out mathematically and the results were compared with the experimental measurement conducted by the Local Environmental Authorities of Muğla city. The study covers a period of 120 hours in December 2000, when the district of Yatağan suffered high levels of SO_2 pollution, exceeding the air quality limits prescribed by the Legislation of Air Pollution and Control (1986). The modeling domain covers an area of 225 km^2.

Yatağan is a small district of Muğla, which is located in the Aegean part of Turkey. The centrum of Yatağan is located in a valley – like part of the region and surrounded with hills, which behave as natural barriers that trap air pollutants, particularly of the Yatağan Power Plant located in the district. The maximum height in the north of the modeling area is 700 m, whereas in the south of the modeling domain is 600 m. The simulation area is divided into 15 x 15 x 9 grids with a grid spacing of 1 km for x and y directions and varying resolution in vertical direction with a ceiling height of 1620m.

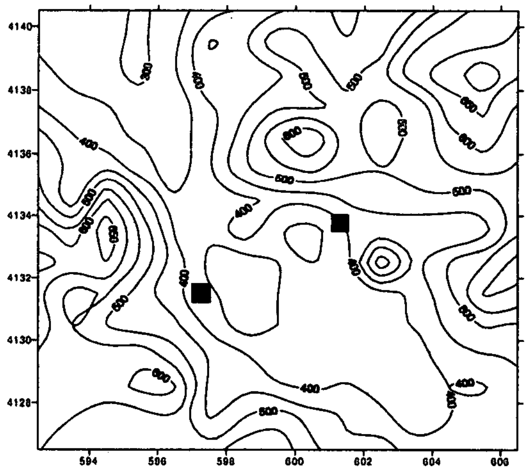

Fig. 1. Contour map in meters) of the model area.

Numerical study was carried out employing the CALPUFF Modeling System. The system includes three main programs: the meteorological model CALMET, the dispersion model CALPUFF, and the post processing model CALPOST. The CALPUFF modeling system was developed by

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Sigma Research Corporation (now part of Earth Tech. Inc.) and sponsored by California Air Resources Board. CALMET is a meteorological model that develops hourly wind and temperature fields on a three – dimensional gridded modeling domain, including two – dimensional fields such as mixing height, surface characteristics and dispersion properties. CALPUFF is a transport and dispersion model that advects puffs" of material emitted from modeled sources, simulating dispersion and transformation processes along the way, using the fields generated by CALMET. A range of averaging times may be selected, and the results may be reported in a number of different formats.

CALMET was used to predict the hourly meteorological fields for 96 hours, starting from December 1, 2000, to December 4, 2000, while CALPUFF was used to predict the hourly ground level SO_2 concentrations over a region of 15 km x 15 km grid with 1 km resolution.

2. Numerical Study

2.1. CALMET Meteorological Model

The diagnostic wind field module uses a two – step approach to the computation of wind fields[2]. In the first step, an initial – guess wind field is adjusted for kinematic effects of terrain, slope flows and terrain blocking effects, to produce a Step 1 wind field. The kinematic effects of terrain on the horizontal wind components are evaluated by applying a divergence – minimization procedure to the initial guess wind field. Slope flow magnitudes are parameterized in terms of terrain slope, terrain height, domain – scale lapse rate and the time of the day. The thermodynamic blocking effects of terrain on the wind flow are parameterized in terms of local Froude number[1]. CALMET consists of two boundary layer models for overland and over water applications. For overland surfaces, the energy balance method of Holtslag and van Ulden[4] is used to compute hourly gridded fields of the heat flux, surface friction velocity, Monin – Obukhov length, and convective velocity scale. Mixing heights are determined from the computed hourly surface heat fluxes and observed temperature soundings. The model also determines the Pasquill–Gifford stability class and optional hourly precipitation rates.

CALMET is designed to require only routinely – available surface and upper air meteorological observations, although special data inputs can be accommodated. CALMET reads hourly surface observations of wind speed, temperature, cloud cover, ceiling height, surface pressure, relative humidity, and precipitation type codes (only if wet removal is to be computed). Missing values of temperature, cloud cover, ceiling height, surface pressure, and relative humidity at surface stations are allowed by the program. The missing values are internally replaced by values at the closest station with non – missing data.

The upper air data required by CALMET include vertical profile of wind speed, wind direction, temperature, pressure, and elevation. If the upper air wind speed, wind direction, or temperature is missing, CALMET will interpolate to replace the missing data. Because the program does not extrapolate upper air data, the top valid level must be at or above the model domain and the lowest (surface) level of the sounding must be valid.

The daytime mixing height is computed using a modified Carson method based on Maul. Knowing hourly variation in the surface heat flux and the vertical temperature profile from the twice – daily sounding data, the convective mixing height at the time t + dt can be estimated from its value at time t in a stepwise manner. The potential temperature lapse rate is determined through a layer above the previous hour's convective mixing height. If only routinely available, twice – daily sounding data are available, the morning (1200 GMT) sounding at the nearest upper air station is used to determine ψ_1 up to 2300 GMT. After 2300 GMT, the afternoon sounding (0000 GMT) is used.

CALMET also requires geophysical data including gridded fields of terrain elevations and land use categories. Gridded fields of other geophysical parameters, such as surface roughness length, albedo, Bowen ratio, a soil heat flux parameter, anthropogenic heat flux, and vegetation leaf area index.

2.2 CALPUFF Dispersion Model

CALPUFF contains algorithms for near – source effects such as building downwash, transitional plume rise, partial plume penetration, subgrid scale terrain interactions as well as longer-range effects such as pollutant removal (wet scavenging and dry deposition), chemical transformation, vertical wind shear, over water transport and coastal interaction effects. A full resistance model is provided in CALPUFF for the computation of dry deposition rates of gases and particulate matter as a function of geophysical parameters, meteorological conditions, and pollutant species. An empirical scavenging coefficient approach is used in CALPUFF to compute the depletion and wet deposition fluxes due to precipitation scavenging. The scavenging coefficients are specified as a function of the pollutant and precipitation type.

CALPUFF includes options for parameterizing chemical transformation effects using the five species scheme (SO_2, $SO_4^=$, NO_X, HNO_3; and NO_3^-) used in the MESOPUFF II model, a modified six – species scheme (SO_2, $SO_4^=$, NO, NO_2, HNO3, and NO_3^-) adapted from RIVAD / ARM3 method, or a set of user specified, diurnally – varying transformation rates.

2.3. Meteorological Data

Meteorological parameters were obtained from two meteorological stations; hourly surface data is provided from Yatağan Meteorological Station, and upper air data is provided from Isparta Meteorological Station. According to the meteorological data, the most frequent wind direction is south – westerly. Atmospheric stabilities used in CALPUFF model were the Pasquill categories[6]. Inversion heights are calculated by the temperature - height profiles provided from the radiosonde data taken from Isparta Meteorological Station.

The meteorological data required are hourly surface observations of wind speed, temperature, cloud cover, ceiling height, surface pressure, relative humidity, and precipitation type codes (only if wet removal is to be computed). The upper air data required by CALMET include vertical profile of wind speed, wind direction, temperature, pressure, and elevation.

2.4. Emission Data

YPP consists of three units, each with a capacity of 210 MW and 120 m stack height.. The primary fuel is lignite and the secondary fuel is fuel – oil. Daily lignite consumption, under full – capacity, is 16500 kg / day. The total emission rate of SO_2 emitted from the Power Plant is 3804 gs^{-1}.

3. Results and Discussion

Winds in the modeling period were light winds; varying from 1 to 8 ms^{-1}. On December 2 and 3, 2000, starting from the early hours of the day to the afternoon hours, wind speeds turned out to be very low, varying from 0.1 to 0.5 ms^{-1}, blowing south – westerly, carrying the pollutants towards the Centrum and leading to the accumulation as shown in Figure 2. Wind speeds less than 2 ms^{-1} are generally considered to be low, as most of the conventional models for dispersion are to some extent, because of their assumptions considering the wind speed falls below 2 ms^{-1}. In most of the Gaussian plume models, when mean wind speed becomes very low (< 2 ms^{-1}) the pollutant concentrations tends to go exceptionally high[5].

The main numerical results indicate that the maximum ground level concentrations are found northeast from the source, which agrees with the measurements. On the other hand, the results obtained with CALPUFF show large discrepancies compared to the measurements, which are due to the presence of complex wind patterns and their influence on the pollutant dispersion This difference between the modeled and measured concentration levels may originate from the inadequencies with meteorological data incorporated into the model. The fact that the meteorological station where radiosonde data are obtained from is outside the modeling domain causes the model not to resolve the meteorological conditions during the simulation efficiently. The predicted concentrations are calculated as the maximum average values within 1 hour intervals inside a 1 km x 1 km resolution whereas the on site observations represent the conditions at the particular moment at a particular point. The concentration distribution over the modeling domain is presented in Figure 3[3].

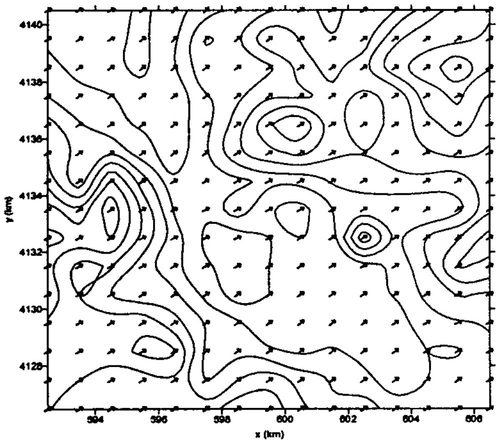

Fig. 2. Wind field for the modeling area

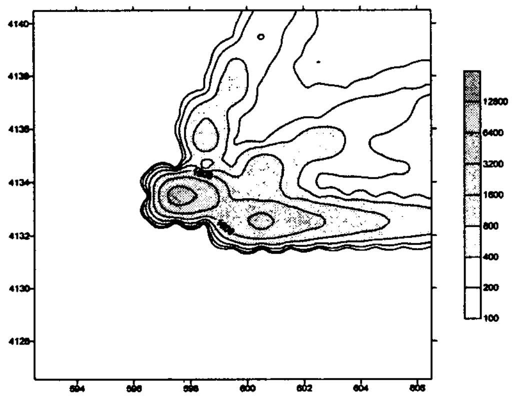

Fig. 3. Concentration distribution (μgm^{-3}) over the domain.

The maximum concentration during the simulation period in the domain is calculated as 3140 μgm^{-3} on the 38^{th} hour of the period, on December 2, 2000, at 13:00, whereas according to the on site measurements recorded by Local Environmental Authority of Muğla, the highest ground level concentration measured is recorded as 4100 μgm^{-3}. It is also concluded that data obtained from only one meteorological station inside the modeling area may not permit to adequately resolve the episode. The fact that the meteorological station where radiosonde data are obtained from is outside the modeling domain causes the model not to resolve the meteorological conditions during the simulation efficiently.

The predicted concentrations are calculated as the maximum average values within 1 hour intervals inside a 1 km x 1 km resolution whereas the on site observations represent the conditions at the particular moment at a particular point. The concentration distribution over the modeling domain is presented in Figure 3.

4. Conclusions

The maximum ground level concentrations are found northeast from the source, which agrees with experimental recordings and meteorological data. On the other hand, these concentrations differed from measurements on magnitude. It should be stated that the modeling studies should be conducted with sufficient and accurate data.

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