POLLUTION DISPERSION MODELING AT CHANIA, GREECE, UNDER VARIOUS METEOROLOGICAL CONDITIONS

K. PHILIPPOPOULOS\textsuperscript{1}, D. DELIGIORGI\textsuperscript{1}, G. KARVOUNIS\textsuperscript{1} and M. TZANAKOU\textsuperscript{2}

\textsuperscript{1}Department of Physics
National and Kapodistrian University of Athens
Building PHYS-5, University Campus, 157 84, Athens
GREECE
despo@phys.uoa.gr

\textsuperscript{2}Hellenic National Meteorological Service (HNMS)
El.Venizelou 14, Hellinikon 167 77
GREECE


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Abstract: Air quality deterioration is related to the capability of the atmosphere to disperse pollutants and to energy production and consumption patterns in the area under investigation. This study aims to identify the pollutant dispersion patterns in complex terrain under various meteorological conditions. The study area is situated at Chania Plain on the Island of Crete, Greece, where the topography is fairly complex. The main source of air pollution in the region is a diesel power generating plant. The ground level distributions of sulfur dioxide (SO\textsubscript{2}), emitted from the power plant, were predicted using AERMOD modeling system, which incorporates all the current understanding of dispersion and micrometeorology, to model the impact of point sources at short distances. In order to assess the meteorological conditions in the region, a meteorological monitoring network of six stations was installed and operated for two years (August 2004 – July 2006). The model was applied for days with well established wind flows and the daily averaged concentrations were obtained.

Key-Words: Dispersion Modeling, Air Quality, Wind, AERMOD, Statistical Modeling, Complex Topography

1 Introduction
Air pollution modeling is a method for providing information on air quality in a region based on what we know of the emissions, and of the atmospheric processes that lead to pollutant dispersion and transport in the atmosphere. In most air quality applications the main concern is the dispersion in the Planetary Boundary Layer (PBL), the turbulent air layer next to the earth's surface that is controlled by the surface heating and friction and the overlying stratification. The PBL typically ranges from a few hundred meters in depth at night to 1 - 2 km during the day. The key issues to consider in air pollution modeling are the complexity of the dispersion, which is controlled by terrain and meteorology effects along with the scale of the potential effects (i.e. human health) [1].

Air pollution models are classified according to the scales of application. Short-range models apply to space scales up to ten kilometers, while urban and long-range transport models to larger scales. The most widely used models for predicting the impact of relative inert gases, such as sulfur dioxide, which are released from industrial point sources, are based on Gaussian diffusion [2]. A Gaussian plume model assumes that if a pollutant is emitted from a point source, the resulting concentration in the atmosphere, when averaged over sufficient time, will approximate a Gaussian distribution in space.

2 Experimental Area and Data
The modeling area is at the Southeastern part of the Chania Plain, located on the island of Crete in Greece. The greater area is constricted by physical boundaries. These are the White Mountains on its Southern side and the Aegean coastline on its Northern and Eastern part. The topography of the region is characterized fairly complex due to the geophysical features of the region. The diesel power generating plant, operated by the Public Power Cooperation S.A. of Greece (PPC), is situated in a suburban area, on the outskirts of the city of Chania (35.59°N and 24.04°E) and is the main source of air pollution in the region (Figure 1). The region’s topography, land-use, along with the existence of a single significant air pollution point source makes the area suitable for identifying the dispersion
patterns in complex terrain under various meteorological conditions.

In order to assess the meteorological conditions in the greater region and more specifically in the modeling domain, an experimental meteorological network of six stations was installed and operated for two years, from August 2004 to September 2006 (Figure 1).

The surface meteorological parameters which are measured at the stations of Souda, Platanias, Malaxa, Technical Education Institute of Crete (TEI), Military Airport of Souda (Airport) and Pyrovoliko are presented in Table 1. Furthermore, upper air measurements are provided from atmospheric soundings at the civil airport of Heraklion. Surface weather maps of Southeastern Mediterranean region at 00UTC and 12UTC are available from the Hellenic Meteorological Service (HMS). The station sites cover the main topographical and land-use characteristics of the study area (Table 2).

Table 2: Characteristics of the meteorological stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Altitude (m)</th>
<th>Station Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Souda (SOU)</td>
<td>118</td>
<td>Suburban</td>
</tr>
<tr>
<td>Platanias (PLA)</td>
<td>23</td>
<td>Rural – Coastal</td>
</tr>
<tr>
<td>Malaxa (MAL)</td>
<td>556</td>
<td>Rural – Inland</td>
</tr>
<tr>
<td>TEI</td>
<td>38</td>
<td>Urban – Coastal</td>
</tr>
<tr>
<td>Airport (AIR)</td>
<td>140</td>
<td>Rural</td>
</tr>
<tr>
<td>Pyrovoliko (PYR)</td>
<td>422</td>
<td>Rural</td>
</tr>
</tbody>
</table>

3 AERMOD Modeling System

AERMOD modeling system is developed by the American Meteorological Society (AMS) and the U.S. Environmental Protection Agency (EPA) [3]. It consists of two pre-processors (AERMET and AERMAP) and the dispersion model. The overall modeling system structure is presented in Fig. 2.

AERMET, AERMOD modeling system’s meteorological pre-processor, provides the dispersion model with the meteorological information it needs to characterize the PBL. AERMET uses routinely measured meteorological data (i.e. wind speed and direction, ambient temperature and cloud cover), surface characteristics (Albedo, Bowen ratio and Surface Roughness Length) and upper air sounding data, to calculate boundary layer parameters (i.e. mixing height $z_i$, friction velocity $u_*$, Monin-Obukhov length $L$, etc.). This data, whether measured off-site or on-site, must be spatial and temporal representative of the meteorology in the modeling domain. AERMAP, the terrain pre-processor, characterizes the terrain, using a Digital Elevation Model (DEM) and generates the receptor grids for the dispersion model. Furthermore, for each receptor grid it generates a representative terrain-influence height. This information along with
the receptor’s location and height above mean sea level are passed to the dispersion model.

The dispersion model in the Stable Boundary Layer (SBL) assumes both vertical and horizontal distributions to be Gaussian. In the Convective Boundary Layer (CBL) the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described by a bi-Gaussian probability density function. AERMOD modeling system may be used for flat and complex terrain as it incorporates the concept of a critical dividing streamline. Where appropriate the plume is modeled as a combination of a horizontal plume (terrain impacting) and a terrain-following (terrain responding) plume. Therefore, AERMOD handles the computation of pollutant impacts in both flat and complex terrain within the same modeling framework.

4 Methodology
This study is focused on the impact of a single air pollution point source at the Chania plain under the various meteorological conditions, which are observed at the area under investigation. The surface pressure maps of the Southeastern Mediterranean region at 00UTC along with the meteorological measurements from the stations network are used for the selection of days and to characterize the weather conditions in the region. In detail, the identification of the distinct meteorological conditions with well established wind flows in the region is performed by analyzing the daily evolution of wind speed and direction from the experimental measurements, with increased significance the measurements from the station of Souda, due to its proximity to the modeled power plant.

Once the representative days are selected, surface daily averaged concentrations of sulfur dioxide are estimated using AERMOD modeling system. Sulfur dioxide is selected as the pollutant of reference because due to its rather inert nature it is suitable to estimate the dispersion patterns in the region, due to the increased tourist activity during the summer months, leads to multiple operational patterns for each substation.

<table>
<thead>
<tr>
<th>Source</th>
<th>Exit Speed (m/sec)</th>
<th>Exit Temp (°C)</th>
<th>Emission Rate(m³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack 1</td>
<td>27</td>
<td>322</td>
<td>0.0099</td>
</tr>
<tr>
<td>Stack 2</td>
<td>15</td>
<td>462</td>
<td>0.0097</td>
</tr>
<tr>
<td>Stack 3</td>
<td>15</td>
<td>478</td>
<td>0.0199</td>
</tr>
<tr>
<td>Stack 4</td>
<td>35</td>
<td>515</td>
<td>0.0555</td>
</tr>
<tr>
<td>Stack 5</td>
<td>30</td>
<td>505</td>
<td>0.0461</td>
</tr>
<tr>
<td>Stack 6</td>
<td>21</td>
<td>170</td>
<td>0.0619</td>
</tr>
<tr>
<td>Stack 7</td>
<td>25</td>
<td>174</td>
<td>0.0703</td>
</tr>
</tbody>
</table>

The selected modeling domain covers an area of 51km² (Fig. 1) and a Cartesian grid was used containing 20,541 receptors with spatial resolution 50m. The power plant is situated at the Northeastern part of the modeling domain.

AERMOD is found to be highly sensitive on the selection of land use parameters and especially to surface roughness length, with an error reaching up to 20%, when inappropriate values are used [4][5]. In our case field measurements were not available and their representative selection was based on observational-qualitative criteria in conjunction with the proposed tables by EPA [3]. These tables provide typical values of Surface Roughness Length, Albedo and Bower Ratio for each season and land use type.

Gaussian type models and therefore AERMOD require spatial and temporal representative meteorological data for the application area. Representativeness is the extent to which a set of measurements taken in a space-time domain reflects the actual conditions in the same or different space-time domain taken on a scale appropriate for a specific application [6][7]. For this purpose, the two year data set is compared with the 50-year climatological data series provided by the Hellenic Meteorological Society. The dataset was found to be a statistical representative sample of the meteorological conditions that occur in the application area. Furthermore, after a qualitative spatial meteorological assessment, Souda measurements are found to be spatial representative for the modeling domain due to the proximity of the Souda site and to the resemblance in land use characteristics with the modeled area. Hourly values of wind speed, wind direction and ambient temperature are used as a meteorological input in AERMOD from Souda station. Cloud cover observations have greater spatial representativeness and therefore are acquired from the Airport Station.
The required upper air observations are obtained from Heraklion airport which is the only station at the island of Crete that performs atmospheric soundings.

5.2 Case Studies
The following case studies correspond to four distinct cases where the typical dispersion patterns in the region are illustrated. For each case the surface pressure map along with the daily wind evolution at the station of Souda is illustrated. In order to study the lower concentrations in the concentration diagrams in more detail, the logarithmic scale of the relative quantity $C/C_{\text{max}}$ has been used.

The first case corresponds to the 27th of August 2004. This day is characterized by a normal field of a relatively high pressure system in the central Mediterranean and Greece in combination with a relative shallow low system in the Southeastern Turkey. Such a system is mainly observed during the warm period of the year and favors local flow development, such as the sea breeze cell. This synoptic condition leads to a weak background West-northwestern flow, which is enhanced during midday hours under the influence of the sea breeze circulation cell (Fig. 3). The relatively strong flow, especially during the midday hours, results to the transfer of the plume along the prevalent direction with relatively low dispersion. The flat terrain at the Eastern part of the power plant results to the above mentioned typical dispersion pattern (Fig. 4).

The main characteristic of the second case (1 April 2005) is the passage of a cold front, which moves Southwards. In the area of Crete, Northern winds prevail as a result of the anticyclone in the central Europe in combination with the low system in East Turkey (Fig. 5). The plume, as a result of the strong flow, is transferred to the wind direction, following the terrain. Due to its high kinetic energy, the plume is concentrated around the main transfer axis, without being trapped in the valley of Chania (Fig. 6).

The 6th of May 2005 corresponds to a complex synoptic case and its main characteristic is the relative shallow low system in the North Aegean with a cold front at the western part of the Peloponnese. Thus, the flow during the day is weak with an Easterly direction, but after the front passage the flow is enhanced. The direction varies from Southeastern to Northeasterly components (Fig. 7). The weak wind regime results to a relative
high concentration background in the plain of Chania. The five distinct concentration components observed at Fig. 8 are the result of the wind fluctuations (Fig. 7).

Fig. 6: AERMOD’s ground level predicted SO$_2$ concentrations for 01/04/2005

Fig. 7: Surface pressure map at 00UTC and daily wind evolution at Souda station for 06/05/2005

Fig. 8: AERMOD’s ground level predicted SO$_2$ concentrations for 06/05/2005

The forth case study corresponds to the 13th of October 2005. The weak synoptic gradient favors the development of local flows during night and day. Such conditions are observed during the transitional periods. During midday hours, the flow is southeastern, with a gradually decreasing intensity and becomes northwestern during the night (Fig. 9). In the whole area under study, a background pollution concentration is observed. The higher concentrations are observed at the western roots of the White Mountains at the valley of Chania. The Southeasterly winds, which prevail during midday hours, transfer the plume towards the city of Chania (Fig. 10).

Fig. 9: Surface pressure map at 00UTC and daily wind evolution at Souda station for 13/10/2005

Fig. 10: AERMOD’s ground level predicted SO$_2$ concentrations for 13/10/2005

6 Conclusions
AERMOD modeling system was applied for the Southeastern part of the Chania plain and for days with well established wind flows. The ground level
daily averaged sulfur dioxide concentrations were obtained. The selection of days was based on the analysis of the surface pressure maps at 0000 UTC and the wind measurements at the six experimental sites. Case studies are presented, which reveal the dispersion patterns of atmospheric pollutants in the region. The effect of topography and the complexity of wind circulation patterns lead to a number of dispersion patterns in the region. Under weak wind regimes the higher concentrations are predicted at the roots of the White Mountains, while under strong wind regimes the top-end concentrations are found along the plume centerline.

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References