ON THE SENSITIVITY OF AERMOD TO SURFACE PARAMETERS UNDER VARIOUS ANEMOLOGICAL CONDITIONS

George Karvounis, Despina Deligiorgi and Kostas Philippopoulos
National and Kapodistrian University of Athens, Department of Physics, Physics of Atmospheric Environment Lab., Athens, Greece

INTRODUCTION

Gaussian type models are widely used in atmospheric dispersion modeling for regulatory purposes. AERMOD is a steady-state plume model for short-range dispersion studies (up to 50km) from stationary industrial-type sources. Its meteorological preprocessor, AERMET, in order to construct Planetary Boundary Layer (PBL) similarity profiles, requires land use surface characteristics namely, Albedo, Bowen Ratio and Surface Roughness Length. These parameters are not directly measured at the meteorological stations and a subjective estimation is often necessary. This study, by examining the sensitivity of AERMOD to land use parameters, evaluates the importance of their representative selection. The analysis is focused on the resulting upper end modeled concentrations, which are the most important in applied regulatory modeling. The study was carried out for sulfur dioxide on a daily averaging period basis, using the various prevalent anemological conditions inherent in the area of study.

AREA OF STUDY

The modeling area is at the southeastern part of the Chania Plain, located on the island of Crete, Greece (Figure 1). The greater area is constricted by physical boundaries. These are the White Mountains Range on its Southern side and the Aegean coastline which lies towards the North and East. The topography in the area is fairly complex. This is due to the proximity to the sea and also because of the hills which rise sharply into mountainous heights.

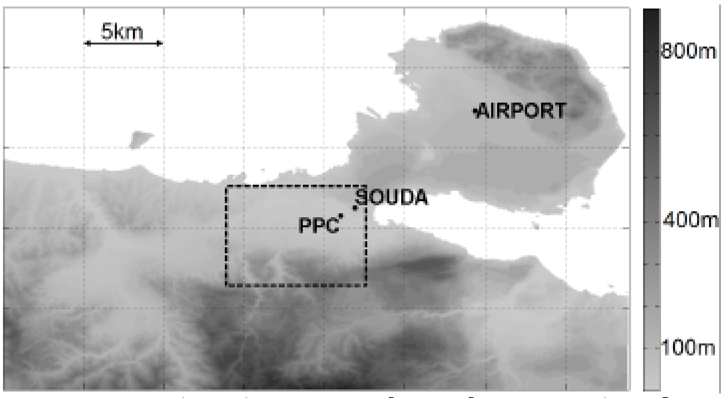

Fig. 1; Study Area, Source (PPC), Meteorological Stations (Souda and Airport) and Modeling Domain.

AERMOD MODELING SYSTEM

The AERMOD modeling system, developed by the American Meteorological Society (AMS) and the U.S. Environmental Protection Agency (EPA), consists of two pre-processors and the dispersion model. Its meteorological pre-processor, AERMET, provides AERMOD with the meteorological information it needs to characterize the PBL. The atmosphere is described in AERMET by similarity scaling relationships using routine meteorological data (wind speed and direction, ambient temperature and cloud cover), surface characteristics (Albedo, Bowen Ratio and Surface Roughness Length) and upper air sounding data. AERMAP, the terrain pre-processor, characterizes the terrain, using a Digital Elevation Model (DEM) and generates receptor grids for the dispersion model. The dispersion model in the Stable Boundary Layer (SBL) assumes both the 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. The AERMOD modeling system may be used for flat and complex terrains as it incorporates the concept of a critical dividing streamline (*Cimorelli, A.J. et al.,* 2004, *Perry S.G. et al.,* 2005, *Holmes N.S. and L.Morawska*, 2006).

AERMOD INPUT

The modeled industrial source is a diesel power generating plant operated by the Public Power Cooperation S.A. (PPC). It is situated in a suburban area, on the outskirts of the city of Chania (35.49^{o}N and 24.04^{o}E) and its seven buoyant point sources have different technical and operational characteristics (Table 1).

Table 1. Technical characteristics of the seven buoyant point sources

Point Source	Stack Height (m)	Diameter (m)	Exit Speed (m/sec)	Exit Temperature (^{o}C)
Stack1	12	2.92	27	322
Stack2	14	4.30	15	462
Stack3	17	5.28	15	478
Stack4	40	3.80	35	515
Stack5	40	3.80	30	505
Stack6	60	3.60	21	170
Stack7	60	3.60	25	175

The model was run to estimate daily averaged concentrations of sulfur dioxide (SO_2) at each receptor, covering an area of 51km^2. The power plant is situated at the Northeastern part of modeling domain (Figure 1). A Cartesian grid was used containing 20,691 receptors with a resolution of 50m.

The input meteorological data was obtained from two monitoring stations. A two-year data set (August 2004 – July 2006) of mean hourly values of wind speed, wind direction and ambient temperature are provided from the station of Souda (35.50^{o}N and 24.05^{o}E), while the required cloud cover observations are acquired from the nearby Military Airport of Souda station. The monitoring station of Souda is found to be representative of the modeling domain, due to its spatial proximity to the modeled area (within its boundaries) and its resemblance in land-use characteristics.

METHODOLOGY

Previous studies have shown that AERMOD is highly sensitive to wind speed and direction (*Steib,* 2005) and to Surface Roughness Length (*Carper E. and E. Ottersburg*, 2004, *Grosch T.G. and R.F.Lee*, 1999). This study aims to identify the degree of sensitivity of AERMOD to the changes in Albedo, Bowen Ratio and Surface Roughness Length under the various anemological conditions, prevalent in the Plain of Chania. In order to determine the predominant anemological conditions in the area, a k-means clustering algorithm was applied to the daily wind sequences. For each of the formed groups a representative day is selected, using as a criterion the resemblance to the centroid of the group (measured by the Euclidian distance, given in Equation 1). For every day, multiple runs of AERMOD are performed with varying surface parameter values in the whole range proposed by EPA for various land types. The two highest estimated concentrations of each simulation are compared with those of a reference case, which corresponds to fixed values for Albedo, Bowen Ration and Surface

Roughness Length, appropriate for the area of study. The range of surface characteristics value used in this study is proposed by EPA.

K-Means Clustering

The term Cluster Analysis encompasses a number of different methods and algorithms for grouping objects into respective categories. K-means is an unsupervised clustering algorithm which classifies a given data set into a certain predetermined number of clusters. The main idea is to define k centroids, one for each cluster, and associate each observation of the data set to the nearest centroid. K-means uses an iterative algorithm which minimizes the sum of distances from each object to its cluster centroid, over all clusters, using the following metric:

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| \vec{x}_i - \vec{c}_j \right\| \quad (1)$$

where $\left\| \vec{x}_i - \vec{c}_j \right\|$ is the distance between observation $\vec{x}_i$ and centroid $\vec{c}_j$. The algorithm moves objects between clusters until the sum can no longer be decreased. The result is a set of clusters that are as compact and well-separated as possible. (*Ankerst M. et al.* , 1999). Since we were interested in finding group of days with similar daily wind evolution, the objects $\vec{x}_i$ to be clustered are defined as:

$$\vec{x}_i = (u_{i1}, v_{i1}, \ldots u_{i24}, v_{i24})$$

where (u_{ij}, v_{ij}) are the j-th hour mean wind components of the i-th day. The days were initially classified into 30 clusters and an additional subjective grouping was performed by examining the centroids of those clusters. The outcome was 10 different clusters, which cover the main anemological characteristics of the region. In Figure 2 the centroid of each cluster is presented along with the members of each cluster.

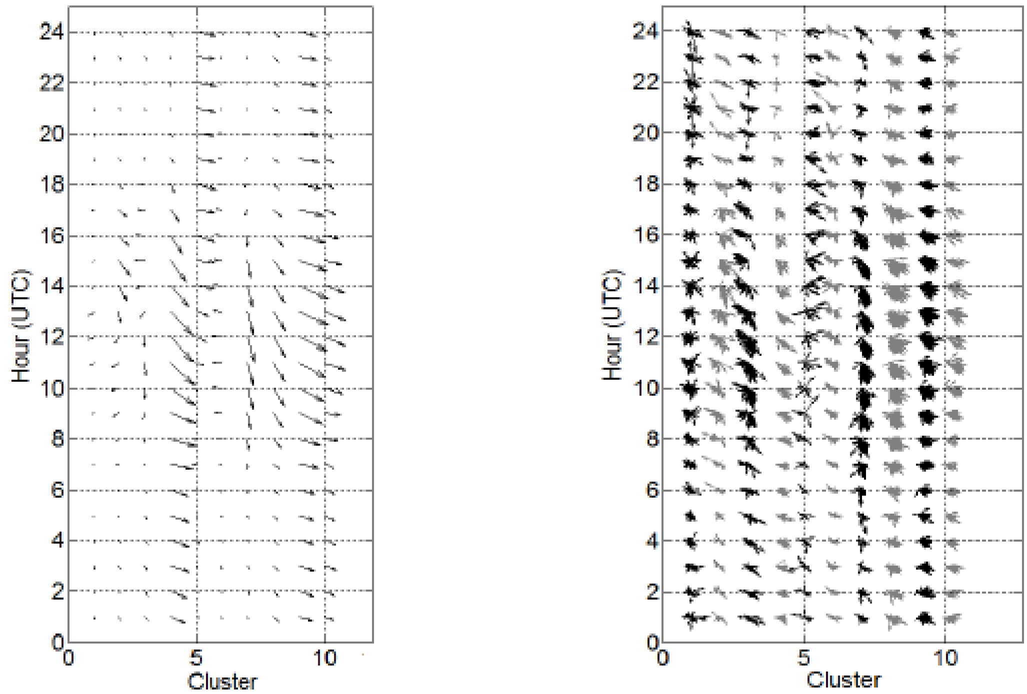

Fig. 2; Cluster Centroids and Wind Vectors of Cluster Members.

The 1st cluster corresponds to a medium intensity random wind field, while the 2nd cluster to a daily anemological pattern dominated by local flows, such as sea and land breeze circulations. Local flows are dominant in the members of the 3rd cluster with the wind vector gradually shifting from north to east between the hours of 11:00 and 16:00 UTC. The members of the

4th cluster are days with medium to high intensity westerly winds, observed during the morning and afternoon with very low winds during the night. In the case of the 5th cluster, we observe the opposite evolution of the wind vector where low winds prevail during the night until mid-day and medium intensity westerly winds for the remainder of the day. In cluster 6, light winds are observed throughout the day, intensifying between the hours of 9:00 and 16:00 UTC with an eastern direction. The daily anemological pattern of cluster 7 is a northern flow, intensifying from mid-morning until 14:00 UTC. In cluster 8 we observe northwestern winds throughout the day, becoming stronger between 8:00 and 14:00 UTC. Westerly winds prevail in the 9th and 10th cluster, the difference being that in the 9th cluster the wind speed is stronger.

Sensitivity Analysis Results

The following figures exhibit that AERMOD is highly sensitive to changes in Surface Roughness Length and rather indifferent to Albedo and Bowen Ratio variations.

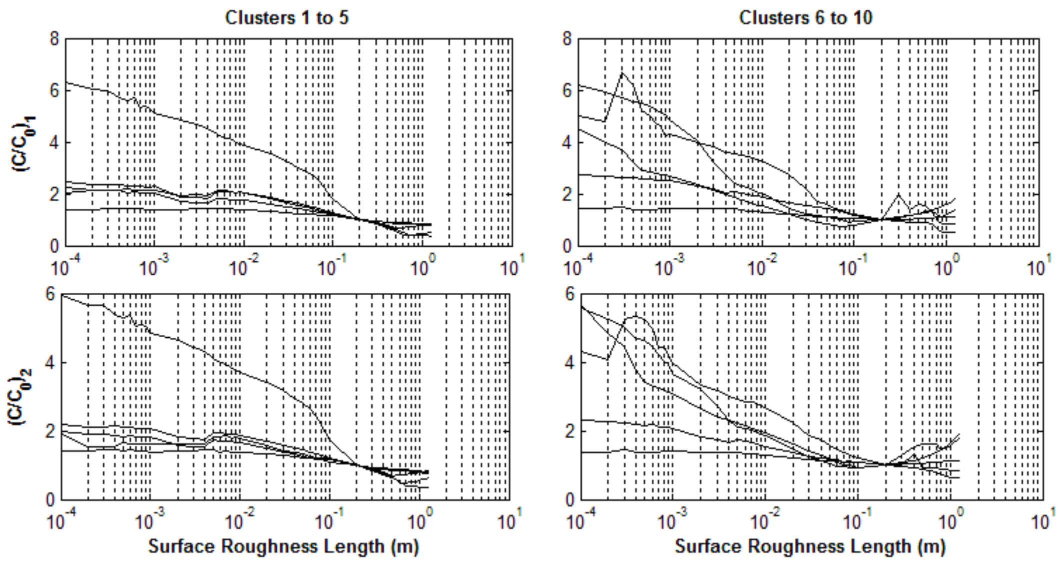

Fig. 3; Sensitivity of AERMOD to changes in Surface Roughness Length. The upper diagrams refer to the maximum concentrations normalized by the maximum concentration of the base case C_0, while the lower ones correspond to the second maximum estimated concentrations.

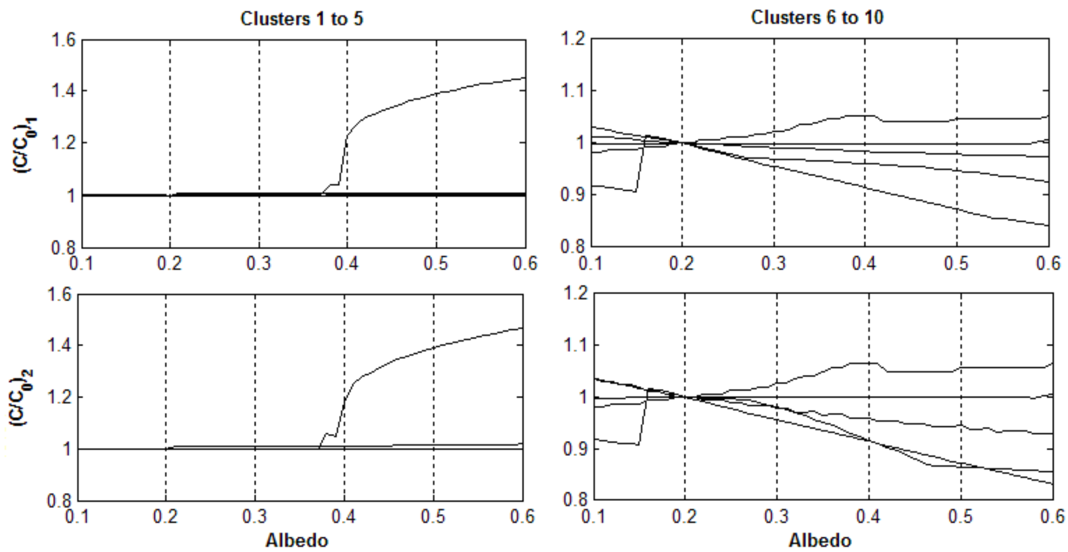

Fig. 3; Sensitivity of AERMOD to changes in Albedo.

In Figure 3 it is observed that for very low values of Surface Roughness Length the peak estimated concentrations might get up to six times higher than the estimation for the base case. Also, in the range of values around 0.2, which are typical for cultivated land, an error in Surface Roughness Length's estimation in the order of 0.1, propagates to estimated concentrations, resulting in an overall error even higher than 20%. Furthermore, as expected, sensitivity to all parameters is not uniform across different anemological conditions.

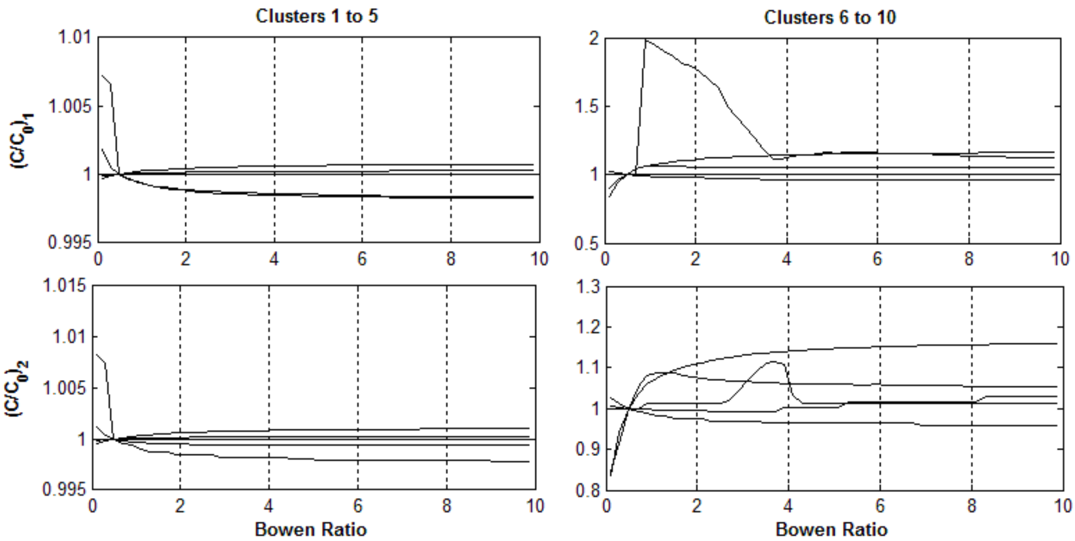

Fig. 5; Sensitivity of AERMOD to changes in Bowen Ratio.

CONCLUSIONS

This study shows that estimated concentrations by AERMOD can vary substantially due to normal variations in the Albedo, Bowen Ratio and Surface Roughness Length. Therefore, their representative selection should be considered as an important part of the modeling process. Reasonably and accurate estimations of these parameters should be not only based on proposed tables, but also on field measurements.

ACKNOWLEDGEMENTS

The work described in this paper has been co-funded by the European Social Fund and Hellenic National Resources under the PYTHAGORAS II programme (EPEAEK II).

REFERENCES

Holmes N.S. and L.Morawska, 2006: A review of dispersion modelling and its application to the dispersion of particles: An overview of different dispersion models, *Atmospheric Environemnt*, **40**, 5902-5928.

Steib R., 2005: Regulatory Modelling Activity in Hungary, *Advances in Air Pollution Modelling for Environmental Security*, 337-347.

Grosch G.T. and R.F. Lee, 1999: Sensitivity of the AERMOD air quality model to the selection of land use parameters, *WIT Transactions on Ecology and the Environm.*, **37**.

Carper E. and E. Ottersburg, 2004: Sensitivity Analysis Study Considering the Selection of Appropriate Land-Use Parameters in AERMOD Modeling Analyses, *Trinity Consultants, Technical Paper.*

Ankerst M., M.M.Breunig, H.P.Kriegel and J. Sander, 1999: OPTICS: Ordering Points to Identify the Clustering Structure., *Proc. ACM SIGMOD '99 Int. Conf. on Management of Data.*

Cimorelli, A. J., S. G. Perry, A. Venkatram, J. C. Weil, R. J. Paine,R. B. Wilson, R. F. Lee, and W. D. Peters, 2003: AERMOD description of model formulation. *U.S. EPA.*