AIR QUALITY MODELING FOR SKOPJE, MACEDONIA

Radmila Bojkovska[1] , Mile Dimitrovski[2], Trajce Stafilov[3]

[1] *Hydrometeorological Institute, Skupi bb, 1000 Skopje, Republic of Macedonia*
Tel. 389 91 397 004, E-mail: rbojkovska@meteo.gov.mk
[2]*Faculty of Mechanical Engineering, Karpos bb, 1000 Skopje, Republic of Macedonia*
Tel.389 91 399 217, E-mail: prof_dimil@yahoo.com
[3]*Institute of Chemistry, Faculty of Science, St. Cyril and Methodius University,*
POB 162,1000 Skopje, Republic of Macedonia
Tel.: ++389 91 117 055; Fax: ++389 91 226 865
e-mail: trajcest@iunona.pmf.ukim.edu.mk

Abstract

Republic of Macedonia is a recently independent inland country with a population of approximately 2,060,000. Many of the cities, including the capital, Skopje are located in valleys surrounded by mountains and experience chronic air pollution problems. Highest concentration occur most frequently during the winter months when strong temperature inversions act to “trap” emissions within a shallow stable layer. Air movement during these conditions is very slow and these conditions are often referred to as “stagnation” conditions. The pollutants of primary concern are SO_2 and SPM. Other pollutants of concern are carbon monoxide (CO) and nitrogen dioxide (NOx). Sources of air pollution which contribute to these problems include mobile (automobiles, buses, trains), industry (steel works, chemical manufacturing, etc.), centralized heating facilities, residential heating and off-road mobile sources (e.g., construction equipment). Skopje, the largest city in Macedonia, has some 30-40 major and mid-size point sources which strongly contribute to the air pollution problem. Two types of modeling approaches are planned for Skopje, receptor and dispersion modeling. An air quality dispersion models simulate the dispersion of air pollutants once they are released into the environment by simulating all of the physical process which take place in the atmosphere (dispersion, transport, deposition, chemical transformation). By simulating these physical processes for all sources of pollutants the model can detail emission source contributions. However, the model is dependent upon reliable measures of emissions and meteorology. Emission estimates are reasonably known for CO, SO_2 and NO_2, but are poorly known for SPM. To strengthen the conclusions regarding SPM source contribution from the dispersion model a receptor model is used to confirm/support the conclusion. A receptor model examines ambient measurement of SPM for their chemical constituents and compares unique chemical elements (tracers) from emission source profiles to establish source contribution. To successfully apply the method with a high degree of confidence many ambient

measurement samples have been made and their subsequent chemical analysis and emission source profile information determined.

Introduction

The study area is the entire country of Macedonia. However, for the modeling effort, the simulation modeling has been limited to one city. The city selected for the modeling is Skopje with some 30-40 major and mid-size point sources which contribute to the air pollution problem. Air simulation modeling provides a rational (scientifically-based) method for estimating source contributions, which can then be used to determine the effectiveness of emission reduction alternatives in meeting Macedonian ambient air quality objectives. The method can also be applied numerous times to answer “what if” question for future year emission changes. The objectives were to develop an example modeling approach and methodology which could be used:

- As a basis upon which further refinements to modeling could be develop;
- To examine control strategy effectiveness in meeting air quality objectives;
- To develop similar approaches for other cities within Macedonia.

To meet these objectives, air quality modeling study was performed for Skopje, for a base year 1998, one future-year (2008) without additional control measures, and one future-year (2008) with implementation of control measures.

Modeling Approach

Two general classes of air models were used in the Study. An air quality dispersion model which simulates the dispersion of air pollutants once they are released into the environment by simulating all of the physical process which take place in the atmosphere (dispersion, transport, deposition, chemical transformation). However, the model is dependent upon reliable measures of emissions and meteorology. Emission estimates are usually reasonably known for CO, SO_2 and NO_2, but are often poorly known for SPM. To confirm and support the calculated regarding SPM source contribution from the dispersion model a receptor model is used. A receptor model examines ambient measurement of SPM for their chemical constituents and compares observed chemical composition to those of emission source profiles to establish source contribution. To successfully the method with a high degree of confidence requires many ambient measurement samples and their subsequent chemical analysis and emission source profile information.

A long-term dispersion model was used to simulate the annual average concentration for the pollutants of SO_2, SPM, CO and NO2. The USEPA’s ISC3 air quality model was selected for simulating long-term averages.

To simulate hourly SO_2 concentrations during the typical SO_2 episode the CALPUFF modeling system was selected. The most widely used receptor model, the Chemical Mass Balance (CMB) was used.

Receptor models are generally contrasted with dispersion models which use estimates of pollutant emissions rates, meteorological transport, and chemical transformation mechanisms to estimate the contribution of each source to receptor concentrations. The two types of models are complementary, with each type having strengths which compensate for the weakness of the other.

Model Result

1) Long-term Dispersion Modeling

For the long-term modeling comparisons were made between modeled and observed for each monitoring site for SO_2, SPM, NO_2 and CO. For all pollutants, including SO_2, the change in emissions and switching from oil to natural gas for all of heating plants resulted in little change to the annual average concentrations. This is because the heating plants contribute little to the overall SPM, NO_2, and CO, emissions. Additionally, these sources only operate for half the year and are emitted from relatively tall stacks. This enables pollutants to be widely dispersed throughout the area. The source contribution from the heating facilities for SO_2 is much smaller in 2008 than for 1996 with the control strategy implemented. However, the 20% growth for other combustion sources erodes the benefit of the control strategy, with a net result of little change in the modeled SO_2 concentration. Conversation of fuel from the heavy oil to low sulfur fuel at other combustion sources is therefore needed.

Figures 1.1 to 1.4 show the spatial distribution within the modeling domain of annual average SO_2, SPM, NO_2 and CO. Figures 1.1.a to 1.4.a show the annual average spatial distribution with implementation of the control strategy.

2) Short-term Dispersion Modeling

Short-term modeling of Skopje were compared with monitored 24-hour average SO_2 concentrations for both January 14 and 15, 1998. Results of present state and future forecast by simulation model are shown in Figures 2.1 and 2.2.

Results showed that the peak modeled SO_2 site (Hotel Panorama) had almost no contribution from the heating plants thus the net result of the control strategy at this location is a net increase from the base year because of the growth in emissions by 20%from combustion sources.

On the other hand, the site that saw the biggest net reduction in average concentration of 313 $\mu g/m^3$ was Karpos IV measuring point because almost three-quarters of the concentration in the base year is attributable to emissions from the heating plants. Thus conclusions about the merit of a particular control strategy

effectiveness have to carefully examine the spatial changes in concentration to determine the overall benefit from a particular strategy.

3) Receptor Modeling

To estimate the sources of trace elements measured at the three sites factor analysis was performed using data for twelve elements from 56 samples collected between December 25, 1997 to February 21, 1998.

	Al	Si	S	Cl	K	Ca	V	Mn	Fe	Zn	Br	Pb
Al	1.00	0.78	0.73	0.48	0.73	0.47	0.79	0.66	0.66	0.55	0.35	0.38
Si	0.78	1.00	0.74	0.47	0.80	0.47	0.58	0.61	0.58	0.55	0.18	0.22
S	0.73	0.74	1.00	0.89	0.98	0.89	0.75	0.62	0.86	0.63	0.59	0.59
Cl	0.48	0.47	0.89	1.00	0.90	0.99	0.55	0.34	0.85	0.54	0.72	0.70
K	0.73	0.80	0.98	0.90	1.00	0.90	0.69	0.56	0.86	0.63	0.57	0.58
Ca	0.47	0.47	0.89	0.99	0.90	1.00	0.55	0.36	0.84	0.52	0.69	0.68
V	0.79	0.58	0.75	0.55	0.69	0.55	1.00	0.61	0.74	0.51	0.53	0.54
Mn	0.66	0.61	0.62	0.34	0.56	0.36	0.61	1.00	0.60	0.49	0.38	0.38
Fe	0.66	0.58	0.86	0.85	0.86	0.84	0.74	0.60	1.00	0.71	0.87	0.87
Zn	0.55	0.55	0.63	0.54	0.63	0.52	0.51	0.49	0.71	1.00	0.57	0.70
Br	0.35	0.18	0.59	0.72	0.57	0.69	0.53	0.38	0.87	0.57	1.00	0.98
Pb	0.38	0.22	0.59	0.70	0.58	0.68	0.54	0.38	0.87	0.70	0.98	1.00

Table 3.1 Correlation Matrix Describing the Correlation Between the Measured Variables

a) **Br** – high fluctuations in the Bromine average is not surprising as Br concentrations can be considerably influenced by local Br emissions from automobile exhaust.

b) **S, Cl, K, Ca** and **Fe** – good correlation is observed between S (Sulfur), Cl (Chlorine), K (Potassium), Ca (Calcium) and Fe (Iron), suggesting that these elements were carried together in the same air mass, either because they arise from a single type of source, or because the spatial and temporal distributions of emissions from contributing source types are similar to those of SO_2 in Skopje.

Particulate sulfur is expected to be primarily the result of secondary sulfate, whose origin is SO_2 from the combustion of oil.

Potassium (K) is known to be more abundant in smoke from wood burning. Those two findings suggest that the correlation of S and K arise from stagnation conditions in cold weather, resulting in an accumulation in the atmosphere over Skopje of concentrations of heating source emission over a long enough time period for some fraction of the SO_2 to oxidize to sulfate (one to two days).

Ca and Fe are not commonly associated with heating sources, and thus may represent another source of fine particles that accumulate during stagnation (cement manufacturing is possibility included here).

c) **Al, Si, K, V, Mn** and **Fe** – There is also a good correlation between Al (Aluminum), K, V (Vanadium), Mn (Manganese) and Fe. Fe, Mn, and K are all present in the aluminosilicate phase (e.g., crustal dust or rock).

d) **Br** and **Pb** – Also, as expected, Br and Pb (Lead) show a strong correlation, as both are present fixed ratios in the exhaust of vehicles fueled with leaded gasoline.

e) **Specific Source Categories** – The specific source categories that are apparent, based on knowledge of elemental abundance in emissions, include mobile sources, crystal material, heating with oil and wood, and potentially refuse incineration. The elements providing the most useful information in identifying the principal components included Pb, Br, Al, Si, K, V, Mn, S, and Zn.

Conclusion:

This study show that differences between the model estimates and measurements are systematic for some components in area –Skopje, and that this could be related to properties of the model, the design of the measurement network and/or errors in the emission and monitoring data. Also, this model could be extended on all teritory of Macedonia and widely of region. It is therefore appropriate to make a new comparison of the measurement data with model prediction which qualifies our present estimate of the (dispersion of SO2, SPM, CO, Nox) pollution in Balkan.

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