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A FIRST APPROACH TO ESTIMATING AIR POLLUTANTS IN TURKEY USING AN AIR QUALITY MODEL

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ABSTRACT

Most of the European countries have their own emission inventories, which gives them a chance to carry out detailed and more accurate research of air pollutants. However, we do not witness any activity in preparing a national emission inventory for Turkey. In the absence of such an inventory, regional-scale studies to depict the concentration of air pollutants have to rely on the EMEP/CORINAIR emission inventory. This inventory provides data covering all of Europe with a 50-km resolution. Recently, Kindap et al., (2005) used this inventory to show the long-range aerosol transport from Europe to Turkey.

In this study, we aim to estimate various air pollutant levels in the city of Istanbul during a specific winter episode. The city has the largest population and is one of the most polluted cities of Turkey. However, there has not been any comprehensive study, nor any regulation to fix and solve the air quality problem. This study may call Turkish authorities' attention to the problem. We developed a framework to model air quality in Europe using MM5 (i.e., for meteorological modeling) and CMAQ (i.e., for transport and chemistry modeling). It should be noted that we developed our own emission modeling techniques to process EMEP emissions. Model results underestimate the concentration of air pollutants over Istanbul as expected. A high-resolution national emission inventory is necessary to get more accurate results.

Key Words: Emission Inventory, Air Pollutants, MM5T, CMAQ.

1. INTRODUCTION

Air quality has become an important issue to societies since it strongly affects human health, and plays an important role in climate change. Since local emission of pollutants can be augmented significantly by long-distance transport, it is important to take into account the transport effect when considering new policies aimed at improving air quality.

Numerous studies have examined the transport of gases and airborne pollutants (e.g., Lelieveld et al. 2002; Rodriguez et al. 2001; Kubilay et al. 2000; Toon et al. 1988; Westphal et al. 1988; Nickovic, and Dobricic, 1996; Kallos, et al. 1998; Hacisalihoglu et al. 1992), but the problem of pollutant transport from Europe to Northern and Western Turkey has received relatively little attention. Recently, a comprehensive study about this transport has already been carried out for PM10 and highly polluted cities in Eastern Europe have been demonstrated, which could be partially responsible for pollution events in Istanbul (Kindap et al., 2005). Yet, such a transport has contributed to two high pollution events that occurred in Istanbul, Turkey on 7-8 and 10-11 January, 2002 (Fig. 1). During these events, the atmospheric circulation over central Europe was dominated by a cold-core surface anti-cyclone, a climatologically favored feature during the cold season (Kallos et al. 1998). Air trajectories associated with this anti-cyclone were capable of transporting high concentrations of pollutants over long distances to Istanbul.

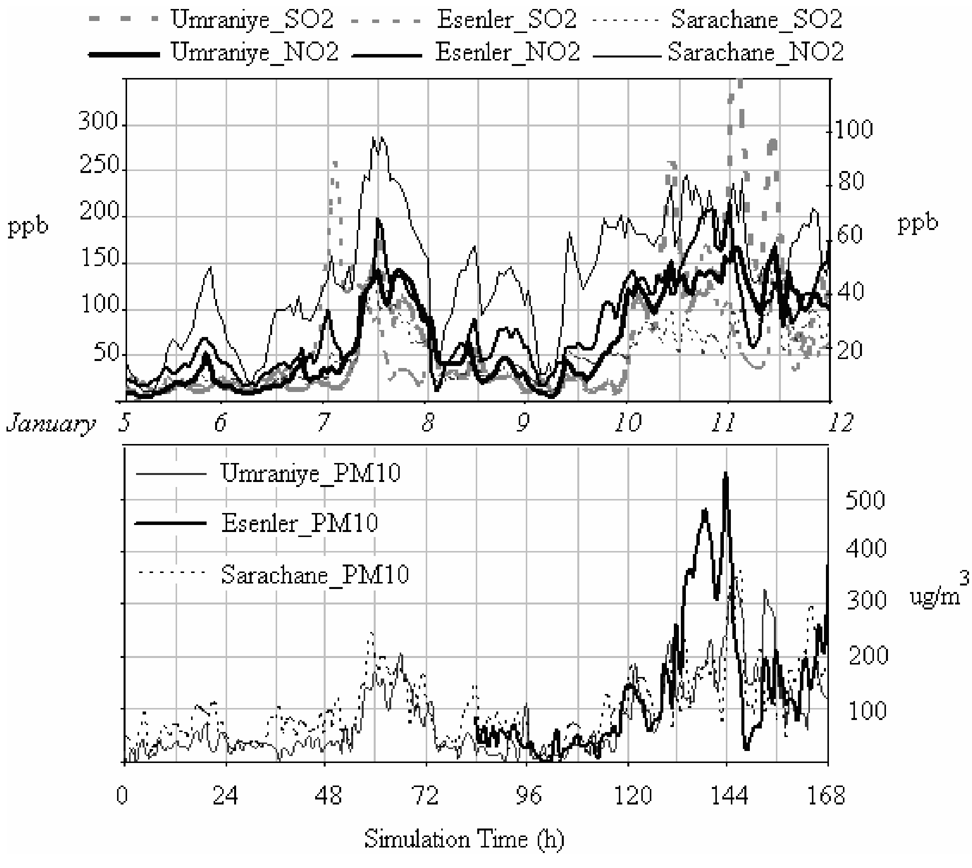

Figure 1. Time series of measured SO2 (left axis) and NO2 (right axis) concentration on the upper panel and PM10 concentrations (right axis) on the bottom panel at Umraniye, Esenler and Sarachane observation stations in Istanbul from 00 UTC January 5 to 00 UTC January12, 2002.

In the present case study, an episode of trans-boundary transport of nitrogen dioxide and sulfur dioxide was investigated. Ground-based measurements of NO2 and SO2 were compared with an air quality model and tracer studies. In this manner, the convective transport of gases and particulate matter within Eastern Europe and the resulting impact over the city of Istanbul was identified. The above mentioned long-range PM10 transport from Europe to Istanbul had already been investigated and the sensitivity analysis had put forward some quantitative results for consideration (Kindap et al., 2005).

It is observed that the lifetime of NO2 in the middle and upper troposphere is several days (Jaegl´e et al., 1998; Seinfeld and Pandis, 1998), which means that it is maintained even in the long-range transport (Stohl et al., 2002). On the other hand, NO2 has a relatively short (about one day) lifetime in the boundary layer (Jaegl´e et al., 1998). Leue et al. (2001) used vertical tropospheric NO2 column densities observed in the Global Ozone Monitoring Experiment over the eastern coast of North America to estimate a NO2 lifetime of 27 h in the PBL and following the plume leaving the coast of India, Kunhikrishnan et al. (2004) estimated a lifetime of 18 h. The lifetime of sulphur dioxide molecules in the troposphere is a few days. It is removed from the troposphere in gas phase by formation of sulfuric acid or directly by way of an uptake on aerosols and clouds.

2. METHODS

Tracer Studies

To prove our hypothesis, we used an on-line tracer model to generate qualitative evidence of pollutant transport during these two pollution events. Furthermore, we used the meteorological parameters of the model to document the favorable weather conditions associated with these events.

The Fifth-Generation NCAR / Penn State Mesoscale Model (MM5; Grell et al. 1994) V3.6 on-line tracer model (MM5T) was used here. A single domain with grid-spacing of 30 km was configured, and it covered the entire European continent and nearby seas and countries. There were 176 x 227 x 38 grids in the east-west, north-south, and vertical directions, respectively. Tracers in MM5T were carried in a 4D array and the transport of tracers due to advection, MRF boundary layer mixing (Hong and Pan 1996), and Kain-Fritsch cumulus convection (Kain 2004) was taken into account. Other chosen physics options were the RRTM (Rapid Radiative Transfer Model) radiation scheme (Mlawer et al. 1997) and simple ice microphysics scheme (Dudhia 1989).

Two tracer simulations were conducted, experiment 1 (EXP1) and experiment 2 (EXP2), corresponding to the two peak events of pollutant concentration in Istanbul, 7-8 and 10-11 January 2002. Model integration run from 00 UTC 5 to 00 UTC 8 January for EXP1 and from 00 UTC 8 to 0 UTC 11 January for EXP2. The National Centers for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS) data (with 2.5° latitude/longitude resolution) were used for MM5T boundary and initial conditions. To mimic emission characteristics, tracers were released at the lowest model level from selected cities at time-varying rates. The selected cities were Warsaw, Silesia, and Krakow in Poland; Kiev in Ukraine; Moscow in Russia; Sofia and Plovdiv in Bulgaria; and Bucharest in Romania. These cities were chosen because they were potentially significant local sources of pollutants and they were positioned upstream of Istanbul on the dates in question.

Several characteristics of the simulated tracer emission are important to note. The emission was specified to vary over a daily cycle according to a half sine curve, with a maximum of about 0.1 units s-1 at 5 p.m. and a minimum of 0 units s-1 at 5 a.m. local time. The area of emission in each city had a radius of 100 km. To further understand the transport characteristics, tracers from the same city but different days (i.e., 00 UTC to 00 UTC next day) were tracked separately. Note that tracers released from Silesia and Krakow were not distinguished.

Air Quality Model

Emission inventory:
When the study was started, the best available emission datasets for this region was the 2001 EMEP, where the data were available as annual averages for each European country. The available data must, therefore, be processed to produce the inputs required by the air quality model, normally as hourly averaged gridded values. As a result, an emission processing module should be developed for this purpose. This kind of study was performed in a PhD thesis (Kindap, 2005). As a result of this study, the time series of PM10 over Istanbul for 3 days can be seen in figure 2 with an accompanying example of the emission model result.

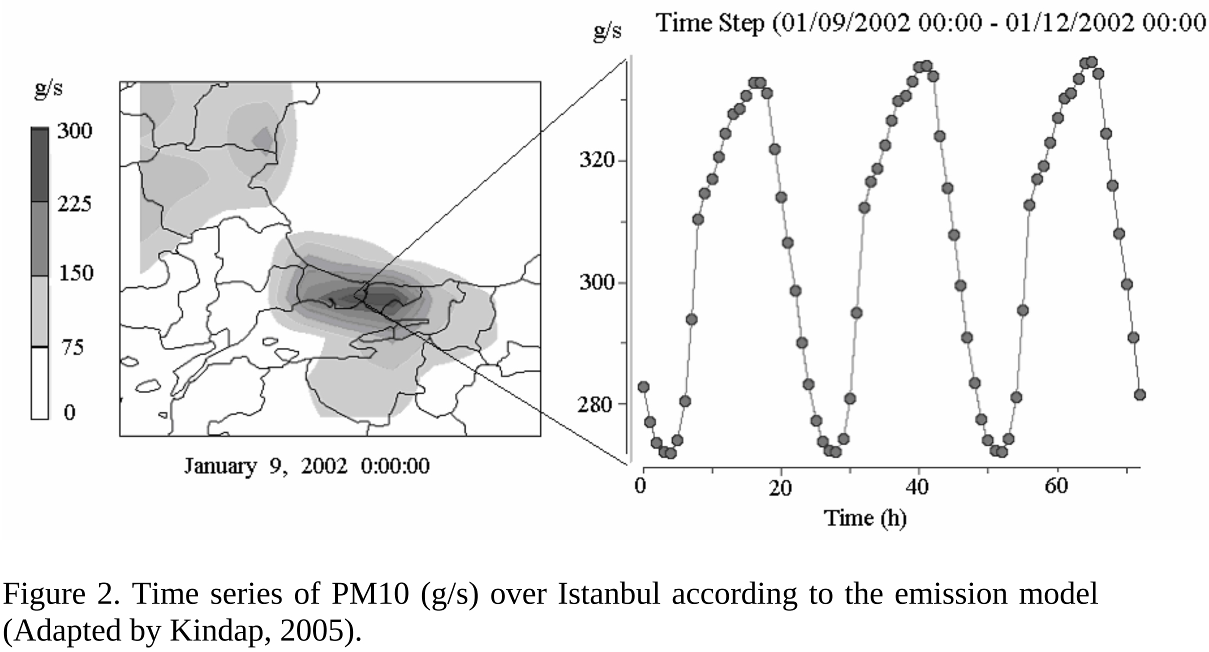

Figure 2. Time series of PM10 (g/s) over Istanbul according to the emission model (Adapted by Kindap, 2005).

Note that at present, the big part of the EMEP/CORINAIR (CO-oRdination d'Information Environnementale) Emissions Inventory is filled with expert information from the main source categories of energy, transport, agriculture, production and processes. Furthermore, this dataset provides emissions for sole anthropogenic sources and a 50-km resolution.

CMAQ Model:
The CMAQ horizontal grid size was set to 50 km with 132 cells along the east-west direction and 111 cells in the north-south direction covering all of Europe. There were 20 layers in the vertical direction. The initial and boundary conditions were set to background concentrations starting from 00:00 UTC January 5, 2002 to 00:00 UTC January 12, 2002.

3. CASE STUDY – RESULTS AND DISCUSSION

After 24 h of integration in EXP1, a synoptic-scale circulation pattern that favors pollutant transport into Turkey is quite evident (Fig. 3). Specifically, a surface high-pressure center is positioned over central Europe while a surface low is located over western Russia. The pressure gradient between these two centers induces a strong boundary-layer flow into Turkey from the north-northwest, creating a mechanism for the transport of pollutants from upstream cities to Istanbul.

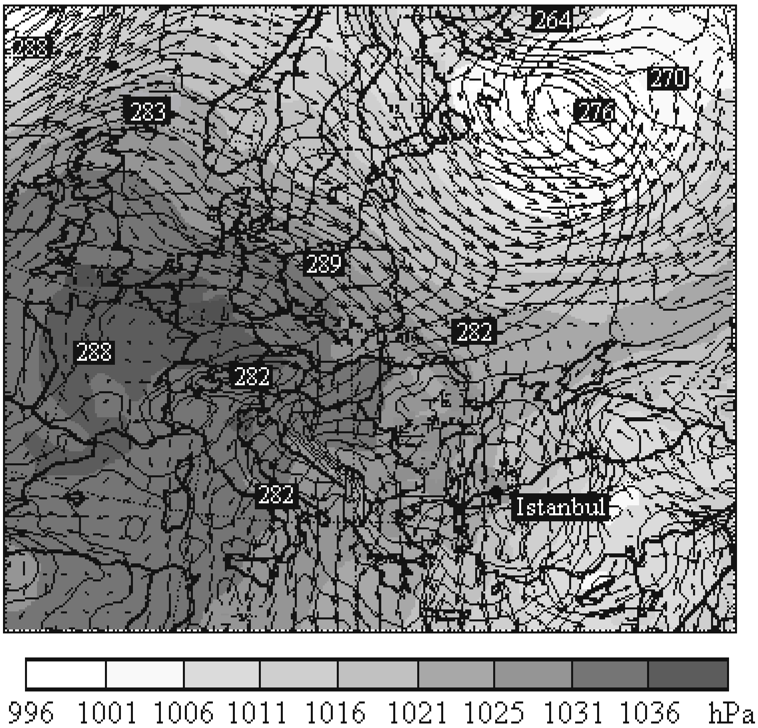

Figure 3. 24 h forecast from EXP1, showing sea level pressure (shaded; hPa), 1.5 km height potential temperature (solid lines; K), and 950-mb height wind vectors at 00 UTC 6 January, 2002. Large dot indicates the location of Istanbul.

Simulated tracer transport from various source cities can be seen in Fig. 4. For the first simulation period (00 UTC 5 January to 00 UTC 8 January), the tracer released from Bucharest on the first day (not shown) had little impact in Istanbul during the first one and a half days. But the tracer released in Bucharest on the second day first reaches Istanbul at 18 UTC 6 January (about 18-h transport time) and gave the maximum pollution impact on the city at 00 UTC 7 January (dashed lines in Fig. 4a). Tracer released from Plovdiv, Bulgaria on the first day moved southward and did not pass over Istanbul, while the edges of the plumes released in Plovdiv on the second and third days skirted Istanbul and contributed relatively small concentrations of pollutants to the city.

Silesia and Krakow in Poland are relatively far away from Istanbul, yet tracers released from both cities on the first day reached Istanbul after about 42 h of transport (by 18 UTC 6 January). Silesia and Krakow tracers from the second day reached the city as well, arriving around at 12 UTC 7 with a higher concentration than the first day’s plume. In our simulation, tracers released from other selected cities, such as Kiev, Sofia, and Warsaw, did not reach Istanbul due to the directions of low-level winds. For the second simulation period (00 UTC 8 January to 00 11 January), the evolution of tracers predicted by MM5T was also similar (Figs. 4b), however, tracers take slightly longer to propagate to Istanbul in this second period.

a) b)

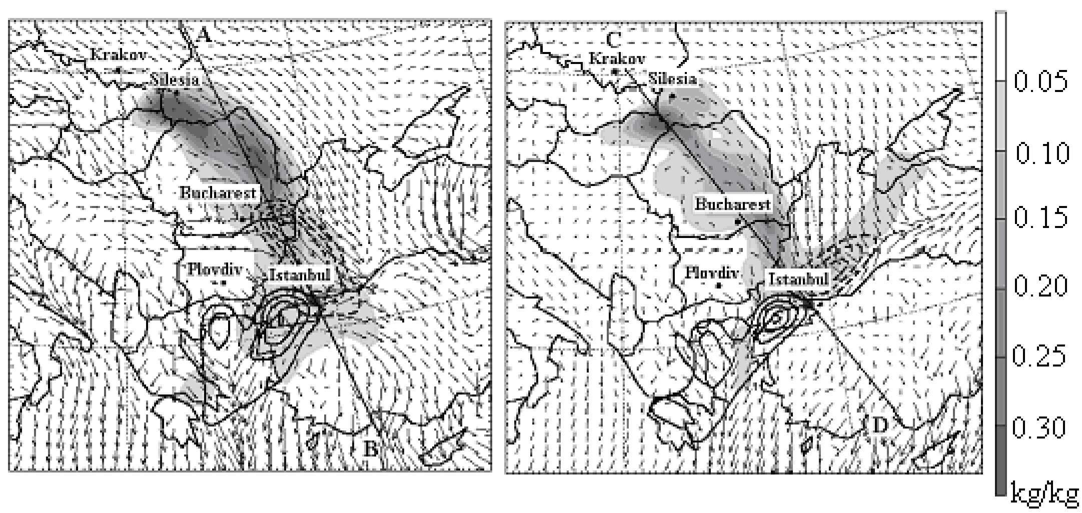

Figure 4. Simulated tracers and wind vectors at the 100 m height at (a) 48-h simulation from EXP1 and (b) 54-h simulation from EXP2. Tracers from Bucharest (dashed lines; 0.05 unit of interval) and Plovidiv (solid lines; 0.1 unit of interval) are released during the 2nd day and from Silesia and Krakow (shaded) are released during the first 2 days.

As for CMAQ Model, model simulated NO2 and SO2 concentrations were compared with those measured at three stations in Istanbul (Fig. 5). The locations of these stations have been chosen on road or industry area of the city without any scientific approach by the authorities. As a result, high concentrations of pollutants could be observed from time to time by the stations. It is worth to mention that there are 10 stations in Istanbul, but only three of them have complete data for the simulation period.

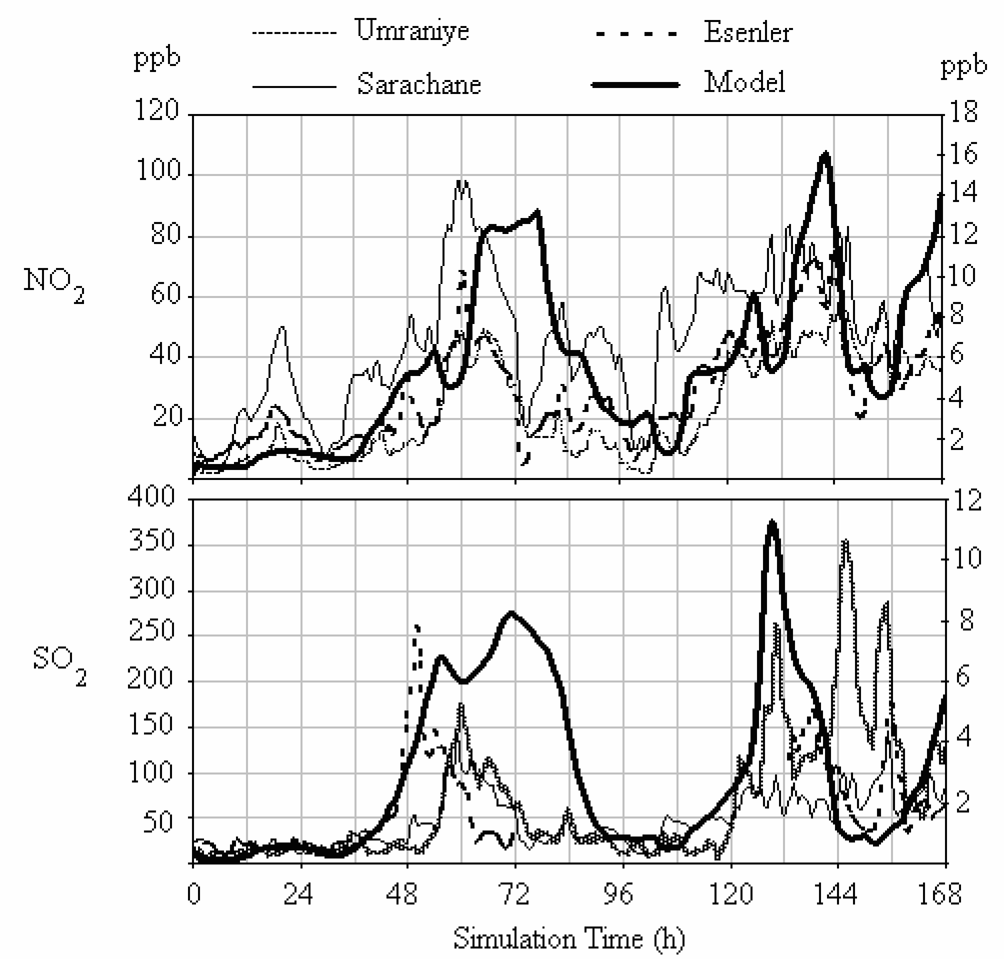

Figure 5. Time series of observed NO2 and SO2 concentrations at Umraniye, Sarachane and Esenler stations in Istanbul (left axis) and model simulated concentrations (right axis) for the 50×50km2 Istanbul cell from 00 UTC January 5 to 00 UTC January12, 2002.

It can be clearly seen in the figure that the trend is captured reasonably well by the air quality model. On the other hand, it is not possible to put forward the similar outcome for the comparison of concentrations of the model and the stations. The difference between the simulated and observed concentrations, which is expected, is noticed at the first glance. The primary reason for this discrepancy is most likely the coarse grid resolution. The first model layer above the ground is 92m and the horizontal resolution is 50 km.

This coarse resolution can substantially dilute the concentration of pollutants. The discrepancies may also be due to the deficiencies in EMEP emission data. The annual emission inventory data are based on data reported from the European countries, and these data are filled with experts' estimates when they are incomplete or inconsistent. Such interpretations may introduce errors. Furthermore, natural emissions are absent in EMEP database. In addition, the use of 2001 emission data (instead of 2002 data, which were not available during the study) in combination with a January 2002 meteorological episode resulted in added uncertainty when comparing the CMAQ model results to monitoring data. For the most part, CMAQ correctly reproduces the trends in observed NO2 and SO2 values for Istanbul. For example, the model is able to catch the relatively high-pollution episodes on January 7 and January 10.

4. CONCLUDING REMARKS

Two high-pollution events that occurred in Istanbul, Turkey on 7-8 and 10-11 January, 2002 were studied qualitatively using the MM5 on-line tracer model (MM5T). Different tracers were used to represent pollutants released from selected cities on different days, using a diurnal cycle of emission rates that maximized at 5 p.m. and approached zero at 5 a.m. local time.

The first step in analyzing model results was to verify accurate simulation of meteorological fields, especially the low-level wind fields that play a crucial role in transport calculations. Time-series of low-level wind and temperature fields in the vicinity of Istanbul had showed a good agreement with local observations of the previous study (Kindap et al., 2005). Furthermore, the model also reproduced the larger-scale patterns well. In particular, it simulated a surface high-pressure system over central Europe and a surface low over western Russia, with a substantial pressure gradient between these two systems. This gradient induced strong north-northwesterly low-level flow, capable of transporting upstream pollutants towards Istanbul. Moreover, the model reproduced a strong frontal inversion over the path of tracer transport, a feature that suppressed mixing at the top of the planetary boundary layer and effectively trapped low-level pollutants near the ground. These weather conditions created a favorable environment for limited dilution and long-range transport of pollutants.

The simulated tracer evolution provided qualitative proof that transport of pollutants emitted from Bucharest in Romania, Plovdiv in Bulgaria, and Silesia and Krakow in Poland could have contributed to two high-pollutant events on 7-8 and 10-11 January, 2002 in Istanbul. Our model suggests that pollutant transport to Istanbul took about one day from Bucharest and Plovdiv and about two days from Silesia and Krakow during these events.

Results obtained from this tracer study are very reasonable and qualitatively support our hypothesis that the long-range transport from the north and northwest played an important role in both high pollutants events in Istanbul in January 2002. Transports nearby from the cities like Odessa, Sevastopol of Ukraine have been studied by various researchers (Kallos et al. 1998). But there is no work done on transports from Central Europe to the vicinity that we are concerned with, yet. This work is the first study on this matter. This study is a very preliminary, qualitative work to understand the causes of these two high pollution events.

Having in mind that a fine emission inventory for the area of interest is difficult to find, it is not entirely reliable. Therefore, these types of qualitative studies are quite useful to understand transports of gases or aerosols in the region.

A quantitative study of pollution arising from local emissions and long-range transports for both pollution events has also been studied using an air pollution model. It is a well-known fact that a regional air quality approach will not give any details of air quality over a city. As a result, the large model underestimation of Istanbul NO2 and SO2 is not surprising for the regional model which is not designed to simulate urban concentration.

Although Istanbul has the largest population and is one of the most polluted cities of Turkey, there has not been any comprehensive study nor any regulation to fix and solve the air quality problem. Using the EMEP emission inventory which is the only available data, we aim to estimate various air pollutant levels in the city of Istanbul during a specific winter episode. Model results underestimate the concentration of air pollutants over Istanbul as expected, but the trend is captured reasonably well. A high-resolution national emission inventory is necessary to get more accurate results. This study may call Turkish authorities' attention to the problem.

5. ACKNOWLEDGEMENTS

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