IMPACTS OF ISTANBUL EMISSIONS ON REGIONAL AIR QUALITY: QUANTIFICATION USING MODEL-3 FRAMEWORK AND TRAJECTORY ANALYSIS

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1. INTRODUCTION

Istanbul, the demographic and economic heart of Turkey, has gone through enormous changes over the past century. The Megacity of about 13 to 16 million inhabitants, 20% of Turkey's total population has registered a dramatic population increase since 1950 (OECD, 2008). The city is located at 41°N 29°E, on the Bosporus strait which connects Black Sea to Aegean Sea via Marmara Sea. The city extends both on the European and on the Asian side of the Bosporus. The metropolitan region covers 6,220 square kilometers. Istanbul has a humid subtropical climate. The summer temperature is about 23 Cº, where the winter temperature is about 7 Cº. The humidity is high during all sessions. Average annual precipitation is about 693 mm and average wind speed is 17 km/h. According to the study conducted by OECD in 2008, Istanbul ranked 12th among 45 OECD metro-regions, growth rate slightly over 4%.

Istanbul is exposed to trans-boundary pollutant transport originating from Europe with the westerly prevailing winds (Kindap, 2008), however the city has a potential to effect its region with its significant anthropogenic pollutant sources. A framework was prepared to model air quality using MM5 for meteorological modeling and CMAQ for chemistry and transport modeling. The goal of the study is to assess the impact of this regional air pollution originated in Istanbul.

2. METHODOLOGY

Istanbul has a unique geographical location spanning two continents; Europe and Asia and the city is located north-western part of the country. There are 10 air quality stations in Istanbul, which are measuring the pollutant parameters of CO, CH_4, SO_2, NO_x, PM_{10}, O_3 and HCs. The data for these variables are available for the last 10 years. Average values are as following : SO_2 level is about 22 μg/m^3 with a 7.5 μg/m^3 minimum and 45 μg/m^3 maximum value; PM_{10} level is about 66 μg/m^3 with a 47 μg/m^3 minimum and 115 μg/m^3 maximum value; O_3 is below 30 μg/m^3 between years 1998-2008, over all the stations.

The research was performed on two main steps. First, a trajectory analysis was carried out for long-term (30 years) meteorological data used for a 10-day trajectory analysis. In the second step, air quality simulations were performed to relate these emissions to regional air quality around Istanbul.

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2.1 Episode Selection

January 13-17, 2008 was selected as the episode to be modeled in this study. The average PM_{10} concentrations of the monitoring stations in Istanbul seems to be increasing in last two years. PM_{10} concentrations reach significant values in the selected episode and this played a major role in this selection. As seen from Figure 1, the 24-hour PM_{10} levels were above the Eeropean Union air quality PM_{10} limit value of 50 µg/m^3 during this episode.

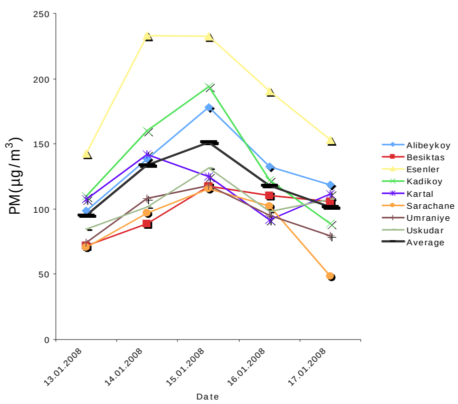


Fig. 1. 24-hour averaged PM_{10} concentrations at the municipality stations.

2.2 Data Preparation

The air quality model requires input of speciated emissions values for each grid box over the entire domain at each model time step (Kindap et al., 2006). The emission data set must be processed to produce gridded, speciated, temporally and vertically distributed hourly averaged values required by the air quality model. Note that the selected episode is in the winter season, consequently biogenic emissions were decided to be ignored.

The emissions have been spatially allocated over the Istanbul using a spatial resolution of 2 km. The emissions grid has been projected in Lambert Conformal Conic covering an area of 92 by 57 grid cells, includes emissions of CO, NO_x, SO_2, NH_3, 6 PM species (organic and elemental carbon, sulfates, nitrates, ammonium and other particles) and 23 NMVOCs species in monthly, weekly and diurnal processing (Friedrich R. (1997). A wide variety of emission sources have been covered including energy production, residential and industrial combustion, road traffic and shipping. A bottom-up methodology was adopted for the most contributing anthropogenic emission sources such as residential and industrial coal combustion, international cargo shipping, utilizing official activity information and high resolution digital maps. Road transport emissions were calculated based on compiled emissions factors specifically for the area which reflect both the status of the circulating fleet as well as the driving conditions within the city (Unal et al., 2009). More details are given in Markakis et al., 2009a and 2009b and references therein.

The emissions were converted to CB-IV species emissions with the use of CB-IV molar splits according to Gery et al. (1989) and the chemical speciation database developed in the framework of the project "Development of an Improved Chemical Speciation Database for processing Emissions of Volatile Organic Compounds for Air Quality Models" (available online at http://www.engr.ucr.edu/~carter /emitdb).

2.3 Trajectory Analysis

Trajectory analysis is generally preferred to define air pollution transport patterns. It is useful to see the possible transport of air pollutants for an area of interest. In this study, this approach was used to identify the effects of Istanbul emissions on other cities in a regional scale. A period of 30-year (1961-1990) reanalysis data (NCEP/NCAR) was used to get a meaningful evaluation. Data are available for every six hours in a 2.5° resolution. The distribution of trajectories was demonstrated at σ = 0.925 level. This level corresponds to approximately a height of 700m and it is suitable to see the bulk transport of pollutants in the boundary layer (e.g. Saltbones et al, 2000; Kindap et al., 2009). The trajectories were computed according to a method described by Pettersen (1956) as a forward trajectory approach in an 81-km grid resolution. An air parcel was released once every 6h and a total of 42,368 air parcels (trajectories) were released during these 30 years.

The computed probability is dependent on the size of the grid squares and the length of the trajectories. In general, the probability of the arrival increases with the length of the trajectories, but for trajectories longer than 8 days it does not change much (Saltbones et al. 2000). In this study, therefore, 10-day trajectories were researched. Figure 2 shows the probability of arrival trajectories for each receptor city (Bursa and Izmir in Turkey and Crete and Athens in Greece) in a seasonal period according to the released trajectories from the source city of Istanbul.

Long-term meteorological observations in Istanbul present northeasterly winds, namely "Poyraz", and southwesterly winds namely "Lodos", prevailing over the city. According to these prevailing winds, the distribution of trajectories were mainly observed in the north and south zones of the city.

a)

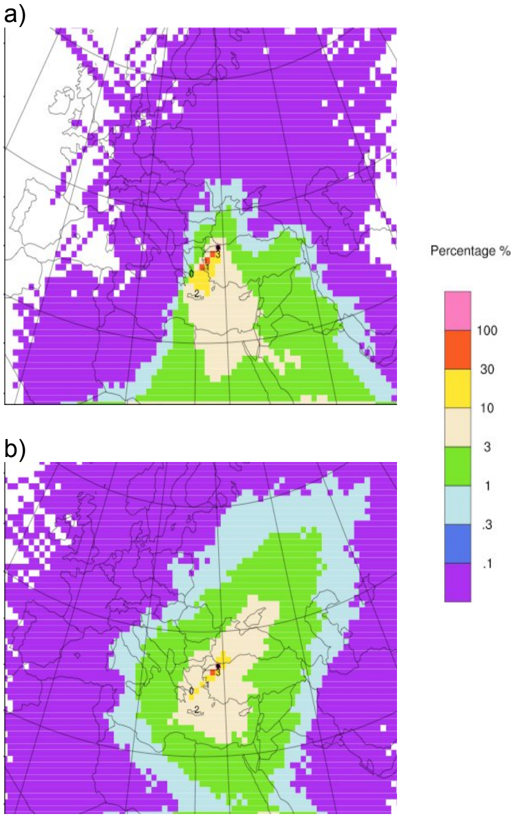


Fig. 2. Map for the probability of arrival of trajectories for a) summer, b) winter. Dot points indicates the city of Istanbul (0-Athens_Greece; 1- Izmir_Turkey; 2-Crete_Greece; 3- Bursa_Turkey).

2.4 Meteorological Modeling

The meteorological model used in this study was the mesoscale, non-hydrostatic PSU/NCAR MM5 (Grell et al., 1994). Three domains have been set up for the meteorological modeling system on Lambert Conformal projection: a mother domain covering Europe of 199 by 175 grid cells on 30 km spatial resolution, the second domain covering the Balkan region of 181 by 202 grid cells on 10 km resolution, and finally, the inner most domain covering the Istanbul area of 136 by 111 gird cells on 2 km resolution (Figure 3). The National Centers for Environmental Prediction (NCEP) Final Analyses (FNL) data of 1 × 1º have been used to provide the initial and boundary conditions required by the MM5 model while 37 sigma layers have been used for the vertical resolution of the model.

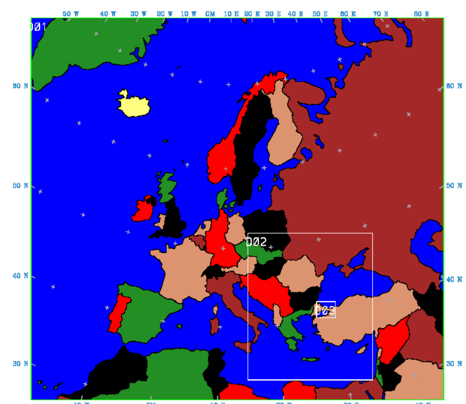


Fig. 3. Meteorological modeling domains used for the MM5 model.

2.5 Chemistry and Transport Modeling

The US EPA Community Multiscale Air Quality (CMAQ) model, version 4.6 was used in this study as the chemistry and transport model (Byun and Ching, 1999). CMAQ is run on three domains, on Lambert Conformal projection, covering Europe in a 163×150 grid system of 30 km resolution, Balkan region in a 140×155 grids domain of 10 km resolution and Istanbul in a 92×57 grids domain of 2 km resolution; and 20 vertical layers. The first three days of the simulation period have been considered as spin-up period and have not been included in the model evaluation procedure.

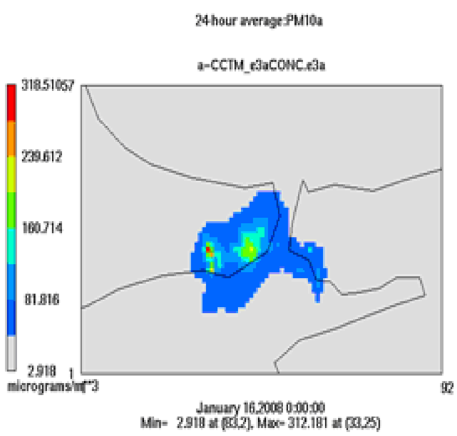
3. MODELING RESULTS

Models 3/CMAQ chemistry and transport model was employed to simulate the PM_{10} concentrations in a 5-day winter episode in January 2008. The results were compared on daily basis with the observations obtained from an intensive campaign conducted at Boğaziçi University (41.09 N and 29.05 E). The statistical evaluation of the model is presented in Table 1.

Table 1. Statistical results for the comparison of CMAQ results with the observations for the Bogazici University.

Measures	PM_{10}
Correlation	0.62
Observed Mean (μgm^{-3})	81.74
Model Mean/Obs. Mean	0.55
Observed STDEV (μgm^{-3})	15.14
Model STDEV/Obs. STDEV	1.25
BIAS (μgm^{-3})	-47.73
ABSE (μgm^{-3})	47.73
RMSE (μgm^{-3})	49.77

Spatial distribution of 24-hour average PM_{10} concentrations are presented in Figure 4. The highest concentrations are calculated for the areas on the coastline surrounding the Bosporus Strait, where most of the population is located, and at İkitelli area, which is one of the largest industrial combustion sources in the İstanbul domain.



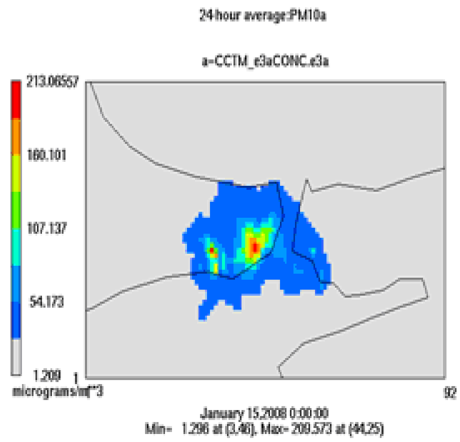


Fig. 4. 24-hour average PM_{10} concentrations for 15th and 16th of January, 2008 for the Istanbul domain.

The daily PM_{10} levels agreed reasonably with the observations in terms of variation (correlation factor of 0.62). The total PM_{10} concentrations are underestimated on average basis by 45% in terms of amount. The smallest underestimation is observed on the fourth day by 20% and the largest on the second day by 40%.

4. DISCUSSIONS AND CONCLUSIONS

An integrated MM5/CMAQ, high resolution modeling system has been employed in order to evaluate the PM_{10} concentrations during a five-day winter episode on January 2008. A detailed emission inventory and an air quality model is used for the first time for this region. The results of the modeling framework showed that, highest concentrations of particulate matter occurs in the center of city as expected, where the population and the industry is densely located. But this quantitative analysis presented the PM_{10} concentrations with an underestimation by 45% for the modeling domain.

Additionally, to identify the effects of Istanbul emissions in a regional case, trajectory analysis is conducted. According to the distribution of trajectories, south zone of Istanbul (e.g. city of Bursa) is effected significantly from Istanbul. Also, long-range transport is observed from the trajectory maps with the arrivals of pollution to the cities in neighbour countries (e.g. Greece).

Overall, it should be noted that, the results of this study are the preliminary results of our continuing research. According to the results of this study, we can conclude that improvement of our modeling set up and individually the emission inventory is crucial for the assessment of air quality in Istanbul and its region. Eventually, this study will be a substructure for also the latter modeling studies for this part of the world.

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