Proceedings of the Third International Symposium on Air Quality Management at Urban, Regional and Global Scales. pp. 546-559, 26-30 September 2005, Istanbul – Turkey

MODELING OF EUROPEAN AIR POLLUTION AND LONG-RANGE TRANSPORT TO THE EAST MEDITERRANEAN REGION

Muwaffaq Freiwan[a,b], Selahattin Incecik[b] and Umit Anteplioglu[c]

[a] Jordan Meteorological Department, P.O. Box: 341011, Amman – 11134, Jordan, mfreiwan@yahoo.com
[b] Istanbul Technical University, Aeronautics and Astronautics Faculty, Meteorological engineering Department, Maslak – 34469, Istanbul, Turkey, incecik@itu.edu.tr
[c] Kandilli Observatory, Bosphorus University, Cengelkoy, Istanbul, Turkey, anteplio@boun.edu.tr

ABSTRACT

Measurements of some air pollution species, mainly SO_4^{2-} in some rural locations in the Eastern Mediterranean revealed high concentrations which are comparable or higher than those of Central and Eastern Europe. Since the area is free of any source of pollution, it is believed that such high concentration of various pollution species are transported from other regions, such as Eastern or Southeastern Europe. The Antalya measurement station (36.47N, 30.34E) which is located on the Mediterranean coasts has recorded high concentrations of SO_4^{2-} during the years 1992 – 2000. Of these a 4 day episode 26 – 29 August 1998 was selected to investigate the long range transport of European air pollution to the east Mediterranean region. Mesoscale Meteorological Model, MM5 was applied to forecast the three dimensional meteorological data. Backward trajectory simulations were also produced by MM5/RIP and HYSPLIT models. Consequently, three main sectors of air mass trajectory originated from Europe were found. Coupled with MM5, the three-dimensional Eulerian photochemical model CAMx is used to simulate the concentration, deposition and the long range transport of the air pollution species PSO_4^{2-} and SO_2. CAMx air quality model simulations have revealed a great agreement with the air mass trajectory simulations produced by HYSPLIT and RIP/MM5 models and demonstrated that sulfate transport from central and southeastern Europe to the eastern Mediterranean has two main paths. The modeling system which is used for the first time in Turkey exhibited a good performance.

Key Words: Long Range Air Pollution Transport, Backward Trajectory, MM5, CAMx, HYSPLIT.

1. INTRODUCTION

The last two decades have been characterized by a growing interest in long-range transport of biogenic and anthropogenic aerosols and other air pollutants, mainly because of serious public health risks for human beings and to ecosystems in local, regional or either in global scales (Draxler, 1987; Galperin, 1991; Syrakov and prodnova, 2002; Chen et al., 2002; Sciare et al., 2002; Park and Lee, 2003; Cakmur and Miller, 2004; Kallos et al., 2004).

Because of its unique topographic and climatic diversity and its location in the mid-latitudes, the Mediterranean region is considered as one of the most attractive regions in the world for studying mesoscale and long-range transport of dust (Kubilay et Al., 2000; Israelevic et al., 2002), aerosol (Dogan and Tuncel, 2003; Kocak et al., 2004a) and other pollutants such as acidic sulfate and nitrate deposition (Gullu et al., 2000; Ozturk et al., 2003).

In Turkey, there are many studies handled aerosol concentrations and investigated their sources using observed wind field (Tuncel and Erduran, 2001), statistical back trajectory method (Tuncel, 2002), by analyzing the air mass trajectories (Kubilay et al., 2002) or by applying a trajectory model to a limited region, such as Izmir city, where Dincer et al. (2003) applied HYSPLIT back trajectory model to determine the pathway of SO_2 pollution in the city. But the transboundary long range air pollution transport modeling is still an absent topic in the Turkish literature. One of the major drawbacks that restrict modeling regional air pollution is the absence of the national emission inventories. Numerous European countries have their own emission models. Using the EMEP national annual emission inventories they can calculate the hourly gridded emission inventories of various pollutant emitting sources in the desired domain. Development of a national inventory model will pave the way for excessive air quality modeling researches.

In this study a modeling system consists of Mesoscale Meteorological Model, MM5, Comprehensive Air Quality Model with Extension, CAMx and the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used to predict the atmospheric condition in large domain that includes the European continent, Turkey and the Mediterranean region, to predict the gridded concentrations and depositions of PSO_4 and SO_2 species, and to simulate their trajectories using the gridded wind field predicted by MM5 during the episodic period 26 – 29 August 1998. This modeling system is used for the first time in Turkey to handle the probable long range air pollution transport phenomenon from Europe to the eastern Mediterranean region represented by Antalya.

2. BRIEF DESCRIPTION OF THE MODELING SYSTEM

The PSU/NCAR **M**esoscale **M**odeling System, **5**th generation (**MM5**) version 3.61 is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. The model is widely used in forecasting the meteorological circumstances those are used in air pollution modeling. Details about the model are available in numerous publications including the MM5 community home page. In this study MM5 model was used to predict the meteorological conditions to be used firstly in the air quality model, CAMx. The model has been applied in a domain of 35° Lat. x 40° Lon. dimensions which lies between 25 – 60° N and 5 – 45° E in a horizontal spatial resolution of 50 km x 50 km and 89 x 78 grid-points in the E-W and in the N-S directions respectively vertical resolution of 34 layers. And secondly in the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model to simulate the backward trajectories. Furthermore MM5/RIP (Read/Interpolate/Plot) has also been used to calculate and plot trajectories. Three-dimensional Eulerian air quality model CAMx (Comprehensive Air Quality Model with Extension) version 4.11s was applied to simulate the predicted concentration, deposition, transport and source origins of anthropogenic pollutants in the study domain during the selected episodic period 26 – 29 August 1998. The photochemical model, CAMx was applied to a mesoscale domain of 89 x 78 grid points with a horizontal resolution of 0.59° x 0.45° in the E-W and N-S directions respectively, and 14 layers vertical resolution. The first layer is 50 m AGL and the highest level is 4000 m AGL.

3. MODELS SIMULATIONS AND RESULTS

3.1. MM5 Model

The MM5 model simulations include hourly gridded predictions for both 2-dimensional and 3-dimensional meteorological variables during the 5 day period 25 – 29 August 1998. The visualization program RIP was used to plot the desired predicted charts of temperature, wind vectors and pressure or geopotential height fields for each time step in the episodic period at the mandatory levels. Additionally a NW – SE vertical cross section of the wind circulation, potential vorticity and potential temperature fields through the domain was predicted for each time step. Furthermore a Skew-T plot for Antalya is also predicted for each time step. Figure 1 shows the MM5 model predicted versus observed 700 hpa level plot of temperature, wind velocity and geopotential height. It is apparently seen from the figure that the model accomplished not only to predict the general pattern of the pressure systems, but also to produce a highly accurate forecast all over the episodic period. The 96 and 120 hours forecasts are as accurate as the 24 and 48 hours, which mean that the model has succeeded to prevent its accuracy and to maintain its performance level during the whole forecast period.

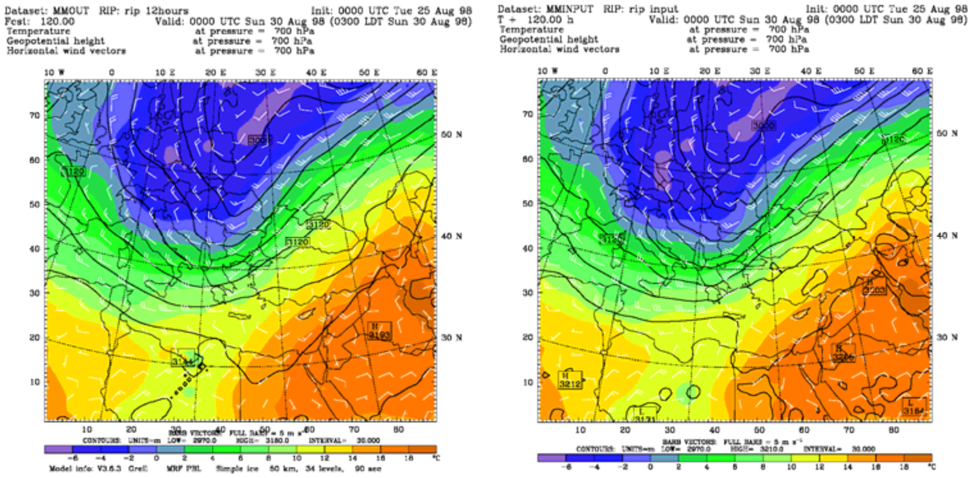
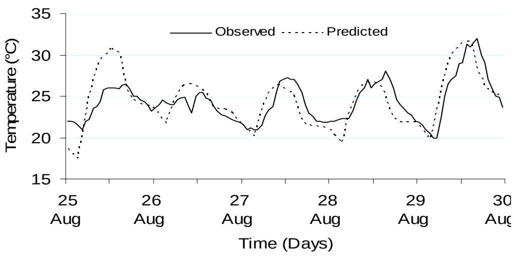
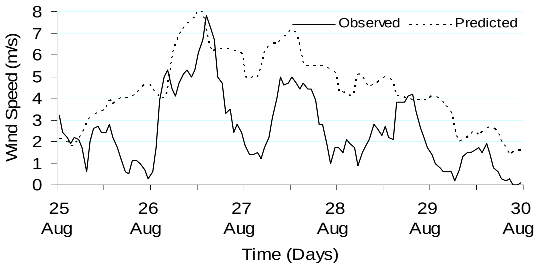


Figure 1. 120 hours forecast (left) and observed (right) of 700 hpa geopotential heights in gpm (black contours), temperature in °C (color shading) and horizontal wind velocity (white vectors), valid at 0000UTC, 30 – 08 – 1998.





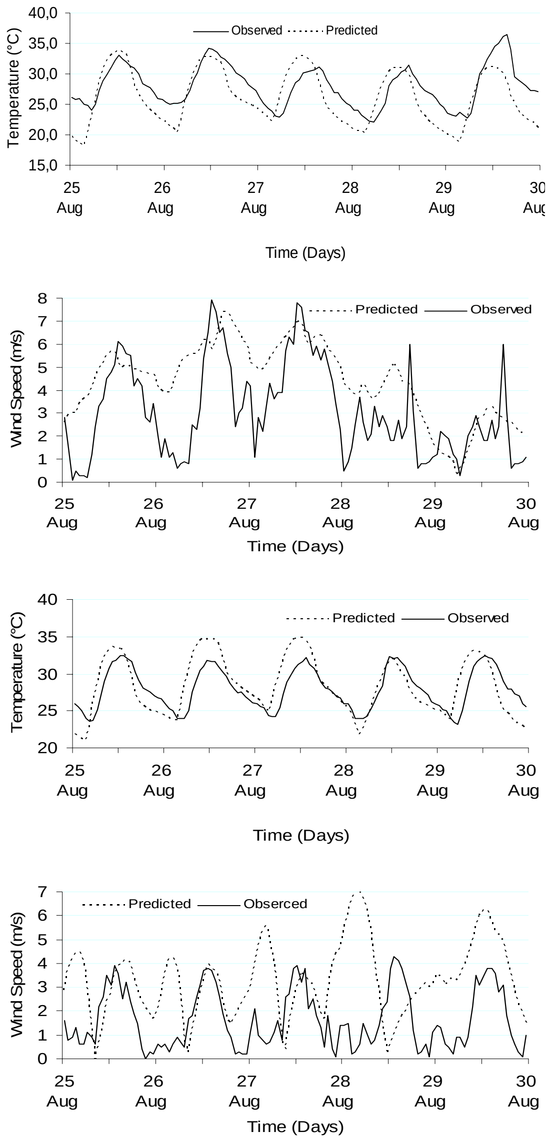


Figure 2. Hourly temperatures (left) and wind speed (right) observed in meteorological stations of Istanbul (upper), Izmir (middle) and Antalya (lower) versus predicted by MM5 model from 25 Aug. 00 Z to 30 Aug 00 Z.

The MM5 model performance was found to be superior in forecasting temperature and wind fields. A comparison between the model predicted and the observed hourly 5 day time series of air temperature and 10 m wind speed at three locations (Istanbul, Izmir and Antalya) have been illustrated in Figure 2. Furthermore scattered diagram of observed values versus MM5 model prediction values for both temperature and wind speed are also plotted for the same stations in Figure 3. It is obvious from the both figures that the model revealed a high accuracy in forecasting the temperature in each of the three stations. The correlation coefficient (R^2) is relatively high for temperature (0.59, 0.55, 0.57) and wind speed (0.47, 0.46. 0.05) in the three stations respectively except in Antalya.

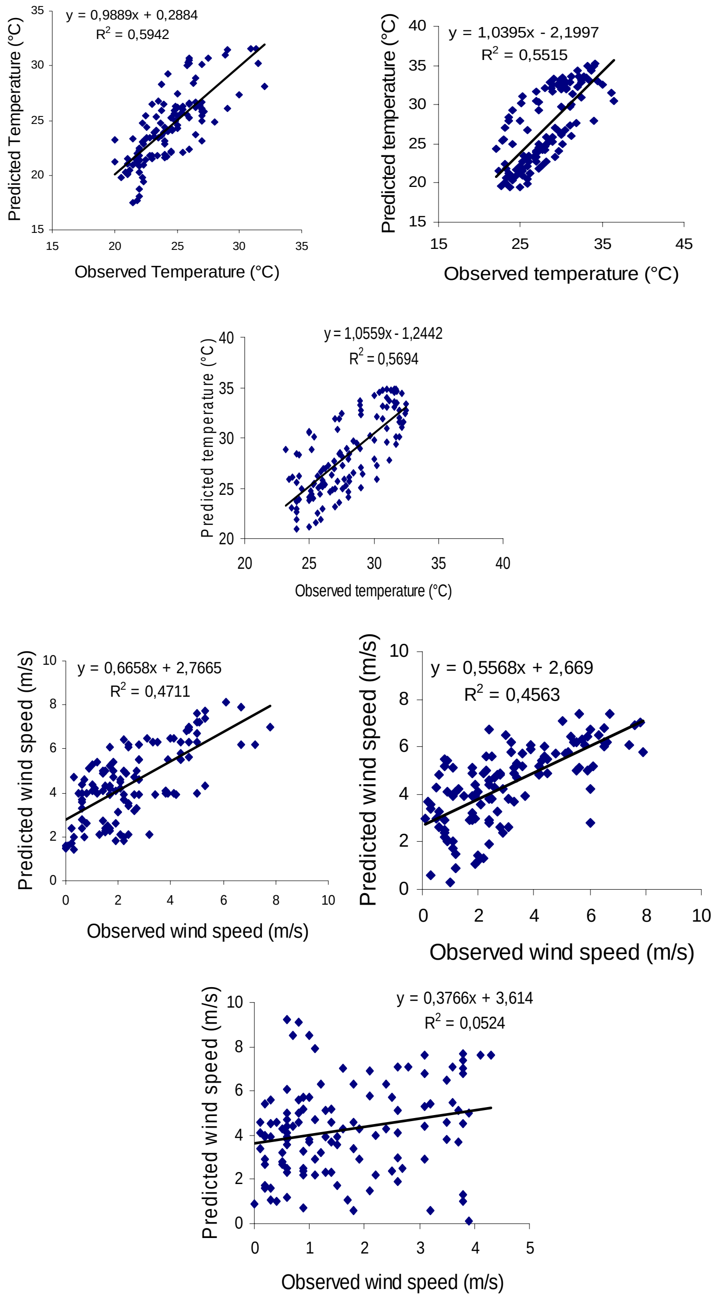


Figure 3. Model predicted versus observed hourly temperature (upper) and 10m wind speed (lower) in Istanbul (left), Izmir (middle) and Antalya(right) meteorological stations for the period from 25 Aug. 00 Z to 30 Aug 00 Z.

3.2. HYSPLIT and RIP Trajectory Model

The prognostic hourly wind field produced by the Mesoscale Meteorological Model, MM5 in 50km x 50km horizontal resolution was used to calculate air pollution trajectories to the eastern Mediterranean region. Two models were employed to calculate and simulate the trajectories using MM5 forecast data through a 96 hour period between 00 UTC, 26 – 08 – 1998 and 00 UTC, 30 – 08 – 1998.

1- The first model is the plot software RIP (Read/Interpolate/Plot).

2- The second is HYSPLIT (the Hybrid Single Particle Lagrangian Integrated Trajectory) model.

Backward trajectories at four sigma levels (0.998, 0.990, 0.900 and 0.850) were plotted for selected 13 points in the Eastern Mediterranean region and western Turkey. It is found that the trajectories are originated from three main sectors taking in account their tracks to the eastern Mediterranean as follows:

1. Sector A: Turkey and Eastern Europe, which includes trajectories originated from Ukraine, Moldavia and Romania through the Black Sea and Turkey to the eastern Mediterranean that is represented by Antalya.

2. Sector B: Turkey and central Europe, which has trajectories originated mainly from Bulgaria, Macedonia, Albania, the former Yugoslavia, Croatia and Slovenia through the western part of Turkey and then the eastern Mediterranean.

3. Sector C: Southern Europe and the Mediterranean Sea, the trajectories in this sector are originated mainly from the central and western Mediterranean Sea, Spain, the southern parts of France, Italy, Greece and the southwestern parts of Turkey to the eastern Mediterranean, which is represented by Antalya.

These results are in a great agreement with the findings of Sciare et al. (2001) regarding to the backward trajectories to Finokalia in the eastern Mediterranean.

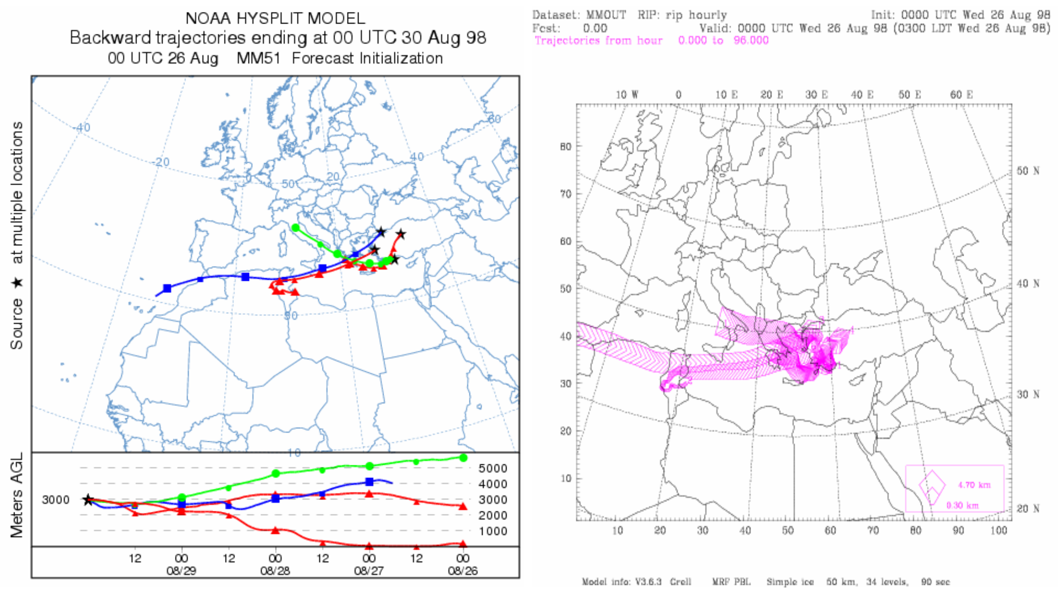


Figure 4. 96 hours backward trajectories at 3000 m AGL for Antalya, Izmir, Istanbul and Ankara plotted by HYSPLIT (left) and RIP (right) using the meteorological data predicted by MM5 model. Trajectories start at 0000 UTC, 30 Aug. 1998 and end at 0000 UTC, 26 Aug. 1998.

Figure 4 shows a simulation of 96 backward trajectory plots produced by both models; RIP and HYSPLIT for Antalya, Izmir, Istanbul and Ankara at 3000 m AGL.

The results are superior; trajectories produced by the two models are completely identical. The figure indicates that the trajectories to the eastern Mediterranean and western parts of Turkey are originated from southeastern Europe and the Mediterranean Sea through Greece and the Aegean Sea.

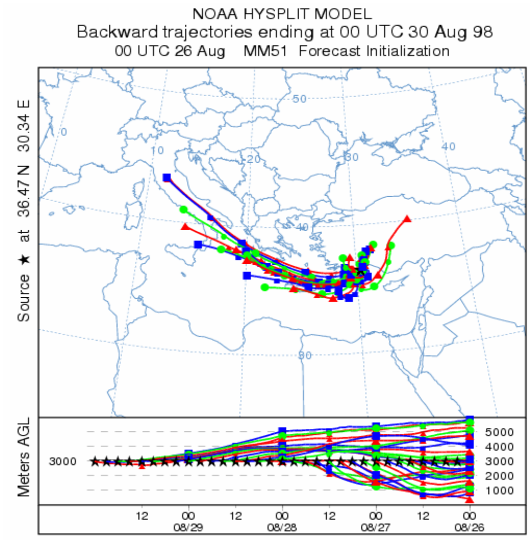


Figure 5. A multiple backward trajectory plot for Antalya at 3000 m AGL. Trajectories are lotted at 3 hour interval between 00 UTC, 30 Aug. 1998and 00 UTC, 26 Aug. 1998.

Furthermore multiple backward trajectory plots for Antalya at several levels are simulated by the HYSPLIT model (one of these simulation is given in Figure 5). In these simulations trajectory generation is renewed every 3 hours all over the entire period that starts at 00:00 Z 30 Aug. 1998 and ends at 00:00 Z 26 Aug. 1998. As a result 32 trajectories are produced during 96 hour period, the first trajectory starts at Antalya at 00:00 Z 30 Aug. 1998 while the last one starts at 0300 Z 26 Aug. 1998 and all trajectories end at the origin source at 0000 Z 26 Aug. 1998.

Backward trajectory plots for Antalya station at 3000 m AGL (Fig.5) indicate that there are few short range trajectories originated from closed areas to Antalya, such as the southern parts of Turkey at levels below 3000 m AGL. Whereas the medium and long range transport is chiefly originated from Italy and Mediterranean Sea through the southern parts of Greece to Antalya within a layer ranges between 3000 – 6000 m AGL.

3.3. Air Quality Model, CAMx

CAMx air quality model, version 4.11s has been applied to simulate the predicted concentration, deposition, transport and source origins of anthropogenic pollutants in the study domain during the selected episodic period 26 – 29 August 1998. The photochemical model, CAMx grid domain is of 89 grids in the east-west and 78 grids in the north-south directions with a horizontal resolution of 0.59° x 0.45° in the E-W and N-S directions respectively, and 14 layers vertical resolution. The first layer is 50 m AGL and the highest level is 4000 m AGL. To solve the pollutant continuity equation including the terms of: horizontal advection/diffusion, vertical transport/diffusion, chemistry, dry deposition and wet deposition, the CAMx model requires a set of input data that include: (i) Temperature, u, v wind components, pressure, geopotential height, cloud cover rain and other meteorological parameters are predicted by the mesoscale model MM5. (ii) The average default values of time/space constant top concentrations of all the species were selected to be used in a preprocessor to generate the initial and boundary concentration gridded data files. (iii) To generate the gridded landuse/surface vegetation cover inputs, the 30 sec., 24 categories USGS landuse / surface vegetation data were converted to CAMx 11 categories at 0.59° x 0.45° resolution. (iv) The UV albedo codes were calculated by a preprocessor depending on the landuse and vegetation distribution. (v) Gridded haze opacity codes, gridded ozone column codes and photolysis rates lookup tables are calculated by the radiative model, TUV assuming clear sky conditions as a function of 5 parameters: solar zenith angle, altitude, total ozone column, surface albedo and atmospheric turbidity. (vi) Emissions: The EMEP annual emission data were used to prepare the hourly gridded emission inventories of various anthropogenic pollutant emitting sources in the study domain. In this study CB-IV gas-phase chemical mechanism (mechanism 4) is used to invoke the aerosol chemistry which includes the gas-phase chemistry that governs the transformation of SO_2 to sulfate via the homogenous gas-phase reaction. The dry deposition of gases is based on the resistance model of Wesely (1989).

CAMx has been run for the 4 day episodic period, 26 – 29 Aug. 1998. Hourly gridded concentration and deposition distribution of the gaseous species SO_2 and the aerosol species PSO_4 were generated and the **P**ackage for **A**nalysis and **V**isualization of **E**nvironmental data (**PAVE**) software was used to simulating and mapping the gridded binary outputs of the CAMx model. Figure 6 shows the concentration simulations of PSO_4 and SO_2 on the first and last days of the study period. The figure indicates that the high sulfate concentrations exist over the southern parts of Italy on 26 Aug. 1200 Z have moved eastward and started to cross the western borders of Turkey on 29 Aug. 1200 Z. the high concentrations of sulfate over central Europe that were simulated in later hours (not seen in the figure) have also moved eastward and taken place over eastern Europe (lower part of the figure). The SO_2 concentration distribution was predicted to be identical through the study period. This means that the SO_2 concentration reveals large values only near sources and SO_2 is not transported to long distances from the origin sources.

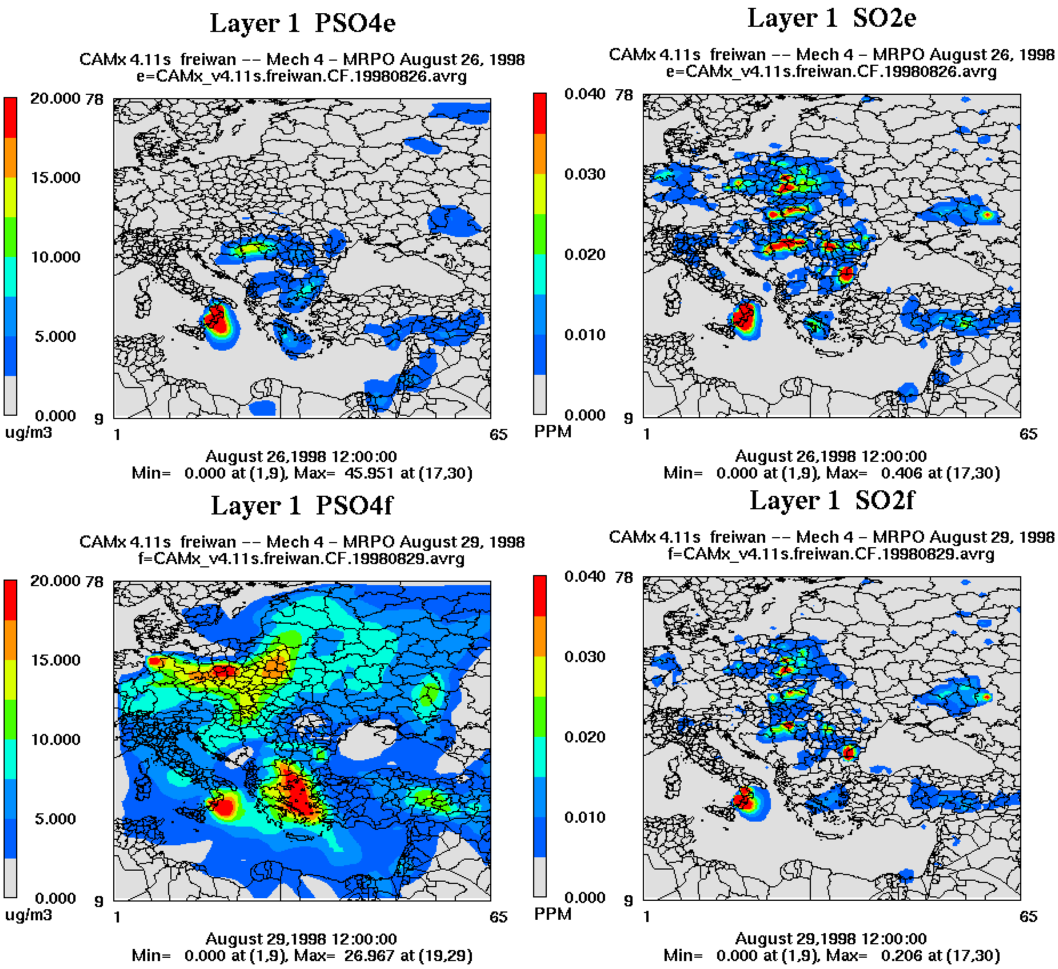


Figure 6. Concentration Simulations of PSO_4 (left) and SO_2 (right) on 26 Aug. 1200 Z (upper) and 3 days later on 29 Aug. 1200 Z (lower).

This result is unexpected, since several studies have reported that most of the SO_2 over the eastern Mediterranean originates from central and eastern Europe. The same findings were derived by Sciare et al. (2002). This can be probably attributed to the active oxidation of SO_2 to SO_4 in the fume of the power plant and to the rapid transformation of the SO_2 to aerosol sulfate in the troposphere which may occur within a short time (may be several hours). In the other hand the PSO_4 concentration simulations indicate obvious evidence to the sulfate transformation from central and southeastern Europe to the eastern Mediterranean region. Two main tracks are identifiable:

1- The first track is the transport of sulfate originated from Italy through Greece and the Aegean Sea to the southeastern Mediterranean. This result is also emphasized by the backward trajectories discussed in section 3.2 and illustrated in Fig. 3 and 5. In this case the transport taking place at high levels ranging between 3000 – 6000 m AGL may explain the long range transport of sulfate rather than SO_2.

2- The second one is the sulfate transport track which is apparently originated from central and Eastern Europe through the northwestern part of Turkey. This track is also identical to sector B of the backward trajectory distributions discussed in section 3.2.

Similar results related to transport and origin source determination of PSO_4 are reported by Kouvarakis et al. (2000), Sciare et al. (2002) and Kallos et al. (2004).

There is no internationally or regionally established methodology for the routine observation of dry deposition. Moreover, research on dry deposition is still limited in comparison with the many research projects and ongoing measurements of wet deposition in Europe.

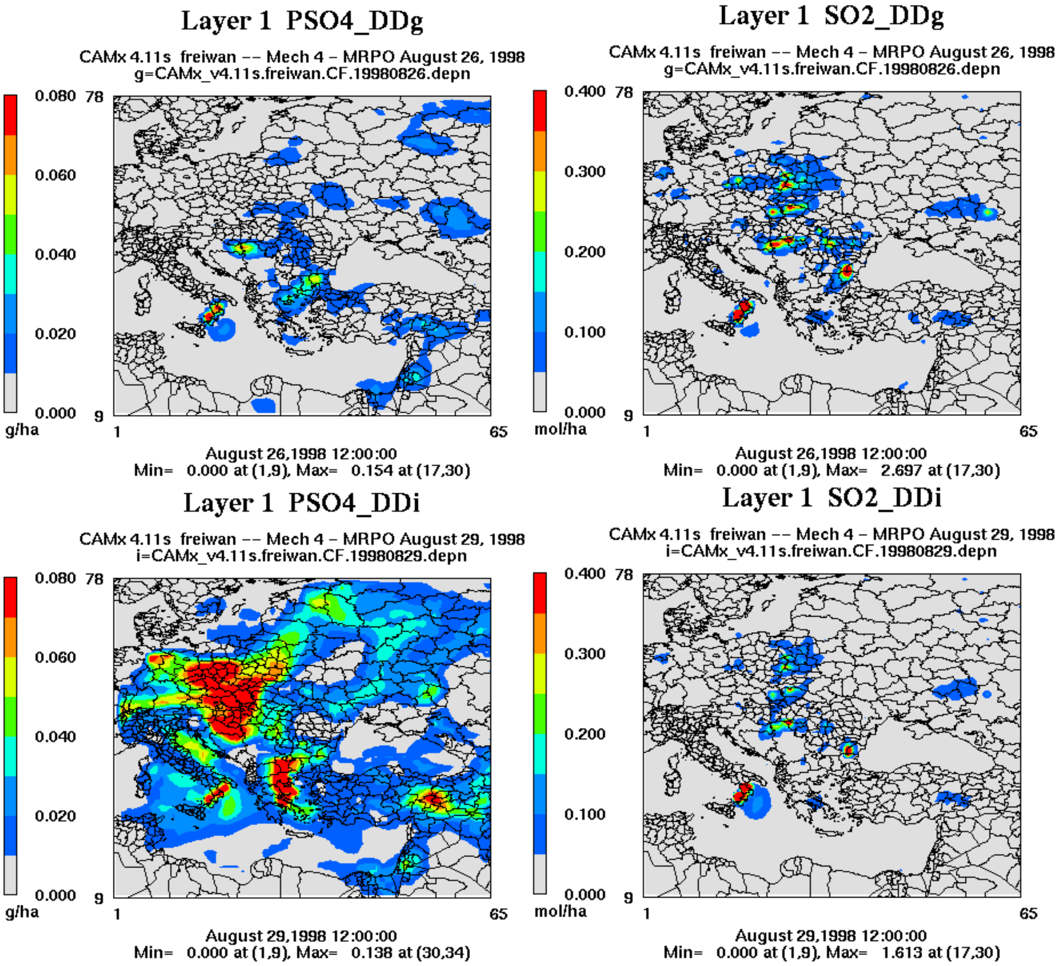


Figure 7. Deposition Simulations of PSO_4 (left) and SO_2 (right) on 26 Aug. 1200 Z (upper) and 3 days later on 29 Aug. 1200 Z (lower).

In this study gridded hourly deposition velocity, wet and dry deposition rates are predicted by CAMx model.The deposition outputs produced by CAMx include: (i) Two-dimensional dry deposition velocity (m/s), (ii) Two-dimensional dry deposited mass (mol/ha for gaseous species and g/ha for aerosols), (iii) Two-dimensional wet deposited mass (mol/ha for gaseous species and g/ha for aerosols) and (iv) Two-dimensional precipitation liquid concentration for species (mol/l for gasses, g/l for aerosols).

The downward flux and consequently the deposition rates are proportional to the concentration of the species near the ground. The eastern Mediterranean region was free of rainfall during the study period and so was a large portion of the domain. Accordingly the wet deposition and the liquid concentration of the both species will not be discussed in this study. Figure 7 shows the deposition simulations of PSO_4 and SO_2 on the first and last days of the study period. It is apparently seen from the concentration and the dry deposition figures 6 and 7 that the areas of high concentration of SO_2 and PSO_4 are also areas of large deposition of the same species and vice versa. Accordingly we can say that the deposited sulfate in the eastern Mediterranean region is originated from central and southeastern Europe.

4. CONCLUSIONS

In this study a modeling system consists of the Mesoscale Meteorological Model MM5, a three-dimensional Eulerian model CAMx (Comprehensive Air Quality Model with Extension) and the Hybrid Single Particle Lagrangian Integrated Trajectory model (HYSPLIT) was used to predict the atmospheric condition in large domain that includes the European continent, Turkey and eastern Mediterranean region, to estimate the gridded concentrations of various air pollution species and to simulate their trajectories using the gridded wind field predicted by MM5. This modeling system is used for the first time in Turkey to investigate the long range air pollution transport phenomenon through such large domain to southwestern Turkey and the east Mediterranean region, represented by Antalya. The air mass backward trajectory simulations by MM5/RIP and HYSPLIT have demonstrated three main sectors of air mass origins and tracks as follows:

Sector A: Turkey and Eastern Europe, which includes trajectories originated from Ukraine, Moldavia and Romania through the Black Sea to the central and western parts of Turkey and then the eastern Mediterranean.

Sector B: Turkey and central Europe, this sector includes trajectories originated mainly from Bulgaria, Macedonia, Albania, the former Yugoslavia, Croatia and Slovenia to the western part of Turkey and then the eastern Mediterranean.

Sector C: Southern Europe and the Mediterranean Sea, the trajectories in this sector are originated mainly from the central and western Mediterranean Sea, Spain, the southern parts of France, Italy and Greece through the Aegean Sea to the southwestern parts of Turkey and then to the eastern Mediterranean.

The air quality model simulations of sulfate concentration and deposition have revealed a great agreement with the air mass trajectory simulations produced by HYSPLIT and RIP/MM5 models. Simulations have demonstrated that sulfate transport from central and southeastern Europe to the eastern Mediterranean has two main paths: (i) the first is the transport of sulfate originated from Italy through Greece and the Aegean Sea to the southwestern parts of Turkey. (ii) The second is the track which is apparently originated from central and Eastern Europe through the northwestern part of Turkey.

Simulations of PSO_4 and SO_2 indicate a remarkable coincidence between concentration and deposition of the both species. The areas of high concentration of SO_2 and PSO_4 are also areas of large deposition of the same species and vice versa. Both SO_2 concentration and deposition have revealed large values only near sources

which indicate that SO_2 is not transported to long distances from the origin sources and deposited on the same areas. In contrast to SO_2, the deposited sulfate in the eastern Mediterranean region is mostly originated from central and southeastern Europe.
The performance of the mesoscale meteorological model, MM5 was found to be superior. The model exhibited a higher accuracy in the forth and fifth days of the forecast period. CAMx model also revealed a good performance in estimating PSO_4 in Ankara, but it underestimated the sulfate in Antalya by a factor of about 8. The model also overestimated SO_2 by a factor of 6. The overestimation of SO_2 concentration may be caused either by boundary conditions or emissions and it may be avoided by sensitivity analysis.

5. ACKNOWLEDGEMENT

The authors would like to thank Dr. Marina Astitha who has prepared the emission inventories that are used in CAMx model.

REFERENCES

Camkur, R. V., and Miller, R. L., 2004: Incorporating the effect of small-scale circulations upon dust emission in an atmospheric general circulation model. *J. Geophys. Res.*, 109, D07201, doi: 10.1029/2003JD004067.

Chen, L.-W. A., Doddridge, B. G., Dickerson R. R., Chow, C. C., and Henry, R. C., 2002: Origins of fine Aerosol mass in Baltimore – Washington corridor: implications from observation, factor analysis and ensemble air particle back trajectory. *Atmospheric Environment*, 36, pp. 4541–4554

Dincer, F., Elbir, T., and Muezzinoglu, A., 2003: Analyzing the impacts of environmental air pollution the air quality in Izmir region using HYSPLIT back trajectory model. *The 6th national symposium on: combustion and air pollution control*, 10 – 12 September, Izmir, Turkey, pp. 161 – 168 (in Turkish).

Dogan G., and Tuncel, G., 2003: Comparison among aerosol concentrations in various regions of Turkey. *The 6th national symposium on: combustion and air pollution control*, 10 – 12 September, Izmir, Turkey (in Turkish).

Draxler, R. R., 1987: Sensitivity of a trajectory model to the spatial and temporal resolution of the meteorological data during CAPTEX. *Journal of Climate and Applied Meteorology*, Vol. 26, No: 11, pp. 1577 – 1588.

Galperin, M., 1991: Routine model for long-range transport calculations of sulfur and nitrogen compounds from continuous sources allowing for non-linear effects. Air Pollution modeling and its Application VIII, Edited by H. Van Dop and D.G. Steyn, *Plenum Press*, New York USA.

Gullu H.G., Olmez I., and Tuncel G., 2000: Temporal variability of atmospheric trace element concentrations over the eastern mediterranean Sea. *Spectrochimica Acta, Part B*, 55, pp. 1135–1150.

Israelevic, P. L., Levin, Z., Joseph, J. H., Ganor, E., 2002: Desert aerosol transport in the Mediterranean region as inferred from the TOMS aerosol index. *J. Geophys. Res.*, 107(D21), 4572, doi: 10.1029/2001JD002011.

Kallos, G., Astitha, M., Gofa, F., O'Connor, M., Mihalopoulos, N., and Zlatev, Z., 2004: "Transport and Deposition Patterns of Ozone and Aerosols in the Mediterranean Region". *27th NATO/CCMS International TechnicalMeeting on Air Pollution Modeling and its Applications,* October 2004, Banff, Canada.
Kocak, M., Nimmo, M., Kubilay, N., and Herut, B., 2004a: Spatio-temporal Aerosol trace metal concentrations and sources in Levantine basin of the Eastern Mediterranean. *Atmospheric Environment,* Vol. 38, pp, 2133 – 2144.
Kouvarakis, G., Tsigaridis, K., Kanakidou, M., and Mihalopoulos, N., 2000: Temporal Variation of Surface Regional Background Ozone over Crete Island in the Southeast Mediterranean. *J. Geophys. Res.* Vol. 105, No. D4. pp. 4399 – 4407.
Kubilay N., Nickovic S., Moulin C., and Dulac F., 2000: An illustration of the transport and deposition of mineral dust onto the eastern Mediterranean. *Atmospheric Environment,* Vol. 34, 8 , pp, 1293-1303.
Miller, M. J., 1974: On the use of pressure as vertical coordinate in modeling conversion. *Quart. J. Roy. Meteor. Soc.*, 100, 155 – 162.
Ozturk, F., SOULTANOV, L., and TUNCEL, G., 2003: Determination of the observed high sulfate concentrations in the Eastern Mediterranean Region. *The 6th national symposium on combustion and air pollution control*, 10 – 12 September Izmir, Turkey. pp. 298 – 309 (in Turkish).
Sciare, J., Bardouki, H., Moulin, C., and Mihalopoulos, N, 2002: Aerosol Sources and their Contribution to the Chemical Composition of Aerosols in the Eastern Mediterranean Sea during Summertime. *Atmos. Chem. Discuss*., 2, pp. 1287 – 1315.
Syrakov, D., and Prodanova, M., 2002: Transboundary exchange of sulfur pollution in region southeastern Europe. Air Pollution and its Application XV, Edited by Borrego and Schayes, *Kluwer Academic / Plenum Publissers*, New York, USA.
Tuncel, G., *2002:* Wet and dry deposition of natural and anthropogenic aerosol components to the Eastern Mediterranean. *Bi-National Israeli-Turkish workshop on: Atmospheric deposition of aerosols and gases in theEastern Mediterranean*, Golden Tulip Hotel, Dead Sea, Israel.
Tuncel, S. G., and Erduran, M. S., 2001: Characteristics of air pollutant in the Eastern Mediterranean coast. *The 2nd international symposium on: Airquality management at: urban, regional and global scales*. Istanbul, Turkey.
Wesely, M.L., 1989: Parameterization of Surface Resistances to Gaseous Dry Deposition in Regional-Scale Numerical Models. *Atmos. Environ.*, 23, 1293-1304.