LONG-RANGE TRANSPORTED AIR POLLUTANTS FROM CONTINENTAL AREAS TO THE REMOTE REGION OF THE NORTH AEGEAN SEA

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ABSTRACT

Long-range transportation of air pollutants from industrial and urban environments can significantly affect the climate in remote regions. In this study, we investigate the transportation of pollutants to the remote environment of the North Aegean Sea (NAS) during the summer period, when the synoptic Etesian wind conditions prevail. A temporary monitoring station was assembled at a remote region on the island of Lemnos, which is located at the center of the NAS at a distance of ca. 250 km from the continent. The observed number concentration of particles in the nucleation mode increased almost four fold while their size decreased to 20 nm when the winds had a north-eastern direction. During these pollution transport events we also observed enhanced concentrations of nucleation mode particles that grew in size with a rate that ranged from 4.6 to 8.0 nm h^{-1}. Corresponding back-trajectory calculations show that the air masses arriving at our station had passed over the wider industrial region of Marmara and Istanbul ca. 9 to 12 hours prior. This is long enough time for newly formed particles to grow up to the climate relevant size of ca. 20 nm at which they are observed. Our data provide evidence that the atmospheric aerosol in the remote region of the NAS can be significantly affected by emissions from the northeastern industrial and urban areas during the summer period.

Keywords: Long-range transportation, Aerosol particle concentrations, Back-trajectory.

1. Introduction

Long range transport can significantly affect the climate at urban (Kubilay et al., 2000; Karaca *et al.,* 2009) and remote (Marclet et al., 1988; Kato *et al*., 2001) regions. Lelieveld et al. (2002) and later Sciare et al. (2008) have specifically shown that the Mediterranean region is significantly affected by transportation of air pollutants. Although a number of studies have focused on the region, particle pollution in the important sub-region of the Northern Aegean Sea (NAS) has rarely been investigated.

The NAS is an important part of the Mediterranean region, surrounded by big Greek (e.g. Athens and Thessaloniki), Turkish (e.g. Istanbul, Izmir, Bursa) and Bulgarian (e.g. Burgas, Plovdiv) cities. Both the position and the meteorological conditions (Kotroni *et al*., 2001) of NAS influence the air pollution pathways between southern Balkans and Turkey during the Etesian period.

In this study, we investigate the transportation of pollutants to the remote environment of the NAS during the Etesian wind patterns of the summer period (from 27 August to 10 September 2011). Atmospheric particle measurements were conducted on the island of Lemnos, a remote island located at the center of the North Aegean with a distance of ca. 250 km from the continent.

2. Measurements

Measurements were carried out in the northwest site of Vigla (420m a.s.l.) in Lemnos island (39˚ 58´N, 25˚´04´E) (Figure 1) from 27 August to 10 September 2011 (Day of Year; DOY 239 - 253). Aerosol number concentration measurements were performed during the entire sampling period. A Scanning Mobility Particle Sizer (SMPS, TSI Model 3034) was used to measure the size distribution of a diameter that ranged between 10 and ca. 500 nm with a 3 min resolution. Air mass back-trajectories (5-days) arriving at the Vigla temporary station were determined by the NOAA HYSPLIT model (NOAA, 2014; Draxler, R.R., Hess, G.D., 1998; Draxler and Rolph, 2003).

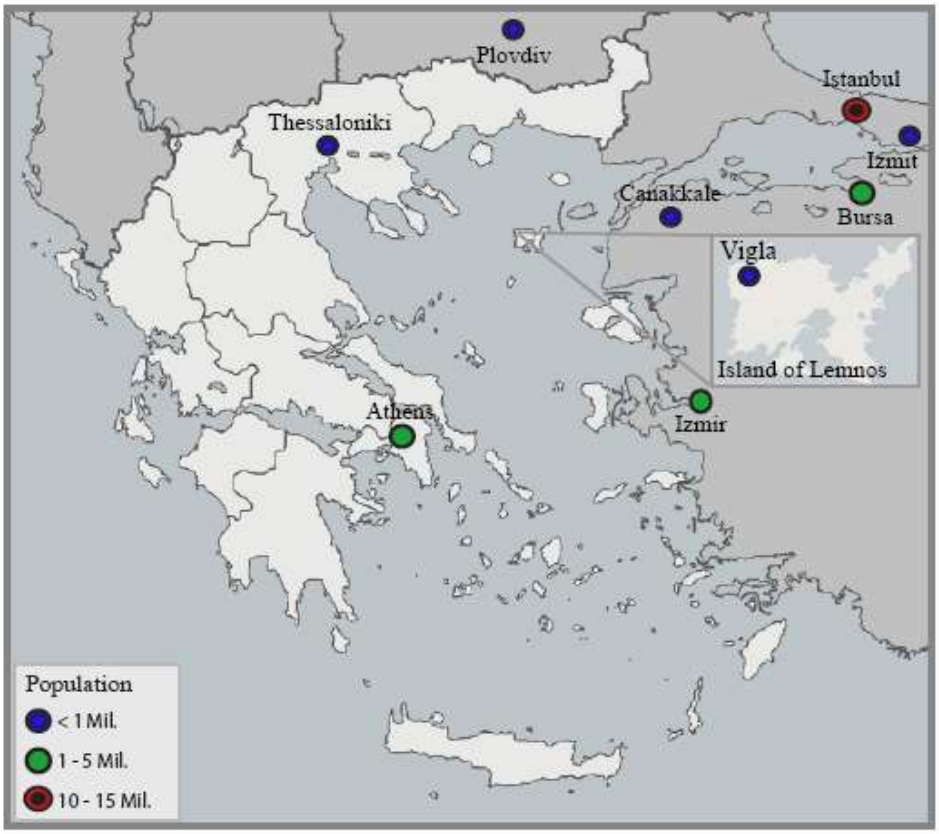

Figure 1: The island of Lemnos (39˚ 55´ N, 25˚ 15´ E) and the location of the station at Vigla (420 m a.s.l., northwestern on the island). The most important urban cities, including indication of the population, close to the monitoring station are also shown.

3. Results and discussion

3.1 Synoptic meteorology and back-trajectory analysis

The meteorological conditions throughout the campaign were characteristic of the Etesians period with strong local winds of N and NE direction (frequency 15 and 46%, respectively) and velocities that ranged from 2.1 to 11.3 m s^{-1}. Calm wind conditions (i.e., average wind speed less than 1 m s^{-1}) were observed for 29% of the cases. Five day back trajectories that were identified as pollution transport episodes were computed using the online HYSPLIT model (cf. Figure 2). With the exception of the episode observed on 10 September (DOY 253), the rest had common source and paths. Air masses before reaching the monitoring station of Lemnos, passed through northeastern regions, such as Turkey and Black sea. On 10 September, air masses originated from the industrial regions of Northern Greece (7h before) and Bulgary (18h before). Back trajectory analysis indicate that air parcels for the rest of the sampling days, were transported under weak wind conditions from the regions of Northern Greece and Balkan.

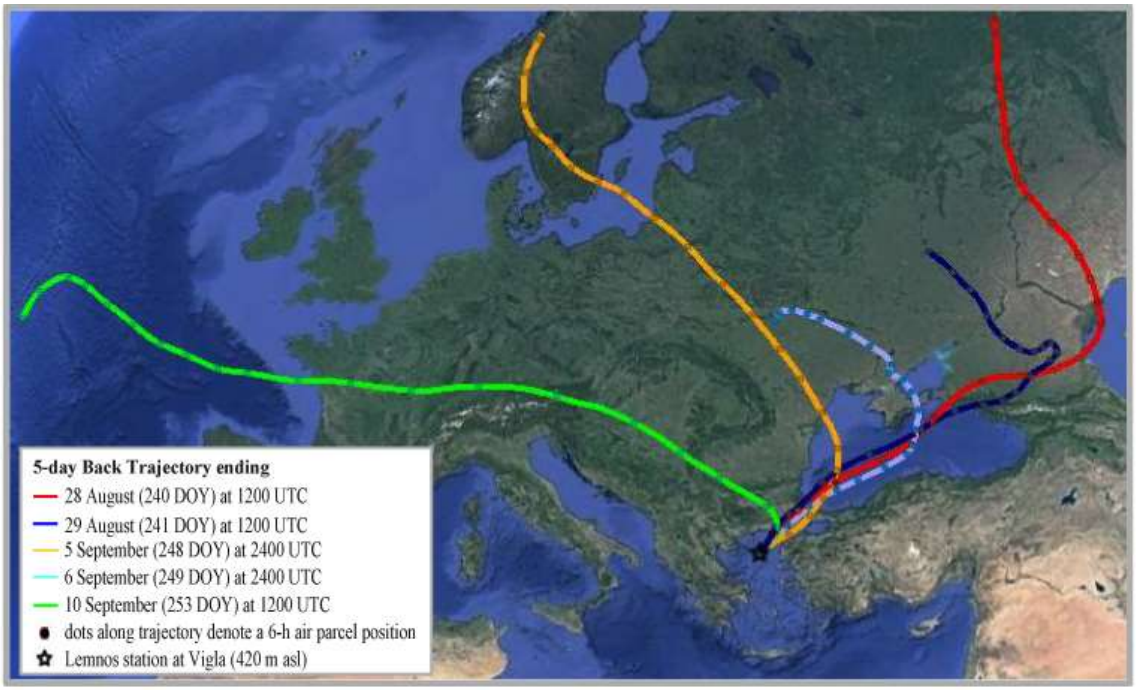

Figure 2: Map showing 5-day backward trajectory calculations for the days of transported pollutants. The trajectories on 28 August-DOY 240, 29 August-DOY 241 and, 10 September-DOY 253 (red, blue and green lines, respectively) start at 12 UTC, while those on 5 September-DOY 248 and 6 September-DOY 249 (orange and cyane lines, respectively) start at 23 UTC.

3.2 Aerosol size distribution and number concentrations

High number concentrations of nucleation mode particles were observed specifically for five days of the sampling period as depicted in Figure 3. Particle formation episodes were determined when high number concentrations of nucleation mode particles related to physic-chemical processes and mechanisms, such as the aerosol condensation sink and the influence of vapor sulphuric acid concentrations (Kulmala *et al*., 2005; data not shown). These episodes occurred on 28 (DOY240), 29 (DOY241) August and on 5 (DOY248), 7 (DOY250) and 10 (DOY253) September. The episodes of transported pollutants were further classified based on whether they were observed during daytime (indicated by the yellow shaded areas in Figure 3) or during nighttime (indicated by the orange shaded areas in Figure 3). The total particle number concentration (with diameters ranging from 10 to ca. 500 nm) ranged from 1×10^3 to 12×10^3 #/cm^3 with a mean value of 2×10^3 #/cm^3.

Transportation episodes are characterized by strong north northeastern winds with speeds of the order of 8.0±1.3 m s^{-1}. The particle number concentration of nucleation mode ($N_{d<25nm}$) increased almost four fold during the transportation episodes compared to the rest of the days, reaching a maximum value of 1.2×10^3 #/cm^3. In addition, the peak size of particle distributions decreased from 140 nm, observed at days with no pollution transport, to 20 nm during the transportation episode days. The particles were most often observed in the Aitken and Accumulation modes (32% and 66%, respectively) during these episodes.

Daytime transportation episodes were observed on DOY 240, DOY 241 and DOY 253 (28, 29 August and 10 September). The episodes started at 10:00 and lasted until 18:00, while their highest number concentration of the nucleation-mode (ca. 1.7×10^3 #/cm^3) was reached at midday. During these episodes, the elevated $N_{d<25nm}$ were associated with mean growth rates that ranged from 4.6 to 8.0 nm h^{-1} (for size range from 17 to 20 nm). Similarly high growth rate values (>4 nm h^{-1}) have been reported at highly polluted or industrial areas (Kulmala *et al*., 2005; Hamed *et al*., 2007).

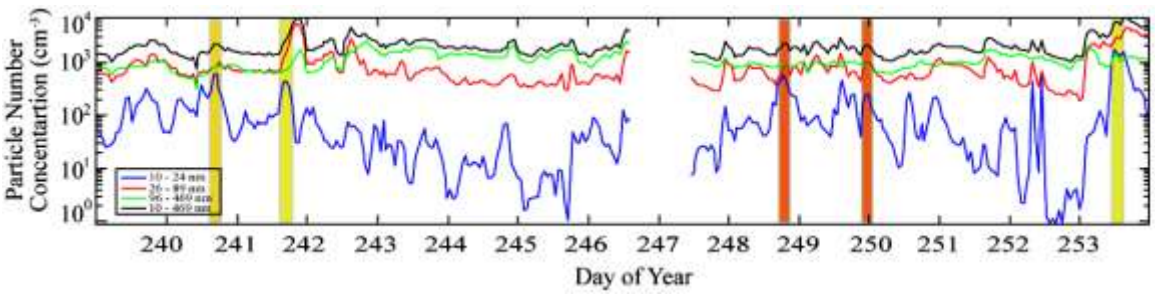

Figure 3: Time series of the number concentration of particles having size in the range of 10-460 nm (black line), 10-25 nm (blue line), 26-89 nm (red line), 96-469 nm (green line) observed on Lemnos from 27 August to 10 September 2011. Days during which transportation episodes are identified during the daytime are indicated by the yellow shaded (28 August-DOY 240, 29 August-DOY 241 and 10 September-DOY 253) and during the nighttime by orange periods (5 September-DOY 248 and 6 to 7 September-DOY 249 and 250).

Nighttime transported episodes were observed on DOY 248 and DOY 249-250 (5 and 6-7 September). These episodes started at 21:00 and lasted until 03:00, while the highest number concentration of the nucleation mode (ca. 0.2 $\times 10^3$ #/cm^3) was observed around midnight. $N_{d<25nm}$ values were about eight times lower than those observed during the daytime episodes. The observed mean growth rates of nucleation mode particles were as high as 5.5 ±0.9 nm h^{-1} (for size range from 21 nm to 25 nm), which correspond to heavily polluted areas.

4. Conclusions

In this study, we report the aerosol number concentration measurements conducted at the remote environment of NAS (on the island of Lemnos) during the period from 27 August to 10 September 2011, when the Etesians wind patterns prevail. Five days exhibited increased aerosol number concentrations of nucleation mode during the sampling period. During these episodes, air masses arriving at the monitoring site had passed through northeastern regions such as Turkey and Black Sea. The particle number concentration of nucleation mode ($N_{d<25nm}$) increased almost four fold, reaching a maximum value of 1.2 $\times 10^3$ #/cm^3 compared to 0.5$\times 10^3$ #/cm^3 during the rest of the days. The elevated $N_{d<25nm}$ were associated with mean growth rates that ranged from 4.6 to 8.0 nm h^{-1} (for size range from 17 to 20 nm), indicating air mass sources from polluted areas. These observations suggest that the atmospheric aerosol in the remote region of the NAS can be significantly affected by transported emissions in northeastern industrial or urban areas during the summer period.

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