Interaction Between Particulate Matter Characteristics and Atmospheric Boundary Height Over Sofia Based on Case Studies

Plamen Savov, Nikolay Kolev, Ekaterina Batchvarova, Hristina Kirova, and Maria Kolarova

Abstract The air quality of the city of Sofia is a result of a complex interplay between anthropogenic and natural factors. In the present paper the aerosol pollution of Sofia is investigated through case studies during different seasons of 2019—two days in spring, four in summer and four in winter. Experimental measuring campaigns for particle concentrations add more extensive knowledge on the distribution and levels of the main problematic pollutants, such as particulate matter (PM). Laser particle counter measurements near an intensive traffic boulevard are presented and discussed. The daily variation with high temporal resolution (10–15 min) of aerosol particle concentrations (number and mass) in channels 0–2.5 μm and 2.5–10 μm are analyzed together with meteorological conditions and results from WRF-GDAS, HYSPLIT and BSC dust models. The influence of long-range transport of dust on the aerosol concentrations is assessed.

Keywords Air quality · Aerosol concentration · Atmospheric boundary layer · Particle number concentrations · WRF-GDAS · HYSPLIT · NMMB-BSC-Dust

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1 Introduction

The Atmospheric Boundary Layer (ABL) height determines the volume in which different gaseous and aerosol pollutants are mixed due to turbulent processes within the atmosphere. To model the ABL height in urban environments is additional challenge due to the specific physical and chemical characteristics which play important role for pollutant dispersion, climate comfort, and weather forecasting [1, 2, 5, 7, 8, 17, 19]. The ABL structure in urban environment is very complex due to the built environment, which requires studies on surface layer meteorology and dispersion of pollutants [3, 4, 6, 9]. Specific studies on the aerosol pollution for Sofia city, including remote sensing measurements, are presented in [11–13, 18]. The combination of models and particle counter measurements provides comprehensive information on both the aerosol concentration characteristics in the urban atmosphere and the vertical structure of aerosol layers and meteorological parameters determining the transport of air masses [14, 15, 20]. Particle counter measurements introduce important details on the aerosol size distribution, which are needed for PM health impact assessments [10, 21, 22].

2 Methodology

2.1 Experimental Site and Instruments

A two-channel BQ20 (TROTEC, Germany) laser particle counter (LPC) with channel PM2.5 (0–2.5 μm) and channel PM10 (2.5–10 μm) denoted further in the paper as PM2.5 and PM10, respectively, was used to measure instantly the size, number of particles or mass concentration with time step 10 or 15 min. The sampling rate was 0.9 l/min. The measuring range for mass concentrations is from 0 to 2000 $\mu g/m^3$ with resolution 1 $\mu g/m^3$. Measurements were performed in a green area near bus stop Pliska, 30 m North of Blvd. "Tsarigradsko shose", one of the largest boulevards in Sofia stretching from West toward East. The core part of the boulevard covers six lanes with intensive traffic of cars and busses allowed with speed limit of 80 km/h. Side streets of two lanes are situated at both directions where speed limit is lower. Meteorological data with 30-min time resolution from Sofia airport automatic weather station were used for the analysis. Here we use PM10 for particles with size 2.5–10 μm, as suggested by the manufacturer TROTEC. In LPC instruments the particle number is measured in size fractions and PM10 is obtained as a sum of all. LPC measurements in different size fractions are advantageous with regards to the assessments of PM health effects [21]. The term PMcoarse is also used for the particles of size in the range 2.5–10 μm in air quality and health related studies.

2.2 Descriptions of Case Studies

Measurements performed in 2019 are discussed. Two spring days (23 and 31 March), characterized with high pressure and sunshine duration of 10–12 h were chosen. Air temperature ranged between minimum of 0 °C and maximum of 15 °C, suggesting stable boundary layer and accumulation of air pollution in the morning.

Four typical summer days (7 and 8 June; 26 and 27 July), characterized by relatively calm anticyclone weather were included. The maximal temperature in June days reached 25–30 °C and sunshine duration (*hours per day*) was 8 and 14 h, correspondingly. The July days were hot with temperature reaching 34 °C. The daily sunshine was 14 h on 26 July and 10 h on the next day.

The first two of the winter days (18–19 December) were characterized with anticyclone conditions and persistent fog suggesting high level of pollution. On December 20 transport of warmer air masses from SW cleared the fog. December 21 was a day with foehn wind and wind gusts of 23 m/s. The temperatures reached 10–15 °C.

2.3 Models Applied

WRF-GDAS (Weather Research and Forecasting Model—Global Data Assimilation System) model was applied to analyze current atmospheric conditions and to obtain the atmospheric boundary layer height (ABLH). The simulation results (GDAS meteorological data) were obtained from READY Web Server of NOAA ARL (https://www.ready.noaa.gov/). GDAS1 data is set on 1° horizontal and 6-h temporal resolution for the globe. The downscaling is performed with WRF forecast on several nested domains with 25 vertical levels between 0.998 and 0.310 sigma coordinates. The ABL height is extracted from WRF on 9 km horizontal and 3-h temporal resolution. GDAS1 includes observations from Sofia airport (LBSF).

Results from the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT, https://www.arl.noaa.gov/ready/hysplit4.htm) initiated with GDAS1 were used. HYSPLIT is a Lagrangian dispersion model, coupled (online) to WRF in such a way that the HYSPLIT calculation is run as part of the WRF-ARW prediction calculation [14, 15]. Based on diverse observations information, Lin et al. [14] conclude that GDAS1 data set is more credible in backward trajectory analysis compared to GDAS0P5 (the GDAS data set on 0,5° horizontal resolution). The embedded HYSPLIT includes dispersion, trajectories, deposition (dry and wet), etc. [8, 16, 20]. The HYSPLYT trajectories allowed to analyze the origin of air masses reaching Sofia on the case studies days.

The NMMB/BSC-Dust model (https://ess.bsc.es/bsc-dust-daily-forecast), developed in the Earth Sciences Department to simulate and/or predict the atmospheric cycle of mineral dust at BSC was used to assess the long-range transport of dust originating from North Africa over the area of Sofia.

3 Results and Discussions

3.1 Spring Cases

The spring case study days were both typical anticyclone spring days with morning temperature close to 0 °C, no clouds, long sunshine duration and transition from stable to convective atmospheric boundary layer (ABL).

The number of PM10 on 23 March 2019 (Saturday) changed from 35 N/l in the morning to 15 N/l in the afternoon and of PM2.5 from 550 to 200 N/l (Fig. 1 left). The corresponding mass concentrations for PM10 ranged from 45 in the morning to 20 μg/m^3 in the afternoon and for PM2.5 from 20 to 5–10 μg/m^3 (Fig. 1 right).

The modelled ABLH on this day was 1000 m at 12 LT and reached maximum of 1350 m at 15 LT, showing favorable dispersion conditions (Fig. 2 left). The wind data from GDAS1 showed wind direction N-NW and wind speed 1–4 m/s. The HYSPLIT trajectories showed northerly flow for levels 1500–2000 m and NNW for level 1000 m (Fig. 2 right).

The number of PM10 on 31 March 2019 (Sunday) changed from 50 N/l in the morning to 10 N/l in the afternoon, and of PM2.5 from 700 N/l to 200 N/l (Fig. 3 left). The corresponding mass concentrations for PM10 were from 60 μg/m^3 in the morning to 20 μg/m^3 and for PM2.5 from 30 μg/m^3 to 5 μg/m^3 after 11 LT (Fig. 3 right).

The abrupt threefold increase in mass concentrations at about 10:30 LT was probably caused by short time local sources. The maximal mass and number concentrations may be shifted in time due to local short time changes of wind speed, wind direction or emission sources (Fig. 3). It can be noted, that PM10 and PM2.5 (both mass and number concentrations) changed with time in the same way, a feature not observed on 23 March. GDAS meteorological conditions showed persistent wind speed in the range 1–4 m/s and wind direction from NE. The ABLH was again

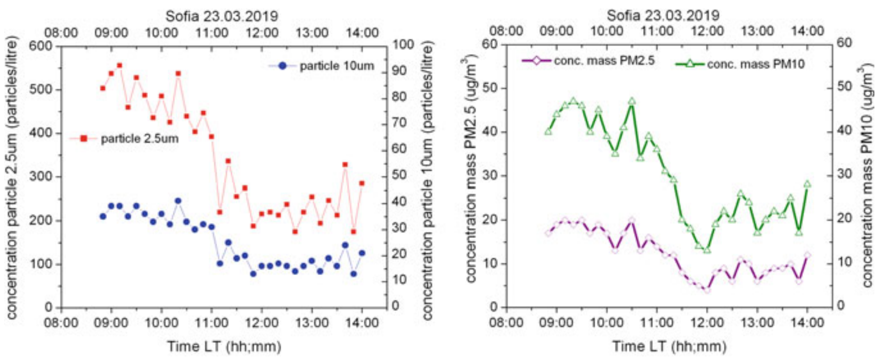

Fig. 1 Daily variations in PM2.5 and PM10 on 23 March 2019, measured as (left) particles per liter (N/l) and (right) concentration mass (μg/m^3)

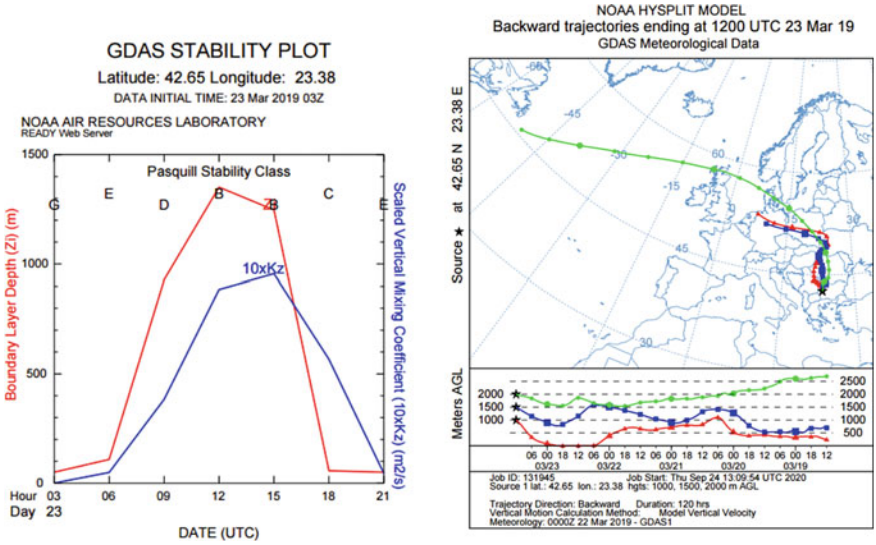

Fig. 2 Model results for Sofia (LAT 42.65; LON 23.38) on 23 March 2019: GDAS stability plot (left) and HYSPLIT backward trajectories (right)

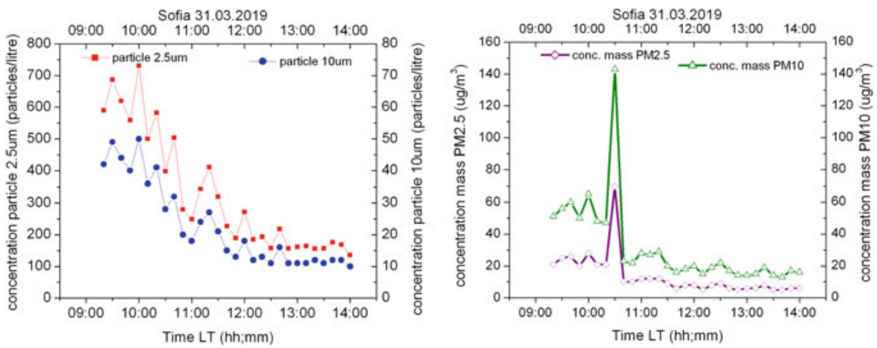

Fig. 3 Daily variations in PM2.5 and PM10 on 31 March 2019, measured as (left) particles per liter (N/l) and (right) concentration mass ($\mu g/m^3$)

1000 m at 12 LT and grew up to 1300 m at 15 LT (Fig. 4 left). The HYSPLIT trajectories (levels 1000–1500–2000 m) were parallel starting over Atlantic Ocean with westerly flow over Europe and turning to northeasterly flow reaching Bulgaria (Fig. 4 right).

During both spring days, the measured concentrations were lower than the limit values, as well as than the diurnal PM10 values at the air quality monitoring stations in the eastern districts of Sofia. The stable conditions in the morning and the growth of the convective ABL towards the afternoon caused decrease of the PM concentrations

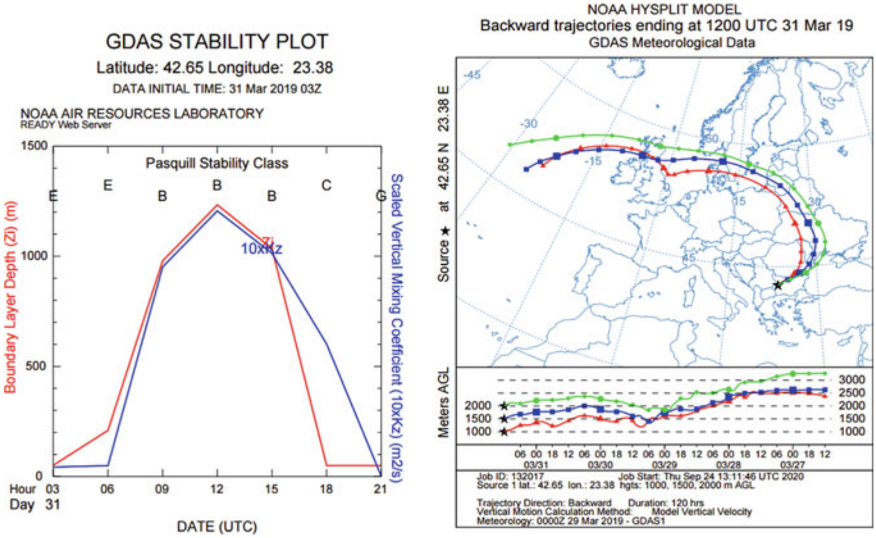

Fig. 4 Model results for Sofia (LAT 42.65; LON 23.38) on 31 March 2019: GDAS stability plot (left) and HYSPLIT backward trajectories (right)

from the morning till afternoon. Both days were weekend days, and so the traffic intensity was expected to be equally distributed with time.

3.2 *Summer Cases*

The summer days with particle measurements were characterized with anticyclone weather and classical daily growth of the ABL reaching 1800–1900 m in cloudless conditions. The maximal temperature on June 7 reached 25 °C as cumulus clouds developed in the afternoon and sunshine duration was 8 h. On June 8, the temperature rose up to 30 °C and the duration of sunshine was 14 h. The July days were hot with temperature reaching 34 °C. The daily sunshine was 14 h on 26 July and 10 h on the next day.

The number of PM10 on 7 June 2019 (Friday) changed from 20 N/l in the morning hours to 10 N/l in the afternoon, and of PM2.5 from 250 to 100 N/l (Fig. 5 left). The corresponding mass concentrations for PM10 were from 25–30 $\mu g/m^3$ to 7 $\mu g/m^3$ in the afternoon and for PM2.5 from 10–12 $\mu g/m^3$ to 5 $\mu g/m^3$ (Fig. 5 right).

GDAS Boundary Layer Depth (Zi) over Sofia is 1200–1300 m (Fig. 6 left). The model suggests prevailing wind from N (1–4 m/s) from 9 to 15 LT. HYSPLIT Backward trajectories of 1000, 2000 and 3000 m ending in Sofia at 12UTC on June, 7 2019 are shown in Fig. 6 right. Transport of air masses from Morocco and Sahara Desert at altitude of 3 km can be traced.

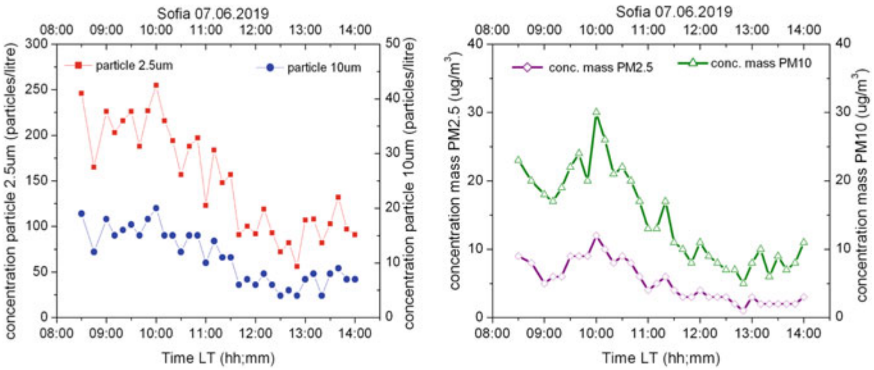

Fig. 5 Daily variations in PM2.5 and PM10 on 7 June 2019, measured as (left) particles per liter (N/l) and (right) concentration mass (μg/m^3)

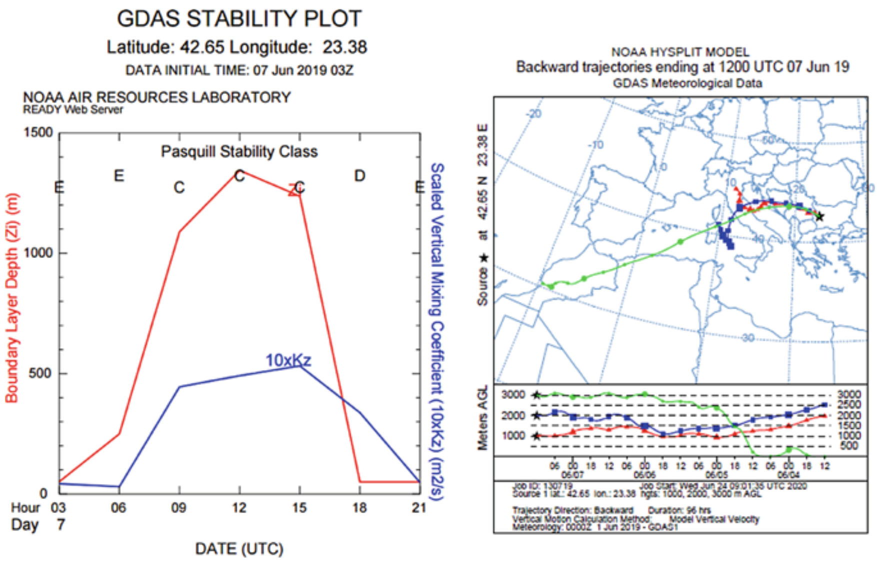

Fig. 6 Model results for Sofia (LAT 42.65; LON 23.38) on 7 June 2019: GDAS stability plot (left) and HYSPLIT backward trajectories (right)

NMMB/BSC Dust (Dust Forecast at 06UTC Friday 07 June) gives a higher concentration in the layer between 3 and 6 km height with maximum of about 20 μg/m^3 at 4 km over Sofia (Fig. 7 left). This intrusion of dust, likely, did not influence the measured aerosol concentrations in the urban surface layer. LON-Height cross-section and LAT-Height cross-section present the distribution of dust concentration across North Africa and Europe (Fig. 7 right). The dashed line indicates the position of Sofia.

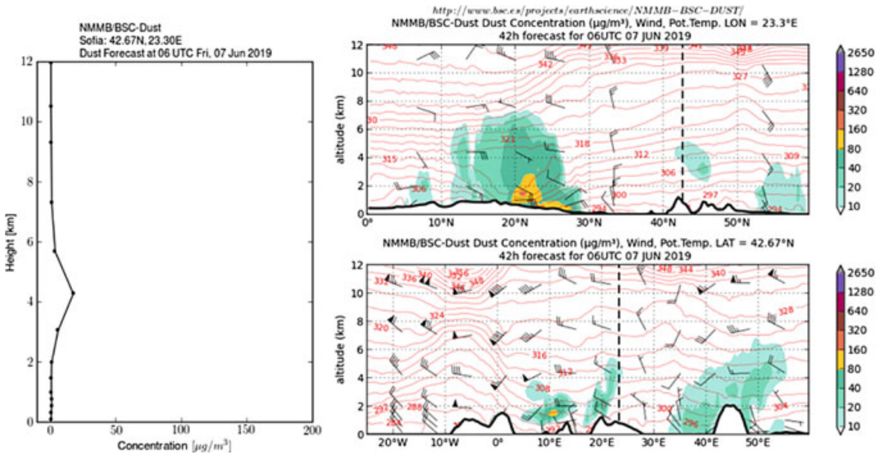

Fig. 7 NMMB/BSC dust forecast concentrations (μg/m^3) at 06 UTC on 7 June: vertical profile (left) and LON&LAT-Height cross-section (right)

Measurements on 8 June 2019 (Saturday) show that the number of PM10 is around 20 N/l with max of 25 N/l from 9:30 to 10:30 LT and for PM2.5 the numbers are 220 N/l in the early morning hours, increasing to 300–350 N/l from 9:30 to 10:30 LT, and then fall to 175 N/l after 12 LT (Fig. 8 left). The corresponding mass concentrations for PM10 are from 15 to 30 μg/m^3. For PM2.5 the concentrations are around 10 μg/m^3 before 12 LT and around 5 μg/m^3 in the early afternoon (Fig. 8 right).

GDAS gives for ABL height for Sofia maximum of 1900 m with unstable (B-C) Pasquill Stability Class at 12–18 LT (Fig. 9 left). GDAS wind speed for Sofia is 7 m/s in the morning hours and 1–4 m/s after 11 LT from NW. The HYSPLIT Backward trajectories of 1000, 1500 and 2000 m ending in Sofia at 12 UTC on June, 8 2019 are

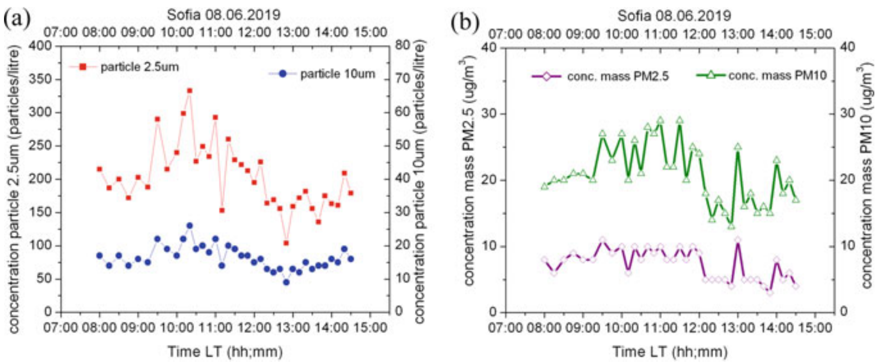

Fig. 8 Daily variations in PM2.5 and PM10 on 8 June 2019, measured as (left) particles per liter (N/l) and (right) concentration mass (μg/m^3)

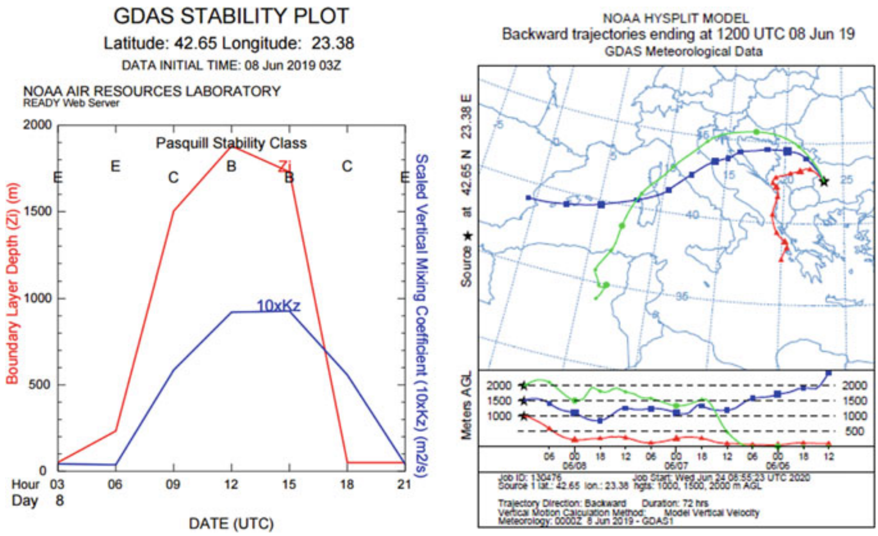

Fig. 9 Model results for Sofia (LAT 42.65; LON 23.38) on 8 June 2019: GDAS stability plot (left) and HYSPLIT backward trajectories (right)

shown in Fig. 9 right. The transport of air masses at the three levels is from different areas. The trajectory of 2000 m starts from NE Sahara Desert.

NMMB/BSC Dust (Dust Forecast at 06 UTC Sat 08 June) shows a higher concentration of about 20 μg/m3 in the layer below 2 km (Fig. 10). This suggests that long-range transport of dust may influence the surface PM concentrations in Sofia in

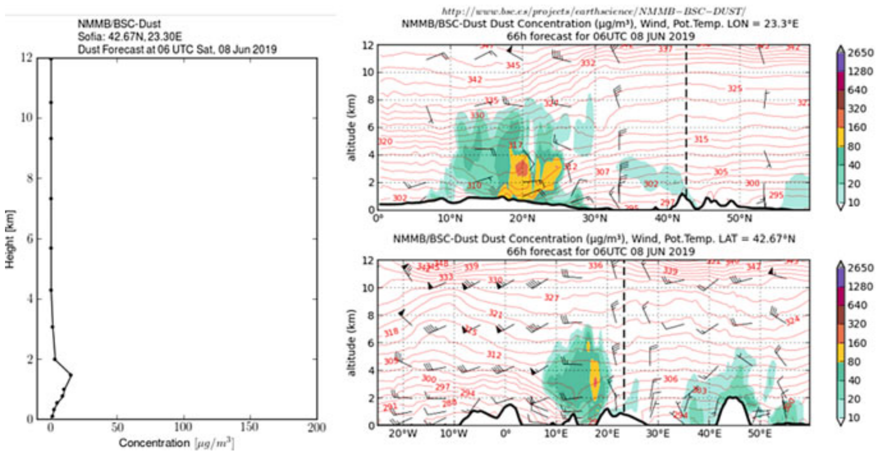

Fig. 10 NMMB/BSC dust forecast concentrations (μg/m^3) at 06 UTC on 8 June: vertical profile (left) and LON&LAT-height cross-section (right)

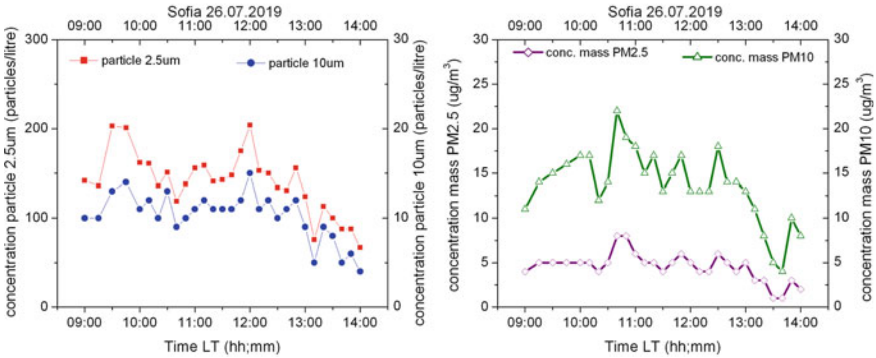

Fig. 11 Daily variations in PM2.5 and PM10 on 26 July 2019, measured as (left) particles per liter (N/l) and (right) concentration mass (μg/m^3)

the afternoon hours when ABL reaches the height of dust intrusion. The LON&LAT-Height cross-sections present different distribution of dust concentration compared to the previous day (Fig. 10 right).

The number of PM10 on 26 July 2019 (Friday) changes between 10 N/l before 13 LT and 5 N/l later on; PM2.5 ranges between 150–200 N/l and 70 N/l following the PM10 variation (Fig. 11 left). The corresponding mass concentrations for PM10 range from 10 to 25 μg/m^3 (15 μg/m^3 in average) in the morning and falls to 5–7 μg/m^3 in the afternoon; PM2.5 varies in the same way from 5 μg/m^3 to less than 2 μg/m^3 (Fig. 11 right).

The atmospheric boundary layer height (Boundary Layer Depth Zi (m)) from GDAS is 1900 m (Fig. 12 left), the wind is from NW with speed in the range 1–4 m/s. HYSPLIT Backward trajectories show flow from NW at 1000–2000 m (Fig. 12 right).

The aerosol concentrations are twice higher and the variation differs significantly on 27 July compared to the previous day: PM10 peak values are 35 N/l around 9 LT and falls to 5 N/l at 14 LT; PM2.5 ranges between 500 N/l and 100 N/l following the PM10 variation (Fig. 13 left). The corresponding mass concentrations vary in the same way with peaks around 9 LT and a secondary peak around 13 LT. PM10 mass concentration ranges from 40 to 5 μg/m^3 and PM2.5 from 15 to 2 μg/m^3 (Fig. 13 right).

Although the Boundary Layer Depth on July 27 reached maximum of 1900 m, the weather was cloudy with sun duration about 10 h and prevailing neutral stratification (Fig. 14 left). The wind speed was in the range 1–4 m/s. The wind direction near the ground, as well as the trajectories 1000–2000 m were from NW (Fig. 14 right).

During all summer days, the measured concentrations are lower than the limit values, as well as at all sites of the air quality monitoring stations in the eastern districts of Sofia. The height of the convective ABL reaches 1350 m on June 7 and 1900 m on the other 3 case study days. On 7 June the morning rush hour concentration

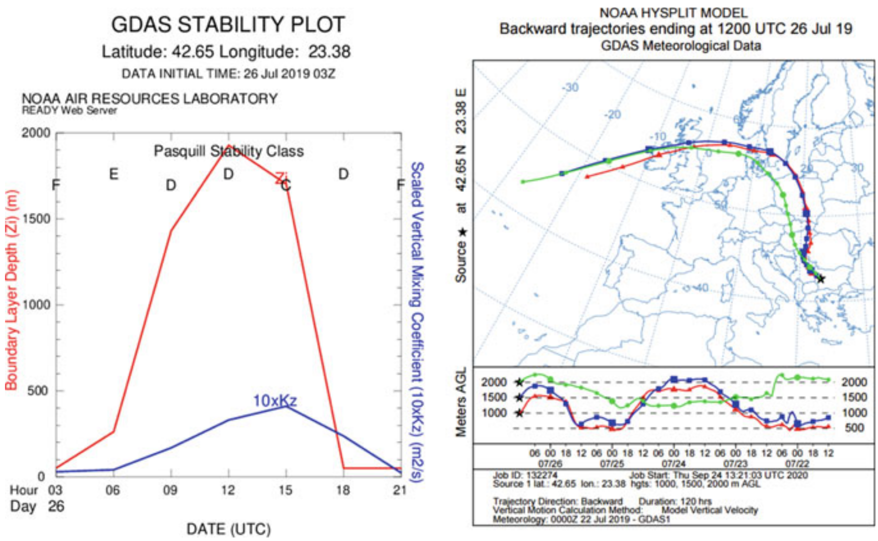

Fig. 12 Model results for Sofia (LAT 42.65; LON 23.38) on 26 July 2019: GDAS stability plot (left) and HYSPLIT backward trajectories (right)

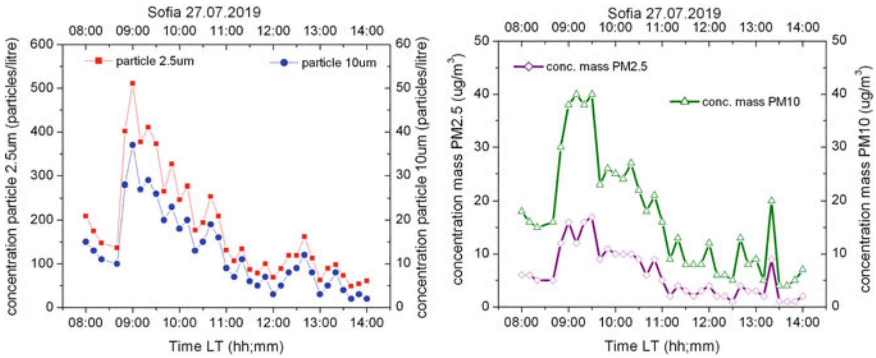

Fig. 13 Daily variations in PM2.5 and PM10 on 27 July 2019, measured as (left) particles per liter (N/l) and (right) concentration mass ($\mu g/m^3$)

peak is at 10 LT and is strongly pronounced. On 8 June (Saturday), high concentrations remain between 9 and 12 LT. Secondary increase is noted at 13 and 14 LT. On 26 July (Friday) the morning rush hour peak is not well pronounced, compared to 27 July. The changes with time on both days differ, since the decrease towards noon on 27 July is sharp. On both days a secondary peak is observed. The meteorological conditions on both days are characterized with flow from NW. The cloudy conditions on 27 July, as well as accumulation of aerosol in the residual layer of 26 July could be the reason for the twice higher concentrations.

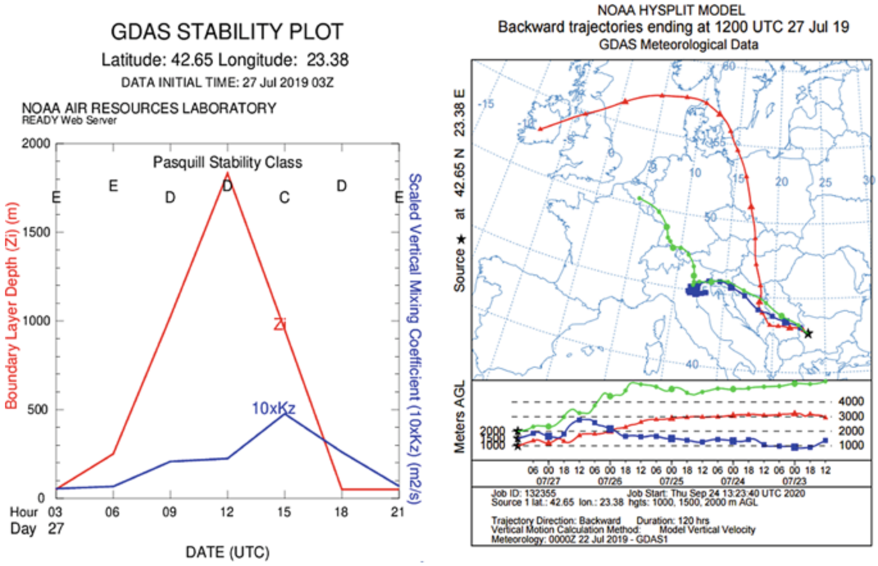

Fig. 14 Model results for Sofia (LAT 42.65; LON 23.38) on 27 July 2019: GDAS Stability plot (left) and HYSPLIT backward trajectories (right)

3.3 Winter Cases

During the period 18–20 December 2019 anticyclone synoptic circulation prevailed causing low wind speed from SW-S, morning fog conditions in the valley and low stratus clouds. The sun shine duration in Sofia on these days was 6, 4 and 4 h, correspondingly, while the weather in the mountains was clear and sunny. In the valley the surface was snow free and temperature ranged between 0 and 10 °C. Starting on 20 December, the weather changed to cyclone circulation bringing warmer south-westerly flow. On 21 December, strong foehn wind from S-SW was registered in Sofia, reaching 16 m/s, gusts up to 23 m/s and high temperatures of 15 °C.

Measurements on 18 December (Wednesday) were performed from 8 to 14 LT under heavy fog conditions and relative humidity of 100%. PM10 was 200 N/l until 10 LST and decreased twice in the afternoon. PM2.5 was 4500 N/l in the early morning hours, reached maximum of 5000–5500 N/l around 10 LT (related to morning rush hours and fog) and gradually decreased to 2000 N/l after 12 LT (Fig. 15 left). The PM10 mass concentration (Fig. 15 right) was from 220 $\mu g/m^3$ at 8 LT, with max of 250–260 $\mu g/m^3$ at 9:30–10:30 LT and 100 $\mu g/m^3$ in the early afternoon. The PM2.5 concentrations showed similar behavior, starting from 140 $\mu g/m^3$ before 9 LT, reaching maximum of 160–170 $\mu g/m^3$ at 10:30 LT and decreasing to 60 $\mu g/m^3$ in the afternoon.

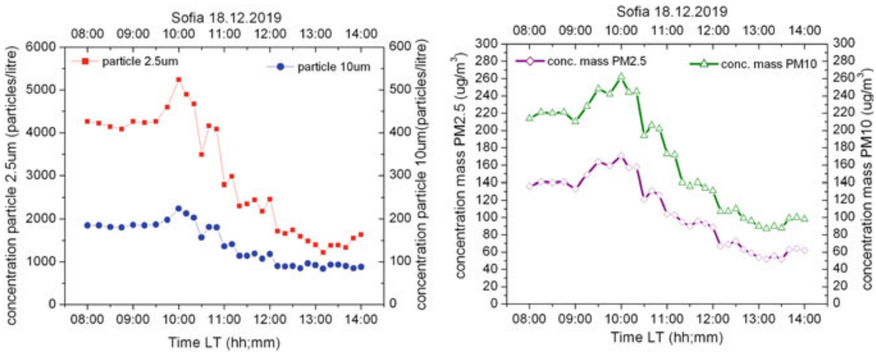

Fig. 15 Daily variations in PM2.5 and PM10 on 18 December 2019, measured as (left) particles per liter (N/l) and (right) concentration mass (μg/m^3)

The fog on 18 December was related to stable stratification and maximal Boundary Layer Depth of 200 m (Fig. 16 left). Southerly wind in the range 1–4 m/s was given by GDAS. The trajectories 200 to 1000 m were from SW (Fig. 16 right).

Measurements on 19 December (Thursday) were performed from 7 to 12 LT. The stable stratification and fog persisted leading to double increase of all maximal particle numbers and mass concentrations compared to the previous day (Fig. 17).

GDAS ABL height over Sofia was below 200 m, stratification was stable to very stable (Fig. 18 left), and wind was of 1–4 m/s constant from S-SE during the day. The

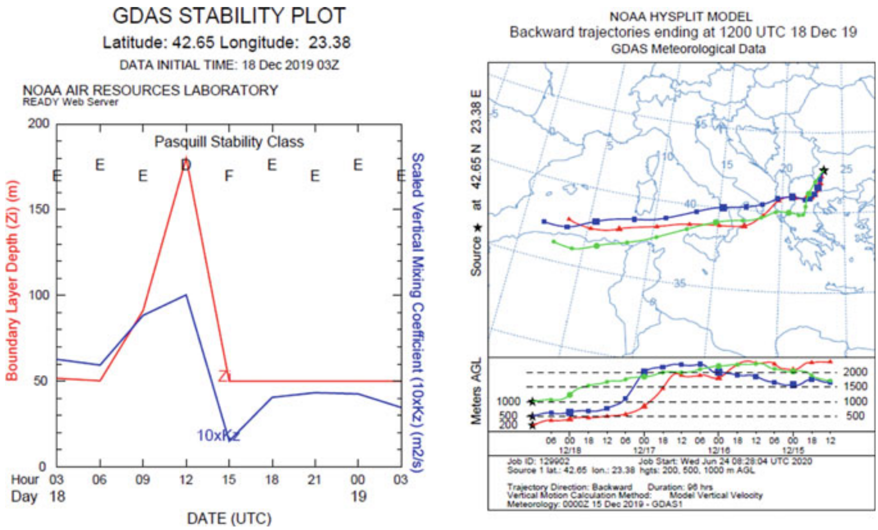

Fig. 16 Model results for Sofia (LAT 42.65; LON 23.38) on 18 December 2019: GDAS Stability plot (left) and HYSPLIT backward trajectories (right)

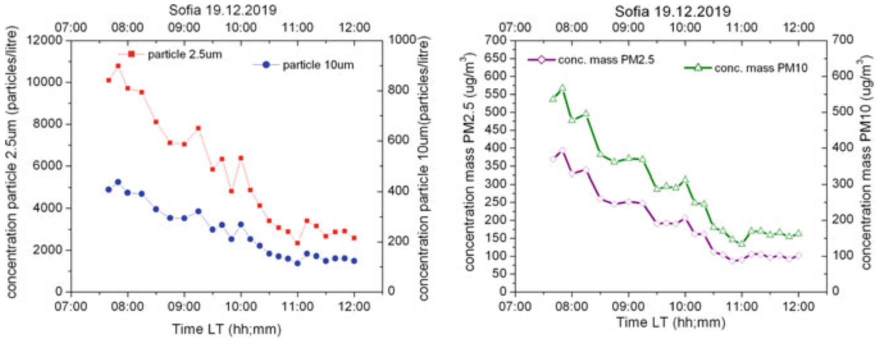

Fig. 17 Daily variations in PM2.5 and PM10 on 19 December 2019, measured as (left) particles per liter (N/l) and (right) concentration mass (μg/m^3)

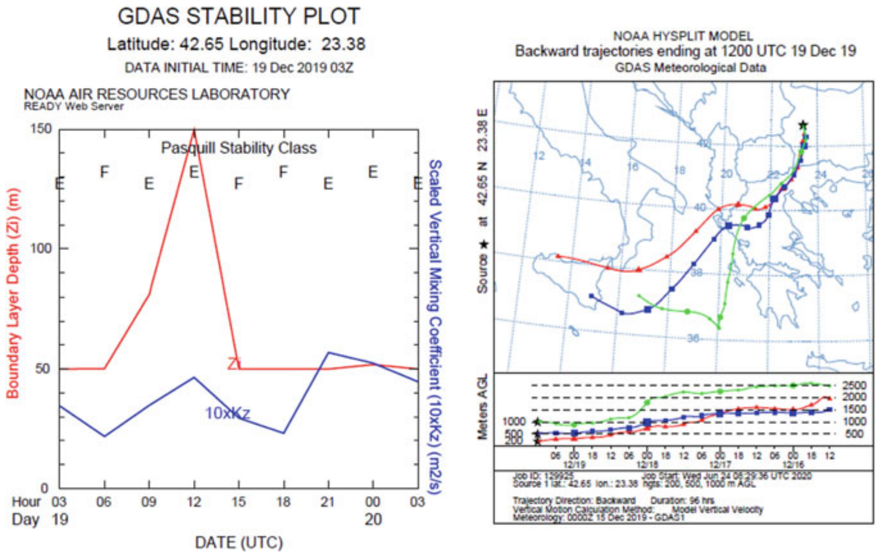

Fig. 18 Model results for Sofia (LAT 42.65; LON 23.38) on 19 December 2019: GDAS Stability plot (left) and HYSPLIT backward trajectories (right)

96–h backward trajectories of height 200, 500 and 1000 m show SW flow originating from Sicily (Fig. 18 right).

The particle number and mass concentration measurements on 20 December (Friday) showed distinct decrease and different from the changes with time of the previous two days. The PM2.5 mass concentration started from 70 μg/m^3 in the early morning and reached a minimum of 30 μg/m^3 between 10 and 11 LT, related to the destruction of the fog. The values increased again between 11:30 and 12:30 LT to 80 μg/m^3, probably related with shorter working day and increased traffic of cars leaving Sofia for the following 6 days of Christmas holydays. The PM10 concentrations showed similar to PM2.5 behaviors, but with higher values, starting from 100 $\mu g/m^3$ in the morning, diminishing to 70 $\mu g/m^3$ and growing again to 120 $\mu g/m^3$ after 11 LT. After 12:30 LT the concentrations slowly decrease (Fig. 19 right).

On 20 December the synoptic conditions started to change to multi-centered low-pressure structure over the Balkan Peninsula. The transport of warm air masses from S-SW (Fig. 4 right) caused increase of temperatures. GDAS1 wind speed near the ground is again in the range 1–4 m/s from South. NMMB/BSC Dust Forecast model (Fig. 21) indicates dust concentration of 40 $\mu g/m^3$ at 4000 m, showing long-range transport, which remains far above the ABL (maximal of 450 m) over Sofia (Fig. 20 left).

The PM10 and PM2.5 concentrations (Fig. 22) show peculiarities related to the new meteorological situation on 21 December (Saturday), starting with low morning concentrations of 10–20 $\mu g/m^3$ for PM2.5 and of 30–45 $\mu g/m^3$ for PM10 registered before 10 LT. After 10 LT the concentrations rapidly increase twice to values of 55 $\mu g/m^3$ and 95 $\mu g/m^3$, correspondingly (Fig. 22 right). After 10:30 LT the concentrations decrease slowly reaching values of 25 $\mu g/m^3$ for PM2.5 and 55 $\mu g/m^3$ for PM10. This behavior is possibly related to short time wind gust situation during the peak period when large amounts of dust are lifted from the ground surface. It is interesting to note that PM10 number concentration increases twice and PM2.5 three times for the period 10–10:30 LT (Fig. 22 left). This peak cannot be explained with high transport traffic, because of its very short duration.

GDAS gives neutral stratification and maximal Boundary Layer Depth of 600 m over Sofia (Fig. 23 left). The measured wind speed reached 16 m/s from S-SW. HYSPLYT also shows transport of air masses from S and SW (Fig. 23 right).

The last 2 days of the winter experimental campaign are peculiar in view of particle concentrations and show the dynamic interplay between meteorology and emission sources, which determines the air quality in the city.

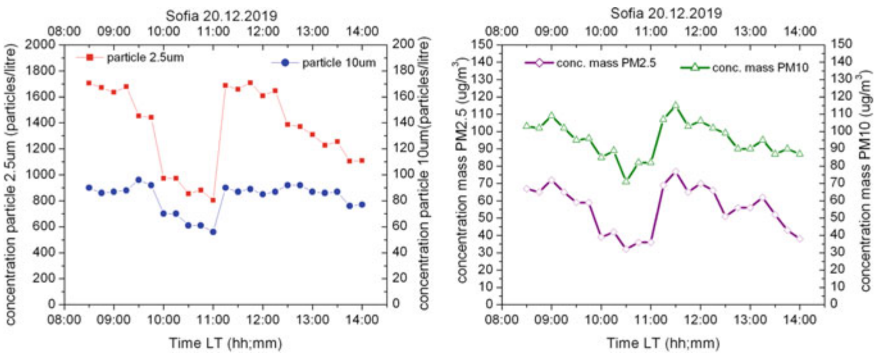

Fig. 19 Daily variations in PM2.5 and PM10 on 20 December 2019, measured as (left) particles per liter (N/l) and (right) concentration mass ($\mu g/m^3$)

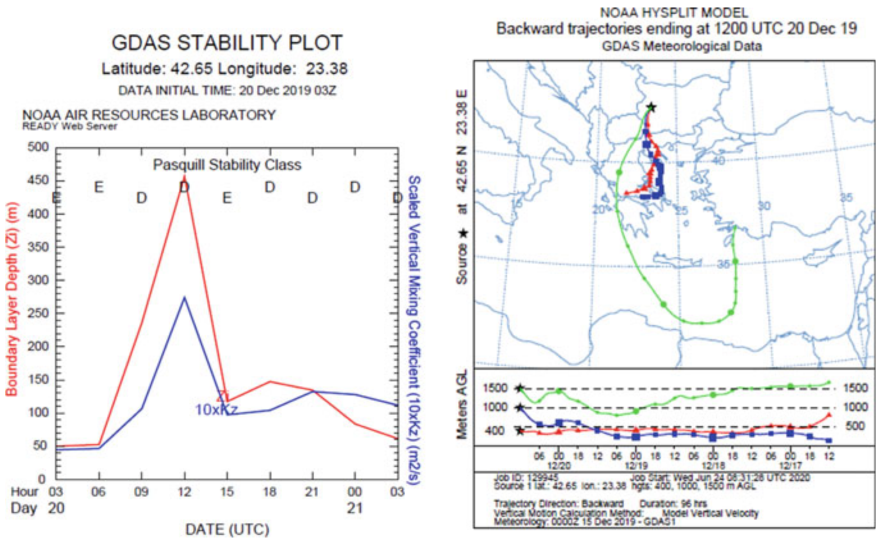

Fig. 20 Model results for Sofia (LAT 42.65; LON 23.38) on 20 December 2019: GDAS stability plot (left) and HYSPLIT backward trajectories (right)

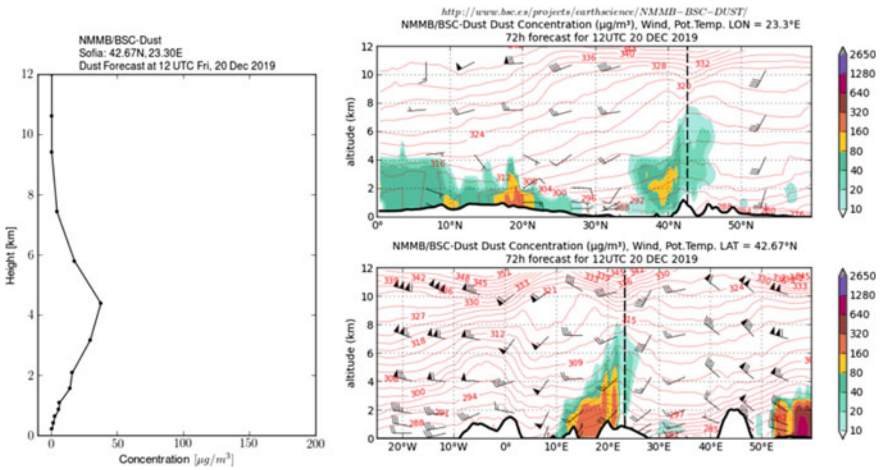

Fig. 21 NMMB/BSC Dust—dust forecast at 06 UTC Fri 20 December and dust concentrations ($\mu g/m^3$) for Sofia (LAT = 42.67 N; LON = 23.30E)

3.4 Common Analysis

In order to assess the contribution of different meteorological factors defining the level of PM concentrations, the ratio of maximal/minimal values for all days are given in Table 1.

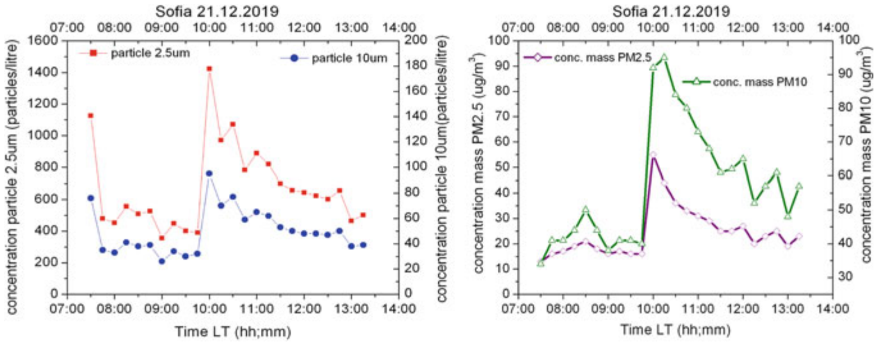

Fig. 22 Daily variations in PM2.5 and PM10 on 21 December 2019, measured as (left) particles per liter (N/l) and (right) concentration mass (μg/m^3)

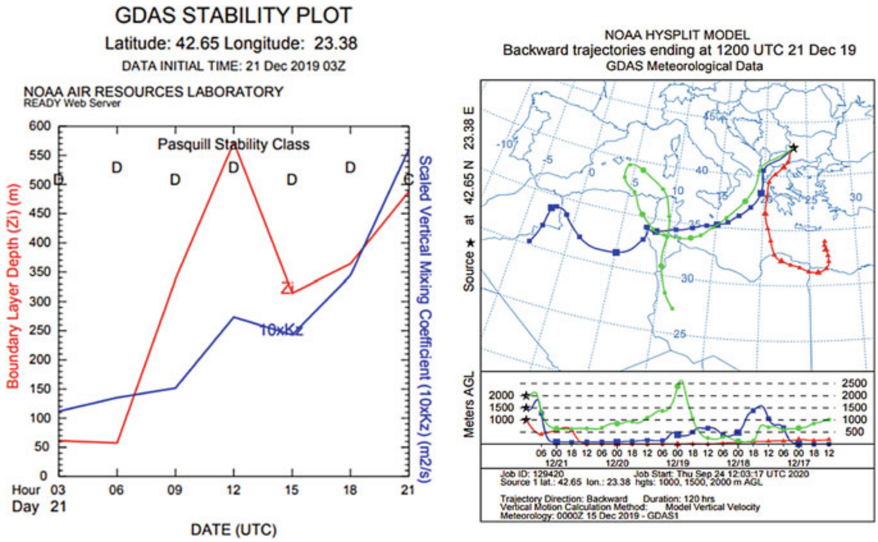

Fig. 23 Model results for Sofia (LAT 42.65; LON 23.38) on 21 December 2019: GDAS stability plot (left) and HYSPLIT backward trajectories (right)

It can be noted that the measured PM2.5 particle number is higher on Saturday, 8 June, despite the expected lower traffic contribution during weekends and deeper ABL. Furthermore, the ratio highest/lowest values is smaller on 8 June (350/100 N/l), compared to the ratio (250/50 N/l) on 7 June. Possible reason for these differences is the long-range transport contribution to the surface particle concentrations according to Dust model on 8 June.

Different phenomenon, as accumulation of aerosol pollution during sequent days, was observed on 27 July, Sunday, when the concentrations were twice higher

Table 1 PM10 and PM2.5 ratios of maximal/minimal concentrations

Day	PM10 mass max/min	PM10 number max/min	PM2.5 mass max/min	PM2.5 number max/min
23 Mar/Sat	50/15	40/15	20/5	550/180
31 Mar/Sun	140/20	50/10	70/5	750/150
7 Jun/Fri*	30/5	20/5	12/2	250/50
8 Jun/Sat*	30/15	30/10	10/5	350/100
26 Jul/Fri	23/4	15/4	8/2	200/70
27 Jul/Sat	40/5	36/2	16/2	520/50
18 Dec/Wed	260/80	200/100	170/50	5500/2000
19 Dec/Thu	600/150	400/100	375/100	11,000/3000
20 Dec/Fri*	120/70	100/50	70/30	1700/1100
21 Dec/Sat	100/10	90/20	40/10	1400/300

*Days with long range transport of dust

compared to the previous day, due to influence of the residual layer and cloudy conditions. Both days were hot summer weekend days with ABLH of 1900 m.

Accumulation of air pollution due to persistent stable stratification conditions was observed for the winter case study days (18–19 December). These days were among the most polluted of the year 2019 according to the official monitoring system. The reported PM concentrations were twice higher than the 24-h limit value in the eastern districts of Sofia (Mladost and Druzhba). In the lower districts (Nadezhda) the excess was 3–4 times. During these fog days the LPC measurements showed that the number of small particles was very high and the ratio between the maximal numbers of particles in the two channels (P2.5/PM10) was much higher compared to other days.

The last 2 days of the winter experimental campaign are peculiar in view of particle concentrations and show the dynamic interplay between meteorology and emission sources, which determines the air quality in the city.

The spring days are characterized with higher maximal number concentrations compared to summer, because of the stronger and longer existence of stable stratification in the morning, although the convective boundary layer height is comparable.

Concerning meteorology, it can be noted that in spring and summer, the wind direction was north-westerly and wind speed in the range 1–4 m/s. In winter, the days of experiments were under south-southwesterly flows, firstly with low wind speed, fog and stagnant stable conditions. Later on, feohn situation developed with wind speed reaching 16 m/s.

4 Conclusions

This study presents experimental results concerning the daily distribution of the aerosol particles in the urban environment and the correlation to the synoptic situations, meteorological parameters and ABL height. The analysis is based on case studies during typical for spring, summer and winter days with aerosol particles measurements (mass and number concentrations) using laser particle counters in channels (0–2.5 μm) and (2.5–10 μm) denoted as PM2.5 and PM10.

In view of health effects assessments, it is important to study the number concentrations of PM of different size fractions. Such studies add specific information on the aerosol pollution in Sofia, not provided by the air quality monitoring system.

In summer, the ABL is high and the observed concentration of aerosol particles is under the limit values. On 8 June, the particles mass concentrations change two times from maximal to minimal values, while on 7 June this ratio is 6. The number concentration maximal to minimal ratios are also bigger on 7 June (5) compared to 8 June (3). The differences might be explained with the contribution of long range transport of dust on 8 June when the ABLH reaches the zone of maximal values in the dust profile, causing intrusion of dust particles and less pronounced daily maximum. The observed maximums on both days are possibly related to intensive transport traffic along the Tsarigradsko shose in the morning hours. The twice higher concentrations on July 27 compared to July 26, could be explained with the effect of accumulation of aerosol due to meteorological conditions.

In winter, the ABL height is low and the observed concentrations of aerosol particles are higher than the norms for 18 and 19 December. The maximal values are 3 times higher than the minimal and are related to fog conditions, pollution accumulation and intensive transport traffic along the Tsarigradsko shose in the morning hours. Typical for the fog is the big number of small particles. On 20 and 21 December the concentrations show peculiar changes with time probably related to the beginning of Christmas holidays and rare meteorological conditions due to feohn event.

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