Investigation of the mixing layer height derived from ceilometer measurements in Athens, Greece and implications for air quality

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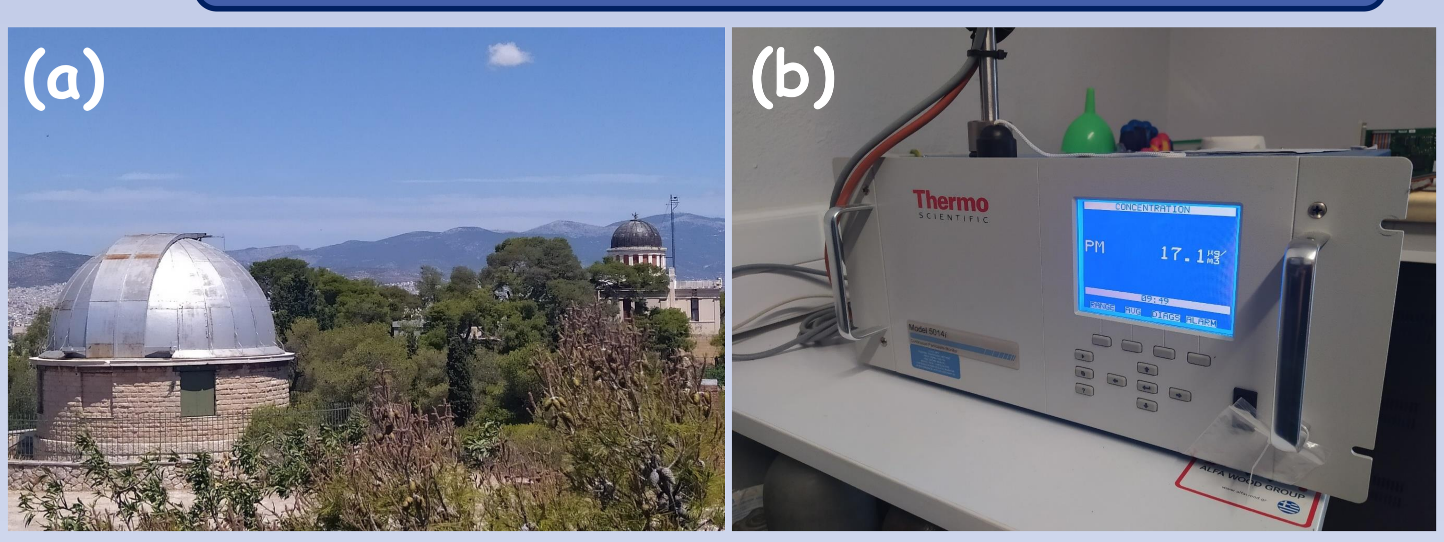
INTRODUCTION

Urban areas are frequently influenced by enhanced air pollution, mainly due to strong emissions and chemical transformation processes. The planetary boundary layer (PBL) is the lower part of the troposphere where the Earth's surface interacts with large-scale atmospheric flows and plays an important role in air-pollution studies over urban/industrial areas. Substances emitted into the PBL disperse gradually through atmospheric turbulence horizontally and vertically (Seibert et al. 2000). The upper level of this layer is called the mixing layer height (MLH) and is a measure for the vertical turbulent exchange within the boundary layer, and one of the controlling factors for the dilution of pollutants emitted near the ground. The height of the mixing layer is a crucial parameter for air quality forecasts, pollutant dispersion and characterization of pollutant variability and source impacts (Haeffelin et al., 2012)

SITE DESCRIPTION - ANALYSIS



The National Observatory of Athens's (NOA) CL31 ceilometer (Fig. 1c) is located at the Actinometric station of NOA at Thissio in central Athens, representing urban background conditions. The station joined the E-PROFILE network in June 2018. The CL31 provides measurements of the backscatter coefficient from 116.9 m to 7786 m at vertical intervals of 30 m with a 5 min time resolution. In the current study, ceilometer measurements in 2021 were used to estimate the MLH on an hourly basis, aiming to analyze its diurnal and seasonal variation and to associate these changes with the concentrations of near-surface aerosols and pollutants obtained from multiple collocated instruments operating at the Thissio air monitoring station of NOA (Fig. 1a). In this respect, PM2.5 measurements from beta attenuation and optical monitors, chemical components (PM_1) from an Aerosol Chemical Speciation Monitor (ACSM) as well as BC data from an aethalometer AE-33 (Fig. 1b) were used.

Figure 1: Photo of the measuring site (a) in Athens city center, (b) aethalometer (AE-33) and (c) CL-31 ceilometer.

DIURNAL VARIABILITY OF MIXING LAYER HEIGHT VS O_3, NO_x, $PM_{2.5}$

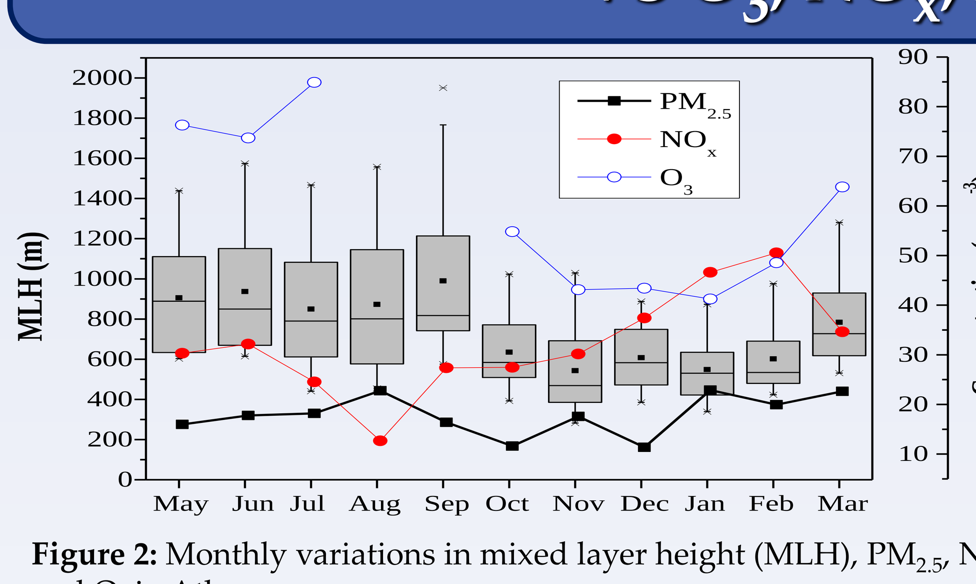


Figure 2: Monthly variations in mixed layer height (MLH), $PM_{2.5}$, NO_x and O_3 in Athens.

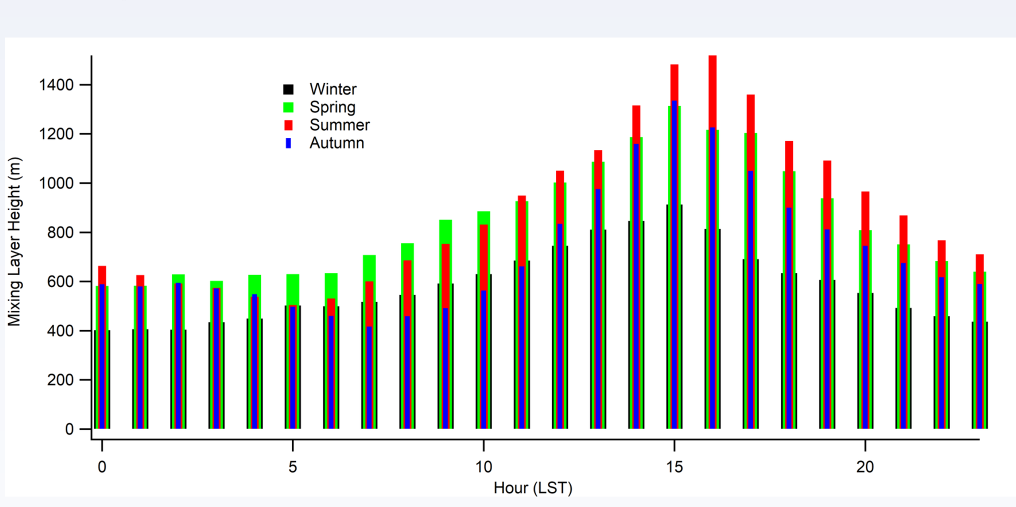


Figure 3: The mean hourly variation of the mixing layer height in four seasons.

The preliminary results demonstrated a distinct annual pattern with higher MLH values during summer and lower in winter (Fig. 2), while on a diurnal basis, the MLH generally increased on midday and the early afternoon hours, following the surface heating, turbulence and mixing processes in the atmosphere (Fig. 3). Long- or shortrange transported aerosol plumes from natural sources such as desert dust or forest fires may highly impact the backscatter coefficient values inferred from the CL31, the vertical profiles and the determination of the MLH.

ASSOCIATION BETWEEN MLH AND POLLUTANTS

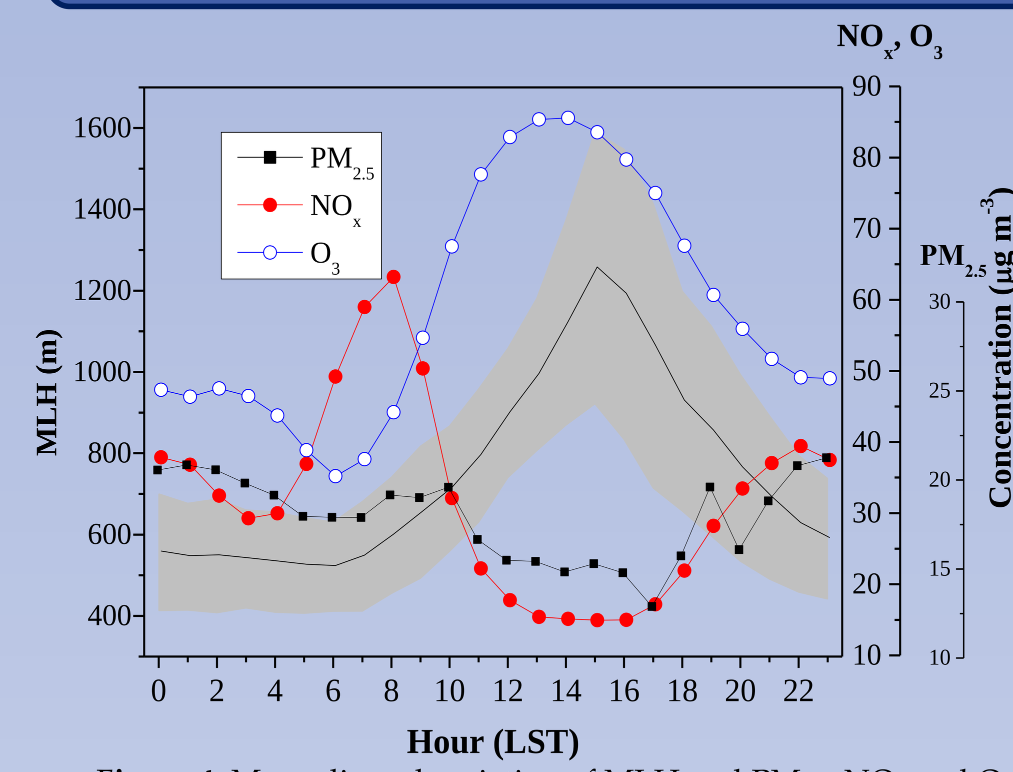


Figure 4: Mean diurnal variation of MLH and $PM_{2.5}$, NO_x and O_3 in Athens. The time is in LST (UTC+2).

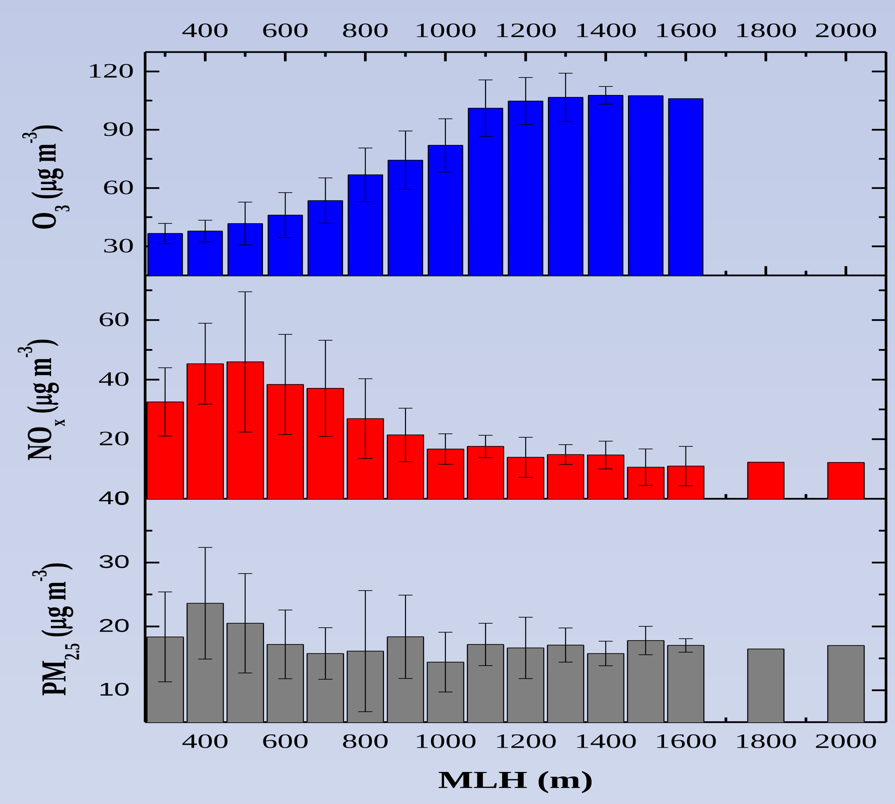
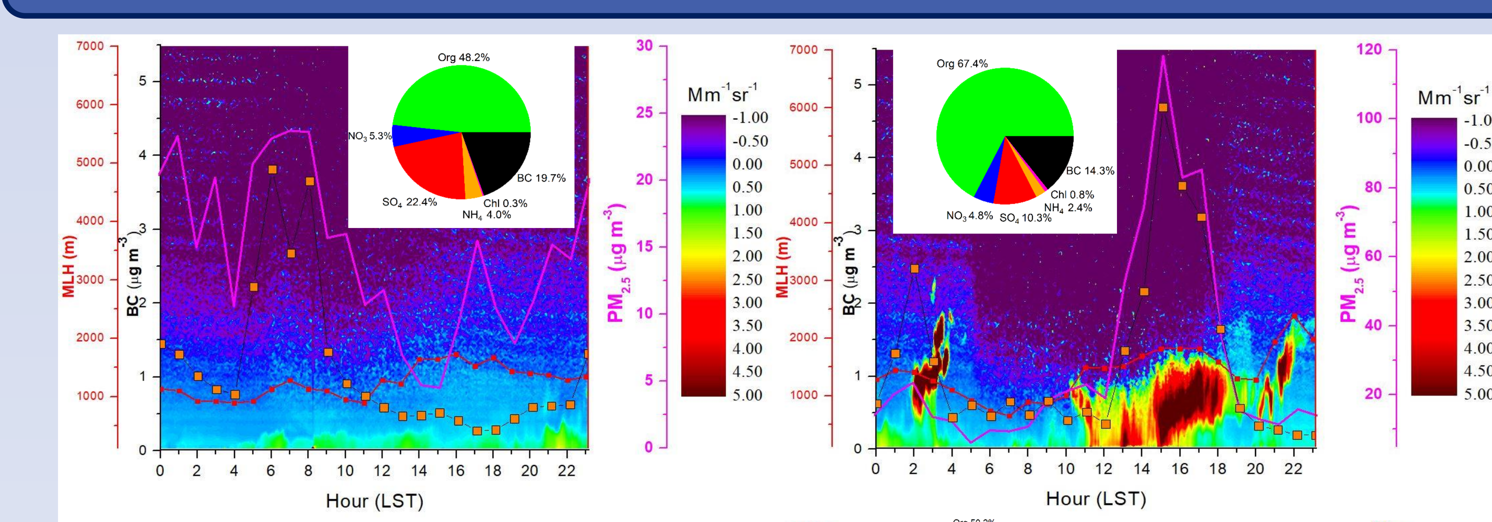


Figure 5: Illustration of impact of MLH on $PM_{2.5}$, NO_x and O_3 .

Air quality is determined by the concentration of standard pollutants like $PM_{2.5}$, NO_x and O_3. Their concentration depends not only on rates of emission and deposition but also on the MLH. MLH starts increasing from 07:00 LST, reaches a peak between 14:00 LST and 16:00 LST (Fig. 4), then reduces till 20:00 LST and almost remains constant till sunrise in all the months of the year. $PM_{2.5}$ shows increase from 07:00 to 10:00 LST, then reduces with a minimum around 17:00 LST. NO_x diurnal variation is similar to that of $PM_{2.5}$ with higher concentration in early morning (traffic effect). O_3 being dependent on solar radiation for its production from its precursors, follows diurnal variation similar to that of radiation. And increases with increase in MLH, while the other two pollutants exhibit a reverse pattern and a decrease with enhancement of the MLH (Fig. 5).

IMPACT OF FOREST FIRES IN ATTICA



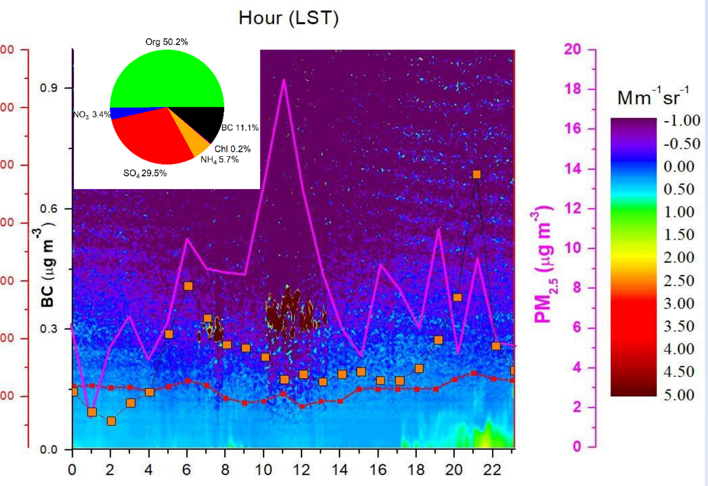


Figure 6: Backscatter coefficient values from CL31 measurements in Athens during 19-21 May 2021, under the influence of transported forest-fire smoke plumes. The MLH estimates, the BC and the $PM_{2.5}$ concentrations are indicated by red, black and purple lines, respectively. The percentage contribution of non-refractory submicron (PM_1) aerosol species measured with the ACSM on the 3 days, are also given. The organic fraction increased dramatically from about 50% to 67% on the fire day.

The diurnal variation of MLH coincides well with the distribution of pollutants in the boundary layer. This was clearly observed on 20 May 2021, when Athens was downwind of an intense wildfire smoke plume that increased $PM_{2.5}$ and BC concentrations (Fig. 6), whose peaks in all days were consisted with the backscatter coefficient values taken from the ceilometer. The results provide essential knowledge about the variation of the MLH in the urban environment that helps in understanding the profiles and effects of emission sources, like for example the accumulation of urban aerosols from traffic or residential biomass burning, as well as the influence of the transported pollution plumes.

CONCLUSIONS

✓The mixing layer height (MLH) is a measure for the vertical turbulent exchange with in the boundary layer, and one of the controlling factors for the dilution of pollutants emitted near the ground. Based on continuous MLH measurements with a Vaisala CL3 1 ceilometer and measurements from an air quality network, we analyzed the seasonal and diurnal variations of MLH and pollutants in Athens urban environment for a period of one year.

✓MLH maximized in summer and was shallower in winter, while BC and NOx concentrations follow a reverse trend, as also shown in diurnal basis. O3 follows the pattern of MLH, as secondary and photochemically-driven pollutant.

Acknowledgments

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References

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