environmental sciences proceedings

Proceeding Paper

# Temporal Variations in Mixing Layer Height in a Rural Environment under Clear Sky Conditions Using a Campbell Ceilometer CS135: Preliminary Results †

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† Presented at the 5th International Electronic Conference on Remote Sensing, 7–21 November 2023; Available online: https://ecrs2023.sciforum.net/.

**Abstract:** The scope of this study is to analyze the variations in the mixing layer height (MLH) under different cloud conditions on a daily and monthly basis. For this scope, the data of the first five months from the Campbell ceilometer CS135 were analyzed. The instrument is operating in a rural place on Euboea Island (Greece), and the study presents preliminary results about the atmospheric profile of this area, which is also related to the air transport of the largest airport in Greece (Athen's airport).

**Keywords:** mixing layer height; ceilometer; planetary boundary layer; Euboea Island; diurnal variation; sky conditions

**Citation:** Papavasileiou, N.; Kolios, S. Temporal Variations in Mixing Layer Height in a Rural Environment under Clear Sky Conditions Using a Campbell Ceilometer CS135: Preliminary Results. *Environ. Sci. Proc.* **2024**, *29*, 6. https://doi.org/10.3390/ECRS2023-15837

Academic Editor: Riccardo Buccolieri

Published: 15 November 2023



## 1. Introduction

The atmospheric mixing layer (AML) is the turbulent layer of the atmosphere adjacent to the earth's surface and determines the vertical mixing of air via thermal and/or mechanical turbulence [1,2]. The AML responds to variations in evapotranspiration and sensible heat fluxes within the timescales of an hour or less. In the context of the planetary boundary layer (PBL), the mixing layer height (MLH) represents a salient parameter because it has a considerable impact on the processes involved in the transportation and dispersion of pollutants from various sources. [3,4]. The development of the AML in a day is governed by a variety of parameters, such as cloud cover, water vapor content, the concentration of air pollutants, strength of synoptic wind patterns, soil moisture, nighttime cloud cover, and stratification in the free troposphere [5]. During the daytime, the AML top represents the entrainment zone; hence, an understanding of the diurnal and seasonal variations in the atmospheric mixing layer height (MLH) is essential for discerning the mechanisms controlling the air quality, chemical processes, and numerical modeling of the lower atmosphere [6,7].

Automatic lidar ceilometers (ALC) with their compact design, and a high range of resolution (∼10 m), making them advantageous to many of the alternative systems for the MLH estimation. AML height estimation from ceilometers can reveal intricate features about the vertical structure of the atmosphere [8–10].

## 2. Data and Methods

For the scope of this study, the first datasets of the Campbell Ceilometer C135, which is continuously operating in the National Kapodistrian University of Athens (Greece), the Department of Aerospace Science and Technology in the facilities of Euboea Island, were used. The ceilometer in this study (Figure 1) used the method of Haij et al., 2007, to estimate the MLH [11,12]. At this point, it is noteworthy to point out that the area around the location of the ceilometer is rural with a significant agricultural sector and a small town with a population of 8000. Also, the location has a straight-line distance of 75 km from the international airport of Athens, which is the largest airport in Greece. This means that the information derived from the ceilometer can be very useful for understanding air transportation safety in the greater area.

(**a**) (**b**)

**Figure 1.** (**a**) Campbell Ceilometer C135, which is operating in the National Kapodistrian University of Athens (Greece), Department of Aerospace Science and Technology in the facilities of Euboea Island. (**b**) The greater area around the ceilometer (red dot).

All the measurements from the instrument (Figure 1a) for the period from 1 June 2023 to 31 August 2023 were collected. During this period, a large number of valid measurements were examined. The initial dataset was filtered to keep only the clear sky measurements from days that were considered to have clear sky conditions. More specifically, as clear sky measurements were considered, in each instantaneous measurement in which there was a “cloud base”, as it was recorded by the instrument, a null value was produced. At this point, it must be stated that the ceilometer provides three different estimations of the MLH for each measurement, labeled according to their accuracy [12]. Considering this information, a second filter was applied based on the difference between the MLH values, retaining only those measurements with a difference of less than 500 m.

In order to identify the mean daily variation in MLH, the final datasets were split by month (June, July, and August), and the mean hourly MLH was calculated (Figure 2). Using the provided estimations of the MLH from the ceilometer, the weighted hourly mean MLH was calculated.

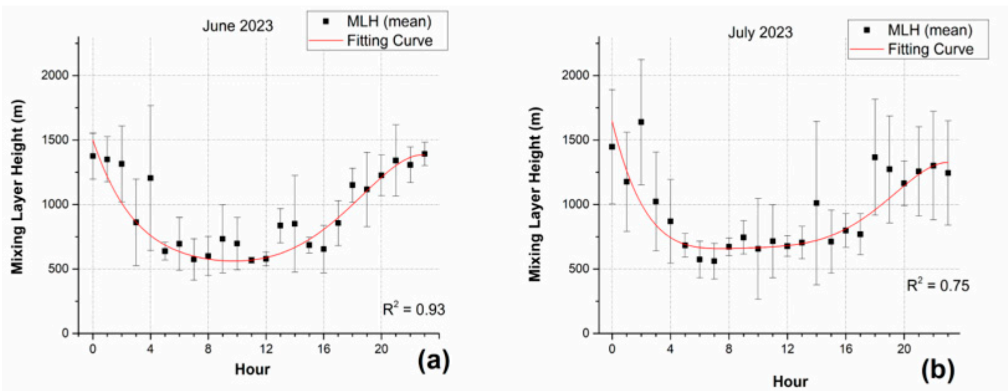


**Figure 2.** *Cont.*

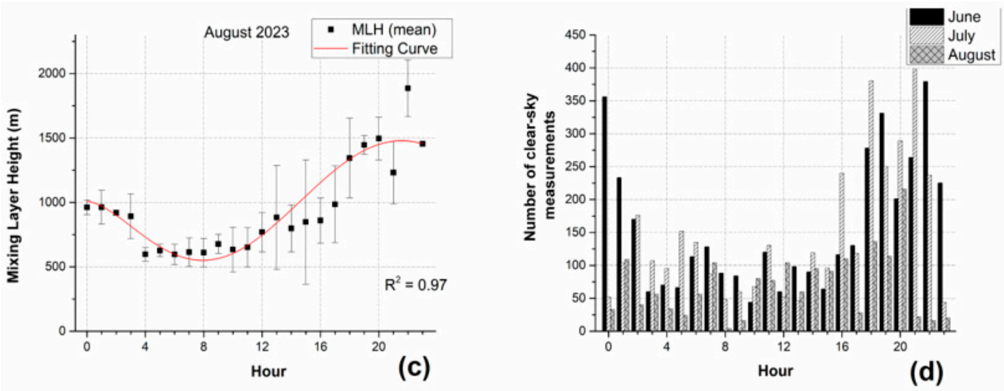


**Figure 2.** Mean daily variation in MLH during (**a**) June, (**b**) July and (**c**) August. (**d**) The total number of valid measurements is also depicted.

## 3. Results and Discussion

The results of the mean daily variation in MLH during the summer months (June, July, and August) can be seen in Figure 2. This Figure depicts the fact that the lowest daily MLH values are recorded from 05:00 to 09:00, which was expected since the land stopped receiving heat from incoming solar radiation many hours before 05:00 (the previous night) and had not yet started heating from solar radiation of the current day (daily heat). The MLH started to rapidly increase after 12:00, with the whole summer period reaching a plateau of 1250–1500 m a little after dusk (around 20:00–22:00) when the impact of solar radiation stopped again due to the Earth's daily heating cycle. The use of a third-order polynomial function to fit the mean hourly MLH values provided a high correlation coefficient (adjusted $R^2$) above 0.75. This type of function can efficiently represent the general shape of MLH variation. The maximum range of values of the MLH in all the examined months indicated a well-mixed atmosphere with significant heating of the land's surface. The role of wind shear is also important, highlighting the need for such a dataset to enrich this finding. An interesting result of Figure 2 is that the mean MLH remains at high values (above 100 m) in a significant part of the night (00:00–04:00), especially during June and July. This result indicates low surface cooling rates after the transition from day to night. This can be explained not only by the vertical stratification of the atmospheric boundary layer (ABL) itself but also by the differentiation of the land cover due to its cultivation in the surrounding areas [13]. Nevertheless, this result needs more data (Figure 2d) and a parallel study of land use/the land cover classification of the study area during the summer period to be evaluated.

Regarding the number of data used (Figure 2d) to calculate the mean hourly MLH (Figure 2a–c) during the summer months, it can be considered quite satisfactory from a statistical point of view to provide preliminary results, but a larger number of data must be used in a future study to record more efficiently the trends and the variations depicted in Figure 2a–c. Also, alternative filters (and thresholds) to characterize clear-sky (and/or cloudy) conditions must be examined in a future study to conclude robust criteria that can represent different atmospheric conditions. Finally, the larger values of the standard deviation of the mean MLH are concentrated mainly (but not exclusively) during the day, which is consistent with the usual turbulence in the ABL afternoon, which, in turn, causes a large variation in the MLH. Finally, the role of land–sea breezes must also be examined in the affection of the MLH daily variation because five kilometers west of the ceilometer's location is extended to the Gulf Euboea (Figure 1b).

## 4. Conclusions

The central scope of this study is to examine the daily variations in the mixing layer height during the summer period in a rural environment (Euboea, Greece) during clear-sky conditions with the use of a ceilometer (Campbell ceilometer CS135). Among the main results of this study are the maximum height, which is located during the late afternoon, as well as the high values of the MLH during the night (00:00–04:00). This may be caused by the low cooling rate of the land's surface and the lowest part of the troposphere after dusk. The daily profile for August differs from June and July, which may be caused by the land use/land cover profile due to the cultivation activities in the agricultural sector.

Moreover, the lowest MLH values are located in the transition period between day and night (05:00 to 09:00), with the August profile having significantly lower MLH values than the other two summer months.

The preliminary results of this study will be enriched in the near future with more data coming from the ceilometer, which is intended to be correlated with wind measurements and land cover data to examine in-depth the MLH variation in the study area.

**Author Contributions:** Conceptualization, S.K.; methodology, S.K.; software, S.K. and N.P.; validation, S.K. and N.P.; formal analysis, S.K. and N.P.; investigation, S.K..; resources, N.P.; data curation, S.K. and N.P.; writing—original draft preparation, S.K.; writing—review and editing, S.K. and N.P.; visualization, N.P.; supervision, S.K.; project administration, S.K. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to research restrictions and relative terms and conditions.

**Acknowledgments:** The authors acknowledge the National Kapodistrian University of Athens (Greece), Department of Aerospace Science and Technology, which supported the supply and the operation of two ceilometers (the second one will be operational by the end of the year 2023) to implement such valuable measurements.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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