A study of the ABL thermal structure over Messogia Plain using one year sodar facsimile record

J.A. Kalogiros, C.G. Helmis, P.G. Papageorgas, D.N. Asimakopoulos

Laboratory of Meteorology, Department of Applied Physics, University of Athens, 33 Ippokratous Street, GR-10680 Athens, Greece

Abstract

The thermal structure of the atmospheric boundary layer (ABL) is an important factor for the vertical diffusion of air pollutants. The sodar has proved to be a reliable tool for the continuous monitoring of the thermal structure of the atmospheric boundary layer sensing the temperature structure parameter. A recently developed algorithm based on image processing and pattern recognition techniques is used to automatically classify the atmospheric thermal structure (and to analyse various characteristics) leading to significant time saving and improvement of the classification. A one year long sodar facsimile record obtained with an 800 m range monostatic sodar that was operating at a rural area of the eastern part of Attika peninsula (Spata), where the new Athens international airport will be built, is statistically analysed using the above algorithm. The statistical analysis of the facsimile data includes information on the frequency of occurrence, the depth of surface layers, and the height and thickness of elevated layers.

1 Introduction

Sodars provide useful information for air pollution monitoring, and mesoscale or micrometeorological studies. Due to the large quantity of facsimile data acquired by sodar for climatological studies, the manual processing is limited to the general features of the facsimile record [2,4,7]. Thus, automated and accurate analysis of the sodar facsimile records is needed [1].

An algorithm based on image processing and pattern recognition techniques that identifies the boundaries of the echo layers described in Kalogiros et al. [3] is used to analyse the one year time period data set (June 1994–May 1995) collected with a conventional, vertically oriented, monostatic 1.6 kHz sodar. The range of the instrument is about 800 m and
was set to operate at the area of the Messogia Plain (Spata), Greece. This area is characterised by a flat terrain with the Hymettos mountain (1000 m high) at about 6 km to the west and the shoreline of Evoikos Gulf at 6 km to the east (a detailed map of the area can be found in the paper “Air mass exchange between the Athens Basin and the Messogia Plain” by Helmis et al. of the same conference). The backscattered echo intensity was recorded and stored, after performing an average of two acoustic shots, as two-tone images using an adaptive noise level estimation [5]. The time length of each facsimile window was 87 min in order to contain a sufficient number of shots for a reliable representation of the atmospheric thermal structure and on the other hand to avoid significant changes of the state of the atmosphere within the data window.

2 Statistical Information of the Facsimile Record

The statistical information presented in this work includes characteristics of the thermal structure of the lower atmosphere that determine its ability to diffuse air pollutants, described as: no echo type (adiabatic conditions or low mechanical turbulence), thermal plumes (convective conditions) or stable surface layer with or without one or more elevated layers (height temperature inversions combined with wind shear), and the height evolution of the different type of echo layers, as well as the thickness of the elevated echo layers through the day during different seasons.

Figure 1 shows the frequency of occurrence of thermal plumes with and without elevated layers (usually only one elevated layer since the cases of multiple elevated layers are limited). The thermal plumes activity is an indication of intense vertical mixing limited by the possible existence of a height inversion. The relatively high frequency of occurrence of thermal plumes with elevated layer (more than 20%) in the afternoons during the warm months (especially during autumn and spring) is due to the sea breeze of Evoikos Gulf arriving at the experimental site usually after

![Figure 1](https://example.com/figure1.png)

Figure 1: The frequency of occurrence of plumes like activity (a) without and (b) with elevated layers during the day for all seasons.
1100 LST. Figure 2 is an example of the destruction of thermal activity with the arrival of the cool and weakly stable sea breeze layer. During autumn and spring the sea breeze is weaker and the thermal plumes activity is maintained while an elevated layer (shown in Figure 2) marks the upper limit of the sea breeze flow. Thus, thermal plumes are combined more frequently with elevated layer during autumn and spring than summer after noon as can be seen in Figure 1. The pattern of plumes activity with elevated layers gives high values (more than 20% during summer) just after the sunrise for all seasons and signifies the usual destruction of the nocturnal surface inversion by the thermal activity. The afternoon local maximum of the frequency of occurrence of plumes activity with elevated layer during winter is possibly due to the incomplete destruction of the height inversion by the thermal activity.

![Figure 2: A facsimile record showing the thermal structure of the sea-breeze flow and the destruction of plumes activity.](image)

Figures 3a, 3b, and 3c shows the frequency of occurrence of stable surface layer (including the sea breeze cases) with or without one or multiple (more than two) elevated layers, respectively. The sea breeze cases correspond to a weakly stable layer above approximately 70 m with significant wind shear (a gravity current as described by Simpson et al. [6]), that has been modified from below due to the 6 km travel over land. The surface layer is an indication of stable lapse rate combined with wind shear (such as in the case of the sea breeze jet) and corresponds to low ability of vertical diffusion, while the multiple elevated echo layers is an indication of the interaction of local scale atmospheric flows leading to vertical wind shear layers under stable conditions. It was found that the stable surface layer presented more frequently abrupt (in less than 10 min) changes of its depth (spikes) and thus it grows up due to mechanical turbulence (significant wind) than long wave radiation of the surface during night [7]. The significant frequency of occurrence of surface layer during the summer and autumn afternoons is due
to the sea breeze circulation. The cases of surface layer with multiple elevated layers are more frequent (up to 35%) during autumn nights because the calm wind conditions during this season favour the development of local atmospheric flows (even though the frequency of occurrence of that type of thermal structure is generally limited due to the flat topography). The destruction of multiple layers just before sunrise during spring and winter (probably because of an increase of wind speed aloft) results in a local maximum of the frequency of occurrence of surface layer with one elevated layer (Figures 3b and 3c).

Figure 3: The frequency of occurrence of surface layer (a) without (b) with elevated layer (c) with multiple elevated layers and (d) its average depth during the day for all seasons.

The daily evolution of the average depth of surface layer is shown in Figure 3d, where the most important feature is the large nocturnal depth
reaching 350 m the first morning hours during all seasons except winter. Figure 4 shows a characteristic example of nocturnal surface layer reaching 600 m and originating from significant wind shear up to that height. The mechanical origin of this layer implies significant turbulence and vertical diffusion capability depending on the intensity of the surface inversion. During summer the stable surface layer (sea breeze) is deeper (250 m) on the average than autumn (less than 200 m) implying less intense sea breeze circulation during autumn. The deep (250 m) stable surface layer during spring days is connected with the transitional character of the season (disturbed weather).

Figures 5a and 5c show the distribution of the average depth and spikes' height of surface layer with or without elevated layers around the time (0000-0500 LST) when the maximum average depth of surface

![Figure 4: A facsimile record showing a deep nocturnal surface layer with significant height variation.](image)

![Figure 5: The distribution of (a) the average depth and (b) the average height of spikes of surface layer during 0000-0500 LST for all seasons.](image)
layer occurs according to Figure 3d. The cases with average depth more than 300 and 400 m reach 45% and 22%, respectively, during autumn and something less during summer and spring, with a peak at about 250 m (the depth of the surface layer during winter is low as already mentioned). But, the average height of spike shows a significant trend towards values higher than 400 m (57% of the cases) implying that the surface layer has quite tall (more than 100 m changes of the surface layer depth) spikes at its top. This is due to the significant wind shear and the resulting mechanical mixing as already discussed.

Elevated layers without thermal plumes or stable surface layer underneath were very rare, since during the afternoon, which is mainly the possible time of occurrence of this type of thermal structure, the boundary layer was well mixed up to the range of the sodar (800 m) from the thermal plumes activity during day resulting in no echo type (adiabatic conditions with frequency of occurrence up to 25% during winter and less frequently during the other seasons) and the nocturnal surface layer began to develop in a short time.

Figure 6: The average (a) top height and (b), (c) thickness of elevated layers during the day for all seasons.
Figures 6a, 6b and 6c show the time evolution of the average (including average over all the layers present in the facsimile window of 87 min with their extent in time as a weight) height and thickness of the elevated layers with plumes activity or a stable surface layer. The average height of elevated layers in Figure 6a is 100-150 m above the surface layer with local minima before sunrise and after sunset except winter. After sunrise the elevated layers rise significantly as a result of the erosion from below of the nocturnal surface layer from the thermal plumes activity. The afternoon height maximum (450 m) of elevated inversions (except winter) results from the late arrival of the sea breeze giving rise to an elevated layer that limits the flow. The thickness of elevated layers in Figures 6b and 6c show a trend for decrease after 0000 LST until sunrise for all seasons, but there are significant local maxima during the day because of the wind shear increase at the height of the elevated layer either during the morning destruction of the nocturnal surface layer or the arrival of sea breeze during summer, autumn, and spring afternoons. We must also note that the cases of nocturnal multiple elevated layers occurred frequently with wavy motions superimposed on them. These waves were mainly stable internal waves with low diffusion ability, having an average amplitude of 30 m and a period of 800-1100 sec. Waves were also observed on the elevated layer resulting from the sea breeze flow during the afternoons in the warm months.

3 Conclusions

The statistical analysis of the one year facsimile record at the area of the international airport of Spata, Greece, revealed interesting results for the thermal structure of the lower atmosphere. The sea breeze of the Evoikos Gulf restricts (up to 30%) the thermal plumes activity (and thus the vertical diffusion) during the warm months. During autumn and spring the less intense sea breeze flow (also inferred from its depth in Figure 3d) results in thermal plumes activity with elevated layer at 450 m on the average. The stable surface layer during the night increases basically due to mechanical turbulence (and less due to long wave radiation of the surface) even up to 600 m during the first morning hours and falls off relatively fast before sunrise for all seasons except winter. The elevated layers are combined almost always with thermal plumes or a stable surface layer and the multiple elevated layers cases resulting from the interaction of local flows are more frequent during autumn (calm wind conditions) and they are combined with stable internal waves of small amplitude on the average.

Acknowledgements

The authors wish to thank the “Athens Airport S.A.” for financial support.

References


