ON THE TURBULENCE PROCESSES OF THE LOWER PART OF THE ATMOSPHERIC BOUNDARY LAYER

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ABSTRACT

The impact of meteorology on the air quality is a subject of study for several works in the last years. Also the Atmospheric Boundary Layer (ABL) meteorological turbulence factors are of major importance and have a substantial influence on the dispersion of air pollutants. The objective of this work is to give information regarding the turbulence processes of the lower part of the ABL by studying the turbulent fluxes at two heights within the surface ABL.

An experimental campaign has been conducted in the framework of the European project ECATS, at the Athens International Airport (AIA), at Messogia Plain of Attika, Greece, from 13th to 25th of September 2007, with the use of remote sensing and in situ instrumentation. More specifically, among other instrumentation, a 10 m high meteorological mast was installed, equipped with high frequency (20 Hz) sampling sonic anemometers (Gill R3-50 at 4 m height and Campbell Scientific CSAT-3 at 10 m height) for three-dimensional wind components (u, v and w) and virtual temperature (T) measurements, as well as fast hygrometers (Campbell Scientific KH-20 at 4 m and Campbell Scientific Licor 7500 at 10 m height) for water vapour (q) measurements. These high frequency measurements yield estimates of the vertical transport of the momentum ($u'w'$ and $v'w'$), the heat ($w'T'$) and the humidity ($w'q'$) fluxes through the eddy correlation method, for 10-min time intervals. In order to quantify the background air flow, additional information related to the synoptic conditions as well as radiosonde data from a nearby station was also used.

The experimental period includes different cases, such as days with the development of local flows or days with strong background flow which are given and discussed. According to the analysis, the turbulence processes over the greater Messogia Plain is related mainly to the diurnal pattern of the intensity and the direction of the background flow as well as to the surface heat flux. Under low background flow, the development of local flows (sea and land breeze cells) over the greater area preserves high heat flux values and increased vapor flux due to the inland penetration of the maritime air mass, while under strong background flow, high momentum flux values were revealed and the stability parameter indicates conditions close to neutral, due to the strong advection and the subsequent mixing of the lower atmosphere.

Keywords: Atmospheric Boundary Layer, ECATS, momentum heat and humidity fluxes, turbulence processes

1. Introduction

The knowledge of atmospheric turbulent parameters is of great interest for different applications, mainly related with air quality studies. In the past decades, the study of the turbulent fluxes has been attracted increased attention for different terrain types, such as forests (Bergstrom and Hogstrom, 1989), bare soil (Maitani and Ohtaki, 1987), low vegetation (Hogstrom and Bergstrom, 1996) as well as over sea surface (Katsouvas *et al*., 2007). The atmospheric surface momentum and heat fluxes have been estimated using different methods based on in-situ or remote sensing instrumentation measurements (e.g. high resolution sodar which can provide continuous and reliable measurements of the ABL vertical turbulent structure, Helmis *et al*. 1994). The purpose of this work is to give information related with the variation and the evolution of the main turbulent parameters of the surface ABL of the Messogia Plain of Attika, Greece, since this area has an increased interest due to the operation of the new Athens International Airport (AIA) and the rapid development of the surrounding area.

2. Experimental area and instrumentation

The Messogia Plain (Figure 1, right) is a significant part of the Greater Athens Area (GAA) (Figure 1, left) and it is physically defined by the elongated mountain Hymettus and mountain Penteli. The Messogia Plain is mainly affected by the two different sea/land breeze circulation cells: the Evoikos Gulf Sea Breeze which is characterized by an eastern direction during the day and a western one during the night while the Saronikos sea breeze blows from SSW during the daytime hours reversing to northerly winds during the night. At Messogia Plain the Athens International Airport (AIA) is located (Figure 1, right). At the north-eastern part of the airport area, at a distance of 4 km from the shoreline, a 10 m mast equipped with sonic anemometers and fast hydrometers at 2 levels (4 m and 10 m) was installed. More specifically the mast was equipped with high frequency (20 Hz) sampling sonic anemometers (Gill R3-50 at 4 m and Campbell Scientific CSAT-3 at 10 m height) for three-dimensional wind components (u, v and w) and virtual temperature (T) measurements, as well as fast hygrometers (Campbell Scientific KH-20 at 4 m and Campbell Scientific Licor 7500 at 10 m height) for water vapour (q) measurements. These high frequency measurements yield estimates of the vertical transport of the momentum (u'w' and v'w'), the heat (w'T') and the humidity (w'q') fluxes through the eddy correlation method, for 10-min time intervals. In order to quantify the background air flow, additional information related to the synoptic conditions as well as radiosonde data from a nearby station was also used.

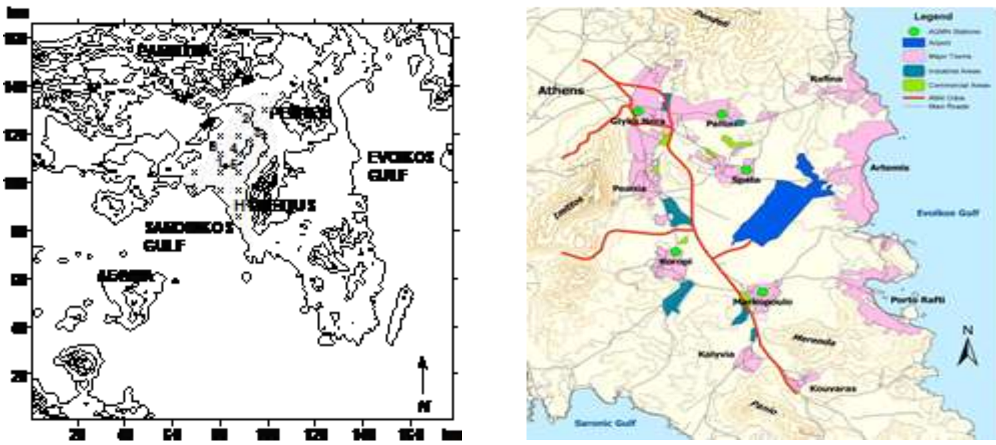

Figure 1: The Greater Athens Area (GAA) (left) and the Messogia Plain (right), with the location of the Athens International Airport.

3. Results

3.1. Synoptic conditions and development of local flows

The experimental period was characterized mainly by a high pressure field at central Europe combined with low pressures at the south-eastern Mediterranean. This interaction produced a persistent north-easterly flow over Greece, with weak to moderate wind speeds. Thus during the 13^{th} of September and for the next four days the moderate north-easterly flow dominated the experimental area while during the 19^{th} of September, the weakening of the horizontal pressure gradient allowed the development of pure local flow (sea – land breeze). At the 20^{th} of September, Messogia Plain was affected by the passage of a cold front, while during the last five days of the campaign, the high pressure field was shifted towards the Balkans and the combination with the low pressures at the south-eastern Mediterranean provided an intense north-easterly wind field with wind speeds exceeding 14 m/sec at 10 m level. Thus moderate background surface flow was observed at 13^{th} to 15^{th}, 16^{th}, 17^{th} and 25^{th} of September, with wind speeds in the range of 7-9 m/sec at 10 m height and NE directions, while strong surface flows were observed during 20th to 24th of September (wind speed in the range of 9-15 m/sec and N-NE directions). A combination of the synoptic field with the local flows was developed during 15th and 18th of September. During these days, a moderate wind field was established over the experimental area (in excess of 6 m/sec) characterized by E-NE directions during the late afternoon hours and higher diurnal variation of the wind vector caused by the interaction of the easterly sea breeze with the northerly background flow. During the strong synoptic flow (20th to 24th September), a decrease of the temperature maximum and the diurnal range was observed.

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3.2. Turbulent fluxes

Figure 2 presents the vertical momentum flux time series (u´w´ - along wind) calculated by the sonic anemometer's dataset at two heights. A clear diurnal pattern is evident with negative values (downward transfer of momentum) during the day and very low values close to zero during the night. This pattern is highly correlated with the wind speed values. High momentum flux values are calculated during the second part of the experimental period due to the strong surface flow that followed the frontal passage. During the sea breeze episodes (15th, 18th and 19th of September), the momentum flux is significantly decreased (in excess of 50% in comparison with days characterized by moderate to strong wind speed).

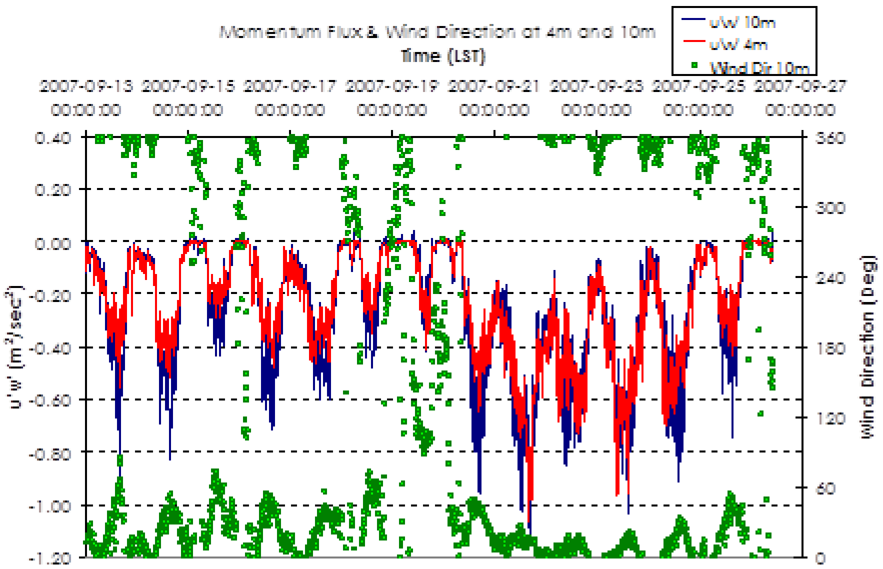

Figure 2: Momentum fluxes at 4 m and 10 m height and wind direction at 10 m height.

An interesting observation is the good correlation of the high night-time momentum flux values (especially for the 21st of September) at the surface layer with the high values of the mixing height estimated by a nearby operating SODAR system. The intense night-time momentum flux values observed at the surface layer reflects the strong mixing that takes place within the nocturnal ABL under strong winds. The time series of the vertical heat flux (w´T´) values are presented in Figure 3. A clear diurnal pattern is evident, with positive flux values during the day and negative ones during the night. During days characterized by cloudiness (e.g. at 16th and 21st of September), during the day-time hours, the heat flux values are slightly reduced. The water vapour flux (w´q´) values time series is presented in Figure 4. Increased values are calculated during the day ranging from negative to positive values, while during the night the vapour flux values are close to zero with decreased variation. Under sea breeze conditions (19th of September) the vapour flux values are significantly increased due to the inland penetration of the maritime air mass.

The stability parameter (z/L) which is not shown was characterized by a clear diurnal cycle. Positive values indicates stable conditions, negative values correspond to unstable ones while neutral conditions are within the range of -0.02 to +0.02. Higher stability values were calculated for the day with the sea breeze event while under moderate to strong surface flow and near sunrise and sunset, the z/L values indicated conditions close to neutral conditions. Especially during the second part of the experimental period and for the subsequent four days, neutral conditions were quite persistent since the increased mixing induced by the strong surface flow, prevented the development of surface based temperature inversions during the night and convective layers with upward motions during the day. The time series of the Turbulent Kinetic Energy values (not shown) follows the pattern of the momentum flux with a highly correlated variation with the wind speed values.

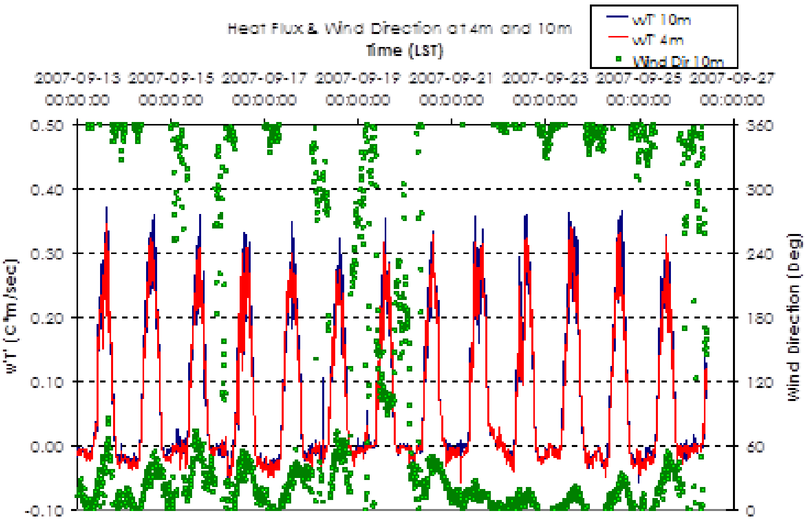

Figure 3: Heat fluxes at 4 m and 10 m height and wind direction at 10 m height.

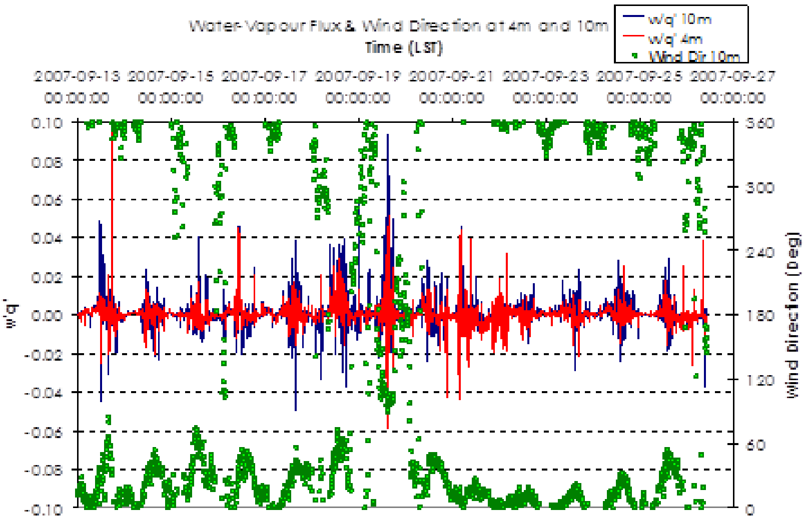

Figure 4: Water vapor fluxes at 4 m and 10 m height and wind direction at 10 m height.

4. Concluding remarks

An experimental campaign has been conducted in the framework of ECATS project, at the Athens International Airport, at Messogia Plain of Attika, Greece, in order to study the turbulent fluxes at two heights within the surface ABL. According to the analysis:

- The turbulence processes over Messogia Plain is related mainly to the diurnal pattern of the intensity and the direction of the background flow as well as to the surface heat flux.

- Under low background flow, the development of local flows (sea and land breeze cells) over the greater area preserves high heat flux values and increased vapour flux due to the inland penetration of the maritime air mass
- Under strong background flow, high momentum flux values were revealed and the stability parameter indicates conditions close to neutral, due to the strong advection and the subsequent mixing of the lower atmosphere

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