EXPERIMENTAL STUDY OF THE SURFACE MARINE ATMOSPHERIC BOUNDARY LAYER OVER AEGEAN SEA, GREECE

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EXTENDED ABSTRACT

Micrometeorological measurements within the surface Marine Atmospheric Boundary Layer (MABL) took place at the shoreline of island of Karpathos, at the South East end of the Aegean Sea (Karpathio Pelagos), during summer 2012. A meteorological mast was installed at a distance less than 30m from the shoreline, instrumented with a sonic anemometer and a fast krypton hygrometer at 14.5m height with a sampling frequency of 10Hz, in order to measure the turbulent transport of mass and energy of the surface MABL. At the same mast slow response sensors (1Hz) were also installed providing vertical profiles of wind speed and direction, temperature and humidity at three levels (3, 8 and 12 m). Satellite sea surface temperature images were also obtained. The spacial and temporal scales of the Aegean Pelagos have not been studied in the past while it is expected to present differences compared with those measured over oceans or open seas. It is worth to mention that this study is a follow-up of a previous study which took place during summer 2011 at Skyros island, northern Aegean provided similar measurements but with different fetch. During Karpathos campaign, more than of 120 hours stationary surface MABL observations of near neutral wind flows were recorded. The vertical profiles of temperature reveal the presence of a coastal internal boundary layer, mostly below 8m height. Eddy correlation analysis is used to study the turbulent fluxes of mass and energy. According to first results on the stable MABL, momentum fluxes depend on stability and give increasing values with the wind speed. The estimated values are higher, almost by a factor of two, compared to typical values measured over the ocean. These increased values could be attributed to a developed sea state since wind stress is greater over young and developing wave fields. Sensible heat flux is found to be increased with stability and rather independent from wind speed while moisture flux seems to not be dependent neither to stability or wind speed. Some part of the records present upward heat fluxes under near neutral conditions and mostly for positive sea-air temperature differences, possibly associated with sea spray or mesoscale heterogeneity of the sea surface temperature. Ongoing investigation of the turbulent exchanges is expected to provide a more thorough insight on the coupling processes between the surface MABL and Aegean sea.

Keywords: surface marine ABL, turbulent fluxes, Aegean

1. INTRODUCTION

Air-sea interaction is known to strongly influence the world's climate. The complex nature of the physical processes involved is still not fully understood although numerous studies addressed this problem over the past decades. Flux measurements of mass and energy within the surface Marine Atmospheric Boundary Layer (MABL) are of fundamental importance in order to understand the structure and the characteristics of the MABL and considered essential for weather and climate predictions since they provide modelers with parameterization schemes for surface turbulent fluxes of momentum, heat and water vapor. Up today, the vast majority of such measurements were conducted mostly over open seas and oceans. The semi-closed sea of Aegean Pelagos consisting of different spatial and temporal scales than the ocean (Sofianos et al. 2002) is thought to have a different impact on the exchanges at the air-sea interface.

Momentum transfer is accepted as an increasing function of the wind speed and the differences found between independent studies are a function of the sea state (Foreman et al. 2010). Short fetched flows wind stress is documented greater over young and developing wave fields compared to older wave fields, which are in more equilibrium with the wind. Heat and moisture exchanges on the other hand were treated up to recent without including the contribution of the sea spray which is found to significant augment the interfacial transfers (Andreas 2009), especially at high winds or of effects of mesoscale heterogeneity of the sea surface temperature (SST), mostly for weak wind cases (Mahrt et al. 2012). Evidence of such contributions, which was found in our data, is presented.

The purpose of this paper is to present the conducted experiment as well as results regarding the turbulent transfer over the Aegean Sea. This study is a follow-up of a previous study, which took place during summer 2011 at Skyros Island, at the northern Aegean sea, which gave similar measurements but with different fetch (Kostopoulos et al. 2012). It is worth to mention that there are no other published measurements over the Aegean.

2. EXPERIMENTAL SITE AND INSTRUMENTATION

Micrometeorological measurements of the surface MABL, took place at the shoreline of island of Karpathos, at the South East of the Aegean Sea (Karpathio Pelagos), during summer 2012. The experimental campaign lasted almost two weeks from the end of July to August, under mostly etesian flows. Karpathos Island is located at the southeastern Aegean approximately 150km from the islands of the center Aegean. Apart from the south end which is relatively flat and has mostly gentle slope shoreline (<100m), the island is characterized by intense orography with dense forests. Mountains extend to about 600m at the north side and over 1km height (1.220m) at the center of the island.

The experimental site as well as the placement height of the fast response sensors was carefully chosen so that the measurements would not be affected from the developed Internal Boundary Layer (IBL) over land. The selection of the mast location was based on the fact that the developed IBL, at a distance of 30 m from the shoreline, will be characterized with heights much less than 10 m (Savelyev et al. 2004). A meteorological mast (figure 1) was installed at the south part of the island, at a distance less than 30m from the shoreline, instrumented with a sonic anemometer and a fast krypton hygrometer at 14.5m height with a sampling frequency of 10Hz, in order to measure the turbulent transport of mass and energy of the surface MABL. At the same mast slow response sensors (1Hz) were also installed providing vertical profiles of wind speed and direction, temperature and relative humidity at three levels (3, 8 and 12 m). The calculation of the turbulent fluxes is conducted using eddy correlation analysis with averaging time of

10min. Wind speed at 10m is produced using similarity theory wind profile equations (Large et al.1980).

More than 120 hours of observations of near neutral and stable marine wind flows were recorded. Data was initially treated with quality control procedures (Lee et al. 2002) in order to find and exclude instrumentation errors. Less than 10^{-3} % of corrections over about 10^{-1} % of the total records were applied. Tilt corrections due to the deviation of the mast from true vertical where also made using the planar fit method (Wilczak et al. 2001). Records were furthermore examined for stationarity (Mahrt et al. 1996). Finally additional data of daily SST images from the satellite INMARSAT-C were collected.

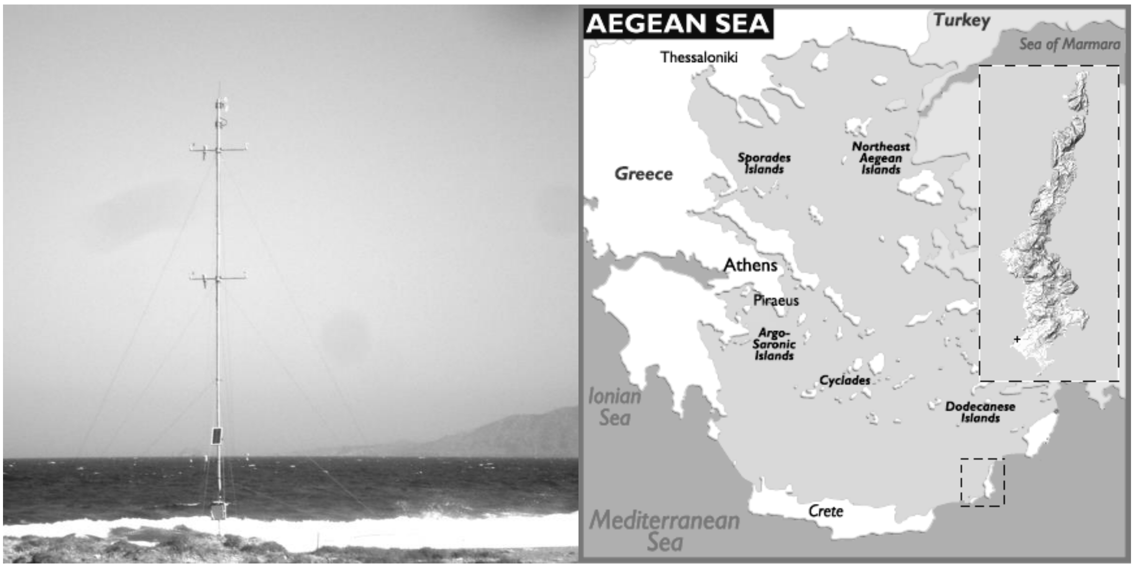

Figure 1. The meteorological mast (facing North) at the experimental site (left) located at the south-west end of Karpathos island (right).

3. MEASUREMENTS OF TURBULENT FLUXES OVER THE AEGEAN SEA

Moderate to strong etesian winds were recorded during the experimental period, ranging up to 11m/s while wind direction varied from west to mostly north-west (NW). Only few records with directions blowing within the golf (>345 degrees) were excluded. Temperature fluctuated from 25ºC to 30ºC and relative humidity from 60% to 85%. During the whole experimental period the sky was cloudless.

The sign of the temperature gradients with height as well as the stability parameter values recorded from the sonic anemometer at 14.5 m, revealed the presence of a coastal internal boundary layer, mostly below 8m height as expected (figure 2). According to this figure the temperature data at 12 m height are characterized by higher values than the ones at 8 m (due to the marine flow), while the stability parameter reveal a stable layer at 14.5 m which was expected for the same reason. Thus, flux measurements should be considered practically uninfected from the presence of the land and the developed IBL.

When taking into account the difference between SST and the potential temperature of the air, several of the recorded heat fluxes are found to strongly correlate with temperature differences. Upward heat fluxes are observed during near neutral conditions and small air-sea temperature differences, mostly positive (figure 3), fluxes that increase with the wind of speed (not shown in this paper) and are possibly related to sea spray conditions or effects of mesoscale heterogeneity of the sea surface temperature. It is worth mentioning that Skyros measurements also revealed several upward heat flux conditions corresponding as well to positive or very small negative air-sea temperature differences. Such conditions are generally excluded from analysis since relatively small errors in the air-sea temperature difference may strongly contaminate the estimated transfer coefficient. On the other hand under such conditions although sensible heat flux is found to be small (less than 10W/m^2), may cover a large fraction of the sea and contribute significantly to the greater area's heat budget thus affecting not only weather but perhaps the local climatology. Analysis results of these records are excluded from this paper and will be addressed in a future study. In this study, records (~200) for negative sea-air temperature differences (<-1°C) are only presented.

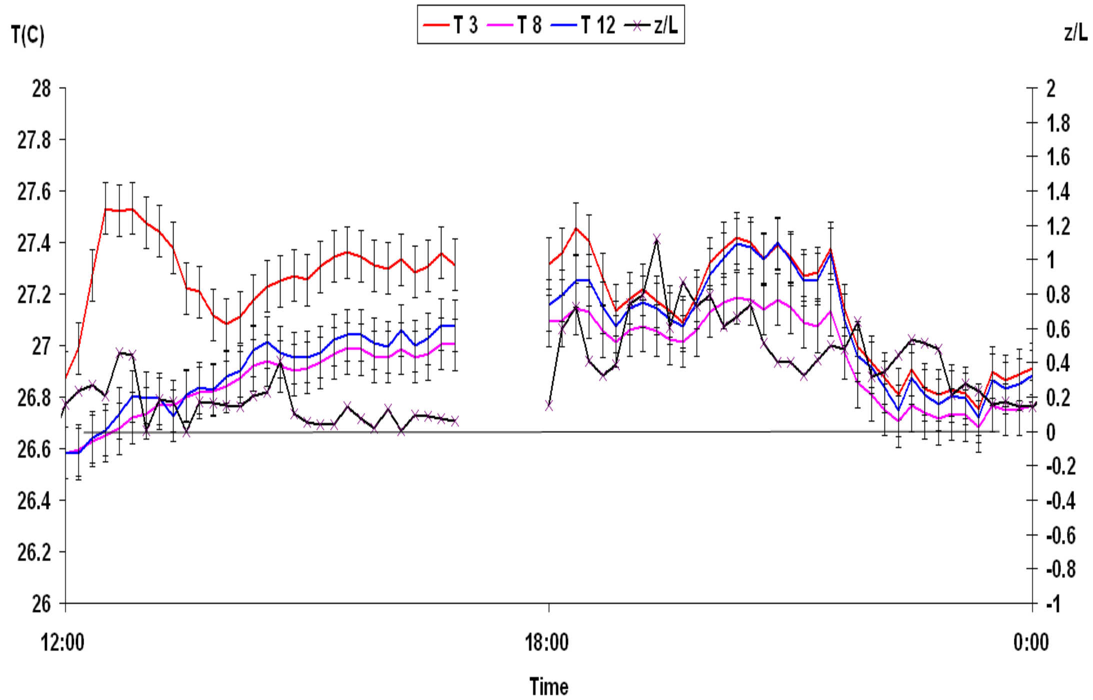

Figure 2. The vertical profile of temperature and the stability parameter (z/L).

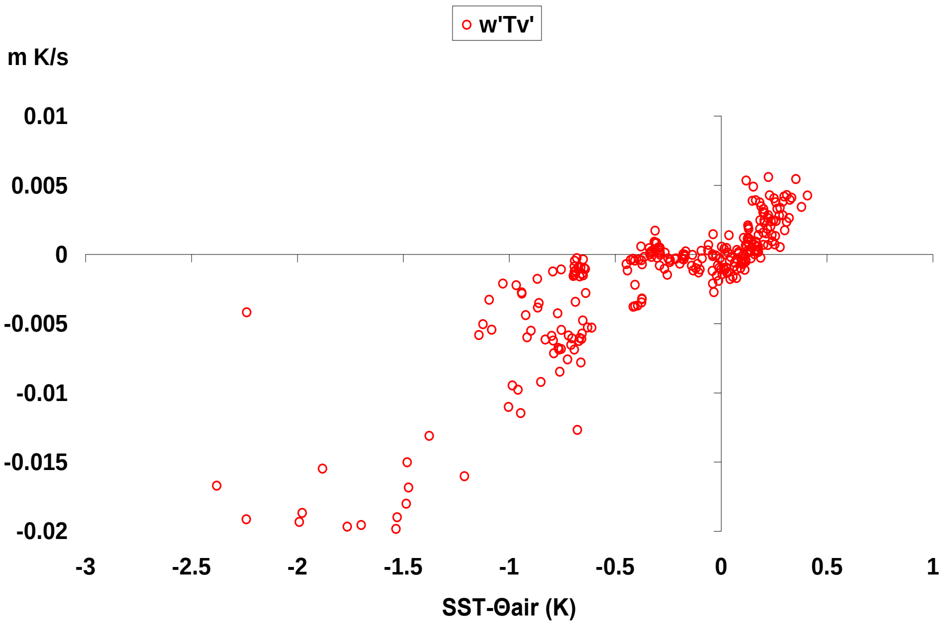

Figure 3. Sensible heat flux as a function of SST-θ(z).

Momentum flux decreases with stability probably reflecting the insufficient generation of turbulence needed to overcome the absorption of energy by buoyant forces and gives increasing values with the wind speed as seen in figure 4. The estimated values are higher, almost by a factor of two, compared to typical values measured over the ocean or even when compared with Skyros different fetch results (Kostopoulos et al. 2012). It is known that the fetch and the duration of an air flow over the sea plays crucial role to the development of the wave field on which momentum flux also depends on (Hasselmann et al.1973). In this case such values should be attributed to the special spatial and time scales found over Kapathio Pelagos.

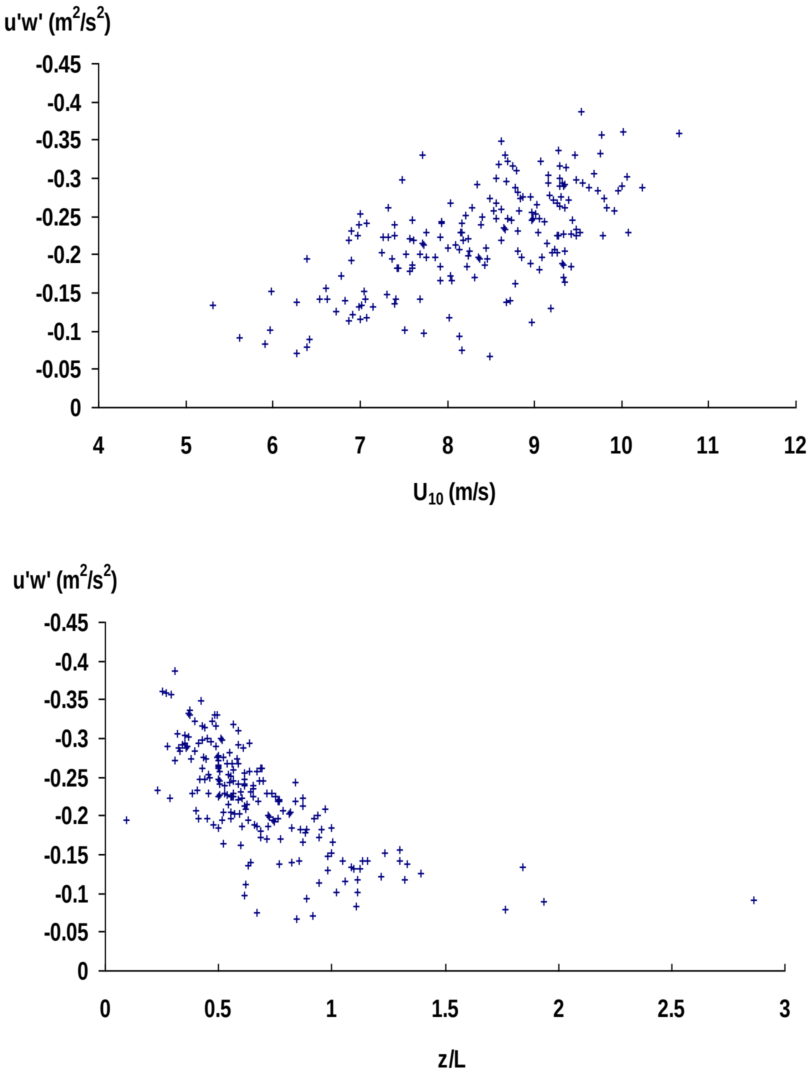

Figure 4. Momentum flux towards wind speed and stability.

Heat and moisture fluxes do not seem to follow the same consequence although appear enhanced compared to Skyros results corresponding to larger air-sea temperature differences. According to figure 5 sensible heat flux is found to be independent from the wind speed even though it increases with turbulence as expected (not shown). When plotted against negative air-sea temperature differences (figure 6), sensible heat flux is seen normally to increase with increasing difference. These values are close to the annual mean net heat flux which is estimated for the Aegean sea at 26 W/m^2 (Poulos et al., 1997) and which implies that the Aegean Sea is, on the average, losing heat through its surface.

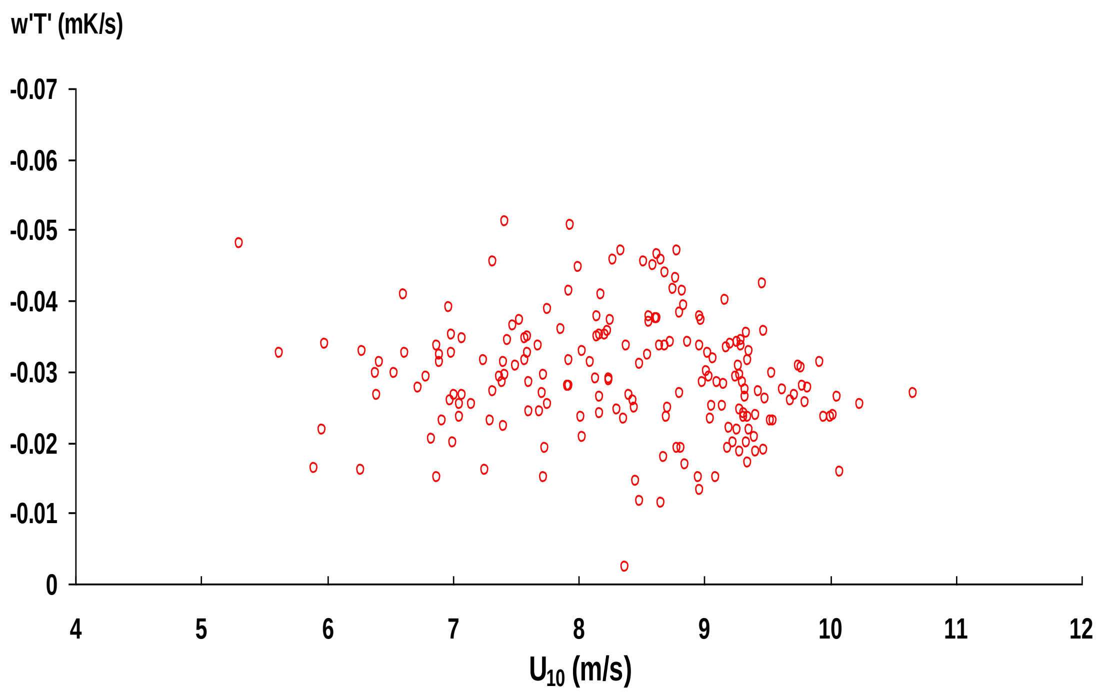

Figure 5. Sensible heat flux towards wind speed

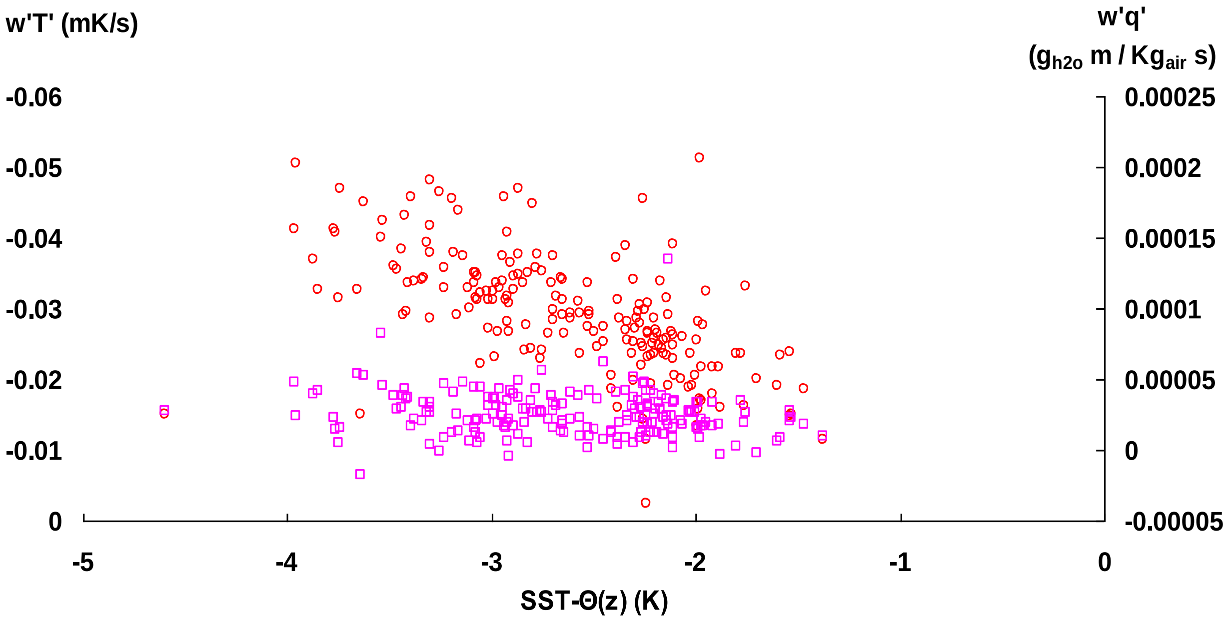

Figure 6. Sensible heat and specific humidity flux as a function of SST-θ(z)

Moisture fluxes (figure 7) appear with rather typical positive values ranging from 10^1 to $10^2 W/m^2$, independent from the wind speed, air-sea temperature difference or stability, except perhaps for increased stability conditions where it seems to slightly decrease possibly as a result of the reducing in turbulence.

Further analysis is in progress in order to investigate the physical processes and the influences of various meteorological and sea state factors to the turbulent transport of momentum and energy in the surface MABL of the Aegean.

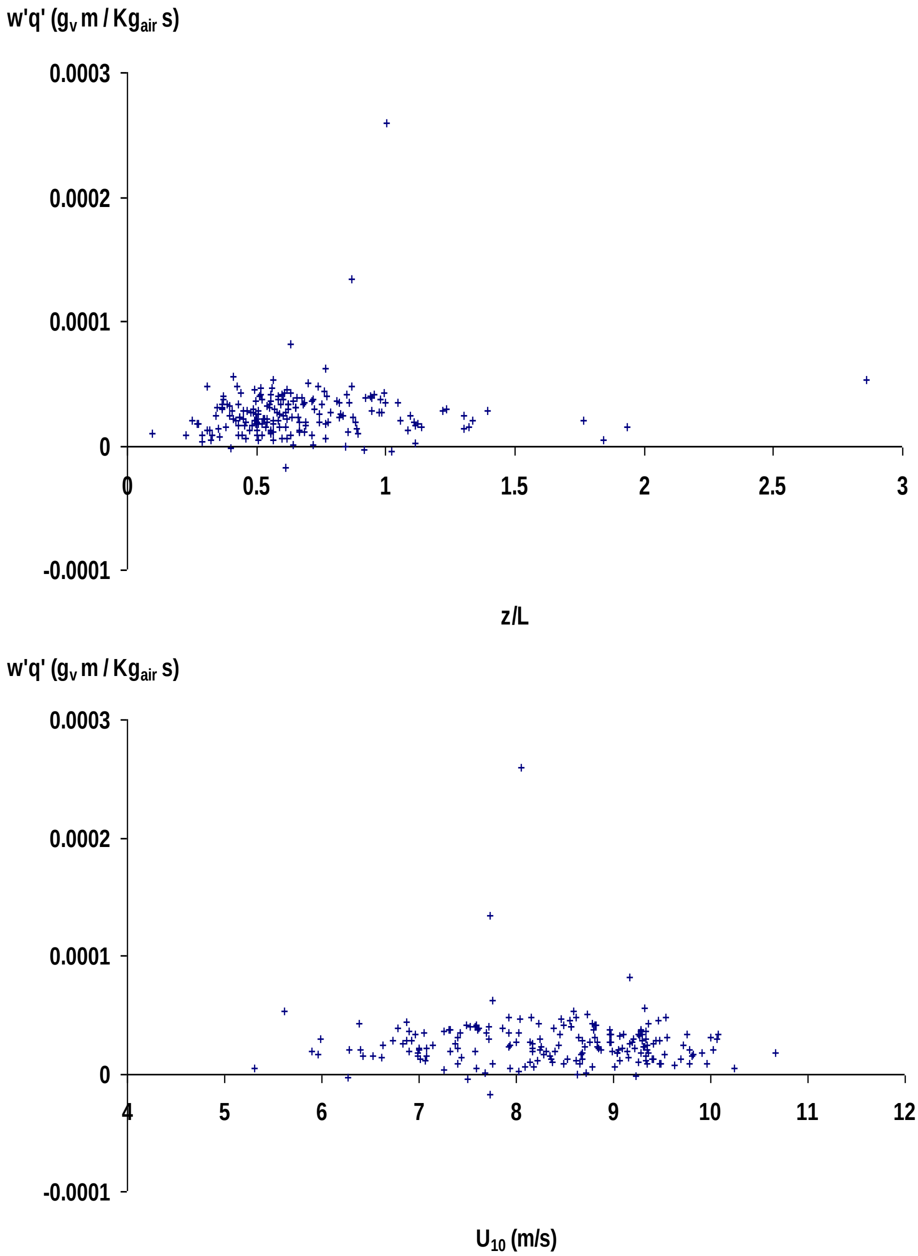

Figure 7. Specific humidity flux towards wind speed and stability

4. CONCLUSIONS

Onshore turbulent fluxes measurements of the surface MABL were conducted at the southern east Aegean sea during summer 2012. This study is a follow-up of a recent study which took place during summer 2011 at Skyros island in the northern Aegean. Upward heat fluxes were found on both campaigns measurements for near neutral conditions with positive sea-air temperature differences. Such processes which are possibly related to sea spray or mesoscale heterogeneity of the sea surface temperature are still not fully understood. Although these fluxes are measured and also documented small (mostly less than 10W/m^2) they could contribute significantly to the heat budget over the Aegean sea where the annual mean estimation of net heat flux is 26W/m^2. For negative sea-air temperature differences, momentum transfer presents enhanced relative to typical values measured over open sea. Such values could be attributed to the special spatial and time scales found over Kapathio Pelagos. Moisture fluxes are found positive and on values ranging from $10^1$to 10^2W/m^2. Sensible heat fluxes are downward and range from 10^0 to 10^1W/m^2. Momentum and moisture fluxes decrease with stability while heat flux increases with augmenting scatter. Heat fluxes are seen to act as a function of the measured air-sea temperature difference.

Ongoing investigation of the turbulent structure and the energy transfer in the recorded surface MABL is expected to provide further understanding on the relative processes over an Archipelago such as the Aegean sea.

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