Science of the Total Environment 494–495 (2014) 166–176

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Flux measurements in the surface marine Atmospheric Boundary Layer over the Aegean Sea, Greece

V.E. Kostopoulos *, C.G. Helmis

Department of Environmental Physics and Meteorology, Faculty of Physics, University of Athens, University Campus, Build, PHYS-5, Zografou, 15784, Athens, Greece

HIGHLIGHTS

- We found that the short fetch of air flow affects the regional air–sea exchanges.
- Latent heat fluxes were influenced by the intense SST spatial variability.
- The drag coefficient was found to be a constant function of wind speed.

ARTICLE INFO

Article history:
Received 2 April 2014
Received in revised form 22 June 2014
Accepted 28 June 2014
Available online xxxx

Editor: Pavlos Kassomenos

Keywords:
Momentum heat and humidity fluxes
Drag coefficient
Aegean Sea

ABSTRACT

Micro-meteorological measurements within the surface Marine Atmospheric Boundary Layer took place at the shoreline of two islands at northern and south-eastern Aegean Sea of Greece. The primary goal of these experimental campaigns was to study the momentum, heat and humidity fluxes over this part of the north-eastern Mediterranean Sea, characterized by limited spatial and temporal scales which could affect these exchanges at the air–sea interface. The great majority of the obtained records from both sites gave higher values up to factor of two, compared with the estimations from the most widely used parametric formulas that came mostly from measurements over open seas and oceans. Friction velocity values from both campaigns varied within the same range and presented strong correlation with the wind speed at 10 m height while the calculated drag coefficient values at the same height for both sites were found to be constant in relation with the wind speed. Using eddy correlation analysis, the heat flux values were calculated (virtual heat fluxes varied from −60 to 40 W/m^2) and it was found that they are affected by the limited spatial and temporal scales of the responding air–sea interaction mechanism. Similarly, the humidity fluxes appeared to be strongly influenced by the observed intense spatial heterogeneity of the sea surface temperature.

1. Introduction

It is well known that air–sea interaction strongly influences the world's climate. The complexity of the physical processes involved, is still not fully understood although numerous studies addressed this issue over the past decades (Foreman and Emeis 2010, Smith et al. 1996). Flux measurements of mass and energy within the surface Marine Atmospheric Boundary Layer (MABL) are of fundamental importance in order to understand its structure and characteristics. They are considered essential for weather and climate predictions since they provide to models parameterization schemes for surface turbulent fluxes of momentum, heat and water vapor. The accurate prediction, particularly of momentum flux, is of crucial importance since it affects additionally, heat and water vapor vertical transportation as well as wave generation and upper sea circulation.

Momentum transfer within the surface MABL is usually parameterized in terms of drag coefficient (C_D), which is defined as,

$$C_D = -\overline{u'w'}/\rho U^2 \tag{1}$$

where $\overline{u'w'}$ is the momentum flux at the sea surface, ρ is the air density and U is the mean wind speed at a reference height (10 m). Drag coefficient parameterization is in the form of a linear function of wind speed mostly for high wind speed values (Smith 1980) while at moderate wind speed, many investigators have proposed constant values (Large and Pond 1981). It is worth mentioning that, C_D depends on stability and together with wind speed are both usually corrected and their neutral values are estimated (see Section 2.3). Geernaert and Katsaros (1986) suggested that since wind stress varies with stability for equal wind speed reference, the sea state or the surface roughness must also vary and the final drag coefficient should be calculated from the neutral drag coefficient and the stability. On the other hand, Sethuraman and Raynor (1975) reported that for height less than 10 m, wind profiles

* Corresponding author. Tel.: +30 210 7276850.
E-mail address: vkostopoulos@phys.uoa.gr (V.E. Kostopoulos).

http://dx.doi.org/10.1016/j.scitotenv.2014.06.127
0048-9697/

were found to follow logarithmic low even for moderately stable conditions ($z/L < 0.1$). They suggested that C_D estimations from different campaigns that stand for near neutral conditions, do not really suffer from large deviations due to stability, comparing to the increase of the resulting uncertainty that comes with corrections.

The choice of using the drag coefficient regression equation under neutral conditions is regionally dependent (Byrne 1983, Geernaert and Plant 1990) and recent studies underline the need of improved parameterization (Edson et al. 2007). The differences that were found between independent experiments are thought to be a function of the sea state (Drennan et al. 2003, Foreman and Emeis 2010, Hwang 2005). The fetch or the duration of air flow over sea plays crucial role to the development of the wave field and the momentum transfer of short fetched flows is documented to be greater over young and developing wave fields than over older wave fields, which are in equilibrium with the wind (Drennan et al. 2003, Hwang 2005, Smedman et al. 2003, Vickers and Mahrt 1997a). Sea surface motion due to waves is additionally an important parameter since the relation between wave phase speed and wind speed can significantly alter the wind profile. Vickers and Mahrt (1997a) noticed that the young age of wind driven waves could also be the result of phase speed reduction caused by wave breaking that usually accompanies wind accelerations and may be site specific. There have been several promising attempts lately towards parameterization of C_D in terms of wave parameters such as age, height or steepness of the wave (Gao et al. 2009, Hwang et al. 2011).

Besides momentum transfer, significant amount of sensible and latent heat are also exchanged at the air–sea interface. Heat fluxes are driven by the air–sea temperature difference and enhanced with increased turbulent mixing over the sea. Under strong winds and consequent wave breaking, sea spray effects are also thought to include a significant contribution to heat exchange, besides the transfer at the interface (Andreas 2010). Over open and homogenous seas, the surface MABL was found mostly under neutral conditions. Near ocean currents, the air flow along large sea surface temperature (SST) gradients, changes the characteristics of the air masses and heat fluxes are produced due to the advection of air over sea surfaces with different temperatures (Small et al. 2008). The Frontal Air–Sea Interaction Experiment (FASINEX), among other studies, revealed the response of the lower marine atmospheric boundary layer to sharp changes in SST. Frieche et al. (1991) reported that for flow towards warm water, a well-mixed thermal internal boundary layer (TIBL) can form presenting upward heat fluxes while the main boundary layer height and air temperature and moisture content increases. Along SST gradients, resulting spatial pressure differences have also been recognized due to differential surface heating that can induce wind speed acceleration towards the warm side and increase turbulence (Small et al. 2008). For air flow towards cooler water, a shallow, stable TIBL is reported with typically lower air temperature and moisture, while increased stability can force the initiation of Low-Level Lets (LLJ) above the surface layer (Vihma et al., 1998). Increased temperature differences over the sea and responding stable or unstable conditions are also usually found downwind of any mainland, similar due to advection.

Up today, the vast majority of relevant studies were conducted mostly over open seas and oceans. Only two relative experimental expeditions have been reported over the Mediterranean, both at its western part (Drennan et al. 2003). During the FETCH experiment that took place in the Gulf of Lion (Fig. 1), mainly near neutral and unstable conditions were observed, with the latter corresponding to downward heat fluxes (Pedreros et al. 2003). These conditions were attributed to the negative air–sea temperature differences that resulted due to cold outbreaks of strong Mistral winds. The air–sea heat exchanges were also found to be influenced from the presence of intense orography and sheltered regions upwind the Gulf, according to Hauser et al. (2003). Regarding momentum transfer, the results from this campaign based on measurements around 50 km southerly from the coasts of south France, underlined the significance of wave age effects on the drag coefficient, which was found weaker under longer fetched (south-westerly flows) than under the much sorter fetched northern flows at common wind speed range (Drennan et al. 2003). The impact of wave age to the drag coefficient over the waters of the Mediterranean was already been pointed out from the early study of Volkov (1970). Similar conclusions came also from the Östergarnsholm field experiment in the Baltic Sea which has relative scales (Smedman et al. 2003). It is worth to notice that both the Baltic and western Mediterranean Sea, lack of the complex topography found over the Aegean Sea and this seems to both areas act favourable for the longer waves to gain importance and have an impact on the wind profile, by reducing the total drag with growing fetch due to swell formation. Thus, it is evident that the air–sea interaction mechanism over a semi-closed sea as the Aegean with complex topography will be probably sensitive to the local fetch and the local scales in time and space. Regarding the relation of the drag coefficient with wind speed, in the case of growing seas which are very frequent in coastal and bounded regions, Smedman et al. (2003) observations resembled the air flow over the Baltic as over

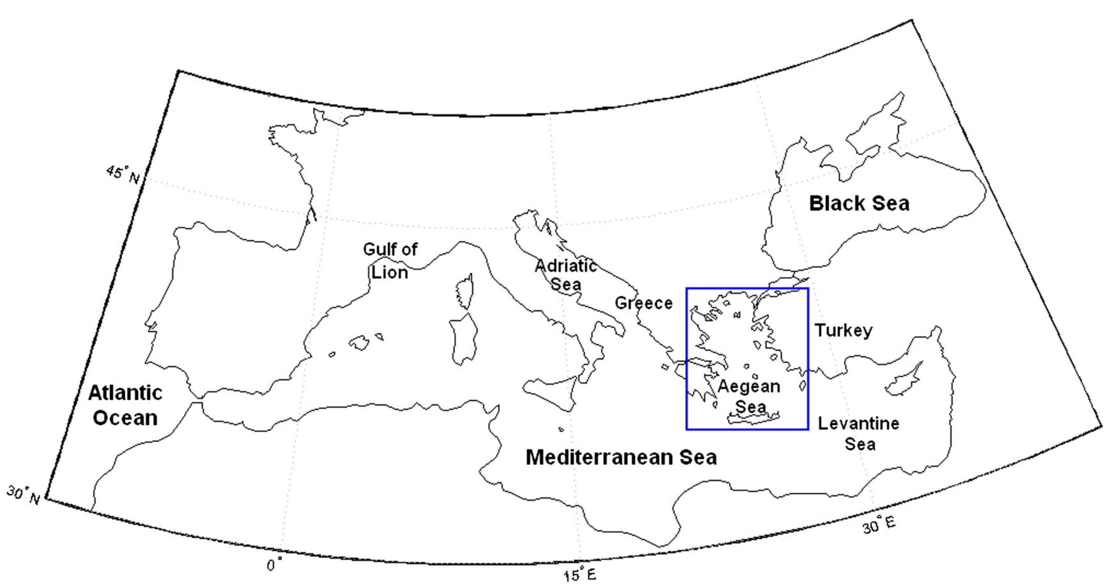

Fig. 1. The Aegean Sea, located at the north-eastern Mediterranean Sea.