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Seasonal evapotranspiration, energy fluxes and turbulence variance characteristics of a Mediterranean coastal grassland

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ABSTRACT

A hydrological year of evapotranspiration (*ET*) and energy exchanges, for a coastal grassland in the Mediterranean-climate of Greece, are reported. Throughout the growing season, available energy (R_{net}-G) was transformed to latent heat flux by 67% while during the senescence period the turbulent exchange was dominated by sensible heat flux accounting for 80.42% of (R_{net}-G). Evapotranspiration reached maxima of 8.2 mm d^{-1} in July while it was negligible during winter. The annual hydrological excess equalled 200 mm y^{-1}. Variation in water exchange depended primarily on (R_{net}-G) and vapor pressure deficit (*VPD*). A significant positive linear correlation was found between values of *ET* and R_{net}-G on a monthly timescale. The monthly mean *ET* had also a positive correlation with the mean Normalized Difference Vegetation Index (*NDVI*). Additionally, the bulk characteristics of the canopy, decoupling coefficient (Ω) and the daytime mean Priestley–Taylor (α) coefficient exhibited seasonal variations with higher values occurring in the rapid emergent period. Annual Ω was nearly 0.50, indicating that the surface was partially decoupled with the atmosphere. Given that this ecosystem is characterized by occasional flooding, the annual mean value of α was 0.52 implying seasonal growth limitation to transpiration. The impact of different wind origins on evapotranspiration was observed. *ET* was smaller than expected for winds of marine origin because of its response to small *VPD*s and the presence of sea salt aerosol. The results of the present study effected the explanation of the temporal patterns of *ET* in relation to the landscape of a Mediterranean coastal grassland and its meteorological and physiological characteristics.

1. Introduction

Grasslands are one of the Mediterranean-type ecosystems threatened by increasing droughts, heat waves, desertification and decreasing precipitation; their degradation is anticipated to significantly affect water resources, biodiversity and agriculture in the near future (IPCC, 2007). Recent research indicates that proximity to the seashore can also have a significant effect on the vegetation cover of a landscape (Makarieva et al., 2013). For these reasons, the determination of the main factors affecting water vapor fluxes, as well as the respective turbulence characteristics over the Mediterranean coastal grasslands, is crucial to redressing some of the climate-related risks of the area.

A large number of seasonal energy exchanges and evapotranspiration (*ET*) studies in grasslands have been reported in the recent literature. However, only few studies exist on *ET* from grassland ecosystems in a Mediterranean-type climate and most of them, have indicated considerable inter-seasonal variation in their surface energy budget components (Baldocchi et al., 2004; Aires et al., 2008; Morillas et al., 2013b).

A study related to this type of climate, conducted near the Pacific coast range of California, monitored *ET* in a perennial C3 grassland, growing in serpentine soils (Valentini et al., 1995). During the growing season latent heat accounted for about 60% of net radiation but late in the growing season the energy dissipation by latent heat decreased rapidly and transpiration was controlled by canopy conductance and vapor pressure deficit. Another study was carried out over an annual-growth C3 grassland, located in the foothills of the Sierra Nevada Mountains in California (Baldocchi et al., 2004; Ryu et al., 2008). The *ET* co-varied positively with solar radiation during winter/spring, reaching a maximum rate of 4 mm d^{-1} in spring and confined by potential *ET* during the wet cool growing season. Under dry hot conditions *ET* was restrained by precipitation (Baldocchi et al., 2004) whilst annual *ET* was modulated by the growing season length (Ryu et al., 2008). In a study conducted in the Mediterranean

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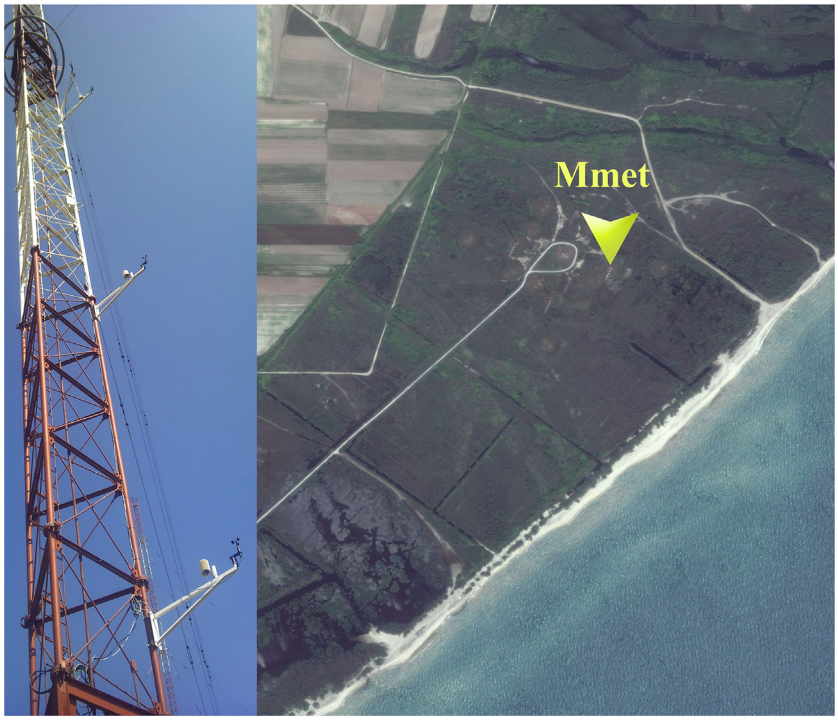

Fig. 1. Micrometeorological (Mmet) tower and Google earth® map illustrating the sampling site at Dasochori, Greece (40° 53′ 22.47″ N 24° 51′ 00.43″ E) and the position of the Mmet tower relative to the seacoast.

basin, in Portugal (Aires et al., 2008), soil water availability and plant canopy growth were the most important factors in determining the seasonal variation in water and energy fluxes for a mixed C3/C4 grassland, with a peak *ET* of 4.5 mm d^{-1} that was observed in spring. On annual basis the major portion of net radiation was consumed in sensible heat flux under dry conditions while in the winter, the dominant consumer of net radiation was switched to latent heat flux. Similarly, in a perennial tussock grassland in Southeast Spain, sensible heat flux was the dominant flux (Morillas et al., 2013a,b). The grassland was growing from fall through the late spring and attained a maximum *ET* of 1 mm d^{-1} in February. The vegetation displayed opportunistic growth patterns with leaf conductance and photosynthetic rates largely dependent on water availability in the upper soil layer. Evidently, the low *ET* fluxes were attributed to the typical asynchrony of energy and water availability in these environments (Serrano-Ortiz et al., 2007). The limited literature on *ET* and energy distribution over Mediterranean C3 or C4 grasslands, combined with conflicting results in the above studies about the magnitude and timing of *ET* and its controlling factors (i. e. energy radiation, vapor pressure deficit, soil water availability), illustrated the necessity of further research on the seasonal variation of evapotranspiration in such ecosystems. Furthermore, our current knowledge on water and energy exchanges in Mediterranean grasslands is generally bereft of information on how these exchanges correspond to changes in climate and vegetation density for C4 grass growing in dry warm months on a coast line in Mediterranean basin. The type of grassland examined in the present study, being composed mainly of tall grasses and scattered rushes, is representative of Mediterranean ecosystems, extending throughout the basin up to the coasts of the Black Sea (Natura 2000, SCI, code GR1150010). It is also distinct from previous reported perennial C3, or mixed C3/C4 grasslands because it has a different phenological cycle and in addition, its coastal location induces idiosyncrasies in microclimate dynamics as well as in air constitution.

The experiment was conducted from November 2013 to November 2014 at the VOCALS station in Northern Greece (http://www.europe-fluxdata.eu/home/sites-list). Because the "field of view" of this station includes both continental and marine air masses, an opportunity arose for the quantification of a possible mechanism that controls the variability of evapotranspiration according to wind origin. After all, a number of studies have suggested that plant productivity, hydrological cycle and land surface energy fluxes can be regulated by the aerosols' direct radiative effects (e.g. Zhang et al., 2010).

Thus, the objectives of the present work were, firstly, to investigate the temporal variability of energy and water exchanges over a typical coastal C4 grassland in real Mediterranean climate conditions, using the eddy covariance (EC) and variance (VAR) methods. Secondly, by specifying the bulk characteristics and the phenology of the coastal grassland, to explain the interplay among physiological and meteorological conditions regarding the water vapor flux dynamics. Thirdly, due to the vicinity of the station to the coast, to quantify the potential contribution of sea salt particles on the water vapor fluxes. Fourthly, to modify and test the reliability of the variance method to replicate turbulent fluxes derived from eddy covariance. It was envisaged that this would simplify the characterization of the field's turbulence. Finally, to calibrate the Priestley and Taylor (1972) evapotranspiration model from measured seasonal rates of water fluxes for this Mediterranean ecosystem, since the model has been mainly applied in temperate climates.

2. Materials and methods

2.1. Site description

The sampling site named VOCALS, at Dasochori, Greece (40° 53′ 22.47″ N 24° 51′ 00.43″ E), is located 200 m from the sea coast. The instrumentation was installed on a 125 m tower (Fig. 1). The surrounding rural area is covered mainly with Mediterranean tall humid grasslands of "*Molinio Holoschoenion*" and small areas of vegetable plants. The coastal grassland maybe flooded with brackish