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Turbulence in a coastal Mediterranean area: surface fluxes and related parameters at Castel Porziano, Italy

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Abstract

During the ACCENT/VOCBAS measuring campaign conducted at Castel Porziano, Italy over a Mediterranean macchia ecosystem located near the coastline, a series of micrometeorological observations were made. Sensible and latent heat fluxes, as well as ozone fluxes, are presented. The behaviour of the main meteorological variables such as temperature, humidity, wind speed and direction, is analysed.

1 Introduction

The main goal of the measuring campaign described in this issue is a study of the chemical exchange between biosphere and atmosphere at a coastal site near Rome, covered by sand dunes and dry Mediterranean vegetation. The determination of exchange fluxes of chemical species (volatile organic compounds, nitrogen oxides, ozone, water vapour, carbon dioxide) largely made use of micrometeorological methods like eddy-covariance. The chemical fluxes are generated by the properties of the air/vegetation interface and driven by turbulence. For example, the emission flux of a given biogenic volatile organic compound (BVOC) is due to the production of the substance inside the cells followed by its release through the stomata or other leaf surface elements, but, once the emitted molecules are present in the air, they are transported aloft by turbulence. So, a study of turbulence is essential if we wish to describe the air/vegetation chemical exchange processes. Several participating groups operated micrometeorological instrumentation, whose working principles are based on the properties of turbulent motion. Turbulent atmospheric variables were thus recorded and used throughout this issue. Further, this campaign constituted a good occasion to study phenomena related with turbulence in a coastal area covered by sclerophyllic vegetation. Important features characterizing turbulent air motion at the measuring site are land-sea breezes, thermal inversions, small-scale phenomena due to the presence of dunes and low, non-homogeneously distributed vegetation. Very few studies (see

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e.g. Valentini et al., 1990) have been carried out previously over an ecosystem similar to the Castel Porziano seashore.

In the present article we deal with physical variables such as temperature, humidity, and wind vector, the chemical and biological aspects being addressed in other contributions of this issue. The characteristics of turbulence presented here have been used in other contributions of this special issue.

2 Site and instrumentation

The observation site was located near the Mediterranean seashore in the Castel Porziano estate near Rome. For a more general description, see Fares et al. (2009). The micrometeorological measurements were located in a dune area covered by non-homogeneously distributed macchia-type vegetation. A description of the instrumental set-up installed by the different groups is outlined below.

1. The group "Università Cattolica del Sacro Cuore", Brescia, Italy (hereafter referred to as UCSC), operated, on a small tower, a METEK USA-1 sonic anemometer and a LI-7500 LI-COR open path infrared absorption sensor for water vapour and CO_2 concentrations placed at a height of 3.8 m above ground level (a.g.l.) to measure turbulent vertical fluxes of sensible and latent heat, as well as related micrometeorological variables such as friction velocitites and fluxes of chemical substances.

A net radiometer (NR lite, Kipp&Zonen, Holland), a sensor for the measurement of the photosynthetically active radiation (PAR; LI-COR, mod. 190SA, Lincoln, Neb., USA) and a temperature and relative humidity probe (50Y, Campbell Scientific, Shepshed, United Kingdom) were placed at 3.8 m a.g.l.

This measuring site was also equipped with additional instrumentation to describe the vertical temperature and humidity profiles, the soil water content, the non-turbulent energy fluxes and the microclimate of the area: two additional temperature and relative humidity probes (50Y, Campbell Scientific, Shepshed, United Kingdom) at 1 m and 0.1 m; three soil heat flux plates, (HFP01SC, Hukseflux, Delft, Holland); three TDR reflectometers (C616, Campbell Scientific, Shepshed, United Kingdom); three leaf temperature probes (Pt100, DeltaT, United Kingdom); two surrogate leaves (237, Campbell Scientific, United Kingdom) to measure leaf wetness, one rain gauge (52202, Young/Campbell Scientific, Cambridge, United Kingdom) and one barometer (PTB101B, Vaisala, Finland).

2. The "Istituto di biologia agro-ambientale e forestale", Porano, Italy (IBAF), operated a Young 81000 sonic anemometer and a LI-COR 7500 open path infrared absorption sensor for water vapour and CO_2 concentrations at 6.0 m a.g.l. on the same tower.

3. The Joint Research Centre, Ispra, Italy (JRC) operated a METEK USA-1 sonic anemometer and a Campbell Sci. KH20 krypton hygrometer at a height of 9.5 m on a tower located at a distance of about 30 m westwards respect to the UCSC-IBAF tower. The JRC tower was erected on a small dune, and the height reported here is expressed respect to the base of the UCSC-IBAF tower.

The general layout of the observation facilities is represented on Fig. 1.

The fluxes and other micrometeorological variables were measured using the eddy covariance technique (see e.g. Swinbank, 1951; Hicks and Matt, 1988). The data recorded by the fast sensors were sampled at 20 Hz (UCSC, IBAF) and 10 Hz (JRC) with home-made software packages written in Delphi 5.0 (UCSC) and Labview 6 (JRC). Slow sensors were sampled every 15 s and data were collected by a data logger (CR10x, Campbell Scientific, Shepshed, United Kingdom) equipped with a signal multiplexer device (AM16/32, Campbell Sci., United Kingdom), and data were averaged every 30 min.

3 Results and observations

Observations during the major part of one month, May 2007, such that the meteorological variables recorded could be averaged. Mean vertical profiles of temperature, absolute and relative humidity, and wind speed and direction, were calculated in order to identify the main features of the daily behaviour of these parameters (Fig. 2a, b, c).

During daytime the vertical temperature profile, averaged over the whole month (Fig. 2a), was strongly superadiabatic near the surface, with a temperature difference of 3 degrees between 0.1 and 3.5 m a.g.l. The solar radiation very efficiently heats up the sandy soil of the dunes, which in turn heats the air aloft. From 06:00 p.m. onwards this strong negative temperature gradient becomes weaker and around 07:30 p.m. the vegetation (canopy) becomes colder than both the soil and the air above, resulting in a complex vertical profile. The full inversion including all levels is established only at 11:00 p.m., and persists during the whole night until 08:30 a.m. At that time, the canopy becomes warmer that both the soil and the above air layer. This transition period is short and at 09:00 a.m. the inversion is completely destroyed.

The night time formation of inversion layers near the soil is regular and the inversions are strong. As a consequence, dew formation is frequent, as indicated by the daily course of the dew point temperature, shown on Fig. 3, together with the surrogate leaf resistance. This latter variable is very close to zero during nigh time, indicating a wet, dew covered surface. The dew may be used by the sclerophyllic vegetation present on the macchia as a way of limiting water shortage, since a part of the water condensed ends up in the soil and is subsequently pumped by the plant roots. It is also possible that a small portion of the dew penetrates directly into the plant tissues. The formation of dew is an element of the coupling between the atmosphere and the surface, as it modifies the hydrological balance.

The behaviour of the vertical profile of absolute humidity χ, as expressed in g/m^3 (Fig. 2b), is similar to the temperature profile in the lower layers. At highest level (9.5 m) the role of advection appears clearly as the air is rather dry during night time, due to advection of dryer air from inland, whereas it is much wetter during daytime hours due to the wet air advected from the sea and transported by the breeze.

The behaviour of the absolute humidity in the upper layers appears decoupled from that observed in the lower layers, with a stronger difference during night time. This is probably due to the advection effect in which wet air is transported from the sea during daytime and dryer air comes from inland during night time.

The wind velocity (Fig. 2c) appears systematically higher in the upper levels, as expected, the difference being weaker in the night time hours. The prevailing night time wind direction (Fig. 4a) is from north. After sunrise and in the upper levels the wind direction becomes more variable between NW and NE. From 09:00 a.m. onwards, the wind rotates to E, and later to S. The daytime, southerly, sea-breeze regime, is reached at 01:00 p.m. The wind direction rotation process is more rapid in the lower layers, where the prevailing daytime wind direction is reached around 10:00 a.m. It is to be noted that, between 09:00 a.m. and 01:00 p.m., the wind directions near ground and at the highest level may differ considerably from each other, with a maximum difference of about 90° clockwise. From 09:00 p.m. onwards the near-ground wind rotates to north, briefly followed by the wind at higher levels. The breeze circulation is also illustrated on Fig. 4b with the wind recorded at 9.5 m a.g.l.

Figure 5 shows the evolution of the main micrometeorological variables during the whole month of May 2007: friction velocity (Fig. 5a), sensible heat flux (Fig. 5b), latent heat flux (Fig. 5c) and total ozone flux (Fig. 5d) during May 2007 at the measuring site.

An important feature in micrometeorology is the constant flux hypothesis, which states that, in a horizontally homogeneous surface layer, the fluxes of turbulent variables (enthalpy or sensible heat, momentum, chemical concentrations) are almost constant with height. Fulfillment of this assumption permits the description of the atmospheric boundary layer in terms of characteristic quantities such as the friction velocity and scaling temperature (see e.g. Stull, 1988) which in turn permit the calculation of vertical profiles of various quantities like concentrations. The presence of three levels of measurement (3.8 m, 6 m and 9.5 m) permitted to check the fulfilment of the constant flux hypothesis and to decide whether these measurements could be used for further studies at the observation site, such as the derivation of vertical profiles. Examination of the fluxes of sensible and latent heat, as well as the ozone fluxes and the friction velocities (which are an alternative expression of the momentum fluxes) measured at the different levels showed the following characteristics: the differences between fluxes where very low between the upper two levels (6 m and 9.5 m) for all variables (see Fig. 6), whereas there is less agreement between the upper two levels and the lowest level (3.8 m), respectively. This is due to the fact that the lowest level is sensitive to the irregularities in the topography due to the presence of dunes (the mean height of the dunes was about 5 m) and the non-homogeneously distributed vegetation with portions of bare sandy soil exposed to strong solar radiation. The upper levels have a wider footprint, and do not "see" the details of the surface elements. As a consequence, it can be stated that the constant flux hypothesis is fulfilled for the levels above 6 m and that the corresponding measurements can be used for further investigations. This was made e.g. to calculated vertical ozone fluxes from ozone concentration profile measurements by using the gradient method (see Mereu et al., 2009), through the derivation of the vertical turbulent diffusion coefficient,

$$K(z)=k \cdot u^* z/\Phi(u^*, H) \quad (1)$$

where z is the height a.g.l., k is the von Karman's constant (∼0.4), u^* is the friction velocity, L is the Monin-Obukhov length, and Φ is the Monin-Obukhov stability function of friction velocity and H, the sensible heat flux. The $K(z)$ coefficient were thus calculated from the measured friction velocities and sensible heat fluxes, shown on Fig. 5a and b.

The different terms of the surface *energy* balance: net radiation, soil heat flux, turbulent sensible and latent heat fluxes, during May 2007, showed a very regular diurnal course, except for the few days in which synoptic perturbations were passing over the area. The Bowen ratio $\beta = H/\lambda E$ was very high during most of the campaign (Fig. 7, upper frame), ranging between 3 and 4 in the central part of the day (11:00 a.m. to 07:00 p.m.), indicating that water availability was very limited, characterising an environment where sclerophyllic, drought-adapted vegetation is dominant. The mean evaporative efficiency, $\lambda E/(H+\lambda E)$ was about 20%. These features show that the coupling between the physical conditions prevailing in the atmosphere and the characteristics of vegetation is strong. This coupling can also be expressed by a decoupling coefficient Ω introduced by McNaughton and Jarvis (1983) and expressed by

$$\Omega = \frac{\frac{s}{\gamma}+1}{\frac{s}{\gamma}+1+\frac{R_c}{R_a}} \qquad (2)$$

where s ist he slope of the saturation curve of water vapour pressure against temperature, γ is the psychrometric constant, R_c and R_a are the canopy and aerodynamic resistances, respectively. Figure 7 (middle frame) shows the mean daily course of the coupling coefficient 1-Ω, which is ranges between 0.6 and 0.7 in the central hours of the day.

The hourly averages of the terms of the surface energy balance are represented on Fig. 7b. Three values of the measured soil heat flux are represented, corresponding to different locations of the flux sensors. One sensor was located in bare sandy soil, where the strongest heating is observed during the central hours of the day, whereas the maximum heating of the soil occurs in the afternoon for the sensors placed beneath plants. Figure 8 illustrates the closure of the surface energy balance, showing the sum of turbulent heat fluxes ($H+\lambda E$) against the available energy at the surface (Rn-G). It appears that, notwithstanding problems which may arise from advection effects or surface non-homogeneities (see e.g. Foken et al., 2006), the closure of the balance is reasonably good.

4 Conclusions

Turbulent fluxes of scalar quantities such as energy and ozone concentration, as well as various micrometeorological variables, were measured during May 2007 by the eddy covariance method in the coastal dune area of the Castel Porziano estate near Rome, Italy. The measurements were carried out in support of the air/vegetation chemical exchange observation campaign conducted in the frame of the ACCENT/VOCBAS project. The observations showed some characteristics of the coastal meteorology in a dry climate, such as land-sea breezes, strong nocturnal inversions, water use schemes used by sclerophyllic plants to save water. The importance of advection was revealed by the different behaviour of some meteorological parameters at higher and lower levels, as the higher levels appeared more influenced by the wet air advected from the sea during day time than the lower levels. The local non-homogeneity of both hypsometry and distribution of vegetation, also plays a role and causes deviations from the theoretically predicted vertical distribution of fluxes.

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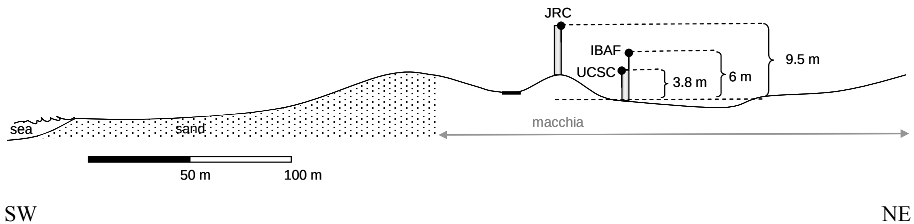

Fig. 1. Topographic profile of the measuring site, showing the location of the three eddy covariance systems (back dots).

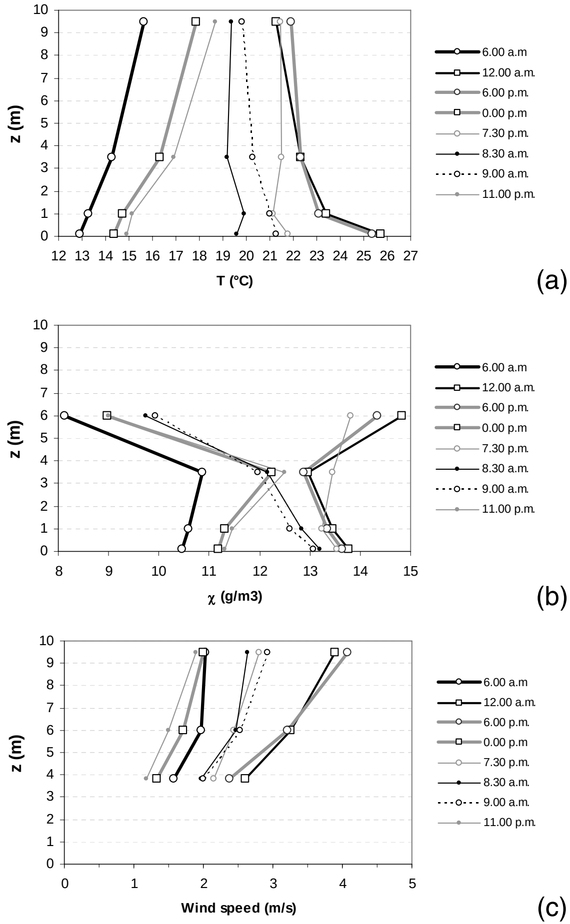

Fig. 2. Vertical profiles of different meteorological variables at synoptic hours (00:00, 06:00, 12:00, 18:00) and at other selected hours (08:30, 09:00, 19:30, 21:00) when inversions occur. **(a)** Mean air temperature; **(b)** Mean absolute humidity; **(c)** mean wind speed.

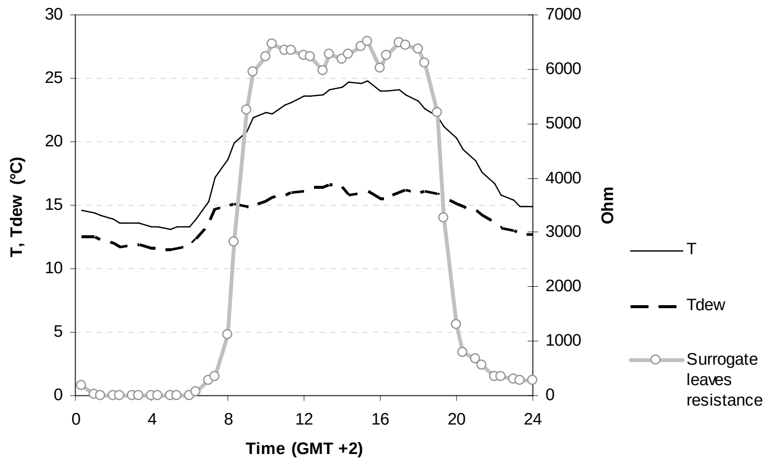

Fig. 3. Mean air temperature and dew temperature at canopy level compared with the surface resistance of the surrogate leaves (values close to 0 Ohm indicate wet surfaces while values around 6999 Ohm, the maximum value, indicate completely dry surfaces).

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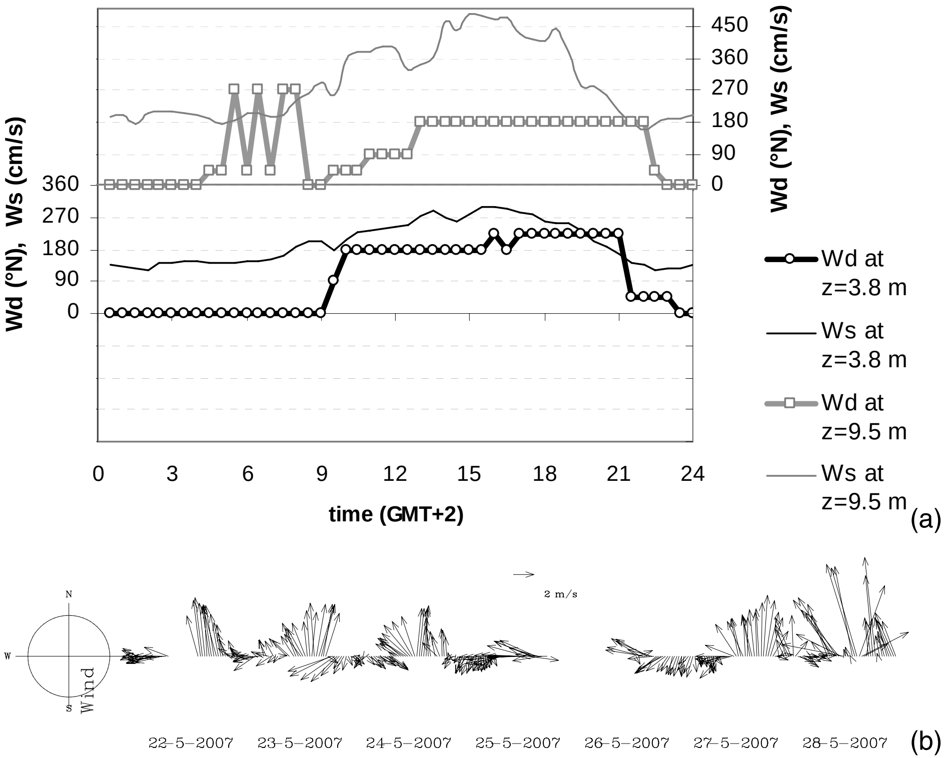

Fig. 4. **(a)** Prevailing wind direction (Wd) and mean wind speed (Ws) during daytime (note than the wind speed is expressed in cm/s) **(b)** Representation of the horizontal wind vector measured at 9.5 m a.g.l., from 22 to 28 May, which illustrates the breeze circulation.

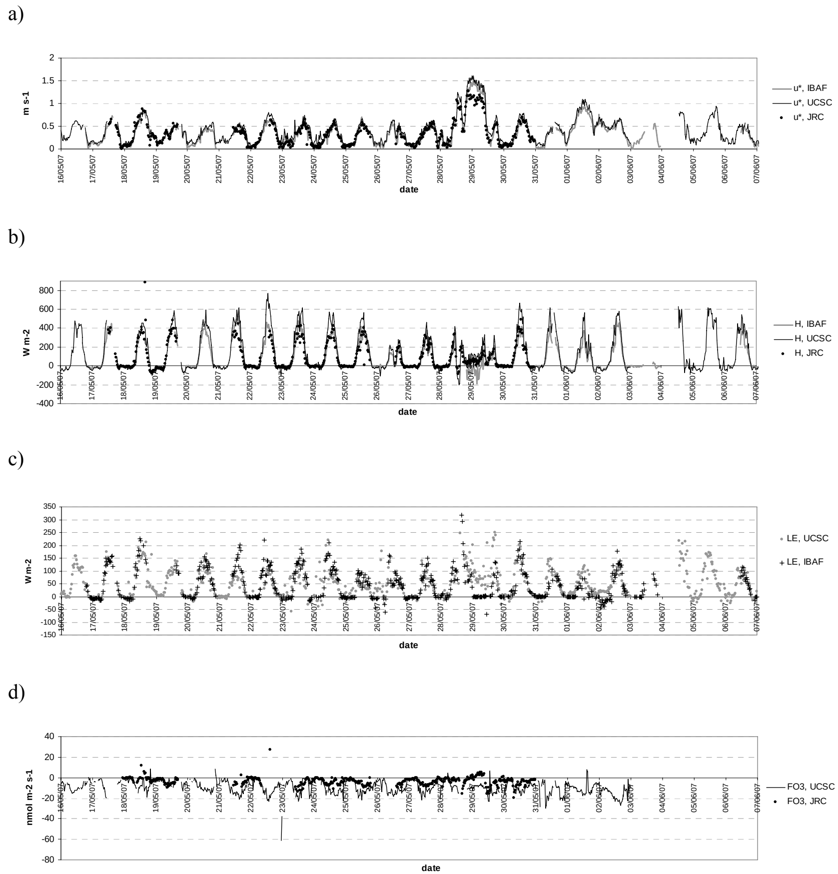

Fig. 5. Turbulent sensible heat flux and ozone flux at different heights: JRC=9.5 m, IBAF=5.5 m, UCSC=3.8 m. **(a)** friction velocity; **(b)** sensible heat flux; **(c)** latent heat flux; **(d)** total ozone flux.

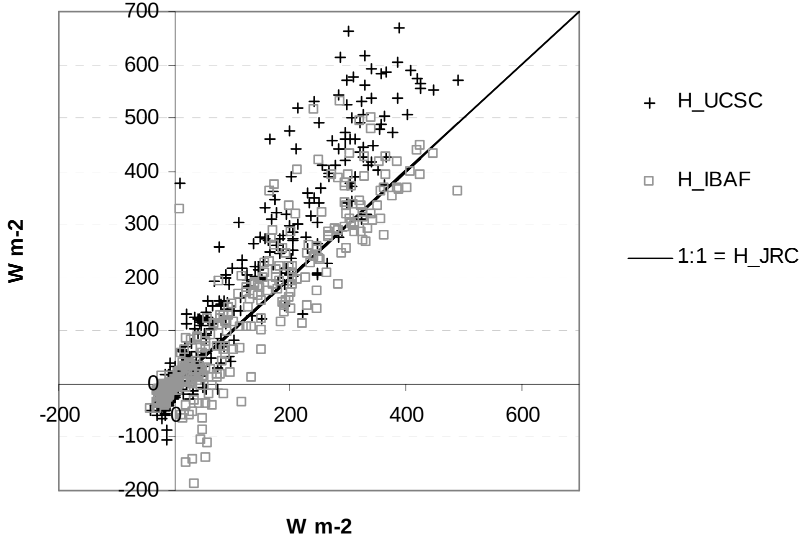

Fig. 6. Comparison between sensible heat fluxes obtained at different levels. Crosses: 3.8 m (UCSC) against 9.5 m (JRC). Squares: 5.5 m (IBAF) against 9.5 m (JRC). The constant flux hypothesis is fully respected between the 5.5 m and 9.5 m levels.

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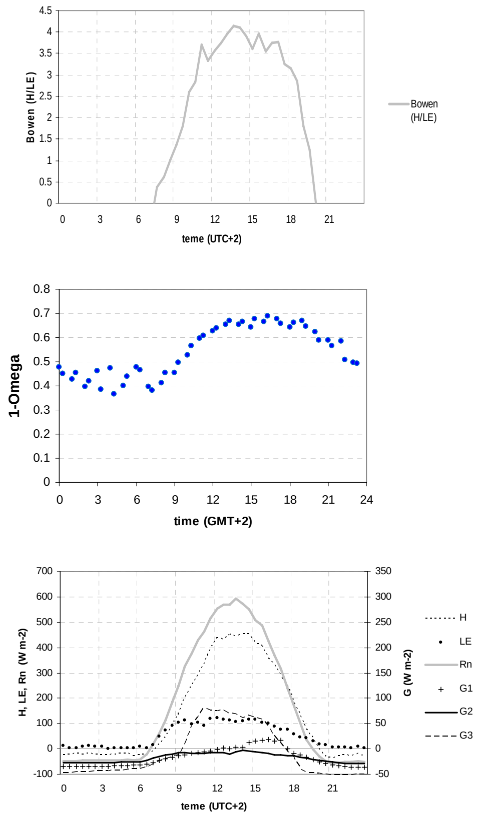

Fig. 7. Mean daily course of the following variables: Upper: bowen ratio, showing rather dry conditions prevailing during the campaign; Middle: coupling coefficient 1-Ω; Lower: the different terms of the surface energy balance: *H* is the sensible heat flux; *LE* is the latent heat flux; *Rn* is the net radiation; *G*1, *G*2 and *G*3 are ground heat fluxes. *G*1 was measured under a juniper, phyllirea and rosemary bush; *G*2 under an Erica bush; *G*3 was recorded in the bare sand. Positive *G* values are in-ground fluxes, negative values are outward fluxes.

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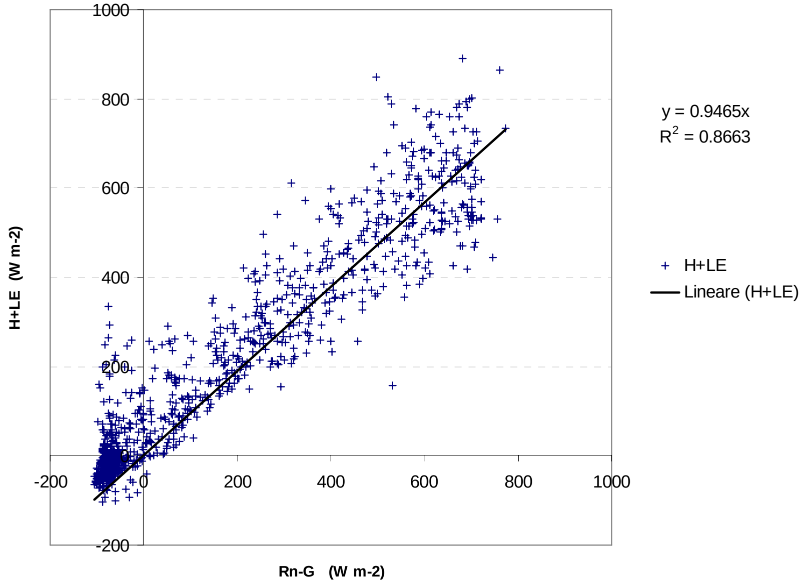

Fig. 8. Energy balance closure, represented as the sum of turbulent fluxes (sensible and latent heat fluxes) against the available energy at the surface (net radiation minus ground heat flux).