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Scaling-up of evapotranspiration measurements: the promising role of scintillometry

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Abstract. The assessment of evapotranspiration (ET) is of primary interest, especially for agricultural and environmental issues. Traditional micrometeorological techniques require homogenous surface and are characterized by limited footprint. Thus, they cannot be applied to assess ET over inhomogeneous and extensive surfaces, typical conditions at the catchment scale and of extensive farming systems. In this context, a suitable technique to measure turbulent fluxes is scintillometry, which can give measurements of sensible heat flux at larger scale, providing averages over heterogeneous surfaces. ET can then be estimated as residual of the energy budget. In this study, we present results from a one-week campaign held during summer 2016 in Southern Italy. We deployed a Large Aperture Scintillometer (LAS) in an extensive vineyard of 140 ha on a path length of 760 m. The site was characterized by gently slope terrain with uniform crop. In order to have reference measurements of local sensible heat flux, we deployed three sonic anemometers along the scintillometer path. The aim of the study was to test the ability of scintillometry to provide a spatially averaged flux, representative of the possibly diverse conditions in an extended footprint upwind to the measurement path. The relationship between sensible heat flux measured by EC and LAS showed to be very good for the EC station in the middle of the path, whereas off-centre areas were less represented.

1. Introduction

Evapotranspiration (*ET*) measurement over inhomogeneous and extensive surfaces – typical conditions at the catchment scale – is still challenging due to spatial variability of vegetation, soil conditions and land topography. Traditional micrometeorological techniques, e.g. eddy covariance (EC), cannot be applied under these conditions, requiring homogenous surface and being characterized by limited footprint. In this context, a suitable technique to measure turbulent fluxes is scintillometry, which can give measurements of sensible heat flux (*H*) at larger scale, providing averages over heterogeneous surfaces. Sensible heat flux is derived from the measurement of turbulent intensity of the air refraction index, in the theoretical framework of Monin-Obukhov similarity theory [1]. Average *ET* over the source area can then be estimated as residual of the surface energy balance [2].

The assessment of *H* and *ET* at large scales is required to validate land surface and meteorological models, but it is also of great interest for extensive farming systems. The first scintillometry measurements over vineyards were performed when the method was still experimental [3]. However, in recent years, with modern and consolidate instruments, application of scintillometry over vineyards is lacking. In this study, we present results from a one-week campaign held during summer 2016 in a vineyard in Southern Italy. The aim of the study was to test the ability of scintillometry to provide a spatially averaged flux, representative of the possibly diverse conditions in an extended footprint upwind to the measurement path.

2. Material and methods

Measurements were carried out from July 31st to August 5th 2016 in the "Tormaresca" estate winery, an extensive private vineyard (*Vitis vinifera*) of 140 ha located in Minervino Murge, South Eastern Italy (41°8′50.08″N, 16°2′33.47″E) (figure 1). The site is characterized by a gentle slope and uniform vegetation, subdivided into different irrigation plots. Sensible heat flux measurements were performed over two irrigation plots of 13 ha (Plot 1) and 6 ha (Plot2) respectively. Both plots are characterized by hedgerow training system with plant spacing of 0.8 m, rows spaced 2.0 m apart and canopy height of 1.8 m. The irrigation was sequentially applied to plots: Plot2 was irrigated from 7:00 for 8 h and Plot1 from 18:00 of the same day for 10 h, with a rate of 1 mm/h.

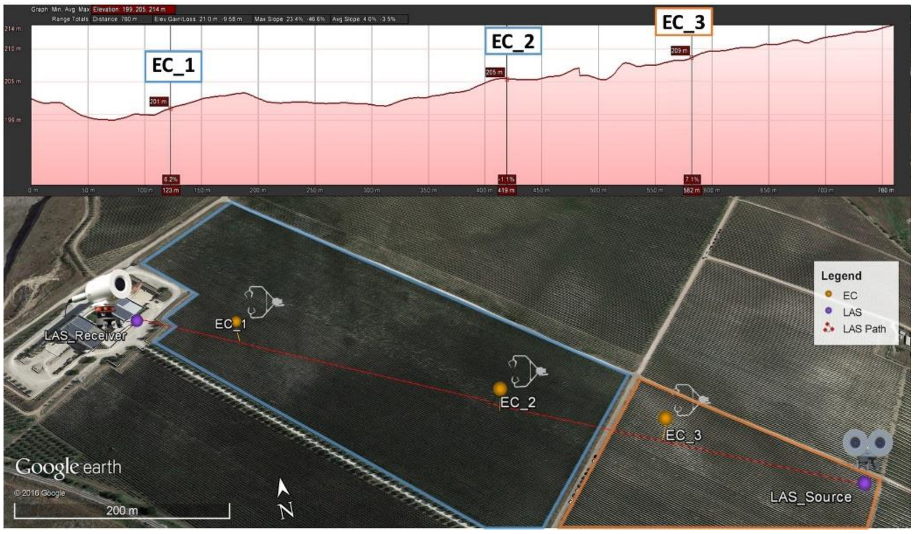

Figure 1. Bottom: satellite image of the study site with Large Aperture Scintillometer (LAS) path (red line); LAS source and receiver positions; EC station positions (*EC_1*, *EC_2*, *EC_3*). Blue contour area: irrigation Plot1; orange contour area: irrigation Plot2. Top: elevation profile along the path and EC station positions.

Area-averaged sensible heat flux over the two plots was determined with a Large Aperture Scintillometer (LAS) BLS900 (Scintec AG, Rottenburg, Germany) on a path length (distance between LAS transmitter and receiver) of 760 m. Raw statistics were calculated every 30 sec and then averaged over 30 min to obtain final fluxes. Data processing was performed using the SRun software vs 1.39 (Scintec AG, Rottenburg, Germany). A crucial input parameter for the calculation of sensible heat flux by LAS is the beam effective height (z_{eff}), which is the distance of the beam from the canopy displacement height (d). If the terrain is undulated, as it is at our site, z_{eff} will vary along the path and an average value should be calculated multiplying the beam distance from d at several points along the path by a specific coefficient obtained from a path weighting function (PWF), as indicated in Scintec Scintillometers Theory Manual, vs 1.04. The PWF describes the relative contribution of turbulent eddies to the average flux in relation to their position on the scintillometer path [4]. We calculated z_{eff} from 10 points along the path, obtaining an average value of 6.4 m.

Local measurements of sensible heat flux were carried out applying the eddy covariance technique at three different points along the LAS path. Two stations (*EC_1* and *EC_2*) were placed in Plot1 and one station (*EC_3*) in Plot2, in order to obtain reference values to compare with the flux by LAS. Each station was equipped with a CSAT3 sonic anemometer (Campbell Scientific, Inc., Logan, UT, USA), where 3D wind components and air temperature were sampled at 20 Hz. In addition, some ancillary meteorological variables (downward/upward shortwave and longwave radiation; soil heat flux, soil temperature and humidity) were measured at *EC_2* station. EC fluxes and other statistics were then calculated on 30–min time intervals.

3. Results and discussion

The timecourse of half-hourly fluxes by EC and LAS during the measurement period is presented in figure 2. The sensible heat fluxes derived from LAS (H_{LAS}) and measured by EC (H_{EC}) showed in general good agreement. Nevertheless, some differences were found among the three EC locations.

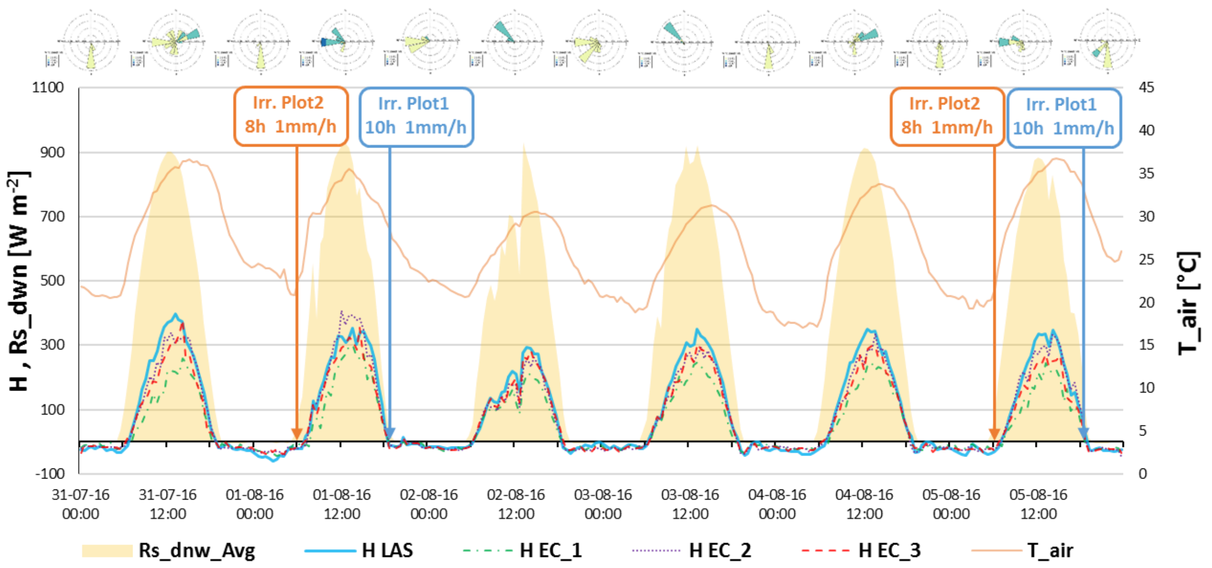

Figure 2. Bottom: timecourse of sensible heat fluxes by LAS (H_{LAS}, light blue thick solid line), EC_1 (H_{EC_1}, green dash dotted line), EC_2 (H_{EC_2}, purple dotted line) and EC_3 (H_{EC_3}, red dashed line); incoming shortwave radiation (yellow area), air temperature (orange thin solid line). Top: nighttime (19:30 – 5:00) and daytime (5:30 – 19:00) wind rose plots during the measurement period.

H_{EC_1} was lower compared to H_{LAS} and the other EC fluxes, even if it was located in the same irrigation plot of *EC_2*. This difference was probably related to the soil characteristics in *EC_1* footprint. In this area the soil is constituted by fine texture with higher water retention capacity compared to the other areas of the vineyard, which would lead to higher evapotranspiration flux and, consequently, lower sensible heat flux. On the contrary, H_{EC_2} and H_{EC_3} were quite similar, except during the days when irrigation was applied. In Plot2 (*EC_3*) irrigation started in the morning, while in Plot1 (*EC_2*) in late afternoon. During the days of irrigation (August 1st and 5th), H_{EC_3} was lower compared to H_{EC_2} as expected, indicating that the evapotranspiration was higher in Plot2.

In general, H_{LAS} was slightly larger than H_{EC} and the best agreement between the two methods was found for the EC station in the middle of the path. This is in accordance with the theoretical PWF for the BLS900, a bell shape curve with a peak in the center of the path [4], meaning that the scintillometer obtains weighted averages instead of arithmetical. However, during the first day of irrigation H_{LAS} was lower than H_{EC_2}, presenting the same pattern of H_{EC_3}, and, on the contrary, during the second day of irrigation H_{LAS} was not reduced, having values very close to H_{EC_2}. This behavior could be explained by the differences in source area for the two days related to wind conditions, even if the prevailing wind direction was the same in both days. During August 1st the wind speed was higher, therefore reducing the footprint area of the scintillometer and increasing the relative importance of Plot2.

4. Conclusions

Large Aperture Scintillometer provided a very reliable estimate of area-averaged sensible heat fluxes over the slightly heterogeneous conditions we have been investigating. However, estimates of sensible heat flux by LAS proved to be very sensitive to the effective beam height used in data processing, therefore a proper knowledge of field morphology is a necessary prerequisite even in gentle slope terrain. Scintillometer proved to be an adequate technique for measuring sensible heat flux at a large scale, which can be used to validate sensible heat by remote sensing methods and improve the evapotranspiration estimation at the farm scale even in heterogeneous conditions.

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