

Comparison of sensible heat fluxes by large aperture scintillometry and eddy covariance over two contrasting-climate vineyards

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Abstract

Measurements of turbulent energy fluxes between land-surface and the atmosphere are commonly carried out applying the eddy covariance (EC) method. Nevertheless, in some cases (e.g. surface heterogeneity, remote sensing or model validation), the use of a Large Aperture Scintillometer (LAS) is more appropriate. We compared LAS and EC measurements of sensible heat flux (H) over two contrasting vineyards of Southern (MIN site) and Northern (LIS site) Italy, mainly differentiating for climate (i.e. dry and humid), water management (i.e. irrigated and rainfed), and LAS setup. The relationship between H by LAS (H_{LAS}) and by EC (H_{EC}) was good at both sites, but with a slightly higher H_{LAS} . At MIN, where multiple EC stations were deployed, the best agreement was found with the station in the center of LAS path. Surface heterogeneity due to irrigation had different impact on H_{LAS} depending on location of the source area. The canopy growth at LIS during the study period caused the approaching of LAS beam to the roughness sublayer, resulting in a reduction of H_{LAS} compared to H_{EC} . The closure of energy balance was higher (79%) at MIN and lower (64%) at LIS, but the agreement

between H_{LAS} and H_{EC} was similar at both sites, suggesting that more attention should be given to latent heat flux measurements by EC in order to better understand the energy balance closure issue.

Keywords: Large aperture scintillometer; Sensible heat flux; Vineyard; Roughness length; Energy balance closure

1. Introduction

The assessment of energy exchanges between land and atmosphere is fundamental for several fields of application, both of practical (e.g. irrigation management, estimation of water requirements in agriculture) and more general (e.g. ecosystem functioning, meteorological and land surface models) interest. The energy balance of a surface is represented by the equation $R_n - G = H + LE$, where R_n is the net radiation at the surface, G is the soil heat flux, H is the sensible heat flux and LE is the latent heat flux. The dominant term in the left-hand side of the equation is R_n , that can be estimated with good accuracy locally by radiometers and at larger scales by combining remote sensing products and modelling (Bastiaanssen et al., 1998). Even if it is usually smaller than H or LE , evaluation of G , either directly measured in the field (Russell et al., 2015) or modeled as a function of R_n (Santanello and Friedl, 2003), is important to determine the available energy at the surface. The assessment of turbulent energy fluxes, right-hand terms of the equation, is more challenging, especially at large scales (basin, regional, etc.). At the field scale, the micrometeorological method of eddy covariance (EC) is the most applied worldwide, allowing direct measurements of H and LE with a temporal resolution from minutes (usually 30 min) to decades (Baldocchi, 2014). The fluxes measured by this technique are representative of a certain upwind area (footprint) that varies with atmospheric conditions and wind direction (Schmid, 2002; Leclerc and Foken, 2014), usually resulting in few hectares. This magnitude is often appropriate to study vegetation-atmosphere exchanges at the field scale, but at larger scales (e.g. basin), or in case of inhomogeneity of the surface, the EC method may not be adequate. Additionally, the accuracy of EC method is uncertain, as revealed by the well-known issue of non-closure of the energy balance at most EC sites (Wilson et al., 2002). The causes are likely manifold and still unclear, despite the large efforts made by the micrometeorological community to analyze the

problem (Onceley et al., 2007; Foken et al., 2011). Studies addressed the issue from a boundary–layer perspective, suggesting that one reason could be that EC does not account for energy carried in large-scale eddies (Finnigan et al., 2003; Mauder et al., 2007). Other researchers investigated the bias linked to measurement errors (Twine et al., 2000), different spatial representativeness of sensors used to measure R_n , G and turbulent fluxes (Schmid and Lloyd, 1999) or EC data processing (Mauder and Foken, 2006), but a thorough explanation is still missing. In this context, independent measurements of turbulent energy fluxes and evapotranspiration with other techniques than EC (e.g. scintillometry, lysimeters) could help clarifying this crucial issue (Liu et al., 2011).

An alternative technique is scintillometry, that can provide area–averaged fluxes at a scale up to few km^2 (Beyrich et al., 2002) and it has been successfully applied over heterogeneous surfaces (Meijninger et al., 2002a; Beyrich et al., 2006; Samain et al., 2011; Evans et al., 2012; Guyot et al., 2012). Thanks to these features, measurement by Large Aperture Scintillometer (LAS) are particularly suitable to provide ground-truth for remote sensing (Meijninger and de Bruin, 2000; Samain et al., 2012; Song et al., 2018) and to validate models with a grid resolution of few km^2 (Tang et al., 2011; Valayamkunnath et al., 2018). A LAS is constituted of a transmitter of electromagnetic waves and a receiver, placed at a certain distance from each other (up to 12 km depending on LAS type). The signal is scattered along the path by turbulent eddies with different characteristics (e.g. temperature, humidity), causing variations in signal intensity observed by the receiver, linked to the air refractive index (n) of these eddies, from which the structure parameter of n (C_n^2) can be determined (Wang et al., 1978). The latter can be related to the structure parameter of temperature (C_T^2), or humidity (C_Q^2), from which H , or LE , can be derived in the framework of Monin-Obukhov similarity theory (MOST) (Monin and Obukhov, 1954; Wyngaard and Clifford, 1978; Hill, 1997). For a detailed description of scintillometry theory, the reader can refer to (De Bruin et al., 1995; Meijninger and De Bruin, 2000). The scintillometers today commercially available operate at visible and near-infrared wavelengths, which are primarily sensitive to temperature fluctuations (Wesely, 1976; Hill et al., 1980), thus allowing measurements of H . A scintillometer operating at wavelengths more sensitive to humidity (i.e. microwaves) can be used to assess LE directly (Green et al., 2000; Meijninger et al., 2002b). Nevertheless, this instrumentation is still experimental and LE is usually derived with an energy balance approach from LAS measurements

of H (Ezzahar et al., 2009; Guyot et al., 2009). In case of heterogeneous landscape, the flux by LAS is the area-averaged of fluxes from each land-surface type. Thus, independent measurements by EC should be performed on each different plot located in LAS footprint to get aggregated fluxes to be compared with LAS measurements (Beyrich et al., 2002; Meijninger et al., 2002b; Evans et al., 2012). Information regarding the beam height and roughness of the underlying surface are required inputs to MOST-based equation for LAS raw data processing. Since results are particularly sensitive to beam height, an accurate estimation of effective measurement height (z_{eff}) should be performed, especially in case of heterogeneous landscape (Hartogensis et al., 2003). Additionally, the LAS height should not be referred to ground but to the canopy displacement height (d) and a further aerodynamic parameter, the roughness length (z_0), is needed for LAS data processing. These parameters depend mainly on canopy structure and leaf area index (Raupach, 1994) and they can be derived by inverting the logarithmic wind profile equation in atmospheric stability conditions close to neutrality. Ideally, the mean wind speed at three or more heights above the canopy is required to estimate d by iteratively solving a system of equations (Dolman, 1986; Monteith and Unsworth, 2013). However, these kind of measurements are missing at most of sites where an estimation of d would be desirable and empirical functions to calculate d and z_0 as a function of canopy height (h) are usually applied, often referred as “rule-of-thumb” equations (Cowan, 1968; Campbell and Norman, 1998):

$$d = \frac{2}{3} h \quad (1)$$

$$z_0 = 0.1 h \quad (2)$$

These equations can give good estimation of roughness parameters for dense canopies, but tend to diverge in case of sparse or row canopies (e.g. vineyards) (Shaw and Pereira, 1982). Indeed, vineyards are highly structured canopies, with a distance (l) between rows that is usually quite large ($l/h > 1$). These structural features highly influence turbulent flow within and above the canopy, resulting in different aerodynamic characteristics depending on wind direction. Indeed, if mean wind blows parallel to rows, the turbulent field is comparable to open canopies, while, as wind approaches a direction perpendicular to rows, turbulence statistics become more similar to closed rough canopies (Weiss et al., 1976; Chahine et al., 2014; Miller et al., 2017). This clearly has an effect on the aerodynamic parameters

of vineyards. Miller et al. (2017) showed that d/h increases from 0.68 (along-row) to 0.85 (cross-row), estimating d from profile measurements of friction velocity within the canopy. However, Chahine et al. (2014) derived d from a Large Eddy Simulation model and found a smaller variation of d/h (from 0.62 to 0.69) depending on wind direction. Similarly, vineyard z_0 shows a sigmoidal relationship with wind direction, with lower and higher values at parallel and perpendicular winds, respectively (Alfieri et al., 2019).

The LAS installation can be challenging, especially in case of surfaces with tall vegetation or urban canopies. Indeed, the LAS should be placed at a minimum height from canopy top such as the beam is located in the surface layer but above the roughness sublayer (RSL), i.e. in the inertial sublayer. The RSL is the part of atmosphere adjacent to the canopy, where characteristics of turbulent flow directly depends on the length scale of individual roughness elements (Raupach et al., 1980) and MOST theory does not apply (Raupach and Thom, 1981). Therefore, if installed in the RSL, alternative functions should be implemented to obtain LAS fluxes (Roth et al., 2006). The extension of the RSL varies from site to site, especially depending on canopy density and the spacing between canopy elements (Garratt, 1980; Raupach et al., 1980). Previous studies found that the RSL can extend from approximately 10 times z_0 over dense forests (Thom et al., 1975) to about 80 times z_0 over sparse trees and shrubs (Garratt, 1978), but higher values were reported by (Garratt, 1980) with 35 and 150 times z_0 for dense and sparse vegetation sites, respectively. A general rule-of-thumb is that micrometeorological instrumentation should be placed at a height $> 1.5 h$ to avoid the RSL (Monteith and Unsworth, 2013). However, in some cases, it is not practical to install LAS transmitter and receiver above the RSL due to technical or footprint limitations (Roth et al., 2006; Zhang et al., 2010).

In this manuscript, we compare measurements of H by EC and LAS collected in two commercial vineyards with different climatic characteristics (i.e. Northern and Southern Italy) and instrument setup. The aims of the study are: a) evaluate the reliability of LAS measurements on the same canopy type but in contrasting environmental conditions (i.e. dry and humid climate), characterized by large differences in the magnitude of H fluxes; b) estimate z_0 in a row canopy using different approaches and assess its impact on LAS data processing; c) investigate how changes in z_{eff} due to canopy development,

approaching the RSL, affect LAS measurements; d) interpret the results from EC and LAS comparison in the framework of the energy balance closure problem.

2. Material and methods

The datasets analyzed in this manuscript were collected during two field campaigns carried out on the same canopy type (vineyard, *Vitis vinifera* L.), but in different geographical locations with contrasting climate.

2.1 Minervino study site and data processing

The first campaign was carried out from 31/07 to 05/08 of 2016 in an extensive commercial vineyard of 140 ha located in Minervino Murge (hereafter, MIN), Apulia region, South Eastern Italy (41°8'50.08"N, 16°2'33.47"E). The region is characterized by hot-summer Mediterranean climate (Köppen climate classification: Csa), with average annual temperature around 16 °C and average winter and summer temperature of 9 °C and 24 °C, respectively. The average total annual precipitation is about 441 mm, mainly distributed in autumn and winter, while summer is usually dry. The soil is Haplic calcisol (WRB, 2015), with accumulation of secondary carbonates starting around 0.8 m depth. The texture is 25% clay, 12% silt, and 63% sand.

The canopy is structured in rows spaced 2.0 m apart. Plant spacing is 0.8 m, canopy height is 1.9 m and row width is 0.4 m. The whole soil surface is kept clear of grass by frequent cultivation, to avoid competition for water and nutrients with grapevine, a common practice in semi-arid Mediterranean regions. The study area is characterized by a gentle slope and uniform vegetation (Fig. 1a). The vineyard is sectioned in plots, where irrigation is sequentially applied. Water is distributed by a drip irrigation system, at a rate of 1 mm h⁻¹ on the row in the middle between two plants. During this study, *H* was monitored over two plots: Plot1 (blue border, 5.46 ha) and Plot2 (orange border, 12.78 ha). Plot1 was irrigated on 01/08 (Irr1) and 05/08 (Irr2) starting at 7:00 for 8 hours, while Plot2 from 18:00 on the same days for 10 hours.

In order to characterize energy fluxes under different irrigation conditions, three EC stations were deployed: EC1 and EC2 in Plot2, and EC3 in Plot1. Each station was equipped with a CSAT3 sonic

anemometer (Campbell Scientific, Inc., Logan, UT, USA) installed on a vertical mast at 3 m height oriented with an azimuth of 312° N, in order to best sample fluxes according to prevailing wind directions (Fig. 1b). Additionally, EC1 was equipped with a LI-7500 open-path CO₂ and H₂O infrared gas analyzer (LI-COR Biosciences, Lincoln, NE, USA). Data from CSAT3 (and LI-7500) were collected and stored at a frequency of 20 Hz by a CR3000 datalogger (Campbell Scientific, Inc., Logan, UT, USA) at EC1 and CR6 dataloggers (Campbell Scientific, Inc., Logan, UT, USA) at EC2 and EC3. Raw data were processed using the open-source software EddyPro (LI-COR Biosciences, Lincoln, NE, USA), obtaining corrected fluxes and statistics every 30 min.

The source area of EC fluxes was calculated and graphically represented adapting the IDL codes by A. Christen (<https://github.com/achristen/Gridded-Turbulent-Source-Area>), following the Kormann and Meixner (2000) analytical footprint model. The LAS footprint area was computed based on the footprint model by Soegaard et al. (2003) combined with the LAS weighting function along the path, as described in Timmermans et al. (2009).

A 2D sonic anemometer (DS-2, Decagon Devices, Pullman, WA, USA) was installed at 5 m at EC1 to measure mean wind speed for the estimation of roughness parameters. Ancillary meteorological variables were also measured at EC1: downward/upward shortwave and longwave radiation at 3 m with a CNR4 4-way net radiometer (Kipp & Zonen, Delft, The Netherlands); air temperature and humidity at 3 m by a shielded HMP45C sensor (Vaisala, Helsinki, Finland). Soil heat flux was measured at EC1 with HFT3 plates (REBS, Seattle, WA, USA) at 8 cm depth in three locations (on the row, at quarter and middle of the alley), in order to properly sampling heterogeneity of soil flux due to canopy shading. Soil temperature and water content were monitored at 4 cm depth nearby each heat flux plate with 5TM probes (Decagon Devices, Pullman, WA, USA). Meteorological and soil variables were collected by a CR3000 at a sampling frequency of 1 Hz, storing statistics every 1 min and 30 min.

Soil temperature and moisture measurements were used to calculate the heat stored above each plate every 30 minutes, which was added to the measured soil heat flux (G_m), in order to obtain a better assessment of the heat transfer close to soil surface. We computed the total soil heat flux (G_t) at each location as (Foken, 2016):

$$G_t = G_m + \frac{C_G |\Delta z| [\overline{T(t_2)} - \overline{T(t_1)}]}{t_2 - t_1} \quad (3)$$

where C_G [$10^6 \text{ W s}^{-1} \text{ m}^{-3} \text{ K}^{-1}$] is the volumetric heat capacity, Δz [m] is the depth of the heat flux plate, $T(t_1)$ and $T(t_2)$ [K] are the 1-min average soil temperatures measured in the soil above it at beginning (t_1) [s] and end (t_2) [s] of the averaging interval. The soil volumetric heat capacity was derived using information on soil texture and water content measured above the plate, using the following equation (De Vries, 1963):

$$C_G = (1.93 \chi_m + 2.51 \chi_o + \chi_w) \quad (4)$$

where χ_m , χ_o , and χ_w are the volume fraction of soil minerals, organic matter, and water, respectively. The overall soil heat flux (G) was then computed as the spatial average of G_t obtained at each location. The average sensible heat flux over the two plots was measured by a LAS BLS900 (Scintec AG, Rottenburg, Germany) along a path of 760 m. The LAS receiver was placed at 5.75 m from ground surface on a terrace of the winery building, while LAS source was installed on the top of a hump in the middle of the vineyard at 2.10 m from ground. However, due to orography of the surface, the LAS source was about 8 m higher respect to the receiver. Both source and receiver were installed on geodetic tripods to ensure sensor stability. LAS measurements were sampled and processed by the Signal Processing Unit provided by Scintec, storing raw data at 5 Hz and computing statistics on diagnosis subperiods of 30 sec. To obtain sensible heat flux by LAS (H_{LAS}) every 30 min, diagnosis data were post-processed with SRun software vs 1.53 (Scintec AG, Rottenburg, Germany) by providing mean wind speed, air temperature and pressure (measured at EC1), beam effective height, and roughness length as additional inputs. For a detailed explanation on d and z_0 estimation please refer to Section 2.3. On uneven terrain, z_{eff} varies along the path and an average value should be assessed by multiplying the beam height at several points by specific coefficients obtained from the path weighting function (PWF) for LAS, as reported in the scintillometer theory manual by Scintec AG (2016) (Fig. 2). The PWF describes the relative contribution of turbulent eddies to the average flux in relation to their position on the LAS path (Wang et al., 1978). In complex terrain, the effect of atmospheric stability should also be taken into account to obtain an accurate estimate of z_{eff} . Thus, we calculated z_{eff} from the weighted

average of the beam height at 10 points along the path, using the expression (Hartogensis et al., 2003; Kleissl et al., 2008):

$$z_{eff} = \left(\frac{\int_0^1 z(x)^b PWF(x) dx}{\int_0^1 PWF(x) dx} \right)^{b^{-1}} \quad (5)$$

where $z(x)$ is the beam height at position x ($0 \leq x \leq 1$), $PWF(x)$ is the LAS path weighting function at position x , and b is a constant accounting for the stability dependence ($b = -4/3$ in unstable conditions, $b = -2/3$ in neutral and stable conditions). Applying this procedure, we obtained z_{eff} estimates of 5.86 m and 6.06 m for unstable and stable conditions, respectively.

The EC stations were deployed along the path of the scintillometer providing three independent measurements of sensible heat flux (H_{EC1} , H_{EC2} and H_{EC3} , respectively). The station EC1 was placed in irrigation Plot2 almost in the middle of the path (45 % relative distance from LAS source), EC2 was in the same irrigation plot but closer to the receiver (84 % relative distance from LAS source), and EC3 was in irrigation Plot1 nearby the source location (24 % relative distance from LAS source). In order to better compare H by the EC stations with H_{LAS} , we calculated the weighted average of H from the EC stations (H_{ECavg}) using the coefficients of the PWF corresponding to the location of each station relative to the LAS source (Evans et al., 2012): $H_{ECavg} = (0.21 H_{EC2} + 0.93 H_{EC1} + 0.36 H_{EC3}) / (0.21 + 0.93 + 0.36)$.

2.2 Lison study site and data processing

The second campaign was carried out from 12/06 to 25/06 of 2017 in a commercial vineyard of 33 ha located in North Eastern Italy at Lison di Portogruaro (hereafter, LIS), Veneto region, North Eastern Italy ($45^{\circ}44'25.80''N$ $12^{\circ}45'1.40''E$). The climate of the area is temperate (Köppen climate classification: Cfb), with average annual temperature of 13 °C, summer and winter average temperature of about 22 °C and 3 °C, respectively. The average total annual precipitation is around 1000 mm, the distribution is homogenous throughout the year, with peaks in autumn and spring. The soil is classified as Endogleyic Calcisol (WRB, 2015), with no skeleton and hydromorphic features below 0.8 m. The texture is 54% clay, 22% silt and 24% sand. The vineyard is rainfed and the alleys are covered with

resident herbaceous vegetation, except for a chemically weeded strip 0.6 m wide under the row. The structure of the vineyard is similar to MIN site, with rows spaced 2.2 m apart and 0.5 m wide, plant spacing of 0.9 m and h of about 2 m at full development. However, during the study period, the latter changed slightly due to shoot growth. We manually measured h and split the dataset in three periods: from 12/06 to 14/06, h was about 1.7 m; from 15/06 to 20/06, it was around 1.8 m; and in the period 21/06 to 25/06, it reached 2 m (Tab. 1).

Eddy covariance measurements of CO₂, sensible and latent heat fluxes have been performed at the site since 2014 as part of a long-term monitoring of vegetation-atmosphere exchange over vineyards. For a more detailed description of the site and instrument setup please refer to Tezza et al. (2019) and Vendrame et al. (2019). The EC system (CPEC200 by Campbell Scientific, Inc., Logan, UT, USA) was placed at 4 m height, where sonic temperature and 3D wind components were measured by a CSAT3A sonic anemometer, sampled at 10 Hz and collected by a CR3000 datalogger. EC data were processed in the same way as described for MIN site. Additionally, mean wind speed was measured at 3.2 m by a A100 cup anemometer (Vector Instruments, United Kingdom) sampled at 1 Hz. Ancillary meteorological variables were sampled at 1 Hz by a CR3000 datalogger and statistics saved every 1 and 30 min. Soil state variables (temperature and water content), as well as soil heat flux measured with four HFP01 heat flux plates (Hukseflux, Delft, Netherlands) at 0.08 m depth, one in the row and at three points along a diagonal transect in the alley, were collected at 0.2 Hz and statistics saved at 30-min intervals. The overall soil heat flux was computed accounting for storage above the flux plate following the approach described in Section 2.1.

The Scintec BLS900 was deployed in the vineyard for this short-term campaign. The receiver was placed nearby the EC tower on a geodetic tripod at 2.9 m height and the source was installed at the same height on the southern border of the field (Fig. 1c). The resulting path length was 212 m, thus reduction disks on BLS900 source and receiver were required to reduce signal strength to a proper level. Raw data were collected at a frequency of 5 Hz by the Scintec SPU and diagnosis subperiod statistics calculated every 30 sec, which were then reprocessed with SRun vs 1.53 (Scintec AG, Rottenburg, Germany). Mean wind speed measurement by the CSAT3A, z_{eff} specific for each of the three periods

(calculated as $z_{eff} = z_{LAS} - d$), and z_0 as a function of wind direction (see Section 2.3) were provided as additional inputs to calculate 30-min H_{LAS} .

2.3 Estimation of canopy roughness parameters

The inversion of the logarithmic wind profile equation for d is quite sensitive to the need of near-neutral conditions (Alfieri et al., 2019), making it difficult to obtain reliable results. In this study, unfortunately, we did not have enough wind profile measurements available to obtain good calculation of site-specific d . Therefore, we estimated d applying the rule-of-thumb equation (Eq. 2). Once d is known, z_0 can be calculated from wind speed and friction velocity measured by a 3D sonic anemometer at a single height by inverting the logarithmic wind profile equation in near-neutral condition:

$$z_0 = (z - d) e^{-\kappa \frac{U(z)}{u_*}} \quad (6)$$

where $\kappa = 0.4$ is the von Kármán constant, $U(z)$ is mean wind speed measured at measurement height z , and u_* is friction velocity. This approach can provide a better estimation of z_0 compared to Eq. 2 because it accounts for site-specific canopy structure and periods with different characteristics (e.g. wind direction) can be isolated, but it is very sensitive to measurement errors and violations of theoretical assumptions (e.g. neutral atmospheric stability conditions). For this reason, we applied the methodology used by Alfieri et al. (2019) to select only appropriate periods for z_0 calculation: a) global radiation $\geq 100 \text{ W m}^{-2}$; $U(z) \geq 1 \text{ m s}^{-1}$; $u_* \geq 0.1 \text{ m s}^{-1}$; $-0.04 < \zeta < 0.02$, where $\zeta = z/L$ is the stability parameter and L is the Monin-Obukhov (MO) length; b) two values of z_0 were calculated from wind measurements at two heights for each selected period, and were considered valid only if their agreement was within 10%. In order to better identify intervals with atmospheric conditions close to neutrality and to have a larger number of valid periods, Eq. 6 was solved with statistics calculated every 5 min. Applying the filtering criteria, about 8% of available 5-min periods during daytime were used in the computation of z_0 at both sites. We split the dataset in three groups based on the absolute value of the difference between wind and row directions ($wdir$, 0 to 90°): down-row ($wdir \leq 22.5^\circ$); diagonal ($22.5^\circ < wdir < 67.5^\circ$); cross-row ($wdir \geq 67.5^\circ$), obtaining z_0 down-row, z_0 diagonal, and z_0 cross-row, respectively. Additionally, an average value (z_0 avg) was calculated neglecting wind direction. The

values of z_0 for each group at both sites are reported in Table 2, at LIS the dataset was additionally split in three periods according to h .

2.4 Calculation of u_* in the context of Monin-Obukhov similarity theory

An accurate estimation of canopy roughness parameters, required inputs for LAS data processing, is particularly important in order to obtain reliable calculation of u_* using the flux profile relationship in the context of MOST:

$$u_{*MO} = \frac{\kappa U(z_u)}{\ln\left(\frac{z_u}{z_0}\right) - \Psi_m\left(\frac{z_u}{L}\right) + \Psi_m\left(\frac{z_0}{L}\right)} \quad (7)$$

where $U(z_u)$ is the mean wind velocity at z_u ($z_u = z - d$), Ψ_m is the stability correction for the transfer of momentum ($\Psi_m = -2 \ln((1+x)/2) - \ln((1+x^2)/2) + 2 \arctan(x) - \pi/2$, with $x = (1 - 15 \zeta)^{1/4}$, for $\zeta < 0$ (Paulson, 1970); $\Psi_m = 4.7 \zeta$, for $\zeta > 0$ (Businger et al., 1971)), and L is the MO length. The latter is derived iteratively in LAS data processing, but it can be calculated directly from sonic anemometer measurements as:

$$L = \frac{u_{*EC}^3}{\kappa \frac{g}{T} \overline{w'T'}} \quad (8)$$

where u_{*EC} is friction velocity from EC measurements, g is the acceleration due to gravity, T is the air sonic temperature and $\overline{w'T'}$ is the kinematic heat flux. We calculated L for each 30-min periods at both sites using Eq. 8 and u_{*MO} with Eq. 7, using z_0 estimated with different methods (Eq. 2 and Eq. 6) and divided for wind direction.

3. Results and discussion

Being quite similar in canopy structure, experimental sites were mainly different for: a) LAS path length and height; b) source surface heterogeneity; c) Bowen ratio ($\beta = H/LE$). First, the influence of z_0 value used as input for H_{LAS} calculation will be evaluated. Afterwards, comparison between H_{LAS} and H_{EC} during the study period at both sites will be presented, considering the differences between sites and their implications on measured fluxes.

3.1 Impact of different methods to estimate z_0 on LAS data processing

The application of rule-of-thumb equation led to lower z_0 compared to the values computed from wind speed measurements neglecting wind direction ($z_0 \text{ avg}$), being more similar to z_0 calculated for periods of wind parallel to rows ($z_0 \text{ down-row}$) (Tab. 2), confirming that the use of rule-of-thumb equation is not appropriate in case of row canopies (Shaw and Pereira, 1982). Indeed, $z_0 \text{ down-row}$ was smaller compared to periods with wind blowing diagonal ($z_0 \text{ diagonal}$) or perpendicular ($z_0 \text{ cross-row}$) to row orientation, with the latter being always larger. A similar pattern, increase of z_0 from parallel to perpendicular wind directions, was found by Alfieri et al. (2019). Indeed, down-row wind can penetrate deeper within the canopy, while as it approaches perpendicular direction to row, most of momentum is absorbed close to canopy top (Chahine et al., 2014; Miller et al., 2017). At LIS, z_0 was also influenced by canopy growth, increasing from T1 to T3. The greatest increment was found for $z_0 \text{ diagonal}$ from T1 to T2 (+ 18%), while from T2 to T3 it did not change notably (+ 2%). A similar pattern was found for $z_0 \text{ cross-row}$, even though not enough valid measurements were available during T1. On the contrary, when wind was blowing parallel to rows, the influence of shoot growth on z_0 was insignificant. Even if the structure of the vineyard was quite similar at the two experimental sites, vine vigor (determining foliage density) and row thickness was higher at LIS, thanks to favorable environmental conditions (good water availability) compared to MIN (dry climate). This reflected in higher canopy roughness at LIS, confirming that z_0 increases with density in sparse canopies (Shaw and Pereira, 1982), but only in case of diagonal and perpendicular flows, while $z_0 \text{ down-row}$ at full development was similar at both sites.

As previously outlined, a good estimation of z_0 is fundamental for LAS data processing and, specifically, for the calculation of friction velocity (u_{*MO}) (Eq. 5). To evaluate the accuracy of estimated z_0 , we compared u_{*MO} , computed using z_0 obtained with different methods, with u_{*EC} (Fig. 3a and 3b). The plots presented include only data for unstable conditions in order to show significant periods in terms of H_{LAS} . A much larger scatter, mainly overestimation of u_{*MO} , was found in stable conditions (data not shown), but its influence on H_{LAS} would have been low because of the small magnitude of H in stable periods. The use of z_0 values obtained from wind speed measurements for selected wind direction gave the best correlation between measured and calculated u_* , with only a slight

underestimation of u_{*MO} at LIS. On the contrary, the correlation was lower using either z_0 *avg* or z_0 *rule-of-thumb*. The latter led to an underestimation of u_{*MO} at both sites, while ignoring the effect of wind direction resulted in higher and lower values of u_{*MO} compared to u_{*EC} at MIN and LIS, respectively. This difference between sites was probably due to the predominant wind direction respect to row orientation. Indeed, at LIS, the wind was mostly coming from South (i.e. parallel to rows), while at MIN the most frequent direction was North-West (i.e. diagonal to rows).

The different z_0 values were also used as input in SRun software for LAS data processing, obtaining distinct H_{LAS} for each one of the three approaches used to derive z_0 . We compared H_{LAS} with H_{EC} at LIS and H_{ECavg} at MIN, in order to evaluate the impact of z_0 on the calculation of H_{LAS} (Fig. 3c and 3d). Unexpectedly, the best agreement was found for H_{LAS} calculated from z_0 *rule-of-thumb*, showing a small underestimation (slope = 0.95) at LIS and overestimation (slope = 1.08) at MIN, respectively. The use of z_0 obtained from EC measurements, whether or not accounting for wind direction, caused a comparable overestimation at both sites. On the contrary, Zhang et al. (2010) reported a better agreement between sensible heat by LAS and EC using an improved estimation of z_0 , but still based on the rule-of-thumb equation and not on the inversion of the wind profile equation as in our case. The largest difference between the use of z_0 *rule-of-thumb* or directly calculated from measurements was found at LIS, while at MIN all z_0 approaches gave comparable results. The higher sensitivity of LIS fluxes to z_0 may be related to higher mechanical turbulence at this site compared to MIN, which increases the sensitivity of H_{LAS} to changes in u_* (Asanuma and Iemoto, 2007). In general, an underestimation of z_0 using the rule-of-thumb approach resulted in underestimation of u_{*MO} , causing a reduction of H_{LAS} (Chehbouni et al., 2000), but a better agreement between H_{LAS} and H_{EC} at our sites. This might be misleading, because there are other aspects (e.g. instrument setup, footprint) to take into account when comparing H_{LAS} and H_{EC} , as it will be discussed later in the manuscript. Despite a worse agreement with H_{EC} , the H_{LAS} values which will be presented from now are those calculated with z_0 derived from wind measurements and specific for wind direction sectors.

3.2 Sensible heat fluxes at MIN

The distance between the LAS source and receiver at MIN was 760 m, crossing two plots with different irrigation schedule. The comparison between H_{LAS} and H_{EC} from each of the three stations is presented in Fig. 4. The best agreement between EC and LAS measurements was found for the station in the middle of the path (EC1), with slope of the linear regression line of 1.05. On the contrary, the station in the same irrigation plot of EC1, but closer to the receiver (EC2), showed the poorest relationship with H_{LAS} (slope = 1.38). The agreement with fluxes measured by the third station (EC3), placed in another irrigation plot and closer to the LAS source, was somehow intermediate, with a slope of 1.15. In theory, the calculation of weighted average H measured by the EC stations (H_{ECavg}), using the PWF coefficients corresponding to station locations, should give a better correlation with LAS measurements. However, we found that H_{LAS} was higher than H_{ECavg} (Fig. 3c, blue squares) and the relationship was poorer compared to H_{EC1} , with a regression slope of 1.12. Actually, this is not surprising because H_{LAS} is determined by the average exchange over a source area that varies with wind direction. Therefore, a combination of PWF and footprint analysis should be performed in case of surface heterogeneity, in order to better compare H_{LAS} with aggregated fluxes from EC stations (Meijninger et al., 2002a; Timmermans et al., 2009; Evans et al., 2012). Indeed, the higher agreement between H_{LAS} and H_{EC3} , compared to H_{EC2} , can be related to the prevailing wind direction during the experiment (North-West) (Fig. 1b), almost parallel to the LAS path and coming from the LAS receiver. In this condition, the footprint area of EC3 was overlapping a part of LAS footprint that has higher influence (towards the middle of the path) on determining H_{LAS} compared to the source area of EC2 (very close to the LAS receiver) (Fig. 5b).

In order to better analyze the dynamics of sensible heat fluxes, the patterns of H measured by LAS and EC stations, together with net radiation, are presented in Fig. 6. In general, during days without irrigation, H_{LAS} was slightly larger than H measured by all EC stations. In particular, it showed good agreement with H_{EC1} and H_{EC3} , but not with H_{EC2} that was always considerably lower than H_{LAS} during daytime, as discussed earlier. However, when homogeneity in LAS footprint was decreased by different timing of irrigation supply to plots, the relationship between H_{LAS} and H_{EC1} or H_{EC3} was modified. On the day after Irr1 on Plot1 (01/08), H_{LAS} was lower than H_{EC1} and similar to H_{EC3} . On the contrary, the day after Irr2 (05/08), H_{LAS} remained very close to H_{EC1} , being apparently not affected by the decrease

of H_{EC3} due to irrigation. The different response of LAS measurements after the two irrigation events can be probably attributed to variations in LAS footprint and inhomogeneity of the source area caused by irrigation (Ezzahar et al., 2007). During the central part of the day 01/08, the wind was blowing from West (diagonal to LAS path) (Fig. 5a), while on 05/08 it was from North West (parallel to LAS path) (Fig. 5b). Consequently, on 01/08 the extension of LAS footprint towards West was larger, showing a smaller relative contribution of Plot2 and resulting in lower H_{LAS} compared to H_{EC1} .

3.3 Sensible heat fluxes at LIS

The instrument setup at LIS was quite different compared to MIN (Tab. 1): the LAS path was shorter (212 m), and z_{LAS} was lower, varying from 1.7h to 1.4h due to vine shoot growth during the study period. These values are close to the suggested $z > 1.5 h$ that would generally ensure that measurements are carried out in the inertial sublayer (Monteith and Unsworth, 2013), where MOST holds (Raupach and Thom, 1981). Deviation from ideal LAS setup could imply higher uncertainty in the calculation of H_{LAS} and, consequently, lower agreement between LAS and EC measurements. However, the relationship of fluxes measured with the two techniques was quite good and similar to MIN site, with a slight overestimation by LAS (Fig. 3d, blue squares). Nevertheless, looking at the time course of sensible heat fluxes (Fig. 7), we observed an increasing accordance between H_{LAS} and H_{EC} along with vine growth. During T1 and T2, H_{EC} was usually lower than H_{LAS} , but towards the end of the measurement period (highest h), they almost overlapped. To better clarify this issue, we selected two half hours at the beginning (13/06 12:30) and end of the field campaign (22/06 12:30) with very similar wind direction and atmospheric conditions, resulting in almost identical EC and LAS footprints (Fig. 8). The magnitude of H_{EC} around midday was very similar on both days (105 W m⁻² on 13/06 and 107 W m⁻² on 22/06), but the ratio H_{LAS}/H_{EC} was 1.33 and 1.15 on the first and second day, respectively. In our opinion, lower H_{LAS} on 22/06 could be related to closer proximity of z_{LAS} to the top of the canopy (1.4h), probably locating the LAS beam in the RSL.

The ratio between z_{eff} and z_0 can be used as non-dimensional parameter to assess whether or not an instrument is placed in the RSL (Zhang et al., 2010). Additionally, De Bruin and Moore (1985) suggested that the higher limit of the RSL (z^*) could be estimated as $z^* = d + 20 z_0$. At LIS,

z^* calculated with this equation was 6 m in T1 and 7.5 m in T3, while the ratio z_{eff}/z_0 avg was about 7 in T1 and 5 in T3, respectively. These estimates suggest the presence of a thick RSL, with the LAS certainly placed in the RSL during the whole campaign. However, turbulence profile measurements over a vineyard with a structure similar to LIS showed that the RSL usually extend to a height between $1.4h$ and $2.3h$ (Miller et al., 2017) and reported absolute values of the skewness of vertical wind velocity at $1.4h$ close to 0.2, the limit identified by Raupach and Thom (1981) to ensure the applicability of MOST. Therefore, the estimates of z^* probably exaggerated the actual thickness of the RSL at our site. The LAS was installed at 2.9 m, corresponding to $1.7h$, $1.6h$, and $1.4h$ in T1, T2, and T3, respectively (Tab. 1). Consequently, LAS measurements were probably conducted above the RSL in T1, but in T2 and T3 the beam was closer to the transition between inertial sublayer and RSL. This would imply an error in the derivation of H_{LAS} because the equations used in LAS data processing do not apply in the RSL (Roth et al., 2006). Furthermore, u_* was calculated with wind speed measurement at z_{EC} , which varied between $2.3h$ to $2.0h$, thus deriving values only representative of the inertial sublayer. The u_* at z_{eff} could be higher because the exchange of momentum is increased in the RSL by the influence of single vegetation elements (Thom et al., 1975; Garratt, 1978). Zhang et al. (2010) suggested that if LAS measurements are carried out in the RSL, the effect would be an underestimation of the sensible heat flux due to greater eddy diffusivities and, consequently, larger momentum and scalar exchanges in this atmospheric layer (Thom et al., 1975). Therefore, we could argue that the enhancing agreement between H_{LAS} and H_{EC} during the measurement campaign was probably caused by an underestimation H_{LAS} due to increasing proximity with canopy elements as vine developed.

3.4 Considerations on energy partitioning and energy balance closure

Another important difference between sites was the magnitude of H . Indeed, despite of similar net radiation, at LIS the midday peak on clear days was just above 100 W m^{-2} , almost 60% lower compared to the maximum H at MIN. This implies that most of the available energy at the surface at LIS was converted to LE , while at MIN to H . Indeed, the average midday Bowen ratio at the two sites was quite different, 0.5 and 2.1 at LIS and MIN, respectively. First of all, this implies diverse environmental conditions, in particular air humidity, that can affect LAS measurements and the application of MOST

to calculate fluxes. Variations in n measured by LAS are caused by fluctuations in both humidity and temperature, which determine the structure parameter C_n^2 . If a scintillometer operates at optical wavelength, as is the case of the BLS900 used in this study, the influence of humidity fluctuations is small and can usually be neglected. Indeed, the SRun software makes this assumption to derive H_{LAS} from C_n^2 . Nevertheless, the magnitude of the effect of humidity fluctuations on C_n^2 depends on the level of air humidity itself and a correction based on β can be applied to calculate C_T^2 from C_n^2 (Wesely, 1976; Moene, 2003). Neglecting this correction can cause a C_T^2 of about $0.03 \beta^{-1}$ higher and a consequent increase in H_{LAS} . Therefore, the error is larger at sites characterized by smaller β (LIS) compared to drier sites (MIN). Nevertheless, at humid sites the absolute magnitude of H is small and the impact on the energy balance closure may be minor (Moene, 2003).

Despite the non-ideal conditions for the application of scintillometry technique at LIS, the agreement between EC and LAS measurements was good (Fig. 3d, blue squares) and similar to MIN (Fig. 3c, blue squares). On the contrary, the energy balance closure calculated with turbulent energy fluxes by EC was quite different at the two sites (Fig. 9). The closure at MIN was 79%, a value very similar to what found on average at various EC sites (Wilson et al., 2002), but at LIS it was only 64%. If independent measurements of H or LE are not available, the general approach is to consider that both H and LE are equally underestimated by EC measurements and the energy balance residual is distributed among them preserving β (Twine et al., 2000). However, our results, showing good agreement between H_{EC} and H_{LAS} at both sites but worst energy balance closure at LIS, suggest that the underestimation of LE by EC was somehow greater compared to that of H . Zhao et al. (2018) found comparable results at a seasonally-inundated wetland in Florida, USA, with lower (60%) and higher (78%) energy balance closure during the wet and dry season, respectively, and similar agreement between H_{EC} and H_{LAS} in both seasons. For this reason, they suggested that the measurement of LE by EC could be more critical compared to that of H in terms non-closure of the energy balance, even if errors in the estimation of G during the wet season might also have contributed. Several studies found a good agreement between H_{EC} and H_{LAS} together with non-closure of the energy balance using turbulent EC fluxes (Meijninger et al., 2006; McGloin et al., 2014; Pozníková et al., 2018), thus probably implying an underestimation of LE by EC. Comparing independent measurements of LE using the EC method and lysimeters, Mauder et al. (2017)

found that LE by EC was about 30% lower compared to lysimeter measurements, this value being very close to the lack of energy balance closure at their site. Additionally, direct comparison of LE derived by lysimeter and scintillometer measurements showed comparable results at an agricultural site (Moorhead et al., 2017). Therefore, our results, in agreement with findings by previous studies, suggest that the reason for the non-closure of the energy balance at EC sites should be investigated especially in regards to LE measurements by EC.

4. Conclusions

The sensible heat flux was measured with EC and LAS over two contrasting (dry and humid) vineyards, with midday H of about 100 W m^{-2} at the humid site and above 300 W m^{-2} at the dry vineyard. In general, there was good agreement between techniques at both sites, with a slight overestimation of fluxes by LAS.

The calculation of z_0 from wind measurements showed that the roughness of the vineyards changed with wind direction, thus direct estimates of z_0 should be preferred in row canopies to improve the accuracy of LAS data processing. Indeed, the best agreement between friction velocity measured by EC and calculated from MOST relationship was found using z_0 values specific for wind direction (i.e. down-row, diagonal, and cross-row).

Where multiple EC stations were deployed, LAS measurements had the best agreement with the EC station located in the middle of the path. In case of surface heterogeneity due to differential irrigation between plots, LAS fluxes were more or less affected depending on the source area, highlighting the importance of combining footprint model with PWF for a better interpretation of LAS measurements. The LAS effective height changed at LIS due to vine growth, affecting measured fluxes. In particular, there was a relative reduction of H_{LAS} compared to H_{EC} along with shoot development, resulting in better agreement between methods. This pattern was probably linked to the approaching of LAS beam to RSL, where MOST relationships do not apply, causing lower H_{LAS} due to underestimation of friction velocity. Thus, special attention should be paid on LAS installation at low height where canopy growth may bring the LAS beam close or even inside the RSL.

The closure of the energy balance assessed with turbulent energy fluxes by EC was higher (79%) at the dryer site and lower (64%) at the humid vineyard. Nevertheless, the agreement between H_{LAS} and H_{EC} was good at both sites, thus suggesting that the reason for the energy imbalance might be sought in systematic low accuracy of LE measured by EC. Under this scenario, scintillometry, combined with high-quality measurements of R_n and G , can represent an alternative and reliable technique to derive LE for agricultural purposes or for validation of remote sensing approaches to estimate LE at larger scale.

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Table 1. Characteristics of canopy structure and instrumental setup at both sites: canopy height (h); displacement height (d); ratio of EC sensor height from ground (z_{EC}) to h ; ratio of LAS path height from ground (z_{LAS}) to h ; LAS effective height (z_{eff}), calculated for neutral and stable ($\zeta \geq -0.02$) and unstable ($\zeta < -0.02$) conditions at MIN; and LAS path length.

Site	Time interval	h [m]	d [m]	z_{EC}/h	z_{LAS}/h	z_{eff} [m]	<i>LAS path</i> <i>length</i> [m]
MI N	Whole period	1.8	1.2 0	1.7	4.2	5.86 ($\zeta \geq -0.02$) 6.06 ($\zeta < -0.02$)	760
LIS	T1 (12-14/06)	1.7	1.1 3	2.3	1.7	1.77	212
	T2 (15-20/06)	1.8	1.2 0	2.2	1.6	1.70	212
	T3 (21-25/06)	2.0	1.3 3	2.0	1.4	1.57	212

Table 2. Roughness length (z_0) at MIN and LIS sites during the study periods. The rule-of-thumb equations (Eq. 2) was used to estimate z_0 *rule-of-thumb*. The average vineyard roughness length (z_0 *avg*) and the roughness length for different wind direction sectors (z_0 *down-row*, z_0 *diagonal* and z_0 *cross-row*) were calculated from measurements of mean wind speed at two heights using Eq. 6. Standard deviation is reported in parenthesis. *Not enough valid periods available (z_0 *diagonal* was used instead of z_0 *cross-row* for calculations in the manuscript).

Site	Time interval	z_0 <i>rule-of-thumb</i> [m]	z_0 <i>avg</i> [m]	z_0 <i>down-row</i> [m]	z_0 <i>diagonal</i> [m]	z_0 <i>cross-row</i> [m]
MIN	Whole period	0.18	0.24 (0.05)	0.19 (0.04)	0.22 (0.05)	0.24 (0.04)
LIS	T1 (12-14/06)	0.17	0.24 (0.07)	0.18 (0.05)	0.25 (0.06)	*
	T2 (15-20/06)	0.18	0.28 (0.09)	0.18 (0.07)	0.31 (0.07)	0.32 (0.07)
	T3 (21-25/06)	0.20	0.31 (0.07)	0.19 (0.03)	0.32 (0.07)	0.33 (0.05)

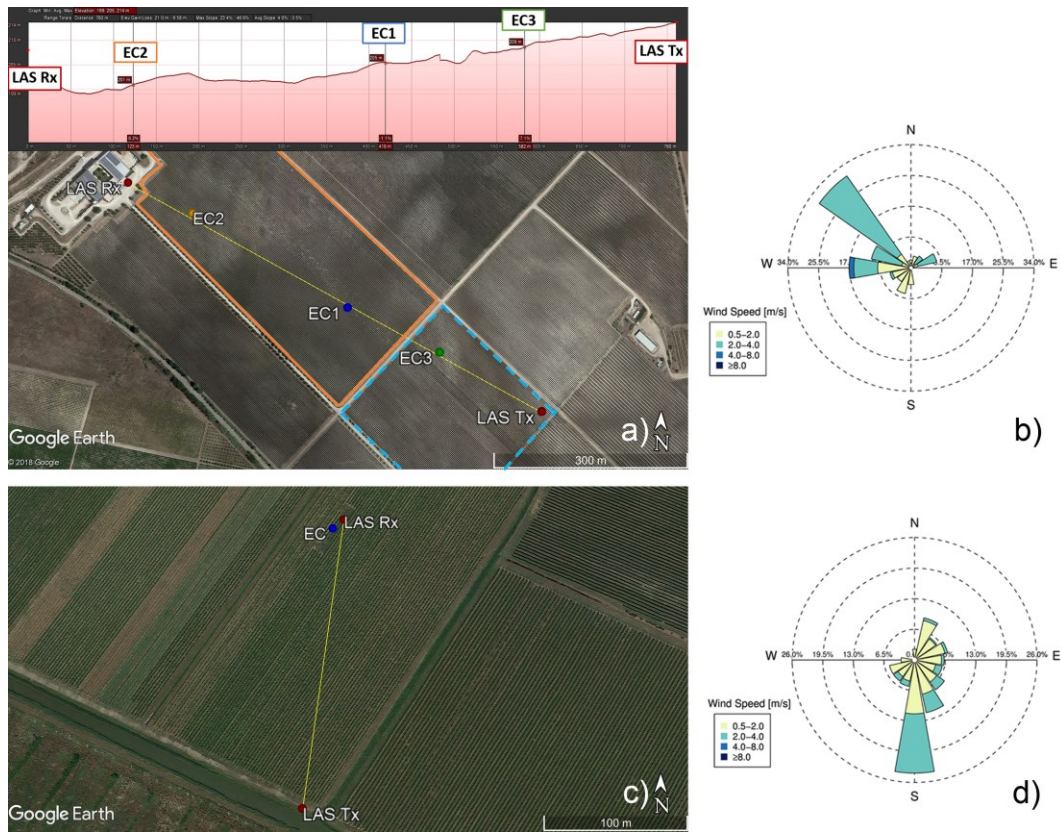


Fig.1 a) Satellite image of Minervino (MIN) site with location of LAS transmitter (LAS Tx), LAS receiver (LAS Rx), and the three EC stations (EC1, EC2, EC3). Plot1 and Plot2 are delimited by dashed light-blue line and solid orange line, respectively. The elevation profile along the LAS path is represented above. b) Windrose plot of daytime mean wind direction at MIN during the study period. c) Satellite image of Lison (LIS) study site with locations of LAS Tx, LAS Rx and the EC station. d) Same as b) at LIS. (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)

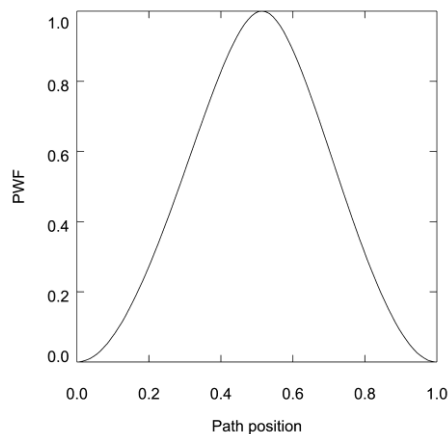


Fig. 2 Normalized path weighting function of LAS signal along the path, where 0 and 1 are the relative positions of LAS source and receiver, respectively.

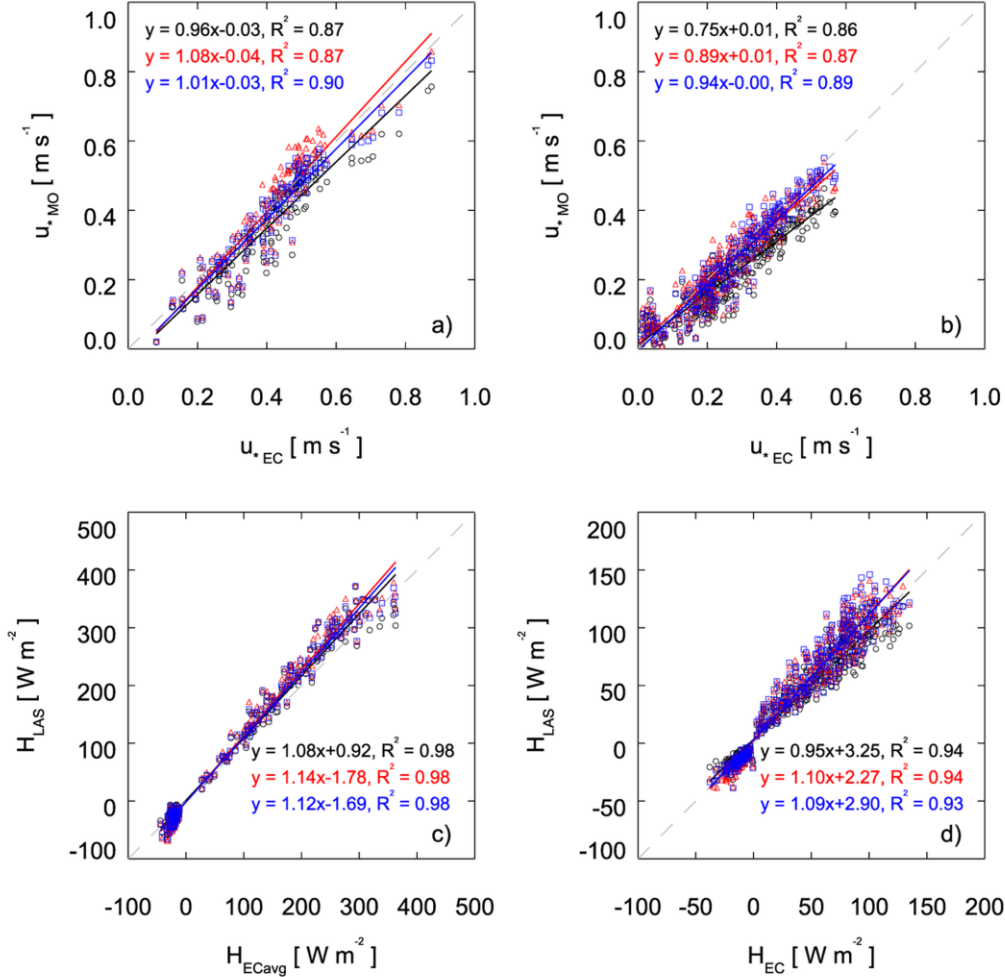


Fig. 3 a) Scatterplot of friction velocity at MIN measured by sonic anemometer (u_{*EC}) and calculated with MOST relationship (u_{*MO}) using z_0 rule-of-thumb (black circles), z_0 avg (red triangles), or z_0 down-row, z_0 diagonal and z_0 cross-row depending on wind direction (blue squares). b) Same as a) but at LIS. c) Scatterplot of sensible heat fluxes at MIN measured by EC, calculated as weighted average of the three EC stations (H_{ECavg}), and measured by LAS (H_{LAS}) using z_0 rule-of-thumb (black circles), z_0 avg (red triangles), or z_0 down-row, z_0 diagonal and z_0 cross-row depending on wind direction (blue squares) in LAS data processing. d) Same as c) but at LIS, where H_{EC} was measured by the only EC station present. The 1:1 line (grey dashed line), linear best fist (solid lines), linear regression equation and

coefficient of determination (R^2) are reported in each graph. (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)

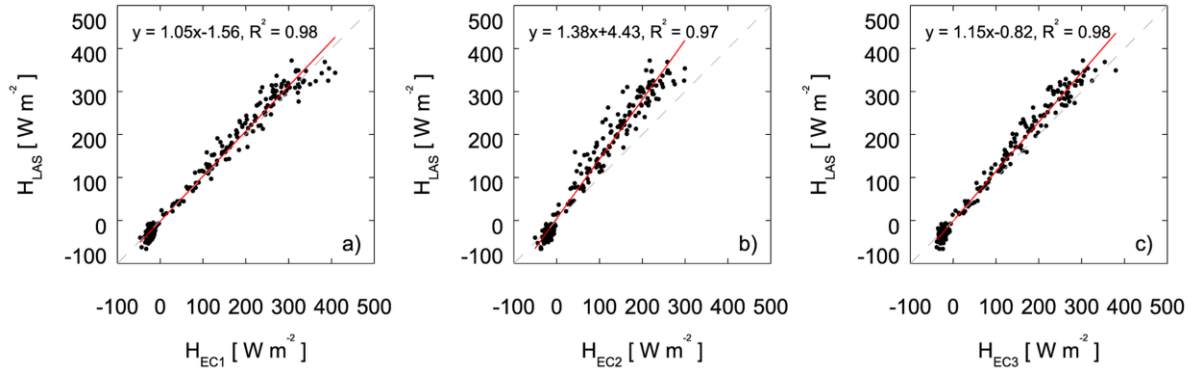


Fig. 4 Scatterplot of sensible heat fluxes at MIN measured by LAS (H_{LAS}) and EC1 (a), EC2 (b), and EC3 (c). The 1:1 line (grey dashed line), linear best fit (red line), linear regression equation and coefficient of determination (R^2) are reported in each graph. (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)

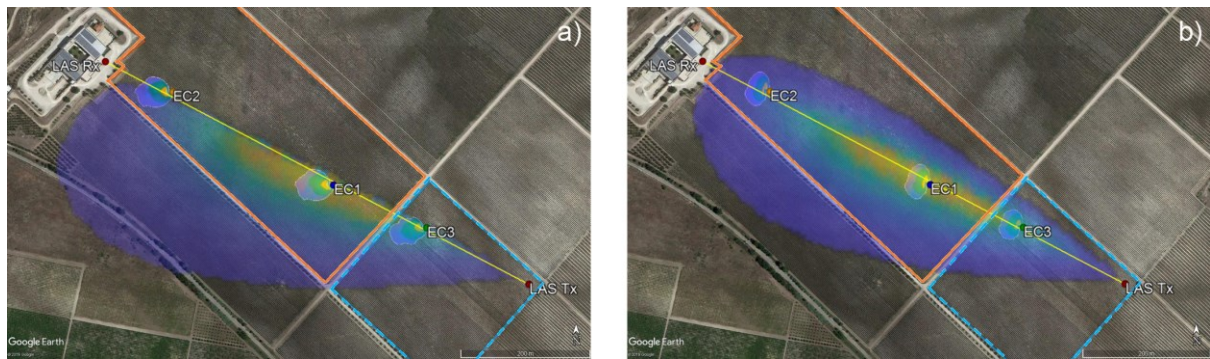


Fig. 5 a) Location and size of cumulative flux footprints at each EC station at MIN from 12:00 to 12:30 on 01/08 (Irrigation 1). The footprint area of EC and LAS corresponds to 80% of cumulative flux, yellow to purple colors represent areas of higher to lower contribution, respectively. Plot1 and Plot2 are delimited by dashed light-blue and solid orange line, respectively. b) Same as a) but from 13:30 to 14:00 on 05/08 (Irrigation 2). (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)

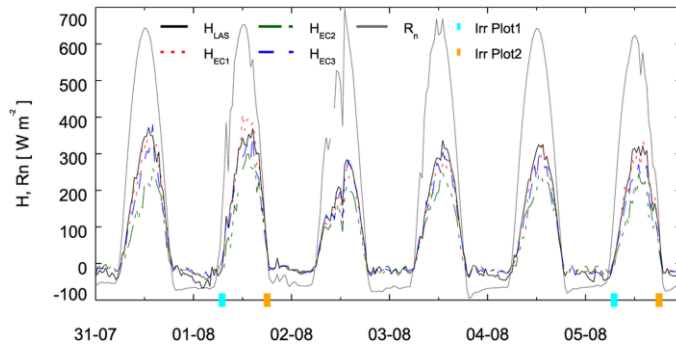


Fig. 6 Time course of sensible heat fluxes at MIN measured by LAS (black solid line), EC1 (dotted red line), EC2 (dash-dotted green line) and EC3 (dashed blue line), and net radiation (grey solid line). The start of irrigation events on Plot1 (light blue rectangle) and Plot2 (orange rectangle) is reported on the time axis. (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)

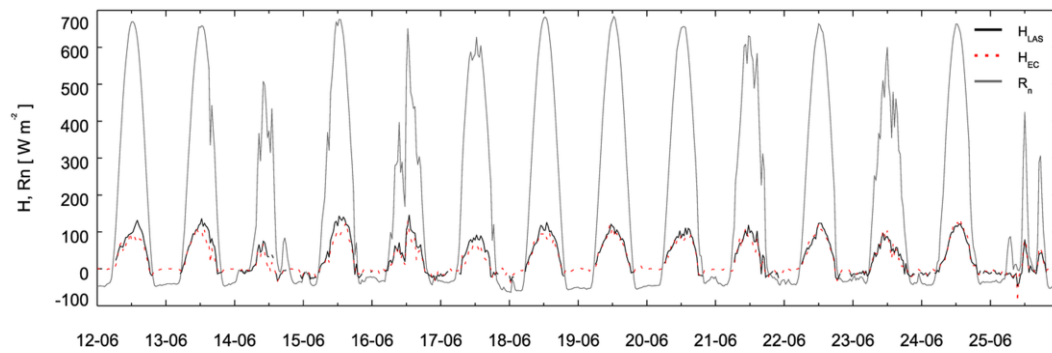


Fig. 7 Time course of sensible heat fluxes at LIS measured by LAS (black solid line) and EC (dotted red line). Net radiation (grey solid line) is also reported. (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)

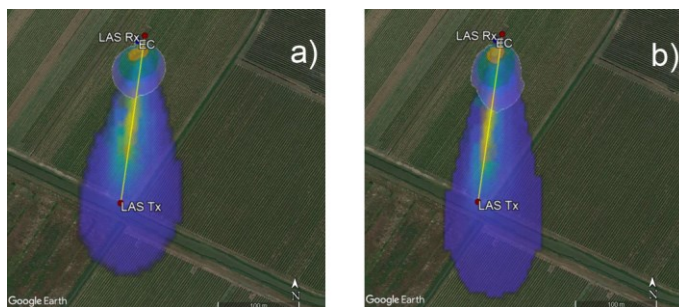


Fig. 8 a) Location and size of cumulative EC flux footprint at LIS from 12:00 to 12:30 on 13/06. The footprint area of EC and LAS corresponds to 80% of cumulative flux, yellow to purple colors represent

areas of higher to lower contribution, respectively.. b) Same as a) but on 22/06. (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)

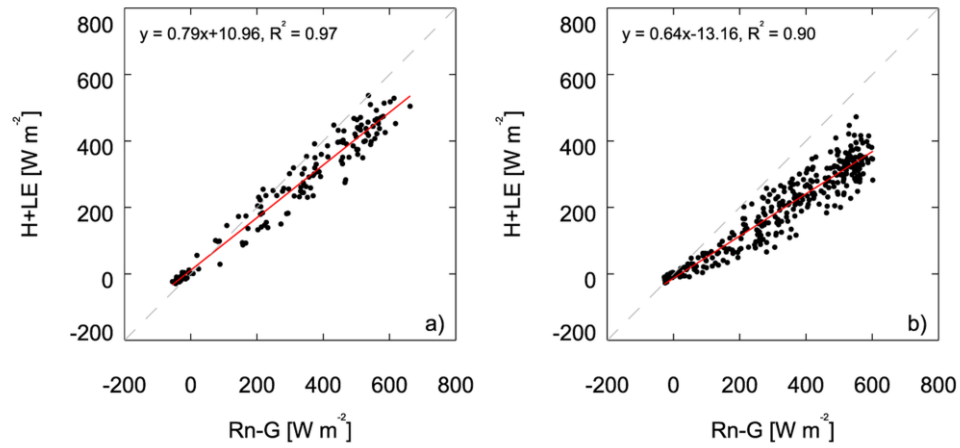


Fig. 9 a) Scatterplot of available energy ($R_n - G$) and turbulent energy fluxes by EC ($H + LE$) at MIN (EC1). The 1:1 line (grey dashed line), linear best fit (red line), linear regression equation and coefficient of determination (R^2) are reported. b) Same as a) but at LIS. (For interpretation of the references to color in this figure legend, the reader should refer to the web version of this article.)