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Large aperture scintillometer used over a homogeneous irrigated area

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Abstract - Scintillometer offer the unique possibility of measuring the vertical flux of sensible heat averaged over distances comparable with the footprint of satellite images. A Large Aperture Scintillometers (LAS) were installed over a wheat field, located in the suburb of Marrakech city (Morocco), surrounded by other parcels of wheat approximately the same growth stage. Pathlength for scintillometer was 690m. Under day time conditions, the comparison against reference fluxes obtained from eddy correlation systems shows a good agreement in dry and wet conditions.

Keywords : Large Aperture Scintillometer, optical scintillations, eddy correlation, sensible heat flux, evapotranspiration, footprint.

1 Introduction

Measurement of surfaces fluxes of sensible heat H and latent heat LvE are required for agricultural, meteorological and hydrological purposes. A way to measure theses fluxes is the use of eddy-covariance (EC) system, which is expensive and difficult to use because of maintenance problems. Another disadvantages of this method is that EC-system only provides local measurements, typically, at the scale of the order of 100 m. A optical method is another way to measure those fluxes, which is able to integrate atmospheric processes along a path length which dimension may range between a few hundred metres to a few kilometres. A number of different scintillation techniques are available. Depending on the strength of the refractive turbulent and height, laser scintillometers are limited to distances of 100 to 200m (Green & al,1994[6]). In what follows, we focus on the use of large aperture scintilometers, which allow path-averaged sensible heat fluxes over several kilometers.

The principle of the scintillometer consists of transmitting a beam of electromagnetic radiation and measuring the intensity variations of the received signal. This leads to a direct measure of the strength of the refractive index of air and then to the structure parameter for the refraction index Cn^2, which can then be related to the structure function parameter of temperature C_T^2 to derive sensible heat flux. In general scintillation methods is relatively cheap and easy to maintain, and LASs path lengths are comparable to the pixel sizes of satellite images, they enable verification of remote sensing models, used to estimate evaporation of crops using satellite images, with ground truth data(e.g. C.J. Watts & al,2000[12]). A disadvantages of the method is that it is based on the semi-empirical

Monin-obukhov similarity theory, while the eddy-covariance involves direct measurements.

Several authors tested the LAS over homogenous areas (e.g, Meijninger and Debruin (2000[7]), Mc Aneny & al.(1995), Debruin & al.(1995[3]) and Hoedjes & al (2002[4]), and over complex terrain (e.g., Chehbouni & al.(2000[1])).

The objective of this study is to check the energy balance closure for an eddy-covariance system and to compare LAS based fluxes against reference fluxes obtained from eddy-covariance system in wet and dry conditions.

1.0.1 Theory

The Large Aperture Scintillometer is a device that measures the turbulent intensity of the refraction index of air. The instrument consists of a transmitter and a receiver. The transmitter emits electromagnetic radiation at wavelength λ (0.94μm)and the fluctuations in the light intensity at the receiver are analysed to give the variation in the refraction index along the path. The turbulent intensity of the refraction index of air can be expressed in the refraction index structure parameter Cn^2, define as :

$$C_n^2 = \frac{A_T^2}{T^2} C_T^2 + \frac{A_T A_q}{T_q}\, C_{Tq} + \frac{A_q^2}{q_2} C_q^2 \tag{1}$$

the constants A_T($\approx 78.7.10^{-8}$ kPa^{-1}) and A_T($\approx 66.310^{-8}$Kpa^{-1}) are a function of wavelength (λ), absolute temperature(T), specific humidity(q) and air pressure(p). Generally, the first term, containing C_T^2, is much greater than the other two terms, expect for the case when the bowen ratio β(=H/LvE) is much smaller than 1. Assuming that temperature and humidity are perfectly corrected. Equation (**??**) can be written as (Wesely, 1976[10]) :

$$C_T^2 = C_n^2 \left(\frac{T^2}{-A_T P} \right)^2 (1 + 0.03/\beta)^{-2} \tag{2}$$

Once C_T^2 is known, the sensible heat flux (H) can be derived from similarity relationships that have been derived for C_T^2 :

$$\frac{C_T^2 (Z_S - d)^{2/3}}{T_*^2} = f_T\left(\frac{Z_S - d}{Lmo}\right) \tag{3}$$

where d is the displacement height, $Z_S$is the high of the scintillometer beam above the surface, T_* is a temperature scale defined as :

$$T_* = \frac{-H}{\rho C_P U_*} \tag{4}$$

1.1 and Lmo is the obukhov length

$$Lmo = \frac{TU_*^2}{KgT_*} \tag{5}$$

$\rho$is the density of air($\approx$1.2kg.m^{-3}), C$_P$ the specific heat of air at pressure ($\approx$0.4) and g the gravitational acceleration($\approx$9.81ms^{-1}). The universal function f_T for unstable conditions can be written as follows (Wyngaard & al.,1971[11]) :

$$f_T(\frac{Z_S - d}{Lmo}) = C_{T1}(1 - C_{T2}\frac{Z^S - d}{Lmo})^{-2/3} \quad (Lmo < 0) \tag{6}$$

in which C$_{T1}$ and C$_{T2}$ are empirical constants. Wyngaard & al.(1971[11]) found for C$_{T1}$=4.9 and C$_{T2}$=7. De Bruin & al.(1993) found slightly different values (C$_{T1}$=4.9 and C$_{T2}$=9).

An independent wind-speed measurements U at height Z$_U$ allows the determination of U* from the wind profile equation, which requires the roughness length Z$_0$ to be known,

$$U_* = kU(LN(\frac{Z_S - d)}{Z_O}) - \Psi_M(\frac{Z_U - d)}{Lmo}))^{-1} \tag{7}$$

where Ψ_M is the classical stability function given by Panofsky and Dutton (1984[8]), the sensible heat flux H(wm^{-2}) is then computed as :

$$H = \rho C_P U_* T_* \tag{8}$$

ρ(kg.m^{-3}) and C$_P$ (J.kg^{-1}.K^{-1}) are the air density and heat capacity respectively and noting U$_*$is in ms^{-1}.

2 Experiment design

2.1 Site description and instrument

The experiment was performed between day of year 73 and 146(2003) in a region called R3, which located in an irrigated area in the haouz plain surrounding Marrakech, where wheat mainly cultivated.

A 3 meter flux tower has been equipped with an eddy-covariance system which consisted of a 3D sonic anemometer(CSAT3, Campbell Scientific), a krypton (KH2O, Campbell Scinetific) and a fast response thermocouple(FW05, Campbell Scientific). Also a temperature and relative humidity probe(Vaisalla) was installed on the tower. Net radiation was measured using Q7. Soil heat flux was measured at deep of 5cm.

The Large Aperture Scintillometer used in this study was designed and built by the Meteorology and Quality Group at Wageningen University (WAU). The aperture size(D) of this LAS is 0.15 m, and the wavelength of the light beam emitted by the transmitter is 940nm. The instrument is similar to the design of Ochs and Wilson (1993[9]). The path length between transmitter to receiver was 690m. The height of both transmitter and receiver was 4.5m. Data from the LAS were stored at a frequency of 1HZ on a Micro-G2 internal datalogger, and average values stored every 10min.

Results and discussion :

Energy balance closure, a formulation of the first law of thermodynamics, requires that the sum of the estimated latent (LE) and sensible(H) heat flux be equivalent to all other energy sinks and sources :

Rn -G-ΔS=H+LvE

Where Rn is the net radiation, G the heat flux into the soil substrate,

In our study the storage term ΔS is neglected. In figure 1 it can be seen that the half-hourly estimates of the dependent flux variables (H+LvE) against the independently derived available energy(Rn -G) yields a linear regression : Rn-G=1.19(H+LvE), R^2=0.9 when forced through the origin, figure 1.

Ideal closure is represented by an intercept of zero and slope of 1. General hypotheses have been suggested to account for the lack of energy balance closure :

1. Sources areas for each instrument.
2. Underestimation of latent heat flux measurement in wet conditions.
3. Soil heterogeneity.
4. Overestimation of flux derived from Q7.

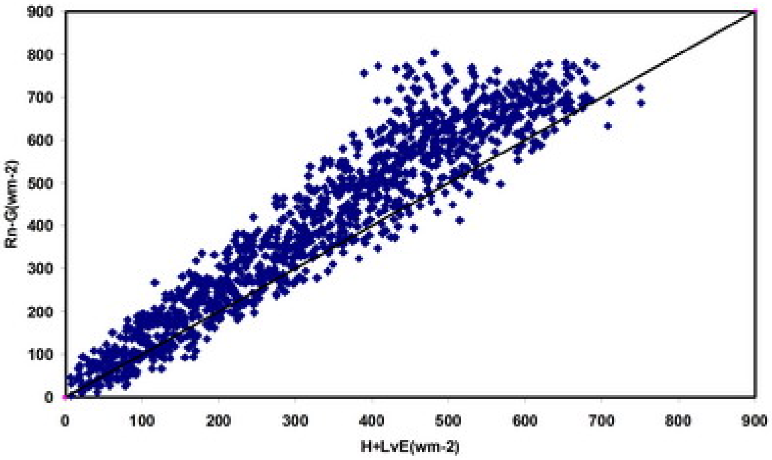

Fig. 1 – Half-hourly energy balance closure for eddy-covariance measurements and observations of Rn and G, during unsatble conditions.

Scintillometer measurements of H and LvE are calculated using an iterative calculation with Rn and G, thus based on the principle of conservation of energy. In this study we are interesting to compare the reference fluxes obtained from eddy correlation systems with LAS calculations in dry and wet conditions. Linear regression in dry conditions yields(units of wm^{-2}) : Hlas=0.98Hec, R^2=0.94 when forced through the origin. This result is very encouraging.

In wet conditions, the comparison should gives very good agreement between the tow methods if we have a ideal homogeneous surfaces and a good fetch for both instruments. But unfortunately, the wind speed direction still not stable and the small heterogeneity of the cover canopy, so linear regression yields (wm^{-2}) : Hlas=Hec,R^2=0.9, when forced through the origin, figure 3. Although, we can consider that this comparison revealed a good agreement.

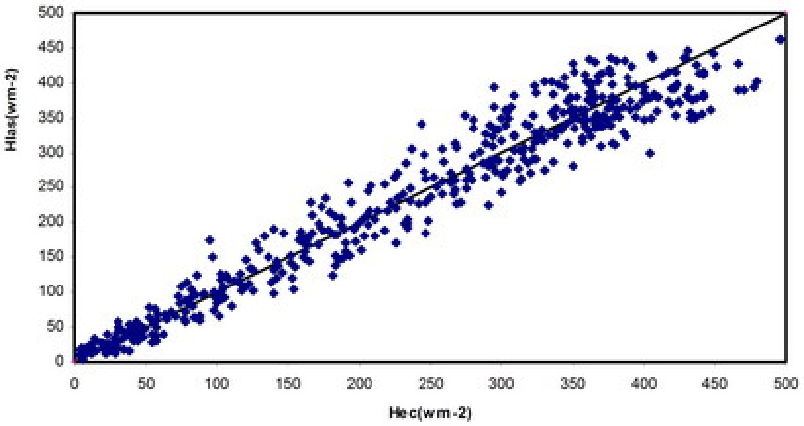

FIG. 2 – Comparison of Hlas and Hec, during dry conditions.

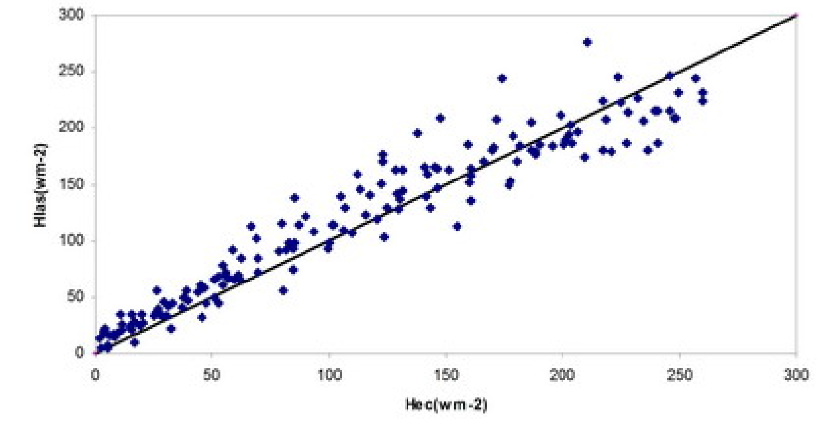

FIG. 3 – Comparison of Hlas and Hec, during wet conditions.

3 Conclusion

In general the result show that the LAS proves to be a robust and reliable instrument to produce "ground-truth" area averaged sensible heat fluxes with a minimum of additional instruments (net-radiometer and anemometer). Even under very wet conditions, sensible heat fluxes show to be in very good agreement with eddy-covariance observations.

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