SCINTILLOMETRY BASED ENERGY FLUXES COMPARED TO BOWEN RATIO/ENERGY BALANCE METHOD FOR EVAPOTRANSPIRATION DETERMINANTION OVER WINTER WHEAT

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Evapotranspiration (ET) is an important part of water and energy balance of the ecosystems. In this paper, two different methods to determine ET are used and compared. First one is the standard and well known technique based on the measurement of air temperature and air humidity gradients called the Bowen Ratio/Energy Balance method (BREB). Second method, called scintillometery, is a relatively new technique based on detecting and evaluating of scintillations - intensity fluctuations of the signal of laser beam.
Our field campaign takes place at the winter wheat field in Polkovice (the Czech Republic) in 2015. We are using a scintillometer type BLS 900 by Scintec and BREB system by EMS Brno equipped with sensors detecting net radiation, soil heat flux, air temperature and air humidity at three levels above ground, and other variables. A path length of the scintillometer is 617 m and the measurement hight is up to 2 m.
The aim of this study is to compare the BREB method as an example of point measurement with the area averaged ET values derived by scintillometry. Due to a short path and low setup of the scintillometer we were expecting slight underestimation of sensible heat flux determined by scintillometry resulting in overestimation of ET compared to the BREB method. The results show 11 % overestioatiom of ET (mm) by scintillometry for our given set-up.

***Keywords:** scintillometry, Bowen Ratio/Energy Balance method, actual evapotranspiration, oil seed rape*

INTRODUCTION

In agriculture evapotranspiration (ET) plays a crucial role in water management. It is a key component of water balance as well as the energy balance equation. There are several approaches towards its derivation. One of them, well known and established is the Bowen Ratio/Energy Balance (BREB) method. This technique was first published by Bowen (1926) and is considerend to be quite simple. On the other hand, there is a relatively new technique called scintillometry. The research of turbulence and scintillometry expanded in 1970s (De Bruin, 2002) and scintillometers for measurement of fluxes are commercially available since the early 1990s. In this paper these two techniques will be comaper based on the 14 days of measurement in the experimental site Polkivice in the Czech Republic over a winter wheat field.

The presented study is a part of larger project focused on determination of actual evapotranspiration for the purposes of studying drought in agriculture. That is why, our field experiment takes place in the farmland in the most fertile part of the Czech Republic (Haná).

To our best knowledge, ther has not been published any field study from the region of the Czech Republic or Slovakia using the scintillometry method in the agricultural experimental field. For that reason, in this contribution we are focusing more on this technique than on the well known BREB method.

This short paper aims to compare two mentioned methods for deriving ET and analyse possible reasons of the discrepancies. For the reference FAO Irrigation and Drainage Paper No. 56 (Allen *et al*., 1998) is used.

MATERIALS AND METHODS

The field experiment is taking place in Polkovice near Kojetín (the Czech Republic). There is a winter wheat in the field this season and for the purposes of this study 14 days period between 24th May 2015 and 6th June 2015 was chosen.

For the scintillometry measurements we use a dual-disk type of the Boundary Layer Scintillometer (BLS) – BLS900 by Scintec (Rottenburg am Neckar, Germany). It comprises of the transmitter and receiver with possible path length 100–6000 m. In our site experiment the path length is 617 m.

Moreover, the BREB system by EMS Brno (the Czech Republic) is placed in the middle of the field to secure adequate footprint for the method. This is a standard meteorological station equipped with sensors detecting net radiation, soil heat flux, air temperature and air humidity at three levels above ground. On the top of it, the system is monitoring also soil temperature and moisture in three depths, surface temperature, air pressure, precipitation, and wind speed and wind direction profiles.

Measuring interval of the meteorological station is 20s and the averaging time step is 10 minutes. Scintillometer measures every minute and afterwards data are averaged for 10 mins intervals. During the experiment, plant height is measured regularly as well as leaf area index (LAI) across the field using the SunScan by Delta-T Devices (Cambridge, England).

As the reference to the actual evapotranspiration of these two methods the reference evapotranspiration (ETo) by FAO Irrigation and Drainage Paper No. 56 (Allen *et al*., 1998) is used. Since the reference evapotranspiration indicates the ETo of a hypothetical grass reference crop with specific characteristics, i.e. shortly cut grassland, to adapt the value of ETo to our crop we need to multiply it by crop coefficient (Kc). In the case of winter wheat Kc for the mid season is equal 1.15 (Allen *et al*., 1998). Both ETo and ETc are ploted in the following section.

Scintillometry

Scintillation or twinkling is the variation of light beam caused by turbulence in the atmosphere. This phenomenon is used to detect turbulence between an optical transmitter and a receiver of the scintillometer.

The scintillations are caused by the fluctuations of the refractive index (n) of air along the propagation path and its magnitude can be described by the structure parameter of the refractive index of air (C_n^2) which is the basic parameter derived from scintillometer data (De Bruin, 2002) Afterwards, the structure parameter of temperature (C_T^2) can be deduced from the C_n^2 measurement. By applying Monin-Obukhov similarity theory (MOST) surface flux of sensible heat (H) can be determined. Further, we can obtain also latent heat (LE) flux incorporating the surface energy balance equation.

As the path length between transmitter and receiver can reach from hundreds of meters up to 4 km this method is suitable for deriving an area averaged fluxes over larger areas. This is the most significant advantage compared to other measurement techniques, e.g. the BREB method. For estimates of ET over large areas the large aperture scintillometer has been used with some success in variable environmental conditions since the 1990s (Rambikur-Chávez, 2012). Moreover, in the last years, the scintillometery has proven to be a reliable method for determining the spatially averaged flux over heterogeneous surfaces (Beyrich *et al*., 2005; Meijninger *et al*., 2002).

Bowen Ratio/Energy Balance method

One of the standard techniques to measure LE indirectly is the Bowen Ratio/Energy Balance (BREB) method (Heilman-Brittin, 1989). The BREB determines LE and H fluxes based on the rearrangement of the surface energy balance equation given by: Rn-G=H+LE, where Rn is the net radiation flux, G is soil heat flux, H and LE are sensible heat and latent heat fluxes, respectively (all in W.m^{-2}) (Bowen, 1926). The Bowen ratio can be expressed as β= H/LE. The combination of energy balance and the Bowen ratio is then following equation: LE= (Rn-G)/(1+β). To divide the available energy between the sensible- and the latent-heat fluxes we measure the temperature and humidity at two heights above a surface (Savage, 2010).

The biggest advantage of the technique is its low demand in instrumentation. On the other hand, there are some issues with nocturnal values and also early morning and evening periods often have to be excluded due to failing the data quality check. A strict quality control is necessary to get reliable flux measurements with this method (Guo *et al*., 2007).

RESULTS AND DISCUSSION

For the purposes of this study evapotranspiration was determined using two different methods for the experimental field in Polkovice (the Czech Republic) for two weeks in 2015. The daily totals can be seen in Fig 1.

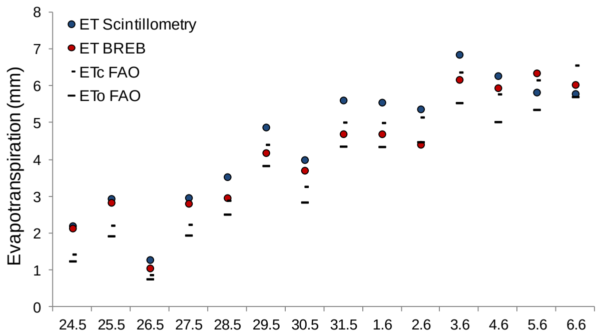

Fig 1 The daily totals of actual evapotranspiration (mm) derived by the BREB method, the scintillometry, and reference ETo and ETc by FAO56 for Polkovice site in 2015

Taking the ETc by FAO59 (Allen *et al.*, 1998) as a reference the BREB method overestimates only by 1.11 % and the scintillometry overestimates by 9.98 % ET. When we compare both methods the scintillometry seems to overestimate ET (mm) in total by 8.86 % over the BREB method. For daily totals scintillometry method overestimates final fluxes in 11 cases varying from 3.52 % (25.5.2015) to 20.87 % (31.5.2015). On the other hand, scintillometry method underestimates ET in 3 cases varying from 0.33 % (26.5.2015) to 7.91 % (5.6.2015). The cumulative ET (mm) can be seen in Fig 2. Reference ETo multiplied by Kc (ETc) and the ET derived by the BREB method show very good agreement.

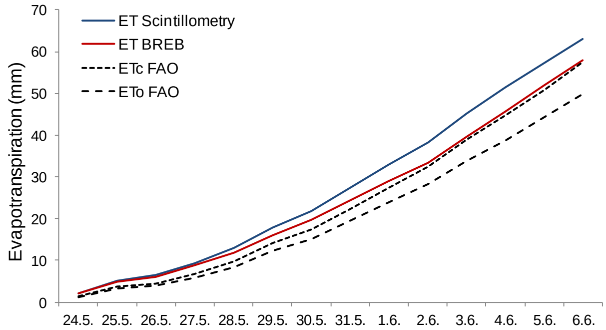

Fig 2 The cumulative evapotranspiration (mm) derived by the scintillometry – solid blue line, the BREB method – solid red line, reference ETo and ETc by FAO56 – black dashed lines, for winter wheat

Fig 3 shows an example of the 10 min values of LE flux derived by two methods in reference with the net radiation. The night values for both methods were removed on purpose to eliminate random scatter of the data for the night period. Neglecting them improved the R^2 only by 0.004 but graphically we decreased the scattering around the zero values. Other values are missing as the result of errors during the measurement (e.g. rain, mist, insect).

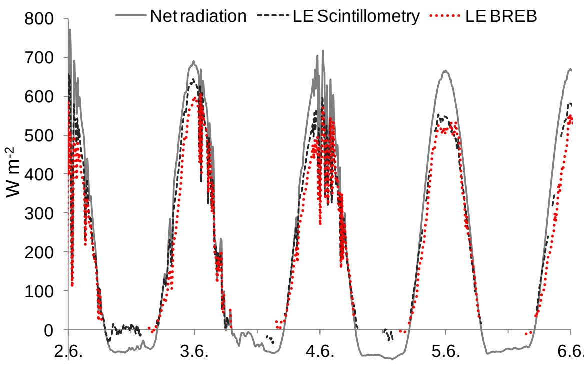

Fig 3 The comparison between LE (W.m^{-2}) derived by the BREB method and the scintillometry from 2.6.2015 12:00 to 6.6.2015 12:00 in Polkovice

The regression of the LE flux (W.m^{-2}) for the 14 days measuring period is plotted in Fig 4. The coefficient of determination R^2 is equal to 0.97 which indicates good fit between two examined methods. Overall, overestimation by scintillometry compared to BREB technique is calculated to be 11.28 % of LE.

If we plot the same regression for the sensible heat (H) flux derived by these two methods the resulting R^2 is equal 0.88 and correlation indicates 47.79 % overestimation of H flux by the scintillometry method. This seems to be unreasonable but it can be explained as follows. The regression is not reaching the value close to 1 and because R^2 is calculated by squared values, larger values of H or LE are counted in with higher significance. In other words, for the regression of H large values of H dominate and vice versa, for the regression of LE, large LE values dominate. It results in better correlation of the methods when LE is high and H is low but on the other hand when H is high and LE is low the methods show higher discrepancy.

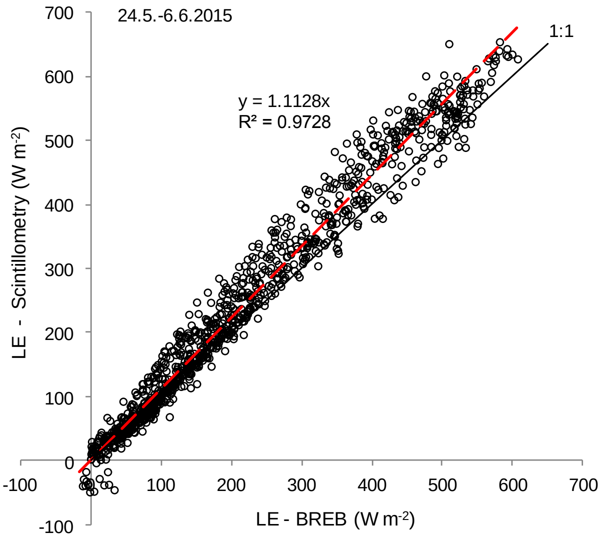

Fig 4 The regression between latent heat (LE) flux (W.m^{-2}) derived by the BREB method and the scintillometry

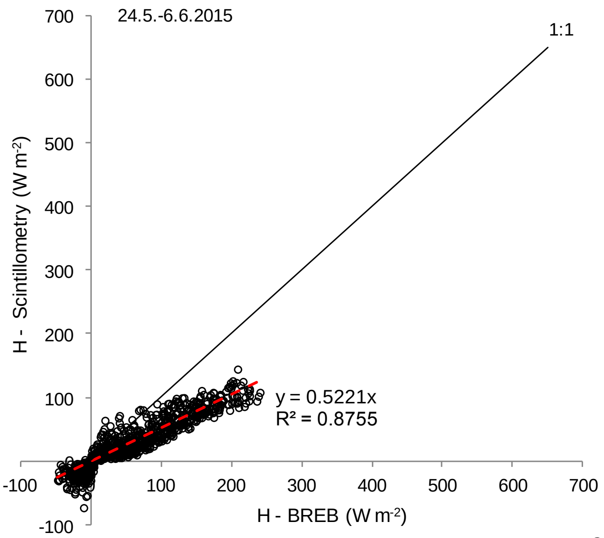

Fig 5 The comparison between sensible heat (H) flux (W.m^{-2}) derived by the BREB method and the scintillometry

The difference in final fluxes can be also explained as the issue of the footprint. It is obvious that the scintillometer footprint is much larger than the BREB footprint. That is why, it reflects some variability in the soil moisture of the field which is also expressed in plant conditions and difference in LAI across the field. For example, ete average LAI on 4thJune was 9.36 with standard deviation 0.86.

Differences between the methods were lower towards the end of the observed period. Because of the lack of precipitation the soil moisture was slowly decreasing. When the soil moisture is lower H is higher which leads to higher Bowen ratio (H/LE) (Fischer, 2012). The variablility of the soil moisture is more pronounced and so we would expect higher discrepancy between the methods resulting from different footprints. However, in our time series the methods correlate better at the end when the soil moisture is lower. More robust dataset is needed to find some acceptable conclusions.

Moreover, the unsatisfactory results of BLE900 can be attributed to a set-up of the scintillometer itself. Due to the technical limitations the effective high of the measurement was only around 2.10 m. Using some construction improvement in the field we icreased the effective height to 3.47 m for the rest of the growing season.

CONCLUSION

Two different methods to calculate ET were compared in this contribution. The Bowen Ratio/Energy balance method, as a traditional and well-known technique established across the micrometeorological community. On the other hand, the scintillometry as the relatively new technique recognized for its application in deriving area averaged fluxes for larger and heterogenous terrains.

The results of our short study show reasonable agreement in comparing these two methods. As a reference, ETo by FAO56 multiplied by Kc for winter wheat was used (ETc). The ETc coresponds very well with the BREB method (only 1.11 % discrepancy) and the scintillometry method overestimates the BREB method by 8.86 % ET (mm). The overestimation can be explained as a result of a larger footprint of the scintillometry method. Also it can be attributed to a set-up of the scintillometer which was due to technical limitations set to only 2 m height above the surface and the effective hight was therefore not satisfactory from the point of view of the MOST teory. For the ongoing experiment, we ensured more adequate position of the BLS900 in the field. We set up a construction to install the scintillometer 4 m above the ground. Further results will be assessed and analyzed with regard to our findings.

Acknowledgement

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