Hydrol. Earth Syst. Sci. Discuss., 10, C3898–C3914, 2013
www.hydrol-earth-syst-sci-discuss.net/10/C3898/2013/

Hydrology and Earth System Sciences
Open Access
Discussions

Interactive comment on "A new method to measure bowen ratios using high resolution vertical dry and wet bulb temperature profiles" *by* T. Euser et al.

T. Euser et al.

t.euser@tudelft.nl

Received and published: 9 August 2013

Dear referee,

We would like to thank you for your critical, but very constructive review. We are sorry to hear it seems we are over-selling the advantages of the method, as this is not our intention to do. However, we think the first results are promising and the method deserves additional research to be improved. The first results generally show a comparable behaviour with other techniques, but the BR-DTS has other possible applications.

Therefore, we think that BR-DTS can become a useful additional method for investigating the evaporation process.

We will go through the manuscript and put in more evidence for an objective comparison. Your comments can help us to present our first results more objectively and we will respond to your comments below.

General comments

1. *The authors do not specify how much water was evaporated by the wet cable. If the amount is significant in comparison to the latent heat flux within the footprint of the different methods, it would bias the results of all methods in a similar way and hence a close correspondence between methods would not necessarily mean that the latent heat flux from the land surface is accurately estimated. In this context, it would be helpful to mention the footprints of the different methods.*

   The amount of water supplied to the wet cable was not measured. However, in another test experiment approximately 60L were supplied during a day. For this experiment water was supplied by a high pressure irrigation system, so the amount of water was probably a bit higher, so we expect it to be in the order of 100L per day. The average derived latent heat flux was is more than 100 W/m^2, so the energy required to vaporise the water supplied to the wet cable is in the order of 1% of the derived latent heat flux from an area of 40*80m^2. In addition, the eddy covariance equipment was installed upwind of the DTS tower for the dominant wind direction, to diminish any possible effects.

2. *The fact that what the authors refer to as the "direct EC method" does not coincide with the results from the proposed and all other energy balance methods*

deserves more attention. I found it highly misleading to point out that the direct EC method can require corrections and dismiss of it while henceforth referring to the "indirect EC method" as "Eddy Covariance" data. To my knowledge, the direct EC method is the standard and most readers think of this method when reading "eddy covariance data". In fact, the big advantage of the EC technique is that both sensible (H) and latent heat flux (LE) can be estimated independently and energy balance closure can then be used as a data quality indicator. In the "indirect EC method", the authors discard the LE measurement and instead derive it by difference from the energy balance. Thus, if there is a big error in one of the other energy balance components, this error would similarly affect the LE estimates of all other methods and create a false sense of correspondence between methods. If the authors have reason to mistrust the direct EC estimate of LE, then they should compare the EC-derived H with that obtained from the new method, in order to use a direct EC measurement and avoid error propagation from the other energy balance components.

On the measured days, the energy balance closure of the EC150 set up often has a residual of more than 30% of $R_n - G$. On the days with the smallest residual, there is only fragmented data available for the BR-DTS system. There can be several reasons for this residual, for example an erroneous measurement of the turbulent fluxes or the ground energy storage, occurrence of advection or heterogeneity of the field (Foken, 2008[1]). It is difficult to determine the main cause for the residual.
The latent heat flux is measured with one method and the sensible heat flux with multiple. We agree that comparing the indirectly obtained latent heat fluxes leads to auto self-correlation, which is undesired. Therefore, we think it is better to compare the sensible heat fluxes of the four different methods. In figure 7, 8 and

[1]Foken, T. (2008): The energy balance closure problem: an overview. The Ecological Society of America, 18, 1351-1367.

9 of the manuscript the latent heat will be replaced by the sensible heat. Table 1 shows the results of the linear regression between all the used methods for the sensible heat. The first column shows the results for the entire height of the DTS tower and with a constant value for the psychrometric constant. However, anonymous referee #2 pointed out that the value of the psychrometric constant depends on the wind speed and that 4.8m is probably too high in comparison with the reference techniques. Therefore, Table 1 also shows the results for a variable value for the psychrometric constant and for only the lower part of the DTS measurements. It can be seen that the correlation of BR-DTS with the other techniques is comparable with the correlation between these techniques.

Fig. 1 shows the correlation between the sensible heat fluxes derived with the BR-DTS in comparison with the sensible heat fluxes derived with the reference techniques.

To prevent confusion whether the latent heat flux is directly measured by the eddy covariance or derived via the energy balance (EB), we will use EC and EC_{EB} instead of EC_{direct} and EC in the revised manuscript.

3. *The improvement in comparison to the 2-point BR method is not very convincing. In Table 2, the authors present a decrease in standard deviations of diurnal BR estimations when using the new 13-point technique. They imply in the text that the reduction in standard deviation means "more constant results and less outliers." Without additional support, this is not convincing, as the Bowen ratio varies naturally during the day, so a decreased standard deviation in the measurements could also stem from missing part of the natural variability. In the conclusions, the authors claim that the new technique is less sensitive to measurement errors and showed a less spurious behaviour of the Bowen ratio values. I could not find much support for these statements in the data.*

Table 1. Specifics of linear regression between sensible heat flux of all different methods. For 'γ variable' the value of γ depends on the wind speed (γ=0.059kPa/°C for u >3m/s and γ=0.071kPa/°C for u <3m/s [a]). For 'DTS 4.8m' the total height of the DTS tower is taken into account, for 'DTS 2.2m' only the lower part

	γ constant, DTS 4.8m		γ variable, DTS 4.8m		γ variable, DTS 2.2m	
	Slope	R^2	Slope	R^2	Slope	R^2
BR-DTS - EC_{EB}	1.09	0.57	1.02	0.61	0.94	0.58
BR-DTS - SLS	1.03	0.62	0.93	0.65	0.97	0.71
BR-DTS - SR	1.00	0.68	0.90	0.71	0.96	0.80
EC_{EB} - SLS	1.17	0.1b	1.17	0.1b	1.17	0.1b
EC_{EB} - SR	1.05	0.70	1.05	0.70	1.05	0.70
SR - SLS	0.95	0.81	0.95	0.81	0.95	0.81

a Values for γ are obtained from: Allen, R. G., Pereira, L. S., Raes, D., Smith, M. (1998): Crop evapotranspiration - Guidelines for computing crop water requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization, Rome, Italy.

b These time series contain some very extreme outliers and there are not much coinciding moments with data for EC_{EB} and SLS

In the contrary, the new method failed under certain wind conditions and the evaporation from the wet cable could lead to a systematic bias.

We acknowledge that the comparison between using 2 and 13 points is not very strong. Therefore, we will rewrite this part of the manuscript and include the following points and plots:

- The trend line between two points always has a R^2 value of 1, which is a disadvantage of the 2-point BR method. By using multiple points in the vertical erroneous points can be filtered out. An example of this can be seen in Fig. 2. The red points represent the data obtained at 1m and 2m above the ground surface. On November 10 using these points leads to a large difference in the obtained bowen ratio value.
- The relation between the bowen ratio and the derived sensible and latent heat fluxes is not linear (eq. 1 and 2). Therefore, a large deviation in bowen ratio does not necessarily lead to a large deviation in the derived fluxes. Fig. 3 shows the sensible heat for using 2 and 13 points, different symbols indicate different moments during the day. It can be seen that differences between the two methods occur on different moments during the day. It can also be seen that the results are influenced by the height of the BR-DTS measurements.

$$H = \frac{\beta(R_n - G)}{1+\beta} \tag{1}$$

$$LE = \frac{R_n - G}{1+\beta} \tag{2}$$

- One of the disadvantages of the BR-method is that results are unreliable when the temperature and vapour pressure profiles are not fully developed. By measuring complete profiles, it is easier to assess what is happening in the air column and whether the profiles are fully developed yet, so if the measurements are useful.

We agree that during this measurement experiment the new method failed under certain wind conditions. However, we think this is not really a failure of the method itself, but a focus for the improvement of the experimental setup. An important step in the improvement process is the development of the DTS technique. Currently, equipment is already available with a spatial resolution of 25cm, which doesn't require spiraling anymore, thus a much smaller amount of water can be supplied.

4. *It is not clear what method is used as a reference in the listing of advantages and disadvantages of the new method. I believe that the surface renewal and 2-point BR approaches are even cheaper methodologies, and the "guaranteed" closure of the energy budget is not an advantage at all, but a result of not being able to measure latent and sensible heat fluxes directly (see Specific comments below). The table would be much more helpful if it did list the advantages and disadvantages of the reference methods as well.*

   We agree that the table is a bit confusing, we will or add the advantages and disadvantages of all the used methods or we will remove the table and describe in the text the advantages and disadvantages with respect to specific other methods. We will remove the point about the closure of the energy balance as an advantage.

Specific comments

1. *P7163, L. 26-: It would be helpful to the reader if the authors explained the principles of the BR method a bit more clearly, before discussing its draw-backs.*

   We will add a couple of sentences explaining the principles of the BR method here.

2. *P. 7166, L. 10: The authors probably mean equivalent, not identical (different units!).*
   Here, the exchange coefficients as used by Verma et al. (1978)[2] are meant. Both K_w and K_h have the unit m^2/s. It might be better to use 'equal' instead, as most important is the values being the same.

3. *P. 7166, L. 1-5: It would be good to remind the reader here that knowledge of R_n and G is also needed.*
   We will add a sentence that R_n and G need to be known as well.

4. *P. 7169, L. 1-6: What was the accuracy of the water bath temperature measurement? Why continuous calibration? Do the calibration parameters change over time?*
   The resolution of the temperature sensors measuring the water bath temperature (4 times TMC6-HD attached to U-12 data logger, HOBO, onset) is 0.03°C and the accuracy is ±0.25°C. The calibration parameters can slightly differ for different temperature conditions. By calibrating continuously this difference in parameter values can be accounted for.

5. *P. 7169, L. 10: Could evaporation from the wet cable affect the results?*
   We think that this influence is negligible (see also our remark at general comment 1). We will comment shortly on it in the revised version of the manuscript.

6. *P. 7169, L. 12: Was the rate of water supply monitored?*
   No, the rate was not monitored. However, it was clear that the amount of water was more than required for just wetting the wet cable. At the same time we do

[2] Verma, S.B., Rosenberg, N.J., Blad, B.L. (1978): Turbulent Exchange Coefficients for Sensible Heat and Water Vapor under Advective Conditions. J. Appl. Meteor., 17, 330-338.

not expect it to be more than about 1% of the derived latent heat flux (see also our remark on general comment 1).

7. *P. 7170, L. 12-14: This section is not entirely clear. Do you mean that the results are sensitive to the water supply rate? How can the appropriate distance for the measurement of the wet bulb temperature be determined in the field? What would be the minimal water supply rate that would allow measuring accurate wet bulb temperature for all relevant points?*
The minimum of water to be supplied depends on the evaporation rate. The required distance can best be derived from the wet temperature profile. In case of doubt, whether the distance is long enough or not, it is better to increase the distance by 1 or 2 measuring points. For this experiment we excluded half of the data points and still we could do the analysis with 13 points. We will make this more clear in the revised version of the manuscript.

8. *P. 7170, L. 25-30: Why was the profile expected to be logarithmic? What is the uncertainty related to fitting a logarithmic curve to 2 points?*
Observing the data, a logarithmic profile seems to give the best fit. The fitting of a logarithmic profile is only used to determine which points should be taken into account and which not. It is not directly used for the derivation of the bowen ratio values. We will investigate how the selected points change if more or other points are used for the fitting of the logarithmic profile.

9. *P. 7171, L. 11: What were the water supply rates in the lab and the field respectively*
The water supply rate in the field is not measured, but was probably in the order of 100L per day, see also remark at general comment 1. The water supply rate in the lab was 180 drips per minute. So, the water supply rate in the lab was higher than in the field.

10. *P. 7172, L. 5: Why humidity probe if an open path gas analyser was used? Did*

the GA not measure water vapour concentration?
All necessary corrections were done for the EC data: correction of the sonic temperature for the effect of moisture, the Webb, Pearman, and Leuning (WPL) correction to the water vapor flux for air density effects (Webb et al.,1980[3]), and coordinate rotation. The humidity probe is used for the WPL correction.

11. *P. 7172, L. 6-7: Why was LE obtained from the energy balance and not directly? After all, the direct estimation of LE is the strength of an EC system.*
See remark at general comment 2.

12. *P. 7175, L. 6-12: To my knowledge, LE is measured directly in the standard Fluxnet approach, so I cannot believe that this technique is less reliable than the energy balance techniques. Instead of removing this contradicting evidence from further analysis, the authors should discuss why the direct and indirect measurements were so different. Perhaps one of the other components of the energy balance was not estimated correctly, which would have led to the same error in all of the indirect approaches.*
See our remark on general comment 2. We will discuss this issue more extensively in the revised manuscript.

13. *P. 7176, L. 14-19: The Bowen ratio varies naturally throughout the day, so why should a lower standard deviation in the measurements imply higher data quality? A lower standard deviation might be the result of fewer outliers, but it might also result from missing part of natural variability.*
We agree that the standard deviation might not the best way to present the differences between the methods. The main difference between using 2 and 13 points is that an erroneous temperature or vapour pressure measurement has a smaller influence (see also the remark on general comment 3).

[3] Webb, E.K. and Pearman, G.I. and Leuning, R. (1980): Correction of flux measurements for density effects due to heat and water vapour transfer. Quarterly Journal of the Royal Meteorological Society, 106, 85-100.

14. *P. 7176, L. 24-27: This is misleading as any absolute error in the BR will result in an infinite relative error when BR=0. Why not show absolute errors, or errors in the subsequent estimation of H and LE?*
By rewriting the comparison between 2 and 13 points, we will include a comparison of the sensible heat obtained by the two methods (Fig. 3) (see also our remark at general comment 3)

15. *P. 7177, L. 12: This is highly misleading, as this refers to the "indirect" method, whereas the deviation from direct eddy covariance results was very high. This ought to be mentioned here.*
At the explanation of the methods we mentioned that with 'EC' the indirect method is meant. However, we acknowledge that this paragraph has become misleading. We will rephrase the sentence (see also the remark at general comment 2).

16. *P. 7177, L. 12-17: The main motivation was to improve on the two level Bowen ratio method, but the relevant comparison is not sufficiently discussed here.*
We will rewrite this paragraph and refer to the plot shown in Fig. 2.

17. *P. 7177, L. 19-21: I did not find clear support in the results for the claim that the BR-DTS method is less sensitive to measurement errors and that it shows less spurious results. Could you be more specific? What about the spurious results due to blowing moisture onto the dry cable?*
We are referring here mainly to two measuring errors, the one of using 13 points instead of 2 (see previous point) and the one of using the same sensor. The advantage of using 13 points instead of 2 is discussed above. For the standard BR method two different sensors are used. These often have a slight deviation in relation to each other, which can lead to additional differences in temperature and vapour pressure. We did not test this during the experiment, but we expect that because the DTS uses only 1 sensor, that this problem of the BR method is solved. We agree that a part of the error is caused by the water blew by the wind,

however we think this is part of the development of the experimental set up and not really of the method itself. With the high resolution DTS systems which are currently available, this problem is mainly solved.

18. *P. 7178, L. 4-5: What would be the disadvantages of increasing the distance between the dry and wet cables? How far apart can they be?*
The disadvantage of placing the two cables further apart is that you are not measuring at the same location anymore. However, increasing the distance might not be needed anymore with the higher resolution computers available.

19. *Table 2: Please clarify in the caption that these are indeed the standard deviations of diurnal BR values. How many values were used for each day? The relative improvement is a bit misleading, as it is highest for days with generally low standard deviation, i.e. where both methods show very constant values, anyway. I would recommend to leave out this column.*
We will rewrite the entire comparison between using 2 points and 13 points and then it is probably better to leave out this table. In case we decide to leave the table in, we will remove the last column (see also our remark on general comment 3).

20. *Table 3: Need to state what the BR-DTS is compared with here. EC or two point BR? What do you mean by guaranteed energy closure? The fact that H and LE are ultimately obtained by difference of the remaining energy balance components? In this case, it should be formulated as a disadvantage, as energy balance closure cannot be taken as a diagnosis tool to assess reliability of the data, as for example in the standard ("direct") eddy covariance method.*
We agree that closure of the energy balance is often a disadvantage instead of an advantage and we will remove it. Further we will make sure that it is clear what is compared with what (see also our remark at general comment 4).

21. *Fig. 6: Maybe clearer: "Top panel: R^2 value of linear regression between T_a and*

e_a *for 13 data points between 1 and 4.6 m (see Fig. 4). Bottom panel: half-hourly Bowen ratio values derived from the linear regression. The vertical red lines mark sun rise and sun set, ..."*
Thank you for the suggestion, phrasing the caption in this way is indeed more clear and we will adapt this.

22. *Fig. 7: Why are there no points for the standard 2-point BR method? Why are there no points for EC measurements related to BREB values above 300W/m^2?*
There are two reasons for not including the 2-point BR method in this plot. First, we think it is more clear to split the analysis: comparing BR-DTS with other methods and comparing 13 points with 2 points. Second, for LE there are only small variations, also for the 2-point method, so the plot would become very full. We will add a graph with the comparison of H for 2 and 13 points (see also our remark at general comment 3). There are no points for EC measurements above 300 W/m^2, as these occurred only on the 9th of November and for that day there were no data for the EC. We will point this out in the caption.

23. *Fig. 8: What does CSAT on the vertical axis stand for? Please mention that the indirect eddy covariance method was used here!*
CSAT is a remaining from our working graphs, thank you for pointing out. We will change this into ECEB.

24. *Fig. 9: Both methods can have an error, so it would be better to call it "relative difference" rather than relative error.*
We agree with you, so we will change the caption accordingly.

25. *Fig. 10: The relative error is not very meaningful here, as it goes to infinity for BR ' 0. Furthermore, errors in the estimation of the Bowen ratio are quite irrelevant for periods when $H + LE$ is small, e.g. in the early morning hours. Why not show the difference in derived LE or H instead? Would it not be helpful to see the data*

points behind the gray bar in order to get a feeling for the error in this period?
The purpose of the gray column is to not directly focus on measurements of which we know they are erroneous. When rewriting the comparison between using 2 and 13 points, we might remove this graph. We can make the gray column in figure 6 of the manuscript a bit transparent and see if that plot is still clear, or that it becomes confusing to interpret.

Technical corrections

1. *P7167, L. 19: "accurately"*
"accurate" will be changed to "accurately"

2. *P. 7171, L. 5: "to come to equilibrium"*
"to become in equilibrium" will be changed to "to come to equilibrium"

3. *P. 7177, L. 4: "concept of"*
"conceptof" will be changed to "concept of"

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 7161, 2013.

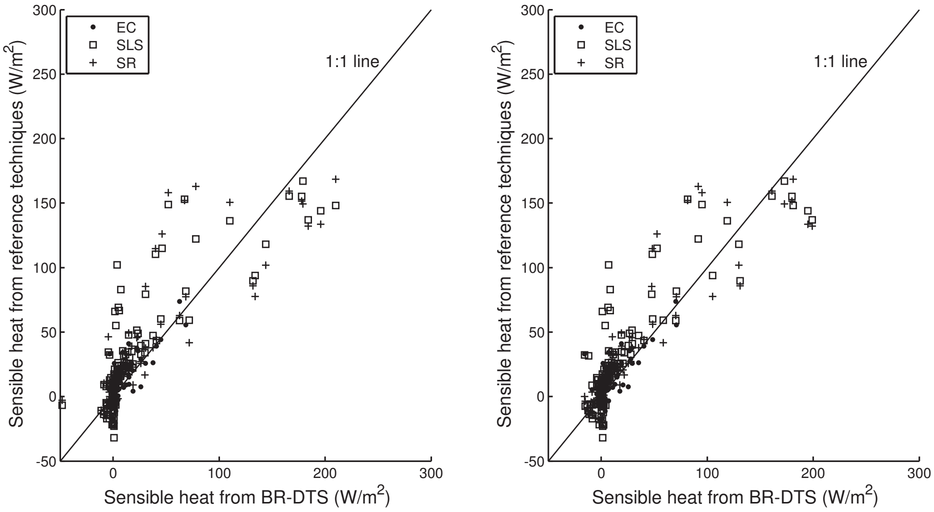

Fig. 1. Sensible heat for BR-DTS and reference techniques. Left: total height of DTS (1-2.2m and 3.2-4.8m), Right: only lower part (1-2.2m) of DTS measurements

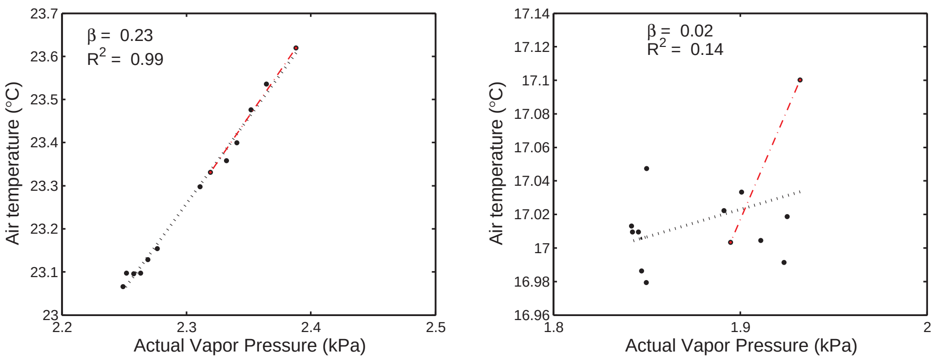

Fig. 2. Measurements of T and ea to determine bowen ratio values. Left panel: November 17, 12:00, right panel: November 10, 14:00

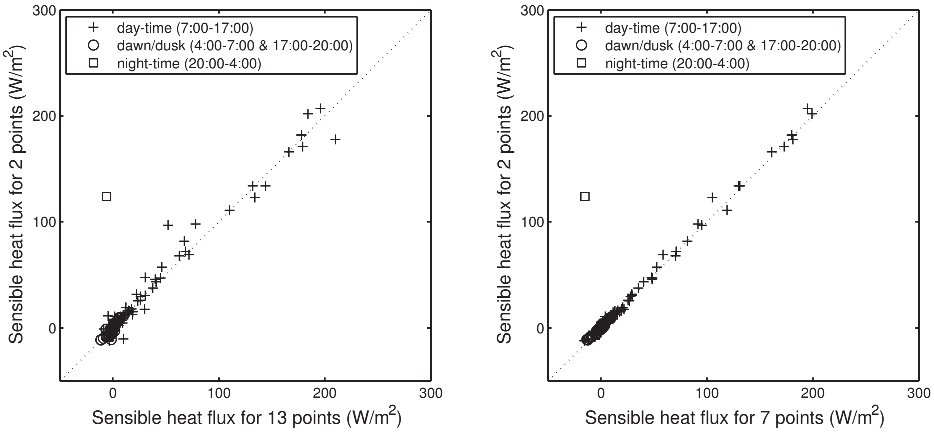

Fig. 3. Left: Sensible heat flux for BR method with 2 points (1m & 2m) and with 13 points (1-2.2m & 3.2-4.8m), Right: Sensible heat flux for BR method with 2 points (1m & 2m) and with 7 points (1-2.2m)