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Evaluating multi-year, multi-site data on the energy balance closure of eddy-covariance flux measurements at cropland sites in southwest Germany

General Comments:

The manuscript is aimed to evaluate the Energy Balance Closure (EBC) on two different experimental sites by using multi-year datasets, and to assess how different factors (as topography, micrometeorological conditions, and different crops) may impact the EBC. The topic is of great interest because understanding the main factors that affect the EBC may have strong implications on the interpretation of energy flux measurements and on improving regional weather and global climate models.

The topic is appropriate for the publication on BioGeosciences. On the whole the paper is well structured and the obtained results are interesting. However, there are some important points that should be revised (specified in major comments). I recommend accepting the paper after having addressed the following major revisions:

Major Comments:

1) My first comment concerns the neglect of the 'minor (?) storage terms'. For example, ground heat flux is a significant component of the surface energy balance. Therefore, an accurate measurement of this term (or also of other terms that could be evaluated) is fundamental for improving the EBC. A lot of studies in literature demonstrated the importance of the correction for heat storage into the soil that greatly improved the global closure rate. I think the authors could easily account for some of these terms with the available data. They should try to first apply the possible corrections to evaluate the EBC as better as possible; subsequently, they can investigate in a more rigorous way the effect of the other factors (as topographical and micrometeorological characteristics).

2) Effect of the wind direction on EBC: Authors observed that the computed EBR was highest for the prevailing wind directions at all the measurement sites. However, in my opinion, it is not the wind direction that affects the EBR, but the wind speed associated to the main wind direction. As a matter of fact, by comparing Figures 3 and 8, it is evident that the main wind directions correspond to the highest values of the wind velocity. As a consequence, I would discuss more the effect of the wind intensities than the effect of the wind directions. My impression is that the EBR is lowest in low-wind conditions (associated to less frequent wind directions) because of a higher uncertainty in the estimation of the turbulent fluxes in these situations.

3) Effect of the atmospheric conditions on EBC: Authors chose three statistics in order to investigate the effect of the atmospheric boundary layer flow on the EBC. In particular, they chose the kinematic virtual temperature flux (*w'Tv'*) as a proxy for buoyancy and they observed that larger heat fluxes (in modulus in stable conditions) correspond to a better EBC. Therefore they concluded that 'strong buoyancy' (that they correlated to high values of the modulus of *w'Tv'*) produce a better EBC.

However, this deduction is misleading because the highest values of |*w'Tv'*| (namely the highest values of downward heat flux) are not related to the highest values of buoyancy, or to very strong stratification of the atmosphere. Recent studies (Acevedo et al., 2016; Lan et al., 2018) investigated the transition between the weakly and the very stable boundary layer and highlighted the different behavior of momentum and heat fluxes as stability increases.
Whereas the momentum flux tends to progressively decrease as the stability increases, the heat flux increases in weakly stable conditions when the mechanical mixing weakens the magnitude of mean temperature gradient and allows turbulent eddies with larger vertical scales to develop. The magnitude of downward sensible heat flux is mainly dependent on the small vertical temperature gradient and the large turbulent heat diffusivity. The downward kinematic heat flux reaches a maximum value under 'moderately stable conditions' (the turning point). This stability turning point marks the transition from weakly to strongly stable regimes, when the weak mechanical mixing favors the buildup of strong stratifications, induced by the surface radiative cooling, which in turn confines turbulent eddies within thin layers locally. Such suppressed turbulent eddies are responsible for the limited downward heat flux that dramatically decreases in very stable conditions (after the turning point).

Therefore the observed low values of downward *w'Tv'* are not necessarily associated to transition periods between daytime and nightime conditions (as the authors claimed, cft text pag. 11, lines 7-9), but they could be related to periods of very stable conditions. These periods are usually associated to low winds and to weak level of turbulence interrupted by intermittent bursts often induced by submeso motions (Cava et al., 2015; 2016; Mortarini et al., 2018). The authors could check the wind intensity and the atmospheric stability correspondent to the low values of *w'Tv'*.

Summarizing, my impression is that the EBC improves in moderately stable conditions, and worsen in very stable conditions due to the high uncertainty in the estimation of the very low turbulent fluxes related to the weak and intermittent character of turbulent flow.

4) Pag., 14 – Lines 6-9 '*Our finding of the highest EBR at the two sites with the most pronounced buoyancy does not fit well with studies that recommended considering secondary circulations to achieve a better EBC (Cava et al., 2008; Foken et al., 2006; Kidston et al., 2010, Mauder et al. 2010). Those studies postulate that heterogeneity-induced and buoyancy-driven quasi-stationary circulations are probably the dominant processes behind underestimated energy fluxes.*'

   The studies that suggested the use of an averaging period higher that 30 minutes usually refer to unstable conditions. These studies suggested that averaging periods of 2–4 h are often needed to statistically resolve the largest **convective** turbulent eddies or also non-stationary mesoscale motions that sometimes can modulate turbulent fluxes (Mahrt, 1998). Differently, in the previous sentence the authors are discussing the behavior of EBR at EC2 and EC4 for negative (downward) heat fluxes (i.e. stable conditions).
   Cava et al. (2008) showed as the application of a larger averaging period improved the short term EBC during the diurnal hours, but not in stable conditions during the night.
   Therefore the previous sentence and the interpretation of results should be modified, accordingly to the previous comment.

5) Pag., 14 – Line 12 '*Finding an optimum averaging period is a very complex to nearly impossible task.* ' – Finding an optimum averaging period for computing turbulent statistics that holds for all the atmospheric conditions is impossible. The choice of the averaging period depends on the aim of the analysis and on the involved characteristic

time scales. The classical averaging period of 30 minutes can be a proper choice for unstable or neutral conditions, even if, as already discussed, a larger period could be useful to better resolve larger scales that contribute to the transport in these conditions. On the other hand, the computation of turbulence statistics in very stable conditions requires the use of a shorter averaging time (few minutes, according to Sun et al., 2012, Vickers and Mahrt (2006) or the various Mahrt's papers). Probably the use of a shorter time scale in stable conditions could improve also the EBC at the corresponding hours.

References:

Acevedo, O. C., Mahrt, L., Puhales, F. S., Costa, F. D., Medeiros, L. E., & Degrazia, G. A. (2016) Contrasting structures between the decoupled and coupled states of the stable boundary layer. Quarterly Journal of the Royal Meteorological Society, 142(695), 693–702.

Cava, D., Giostra, U., & Katul, G. (2015). Characteristics of gravity waves over an antarctic ice sheet during an Austral summer. Atmosphere, 6(9), 1271–1289.

Cava, D., Mortarini, L., Giostra, U., Richiardone, R., & Anfossi, D. (2016). A wavelet analysis of low-wind-speed submeso motions in a nocturnal boundary layer. Quarterly Journal of the Royal Meteorological Society, 143(703), 661–669.

Lan, C., Liu, H., Li, D., Katul, G. G., & Finn, D. (2018) Distinct turbulence structures in stably stratified boundary layers with weak and strong surface shear. Journal of Geophysical Research: Atmospheres, 123, 7839–7854.

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Sun J, Mahrt L, Banta RM, Pichugina YL. 2012. Turbulence regimes and turbulence intermittency in the stable boundary layer during CASES-99. J. Atmos. Sci. 69: 338–351.

Vickers D, Mahrt L. 2006. A solution for flux contamination by mesoscale motions with very weak turbulence. Boundary-Layer Meteorol. 118: 431–447.

Minor Comments:

1) Abstract: Pag. 1 - Line 20: '*To investigate the reasons behind EBC more closely for agro-ecosystems, ...*' – This sentence is not clear; please, rephrase.
2) Abstract: Pag. 1 - Line 31: '*The measurement site exerted a statistically significant effect on EBC, but not crop or region*' – What does it mean that the 'measurement site affect the EBC, but not the 'region'?. I cannot understand the difference. Please, better explain.
3) Pag. 7 – Lines 16 - 17 '*Data for footprint analyses were constrained to* $u^* > 0.1\ m\ s^{-1}$ *and* $\zeta \geq -15.5$.' What is the motivation of the choice (-15.5) as a threshold for stability?
4) Pag. 10 – lines 16 - 17 : '*The statistical analyses showed that the EBC did not differ between the two regions (Fig. 7a) over the main vegetation period from April to June.*' Why from April to June? Are the statistics shown in Figure 7 relative to all data sets or are restricted only to two months each year? If this is the case, please, motivate this choice.
5) Pag. 10 – lines 17 -18: '*The EBC measured at stations EC2 and EC4 was significantly higher* ($p < 0.001$) *than ....*' - What is '*p*'? I missed its definition in the text.
6) Pag. 13 – Line 2: '*In both KR and SJ, EBR was highest for winds blowing from the prevailing wind direction*'- This is due to the higher wind speeds, as already discussed (see major comment 2).
7) Pag. 13 – Lines 6-15: This discussion should be inserted in a section relative to the effect of the instrumental setup ... not in this section (*Effect of atmospheric conditions on EBC*)!

8) Pag. 13 – Line 18: '*Their results confirm that their EC site had various turbulence and closure patterns*'. Please, rephrase the sentence because it is unclear.
9) Pag. 14 – Lines 4-5: '*At these two sites, strong negative buoyancy fluxes below −0.15 K m s−1 were recorded. This means that the atmosphere was not heated by the land surface, but that the land surface was significantly heated by the atmosphere.*' Probably, the authors would like to say that in stable atmosphere there is a downward heat transfer? I cannot understand the motivation of this sentence and its connection with the next sentence (see major comment (4)). Please, rephrase (or cut) the sentence because it is unclear.
10) References: Please, pay attention to the references because some papers are cited in the text, but are missing in the list.