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Interactive comment on "Understanding model biases in the diurnal cycle of evapotranspiration: a case study in Luxembourg" *by* Maik Renner et al.

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The reviewer claimed three critical shortcomings of the manuscript that we think are not shortcomings, but rather misunderstandings. This is why we want to address them immediately to avoid further misunderstanding. A more detailed response is posted at a later time.

1 Input to models

Reviewer2: "descriptions of what was assumed or used as input to the models, (specifically the PT and FAO-56 PM equations) is not adequate ... Based on the

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lack of clarity as to what R_n and G model was used in the FAO-56 approach, those results cannot be assessed as is."

Reply: All models have been driven by the observational data which is important because this allows a fair comparison between models. A list of input is provided in Table 2 of the manuscript.

Specifically, both potential evapotranspiration estimates, the Priestley-Taylor evapotranspiration and FAO Penman-Monteith estimate, use available energy ($R_n - G$) as input. We apologize that the soil heat flux was missing in the Priestley-Taylor Equation (Eq. 7) and will correct this typo in the revision. The calculations are, however, not affected by this typo. Also, the FAO Penman-Monteith equation was driven with net radiation and soil heat flux from the observations and not from one of the empirical replacements as provided in the FAO-56. Hence we can assure that the findings of systematically different diurnal cycles of the Penman-Monteith driven models is indeed related to the model formulation and not to errors in the analysis.

All code (and data) to reproduce the analysis will be provided in a public accessible repository with the revision of the manuscript.

2 Solar radiation vs. Available Energy ($R_n - G$)

Reviewer2: "The major concern I have is that incoming solar radiation (R_{sd}) is used rather than the available energy ($R_n - G$)." "I don't see that why R_n (and $R_n - G$) is not used if the authors are indeed trying to better understand controls on LE"

Reply: Our main reasoning is that available energy is not an independent variable as it depends on surface temperature. We specifically choose incoming Solar radiation (= Global Radiation) (R_{sd}) as the reference for the phase shift analysis. While the term available energy (R_n – G) is often used as input to evapotranspiration schemes, it is important to remind that the net radiation R_n is the radiation budget comprised of shortwave and longwave components:

$$R_n = R_{sd} - R_{su} + R_{ld} - R_{lu} \quad (1)$$

With upwelling shortwave radiation (R_{su}), downwelling longwave radiation R_{ld} and upwelling longwave radiation R_{lu}. R_{lu} is strongly related to skin temperature and cannot be regarded as an independent variable. Therefore, the radiation budget ($R_n - G$) cannot be regarded as independent from the surface heat fluxes (see e.g. Ohmura (2014) page 3 for a review on the surface energy balance).

3 Novelty

Reviewer2: "It is expected that phase lags would occur between R_{sd} and LE since much energy is stored in the ground surface during the day and then released at night, so it is unclear what the novel aspects of the paper really are." "By not considering G, you get phase lags. . . is there something novel to see here?"

Reply: The reviewer is unclear about the novelty of our findings and states that we find a phase lag (e.g. to the Latent heat flux but also to Potential evapotranspiration") because we use Incoming Solar Radiation and not Available Energy ($R_n - G$) as reference variable. The argument being that the phase lag we observe is mainly caused due to heat storage in the soil as reflected by the soil heat flux.

We disagree on this perspective. First of all the soil heat flux is not sufficient to buffer the diurnal imbalance caused by solar heat of the land surface. Most of the diurnal imbalance is buffered in the lower atmosphere leading to the development of a convective boundary layer (Oke, 1987). To substantiate our argument we repeated to phase lag analysis with Available Energy ($R_n - G$) as reference variable. The results are attached in Table 1 of this reply. The table is similar to table 4 of the manuscript. For brevity we report the phase lag in minutes to R_{sd} and to $(R_n - G)$. Overall, there is only a minor difference between the two reference variables. This is to be expected since R_{sd} has the largest diurnal variations of the compents of Available Energy. There is only a minor reduction of phase lag (3 min) with respect to the evapotranspiration estimates. This highlights that the soil heat flux is not the main cause of the observed phase lag of the turbulent heat fluxes.

We believe that our analysis is relevant and we show in the manuscript that the diurnal signature of a phase lag to solar radiation provides a mechanistic insight into the diurnal heat exchange processes of the surface with the atmosphere. While the surface energy balance fluxes show rather small phase lags, the temperatures of the surface, the air and the related vapor pressure deficit of the air show very large phase lags. Including these variables as forcing for models (such as Penman-Monteith) may cause that the predicted fluxes yield a phase lag that is larger than what is typically observed. In contrast the surface to air temperature gradient used in well-established remote sensing based approaches (e.g. Timmermans et al. (2007)) corresponds well in its diurnal phase shift with the observed sensible heat flux and therefore yields a better agreement of the phase lag with observations (see Fig. 7). We did not find a similar analysis and interpretation in the literature, but we are open for suggestions to include further relevant literature during the revision.

We hope that our arguments help to avoid potential misunderstandings which have arisen by the critical comments of the reviewer. We will improve the clarity of the manuscript during revision. The other more minor comments of the reviewer will be addressed in another author reply.

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Table 1. Calculation of the phase lag of different variables to either incoming solar radiation (R_{sd}) or to Available Energy (AE). Nummers in parantheses show the standard deviation of the phase lag.

Variable	wetdry	PhaseLag(min) to Rsd	PhaseLag(min) to AE
Net Radiation	wet	1 (3)	-2 (2)
Net Radiation	dry	-1 (2)	0 (1)
Soil Heat Flux	wet	-6 (8)	-8 (9)
Soil Heat Flux	dry	-0 (8)	2 (7)
Available Energy	wet	3 (3)	NA (NA)
Available Energy	dry	-1 (2)	NA (NA)
Sensible Heat Flux	wet	-22 (6)	-25 (7)
Sensible Heat Flux	dry	-3 (8)	-3 (8)
Incoming Longwave	wet	133 (84)	124 (77)
Incoming Longwave	dry	176 (51)	158 (49)
LE BRC	wet	15 (4)	11 (3)
LE BRC	dry	3 (12)	3 (11)
LE uncor	wet	14 (5)	10 (4)
LE uncor	dry	2 (16)	3 (14)
Priestley-Taylor	wet	9 (5)	5 (2)
Priestley-Taylor	dry	6 (4)	6 (3)
Penman-Monteith const. gs	wet	30 (9)	25 (6)
Penman-Monteith const. gs	dry	35 (11)	32 (10)
FAO Penman-Monteith	wet	31 (11)	26 (9)
FAO Penman-Monteith	dry	31 (12)	29 (12)
LE OSEB	wet	9 (6)	5 (4)
LE OSEB	dry	-2 (5)	-1 (5)
LE TSEB	wet	9 (5)	5 (2)
LE TSEB	dry	1 (6)	1 (4)
LE STIC	wet	20 (19)	15 (19)
LE STIC	dry	14 (14)	13 (12)
Air Temperature	wet	130 (41)	122 (41)
Air Temperature	dry	138 (35)	130 (37)
Surface Temperature	wet	51 (18)	46 (16)
Surface Temperature	dry	51 (13)	49 (13)
Ts - Ta	wet	-22 (8)	-24 (10)
Ts - Ta	dry	-10 (7)	-7 (7)
Vapor Pressure	wet	125 (188)	113 (185)
Vapor Pressure	dry	52 (247)	71 (251)
Vapor Pressure Deficit	wet	145 (39)	134 (40)
Vapor Pressure Deficit	dry	153 (46)	144 (47)

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