Peer review of "Understanding the diurnal cycle of land-atmospheric interactions from flux-site observations"
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In this paper, land-atmospheric interactions are investigated based on observations of surface fluxes in 230 vegetated sites during the warm season (Figure 1). The overarching goal is the characterization of the main sub-daily features of the land-atmospheric couplings worldwide. The fluxes sites were part of the networks FLUXNET2015, AmeriFlux and European Drought-2018. The sites are classified as 7 different land types: (1) Wetlands, (2) Forest, (3) Grassland, (4) Cropland, (5) Shrubland, (6) Savannas and (7) Barren. The variables in which this study is based upon are: (1) soil water content in the top soil layer, (2) sensible heat flux, (3) latent heat flux, (4) surface air temperature, (4) humidity, (5) surface pressure and (6) vapor pressure deficit.

To investigate the land-atmospheric interactions two tools were mainly used: (1) the terrestrial coupling index and (2) mixing diagrams. The terrestrial coupling index is applied to both the land and the atmosphere. Furthermore, it is applied a third time in an integrative way to both land and atmosphere. In the paper, it is also applied a methodology to separate water and energy-limited regions based on the correlation of soil water content and the evaporative fraction. This separation makes possible to evaluate the couplings in each of both regimes.

Some interesting patterns are found. For instance, the fact that the two-legged coupling through the pathway of sensible heat is generally larger than that of latent heat at the sub-diurnal scale. This fact is obscured when considering the net diurnal contribution in which the latent heat coupling is stronger. Another relevant scientific acquisition is the corroboration with an extended data that the evening path of evaporation is characterized by a different behavior than the morning path.

In our opinion, the key strength of the research is the novelty of providing a first in-depth analysis of the sub-diurnal scale of the land-atmospheric coupling indexes. Since, these couplings are being used in climatological research, we find necessary to investigate their diurnal variability, and more specifically the sub-diurnal scales, and the sensitivity in these scales due to the clear diurnal behavior of the land-atmosphere interactions.

The manuscript lay down very well the actual state of art with the land-atmosphere interactions from a climatological point of view. It provides relevant past and ongoing research in the introduction. In addition, the methodology is well-explained and documented. In our opinion, the addition of the two-legged coupling which was proposed by Dirmeyer et. al. (2014) adds to the analysis. Even though this two-legged coupling is proportional to both the land and atmospheric couplings, when visualized for a large dataset it can uncover patterns not so easily identifiable by investigating the land and atmospheric coupling in isolation. Finally, we highly appreciate the scientific transparency. Developed code is available in GitHub.

We propose a major revision of the paper that we think could enrich the quality manuscript. Nonetheless, we find the publication valuable to the scientific community and of interest to the journal "Hydrology and Earth Systems".

Find below our main points:

Major comments

1.- Although the processes of entrainment and boundary layer growth is acknowledged throughout the paper, we have the feeling that is played down in the research. We realized that with a surface data set is difficult to quantify, although the mixed-layer diagrams proposed by Santanello et al. (2009) could be an adequate tool to further quantify the relevance of entrainment of warm and dry air at the different sites. Could the authors elaborate and quantify more regarding the role of entrainment?

2.- Closely connected to this, we miss key references at the introduction that can help the reader to position this research with respect to research that have already dealt with the relevance of processes happening at the sub-daily scales. For instance, Ek et al. (J. Hydro meteorology. **5**, 86–99, 2004) and van Heerwaarden et al (Quarterly Journal of the Royal Meteorological Society 135, 1277-1291, 2009). Could the authors introduce these or similar references in the introduction?

3.- At section 2.2 a key assumption is the use of the ERA5 to get information on the planetary boundary layer. Here, we disagree with the authors that the mesoscale variability of the boundary layer height is small compared to its temporal variability. There are clear examples in which the surface fluxes are not representative of the boundary layer development (see for instance figures 1 and 16 at Vilà-Guerau de Arellano et al (Biogeosciences 17, 2022). In that respect, there are already tools that enable us to make use of the worldwide soundings to determine the properties of the boundary layer dynamics (see Figures 3 and 4 at Hendricks et al., Geoscience Model Development 12, 2019). Although we realize that the use of this data set is beyond the scope of the paper, I believe the reader will appreciate a more elaborated and thorough sensitivity analysis on the uncertainty of ERA5 with respect to surface heterogeneity below the horizontal grid size of 31 km.

4.- Equation (5) describes how the pressure at the planetary boundary layer height was calculated by integrating equation (4). In doing so, the temperature must be expressed as a function of height. Assuming a linear dependency with height the following equation is reached.

$$P_{PBL} = P_{sfc} e^{-\frac{g\,(z_{PBL}-2)}{R\,(T_{PBL}-T_{2m})} ln\frac{T_{PBL}}{T_{2m}}}$$

In equation (5) a factor is missed inside the exponential. This factor is the inverse of the temperature lapse rate in the boundary layer, $\Gamma = \frac{T_{PBL}-T_{2m}}{z_{PBL}-2}$. In addition, in equation (5) the exponent has units when it must be dimensionless. I highly recommend correcting for this factor or for a similar corresponding factor if other assumptions were made.

5.- Along the results section in part *4.2 Diurnal mixing diagrams* and *4.3 Climate regime dependence,* hysteresis of the thermal process chain versus the moist process chain is discussed. Regarding the discussion of hysteresis, we have three comments:

1. We highly encourage to define in this context the term hysteresis. Hysteresis is a word originally coined in science to describe systems which state depends on their history. The typical scientific example is the magnetic hysteresis. This refers to a magnet that is able to experience different magnetic moments when subject to the same magnetic field. Those magnetic moments depend on the previous states of the magnet. To us, using hysteresis in land atmospheric context may be misleading since the state of the system may be different between morning and afternoon because the external factors are also different. For instance, soil water content and vapor pressure deficit are generally different between morning and afternoon. Therefore, the sub-diurnal asymmetry may be attributed to it not because an inherent change on the interactions due to the previous history. Nonetheless, we acknowledge that hysteresis term is generally used in land-atmospheric interactions context. We recommend defining the term in this context. We already find a definition in conclusions section, line 417, the fact that "the evening path through the water-energy phase does not retrace the morning path". We would move or repeat the definition to results because there is where the hysteresis is widely discussed. In addition, we think it would be valuable to specify in which way we consider it a hysteresis. In essence, which system is subject to its previous history? Is it the vegetation, is it a vegetation-soil system? What are considered the external factors? Another simpler solution is to coin another term such as temporal asymmetry which does not imply previous history relations.
2. We highly recommend discussing the hysteresis' possible causes both on the land and the atmospheric coupling. We argue that due to many processes that peak at different times (e.g., radiation peaks around noon, sensible heat flux peaks in the early afternoon and latent heat flux which with peaks later in the afternoon), morning-afternoon asymmetry can be expected.

It is not clear to us what is the added value of assessing the asymmetry or if the aim of the research is simply to characterize it. We recommend clarifying either if the paper aims to characterize them as a general characteristic observed or if the asymmetry is seen as a possible option to evaluate land atmosphere interactions.

Omissions

Code not available yet in GitHub
We just wanted to mention that the code is not yet available in the mentioned Github website. We guess that this may be made available after the publication. We just wanted to mention it to be sure that that was the case.

Minor comments and typos

Comments about the introduction

- We recommend reinforcing the importance of sub-diurnal variability to understand land-atmosphere interactions at longer time scales (e.g., seasonal, and climatological). In the paragraph of the introduction that goes from *line 55* to *line 68*, some examples are given. For instance, it is mentioned that it has been found links between morning evaporation and probability of rainfall, and between morning convective inhibition and convective initiation. If possible, we find interesting to include some more examples.
- The next paragraph that goes from *line 69* to *line 80* states that "… thorough examinations of complete diurnal cycle of land-atmospheric interactions have been lacking". We recommend clarifying that this is the case from the climatological point of view. Detailed study cases in which the diurnal cycle of land-atmospheric interactions is researched have been previously published. What we find relevant and innovative in this research is that the thorough sub-diurnal analysis focus on the coupling terms using long temporal time series spanning from 1996 to 2020. This climatological approach may reveal more generalizable land-atmospheric interactions.

Comments on the methodology

- *In line 109,* the lifting condensation level is used as the variable to understand the coupling of the land with the atmosphere. We think the reader would appreciate a short sentence in which it is stated why this variable is an important indicator of the coupling to the atmosphere (e.g., because its strong relation with cloud initiation or its importance in convection schemes in atmospheric models).
- *3.3 Mixing diagrams* section. Along this section mixing diagrams are introduced. It is stated that for computing them, 2-m temperature and humidity or vapor pressure deficit are used. In the last paragraph of the section, some shortcomings of this approach are addressed. For instance, it is mentioned that embedded in this method it lies one hypothesis. The hypothesis that 2-m measurements reflect mixed-layer values. We find this hypothesis to be dubious for certain ecosystems. For instance, in vegetated areas whose trees are taller than 2-m, the measurements fall into the in-canopy range. Many forests have trees that surpasses this height. Therefore, unlike many of the observations in other land types, observations in forests lie inside the canopy. In the research 102 from 230 sites (approx., 44 %) are classified as forests. Consequently, for forests sites, we wonder how much sensitive the land and surface couplings are to the height in which the surface heat fluxes, temperature and humidity are measured. We would expect that using measurements located right above the canopy would reflect different land and atmospheric coupling. We do acknowledge the challenge of comparing the diverse land-types considered in the study within the same methodological framework. Nonetheless, we would appreciate a justification of using the 2-m height measurements for forests or at least addressing the special advantages and shortcomings of such approach for forests. In addition, we wonder how the inclusion of these observations

affect the general conclusions for the land-atmospheric interactions. For instance, are patterns more easily generalizable (in figures 2, 3, 4 and 5) when forests are excluded?

- *Equations (6 and (8), page 7.* We find misleading the notation H_{sfc} and H_{atm} to term the hourly land and atmospheric vector component. H is generally used to depict a sensible heat surface flux. Therefore, in our opinion, a subindex to it would be a logical notation to indicate a partitioning of the flux. Nonetheless, in the notation used in the manuscript, the subindex is not indicating a partitioning of the flux itself but a partitioning of a slightly different variable. In this case instead of being a flux of energy per square meter (such H), H_{sfc} and H_{atm} refer to the amount of energy contained in a kilogram of air that has been introduced in a certain time (in this case one hour) due to either surface of atmospheric processes. Since the units and the physical variable are different, we recommend finding another symbol such M was used for the moisture vector components.

Example when introducing terrestrial coupling
p5, line 137. If the terrestrial *coupling* index is being introduced, it could be applied for both the land and atmosphere. In the text, the example of the land coupling index is stated. In this case, the target variable are the surface fluxes and the source variable the soil moisture content. Because this index will also be applied to the atmospheric coupling index, we suggest to propose the examples later or to substitute "i.e.," for "e.g.," when proposing the land coupling index as an application of the terrestrial coupling index.

Asymmetry of L(SWC1,H)
p9, line 241 "This means that the asymmetry of L(SWC1,H) in the sub-daily time scale is larger than that of L(SWC1,LE), a characteristic that is explored in more detail later" we see that this is mentioned afterwards, but we recommend to indicate already here what processes may be affecting this asymmetry. These processes seem to be mostly diurnal. We think some interpretation of the physical processes, when possible, in the results may be enriching.

Definition of significant relationships
p9, line 244 "The relationship between A(H,LCL) and A(LE,LCL) is not significant during midday due to their opposite relationships on either side of A(LE,LCL) = 0" What is specifically meant by "not significant"? It can be identified the two peaked distribution of A(LE,LCL) with one peak more predominantly in the region A(LE, LCL) > 0 and another less predominant in the region A(LE, LCL) < 0. What is the specific criteria to classify as "no significant"? Is it the fact that two feedbacks are identifiable? We would consider clarifying this point.

Strength of the couplings
p9, line 256 Referring to figure 2c "Points on the right of the diagonal x=y line indicate stronger two-legged coupling through LE than trough H, which arise mainly from the larger correlation terms of land and atmosphere coupling via LE."
It is true that the points on the right of the diagonal y = x indicate that T(SWC1,LE,LCL) > T(SWC1, H, LCL). Nonetheless, in our opinion, that does not immediately mean that the two legged coupling is stronger because the coupling can be either positive (meaning a correlation between SWC1 and LCL through that pathway) or negative (meaning an uncorrelation between SWC1 and LCL through that pathway). To me, what indicates the strength of the coupling is the absolute value, that is: |T(SWC1,LE,LCL)| > |T(SWC1,H,LCL)|.
We have inserted a figure where the four regions that arise when the absolute values are considered are colored. Following that logic, the coupling following the LE pathway would be stronger for the regions II and IV. On the contrary, the coupling following the H pathway would be stronger for the regions I and III. In that case, by naked eye, the strength of both couplings seems comparable, and it depends mainly on the density of points in regions I and IV. We would even argue that probably the coupling via the sensible heat flux pathway is stronger because in figure 4a, all values of the part where both couplings are negative are in the half corresponding to region I. In fact, in lines 292-294 it is accurately described this by stating: "During the daytime, both two-legged couplings are negative,

with T(SWC1, H, LCL) being almost three times as strong as T(SWC1,LE,LCL) around midday, showing the importance of sensible heating for ML growth".