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Hydrology and Earth System Sciences
Discussions

Interactive comment on "The influence of water table depth on evapotranspiration in the Amazon arc of deforestation" *by* John O'Connor et al.

John O'Connor et al.

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Reviewer 1: O'Conner et al present an interesting and novel study on the effect of ground water depth (GWT) on evapotranspiration (ET), land surface temperature (LST) and the enhanced vegetation index (EVI). More precisely they study if the effect of GWT on ET, LST and EVI differs between vegetation types and season (with respect to rainfall). The authors find a strong difference in ET, LST and EVI between crop- and forest areas. Furthermore for crops they find a higher ET and lower LST in areas with shallower water table depth during the dry season transition.

The topic of the study is interesting and, as far as I know, they are the first to include the effect of GWT on ET at this scale. The set-up of the study (three land cover types,

combined with two WTD classes) is easy to understand and effective. Figure 2 provides a good overview this set-up.

Reply: Thank you for your assessment

I have a few questions for the authors regarding the methodology (the used data sets and different choices made). Afterwards I wrote some general remarks on the content of the paper, followed by some suggestions with respect to the structure of the paper.

Methodology Reviewer 1: Three land cover types are studied: forest, savanna and cropland. The motivation for the inclusion of forest and cropland is clear: both are very different in structure and effect on the moisture recycling system. Also with respect to deforestation, these two land cover classes are a logical choice to study. The motivation for the inclusion of savanna is however not clear to me. What are the characteristics of the Cerrado savanna with respect to the water balance and what can be expected for this ecosystem? To make this more clear, I suggest to add root characteristics of savanna to figure 2.

Reply: We decided to include the savanna land cover class as it is under even greater pressures than forest in terms of land use change; recently cerrado has experienced twice the deforestation rates of forest (Zalles et al. 2019). The savanna system in the Amazon is a very interesting land cover class, as both through land cover or climatic change it hypothesized to represent a new stable system (see for instance Hirota et al. 2011, Staal et al. 2015). We agree with your suggestion to include savanna in Figure 2, thank you. In addition to the updated image we will include more detail on the mixed composition of the cerrado with both tree and grass layers and that this is important both due to differences in leaf area for interception evaporation and transpiration and that the mixed rooting depth of savanna can facilitate hydraulic redistribution (Miguez-Macho & Fan., 2012), where the shallow rooted grasses benefit from the groundwater through the uptake of the deeply rooted trees. We also will add savanna's typical precipitation range (700 to 2000 mm/year), which differs from that of forest (1000-2500

mm/year).

Reviewer 1: Three different time frames are studied: mean annual values, the dry season transition (DST) period and wet season transition (WST) period. The DST and WST are discussed in paragraph 2.3.2. Nevertheless it remains unclear to me why the WST and DST periods are selected, instead of the more extreme dry (and wet) season. Is it related to the planting and harvesting season of the crops?

Reply: Thank you for your comment. Land use land cover change in the arc of deforestation is correlated with a lengthening of the dry season (Dubreuil et al., 2012) and that the onset of the wet season has been related to forest evapotranspiration (Wright et al., 2017). The dry season length is a major concern in the arc of deforestation as future projections indicate drier and longer periods of water stress. We felt that vegetation with deeper rooting depth and/or shallow water table depth increase access to soil moisture effectively delaying the negative effects of the dry season transition and shortening the dry season. While if deeper roots or a shallow water table depth increases access to soil moisture towards the end of the dry season this may increase evapotranspiration and vegetation growth during the wet season transition. Therefore we choose these two periods for further investigation.

We will address this more clearly in the new manuscript why we feel the dry and wet season transition are of special interest.

Reviewer 1:The authors selected the MOD16A2 data product to derive ET and briefly present the product as well as why this product is selected (one of the best available datasets, high spatial and temporal resolution, it is widely used). Also the authors describe that the remote sensing data has “obvious limitations” (L475). I have some concerns regarding this dataset and would like the authors to elaborate a bit on the characteristics and main limitations of using this MODIS data product in their study. Several studies validated the product (E.g. Velpuri et al., 2013) or wrote that especially for tropical sites across the amazon basin, the MODIS ET remains challenging (e.g.

the recently published paper Xu et al., 2019).

Reply: We thank the reviewer for this comment and have added a couple sentences describing the potential and the limitations of the ET product. Xu et al (2019) propose a new method to estimate ET that is better fit to the flux tower data. However, this method has yet to be applied to a remote sensing time series data, and this is beyond the scope of our study. Thus we have added the following in our methods section: “While MODIS ET product is known to be underperforming at fine temporal resolutions and newer novel methods show promising results at nine flux sites across the Amazon (Xu et al. 2019), we believe that the application of the new method for our question on the influence of WTD and our time series analysis was beyond the scope of this study. This is also the reason why we chose to also analyse the effects of WTD on satellite retrieved EVI and LST..”

Reviewer 1: At the studied scale, the modelled water table depth classes are mainly based on the topography of the landscape. Are the MODIS products unbiased for this topography? E.g. is the LST corrected for topography and are the meteorological data required for MODIS ET calculation independent of topography?

Reply: Thank you for your comment. We have now provided more information on the effects of topography on both the ET and LST products. Both account for topography to some extent, explicitly the LST v5 dataset includes issues arising from topography in the quality assessment and in the ET product it is implicit in the meteorological data. We have added this information and it now reads “Each of the three MODIS products used has detailed quality control products allowing low quality pixels to be excluded from the analysis. This removing much of the concern regarding cloud cover or topography.”.

Reviewer 1: A few smaller points that unclear to me are: o Are the start and end of the DST and WST calculated for each TRMM pixel? Reply: We thank the reviewer for this question, DST and WST were calculated based on average TRMM across

our study area and not per pixel. We will clarify this in the manuscript o How many (cloudless) remote sensing data points are available? And is this enough to present the results (LST or ET values) with three decimal digits (e.g. L317, 329)? Reply: Thank you for your question. Each of the MODIS datasets contains a quality assessment. Pixels obscured by cloud cover were excluded from the analysis. The percentage of pixels affected by cloud cover is highly correlated with rainfall and therefore impacts our analysis differently. As our number of samples is very large, 1000 pixels per land cover class per timestep even when cloud cover is high we still have a large enough sample size for statistical analysis. Mean number of pixels affected by cloud cover is 40%, during the wet season it reaches as high as 90% while inversely for the dry season < 10% of pixels were affected. The dry season transition had low cloud cover overall with mean cloud cover of 15 - 20 %. On the other hand the wet season transition has relatively high cloud cover with an average of 65 - 70 %.

More information on cloud cover and the number of effective pixels will be included in the methods section 2.3 sampling design. In the discussion section we will discuss how cloud cover may increase uncertainty in our analysis .

General remarks and questions Reviewer 1: The results show that for cropland, EVI is higher for areas with a shallow WTD (paragraph 3.3 / L391). From the supplementary figures, it seems that deep WTD areas lag behind shallow WTD croplands. Is this due to water conditions only, or could this be an effect of a different cropping regime? Do farmers adapt the species and timing of agricultural practices to the local conditions, e.g. length of the dry season?

Reply: We agree with the reviewer comment that the difference seen in crop lands may not be solely driven by water availability. Unfortunately for this study we did not know the details on the local cropping regimes of farmers. It is possible that differences occur between farms and cropping is “optimised” for the local conditions. Sowing of soybean occurs during the wet season transition and can vary between September at October (Gusso et al., 2014). Therefore it is possible that crops in areas with higher water

availability will be sown earlier. Even so, we believe that this indicates that shallow WTD may be better locations for agricultural activity because then crops are not limited in their growth by having to first develop a deep root system. Most crops in the region have shallow root depths (< 2 m – (Setiyono et al., 2008)). We will address this point in the discussion.

Reviewer 1: L184 “This MODIS product ... is correlated to photosynthesis/evapotranspiration” (Sims et al., 2006). Please adjust this sentence, or add a reference (Sims et al., 2006 did not study evaporative fluxes).

Reply: Thank you for the comment, we have replaced this reference with Mu et al., 2011.

Reviewer 1: Caption figure 2: “while other vegetation has a lower maximum rooting depth”. By other, do you mean crops and/or savanna? What is the rooting depth of savanna trees?

Reply: Thank you for your comment and we agree it was not clear. By other we mean both crops and savanna, with crops having a maximum rooting depth of 2 m and savanna having a maximum rooting depth > 10 m (Canadell et al., 1996). We have added this information to the manuscript.

Reviewer 1: A few lines are unclear to me: o L196 “Further, this choice avoids potential circularity in using land cover classification to detect an effect on a parameter that uses land cover classification to produce its modelled value” Reply: Thank you for your comment. Our main point was that there are advantages in using the same land cover classification maps that are used in the other MODIS products to avoid effects of land cover classification errors across land cover mapping products. We have changed the text and it now reads: “ Further, we used the same land cover classification map as is used for the MODIS ET product to avoid effects of land cover classification errors from different maps.” o L395 “if this extra warming above the canopy is caused by a change in ET, then better estimates of ET should be possible, however, this is not trivial” Reply:

Thank you for pointed this out. We agree that this line is unclear decided to remove it from the current version of the manuscript o L400 “therefore, the modelled data was expected to underperform, making the differences we found for the dry season even more important” Reply: We agree and have changed this sentence to “Therefore the differences we found for the dry season transition may be under estimated in the MODIS ET values.”

Structure and writing

Reviewer 1: I recommend to check the manuscript for spelling, punctuation and sentence structure. Below I give some suggestions that the authors could consider. Reply: thank you, we took those into consideration.

Reviewer 1: I recommend to more clearly differentiate between introduction, methods, results, discussion and conclusion. For example avoid hypothesis-like sentences in the methods section (“We expected that”, L178), avoid discussion-like sentences in the results section (e.g. “as hypothesised”, L316) and do not add new information to the conclusion.

Reply: We thank you for this comment, and we will carefully go through the manuscript and will remove the more discussion liked phrases from results and methods.

Reviewer 1: Personally I read the lines 490-502 like a discussion, instead of as the conclusion.

Reply: We will move some of the these sentences to the discussion so that they fit the overall text better and give more precise previously introduced conclusions from our paper.

Reviewer 1: Furthermore, I recommend to group the hypotheses in one paragraph and align these hypotheses with the discussion and / or conclusion, to guide the readers through the presented story. Reply: While this is a good suggestion, we also think that this would make a paragraph with all the hypothesis very lengthy. Instead we opted to

divide it into two themes of hypothesis: The relationship of rooting depth and WTD and the resulting effect on vegetation seasonally. We also aligned the discussion along this new structure.

Reviewer 1: From the introduction I deducted four hypotheses and some of them are explicitly discussed, while one is not mentioned in the discussion. Reply: Thank you for pointing this out. We have now included in the discussion comments regarding the delay of the dry season.

Reviewer 1: Also, some new (parts of) hypothesis are introduced in the discussion, which were not introduced earlier. E.g. 1. L102: “We hypothesise that areas of shallow WTD allow vegetation to access soil moisture, with both shallow and deep rooted vegetation potentially facilitating vegetation productivity and higher ET when compared to areas of deep WTD.” o L369: “In this study, we tested the hypothesis that areas of shallow WTD would have higher ET when compared to areas of deep WTD, primarily in shallow rooted crop vegetation → Last part of this hypothesis is not mentioned in the introduction. Reply: We agree with your comment and have now included it in the introduction, and it reads as follows “We hypothesize that areas of shallow water table depth (WTD) allow shallow rooted vegetation to access soil moisture, potentially facilitating vegetation productivity and higher evapotranspiration when compared to areas of deep WTD.” Reviewer 1: 2. L116: “In areas of shallow WTD, the saturated zone is closer to the root zone of the vegetation. In these locations we, therefore, expect vegetation to be buffered against the reduction in rainfall during the dry season transition and experience drought conditions later, thus delaying the effect of the dry season”. → This one is not (directly) referred to in the discussion

Reply: We have now included a sentence in the discussion regarding this prediction and reference the supplemental figures showing the seasonality of the MODIS products and highlight the difference in timing.

Reviewer 1: 3. L428: “As forests has been shown to maintain ET throughout the sea-

sons as its deep roots access deeper groundwater, we hypothesised that no change should be observed in ET, LST and EVI." → I didn't find this hypothesis in the introduction.

Reply: thank you for pointing this out. We have added it to the introduction, and it now reads: "The influence of WTD should be not be visible for deep rooted vegetation like forest and some savanna species."

Reviewer 1: Some spelling related suggestions: âĂć L51 "changes (reduction / decline) in evapotranspiration reduce the available atmospheric moisture". Reply: We have changed it as suggested to "a decline in evapotranspiration reduces" âĂć L57 "forests can maintain a high rate of evapotranspiration during the dry season, they are not affected by low rainfall". Reply: We have changed it as suggested to "Therefore, forest evapotranspiration remains high throughout the year, unaffected by periods of low rainfall" âĂć L92 "agricultural vegetation ... experiences high seasonality during the dry season unseen in forest vegetation". Seasonality in what? Reply: We have changed it as suggested to "Crops in the Amazon arc of deforestation are impacted by the high seasonality in rainfall affecting vegetation growth unseen in forest vegetation" âĂć L130 "annual average temperatures ranging between 22 – 26 âĄřC". Are 22 and 26 monthly mean temperatures? Reply: These values refer to monthly means and we have included that in the text. âĂć L167 "the MODIS ET products were previously tested ... more accurate over longer temporal scales and larger areas". By this do you mean more accurate than shorter time/spatial scales? Reply: We have added clarification on what we meant by longer temporal scales and larger areas - "The MODIS ET product was previously tested over the Amazon by comparing its outputs with eddy covariance tower data showing that the ET modelled with MODIS data is more accurate over longer temporal scales (monthly timesteps) and larger spatial extents (e.g. drainage basin)"

âĂć L180 "a 16 day repeated observation". Reply: We have changed it as suggested to "a frequency of 16 days"

âĂć L210 "and found good agreement at/for shallower WTD however,". Reply: We have changed it as suggested to "found good agreement for shallower WTD; however,"

âĂć L229 "these roots may penetrate into the soil until the saturated zone in shallow WTD; however, do not penetrate further in deep WTD". Reply: We have changed it as suggested to "These roots may infiltrate soil until the saturated zone in shallow WTD; however, they cannot penetrate the saturated zone in deep WTD."

âĂć L240 "three primary time periods". Reply: We have changed it as suggested to "three primary time periods"

âĂć L265 "we used an average value over these transition periods" (value of what?). Reply: We have changed it as suggested to "We used an average of each remote sensing product over these transition"

âĂć L287 "a year was considered statistically significant". E.g. "for one year, the difference in .. was considered statistically significant". Reply: We have changed it as suggested to "For one year, the difference in ET,EVI or LST was considered statistically significant when..."

âĂć L302 "3.967 $\pm$ 0.0.09". Reply: We have changed it as suggested to "0.09"

âĂć E.g. L371/L379 "since crop experiences". I recommend to use for example "crop species" or "a crop" or "cropland". Reply: We have changed it as suggested to "a crop experiences"

âĂć L377 "indicate that local conditions can be much warmer in deep WTD areas". Reply: We have changed it as suggested to "indicate that LST in deep WTD areas can reach much higher temperatures than shallow WTD areas."

âĂć L380 "the roots of crop vegetation only penetrates to a maximum of 2 m, in shallow..". Reply: We have changed it to "The maximum rooting depth for most crops in the region is 2 m, in shallow..."

âĂć L408 “this could mean that in deep WTD areas temperature could even be ..” Reply: We have changed it to “This increase in temperature could be influenced by WTD and land cover change; in shallow WTD areas this may result in a less severe temperature change while in deep WTD it could lead to a greater change in temperature”

âĂć L409 “WTD was not”. Reply: We have changed it as suggested

âĂć L444 “the difference in ET was very small, < 1% difference between deep and shallow rooted areas”. Reply: We have changed it as suggested to “The difference in ET was very small, less than 1 % difference between deep and shallow WTD areas”.

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