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Discussions

# *Interactive comment on* "Evapotranspiration in the Amazon: spatial patterns, seasonality and recent trends in observations, reanalysis and CMIP models" *by* Jessica C. A. Baker et al.

**Jessica C. A. Baker et al.**

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This work is generally well-written and addresses an important topic: hydrometeorology/hydroclimatology in the Amazon. The methodology is sound and very well explained. I particularly liked the discussion about errors estimated for the catchment-based ET estimates. The idea is to compare those estimates against a number of other sources including satellite-based products, reanalysis, and CMIP5/CMIP6 model outputs for the region.

We would like to sincerely thank you for taking the time to read our paper and make suggestions for its improvement. We have revised the manuscript according to your



suggestions, and feel that is now a stronger paper as a result. We respond to each of your comments in the text below.

I believe this paper will be a good addition to HESS and I only have some minor comments to the authors (in no specific order of importance):

1. The abstract ends with a recommendation for the need for more ground based ET observations. If that is the case, I suggest the authors to expand more on that in the discussion including challenges, especially those associated with spatial scaling of ET flux tower estimates to catchment-/basin-wide estimates.

Answer: This is a good point, because although we highlighted the need for more ground-based observations in the abstract, we had not fully discussed the implications of this, or mentioned the challenges of comparing point-based ET measurements with grid-cell level estimates. We have expanded the discussion describing these issues, and possible solutions to overcome them. For example, the establishment of the Amazon Tall Tower Observatory in 2015, which has a footprint on the order of a thousand kilometres (compared to just a few kilometres for conventional towers), may offer a way to monitor ET over scales that are more directly comparable with coarse-scale models and satellite products.

2. Note Barlow et al. 2020 reference is not provided

Answer: Thanks for drawing this to our attention – we have added in the reference.

3. The addition of GRACE as the ds/dt term and propagation of error was very nicely included. Just a comment

Answer: We thank the reviewer for this comment on our work.

4. Figure 2 (data analysis in general): Have the authors considered comparing the PDFs of those? Perhaps apply Kolmogorov-Smirnov test to check whether these series come (or not) from the same distribution? Assuming this can be done at highest common temporal resolution possible among different data sources (monthly???).

Answer: Thanks for this interesting and useful suggestion. We calculated the two-sample Kolmogorov-Smirnov statistic to identify whether monthly Amazon ET values from 2003 to 2013 from satellite, reanalysis and climate models were drawn from the same distribution as the catchment-balance ET values. All of the ET datasets that we analysed were shown to be from statistically different distributions to the catchment-balance data. We plotted the cumulative probability and probability density functions, as shown below. ET products and models show much narrower distributions of ET, and miss the low values present in the catchment-balance data. This additional analysis helps to further explain why climatological Amazon annual mean ET is overestimated (see attached Figure 1). We have added this figure to the Supplementary Material (Fig. S5).

Caption Figure 1– Kolmogorov-Smirnov analysis. The cumulative probability (a) and probability density (b) functions for monthly Amazon ET from catchment-balance, satellites (MODIS, P-LSH, GLEAM), ERA5 reanalysis, and climate models (CMIP5 and CMIP6) from 2003 to 2013. Dashed lines indicate the data come from a statistically different distribution from the catchment-balance data (determined using a two-sample Kolmogorov-Smirnov test).

5. Figures 2 and 3 (and in general): Have the authors masked out the regions from the satellite and model products where P-R and catchment were not computed, to ensure direct comparison?

Answer: Yes, when comparing catchment-balance ET and data extracted from gridded products we only analysed data over the region drained by Obidos (indicated by blue hatching in Fig. 1 and on the inset map in Fig. 2). We have added clarification to the figure caption.

6. Figure 4 and 7: How much confidence on those statistics and ultimately interpretation of results with too fewer points? Can the authors expand this discussion and implications?



Answer: The small sample sizes were partly due to our decision to separate out the seasonal signal from the interannual signal in ET, as we felt that this could potentially provide more useful information about controls on ET over the Amazon. But admittedly a drawback of this approach was that statistical power was correspondingly low. This means when we did not detect a statistically significant signal then it could either be because there was no signal to detect, or because the signal-to-noise ratio was too low. For the seasonal analysis, we did find statistically significant relationships between catchment-balance ET and radiation ($r=0.93$, $p<0.001$) and between catchment-balance ET and LAI ($r=0.63$, $p<0.05$). However, spatial and interannual correlations were generally weaker and found not to be statistically significant. We have revised the Methods and Discussion sections to specifically acknowledge that by focussing our analysis on the satellite era, and the period of overlap with the CMIP models, the time period of evaluation was relatively limited, and that our decision to distinguish between seasonal and interannual controls on ET meant analysing relationships between short time series, which should be taken into consideration when interpreting the results.

Other changes

We noticed that our Amazon LAI values were implausibly low (Amazon mean LAI value of 3.6 m2/m2), likely due to inadequate quality control during data processing. We have changed to use a quality-controlled MODIS MOD15A2H Collection 6 LAI dataset provided by Boston University (Amazon mean LAI value of 4.4 m2/m2). The main difference to the results arising from this change is that catchment-balance ET is no longer well related to spatial variation in LAI. The new figure and paragraph describing these results are copied below (see attached Figure 2). There were no meaningful changes to any of the rest of the results.

"To understand the drivers of spatial variation in Amazon ET, we compared catchment-scale estimates against catchment-means of precipitation, surface radiation and LAI (Fig. 4). Since there were only eleven data points in the analysis (representing the Amazon and ten sub-catchments), statistical power was relatively low. However, we found spatial variation in catchment-balance ET showed some indication of an influence from radiation (r=0.38, p=0.25, Fig. 4h), but not precipitation (r=0.14, p=0.68, Fig. 4a) or LAI (r=0.06, p=0.87, Fig. 4o). This result tentatively suggests that spatial variation in radiation explains more of the spatial variability in ET across Amazon sub-catchments than other variables. None of the ET products and models analysed captured positive relationships between catchment-mean ET and radiation. ET from ERA5 and the CMIP ensembles instead showed negative associations with radiation (Fig. 4l–n), and, along with GLEAM ET, positive relationships with precipitation (Fig. 4d–g), indicative of water availability influencing spatial variation in ET (Fig. 4d–g). These results confirm that the reanalysis and climate models analysed here struggled to capture spatial patterns in Amazon ET due to misrepresentation of the controlling drivers, specifically the relative importance of precipitation and net radiation. ET from ERA5 and the models also showed positive correlations between LAI and ET (Fig. 4s–u), not seen in the satellite observations. However, it should be noted that satellite LAI was generally lower and showed less spatial variability than other LAI datasets over the Amazon (Fig. S8i–l), likely due to the satellite sensor being insensitive to variation in LAI over areas of dense tropical forest (Myneni et al., 2002, Yan et al., 2016a). This could hamper our ability to accurately assess the extent to which LAI influences spatial variation in ET."

Caption Figure 2 – Controls on spatial variation in Amazon evapotranspiration. Annual mean ET (in mm month-1) for the Amazon and ten sub-catchments (Fig. 1) from catchment-balance, satellites (MODIS, P-LSH, GLEAM), ERA5 reanalysis, and climate models (CMIP5 and CMIP6), plotted against (a–g) precipitation (P, mm month-1); (h–n) surface shortwave radiation (RDN, W m-2); and (o–u) leaf area index (LAI, m2 m-2). Satellite ET data are plotted against P from CHIRPS, RDN from CLARA-A1 and LAI from MODIS; ERA5 and climate model ET are plotted against ERA5 and model P, RDN and LAI, respectively. Data are from 2003 to 2013, with the exception of CMIP5, where the data are from 1994–2004. Note that the axes do not start at zero.



Please also note the supplement to this comment:
https://hess.copernicus.org/preprints/hess-2020-523/hess-2020-523-AC2-supplement.pdf

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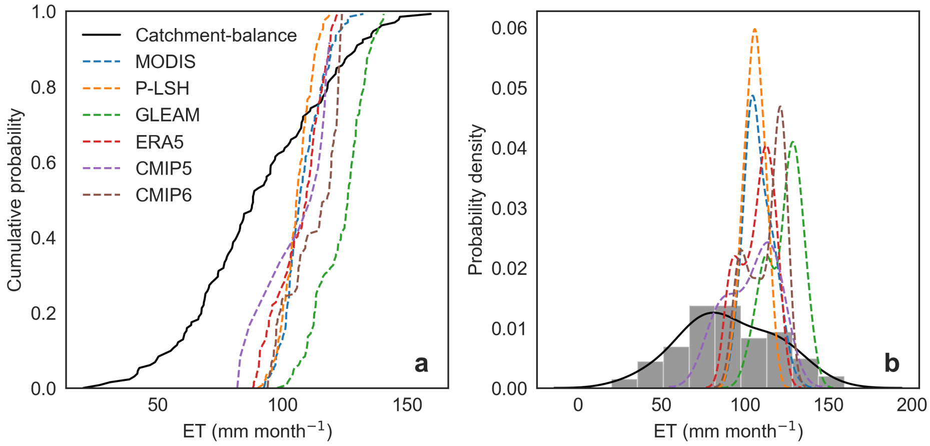


**Fig. 1.** Kolmogorov-Smirnov analysis



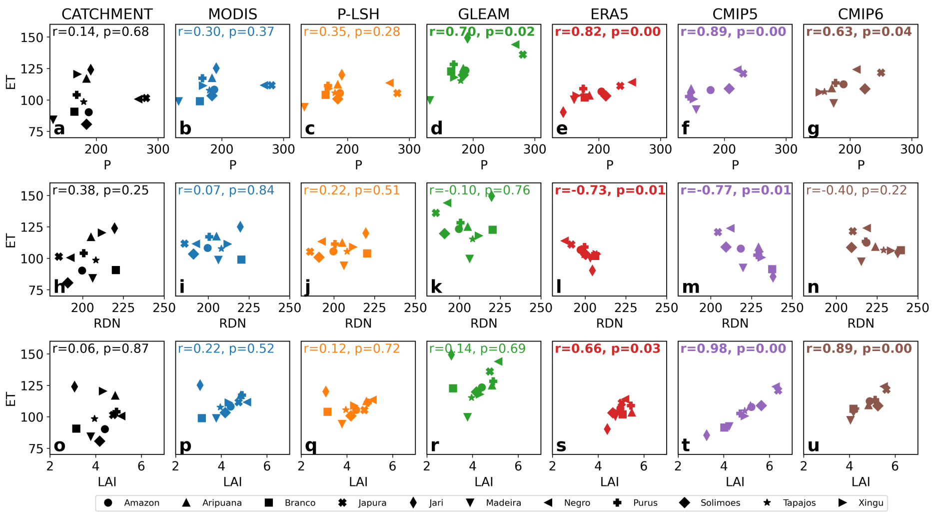


**Fig. 2.** Controls on spatial variation in Amazon evapotranspiration