Response to reviewer David K. Adams: "What Drives Daily Precipitation Over Central Amazon? Differences Observed Between Wet and Dry Seasons" by Thiago S. Biscaro, Luiz A. T. Machado, Scott E. Giangrande, and Michael P. Jensen

General Comments:

The authors present an innovative study with respect to our understanding the diurnal cycle of precipitation events with respect to the previous night´s environmental conditions for the Central Amazon. These types of studies should prove useful in understanding the dynamic/thermodynamic conditions that lead to days with or without a shallow-to-deep convective transition. The study is thorough and straightforward and takes advantage of the diverse datasets available from the GOAmazon campaign. Even in regions with much less instrumental measurements, this type of study should be easily replicable.

I think one weakness of the study is its very limited scope and literature review presented. The authors should include other studies on the shallow-to-deep transition in the Amazon as well as other tropical regions. The diurnal cycle and the shallow-to-deep convective transition are, unlike other tropical regions, intrinsically tied. And even more importantly, they should reference some of the vast number of recent studies of convective parameterization and modeling, in general, that attempt to address the difficulties of therefore temporal evolution from shallow to deeper cumulus. The authors can contact me directly for my large collection of articles on this theme.

Also, this manuscript was in bad need of proofreading. I found numerous grammatical errors as well as odd sentences or usage of the English language. Below, I have made many corrections and offered suggestions for improving the text.

We would like to thank David Adams for his insights, comments, suggestions, and careful reading of our manuscript. We have thoroughly revised the manuscript based on his comments, also we have attempted to address his concerns and incorporate the changes suggested. The literature was expanded, especially regarding studies of shallow-to-deep transition and diurnal cycle of precipitation.

Minor Comments:

Line 10 Write “Local observations of cloud occurrence,...”

Line 12 Write “... in the Central Amazon ...” Amazonas will not mean much to readers.

Line 12 Write “This is accomplished by evaluating atmospheric properties during nocturnal periods from the days prior to rainfall and non-raining events.”

Line 17 Write “large mesoscale circulations” unless you want to specify meso-beta scale circulation and that is what you mean by “large mesoscale”

Line 19 Write “...representations in tropical regions...”

Line 20. There are a lot more recent studies studies with respect to convection in models, many focusing on the parameterization and model resolution (i.e., convection-resolving GCMs) as well as the traditional problem which strongly motivated Betts work in the Amazon, that is, the poor representation of the shallow-to-deep convection. You should cite these more recent works to be complete.

Line 24 Write “... model issues in the tropics ...”

Line 26 This sentence is odd. Propensity is not really the appropriate work. Also you have “feedbacks on the general circulation” no “to”.

Line 44 Change Amazonas to the Central Amazon. Amazonas is a state, not a region.

Line 81 2pm maxima is also consistent with Tanaka et al. 2014 and Adams et al. 2013.

Line 85 Write “To understand what controls convection ...”

Line 88 “which comprise separate 24-hour events.” is a bit confusing language. I don´t think it is necessary to include the “24-hours”.

Line 88-90 Do you want to say “controls during nocturnal periods that may initiate or stifle precipitation”, given that stifling precipitation is as important.

Line 92 Write “diurnal cloud cycle”, cycling sounds strange.

Line 95 Write “result in including precipitation in the observations”

Line 109 Write “No intra-seasonal variability is observed in these distributions; however, the ENSO event of 2015 is...”

Line 118 Write “surroundings”

Line 119 Write “...from the Brookhaven National Laboratory has shown that...”

Line 131 Write “from a distance”

Line 132 Write “..., however, these upper-level clouds ...”

Line 134 Write “...these images have been extended…axes is plural, not singular

Line 136 I would write “reveals”, “presents” sounds strange in English.

Line 140 Write “These near-surface, shallow clouds...”

Line 144 I would write “During the transition to rainy conditions ....”

Write 161 Write “...events, therefore, reduced...”

Line 212 Write “...dry season composites are much drier than those of the wet season.”

Line 220“A higher (lower) cloud cover” You need to be careful here. You probably mean “greater/lesser”. As stated one may think of cloud elevation which also impacts in different ways earth ´s albedo.

Line 229 “... have approximately the...”

Line 233 Write “The flux analysis...”

Line 236 Write “...and, therefore, surface heating ...

Line 295 Do you mean “Also, the following features are correlated:...”?

Line 300 Write “... , nor did we analyze moisture advection, instead we focus on a large-mesoscale cloud analysis in the next section.” As I noted above, you should use the meteorological terminology for large-mesoscale; i.e, meso-beta scale

Line 317 Write “The differences among the two transition modes in the wet season are related to the terrain. The regions in the north and southwest of the domain, that presents the main differences, are areas where there the dominant wind flow (from northeast) are lifted over areas where the terrain elevation increases (Figure 13)."

Line 328 Write "... identify the differences found between seasons and transitions therein."

Line 339 Write "convective characteristics have approximately the...

Line 345-347. Yes, agreed. Convection is more intense when it occurs in the drier season.

Line 358 I think it is clearly to say "... cloud development is a direct effect of the locally forced vertical motions." that is, clouds are strongly tied to local bouyant vertical flows.

Line 363 Write "...that the local-scale, nocturnal, vertical motion ..."

Thank you for the careful reading. All grammatical errors pointed, and suggestions made were corrected/incorporated to the manuscript.

Line 21. You should give some detail with respect to the observational studies carried out to look at convection in the Central Amazon over the years. For example, our GPS observations of the diurnal cycle (see figures 2 and 4 from Adams et al. 2013) is a unique observation technique reference. Also, Ludmila´s paper should be included (Tanaka et al. 2014) with respect to work on the diurnal cycle.

Thanks for the comment and references. The citation to Adams et al. 2013 was included: "Given its unique tropical location and propensity for deep convective clouds having feedbacks to on the global circulation, several scientific campaigns have focused on convective clouds, aerosol transportation, and land-atmosphere process interactions over the Amazon forest (Adams et al., 2013; Machado et al., 2014; Martin et al., 2016; Silva Dias et al., 2002; Wendisch et al., 2016)."

The Tanaka et al. 2014 reference was included in the introduction of section 3: "In the Amazon, convection typically initiates around noon and precipitation presents its maxima around 14 LT (Adams et al., 2013; Machado et al., 2002; Tanaka et al., 2014)."; also, it was cited again in the discussion about river-breeze influences. “For example, land-breeze effects are known to enhance the nocturnal and early morning rainfall in near-river areas (Cohen et al., 2014; Fitzjarrald et al., 2008; Tanaka et al., 2014) and affect local low-level circulation in near-river areas (de Oliveira and Fitzjarrald, 1993).”

References added:

Adams, D. K., Gutman, S., Holub, K. and Pereira, D.: GNSS Observations of Deep Convective timescales in the Amazon. Geophysical Research Letters, 40,16, doi:10.1002/grl.50573, 2013.

Tanaka, L. M. D. S., Satyamurty, P. and Machado, L. A. T.: Diurnal variation of precipitation in central Amazon Basin, International Journal of Climatology, 34(13), 3574–3584, doi:10.1002/joc.3929, 2014.

Line 25 Also related to my comment on Line 20, your category a) is closely tied to the problem of proper representation of the shallow-to-deep convective transition. It just happens to be the nature of central Amazon convection that the shallow-to-deep transition is intrinsically linked to the morning-to-afternoon evolution of deep convection. This is not true of all tropical regions, particularly those where topography or proximity to the ocean plays an important role in convective cloud development. Given that research on convective parameterizations which perform well with respect to this transition is a very important line of research, I suggest tying this study more clearly to that issue specifically.

Line 30-31 Include our work Adams et al. 2015. It was the world´s first GPS dense network in an equatorial region to study convection, pre-GOAmazon and was strongly motivated by the studies of Betts and Jakobs 2002 and Khairoudinov and Randall 2006. See Adams et al. 2017 for more general references on shallow-to-deep convection research which you should cite to make this open this study to a broader audience.

Thank you for the comments and references, the text now reads: “Specific to the diurnal cycle of cloud systems in the Amazon, the deficiencies in model treatments of shallow convection and cloud transitions to deeper convective modes have been identified as a continuing challenge towards its correct representation in GCMs (Khairoutdinov and Randall, 2006; Adams et al., 2015; 2017). Recently, Zhuang et al., (2017) carried out an observational analysis and proposed that diurnal shallow-to-deep transition are highly correlated with large scale moisture transport convergence, lower surface temperature, higher surface humidity, shallower mixed layer, and smaller sensible heat flux and smaller surface wind speed. Similarly, Meyer and Haerter (2020) showed numerically that in the absence of large-scale moisture advection, cold pool collisions act as precursors of shallow-to-deep transition. Shallow-to-deep transition are also connected with the representation of the diurnal cycle of precipitation (Couvreux et al, 2015) and medium-range predictability associated with the Madden-Julian Oscilation (Klingaman et al, 2015). While proximity to topography or coastlines that drive local circulations can play an important role in Amazonian convective lifecycle, shallow clouds over the Central Amazon and their transition to deep convection are associated with the growth of diurnally-driven evening deep convection Chakraborty et al., 2020)."

References added:

Adams, D. K., Fernandes, R. M. S., Holub, K. L., Gutman, S. I., Barbosa, H. M. J., Machado, L. A. T., Calheiros, A. J. P., Bennett, R. A., Kursinski, E. R., Sapucci, L. F., DeMets, C., Chagas, G. F. B., Arellano, A., Filizola, N., Amorim Rocha, A. A., Silva, R. A., Assunção, L. M. F., Cirino, G. G., Pauliquevis, T., Portela, B. T. T., Sá, A., de Sousa, J. M., and Tanaka, L. M. S.: The Amazon Dense GNSS Meteorological Network: A New Approach for Examining Water Vapor and Deep Convection Interactions in the Tropics. Bulletin of the American Meteorological Society 96, 12, 2151-2165, https://doi.org/10.1175/BAMS-D-13-00171.1, 2015.

Adams, D. K., Barbosa, H. M. J., and Gaitán De Los Ríos, K. P.: A Spatiotemporal Water Vapor–Deep Convection Correlation Metric Derived from the Amazon Dense GNSS Meteorological Network. Monthly Weather Review 145, 1, 279-288, https://doi.org/10.1175/MWR-D-16-0140.1, 2017

Chakraborty, S., Jiang, J. H., Su, H., and Fu, R.: Deep convective evolution from shallow clouds over the Amazon and Congo rainforests. Journal of Geophysical Research: Atmospheres, 125, e2019JD030962. https://doi.org/10.1029/2019JD030962, 2020.

Couvreux, F., Roehrig, R., Rio, C., Lefebvre, M.-P., Caian, M., Komori, T., Derbyshire, S., Guichard, F., Favot, F., D'Andrea, F., Bechtold, P. and Gentine, P.: Representation of daytime moist convection over the semi-arid Tropics by parametrizations used in climate and meteorological models. Quarterly Journal of the Royal Meteorological Society, 141: 2220-2236. https://doi.org/10.1002/qj.2517, 2015.

Klingaman, N. P., Jiang, X., Xavier, P. K., Petch, J., Waliser, D., and Woolnough, S. J., Vertical structure and physical processes of the Madden-Julian oscillation: Synthesis and summary, Journal of Geophysical Research: Atmospheres, 120, 4671– 4689. doi:10.1002/2015JD023196, 2015.

Meyer, B., and Haerter, J. O. Mechanical forcing of convection by cold pools: Collisions and energy scaling. Journal of Advances in Modeling Earth Systems, 12. https://doi.org/10.1029/2020MS002281, 2020.

Zhuang, Y., Fu, R., Marengo, J. A., and Wang, H. Seasonal variation of shallow-to-deep convection transition and its link to the environmental conditions over the Central Amazon, Journal of Geophysical Research Atmospheres, 122, 2649–2666, doi:10.1002/2016JD025993, 2017.

Line 33-35. This sentence is unclear. Can you specify what you mean by “the differences in the convective scale driven by the large-scale circulation should be considered in convection parametrization schemes”?

Agree. We have altered this whole sentence to: “Since convection is parameterized in GCMs, with convective cloud scales ranging from smaller to larger than the typical GCM grid resolution, the variability in the convective scale driven by the large-scale circulation needs to be considered in convection parametrization schemes and satellite-based rainfall retrievals (Rickenbach et al., 2002).”

Also, the “dynamical, microphysical, and environmental differences” between organized and isolated convection, are you referring to the conditions which help to organize convective into MCS? And these must be properly represented in the models and the parameterization must be able to respond properly to the factors? Clarify this idea.

Agree. The text now reads: "Knowledge of the factors controlling the dynamical, microphysical, and environmental differences between the organized (i.e., larger areal coverage cloud regimes, Mesoscale Convective Systems MCS; Houze 2018) and/or isolated convective cloud regimes (Schiro and Neelin, 2018) have also been highlighted as challenges for the correct representation of convective processes in the Amazon."

Line 112 This Kelvin wave study and shallow-to-deep transition study of Serra et al. 2020 has now been published so you can cite it. See references below.

Thanks for the reference, the text now reads: "While not the focus of this study, NR-RR days with an active Kelvin wave mode were only found associated with 7% of our wet season dataset (not shown, a classification of Kelvin wave activity was kindly provided by Dr. Yolande Serra from the Joint Institute for the Study of the Atmosphere and Ocean – University of Washington). Additional discussion on the relationships between Kelvin Wave activity and deep convection over Central Amazon can be found in Serra et al., 2020."

Line 116 See also Figure 4 (Adams et al. 2015) for water vapor convergence reflective of low-level circulation in near-river sites.

Thank you for the reference. We have modified the text where river-breeze influences are discussed to "For example, land-breeze effects are known to enhance the nocturnal and early morning rainfall in near-river areas (Cohen et al., 2014; Fitzjarrald et al., 2008; Tanaka et al., 2014) and affect local low-level circulation in near-river areas (de Oliveira and Fitzjarrald, 1993). Moreover, the diurnal cycle of precipitable water vapor near river areas are influenced by their location with respect to the dominant lower-tropospheric easterly winds (Adams et al., 2015)."

4.1.2 Radiosonde analysis

In this section, you need to be very clear how you are calculating CAPE. The values of CAPE are critically dependent on the parcel you lift as well as the thermodynamic process, reversible or pseudoadiabatic. Using surface value of temperature and humidity can bias the values. Using virtual temperature as opposed to regular temperature can likewise affect CAPE values. More typically, CAPE calculations are based on some mixing/averaging of near-surface values, say, for example lowest 50mb. So please clarify this issue for the readers.

Line 185 Have you check the nature of the parcel you are lifting?

Convective cloud energy consumption results from vigorous deep convection, not from shallow to midlevel cumulus depths. Lower near-surface temperatures and drier near-surface conditions would also lead to lower CAPE. Another issue is if the sounding rises through cloudy air. This is not representative of larger, grid-scale (~50km) conditions and may appear to have a warmer/wetter trajectory than what is really representative of thermodyamic conditions on the larger-scale.

Thank you for the question. The following text and reference were added to the text:

"For CAPE and CIN calculations, the traditional approach of parcel theory was applied – water vapor phase changes only, and irreversible parcel ascent in a virtual potential temperature framework (Bryan and Fritsch, 2002). We define the originating level of the convective parcels as the level of maximum virtual temperature in the lowest 1000 m of the atmosphere representing the most buoyant parcel in the boundary layer, maximizing the CAPE and minimizing the CIN."

Bryan, G. H., and Fritsch, J. M. (2002). A Benchmark Simulation for Moist Nonhydrostatic Numerical Models. Monthly Weather Review 130, 12, 2917-2928, https://doi.org/10.1175/1520-0493(2002)130<2917:ABSFMN>2.0.CO;2

Line 215 From all of my years of research and my field campaigns in the Amazon, I would definitely argued for wv profile control on convective outbreaks, to a first-order approximation. See Lintner et al. 2017 and literature referenced for a GCM comparison of GOAmazon wv profiles.

Thank you for the reference. We have added the following sentence to the manuscript: "A model comparison study by Lintner et al. (2017) shows that the water vapor profile is associated with precipitation, and the models examined are typically too dry compared to mean radiosonde profiles, especially during the dry season."

Reference added:

Lintner, B. R., Adams, D. K., Schiro, K. A., Stansfield, A. M., Amorim Rocha, A. A., and Neelin, J. D.: Relationships among climatological vertical moisture structure, column water vapor, and precipitation over the central Amazon in observations and CMIP5 models, Geophysical Research Letters, 44, 1981–1989, doi:10.1002/2016GL071923, 2017.

Line 350. What is curious is that regardless of dry versus wet season or intense vs less intense, the shallow-to-deep transition time scale is the same ~4 hours. See (Adams et al 2013, 2017)

Yes. Although we did not perform the calculations (e.g.: Adams et al., 2013), our local observations seem to corroborate the mentioned time scale.

Line 392-398 This summary is exactly why I make the argument for expanding your literature review and making sure you tie this "diurnal evolution" to the more general problem of replicating properly the STD transition in the tropics with model convective parameterizations. Even for cloud-resolving models or LES models, the microphysical parameterizations may be responsible (e.g., cold pool formation) for properly representing the STD transition.

Thanks. We have added the literature suggested (also new references we have found) in different parts of the manuscript and have attempted to emphasize the link between shallow-to-deep transition and the diurnal cycle of precipitation and the implications thereof in numerical models and their parameterizations.