Dear Editor,

First of all, we thank the Editor and the referees for their careful reading and the opportunity to improve our study. We have accounted for the comments and suggestions in the revised manuscript version. We believe these and other changes have addressed the reviewer's comments.

Please find below, the modifications made at the manuscript. The referees' comments are in black, our point-by-point responses are in red color, and the changes to the manuscript are in blue color.

Sincerely,

Alice Henkes on behalf of all coauthors

Responses to referee comments on the acp-2021-87 Manuscript "Morning boundary layer conditions for shallow to deep cloud evolution during the dry season in the central Amazon", by Henkes et al.

Referee Comments 1

This paper provides a comprehensive study contrasting meteorological variables between shallow and shallow-to-deep convection transition cases, with a focus on boundary layer processes, using the GoAmazon field campaign data collected during the dry season (IOP2) of 2014. Some results are overall consistent with previous studies. However, there are two major issues for this study, one is new findings are not clearly presented and discussed, and the other one is the very small sample size. And the overall writing and English should also be improved. My recommendation is a rejection but I encourage a re-submission after these issues are addressed.

We thank you for your constructive comments and suggestions to improve our study. We have carefully addresses all comments/suggestions made by reviewer. Please find below our point-by-point responses in red color, and the changes to the manuscript are in blue color response.

1. After reading through the manuscript, one major issue is that I'm confused about what's new findings in this study. Many mechanisms related to BL processes and development are either well taught in university textbook or discussed in previous studies. Mechanisms or results unique to this study should be clearly discussed in either results or discussion section.

   Thank you for your suggestion. As far as we know, the BL evolution, based on stages of the development of convective cloudy-BL, has been shown only for undisturbed conditions over Amazonia (e.g., Martin et al. 1988; Fisch et al., 2004; Carneiro and Fisch, 2020). A detailed analysis of the erosion of nocturnal BL and growth of the convective boundary layer has not yet been reported under shallow-to-deep conditions. This erosion is important because the timing of increased convective turbulence in the morning transition is essential for the convection to penetrate throughout the BL, the transports of aerosol, and the formation of cumulus clouds upper BL.

   The main findings are shown in the conceptual model under ShCu and ShDeep conditions, which were not discussed in detail in the previous work. As suggested by both referees, we included a new section with statistical analysis of BL processes, especially during stable and morning transition stages (also note our response to the specific comment below). In summary, we rewrite part of the introduction, and we include a new section with BL processes statistics (Sec. 4) and rewrite the conclusions to be more focused on the new findings.

2. A big limitation of this study is the very small sample. With only four samples for each category, it's very hard to convince the readers that the average profile and the standard deviation capture the whole picture. The large error bars in many figures render many differences between two categories insignificant and thus some statements related to comparisons are not backed up by the figures. The authors argue that their samples show certain variations and are consistent with previous studies. To me, however, a few samples being consistent with previous studies (Line 403-405) cannot be used to justify why they are not using a larger sample when they can. I understand the GoAmazon only has very limited data in the IOP period for dry season, however, as far as I know, the main difference between IOP2 and non-IOP periods is only the additional 10:30 sounding, which only affects the results of Figure 2 and part of Figure 3. Thus, I think data of two whole dry seasons during GoAmazon should be utilized. On the other hand, the criteria for selecting ShCu and ShDeep can be modified as well to incorporate more samples. For example, shallow convection that did not directly pass

over the site cannot be observed by ARSCL, but it can be shown in S-band radar. Also, it's also not clearly explained why the authors only focus on the dry season.

As suggested by both referees, we have included a new section with BL processes statistics shown in the conceptual model for 45 ShDeep and 30 ShCu cases. The BL process statistics are discussed during the two dry seasons of the GoAmazon campaign (Sect. 4). Despite the case-to-case variability, the statistic analysis shown that the analyzes done in the case studies are representative of the cases for the dry seasons in Central Amazonia ((Line 460-514):

4. Boundary layer processes statistics during the two dry seasons of the GoAmazon 2014/5 campaign

In order to evaluate the significance of the conceptual model built based in the case studies, a statistical analysis was performed. The statistical analysis was developed by comparing the cases of shallow and deep convective clouds using the same classification and relaxing the premise of having convection under the T3 site. ShDeep days were classified as hot-tower clouds with little external disturbances in the morning based on cloud boundaries of the RWP-WACR-ARSCL product and the precipitation properties for the domain within the 75 km radius of the T3 site estimated by S-band Radar scanning (Tian et al., 2021). ShCu days were classified as days with no precipitation in the 75 km radius of the T3 site. Using the two dry season years, 45 cases of ShDeep and 30 cases of ShCu were selected. On the majority of days, the shallow-to-deep cloud evolution did not occur at the T3 site but in the 75 km radius domain of S-Band Radar. The statistic analysis of the BL processes mainly focus on the stable to the morning transition stages as it has been shown in the conceptual model of the BL process (Fig. 10). This large number of events is robust to significantly describe the daily evolution of a typical day of ShCu and ShDeep.

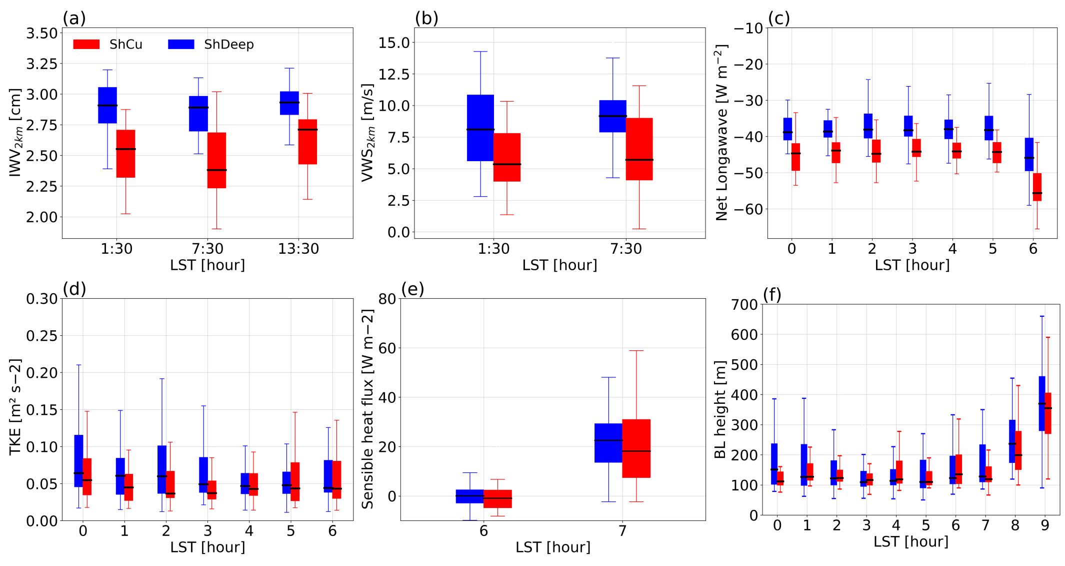
The composites of the BL processes, discussed in detail in the previous section, are shown in Fig. 11 as box-and-whisker plots. As previously discussed, Ghate and Kollias (2016) suggested that greater fluctuation over short periods in IWV is the primary factor controlling meteorology and precipitation during the dry season. In fact, the median $IWV_{2\ km}$ composite, at the lower 2 km, shows large values and exhibits small variability in the ShDeep (blue boxes) than ShCu (red boxes) regimes since nighttime (stable stage) (Fig. 11a). In the lower troposphere, distinct variability in ShDeep conditions is also observed in $VWS_{2\ km}$ from the stable stage to the morning transition stage, with larger median values than that for ShCu (Fig. 11b). Zhuang et al. (2017) found a similar result, concluding that the contrast between ShDeep and ShCu days could be associated with weak surface wind and strong wind shear in the lower troposphere. Moreover, this result indicates that turbulent mixing may be transported from aloft down to the surface, linking to the evolution from stable to unstable BL conditions.

During the stable stage at near surface, less radiative cooling and intense periods of turbulent mixing characterized the ShDeep composite in comparison with ShCu. The net longwave showed very similar results to the case studies (Fig. 11c) with a well-defined difference of around 5 W m^{-2} between the ShDeep and ShCu composites. The median shows more intense radiative cooling during the ShCu regime than for ShDeep. For example, Edwards et al. (2014) using large-eddy simulations showed that radiative cooling has an important effect on the morning transition and in the development of the convective BL. The mechanical turbulence is seen in Fig. 11c by the TKE. The magnitude of the TKE is comparatively higher for the ShDeep between 00:00 and 03:00 LST than those of the ShCu composite. Similar small median values occur at around 06:00 LST for both regimes when the increase in turbulence is weak, probably caused by weak wind at late night and cumulative thermal cooling inducing stable stratification near the ground through the nighttime.

In contrast to the longwave radiative cooling, the sensible heat flux showed a less pronounced difference with increasing sample size, being slightly higher in the median ShDeep values than in the median ShCu values during the crossover event (Fig. 11e). One explanation for this difference is that the sensible heat flux is affected by cloudiness and the surface thermal properties, such as the one shown in Fig 1g, on day 7 of the case studies. In that case, the sensible heat flux is influenced, before or during the morning transition, by reducing incident solar radiation, surface temperature, and therefore its magnitude and time crossover (e.g., reduce the intensity of convection). However, considering that under ShDeep conditions there is less radiative cooling, a small variation in the sensible heat flux at the time of crossover can resulting in early erosion of the nocturnal inversion that develops during the stable stage. Such cloud cover is less frequent in the ShCu regime during the early morning, if clouds are more frequent in the afternoon period attributed to the shallow cumulus cloud type (Giangrande et al., 2020).

During the stable stage, the ShDeep BL height is higher than that of the composite ShCu. The relatively high BL height values are consistent with relatively higher mechanical turbulence as the source of TKE (Fig. 11d). The hourly median BL height values from sunrise to early morning vary from about 110 to 250 m between 07:00 and 08:00 LST in the ShDeep regime (Fig 11f). For the ShCu regime, the median hourly BL height values vary from around 110 to 200 m, suggesting that the onset of convective BL is earlier in the ShDeep composite regime than in the ShCu composite regime. The BL height evolution exhibited in both regime composites is consistent with the evolution observed in the case studies during the morning transition.

The statistical analysis is in agreement with the conceptual model developed based on the case studies, even do not considering convection over the T3 site. The pronounced feature that emerges from this analysis is the clear difference between the two regimes for IWV and VWS and the BL height. This impact in the time needed to eliminate the nocturnal stable BL inversion used to promote convection having important effect in characterizing the convective strength in the morning transition stage and the rapid growth stage. This energy of BL growth is in agreement with the large, positive BL disequilibrium values on ShDeep days and the mostly negative BL disequilibrium values in early morning on ShCu days showed by Tian et al. (2021). Therefore, the enhanced water vapor at low and mid-level is important not only for the initiation of deep convection in the cloudy mixing layer stage but also for the characterization of the cloud-BL interaction from the stable to the rapid growth stage. This feature, observed during the dry season over Central Amazonia, was corroborated by Chen et al. (2020) who showed that large-scale advection is vital for characterizing land-atmosphere interactions both in magnitude and type of relationships in the transition from clear-sky to precipitation clouds over the U.S. SGP site.



. **Figure 11**. Box-and-whiskers plot of (a) $IWV_{2\ km}$ during the stable, morning transition, and cloudy mixing layer stages, (b) $VWS_{2\ km}$ at stable stage and morning transition, (c) radiative cooling during the stable stage, and (d) TKE during the stable stage, (e) sensible heat flux crossover, and (f) BL height from stable to onset of convective BL. In each box, the central bar is the median and the lower and upper limits are the first and the third quartiles, respectively. The lines extending vertically from the box indicate the spread of the distribution with the length being 1.5 times the difference between the first and the third quartiles. The red and blue boxes correspond to shallow convective (ShCu) and shallow-to-deep convective (ShDeep) days, respectively.

Also, the manuscript was amended in some parts of introduction in order to be consistent with the manuscript purpose (comparative analysis of the BL processes under ShCu and ShDeep conditions during the dry season). For example Line 68-79:

Although previous studies, such as those by Ghate and Kollias (2016); Tang et al. (2016); Zhuang et al. (2017); Chakraborty et al. (2018); Tian et al. (2021) provide observational evidences and explanations for understanding the physical processes controlling the transition from shallow to deep convective clouds, some information is still missing regarding the role of water vapor and wind shear in the erosion of the nocturnal BL and the evolution to deep convection. The dry season is predominantly associated with large-scale subsidence that dries out the troposphere and suppresses large-scale deep convective clouds. However, it has been demonstrated that the probability of locally occurring daytime deep convective clouds, in the drier months (e.g., June, July, August and September), is strongly tied to both the lower-free tropospheric and the BL moisture (e.g., Schiro and Neelin, 2018). In the dry season, the diurnal cycle of the convective BL includes periods of convective activity from mid-morning to afternoon that are attributed to enhanced shallow and deeper convection (Giangrande et al., 2020) in response essentially to lower free troposphere water vapor (Ghate and Kollias, 2016). This study examines the BL processes that influence convective cloud development, particularly during the dry season, when the BL contributes more to the total column moisture than during wet season (Schiro and Neelin, 2018).Line 68-79

3. Although the focus is different, some of the composite analysis results are actually quite very similar to Zhuang et al. 2017, eg. part of Figure 2-5. This point should be mentioned and explained specifically why presenting these similar results about shallow-deep difference are necessary for understanding the boundary layer processes. In addition, similarity, difference, and new findings regarding to the results of this study compared to Zhuang et al. 2017 should also be discussed more clearly.

To describe the environmental conditions in which the BL grows during the early morning, we describe vertical structure during all cloudy-BL stages, thanks to the additional radiosonde in the morning, which allowed us to investigate the rapid growth of BL. In contrast to the related study convective clouds evolution which characterizes seasonal variations (e.g., Zhuang et al., 2017), we provided an overview of environmental conditions associated with the BL evolution. We included sentences with this discussion throughout section 3.1. Also, we included a new sentence on conclusion:

"This finding supports the previous results (Ghate and Kollias, 2016; Zhuang et al., 2017; Tian et al., 2021), but extends the knowledge by showing in detail the different BL processes evolved in the shallow to deep convection transition. In addition, our results show that the time taken to eliminate the nocturnal stable boundary layer inversion is used to promote convection having an important effect in characterizing the convective strength in the morning transition stage." Line 559–562

The overall writing should be improved. There are many unclear sentences and I list some of them below as well as some minor comments. The manuscript has been completely checked by all authors. Also, we have corrected the points below:

- Line 8: I don't think the vertical wind shear presented here qualified as "intense". We rewrote the sentence: "[...] well established vertical wind shear pattern." Line 8

- Line 24: convection -> convective - Corrected Line 43

- Line 25: central or Central? Please be consistent throughout the paper, including the title. Corrected throughout the manuscript.

- Line 79-80: This sentence should either be split or reorganized. "The vegetation cover (...) nearby the intersection ..." does not make sense. We rewrote the sentence:

  The T3 was a pasture site of 2.5 km by 2 km surrounded by forest, with the forest canopy height of approximately 35m (Martin et al. (2016)). Line 113-114

- Line 83: do you mean "meteorological variables at near-surface level"? Corrected Line 118

– Line 84-85: what is “conditional rain rate”? and what does “threshold” here mean for rainfall We rephrased the sentence as:

"Precipitation is used from the Present Weather Detector herein in the conditional rain rate (e.g., mean rain rates are determined only for the periods when rainfall is equal to or greater than 1 mm h^{-1}) to selected the days with precipitation." Line 121-122

– Line 92-94: what is the difference between three BL candidates? We rephrased this part of the manuscript according to your question and it now reads as follows:

"The BL height was retrieved by a laser ceilometer (ARM, 2014) operating at 905-nm wavelength. The ceilometer retrieves three BL height candidates provided by Vaisala BL-view software at 16 s resolution. The standard approach used consists of determining the layers associated with the backscatter gradient profile as possible BL height candidates. As aerosol concentration often occurs at the base of (or within) the entrainment zone in convective conditions or at the level of the temperature inversion capping the residual layer in neutrally stratified conditions. The first BL candidate is associated with the BL height while the others (second and third estimates) with residual layers (Poltera et al., 2017; Carneiro and Fisch, 2020). Therefore, the first BL height candidate was used to determine the height during the diurnal evolution of the atmospheric BL in 5 min average. We refer to the BL height alternatively as the BL top or the BL depth associated with the BL mixing layer. The second and third BL candidates were used to estimate the hourly average of residual layer height. [...]" Line 130-134

– Line 133-134: The ARSCL cloud top and Are these criteria need to be met simultaneously or only one is OK?

The definitions according to the height of cloud and thickness of ARSCL product and the reflectivity of the S-band radar less than 20 dBz should be satisfied simultaneously. We remove any cases from the ShCu/ShDeep analysis if deep convection occurs during the nighttime, to avoid modification in the stable stage due to precipitation processes. We rephrased the sentence:

" [...] A day was classified as representative of shallow or shallow-to-deep cloud day if it simultaneously satisfied the following day conditions" Line 176-177

– Line 150: profile -> profiles Corrected.

– Line 151: times -> time Corrected.

– Line 155-170: Why discuss temperature in between humidity variables. If there is no particular reason, I think the discussions of moisture profile should be placed together. We changed the text accordingly.

– Line 183-184: “12m/s” and “10m/s” do not matched what’s shown in Figure 2d.

Thank you for noticing. There was a mistake in the label of the horizontal axis in Fig2d. Figure 2 was updated and replaced.

– Line 190-191: This sentence is hard to understand. I suggest split and rewrite to make it clearer.

We rephrased the sentence:

"The BL evolution is influenced by cooling and moistening in the first 1000 m leading to a higher RH profile throughout the lower atmosphere." Line 261-262

– Line 194: what produces a lower LCL and CIN. Please rewrite this sentence as well. We rephrased the sentence:

"Both LCL and CIN show a stronger diurnal cycle due to the strong increase in BL temperature and moisture. The environmental condition relatively moister than the environmental conditions on ShCu days leads to lower LCL and CIN on ShDeep days. ShCu days have lower free-tropospheric and BL moisture and thus higher LCL and CIN value (Zhang and Klein, 2010, 2013) creating a larger barrier for BL processes (Tian et al., 2021). Line 265- 268.

- Line 208: it is convective clouds that reduce solar radiation not precipitation. Line 208-210: This statement is not clear.

  We rephrased the sentence:

  " On days with ShDeep, during the cloudy mixing layer stage, clouds are deeper, with larger optical depth, reflecting more shortwave radiation. Consequently, they reduce the shortwave radiation and cool the surface. This differences is very clear when ShDeep days are compared to ShCu days during the late morning or afternoon. ShDeep days have lower net shortwave radiation than ShCu days by an average value of around 70 W m^{-2} between 09:00 and 10:00 LST, and 200 W m^{-2} between 12:30 and 15:00 LST." Line 284-288

- Line 220: Fig. 4c -> Fig. 4d Corrected.

- Line 241: These differences are not statistically significant due to the very large errorbar. We removed this sentence.

- Line 282: what does the plus-minus sign mean here? Is it standard deviation or confidence interval. The plus-minus means the average for the whole stable stage plus standard deviation. We rephrased the sentence:

  " on average and standard deviation of 80 $\pm$ 50 m over the whole stable stage" Line 370-371

- Line 383: “different nighttime and environment”?

  We rephrased the sentence: “During the stable stage, the combination of environment conditions and nocturnal BL characteristics favor such marked variations observed in the morning transition stage.” Line 534-535

- Line 386: Please correct this sentence “2 m specific moisture, such as warm air temperature”. Also, the term should be specific humidity not moisture. We changed the text accordingly.

- Figure 1e: why is there no deep convection observed? We fixed this error in Figure 1e.

- Figure 2: in the second row, x axis range should be narrowed down to better shown the difference. Figure 2 was updated and replaced.

Referee comments 2

We thank you for your constructive comments and suggestions to improve our study. We have carefully addresses all comments/suggestions made by reviewer. Please find below our point-by-point responses in red color, and the changes to the manuscript are in blue color response.

This manuscript used field observations to study the shallow to deep convective cloud evolution in the central Amazon. Several transition cases are comprehensively discussed. In general, this study discussed an important issue with solid analyses. However, the limited cases may not support statistically significant conclusions. Meanwhile, the significance of this study needs to be better summarized in the conclusion section. Therefore, this paper needs major revisions before potential publication in Atmos. Chem. Phys.

The main findings are shown in the conceptual model under ShCu and ShDeep conditions, which were not discussion in details in previous work:

"This finding support the previous results (Ghate and Kollias, 2016; Zhuang et al., 2017; Tian et al., 2021), but extends the knowledge by showing in detail the different BL processes evolved in the shallow to deep convection transition. In addition, our results show that the time taken to eliminate the nocturnal stable boundary layer inversion is used to promote convection having important effect in characterizing the convective strength in the morning transition stage." Line 559–562

As suggested by both referees, we included a new section with statistical analysis of BL processes, especially during stable and morning transition stages (also note our response to the specific comment below). In summary, we rewrite part of the introduction, and we include a new section with BL processes statistics (Sec. 4) and rewrite the conclusions to be more focused on the new findings.

Specific Comments:

1. The evolution of boundary layer cloud can largely differ case by case. Therefore, the mechanism and evolution pattern observed in the several cases may not be representable enough.

   Thanks for your comment. This concern was also raised by Reviewer 1. Motivated by both suggestions, a new section with BL processes statistics based on the overview of case studies is now presented in Sect. 4 (Line 460-514).

   4. Boundary layer processes statistics during the two dry seasons of the GoAmazon 2014/5 campaign

   In order to evaluate the significance of the conceptual model built based in the case studies, a statistical analysis was performed. The statistical analysis was developed by comparing the cases of shallow and deep convective clouds using the same classification and relaxing the premise of having convection under the T3 site. ShDeep days were classified as hot-tower clouds with little external disturbances in the morning based on cloud boundaries of the RWP-WACR-ARSCL product and the precipitation properties for the domain within the 75 km radius of the T3 site estimated by S-band Radar scanning (Tian et al., 2021). ShCu days were classified as days with no precipitation in the 75 km radius of the T3 site. Using the two dry season years, 45 cases of ShDeep and 30 cases of ShCu were selected. On the majority of days, the shallow-to-deep cloud evolution did not occur at the T3 site but in the 75 km radius domain of S-Band Radar. The statistic analysis of the BL processes mainly focus on the stable to the morning transition stages as it has been shown in the conceptual model of the BL process (Fig. 10). This large number of events is robust to significantly describe the daily evolution of a typical day of ShCu and ShDeep.

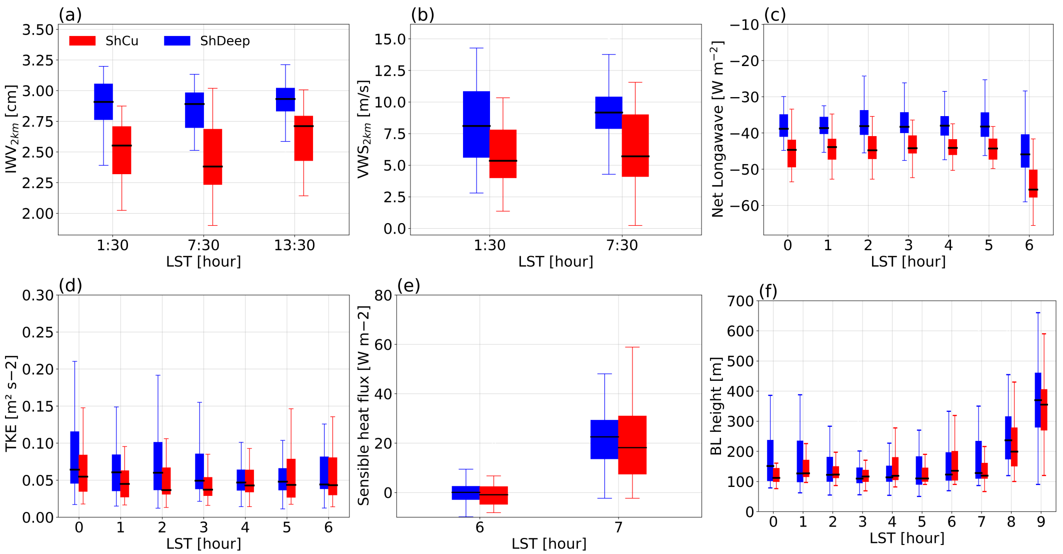
   The composites of the BL processes, discussed in detail in the previous section, are shown in Fig. 11 as box-and-whisker plots. As previously discussed, Ghate and Kollias (2016) suggested that greater fluctuation over short periods in IWV is the primary factor controlling meteorology and precipitation during the dry season. In fact, the median $\mathrm{IWV}_{2\ km}$ composite, at the lower 2 km, shows large values and exhibits small variability in the ShDeep (blue boxes) than ShCu (red boxes) regimes since nighttime (stable stage) (Fig. 11a). In the lower troposphere, distinct variability in ShDeep conditions is also observed in $\mathrm{VWS}_{2\ km}$ from the stable stage to the morning transition stage, with larger median values than that for ShCu (Fig. 11b). Zhuang et al. (2017) found a similar result, concluding that the contrast between ShDeep and ShCu days could be associated with weak surface wind and strong wind shear in the lower troposphere. Moreover, this result indicates that turbulent mixing may be transported from aloft down to the surface, linking to the evolution from stable to unstable BL conditions.

During the stable stage at near surface, less radiative cooling and intense periods of turbulent mixing characterized the ShDeep composite in comparison with ShCu. The net longwave showed very similar results to the case studies (Fig. 11c) with a well-defined difference of around 5 W m^{-2} between the ShDeep and ShCu composites. The median shows more intense radiative cooling during the ShCu regime than for ShDeep. For example, Edwards et al. (2014) using large-eddy simulations showed that radiative cooling has an important effect on the morning transition and in the development of the convective BL. The mechanical turbulence is seen in Fig. 11c by the TKE. The magnitude of the TKE is comparatively higher for the ShDeep between 00:00 and 03:00 LST than those of the ShCu composite. Similar small median values occur at around 06:00 LST for both regimes when the increase in turbulence is weak, probably caused by weak wind at late night and cumulative thermal cooling inducing stable stratification near the ground through the nighttime.

In contrast to the longwave radiative cooling, the sensible heat flux showed a less pronounced difference with increasing sample size, being slightly higher in the median ShDeep values than in the median ShCu values during the crossover event (Fig. 11e). One explanation for this difference is that the sensible heat flux is affected by cloudiness and the surface thermal properties, such as the one shown in Fig 1g, on day 7 of the case studies. In that case, the sensible heat flux is influenced, before or during the morning transition, by reducing incident solar radiation, surface temperature, and therefore its magnitude and time crossover (e.g., reduce the intensity of convection). However, considering that under ShDeep conditions there is less radiative cooling, a small variation in the sensible heat flux at the time of crossover can resulting in early erosion of the nocturnal inversion that develops during the stable stage. Such cloud cover is less frequent in the ShCu regime during the early morning, if clouds are more frequent in the afternoon period attributed to the shallow cumulus cloud type (Giangrande et al., 2020).

During the stable stage, the ShDeep BL height is higher than that of the composite ShCu. The relatively high BL height values are consistent with relatively higher mechanical turbulence as the source of TKE (Fig. 11d). The hourly median BL height values from sunrise to early morning vary from about 110 to 250 m between 07:00 and 08:00 LST in the ShDeep regime (Fig 11f). For the ShCu regime, the median hourly BL height values vary from around 110 to 200 m, suggesting that the onset of convective BL is earlier in the ShDeep composite regime than in the ShCu composite regime. The BL height evolution exhibited in both regime composites is consistent with the evolution observed in the case studies during the morning transition.

The statistical analysis is in agreement with the conceptual model developed based on the case studies, even do not considering convection over the T3 site. The pronounced feature that emerges from this analysis is the clear difference between the two regimes for IWV and VWS and the BL height. This impact in the time needed to eliminate the nocturnal stable BL inversion used to promote convection having important effect in characterizing the convective strength in the morning transition stage and the rapid growth stage. This energy of BL growth is in agreement with the large, positive BL disequilibrium values on ShDeep days and the mostly negative BL disequilibrium values in early morning on ShCu days showed by Tian et al. (2021). Therefore, the enhanced water vapor at low and mid-level is important not only for the initiation of deep convection in the cloudy mixing layer stage but also for the characterization of the cloud-BL interaction from the stable to the rapid growth stage. This feature, observed during the dry season over Central Amazonia, was corroborated by Chen et al. (2020) who showed that large-scale advection is vital for characterizing land-atmosphere interactions both in magnitude and type of relationships in the transition from clear-sky to precipitation clouds over the U.S. SGP site.



. Figure 11. Box-and-whiskers plot of (a) IWV$_{2\ km}$ during the stable, morning transition, and cloudy mixing layer stages, (b) VWS$_{2\ km}$ at stable stage and morning transition, (c) radiative cooling during the stable stage, and (d) TKE during the stable stage, (e) sensible heat flux crossover, and (f) BL height from stable to onset of convective BL. In each box, the central bar is the median and the lower and upper limits are the first and the third quartiles, respectively. The lines extending vertically from the box indicate the spread of the distribution with the length being 1.5 times the difference between the first and the third quartiles. The red and blue boxes correspond to shallow convective (ShCu) and shallow-to-deep convective (ShDeep) days, respectively.

2. The impacts of humidity on the development of convective clouds have been intensively investigated in previous studies (e.g., Zhang et al. 2010, 2013). The authors need to address the differences in their findings comparing to previous studies. Thank you for the suggestion. We added references to the text. Also, we added the recent GoAmazon work about diurnal cycle of clouds of Tian et al., (2021) which expands the previous classification of Zhang and Klein (2010,2013) based on US Southern Great Plains to GoAmazon main site. This new classification of ShDeep events was used to provide statistical analysis (e.g. New Sec. 4) of our conclusions which is based in the cloudy-BL stages of conceptual model.

3. As a key parameter, this study discussed the positive role of sensible heat flux on shallow-to-deep convective clouds. However, strong sensible heat also can lead to strong entertainment at the boundary layer top, which would induce dry air masses into the boundary layer. Thus, sensible also may negatively affect cloud development. Moreover, besides the impacts of sensible heat on cloud development, clouds can significantly alter sensible heat. Thus, this issue needs to be discussed more carefully. We agree. We added the information to the text about sensible heat flux on clouds and entrainment during the ShCu and ShDeep conditions:

   Line 315-321 "A pronounced feature of the diurnal evolution of the sensible heat flux, often seen on ShDeep days, is the effect of sensible heat flux promoting the erosion of nocturnal BL driving a higher growth rate of the BL in the morning transition stage than on ShCu days. At the cloudy mixing layer stage, for ShDeep days, clouds affect the surface sensible heat flux, either positively by increasing the sensible heat flux due to processes associated with the arrival of the gust front or negatively by diminishing the sensible heat flux due to the transport of cool air from aloft into the BL (e.g. Oliveira et al., 2020). On the other hand, the large sensible heat flux during the cloudy mixing layer stage on ShCu days may be a response to BL turbulence and more entrainment of dry air from the free tropospheric into the BL (that drives more sensible heat flux)"

   Line 345-349 [...] "While on ShCu days, the surface specific humidity is maximum around 08:00 LST followed by a drying throughout the rapid growth stage and cloudy mixing layer stage of around 2.0 g kg^{-1} until the sunset, followed by a later maximum at 19:00 LST. These findings are consistent with those of Zhang and Klein (2013), where a large sensible heat flux during the cloudy mixing layer were observed to contribute to greater entrainment of dry air into the BL in ShCu in the SGP site.

4. Some variations in the meteorological data may not cause by natural variability, but due to the instrument deficiency. In Figure 4-5, some signals seem a little bit noisy. In Figure 4f, there are some sharp decreases in sensible heat during the daytime. The authors may clarify these odd variations.

We agree that some plots of Fig. 4 and Fig. 5 in the same panel seem to have more variability. This variability is due to the different time interval resolution used in the plot, such as 1 min for the surface meteorological system and 30 min for ECOR. However, we do not believe that it is due to instrument deficiency since, for the analysis, we have used all good-quality flagged by the ARM user facility. To clarify this point, we have changed the time interval of the surface meteorological system by 30 min on average since it does not alter the results of our discussion. Thus, we have updated and replaced Figures 4-5.

References

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