General Response to Referee #1

Original referee comments are in blue.
Our responses are in black with regular font format. Text from the updated manuscript:

Appears in italics with 1⁄2 inch indentation with the removed parts exhibited with a ~~strikethrough~~ and red color while new text added is shown in green.

Summary of RC1 comments:
The authors introduced a clear and robust regime classification methodology. Their novel findings underscore the significance of low-level wind shear and estimated moisture flux convergence for each regime.

We are grateful for the encouraging comments and would like to acknowledge the thoughtful revision, which helped improve our manuscript.

However, the authors' broad investigation of potential forcings may have compromised the depth of certain analyses, such as the water budget closure, which merits further exploration. (1) Additionally, they should address uncertainties related to rain gauge-measured precipitation and surface fluxes.

(2) Suggestions include incorporating symbolic error terms to account for measurement errors and exploring error budget analyses within each regime.

(3) Furthermore, they should consider alternative precipitation sources for water budget closure could strengthen the study.

In order to provide uncertainty estimates with respect to the water budget, we followed the reviewers' suggestions and considered different sources of precipitation in our updated analysis. In addition to the surface AOSMET precipitation [1], we are now also using the tipping bucket [2] and laser disdrometer (LD) [3]. Figure 9 in the current manuscript will be replaced by the figure below, which displays the updated results.

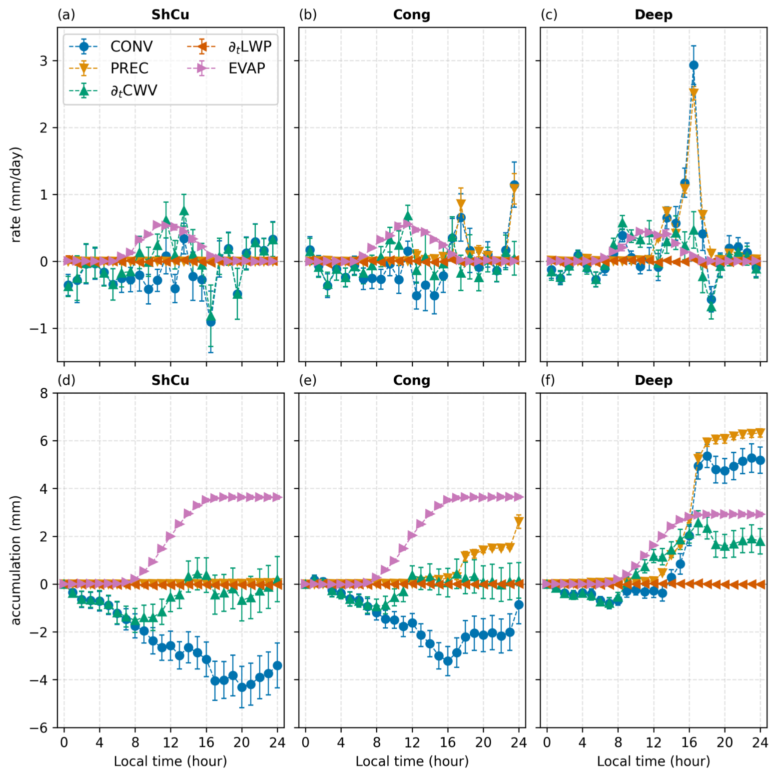


Figure 9. Surface water balance for (a,d) ShCu regime, (b,e) Cong regime, and (c,f) Deep regime. The upper panels represent the rates of change (mm/day) for water vapor convergence (CONV), evaporation (EVAP), precipitation (PREC), and the time derivatives of column water vapor ($\partial_t CWV$, where $\partial_t = \partial/\partial_t$) and liquid water path ($\partial_t LWP$). The lower panels display the accumulated water amounts for each term in the water budget along the day (mm). Note that CWV and LWP changes rely on microwave radiometer observations, evaporation on eddy correlation flux measurements, and precipitation ~~on aerosol observing system surface data~~ is estimated utilizing different sources, namely, the aerosol observing system surface data, tipping bucket, and laser disdrometer. The water vapor convergence term is estimated as a residual in the water budget equation (Section 2.2).

For the rate amounts, the time derivative of CWV or LWP corresponds to the microwave radiometer (MWR) data source. Evaporation rate is calculated from the Eddy Correlation (ECOR) Flux Measurement. Precipitation is the mean composite from the AOSMET, tipping bucket, and laser disdrometer sources. The precipitation uncertainty is estimated from the standard deviation of the different sources. Mean convergence is estimated from the water balance closure, i.e., equation (2) at line 137 from the manuscript. The standard deviation of mean convergence is estimated from the standard deviation of the mean $\partial_t CWV$, $\partial_t LWP$, EVAP, and PREC, i.e.,

$$\sigma_m = \sqrt{\sigma_m(\partial_t CWV)^2 + \sigma_m(\partial_t LWP)^2 + \sigma_m(EVAP)^2 + \sigma_m(PREC)^2} \quad .$$

Mean accumulation amounts and their standard deviations are obtained analogously. Note that the convergence uncertainty is mainly attributed to the uncertainty of CWV. More importantly, the main message of our analysis remains unchanged despite the uncertainties included, i,e., shallow days are dominated by divergence while deep days by convergence. Finally, to provide additional information to the readers, we will also include the precipitation and convergence term associated with each data source in the Supplementary Materials, as indicated by the Figure below:

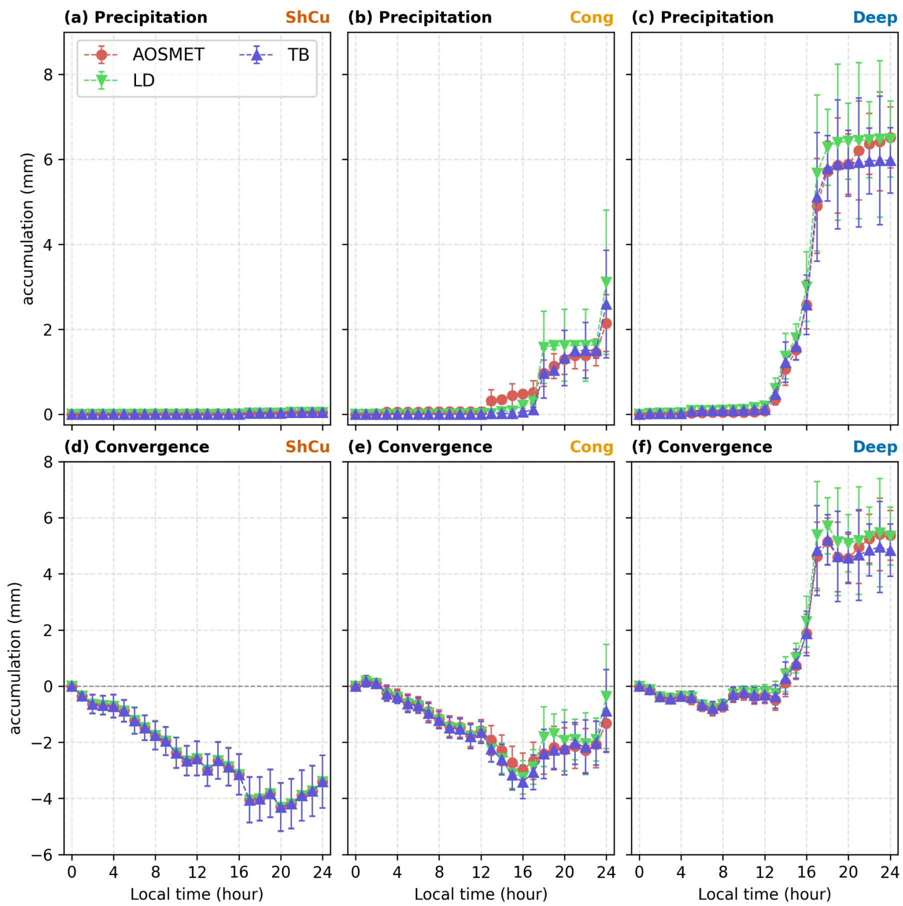


Figure A1. Accumulated surface precipitation (mm) for the aerosol observing system surface data, tipping bucket, and laser disdrometer are shown in the upper panels (a-c). The corresponding convergence (mm) term for each instrument is displayed in the lower panels (d-f). The ShCu, Cong, and Deep regime results are shown in the first, second and third columns, respectively.

With this improved analysis, we believe that all the uncertainties related to the water budget are resolved consistently, given the available observational data. Likewise, the results are statistically significant.

To include the updated version of the surface water balance, the current manuscript must be modified as follows:

Line 115:

Instead of using the S-band radar precipitation, the water balance analysis ~~uses the AOSMET surface precipitation~~ utilizes a combination of rain-gauge source measurements to provide a more robust estimation of the mean surface precipitation and its uncertainties. Specifically, we use the surface AOSMET precipitation [1], tipping bucket [2], and a laser disdrometer (LD) [3].

Line 141-143:

Specifically, CWV and LWP are based on the MWR. ECOR latent heat flux data is utilized for estimating the evaporation term. Precipitation is ~~taken from the AOSMET surface measurements~~ obtained utilizing different sources, namely, aerosol observing system data, tipping bucket, and laser disdrometer (Section 2.1).

Line 248-250:

The water balance results are shown in Fig. 9, with the top panels showing the hourly average rate values (mm/day) and the bottom panels showing the corresponding accumulated values (mm). The separate precipitation and convergence associated with each rain gauge used to estimate the mean surface precipitation and its uncertainty in the water budget results are provided in fig. A1. First, we notice that the variation in LWP appears negligible, and it does not contribute significantly to the water budget.

Line 254-255:

At day's end, the ShCu regime is estimated to lose 3.4 mm of water vapor due to divergence, while the Cong regime loses ~~1.3~~ 0.9 mm. In contrast, the Deep regime gains ~~5.4~~ 5.2 mm of water vapor due to convergence.

Figure 9, page 14:

Figure 9 is replaced by the updated one, shown above. To consider the new sources of surface precipitation, the caption is updated as follows:

Note that CWV and LWP changes rely on microwave radiometer observations, evaporation on eddy correlation flux measurements, and precipitation ~~on aerosol observing system surface data.~~ is estimated utilizing different sources, namely, the aerosol observing system surface data, tipping bucket, and laser disdrometer.

(4) Enhancing visualization clarity in Figure 6.

We updated Fig. 6 to limit the y-axis from surface to 5 km and also included the estimated standard deviation for the difference in potential temperature and mixing ratio ($\sqrt{\sigma_m(Deep)^2 + \sigma_m(ShCu\ or\ Cong)^2}$), as shown on figure below.

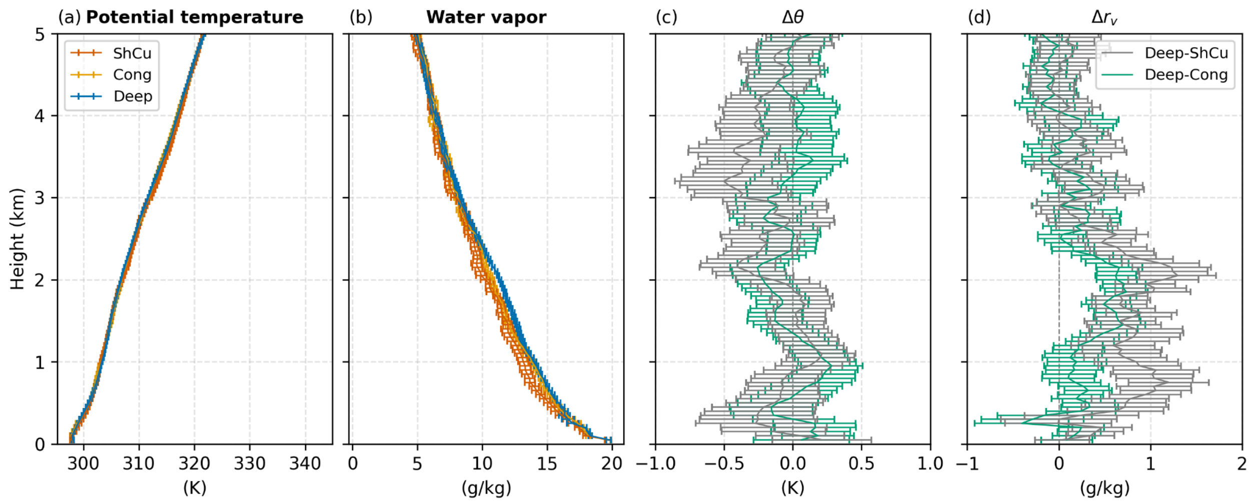


Figure 6. Atmospheric conditions. (a) Potential temperature (K) and (b) water vapor mixing ratio (g/kg) at 08 LST radiosonde observations. The corresponding convective regime differences (Deep-ShCu and Deep-Cong) for potential temperature (Δθ, c) and mixing ratio (Δr_v, d) are also included.

Despite the uncertainties in the difference of mixing ratio between Deep and ShCu composites, values are greater than 0 from the surface up to 3 km. Hence, our main message remains the same: Deep days are relatively moister than shallow days only in the lower levels. The differences between congestus and deep days are less pronounced, albeit the deep composite tends to be slightly moister than the congestus profile.

(5) Suggestions for future research, such as applying constrained variational analysis for moisture flux convergence estimation, are recommended.

We thank the reviewer for the suggestion. We agree that the variation analysis could be an interesting source of data to investigate the water balance, particularly because all the inputs and outputs of the model estimates are forced to be physically consistent.

However, the VARANAL horizontal scale is ~100 km and the temporal scale is about 3 hours, which is not exactly the same scale involved in our manuscript. Thus, further analysis would be necessary to directly compare the constrained analysis and our results, if we were to include here. That is why we intentionally focused solely on direct observations in this current manuscript.

Nonetheless, we added the following in the conclusions of the manuscript to indicate that future studies should look into VARANAL (or Data Assimilation in general) to investigate further the water budget of the STD transition:

Lines 415-418:
While numerous studies have explored these recent observations over the Amazon, only a few have utilized high-resolution simulations to investigate the environmental controls of convection (e.g., Cecchini et al., 2022). The VARANAL large-scale data could be used to force cloud-resolving models or even directly evaluate the water budget (but note that it operates on a different spatial and temporal scale than the one analyzed in this study). Likewise, longer-term, high-density observational networks in the Amazon, such as Adams et al. (2015), would be of great value for constraining or evaluating numerical model results.

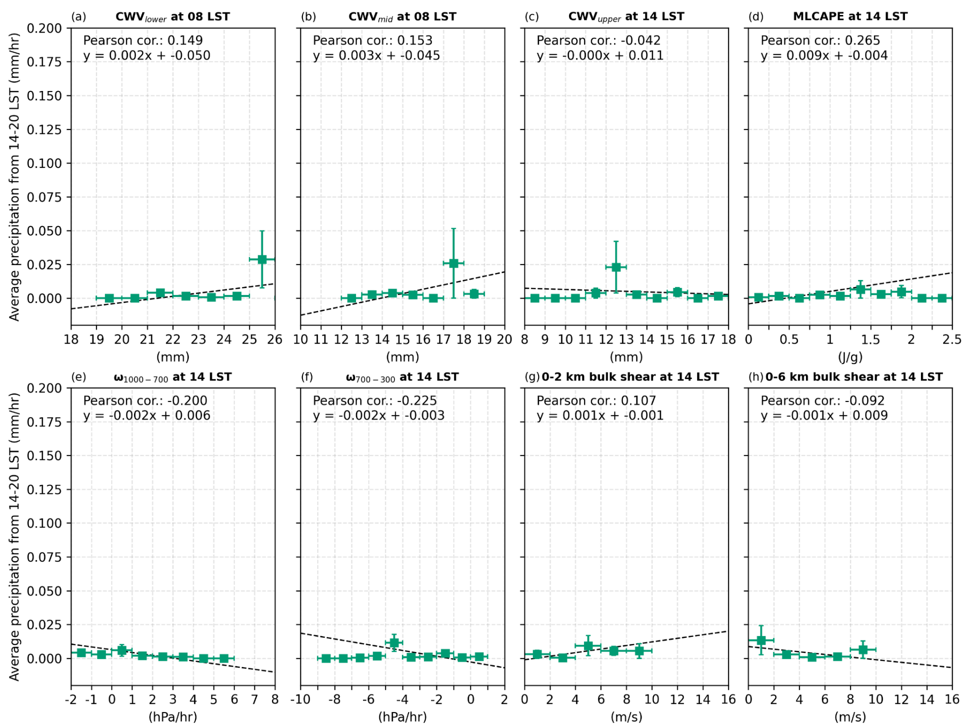
(6) The authors should consider presenting conditionally average precipitation findings related to rain gauge-averaged sources between 14-20 LST as an appendix or mention if differences are negligible.

We considered it, but this would cause a mismatch of spatial scales. We remind the reviewer that our "conditional analysis" uses the S-band radar precipitation data averaged over a domain of 100x100 km^2. Moreover, the precipitation in Figure 14 is the afternoon precipitation (14-20 LST), while the variables are shown either at 8 or 14 LST. Last but not least, this analysis includes all days; hence it is different from all the previous figures that distinguished between ShCu, Cong, and Deep days.

The other sources of precipitation, such as AOSMET, TB, and LD, are local point measurements. Thus, unless the rain is exactly over the T3 site, only the S-band radar will capture it. This significantly reduces the correlation between the precipitation metric (which is now local) and the evaluated variables (atmospheric state based on sounding measurements or large-scale wind). To support our argument, the figure below shows the conditional analysis based on the AOSMET precipitation, and no correlation is seen.

Essentially, our methods evaluate how the atmospheric state in the morning or a few hours preceding the STD convective transition (at 14 LST) relates to the mean precipitation over a large-scale domain during the entire afternoon. That is why we employed the S-band radar for this particular analysis.

To include local sources of precipitation, a possible alternative approach would be to follow the methods in [4], i.e., apply a more instantaneous comparison (average precipitation and other variables at the same time range) instead of evaluating 8 or 14 LST atmospheric state conditionally to the diurnal (14-20 LST) averaged precipitation. However, this would be more similar to evaluations conducted on previous studies (except that they did not evaluate large-scale wind).



(7) Additionally, there have been a few technical corrections reported regarding the text, aimed at enhancing sentence structures.

- Lines 222-223: CWV difference at 8 LST doesn't appear statistically significant for Deep – Cong
  Answer: Thank you for your observation. The text was modified as follows:

  Previous version:
  ~~Interestingly, CWV for Cong and Deep regimes is similar before the diurnal cycle starts, at 2 LST, but is already larger for the Deep by 8 LST. The difference is maximum at 14 LST when it reaches 2.1 mm.~~

  Updated version:

The differences in CWV among Cong and Deep regimes show little statistical significance from nighttime to early morning, while their difference is maximum at 14 LST when it reaches 2.1 mm.

- Lines 226-227: Change “A similar, albeit less pronounced, pattern is also observed in the lower free troposphere.”

  To e.g.,:

  “A similar, albeit less pronounced diurnal moistening is also observed in CWVmid for all regimes.”
  Answer: done

- Lines 230-231: Remove “, and associated with low-level moisture divergence, which would explain the slower accumulation of moisture below 700 hPa despite slightly larger latent heat.” Current logic is too speculative.
  Answer: done

- Lines 239-242: Avoid comparing Cong vs. Deep when differences are negligible. Consider reframing certain comparisons as Cong+Deep vs. ShCu in this section in general e.g.,

  “In the afternoon, MLCAPE is higher for the Deep regime (1237 J kg−1), a few hours before the late afternoon STD transition, slightly surpassing the value for the Cong regime (1111 J kg−1) and significantly exceeding the value for the ShCu regime (671 J kg−1).”

  could be changed to:

  “At 14 LST, MLCAPE for the Deep regime (1237 J kg−1) and Cong regime (1111 J kg−1) significantly exceed the value for the ShCu regime (671 J kg−1).”
  Answer: Thank you for the comment. We modified the text as suggested.

- Line 258: CWP should be CWV
  Answer: done

- Lines 259-260: Combine these 2 sentences. “By the end of the day, the accumulation of water vapor in the column is negligible. This term is also nearly zero during Cong days.”

Answer: Everything mentioned previously relates to the shallow regime description. Hence, it would not be reasonable to apply the same conclusion to both regimes unless the entire paragraph is readjusted.

- Lines 261-262: Change "which might affect the convective regimes developing the following day."

  To e.g.,:

  "which might act as a positive feedback for the continuation of nocturnal deep convection into the following day after Deep regime conditions"
  Answer: done

- Lines 265-266: Change "There is a characteristic low-level jet during the wet season. Anselmo et al. (2020) also reported an Amazonian low-level jet, occurring 10-40% of the time during March-May 2014-2015."

  To e.g.,:

  "The wind profiles for all regimes peak between the 900-800 hPa layer, characteristic of a low-level jet also reported by Anselmo et al. (2020), which they observed 10-40% of the time during GoAmazon between March-May 2014-2015."
  Answer: done

- Lines 265-272: Avoid describing relative wind speed maxima of a point sounding as "jets".
  Answer: Thank you for pointing out that inconsistency. Please note that we are using the 3-hour mean large-scale wind field from the VARANAL data instead of radiosonde data. For the low-level wind, we have cited Anselmo et al. (2020) as noted in the previous comment.

  Regarding the upper-wind, we only noticed one reference to the maxima as being the jet, on line 271. We modified this as:

  (...) upper-level ~~jet~~ maxima. (...)

- Line 286: Word choice of "important subsidence"
  Answer: replaced by "robust subsidence"

- Lines 288-289: Remove sentence beginning “However, solely through differences in…”
  Answer: done

We hope these answers provided clarifications and answers for the comments raised in this revision. Below you can find the papers mentioned explicitly in our response.

References:

[1] Atmospheric Radiation Measurement (ARM) user facility. 2013. Meteorological Measurements associated with the Aerosol Observing System (AOSMET). 2013-12-12 to 2015-12-01, ARM Mobile Facility (MAO) Manacapuru, Amazonas, Brazil; MAOS (S1). Compiled by J. Kyrouac, S. Springston and M. Tuftedal. ARM Data Center. http://doi.org/10.5439/1984920.

[2] Atmospheric Radiation Measurement (ARM) user facility. 2014. Rain Gauge (RAINTB). 2014-10-14 to 2015-07-03, ARM Mobile Facility (MAO) Manacapuru, Amazonas, Brazil; Supplemental Site (S10). Compiled by J. Kyrouac, Y. Shi, M. Jane and D. Wang. ARM Data Center. http://doi.org/10.5439/1224827.

[3] Atmospheric Radiation Measurement (ARM) user facility. 2014. Laser Disdrometer (LD). 2014-09-24 to 2015-08-13, ARM Mobile Facility (MAO) Manacapuru, Amazonas, Brazil; Supplemental Site (S10). Compiled by D. Wang, M. Bartholomew, Z. Zhu and Y. Shi. ARM Data Center. http://doi.org/10.5439/1973058.

[4] Schiro, K. A., J. D. Neelin, D. K. Adams, and B. R. Lintner, 2016: Deep Convection and Column Water Vapor over Tropical Land versus Tropical Ocean: A Comparison between the Amazon and the Tropical Western Pacific. J. Atmos. Sci., 73, 4043–4063, https://doi.org/10.1175/JAS-D-16-0119.1.