Response to comments of Referee #1

We thank the reviewer for the thoughtful and constructive comments on the manuscript. We have been carefully considering each of the comments. The reviewer's comments are repeated in normal font and our responses are followed in blue.

This study investigates the impact of convective treatment (particularly, parameterized vs explicit deep convection) on the simulation of mean tropical precipitation (particularly, the ITCZ), using a 13km ICON model in a semi-aquaplanet simulation with walls at 30N/S. They find, with explicit deep convection, rainfall in the ITCZ increases by 35% and the Hadley circulation as well as surface winds become stronger. Based on a diagnostic framework based on Emanuel (2019), they attribute the difference to the stronger surface horizontal winds with explicit deep convection, which modifies the boundary layer equilibrium and consequently the updraft mass flux.

I have some concerns about the model setup and the derivation of Eq. 1. I suggest a major revision with the following comments.

Major comments:

1. Uncertainty due to model setup

Resolution:
The effect of explicit versus parameterized deep convection is investigated at a horizontal resolution of 13 km. It is generally believed that the horizontal resolution needed to partially resolve deep convection should be ~1km, the 13km resolution used here is not sufficient to resolve deep convection, so the setup of the S13 experiment would not be recommended. It is unclear how sensitivity is the effect of explicit deep convection to the background horizontal resolution. Will the conclusion be different if a higher horizontal resolution, e.g. 3km, is used?

Thank you to raise this important point. We add originally planned to include higher-resolution simulations but then had to abandon this for technical reasons. Fortunately, the simulations have now become available as originally planned and we are in the process of adding 5-km aquachannel simulations with explicit and parameterized deep and shallow convection. Their convective treatments correspond to those of E13 and P13 in the submitted manuscript. This entire set of aquachannel simulations exhibits that mean tropical rainfall is sensitive to convective treatment and horizontal resolution (Fig. 1). We apply the ITCZ diagnostics presented in the submitted manuscript to investigate what processes are responsible for the sensitivities. For the resolution dependency, the vertical difference in moist static energy (h_b-h_m) gains importance to shape mean rainfall while the role of surface enthalpy fluxes remains substantial. Our plan for a revised manuscript is including the entire set of simulations and results using the same ITCZ diagnostics.

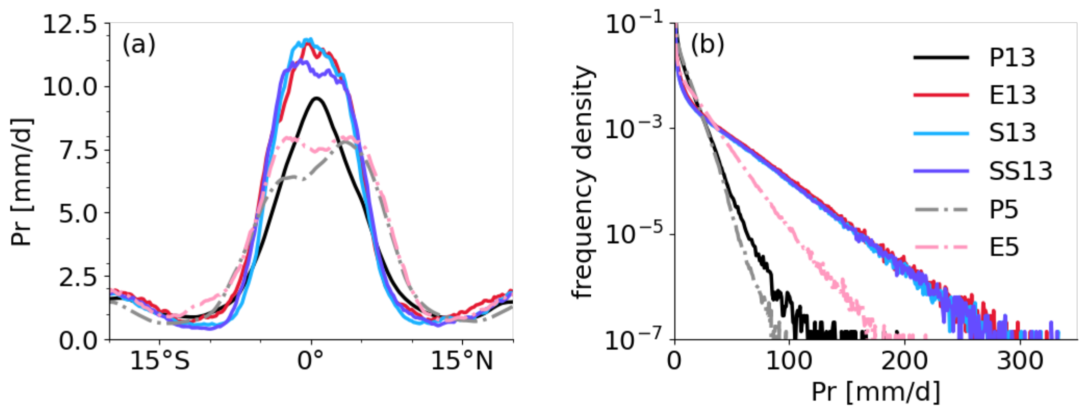

Figure 1. Distributions of (a) time and zonal mean of precipitation rate and (b) precipitation intensity between 20°N/S. Precipitation fields are coarsened on a 0.2° lat-lon grid using a conservative remapping. P5 is the 5-km aquachannel simulation with parameterized deep and shallow convection and E5 is the one with explicit deep and shallow convection.

Walls at 30N/S:
The aquaplanet simulations has a wall at 30N/S. This setup is likely to affect many aspects of the simulations including the ITCZ. It is unclear to me if the conclusion of this study would be different if there is no wall but a global aquaplanet.

We agree that the closed walls at 30N/S exclude many important aspects such as tropical-extratropical interactions on the ITCZ and leads to a narrower-than-normal Hadley circulation. On the other hand, this exclusion simplifies our problem, such that we can concentrate on processes in the equatorial region in full isolation, which we deem an important building block in understanding predictability in the tropics fully in subsequent works. The important role of surface enthalpy fluxes for mean rainfall may not hold to the same degree using an aquaplanet simulation, but we emphasize that the ITCZ diagnostics we propose in our manuscript can, of course, be applied to any simulation geometry to test the sensitivity of mean rainfall. So, we see this also as a first step towards a more comprehensive intercomparison in the long run, which will help gain a deeper understanding of important processes. We will discuss this aspect in more detail in Sect. 2.2 and will leave the sensitivity of tropical rainfall to simulation geometry for future study.

2, The derivation of Eq. A5, which leads to Eq. 1

Eq. A1 is for the top of the BL (the subsidence is w_e) while the equation at L686 is from the balance between radiative cooling and descending is for free troposphere (i.e., the subsidence is not w_e), then, how could these two equations be combined into Eq. A5.

Right, they are not identical. Assuming mass conservation and approximately constant vertical velocity, w_e at the top of BL and in the free troposphere are similar, which was also argued in Emanuel (2019) for simplification. Besides, we believe that the beauty of his framework lies in traceability, providing the simplest solution that one could come up with to explain atmospheric phenomena in the tropics. What we learned from our research is that despite its simplicity, it is nontrivial to understand the behavior of mean tropical rainfall. We will elaborate explaining different w_e in Appendix A in the revised manuscript.

Minor comments:

L54: Not sure if "appropriate" is the right word here. Each model center has chosen the model resolution appropriately, according to their needs and computational resources.

Thank you for the insightful thought. We will change the wording in L54.

L60-70: According to Zhou et al. (2022), the storm-resolving simulation (res ~3km) does not reduce the bias in tropical precipitation characteristics (except for the better representation of strong convection events and tropical cyclones) and is not likely to alleviate the double-ITCZ bias.

Zhou W., L.R. Leung, J. Lu, (2022): Linking large-scale double-ITCZ bias to local-scale drizzling bias in climate models. Journal of Climate 35 (24), 4365-4379.

We will include the suggested paper when we discuss the added value of convection-permitting models in a revised manuscript.

L71: resolving (deep) convection

This will be changed in the revised manuscript.

I suggest moving section 4 (description of the diagnostic framework) to section 2.

We appreciate the suggestion and discussed it at length. At the end, we decided to leave the structure largely as it is. The diagnostic framework is in some sense part of results while being a method at the same time. Placing the description of the method closer to the application certainly has the advantage for the reader to better remember the meaning of the individual terms and their relationships. To avoid confusion or creating false expectations, we have decided to rename Sect. 2 as “Aquachannel experiments”.