General response: We thank the reviewer for these important comments and for raising the question of the novelty and broader motivation of the study. We agree that many of the large-scale features identified here—such as a weakening and widening of the Hadley circulation and changes in the intensity and position of tropical precipitation—have been documented in previous observational and model-intercomparison studies.

We would like to emphasize, however, that the TIPMIP experimental protocol, which this study is among the first to utilize for examining the tropical precipitation and circulation response to global warming, provides an opportunity to investigate these responses within a different experimental framework. Although the primary aim of TIPMIP is to investigate the potential for tipping behavior in the Earth system, its idealized simulations also provide a valuable opportunity to examine the evolution of climate responses across a range of global warming levels and, along different forcing trajectories. This allows for a systematic comparison of climate states that is not readily available from conventional model-intercomparison experiments.

In response to the reviewer's suggestion, we will extend the analysis to make greater use of the different TIPMIP forcing pathways by comparing the transient ramp-up simulations with the early and late stabilization periods at comparable global warming levels. This additional analysis will allow us to investigate whether the tropical circulation and precipitation response depends on the forcing trajectory and climate state, and will better exploit the experimental design of TIPMIP.

Comments:

1. Reference to previous works. The findings of the present analysis reproduce similar finding in analyses of other MIPs (e.g., Lionello et al. 2024, Ma et al. 2018). These, however, are scarcely cited in the text. Aside for the problematic lack of referencing, the novel results of the present analysis, if any, are not clear. A single reference is mentioned in the Conclusions (Hu et al., which is also not properly cited in the references), and with no context.

Response: We thank the reviewer for this comment. We will correct the reference to Hu et al. (2018) in the reference list, and give context for it in the Conclusions (see our response to the comment on line 335). We will also revise the paragraph at lines 323–328 to place our regional results within the context of previous CMIP-based studies:

Rephrasing paragraph at 323 and 328:

“At the regional scale, changes in ITCZ position generally correspond to projected precipitation changes shown in Fig. 1. For example, the northward displacement of the southern edge of the Indian Ocean ITCZ is consistent with the projected precipitation dipole in this region during both seasons. ITCZ precipitation intensity increases across most regions, with exceptions over the continental equatorial America and Africa in JJA. This widespread intensification is consistent with the projected increase in precipitation across much of the equatorial belt.

Regional ITCZ displacements generally become more pronounced at the higher GWL, although uncertainty also increases where the simulated changes are small. This is evident, for example, for the northern edge of the central Pacific ITCZ during both seasons.”

to:

“At the regional scale, changes in ITCZ position generally correspond to projected precipitation changes shown in Fig. 1. For example, the northward displacement of the Indian Ocean ITCZ is consistent with the projected precipitation dipole in this region during both seasons. The general northward displacement of the ITCZ over Africa and the Indian Ocean, along with the southward displacement over the Eastern Pacific, is in agreement with the findings of Mamalakis et al. (2021)

and Lionello et al. (2024) that relied on CMIP6 projections. Regional ITCZ displacements generally become more pronounced at the higher GWL, although uncertainty also increases where the simulated changes are small. This is evident, for example, for the northern edge of the central Pacific ITCZ during both seasons. The ITCZ precipitation intensity is projected to increase across most regions, with exceptions over continental equatorial South America and Africa during JJA. This widespread intensification is consistent with the projected increase in precipitation across much of the equatorial belt. However, the spatially heterogeneous response reflects the influence of competing mechanisms over land and ocean, which can lead to contrasting precipitation responses in these regions, as described by Ma et al. (2018)."

2. Sensitivity to biases. Systematic tropical precipitation biases in modern climate models are well known. Given that the simulations considered here involve specific global warming targets, there clearly would be a thermodynamic component. See comment related to how to correct for that in relation to Fig.1. Similarly, models generally show equatorial warming while over the past decades, the equatorial central Pacific has cooled. This is important context that should be provided when interpreting the results.

Response: We thank the reviewer for this comment. We address both points in detail in our responses to the line-specific comments below: the precipitation bias correction under Fig. 1, and the central Pacific cooling under lines 234–244.

3. Utilization of TIPMIP. It is not clear to me why the authors do not also analyze the ramp-down simulations. Given that there has been so much work on the response of the tropical rain belt to global warming, one clear novelty that TIPMIP may provide is in contrasting the ramp-up and ramp-down simulations. For example, if such differences exist, they would inform us on state dependence and would be helpful in disentangling dynamic and thermodynamic responses (cf. Kug et al. 2022).

Response: We thank the reviewer for this valuable suggestion. We will add further complementary analysis comparing the state of the tropical atmospheric circulation and precipitation during the transient ramp-up period with that during the early and late zero-emission periods at different GWLs. This analysis will complement the existing analysis on the responses of the tropical atmosphere at the various GWLs, compared to the pre-industrial conditions.

This comparison will allow us to examine whether the tropical circulation and precipitation response differs between periods of increasing CO_2 concentrations and stabilized warming under zero-emission conditions at similar levels of global warming, but also how the tropical atmosphere adjusts during zero emission at the various GWLs. In particular, it will provide insight into whether the tropical rain belt and associated circulation exhibit a dependence on the forcing trajectory and climate state. Such an analysis can also help assess the relative roles of dynamical and thermodynamical processes in shaping the tropical response to warming.

We believe this additional analysis will make fuller use of the TIPMIP experiments to study differences between transient and stabilised climate states, and that it will usefully complement the results already presented.

Comments by line number:
Lines 25—27: The subtropical convergence zones, such as the SPCZ, SACZ are regional features closely related to storms and adjacent monsoonal regions. Hence, they are not necessarily related to the ITCZ — which is specifically a associated with the tropical meridional overturning circulation. Counting these as 'extensions' of the ITCZ is an error in my opinion. Please change the phrasing or provide support for this idea.

Response: We thank the reviewer for this clarification and agree.

Rephrasing:
"Branching off from the ITCZ are several persistent, semi-permanent areas of convergence located primarily over oceanic regions of the Southern Hemisphere. While distinct from the main ITCZ, features such as the South Pacific Convergence Zone (Vincent, 1994; Brown et al., 2020) and the South Atlantic Convergence Zone (Villela, 2017) act as prominent poleward extensions of this system"
to:
"Adjacent to the ITCZ there are several persistent, semi-permanent areas of convergence located primarily over oceanic regions of the Southern Hemisphere, which are distinct from the main ITCZ, such as the South Pacific Convergence Zone (Vincent, 1994; Brown et al., 2020) and the South Atlantic Convergence Zone (Villela, 2017)"

Line 41: It would be appropriate to also cite here Byrne and Scheider 2016a

Response: We thank the reviewer. We will add the suggested reference:
"The width of the ITCZ is partly governed by the radiative effect of upper-tropospheric clouds on the lower troposphere (Byrne and Schneider, 2016a; Dixit et al., 2018)."

Fig. 1 Some information on the precipitation bias in the models would be critical here. Given that the experiments a specifically designed to change the global mean temperature by 2 and 4 °C, there would be a thermodynamic component to the change in precipitation that is entirely due to biases. See Adam et al. 2023 for how to correct for that.

Response: We thank the reviewer for this important suggestion. We have recalculated the precipitation changes in Fig. 1 using the bias-adjustment method of Adam et al. (2023). This removes the part of the thermodynamic response that comes from biases in each model's climatological precipitation and evaporation. Fig. 1 will be replaced and the caption will be revised:

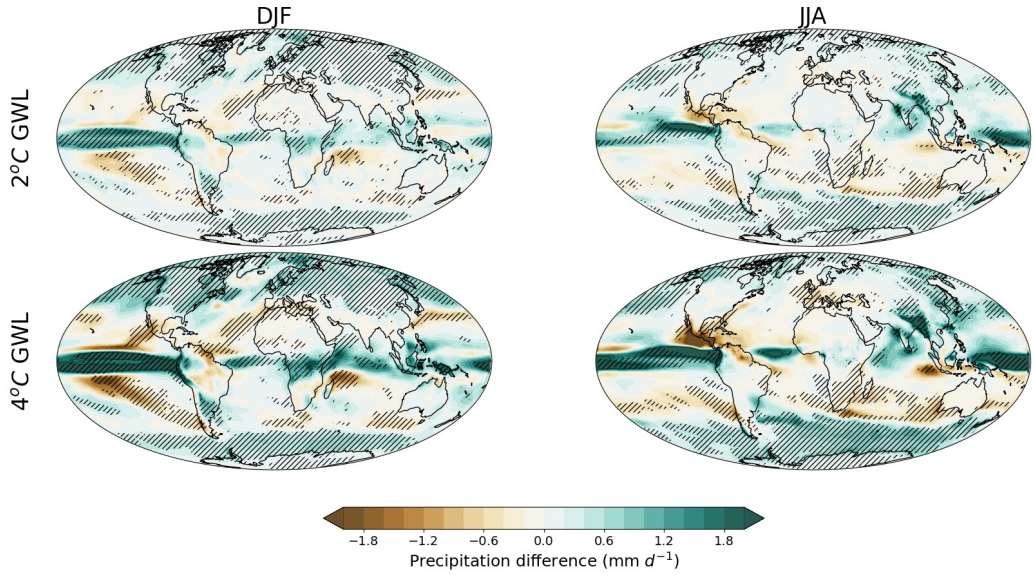


Figure 1. Multi-model mean adjusted precipitation differences between idealised stabilisation runs at 2 °C (top) and 4 °C (bottom) Global Warming Levels and Pre-Industrial control, for the December-to-February (DJF) season (left) and the June-to-August (JJA) season (right). Hatching denotes regions where all 7 models agree on the sign of change.

We also plan to revise lines 201–202:
Original text: "As the mean global temperature rises, precipitation patterns are expected to change across the globe. Figure 1 reveals a robust signal of wetter tropical and, to a lesser extent, polar regions and generally drier sub-tropics, especially for the 4 oC GWL."

Revised text: "As the mean global temperature rises, precipitation patterns are expected to change across the globe. Some of the changes are due to the shifting precipitation patterns, but others can be attributed to the thermodynamic component, which is due to existing biases in the models. Figure 1, which shows the precipitation changes adjusted for the precipitation and evaporation biases of the models, following the methodology of Adam et al. 2023,reveals a robust signal of wetter tropical and, to a lesser extent, polar regions and generally drier sub-tropics, especially for the 4 oC GWL."

213—233 How do these regional responses agree with previous analyses of the sensitivity of the tropical rain belt to global warming (e.g., Mamalakis et al. 2020)?

Response: We thank the reviewer for this suggestion. We will add the following paragraph after line 233:
"These regional shifts in the ITCZ are consistent with the findings of Mamalakis et al. (2020). In the global zonal mean, the equatorward shift is also consistent with Zhou et al. (2020), although they differ in the expected change in ITCZ width. This discrepancy likely arises from differences in the methodologies used to define the ITCZ and its edges."

234—244 In recent decades the central Pacific has been cooling, in contrast with projected warming by most climate models (e.g., Seager et al. 2019). The response to equatorial warming may therefore be spurious.

Response: We thank the reviewer for pointing out this important caveat. We will add a discussion to two places.

At end of line 54:
"In the central Pacific, most climate models fail to reproduce the observed cooling over recent decades (McGregor et al., 2014) and instead simulate a warming tendency in this region (Seager et al., 2019). This systematic discrepancy raises uncertainty in the reliability of model-projected changes in the tropical Pacific, particularly where these changes depend on the spatial structure of sea surface temperature and its associated atmospheric circulation."

At end of line 326:
"This intensification, or at least its magnitude, may be partly influenced by model biases over the central Pacific. In particular, the inability of most models to reproduce the observed changes in the sea surface temperature gradient between the western and central Pacific may affect the simulated atmospheric circulation and precipitation response in this region. Consequently, the magnitude of the projected intensification over the central Pacific should be interpreted with caution."

Lines 250—254 In order for Figs. 3 and 4 be associated with the mean meridional overturning circulation, you would need to remove the component of the vertical wind associated with zonal overturning circulations (see Schwendike et al. 2014)

Response: We thank the reviewer for this important clarification. We agree that the vertical velocity presented in Figs. 3 and 4 includes contributions from both the mean meridional circulation and zonal overturning circulations. Since we have not separated these components, we will revise the wording throughout the relevant sections to ensure that our interpretation does not attribute the changes in vertical velocity solely to changes in the meridional circulation.

Line 335 Hu et al. is a review. One of several. Please provide context on what is in agreement here.

Response: We thank the reviewer and we plan to revise the statement in line 335.

Original text: "This weakening of the Hadley cell agrees with Hu et al. (2018)."

Revised text: "This weakening of the Hadley cell is in agreement with Hu et al. (2018) and Lu et al. (2007), that show that CMIP5 models show both a widening and a weakening of the Hadley cell in higher mean temperatures of the planet."