Dear Editor Dr. Yi Huang,

Thank you very much for handling our manuscript. Please find below our itemised responses to the reviewers' comments and a marked-up manuscript. We have addressed all the comments raised by the reviewer and incorporated them in the revised manuscript.

Thank you for your consideration.

Sincerely,
Bosi Sheng et al.

Reviewer #1

Comment [1-1]: One major comment the reviewer has is that current version of the paper lacks quantified statements in some places. This aspect needs to be improved through the whole manuscript. Some places are in my specific comments.

Response [1-1]:

We thank the reviewer for raising this point. We agree that quantification strengthens the manuscript, and we have added quantitative statements throughout, replacing qualitative descriptions with specific values, trends, and statistical measures where appropriate. The individual changes are detailed in our responses to the specific comments below.

Comment [1-2]: Lines 157-159. Please clarify whether monthly or seasonal mean specific humidity and horizontal wind are used to calculate vertically integrated moisture flux convergence. If this the case, the calculation does not include the contribution from transients and it is therefore better to make some comments on this aspect.

Response [1-2]:

We thank the reviewer for this constructive comment. We confirm that monthly mean specific humidity and horizontal wind from CMIP6 were used to compute the vertically integrated moisture flux convergence; this quantity therefore does not explicitly include the transient-eddy contribution.

To assess its importance, we estimated the transient component as the residual of the vertically integrated moisture budget from ERA5, i.e., P−E minus the moisture flux convergence computed from monthly mean fields. Assuming the storage tendency term to be negligible on long time scales, the residual (transient) component is much smaller than the mean-flow moisture flux convergence over the study region, indicating that the mean circulation dominates the climatological moisture budget. The use of monthly mean fields is therefore sufficient to capture the dominant features of moisture transport and appropriate for diagnosing long-term changes.

We added the following clarification (Section 3.2):
L333–335: "ERA5 climatology shows that mean-flow moisture flux convergence explains most of the spatial variability in P−E, whereas transient eddy moisture transport plays a minor role (Fig. S6). Therefore, monthly mean fields provide a reasonable basis for subsequent analysis of long-term moisture transport changes."

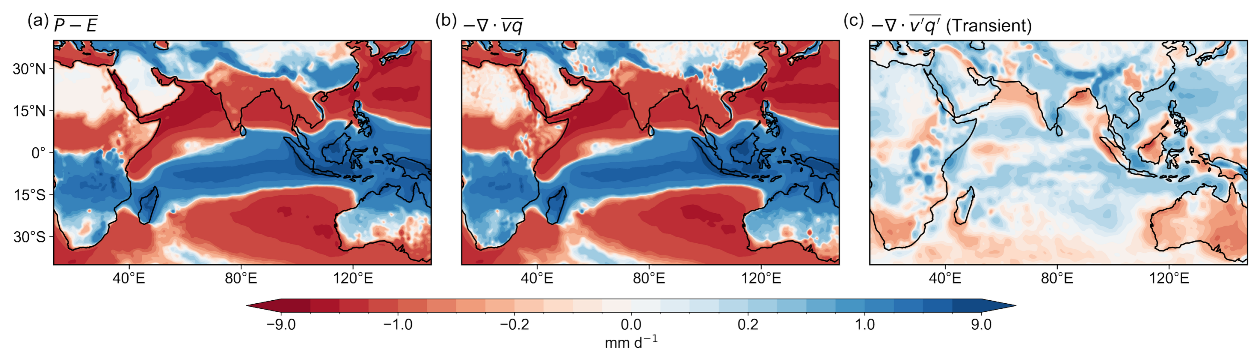

Figure S6. DJF climatological mean (1991–2020) of (a) precipitation minus evaporation, (b) vertically integrated moisture flux convergence, and (c) transient eddy contribution, estimated as the residual of (a) minus (b), from ERA5 reanalysis. Units: mm d^{-1}.

Comment [1-3]: Figure 1c and d. What are right y coordinates in both panels. Are they for CMIP6-hist simulations? If they are, the trends in model simulations are about 25% of those based on observations. Please clarify.

Response [1-3]:

We thank the reviewer for this helpful comment. The right y-axes in Figs. 1c and 1d represent the DJF precipitation trends from the CMIP6 hist-All multimodel mean (MMM). As the reviewer noted, the MMM trends are substantially weaker than observed. This is expected: the observations represent a single realisation containing both externally forced changes and internal variability, whereas the MMM largely isolates the forced response by averaging across many realisations, thereby largely suppressing internally generated variability that may amplify or offset the forced signal in individual simulations. To illustrate the model spread, we added a new figure showing the individual-model trends over SSA and MDG; although magnitudes vary considerably, most models reproduce the observed sign, indicating a robust externally forced signal.

We clarified the figure caption (Fig. 1 caption):
L312–314："<u>The black and blue lines (left y-axis) represent the CRU and GPCC observations, respectively, whereas the gray line (right y-axis) denotes the CMIP6 hist-All multimodel mean (MMM).</u>"

and added a quantitative explanation in the main text (Section 3.1):
L270–277: <u>"The DJF precipitation trends simulated by the CMIP6 hist-All multimodel mean are +0.03 mm d^{-1} over SSA and +0.18 mm d^{-1} over MDG during 1945–2005, both substantially weaker than the observed trends. This amplitude difference is expected because the multimodel mean largely removes internally generated climate variability, thereby isolating the externally forced response, whereas the observations correspond to a single realisation that retains the full internal variability in addition to the forced response. Individual models exhibit a wide range of trend magnitudes, with most reproducing the observed sign and a few produce trends comparable to or even larger than the observations (Fig. S5)."</u>

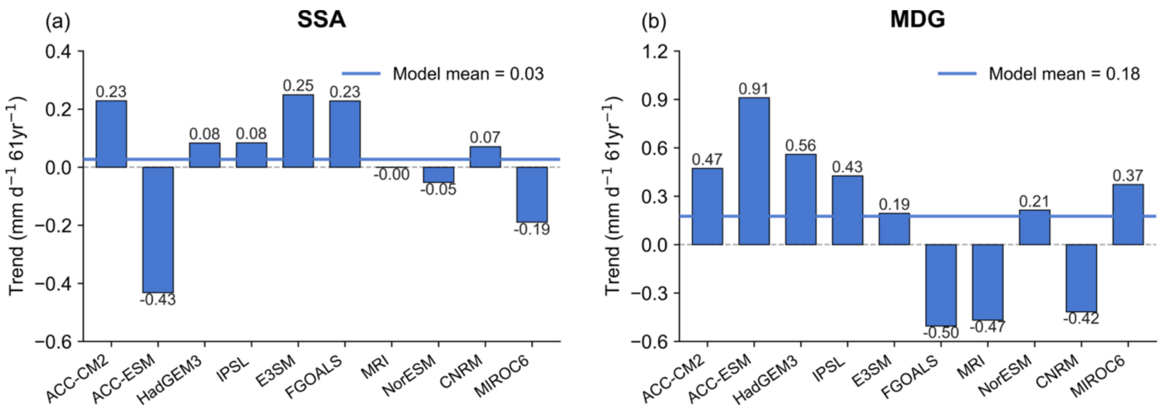

Figure S5. DJF precipitation trends (mm d^{-1} 61yr^{-1}) over 1945–2005 from individual CMIP6 hist-All simulations for (a) SSA and (b) MDG.

Comment [1-4]: Lines 226-243. Related to specific comment 2. It would be helpful for readers if authors can quantify the discrepancy of trends between observations and model simulations. Another important message form Figure 2 is the opposite patterns of precipitation trends resulted from AER and GHG forcings. It would be helpful if their relative roles on regional precipitation trends can be quantified as well.

Response [1-4]:

We thank the reviewer for this helpful suggestion.

Regarding the discrepancy between observations and model simulations, we have added quantitative comparisons in the revised manuscript:

L270–277: "The DJF precipitation trends simulated by the CMIP6 hist-All multimodel mean are +0.03 mm d^{-1} over SSA and +0.18 mm d^{-1} over MDG during 1945–2005, both substantially weaker than the observed trends. This amplitude difference is expected because the multimodel mean largely removes internally generated climate variability, thereby isolating the externally forced response. Individual models exhibit a wide range of trend magnitudes, with most reproducing the observed sign, although some simulate opposite-sign trends and a few produce trends comparable to or even larger than the observations (Fig. S5)."

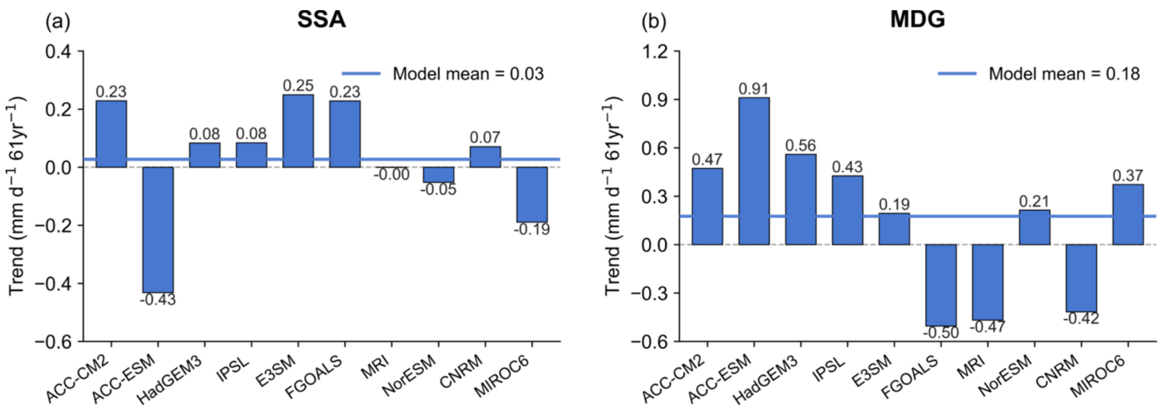

Figure S5. DJF precipitation trends (mm d^{-1} 61yr^{-1}) over 1945–2005 from individual CMIP6 hist-All simulations for (a) SSA and (b) MDG.

Regarding the relative roles of AER and GHG forcing, we address this through spatial pattern comparison rather than domain-averaged metrics, as the latter are sensitive to orographically-complex sub-regions where coarse-resolution models produce spurious signals. We have added a brief explanation in the revised manuscript:

L302–305: "<u>Domain-averaged trend decomposition over these sub-regions is therefore not pursued here, as the inclusion of high-elevation interior terrain over southeastern South Africa and Madagascar would introduce substantial representation uncertainty at the coarse resolution of CMIP6 models (~2°).</u>"

Comment [1-5]: Lines 260-265. It is confusing whether author describe the climatology of observations or model simulations. It would be much easy to follow if authors describe features of observations first, and then describe what feature model capture well and what feature model has bias.

Response [1-5]:

We thank the reviewer for this comment.

We thank the reviewer for this helpful comment. Following the suggestion, we reorganized this section to first describe the observed climatological features and then evaluate how well CMIP6 models reproduce them, including their biases. The revised text reads:

L324–335: "To provide context for the circulation and precipitation responses discussed below, we first examine the DJF climatological mean state during 1961–1990 (Fig. S2). In CRU observations, precipitation is mainly concentrated over central Africa and northern/eastern Madagascar, while southern Africa and southern Madagascar remain relatively dry (Fig. S2c). The corresponding ERA5 circulation features low-level easterly trade winds over the tropical Indian Ocean and a subtropical anticyclonic circulation over the southern Indian Ocean (Fig. S2d), providing the background atmospheric conditions for regional moisture transport. The CMIP6 multimodel mean broadly reproduces the observed precipitation distribution and large-scale circulation features (Figs. S2e, f). However, the models exhibit a wet bias over southern Africa, whereas precipitation over Madagascar is generally comparable to CRU observations (Fig. S2a, b). The simulated circulation patterns, including the subtropical high and low-level winds, are also reasonably represented by the CMIP6 ensemble (Fig. S2f)."

Comment [1-6]: Line 372-376. These statements are better to be rephrased by restructuring them in the order of 1) role of external forcing, 2) AER forcing, GHG forcing. It would be helpful for readers if authors add some quantitative statements.

Response [1-6]:

We thank the reviewer for this helpful suggestion. We restructured the paragraph to follow the order (1) role of external forcing, (2) aerosol forcing, and (3) greenhouse-gas forcing, and added quantitative statements. The revised text reads as follows:

L507–517: "CMIP6 single-forcing simulations indicate that external forcing contributes to the observed multidecadal precipitation changes over SA and the southwestern Indian Ocean. The hist-All MMM captures the observed meridional precipitation contrast, with forced DJF trends of +0.03 mm d^{-1} over SSA and +0.18 mm d^{-1} over MDG during 1945–2005. These trends are weaker than observed, which is expected because the MMM largely averages out internally generated variability. Anthropogenic aerosol forcing as a whole is the primary contributor to this externally forced response: the hist-AER ensemble closely follows the hist-All pattern, reproducing the precipitation dipole of increased rainfall over SSA, MDG, and the adjacent southern Indian Ocean, together with drying over northern SA and the neighbouring tropical ocean. Greenhouse gas forcing, by contrast, produces a response of opposite sign that is consistent with the "wet-gets-wetter, dry-gets-drier" paradigm, partly offsetting the aerosol-driven changes. Overall, these results identify anthropogenic aerosols as the primary driver of the simulated externally forced precipitation response over SA and the southwestern Indian Ocean."