## Response to Editor:

There is a nice experiment, and some nice analysis of it in this paper, but there are still major concerns about the framing of the work and the interpretation of the results, and we cannot proceed to publication until these are resolved. It might be that they cannot be resolved. In which case, the authors should motivate their study based on the large emission changes, rather than the observed precipitation, and frame it as a speculative study of the potential responses. However, the issues with interpretation raised by all reviewers must be addressed regardless.

Thank you for your valuable suggestion. We will revise the framing of the manuscript to present it as a speculative study exploring potential climate responses based on the large emission change. We will also ensure that all issues raised by the reviewers are thoroughly addressed. Please see our detailed point-by-point responses (in blue) regarding framing, analysis, and interpretation below.

Framing

The premise of the paper is that Australia has experienced anomalously dry and warm conditions since the 2010. The authors then hypothesise that aerosol reductions in China since 2013 have contributed to this.

We have revised the manuscript to motivate the study based on the large emission changes rather than the observed precipitation, and frame it as a speculative study exploring the potential climate responses throughout the manuscript. Please check the revised paper.

The observed precipitation trend is based on only 10 years of data, and there is still no discussion of how this trend compares to internal variability. The additional Figure S12, provided in response to my comments, raises more concerns here than it solves. The abstract claims that the period since 2010 was warm and dry in Australia, but the mean of the two periods highlighted in Figure S12 are almost identical. There is no evidence in that figure that Australia was anomalously dry since 2010.

We also performed additional analysis examining different time periods, including the 2013–2019 period (Figure S21) and a longer period (2010–2023; Figure S22). Both patterns consistently show a decreasing trend in Australia's precipitation, supporting the robustness of the recent drying trend in Australia, even considering the potential influence of internal variability.

We apologize for the confusion caused by our wording "anomalously dry and warm conditions" in the Abstract. Our intended meaning is that Australia experienced drier and warmer trend since 2010, referring to relative changes within the 2010s, rather than implying that the conditions in 2010s were anomalously dry and warm compared to the long-term historical average. We have revised all similar descriptions.

Figure S14, provided in response to my comments, is reassuring, as it shows that multiple datasets agree that there has been a drying since 2010. However, I disagree with the authors' conclusion that Figure S12 'clearly shows an increasing precipitation trend during 2001-2010, followed by a decreasing trend during 2010-2019.' What I see here is variability. To be convinced that the trend since 2010 is anomalous, it needs to be compared to all other 10-year trends in ERA5 (using the available data from 1940 to the present to evaluate this). Is the negative trend from 2010-2019 unusually large in the context of 1940-2019?

We agree that variabilities contribute significantly to the trends, and therefore we have removed the previous description stating that Figure S12 "clearly shows an increasing precipitation trend during 2001–2010, followed by a decreasing trend during 2010–2019." As suggested, we have calculated all 10-year precipitation trends in ERA5 from 1940 onwards, as follows (unit: mm day$^{-1}$ year$^{-1}$): +0.016 (1940–1949), –0.012 (1950–1959), +0.001 (1960–1969), +0.031 (1970–1979), –0.002 (1980–1989), +0.030 (1990–1999), –0.032 (2000–2009) and –0.086 (2010–2019). These results indicate that the drying trend during 2010–2019 is unusually large in Australia since 1940 from the ERA5 data.

Figure S12 also highlights the dependence of the 2010-2019 trend on what appears to be anomalously high precipitation in 2010 and 2011. Without these years, the trend would be markedly reduced. This is important, and more so in this case, since the driver that is being explored in the study occurs over 2013-2019. The authors should address the concerns from Reviewer 1 about the sensitivity of the trend to these years, particularly in light of Figure S12.

As per the reviewer's suggestion, we have replotted the spatial distribution of precipitation trends specifically for 2013–2019 (Figure S21). The updated results show an overall decreasing trend across most regions of Australia during this period (except for some localized increases in the northeastern corner). Notably, most regions in northern Australia, which are mainly affected by the trade winds, exhibit even stronger decreases in precipitation during 2013–2019 compared to 2010–2019.

Analysis

The authors perform an equilibrium experiment to examine the Australian response to emission changes in China, North America and Europe, and everywhere except China. This shows that the response to Chinese emission changes between 2013 and 2019 is larger than that to emission changes in other regions. It also shows that the pattern of the precipitation response to Chinese emission changes is different to the response to emission changes elsewhere. The authors also show a strong seasonal component to the response. They also discuss the mechanisms for the response.

Neither the reviewers nor I have substantial comments on the analysis at this stage, as the points raised in review have focused on the framing and interpretation of the study.

The precipitation responses to emission changes in other regions are primarily influenced by emission changes in South Asia and Southeast Asia. The mechanisms of their impacts on Australia's precipitation are generally similar to those of China's emission reductions. Regarding the strong seasonal component observed in the responses, there are two main contributing factors: (1) the background seasonality of the Southern Hemisphere trade winds, and (2) the seasonality of China's emission changes themselves. However, determining which of these factors dominates requires further detailed quantitative analysis, which we acknowledge as an area for future investigation.

Interpretation

The authors claim that the warming and drying seen in response to Chinese emission reductions in their equilibrium experiments accounts for some of the drying and warming seen in the real world.

Reviewer 1 is concerned about the use of an equilibrium experiment to interpret real-world changes that have happened over a 7-year period. They point to literature that shows that the fast response of Australian precipitation to Asian aerosols can have the opposite sign response to the slow response, and therefore caution that an equilibrium experiment cannot be used to interpret the drivers of a fast change in the real world. It is important that the authors address these concerns.

We have addressed these issues by conducting additional experiments designed specifically to examine the fast climate responses. These new experiments were run for 30 years, with the last 15 years analyzed using the CESM atmospheric component (CAM5) with fixed sea surface temperature. The results show a decreasing pattern in Australian precipitation (Figure S23), which is consistent with the responses obtained from the 150-year equilibrium simulations. This indicates that the precipitation changes in Australia resulting from China's emission reductions are largely contributed by fast responses. We have included these new results and their interpretation in the revised manuscript to address the reviewer's concerns.

There are also some inconsistencies and errors in the response to my comments on the interpretation of the experiment. The authors correctly note that 'the relatively short period from 2013 to the present may not provide enough time for the climate system to fully respond to aerosol changes'. There then needs to be some discussion of the differences between the fast and the slow responses to aerosol changes. As the climate system may not have had time to fully respond to the aerosol changes, how do we expect an equilibrium simulation (where this has happened) to compare to the real world (where it may not have happened)? Can the authors demonstrate that the equilibrium response can be reached within the observational period, so that we can use this experiment to interpret real-world changes? If not, can they comment in detail on where they might expect their experiment to differ from the real-world response? The perturbation is applied as a step change in the equilibrium experiment, so it should be possible to find the time taken for the system to reach equilibrium in this case, and to assess whether the short-term response differs to the equilibrium response. Reviewer 1 also suggests an additional experiment to examine the fast response explicitly. This is a relatively cheap simulation compared to the equilibrium runs, and would only need to be performed for the China experiment.

We have added detailed discussions in the revised manuscript to clarify the differences between fast and slow responses and the consistency between our fast response and long-term equilibrium experiments. We also acknowledge that while equilibrium simulations provide insights into the long-term full response, fast response experiments are more appropriate for attribution of short-term observed trends, and we have reframed our study accordingly to explore potential climate responses based on the large emission changes rather than direct attribution.

"Both fast and slow climate responses contribute to the simulated precipitation changes in Australia resulting from China's emission reductions. Fast responses are primarily driven by rapid atmospheric adjustments to aerosol-induced radiative forcing without requiring full ocean adjustment, while slow responses involve gradual changes mediated by ocean circulation and sea surface temperature adjustments over longer timescales.

In our additional fast response experiments using the CAM5 atmospheric component, we found a decreasing pattern in Australia's precipitation (Figure S23), which is consistent with the long-term equilibrium simulation results. Although the equilibrium simulations represent the fully adjusted climate system response and are not appropriate to be directly compared to short-term observational changes, the fast response experiments suggest that fast response accounts 86% of the fully climate system response in the changing precipitation in Australia. It demonstrates that the immediate atmospheric response to Chinese aerosol reductions alone can produce a drying effect similar to that found in long-period equilibrium experiments, providing confidence in the robustness of the results."

The authors have removed most direct attribution statements from the text, but Reviewer 2 highlights one that remains, and should also be removed.

We have carefully reviewed the manuscript again and removed the remaining attribution statement highlighted by Reviewer 2.

# Response to Reviewer#1:

The manuscript now includes more relevant in the main and supplementary material. However, the manuscript still has some major caveats related to the experimental setup and observational comparison after the comments from the reviewers and editor. I recommend another round of major revision based on the comments below. If the authors would not be able to give a scientific reasoning why a comparison of the equilibrium simulations with the transient (fast) observed precipitation response over Australia (see major comment 1) is valid, I would recommend that the article is rejected but could be considered for resubmission if the author's performed simulations to assess the fast climate response and find that these simulations justify their hypothesis.

Thank you very much for your overall evaluation and comments. We have provided detailed point-by-point responses (in blue) to each of your comments below and revised the manuscript accordingly to address these remaining concerns.

Major comments

1. My main concern is still regarding the experimental setup since the changes over Australia in an equilibrium climate simulation (around 100 years) are compared to the fast climate response in observations (less than 10 years). A paper by Liu et al 2018 examined the fast and slow precipitation response over Australia shows that while the fast response shows a drying to Asian sulfate aerosols, the slow response shows a wettening (see Figure 1). Additionally, a recent paper by Hwang et al 2024 shows very different east-west Pacific and Indian Ocean SST patterns which lead to differences in the flow towards Australia (see Figure 3). Based on this previous literature, it does not seem justified to attribute the recent short-term drying (fast response) in Australia using equilibrium simulations which only show the slow responses.

In our new experiments designed to additionally examine the fast climate responses to aerosol reductions in China, which were run for 30 years with the last 15 years analyzed using the CESM atmospheric component (CAM5), we also found a decreasing pattern in Australian precipitation (Figure S23). This is consistent with the total long-term equilibrium responses, suggesting that the precipitation changes in Australia resulting from China's emission reductions are largely contributed by fast responses. Moreover, in some regions where the changes pass significance tests, such as northern and eastern Australia, the precipitation decrease in the fast response experiments is even larger than that in the fully-coupled simulations. It demonstrates that the immediate atmospheric response to Chinese aerosol reductions alone can produce a drying effect similar to that found in long-period equilibrium experiments, providing confidence in the robustness of the results.

We note that Figure 1 of Liu et al. (2018) shows statistically insignificant precipitation changes over Australia in both the fast and slow responses to Asian sulfate aerosols. In addition to the drying induced by Chinese emission reduction, we also evaluated the influence of emission increases in South Asia and Southeast Asia and found aerosol increases in these regions could reduce precipitation over Australia (Figure 1j). Liu et al. (2018) examined emissions from the entire Asian region, and therefore, the precipitation signals over Australia were not significant. Hwang et al. (2024) focused on aerosol changes at the global scale rather than on emission changes in a specific region. Both their study did not specifically assess how the fast and slow climate responses would manifest in response to emission decreases from China alone.

It should also be noted that we did not attempt to directly explain the recent short-term drying in Australia using the more than 100-year equilibrium model runs. The equilibrium experiments were designed to explore the potential climate effects of China's aerosol emission reductions on Australia and to investigate the associated mechanisms by which these emission reductions could influence Australian precipitation. While the fast responses provide more relevant insights for explaining short-term changes, the long-term equilibrium experiments remain valuable for understanding the potential long-term impacts, especially considering that emission reductions are expected to continue in the future.

In response to the reviewer and editor the authors write the following:

- "While transient simulations offer a more dynamic representation of temporal changes, the relatively short period from 2013 to the present may not provide enough time for the climate system to fully respond to aerosol changes."
- "As the climate system responds more robustly over time, transient simulations will likely become a more appropriate tool."

I would argue that both these statements are not correct: In the former, if the authors argue that the "real world climate" did not have enough time to fully respond to the aerosol changes then the same reasoning should be applied to the modelled climate. Thus, it seems incorrect to compare equilibrium climate simulations where the climate system had a lot of time to fully respond to the aerosol changes with the transient "real world climate". Similarly, the second comment is incorrect as over time the equilibrium simulations will become more appropriate (e.g. if it is a long-term Australian drying trend that should be attributed) while the short-term trend that the authors try to assess would be more accurately captured by a fast response.

Thanks for pointing out these improper expressions. As noted in our previous response, we did not attempt to directly explain the recent short-term drying in Australia using equilibrium simulations with more than 100 years. The equilibrium experiments in this study were designed to explore the potential influence of China's emission reductions on Australia's precipitation and to investigate the underlying physical mechanisms, rather than to attribute the recent short-term observed changes. This study is not intended as an attribution analysis and we have now reframed the manuscript to avoid the misleading. Another purpose of using long-term equilibrium simulations is to assess whether the precipitation changes induced by China's emission reductions would persist under continued emission reduction scenarios in the future. Moreover, we have also added atmosphere-only simulations to quantify the fast response in precipitation to the aerosol reductions in China. For the second point, we decide to withdraw our previous response.

> The authors now added a short paragraph in the discussion (L432-439). However, the authors will have to add a detailed discussion of their results (and choice to use an equilibrium simulations) in the light of the papers by Hwang et al 2024 and Liu et al 2018 as well as any other relevant papers. How can this attribution of the fast Australian drying based on equilibrium simulations be trusted if previous literature shows large differences in the precipitation patterns over Australia and SST around Australia (and related mechanisms) in the fast and slow response? If the authors would be unable to give a scientific reasoning, I would recommend that the article is rejected but could be considered for resubmission if the author's performed simulations to assess the fast climate response and find that these simulations justify their hypothesis.

Thank you for your comment. As noted earlier, this study is not intended as an attribution analysis. Regarding the studies by Hwang et al. (2024) and Liu et al. (2018), we would like to clarify their findings and relevance to our work.

"Liu et al. (2018) used multi-model simulations to investigate the fast and slow precipitation responses to regional aerosol forcing from Asia and Europe under the PDRMIP framework. They showed that Asian sulfate aerosols were stronger drivers of global temperature and precipitation changes compared to European aerosols. However, their analysis focused on aerosol forcing from the entire Asian region, rather than emission reductions from China alone, and the precipitation responses over Australia were not significant in their results. Hwang et al. (2024) explored the combined fast and slow climate responses to aerosol emission changes at the global scale. They reported that an increase in aerosol emissions, followed by a decrease, can sustain La Niña-like patterns in the equatorial Pacific for decades. However, neither study specifically examined the climate impacts of China's recent emission reductions. We acknowledge that fast and slow climate responses can have different mechanisms and regional impacts, and there can be differences between the slow and fast responses. Our additional experiments with atmosphere-only indicate that the fast response dominated the drying pattern over Australia (Figure S23), account for 86% of the fully-coupled response, suggesting that the precipitation decrease is mainly driven by the fast response."

We have added a detailed discussion in the revised manuscript to highlight these findings and clarify the differences in experimental focus and implications.

2. Thanks for providing the additional Figures S12 and S14 which help to examine the effect of different datasets and time periods. However, the authors still focus on the observational 2010-2019 and do not address how the anomalously wet year in 2010/11 might bias their assessment. This is particularly relevant since the authors theoretically want to compare the influence of Chinese aerosols on precipitation trends over Australia from 2013-2019.

   In order to assess the impact of including these three additional years, I recommend to create a spatial precipitation trend figure based on observational data showing the 2013-2019 trend in comparison to the 2010-2019 trend that the authors already show. If the 2013-2019 trend plot shows similar changes as the 2010-2019 plot, then this could help to make their statement of including the additional 3 years to reduce the influence of internal variability more robust.

   Additionally, the large impact of internal variability in the observational data should be discussed in the discussion further.

We have drawn the spatial distributions of precipitation trends based on observational data for 2013–2019 (Figure S21). The new plot shows a broadly similar drying pattern to the 2010–2019 trend, with widespread decreases in precipitation across northern Australia (except for slight increases in the northeast).

"It should be noted that the short-term precipitation trends examined in this study may be influenced by internal climate variability, especially given the relatively short period since 2013. Therefore, we extended the analysis back to around 2010, when emission reductions in China had already begun. We also performed additional analysis examining different time periods, including the 2013–2019 period (Figure S21) and a longer period (2010–2023; Figure S22). Both patterns consistently show a decreasing trend in Australia's precipitation, supporting the robustness of the recent drying trend in Australia. However, we acknowledge that these observed short-term trends could still be affected by internal climate variability, and the potential contribution from internal variability should not be ignored."

We agree that internal variability can have a large influence on short-term trends. Therefore, we have added the discussion above to the revised manuscript.

Liu, L., et al. (2018): "A PDRMIP multimodel study on the impacts of regional aerosol forcings on global and regional precipitation." *Journal of climate* 31.11, 4429-4447.

Hwang, Yen-Ting, et al. (2024): "Contribution of anthropogenic aerosols to persistent La Niña-like conditions in the early 21st century." *Proceedings of the National Academy of Sciences* 121.5

## Response to Reviewer#2:

The authors have improved the manuscript in light of the reviewers' comments. However, I am still not fully convinced by the analysis performed and the use of the specific experimental design. While the revised manuscript, as suggested, more cautiously uses the results of the CESM simulations to attribute the recent observed trends, it still relies on the analysis of the long-term century-long output, which is not what happens in the real world (a ~10-year trend). Do the simulated circulation patterns resemble observations? The analysis of the observational record should also extend to more recent years, leading to 15-year time series. Finally, some paragraphs still suggest an attribution-like approach ("In contrast, our study focuses on the recent reductions in anthropogenic aerosols in China since 2013, showing that the aerosol reductions reversed circulation changes induced by the previous aerosol increases and contributed to drying rather than increased rainfall over Australia.").

Thank you for your comments. In our new experiments designed to examine the fast climate responses, we also find a decreasing pattern in Australian precipitation (Figure S23). This is consistent with the total 150-year equilibrium responses, suggesting that the precipitation changes in Australia resulting from China's emission reductions are largely contributed by fast responses. It demonstrates that the immediate atmospheric response to Chinese aerosol reductions alone can produce a drying effect similar to that found in long-period equilibrium experiments, providing confidence in the robustness of the results.

Following the editor's suggestion, we have revised the framing of the manuscript to motivate our study based on the large emission changes in China rather than the observed precipitation trends, presenting it as a speculative study exploring potential climate responses. With this reframing, the purpose of the study is no longer to attribute the observed drying trend in Australia to China's emission reductions but to examine the possible climate impacts of these emission changes on Australia. We believe this revision addresses the core concerns raised regarding attribution.

Regarding the simulated circulation patterns, they show a reasonable resemblance to the observed circulation anomalies. However, under the revised framing, even if the circulation patterns in the model do not exactly match the observations, it does not undermine the scientific value of analyzing the model results, as many factors influence circulation and precipitation variability around Australia, and an exact match with observations is not necessarily expected.

We have also extended the observational precipitation time series to include more recent years as suggested (Figure S22), providing a longer context for the analysis.

Finally, we have revised or removed all paragraphs suggesting an attribution-like interpretation to ensure consistency with the new framing of the manuscript.

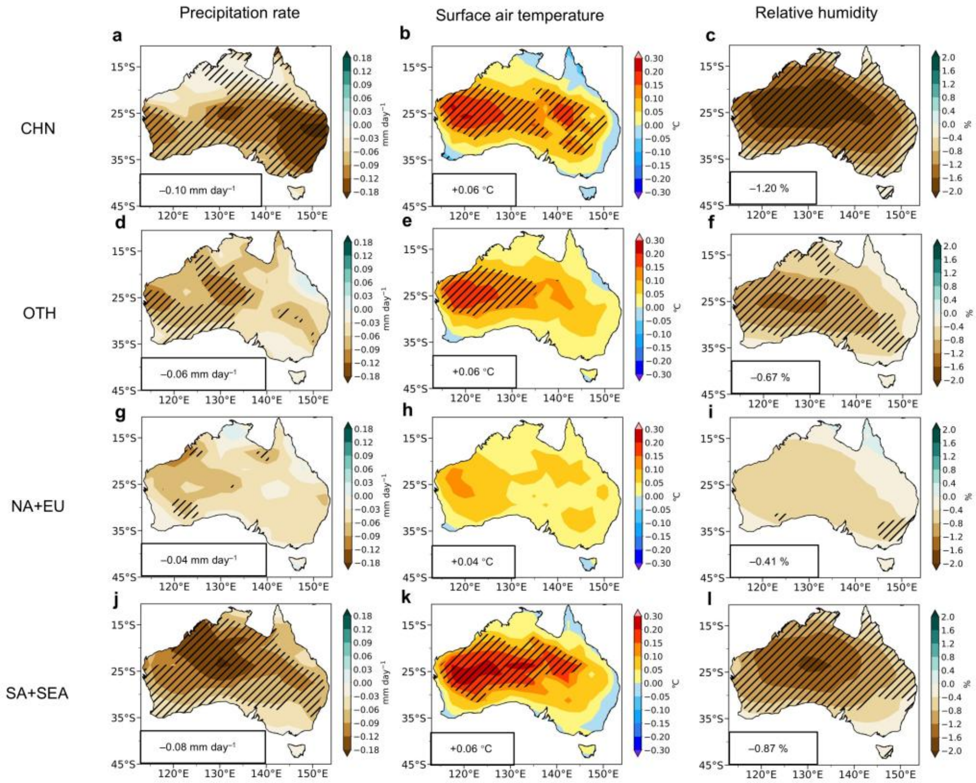


**Figure 1. Simulated changes in precipitation rate, surface air temperature and relative humidity in Australia due to aerosol changes between 2013 and 2019.** Spatial distributions of simulated differences in annual mean precipitation rate (Pr, **a**, **d,** and **g**, unit: mm day$^{-1}$), surface air temperature (TS, **b**, **e**, and **h**, unit: °C) and relative humidity (RH, **c**, **f**, and **i**, unit: %) in Australia between BASE and CHN (CHN minus BASE, **a**–**c**), between BASE and OTH (OTH minus BASE, **d**–**f**), between BASE and NAEU (NAEU minus BASE, **g**–**i**), and between BASE and SASEA (SASEA minus BASE, **j**–**l**). The shaded areas indicate results are statistically significant at the 90% confidence level. Regional averages over Australia are noted at the bottom-left corner of each panel.

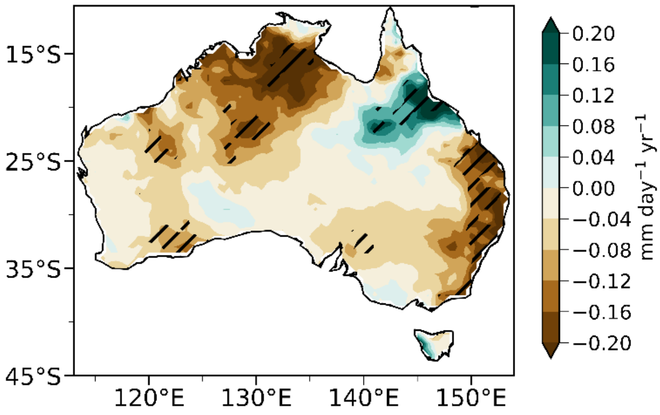


**Figure S21. Linear trends of observed precipitation rate in Australia during 2013–2019 based on ERA5.** Spatial distributions of linear trends annual mean precipitation rate (unit: mm $day^{-1}$) in Australia during 2013–2019 from ERA5. The shaded areas indicate trends are statistically significant at the 90% confidence level.

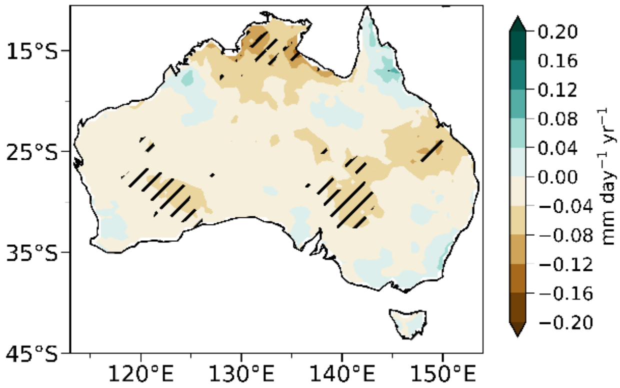


**Figure S22. Linear trends of observed precipitation rate in Australia during 2010–2023 based on ERA5.** Spatial distributions of linear trends annual mean precipitation rate (unit: mm $day^{-1}$) in Australia during 2010–2023 from ERA5. The shaded areas indicate trends are statistically significant at the 90% confidence level.

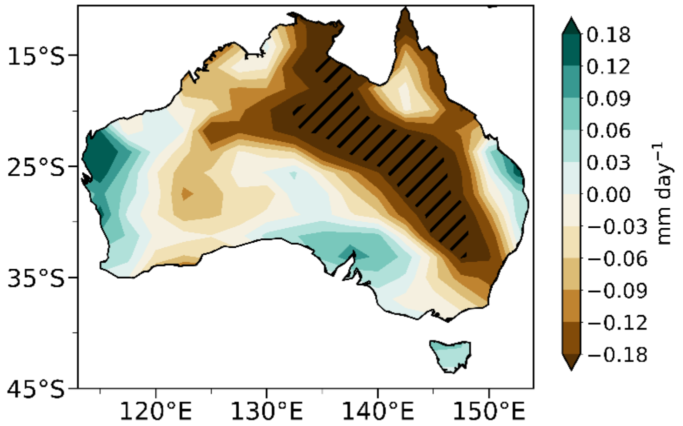


**Figure S23. Simulated changes in precipitation rate in Australia due to aerosol changes in China between 2013 and 2019.** Spatial distributions of simulated differences in annual mean precipitation rate (unit: mm $day^{-1}$) in Australia between BASE_FAST and CHN_FAST (CHN_FAST minus BASE_FAST). The shaded areas indicate results are statistically significant at the 90% confidence level. These experiments were run for 30 years, with the last 15 years analyzed using the CESM atmospheric component (CAM5) with fixed sea surface temperature.