Investigating the factors affecting Monsoon precipitation under climate change

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(A) Introduction

Improved understanding of the drivers of monsoon precipitation change are needed in order to identify sources uncertainty in precipitation projections, aid model development and assist adaption policy. This is important since the Monsoons produce some of the largest levels of uncertainty in global precipitation projections, and a large population depends on the rain that the monsoons bring. (Ni and Hsu 2018; Hill 2019).

(B) Scientific Questions

- How are the monsoons projected to change?
- What drives monsoon precipitation change?
- What are the mechanisms behind these drivers?
  - How certain can we be?
  - How does this vary across different monsoon regions?

(C) Data and methods

Data:

- Global Precipitation Climatology Project (GPCP) monthly precipitation data.
- Datasets from 15 CMIP6 models; BCC-CSM2-MR, BCC-ESM1, CESM2-WACCM, CESM2, CanESM5, E3SM-1-0, EC-Earth3-Veg, GISS-E2-1-G, GISS-E2-1-H, IPSL-CM6A-LR, MIROC6, MRI-ESM2-0, SAM0-UNICON, CNRM-CM6-1, HadGEM3-GC31-LL.

Methods:

- Monsoon regions defined using method adapted from Wang and Ding (2006).
- Analysed piControl and Abrupt-4xCO_2 experiments to investigate projected precipitation change in 13 coupled models.
- Used 'Timeslice' experiments to decompose full CO_2 forcing into individual components (CNRM-CM6-1). As described in Chadwick et al. (2017).
- Investigated the direct radiative effect mechanism using a set of amip experiments (9 models).

(D) Coupled model analysis

- 0.34 mm day^{-1} projected increase in global monsoon rainfall.
- Large regional differences in precipitation change.
- Considerable spread across models indicating high levels of uncertainty.

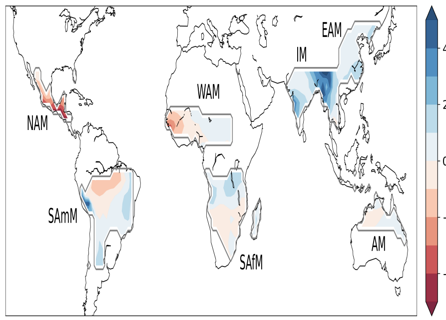


Fig 1: Projected precipitation change with a quadrupling of CO_2 (Abrupt-4xCO2 – piControl). Map of 13 model mean precipitation change, masked to show only land monsoon regions and only the summer hemisphere i.e. JJAS in northern hemisphere and DJFM in southern hemisphere.

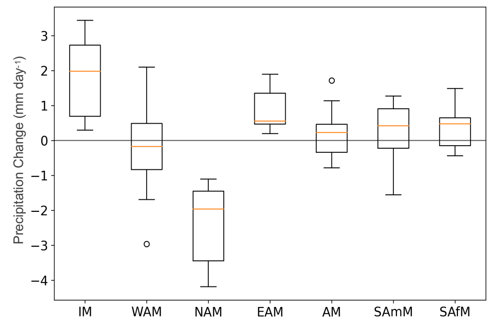


Fig 2: Box plots indicating precipitation change and inter-model spread in each region; box plots show median, quartiles, most extreme values and outliers.

(E) Timeslice experiments

- Direct radiative effect of increased CO_2 and SST changes have largest affect on monsoon precipitation.
- Across each region, the direct radiative effect and a patterned SST change have the most consistent response.
- Using a set of amip experiments; the direct radiative effect response was consistent across different models but the impact of a patterned SST change was more uncertain (uncertainty stemmed from differences in projected SSTs, and different atmospheric responses to changing SSTs).

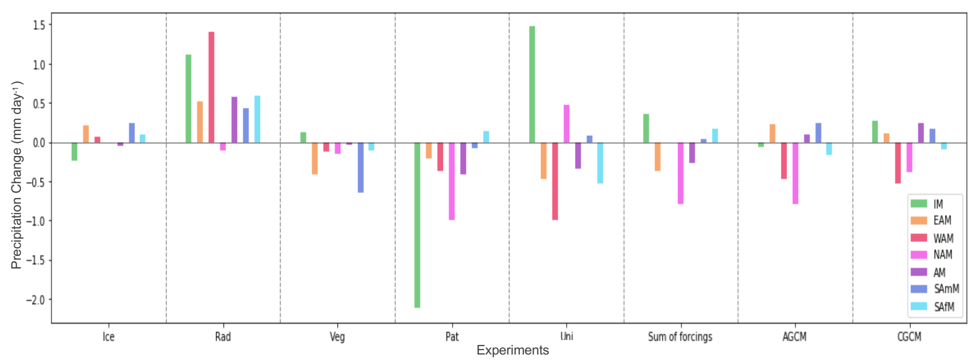
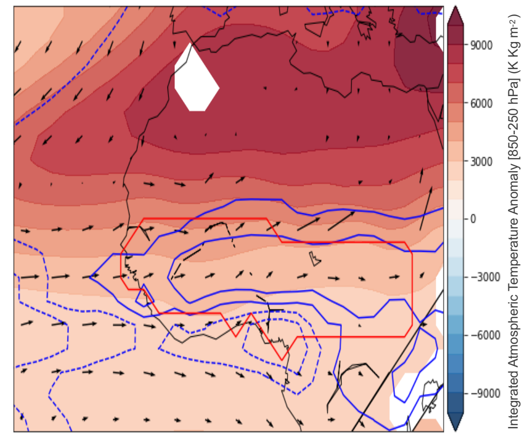


Fig 3: Results of Timeslice experiments indicating how each forcing impacts precipitation in each monsoon region; Ice – impact of melting sea ice, Rad – the direct radiative effect, Veg – the plant physiological effect, Pat – Impact of a patterned SST change, Uni – impact of a uniform SST increase.

(F) Direct radiative effect

- The direct radiative effect of increased CO_2 results in increased monsoon precipitation. Initially, the analysis of this mechanism was focussed on the West African Monsoon.
- Increase in precipitation may be related to an anomalously warm region to the north of the monsoon. Circulation around this region may be associated with a stronger monsoonal flow.
- Found similar phenomena in other monsoon regions; models that predict a stronger temperature anomaly also tend to project a larger precipitation increase.



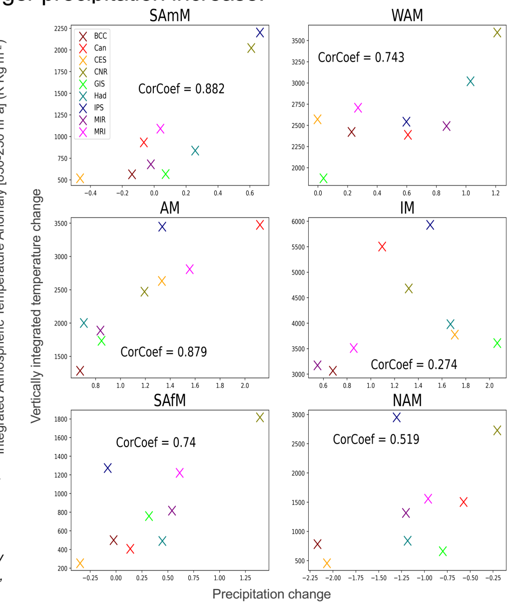


Fig 4: (Above) change caused by the direct radiative effect of 4xCO_2 (amip-4xCO2 – amip) - mass weighted vertically integrated temperature [shaded], precipitation change {intervals of 0.5mm day^{-1}, values above 0.75 masked} [blue], winds at 925 hPa [arrows], monsoon region indicated with red line.

Fig 5: (Right) Scatter plots of monsoon precipitation change against vertically integrated temperature change in each model for each monsoon region, correlation coefficient shown for each scatter.

(G) Key findings and future work

- Global monsoon precipitation is projected to increase (from coupled model analysis). However, there are large regional variations in this response and high levels of uncertainty.
- The direct radiative effect and changes in SSTs are the largest drivers of monsoon precipitation change. Across different regions and models, the direct radiative effect resulted in the most consistent precipitation response (increase in monsoon precipitation).
- The increase in precipitation due to the direct radiative effect appears to be well correlated with a warming nearby, driving a stronger monsoon circulation.
- Further investigation into this direct radiative effect mechanism is currently taking place, questioning the cause of the anomalously warm region.

References

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