Model uncertainty in future changes in West African precipitation: component replication

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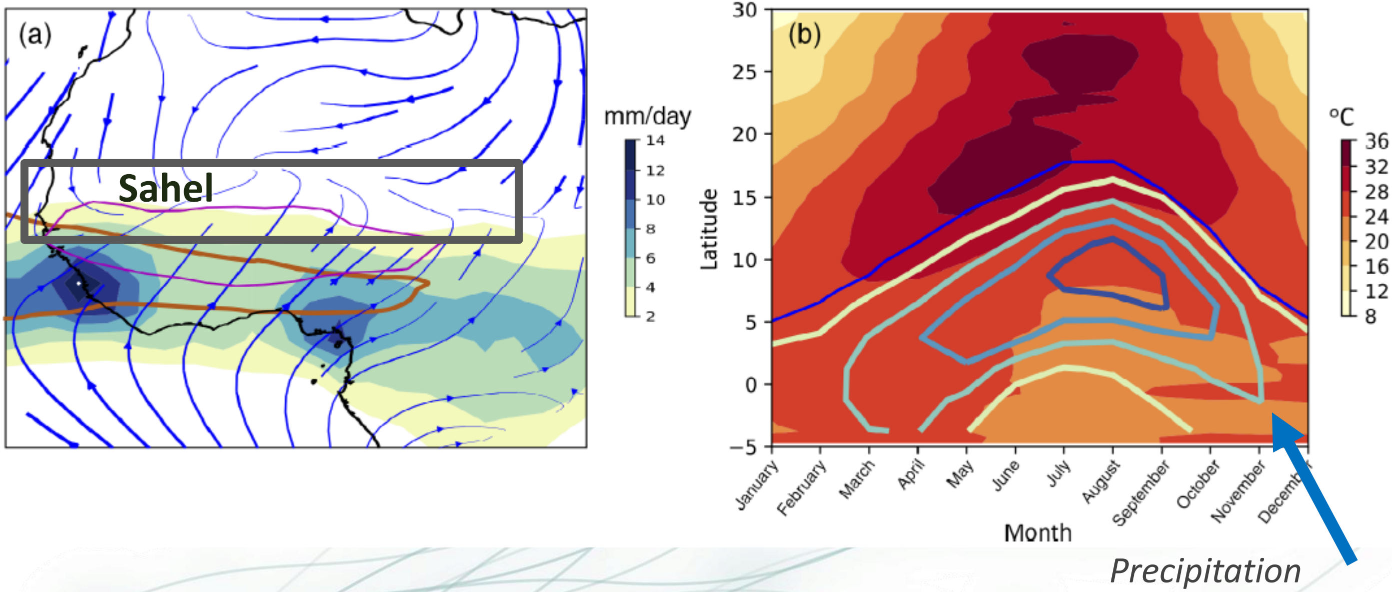
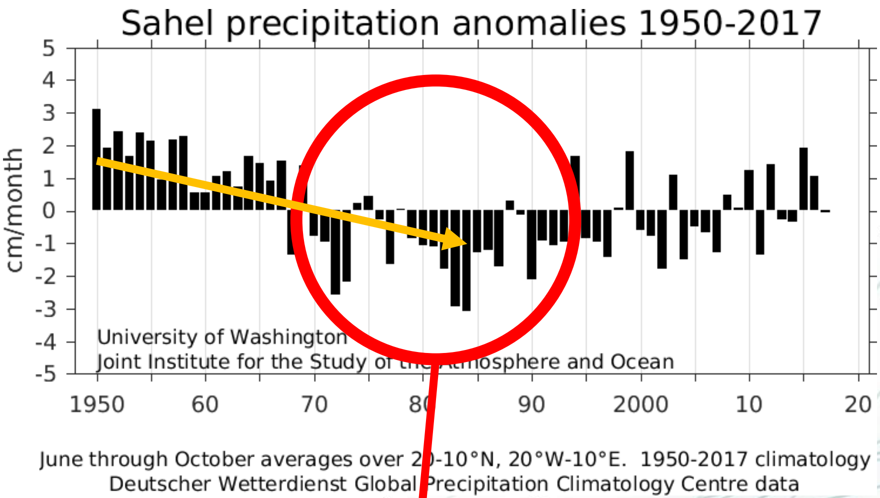
The West African Monsoon



[Left] Precipitation (May-October colour), and 925 hPa wind (arrows).
[Right] Precipitation (contours) and zonal mean temperature (colour) [20°W-30°E].

From Biasutti 2019

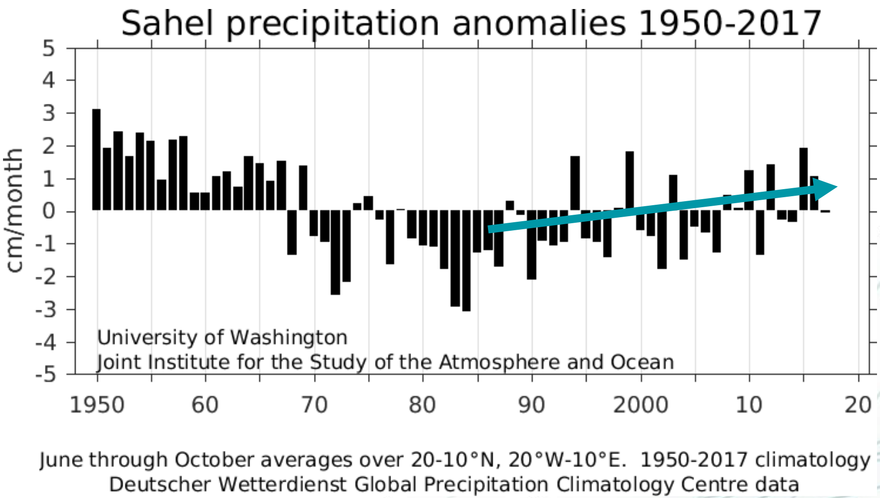
Motivations



Strong variability in Sahel precipitation

1970's-1980's : The drought

Motivations



A recent positive trend, the "recovery" period

Nicholson et al. 2013

Future?

The **West African Monsoon** brings precipitation to around 80 million people from Senegal to Chad, in summer.

- **Human health .***e.g.,* Jankowska et al. 2012; Cissé 2019
- **Agriculture .***e.g.*, Sultan and Gaetani 2016
- **GDP .***e.g*, Sainte Fare Garnot et al. 2018; Baarsch et al. 2020
- Among others

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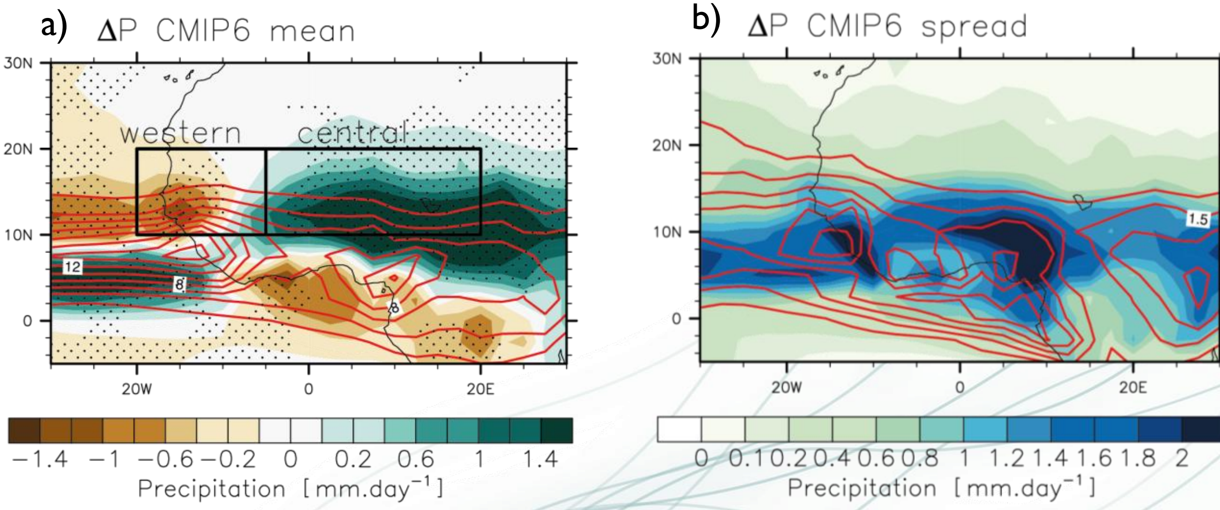
Future changes in precipitation are uncertain

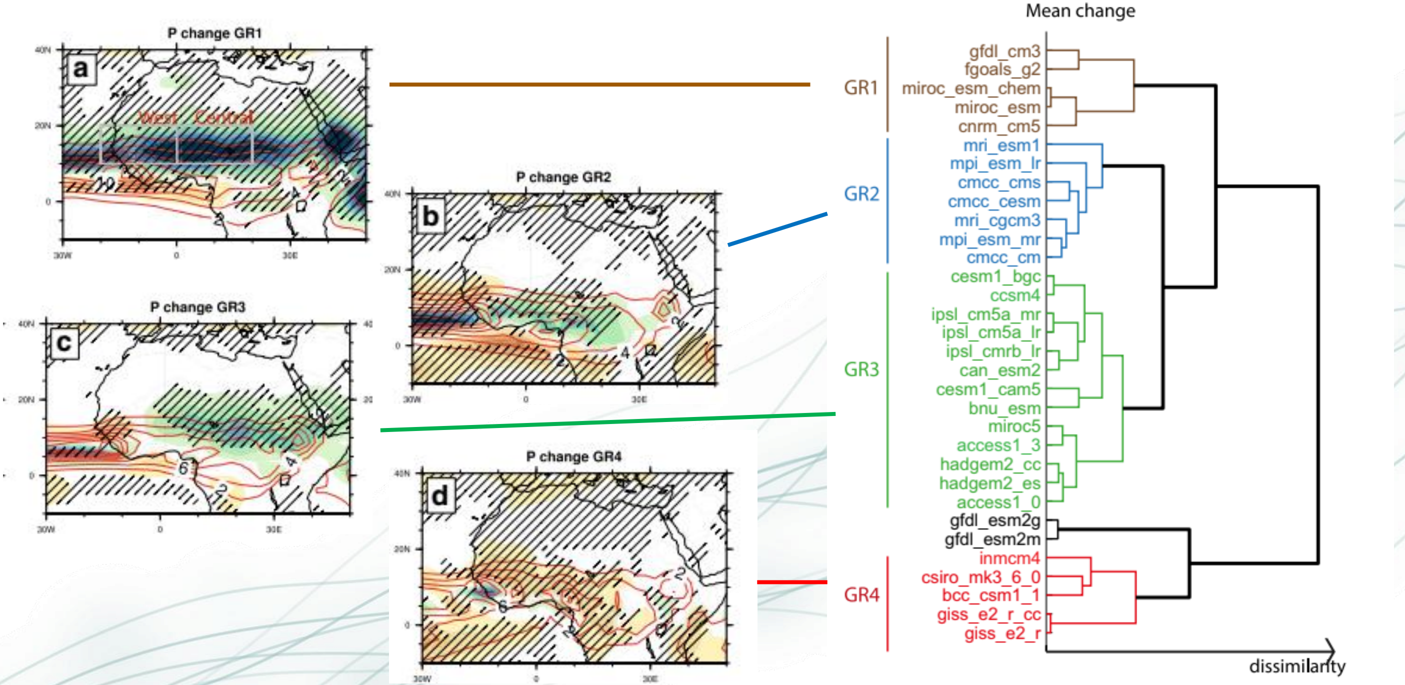


Effect of climate change on precipitation [mm.d^{-1}] for an ensemble of CMIP6 simulations: (a) ensemble mean and (b) ensemble spread (uncertainty). The effect of climate change on precipitation is defined as the difference between a future period (2060-2099; SSPP5-8.5) relative to an historical period (1960-1999) in summer (JAS). Monerie et al. 2020.

A zonal contrast in precipitation change

Changes are uncertain

Future changes in precipitation are uncertain



Monerie et al. 2017

The different trajectories in Sahel precipitation change for the end of the 21st century, emissions scenario RCP8.5

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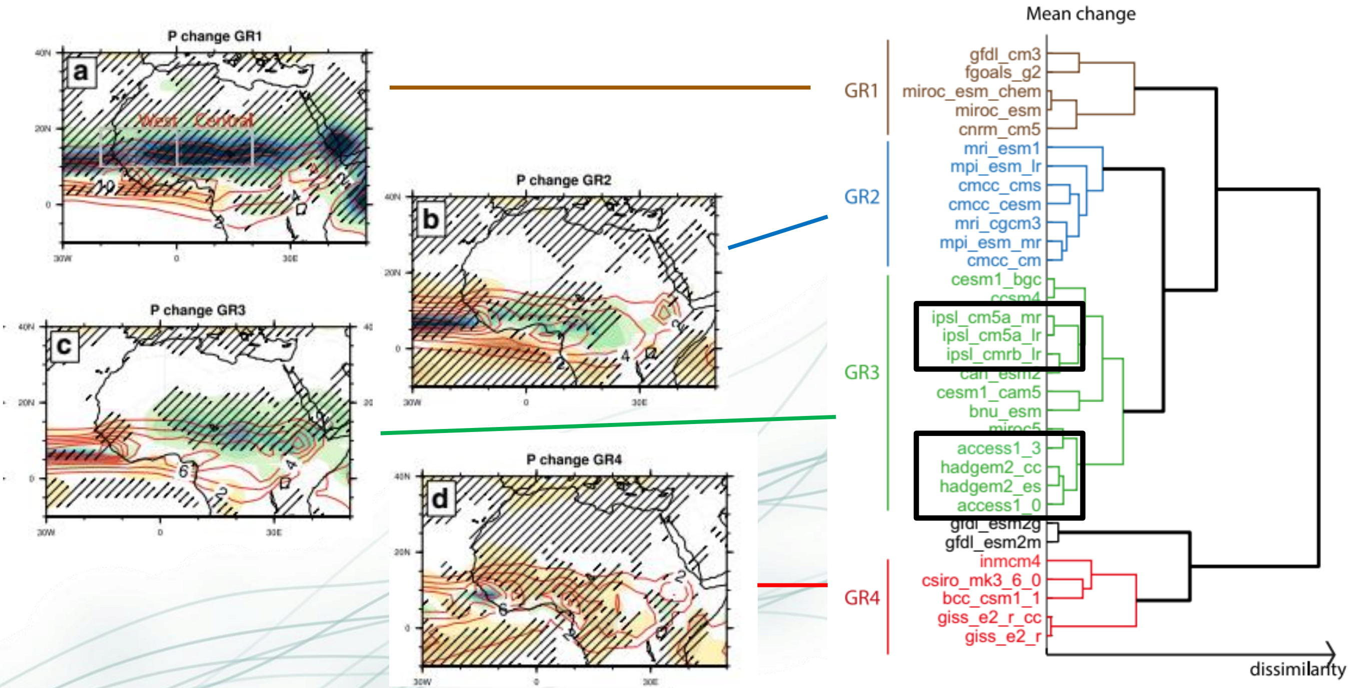
Future changes in precipitation are uncertain



Monerie et al. 2017

The different trajectories in Sahel precipitation change for the end of the 21st century, emissions scenario RCP8.5

Role of the structural uncertainty?

(How do we account for model independence?)

Data

We use the data from **39 CMIP6 models**, under the SSP5-8.5 emissions scenario. One ensemble member for each model.

We further assess the effects of **internal climate variability** using outputs from four Single Model Initial-condition Large Ensembles (between 30 and 50 ensemble members).

Similarity between models

We computed the Root Mean Square Error between simulations of different models

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2}$$

For two models, X and Y, and each grid point i, over West Africa [20°W-20°E; 5°S-25°N]

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Components selection

Model	Atmos.	Ocean.	land.	Sea ice.
ACCESS-CM2	GA7	MOM5	CABLE2	CICE5
ACCESS-ESM1-5	GA7	MOM5	CABLE2	CICE4
HadGEM3-GC31-MM	GA7	NEMO3	JULES7	CICE4
INM-CM5-0	AM5	OM5	LND1	ICE1

3 components in common

1 components in common

No component in common

Following Boé et al. 2018

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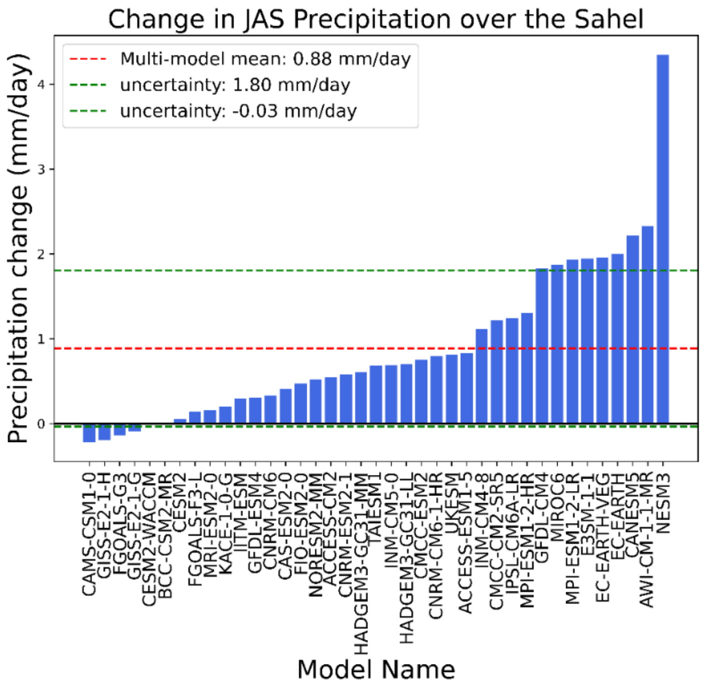
Results: changes in Sahel precipitation



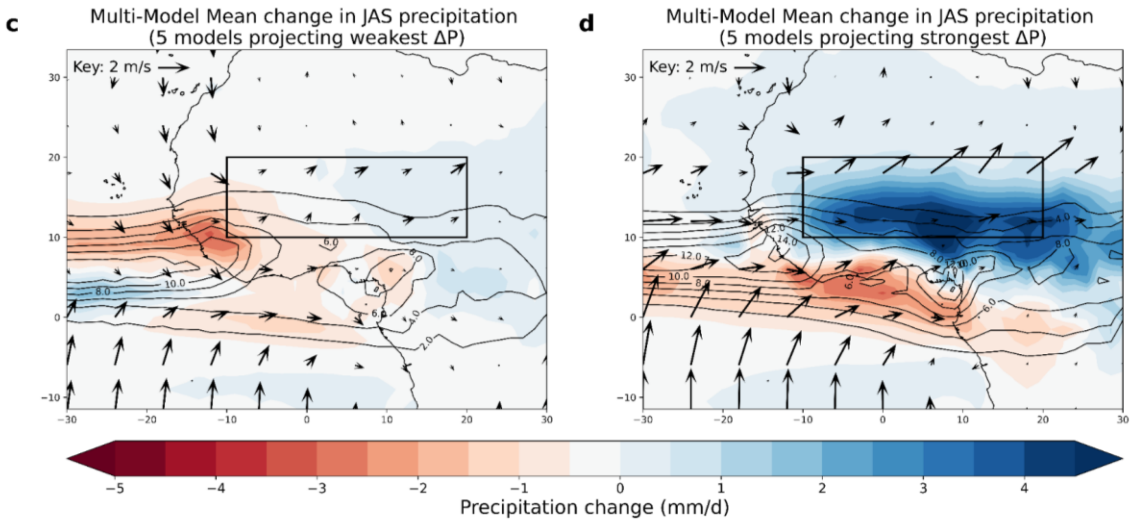
Increase in precipitation over the Sahel, but results are model-dependent

Multi model mean

Uncertainty (spread)

Effect of climate change on precipitation [mm.d^{-1}] for an ensemble of CMIP6 simulations (2060-2099; SSPP5-8.5) relative to an historical period (1960-1999) in summer (JAS).

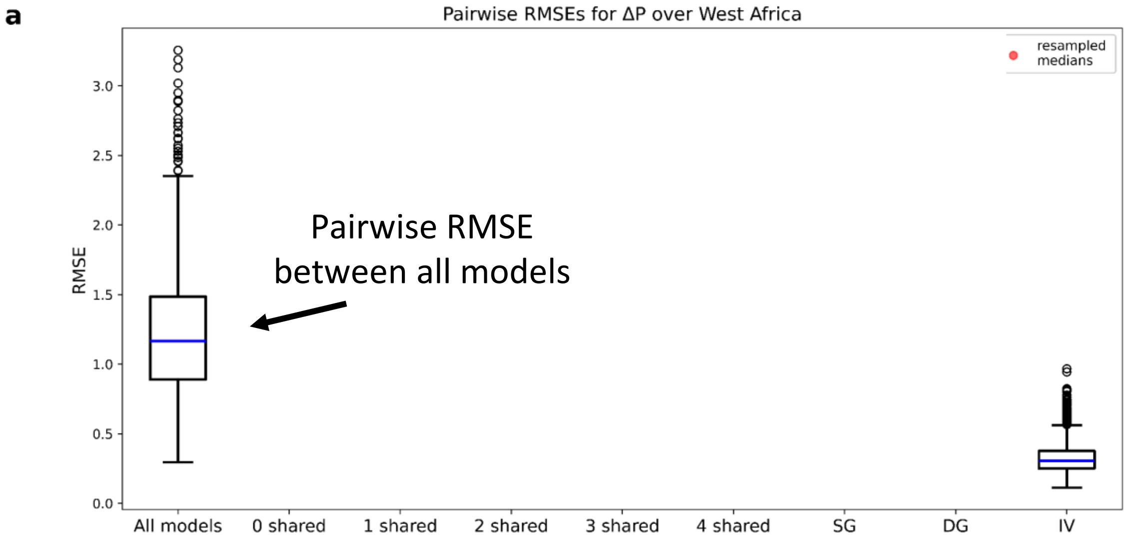
Results: changes in Sahel precipitation



Effect of climate change on precipitation [mm.d^{-1}] for an ensemble of CMIP6 simulations (2060-2099; SSPP5-8.5) relative to an historical period (1960-1999) in summer (JAS), using (left) the five models that show the more negative/smallest change in precipitation and (right) the five models which show the strongest increase in precipitation. The arrows show the 850 hPa wind. The contours show the climatology.

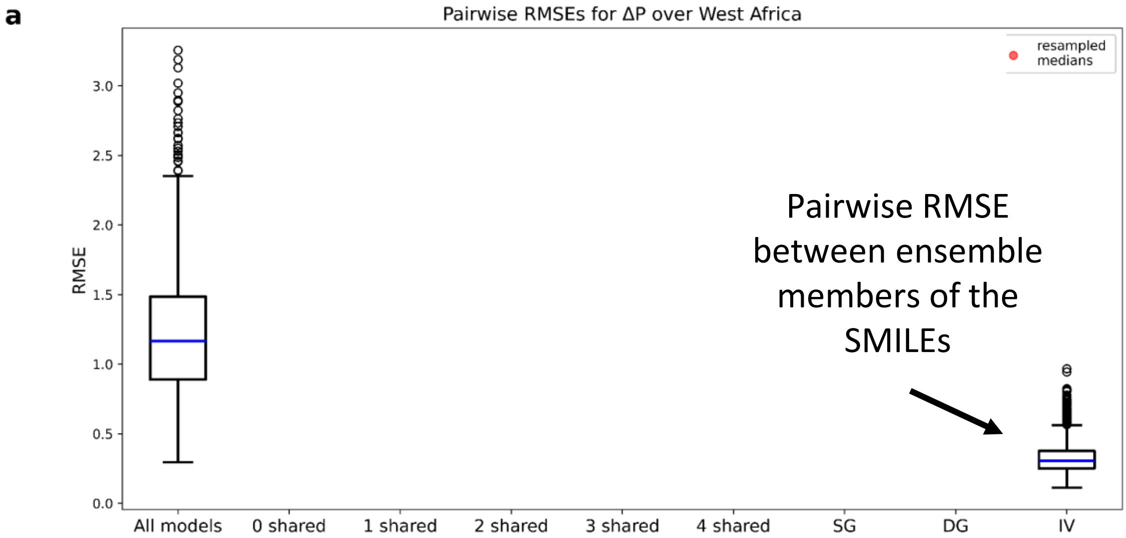
Two different futures

Results: the component replication



Pairwise RMSEs for (a) precipitation change and (b) model bias over West Africa [20°W-20°E; 5°S-25°N] *based on the number of shared model components. In both (a) and (b), SG and DG show the pairwise RMSEs when model pairs are in the same modelling group and different modelling groups respectively. The boxplot denoted 'IV' represents the pairwise RMSEs between multiple ensemble members from four different models. This represents internal variability. The red dots on both plots show the result of random resampling outlined in data/methods section. The median for each boxplot is shown by the dark blue line.*

Results: the component replication



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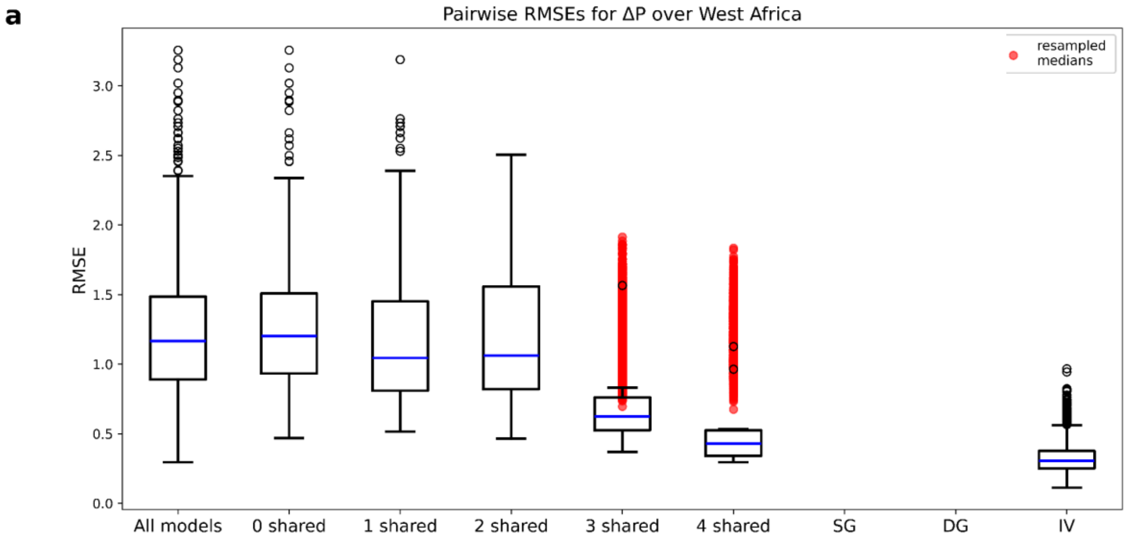

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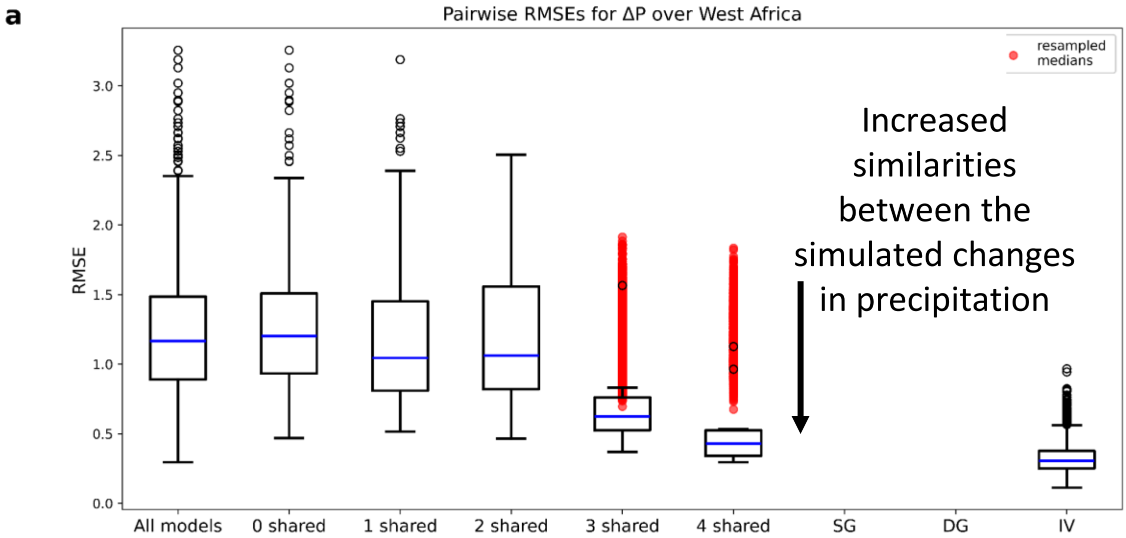

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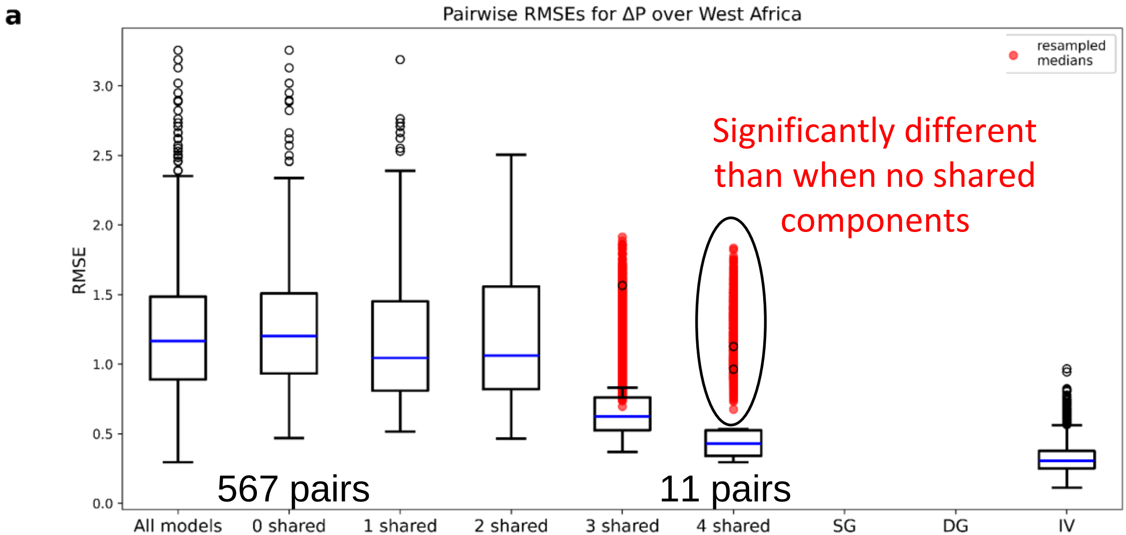

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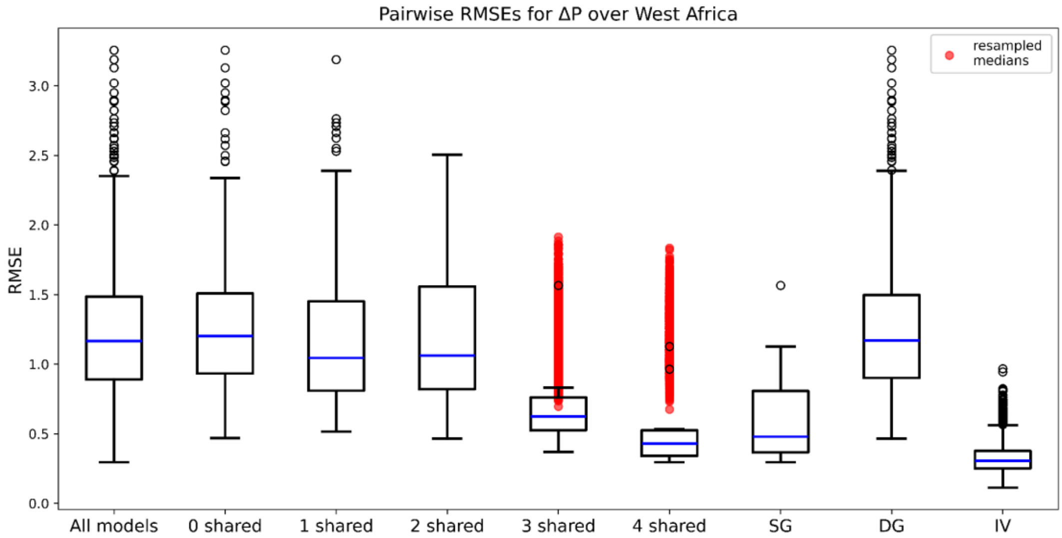
Results: the component replication

a



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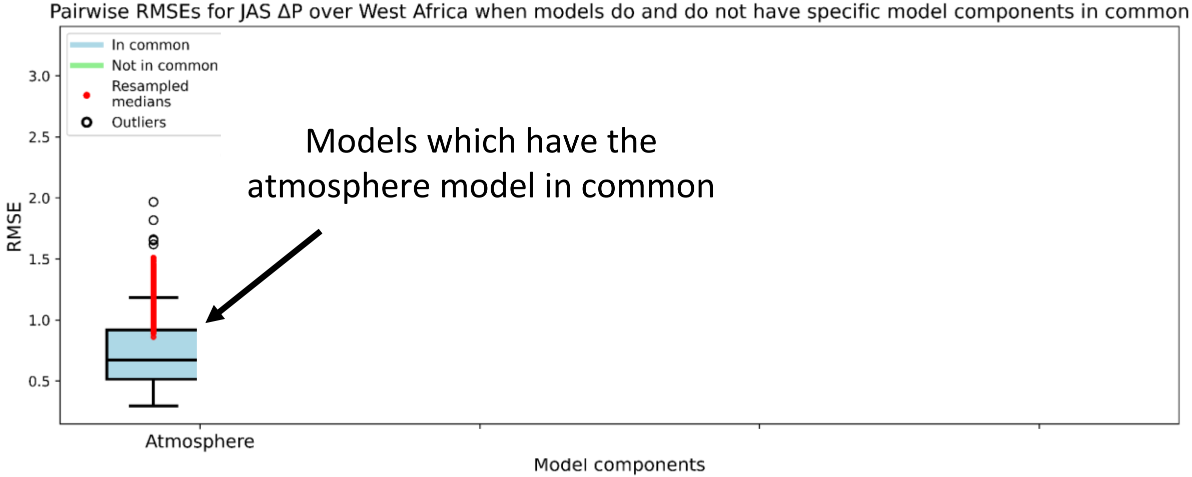
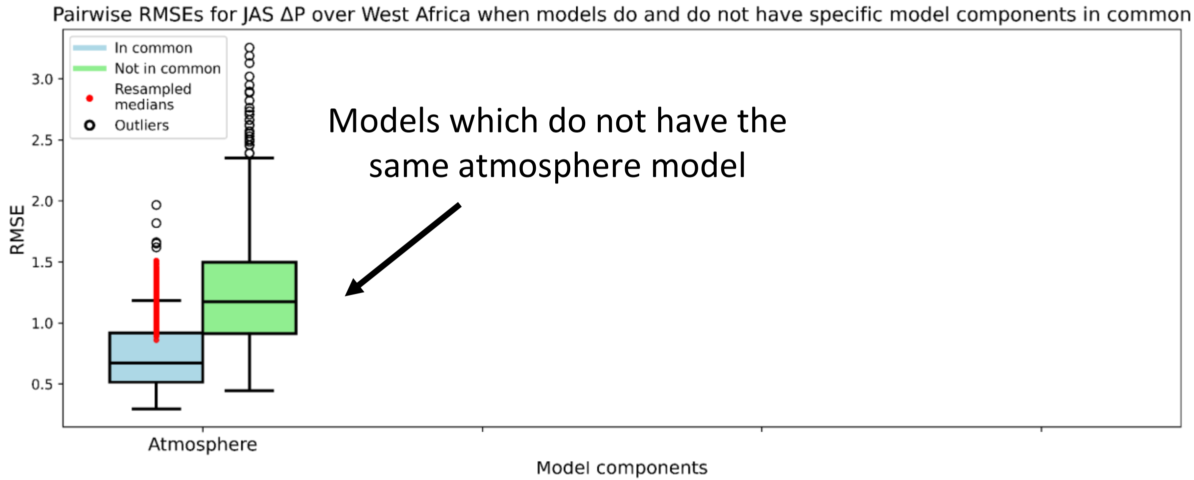
Results: by components



Pairwise RMSEs for change in land precipitation over West Africa when models do and do not have atmosphere/ocean/land/sea ice model components in common. The light blue boxes indicate the samples when a specific model component was in common whereas the light green boxes indicate samples when a specific model component was not in common. The red dots on both plots show the result of random resampling outlined in data/methods section.

Results: by components



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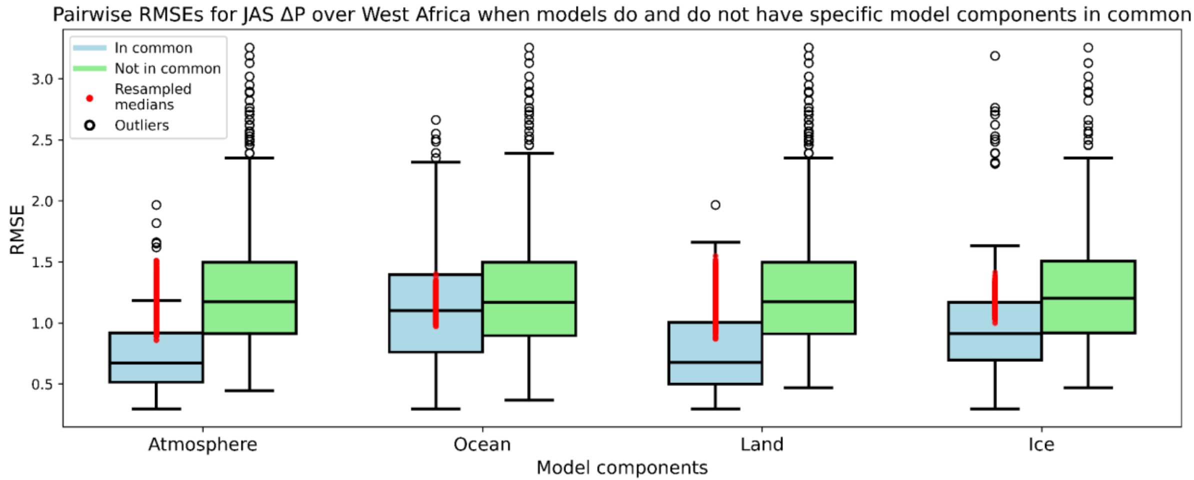

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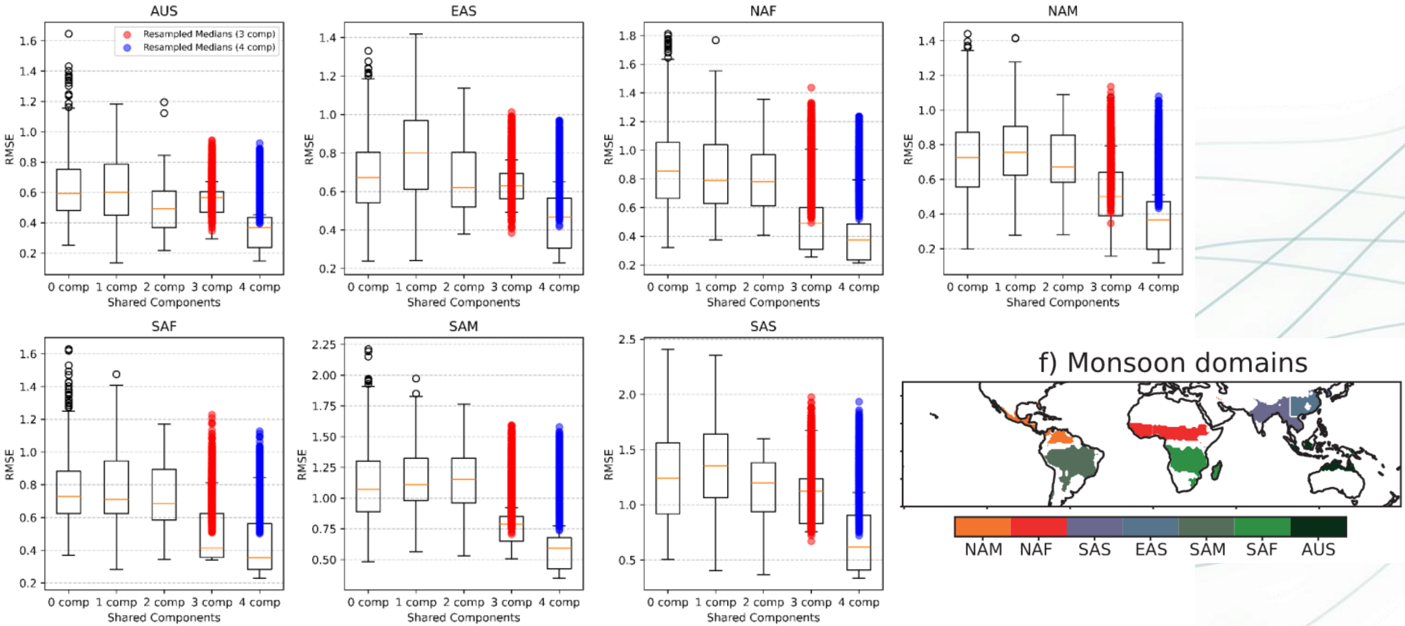
Strong effect of the atmosphere and land models

Results: other monsoon domains



Pairwise RMSEs for (a) precipitation change over West Africa [20°W-20°E; 5°S-25°N] *based on the number of shared model components. The red/blue dots on both plots show the result of random resampling outlined in data/methods section. The median for each boxplot is shown by the orange line.*

Results are monsoon-domain dependent

Take home message

The future change in Sahel precipitation is **uncertain**.

- direction/magnitude
- strong model uncertainty

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Take home message

The future change in Sahel precipitation is **uncertain**.
- direction/magnitude
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We show that similarities between **model components** matter
- having at least 3 components in common increases similarity
- the use of a same atmosphere and land models increases similarities between projections
- the effect is primarily associated with the change of the atmospheric circulation

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Take home message

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Our results have implications for accounting for **model independence** (e.g. to perform the ensemble mean) and **model selection** (e.g. impact studies).

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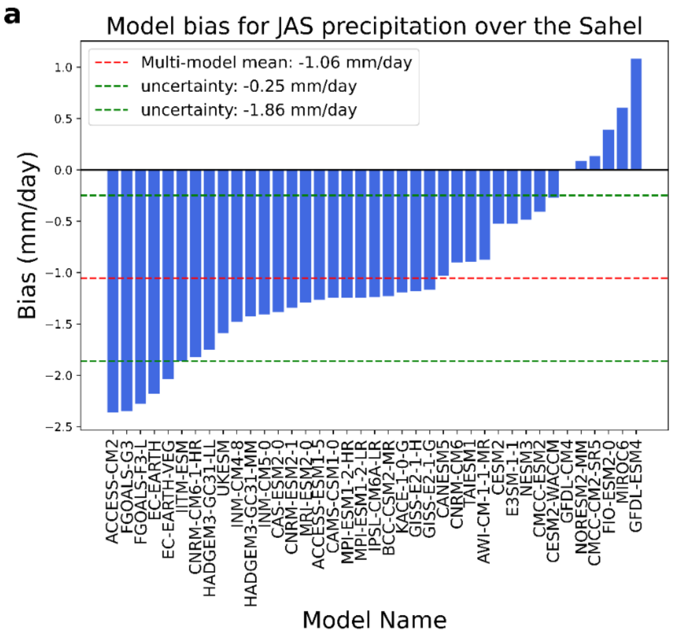
Results



Precipitation biases [mm.d^{-1}] relative to GPCC; 1960-1999 in JAS.

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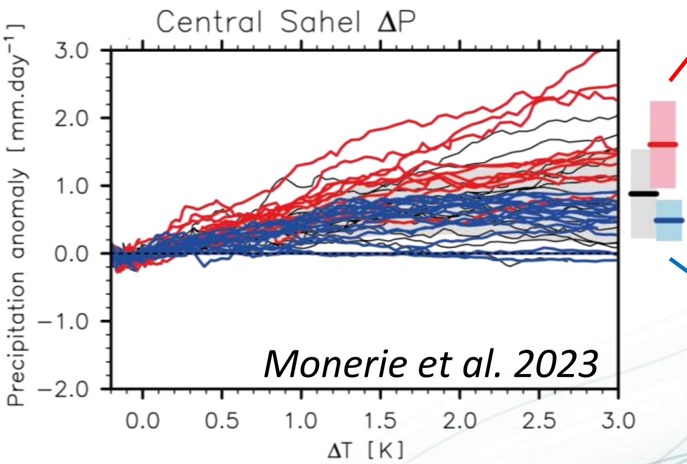
Future changes in precipitation are uncertain



The change in the North Atlantic and Euro-Mediterranean area is higher than for the multi-model mean

The change in the North Atlantic and Euro-Mediterranean area is lower than for the multi-model mean

Changes in central Sahel precipitation [mm day-1] as a function of global-mean warming (Δ*T*) for all models (black lines), the CMIP6 envelope (gray shading, spanning 2 times the CMIP6 standard deviation), the A+M+ models (red), and the A-M- models (blue). On the right-hand side of each panel, the horizontal thick lines indicate the ensemble mean, and the bars indicate the ensemble envelope (spanning 2 times the ensemble standard deviation), computed across the CMIP6 models (black), the A+M+ models (red) and the A-M- models (blue), for a warming of 2.5–3°C.

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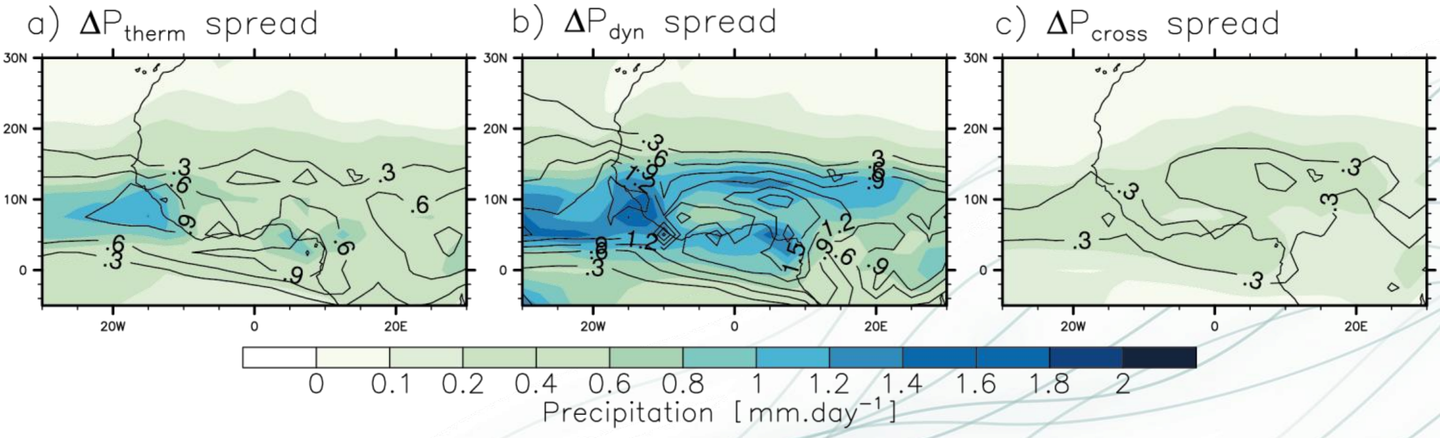
Future changes in precipitation are uncertain



Ensemble spread (uncertainty) in the (a) thermodynamic, (b) dynamic, and (c) cross non-linear change in precipitation.

Monerie et al. 2020

The uncertainty mainly arises from differences between models in simulating future changes in atmospheric circulation.

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Partitioning precipitation

$P = M^* q$ *(and $M^* = P/q$)*

where P is the precipitation

q is the near surface specific humidity

M^* is a proxy for convective mass flux from the boundary layer to the free troposphere

Held & Soden (2006)

We make the assumption that precipitation can be approximates from the circulation and the near surface humidity

$$\Delta P = M^* \Delta q + q \Delta M^* + \Delta q \, \Delta M^*$$

Kent et al. (2015); Chadwick et al. (2016); Rowell and Chadwick (2018)

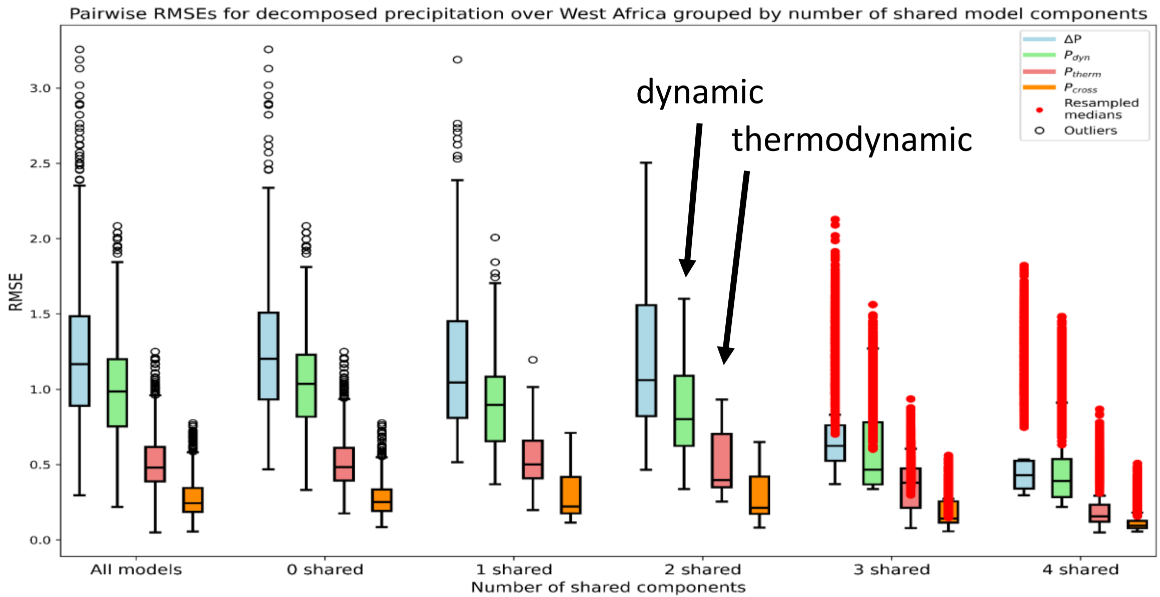
$$\Delta P = \Delta P_{therm} + \Delta P_{dyn} + \Delta P_{cross}$$

thermodynamic

dynamic

cross non-linear

Results: Mechanisms



Pairwise RMSEs grouped by number of shared components for precipitation change decomposed into dynamic, thermodynamic and cross components over West Africa. The light blue, light green, pink and orange boxplots show the pairwise RMSEs for change in precipitation over West Africa, the dynamic component of precipitation, the thermodynamic component of precipitation and the cross term of precipitation respectively. The red dots on both plots show the result of random resampling outlined in data/methods section.

Differences mainly come from the dynamic change of the atmospheric circulation

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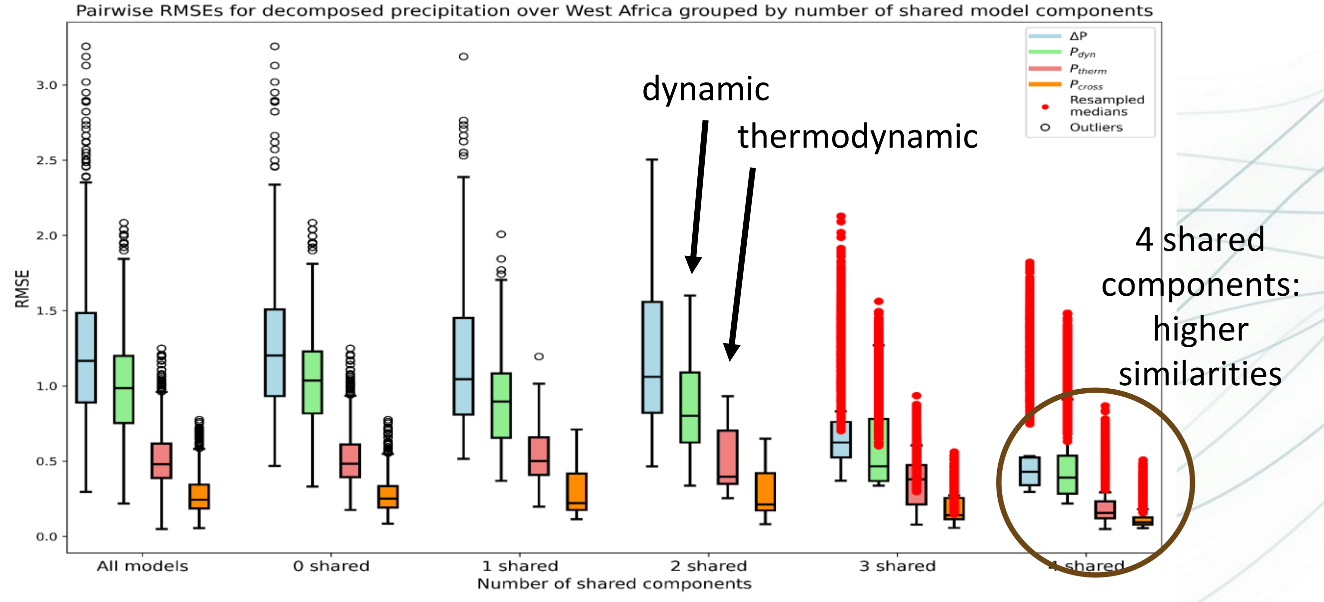

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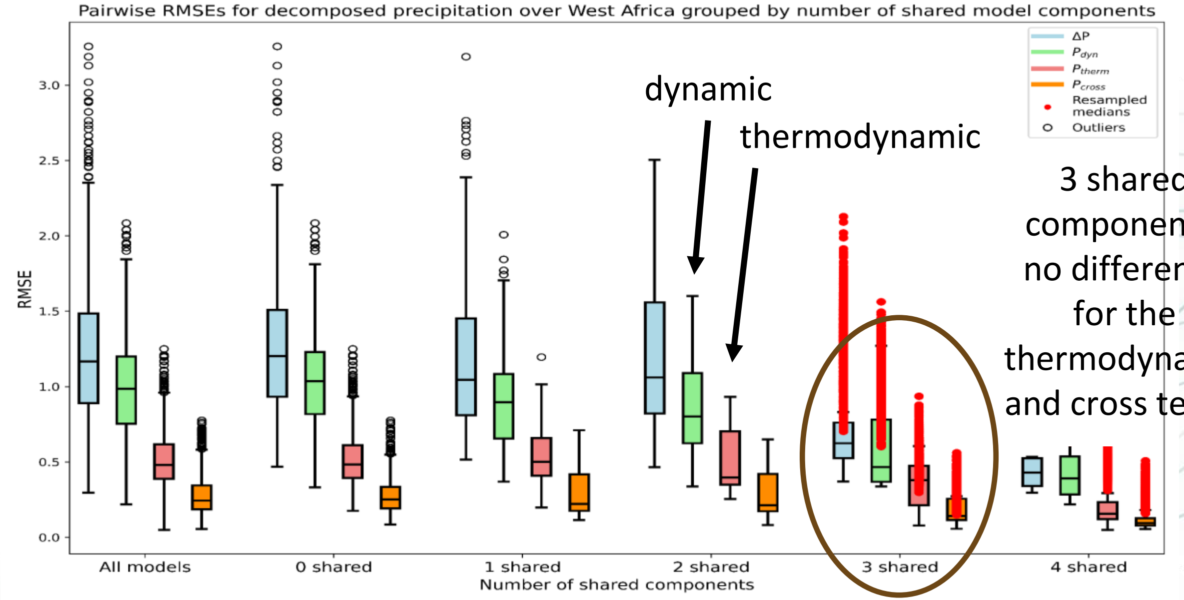

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