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HUMAN INFLUENCE STRENGTHENS THE CONTRAST BETWEEN TROPICAL WET AND DRY REGIONS

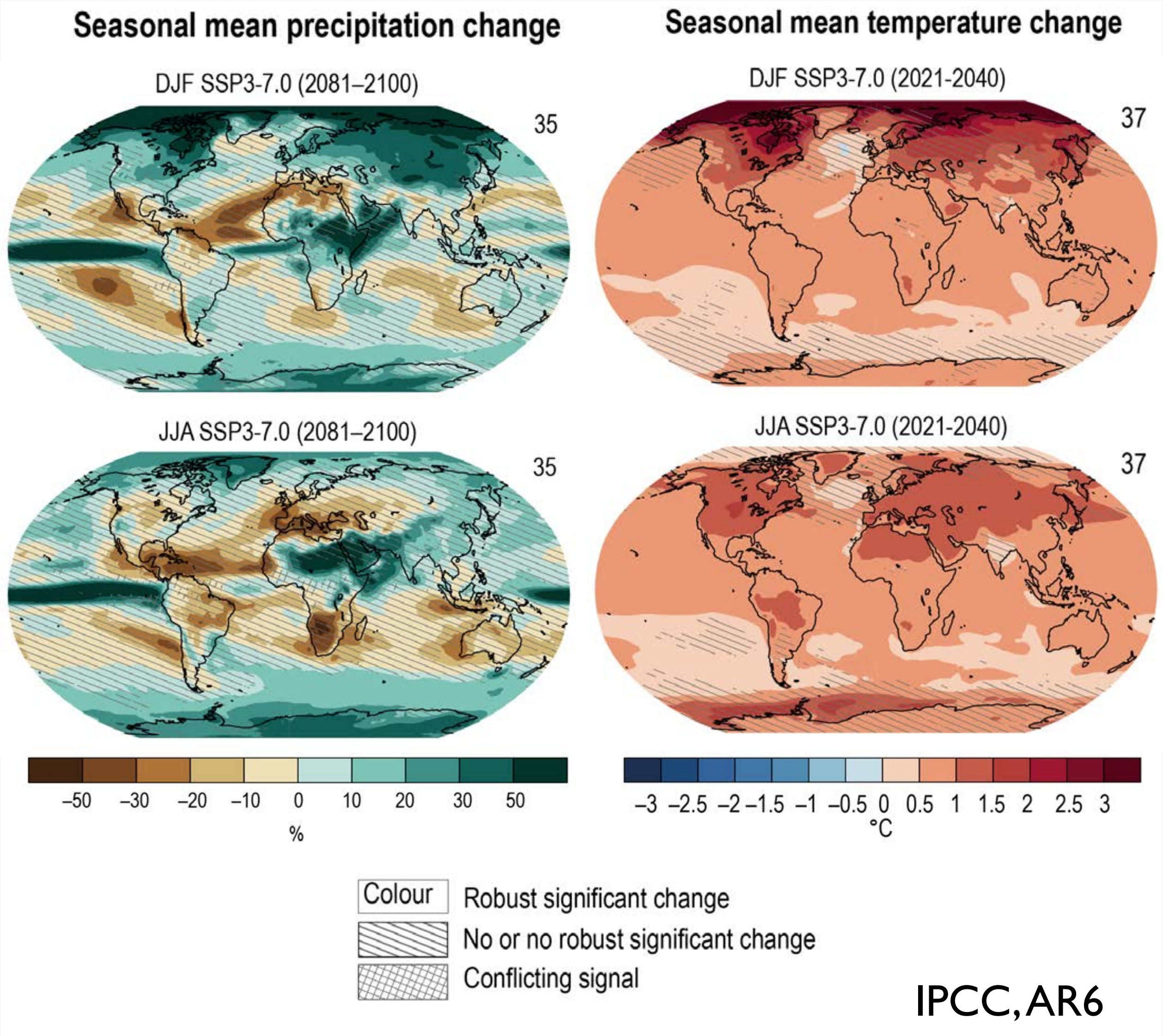
Confronting Earth System Model Trends with Observations

Andrew Schurer, A. Friedman, A. Ballinger, and G. Hegerl

March 2024

MOTIVATION

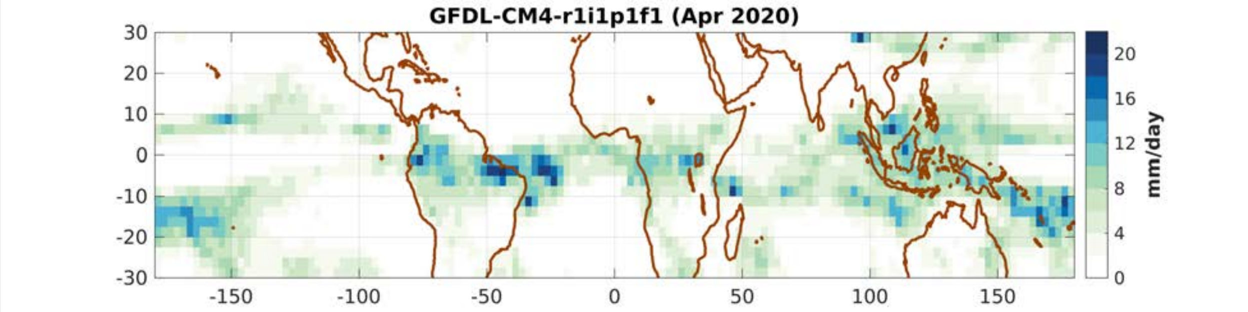
- Precipitation is controlled by both temperature (thermodynamics) and circulation (dynamics).
- Compared with temperature, circulation-related changes in climate are not as robust in observations, theory or models.
- GCMs are much less consistent in prediction of rainfall changes than temperature



IPCC, AR6

TRACKING WET AND DRY REGION RAINFALL

- We analyse monthly rainfall over the tropical (30°S-30°N) region:
  - For each individual GCM model ensemble member
  - For each month separately



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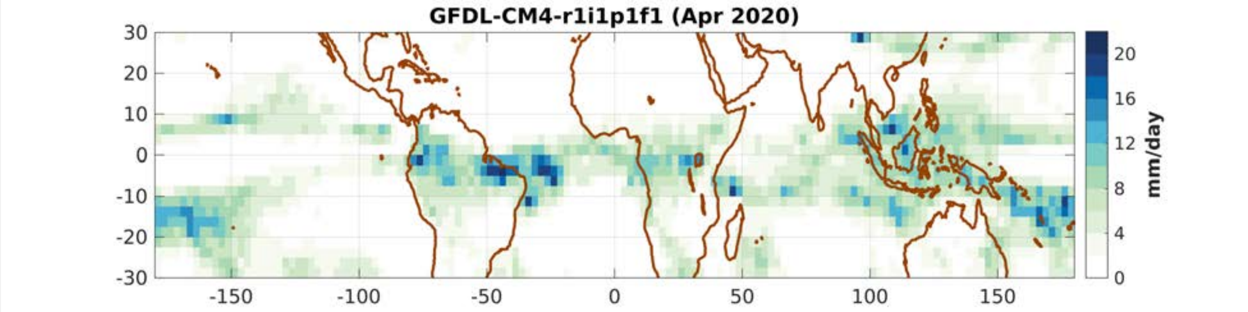
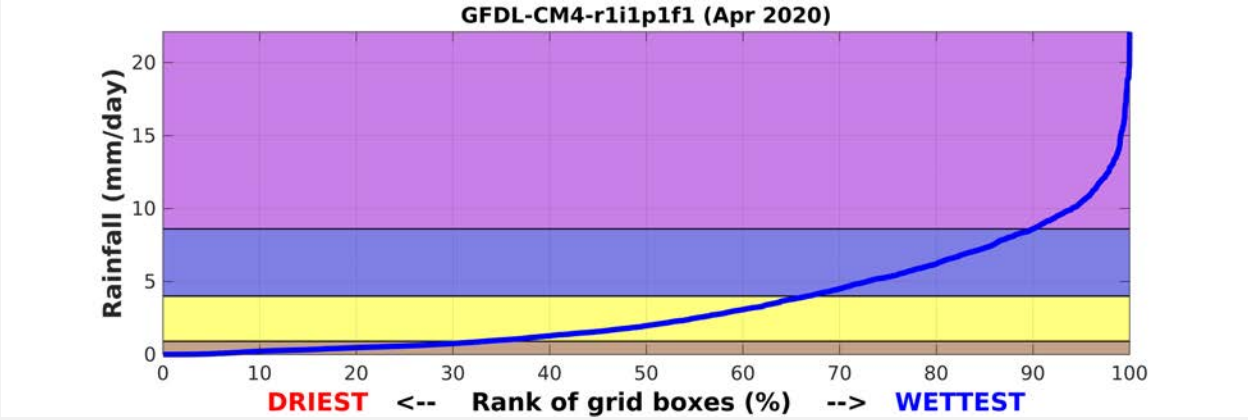
- Rank all of the 2.5°x2.5° grid boxes (*n=3456*) from the least to most rainfall

- Define wet/dry regions based on rank:
  - Lowest tercile – "dry regions"
  - Middle tercile – "moderate"
  - Highest tercile – "wet regions"
  - Highest decile – "wettest regions"





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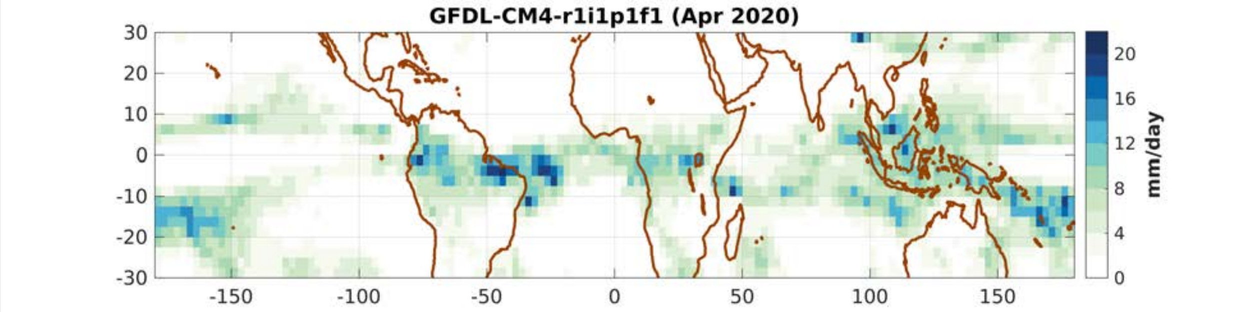

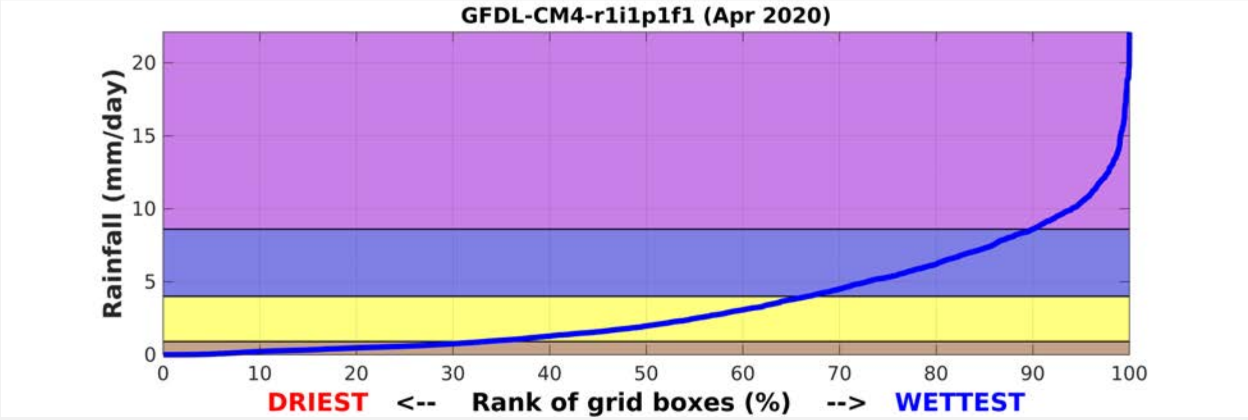

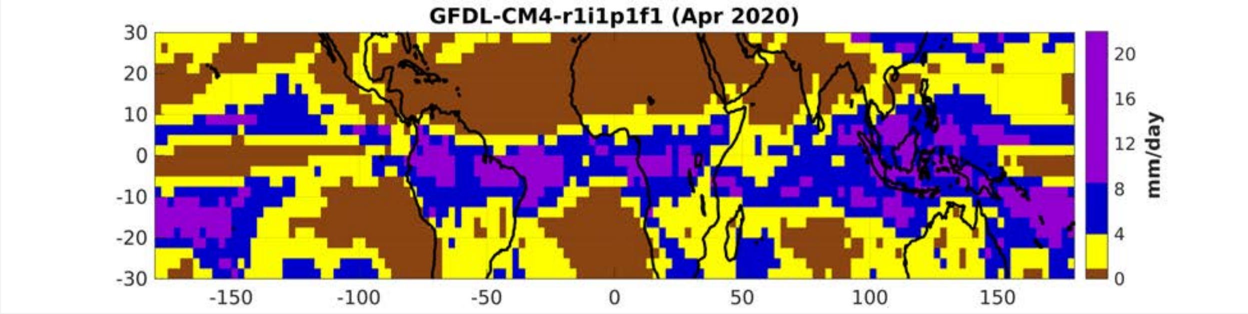

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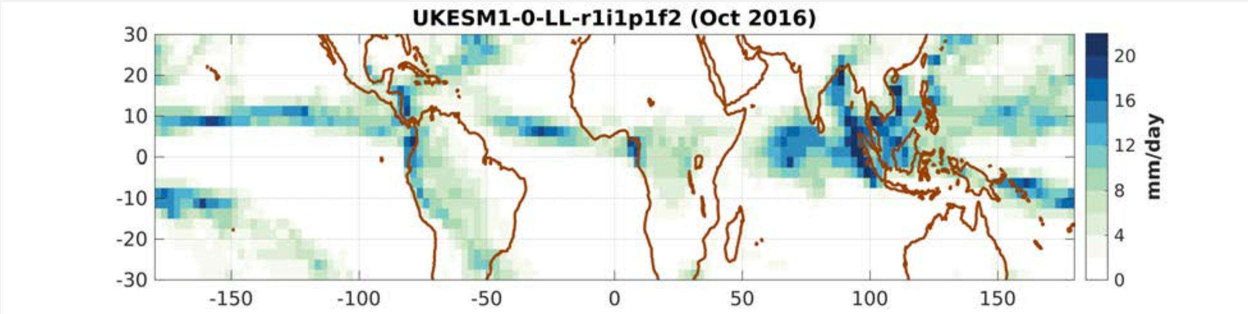
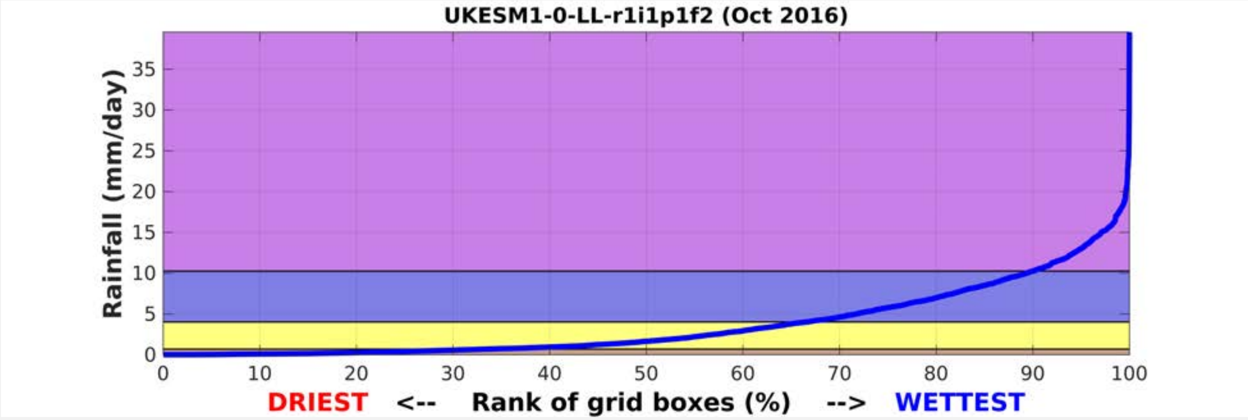
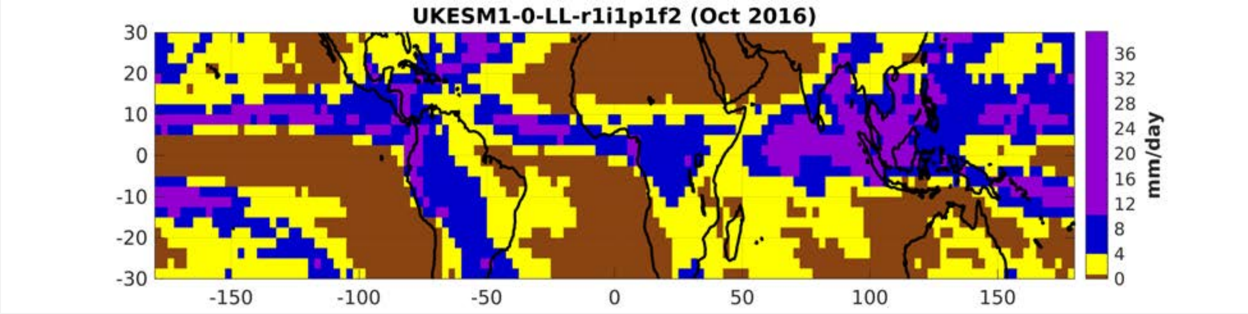
- Repeat for all models, obs, months, etc.



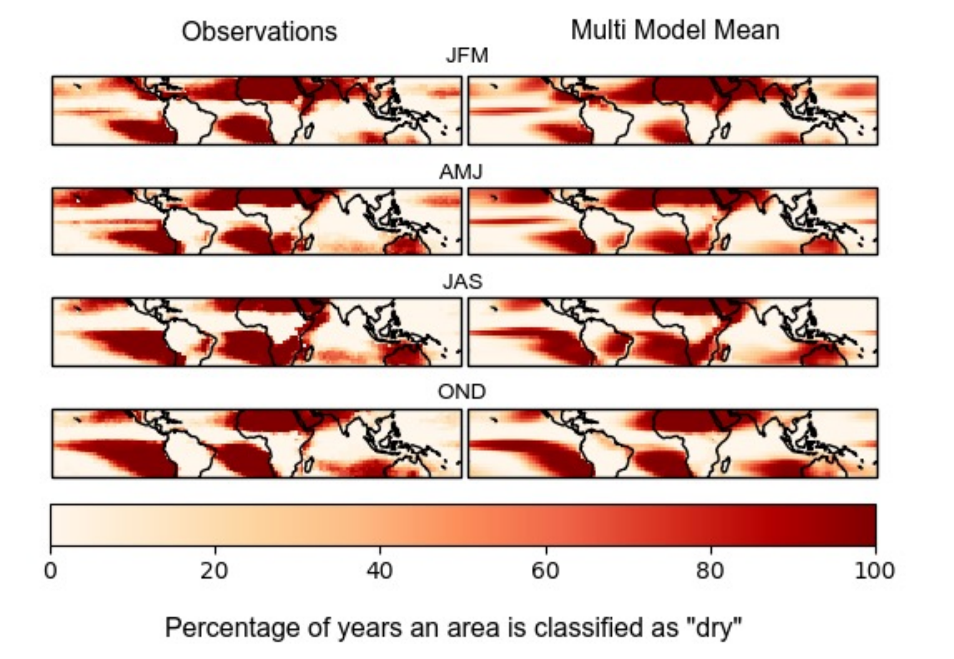


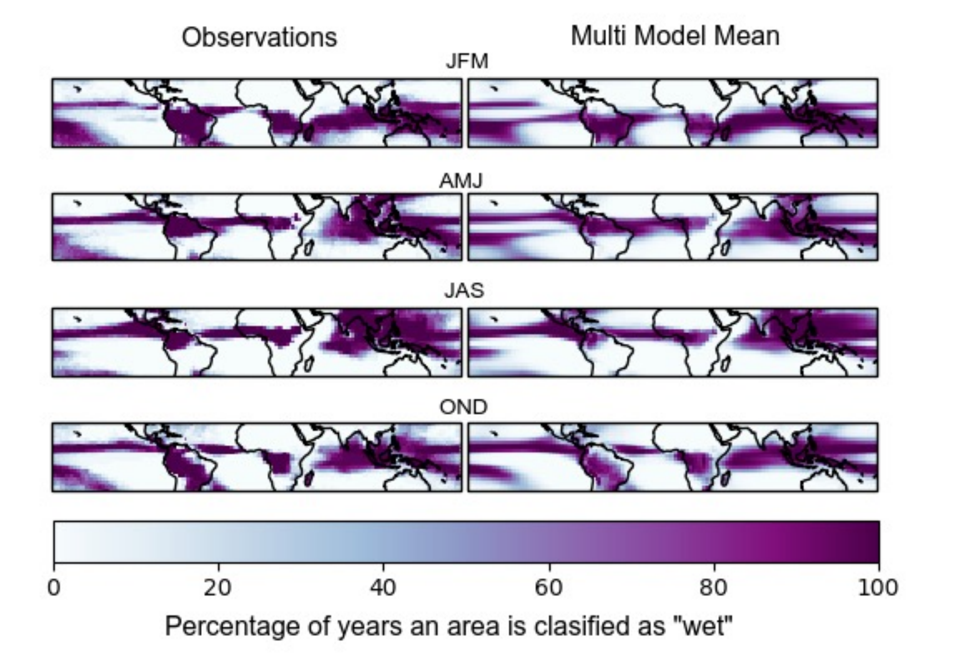


TRACKING WET AND DRY REGION RAINFALL

- Define wet/dry regions based on rank:
  - **Lowest tercile – "dry regions"**
  - Middle tercile – "in-between"
  - **Highest tercile – "wet regions"**
  - Highest decile – "wettest regions"

- General consistency in the wet- and dry-region patterns between the observations (GPCP) and the CMIP6 multi model mean





ANALYSIS RESULTS FROM

IOP Publishing

Environ. Res. Lett. **0** (2020) xxxxxx

https://doi.org/10.1088/1748-9326/ab83ab

Environmental Research Letters

CrossMark

OPEN ACCESS

RECEIVED
20 December 2019

REVISED
16 March 2020

ACCEPTED FOR PUBLICATION
26 March 2020

PUBLISHED
xx xx xxxx

LETTER

Human influence strengthens the contrast between tropical wet and dry regions

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Keywords: climate change, tropical precipitation, detection and attribution

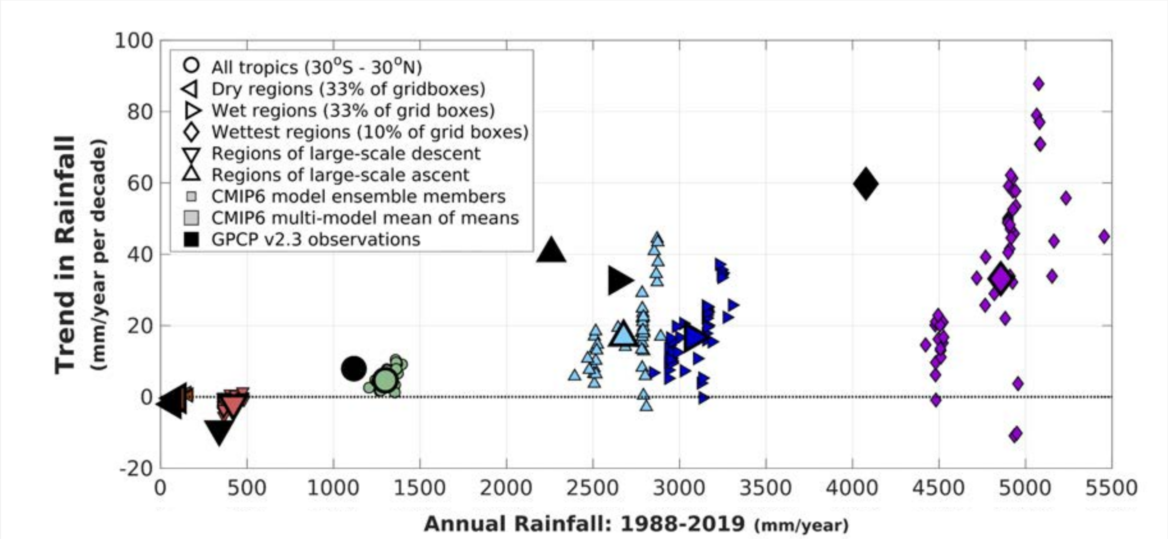
Supplementary material for this article is available online

Schurer et al. 2020 (ERL)

TRACKING WET AND DRY REGION RAINFALL

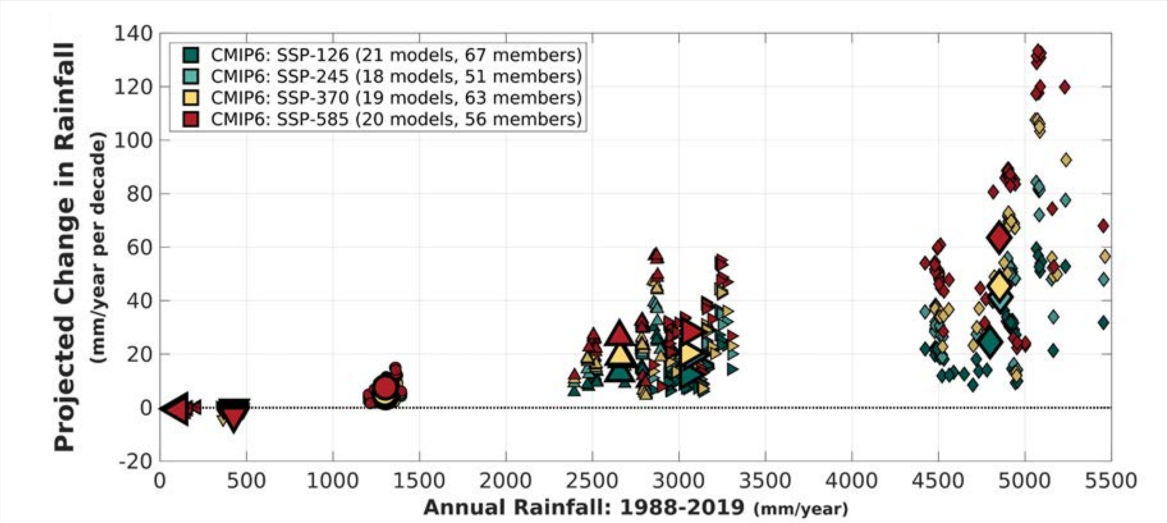
- Projected changes in rainfall show that wet regions get wetter and dry regions get drier in all CMIP6 models by end of 21st century
- Robust fingerprint of anthropogenic forcing
- Observed trends (GPCP) over the past 32-years also show same signal

Trend 1988-2019



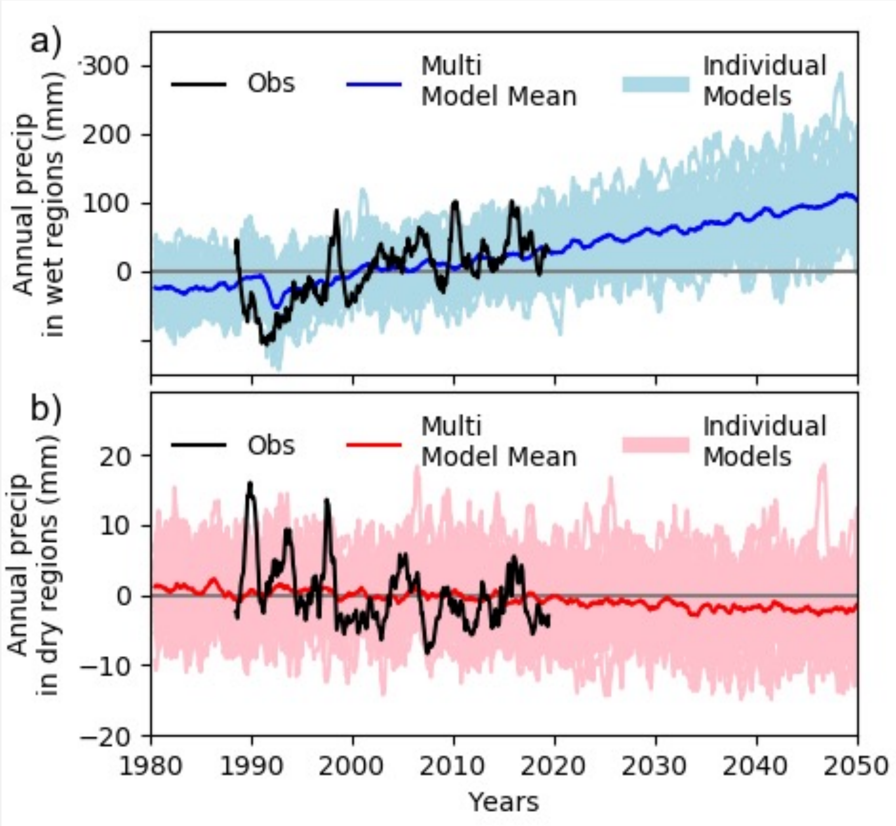
Driest 33%
Descending regions
All tropics
Ascending regions
Wettest 33%
Wettest 10%

Change by 2068-2099



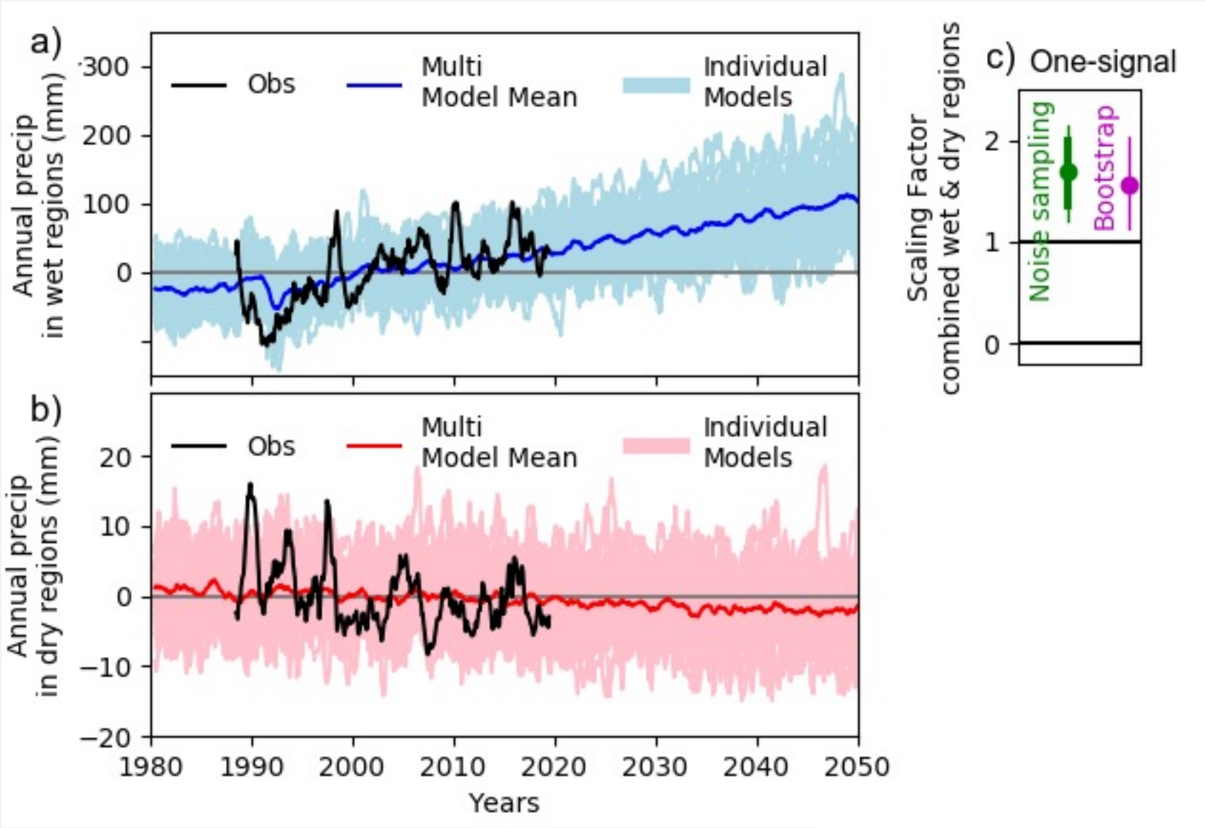
TRACKING WET AND DRY REGION RAINFALL

- Time-series of seasonal rainfall anomalies over wet and dry regions in GPCP (black) and CMIP6 (colours)



TRACKING WET AND DRY REGION RAINFALL

- Time-series of seasonal rainfall anomalies over wet and dry regions in GPCP (black) and CMIP6 (colours)
- Detection and attribution by regressing the multi-model-mean onto the observations using TLS
- The scaling factors show that the signal is clearly detected, but the magnitude is not consistent with the observations - needs to be scaled up!



$$obs = \sum_{i=1}^{l} \beta_i (mod_i - \nu_i) + \nu_0$$

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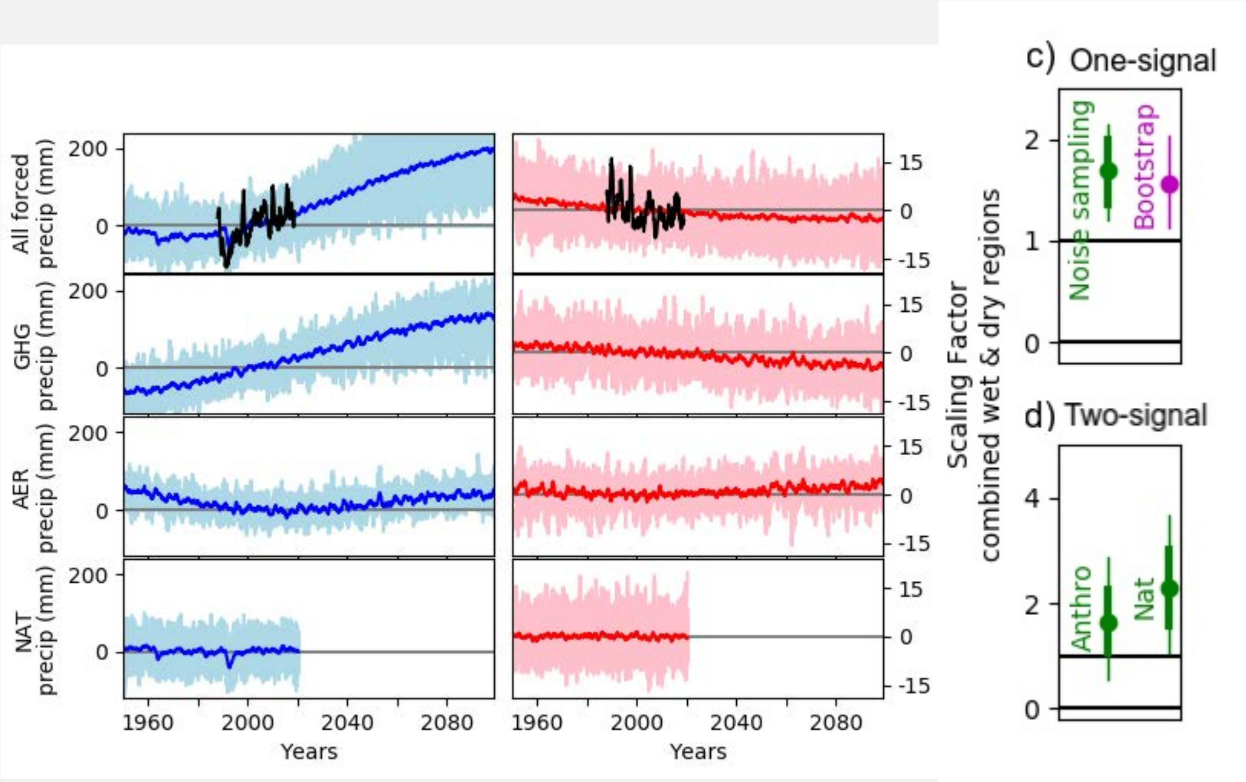
- Anthropogenic attribution



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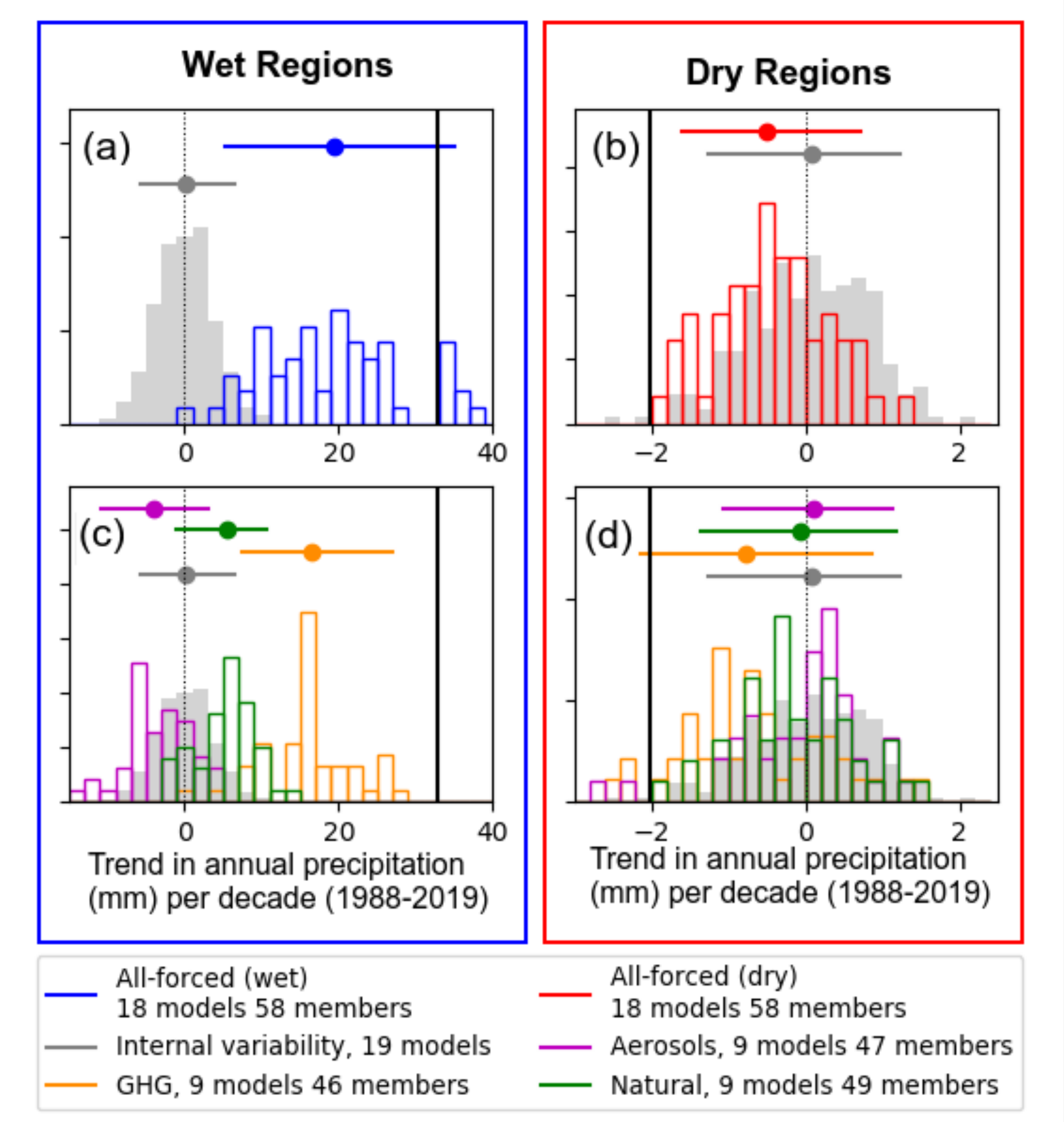
TRACKING WET AND DRY REGION RAINFALL

- Normalised histograms of precipitation trends in wet and dry regions
- Observed trends are outside what could be expected from internal variability alone (from piControl runs)
- **Further suggests that the observed change is larger than nearly all model simulations**



TRACKING WET AND DRY REGION RAINFALL

Polson et al. 2013 (GRL)

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 4783–4787, doi:10.1002/grl.50923, 2013

Have greenhouse gases intensified the contrast between wet and dry regions?

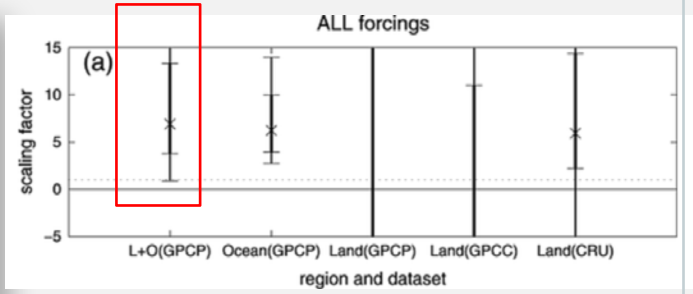
D. Polson,[1] G. C. Hegerl,[1] R. P. Allan,[2] and B. Balan Sarojini[3]

Received 12 July 2013; revised 27 August 2013; accepted 29 August 2013; published 13 September 2013.

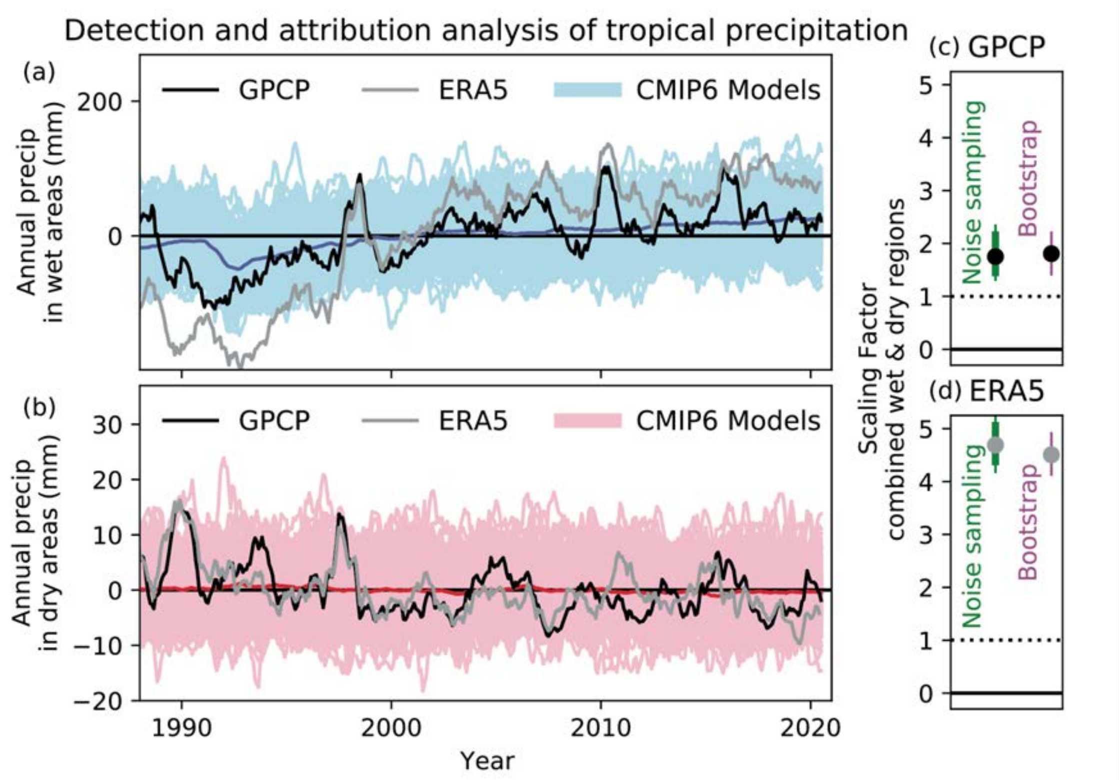
[1] While changes in land precipitation during the last 50 years have been attributed in part to human influences, results vary by season, are affected by data uncertainty and do not account for changes over ocean. One of the more physically robust responses of the water cycle to warming is the expected amplification of existing patterns of precipitation minus evaporation. Here, precipitation changes

data [*Zahn and Allan*, 2011], modeling studies of past and projected changes [*Sun et al.*, 2007; *Seager and Naik*, 2012; *Lau et al.*, 2013; *Liu and Allan*, 2013] and changes suggested by ocean salinities [*Durack et al.*, 2012]. It is also consistent with a wider frequency distribution of precipitation [*Lintner et al.*, 2012; *Giorgi et al.*, 2011; *Biasutti*, 2013].

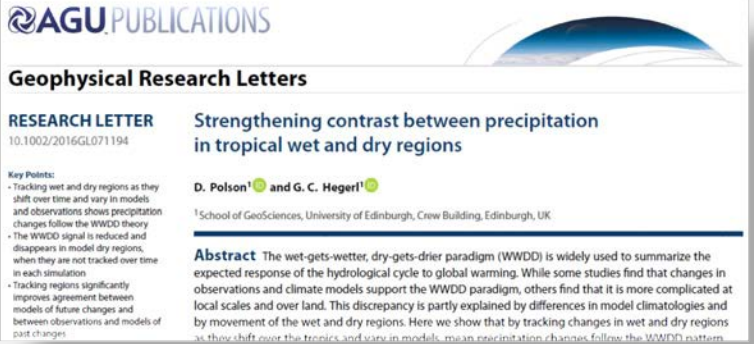
[4] Changes in zonally averaged land precipitation since



AR6 IPCC Chapter 3



Polson and Hegerl, 2017 (GRL)



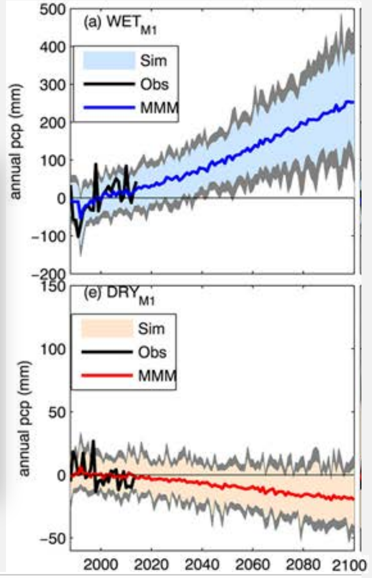
AGU PUBLICATIONS
Geophysical Research Letters
RESEARCH LETTER
10.1002/2016GL071194

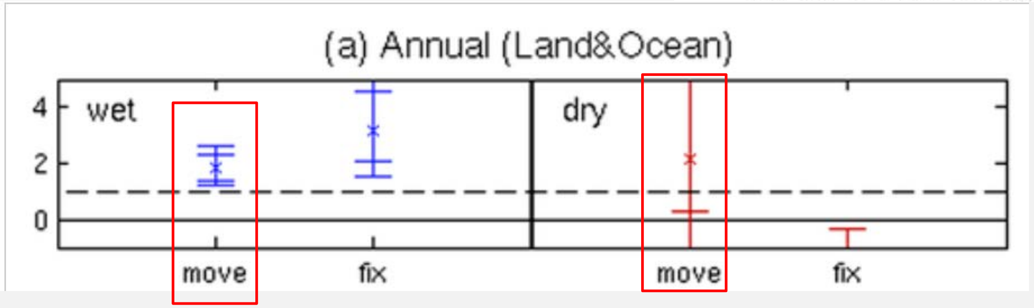
Key Points:
- Tracking wet and dry regions as they shift over time and vary in models and observations shows precipitation changes follow the WWDD theory
- The WWDD signal is reduced and disappears in model dry regions, when they are not tracked over time in each simulation
- Tracking regions significantly improves agreement between models of future changes and between observations and models of past changes

Strengthening contrast between precipitation in tropical wet and dry regions

D. Polson[1] and G. C. Hegerl[1]
[1]School of GeoSciences, University of Edinburgh, Crew Building, Edinburgh, UK

Abstract The wet-gets-wetter, dry-gets-drier paradigm (WWDD) is widely used to summarize the expected response of the hydrological cycle to global warming. While some studies find that changes in observations and climate models support the WWDD paradigm, others find that it is more complicated at local scales and over land. This discrepancy is partly explained by differences in model climatologies and by movement of the wet and dry regions. Here we show that by tracking changes in wet and dry regions as they shift over the tropics and vary in models, mean precipitation changes follow the WWDD pattern





Question

Does this suggest that the simulated increase in the contrast between tropical wet and dry regions is an underestimate?

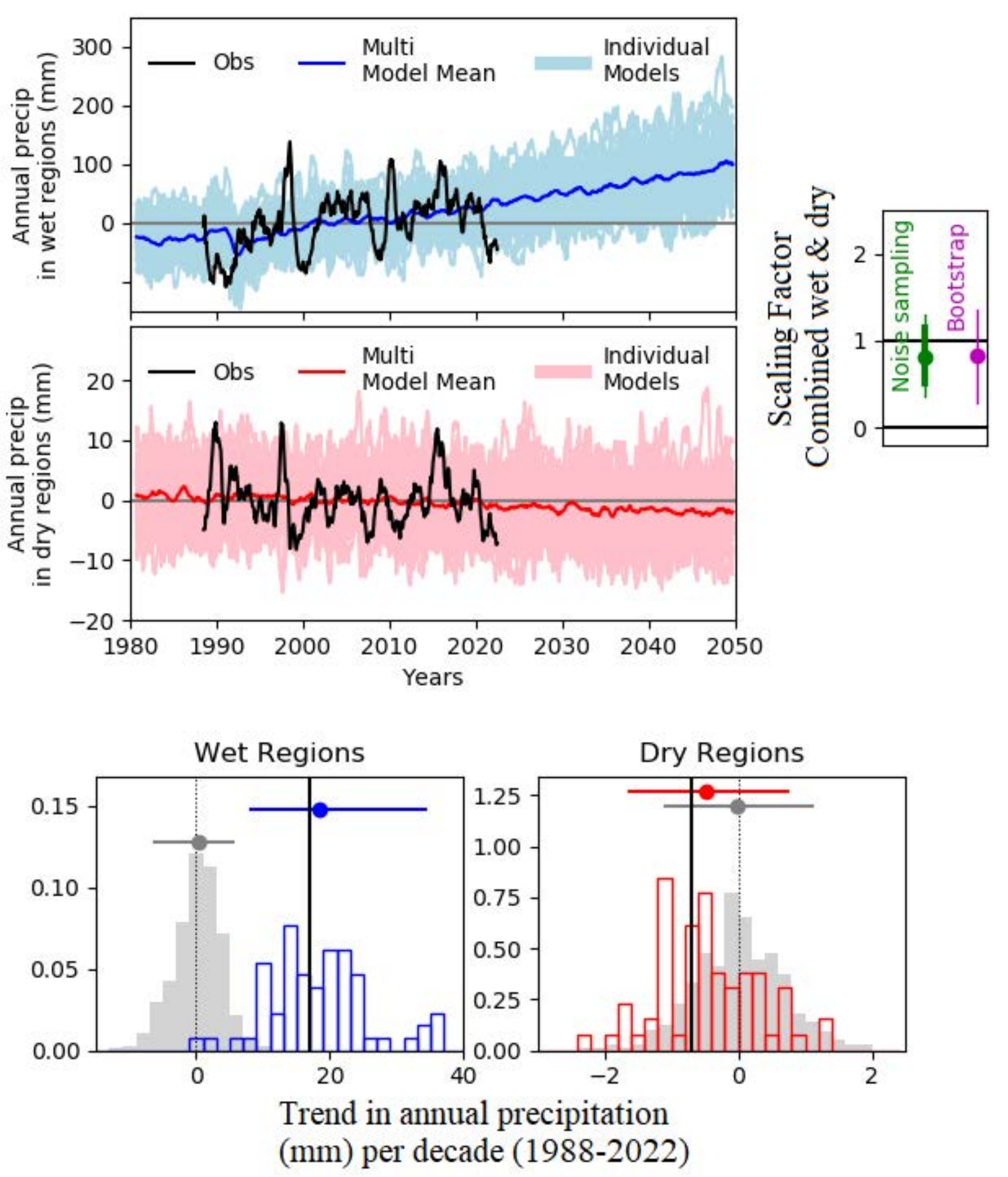
If so this would have large implications for future hydroclimate projections.

UPDATE (2024)

- A new an updated version of GPCP has been released (version 3.2).
- With new data (up to 2023)
- A new algorithm.
- And at a finer resolution (0.5° x 0.5°)

- Have re-run analysis with new data

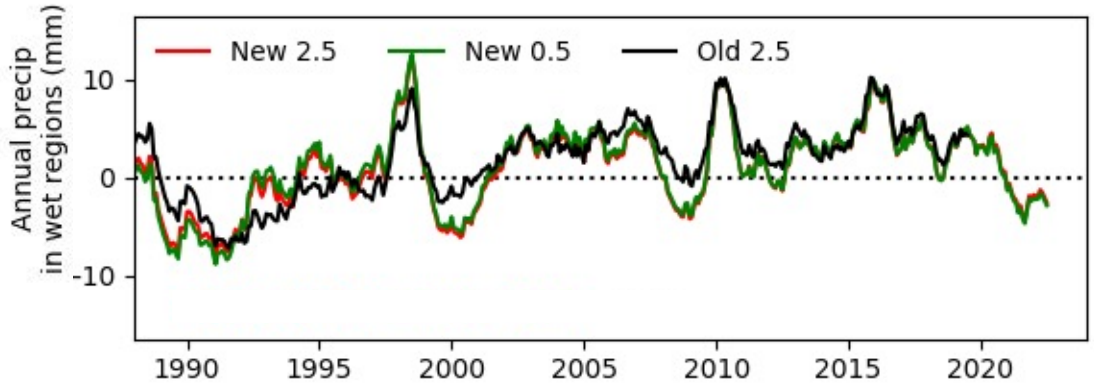
Models are now consistent with observations



UPDATE (2024)

- Change in trend in wet regions comes predominantly from increasing the length of the dataset
- Change in trend in dry regions comes predominately due to the updates introduced into the new GPCP version

WET REGIONS

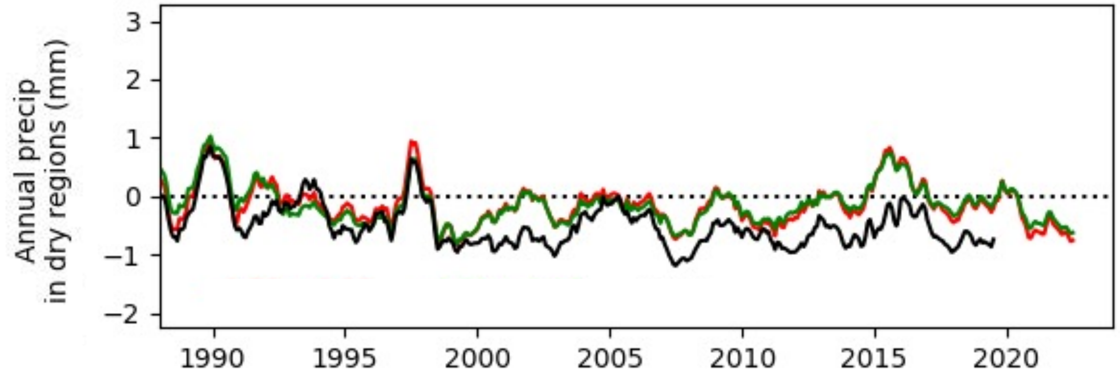


Trend per decade:

1988-2019: *Old* 32.67; *new*$_{2.5}$ 29.78 ; *new*$_{0.5}$ 30.27

1988-2023: *Old* ; *new*$_{2.5}$ 19.41 ; *new*$_{0.5}$ 18.97

DRY REGIONS



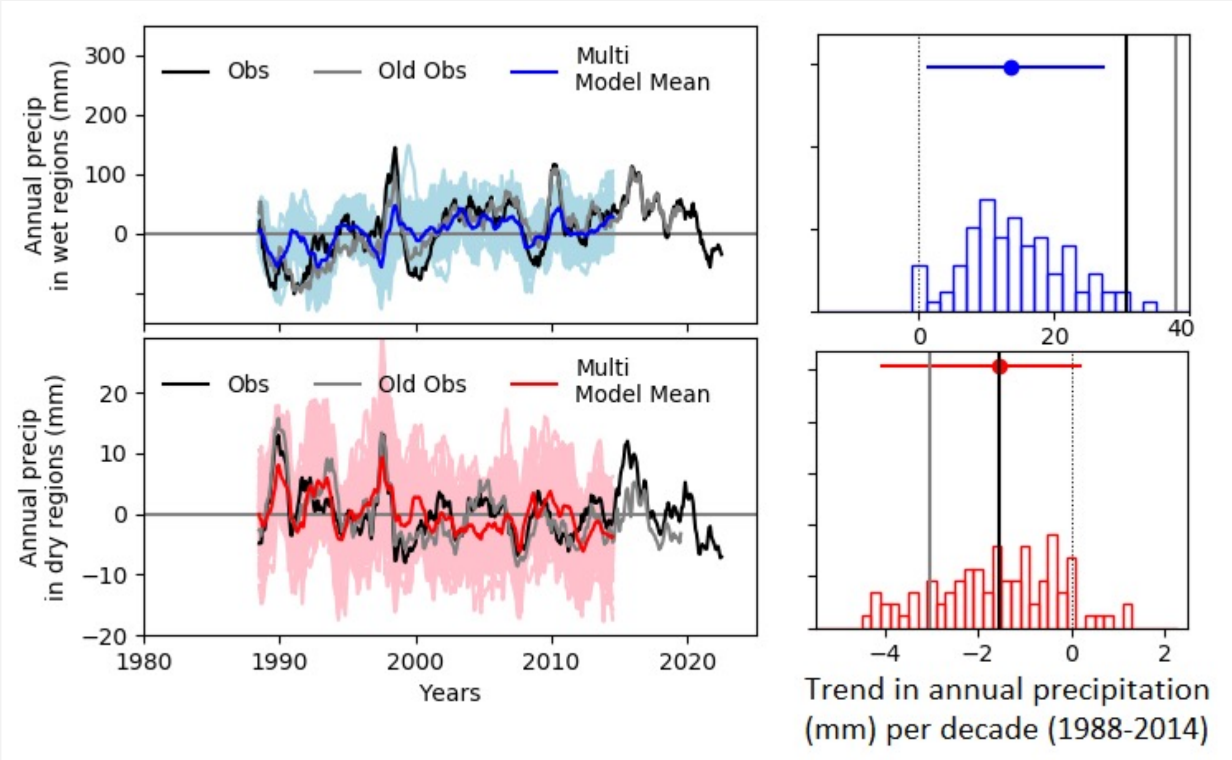
Trend per decade:

1988-2019: *Old* -2.02 ; *new*$_{2.5}$ -0. 23 ; *new*$_{0.5}$ -0.13

1988-2023: *Old* ; *new*$_{2.5}$ -0.78 ; *new*$_{0.5}$ -0.52

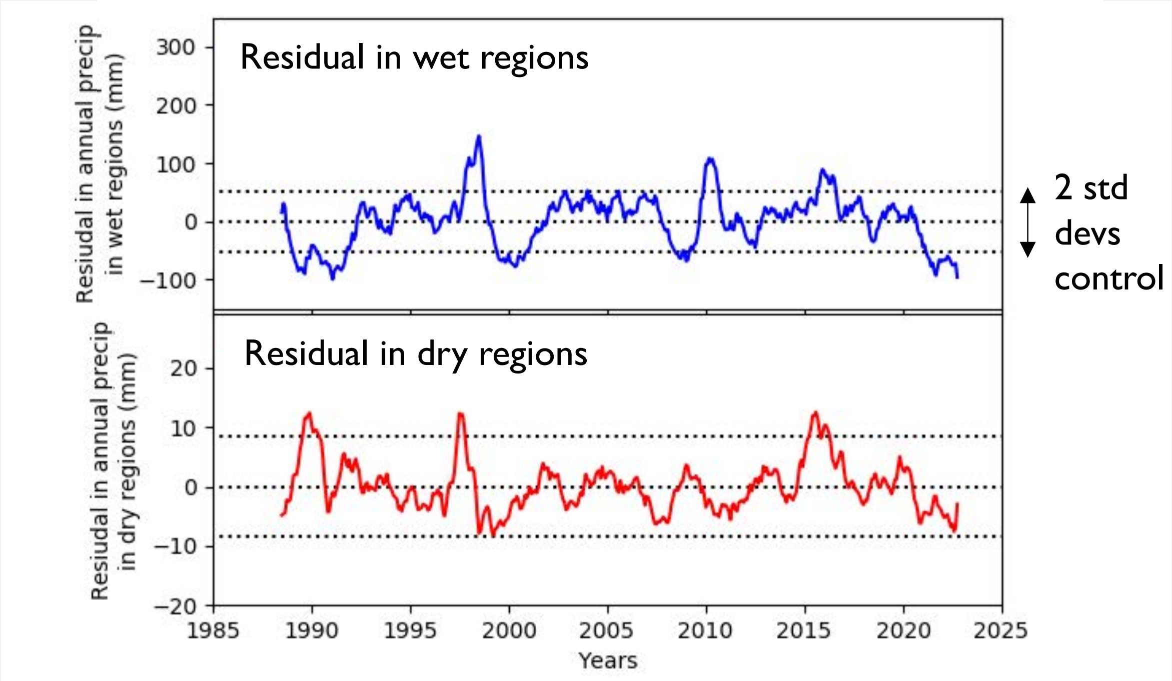
AMIP SIMULATIONS

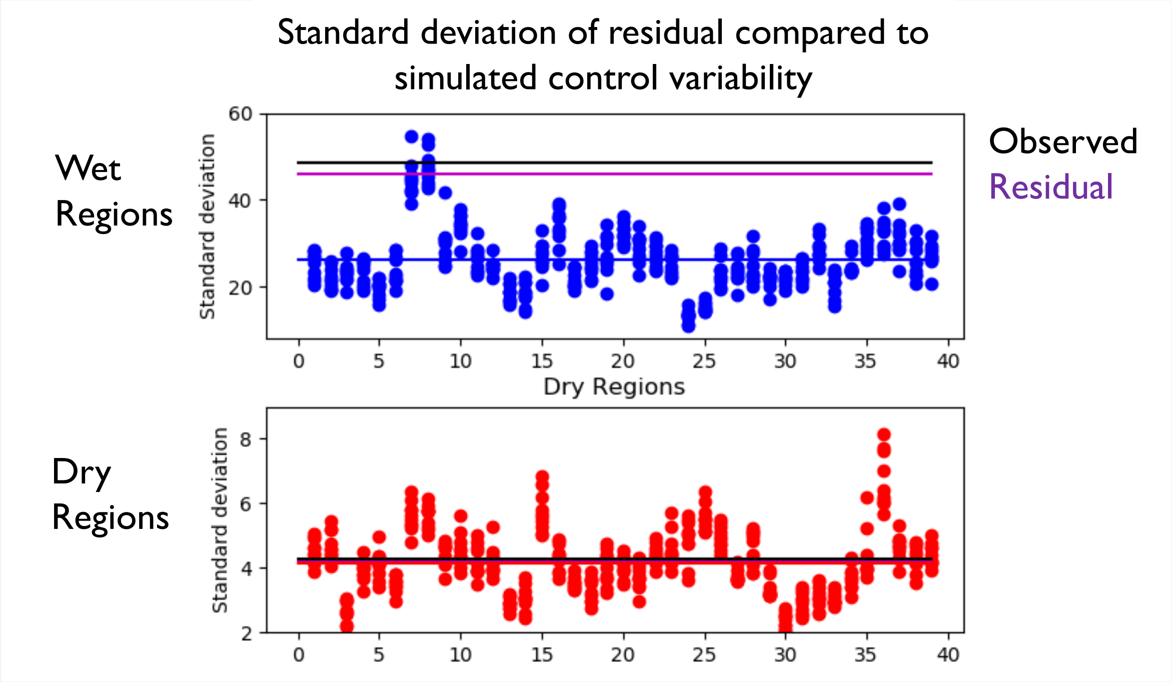
- CMIP6 AMIP simulations (which have SSTs fixed to observations) do a good job of capturing much of variability.



VARIABILITY

- So everything is OK!
- No observed variability is still larger than simulated in wet region in nearly all models
- And this is only a simple metric – the actual details are far more complex.
- More work needed….





SUMMARY

- Analysed monthly rainfall over the tropical (30°S-30°N) region
- Defined regions as wet and dry depending on amount of rainfall in any given month
- Model projections show a robust pattern of wettest third getting wetter driest two thirds getting dryer
- Observations (GPCP) of the last 35 years shows same pattern
- This signal is clearly detectable, and the magnitude is now consistent with the observations.
- Can be attributed to anthropogenic forcing.