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MIAMI

Recent tropical Atlantic Multidecadal Climate Variability is mostly driven by external forcings

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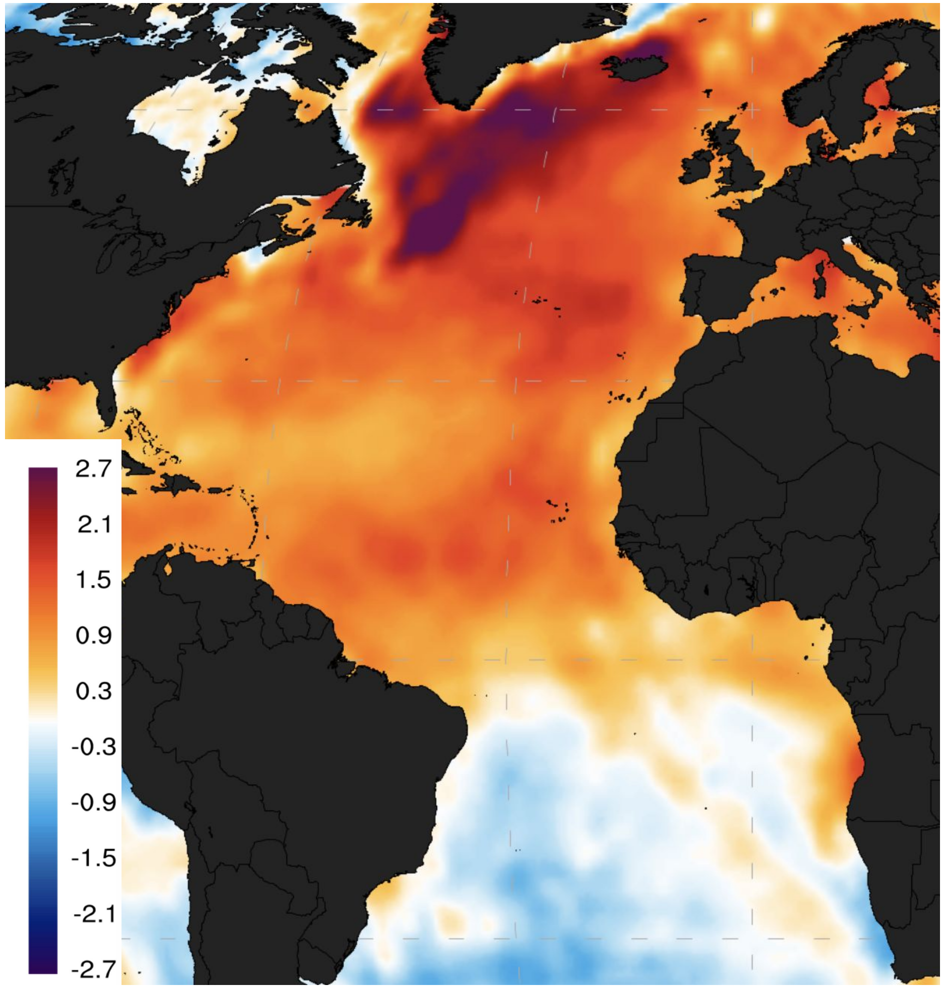
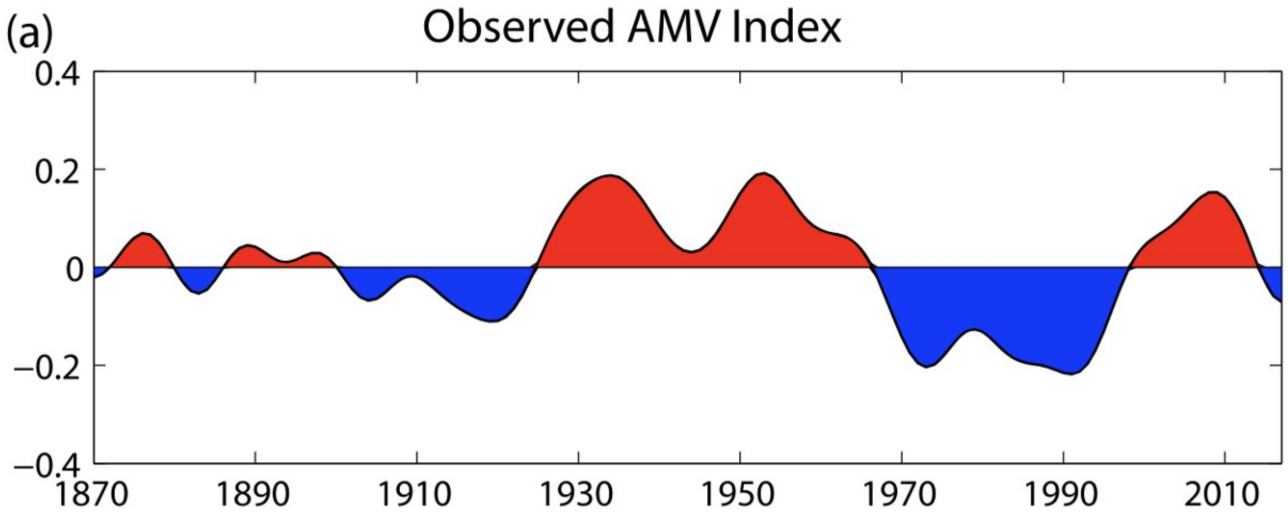
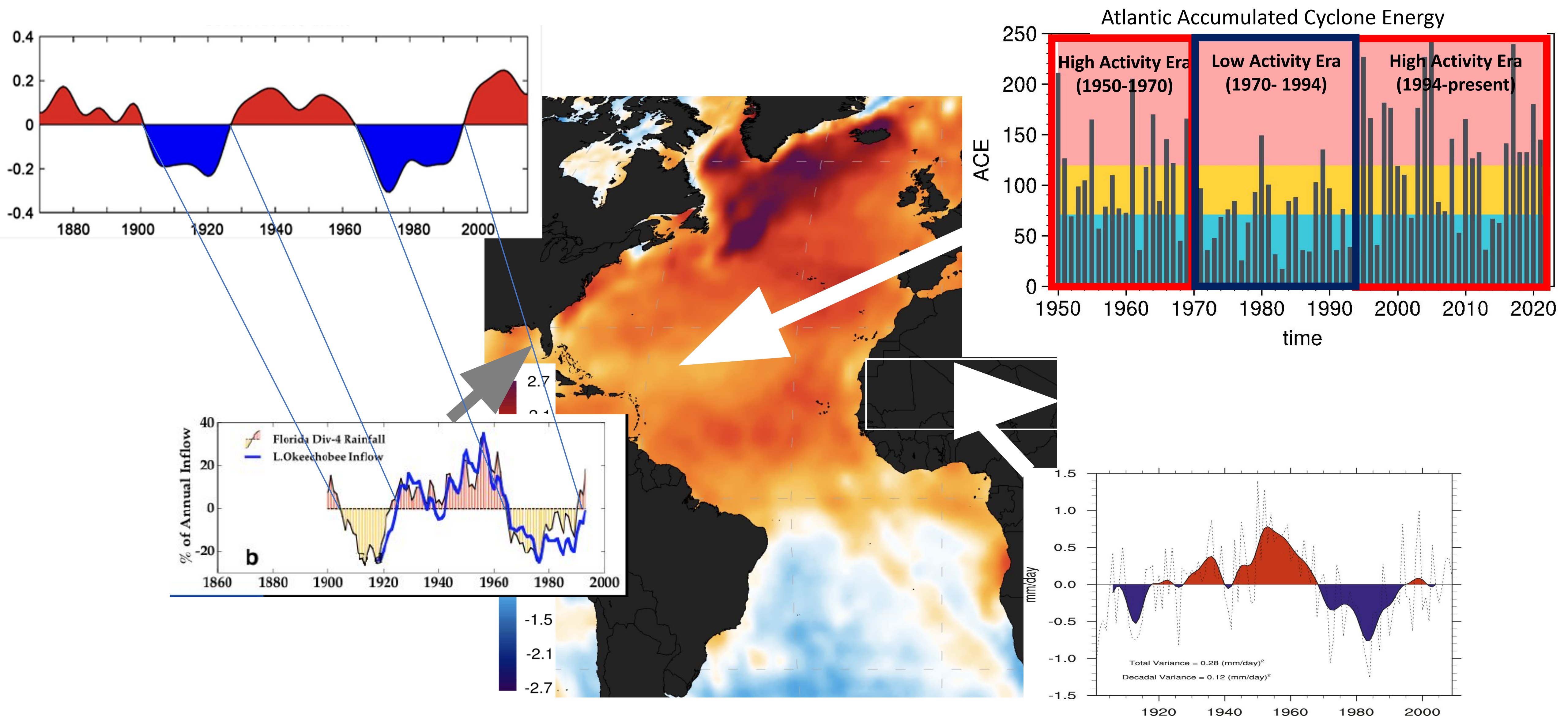
He et al. 2023. Recent tropical Atlantic Multidecadal Climate Variability is mostly driven by external forcings, under revision. Preprint: https://www.researchsquare.com/article/rs-2561784/v1

Atlantic Multidecadal Variability (AMV) is SST fluctuation over multidecadal time scale

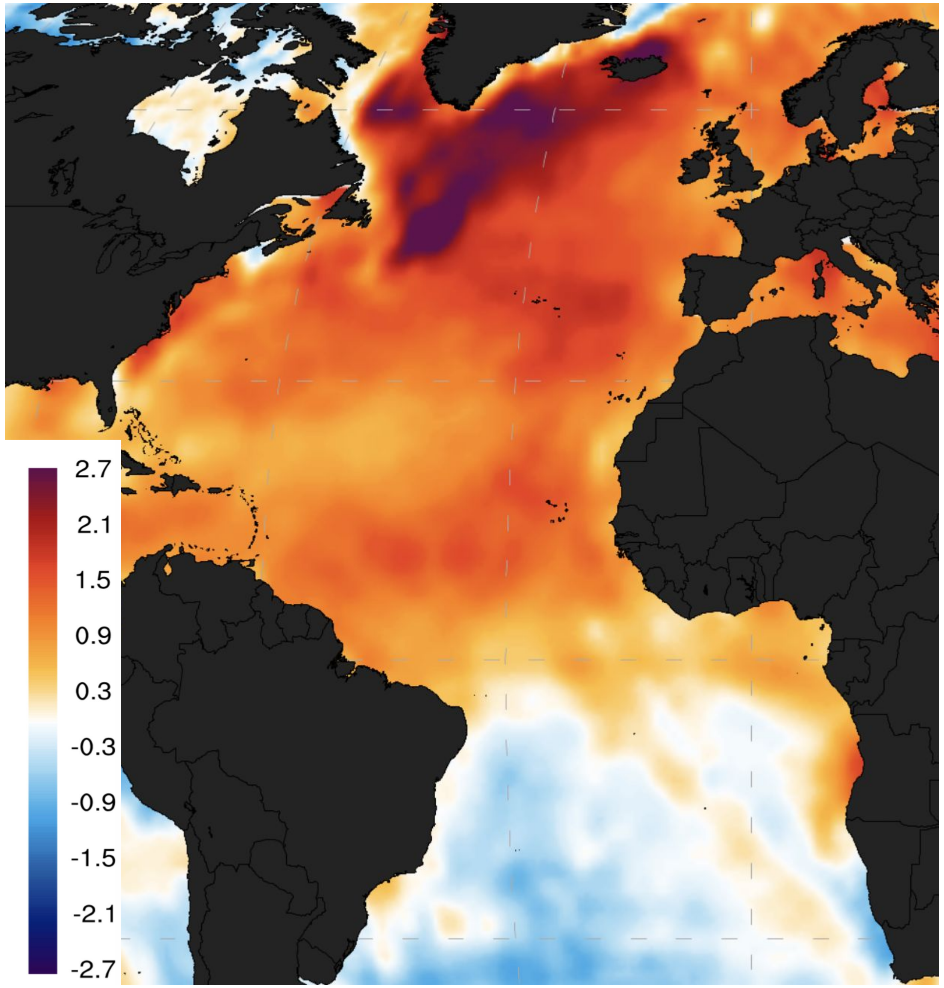




Tightly coupled tropical Atlantic Multidecadal Climate Variability(AMCV)



The cause of the AMCV is controversial



Internal dynamics

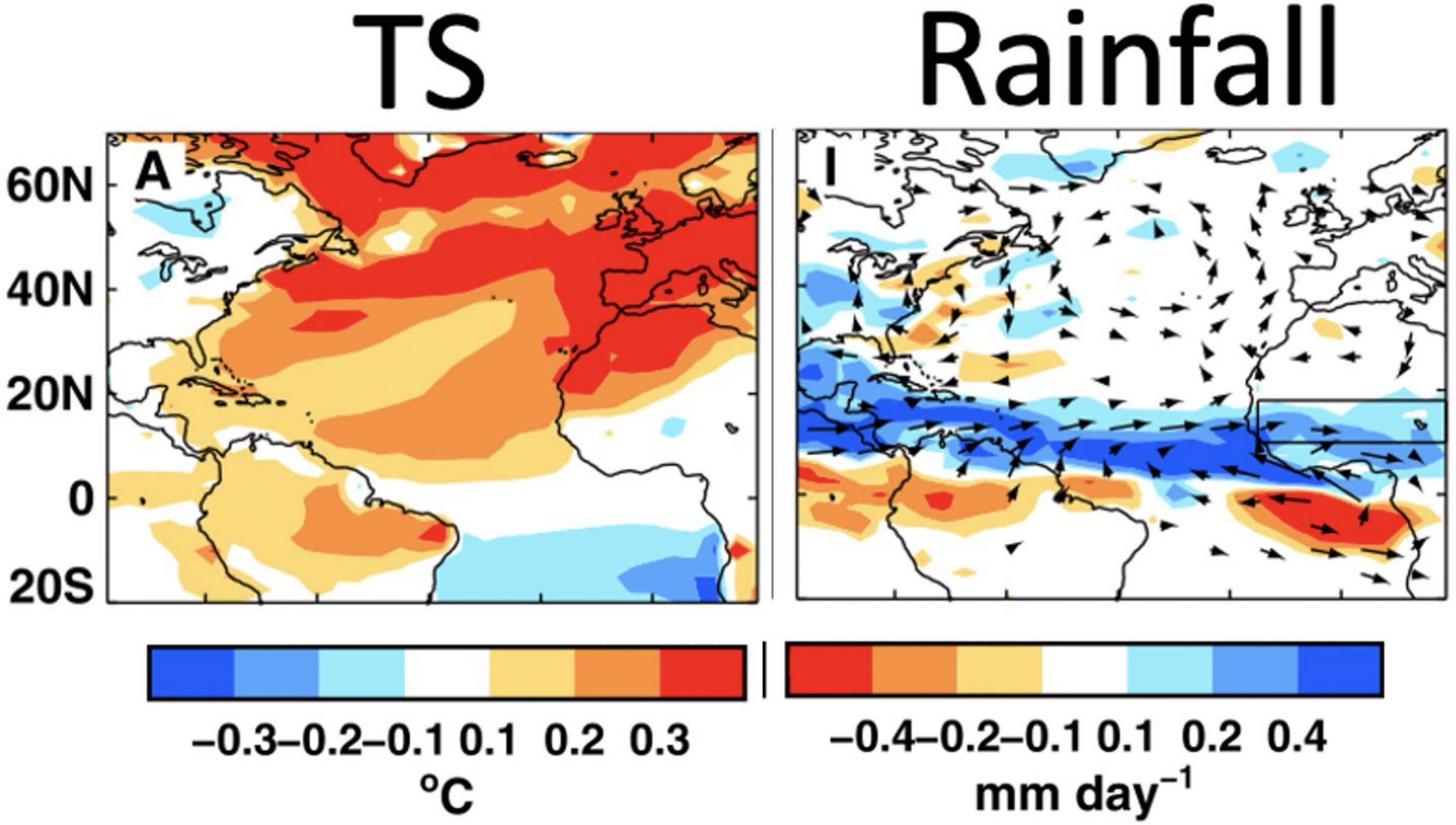
- AMOC (e.g., Zhang et al. 2019, Yan et al. 2017)
- NAO (e.g., Clement et al. 2015)

External forcings

- Anthropogenic Aerosols (e.g., Booth et al. 2012, Dunstone et al. 2013)
- Volcanic eruptions (e.g., Birkel et al. 2018, Otterå et al. 2010)

Motivation: What is the cause of the recent AMCV?

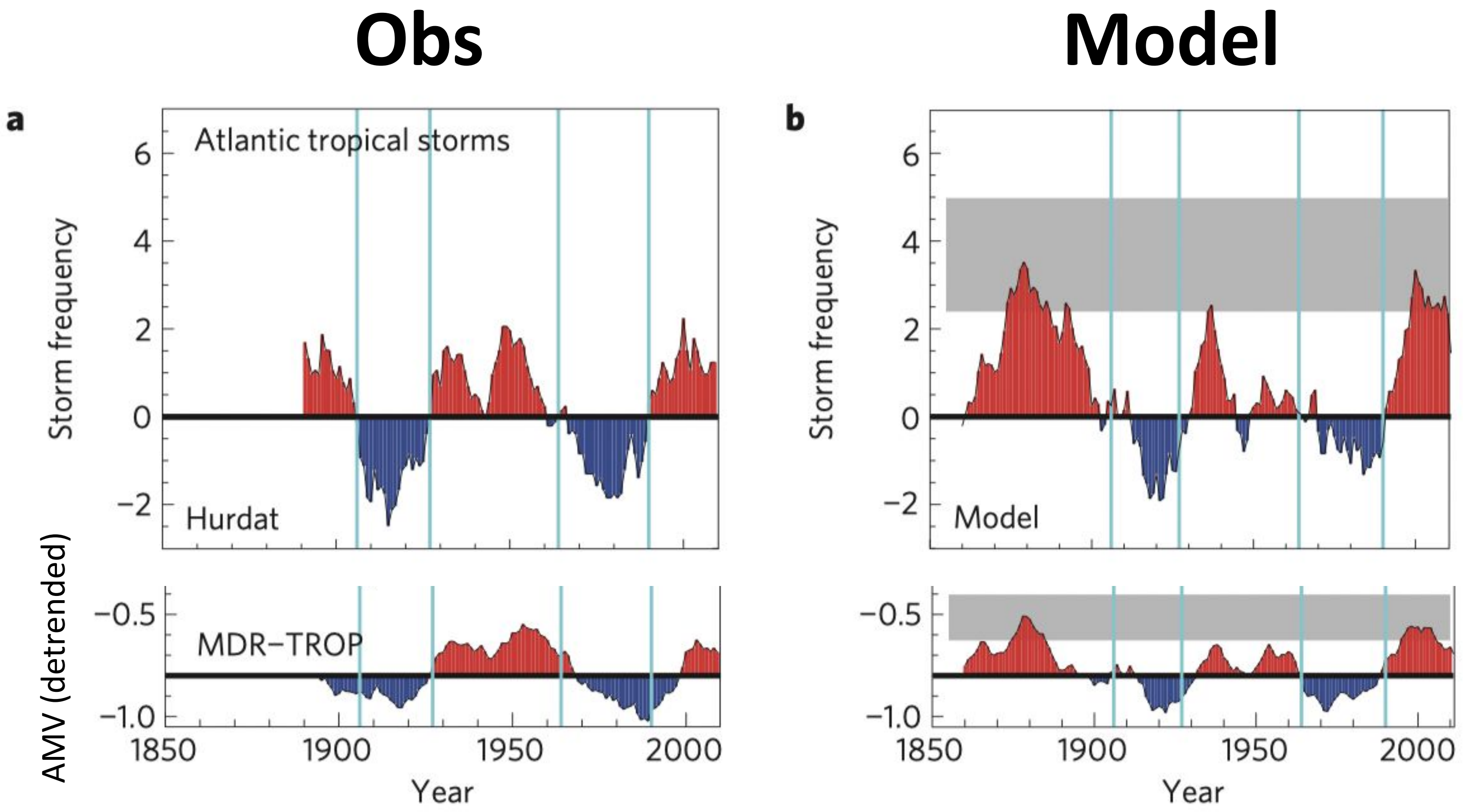
Internal variability shows some covariabilities in AMCV, but not close to those in the observation



- r<AMV, SPR> = 0.21 in model, 0.83 in OBS
- r<AMV, VWS> = -0.41/-0.5 in model, -0.81 in OBS

Knight et al. 2006;
Yan et al. 2017

External forcing improves the covariability in AMCV but only shows in a subset of models

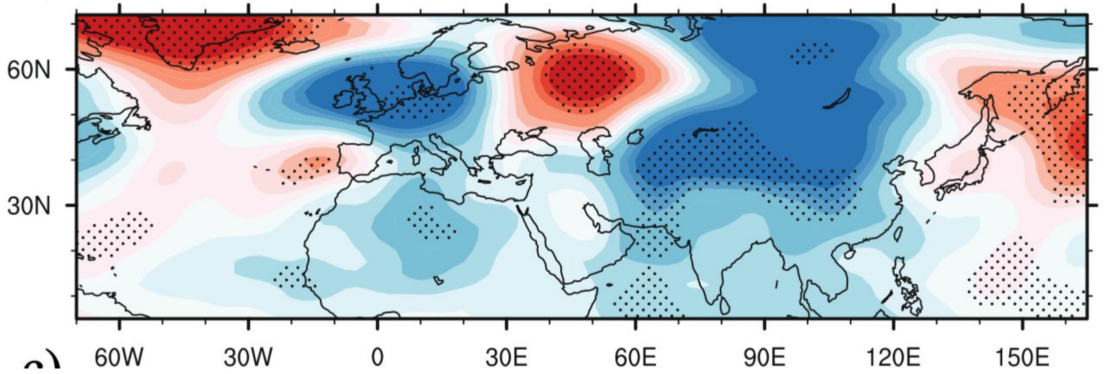


- Mostly in Hadley center models;
- The aerosol forcing is too large? (e.g., Zhang et al. 2013)

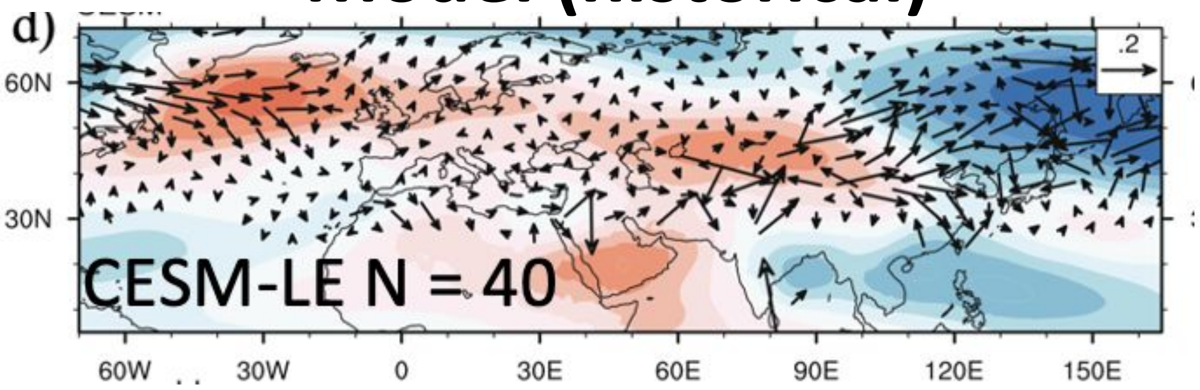
Dunstone et al. 2013;
Booth et al. 2012

External forcing and internal variability cannot explain the AMCV teleconnection

Obs



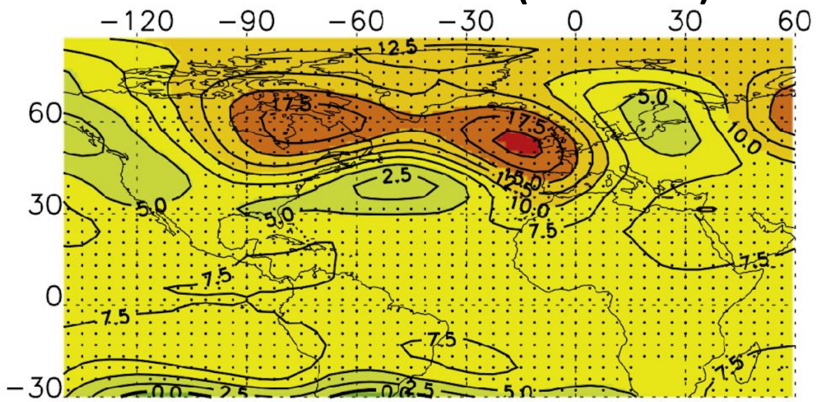
Model (historical)



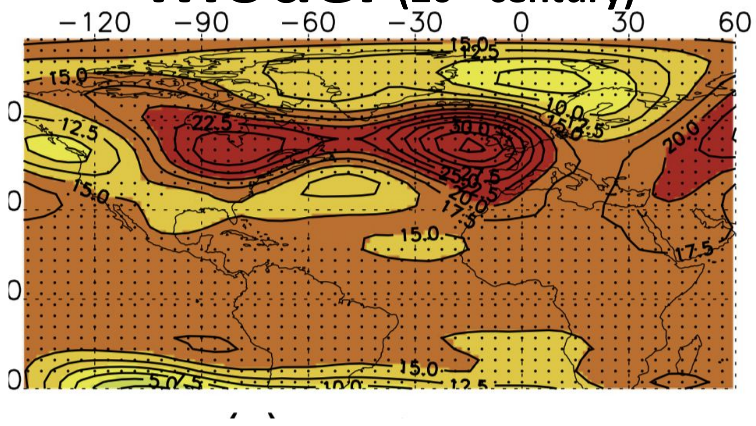
Regression of Z500 onto AMV

CMIP3

Model **(PI control)**



Model **(20th century)**



Si et al. 2022;
Ting et al. 2014

Method

CMIP6

- Historical simulation: 46 models (in total 402 ensemble members)
- Pi Control simulation: ~31 models (r1p1i1l1) to quantify internal variability
- DAMIP, each single-forcing run has 70~100 members to quantify externally forced response

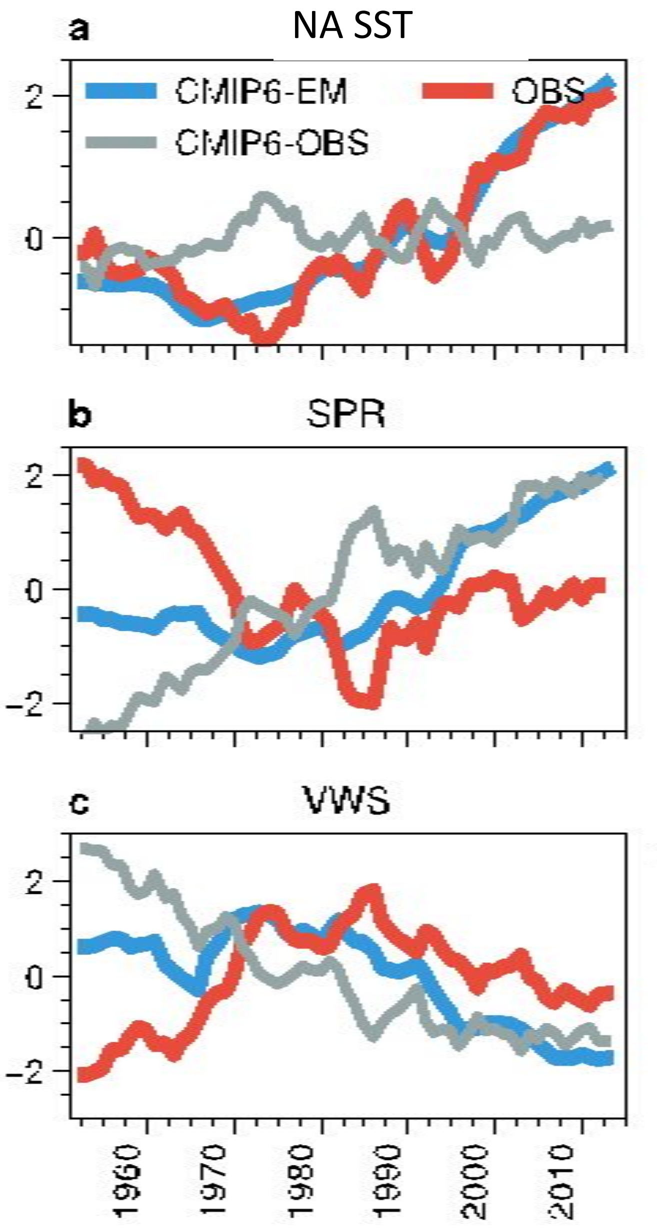
Observation

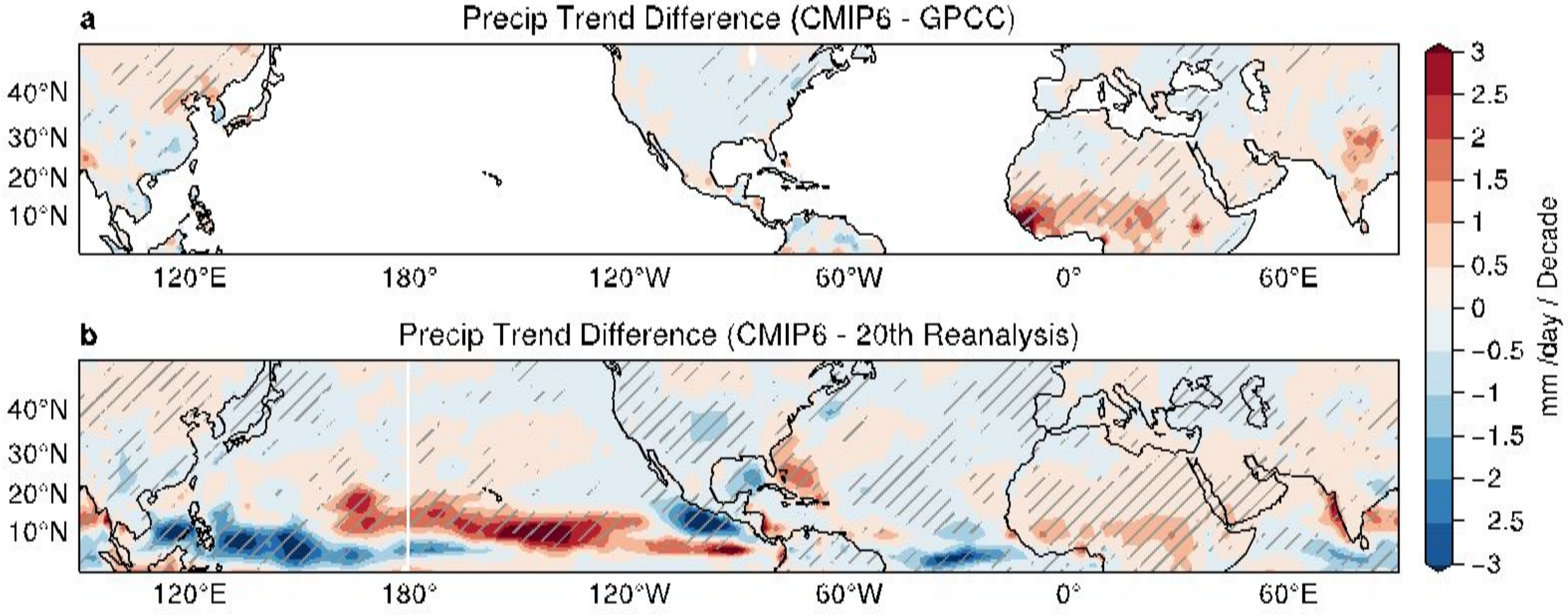
- VWS: NCEP reanalysis1, 20th reanalysis
- Sahel Rainfall: GPCC, CRU, UDEL
- SST: ERSSTv5, HadISST, COBE SST2

Time period

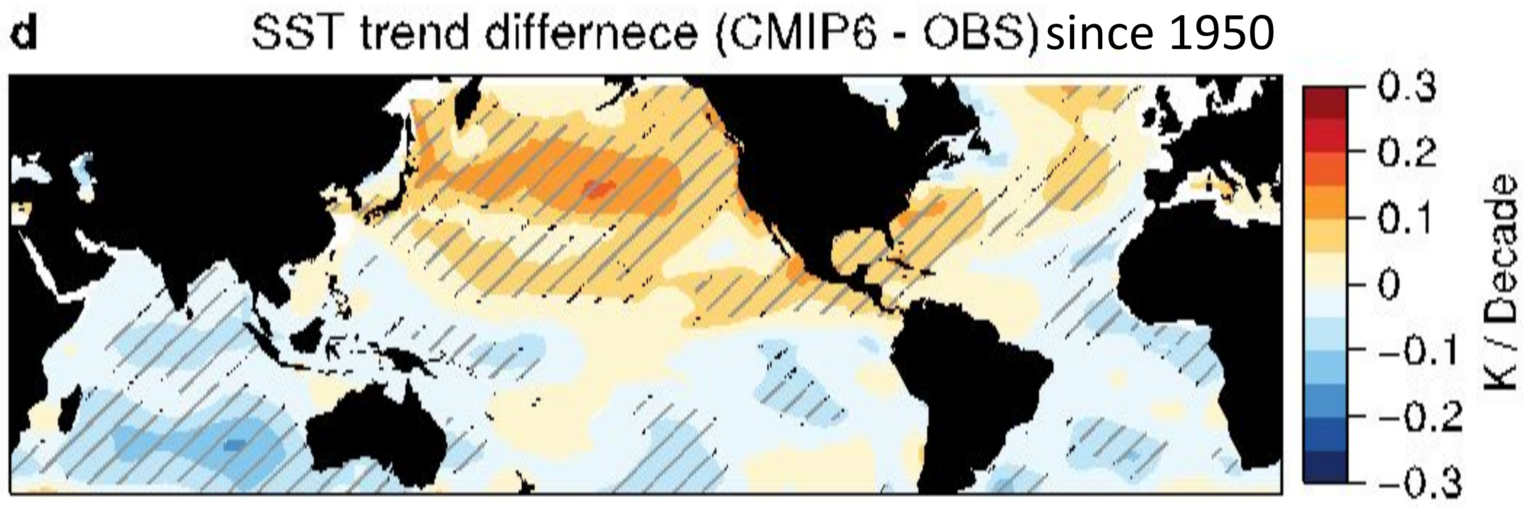
- 1950-2014, when reliable OBS are available for Hurricanes and Sahel Rainfall
- All data here are Jun-Oct (JJASO) as we focus on summer impacts

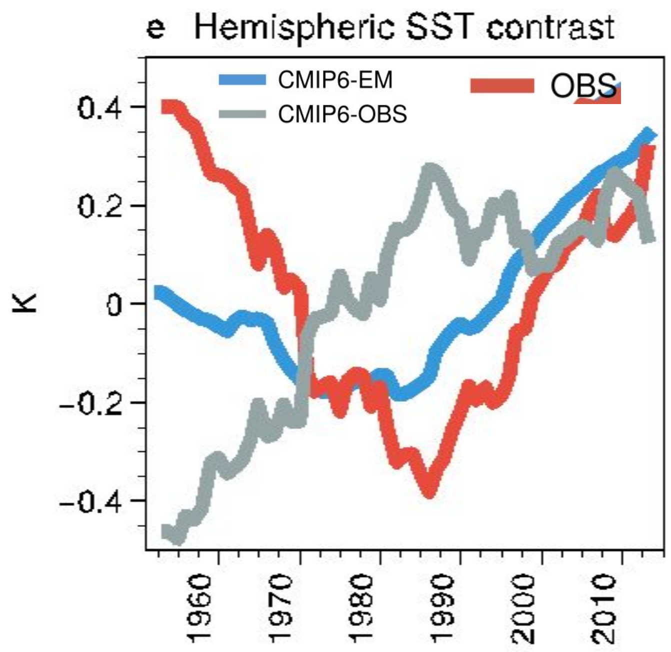
A spurious trend in tropical climate in CMIP6 models since 1950





The spurious trend is due to model-data difference in Hemispheric SST contrast (HSSTC)



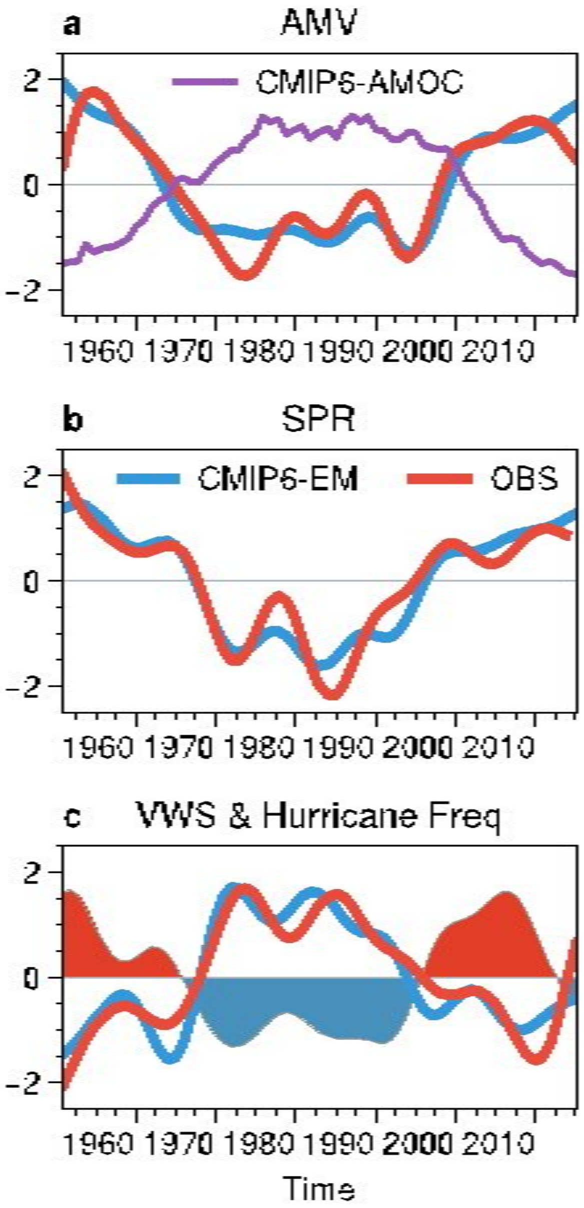


More than 80% variance in real world AMCV is forced.

AMV

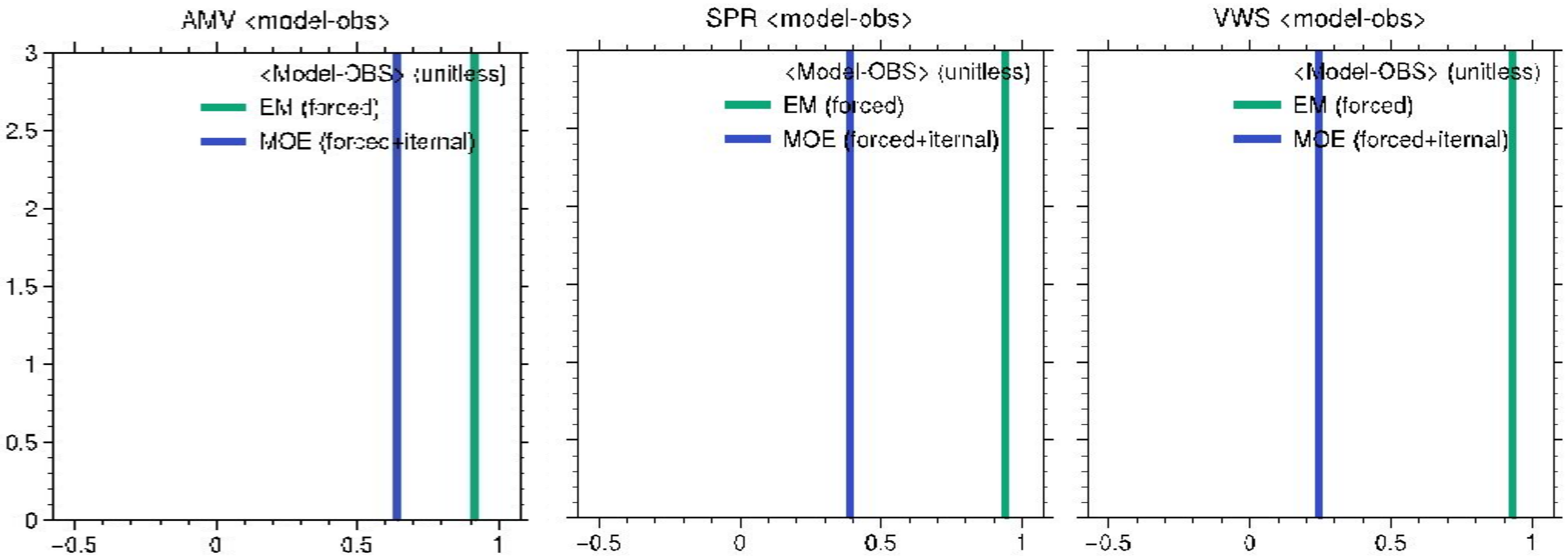
Sahel rainfall

Vertical wind shear



- Detrended, lowpass filtered and normalized
- Modeled AMV, SPR, and VWS are highly correlated with OBS, r>0.9
- More than 80% variance is forced

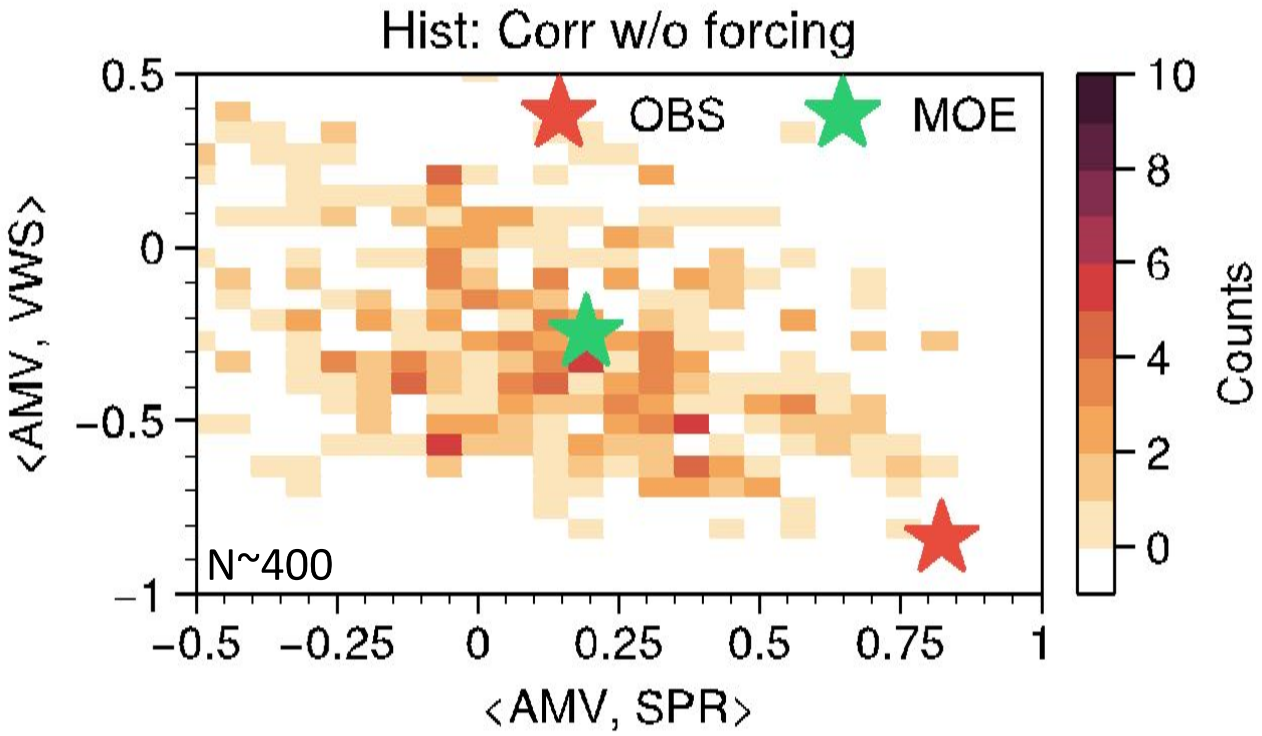
Correlation between simulation and obs supports a forced AMCV since 1950, but cannot rule out the role of internal variability



Correlation between model and obs

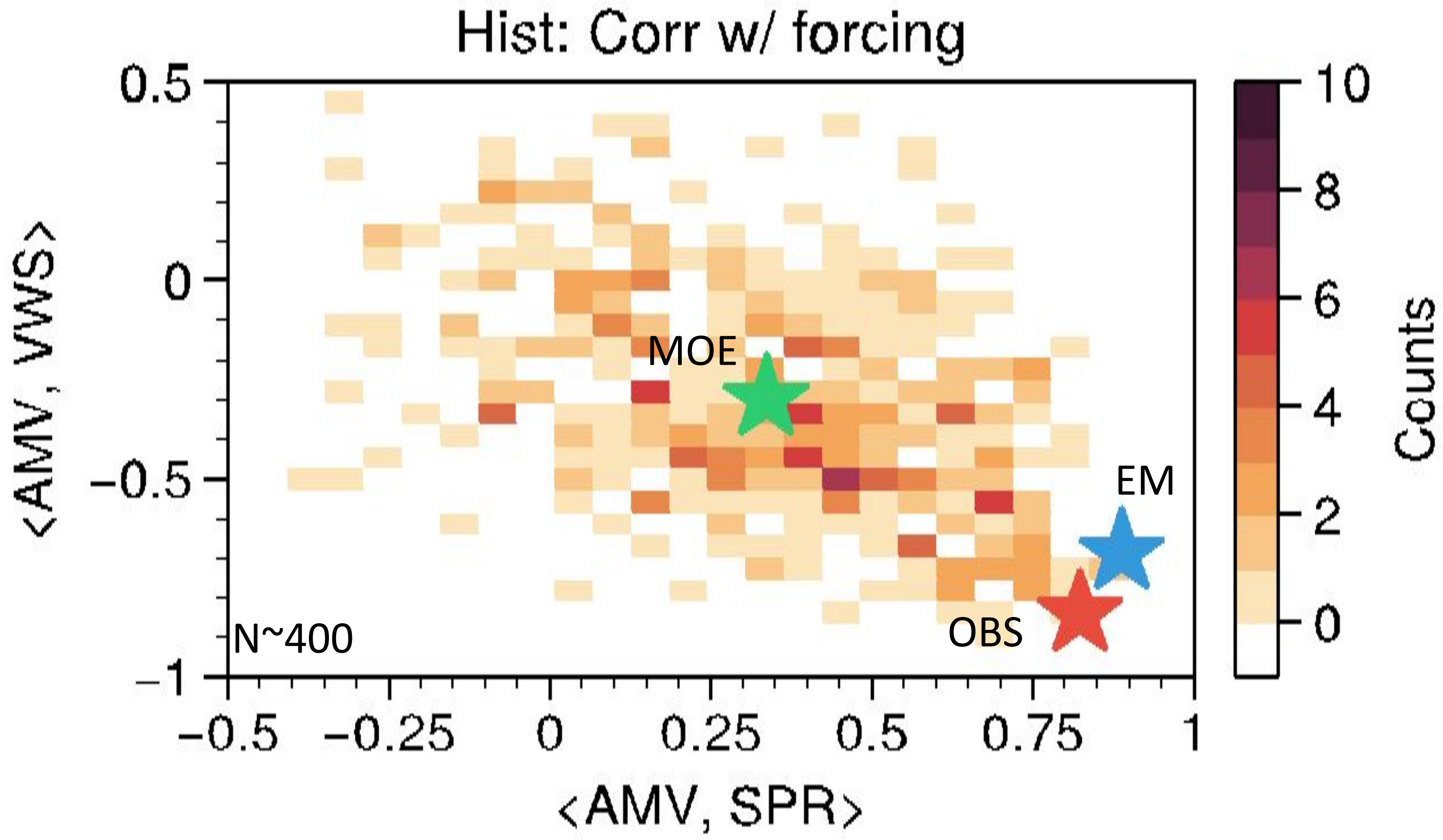
But this doesn’t rule out the possibility the internal variability may also … at the same time.

Internal Variability alone cannot produce the real world AMCV

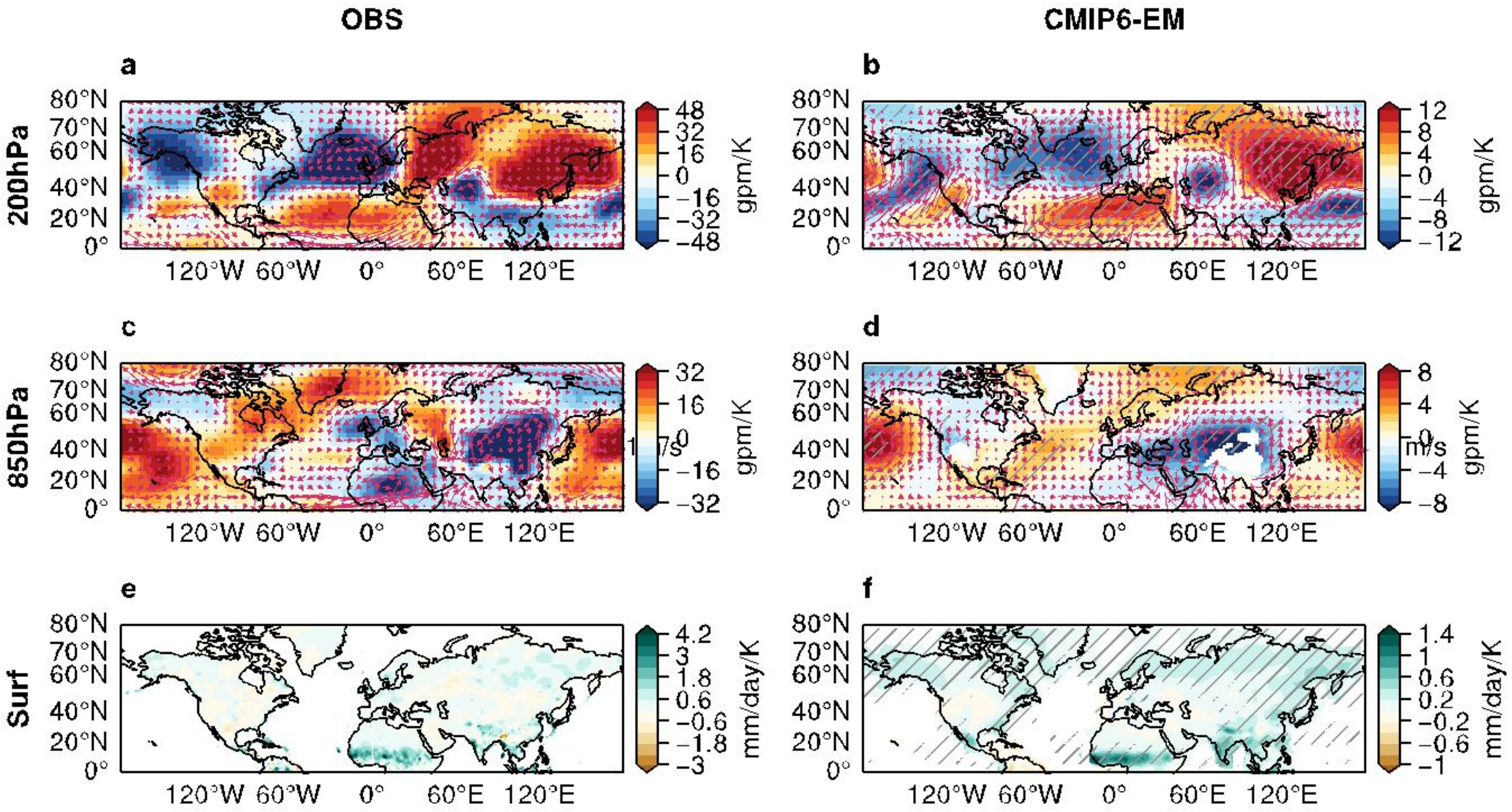


- If the observed tropical AMCV could arise due to internal variability alone, the statistics of the AMCV system must be similar in both model and observation.
- One statistics: **covariability in AMCV**
- 0 out of 400 in historical run

The high covariability in real world post-1950 AMCV only emerges in forced response

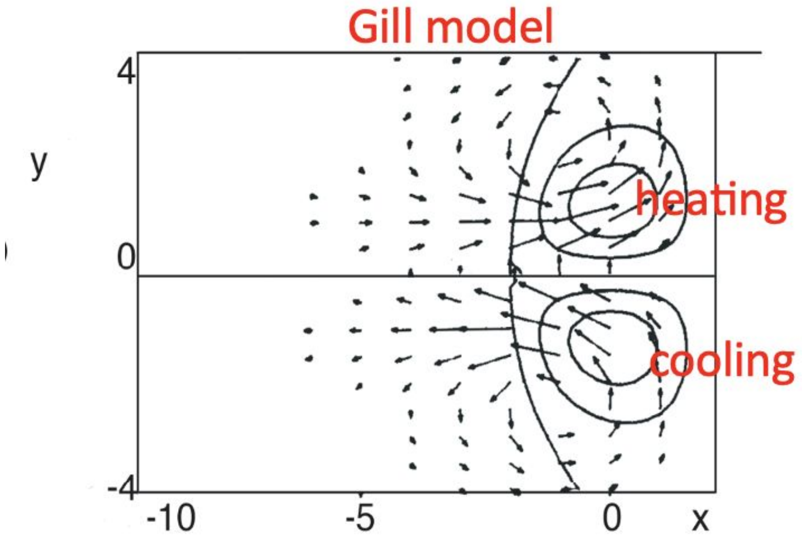


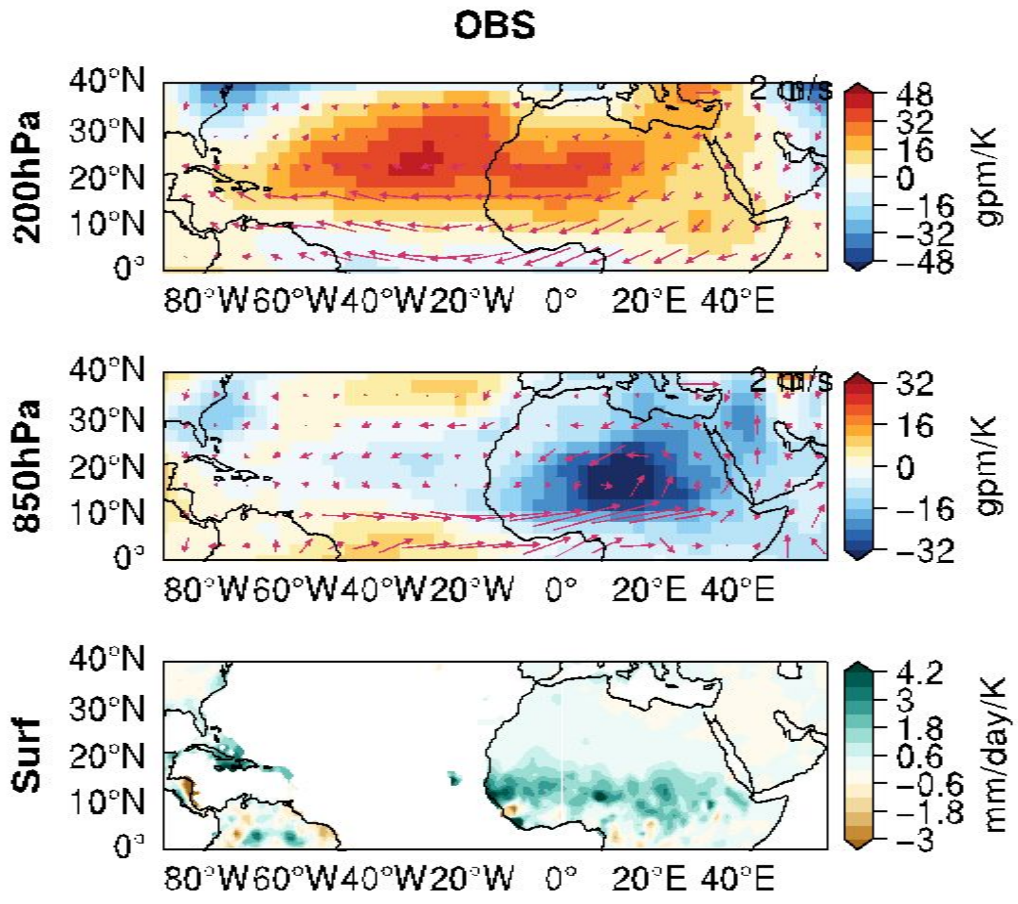
AMCV-related teleconnection is also consistent in model and OBS



- Regressing circulation and rainfall on AMV

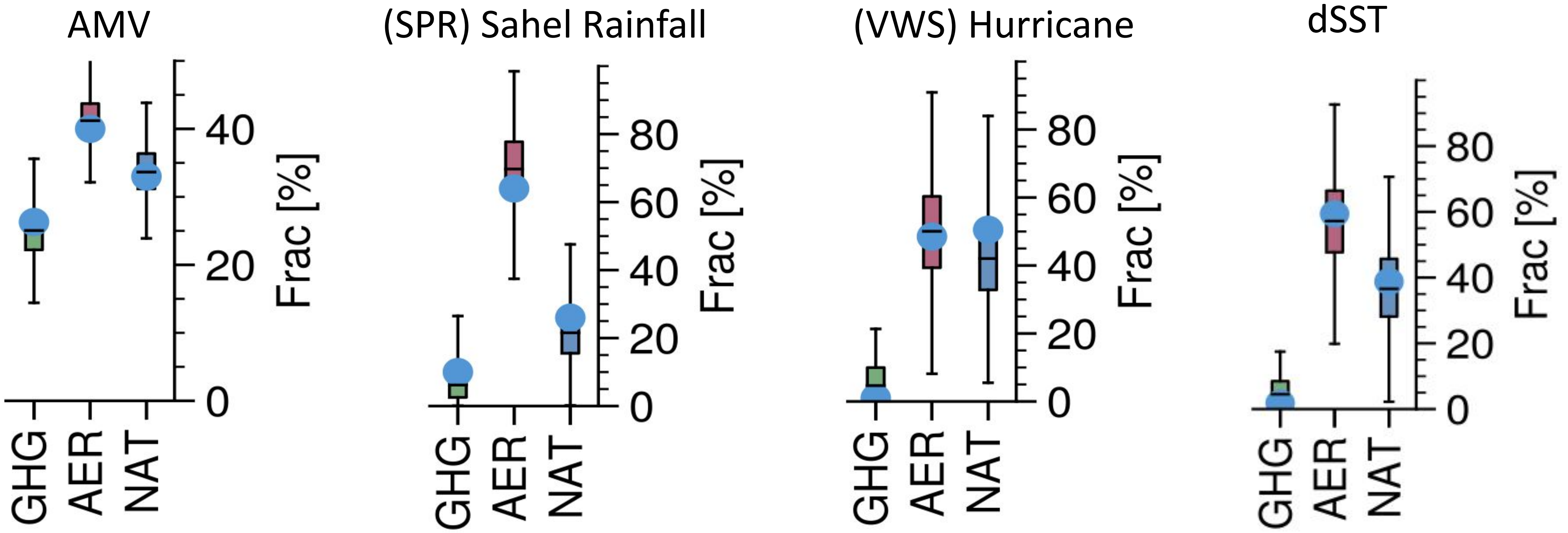
Sahel rainfall and NA hurricanes driven by tropical Atlantic SST contrast (dSST)



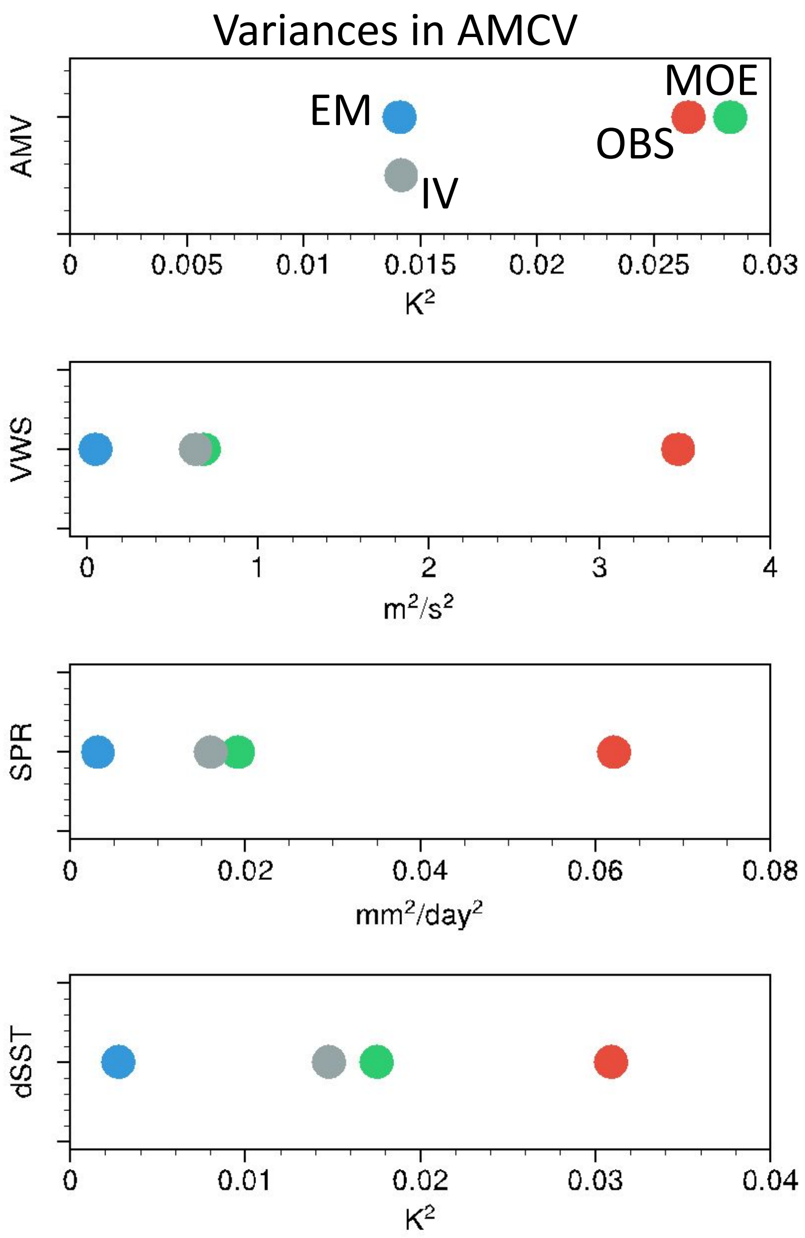


- Asymmetric heating in the tropics
- dSST could be an index of AMV for tropical impacts

Most of the multidecadal variability in the ensemble mean comes from AER and NAT, and dSST is a better metric for tropical impacts



Variance of AMCV shows signal to noise paradox

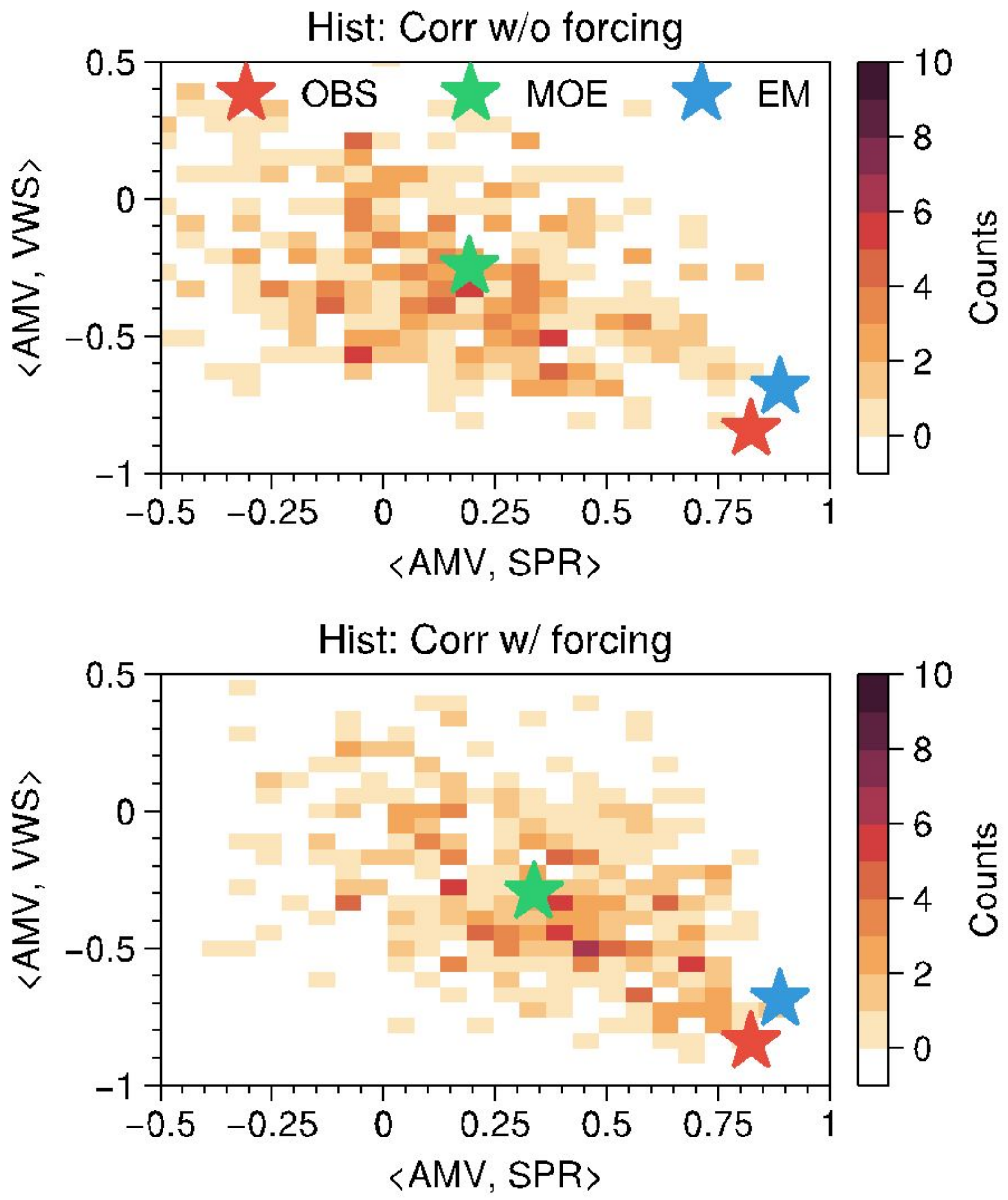


In CMIP6:
MOE = EM (signal) + IV(noise)
EM/IV = 1

In OBS:
OBS is mostly forced, as EM and OBS are highly correlated
EM/IV >> 1

In CMIP6	In OBS
EM/IV << 1	EM/IV >> 1
EM/IV << 1	EM/IV >> 1
EM/IV << 1	EM/IV >> 1

Signal to noise paradox in the post-1950 AMCV



- Single model realization is dominated by internal variability (noise)
- Single real-world realization (OBS) is dominated by forced response (signal)
- Signal to noise paradox (Scaife and Smith 2018)

Take home message

1. The tropical AMCV is driven by external forcings, NAT and AER.

2. Tropical Atlantic SST contrast (dSST) is a better metric to explain the tropical impacts via Gill-Type response.

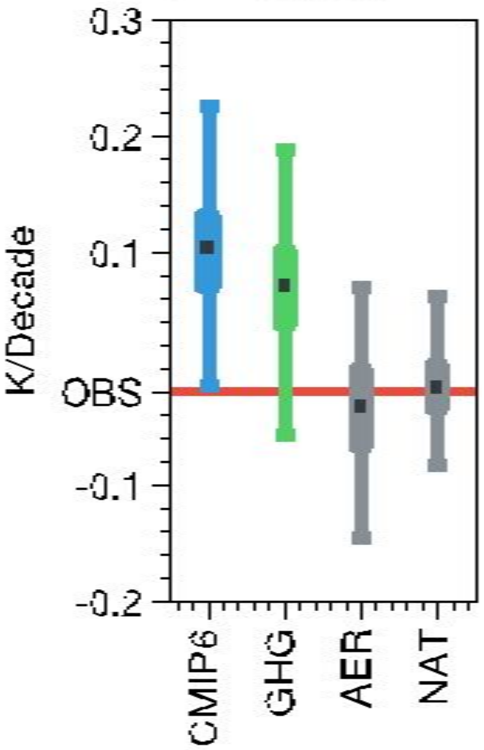
3. Implication: Hurricanes and Sahel rainfall are more predictable than previously thought

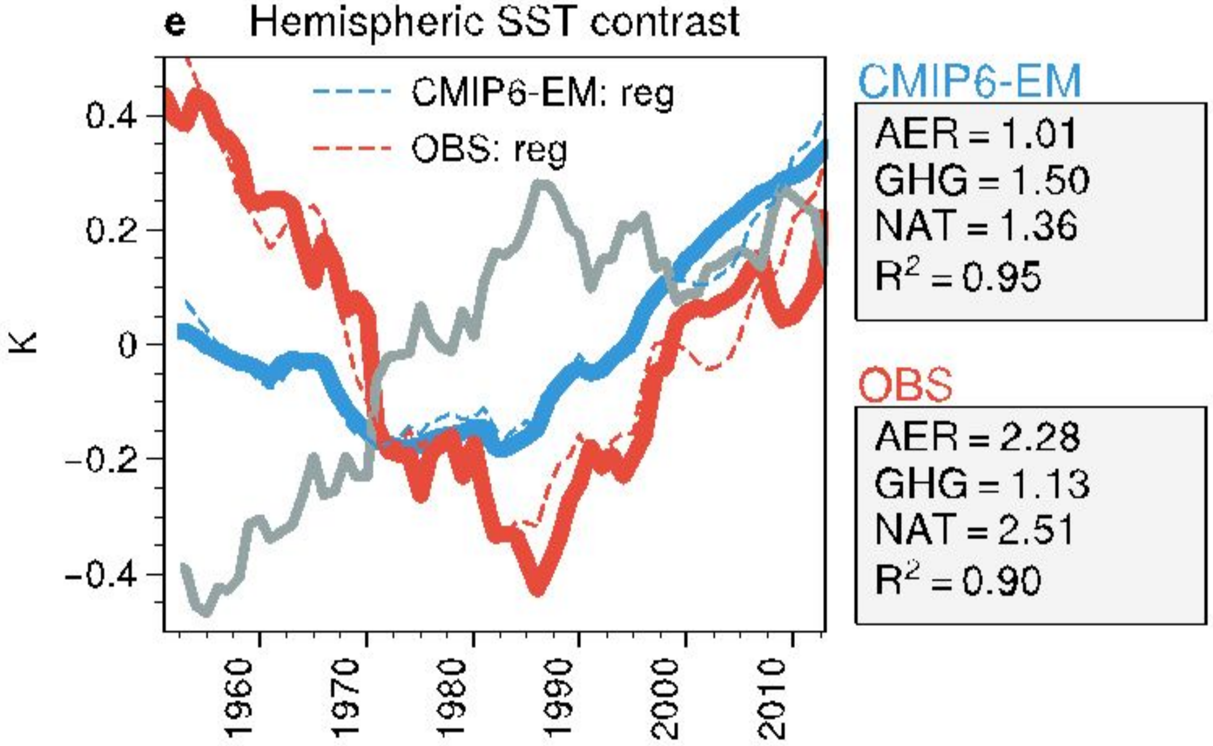
4. Open question: why is the signal-to-noise ratio so low in the model?

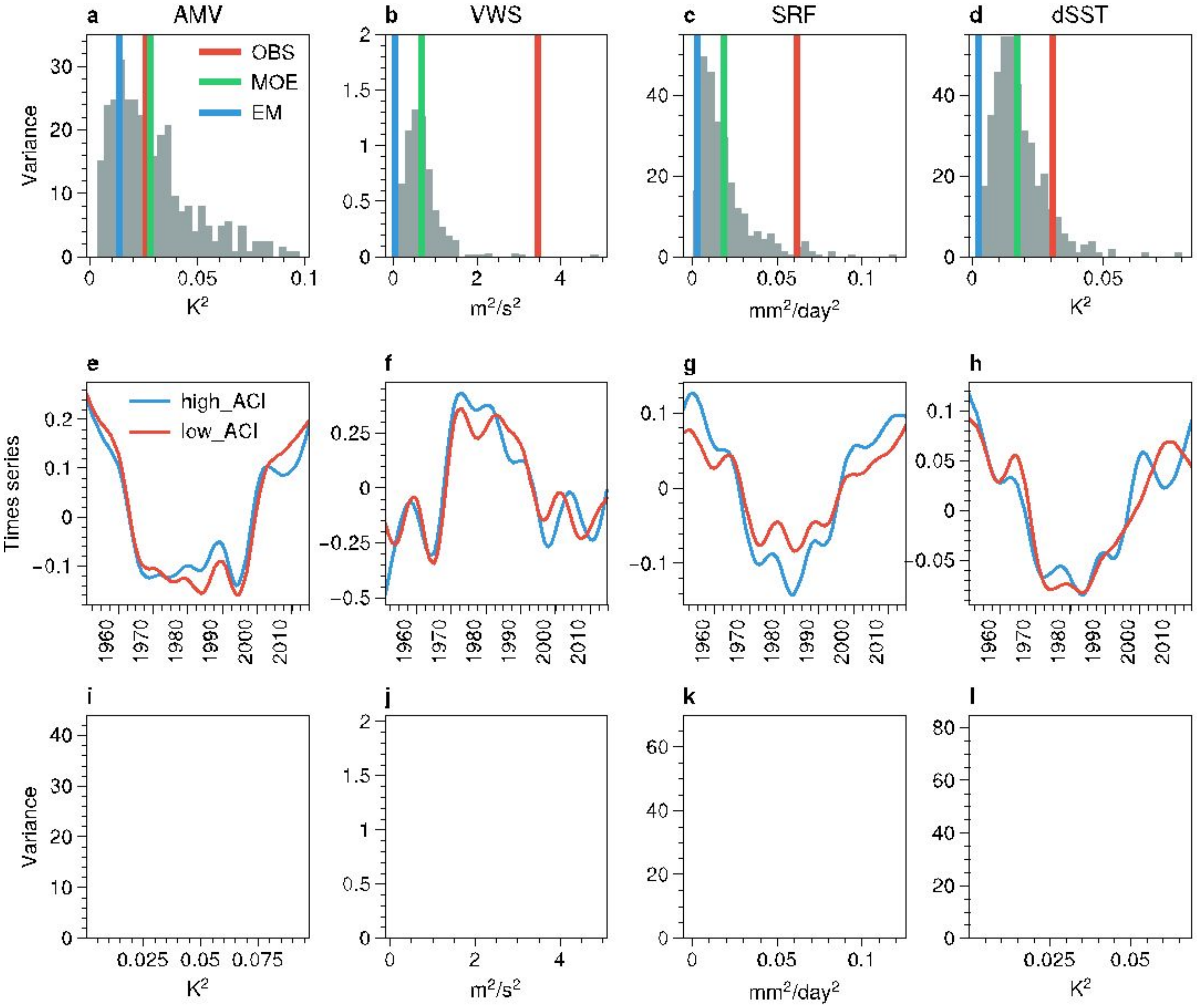
backup

CMIP6 model overestimates the GHG impacts, but underestimates the AER and NAT impacts, leading to HSSTC difference.

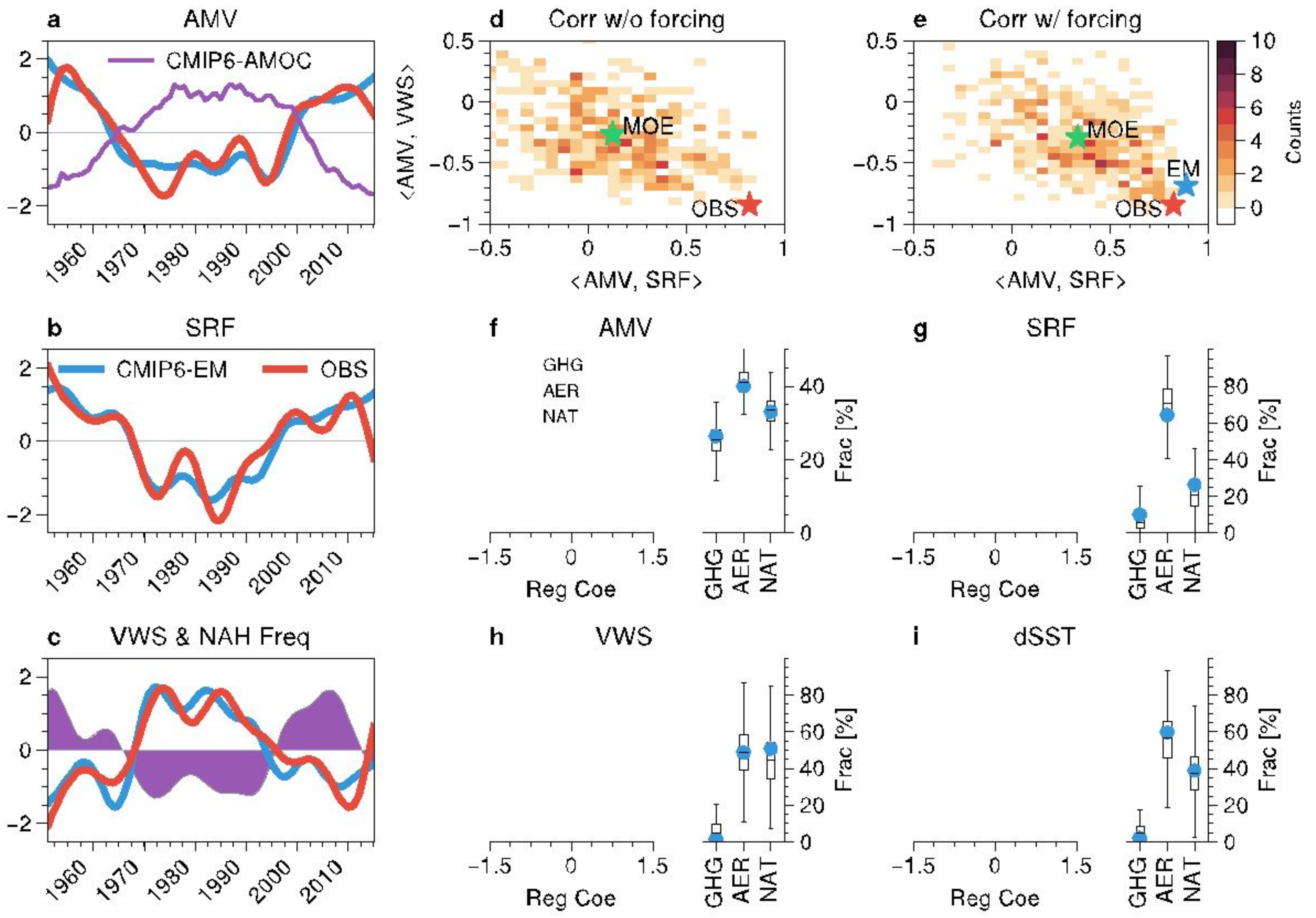
HSSTC trend



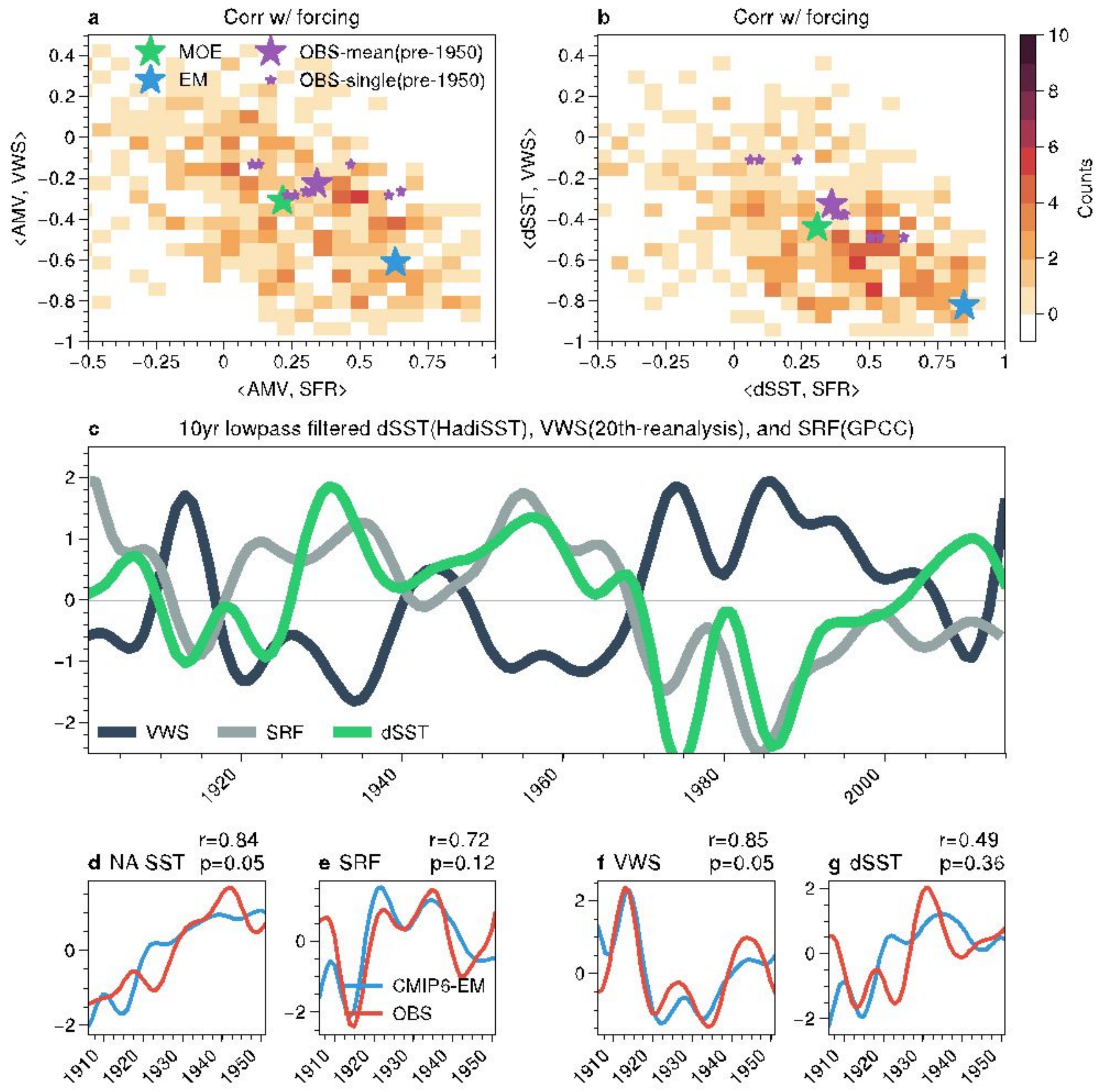




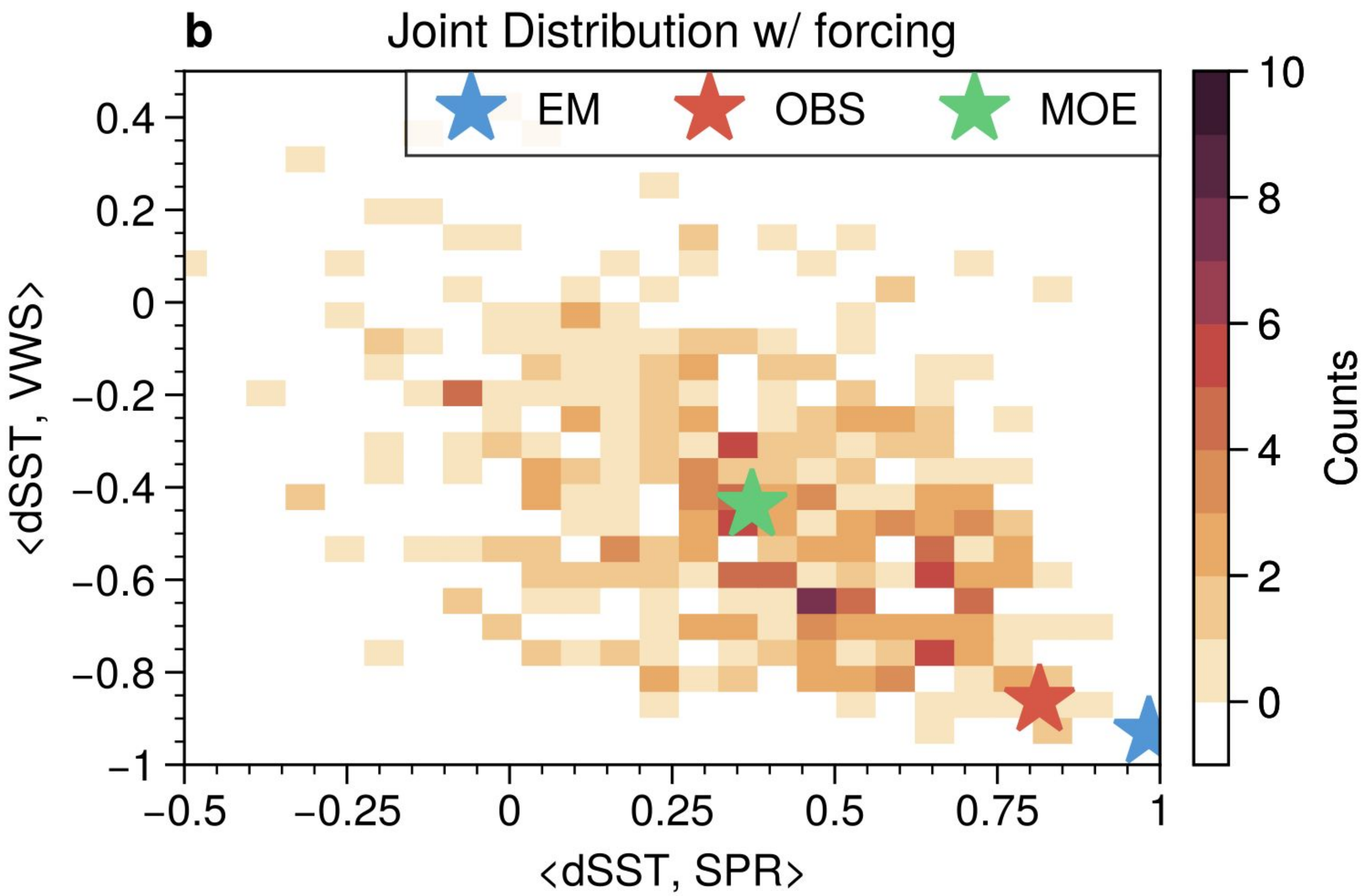
a
AMV
OBS
MOE
EM
Variance
K²
b
VWS
m²/s²
c
SRF
mm²/day²
d
dSST
K²
e
high_ACI
low_ACI
Times series
f
g
h
i
Variance
K²
j
m²/s²
k
mm²/day²
l
K²

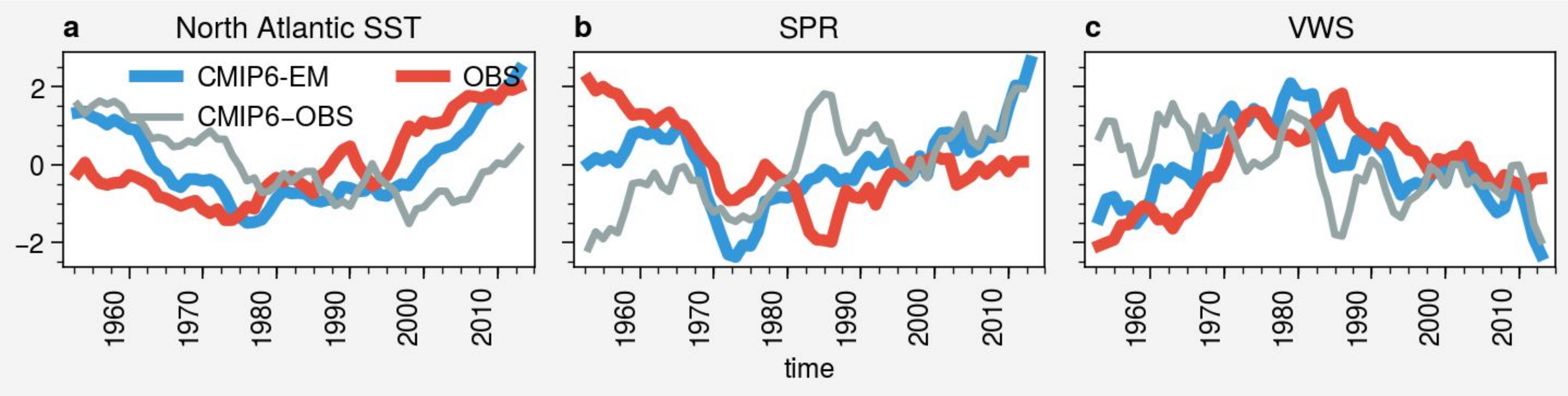


post1950 AMCV



Pre1950 AMCV


b
Joint Distribution w/ forcing
EM
OBS
MOE
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
⟨dSST, VWS⟩
−0.5
−0.25
0
0.25
0.5
0.75
1
⟨dSST, SPR⟩
10
8
6
4
2
0
Counts


a
North Atlantic SST
CMIP6-EM
OBS
CMIP6–OBS
2
0
−2
1960
1970
1980
1990
2000
2010
b
SPR
time
c
VWS

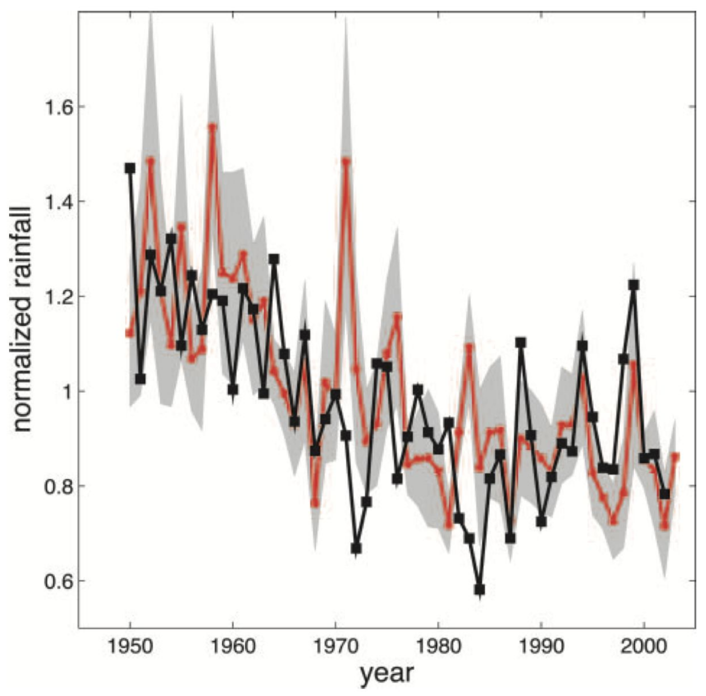
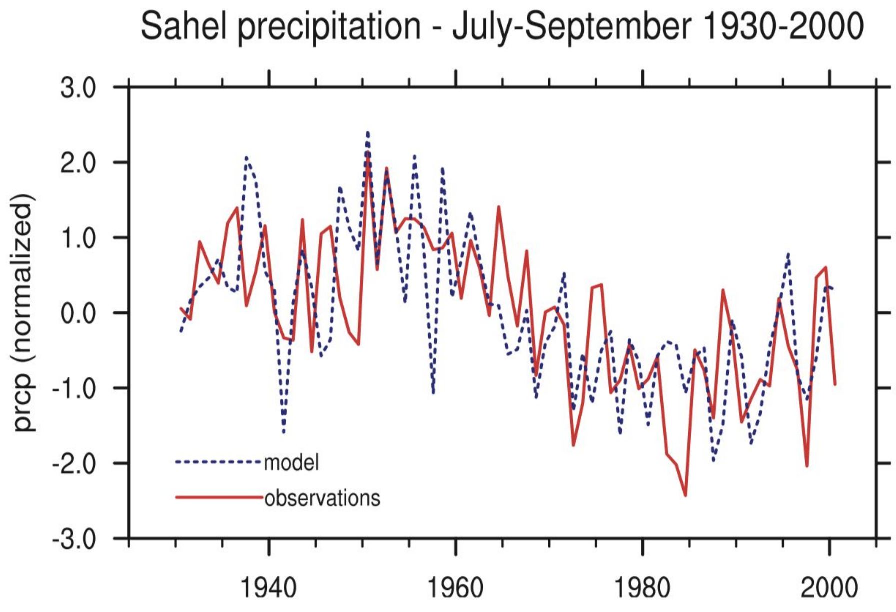


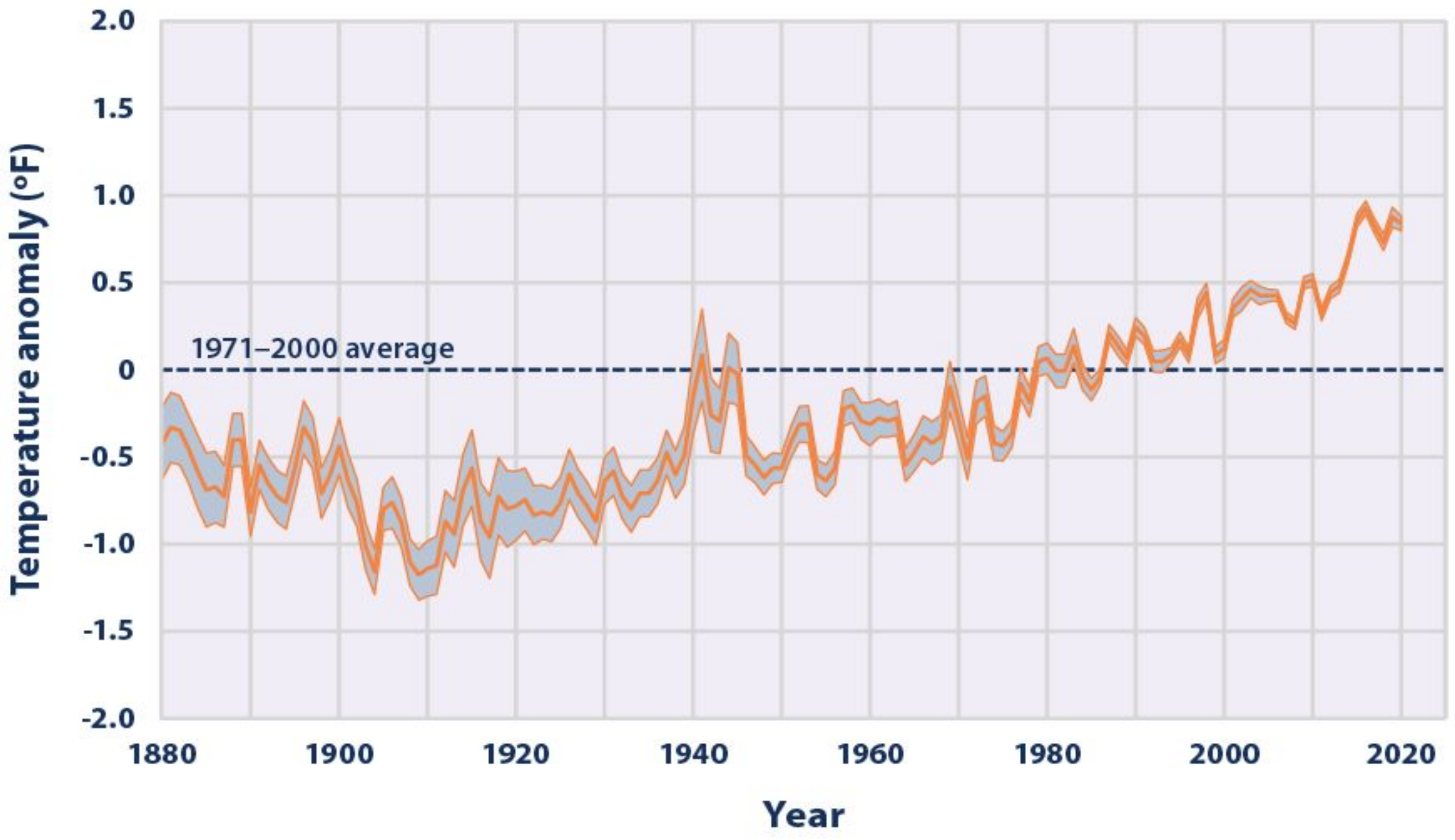
Fig. 1. Indices of Sahel rainfall variability. Observations used the average of stations between 10°N and 20°N, 20°W and 40°E. Model numbers were bases on the ensemble-mean average of grid-boxes between 10°N and 20°N, 20°W and 35°E. The correlation between observed and modeled indices of (JAS) rainfall over 1930–2000 is 0.60. (Time series are standardized to allow for an immediate comparison, because variability in the ensemble mean is muted in comparison to the single observed realization. The ratio of observed to ensemble-mean standard deviations in the Sahel is 4.)



Held et al. 2005 PNAS

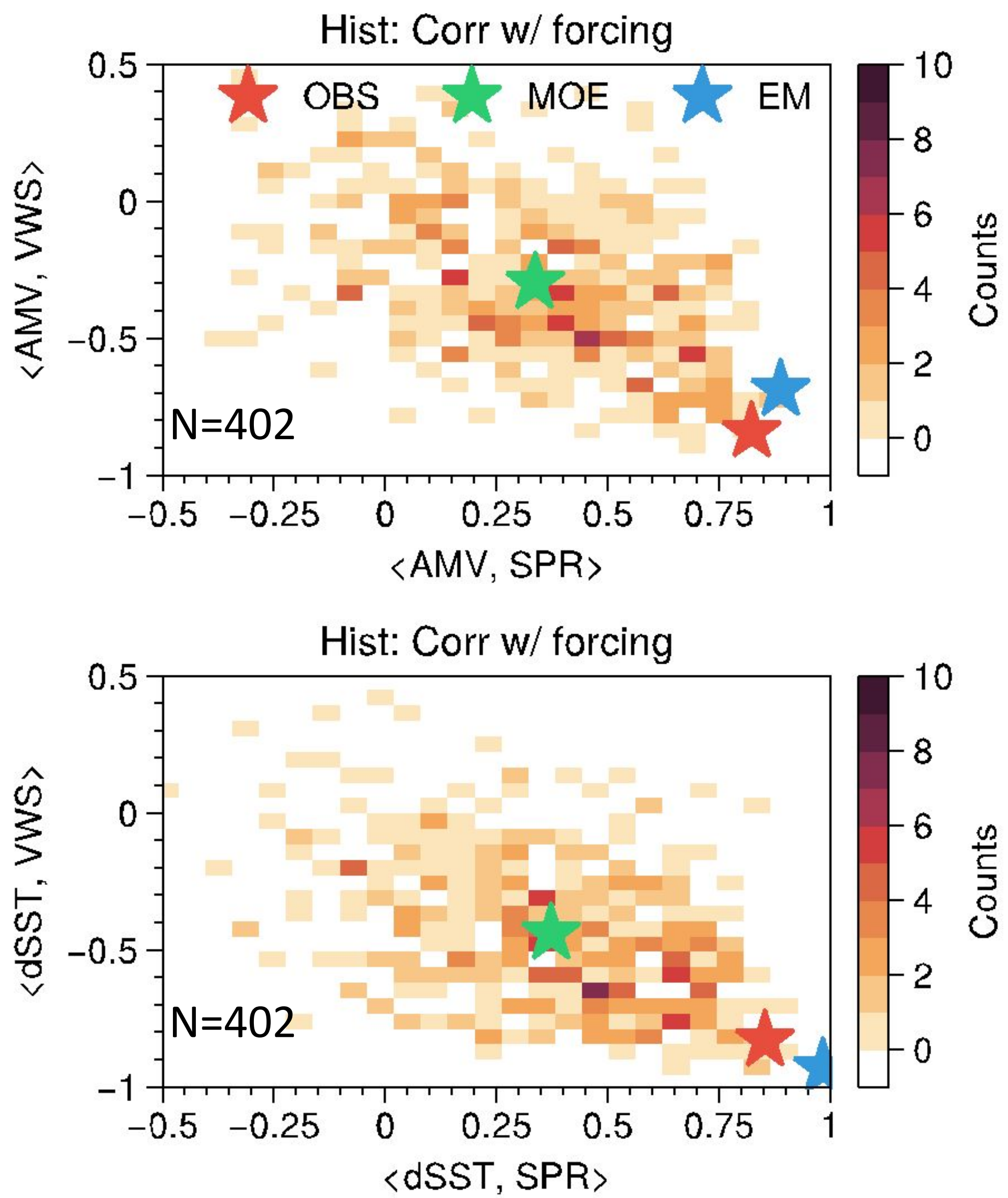
Giannini et al. 2003 Science

Backup

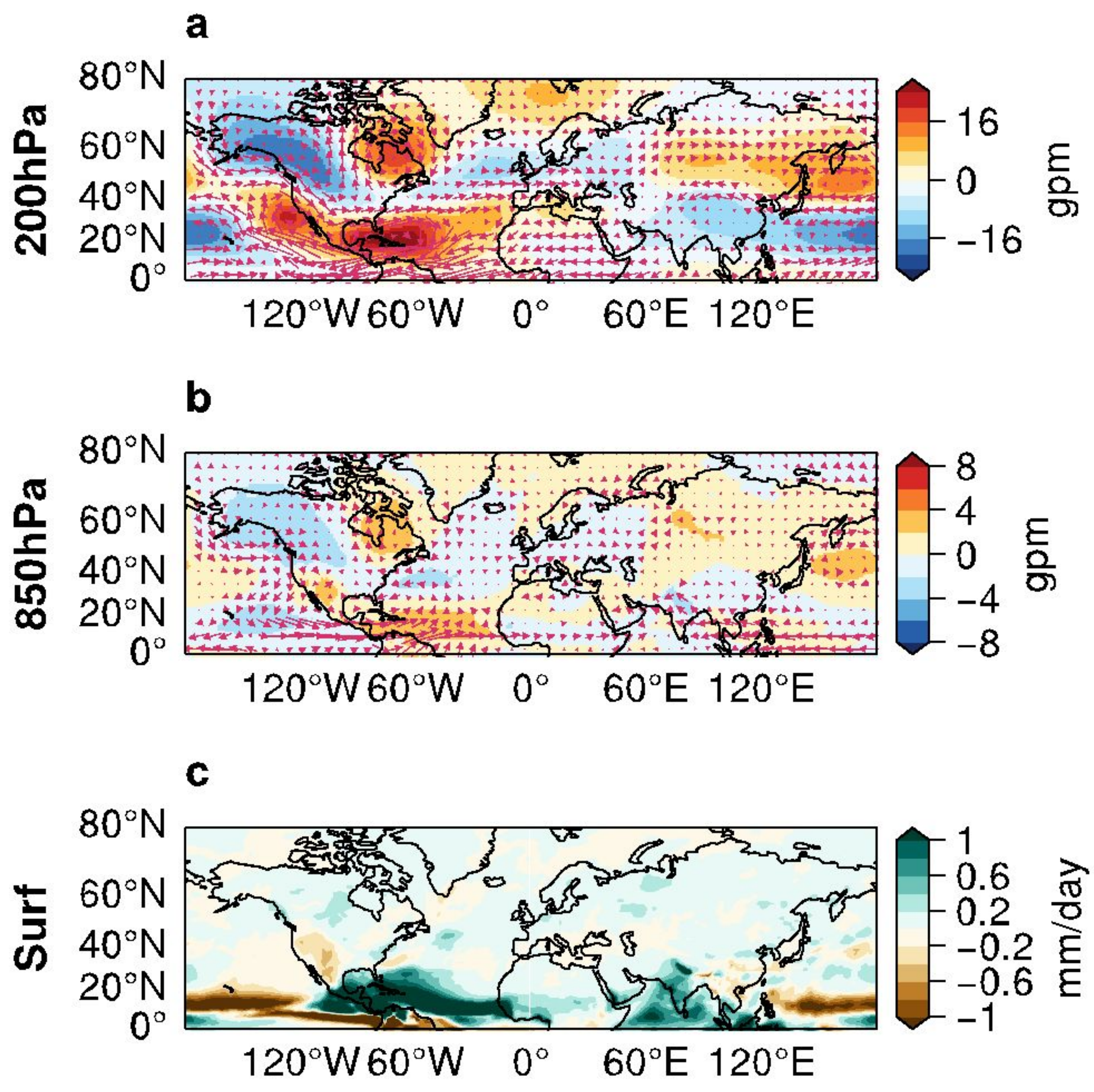


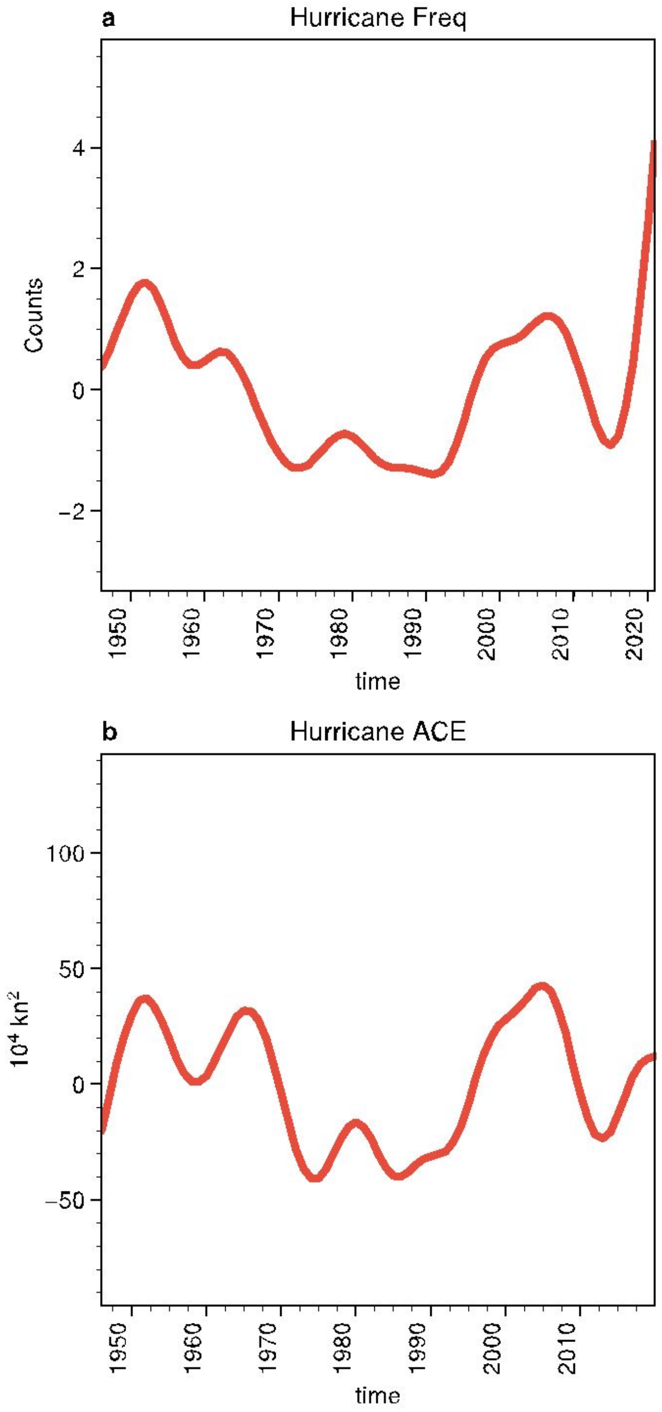
Global SST since 1880

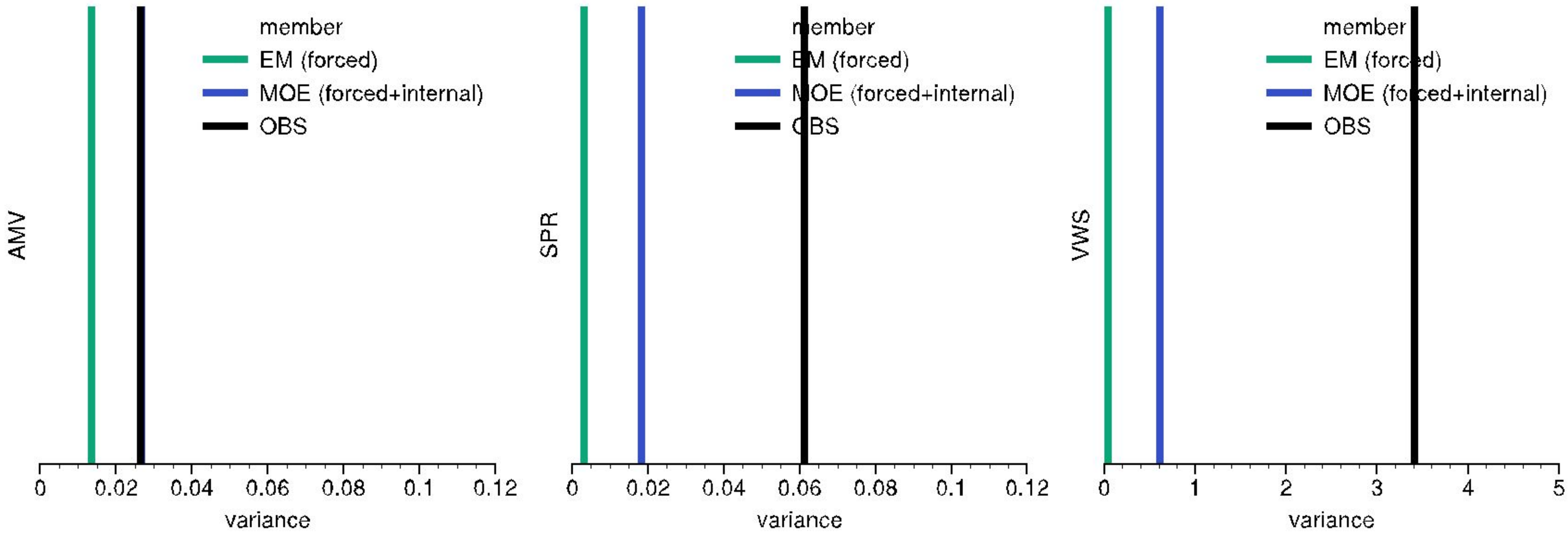
🤖 Mechanism: dSST to SPR and VWS



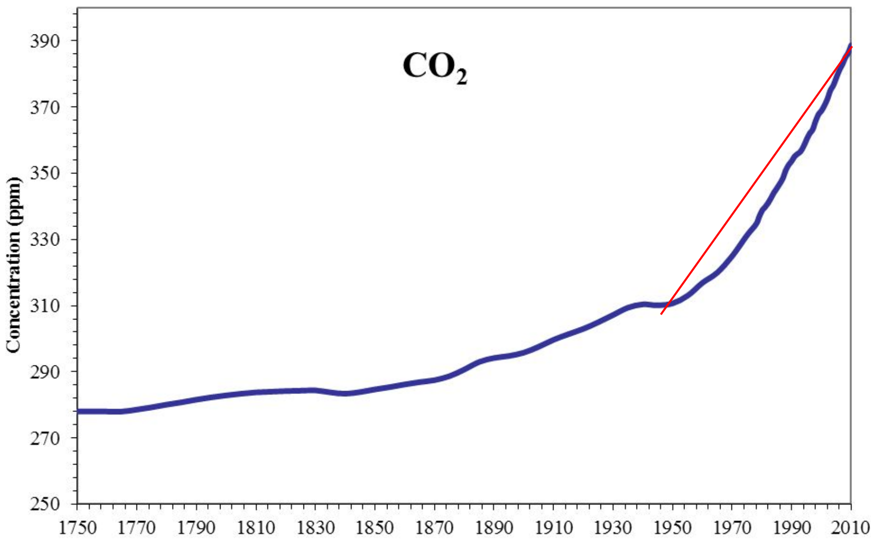
- dSST: Tropical NA SST [0-35°N]-Tropical SA SST [35°S-0]
- Model correlation for dSST shifts to a higher value
- So does EM


a
200hPa
80°N
60°N
40°N
20°N
0°
120°W 60°W 0° 60°E 120°E
16
0
−16
gpm
b
850hPa
80°N
60°N
40°N
20°N
0°
120°W 60°W 0° 60°E 120°E
8
4
0
−4
−8
gpm
c
Surf
80°N
60°N
40°N
20°N
0°
120°W 60°W 0° 60°E 120°E
1
0.6
0.2
−0.2
−0.6
−1
mm/day

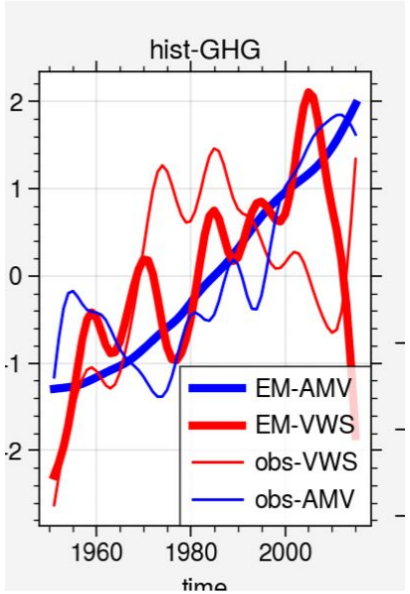

a
Hurricane Freq
Counts
4
2
0
−2
1950
1960
1970
1980
1990
2000
2010
2020
time
b
Hurricane ACE
10^4 kn^2
100
50
0
−50
1950
1960
1970
1980
1990
2000
2010
time



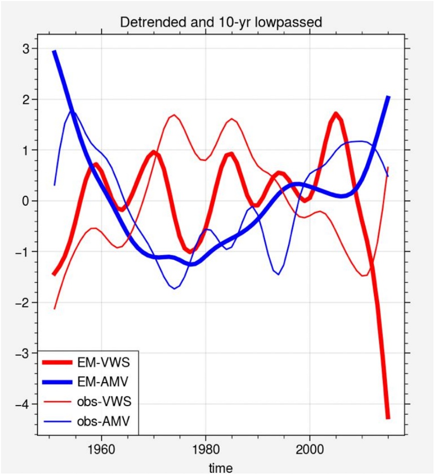
AMV
SPR
VWS
member
EM (forced)
MOE (forced+internal)
OBS
0
0.02
0.04
0.06
0.08
0.1
0.12
1
2
3
4
5
variance



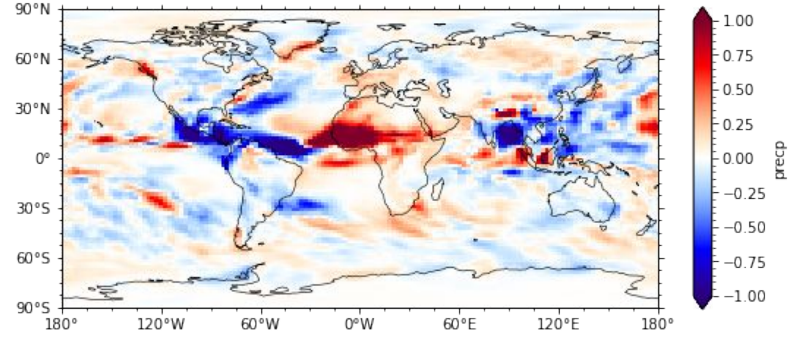
10yr lowpass



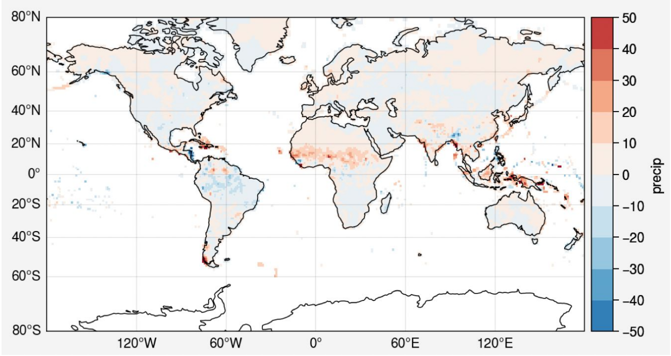
10yr lowpass and detrended

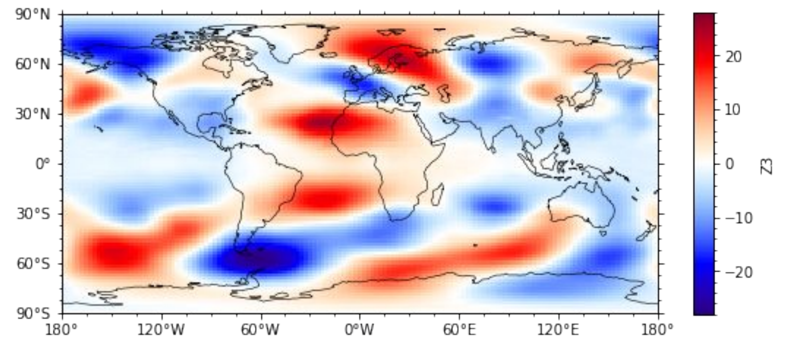


CO2 global warming -> no strong N-S Atlantic SST gradient

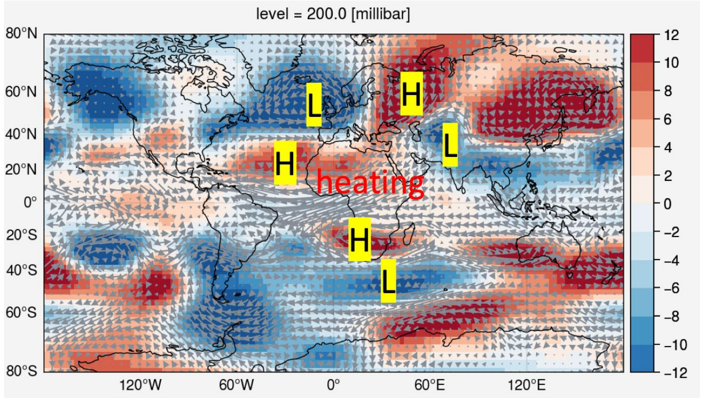


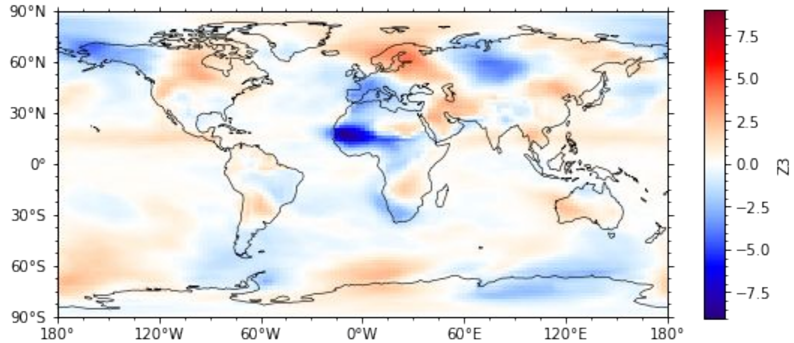
Precip



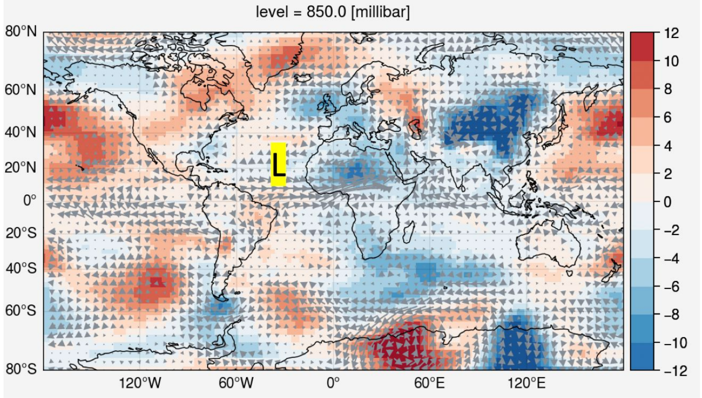


Geopotential height 200hPa

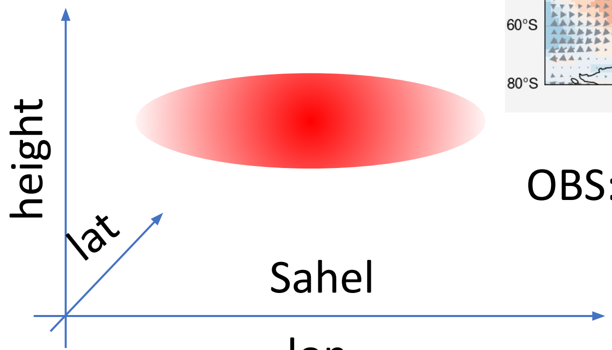




Geopotential height 850hPa



Response of Diabatic heating in Sahel



OBS: [AMV+] – [AMV-]