Constraining the model spread in projected warming of hot days

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National Center for Atmospheric Research

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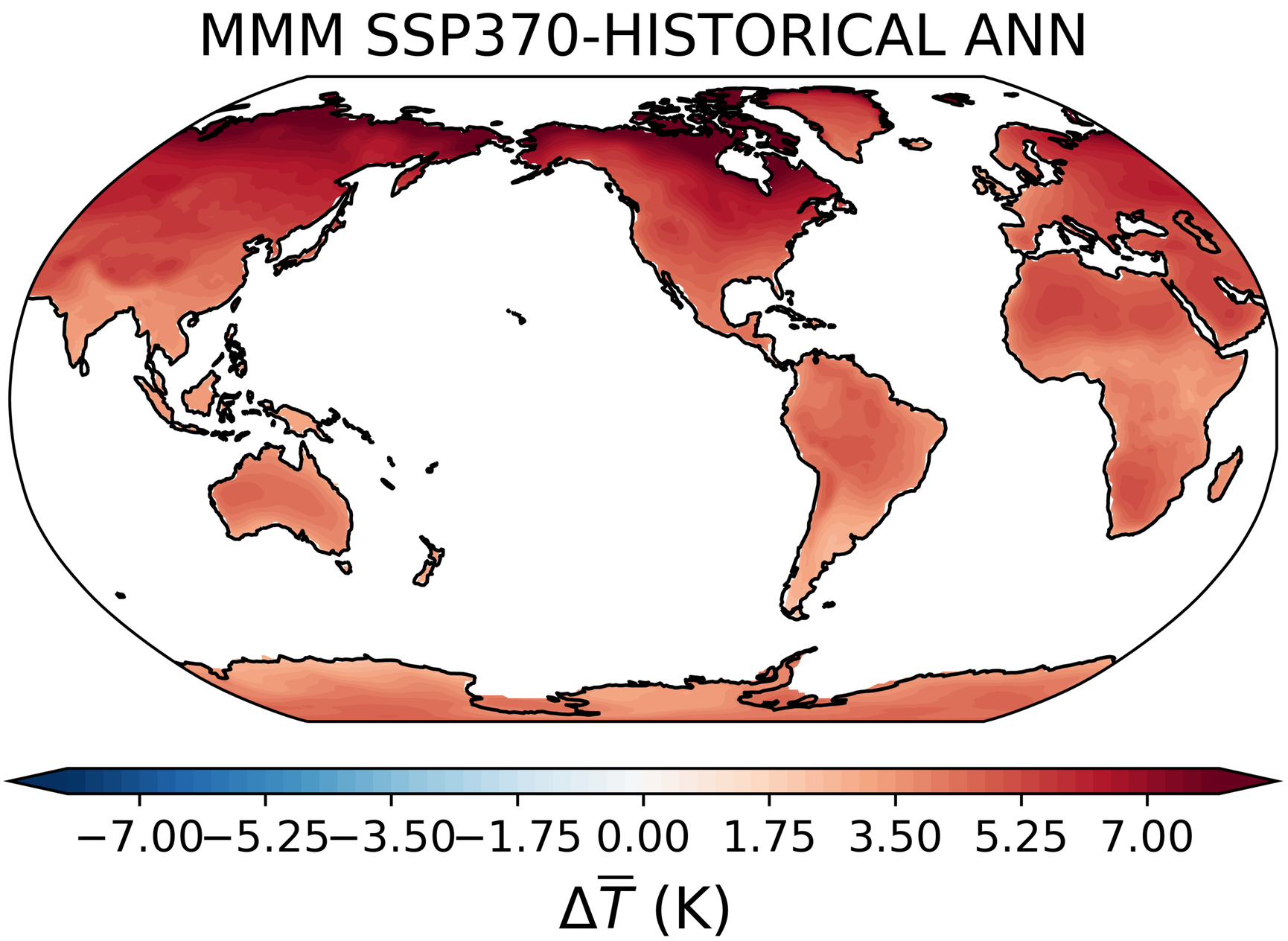
Spatial structure of mean surface warming has been extensively studied



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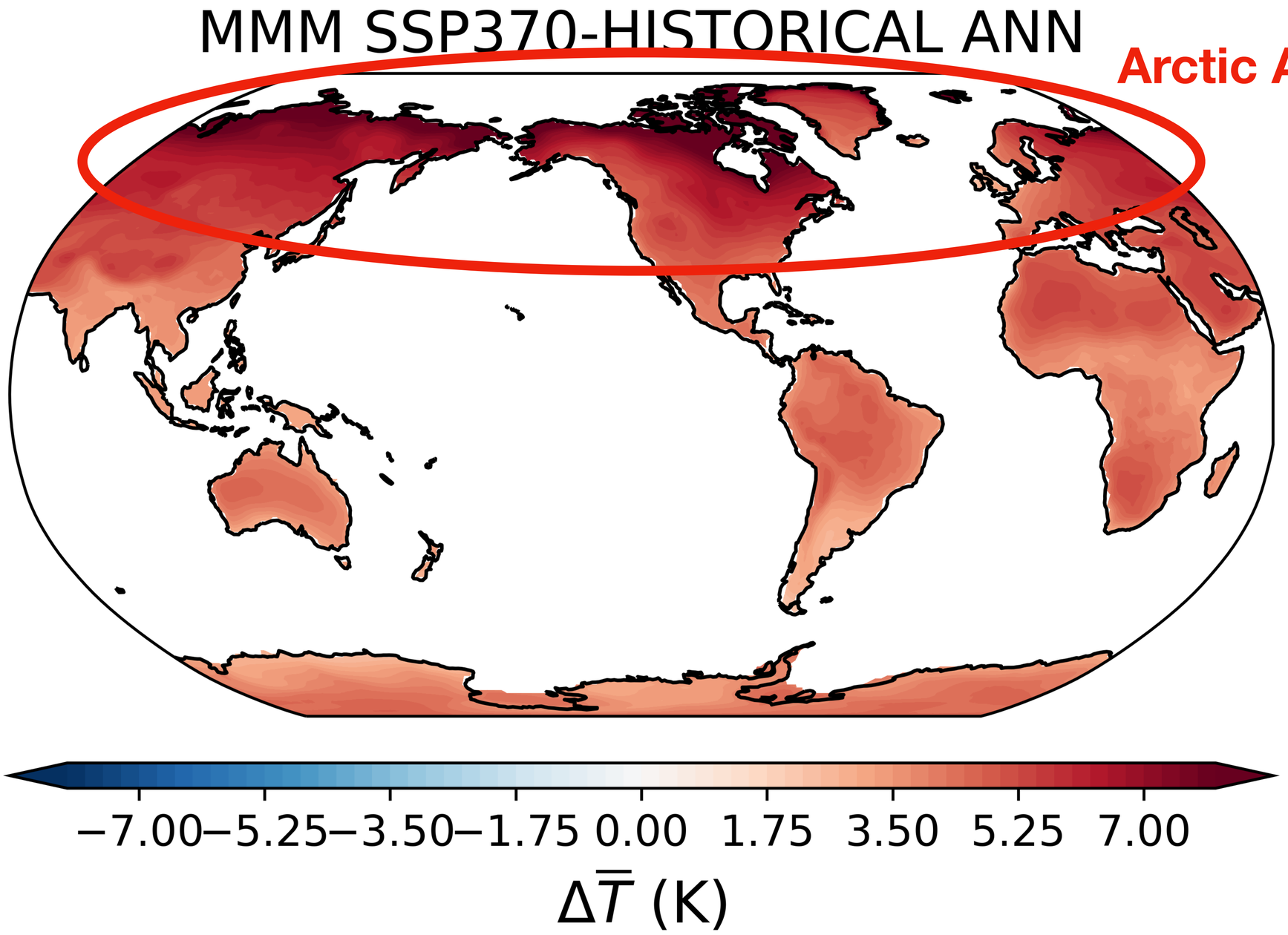
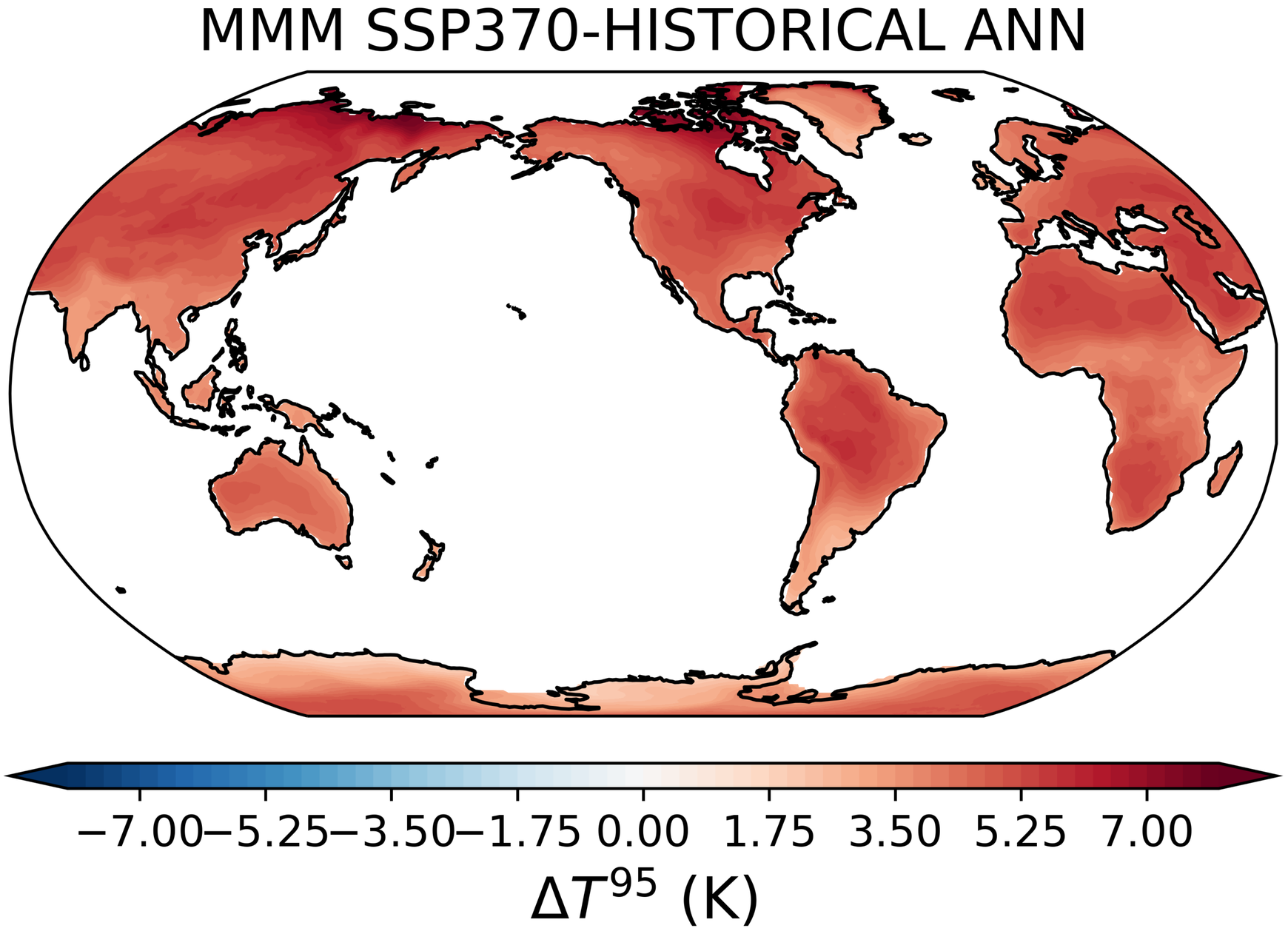
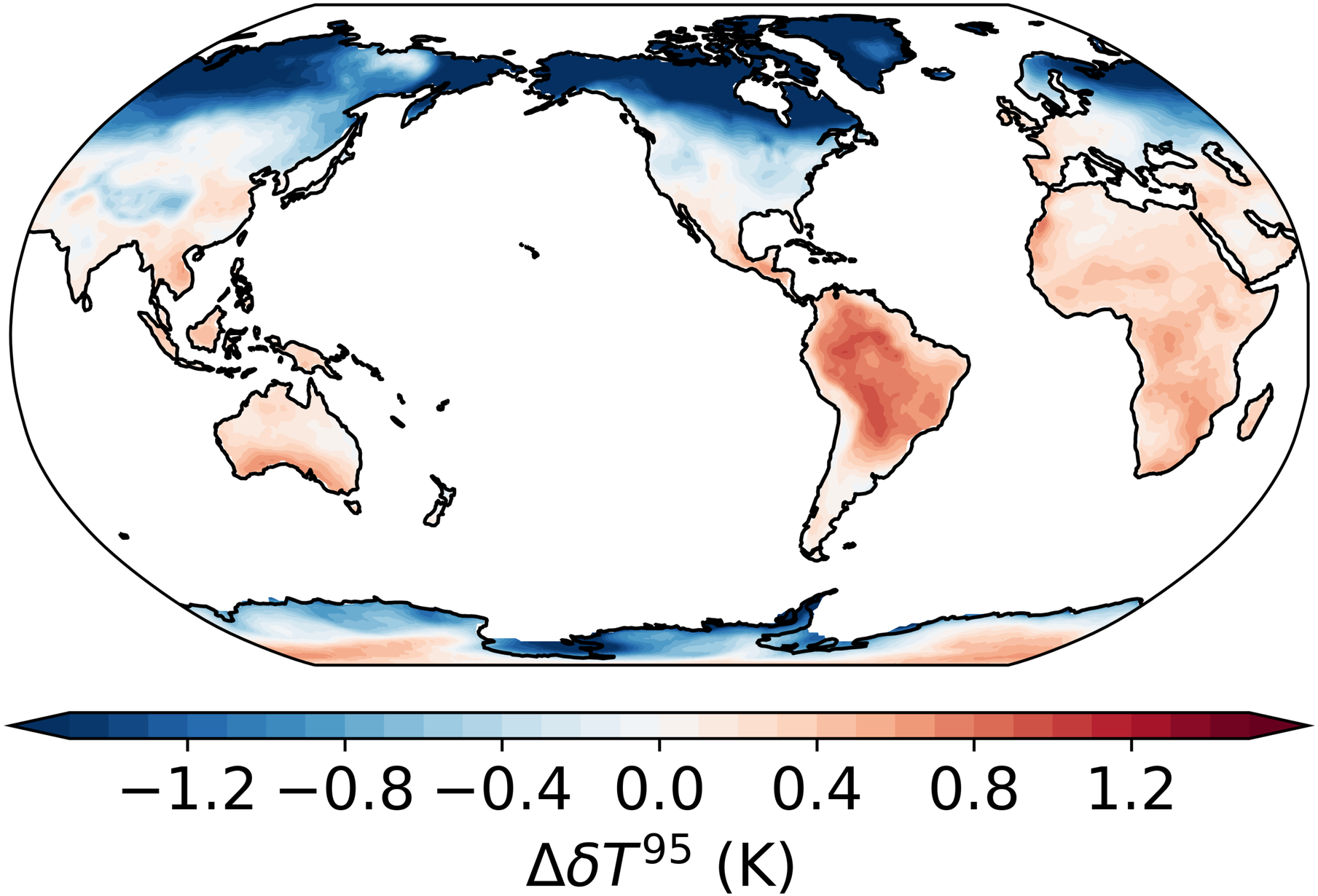


Warming of hot days (95th perc) exhibit differences from mean warming

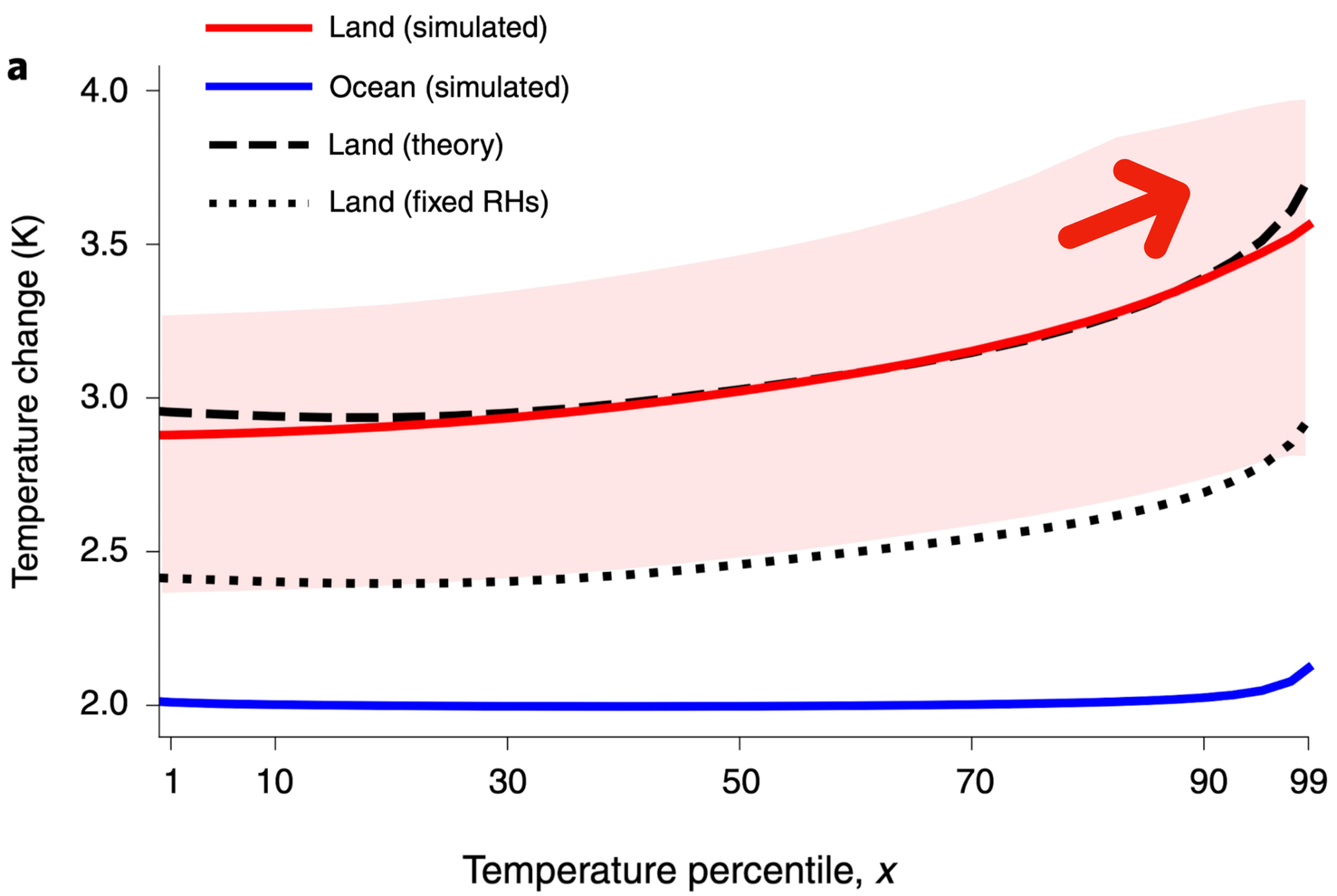


Warming of hot days (95th perc) relative to mean warming

MMM SSP370-HISTORICAL ANN



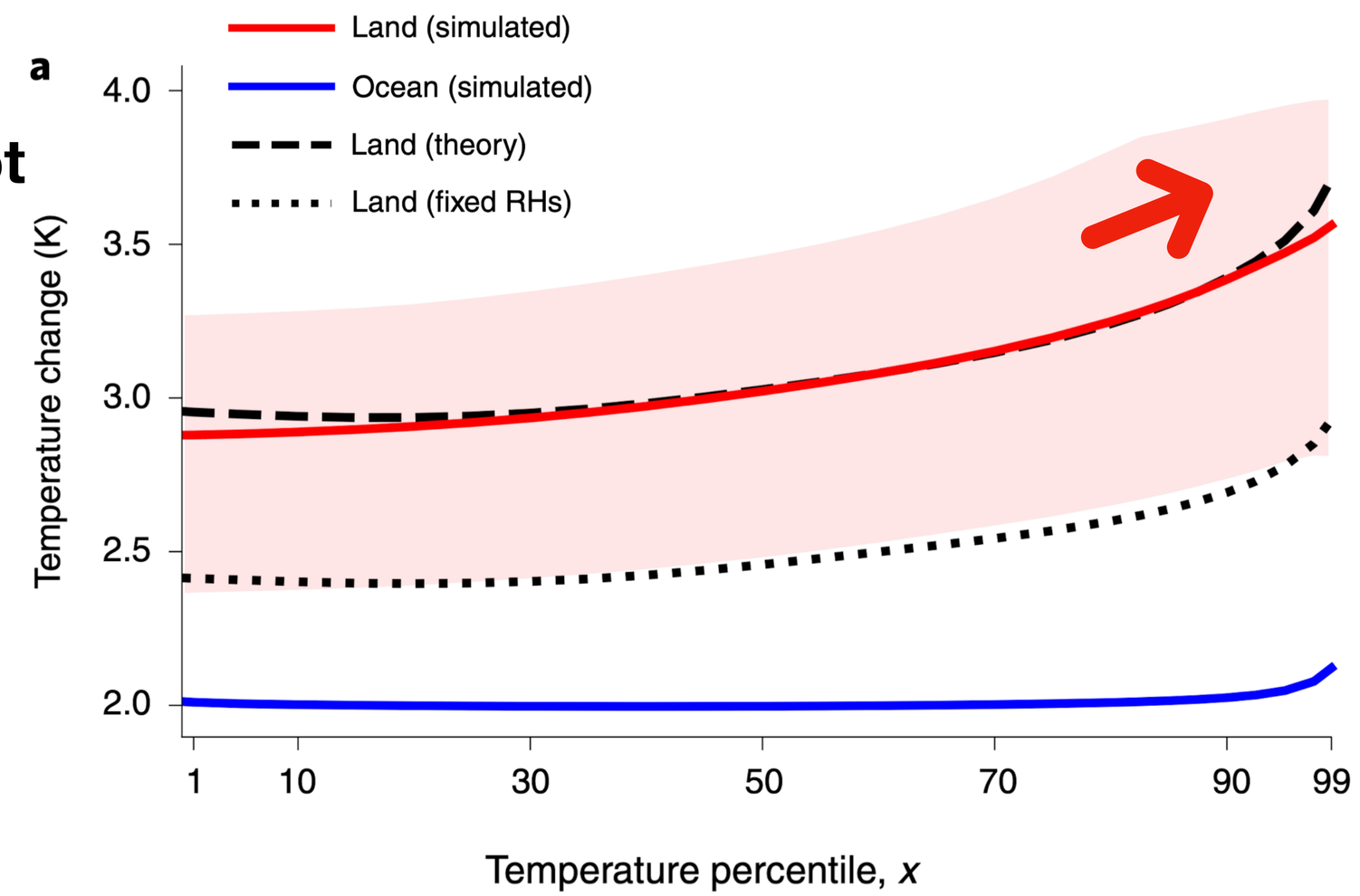
Byrne (2021) showed warming of hot days is amplified over tropical land



Mean → **Hotter days**

Byrne (2021)

1. What is the spatio-temporal pattern of amplified warming of hot days?



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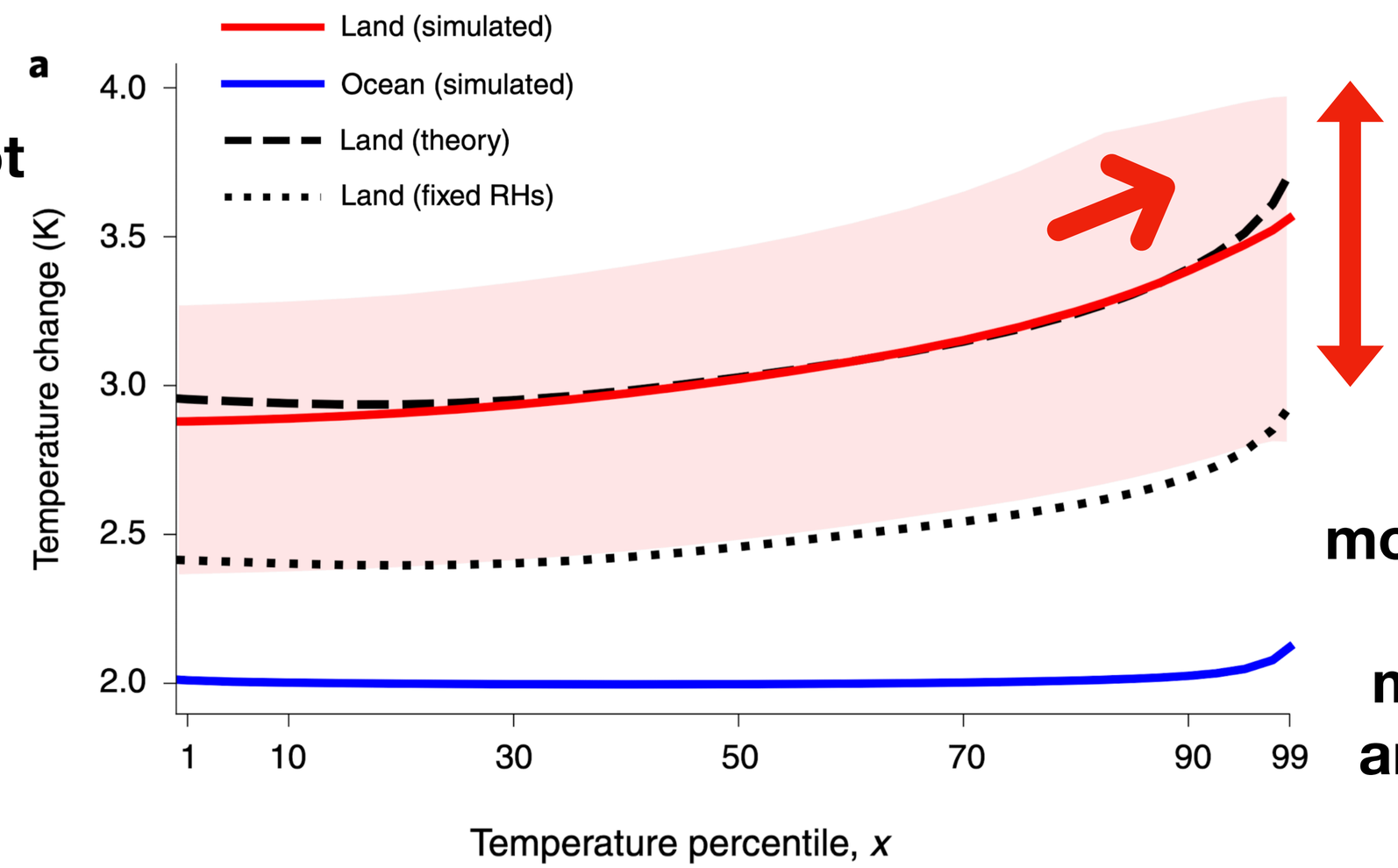
1. What is the spatio-temporal pattern of amplified warming of hot days?

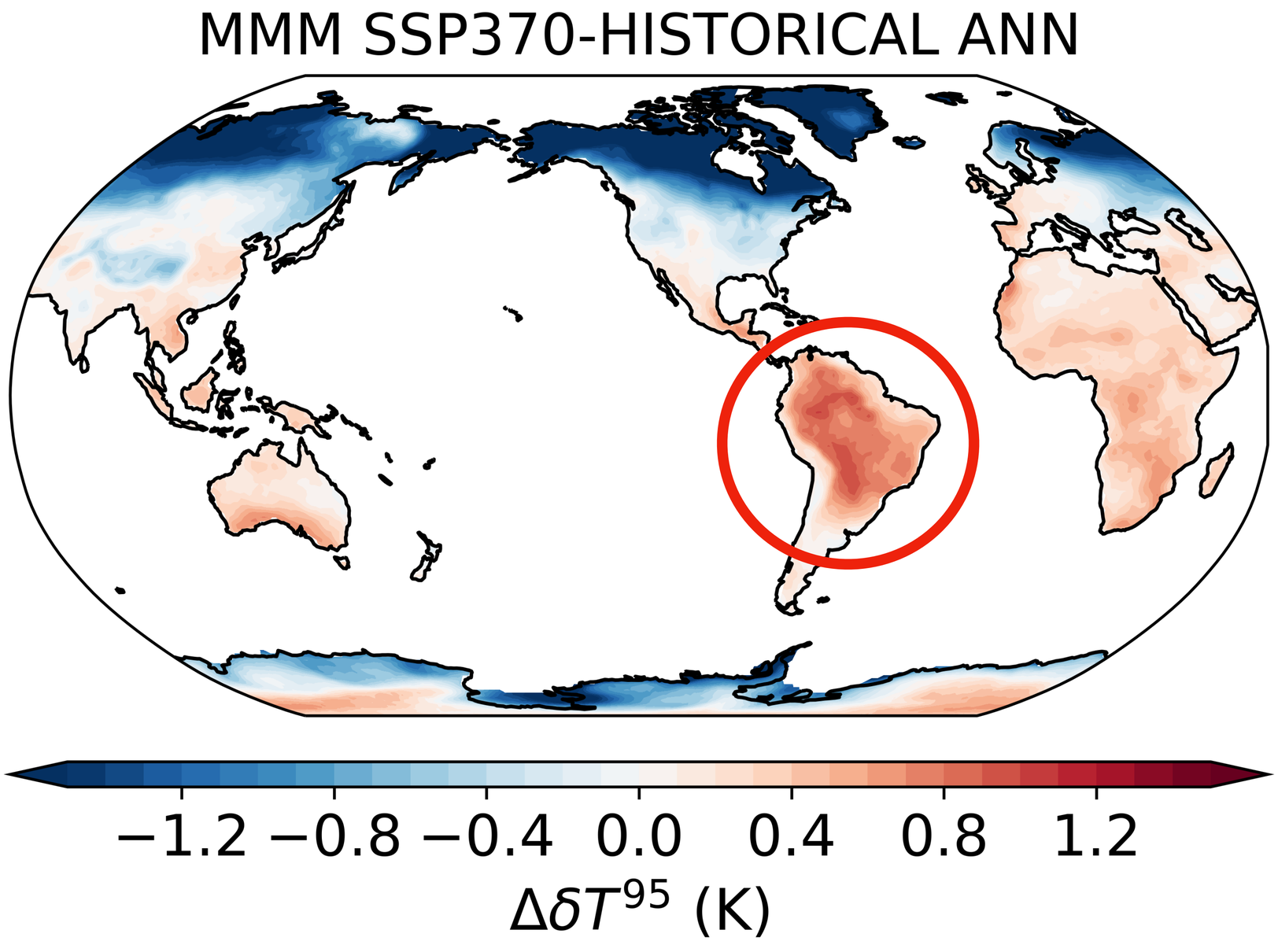


2. Why do models disagree on the magnitude of amplification?

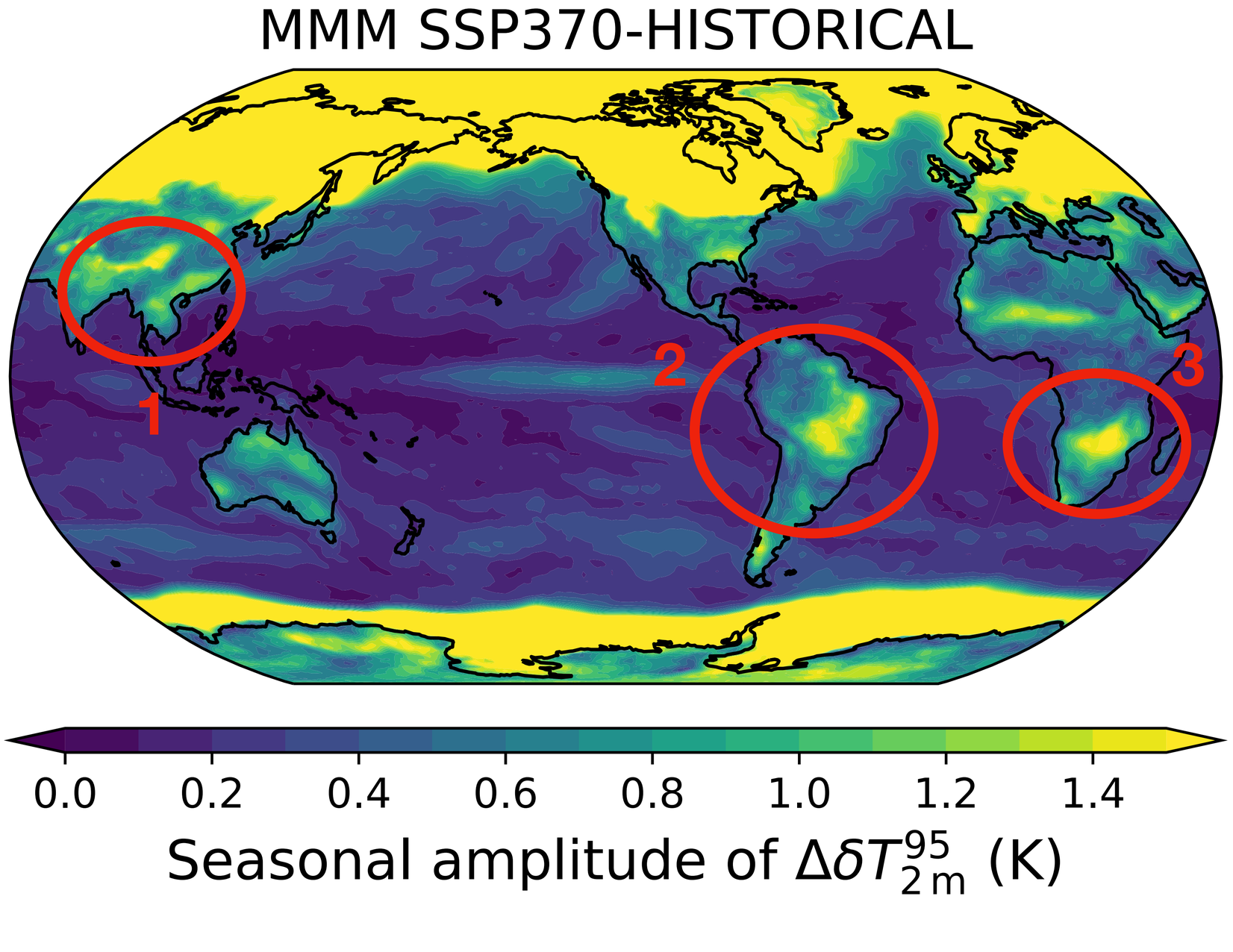
Mean → **Hotter days**

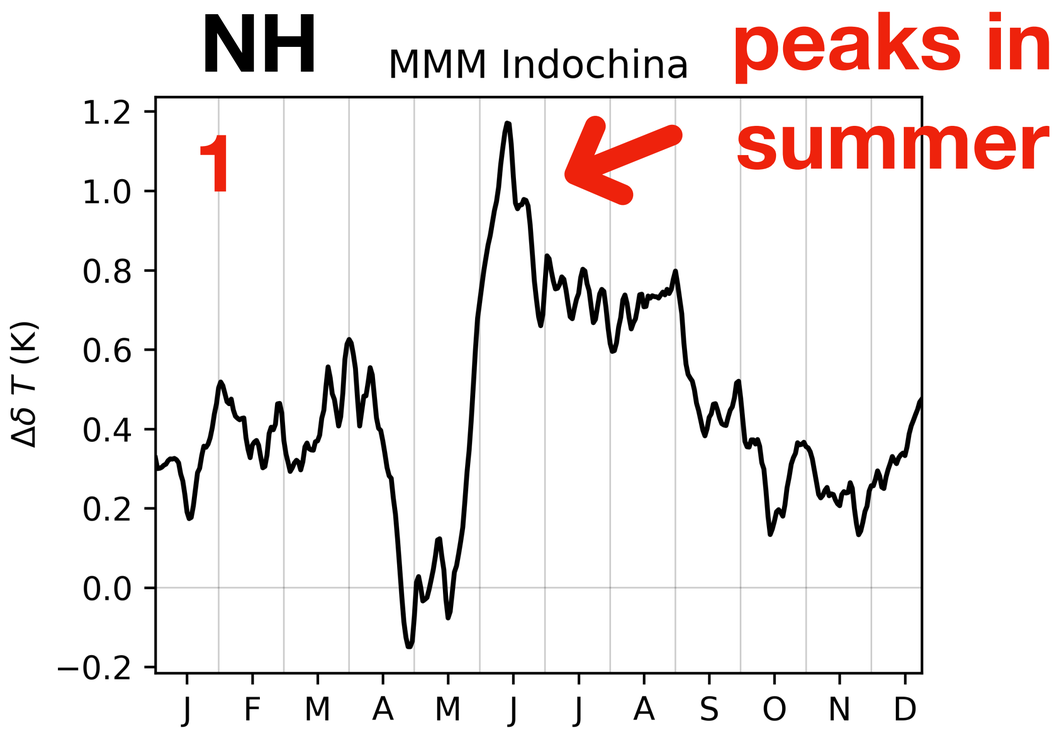
Byrne (2021)

Annual mean amplified warming of hot days projected to be largest over South America

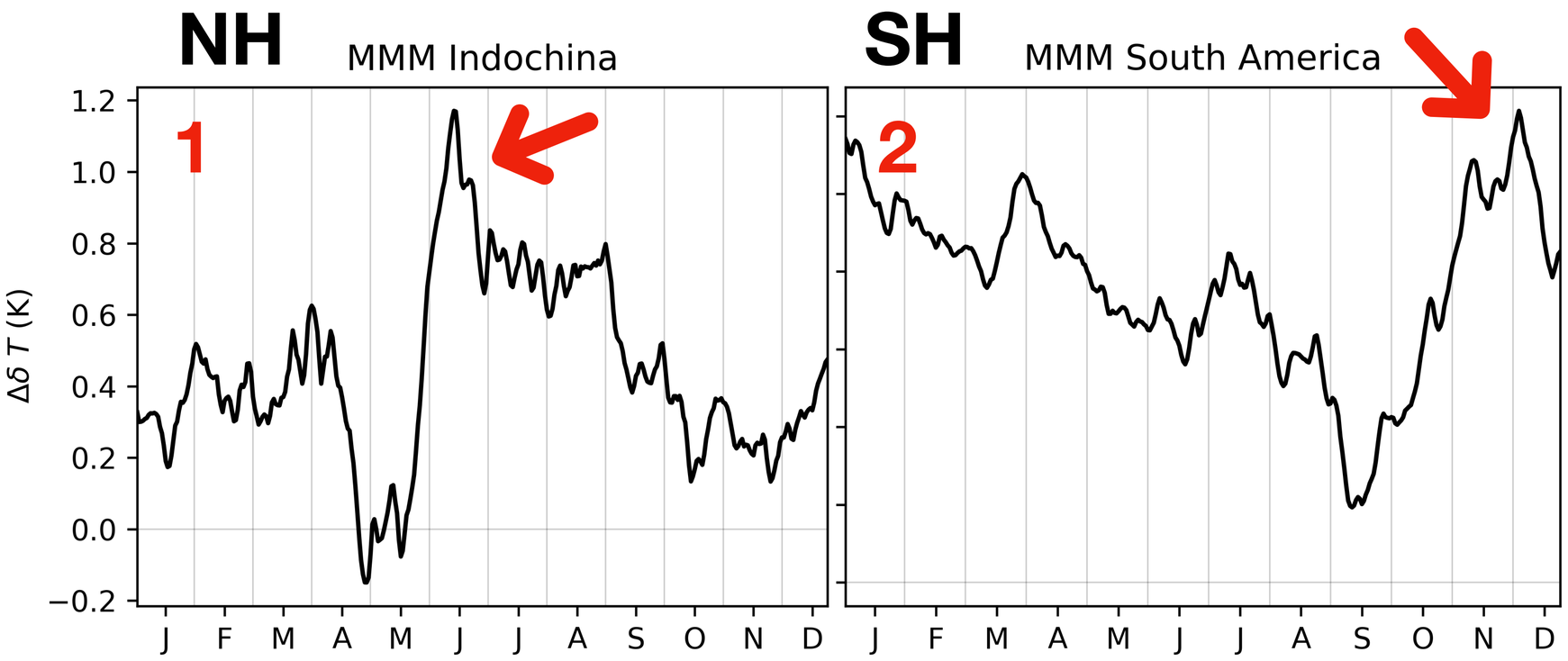


Amplitude of seasonal cycle exhibit various hot spots across tropics

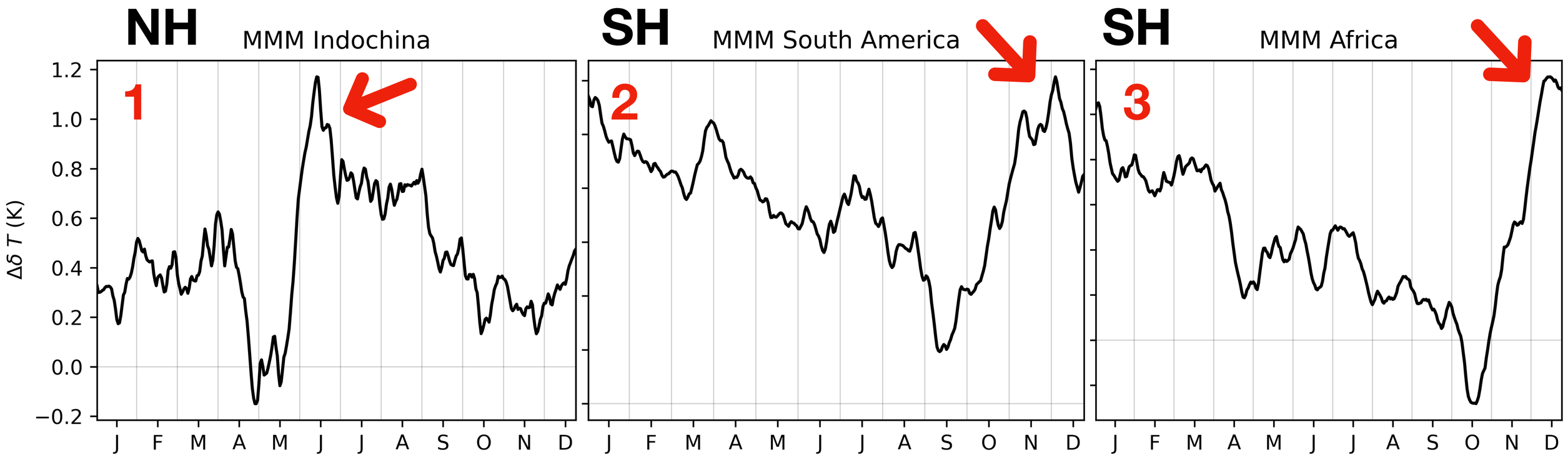



NH
MMM Indochina
peaks in
summer
1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
Δδ T (K)
J
F
M
A
M
J
J
A
S
O
N
D

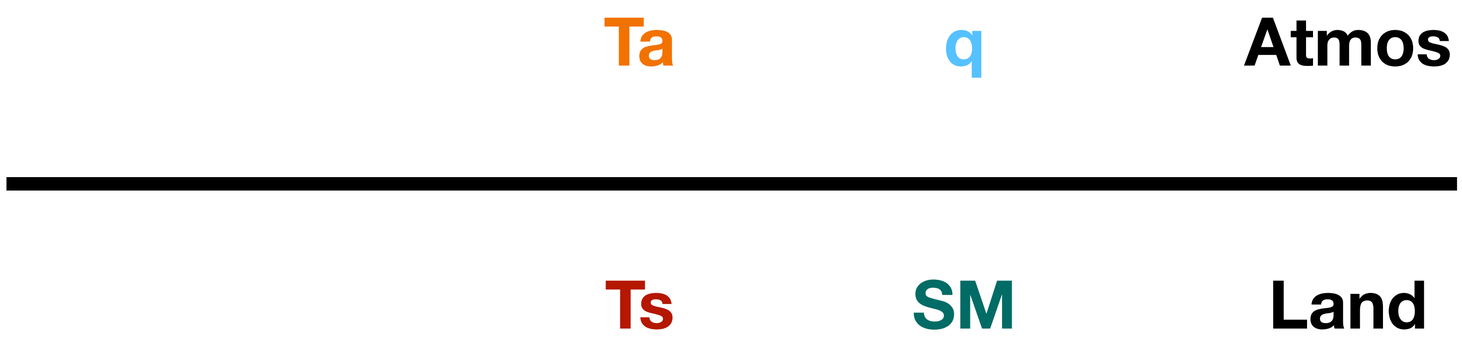
peaks in summer



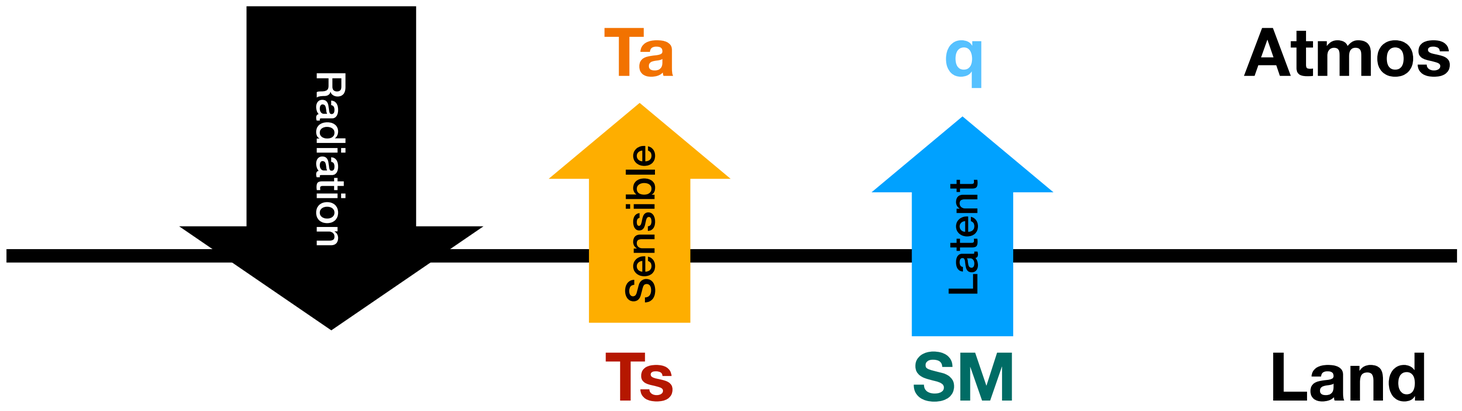
Amplified warming of hot days peak in local summer season



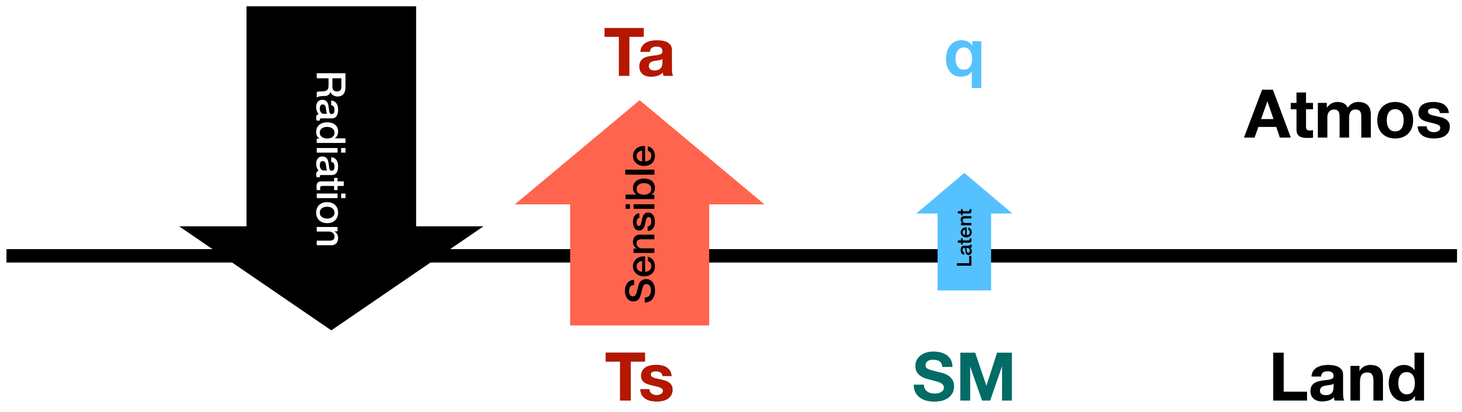
A simple starting point to understand source of variations in surface warming: Surface energy budget



In equilibrium, surface radiative heating is balanced by surface sensible and latent cooling

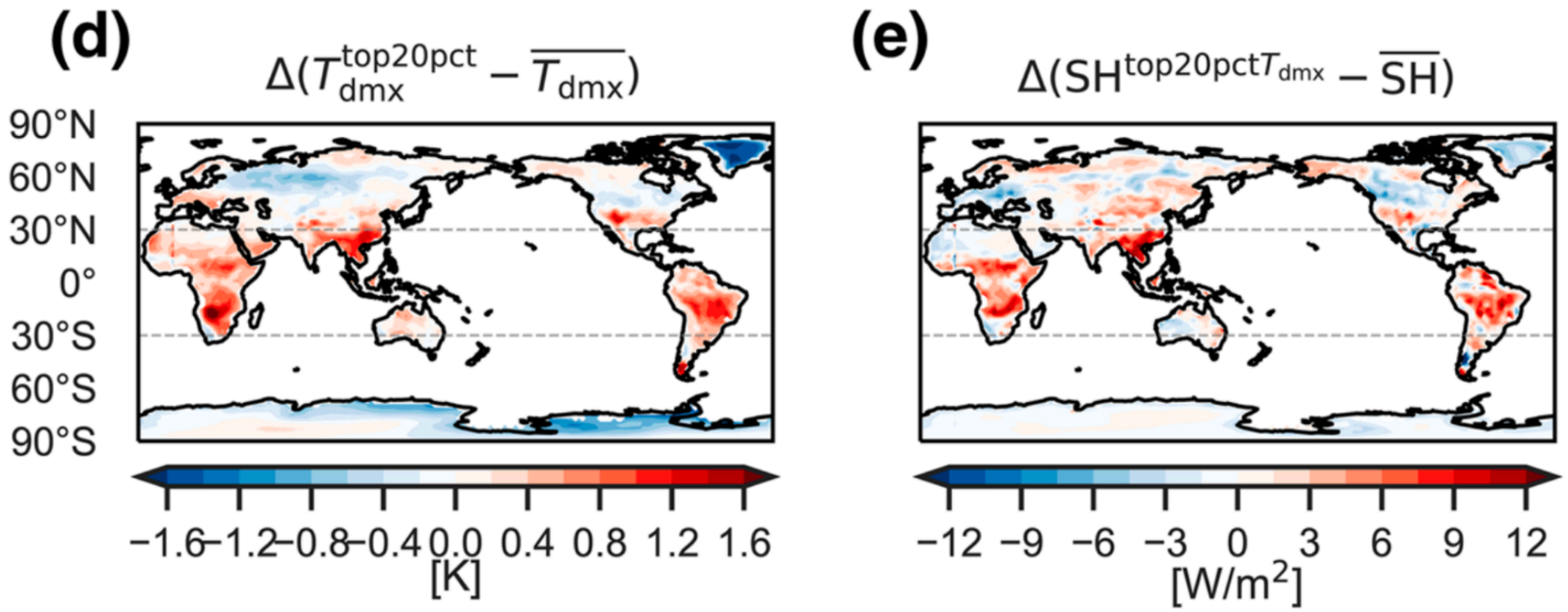


On hot days, latent cooling weakens so sensible cooling compensates to maintain energy balance



Enhanced warming of hot days

Enhanced sensible heating on hot days

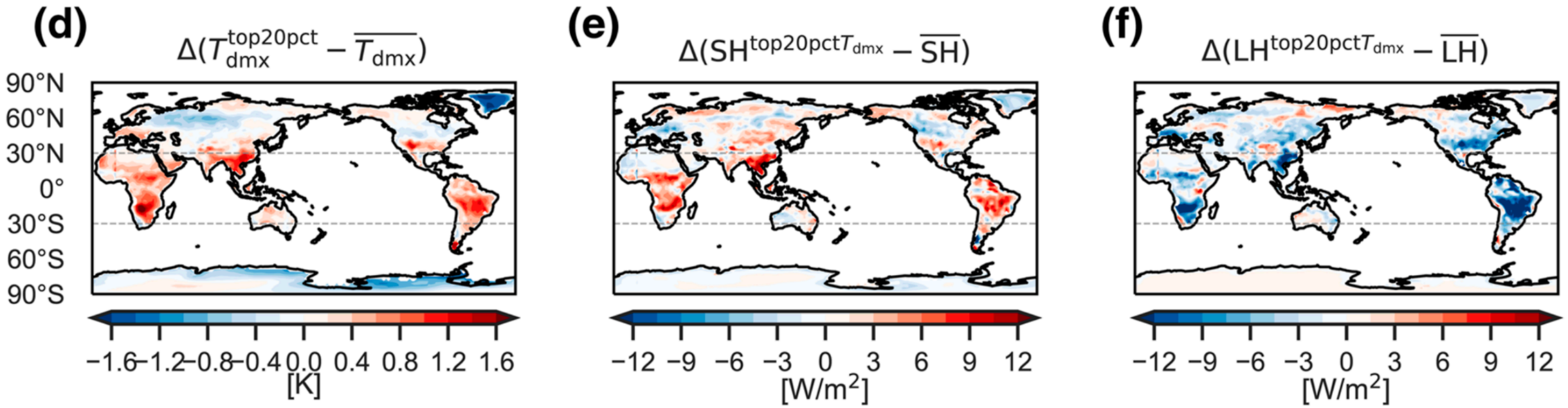


Duan et al. (2020)

Enhanced warming of hot days

Enhanced sensible heating on hot days

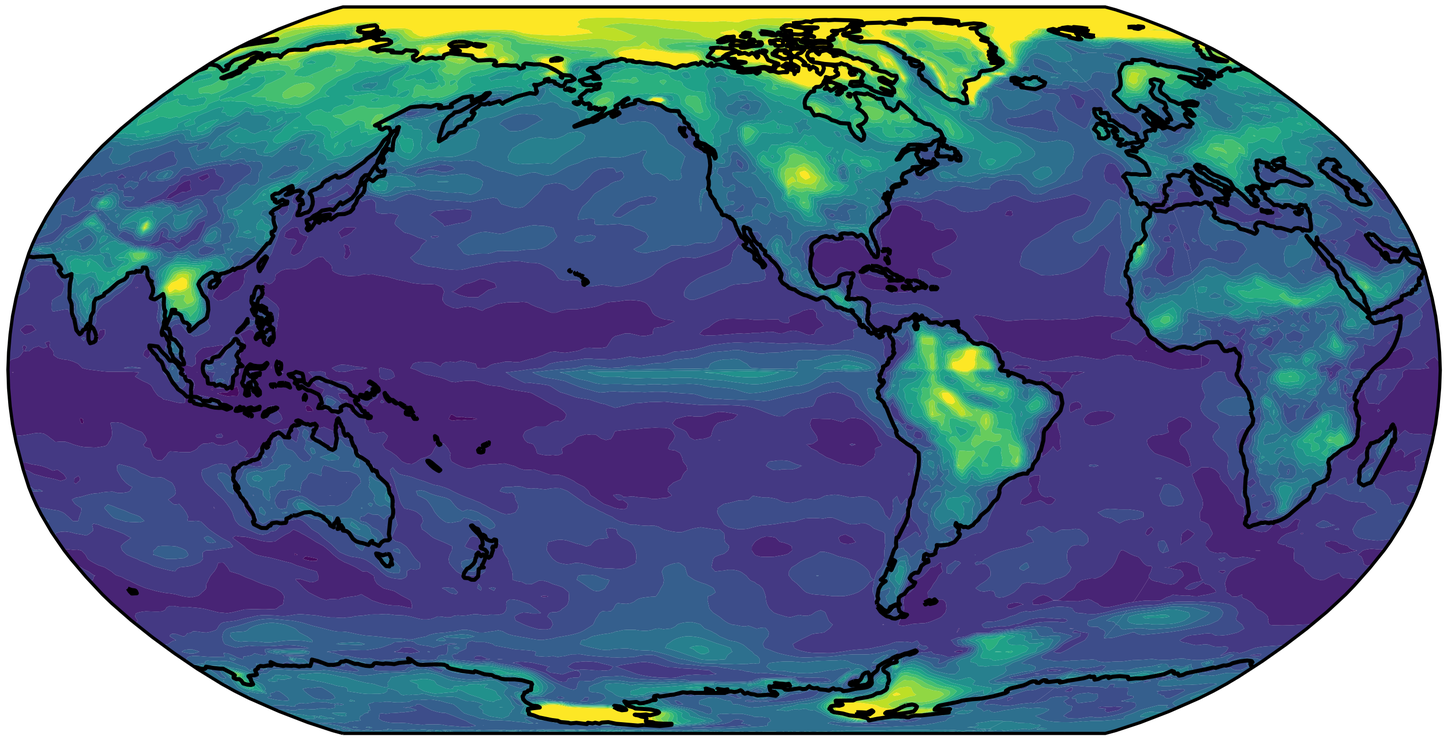
Reduced evaporative cooling



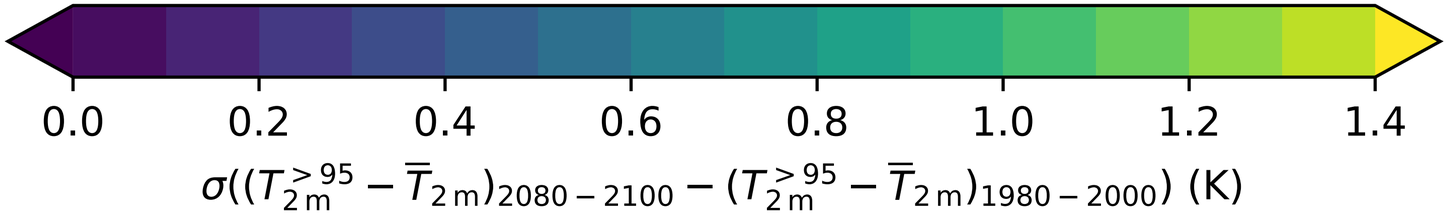
Duan et al. (2020)

Does the same relationship explain intermodel spread?

JJA+DJF MMM SSP370



Model Spread



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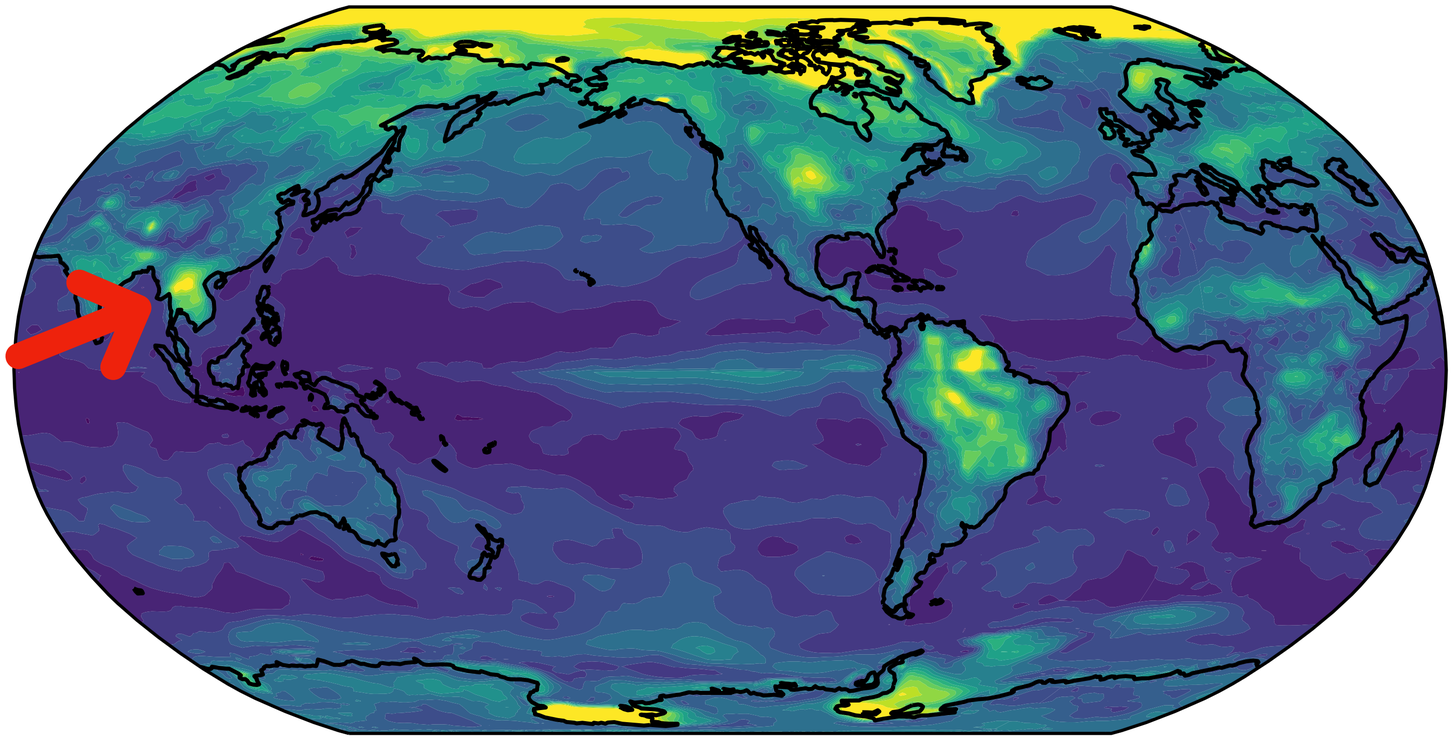
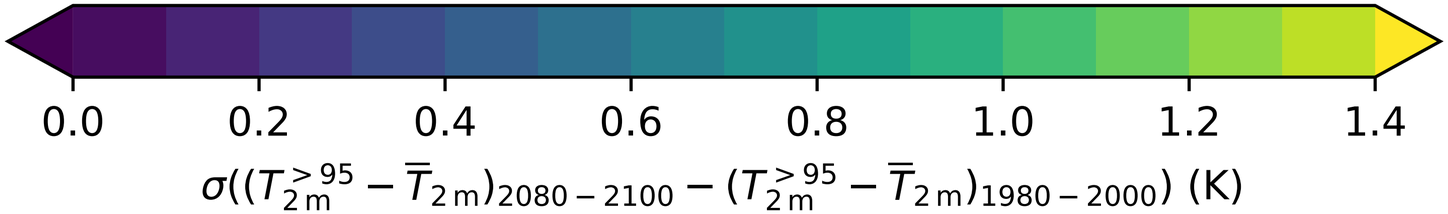
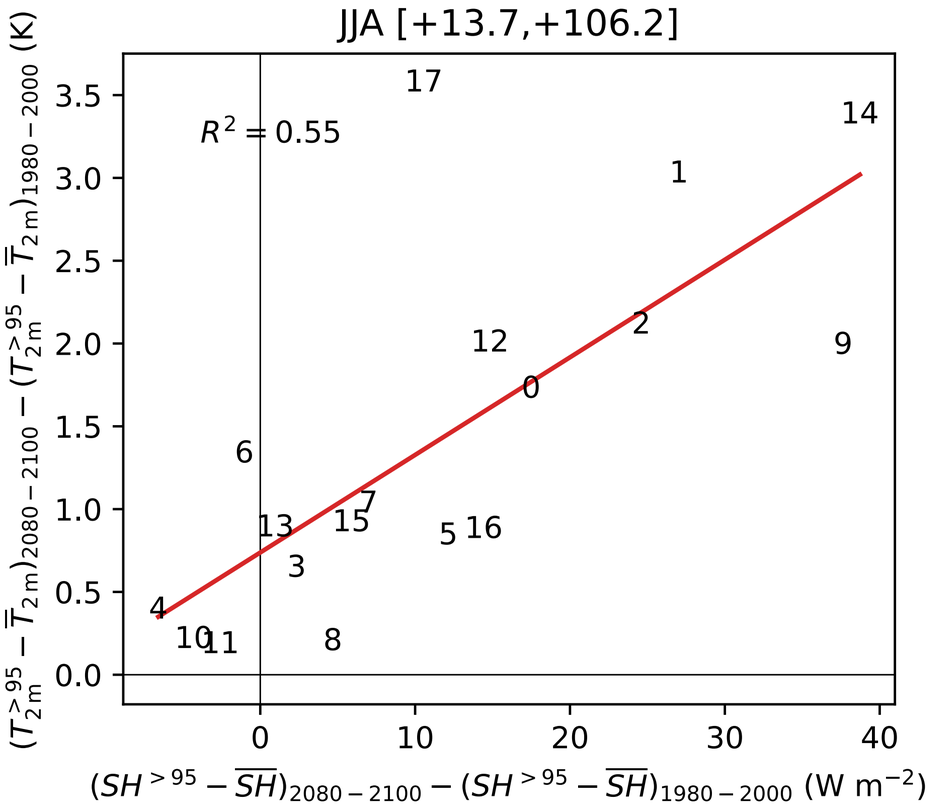


Model Spread

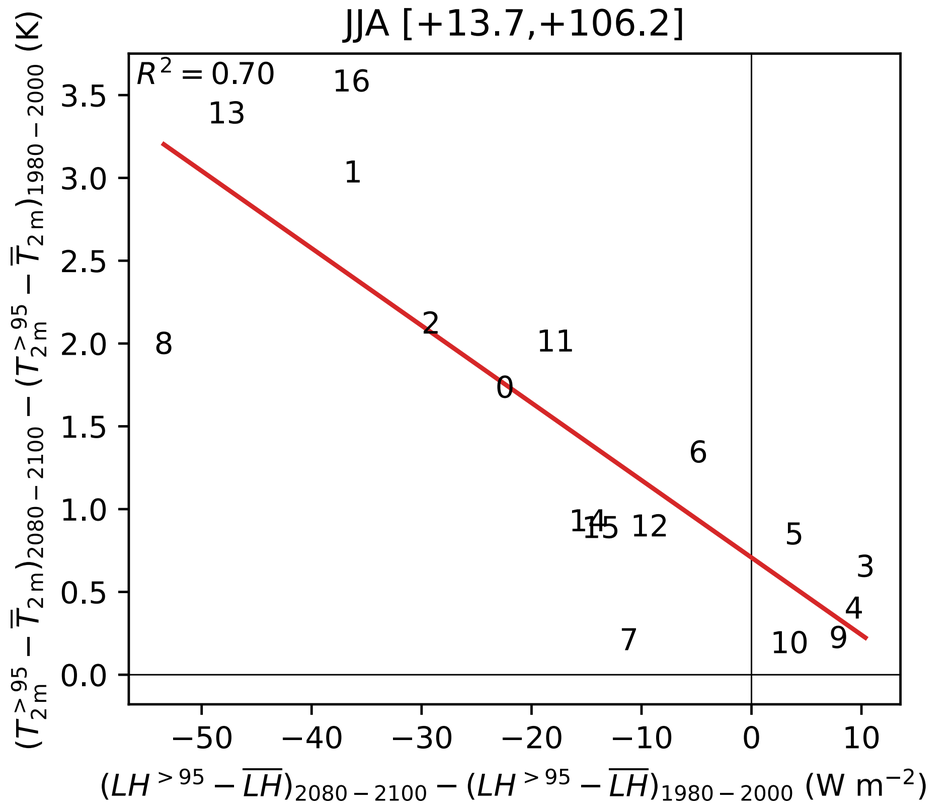


Intermodel spread in 1 grid point in Southeast Asia

Amplified warming of hot days



Enhanced sensible heating on hot days

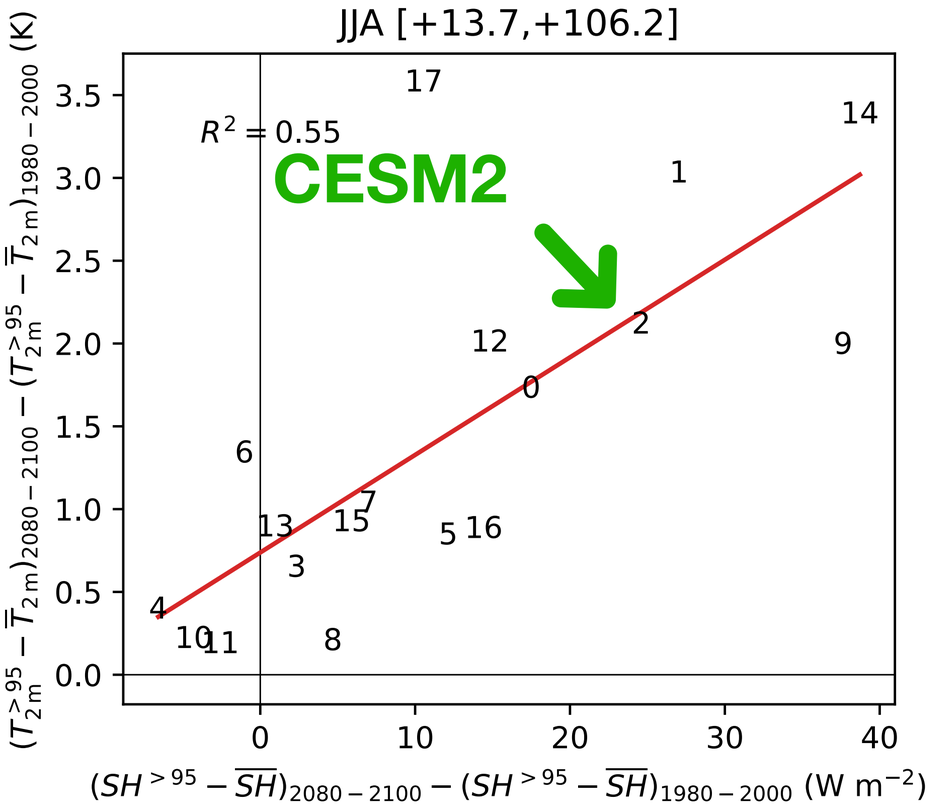


Reduced evaporative cooling

0=ACCESS-CM2
1=ACCESS-ESM1-5
2=CESM2
3=CMCC-CM2-SR5
4=CMCC-ESM2
5=CANESM5
6=EC-EARTH3
7=IITM-ESM
8=KACE-1-0-G
9=MIROC-ES2L
10=MIROC6
11=MPI-ESM1-2-HR
12=MPI-ESM1-2-LR
13=MRI-ESM2-0
14=NORESM2-LM
15=NORESM2-MM
16=UKESM1-0-LL

CESM2 sits around the middle of the pack

Amplified warming of hot days



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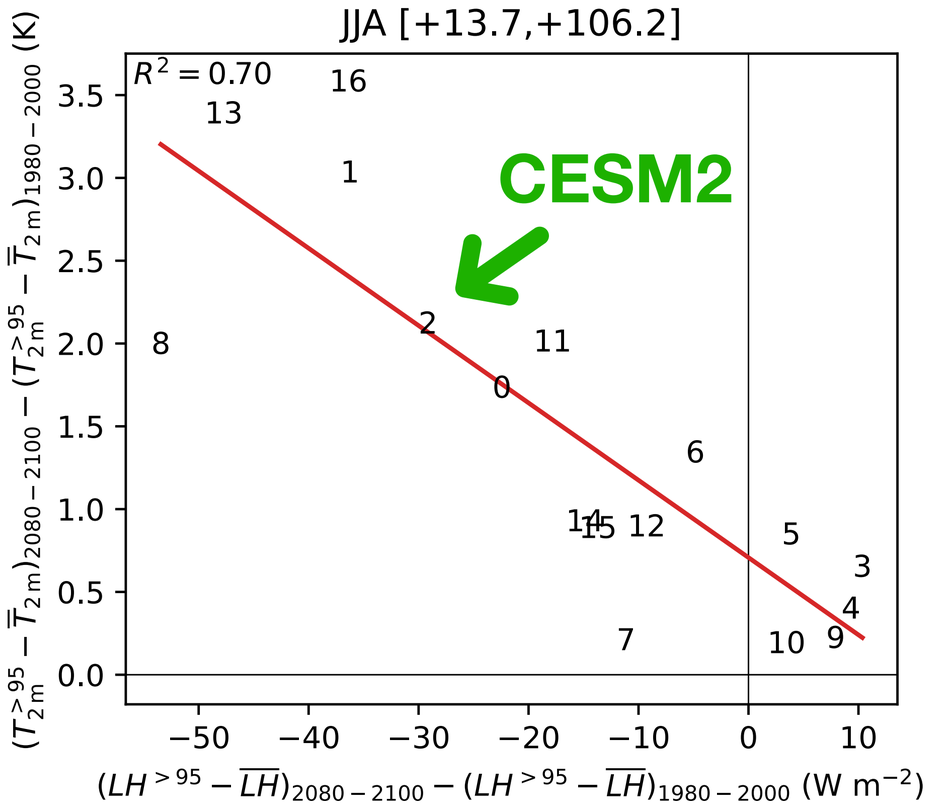

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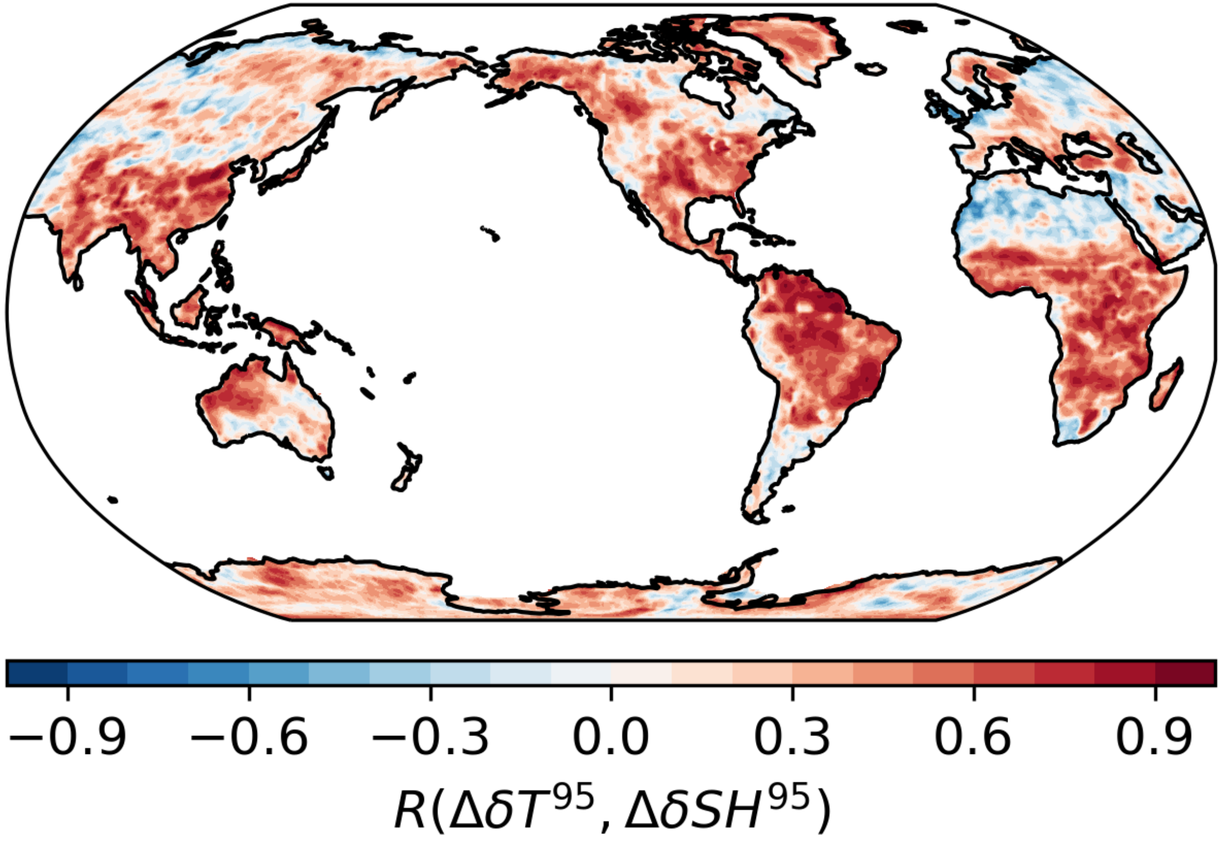
8=KACE-1-0-G
9=MIROC-ES2L
10=MIROC6
11=MPI-ESM1-2-HR
12=MPI-ESM1-2-LR
13=MRI-ESM2-0
14=NORESM2-LM
15=NORESM2-MM
16=UKESM1-0-LL

Enhanced sensible heating on hot days

MI SSP370-HISTORICAL



Reduced evaporative cooling

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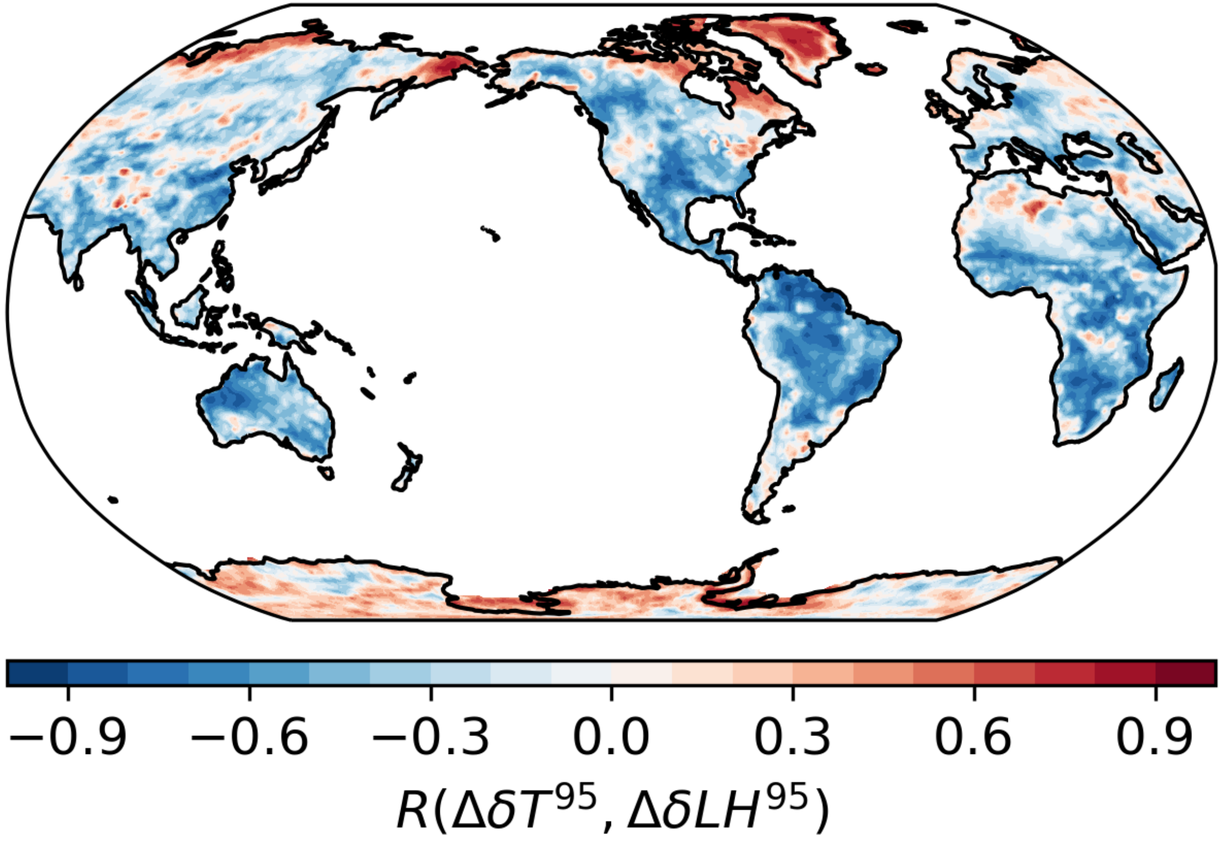
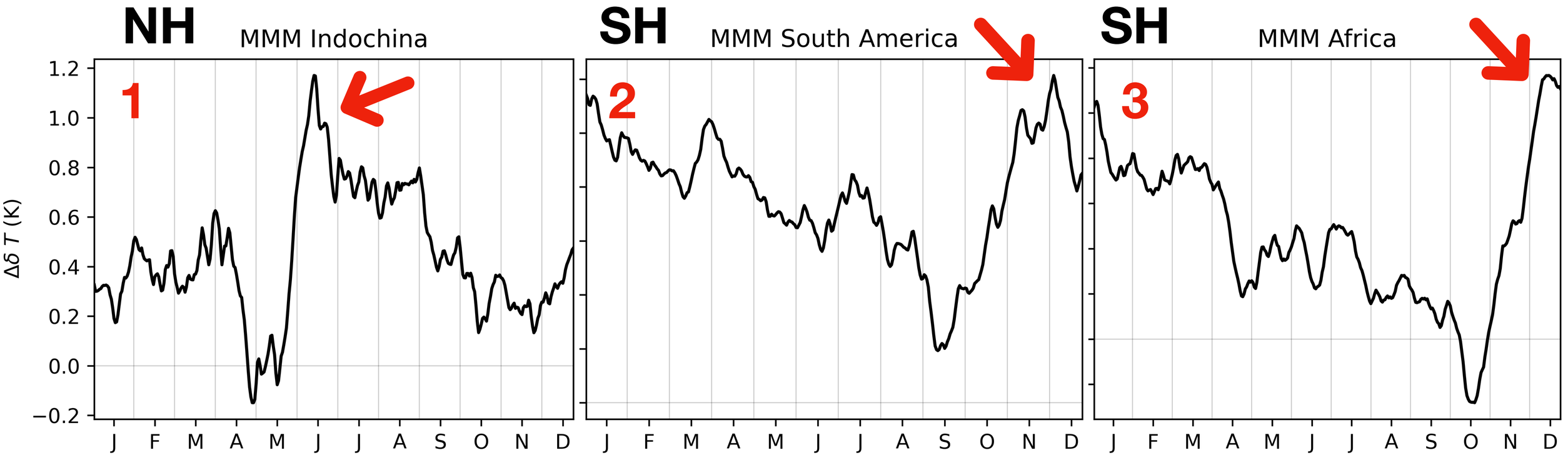


Takeaways

- Amplified warming of hot days exhibits a robust seasonal cycle
  - Warming strongest during summer season



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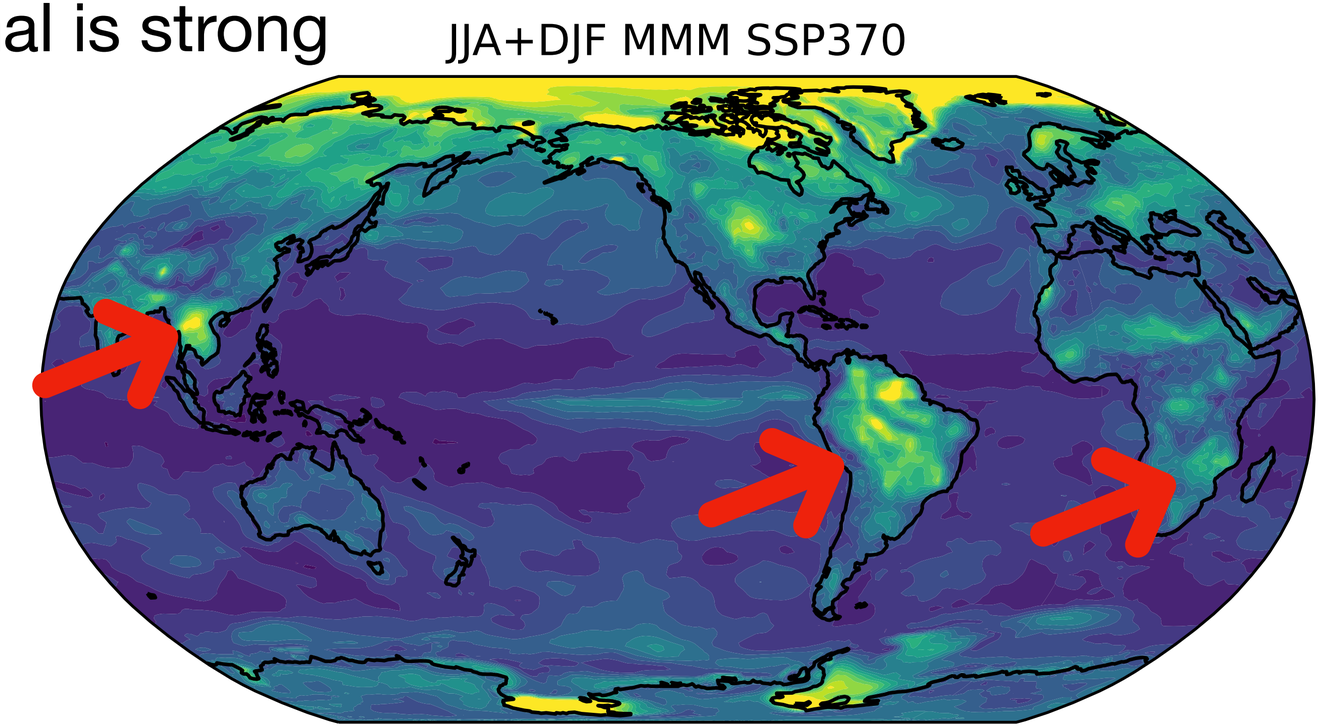
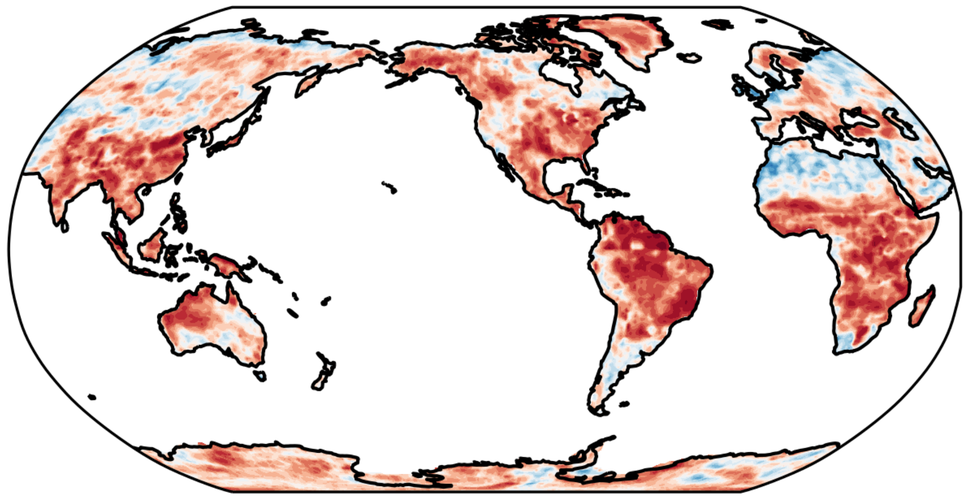


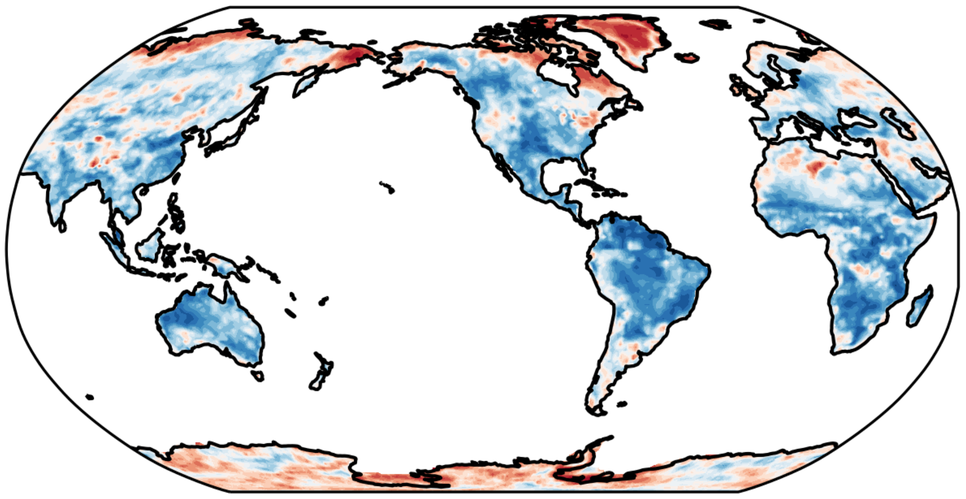
Takeaways

- Amplified warming of hot days exhibits a robust seasonal cycle
  - Warming strongest during summer season
- Models disagree on the magnitude of the amplification where the signal is strong
- Model spread in amplified warming is correlated with the reduced ability to cool evaporatively on those days

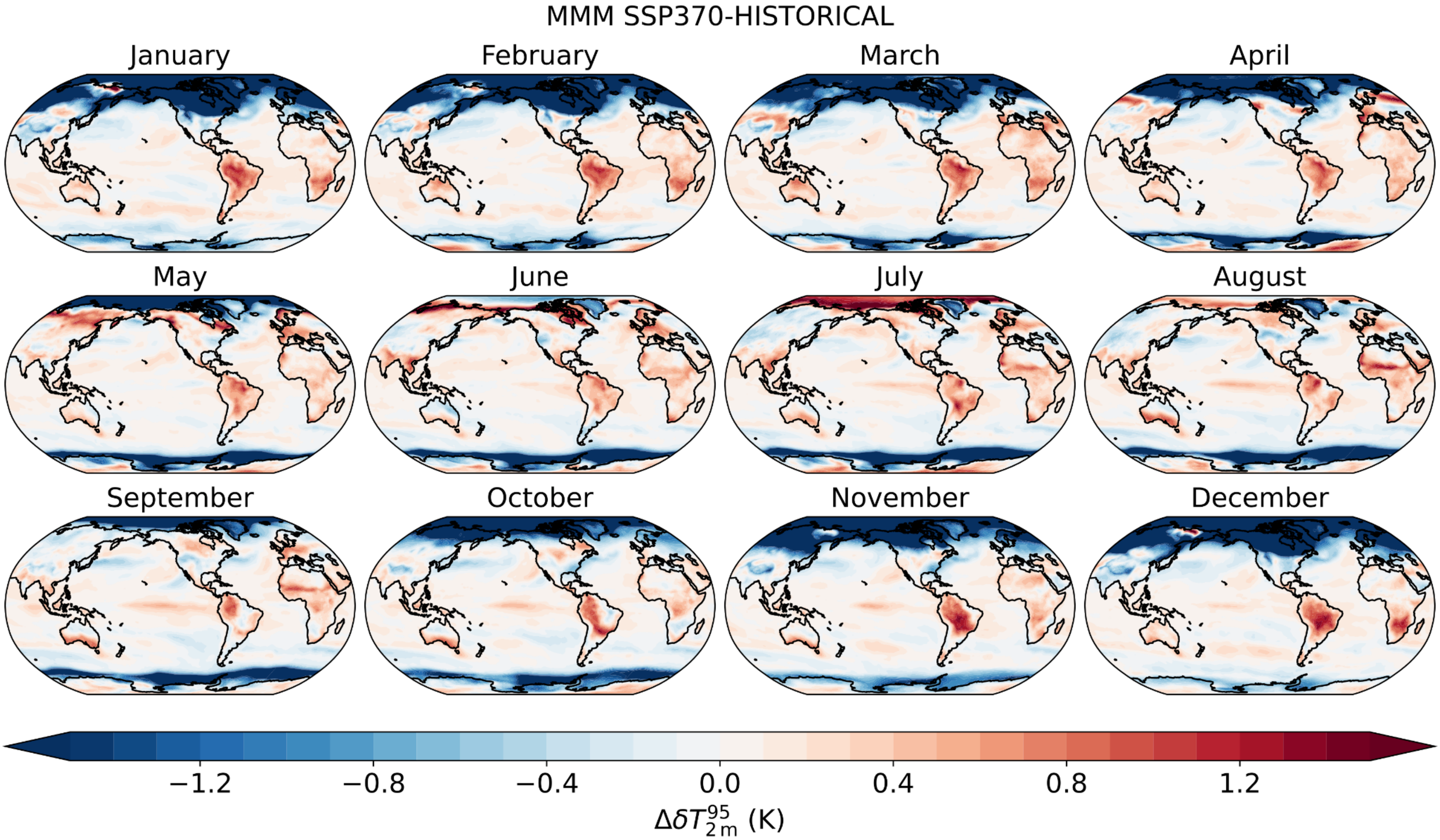
MI SSP370-HISTORICAL



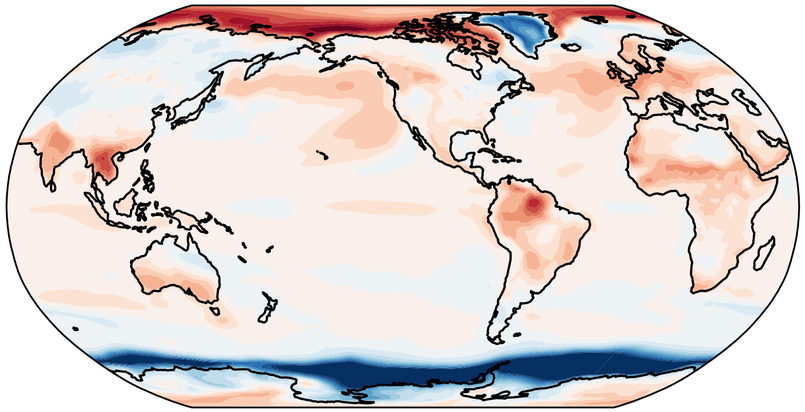
MI SSP370-HISTORICAL



Extras


MMM SSP370-HISTORICAL
January
February
March
April
May
June
July
August
September
October
November
December
−1.2
−0.8
−0.4
0.0
0.4
0.8
1.2
$\Delta\delta T_{2\,\mathrm{m}}^{95}$ (K)

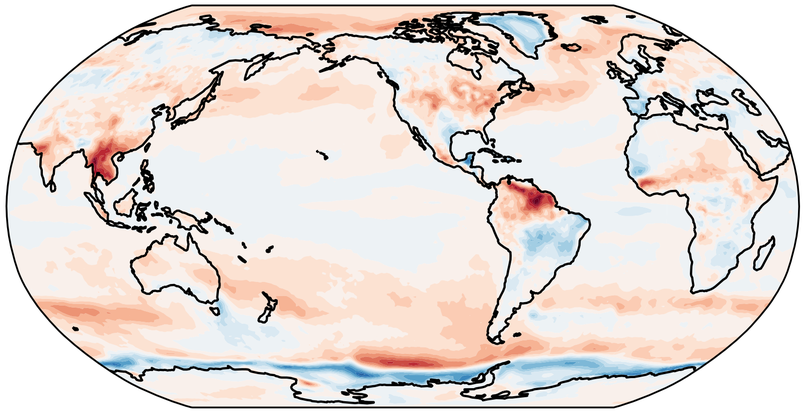
JJA MMM SSP370



−2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0

$(T_{2\,\mathrm{m}}^{>95} - \overline{T}_{2\,\mathrm{m}})_{2080-2100} - (T_{2\,\mathrm{m}}^{>95} - \overline{T}_{2\,\mathrm{m}})_{1980-2000}$ (K)

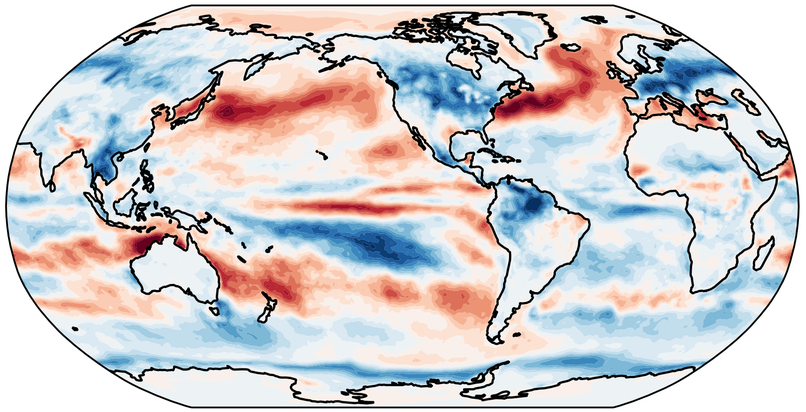
JJA MMM SSP370



−18 −12 −6 0 6 12 18

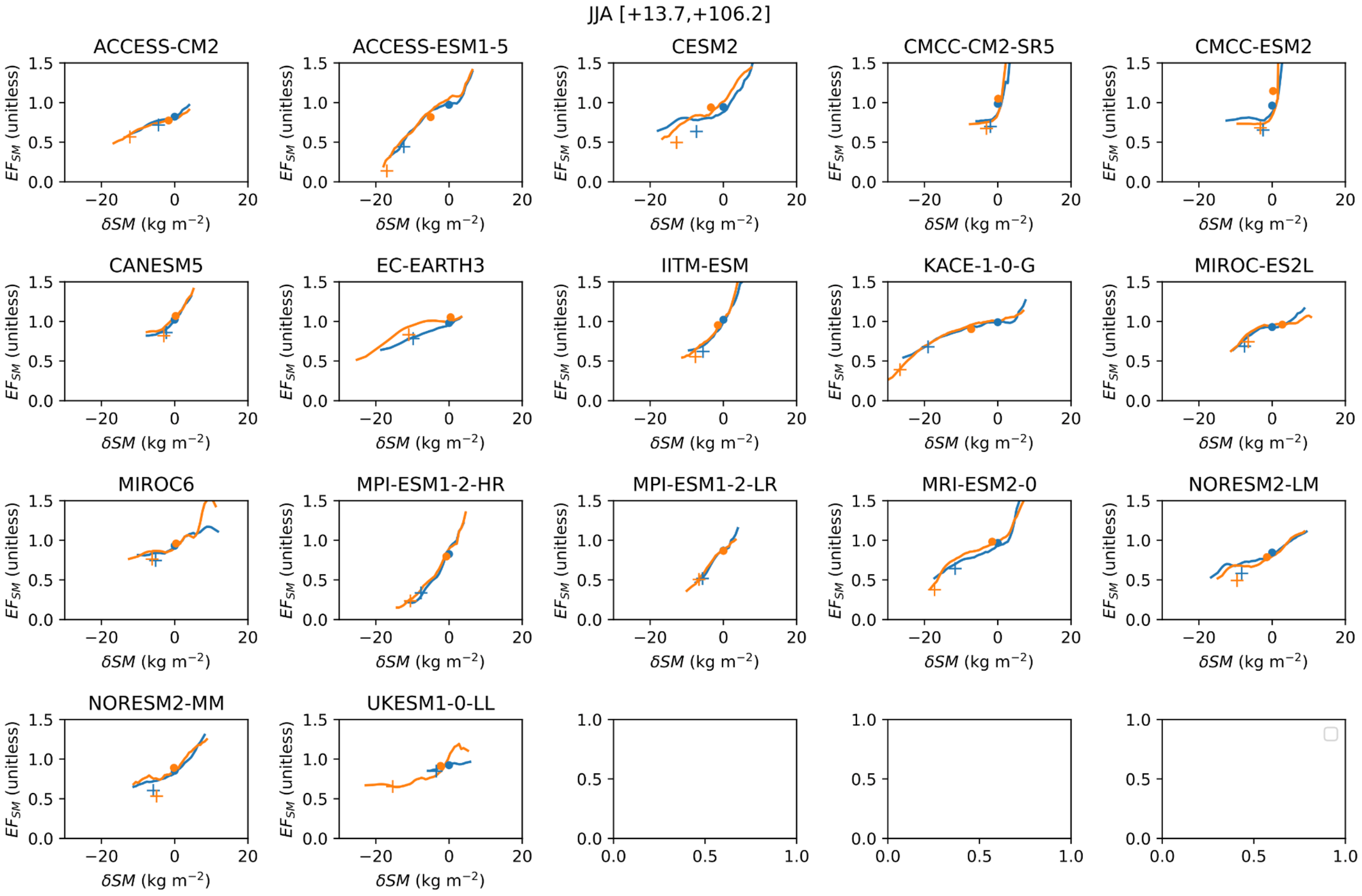
$(SH_{2\,\mathrm{m}}^{>95} - \overline{SH}_{2\,\mathrm{m}})_{2080-2100} - (SH_{2\,\mathrm{m}}^{>95} - \overline{SH}_{2\,\mathrm{m}})_{1980-2000}$ (W m^{-2})

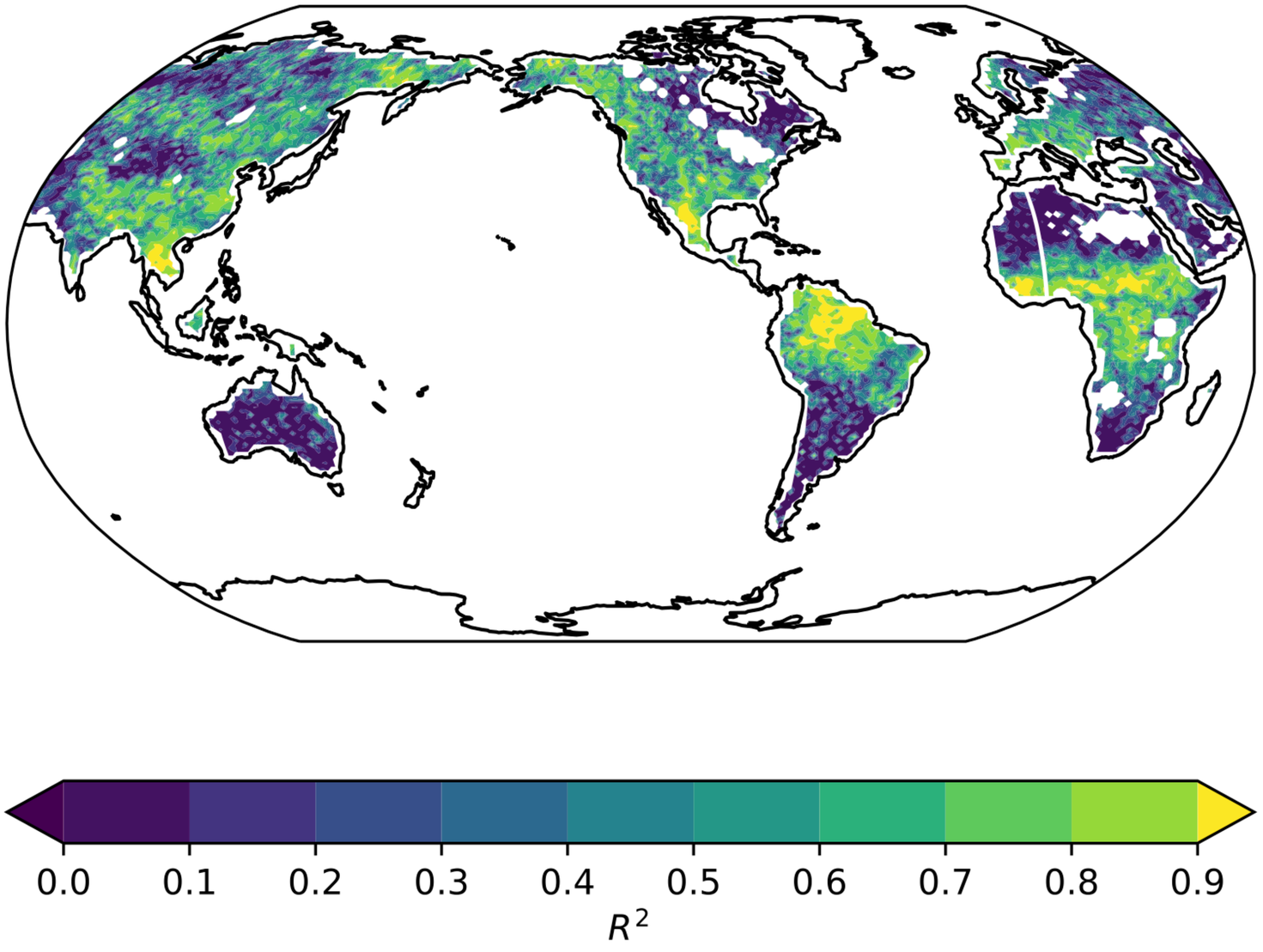
JJA MMM SSP370



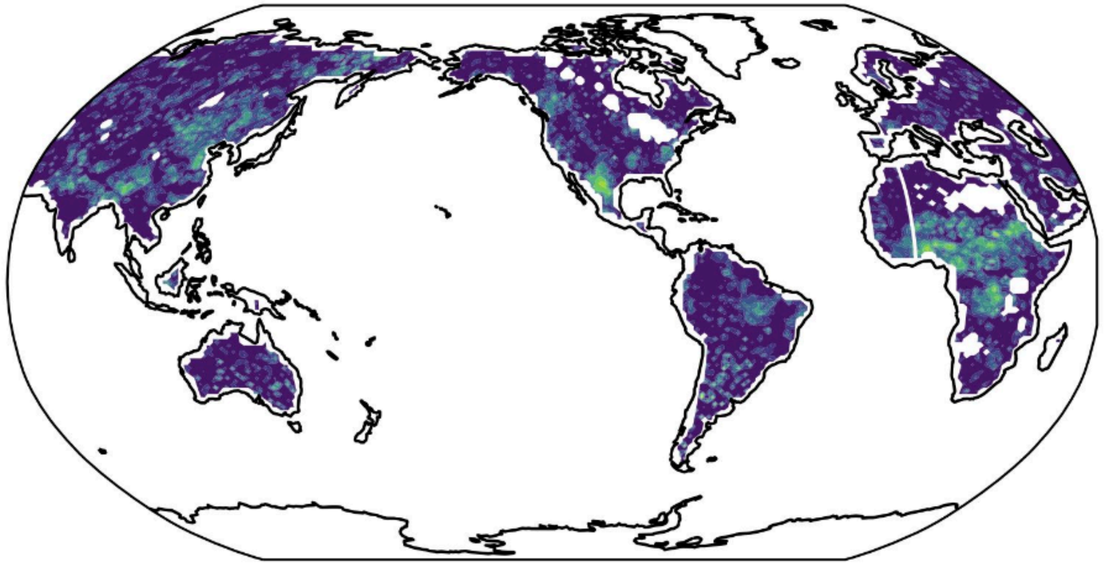
−18 −12 −6 0 6 12 18

$(LH_{2\,\mathrm{m}}^{>95} - \overline{LH}_{2\,\mathrm{m}})_{2080-2100} - (LH_{2\,\mathrm{m}}^{>95} - \overline{LH}_{2\,\mathrm{m}})_{1980-2000}$ (W m^{-2})

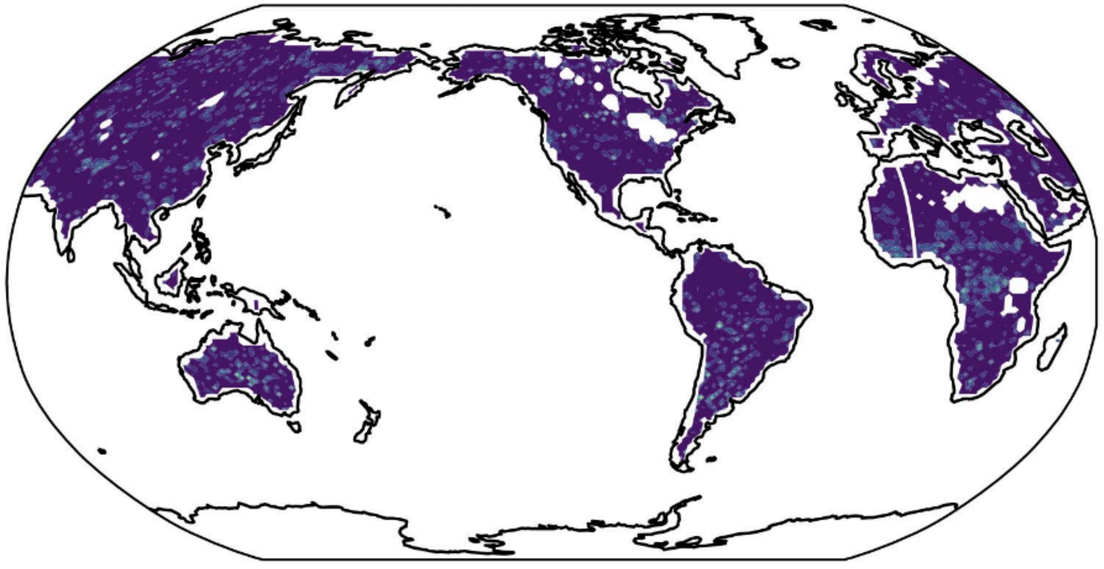

JJA [+13.7,+106.2]
ACCESS-CM2
ACCESS-ESM1-5
CESM2
CMCC-CM2-SR5
CMCC-ESM2
CANESM5
EC-EARTH3
IITM-ESM
KACE-1-0-G
MIROC-ES2L
MIROC6
MPI-ESM1-2-HR
MPI-ESM1-2-LR
MRI-ESM2-0
NORESM2-LM
NORESM2-MM
UKESM1-0-LL
EF_{SM} (unitless)
δSM (kg m^{-2})


ΔEF^{95} Intermodel Variance Explained by
ALL
JJA SSP370
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
R^2

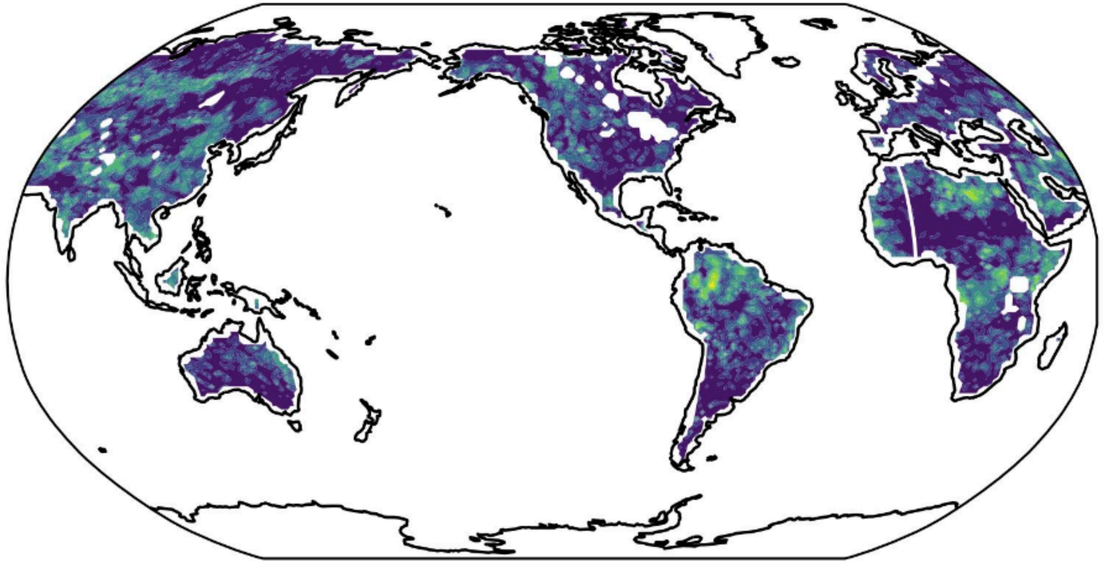
ΔEF^{95} Intermodel Variance Explained by
ΔBC
JJA SSP370



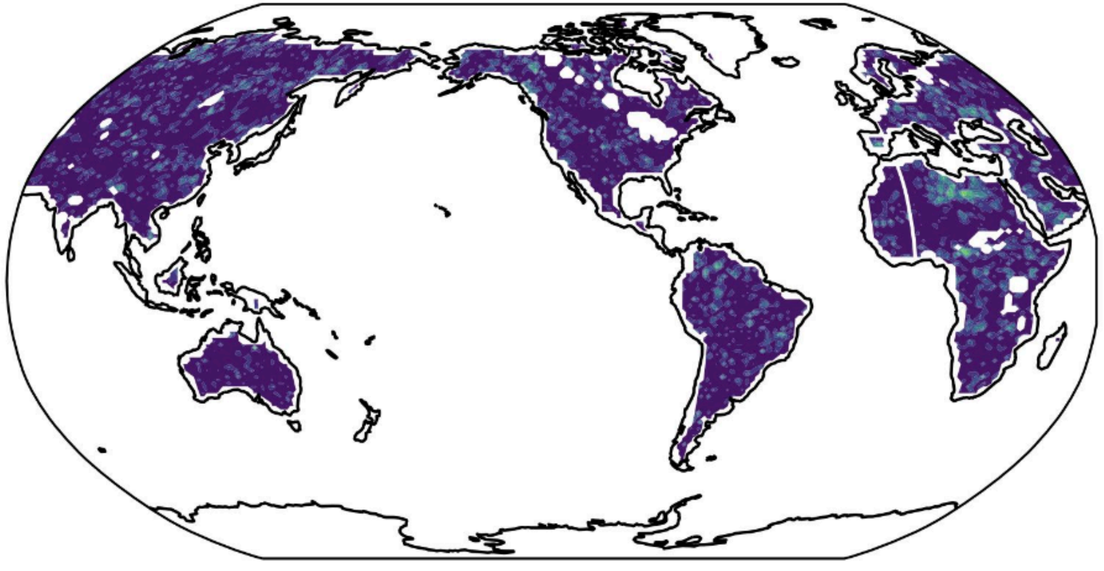
ΔEF^{95} Intermodel Variance Explained by
BC_H
JJA SSP370

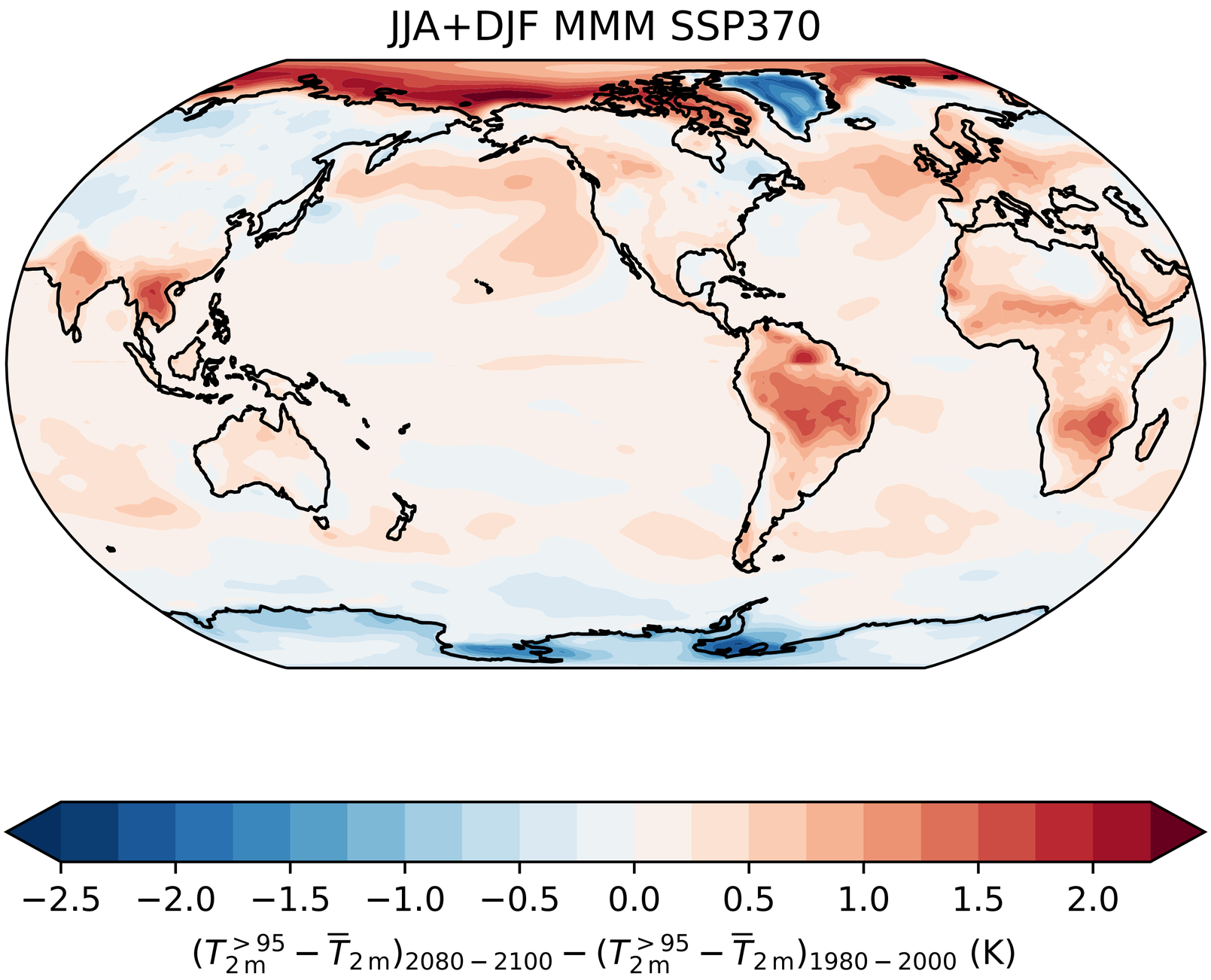


ΔEF^{95} Intermodel Variance Explained by
$\Delta \delta SM$
JJA SSP370



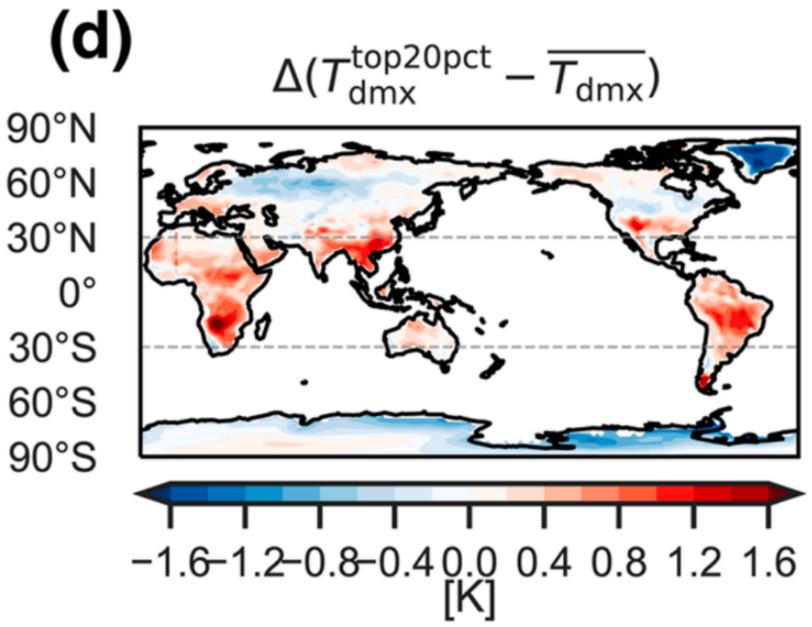
ΔEF^{95} Intermodel Variance Explained by
δSM_H
JJA SSP370




JJA+DJF MMM SSP370
−2.5
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
$(T_{2\,\mathrm{m}}^{>95} - \overline{T}_{2\,\mathrm{m}})_{2080-2100} - (T_{2\,\mathrm{m}}^{>95} - \overline{T}_{2\,\mathrm{m}})_{1980-2000}$ (K)

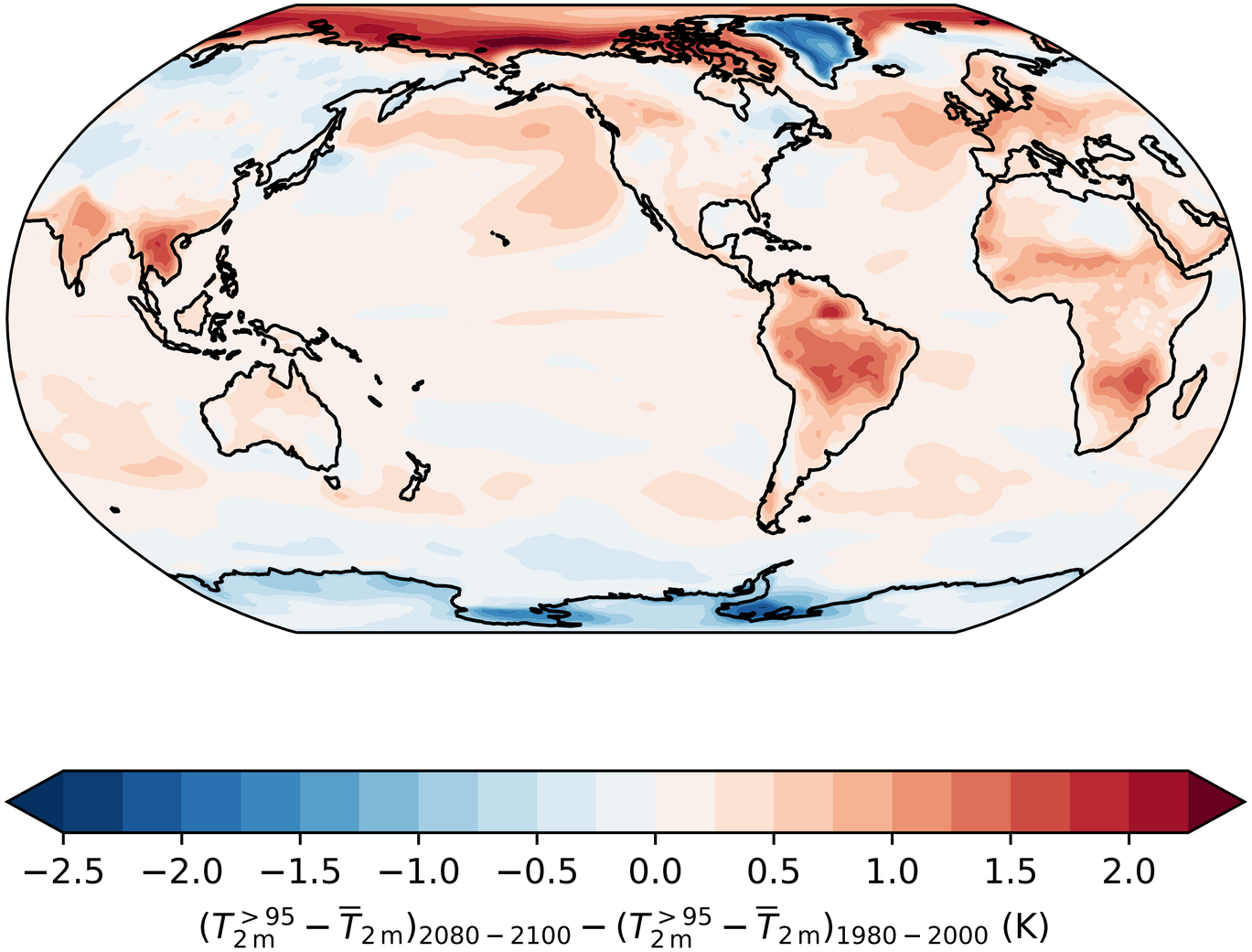
Spatial pattern of amplified warming is robust

CMIP5



CMIP6

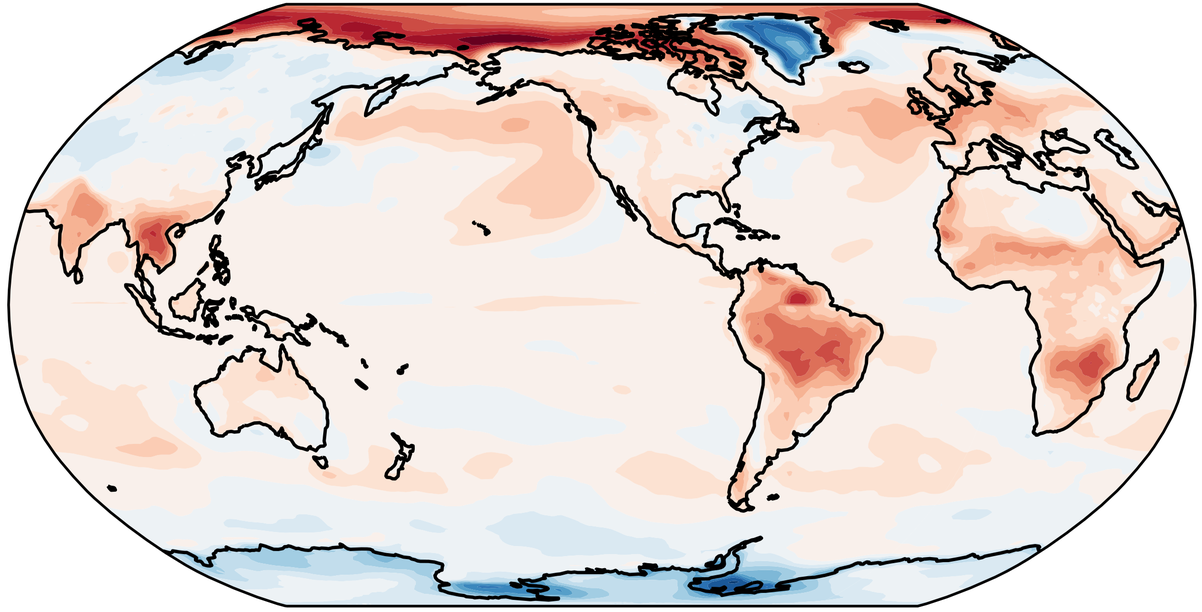
JJA+DJF MMM SSP370

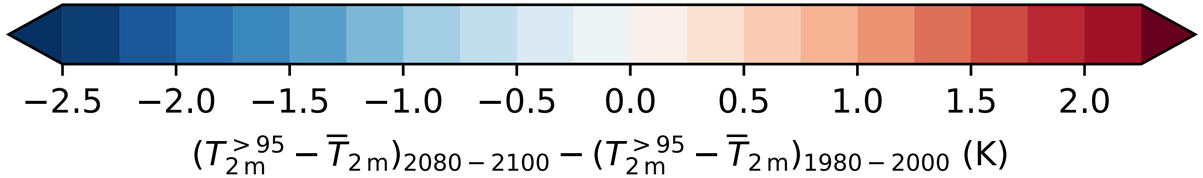


Duan et al. (2020)

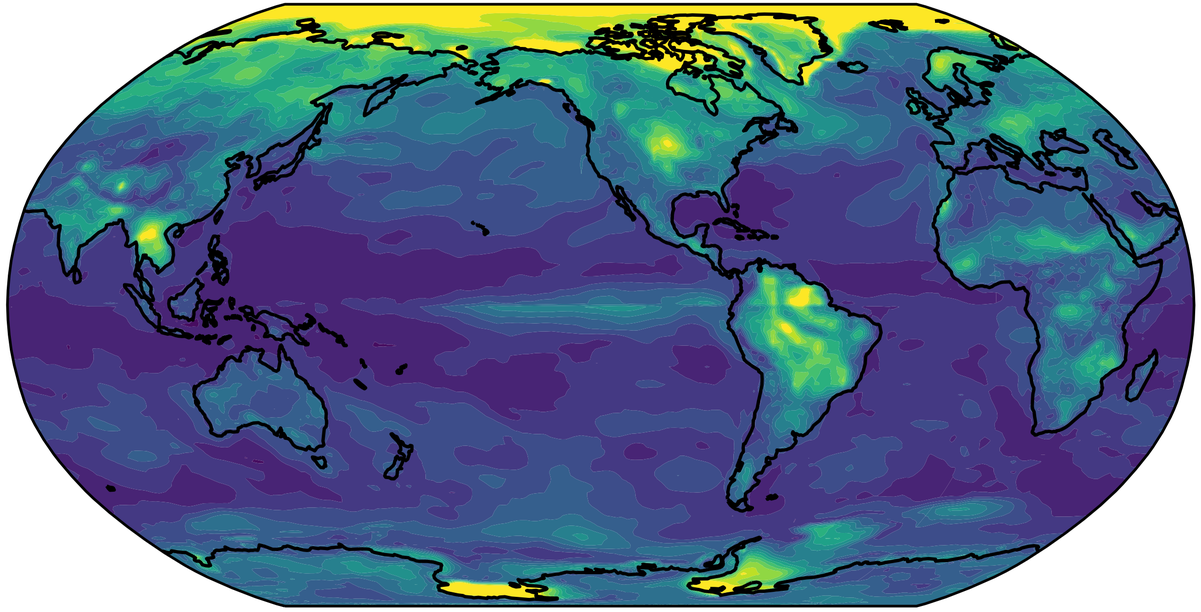
However, models disagree on the magnitude of amplification

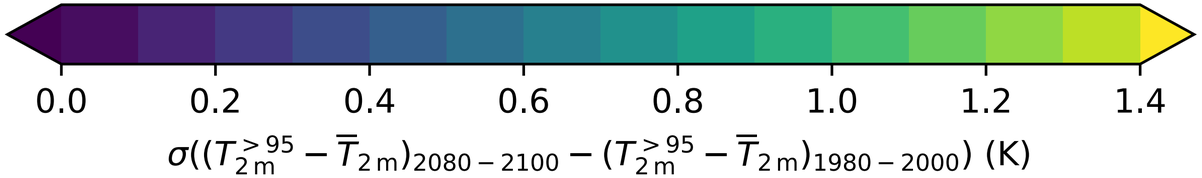
JJA+DJF MMM SSP370





JJA+DJF MMM SSP370





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