"Local and remote climate effects of regional pollutant emissions"

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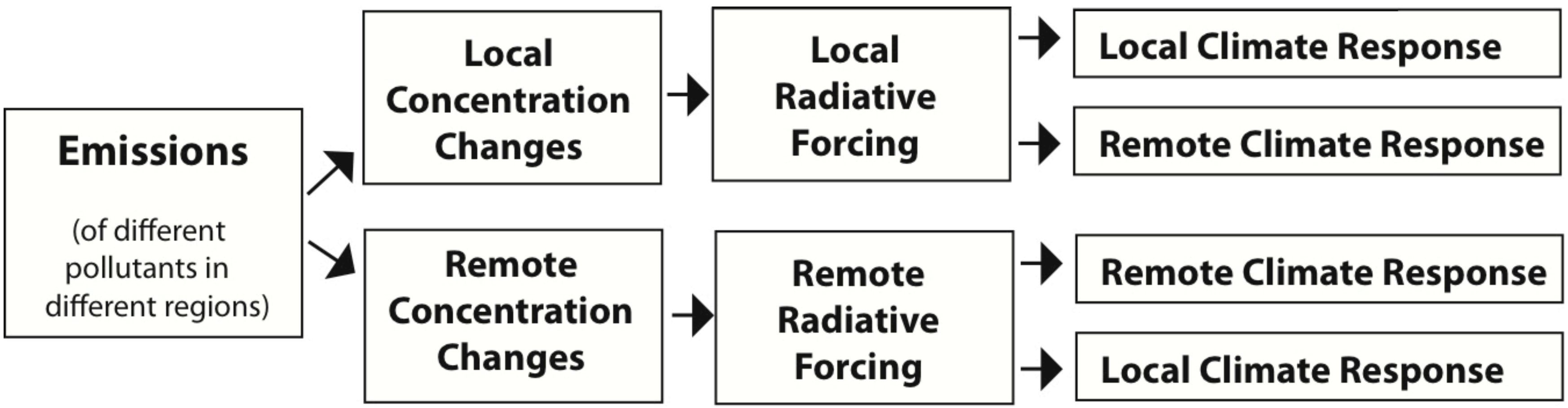
(+thanks to the Met Office for computing)

Imperial College London

NERC SCIENCE OF THE ENVIRONMENT

Processes involved



- A combination of model diagnostics (chemistry, radiation, thermodynamics, dynamics) and sensitivity experiments can facilitate breaking down the *emission-concentration-forcing-response chain* into its individual parts.

Regional emission reduction simulations with

HADGEM3-AO

Kasoar, Voulgarakis et al. *(in prep. 1)*

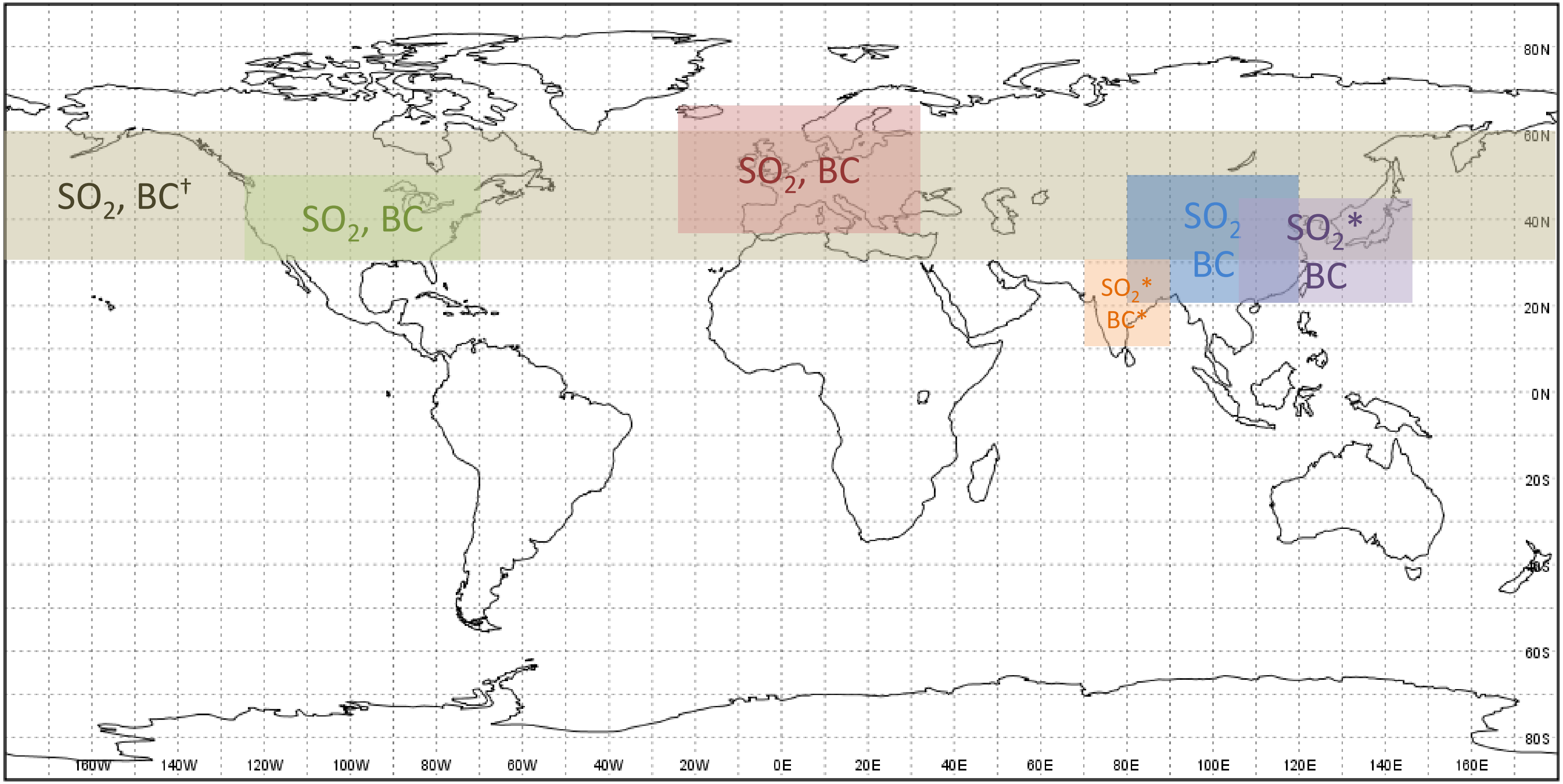
1.875°x1.25° resolution, 85 levels up to 85km
1° NEMO ocean (75 depth levels) and CICE sea-ice
CLASSIC aerosol scheme

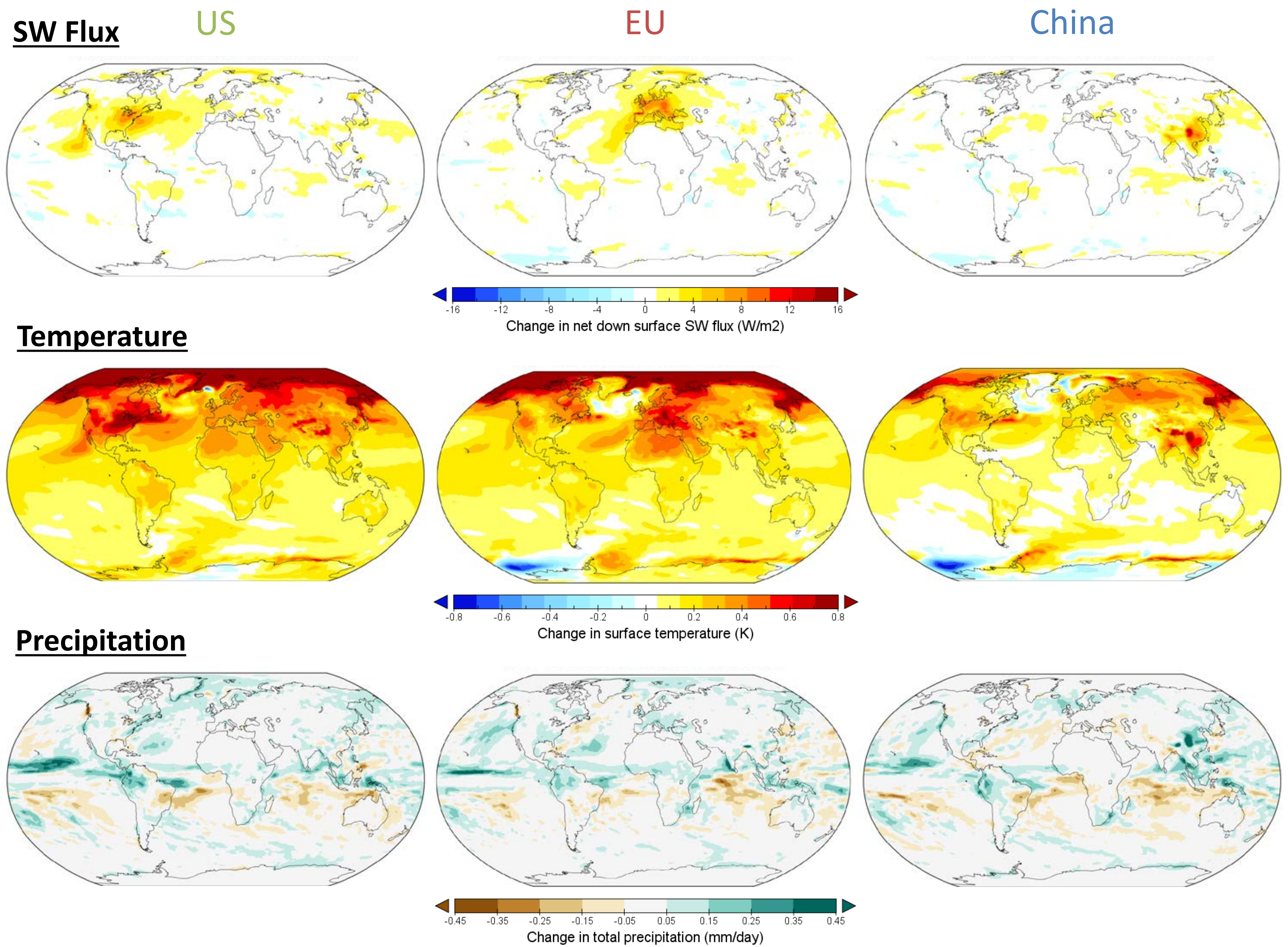
200 year simulations, repeating year 2000 emissions
Remove emission of interest from individual regions

Met Office

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

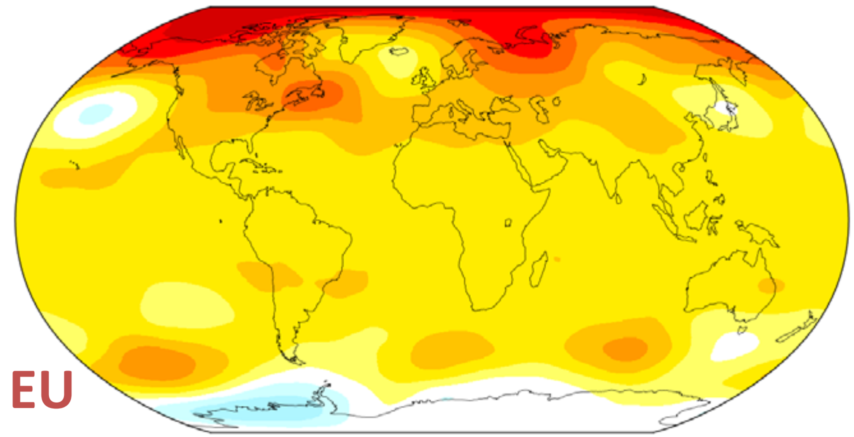
Regions where emissions are perturbed

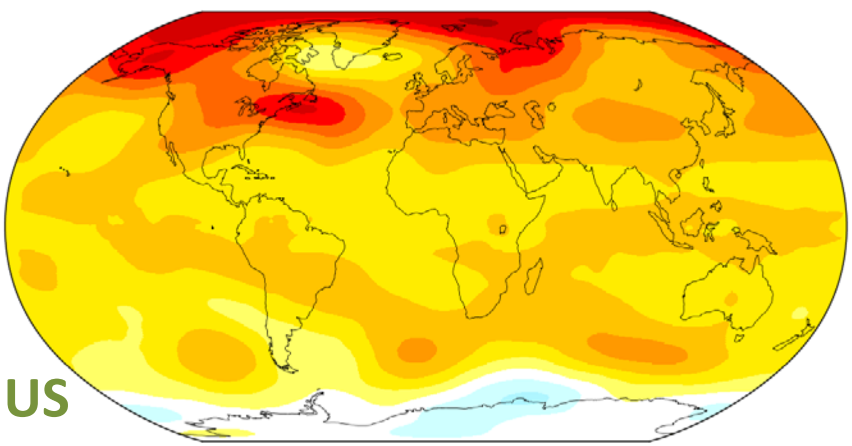


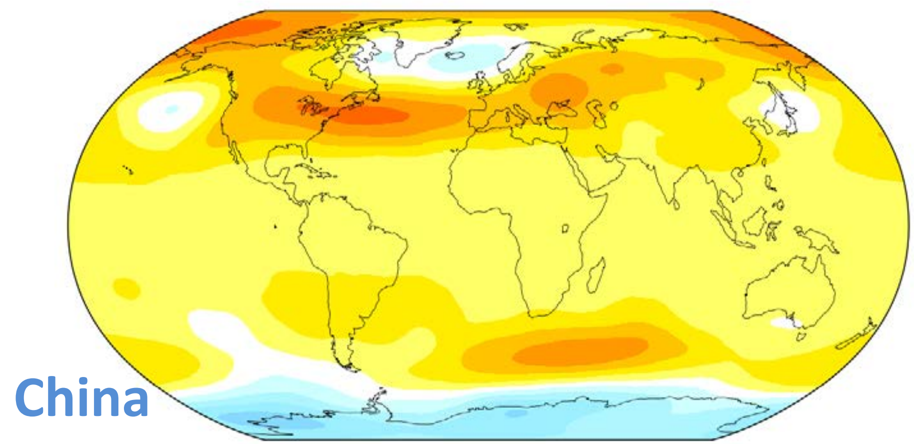

SW Flux
US
EU
China
-16 -12 -8 -4 0 4 8 12 16
Change in net down surface SW flux (W/m2)
Temperature
-0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8
Change in surface temperature (K)
Precipitation
-0.45 -0.35 -0.25 -0.15 -0.05 0.05 0.15 0.25 0.35 0.45
Change in total precipitation (mm/day)

Dynamical changes (geopotential height anomalies) in above SO_2 cases

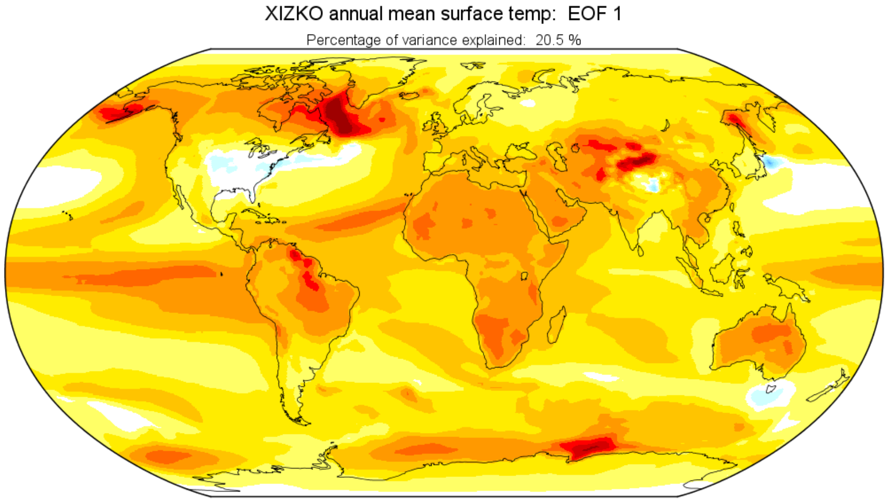
- Similarity in pattern of responses
  corresponds to similar dynamical structure.



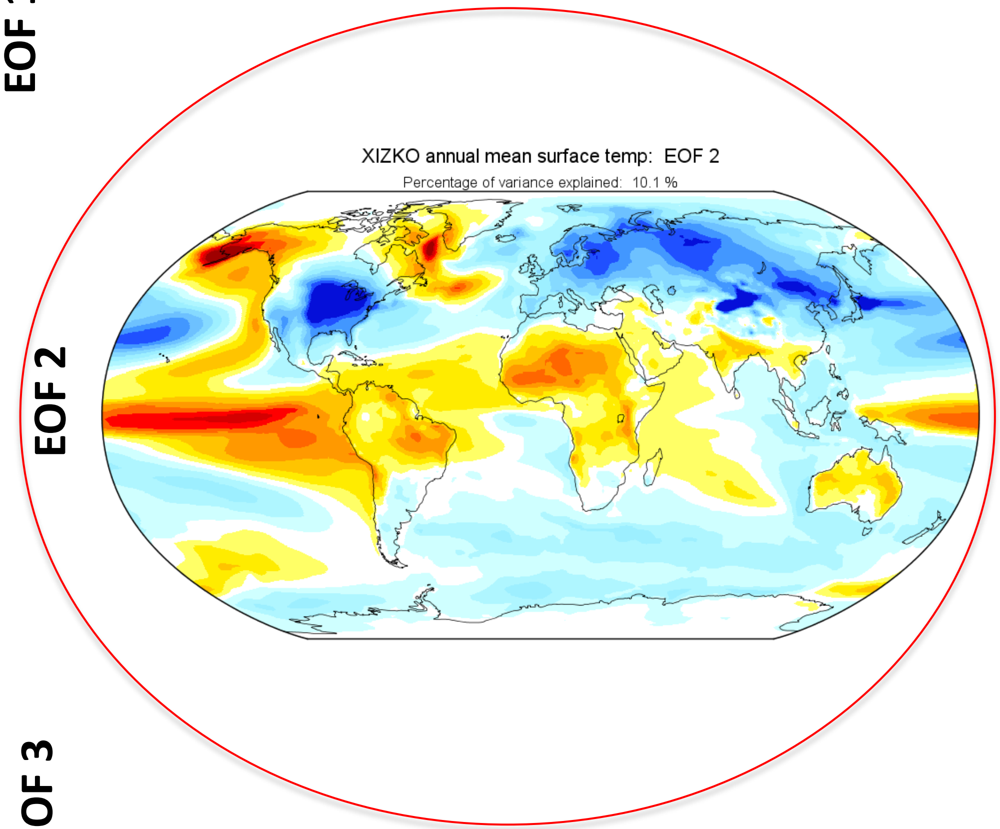




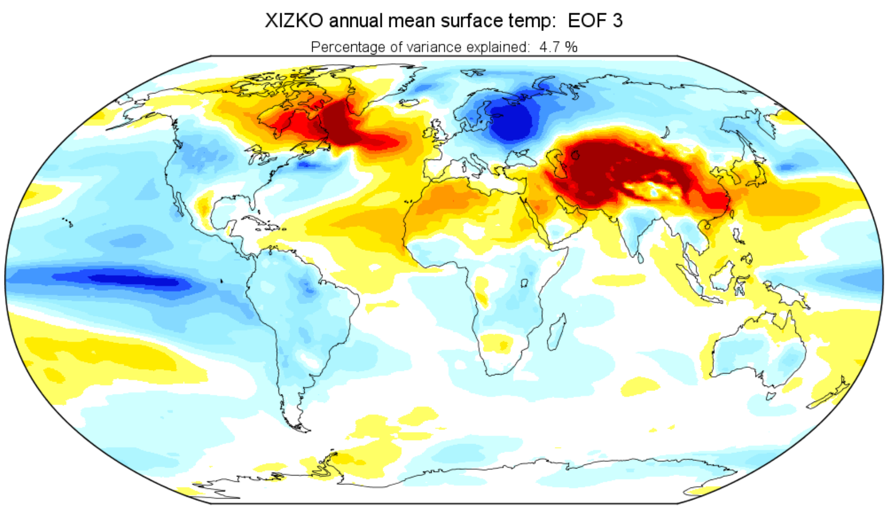
Leading EOFs in temperature in the control run



EOF 1

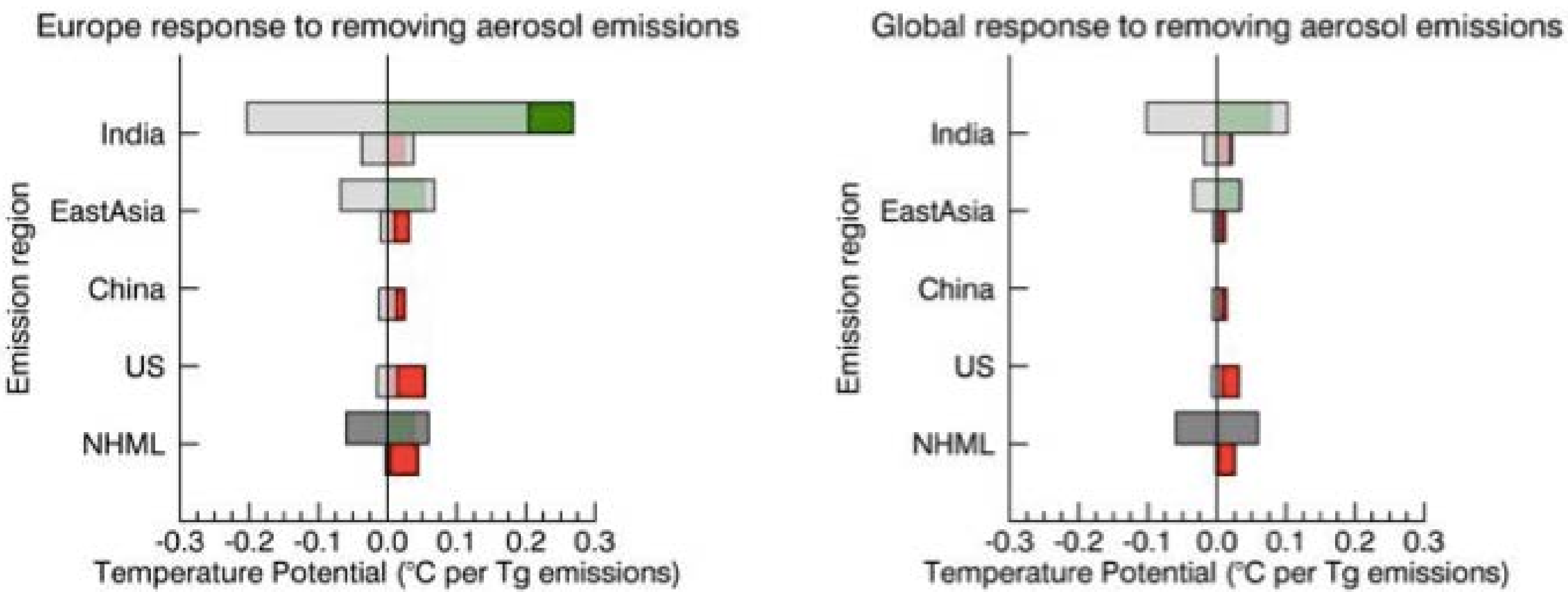


EOF 2



EOF 3

Such simulations can be valuable for creating regional emission metrics



Green: BC, Red: Sulphate, Grey: Uncertainty.

HadGEM3
1.875° x 1.25°; 85 vertical levels

CESM1
2.5° x 1.875°; 30 vertical levels

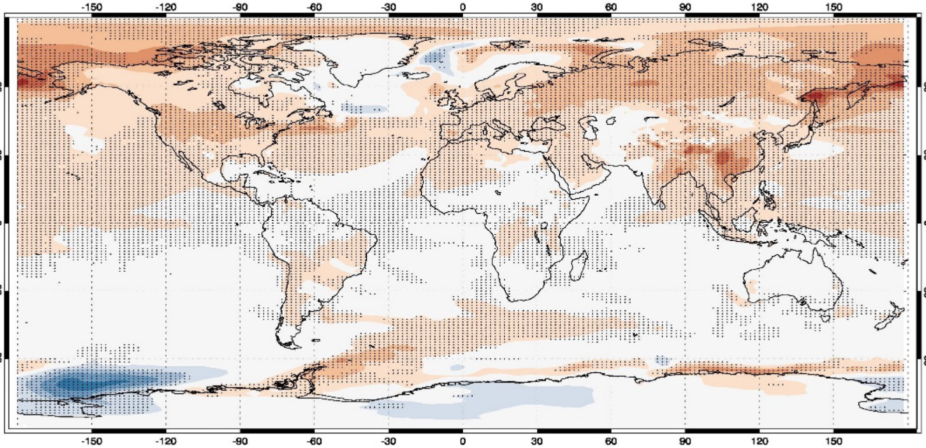
GISS-E2
2.5° x 2°; 40 vertical levels

Investigating China SO_2 removal with

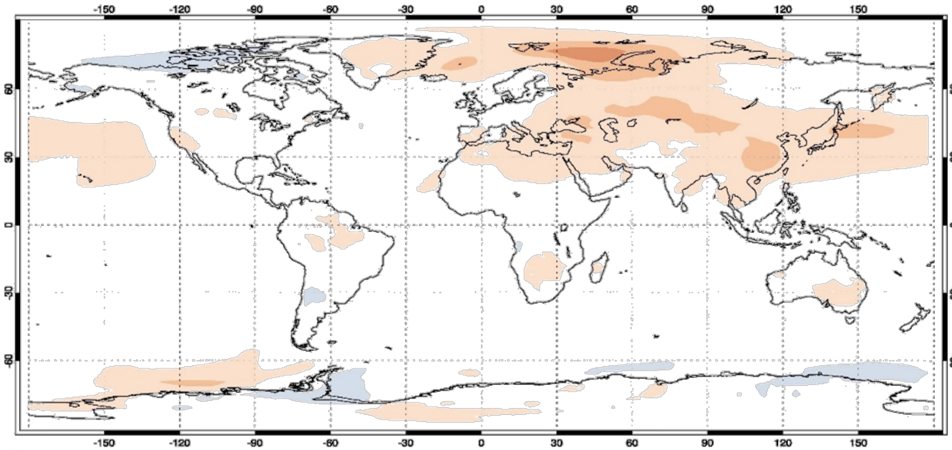
3X AS MANY MODELS

Kasoar, Voulgarakis et al. *(in prep. 2)*

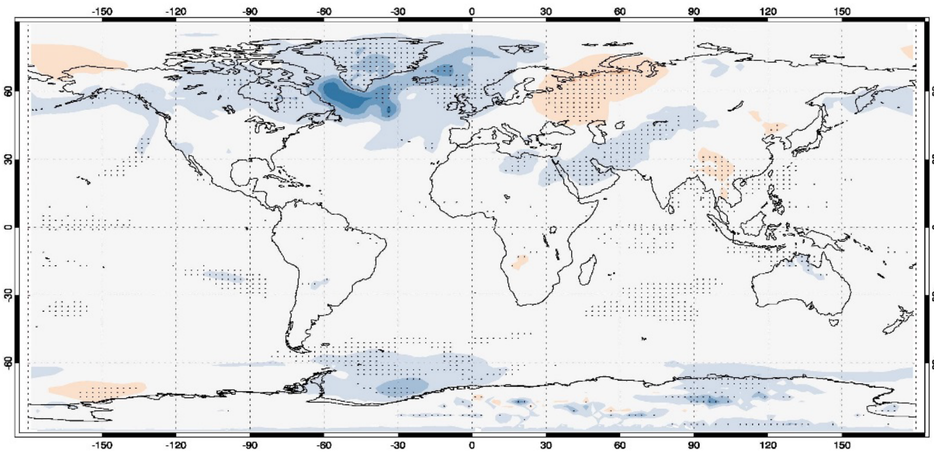
Temperature response in three CCMs



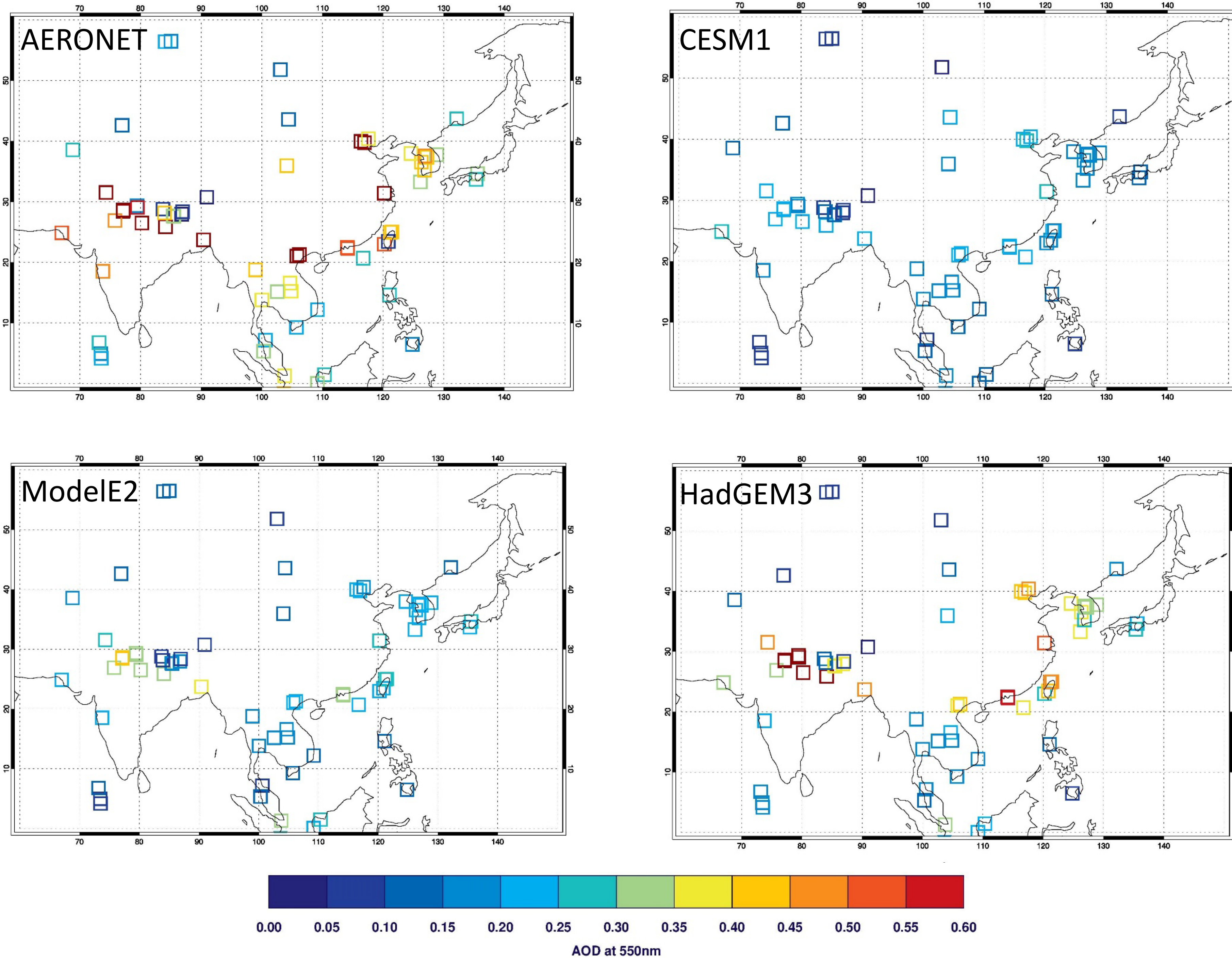
Met Office HadGEM3



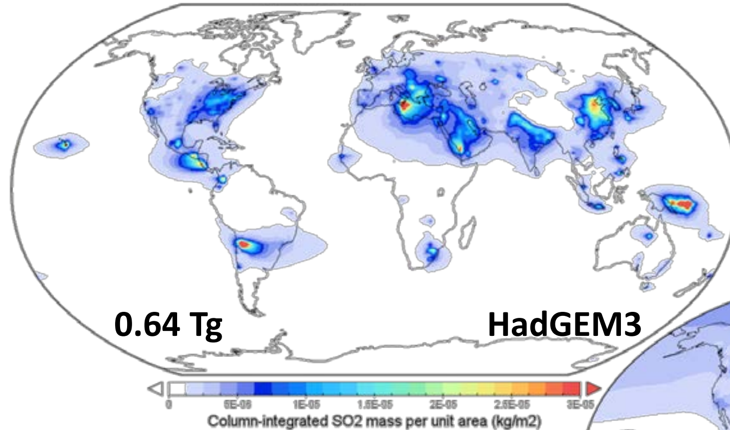
NCAR CESM1

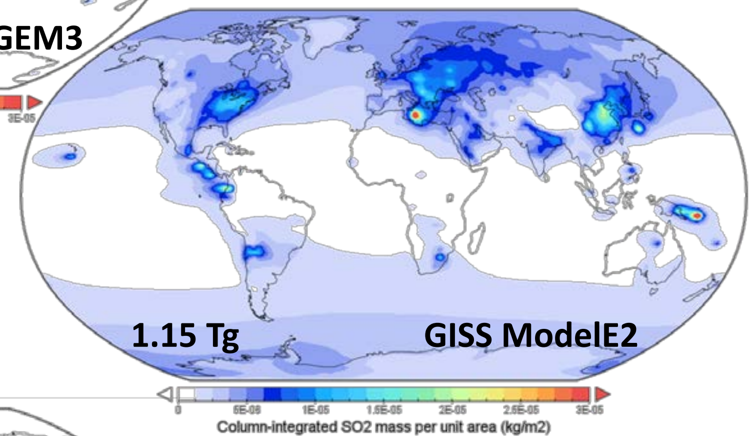


NASA GISS ModelE2


AERONET
CESM1
ModelE2
HadGEM3
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
0.60
AOD at 550nm

Differences between HadGEM3 and GISS-E2

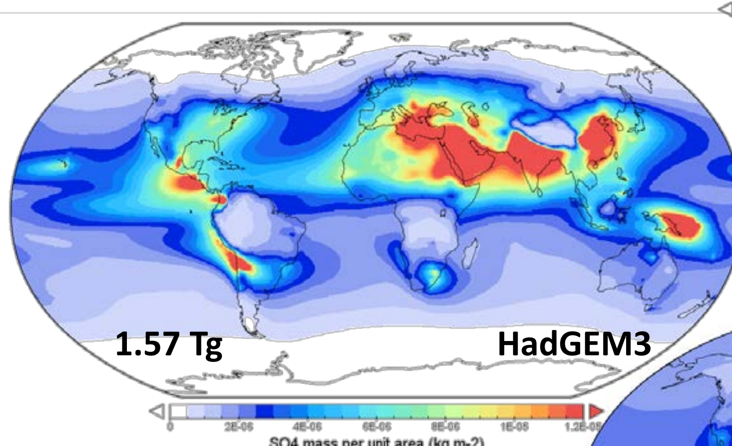


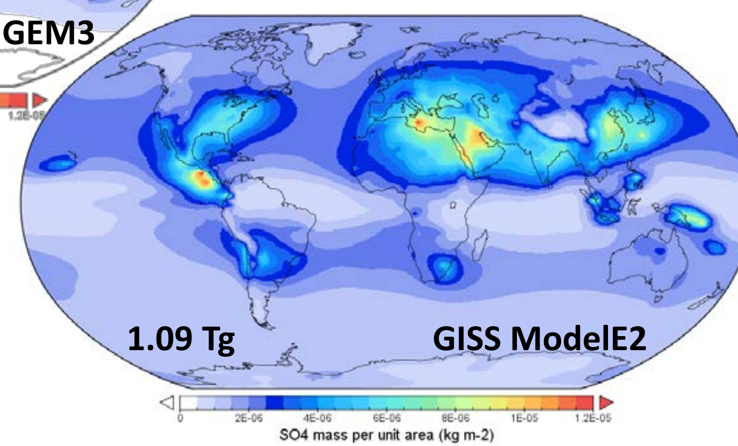


SO_2

Global SO_2 dry deposition:

- HadGEM3 = **406.2** kg(S)/s
- GISS-E2 = **1399** kg(S)/s





SO_4

Global SO_2 dry oxidation:

- HadGEM3 = **609.3** kg(S)/s
- GISS-E2 = **681.9** kg(S)/s

Global SO_2 wet processing:

- HadGEM3 = **1419** kg(S)/s
- GISS-E2 = **742.5** kg(S)/s

Conclusions

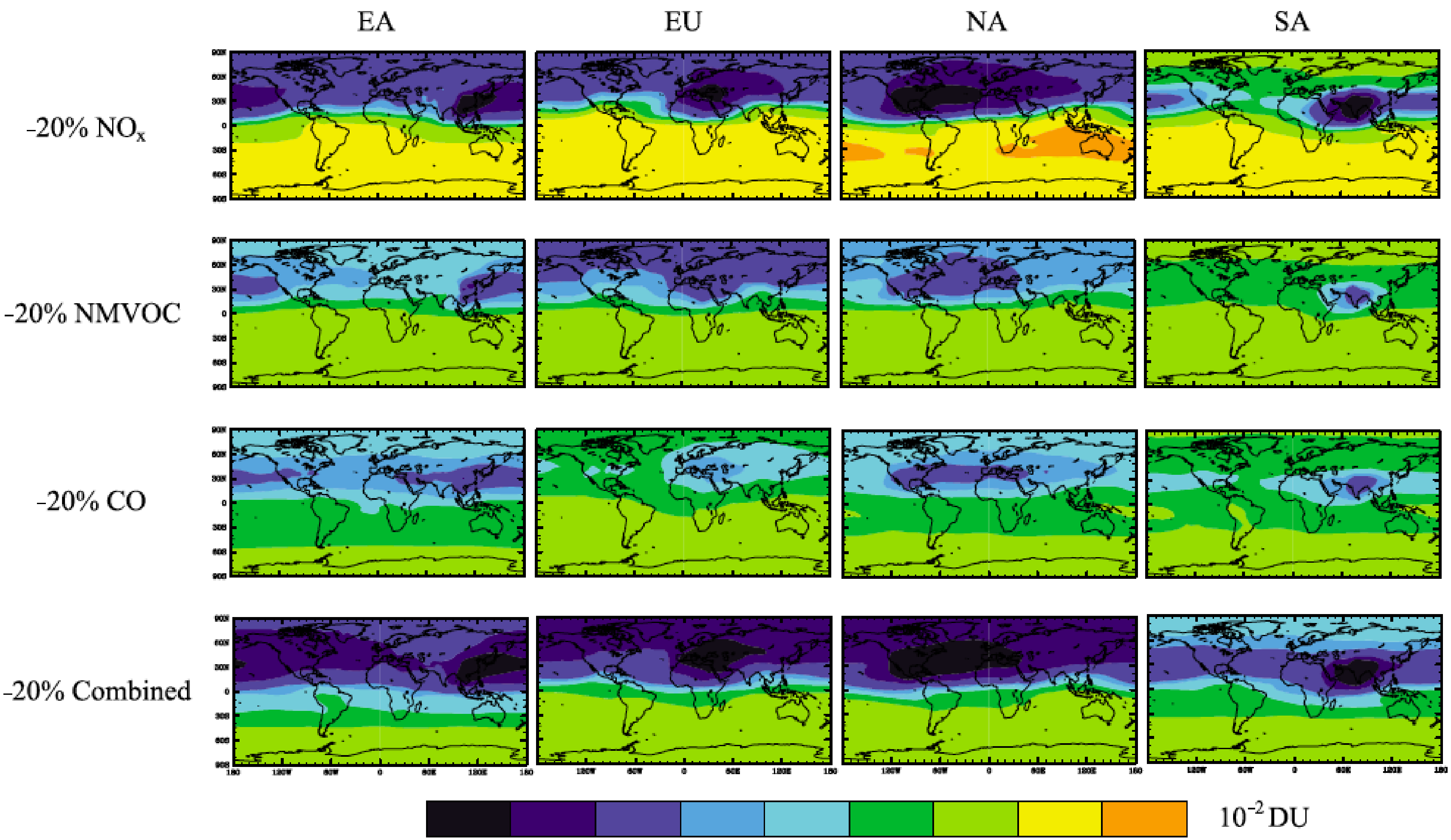
- Present-day BC effects are small compared to SO_2.
- Strong hemisphere-wide response to localised mid-latitude forcing. International agreements needed.
- Large model diversity in sensitivity to SO_2 emission reductions, mainly due to aerosol processing.

Future Work

- Perform more simulations (e.g. Europe, tropics, ozone precursors, organic carbon).
- Further investigate the processes (& connection to modes of variability).
- Include more models; dedicated intercomparison?
  -> Links with PDRMIP & beyond.

THANK YOU!!

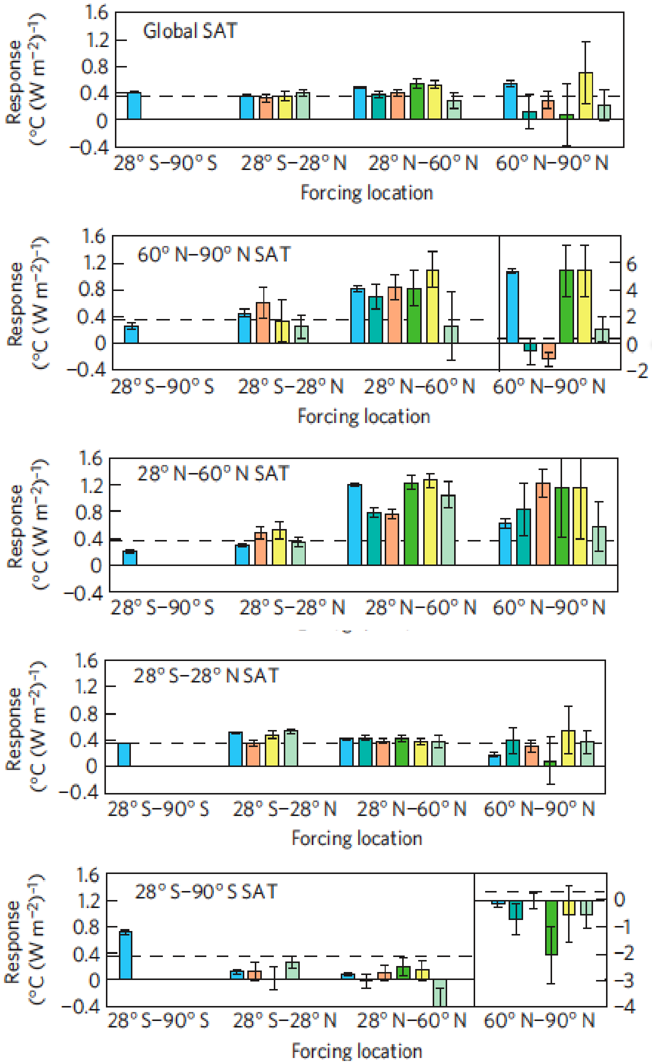
Systematic studies on source-receptor relationships

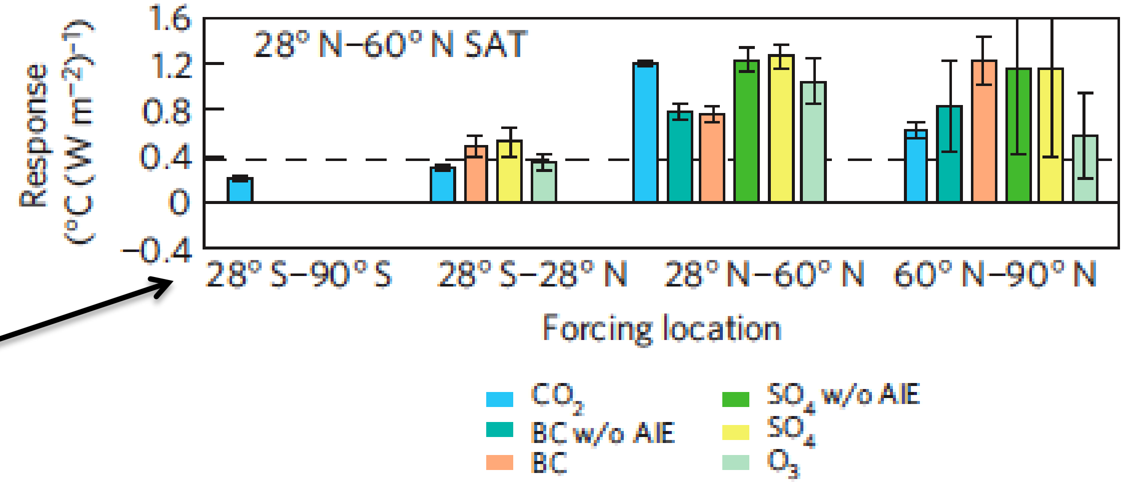


Fry et al., *JGR* (2012)

- Typically pollution-oriented.
- Occasionally look at radiative forcing, but not at climate responses.

One study systematically examined regional forcing-response relationships



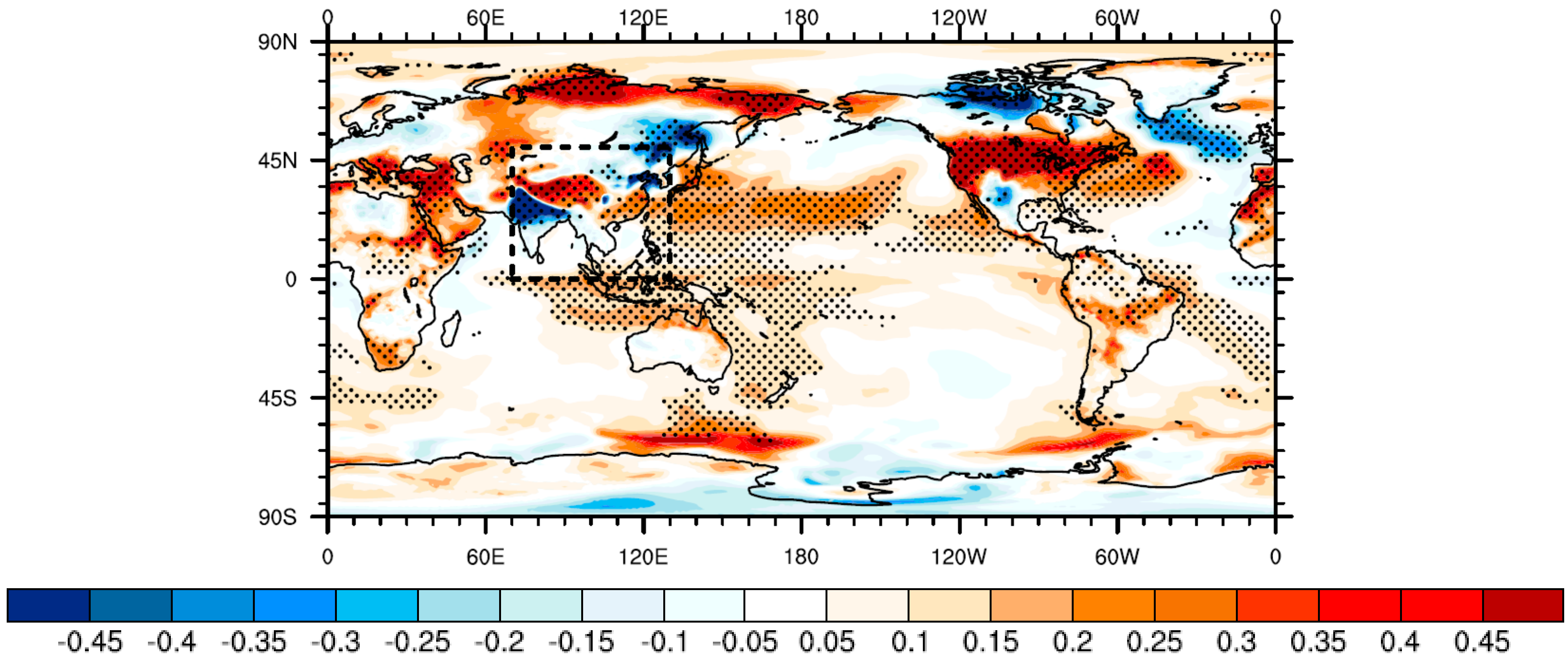


- WMGHGs, aerosols and O_3 were perturbed, to examine how global and regional temperature responds to forcings in different latitude zones (tropics, northern midlatitudes etc).

Shindell and Faluvegi, *Nature Geosci.* (2009)

Also see: Voulgarakis & Shindell *J. Climate* (2010); Shindell, Voulgarakis et al., *ACP* (2012)

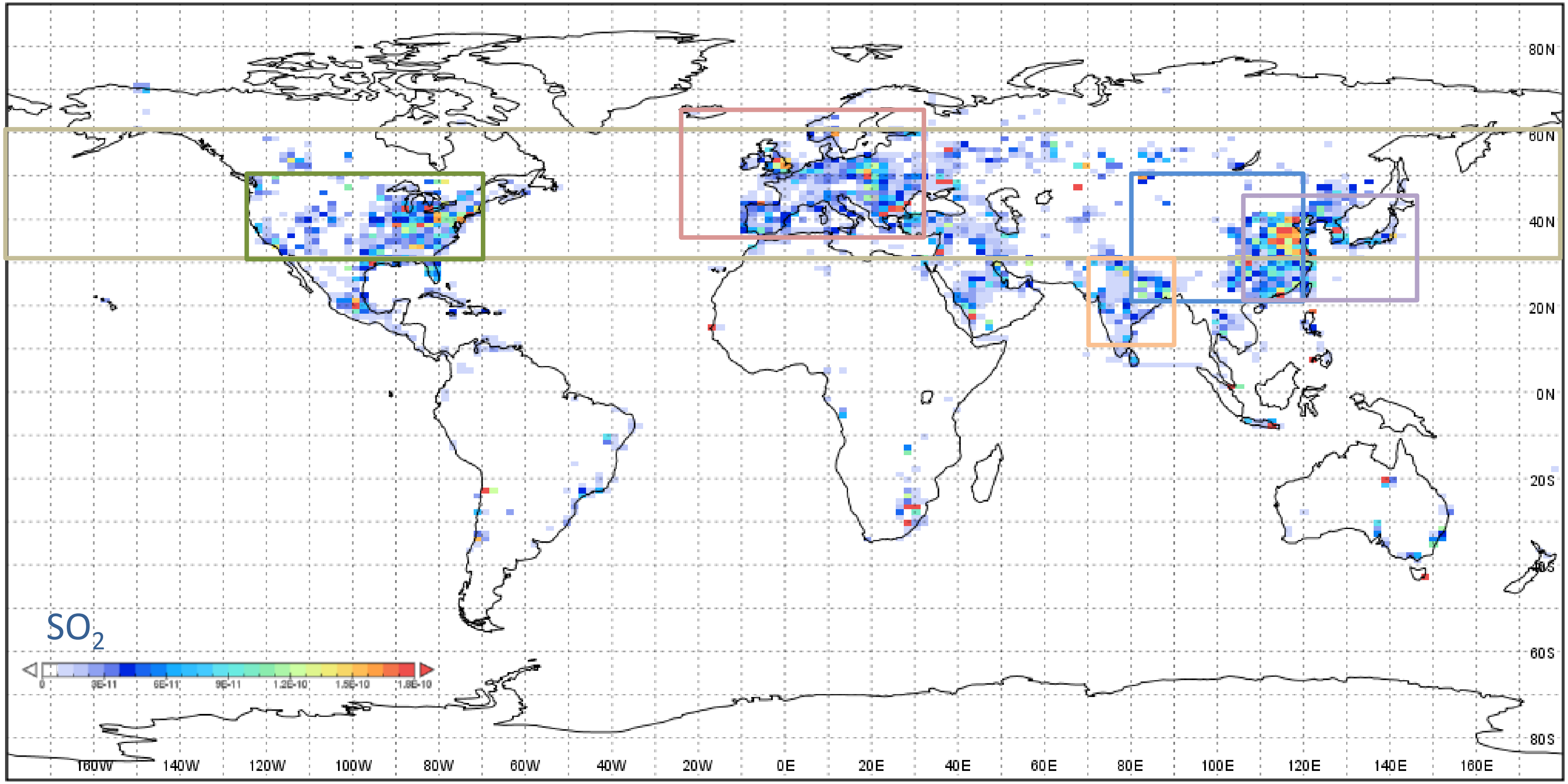
Very few studies actually separated remote effects on climate



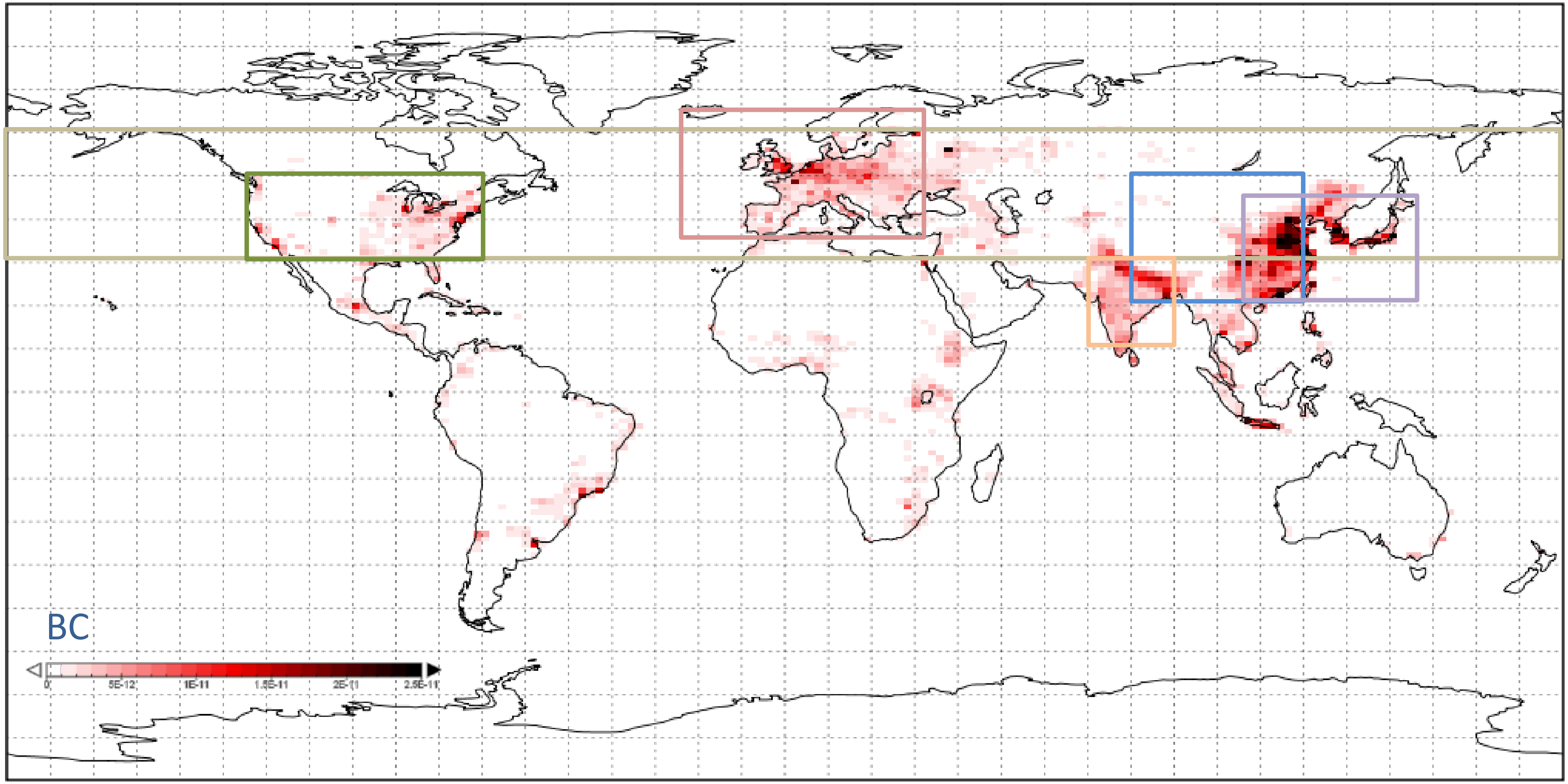
Teng et al., *GRL* (2012)

- Have only focused on particular regions/species; did not systematically examine different effects, or thoroughly explored the mechanisms.
- E.g. above study found that East Asian carbonaceous aerosol emissions can have drastic effects on US temperature.

Why those regions?



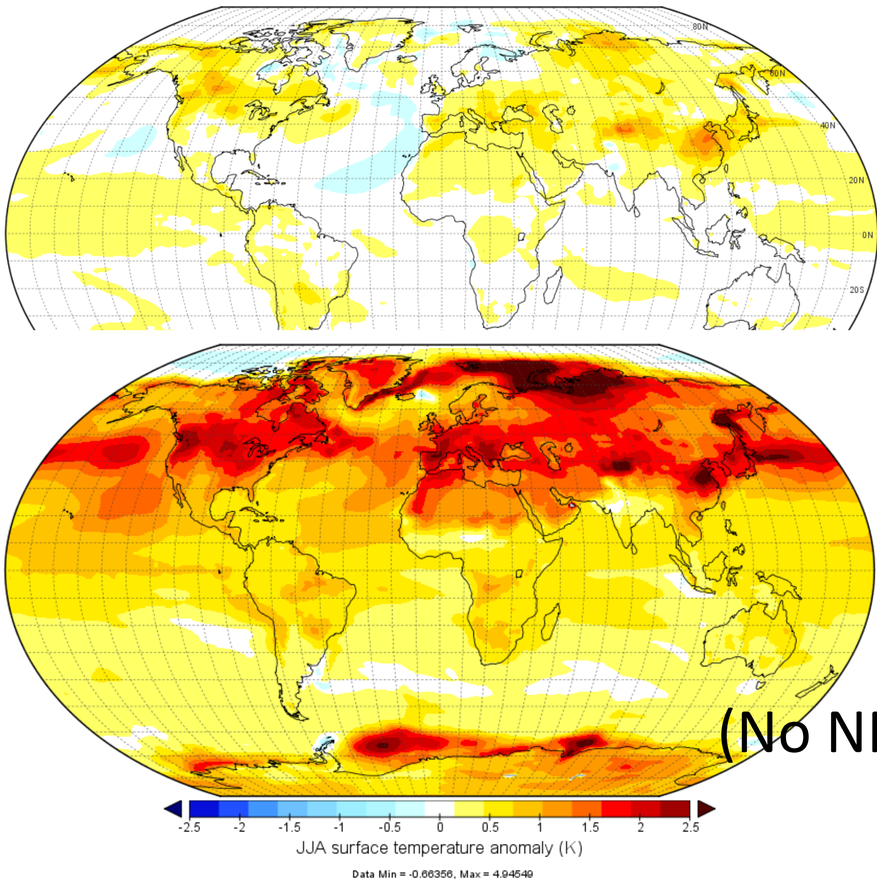
Why those regions (2)?



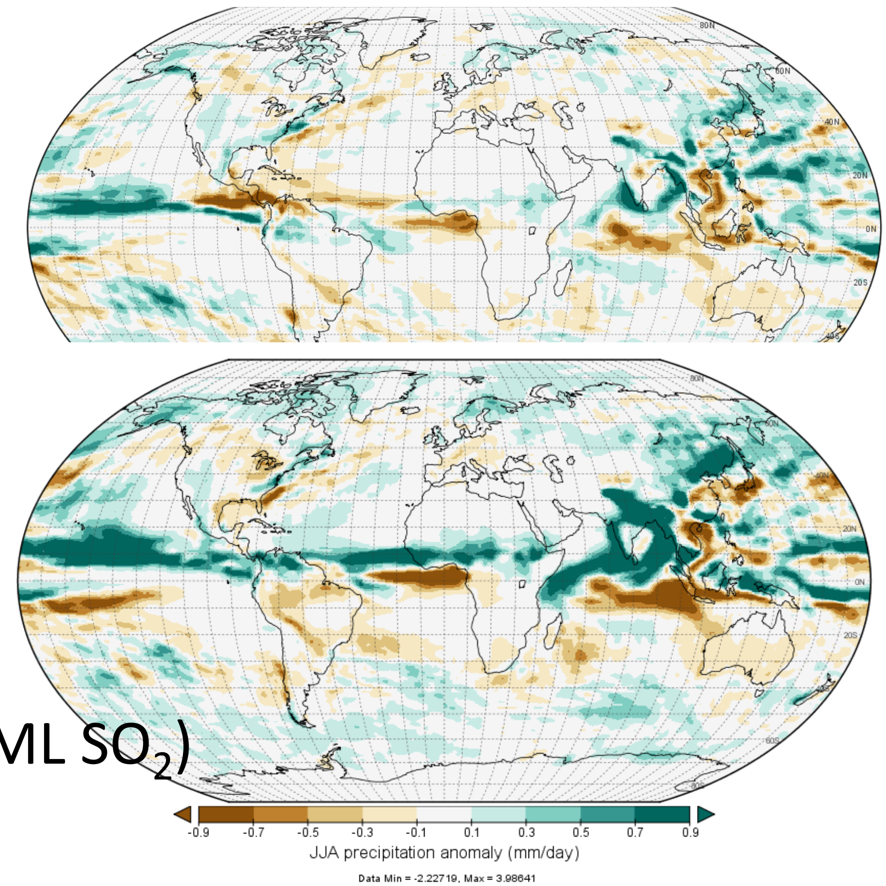
Removing SO_2 emissions from East Asia

Temperature and Precipitation response (JJA)

Temperature



Precipitation

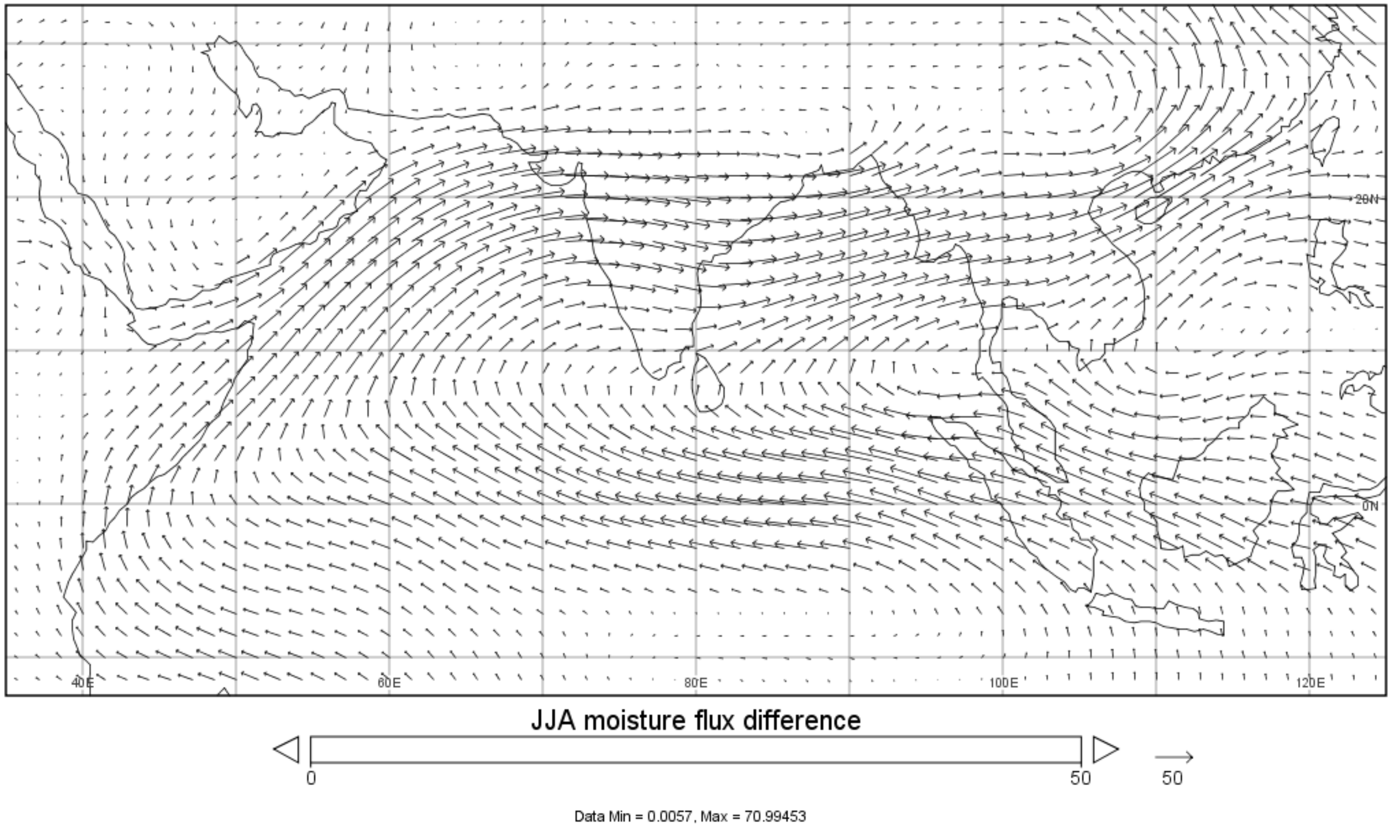


(No NML SO_2)

- Similar changes though weaker, even in Asia, indicating non-local influences).

Removing SO_2 emissions from NH mid-latitudes

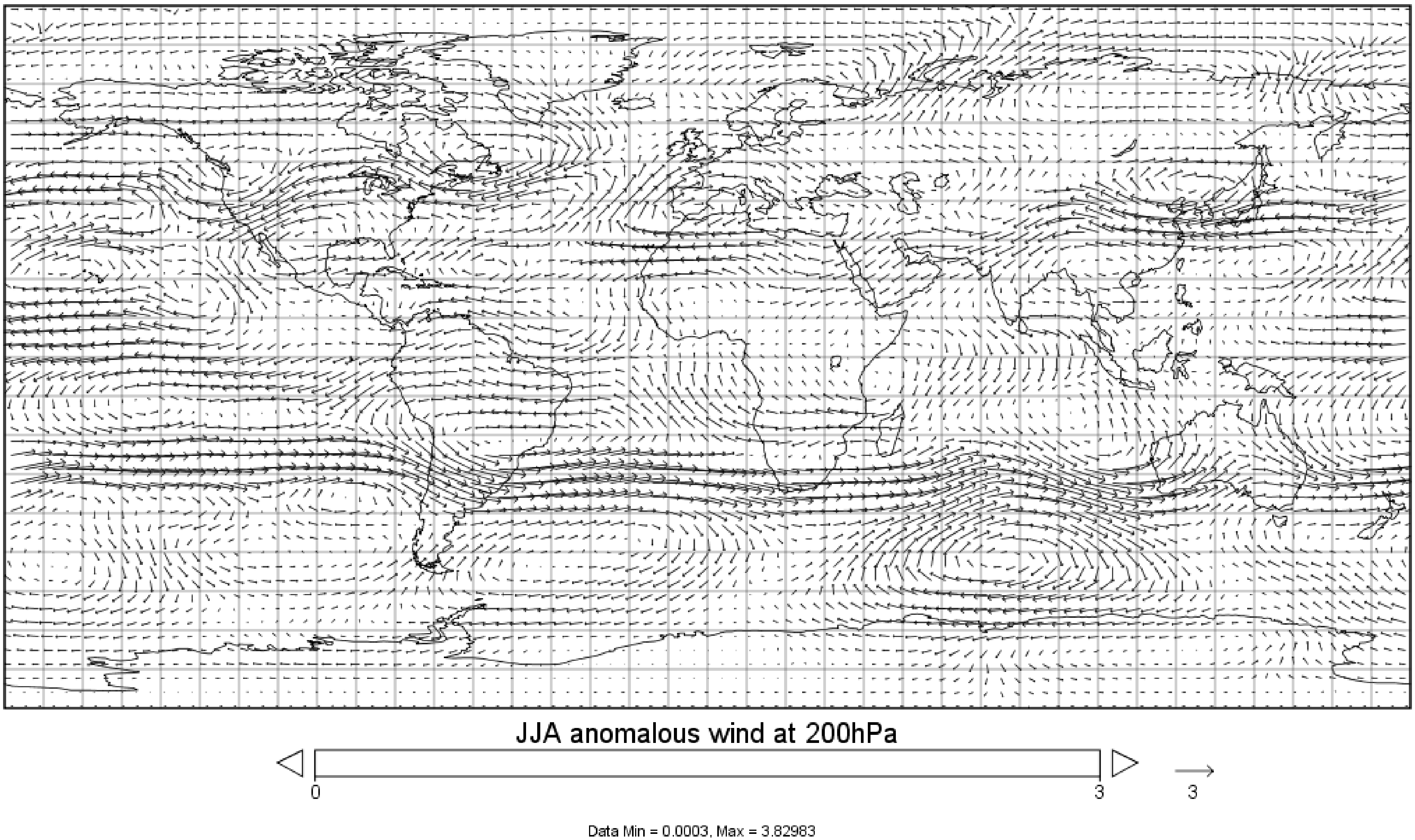
<u>Moisture flux over South Asia (JJA)</u>



- A strengthening of the monsoon circulation leads to more moisture flowing into South Asia.

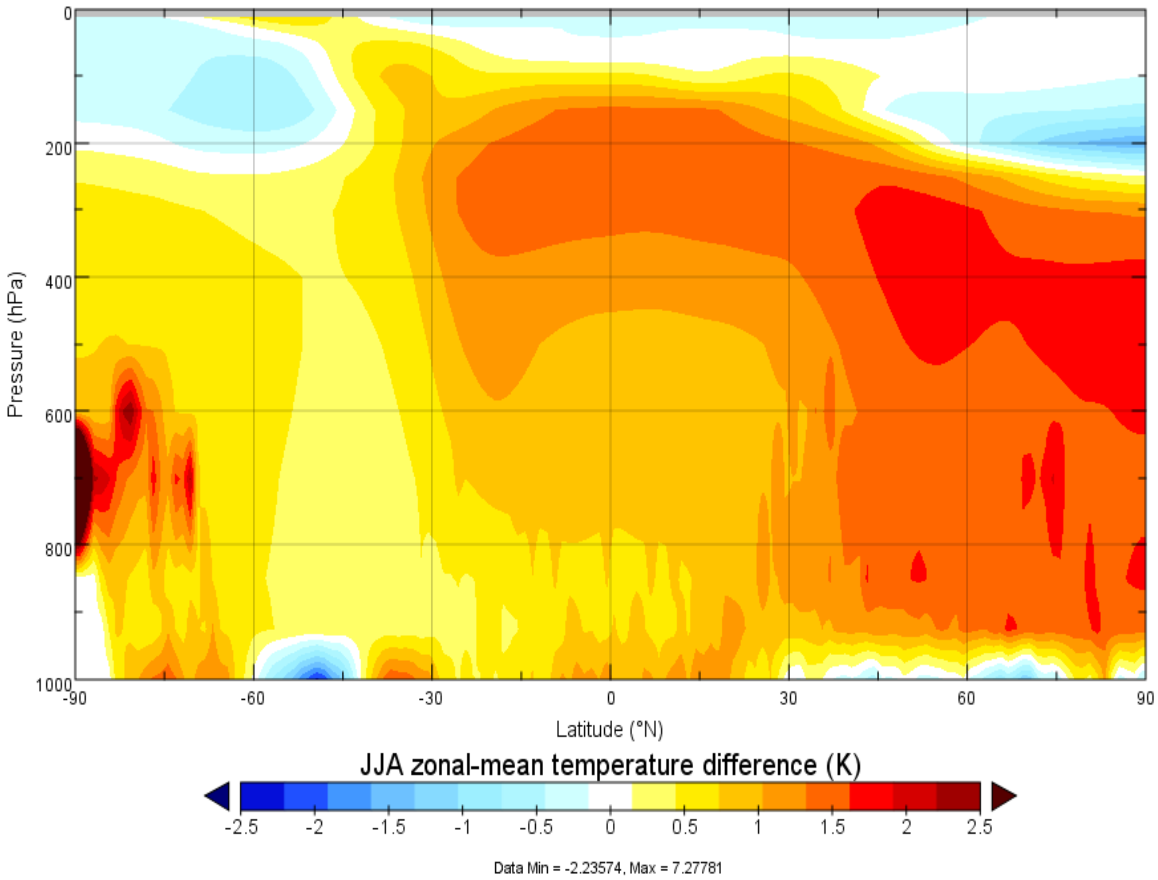
Removing SO_2 emissions from NH mid-latitudes

200hPa wind change (JJA)



Removing SO_2 emissions from NH mid-latitudes

Zonal mean temperature change (JJA)

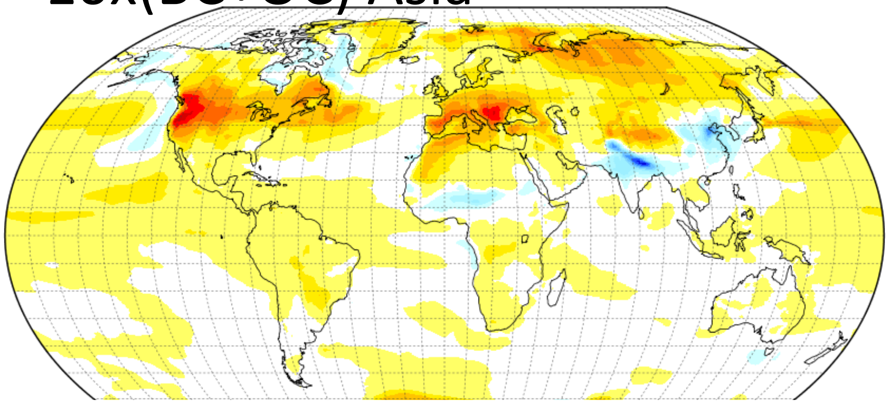


- Heating stronger in northern mid-latitudes and tropical upper troposphere.
- Temperature gradients become weaker in the NH and stronger in the SH.
- This may explain the jet speed changes.

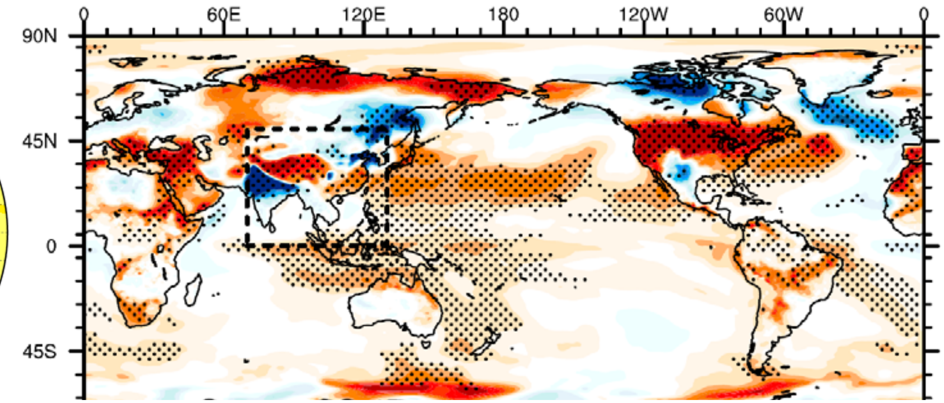
10x carbonaceous aerosol emissions from Asia

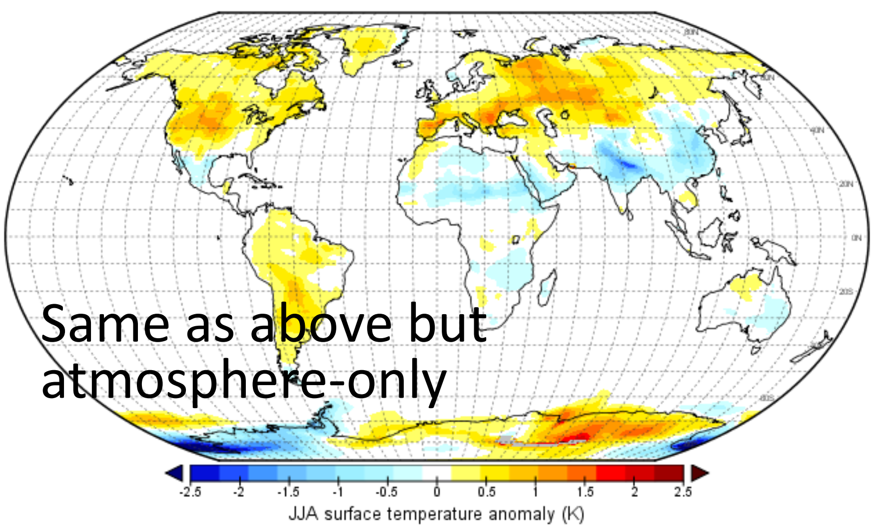
<u>Temperature response (JJA)</u>

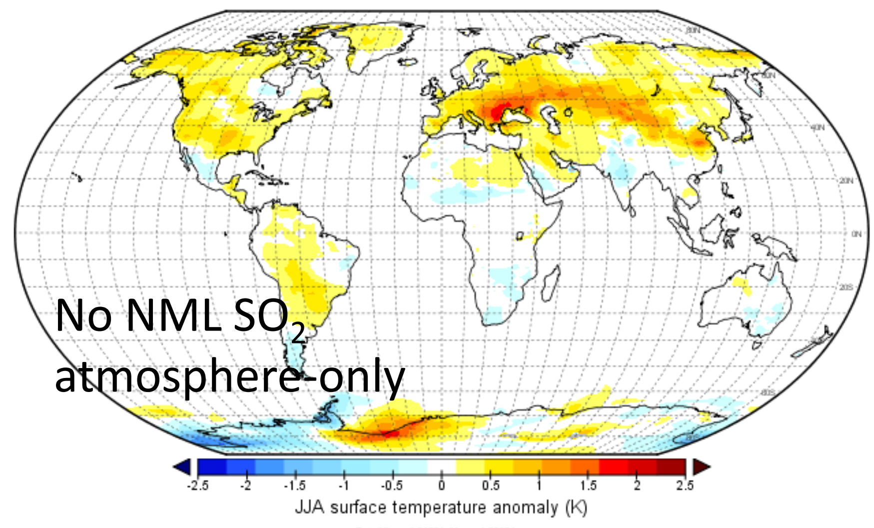
10x(BC+OC) Asia



Teng et al. (2011)



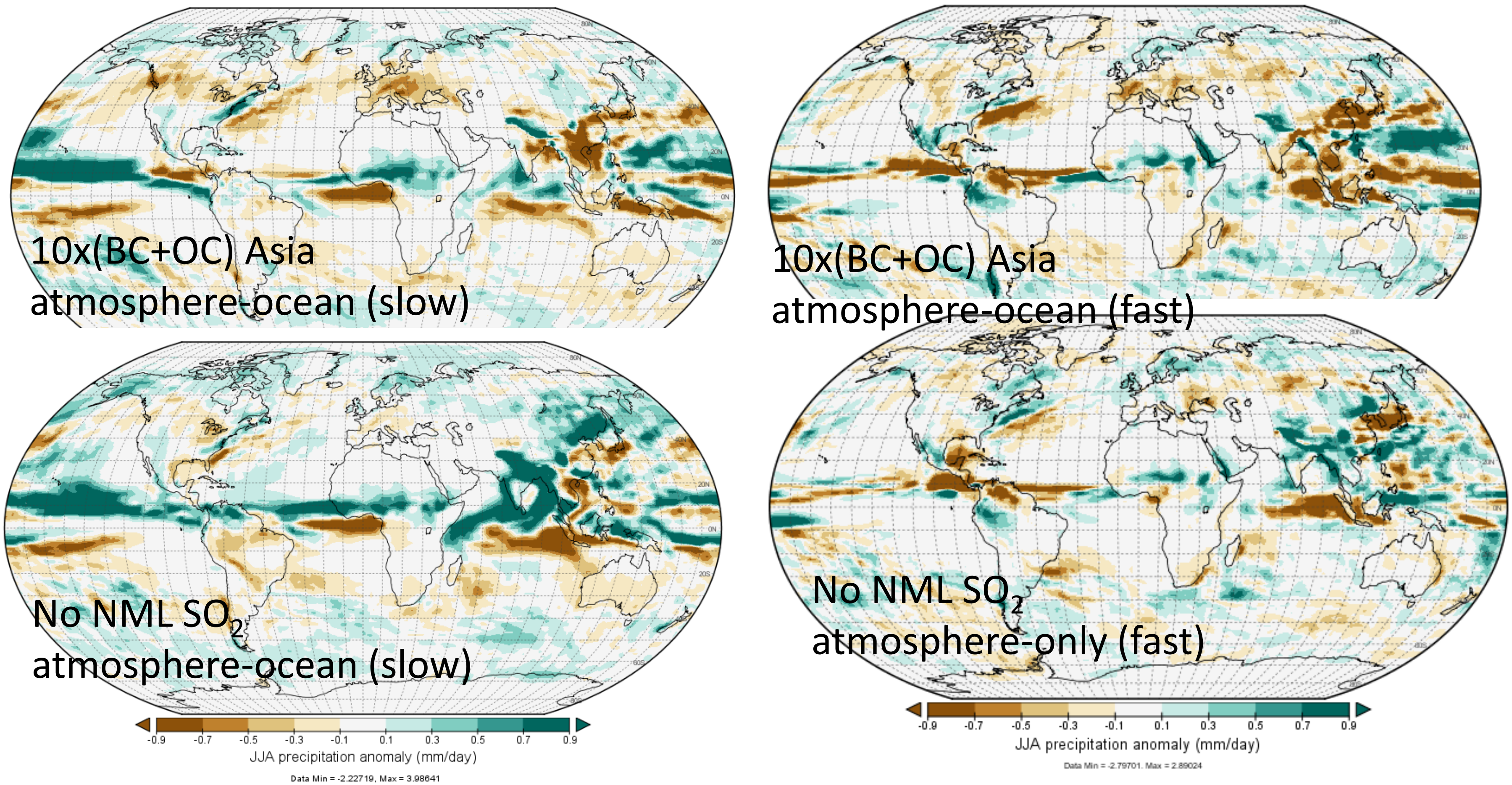




- Similar effects (qualitatively) in all runs.

Slow and fast precipitation response

(June-July-August)

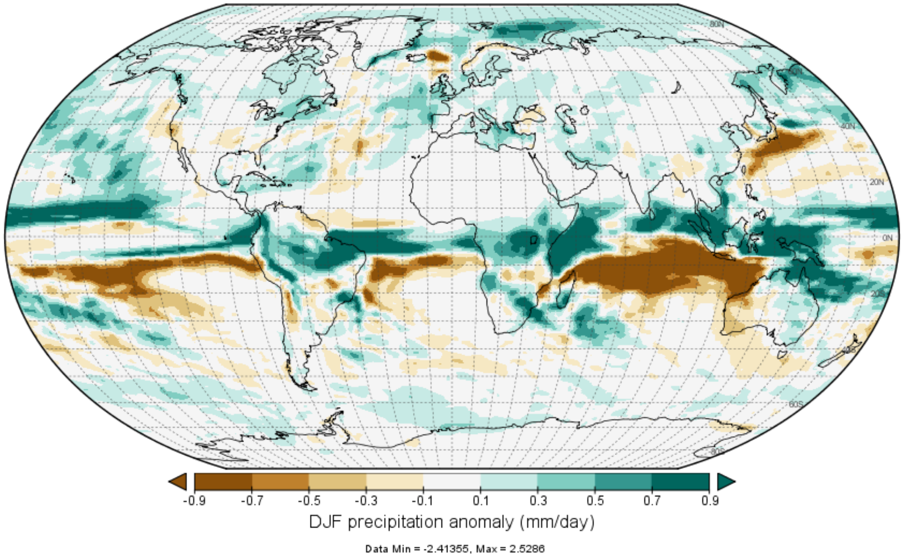


- For precipitation, the bulk of the effect is modulated by the ocean (slow).

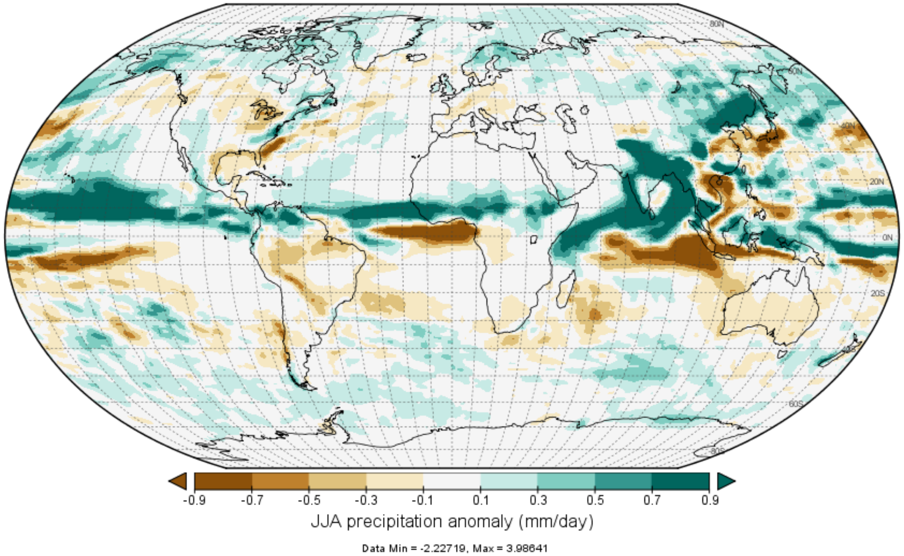
Removing SO_2 emissions from NH mid-latitudes

Precipitation response

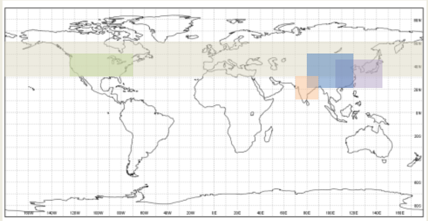
Dec-Jan-Feb



Jun-Jul-Aug

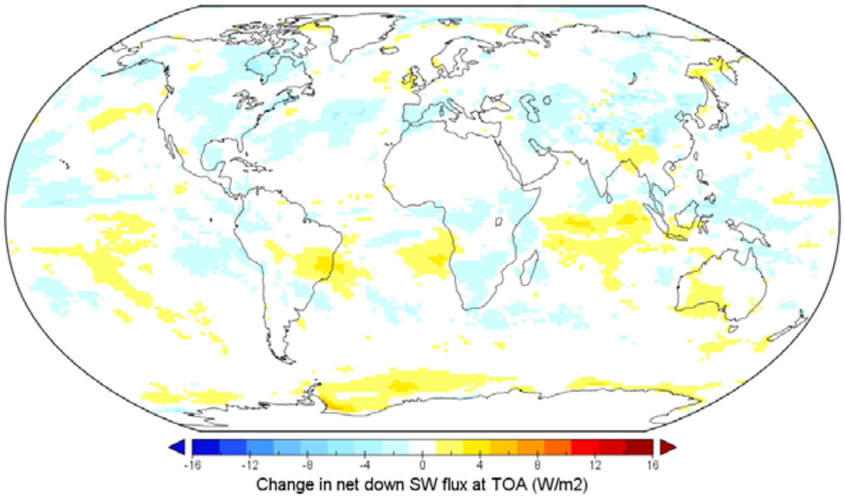


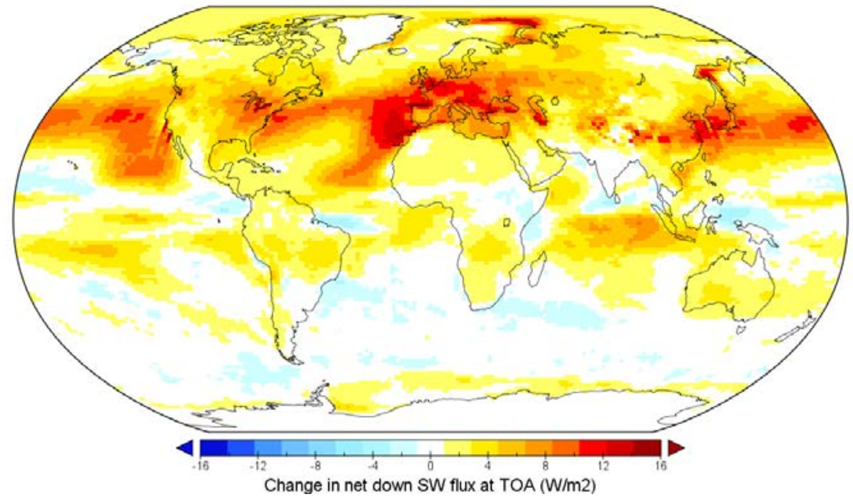
- Drastic changes in precipitation, especially in the tropics.
- ITCZ shifts northward, due to changes in interhemispheric heating. Large increases in Sahel and South Asian precipitation.



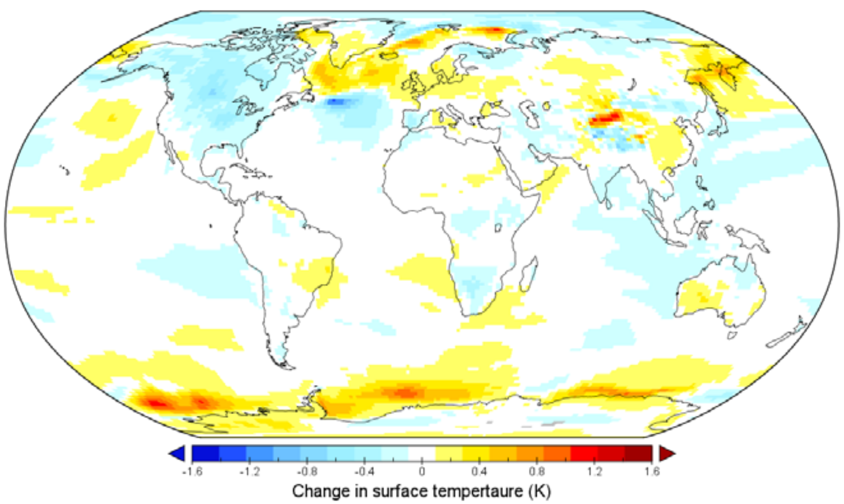
BC vs. SO_2 (no NML)

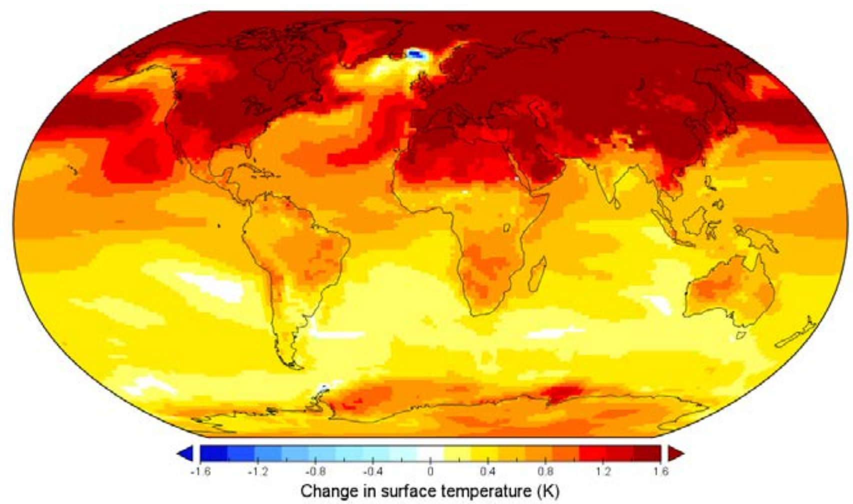
TOA SW

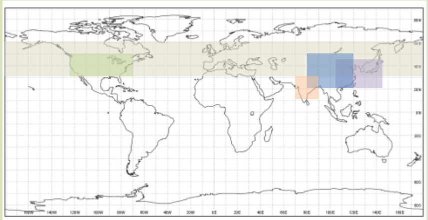




Temp

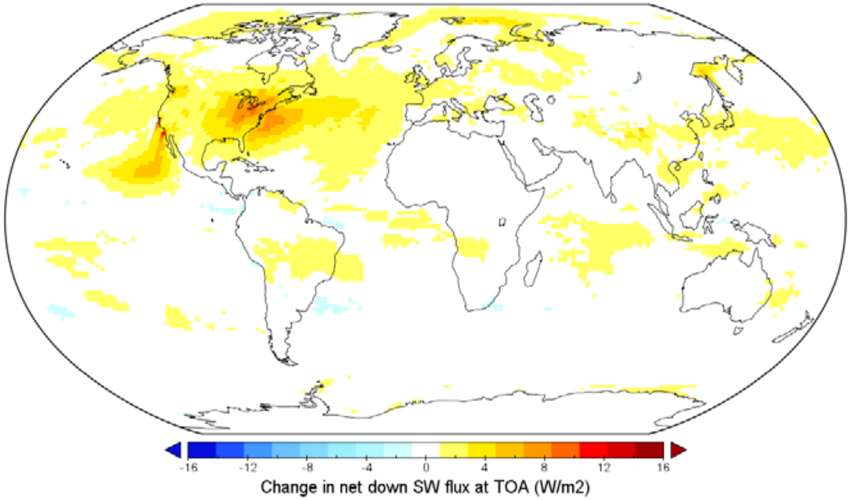


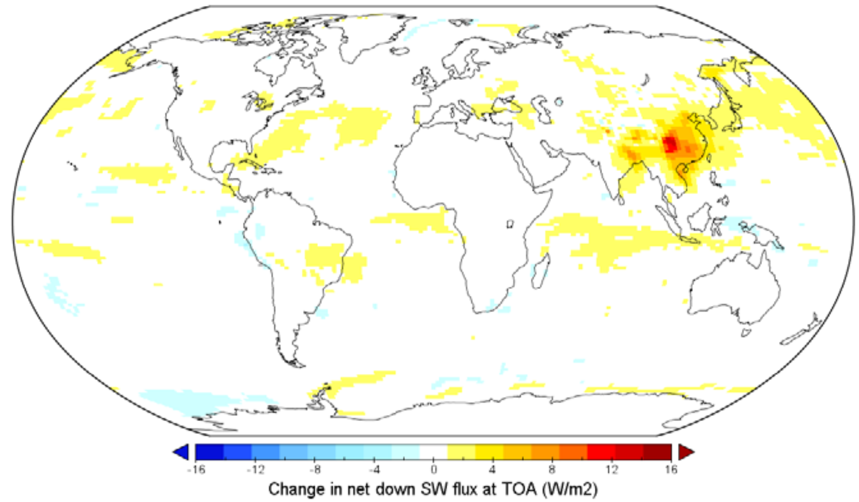




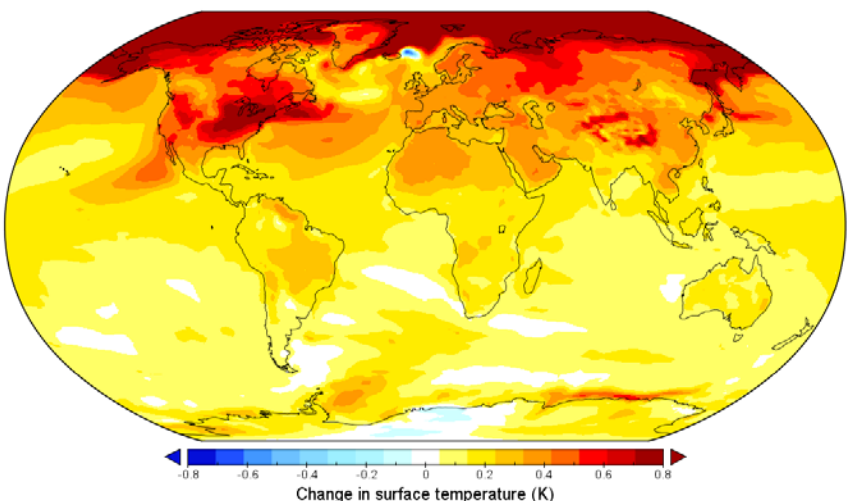
US vs. China SO_2

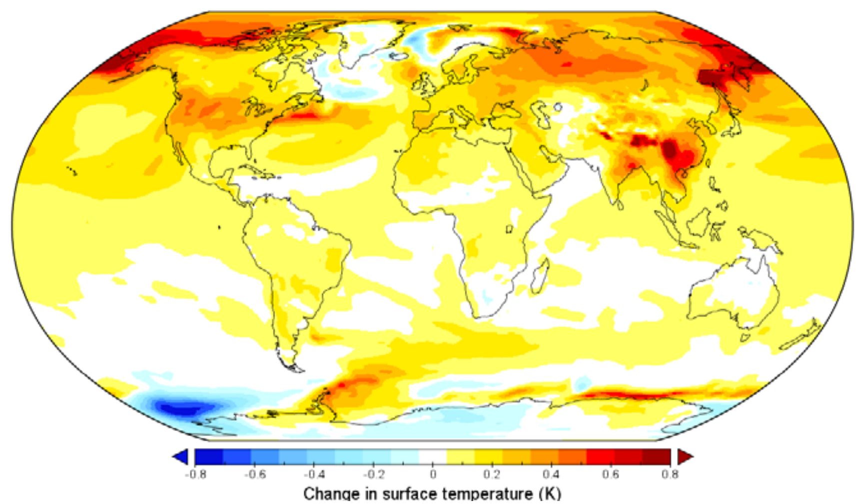
TOA SW

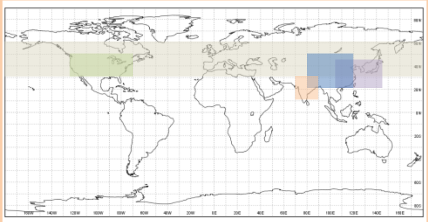




Temp

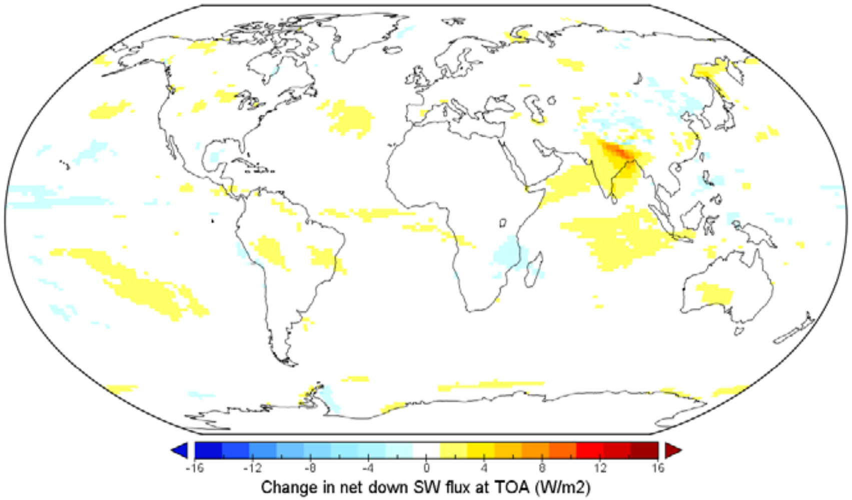


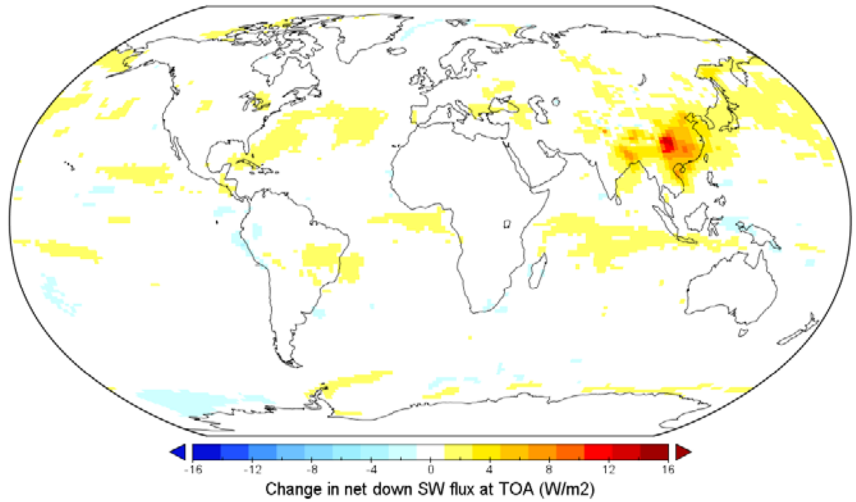




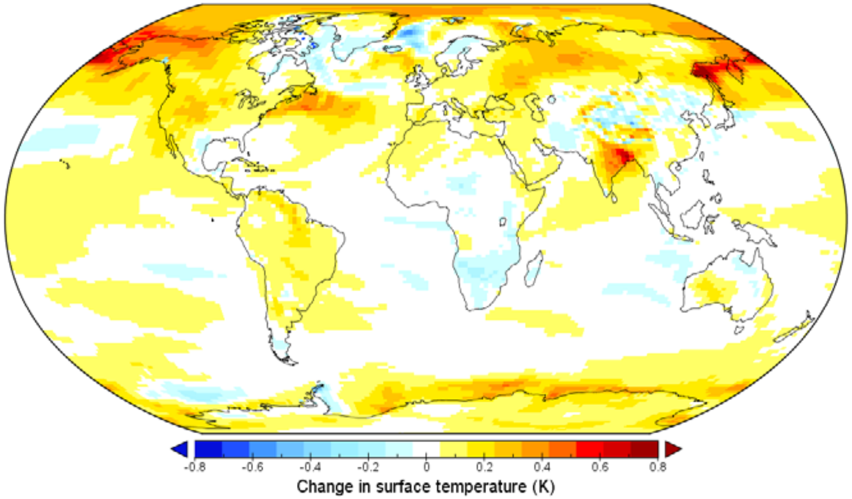
India vs. China SO_2

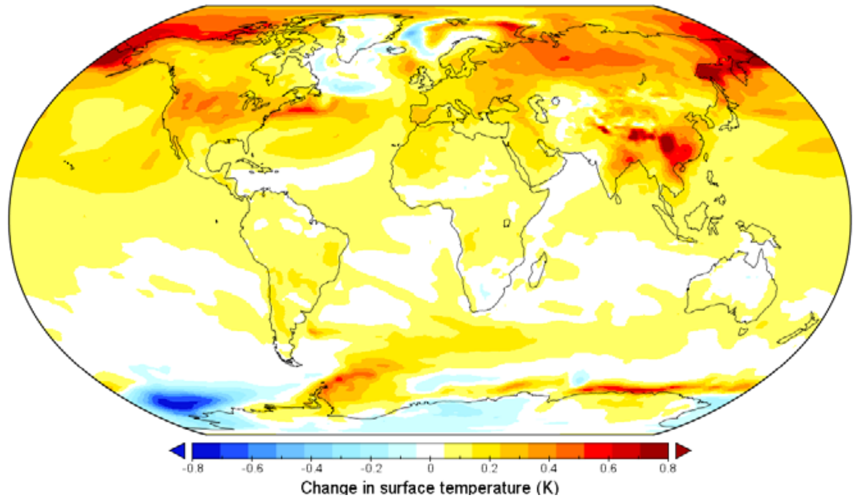
TOA SW

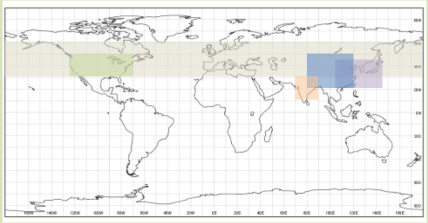




Temp

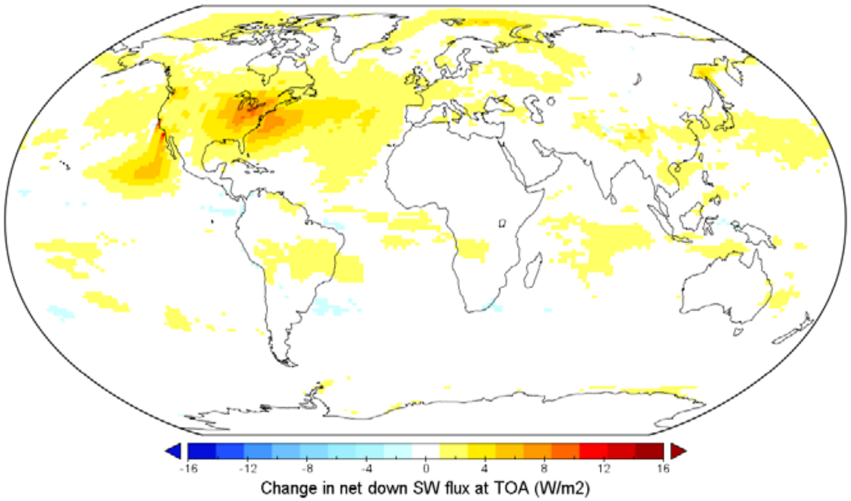


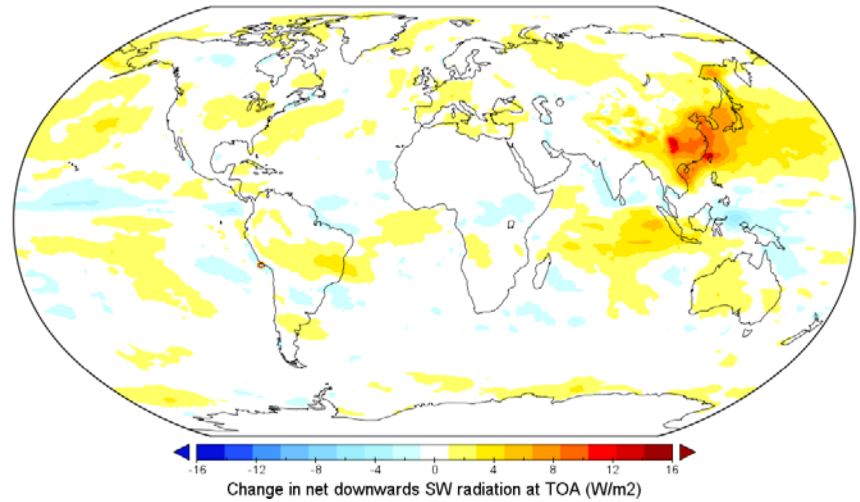




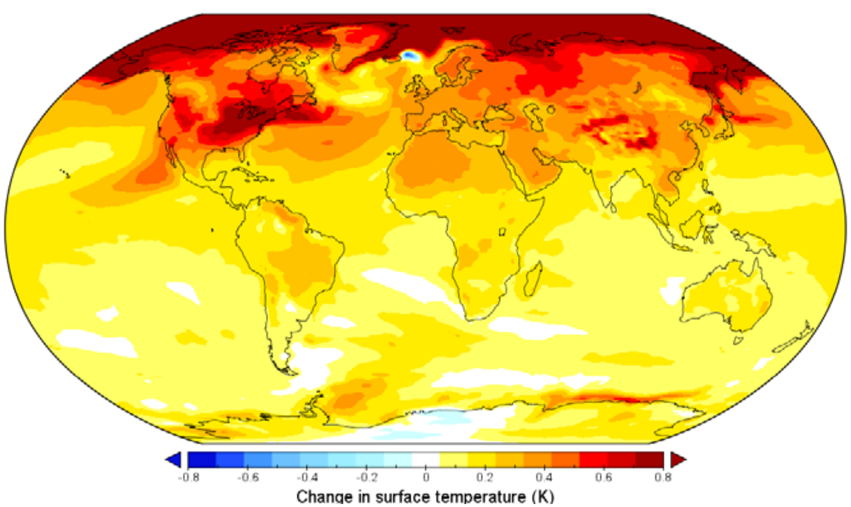
US vs. EA SO_2

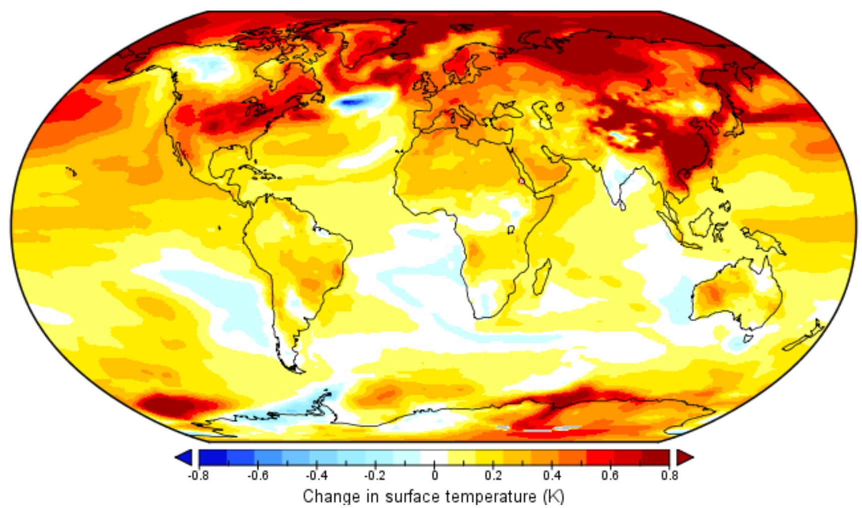
TOA SW

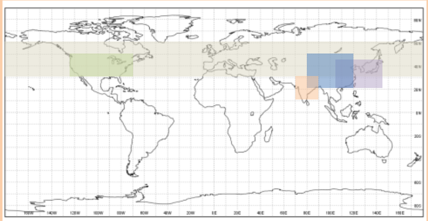




Temp

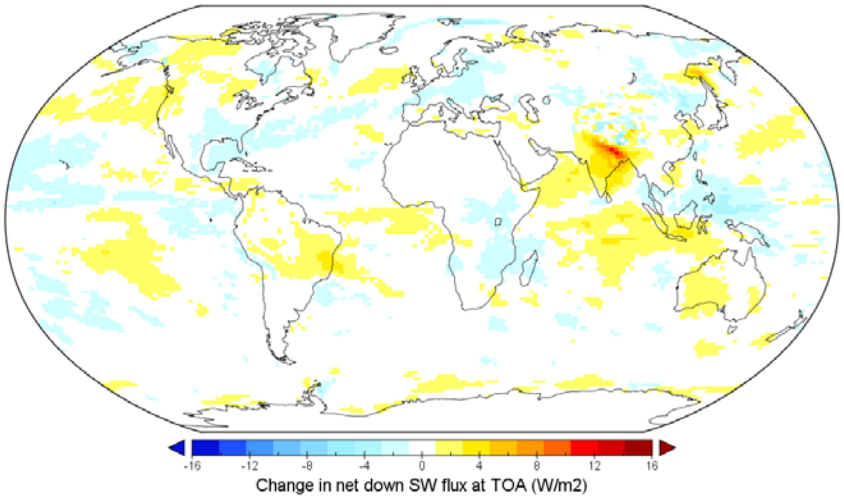


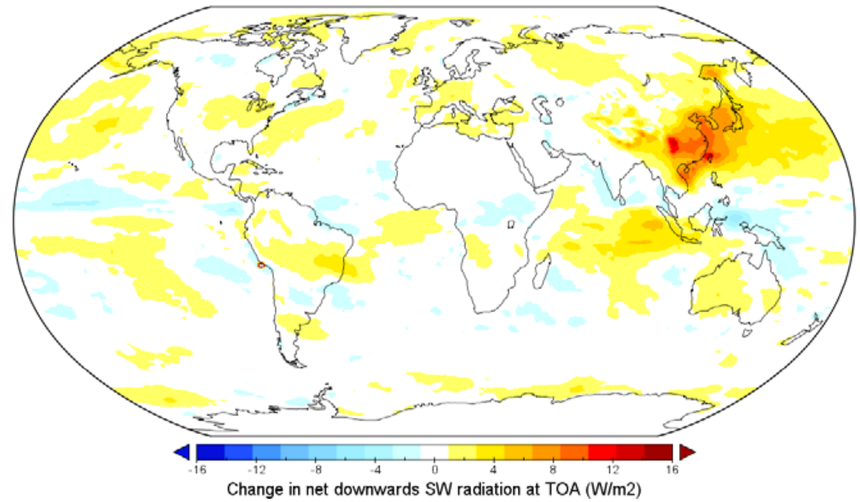




India vs. EA SO_2

TOA SW





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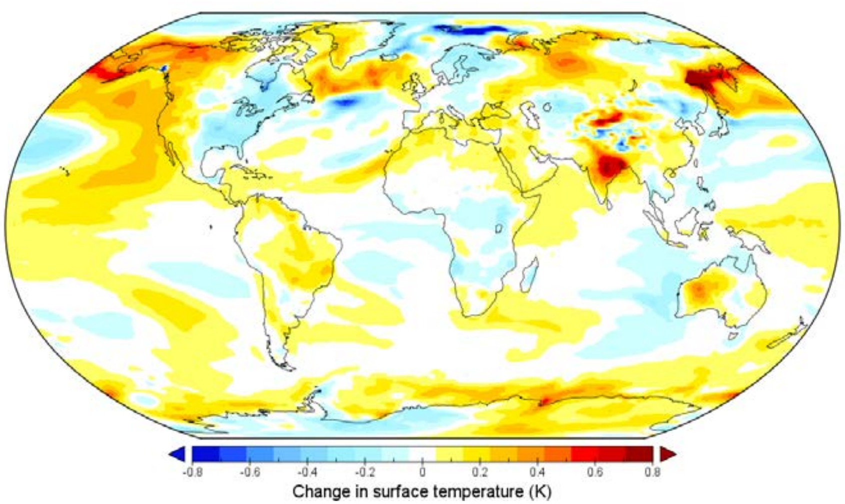
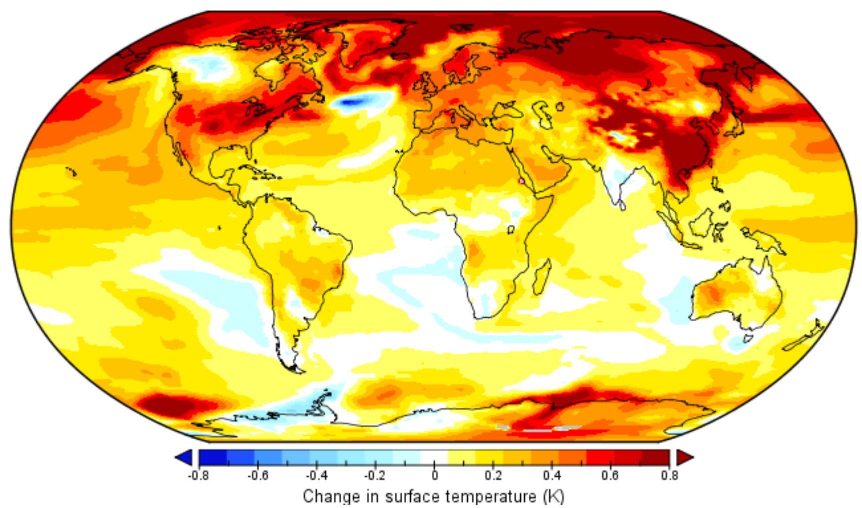
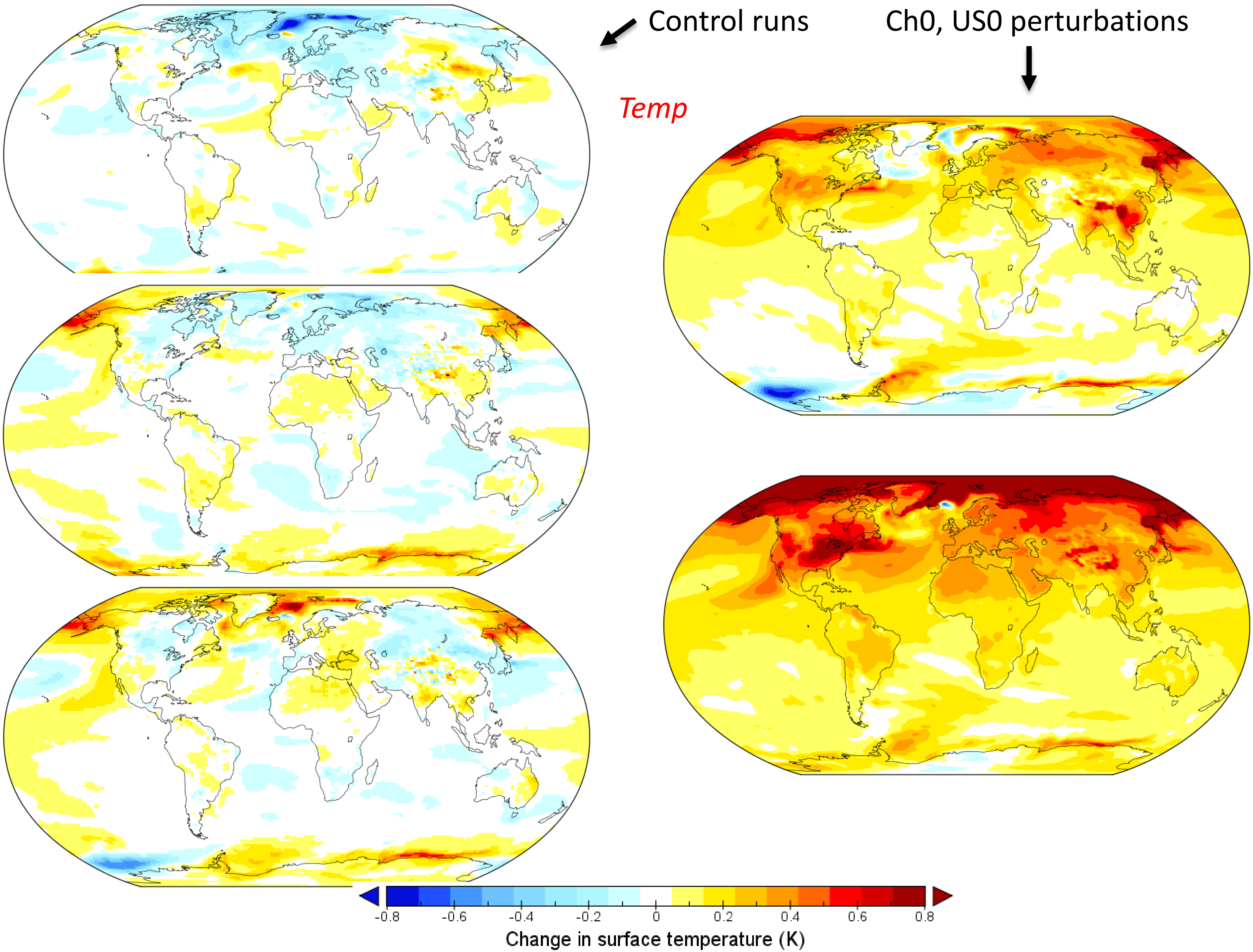
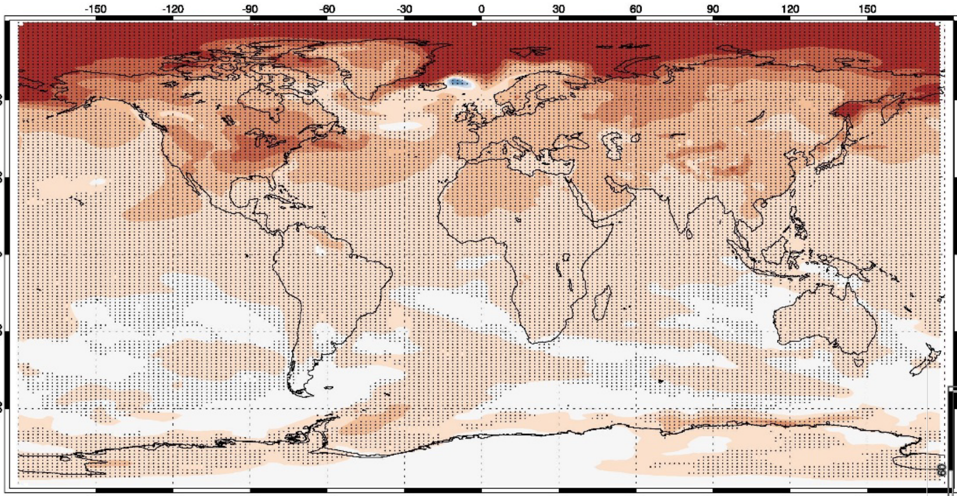




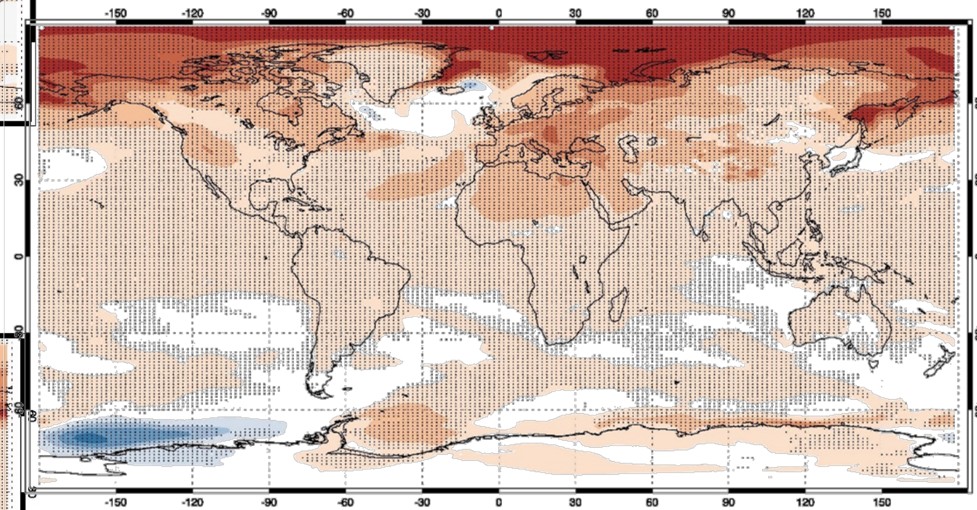

Control runs
Ch0, US0 perturbations
Temp
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Change in surface temperature (K)

Temperature anomalies in HadGEM3 & significance

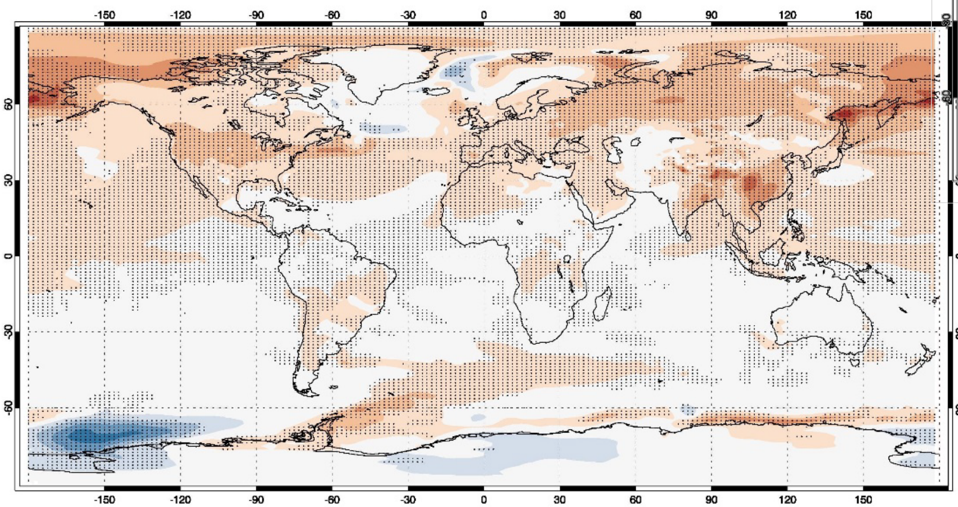
US

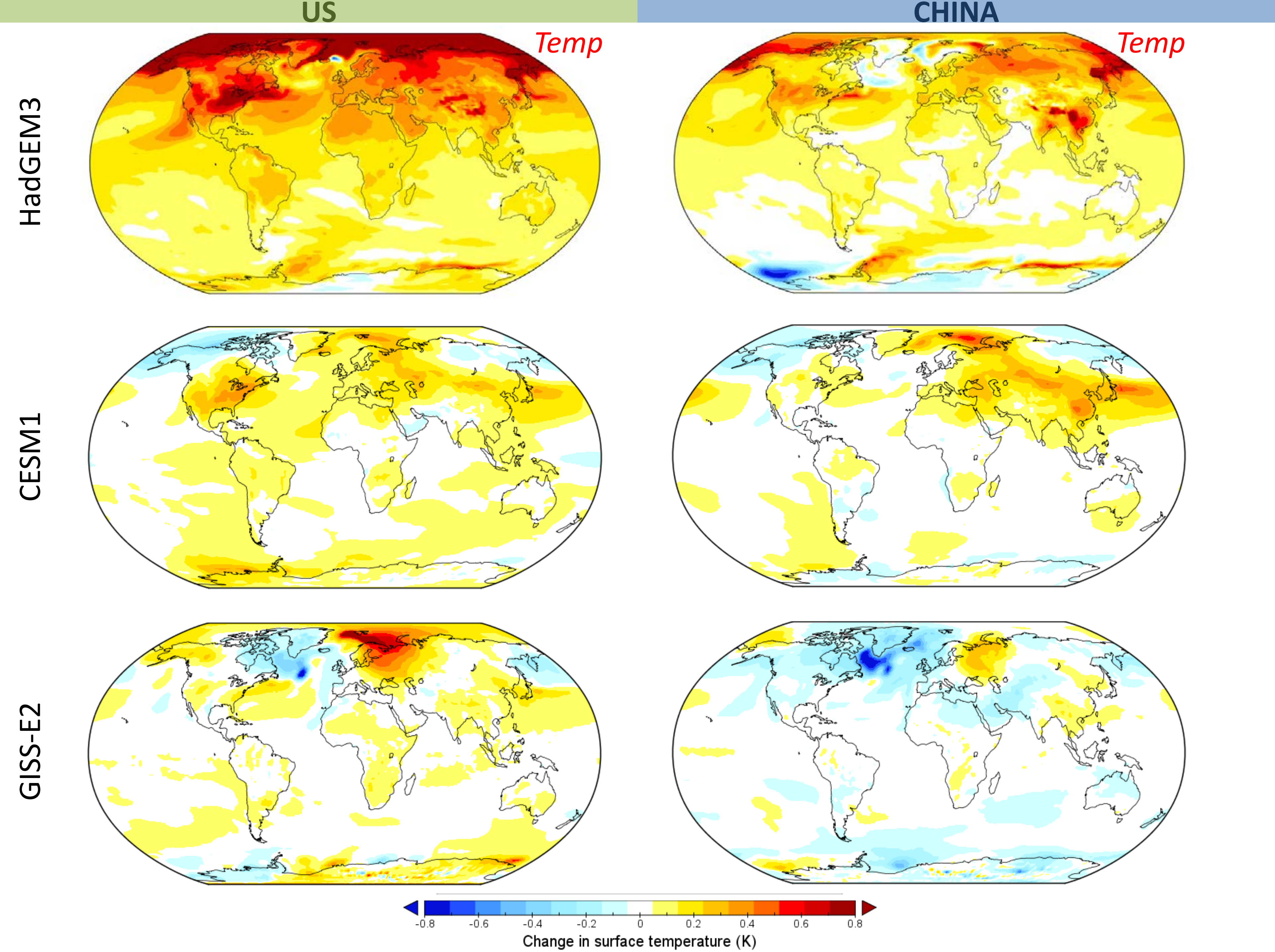


EU

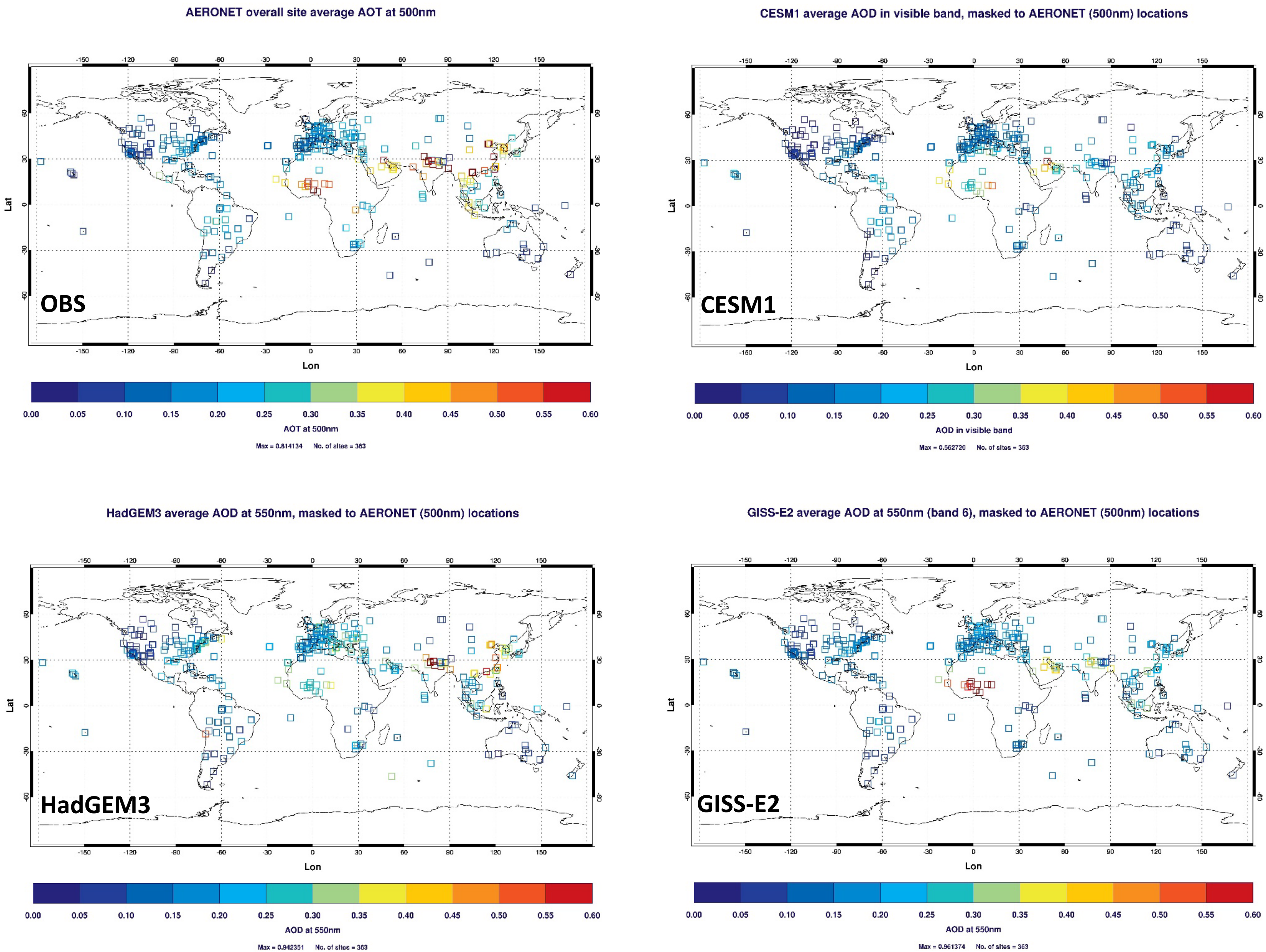


China





US
CHINA
HadGEM3
CESM1
GISS-E2
Temp
Temp
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Change in surface temperature (K)


AERONET overall site average AOT at 500nm
OBS
Lat
Lon
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60
AOT at 500nm
Max = 0.814134 No. of sites = 363
CESM1 average AOD in visible band, masked to AERONET (500nm) locations
CESM1
Lat
Lon
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60
AOD in visible band
Max = 0.562720 No. of sites = 363
HadGEM3 average AOD at 550nm, masked to AERONET (500nm) locations
HadGEM3
Lat
Lon
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60
AOD at 550nm
Max = 0.942351 No. of sites = 363
GISS-E2 average AOD at 550nm (band 6), masked to AERONET (500nm) locations
GISS-E2
Lat
Lon
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60
AOD at 550nm
Max = 0.961374 No. of sites = 363

PDRMIP

Precipitation Driver Response Model Intercomparison Project

PDRMIP
Precipitation Driver Response Model Intercomparison Project

PDRMIP core experiments

Name	Description	Fixed-SST Nyears	Slab/full ocean Nyears (all output)
Base	Specified present day CO_2, CH_4, solar constant, aerosol concentration	15	100
CO2 x 2	CO_2 from PDC to 2xPDC	15	100
CH4 x 3	CH_4 from PDC to 3xPDC	15	100
Solar	Solar constant increased by 2%	15	100
Sul	Sulphate concentration from PDC to 5xPDC	15	100
BC	BC concentration from PDC to 10xPDC	15	100

PDC – Present day concentration

PDRMIP

Precipitation Driver Response Model Intercomparison Project

PDRMIP
Precipitation Driver Response Model Intercomparison Project

PDRMIP additional experiments

Name	Description	Fixed-SST Nyears	Slab/full ocean Nyears (all output)		
Sulred	Sulphate concentration from PDC to PIC	15	100	✓	✓
Suleur	Sul multiplied by 10, Europe only	15	100	✓	✓
Sulasia	Sul multiplied by 10, but Asia only	15	100	✓	✓
BCasia	As BC, but Asia only	15	100	✓	✓
Sulasired	As Sulred, but Asia only	15	100		
O3asia	Add O3, Asia only, comparable forcing to Sulasia	15	100		

PDC – Present day concentration
PIC – Pre-industrial concentration

Work for PDRMIP

(5xSO_4 shown here)

- ITCZ shifts not occurring in this case (top).

- That is counterintuitive, as the largest aerosol changes are in the northern hemisphere (mid).

- However, large-amplitude cloud changes occur also in the SH (bottom) -> smaller inter-hemispheric energy imbalance as a result.

- Possibly in NH the AIE is saturated?