

**Substantial Global
Influence of
Anthropogenic Aerosols
on Tropical Cyclones over
the Last 40 years**

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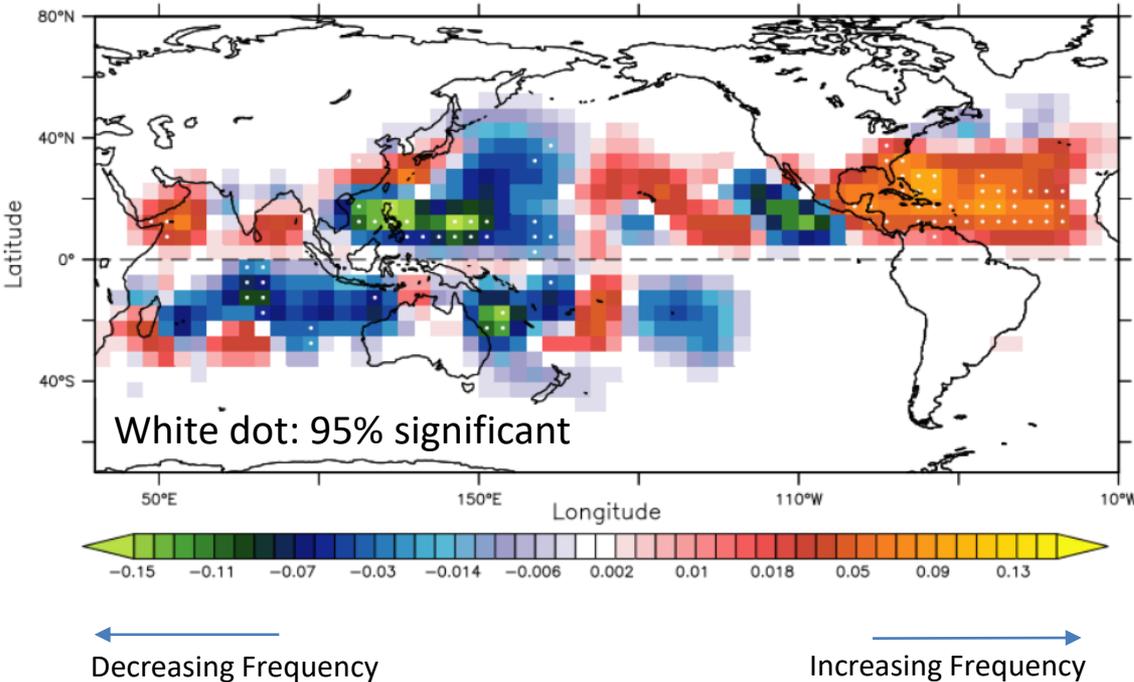
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NE Tropical Workshop 06/05/2023

Observed Trend in Global TC Activity (1980-2018)



Observed Trend in TCF (1980–2018)



Murakami et al. (2020, *PNAS*)

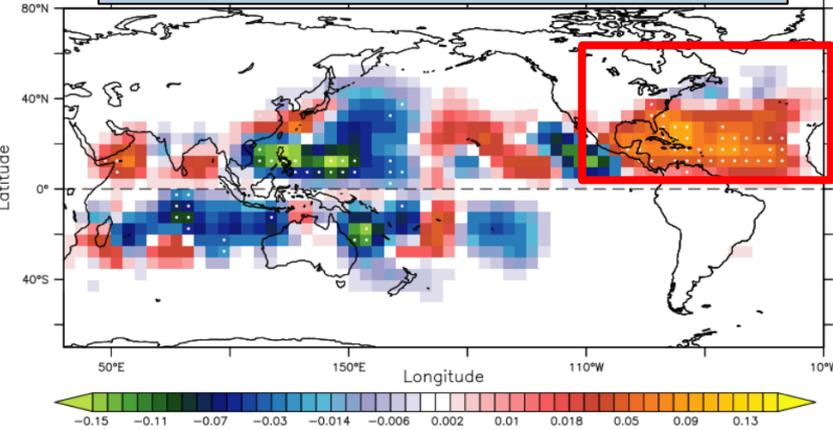
- TCF (or TC density) is defined as the total TC frequency of occurrence for every 5x5 degree grid cell.
- TCF shows significant negative and positive trends depending on region over 1980-2018.
- We concluded in the previous study that this **spatial pattern of the trends is largely influenced by the external forcing (greenhouse gases, aerosols, etc.) and beyond the influence of internal variability.**

More details on coastal TCs in Shuai Wang's talk this afternoon.

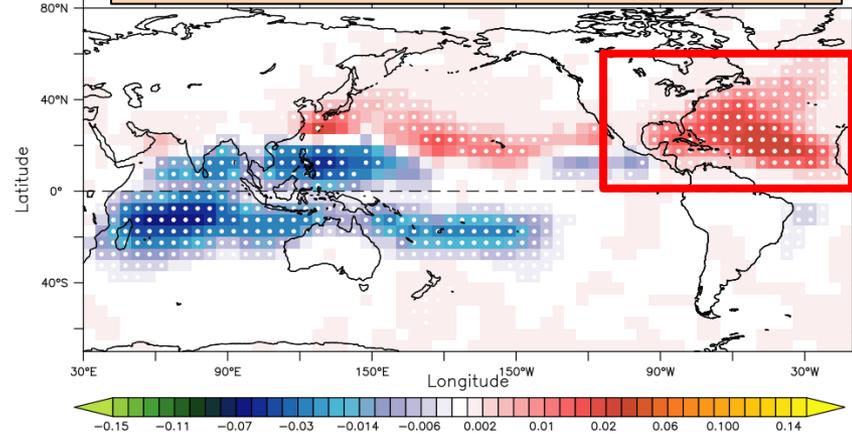
Effect of External Forcing on the TCF Trend



Observed Trend in TCF (1980-2018)

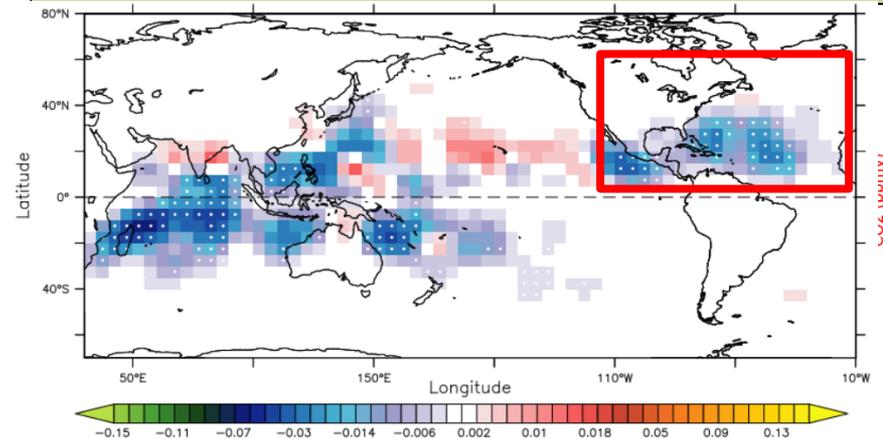


AllForc (95-member mean, 1980-2018)



All forcing includes greenhouse gases, anthropogenic aerosols, ozone.

Transient 2xCO₂ (3-member mean, 70 yrs)



transient +1%/yr CO₂ experiment

- Fully Coupled
- +1% CO₂ increase up to 2xCO₂ (at year 171) then fixed

Hypothesis:
External forcings other than greenhouse gases are responsible for the increased hurricanes in the North Atlantic.

Anthropogenic aerosols may be the key.

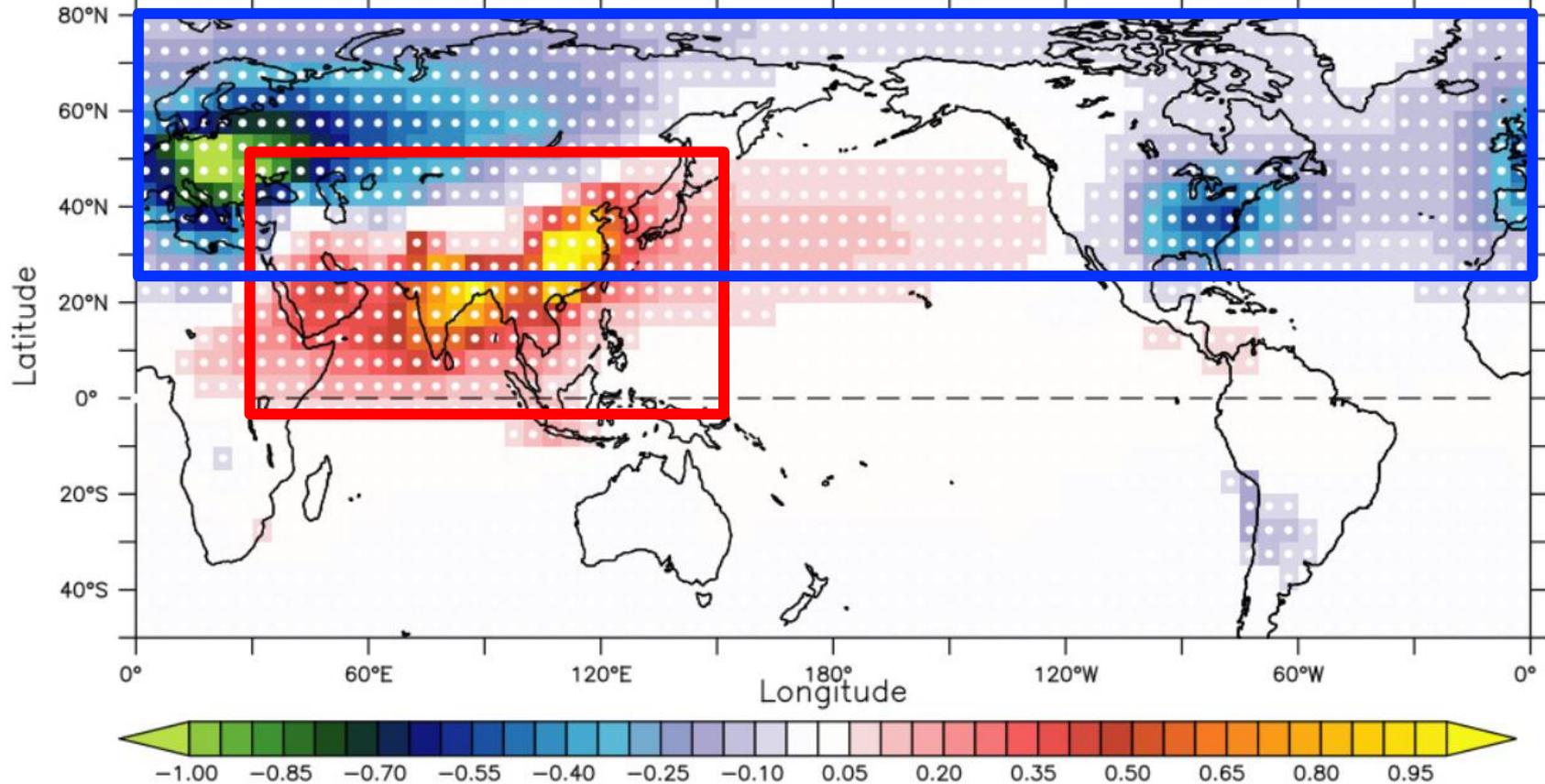
Murakami et al. (2020, *PNAS*)

Changes in anthropogenic aerosols in the past 40 years



Sulfate changes (2001-2020 minus 1980-2000)

(a) Difference in Prescribed Sulfate Aerosols (2001–2020 minus 1980–2000)

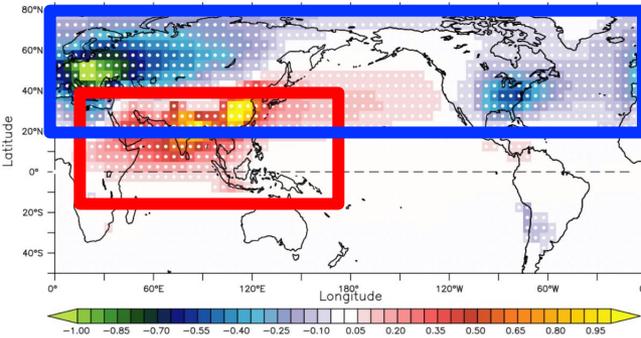


Decreased aerosols from Europe and the United States
Increased aerosols from China and India

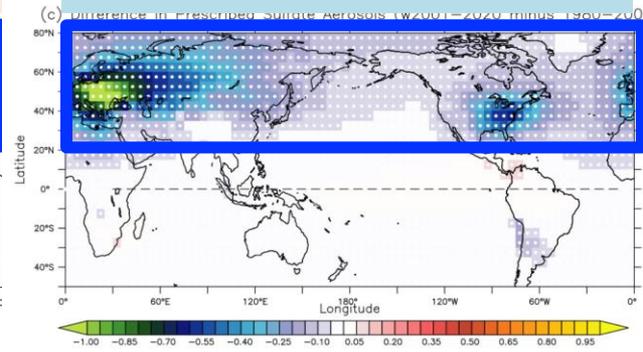
How have these regional changes in aerosols exerted changes in global TC frequency?

Experimental Setting

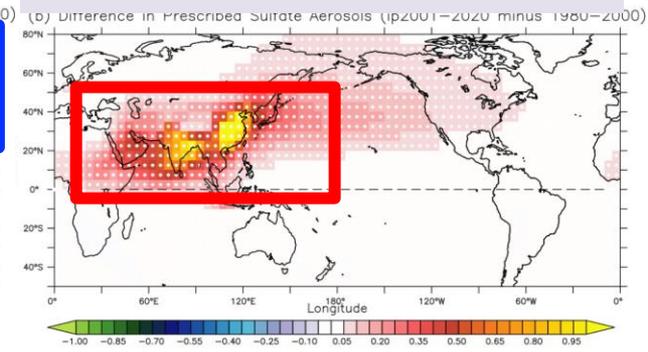
Δ ALL21, Sulfate



Δ W21, Sulfate



Δ IP21, Sulfate



We conducted idealized model experiments using GFDL-SPEAR by imposing different aerosol emissions.

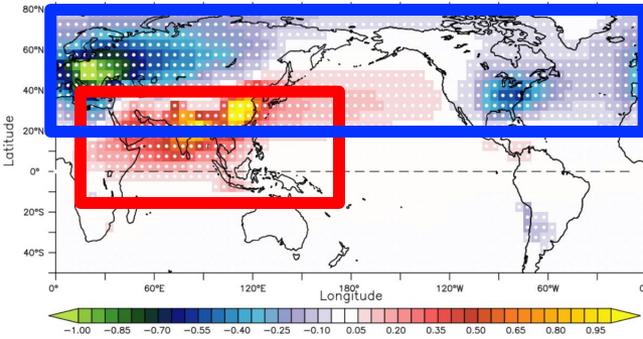
Exp name	Specified emission of anthropogenic aerosols (sulfates, black carbon, organic carbon etc.)	Other external forcings (e.g., CO ₂)	Simulation years	Difference from CNTL
CNTL	Mean of 1980-2000	Fixed level at 2000	200 years	—
ALL21	Mean of 2001-2020			Δ ALL21
W21	Mean of 2001-2020 for Europe and the US, mean of 1980-2000 for the rest of the world			Δ W21
IP21	Mean of 2001-2020 for China and India, mean of 1980-2000 for the rest of the world			Δ IP21

Effect of anthropogenic aerosols on global tropical cyclones



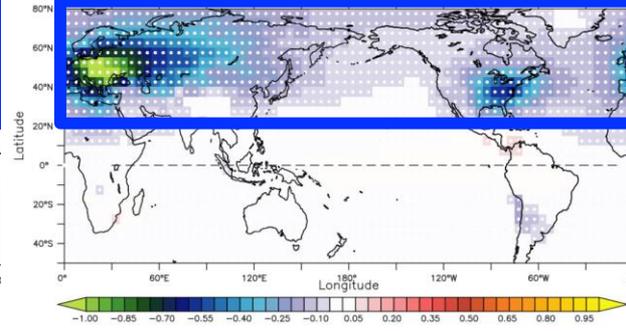
Δ ALL21, Sulfate

(a) Difference in Prescribed Sulfate Aerosols (2001–2020 minus 1980–2000)



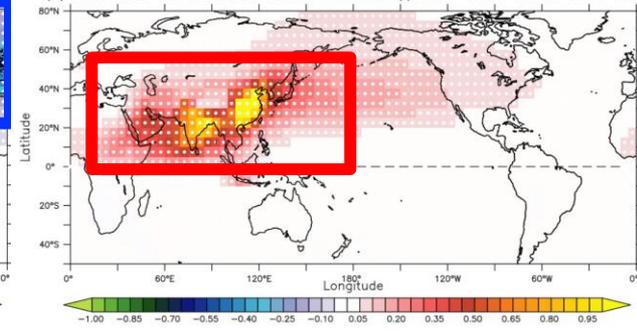
Δ W21, Sulfate

(c) Difference in Prescribed Sulfate Aerosols (w2001–2020 minus 1980–2000)

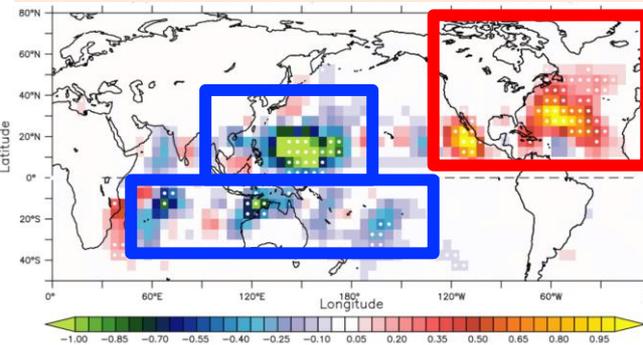


Δ IP21, Sulfate

(b) Difference in Prescribed Sulfate Aerosols (ip2001–2020 minus 1980–2000)

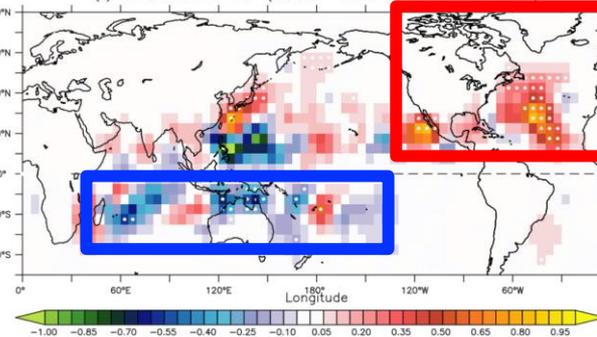


Δ ALL21, TCF



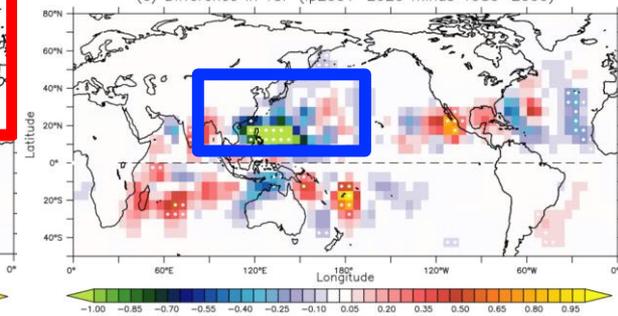
Δ W21, TCF

(f) Difference in TCF (w2001–2020 minus 1980–2000)



Δ IP21, TCF

(e) Difference in TCF (ip2001–2020 minus 1980–2000)



Decreased aerosols from Europe and the United States =>

Increased TCF in the North Atlantic

Decreased TCF in the Southern Hemisphere

Increased aerosols from China and India =>

Decreased TCF in the western North Pacific

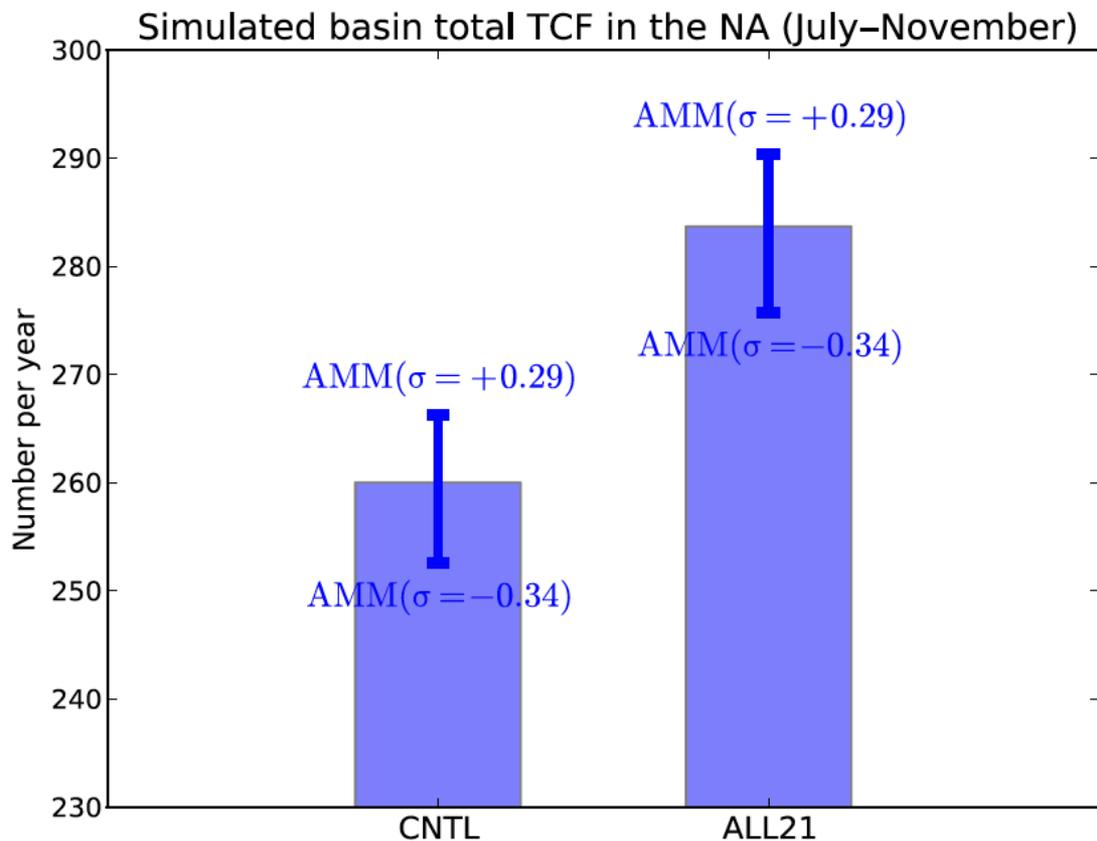
Observed and simulated changes in TCF



	Period or Difference	TCF		
		Fractional Difference (p-value)		
		WNP	NA	SH
Observations	2001-2020 minus 1980-2000	− 22.3% (0.03)	30.6% (0.01)	− 34.5% (0.00)
δ ALL21	ALL21 minus CNTL	− 4.8% (0.01)	8.7% (0.00)	− 6.4% (0.01)
δ W21	W21 minus CNTL	−1.4% (0.46)	6.5% (0.03)	− 4.8% (0.03)
δ IP21	IP21 minus CNTL	− 4.1% (0.04)	−1.8% (0.60)	1.9% (0.36)

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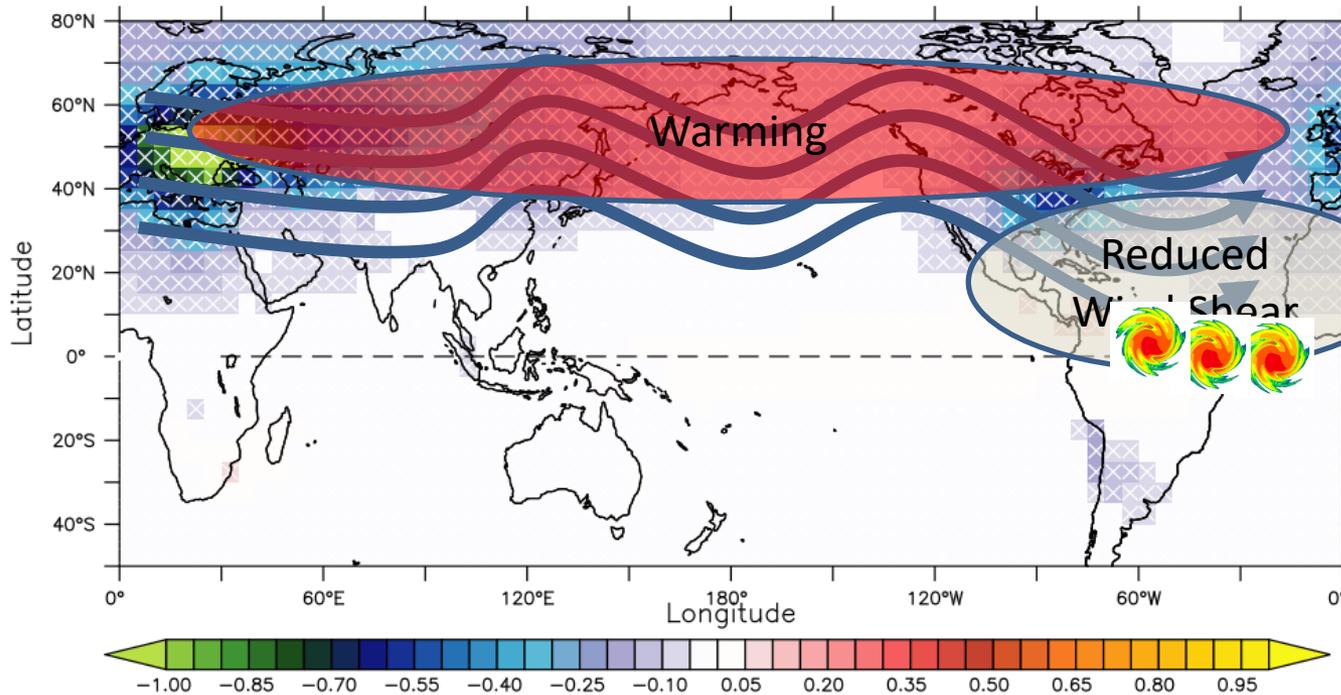
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Physical Mechanisms behind the TCF change



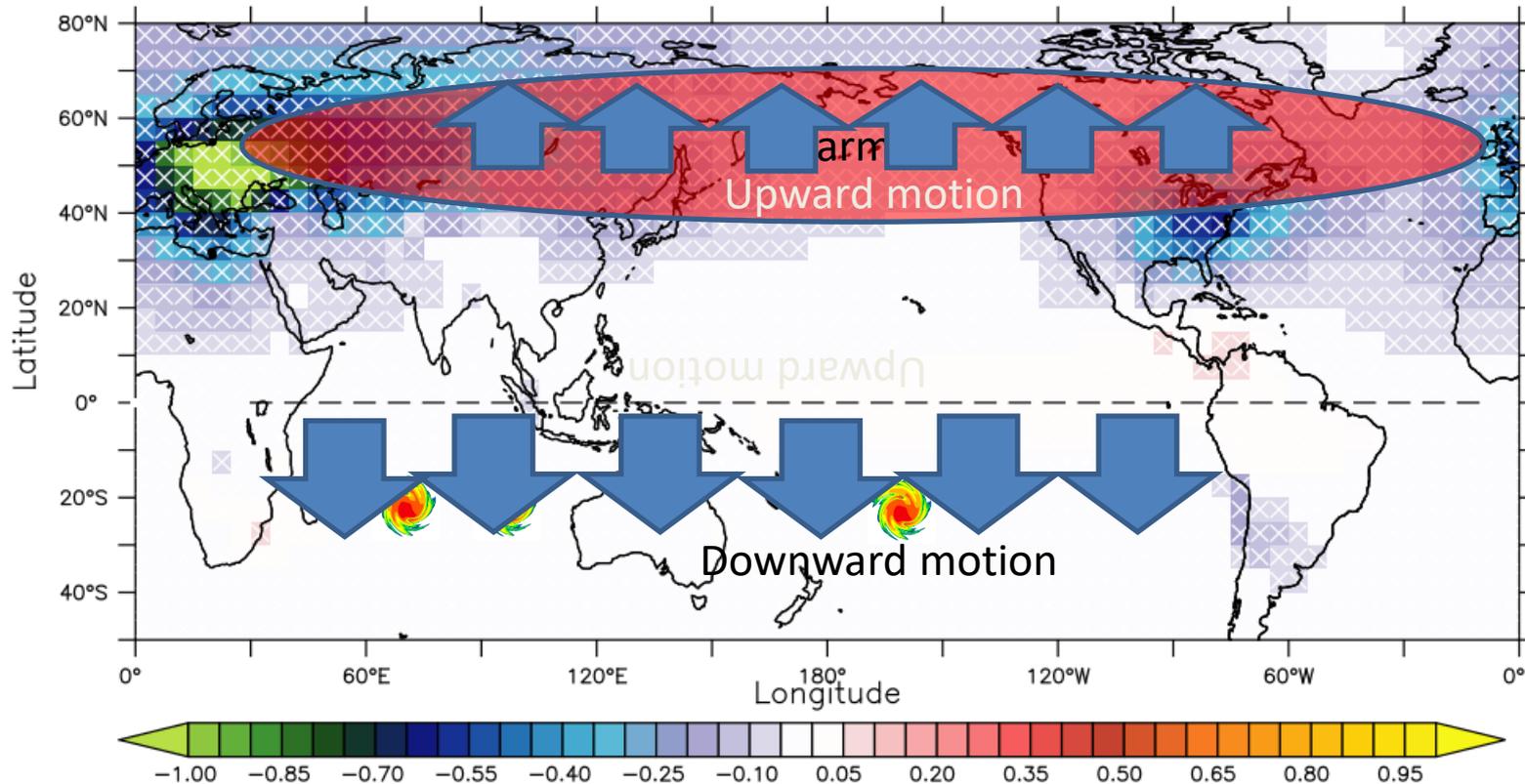
Shading: Linear trend in sulfate concentration over the period 1980-2020

Cross mark: Statistically significant decrease in sulfate over the period 1980-2020

The tropospheric warming in the mid-latitudes by reduced aerosols causes a weakening of the subtropical jet.

This leads to reduced vertical wind shear (reduced difference in wind speeds between lower and upper troposphere), which is favorable for tropical cyclone activity in the North Atlantic (indirect effect).

Physical Mechanisms behind the TCF change

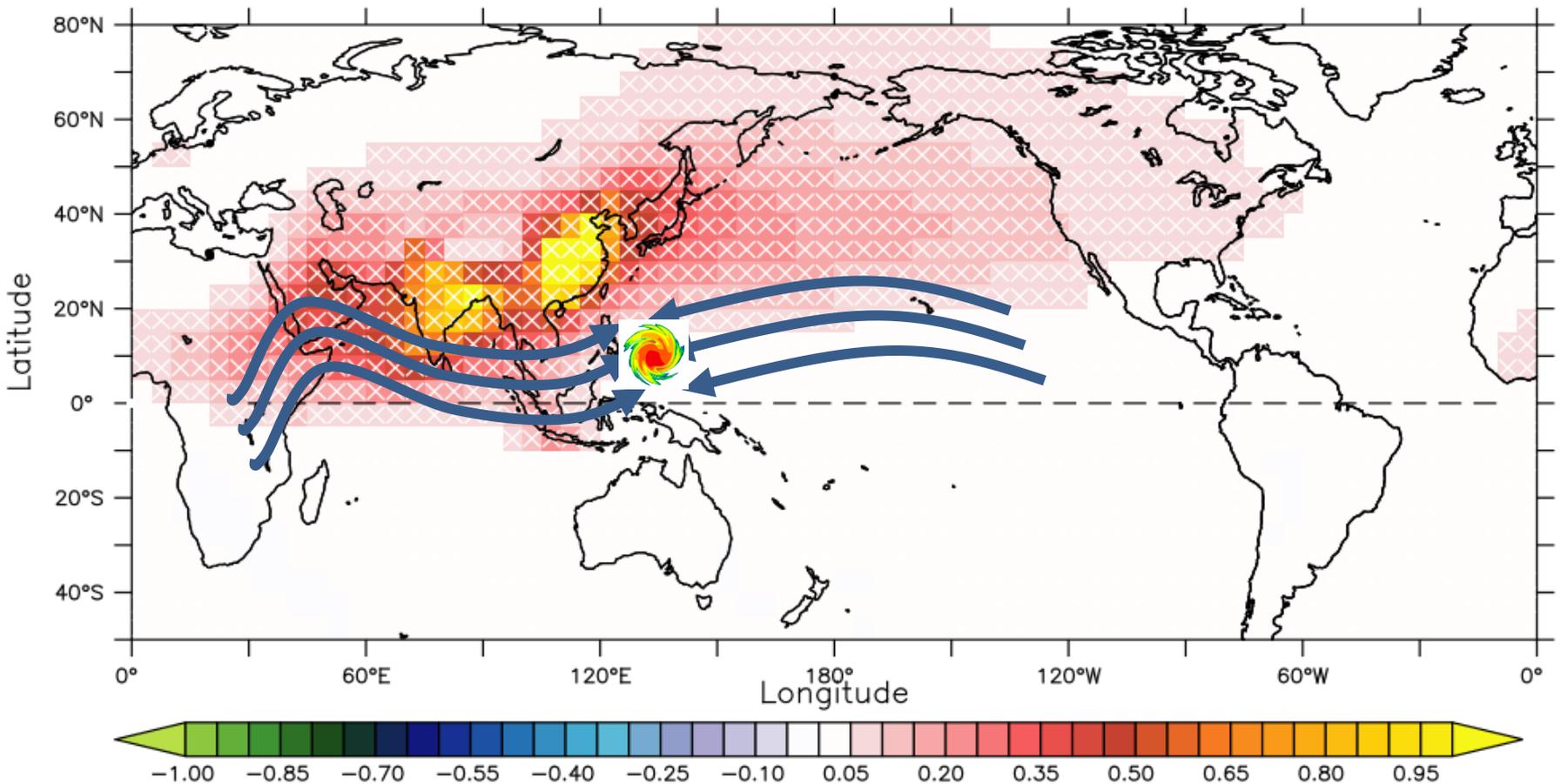


The warming in the mid-and high-latitudes in the Northern Hemisphere also caused Hemispheric circulation anomaly.

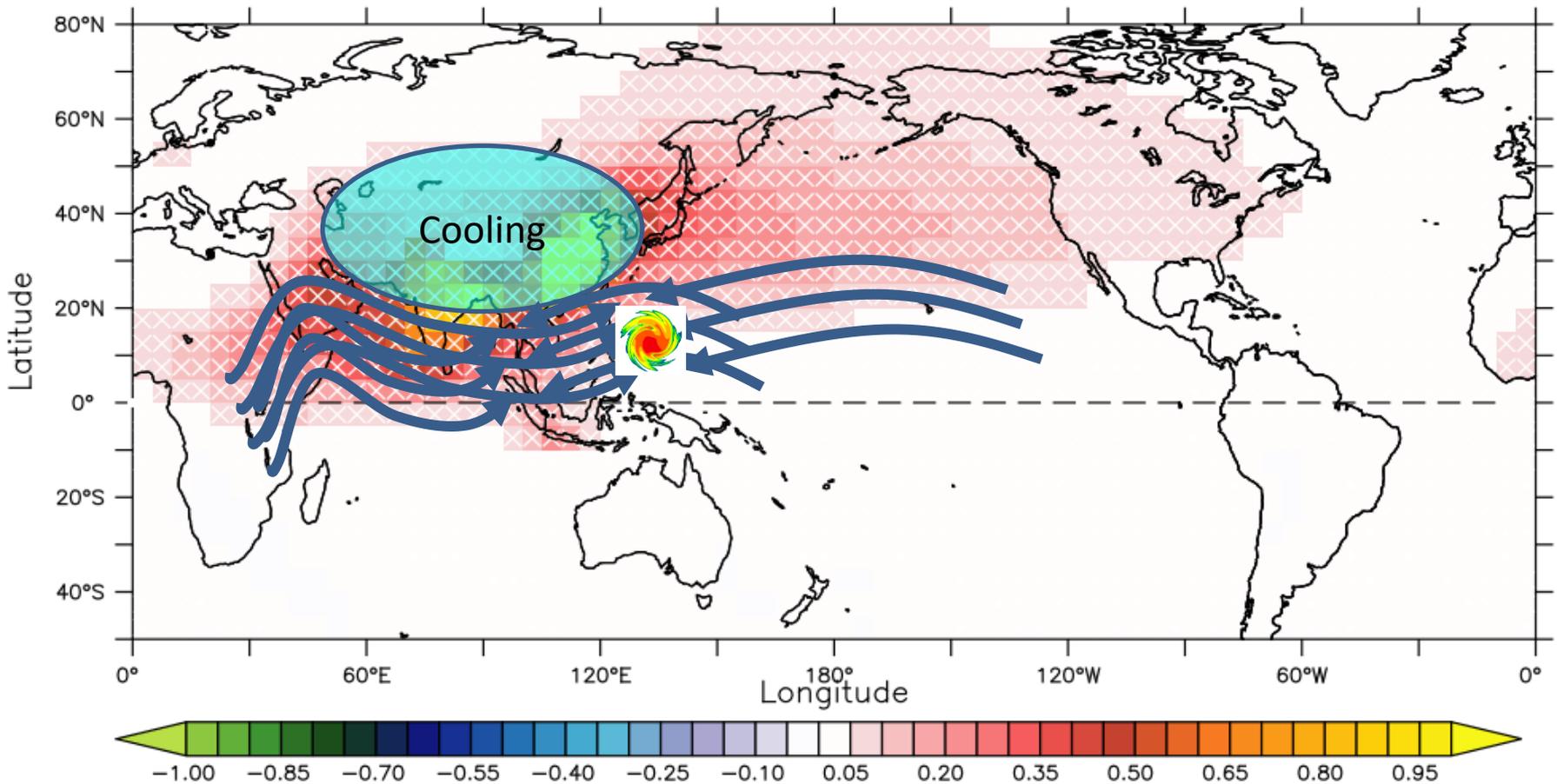
The warming causes anomalous upward motions by the enhanced convective activity.

The anomalous upward motion leads to downward motion in the Southern Hemisphere, in turn reducing tropical cyclones

Physical Mechanisms behind the TCF change



Tropical cyclones in the western North Pacific generally develop around the monsoon trough in the boreal summer.



The cooling over the land surface caused a weakened Indian monsoon, resulting in a weakened monsoon trough.

This in turn led to decreased tropical cyclones over the western North Pacific over the period 1980-2020.

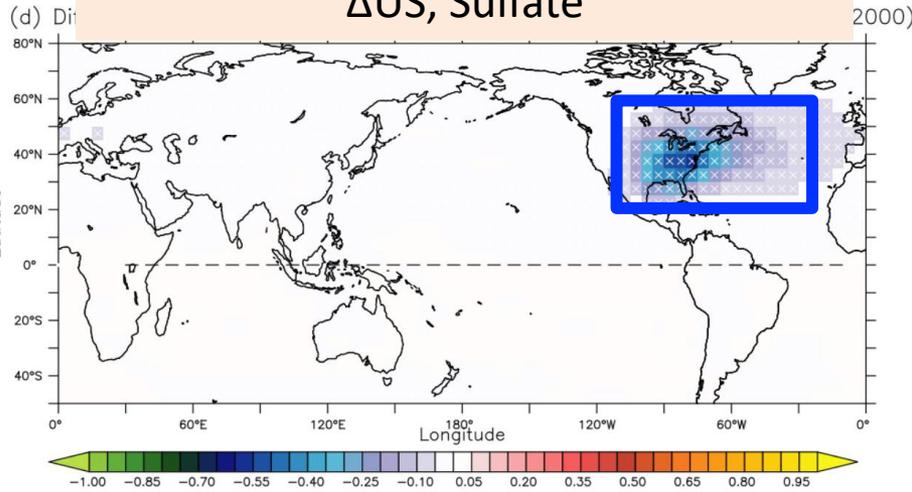
Increased aerosols from China and India helped to reduce tropical cyclones.

- A substantial influence of anthropogenic aerosols on the changes in global TC frequency of occurrence over 1980–2020.
- The decreased aerosols emission from Europe and the United States might have led to increased hurricanes in the North Atlantic and decreased tropical cyclones in the Southern Hemisphere.
- The increased aerosols emission from China and India might have led to decreased typhoons in the western North Pacific.

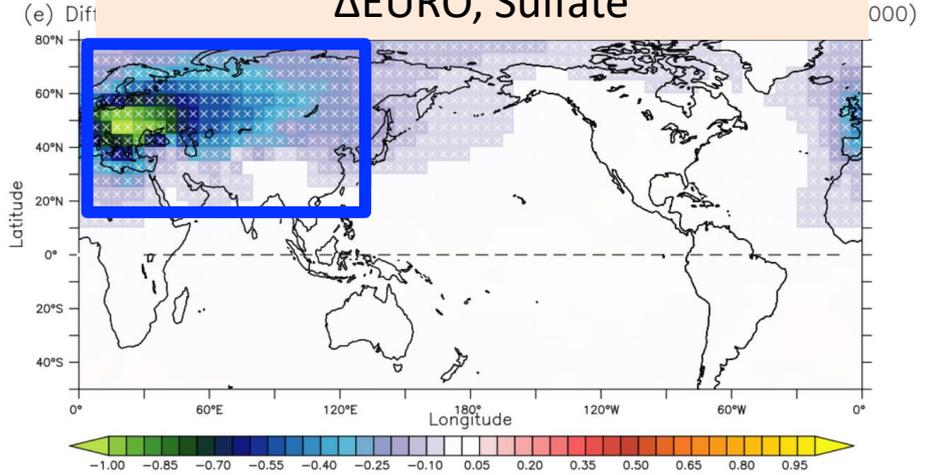
Additional Aerosol Experiments (US and EURO)



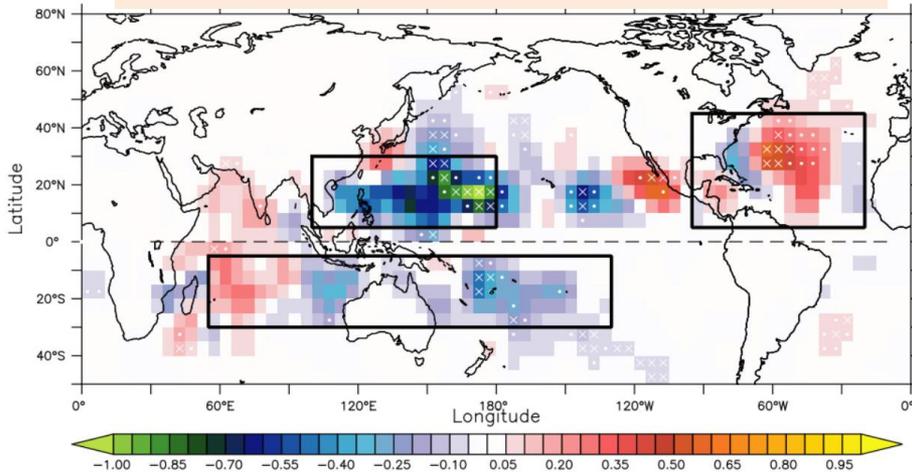
Δ US, Sulfate



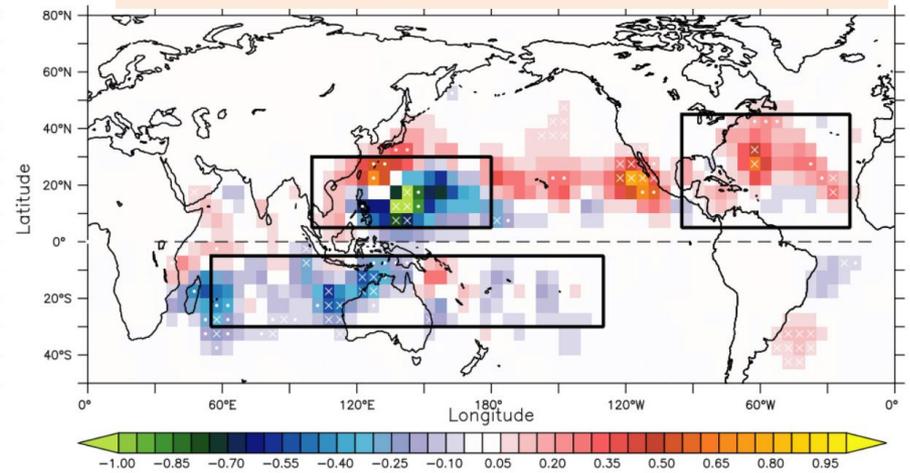
Δ EURO, Sulfate



Δ US, TCF



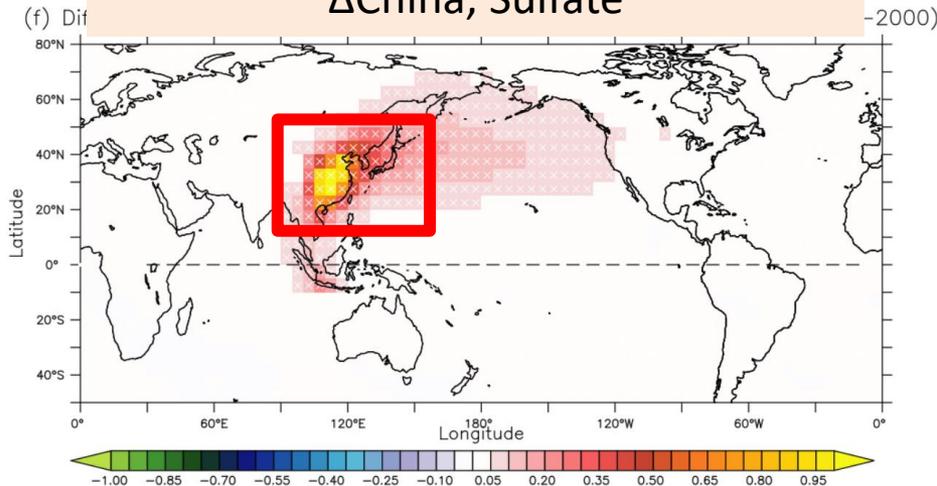
Δ EURO, TCF



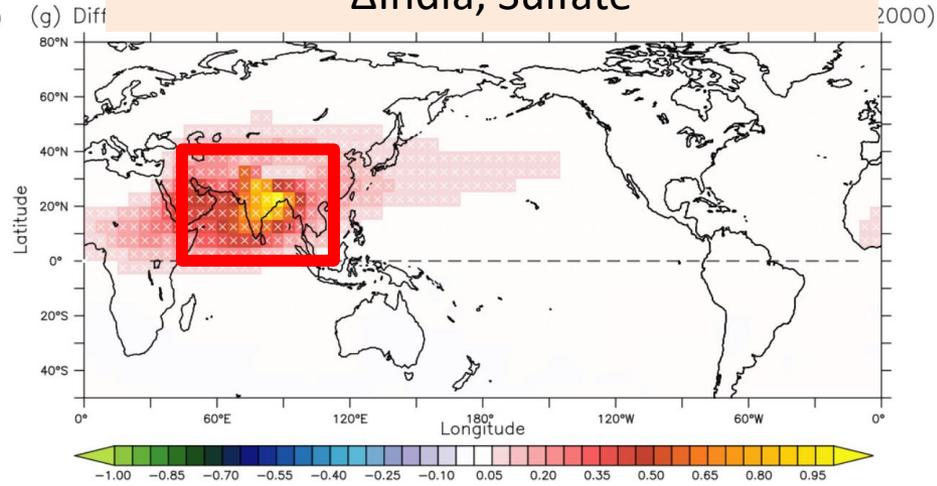
Additional Aerosol Experiments (China and India)



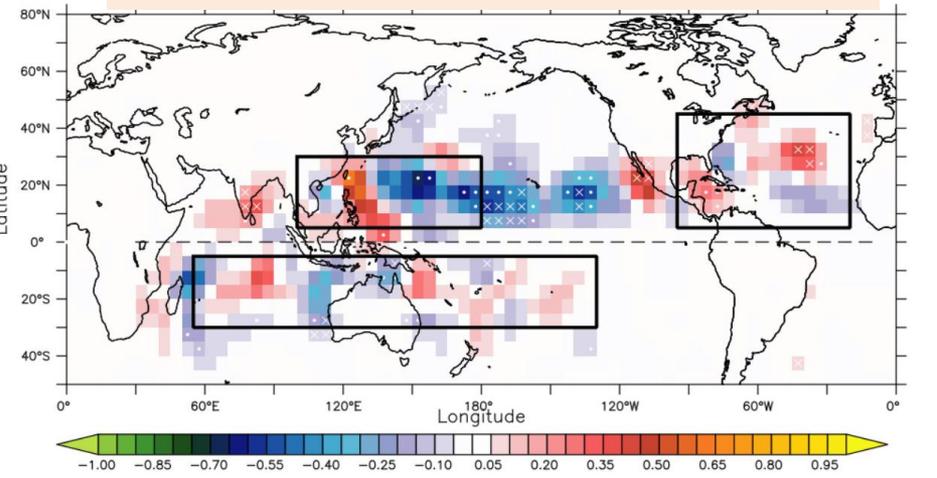
Δ China, Sulfate



Δ India, Sulfate



Δ China, TCF



Δ India, TCF

