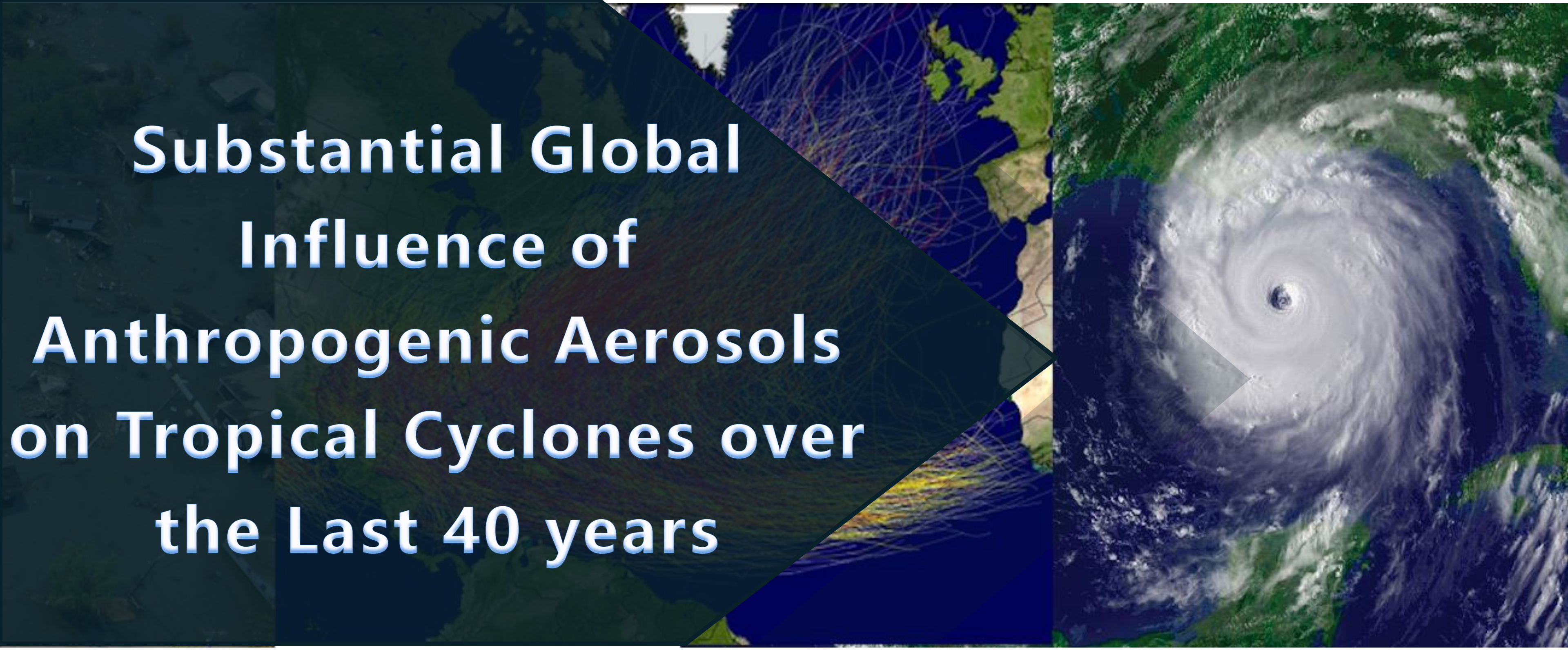
Substantial Global Influence of Anthropogenic Aerosols on Tropical Cyclones over the Last 40 years



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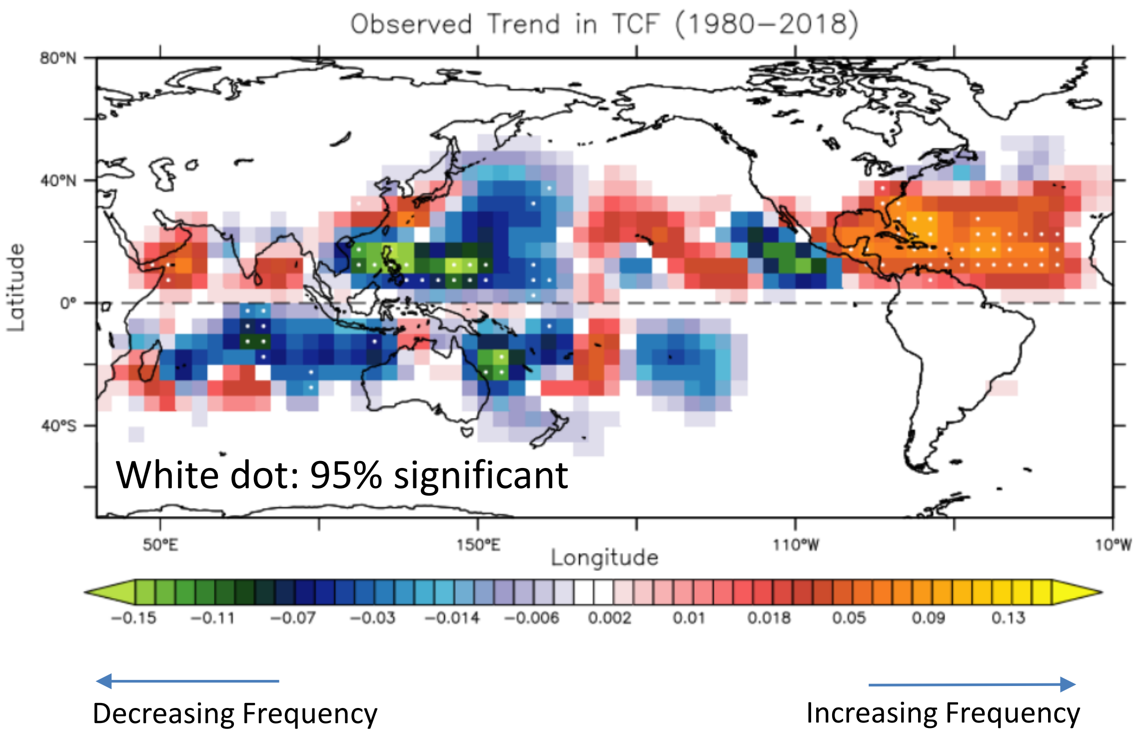
Observed Trend in Global TC Activity (1980-2018)

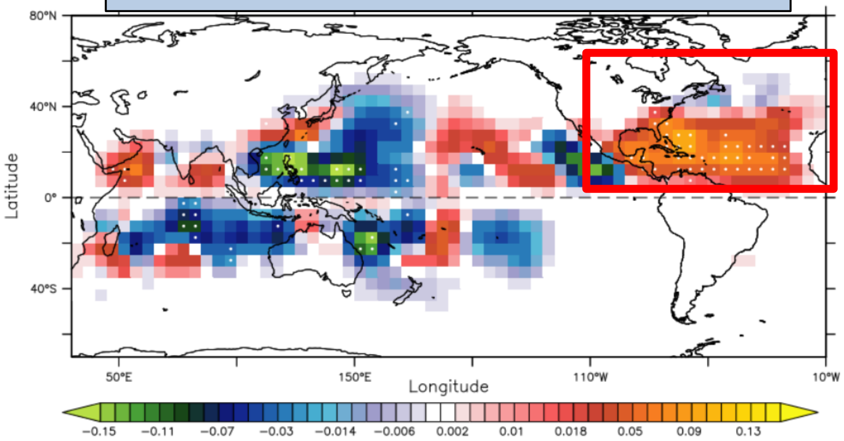


- TCF (or TC density) is defined as the total TC frequency of occurrence for every 5x5 degree grid cell.
- TCF shows significant negative and positive trends depending on region over 1980-2018.
- **We concluded in the previous study that this spatial pattern of the trends is largely influenced by the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

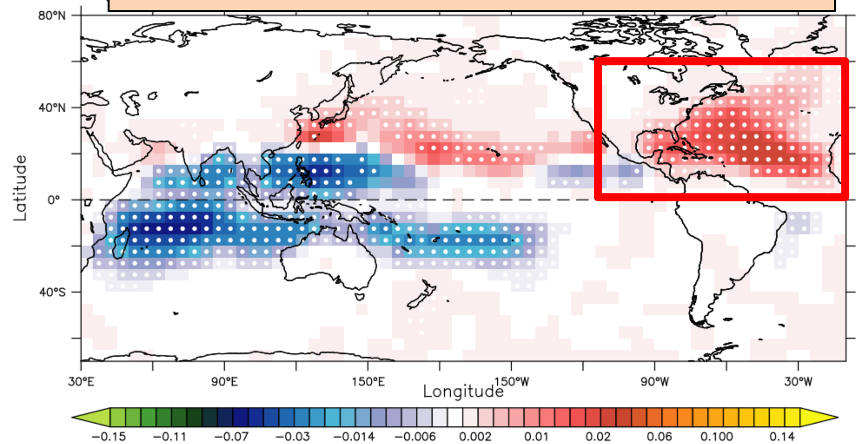
Murakami et al. (2020, *PNAS*)

Effect of External Forcing on the TCF Trend

Observed Trend in TCF (1980-2018)

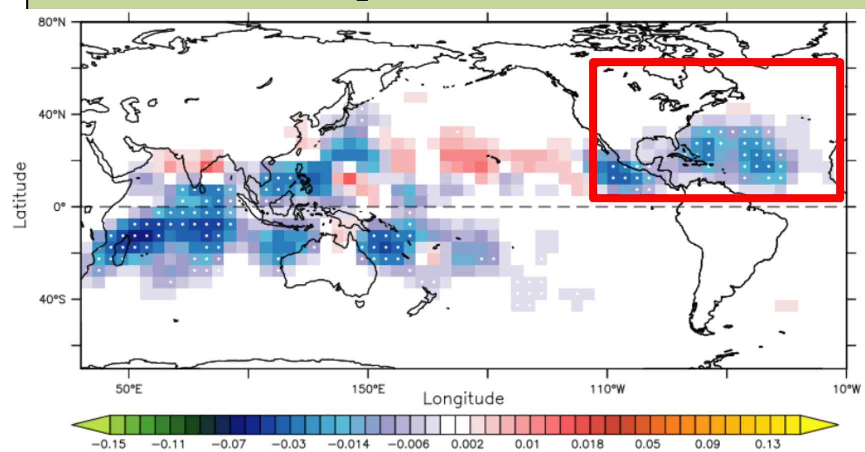


AllForc (95-member mean, 1980-2018)



All forcing includes greenhouse gases, anthropogenic aerosols, ozone.

Transient 2xCO_2 (3-member mean, 70 yrs)



Transient +1%/yr CO_2 Experiment

- Fully Coupled
- +1% CO_2 increase up to 2xCO_2 (at year 171) then fixed

Hypothesis:

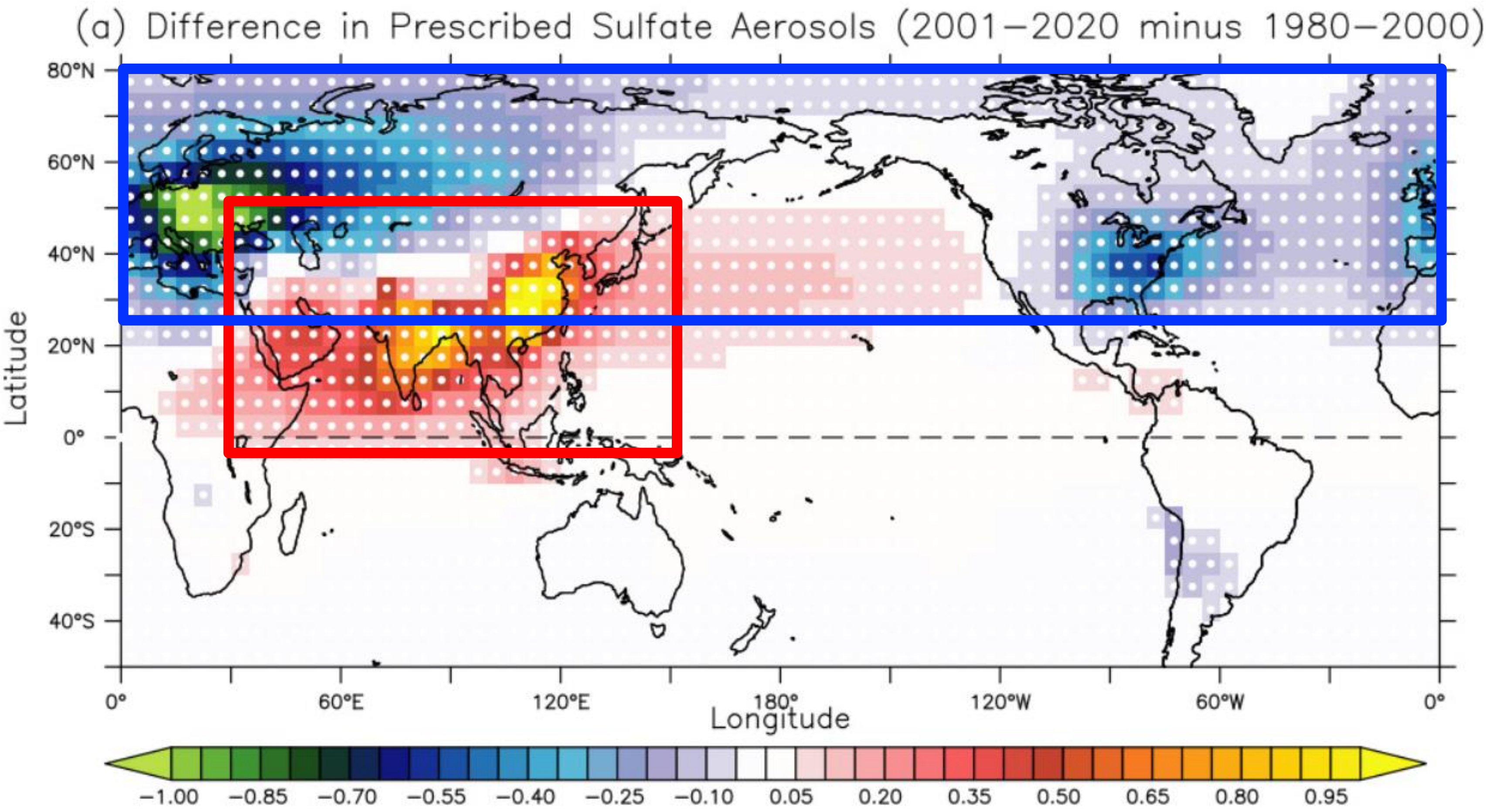
External forcings other than greenhouse gases are responsible for the increased hurricanes in the North Atlantic.

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)

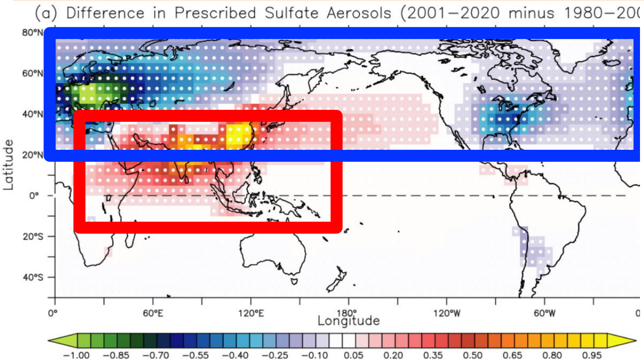


Decreased aerosols from Europe and the United States

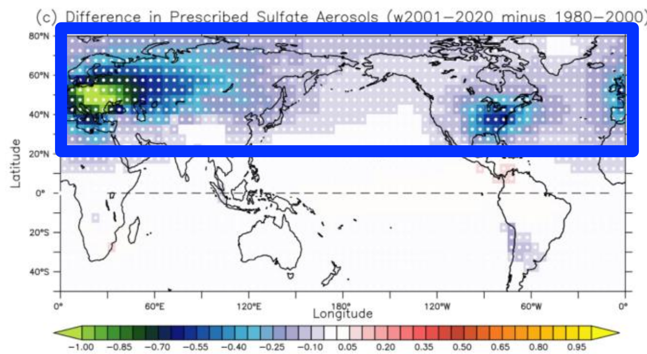
Increased aerosols from China and India

Experimental Setting

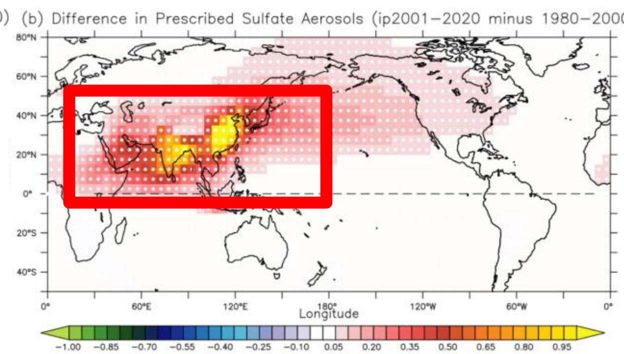
ΔALL21, Sulfate



ΔW21, Sulfate



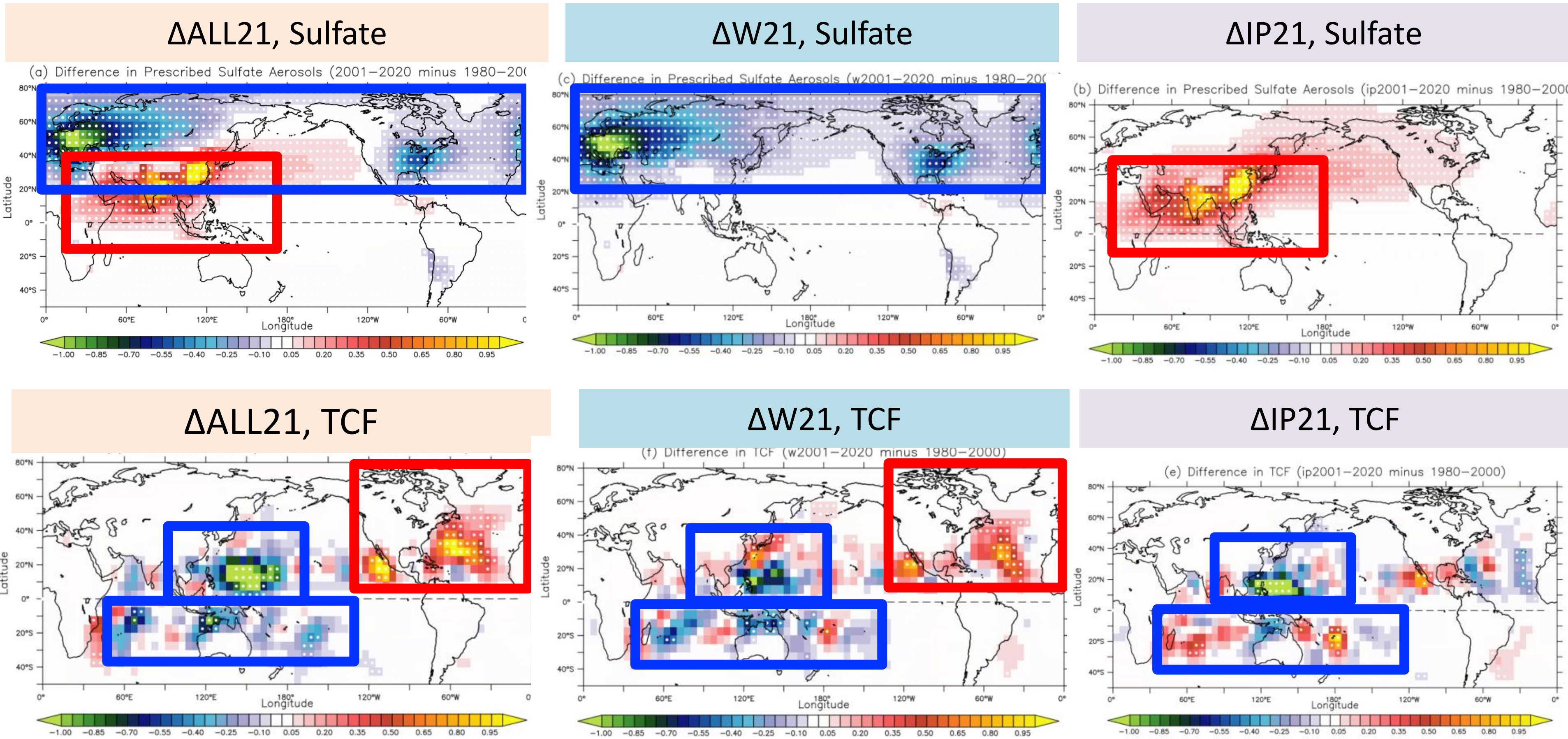
ΔIP21, Sulfate



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

Exp Name	Specified Emission of Anthropogenic Aerosols	Other External Forcing	Simulation Eyears	Difference from CNTL
CNTL	Mean of 1980-2000	Fixed level at 2000	200 years	—
ALL21	Mean of 2001-2020			ΔALL21
W21	Mean of 2001-2020 for Europe and the US, mean of 1980-2000 for the rest of the world			ΔW21
IP21	Mean of 2001-2020 for China and India, mean of 1980-2000 for the rest of the world			ΔIP21

Effect of anthropogenic aerosols on global tropical cyclones



Decreased aerosols from Europe and the United States =>

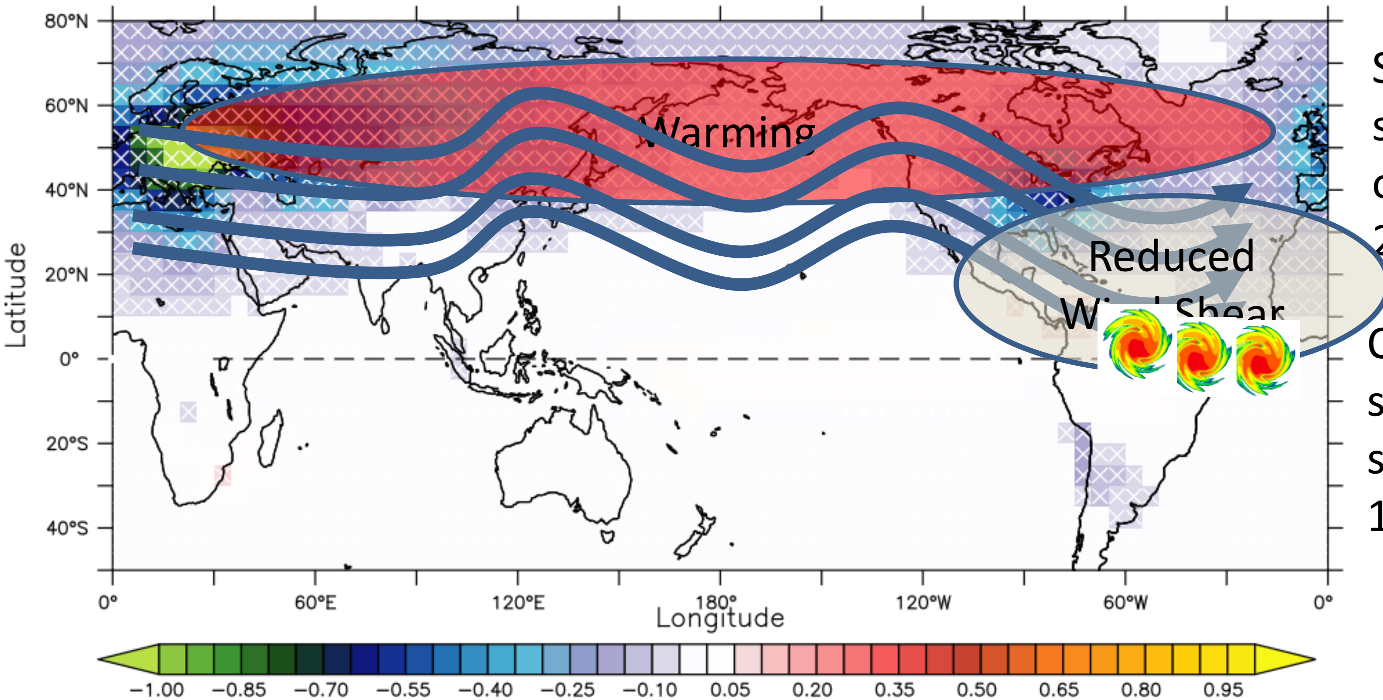
Increased TCF in the North Atlantic

Decreased TCF in the Southern Hemisphere

Increased aerosols from China and India =>

Decreased TCF in the western North Pacific

Physical Mechanisms behind the TCF change



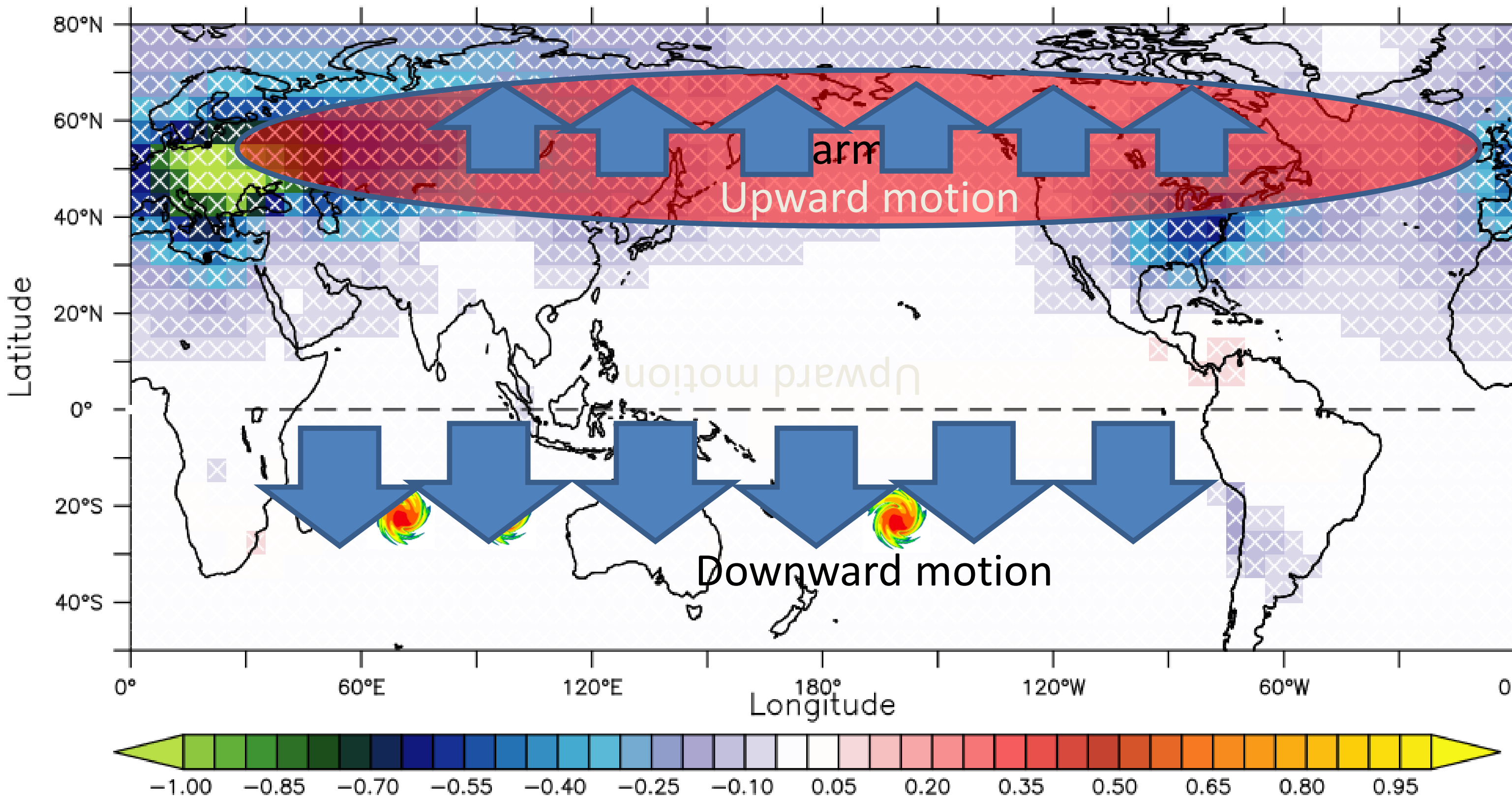
Shading: Linear trend in sulfate concentration over the period 1980-2020

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

The warming caused a poleward shift in a 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 (indirect effect).

Physical Mechanisms behind the TCF change

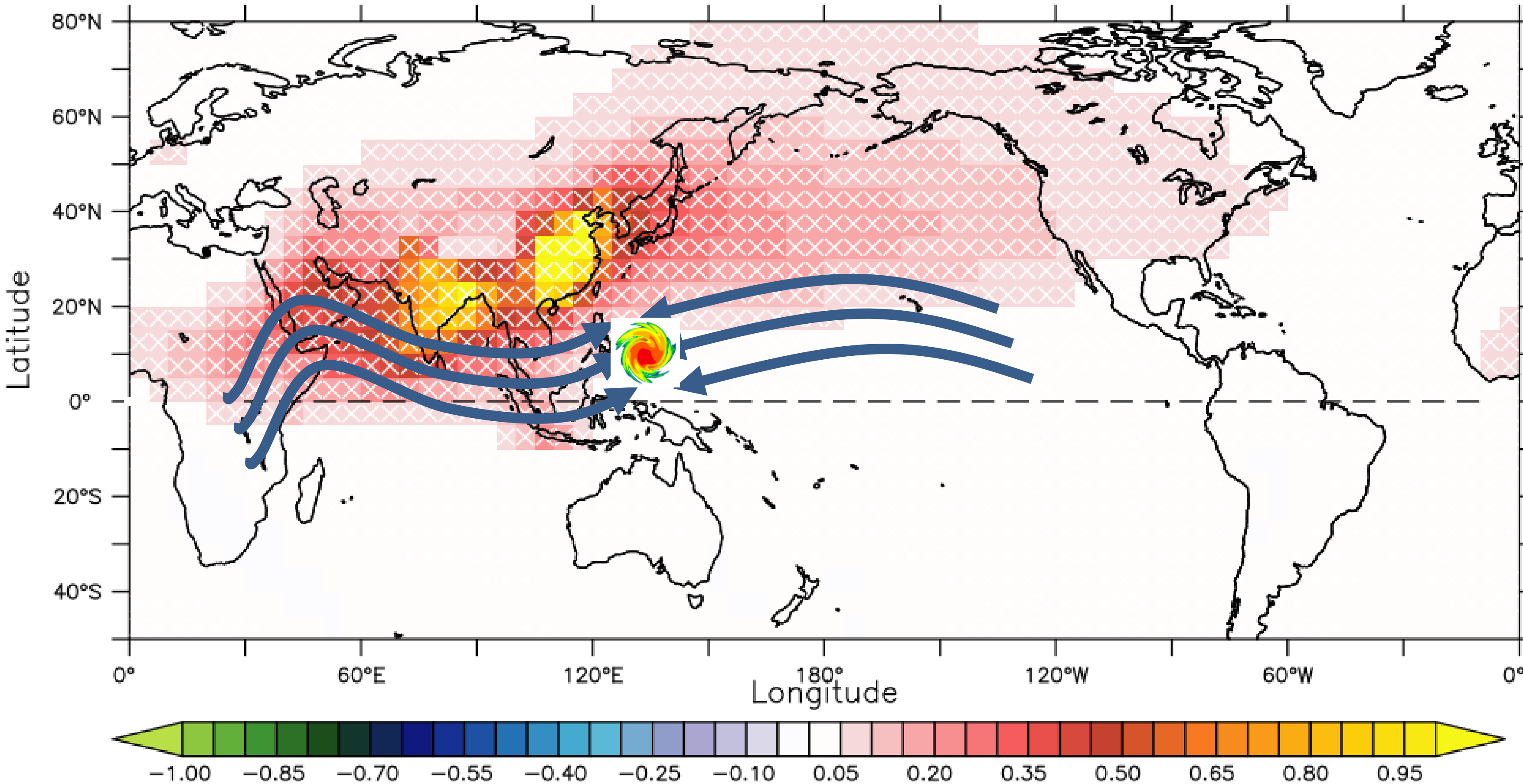


The warming in the mid-and high-latitudes in the Northern Hemisphere also caused Hemispheric circulation.

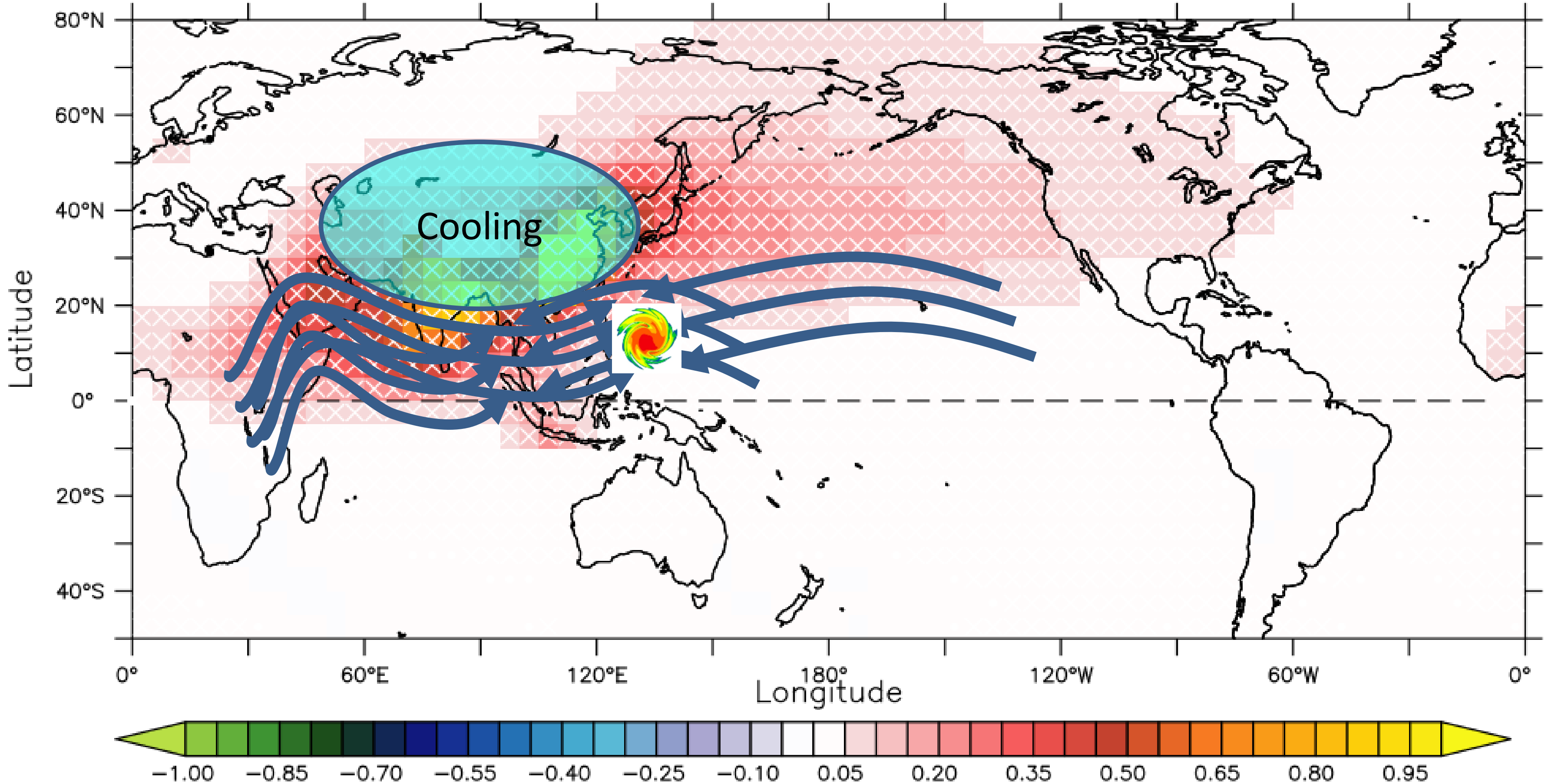
The warming causes anomalous upward motions by the enhanced convective activity.

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.

Takeaway Message

- A substantial influence of anthropogenic aerosols is shown for climate change in global TC activity 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.