Synthesis of Hurricane Prediction and Projections, from Seasonal Prediction to Decadal Attribution and Projection

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Advancing Innovative Research (AIR) Seminar on Aug 14th, 2024

Background

Tropical cyclones (TCs) have large societal and economic impacts on the United States (and many other countries)

Disaster Type	Number of Events	Percent Frequency	CPI-adjusted Losses ($ billions)	Percent of Total Loss	Average Event Cost ($ billions)
Drought	21	12.4	199	19.1	9.5
Flooding	19	11.2	86	8.3	4.5
Freeze	7	4.1	25	2.4	3.6
Severe Storm	65	38.2	143	13.7	2.2
Tropical Cyclone	34	20.0	530	50.9	15.6
Wildfire	12	7.1	26	2.5	2.2
Winter Storm	12	7.1	35	3.4	2.9

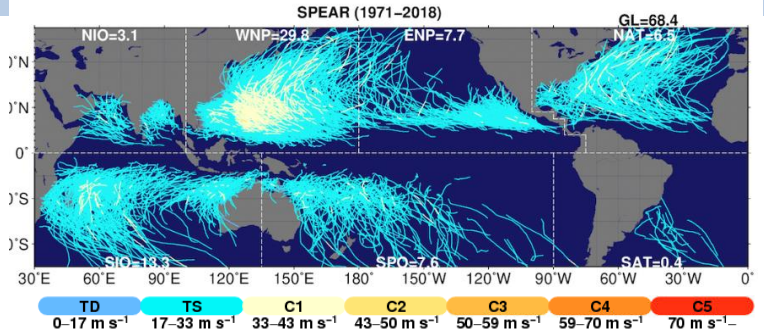
Table: Damage cost from U.S. Billion-dollar disaster events (1980-2013)

Smith and Matthes (2015, Natural Hazards)

- Developing dynamical seasonal prediction capabilities for TCs a few months in advance is highly relevant to both society and NOAA's mission.
- Understanding the characteristics and causes of both past and future climate changes in TCs is of profound scientific and public interest, and is central to NOAA's mission

GFDL-SPEAR, HiFLOR –High-Resolution Global Coupled Model–

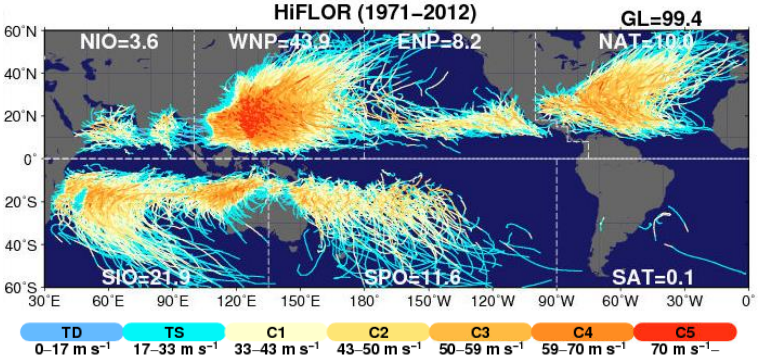
GFDL-SPEAR
Delworth et al. (2020)



A modified version of AM4 (atmosphere) & MOM6 (ocean) & SIS2 (ice) & LM4 (land)

- **50km** cubed-sphere atmosphere/land surface
- 1° ocean/sea ice
- Current operational seasonal forecast model for NMME (Lu et al. 2020)

GFDL-HiFLOR
Vecchi et al. (2014)
Murakami et al. (2015)



A modified version of CM2.5 (Delworth et al. 2012):

- **25km** cubed-sphere atmosphere/land surface
- 1° ocean/sea ice

TC tracks are detected using 6-hourly outputs considering maximum wind speed (15.75m/s), warm core (1K), and duration (36 hours) (Harris et al. 2016).

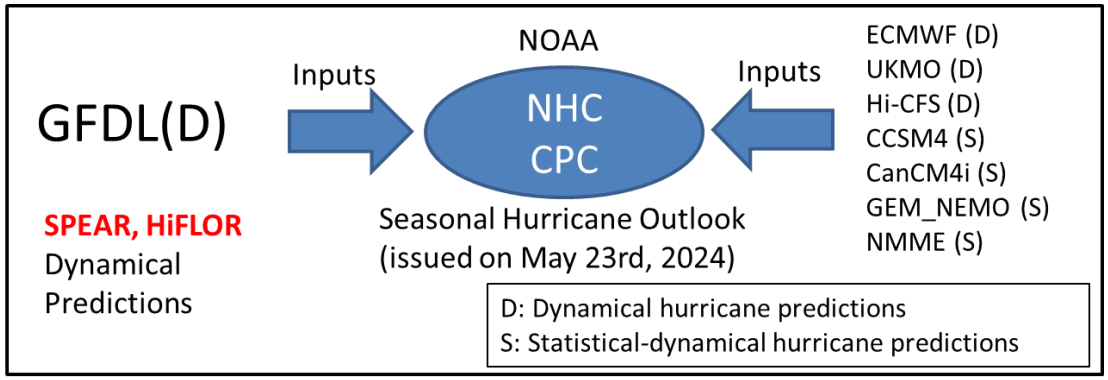
Questions to answer in this talk

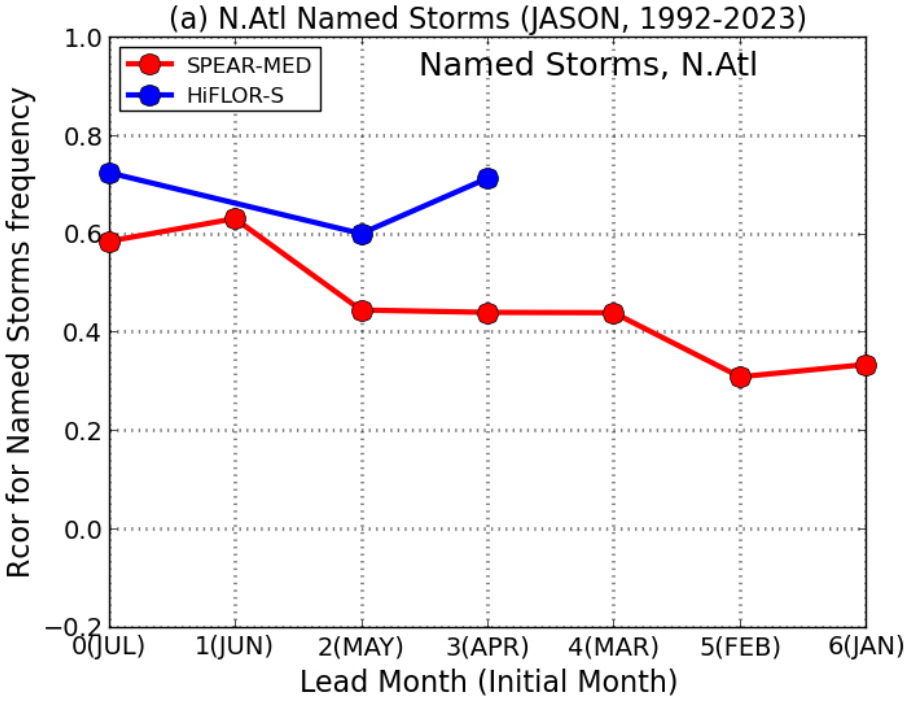
This presentation aims to clarify the following open questions using state-of-the-art GFDL global dynamical models.

1. What does Hurricane seasonal outlook foresee for the summer of 2024?
2. Why is the 2024 hurricane season predicted so active?
3. Will we see more active hurricane season like 2024 in the future?
4. How did anthropogenic forcing change tropical cyclones over the past 40 years?

Experimental Seasonal Hurricane Predictions at NOAA's GFDL

- NOAA-GFDL has been supporting experts at the National Hurricane Center and Climate Prediction Center since 2017 for the hurricane seasonal outlook.
- NOAA-GFDL is one of the two U.S. institutions that provides **dynamical** seasonal hurricane forecasts (**SPEAR and HiFLOR**)



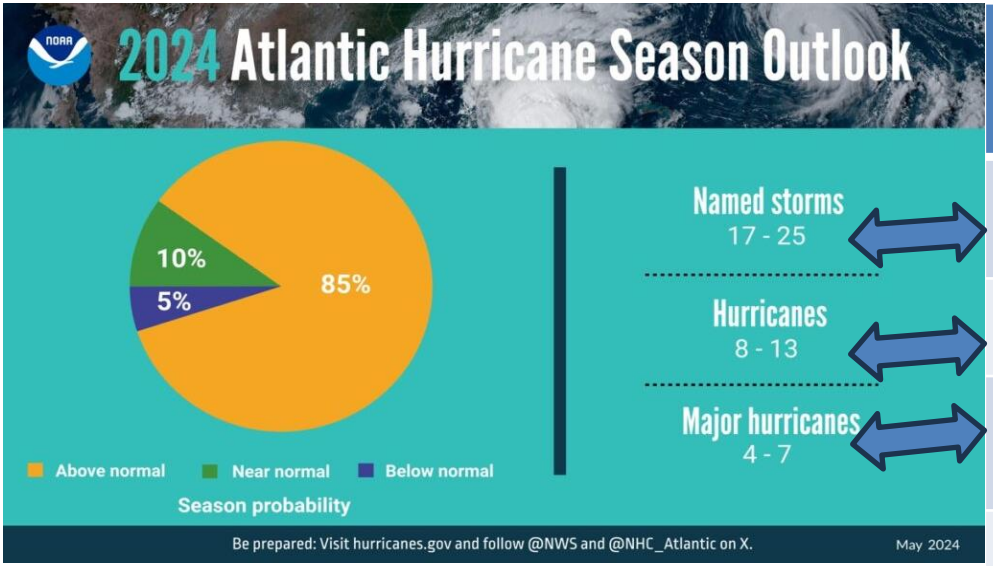


- GFDL's seasonal predictions have demonstrated high skill in forecasting tropical cyclones in the North Atlantic.
- The correlation between observed named storms and predictions from the initial July 1st forecast is **+0.7**.

Murakami et al. (2024, submitted)

Extremely active hurricane season is predicted for the 2024 summer in the North Atlantic

NOAA's 2024 Seasonal Hurricane Outlook (issued on May 23rd)



Predicted from the May 1st GFDL predictions

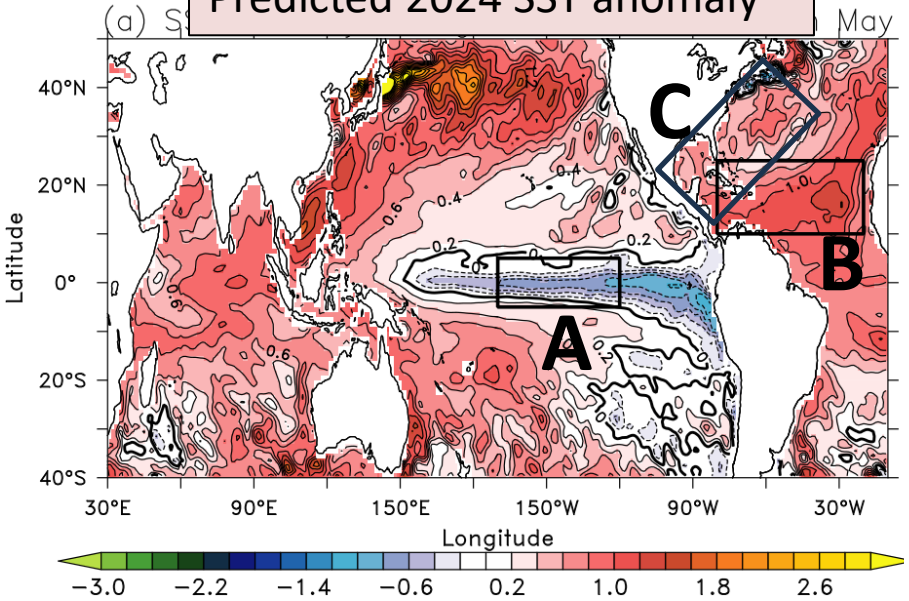
	GFDL predictions	Observed climatology	Anomaly (Standard deviation)
Named Storms	17-23	15	+1.8σ
Hurricanes	9-14	7	+2.4σ
Major Hurricanes	4-7	3	+2.3σ
ACE (10^5 m^2 s^{-2})	4-6	3.2	+1.9σ

- An extremely active hurricane season is predicted for the summer of 2024 in the North Atlantic
- The GFDL's 2024 hurricane predictions are consistent with NOAA's hurricane seasonal outlook

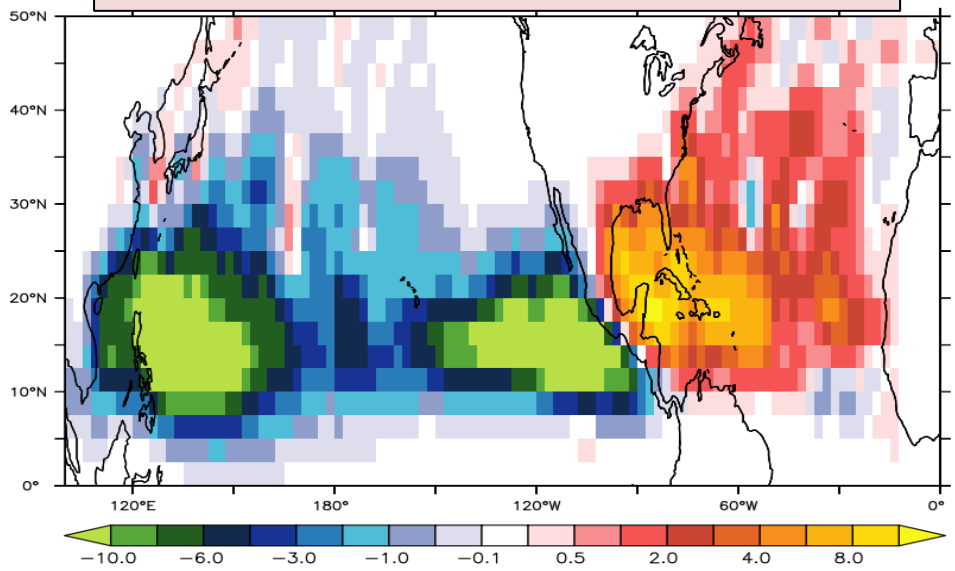
What causes the predicted active hurricane season in 2024?

The May 1st initial predictions for this summer by the GFDL-SPEAR model

Predicted 2024 SST anomaly



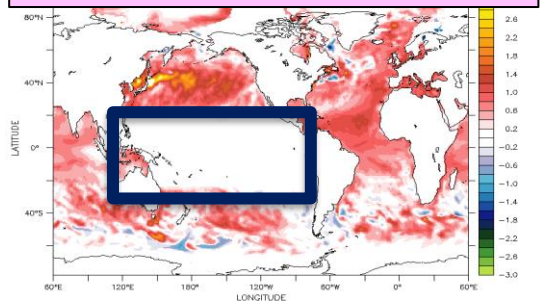
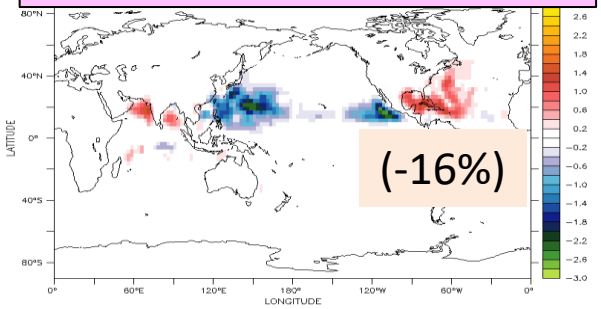
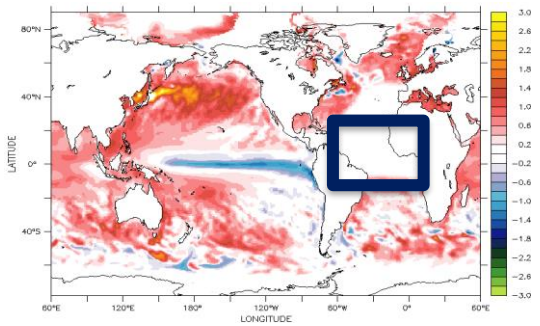
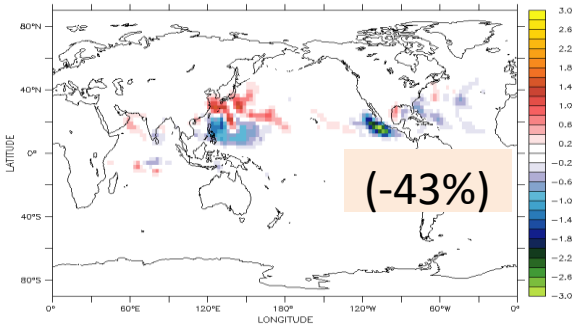
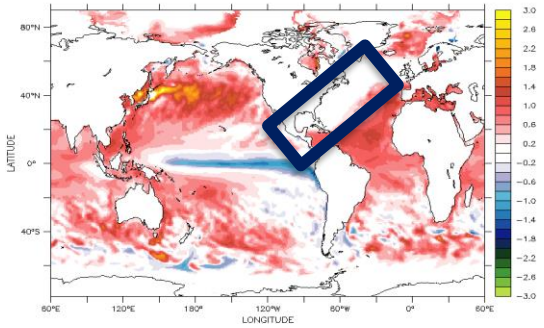
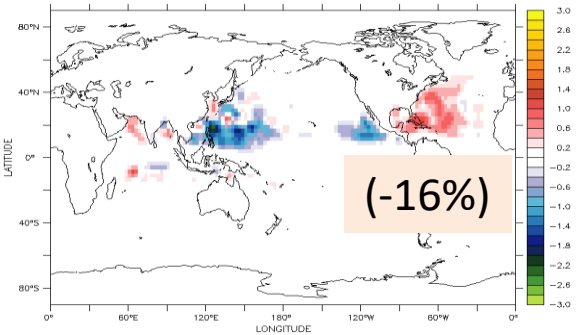
Predicted 2024 storm density anomaly



Anomaly relative to the 1992-2023 mean

A. Developing La Niña?
B. Warmer Tropical Atlantic?
C. Warmer off the coast of North America?

Idealized Seasonal Prediction for the Summer of 2024 by SPEAR

Prescribed SST Anomaly	Predicted TC density Anomaly
	
The La Nina condition was removed	
	
The warmer SST anomaly in the tropical Atlantic was removed	
	
The warmer SST anomaly off the coast of the US was removed	

Detailed methodology: Murakami et al. (2018, Science)

A. La Niña?

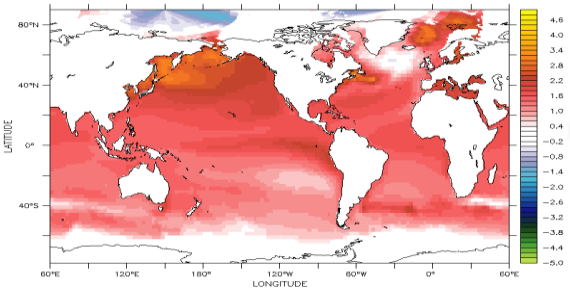
B. Warmer Tropical Atlantic?

C. Warmer off the coast of North America?

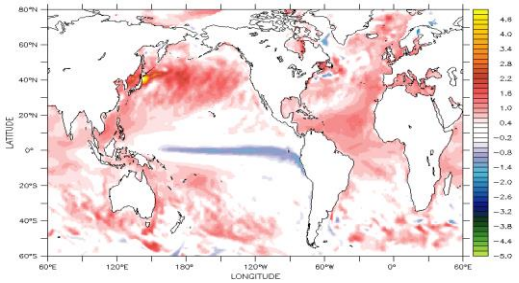
<u>The warmer tropical Atlantic could be a major contributor to the active 2024 hurricane season.</u>

What would the future look like if conditions similar to those in 2024 were to happen again?

SSP2-4.5 mean SST change (2081-2100 minus 1991-2010 by CMIP6 models)

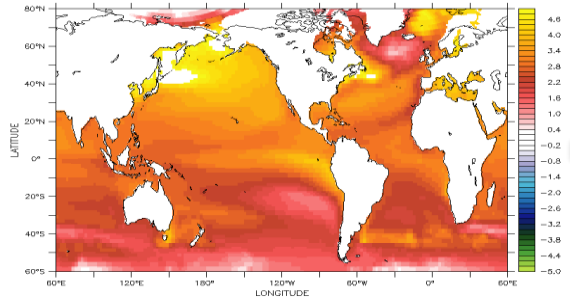


Predicted 2024 SST Anomaly

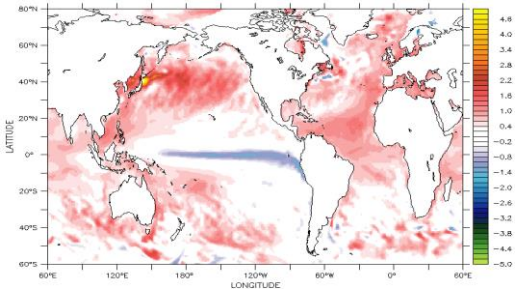


CO_2: 597 ppmv

SSP5-8.5 mean SST change (2081-2100 minus 1991-2010 by CMIP6 models)



Predicted 2024 SST Anomaly



CO_2: 998 ppmv

Will we see more active hurricane season than 2024?

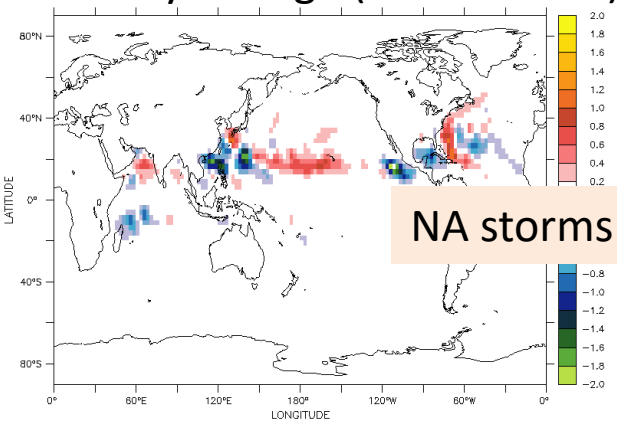
(The current CO_2 level is around 425 ppmv)

Detailed methodology: Murakami et al. (2018, Science)

What would the future look like if conditions similar to those in 2024 were to happen again?

SSP2-4.5 mean SST change (2081-2100 minus 1991-2010)

TC Density Change (2090 – 2024)

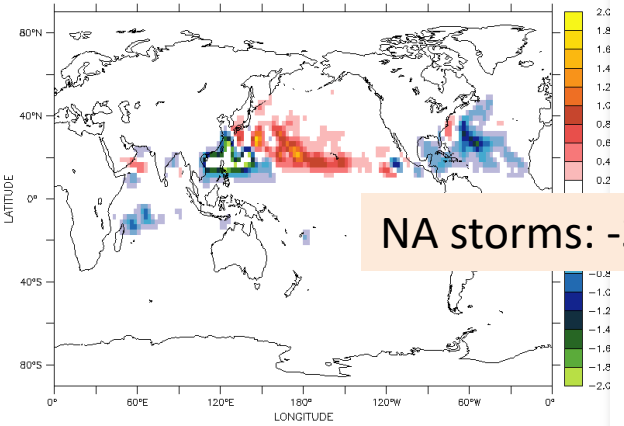


No change under the SSP2-4.5 scenario

NA storms: 0% change relative to 2024

SSP5-8.5 mean SST change (2081-2100 minus 1991-2010)

TC Density Change (2090 – 2024)

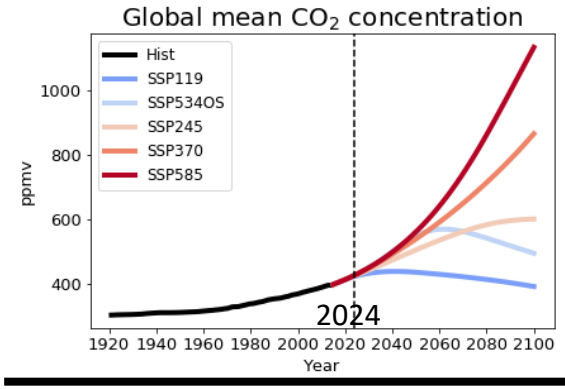


Projected decrease under the SSP2-4.5 scenario

NA storms: -30% change relative to 2024

GFDL-SPEAR tends to project decreased frequency of tropical cyclones in the North Atlantic in the future

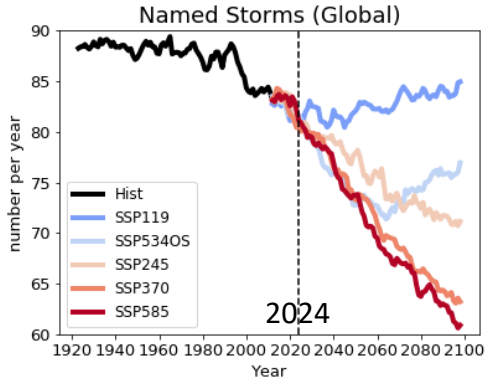
Long-term historical & future simulations by the GFDL-SPEAR model

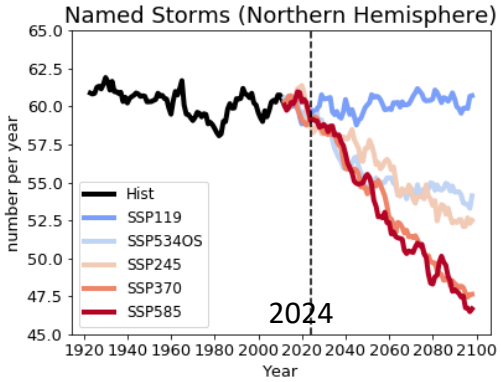


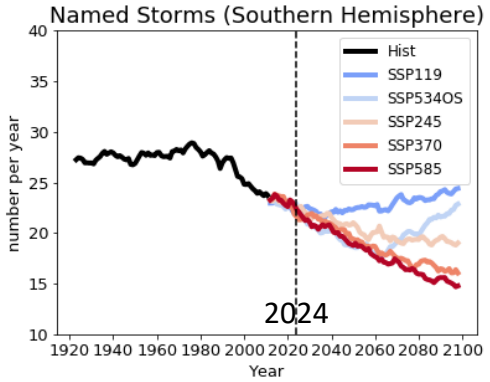
Large-ensemble simulations by the GFDL-SPEAR model

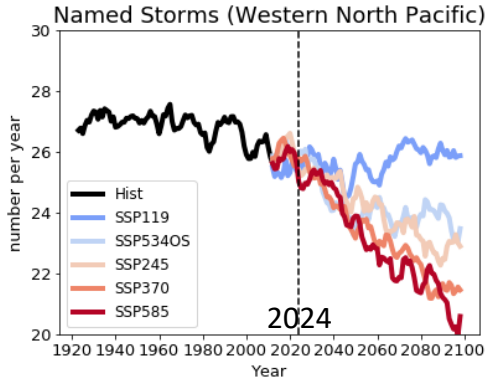
- 30 ensemble member initialized in 1921.
- 1921-2014: Historical forcing (CO_2, Aerosols, etc.)
- 2015-2100: Future forcing under the various SSP scenarios

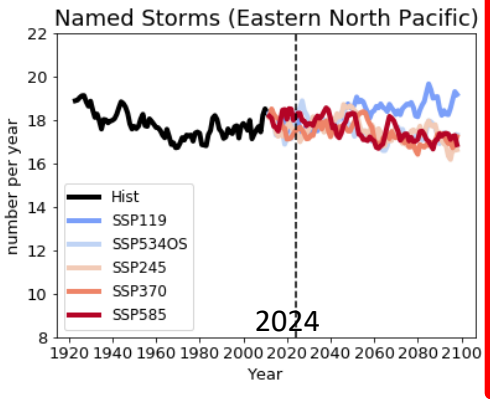
Simulated frequency of named storms (≥ 34 knots)

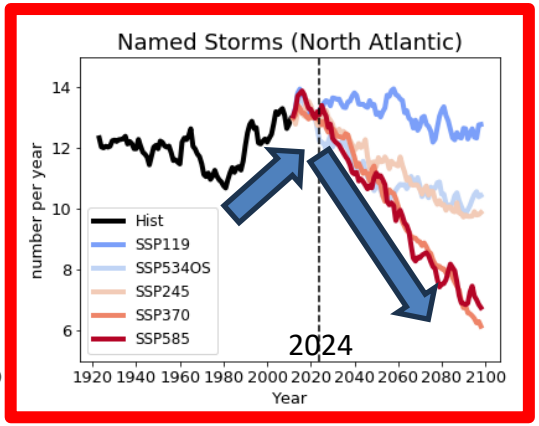








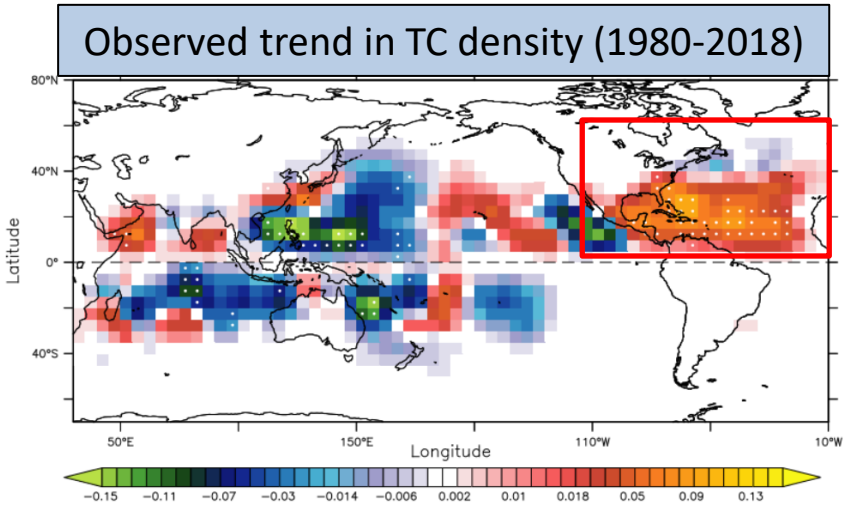


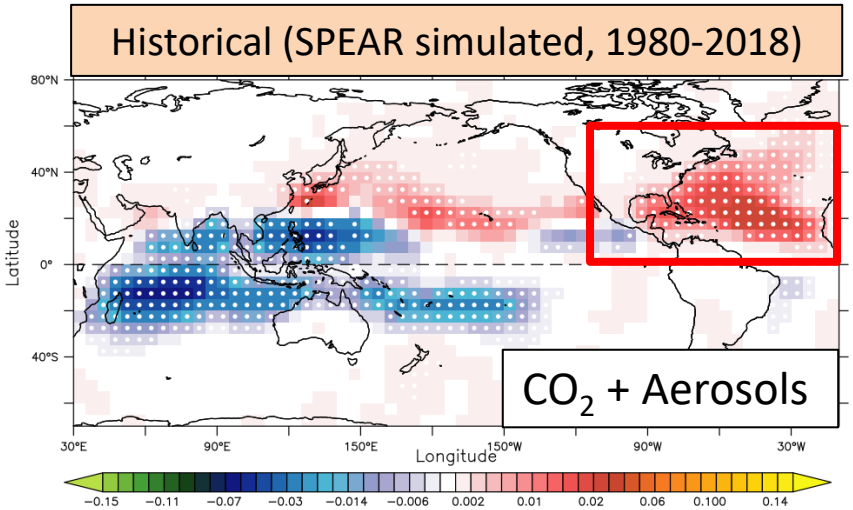


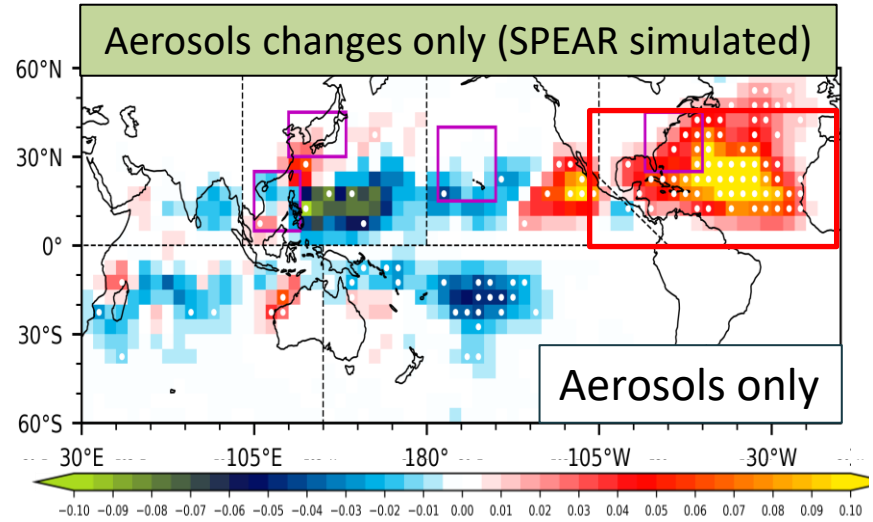
Murakami et al. (2024, submitted)

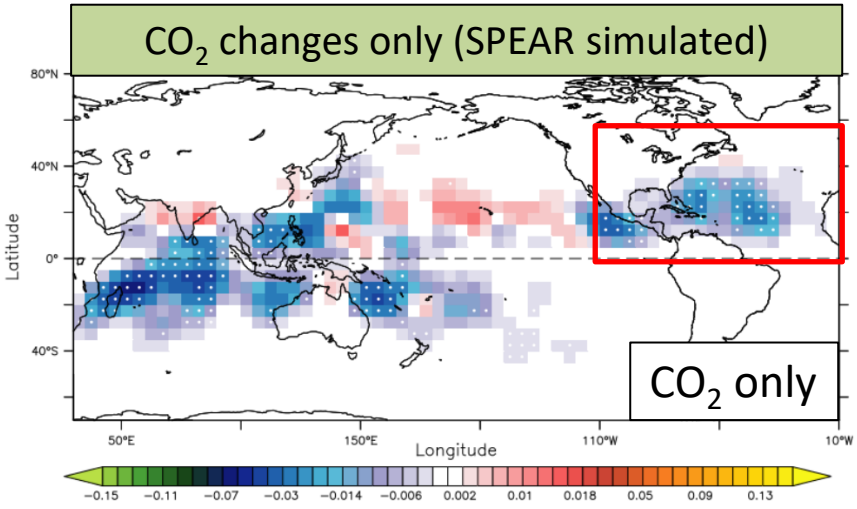
The changes observed in tropical cyclones in the past may not necessarily apply to the future.

Observed and simulated trends in storm density over the period 1980-2018





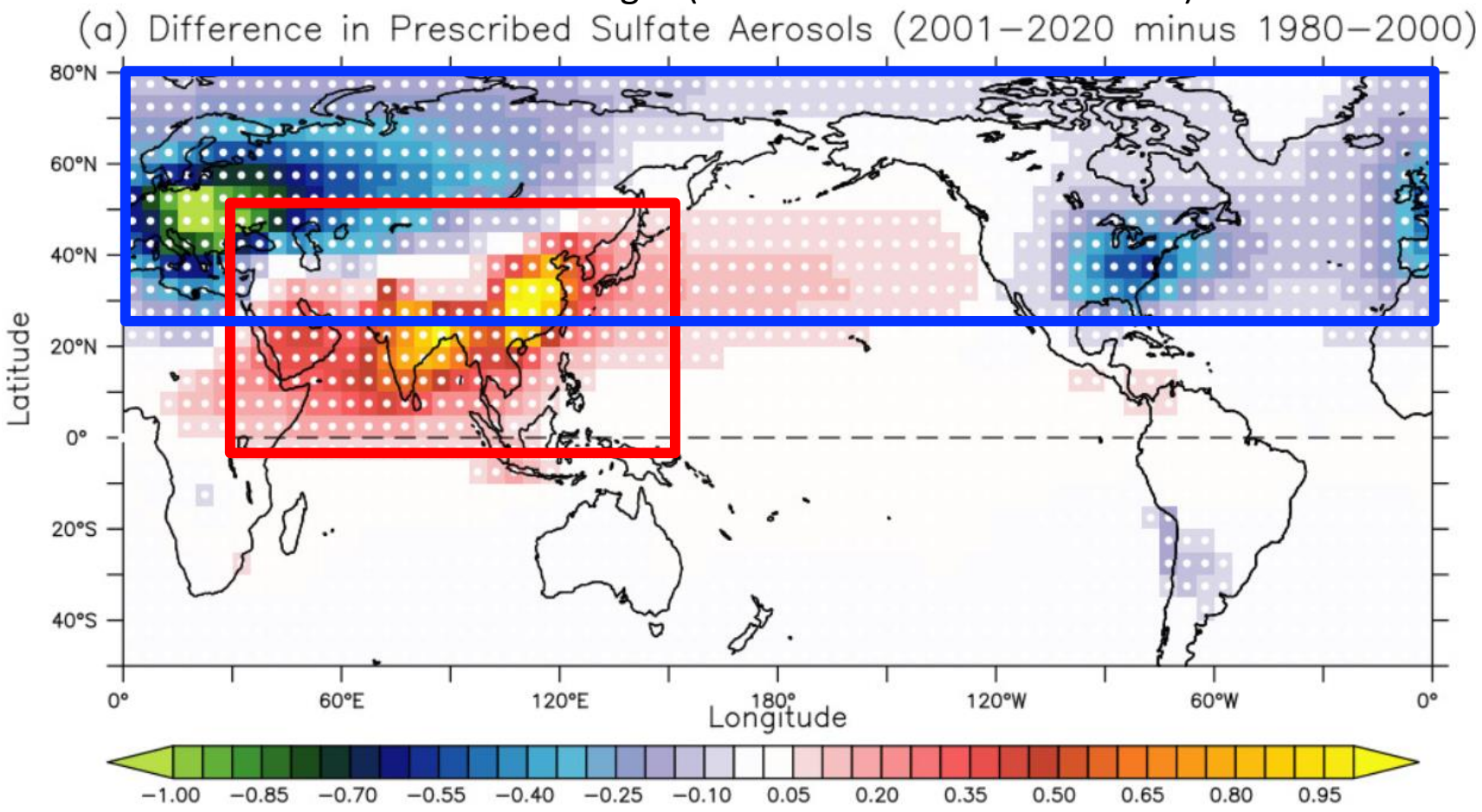




Murakami et al. (2020, PNAS), Murakami (2022, Sci. Adv.), Wang et al. (2023, npj. Clim. Atmos)

Changes in anthropogenic aerosols in the past 40 years

Sulfate changes (2001-2020 minus 1980-2000)



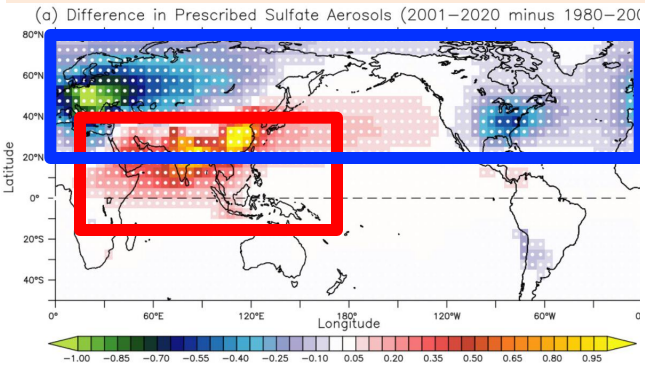
Decreased aerosols from Europe and the United States

Increased aerosols from China and India

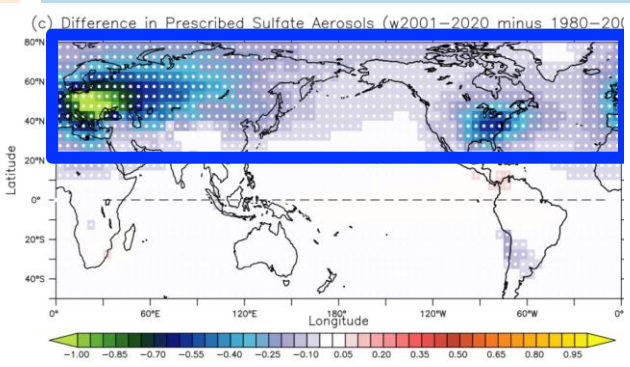
How have these regional changes in aerosols exerted changes in global TC frequency?

Effect of anthropogenic aerosols on global tropical cyclones

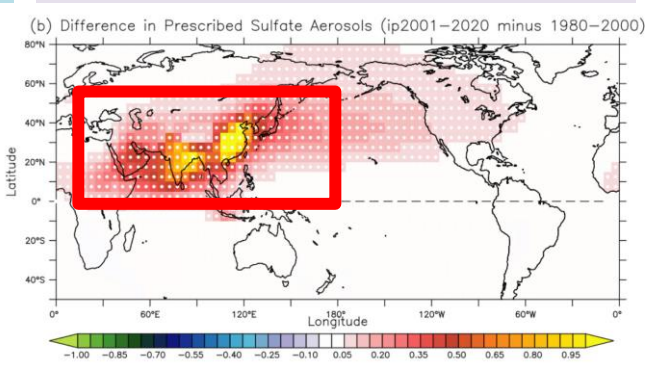
ΔALL21, Sulfate



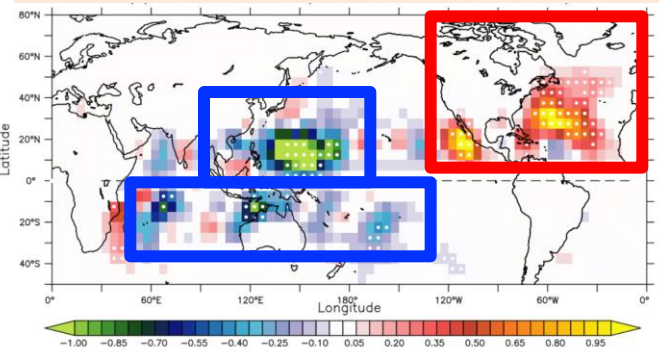
ΔW21, Sulfate



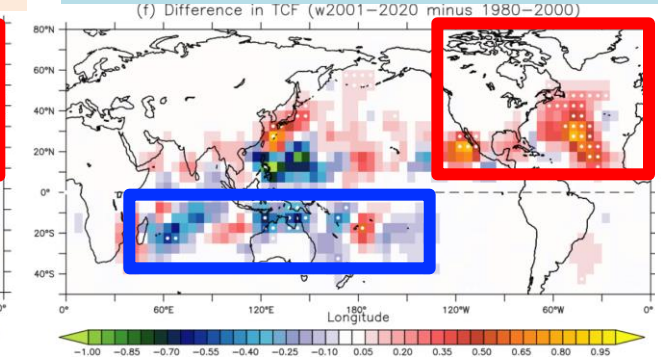
ΔIP21, Sulfate



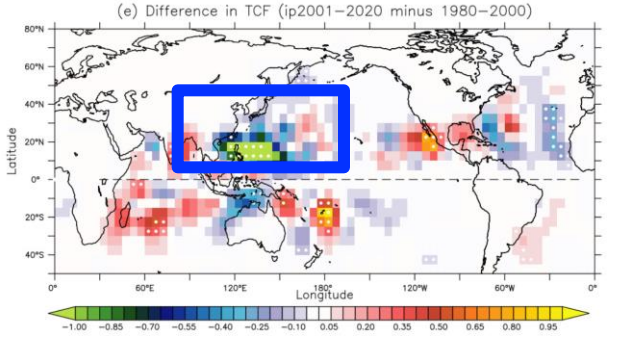
ΔALL21, TCF



ΔW21, TCF



ΔIP21, TCF



Decreased aerosols from Europe and the United States =>

Increased TCF in the North Atlantic

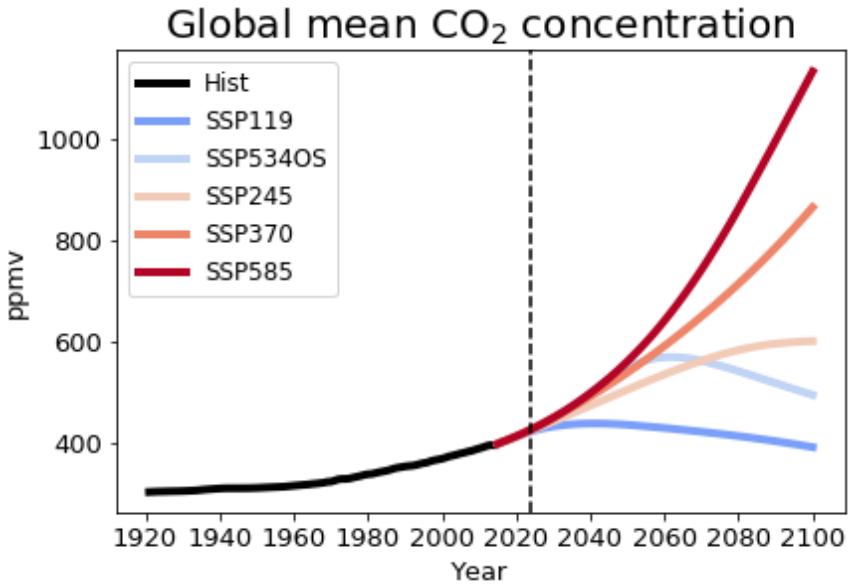
Decreased TCF in the Southern Hemisphere

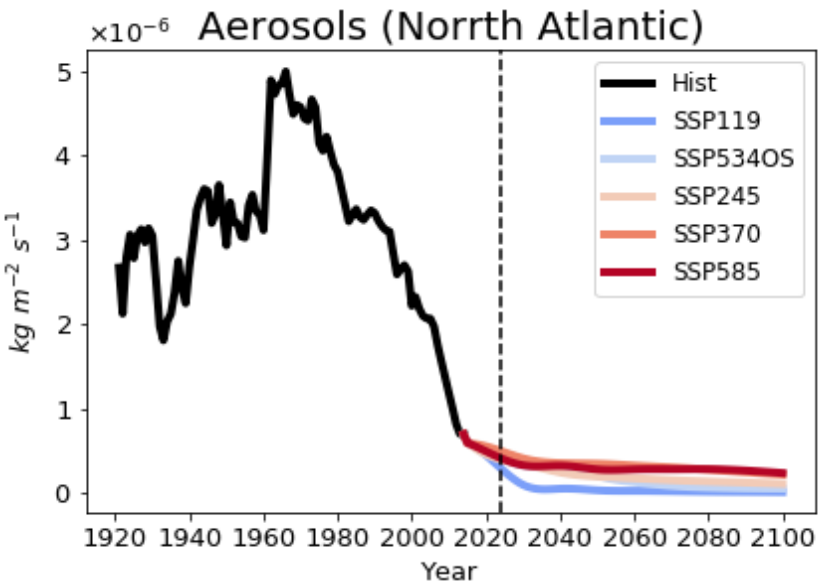
Increased aerosols from China and India =>

Decreased TCF in the western North Pacific

Murakami (2022, Sci. Adv.)

The past changes in tropical cyclones may not apply to the future





Substantial increases in CO_2 are expected, whereas anthropogenic aerosols over the North Atlantic may not change much in the future

According to the SPEAR future projections, frequency of tropical cyclones in the North Atlantic is projected to decrease due to the dominant effect of CO_2

Murakami et al. (2020, PNAS), Murakami (2022, Sci. Adv.), Murakami (2024, submitted)

Key takeaways

- GFDL-SPEAR and HiFLOR predict an extremely active hurricane season in the North Atlantic in 2024, consistent with NOAA's hurricane seasonal outlook.

- The predicted active 2024 hurricane season is largely attributed to the anticipated warm sea surface temperatures in the tropical Atlantic Ocean.

- A hurricane season similar to 2024 in the future climate may be less active than 2024.

- Anthropogenic aerosols have substantially influenced global storms over the past 40 years.

- GFDL-SPEAR projects a decrease in the frequency of tropical cyclones in the North Atlantic in the future, primarily due to the dominant effect of increasing CO_2 levels. This trend contrasts somewhat with the past 40 years, which have shown an increased frequency of tropical cyclones, partially attributed to decreased aerosol emissions from Europe and the US.

References

Murakami, H., G. A. Vecchi, S. Underwood, T. L. Delworth, A. T. Wittenberg, W. G. Anderson, J. -H. Chen, R. G. Gudgel, L. Harris, S. -J. Lin, and F. Zeng, 2015: Simulation and prediction of Category 4 and 5 hurricanes in the high-resolution GFDL HiFLOR coupled climate model. *J. Climate,* **28,** 9058-9079.

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Wang, S., H. Murakami, and W. F. Cooke, 2023: Anthropogenic forcing changes coastal tropical cyclone frequency. *npj Clim. Atmos. Sci.,* **6,** 187.