Atlantic Hurricanes and Climate Change

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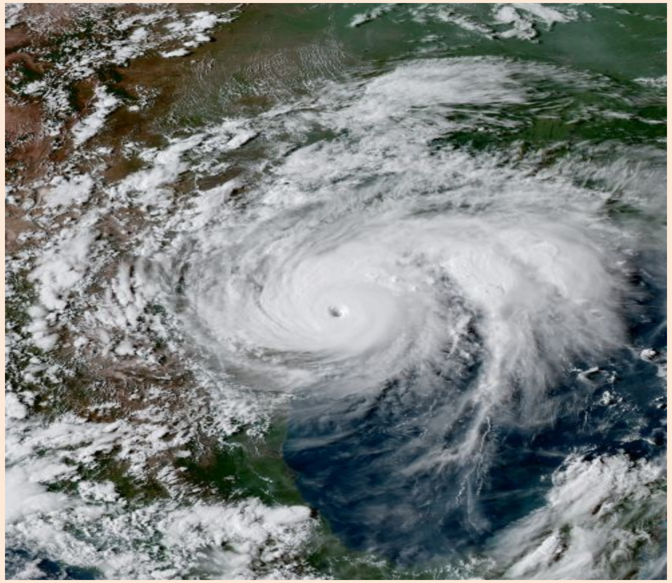


NOAA Science Contributions:

- Observational data sets
- Analysis of observations/trends
- Climate model projections
- Assessments of climate change influence

More information:
www.gfdl.noaa.gov/global-warming-and-hurricanes/

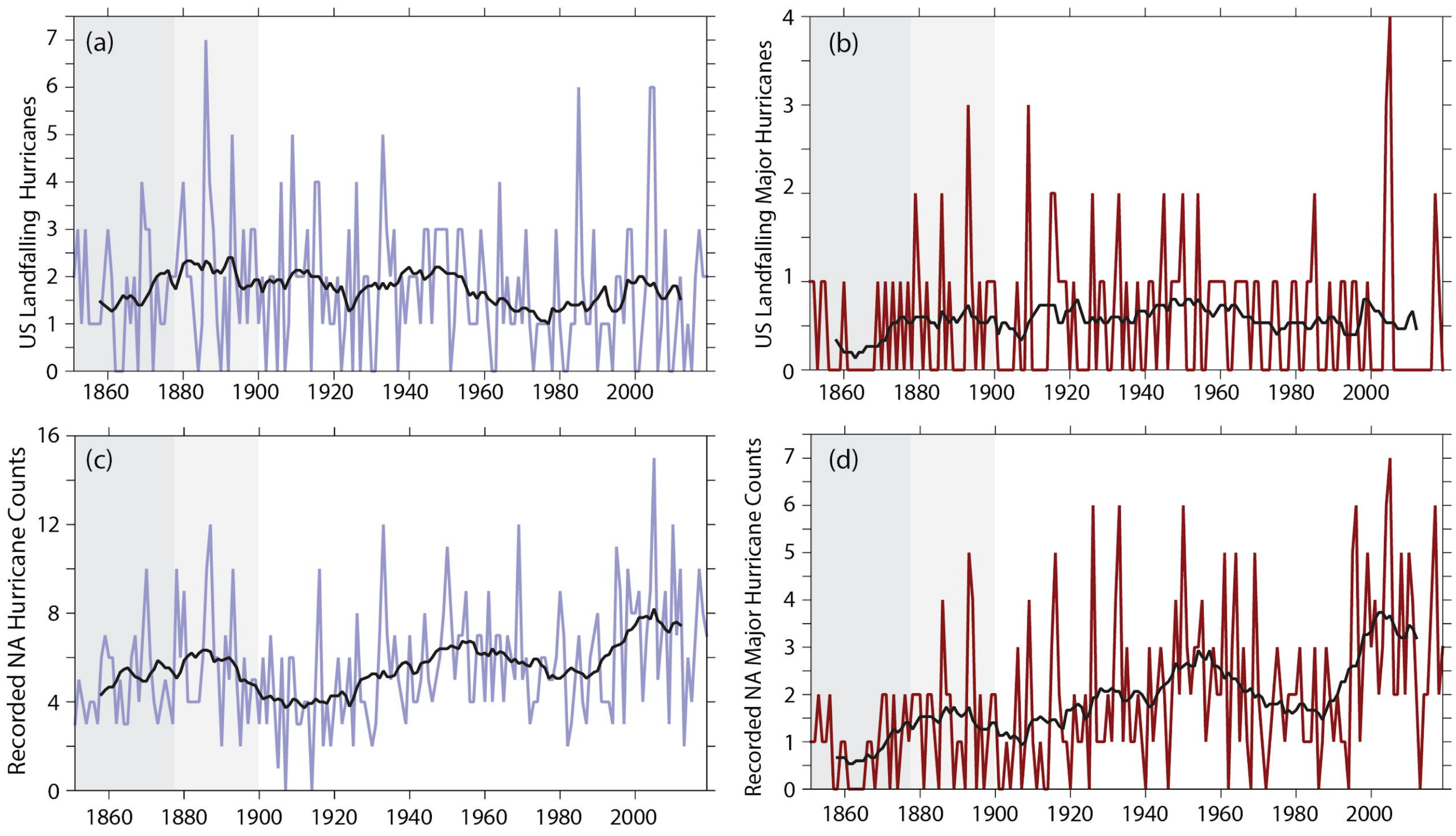
For Hurricanes and Major Hurricanes: US landfalls have no trend; basin-wide shows an “increase”

Hurricanes

Major Hurricanes

U.S. landfalls

Entire Basin

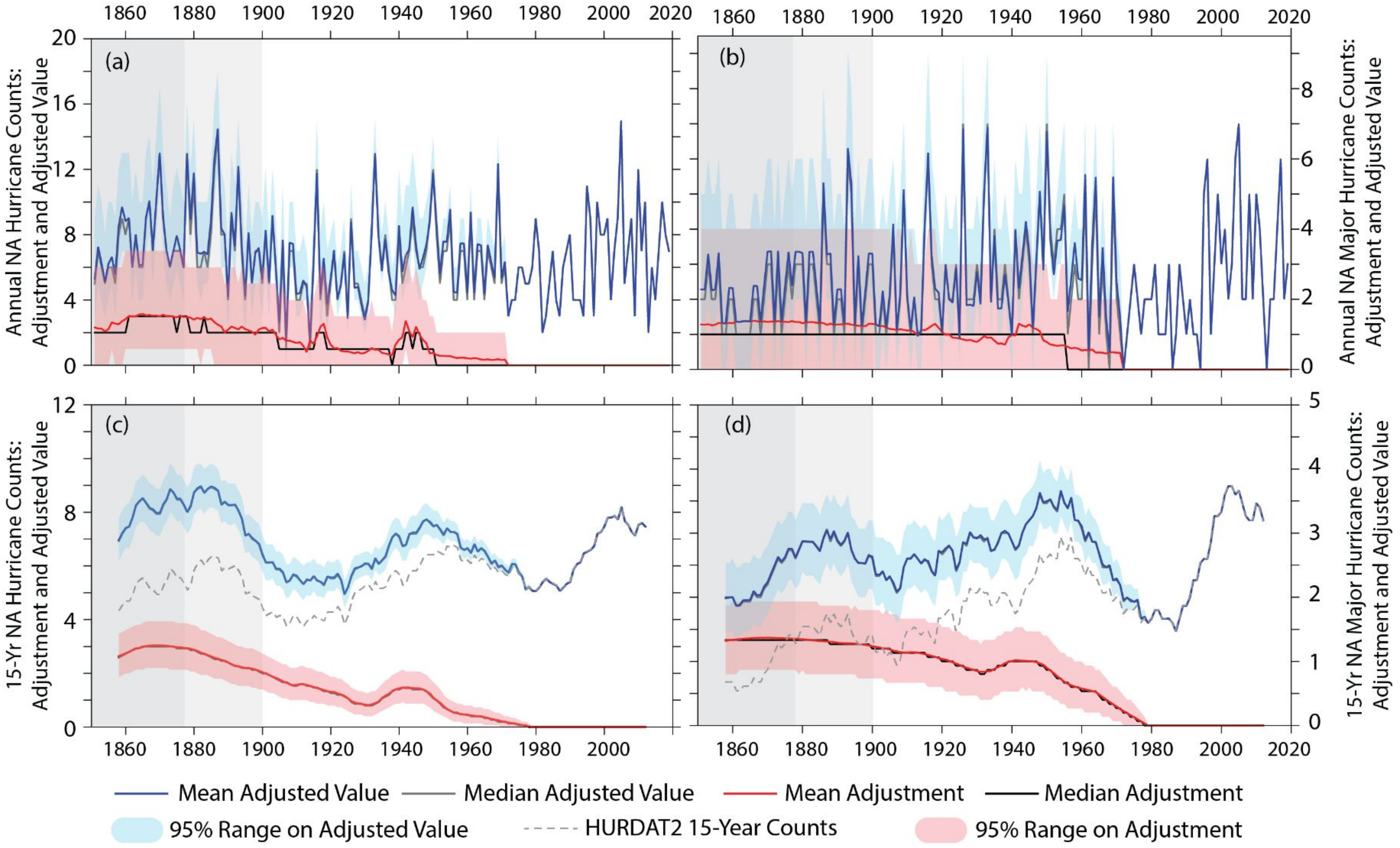


Source: Vecchi et al., Nat. Comm. 2021.

After adjustment for ship track density changes, increasing trends are no longer evident.

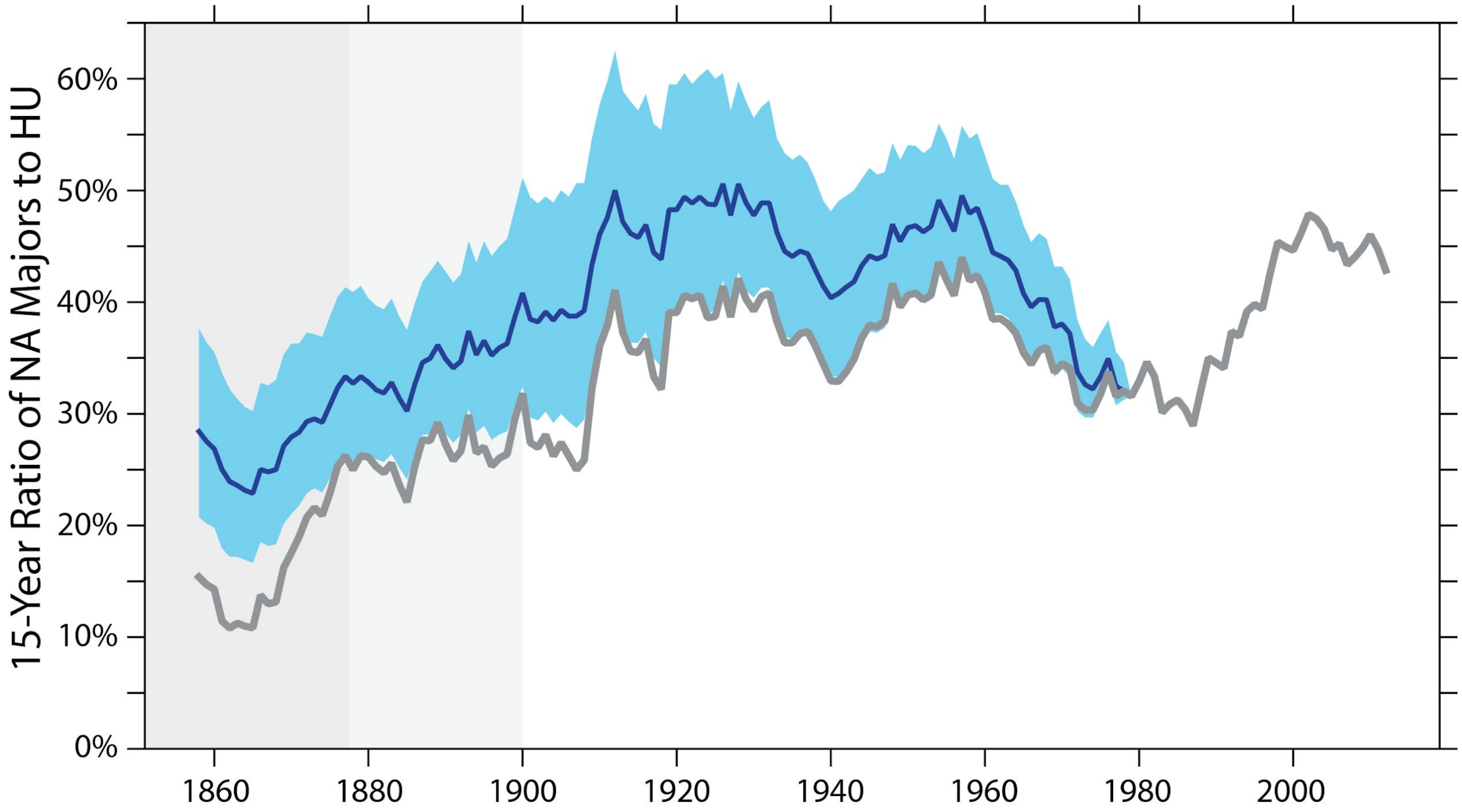
N. Atlantic hurricanes N. Atlantic major hurricanes

Blue = adjusted; Gray-dashed = unadjusted



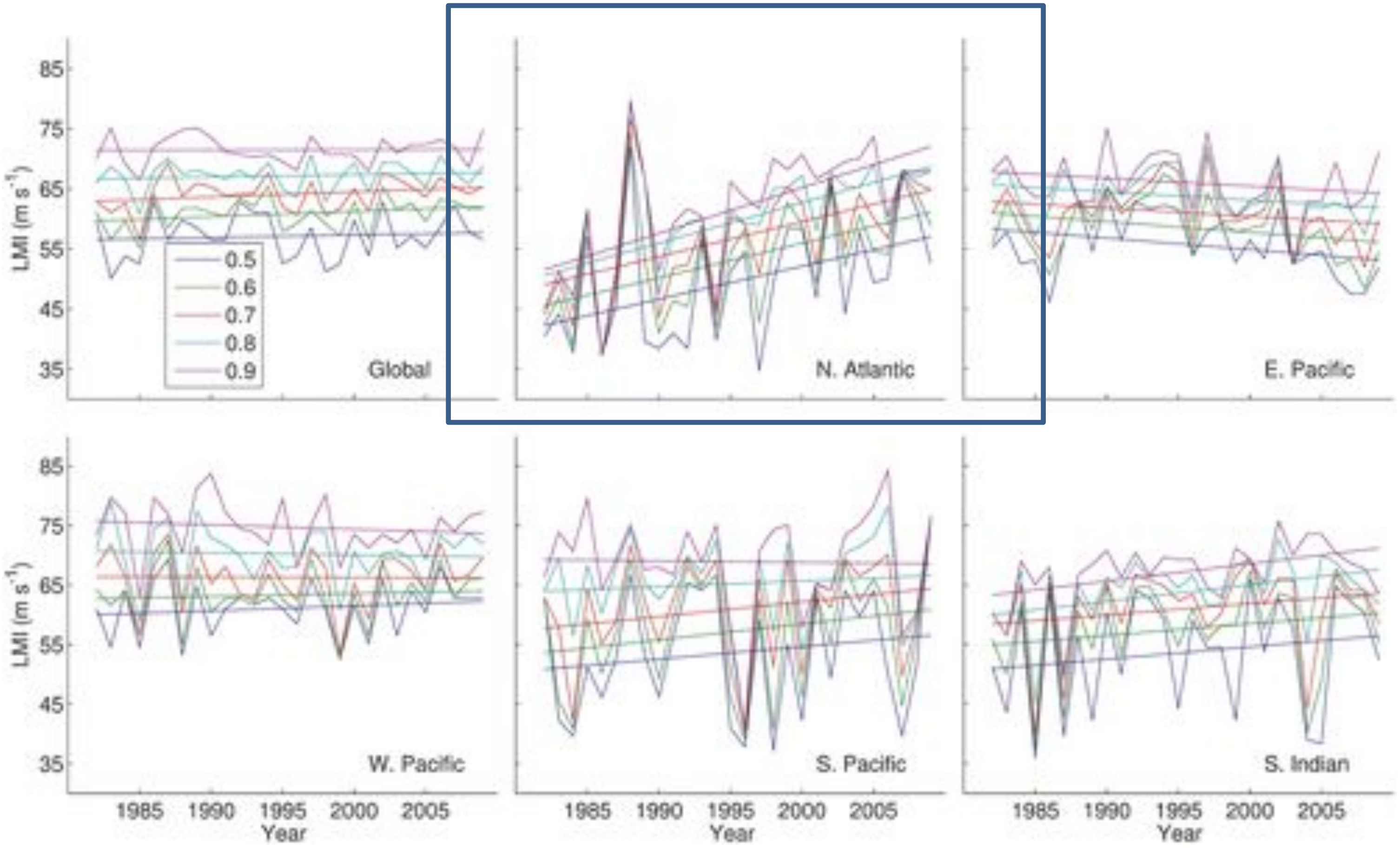
Source: Vecchi et al., Nat. Comm. 2021.

Ratio of major hurricanes to all hurricanes (North Atlantic)
Blue = adjusted; Gray = unadjusted



Source: Vecchi et al., Nat. Comm. 2021.

TC maximum intensity trends by quantile from ADT-HURSAT

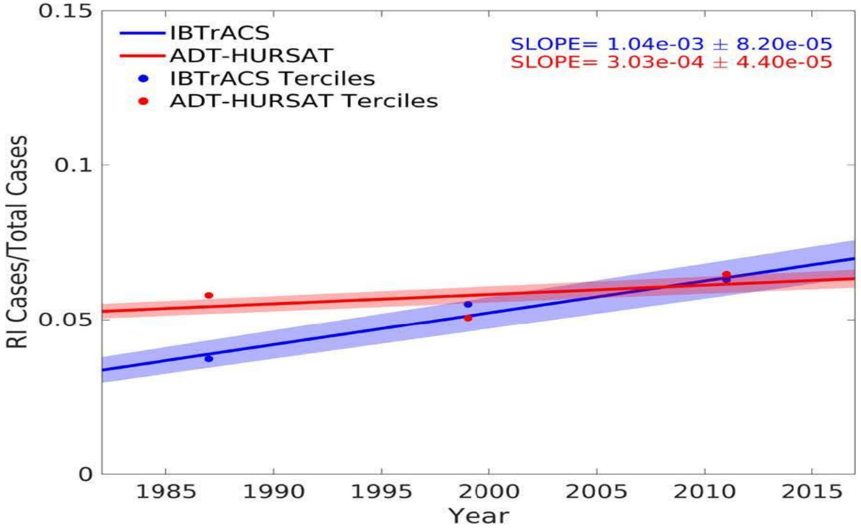


- Global: Marginally significant trend ($p = 0.1$) in LMI of relatively strong (> 60 m/s) TCs
- **N. Atlantic: Strong upward trend, but record is short compared to multidecadal variability there.**
- Increase is consistent with expected sign of response to greenhouse warming
- ** *Balance of evidence: global detectable anthropogenic increase for strongest TCs (Type II error approach)*

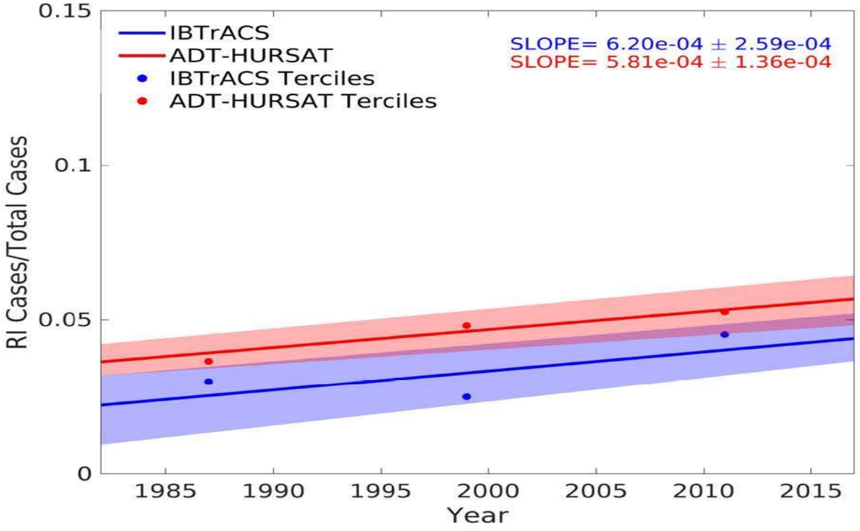
Source: Kossin et al., J. Climate (2013)

Observed increase in rapid intensification (fractional rate of occurrence)

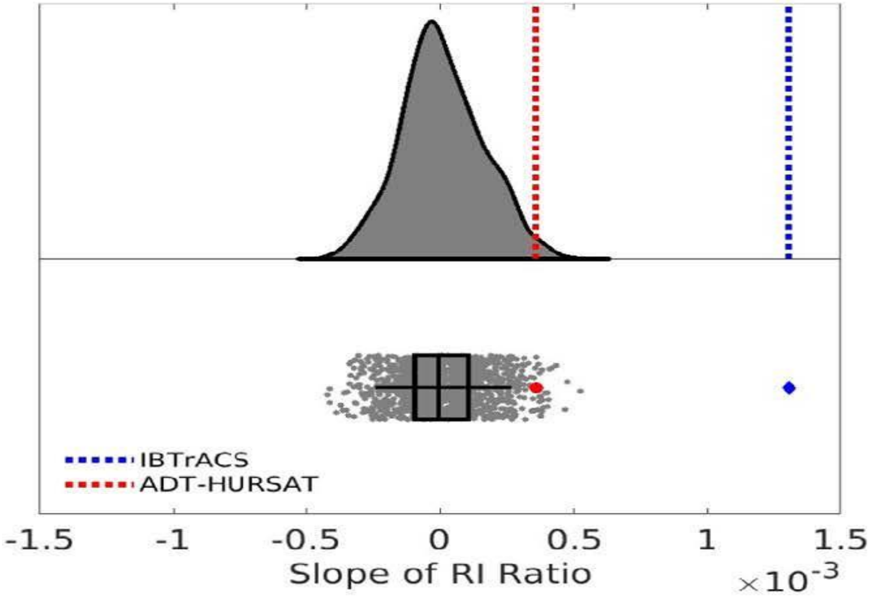
Global

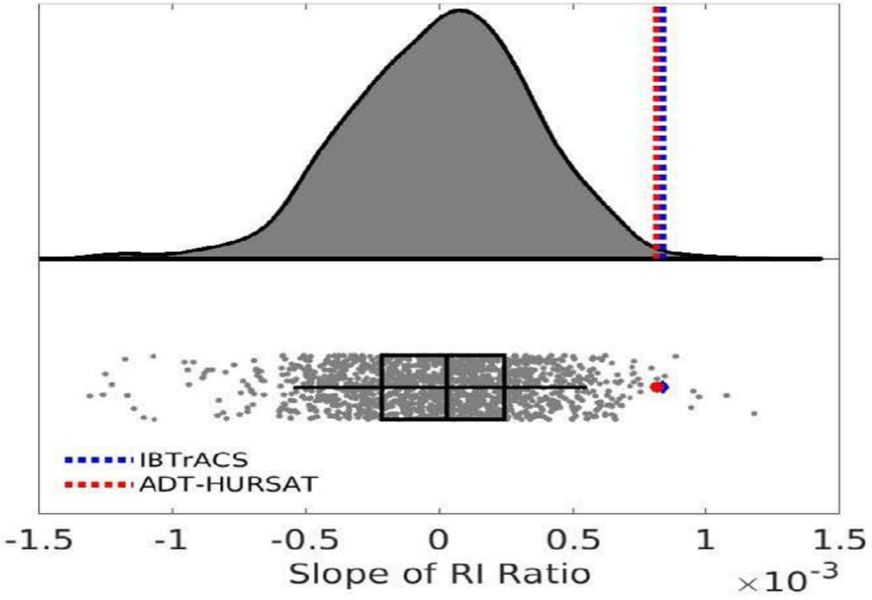


Atlantic Basin



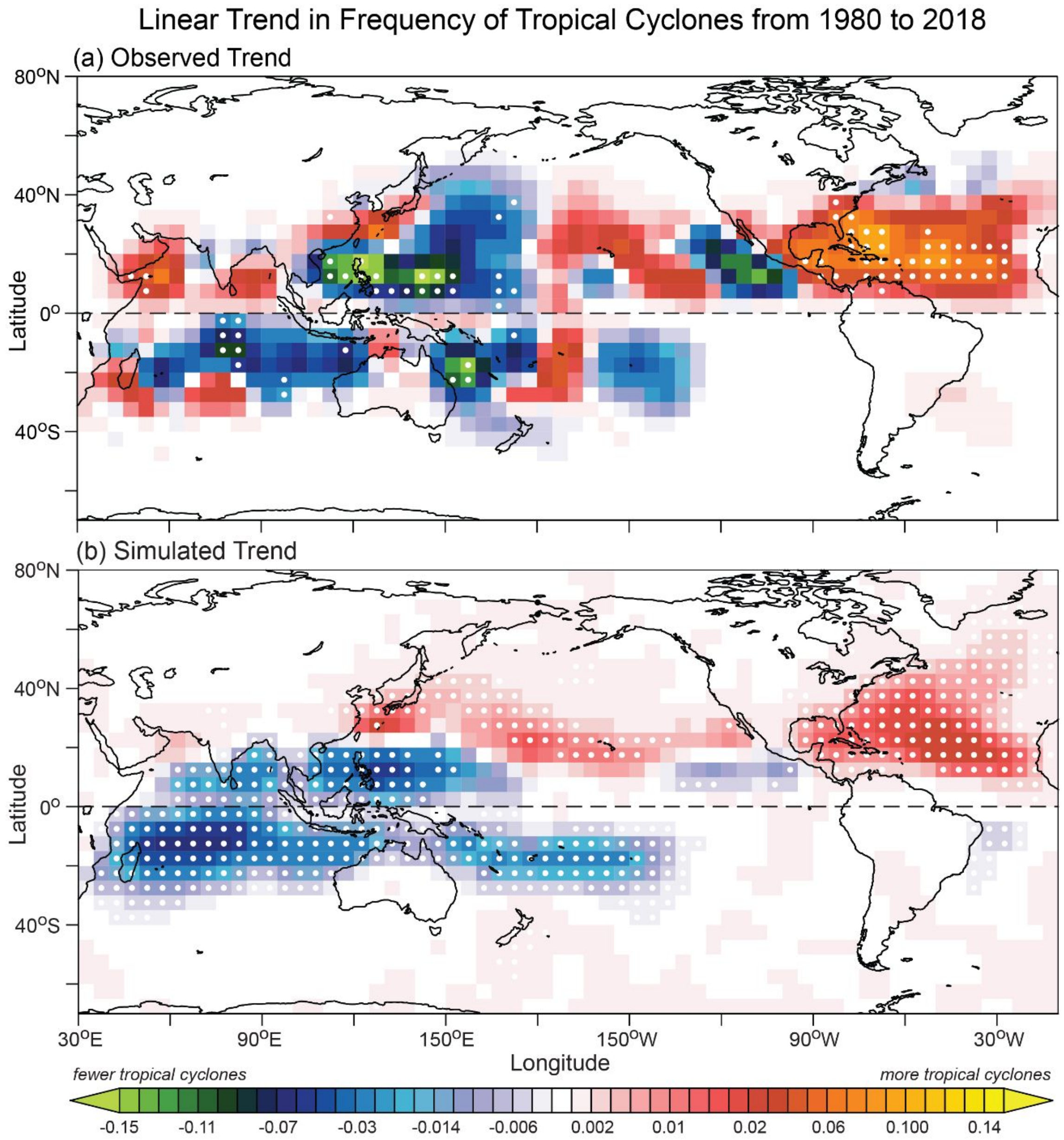
Observed trends are highly unusual compared to model simulated internal variability:





Source: Bhatia et al., Nature Comm. 2022

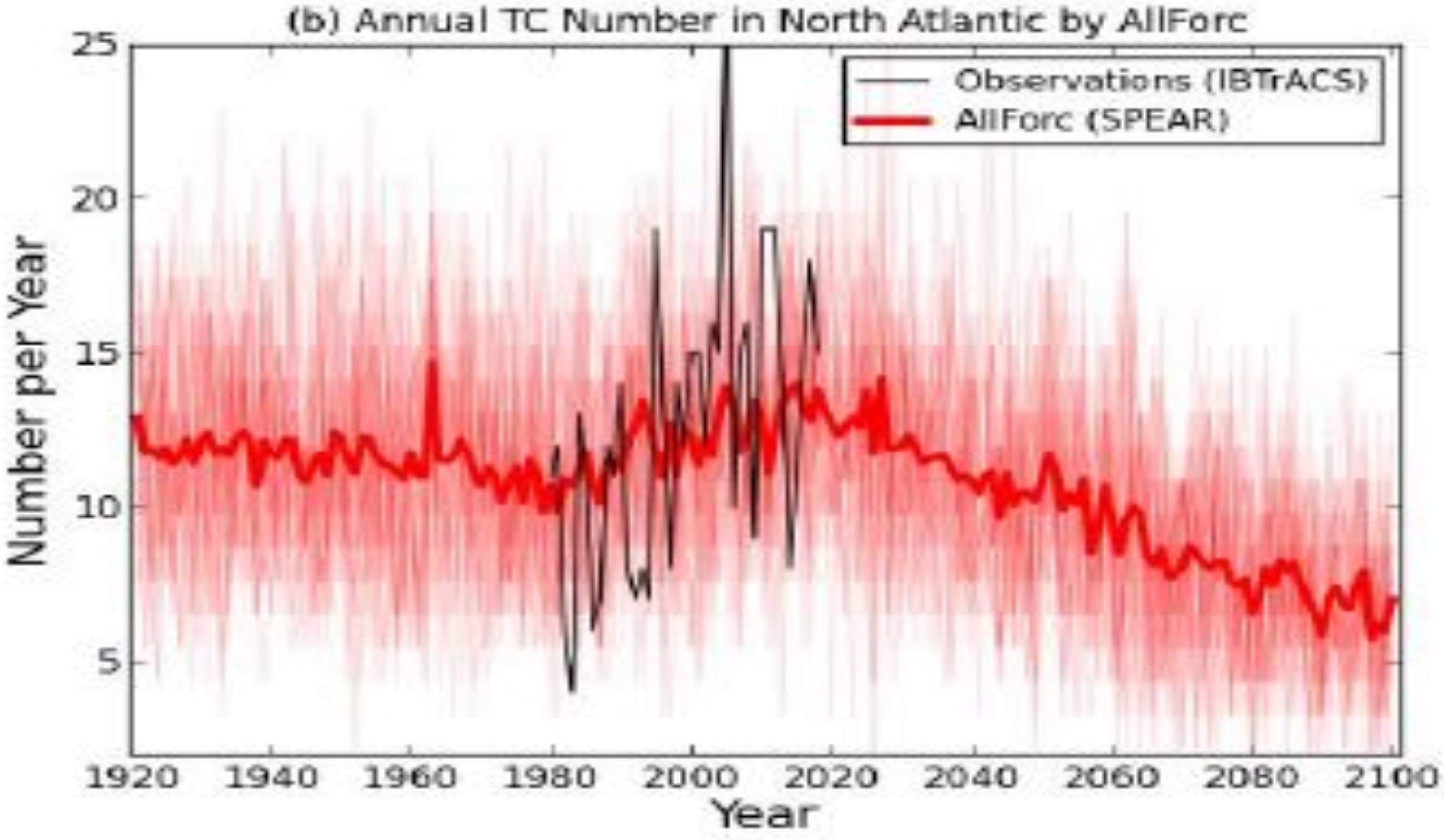
GFDL SPEAR model captures recent trend pattern in TC frequency (since 1980)



Source: Murakami et al. PNAS (2020)

GFDL SPEAR model: Reduced aerosol forcing (primarily) produces a temporary rise post 1980 in Atlantic TC frequency… while greenhouse warming produces a long-term decrease.

Implication: linear trends over 1980-2018 in observations in the Atlantic may not be good predictors of future changes due to greenhouse gas-induced warming…

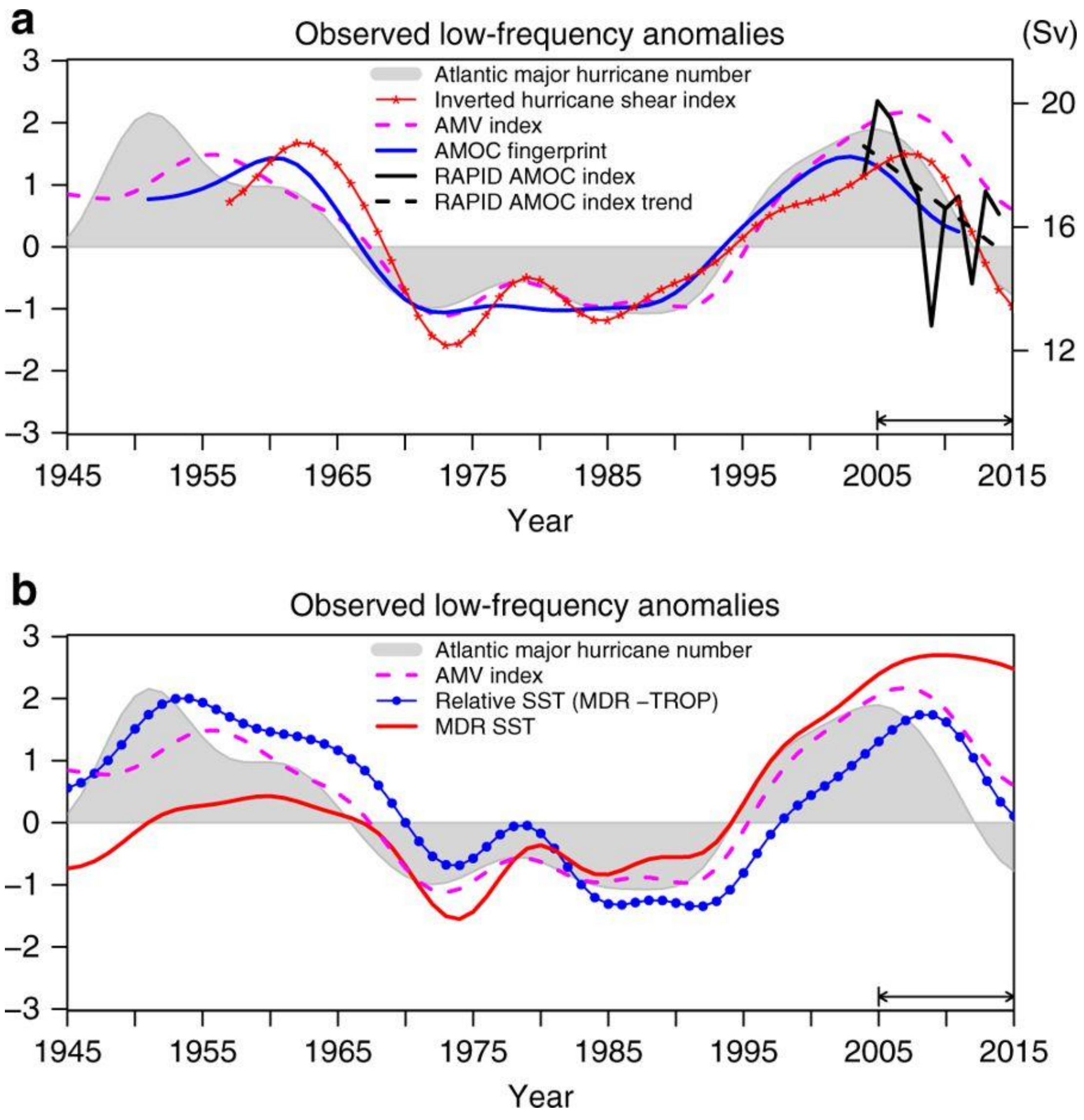


Source: Murakami et al. PNAS (2020)

Atlantic Major Hurricanes since 1945: Strong Multidecadal Variability (grey shading)

NOTE: The shorter the time-horizon, the more important this variability likely is relative to GHG-induced climate change.

Key question: What causes Atlantic Multidecadal Variability?



Source: Yan, Zhang, & Knutson, *Nat. Comm*. 2017

Re-Cap: What does past Atlantic TC/climate data show? Interpretations?

Trends since 1901:

- No significant increasing trend in US landfalling hurricane or major hurricane frequency since 1901, nor in US landfalling hurricane power dissipation (not shown).
- Attributable human-caused SST warming tropical Atlantic basin and Gulf of Mexico.
- Global warming likely contributed to increased multi-day precipitation extremes in eastern Texas.
- Sea level rise along the U.S. coast exacerbates coastal flood risk. Anthropogenic climate change very likely contributes to this.
- Slowing of TC propagation speeds over CONUS since 1901 (Kossin, Nature 2019); cause not determined.
- Time to dissipation for TCs after landfall decreased from 1901 to 1980, then increased after 1980.
- Increase in a US major storm surge index since about 1920 but not yet a detectable anthropogenic trend.

Trends since 1950:

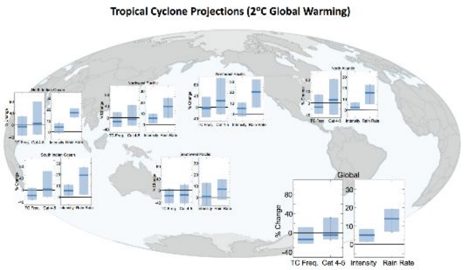
- Multidecadal variations in Atlantic basin major hurricane counts, MDR vertical shear, MDR SSTs and possibly Atlantic Meridional Overturning Circulation (inferred).
  - Causes: Changes in aerosol forcing or internal climate variability.
  - Little long-term trend apparent (except for SSTs) due to large multidecadal variability (Greenhouse gas signal?).

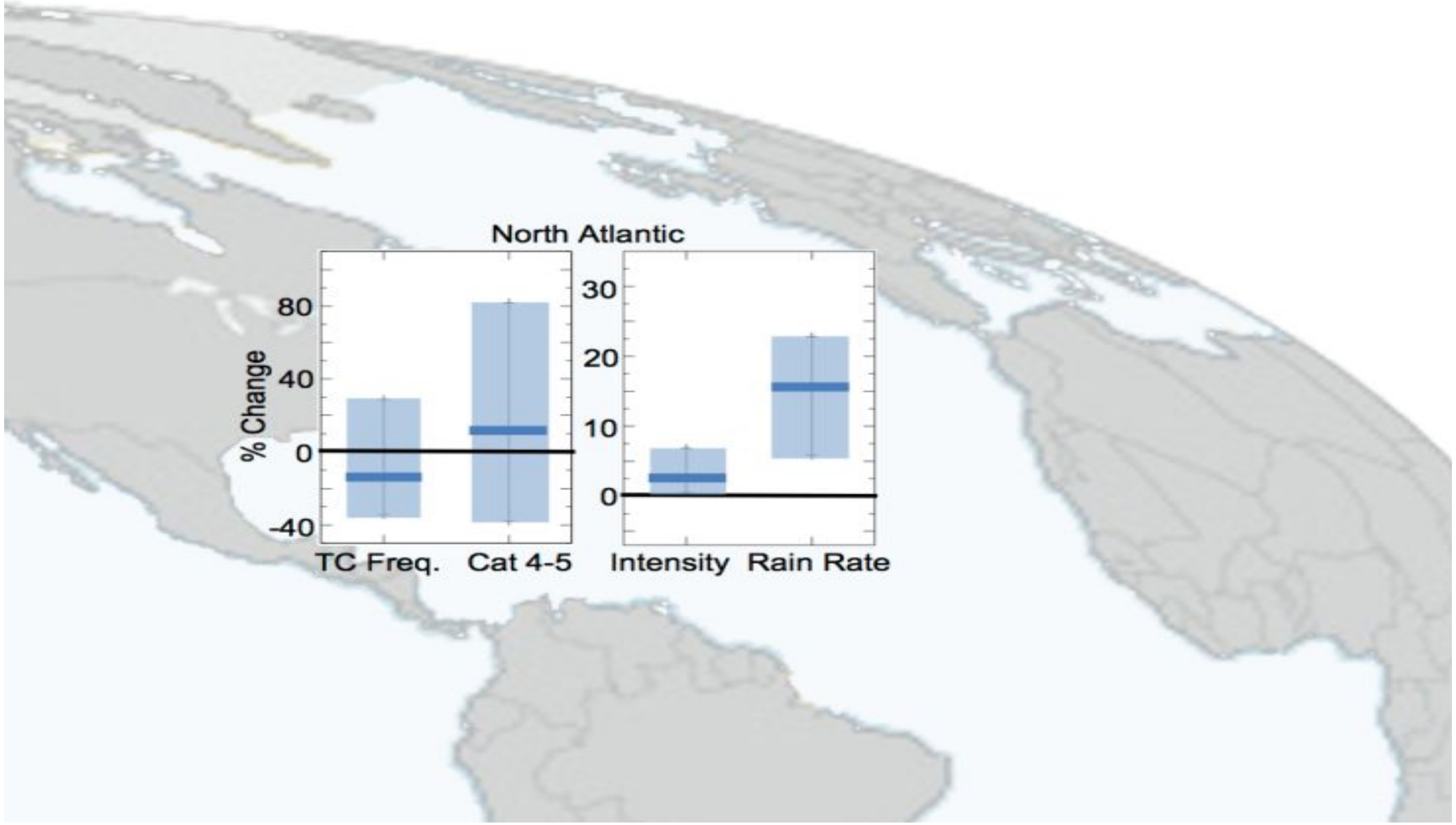
Trends since 1980:

- Recent increase in TC Rapid intensification rates, TC intensities, proportion of Cat 3-5 TCs over the Atlantic and globally, hurricanes and major hurricanes. Are these due to the latest increasing phase of multidecadal variability (internal variability, aerosol reductions) or do they also contain a substantial greenhouse warming component (which would continue)? No formal detection/attribution as yet.

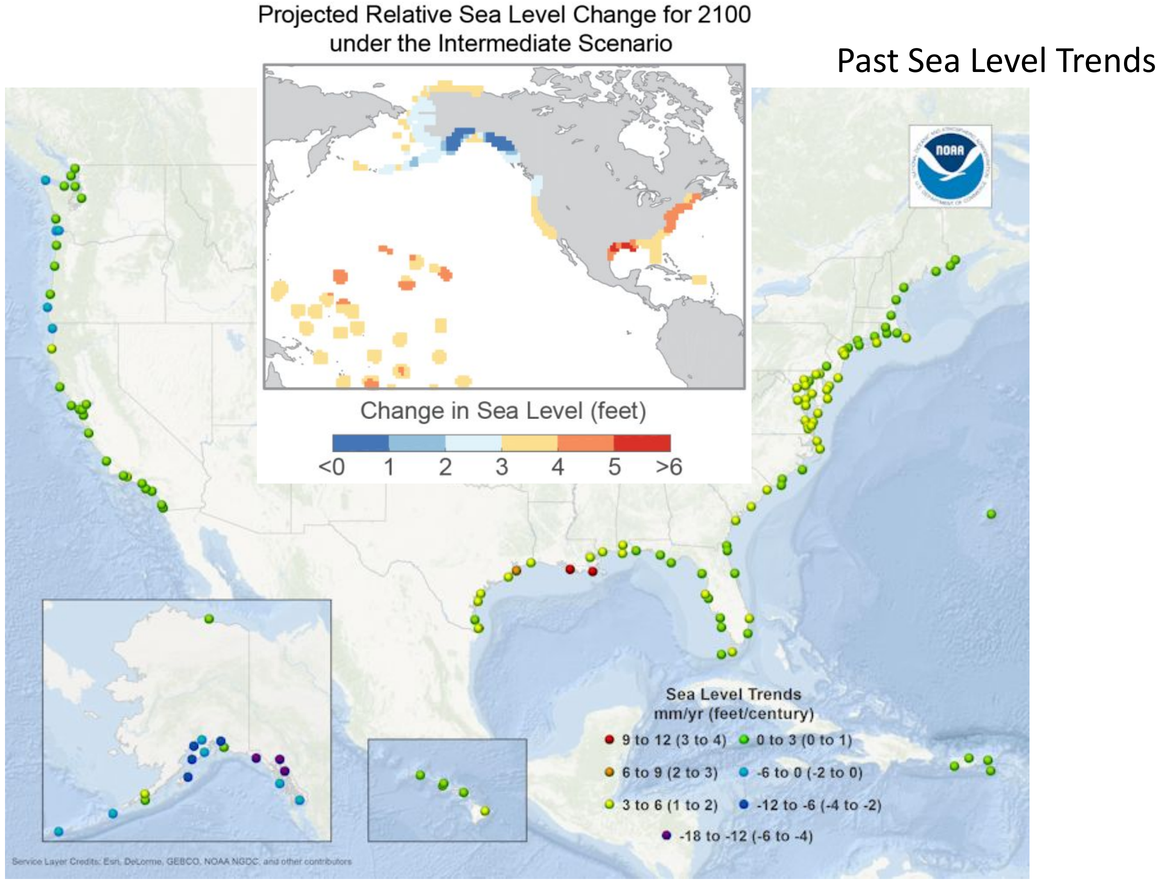
- Recent increase in Atlantic TC frequency (Cat 0-5) may be temporary and mainly due to reduced aerosol and not increasing greenhouse gases (which acts decrease TC frequency according to the GFDL SPEAR model (Murakami et al. PNAS 2020)).

Tropical Cyclone Projections for the North Atlantic Basin (for 2°C global warming): Assessment of multiple studies (NOAA and non-NOAA)





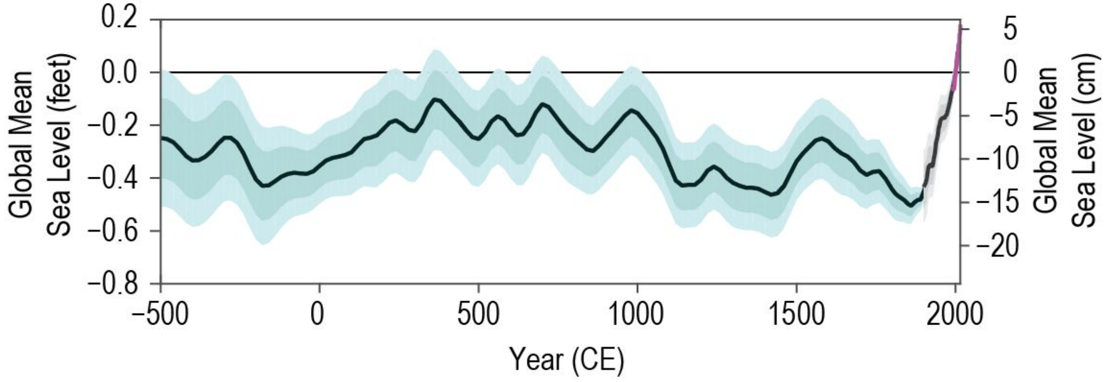
Source: WMO Task Team on TCs and Climate Change (2020), *Bulletin of the American Meteorological Society*



Projected Relative Sea Level Change for 2100 under the Intermediate Scenario

Past Sea Level Trends

Historical Global Mean Sea Level



Sea Level Rise

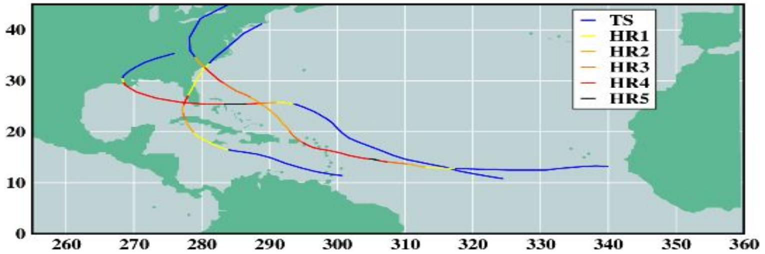
- Global sea level has risen by about 7–8” inches since 1900, and about 3” since 1993 (very high confidence).
- Human-caused climate change has made a substantial contribution to global sea level rise since 1900 (high confidence).
- Global sea level (relative to year 2000) is very likely to rise by 0.3–0.6 feet by 2030, 0.5–1.2 feet by 2050, and 1.0–4.3 feet (30–130 cm) by 2100 (very high confidence in lower bounds; medium confidence in upper bounds for 2030 and 2050; low confidence in upper bounds for 2100).

Source: Climate Science Special Report, 2017.

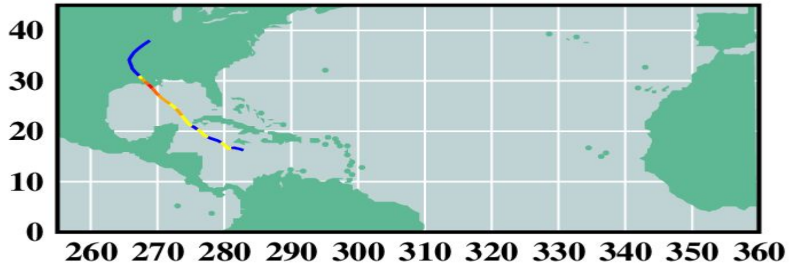
US Landfalling Cat 4-5 tracks in warm climate simulations vs. present-day (Control)

(27 seasons: Aug-Oct.) Observations also shown for comparison to present-day (Control)

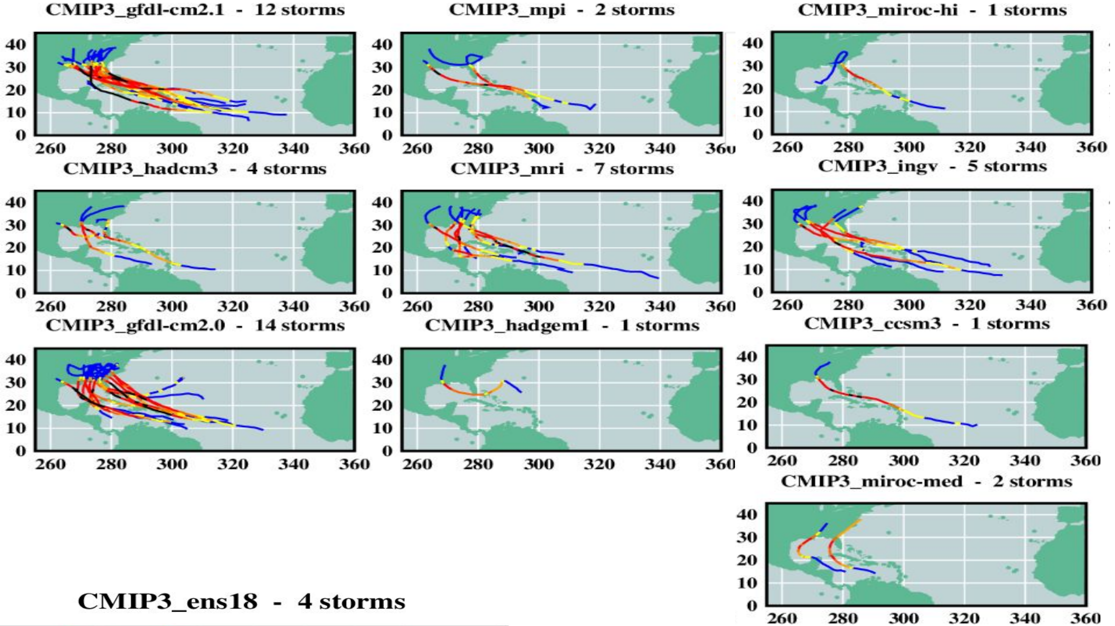
Observed (1980-2006) – 3 storms



Present-Day (1980-2006) simulation – 1 storm



CMIP3 Individual Models – Warming Scenarios


CMIP3_gfdl-cm2.1 - 12 storms

CMIP3_mpi - 2 storms

CMIP3_miroc-hi - 1 storms

CMIP3_hadcm3 - 4 storms

CMIP3_mri - 7 storms

CMIP3_ingv - 5 storms

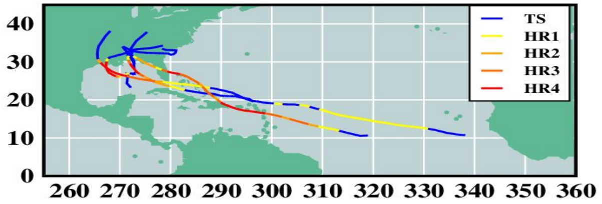
CMIP3_gfdl-cm2.0 - 14 storms

CMIP3_hadgem1 - 1 storms

CMIP3_ccsm3 - 1 storms

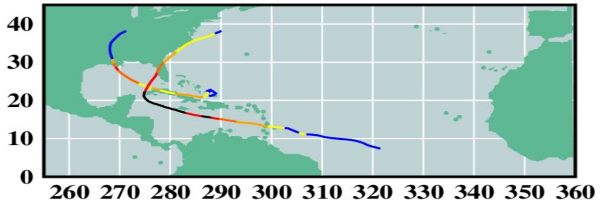
CMIP3_miroc-med - 2 storms

CMIP3_ens18 - 4 storms

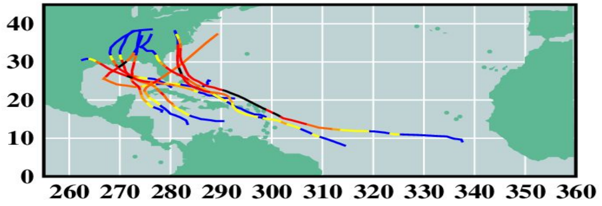


Warming Scenarios:
(ensemble means)

CMIP5_EARLY - 2 storms

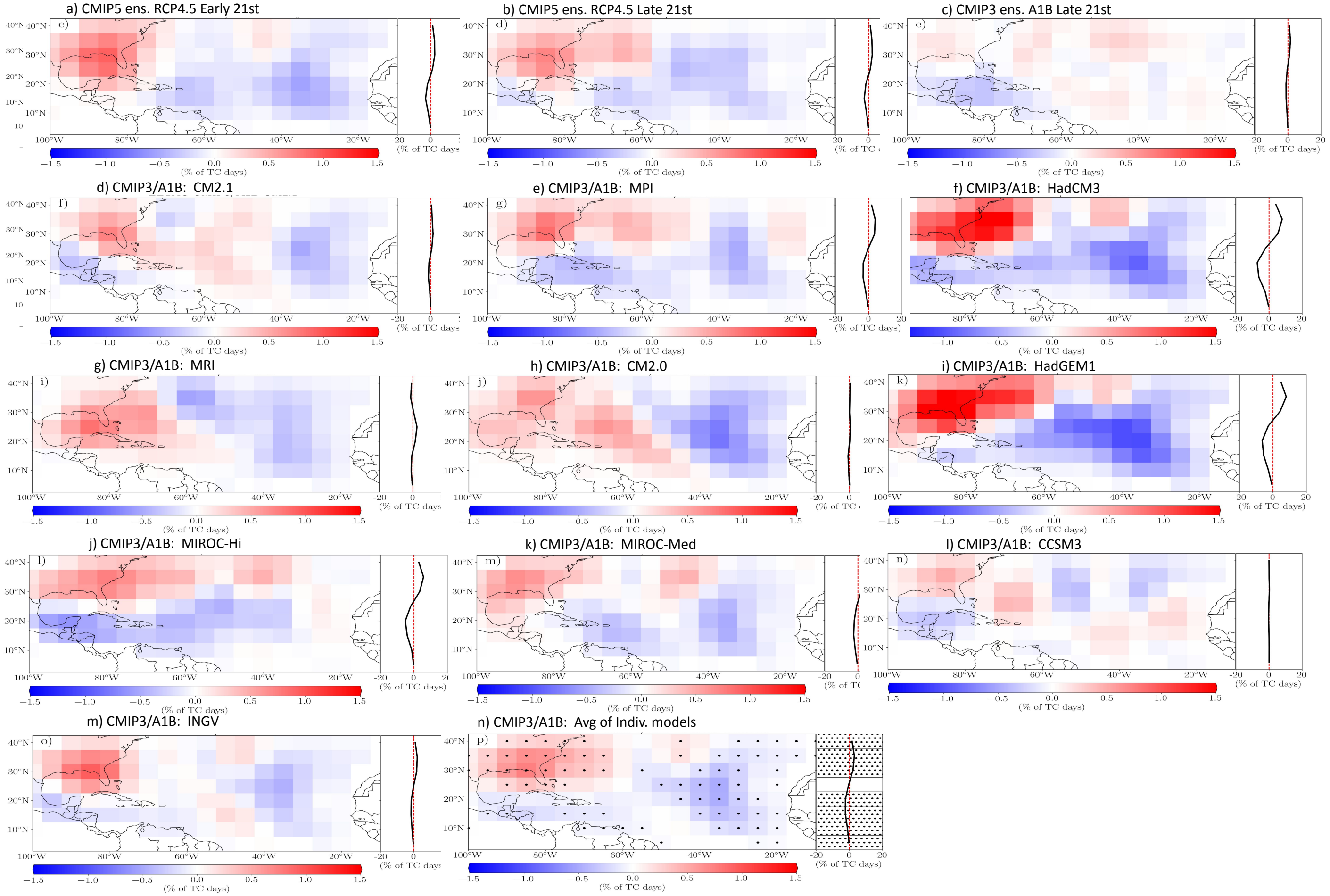


CMIP5_LATE - 9 storms



Source: Knutson et al., Clim. Change 2022

Relative Change in Location of TC Occurrence: Warm Climate Minus Control


a) CMIP5 ens. RCP4.5 Early 21st
b) CMIP5 ens. RCP4.5 Late 21st
c) CMIP3 ens. A1B Late 21st
d) CMIP3/A1B: CM2.1
e) CMIP3/A1B: MPI
f) CMIP3/A1B: HadCM3
g) CMIP3/A1B: MRI
h) CMIP3/A1B: CM2.0
i) CMIP3/A1B: HadGEM1
j) CMIP3/A1B: MIROC-Hi
k) CMIP3/A1B: MIROC-Med
l) CMIP3/A1B: CCSM3
m) CMIP3/A1B: INGV
n) CMIP3/A1B: Avg of Indiv. models

Difference in % of total TC days (warm – control).
Red: increase. Blue: decrease.
Inset: zonal average

□ Relative Track density increases over and near the U.S. TC landfall regions.

Dots: 8 of 10 individual CMIP3 models agree on sign of change.

Source: Knutson et al., *Clim. Change* 2022

Summary of U.S. landfalling projections

- Robust large-scale circulation changes (reduced westerlies) favor TC track shifts toward the U.S. East Coast in these CMIP3 and CMIP5-based dynamical downscaling simulations.

- A shift of relative TC genesis toward the U.S. coastal regions in most models also favors a greater fraction of U.S. landfalling TCs.

- Thus, while a decrease in Atlantic basin TC genesis and track density is simulated in most models we downscaled, the above affects lead to a greater proportion of U.S. landfalling TCs.

As a result of this increasing proportion of U.S. landfalling TC:

  - Reduced overall Atlantic basin hurricane frequency (Cat 1-5) translates to no change for U.S. landfalling Cat 1-5 frequency.
  - No change in Atlantic basinwide intense hurricane frequency (Cat 4-5) translates to an increase in U.S. landfalling Cat 4-5 frequency. (Still only tentative confidence in this finding.)

- Other changes: increase in precipitation rates of U.S. landfalling TCs (within 100 km radius), as expected from previous studies.

To increase confidence in projections, we need:

- Clearly detectable signal that has already emerged
- Robust attribution/projections across model studies
- Confident understanding of physical mechanisms

Source: Knutson et al., Climatic Change 2022