U.S. DEPARTMENT OF ENERGY | Office of Science

Early Career Research Award

Future Changes in Tropical Cyclone Activity: Physical Mechanisms and Coastal Impacts

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Jaison Kurian, I-I Lin, Burlen Loring, and Adam H. Sobel

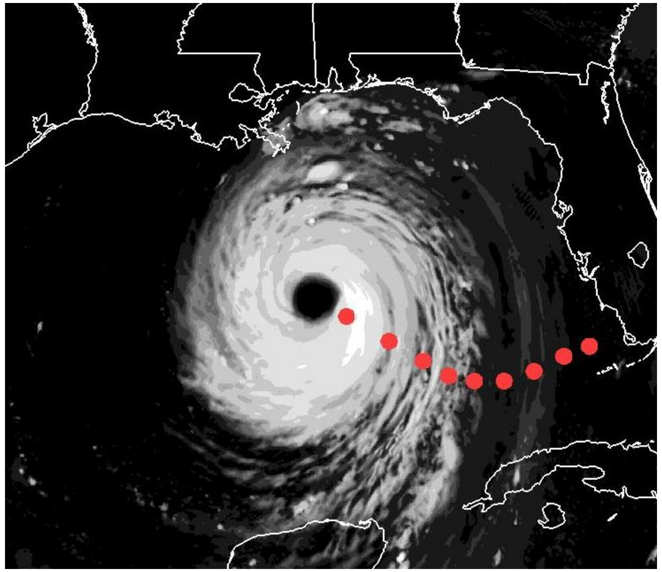
IOWA STATE UNIVERSITY OF SCIENCE AND TECHNOLOGY in collaboration with:

BERKELEY LAB, CASCADE, NERSC National Energy Research Scientific Computing Center, E3SM Energy Exascale Earth System Model, TEXAS A&M UNIVERSITY, COLORADO STATE UNIVERSITY, 國立臺灣大學 National Taiwan University, COLUMBIA UNIVERSITY

Project objectives

Local coupled TC-ocean processes

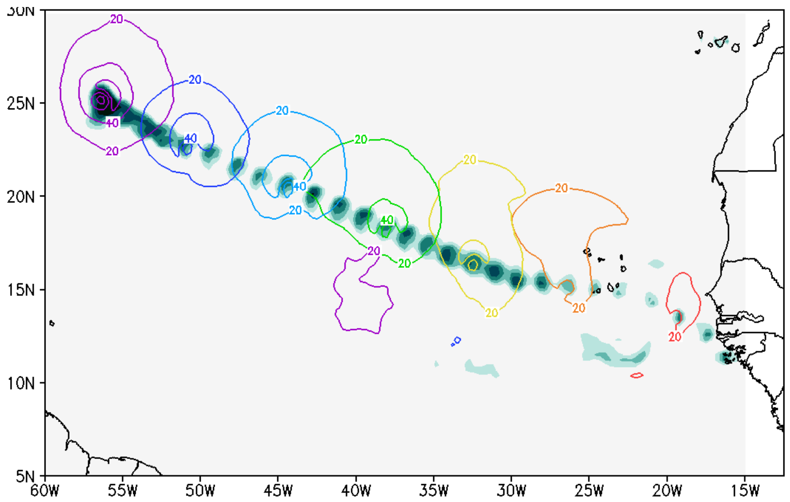
Quantify how atmosphere-ocean interactions shape future TC characteristics, using convection-permitting atmosphere-ocean models.



3km resolution tropical cyclone simulation

Large-scale TC drivers

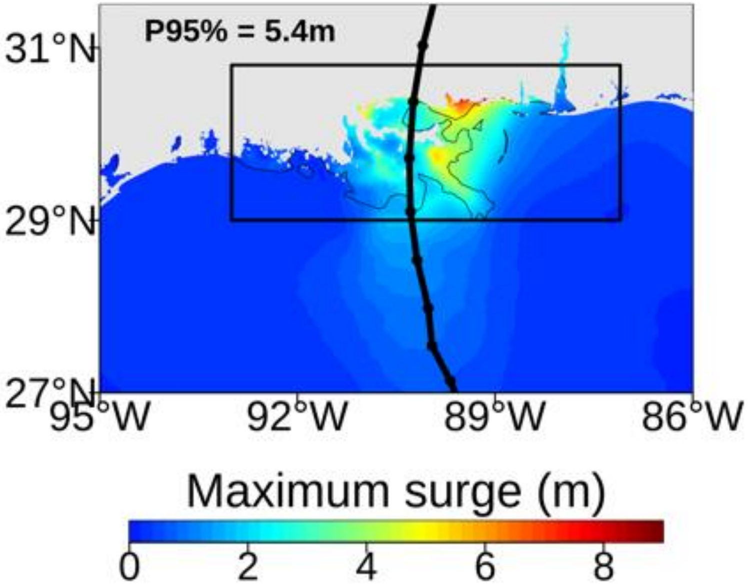
Understand how large-scale drivers and TC precursors control global TC frequency, landfall, and track, using high-resolution E3SM simulations.



A simulated tropical cyclone forms from an African Easterly wave

Coastal impacts

Project coastal impacts from TCs and sea-level rise due to storm surge, precipitation, and wind, using a storm surge model.



Simulated peak storm surge heights for Hurricane Katrina

Project objectives

Derrick Danso: Combined Impacts of Projected Sea Level Rise and Tropical Cyclone Intensity on Future Storm Surges

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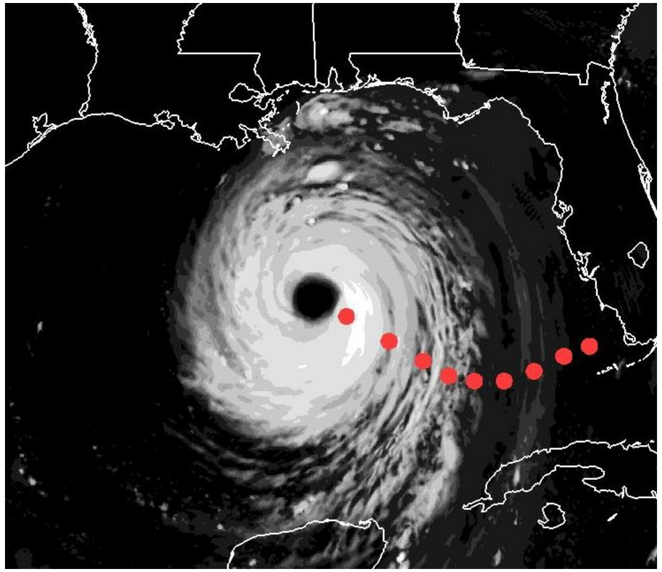
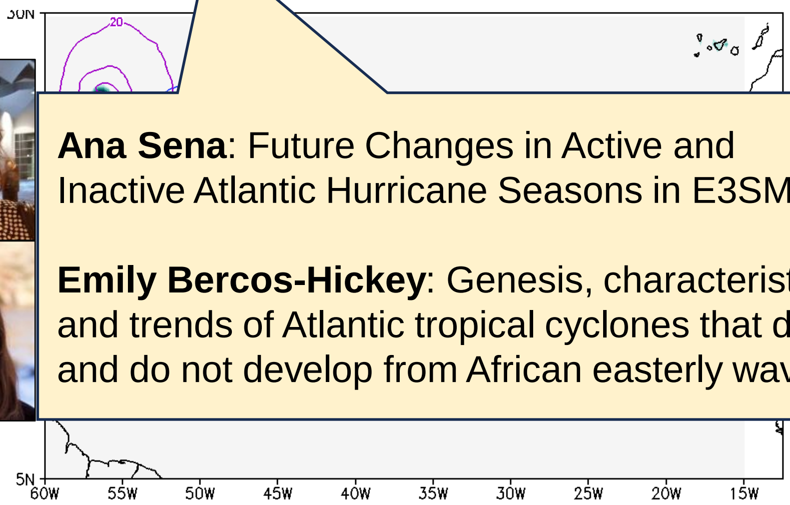


3km resolution tropical cyclone simulation

Ana Sena: Future Changes in Active and Inactive Atlantic Hurricane Seasons in E3SM

Emily Bercos-Hickey: Genesis, characteristics, and trends of Atlantic tropical cyclones that do and do not develop from African easterly waves



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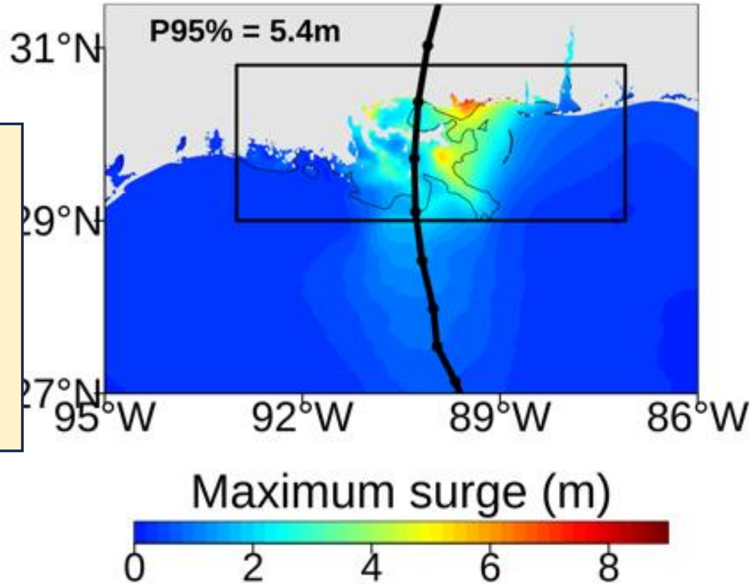
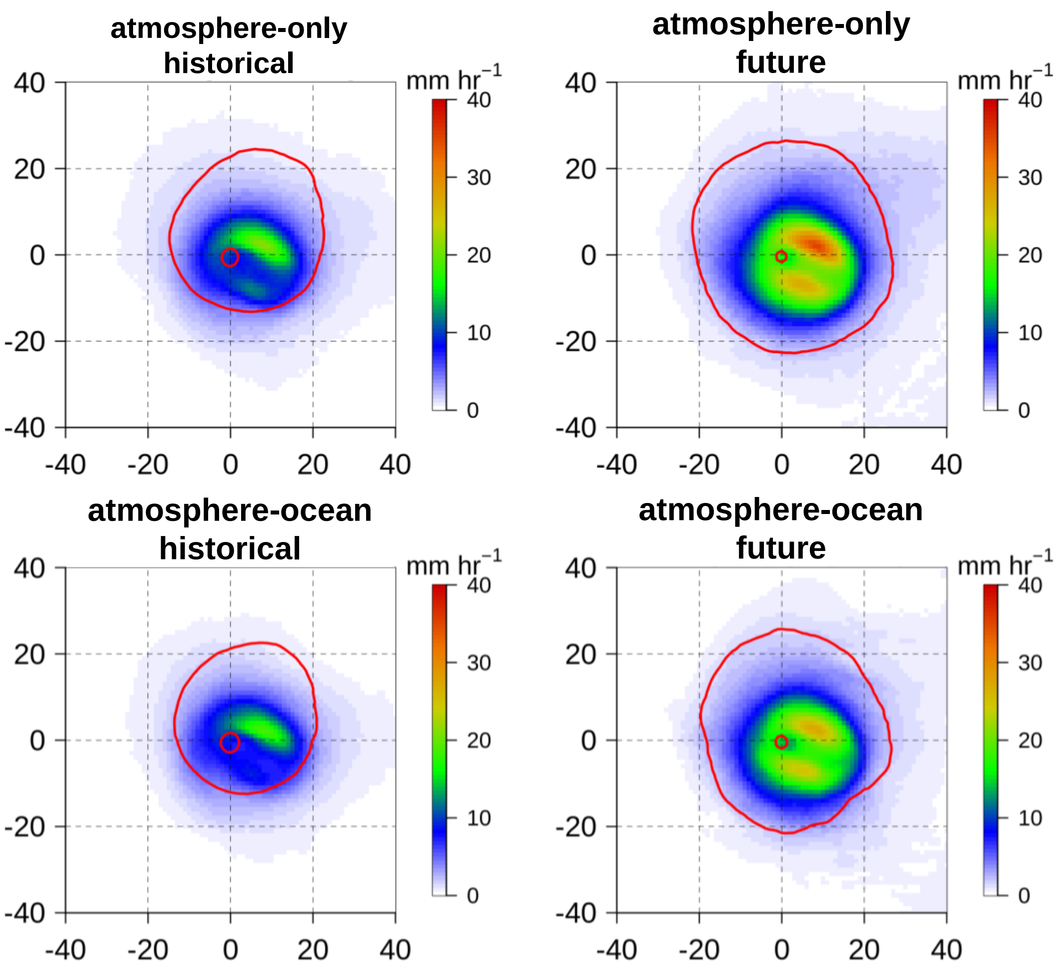


Simulated peak storm surge heights for Hurricane Katrina

Air-sea Coupling Influence on Future Changes in Atlantic Hurricanes



Ensemble mean precipitation (mm/hr) from Hurricane Irma composited within a 500km radius around the TC center over the TC lifetime. (top) atmosphere-only and (bottom) atmosphere-ocean simulations for the (left) historical and (right) future climates. The red contour denotes the 18 m/s 10-m wind speed.

Problem: TC-ocean coupling is necessary to represent the processes important for TC intensity. However, typical biases in global coupled models can cause substantial errors in simulated TC activity.

Question: How does the treatment of the ocean (coupled or prescribed sea-surface temperatures) influence future projections of Atlantic TCs?

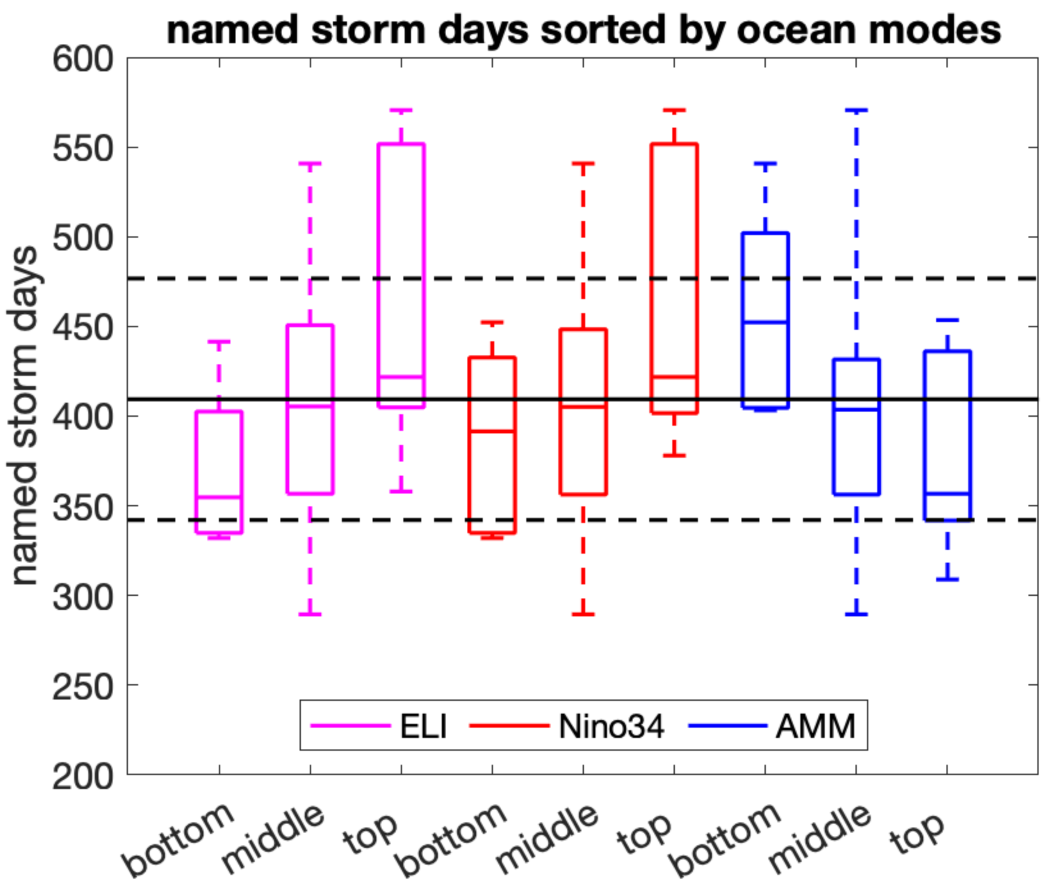
Method: Ensembles of atmosphere-only and atmosphere-ocean simulations of five historically-impactful Atlantic hurricane events in historical and future climates.

Results: Regardless of the treatment of the ocean, future TC intensity, precipitation, and size are projected to increase.

Significance: Projections of future TC precipitation increases are 3-59% weaker in the coupled simulations than in the atmosphere-only simulations.

Danso, D. K., Patricola, C. M., Kurian, J., Chang, P., Klotzbach, P., & Lin, I-I. (2024). Air-sea Coupling Influence on Projected Changes in Tropical Cyclone Events. *Weather and Climate Extremes*, 43, 100649. https://doi.org/10.1016/j.wace.2024.100649

Tropical Oceanic Influences on Observed Global Tropical Cyclone Frequency



Boxplots of annual global named storm days for years in which the Jan–Dec averaged ENSO Longitude Index (°E; magenta), Niño 3.4 index (red), and AMM index (blue) were observed within the bottom, middle, and top percentiles over the years 1980–2021. Solid and dashed black lines denote the mean and mean +/- one standard deviation, respectively.

Problem: Although the number of global TCs has been relatively constant from year-to-year in recent decades, the reason remains unknown.

Question: How does ocean variability influence global TC frequency?

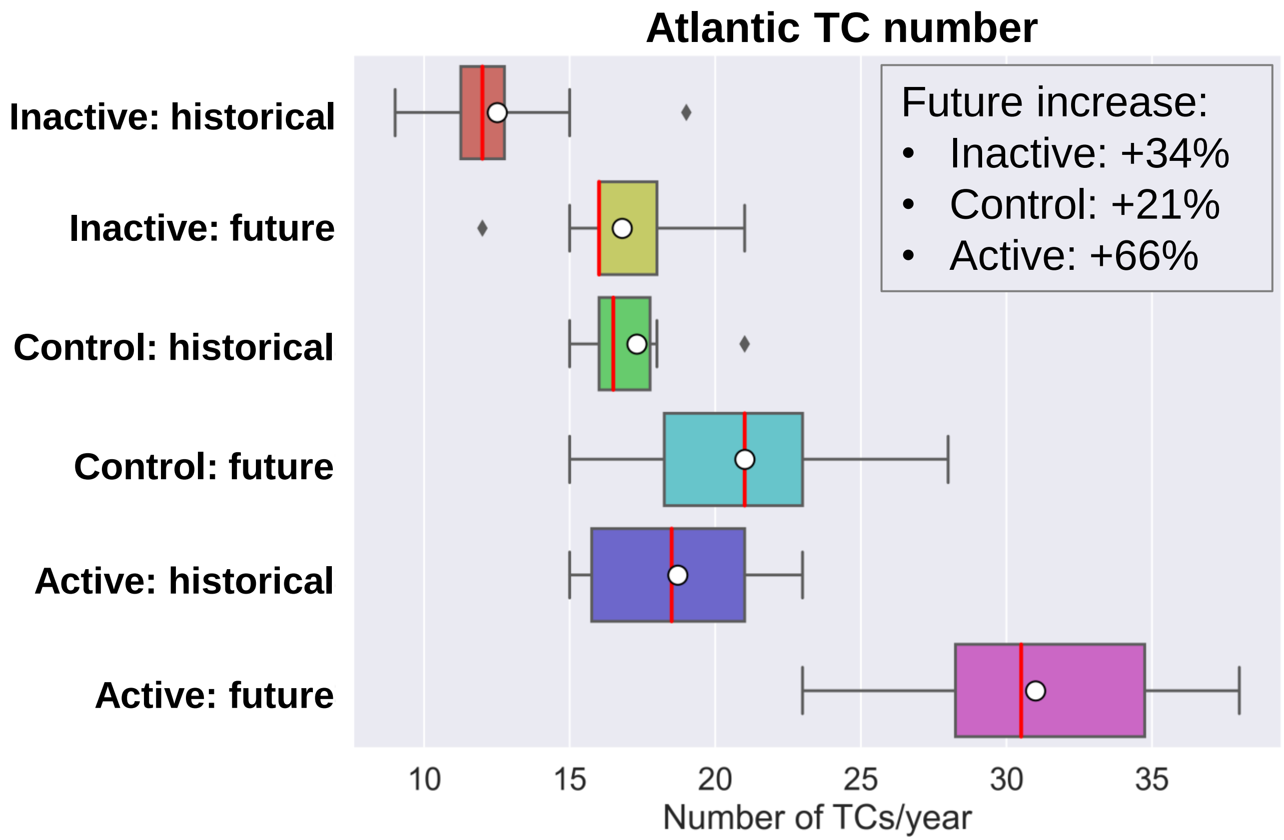
Method: Observations from 1980-2021

Results: La Niña is associated with reduced global TC frequency, whereas El Niño is associated with increased global TC frequency.

Significance: Reliable future projections of ENSO are necessary, but not sufficient, to understand how global TC frequency may change in the future. Improving model biases in the tropical Pacific can reduce uncertainty in future projections of TC frequency.

Patricola, C. M., Cassidy, D. J., & Klotzbach, P. J. (2022). Tropical Oceanic Influences on Observed Global Tropical Cyclone Frequency. *Geophysical Research Letters*, 49(13), e2022GL099354. https://doi.org/10.1029/2022GL099354

Future Changes in Active and Inactive Atlantic Hurricane Seasons in E3SM



The number of North Atlantic TCs per year from the 10-member ensemble of the active season (La Niña and positive AMM), inactive season (El Niño and negative AMM), and control (neutral ENSO and AMM) E3SM experiments in historical and future climates.

Problem: Previous studies have largely focused on *mean* changes in TC activity, despite the importance of *seasonal* extremes for societal impacts.

Question: How are active and inactive Atlantic hurricane seasons projected to change in the future?

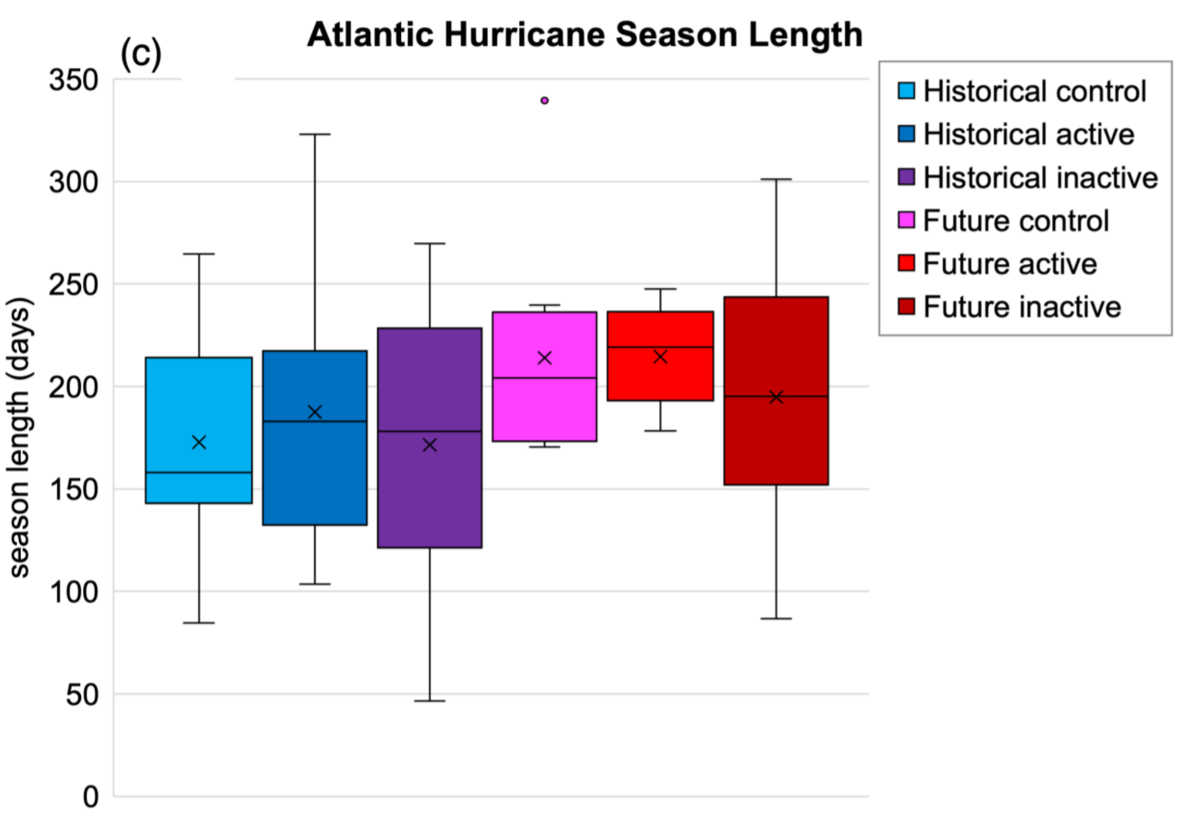
Method: Ensembles of E3SM simulations forced with sea-surface temperature patterns characteristic of El Niño – Southern Oscillation (ENSO) and Atlantic Meridional Mode (AMM) in historical and future climates.

Results: Future Atlantic TC frequency increases by 66% during active seasons and by 34% during inactive seasons.

Significance: The projected shift in both extremes in seasonal Atlantic TC activity indicates a potential worsening of Atlantic TC impacts in the future.

Sena, A. C. T., Patricola, C. M., & Loring, B. (2022). Future Changes in Active and Inactive Atlantic Hurricane Seasons in the Energy Exascale Earth System Model. *Geophysical Research Letters*, 49, e2022GL100267. https://doi.org/10.1029/2022GL100267

Influence of Climate Variability and Change on Atlantic Hurricane Season Length



North Atlantic hurricane season length from the 10-member ensemble of E3SM experiments in historical and future climates representing conditions for active hurricane seasons (La Niña and positive Atlantic Meridional Mode; AMM), inactive seasons (El Niño and negative AMM), and the control (neutral El Niño – Southern Oscillation and AMM).

Problem: Drivers and future changes in Atlantic hurricane season length are poorly understood.

Objectives:

- We investigated oceanic sources of predictability in Atlantic hurricane season length, start, and end using historical observations.
- We projected future changes in Atlantic hurricane season length using E3SM.

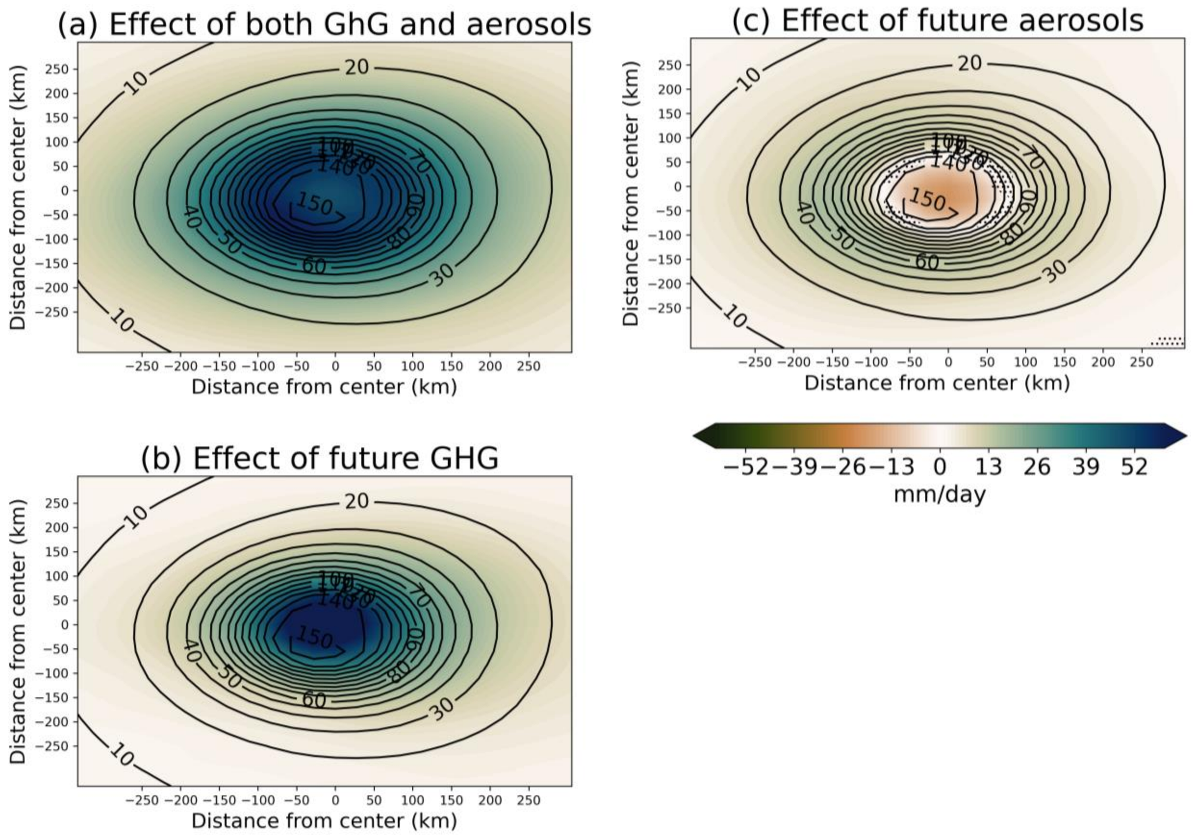
Results:

- A warm western subtropical Atlantic ocean in boreal spring drives early Atlantic hurricane season starts and La Niña events in autumn drive late hurricane season ends.
- E3SM projected a 27-41 day increase in Atlantic hurricane season length in the future.

Significance: A future lengthening of the hurricane season may exacerbate impacts associated with more intense TCs.

Patricola, C. M., Hansen, G. E., & Sena A. C. T. (2024). The Influence of Climate Variability and Future Climate Change on Atlantic Hurricane Season Length. *Geophysical Research Letters*, 51(8), e2023GL107881. https://doi.org/10.1029/2023GL107881

Atmospheric Effect of Aerosols on Future Tropical Cyclone Frequency and Precipitation



The response in simulated TC precipitation within a 300 km radius of the TCs to (a) future aerosols and greenhouse gases, (b) future greenhouse gases given historical aerosols, and (c) the atmospheric effect of the future aerosols given historical greenhouse gases (shaded). Contours represent the climatological mean precipitation.

Problem: Although future greenhouse gas and aerosol concentrations are typically considered together, they follow different trajectories and influence TC activity differently.

Question: How do greenhouse gases and the atmospheric effects of aerosols influence TCs frequency and precipitation?

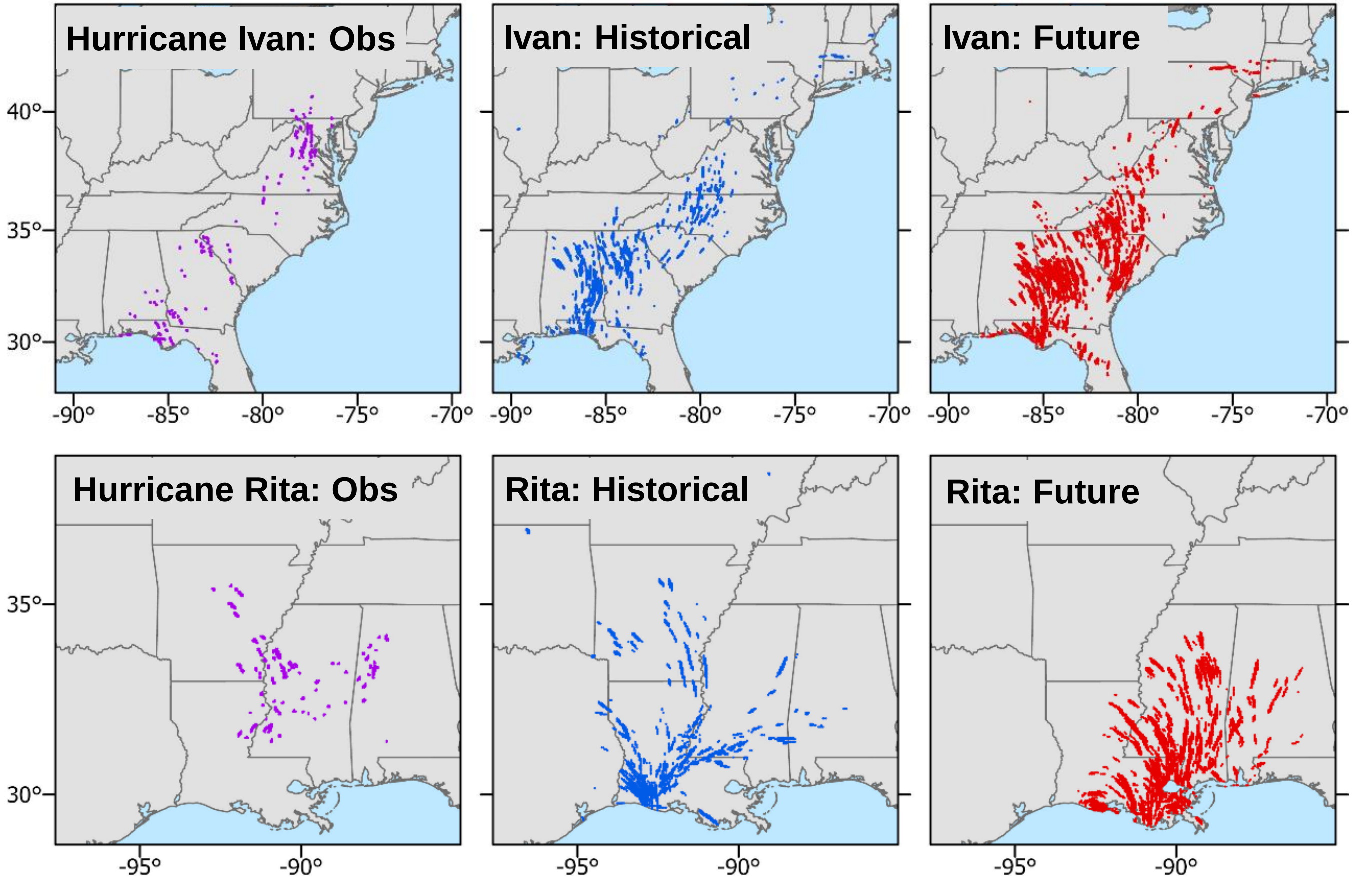
Method: Ensembles of E3SM simulations with individual and combined forcings.

Results: While both forcings enhance TC precipitation, increased greenhouse gases preferentially enhance TC precipitation in the inner-core, whereas decreased aerosols lead to TC precipitation decreases in the inner-core and increases in the outer-bands.

Significance: Proper representation of the spatial distribution of aerosols is needed when studying future projections of TC frequency and precipitation.

Sena, A. C. T., Patricola, C. M., Camargo, S. J., & Sobel, A. H. (2024). The Atmospheric Effect of Aerosols on Future Tropical Cyclone Frequency and Precipitation in the Energy Exascale Earth System Model. *Climate Dynamics*, in press. http://doi.org/10.1007/s00382-024-07359-z

Future Changes in Tropical Cyclone Tornadoes



Problem: TC-tornadoes are a dangerous but understudied co-occurring coastal extreme.

Question: How is TC-tornado activity expected to change in the future?

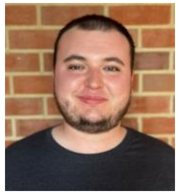
Method: Convection-permitting “storyline” simulations of four TCs that produced the greatest TC-tornado outbreaks on recent record in the US.

Results:

- Future TC-tornado activity increased for all four events (~1.5-4 times the historical).
- Nocturnal TC-tornado activity increased for three of the four events.

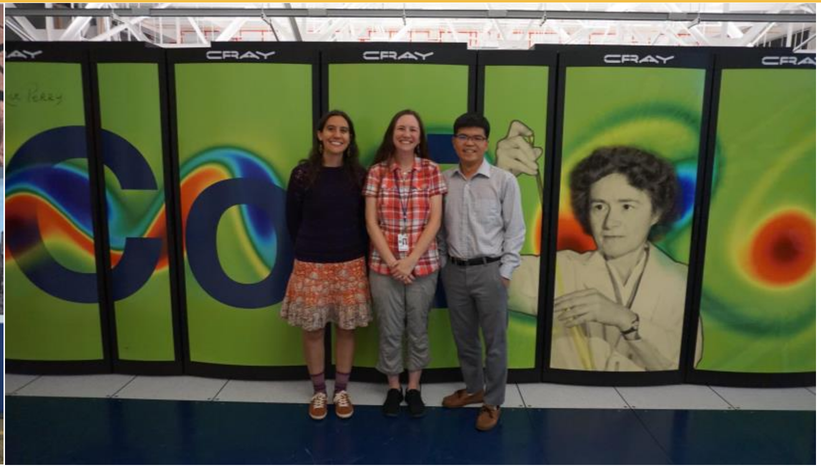
Significance: Future increases in total and nocturnal TC-tornado activity, together with an increasing coastal population, can lead to greater TC hazards in the future.

(left) Observed TC-tornadoes. TC-tornado surrogates from (middle) historical and (right) future simulations for Hurricanes (top) Ivan and (bottom) Rita. *The simulations consist of 4-member ensembles, which explains the appearance of greater TC-tornado activity in the model than observations.*



Forbis, D. C., Patricola, C. M., Bercos-Hickey, E. & Gallus, W. A., Jr. (2024). Mid-Century Climate Change Impacts on Tornado-Producing Tropical Cyclones. *Weather and Climate Extremes*, 44, 100684. https://doi.org/10.1016/j.wace.2024.100684

Early Career Research Award: Benefits and Strategies



5 years of support enables me to train the next generation of climate scientists, grow my research portfolio, and build external collaborations.

NERSC

Taught a course on numerical modeling using Perlmutter

Strategies:

- Identify grand challenges by immersing yourself in the literature and attending conferences.
- Propose what inspires you.
- Write as often as possible.
- Build on your expertise and include new pursuits.
- If at first you don’t succeed, learn from the feedback and try again!

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