A Study of Extratropical Cyclone Statistics in Present-Day and Warmer Climates

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Abstract

Extratropical cyclone (ETC) tracking algorithms are essential for understanding ETC behavior and their response in a warming climate. This study employs GFDL's C192AM4 (or 50 km resolution AM4) model to simulate current and warmer climates, using two tracking methods: TempestExtremes, which identifies ETCs based on sea level pressure anomalies, and Hodges, which relies on maximum relative vorticity. These methods offer valuable insights into ETC trajectories and intensities, though differences between the algorithms introduce uncertainties. Preliminary analysis suggests a poleward shift in the density and intensity of ETC tracks under global warming, aligning with previous studies. However, the model's constant sea ice concentration and uniform increase in sea surface temperatures may influence these results, highlighting the need to further investigate biases in tracking methods and model configurations. Continued research is crucial for understanding the mechanisms driving ETC changes and the robustness of the the robustness of the poleward shift of the storm tracks.

Background

Why the GFDL Global Atmospheric Model? Zhao et al. (2018)

- Ability to realistically simulate ETC, Gentile et al. (2023)
- Representation of atmospheric rivers, mesoscale convective systems, and tropical storms Zhao et al (2022)
- 50 km horizontal resolution with 33 vertical levels

What was used within the C192AM4 model?

- A present-day control simulation: forced by the observed SSTs, sea ice concentrations, radiative gases, and aerosol emissions.
- Future warmer climate simulation: SSTs uniformly increased by two kelvin

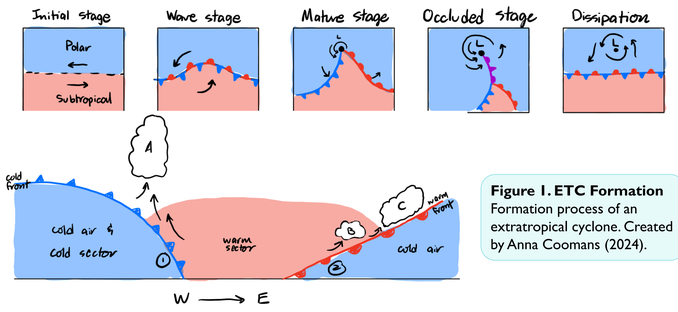


Figure 1. ETC Formation Formation process of an extratropical cyclone. Created by Anna Coomans (2024).

Methods

- The two distinct tracking algorithms, TempestExtremes and Hodges Tracker, were utilized alongside GFDL's Global Atmospheric Model 4.
- Sea level pressure anomaly and maximum relative vorticity were used as input variables for TempestExtremes and Hodges, respectively, to calculate extratropical cyclone (ETC) statistics.
- Python, a Linux system, and NCAR Command Language (NCL) were utilized to analyze the data and produce climate visualizations of the ETC statistics.

Results

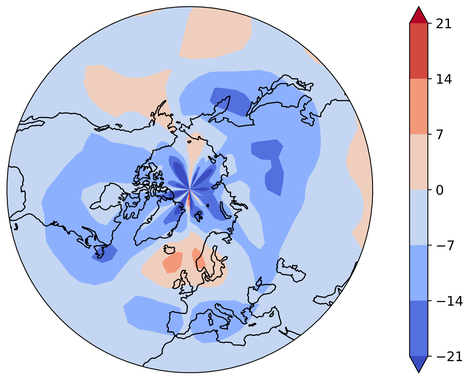


Figure 2. TempestExtremes, SLP Anomaly Difference in Track Density (10^{-6} km^{-2} yr^{-1}) Sea level pressure anomaly arming (p2k) – present data from 1979-2014.

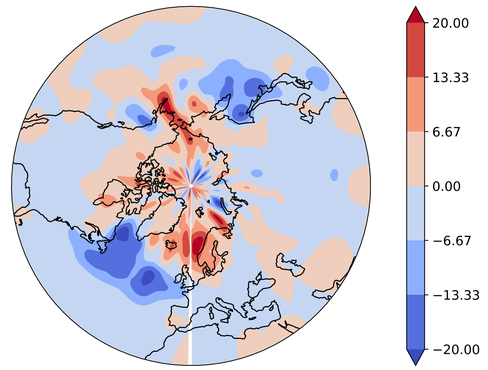


Figure 3. TempestExtremes, SLP Difference in Track Density (10^{-6} km^{-2} yr^{-1}) Sea level pressure warming (p2k) – present data from 1979-2014.

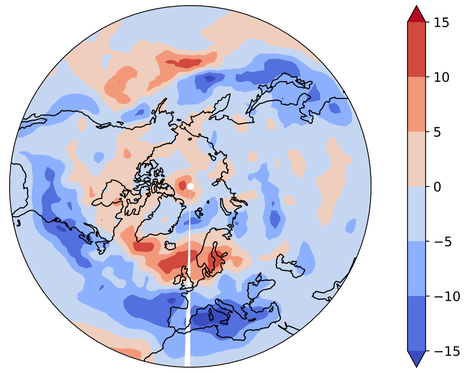


Figure 4. Hodges Tracker, Difference in Track Density (10^{-6} km^{-2} yr^{-1}) Track density of ETC from 1949-2019.

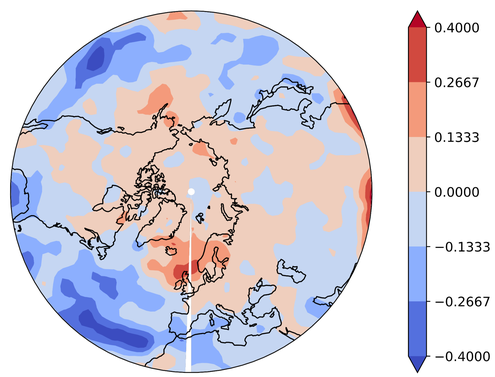


Figure 5. Hodges Tracker, Difference in Track Intensity (10^{-5} s^{-1}) ETC track intensity from 1949-2019, measured with relative vorticity.

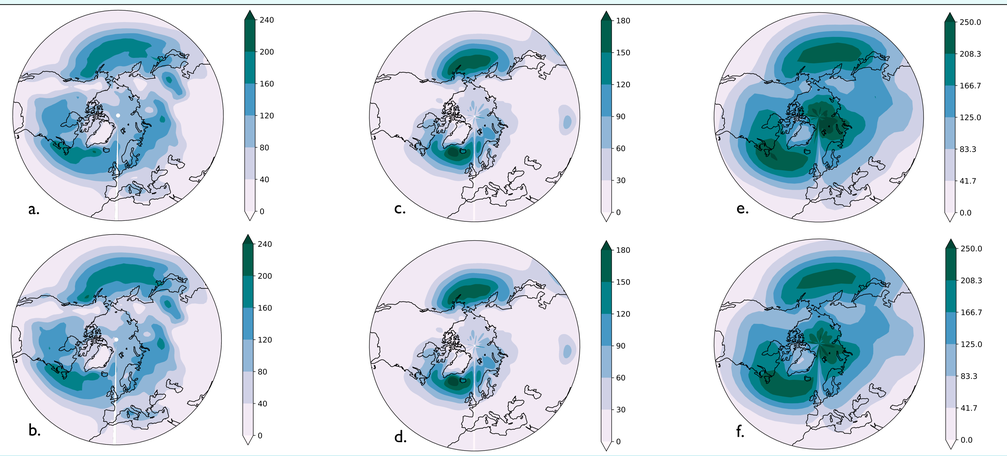


Figure 6 (a-f). Track density differences (10^{-6} km^{-2} yr^{-1}) from Hodges Tracker and TempestExtremes. Hodges Tracker results show present-day (6a) and warming climate (6b) track densities (1949–2019). TempestExtremes results show track densities for present-day SLP (6c) and SLP anomaly (6e), and warming SLP (6d) and SLP anomaly (6f) from 1979-2014.

Conclusion



Both trackers predict a systematic shift in track density; however, this shift could be attributed to the usage of the AM4 model.

An extratropical cyclone impacting the eastern United States (USGS 2018)

- A constant sea ice concentration and uniformly adding 2K to the SST might lead to an artificially enhanced zone of baroclinicity at the sea-ice edge.
- Realistically in a warmer climate Arctic Amplification is expected to cause surface baroclinicity around the sea-ice edge to decrease, weakening the upper-level westerlies as polar regions warm more strongly than the tropics. Shaw (2016), Smith (2022)
- Because ETCs develop from baroclinic instabilities, weakening these instabilities could potentially decrease the frequency and intensity of ETCs, especially in the Northern Hemisphere, where sea ice loss is expected to be most significant.

Future directions

- Further investigation is required to evaluate the robustness of the poleward shift of storm track, and to better understand the possible mechanisms of these ETC changes in a warming climate.
- More models, like coupled models, could be used to analyze the representation of ETC statistics
- Other variables such as precipitation and extreme winds can be analyzed as well.

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