Investigating the role of extratropical cyclones in deep water formation in the Labrador and Nordic Seas

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Background

- Deep convection replenishes the intermediate to deep waters of the AMOC and transmits surface water properties to depth.
- Atmospheric forcing plays an important role both in priming the sea surface for convection by cooling and increasing the density of surface water, and in initiating convection.
- Extratropical cyclones, or ETCs, have a large radius of influence (1000s of km) and can cool the sea surface below them by up to 2°C over 2-5 days (Nelson et al. 2014).
- Cyclone characteristics are expected to change with continued climate change, so it is valuable to understand how they influence the water column in the present to predict how this role might change.

KEY QUESTION: To what extent do ETCs contribute to deep convection in the North Atlantic and how do they affect the properties of the deep water masses formed?

Methods

Storm tracking:

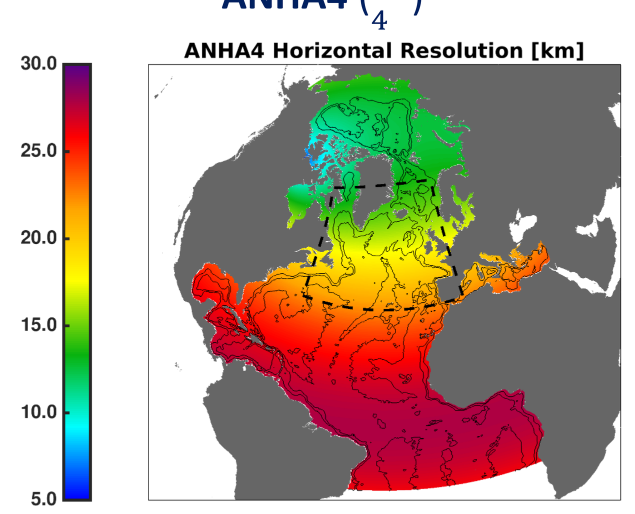
Atmospheric datasets: **ERA5**, **CGRF**.

To isolate extratropical cyclones within them, we use a suite of feature detection and tracking algorithms, TempestExtremes, by Ullrich and Zarzycki.

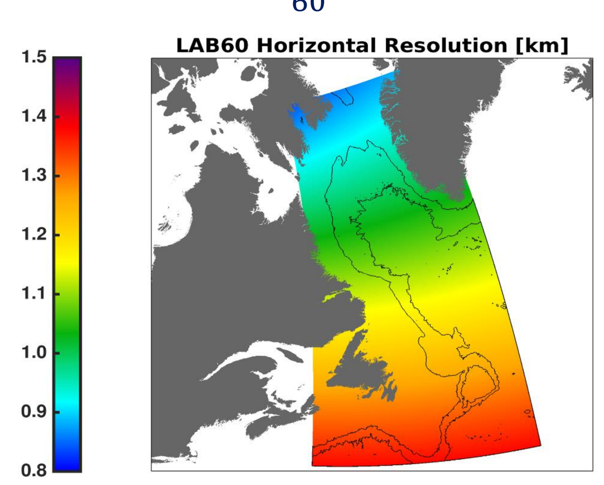
Model:

- NEMO Model v. 3.6
- Our configurations:

ANHA4 ($\frac{1}{4}$°)

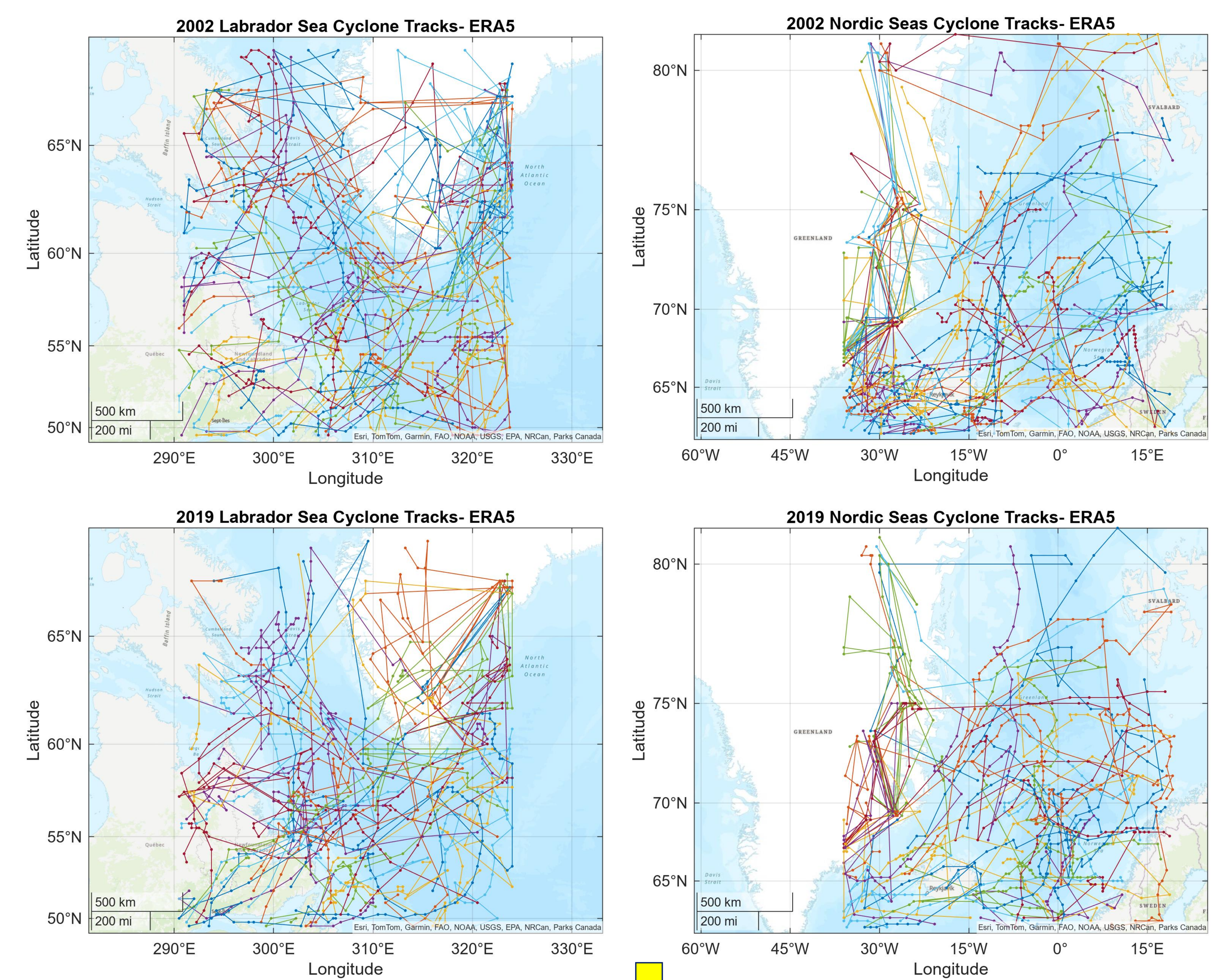


LAB60 ($\frac{1}{60}$°)

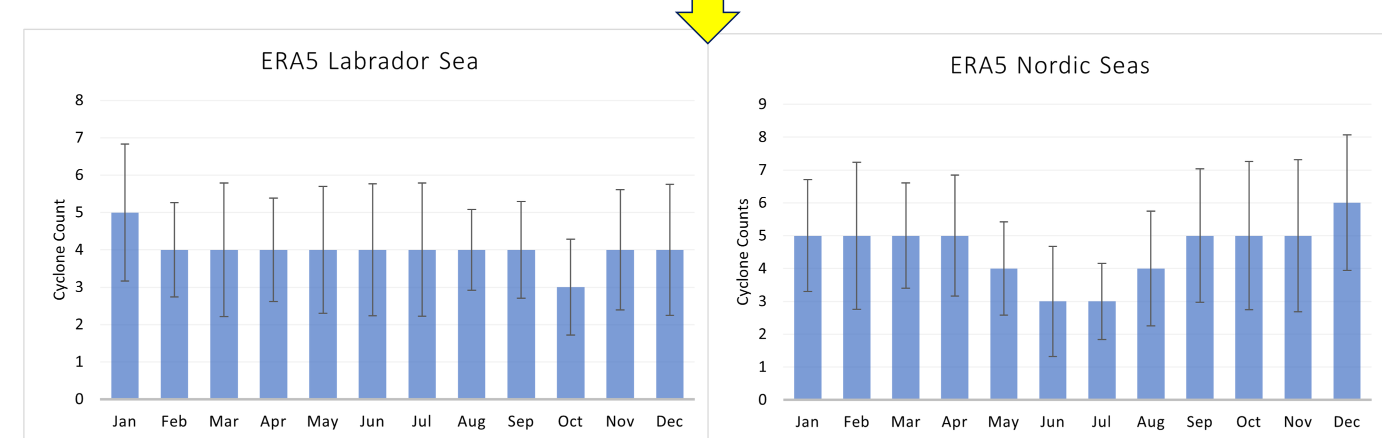


Previous experiments have run the model with ERA5 or CGRF as the atmospheric forcing, from 2002-2019 (Pennelly and Myers 2021). Using the output from these runs, we will examine properties of the water column below the cyclones that we identify using TempestExtremes.

Results



(Left) All cyclone tracks identified within each study domain in the ERA5 dataset for two example years, 2002 and 2019. Positions are plotted every three hours.

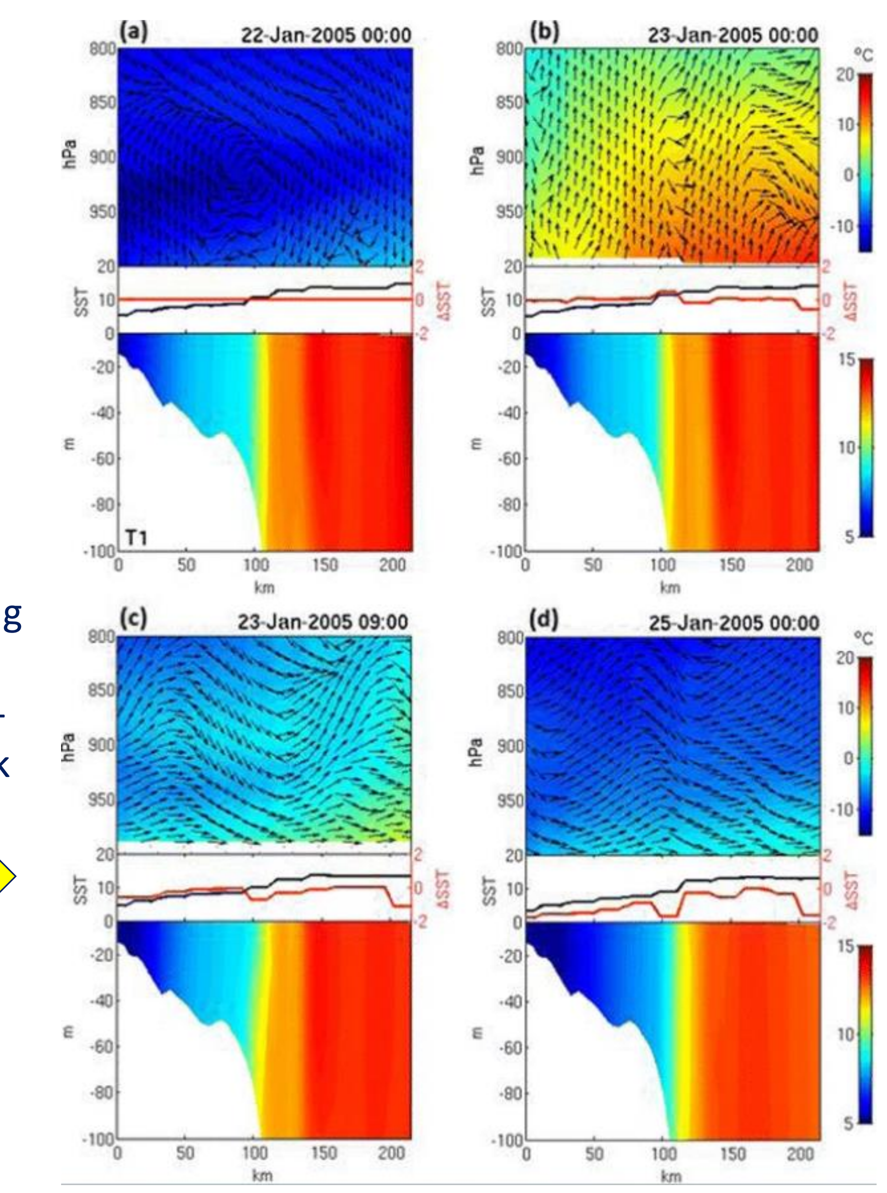


Average number of cyclones per month over 2002-2019 for each of the study domains. Error bars are the standard deviation for each month.

The bar charts indicate that at a glance, winter months only have slightly more cyclones than others, if any; however, the range of variability for most months is very high, so further analysis may not find a statistically significant difference.

We expect to see changes in temperature and salinity, heat content, convective resistance, and mixed layer depth as a cyclone tracks over a location. Nelson et al. (2014) show an example of an individual cyclone here:

Most cooling takes place during cold-air outbreak



From Nelson et al. (2014)

For a)-d): Atmospheric temperature and velocity fields, change in sea surface temperatures relative to pre-storm values (red line), and corresponding ocean temperature profiles across a Gulf Stream transect a) before storm, b) during storm formation, c) onset of cold-air outbreak, and d) end of cold-air outbreak.

Next Steps

- Equivalent plots will be generated for CGRF
  - Assess differences between ERA5 and CGRF
- Compute vertical profiles of mixed layer depth, convective resistance, heat content, and upper-ocean temperature and salinity for each storm track
  - Investigate direct response of ocean in very high resolution model
- Potentially look at the effect of storms of different intensities, how storm intensity affects water column
- Evaluate how differences in model resolution affect the results
  - Between 1/4 and 1/60 degree resolution
- Investigate any effect of NAO index on the results

Key Points

- Extratropical cyclones have the potential to contribute to the initiation of deep convection (and thus deep water formation), and they may influence the properties of the deep water formed
- Extratropical cyclones can exert noticeable effects on the sea surface and the water column
  - Cooling mostly occurs in the cold sector of the cyclone
- Variability is large compared to the spread of cyclone counts per month averaged over 2002-2019
  - May not be a significant difference in number of cyclones between months- further investigation needed
- Will examine very high resolution NEMO ocean model output (convective resistance, heat content, mixed layer depth) to determine the response of the ocean to cyclones tracked in the atmospheric datasets

References
Nelson J, He R, Warner JC, Bane J. 2014. Air-sea interactions during strong winter extratropical storms. Ocean Dynamics 64:1233-1246.
Pennelly C and Myers PG. 2021. Impact of different atmospheric forcing sets on modeling Labrador Sea Water production. JGR Oceans 126.
Ullrich PA, Zarzycki CM, McClenny EE, Pinheiro MC, Stansfield AM, Reed KA. 2021. TempestExtremes v2.1: A community framework for feature detection, tracking and analysis in large datasets. Geosci. Model. Dev. 14:5023–5048. doi: 10.5194/gmd-14-5023-2021. Ullrich PA and Zarzycki CM. 2017. TempestExtremes v1.0: A framework for scale-insensitive pointwise feature tracking on unstructured grids. Geosci. Model. Dev. 10:1069-1090. Zarzycki CM and Ullrich PA. 2017. Assessing sensitivities in algorithmic detection of tropical cyclones in climate data. Geophys. Res. Lett. 44(2):1141-1149.