How does the upper water column respond to cyclonic storms?

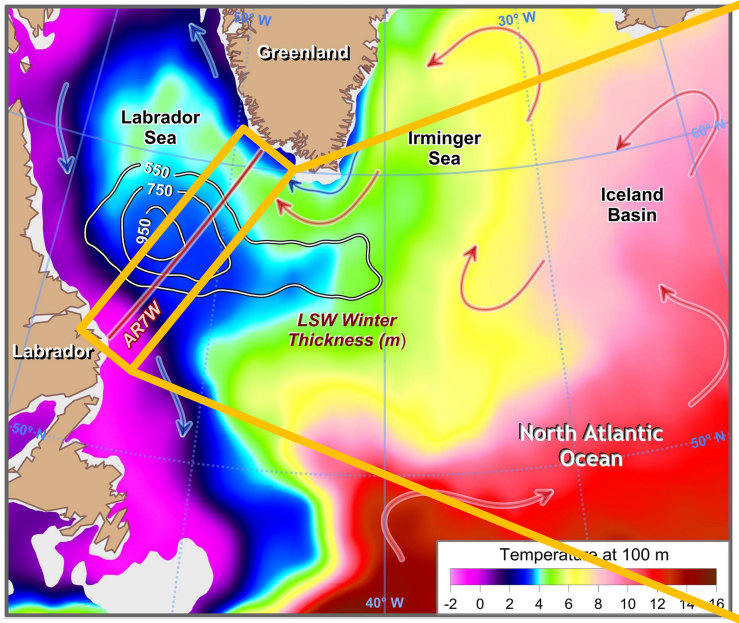
Analysis of 15 years of Labrador Sea cyclones and a case study in the North Pacific

Robin Whincup, Clark Pennelly, Paul Myers

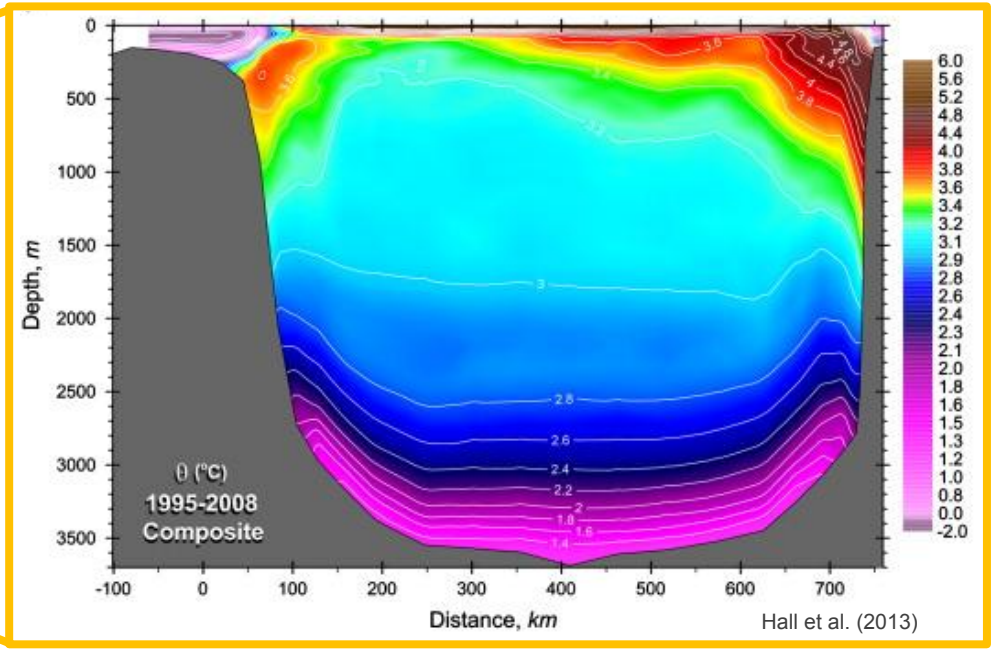
UNIVERSITY OF ALBERTA

NSERC CRSNG

North Atlantic & Labrador Sea



Yashayaev and Loder (2016)

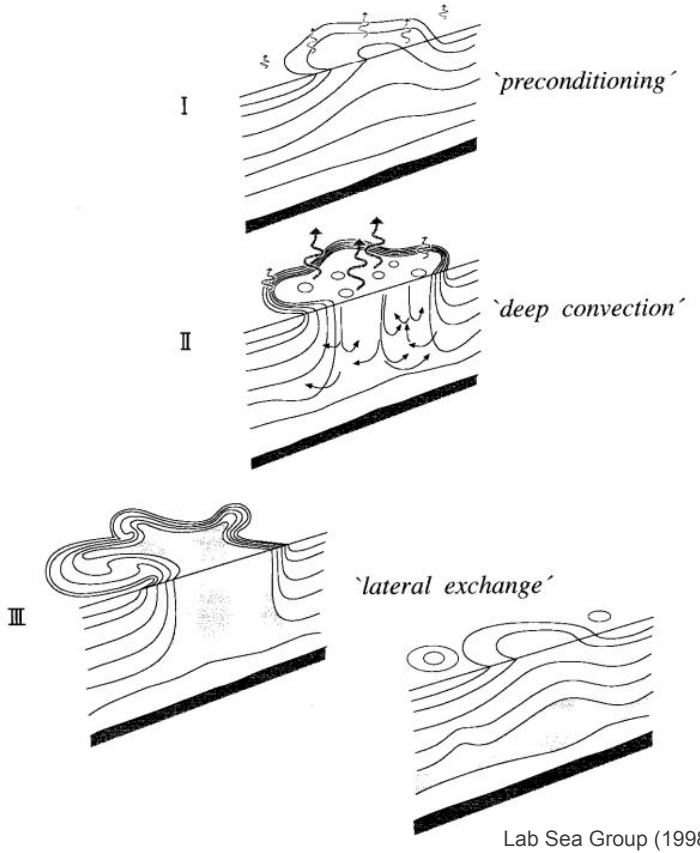


Hall et al. (2013)

- Deep water formation occurs in the Greenland/Iceland/Norwegian (Nordic) Seas and the Labrador Sea
- Lab Sea boundary currents contain fresh cold water near surface and warm saline water below
- Irminger Water (warm, saline) below fresher and colder water in the Labrador Sea

Convection and Deep Water Formation

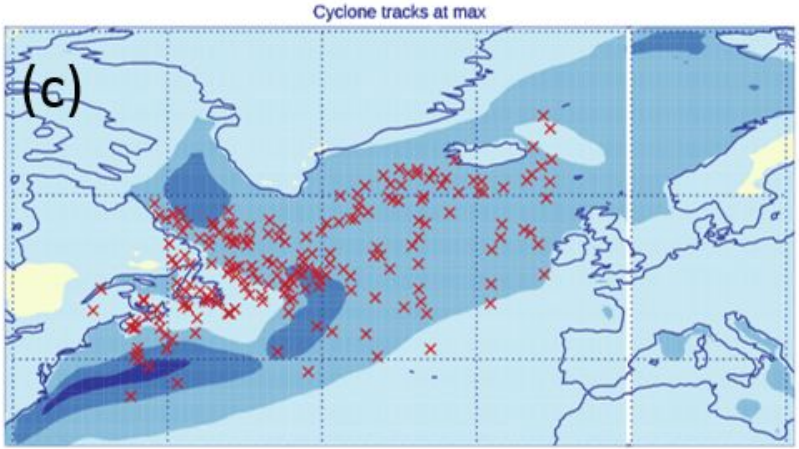
1. Preconditioning
   - Heat removed from sea surface, largely by atmospheric forcing
   - Upper ocean becomes denser
2. Deep Convection
   - Upper ocean becomes dense enough to sink
   - In the Labrador Sea, can exceed 2000m depth (Lab Sea Group, 1998)
   - This forms deep water masses
3. Restratification
   - Processes restore stratification (e.g. add heat to sea surface)



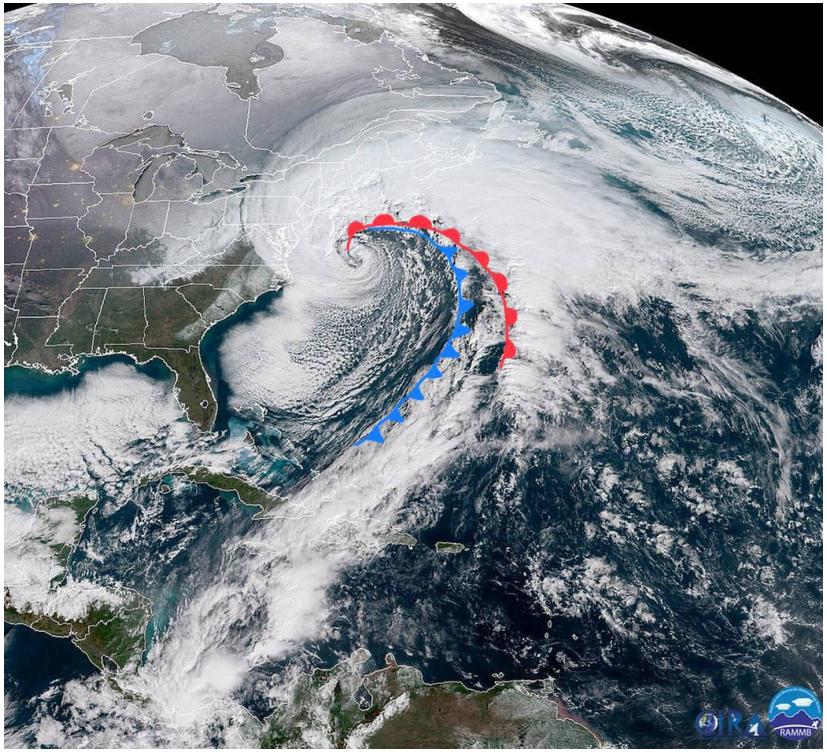
Lab Sea Group (1998)

Extratropical Cyclones

- Synoptic-scale low pressure systems
- Cold air temperatures and high wind speeds behind cold front
- Individual cyclones can lower SST by up to 2° C over 2-6 day lifespan (Nelson et al., 2014)



Dacre et al. (2020)



Ocean Response to Labrador Sea Cyclones 2003-2018

Storm Tracking

Study period: 2003-2018

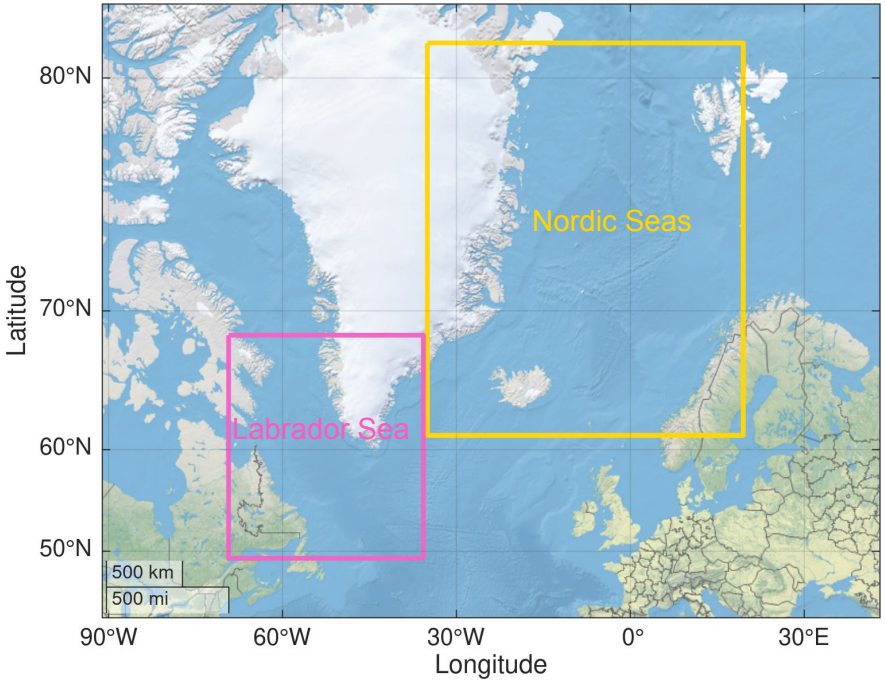
- Atmospheric dataset:

  ERA5

- Storm tracking software:

  TEMPEST EXTREMES

- ETC detection criteria:
  - Minima in sea level pressure
  - Closed contours of 20 hPa within 6° of center
  - Must persist >=48 hours
  - Must travel >=6° over lifespan

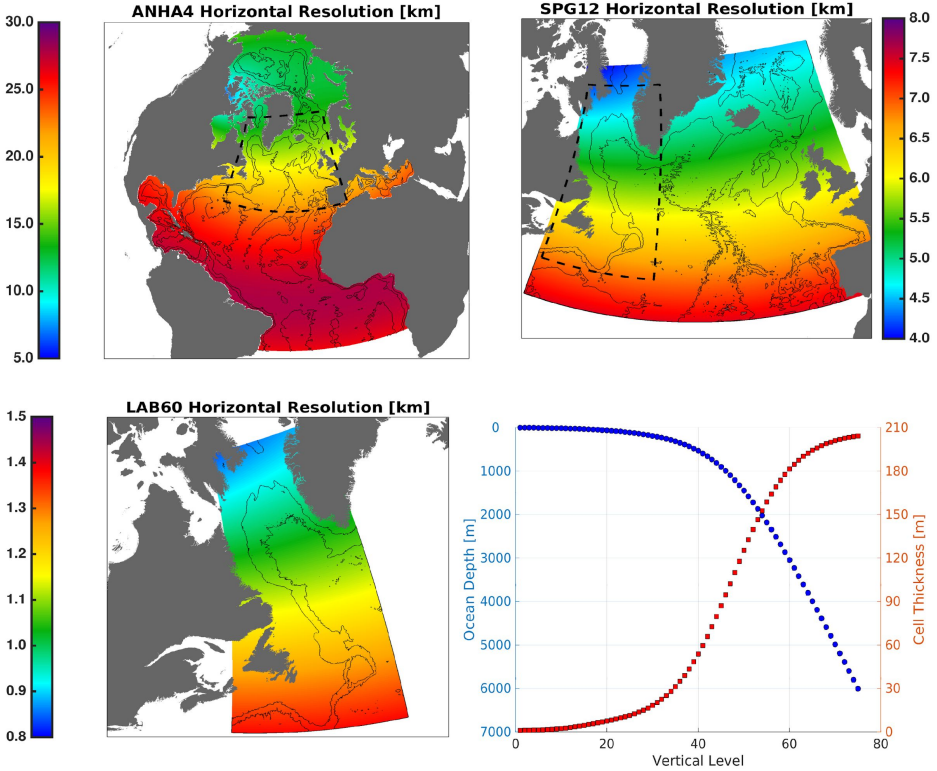


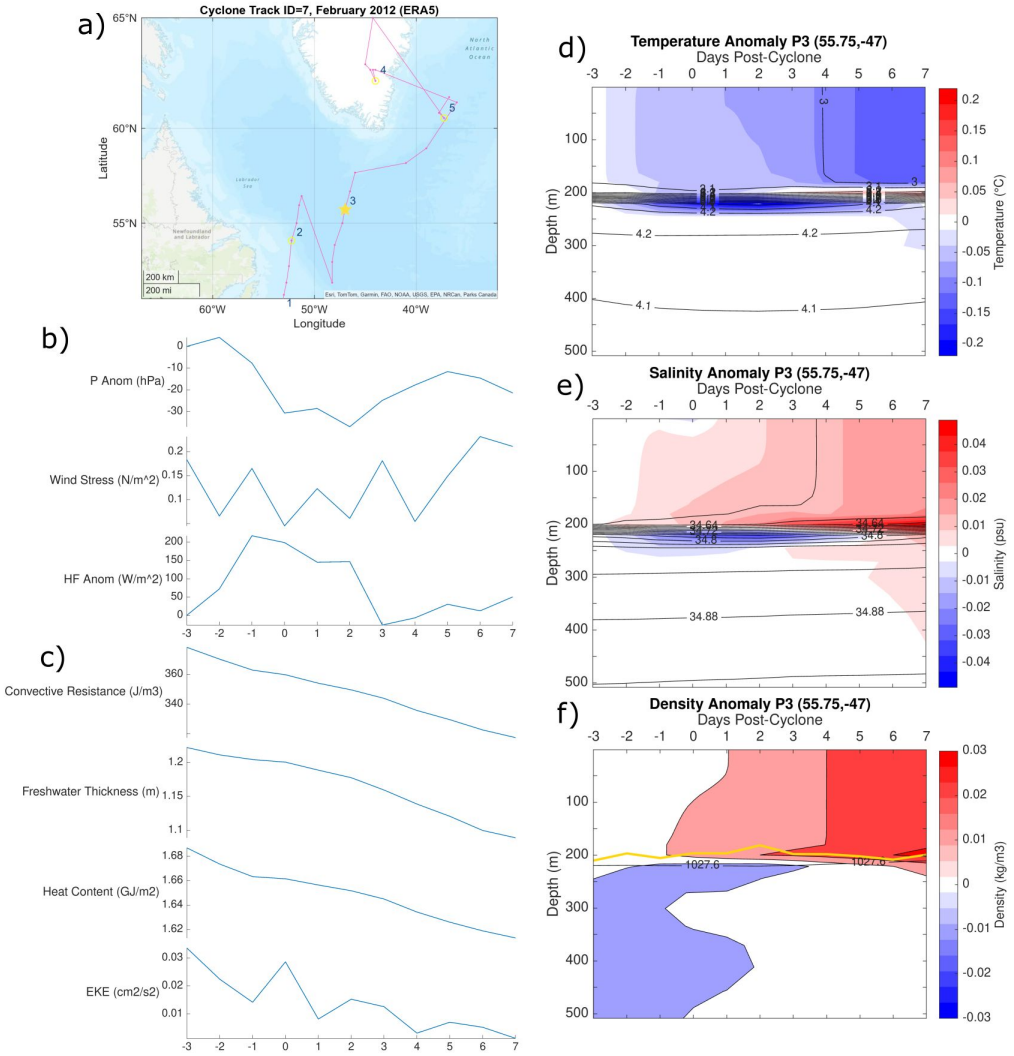
Ocean Model

- NEMO Ocean Model v3.6
- Configuration:

ANHA4	SPG12	LAB60
$\frac{1}{4}°$	$\frac{1}{12}°$	$\frac{1}{60}°$

- Model Experiments:
  - Initial conditions: GLORYS1v1
  - Runoff: DT/Bamber2018
- Study period: 2003-2018





Ocean Response

Time series:

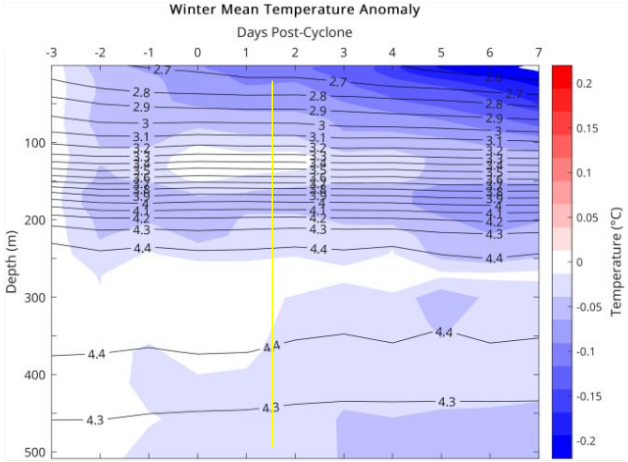
3 days pre-cyclone (-3) to

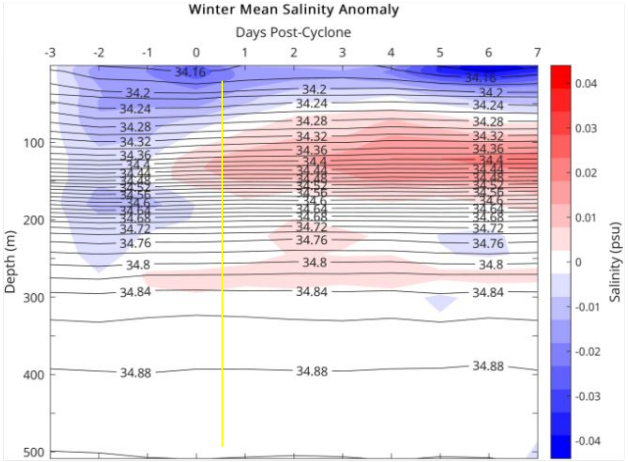
7 days post-cyclone (7)

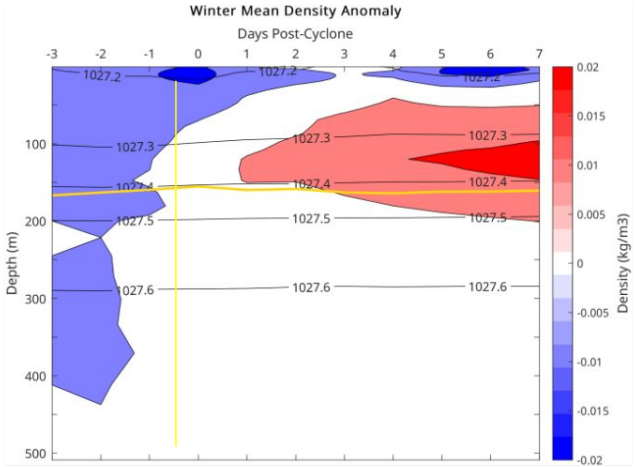
Note: Anomalies calculated with respect to day -3 (first day of the time series)

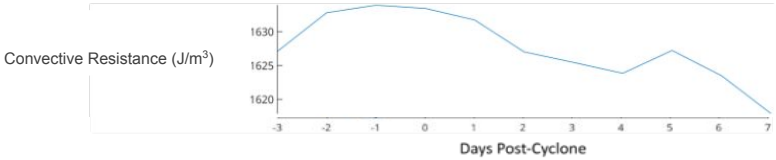
Note: Anomalies calculated with respect to day -3 (first day of the time series)

Mean Response to Winter Storms









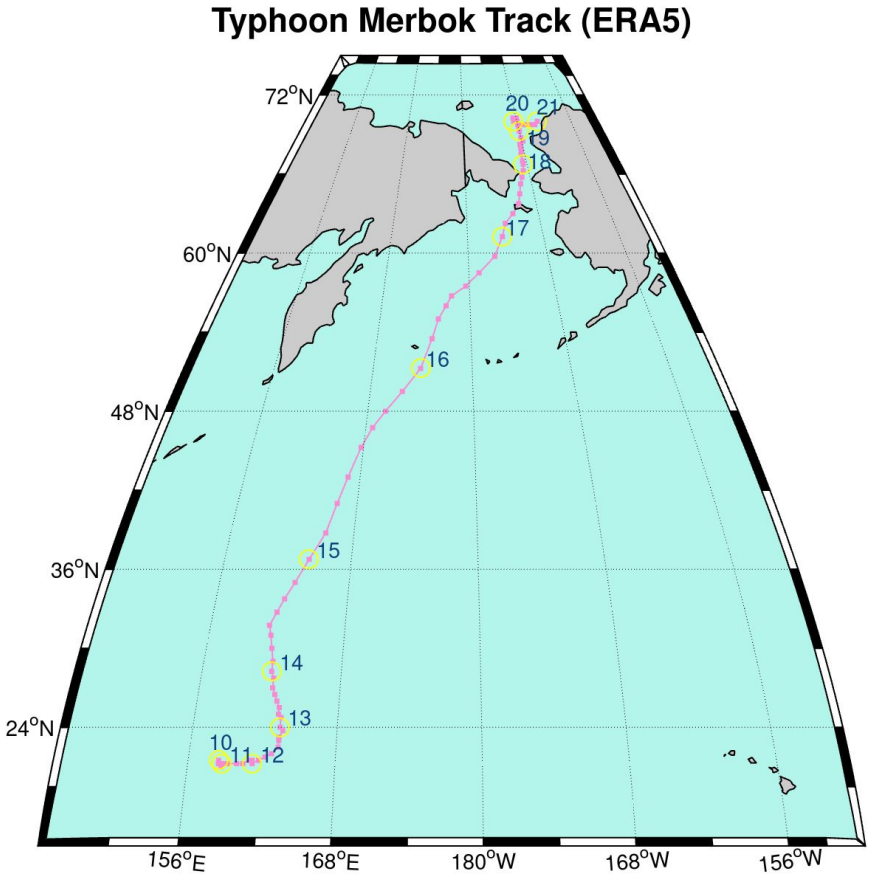
KEY POINTS:

- Mean cooling in mixed layer ~0.2-0.6°C
- Mixed layer deepens post-cyclone, then shoals again, but usually remains deeper than day -3

Case Study: Typhoon Merbok (September 2022)

Typhoon Merbok

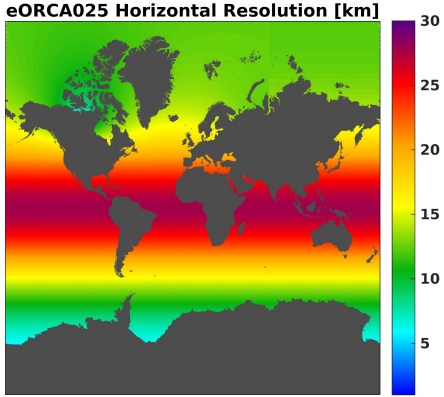
- September 10-21, 2022
- September 11: Tropical Storm forms
- September 13: Upgraded to TC
- September 15: transitions to ETC



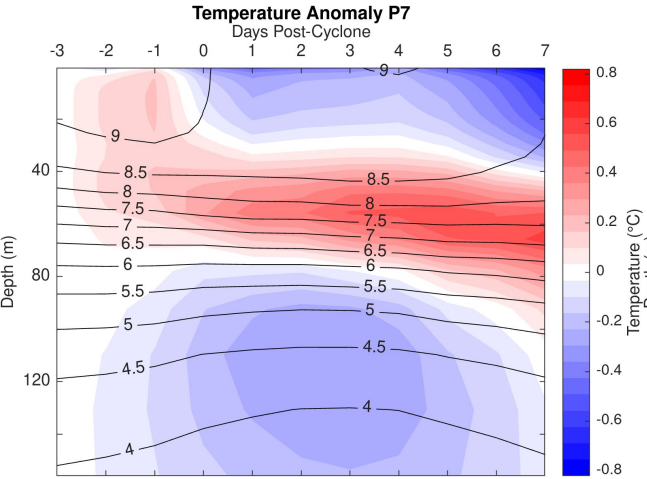
Model Configuration:

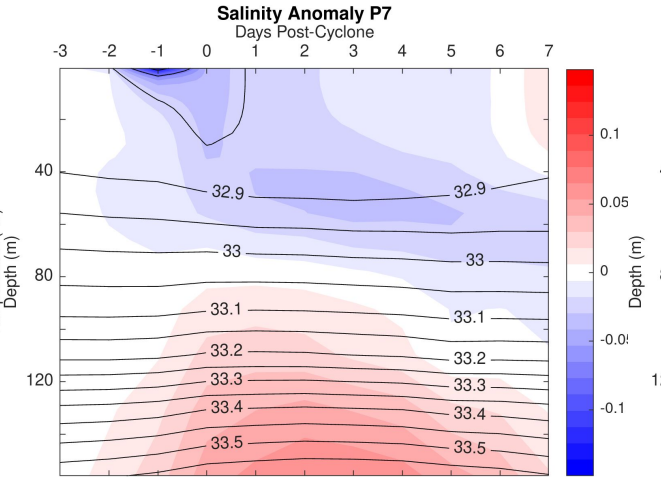
eORCA025,

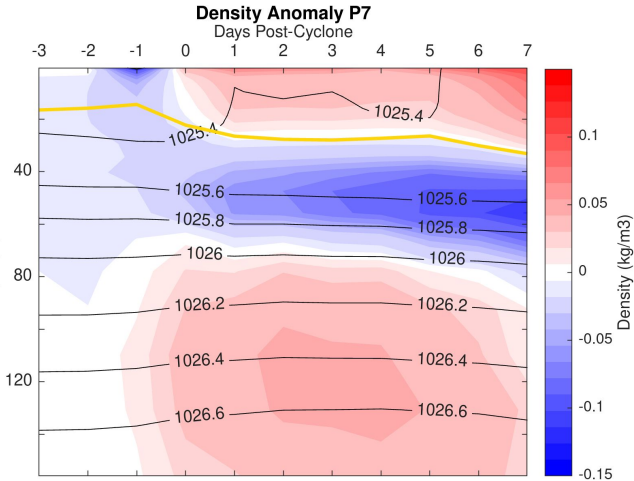
global configuration at ¼ degree horizontal resolution

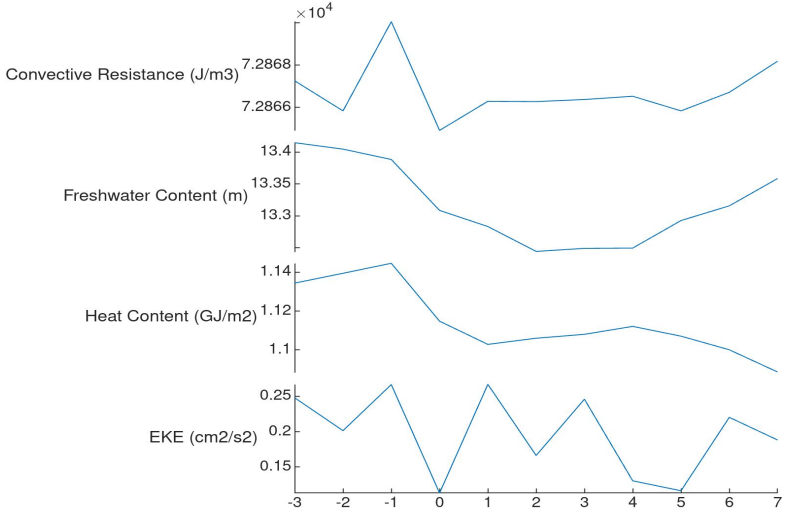


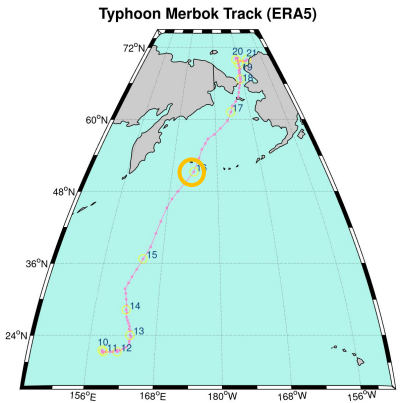
Canadian NEMO Ocean Modelling Forum Community of Practice [Link]


Temperature Anomaly P7
Days Post-Cyclone
Depth (m)
Temperature (°C)


Salinity Anomaly P7
Days Post-Cyclone
Depth (m)


Density Anomaly P7
Days Post-Cyclone
Depth (m)
Density (kg/m3)


Convective Resistance (J/m3)
Freshwater Content (m)
Heat Content (GJ/m2)
EKE (cm2/s2)


Typhoon Merbok Track (ERA5)

Conclusions

How do storms affect the upper ocean in the Labrador Sea?

- Mean upper-ocean cooling of ~0.2°C in response to winter cyclones
  - → Some individual cyclones able to generate cooling up to 2°C
- Mixed layer deepens in days 0-2, shoals days 4+ BUT often remains deeper than its original depth
  - → Possible cumulative deepening due to successive cyclones

Ex-Typhoon Merbok

- At peak intensity, produces surface cooling and subsurface warming up to 0.8°C

References

Dacre HF, Josey SA, Grant ALM. 2020. Extratropical cyclone induced sea surface temperature anomalies in the 2013/14 winter. Weather Clim. Dyn. 1:27-44. https://doi.org/10.5194/wcd-1-27-2020

Hall MM, Torres DJ, and Yashayaev I. 2013. Absolute velocity along the AR7W section in the Labrador Sea. Deep Sea Res. I 72:72-87. https://doi.org/10.1016/j.dsr.2012.11.005

Lab Sea Group (Marshall J et al.). 1998. The Labrador Sea deep convection experiment. Bull. Amer. Meteor. Soc. 79:2033–2058. https://doi.org/10.1175/1520-0477(1998)079%3C2033:TLSDCE%3E2.0.CO;2

Pinto JG, Zacharias S, Fink AH et al. 2008. Factors contributing to the development of extreme North Atlantic cyclones and their relationship with the NAO. Clim Dyn 32:711–737. https://doi.org/10.1007/s00382-008-0396-4

Yashayaev I and Loder J. 2016. Further intensification of deep convection in the Labrador Sea in 2016. Geophys. Res. Lett. 44(3):1429-1438. https://doi.org/10.1002/2016GL071668