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Ice melt from ocean warming in a global ultra high-resolution ocean/sea-ice model

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Motivation

- At the margins of the Greenland and Antarctic Ice Sheets (GrIS and AIS) warming waters sourced from the open ocean at lower latitudes are enhancing land ice melt. Off west Greenland, this surplus meltwater enters the Labrador Sea impacting stratification.
- Accelerated warming in the Arctic over past decades has resulted in enhanced sea-ice loss. As well as sea-ice loss arising from atmospheric warming and feedbacks, the influence of warming and shoaling sub-surface Atlantic Water (AW) in the Eurasian basin is becoming increasing important.

Approach:

1. An ultra-high resolution global ocean/sea-ice model was configured to explore cross-shelf exchange and its drivers between the Greenland and Antarctic continental shelf and the deep interior basins. Here, we focus on Greenland.
2. Two different very high-resolution ocean/sea models are used to study the impact of AW on sea-ice in the eastern Eurasian basin.

UH8to2: Global Coupled POP2/CICE5

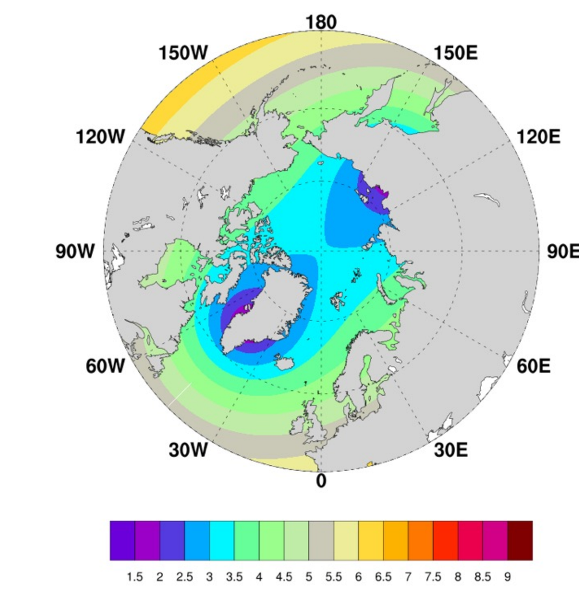
- The ocean/sea-ice model Is configured on an ultra-high (UH) resolution global tripole grid: 8 km at the equator reducing to 2 km at the poles and is designated UH8to2.
- Its horizontal resolution around the Antarctic and southern Greenland is~2-4 km and ~2-3 km, respectively. In the Arctic, it is roughly 2-4 km.
- It has 60 vertical levels & partial bottom cells.
- Code: Parallel Ocean Program2 (POP2)/CICE5 (sea-ice) run in "HiLat" (E3SMv0/CESM) framework (partially coupled via model SST, surface velocity & ice drift in bulk formulae).
- Bathymetry: (GEBCO)_2014: 30-arc 2nd interval grid.

UH8to2 Simulation 1: 1975-2009 (Morrison et al. 2024, Journal of Physical Oceanography)

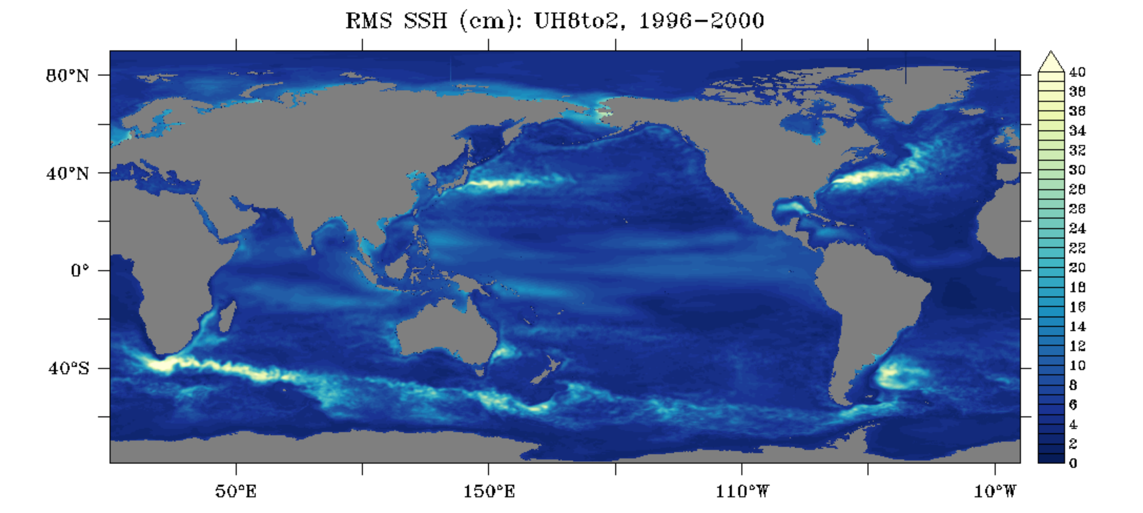
- Forced with Interannual Co-ordinated Ocean-ice Reference Experiments CORE-II
- GrIS: Bamber et al (2018); AIS melt: Hammond and Jones (2017).
- Spin-up: 1975-1985.

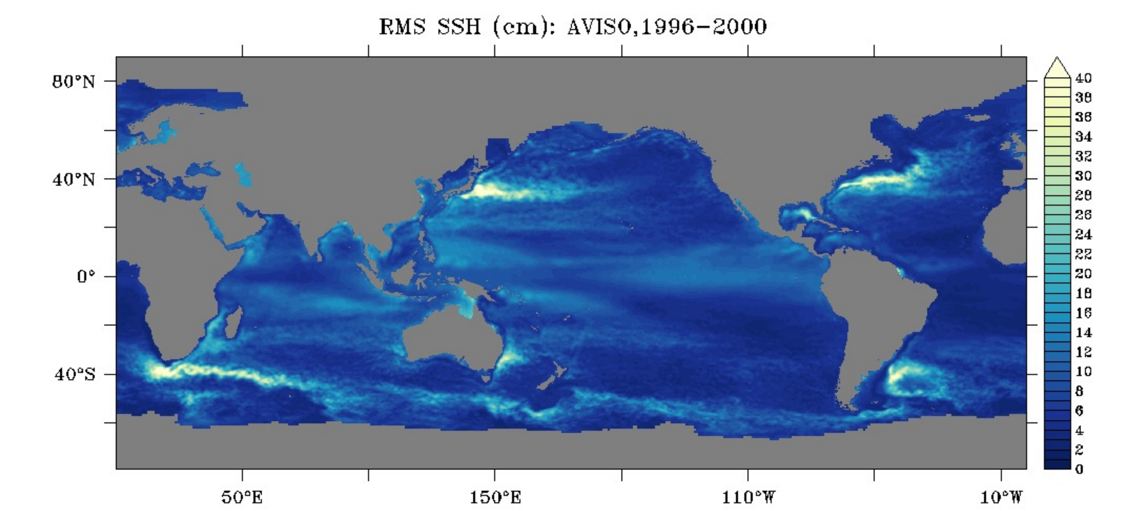
UH8to2 Simulation 2: 07/2016-2020 (Fine et al. 2023, Ocean Modelling)

- 55-year Japanese Atmospheric Reanalysis-driving ocean (JRA55-do); resolution ~0.25º & 3-hourly, includes representations of GrIS & AIS melt.
- Initial Conditions: data assimilative 1/25° Global Ocean Forecasting System 3.5 (GOFS3.5 uses HYCOM and CICE5) from 01/07/2017.
- Spin-up: 07/2016-12/2016; Production run: 2017-2020.



Average horizontal grid spacing (km)





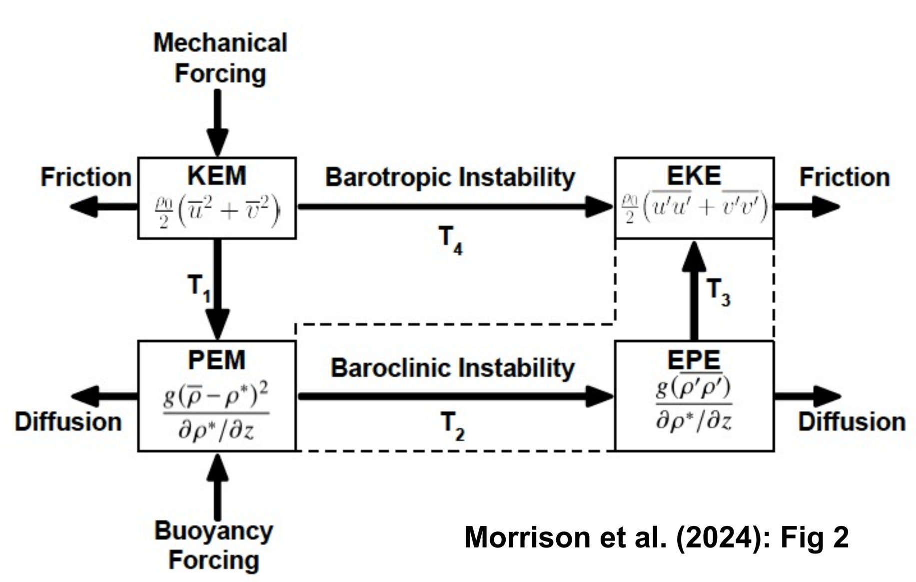
Morrison T.J., J.L. McClean, S.T. Gille, M. E. Maltrud, D.P. Ivanova & A.P. Craig, 2024:

Sensitivities of the West Greenland Current to Greenland Ice Sheet Meltwater in a Mesoscale Ocean/Sea ice Model, *Journal of Physical Oceanography*, 54, 1329-1346, *DOI: 10.1175/JPO-D-23-0102.1*

A suite of UH8to2 simulations are used to investigate the sensitivity of the ocean circulation over the West Greenland continental shelf/slope and in the eastern Labrador Sea to meltwater perturbations from the GrIS.

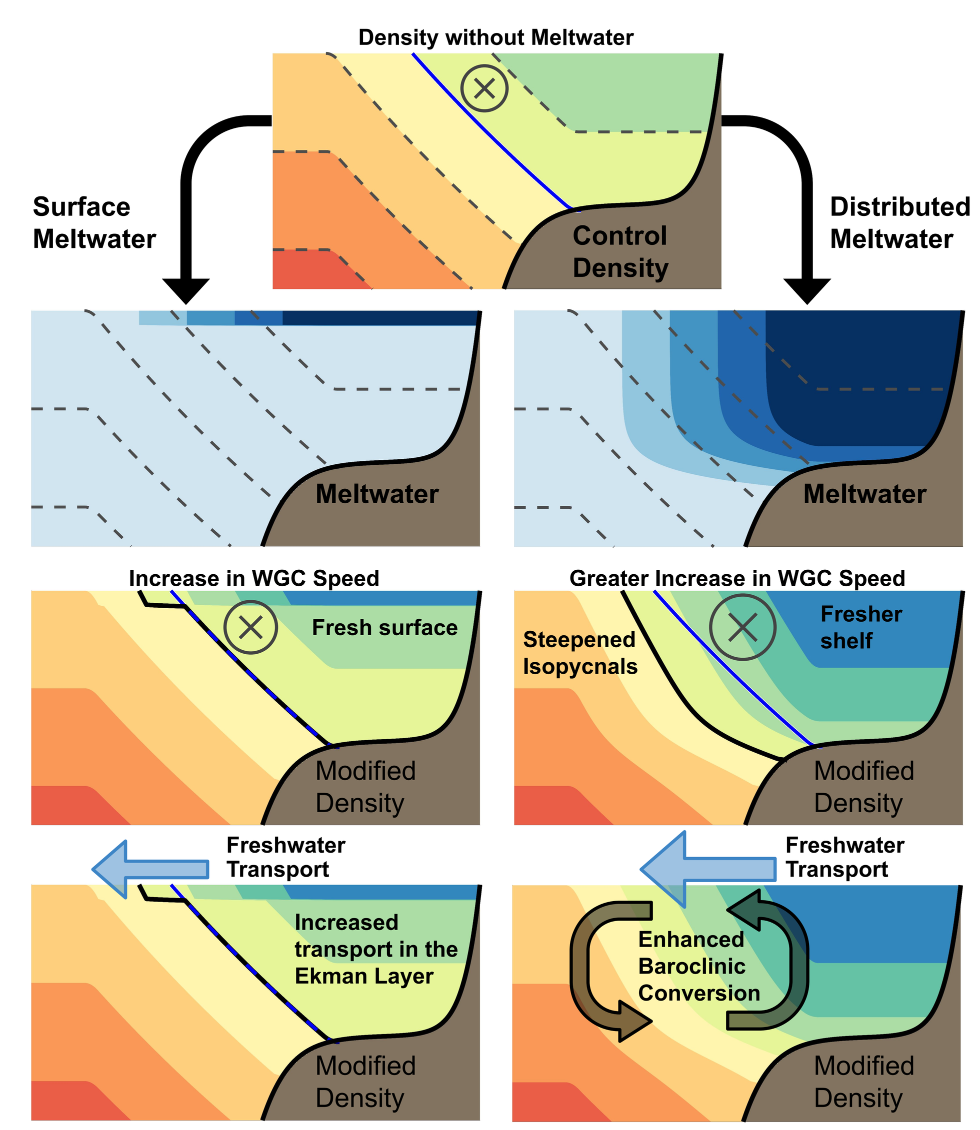
The simulations have: 1) no meltwater (control), (2) meltwater released at the ocean surface (as is standard in forced ocean/sea-ice models), and (3) meltwater vertically distributed over the top 200 m to account for mixing within fjords.

Sensitivities are investigated by comparing components of the energy budget on the West Greenland shelf and in the Labrador basin along with cross-shelf freshwater transports.



Morrison et al. (2024): Fig 2

Oceanic energy budget, after Böning and Budich (1992). Definitions for mean kinetic energy (KEM), eddy kinetic energy (EKE), mean available potential energy (PEM), and eddy available potential energy (EPE) are given in the boxes. The energy conversion terms representing barotropic instability (T_4) and baroclinic instability (both T_2 and T_3, as indicated by the dashed box) are also labeled.



Morrison et al. (2024): Fig 10.

In the top row, the cross-shelf ocean density gradient and slope current, representing the West Greenland Current (WGC), are shown with no GrIS meltwater (the control).

The 2nd row shows the two meltwater perturbations, with the initial isopycnals (surfaces of constant ocean density) shown as dashed lines. In the left column, the surface meltwater forcing freshens the surface. In the right column, vertically distributed meltwater forcing steepens the isopycnals at the shelf break.

In the 3rd row, the presence of the surface meltwater produces increases the speed of the WGC relative to the control (left). However, in the presence of vertically distributed freshwater the increase in the speed of the WGC is greater than the case on the left. The blue line is the original position of an isopycnal, and the black line is the same isopycnal after the meltwater forcing is applied.

The bottom row shows the increased freshwater transport off the shelf in the Ekman layer in the surface case and the enhanced baroclinic conversion in the vertically distributed case.

Conclusions:

In the presence of meltwater, the West Greenland and West Greenland Coastal Currents are faster in the two meltwater perturbation cases than in the control; their mean surface speeds are highest in the vertically-distributed meltwater case.

Relative to the control, cross-shelf fluxes of freshwater into the Labrador Sea increase in the Ekman layer in the surface meltwater case and due to enhanced baroclinic conversion/eddy formation over the upper water column in the vertically-distributed meltwater case. These cross-shelf fluxes are greater in the latter versus the former case.

In the eastern Labrador Sea, the salinity is lowest and the meltwater volume greatest in the vertically-distributed case. Therefore, West Greenland continental shelf/slope currents are sensitive to how meltwater is added to ocean models.

Fine, E.C., J.L. McClean, D.P. Ivanova, A.P. Craig, A.J. Wallcraft, E.P. Chassignet, E. Hunke, 2023: Arctic Ice-Ocean interactions in an 8-2- kilometer resolution global model. *Ocean Modelling*, 184, 102228, *10.1016/j.ocemod.2023.102228.*

UH8to2, forced with JRA55-do, for 2017-2020 reproduces observed distributions of seasonal sea-ice thickness and concentration realistically, although concentration is biased low in the spring and summer and low biases in thickness occur in the central and eastern basins in the fall.

Comparisons with climatology reveal that the UH8to2 AW is shallower, warmer, and saltier than the World Ocean Atlas 2018 climatology for 2005-2017 in the eastern basin. Comparisons of Ice-tethered profiler transects in the eastern Arctic show that the model is warmer below the mixed layer, mixed layers are deeper, and stratification is lower in the model relative to observed quantities (see figure to the right of ITP#111 and POP from the UH8to2). Our analysis suggests that these AW biases, combined with unrealistically low stratification in the upper 100 m of the simulated ocean, contribute to the winter biases in modeled sea-ice thickness.

The influence of Atlantic Water on Eastern Arctic ice/ocean interactions from two mesoscale ocean/sea-ice simulations: J. McClean, D. Dukhovskoy, E. Douglass, E. Chassignet, A. Wallcraft, A. Bozec, R. Helber

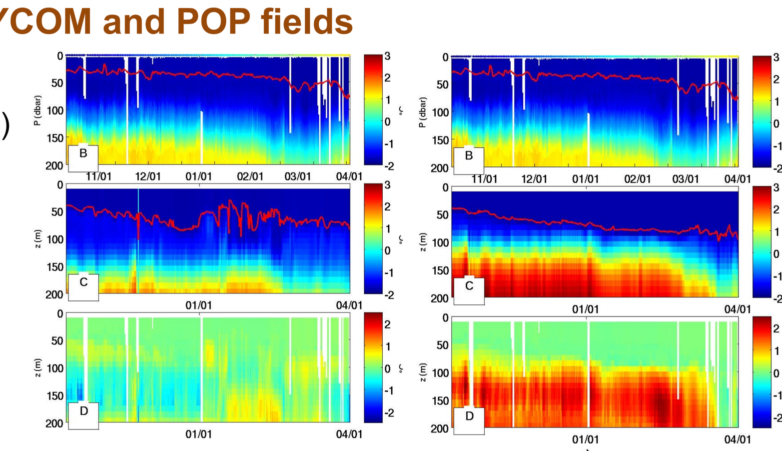
The UH8to2 was then compared with a regional Arctic 1/25 HYCOM (Hybrid Vertical Coordinate Model)/CICE5 simulation forced with JRA55-do and initialized from GOFS3.5 for 2017-2020

Ice-Tethered Profiler (ITP) #111 section in the eastern Arctic (10/2019-04/2020) compared with concurrent & co-located HYCOM and POP fields

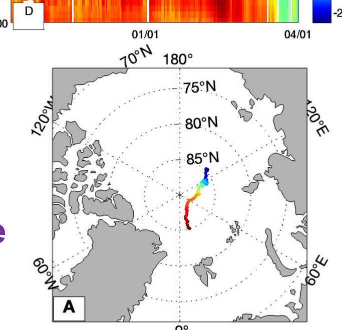
ITP temp. (°C)

HYCOM (left) & POP (right) temp. (°C)

HYCOM-ITP (left) & POP-ITP(right)

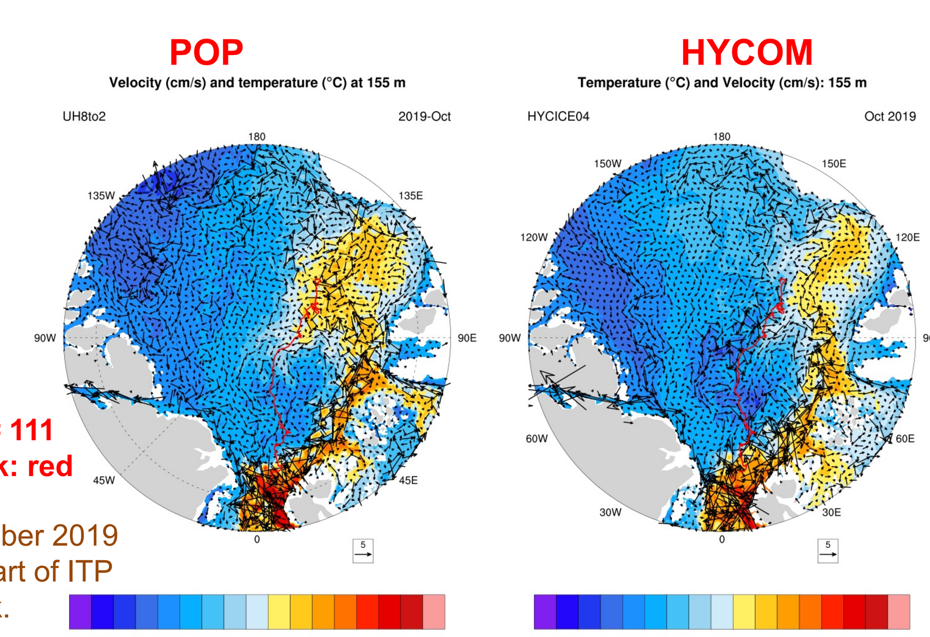


Mixed layer depth (MLD): red lines in panels B and C. Colors corresponding to locations in panel A) are plotted across the top of B.



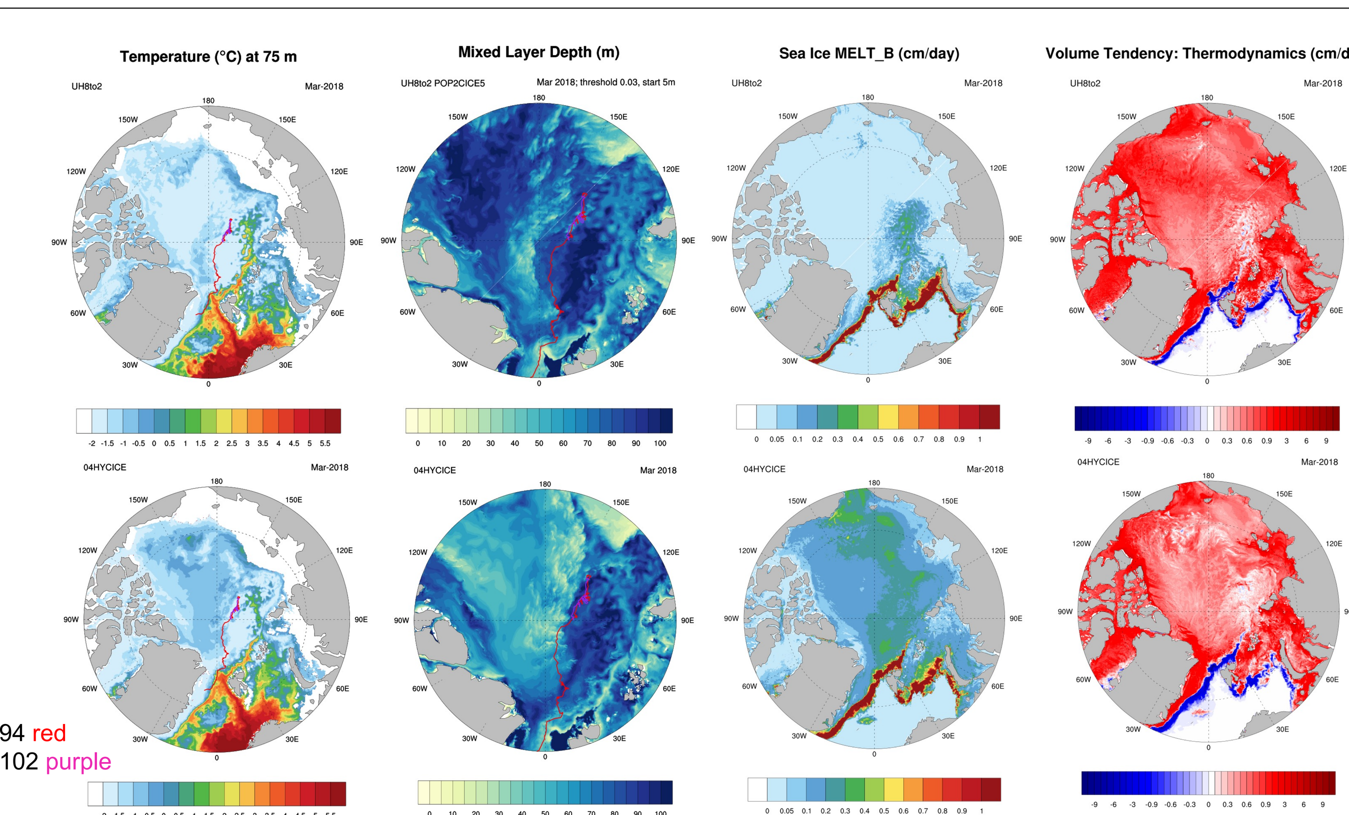
POP comparison with ITP#111 in Fine et al. (2023, Ocean Modell., Fig. 14)

- All MLDs (near freezing) deepen in time.
- ITPs: cold MLD above cold halocline layer to ~100m
- POP: deeper MLD, thin cold halocline layer & AW biased warm.
- HYCOM less biased.
- Models have weaker stratification than obs. in upper 100m – lowest in POP (from N^2 sections, not shown)
- Simulated halocline structure less of a barrier to entrainment of AW into ML than in the real ocean.



ITP# 111 track: red line
October 2019 is start of ITP track.

- An eddy-rich warm AW signature is seen in both models in subsurface waters in the eastern Arctic. It is located further north in the Eastern Eurasian Basin (EEB) in POP than in HYCOM explaining why HYCOM better agrees with temperatures in ITP#111 than POP.
- Visualizations indicate that this is a "pulse" of AW; warmest AW temperatures occur in the EEB (90ºE-150ºE) in early 2018. Warming signatures spread and cool through 2020.
- AW signature in the Arctic is in the initial conditions taken from GOFS3.5



ITP#94 red
ITP#102 purple

Summary:

- HYCOM & POP simulate a mesoscale-rich pulse of AW in the EEB. Maximum warm anomalies occur in late winter 2018; AW pulses then spread out & cool through 2020. Pulses also in GOFS3.5 and 3.1.
- Simulated winter mixed layers (MLs) are overly deep, halocline layer is too thin (POP only), & upper-ocean stratification is too low relative to ITP-derived counterparts under an ITP track in EEB.
- Doming isopycnals associated with anticyclonic mesoscale eddies just below the ML likely transfer heat into the base of the mixed layer through mesoscale stirring with convection bringing heat into the vicinity of sea-ice.
- Basal melt & negative thermodynamic volume sea-ice tendencies are co-located with AW signatures in the EEB in winter, particularly in 2018. An over-supply of heat to the surface from mesoscale eddies could contribute to the low sea-ice thickness biases seen in the models in the EB.

ITP data: collected & made available by the Ice-Tethered Profiler Program (Toole et al., 2011; Krishfield et al., 2008) at WHOI (https://www.whoi.edu/itp).