A Tale of Two Models: Intercomparison of Bering Sea simulations from structured (ROMS) and unstructured (SCHISM) grid models

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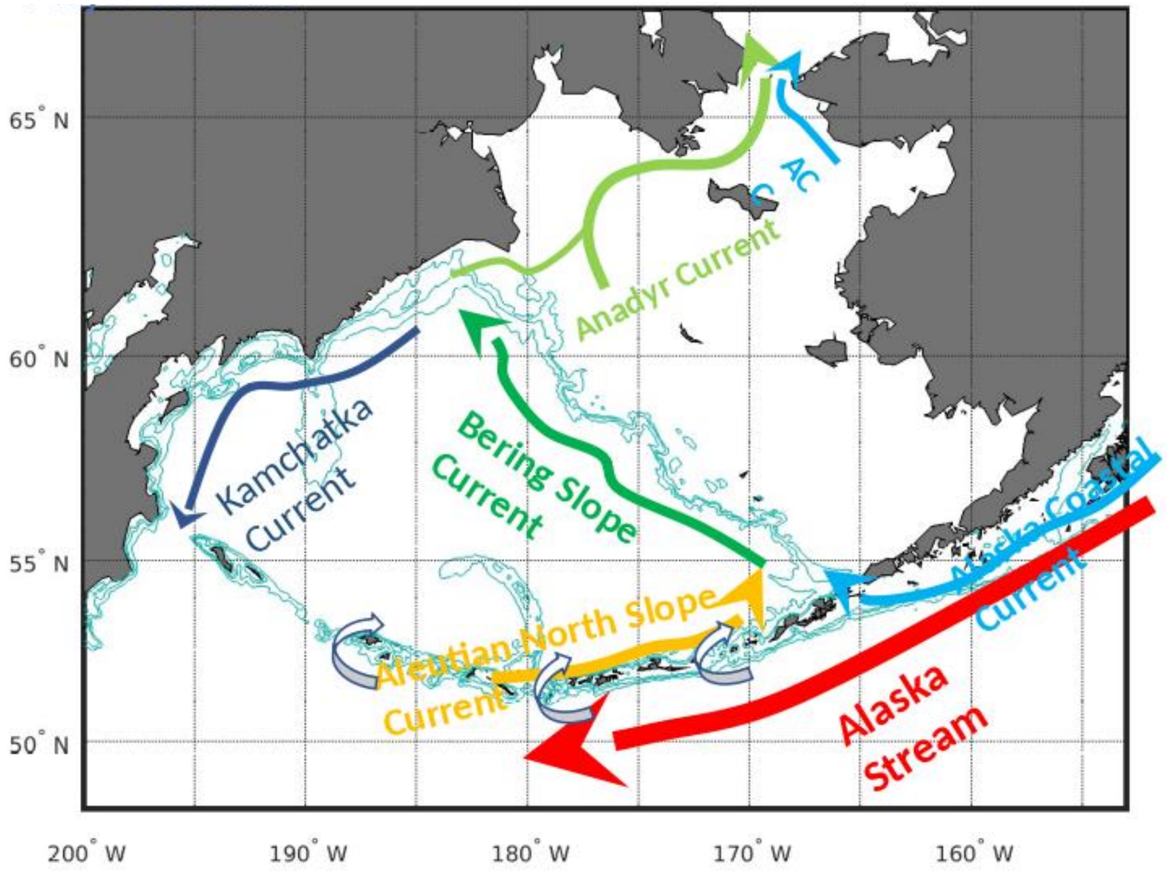
Why the intercomparison?

- We have an ‘established’ structured-grid model that performs well in the domain but has *potential* limitations regarding how much further it can be extended (tracer time step, vertical coordinate)
- Unstructured-mesh models have advantages for covering large areas while highly resolving regions of interest.
- Greater weight-of-evidence supporting the performance of the structured model for regional 3-dimensional baroclinic flows.
- Strong storm-surge/ inundation modeling performance of the unstructured grid model
- Disrupt the established numerical-modeling orthodoxy?
- Mandate from NOAA-CSDL – from navigation to storm surge in a 3-D hydrodynamic model

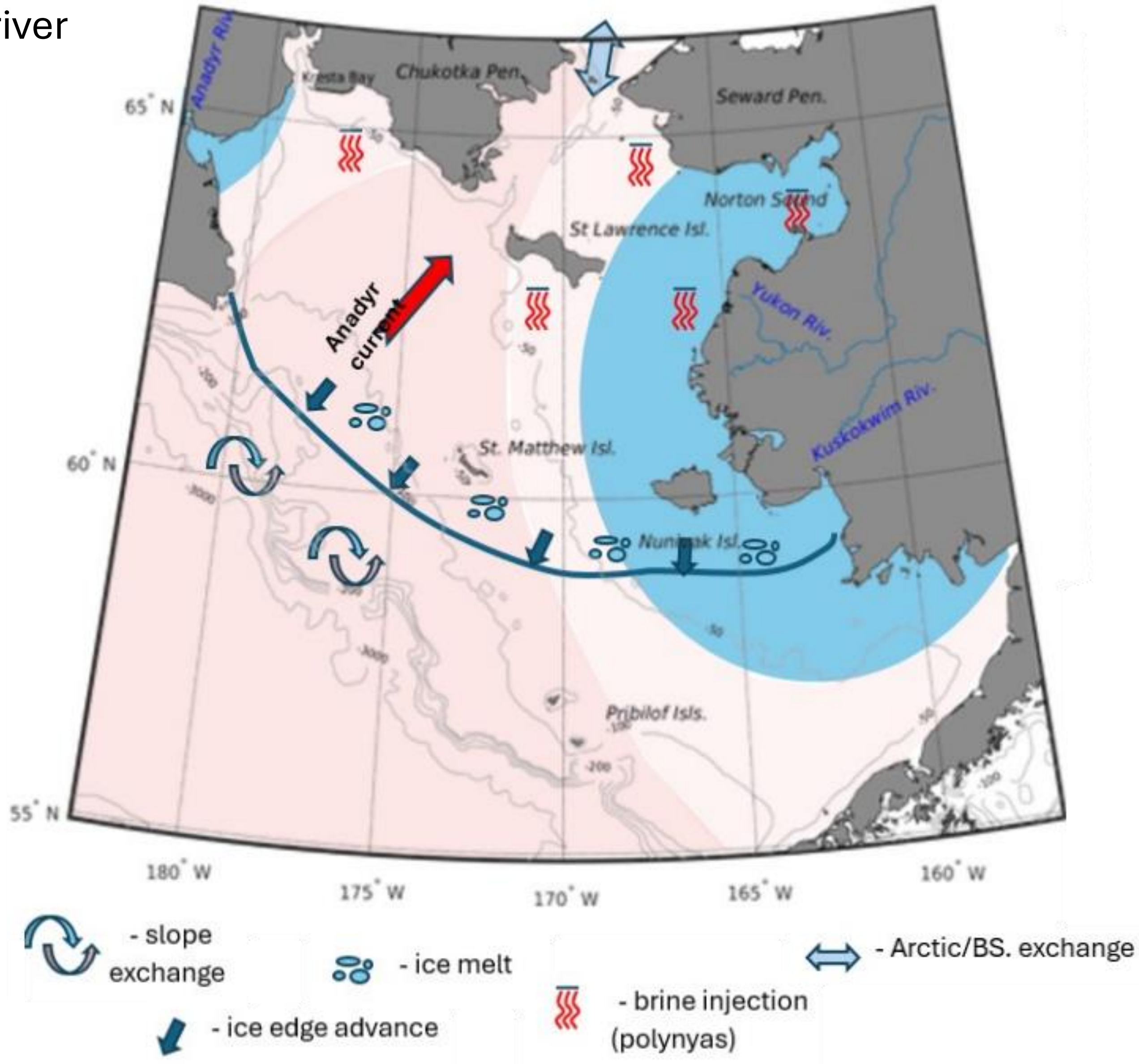
Basic characteristics of the Bering Sea

A broad eastern Bering Sea shelf characterized by extensive seasonal sea ice advance and retreat and large freshwater river fluxes

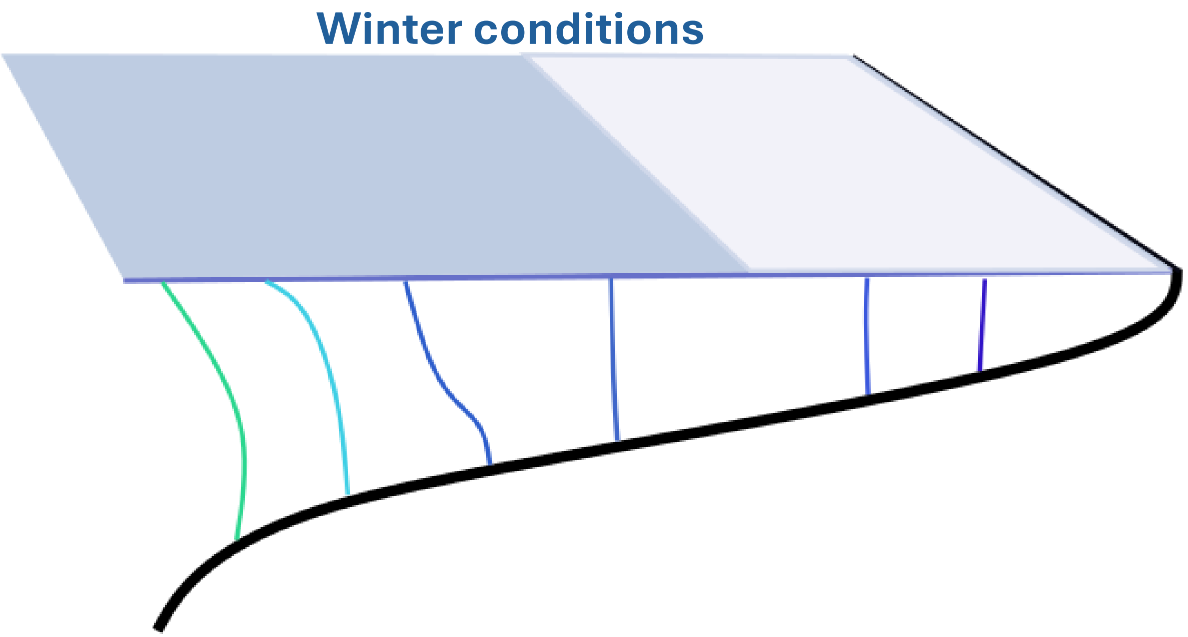
Major currents



Processes determining salinity variability on the Easter Bering Sea shelf

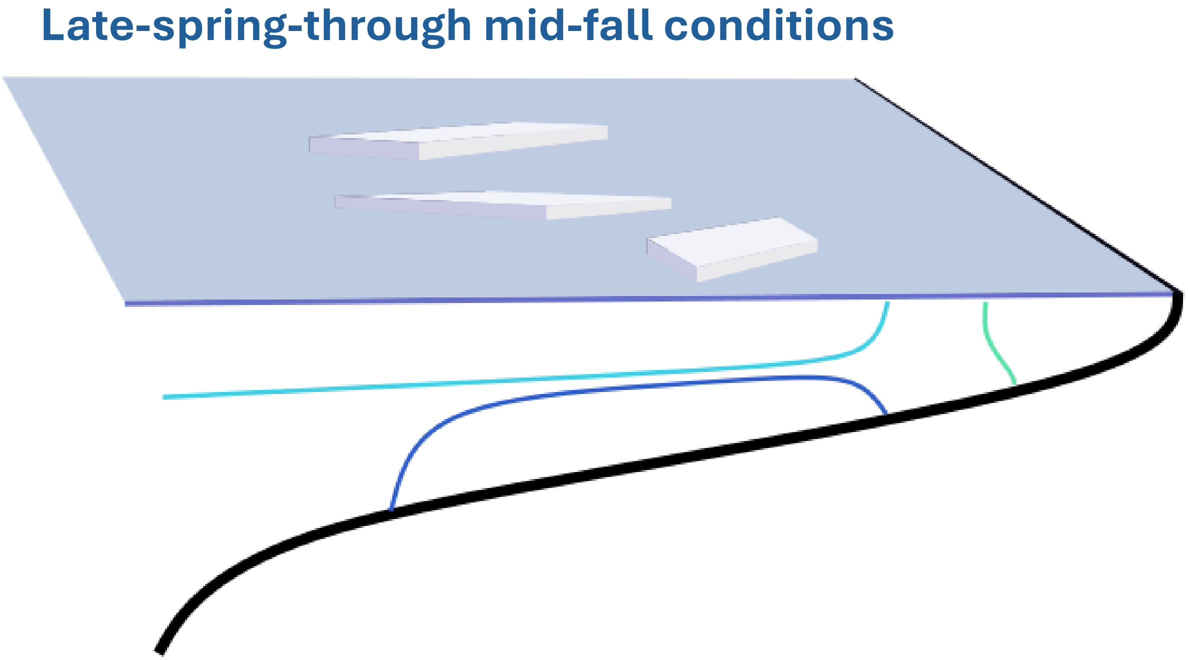


Evolution of the EBS cold pool



In the winter

- The ocean cools fastest near the coast,
- much of the mid-to-inner shelf becomes unstratified,
- sea ice coverage advances, from coastline offshore
- Ice advance falters where it meets warm and saline slope waters



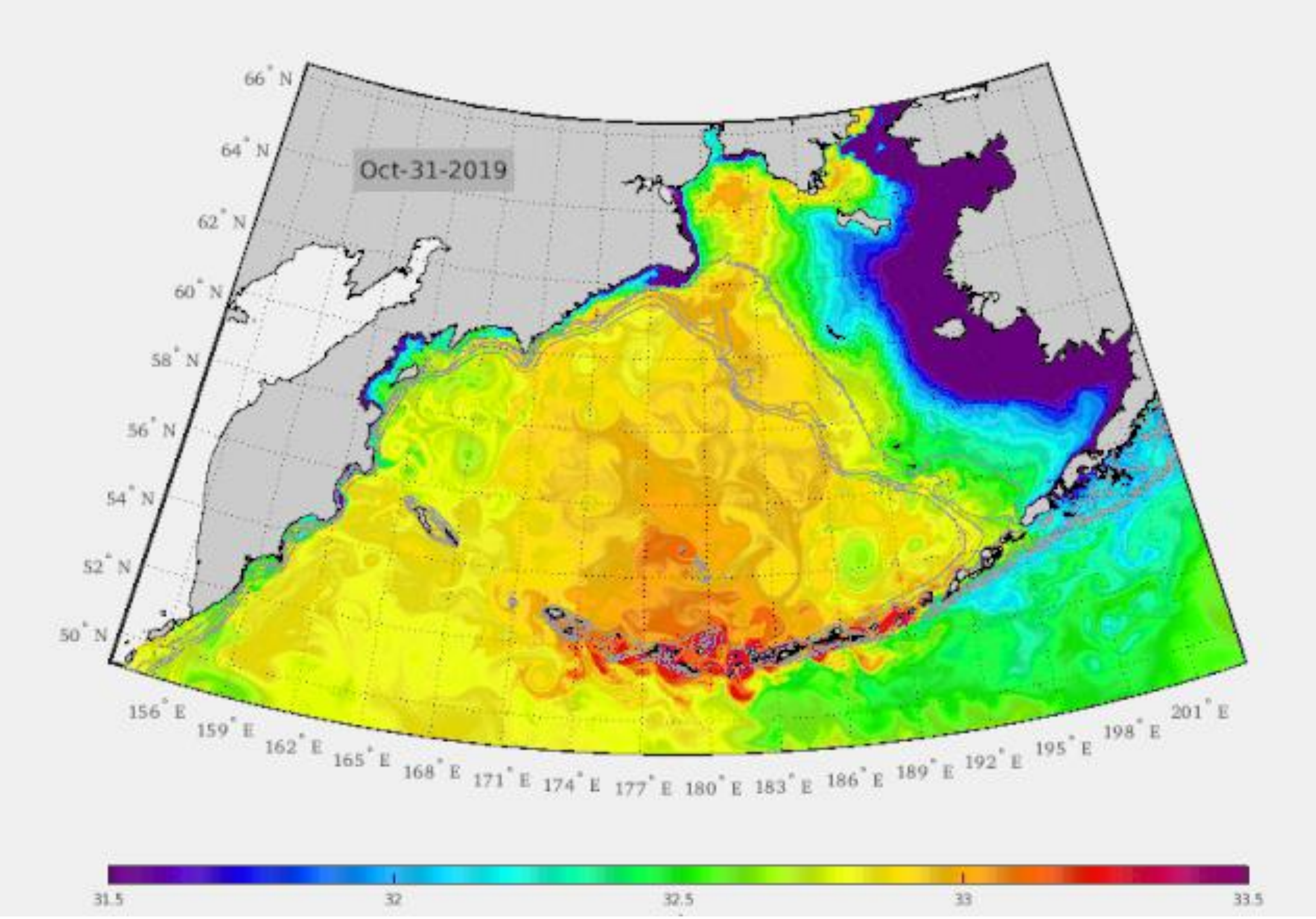
In the late spring

- Ocean warms earliest on the inner shelf,
- Strong tides generate well-mixed conditions shoreward of the -50m isobath
- Sea ice melt on the mid to outer shelf establishes a strongly stratified water column <u>*– in typical years*</u>
- Cold –relatively fresh cold pool water is trapped by well mixed conditions shoreward and warmer more saline slope waters

ROMS 2km-resolution Bering Sea coupled sea ice-ocean model

Model setup

- 3D hydrostatic s-coordinate model
- ~2km resolution, 45 vertical levels
- Forced with tides
- Atm forcing from 3-hourly ERA5 reanalysis
- River and coastal freshwater runoff from GLOFAS
- B.Cs from global HYCOM 9km resolution model
- Sea ice model embedded in ROMS (a modified version of the Hedstrom-Budgell model)
- Simulations run from July 2018 through July 2023 currently



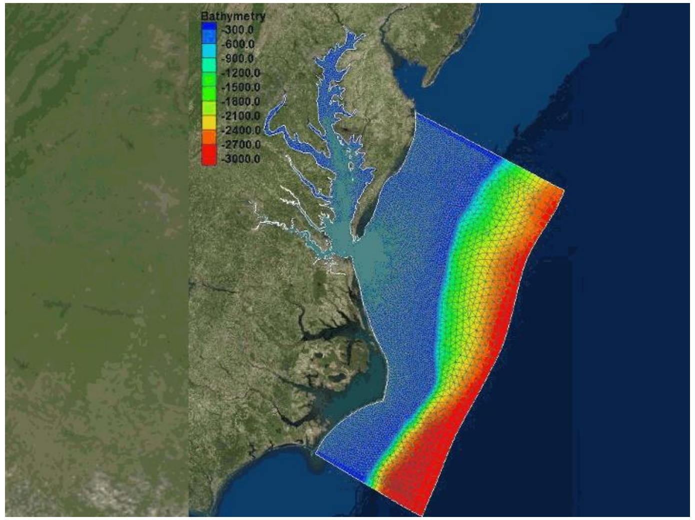
Model surface salinity with sea ice concentration (very low-ice winter)

SCHISM

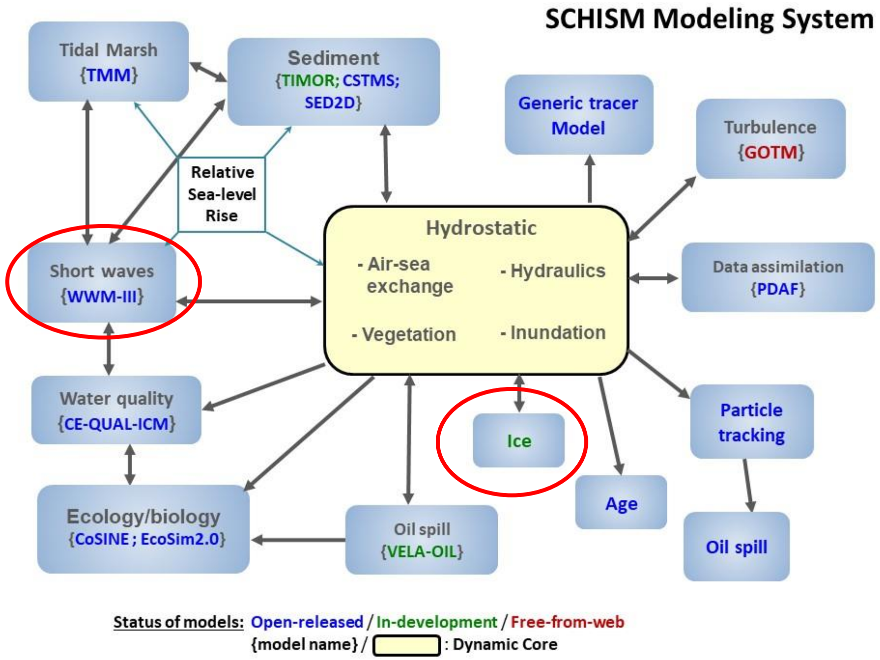
Major Characteristics of SCHISM

- Finite element/volume formulation
- Unstructured mixed triangular/quadrangular grid in the horizontal dimension
- Hybrid SZ coordinates or new LSC2 in the vertical dimension
- Semi-implicit time stepping (no mode splitting): no CFL stability constraints → numerical efficiency
- Higher-order Eulerian-Lagrangian treatment of momentum advection (with ELAD filter)
- Natural treatment of wetting and drying suitable for inundation studies
- Mass conservative, monotone, higher-order transport solver: TVD2; WENO

NOAA project objective – couple SCHISM, CICE and WW3 using NUOPC (an extension/abstraction of ESMF) to continue to build-out the UFS



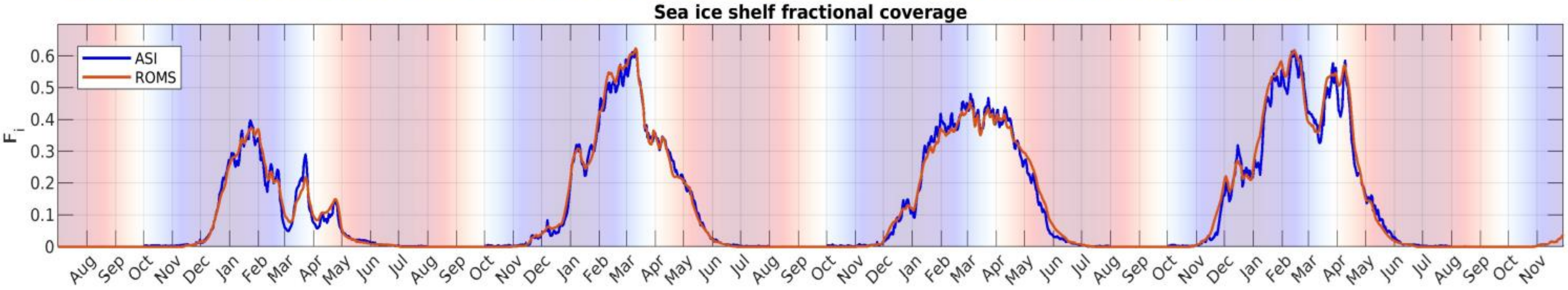
Chesapeake Bay grid animation by Laura Patrick



Demonstrations of ROMS model performance

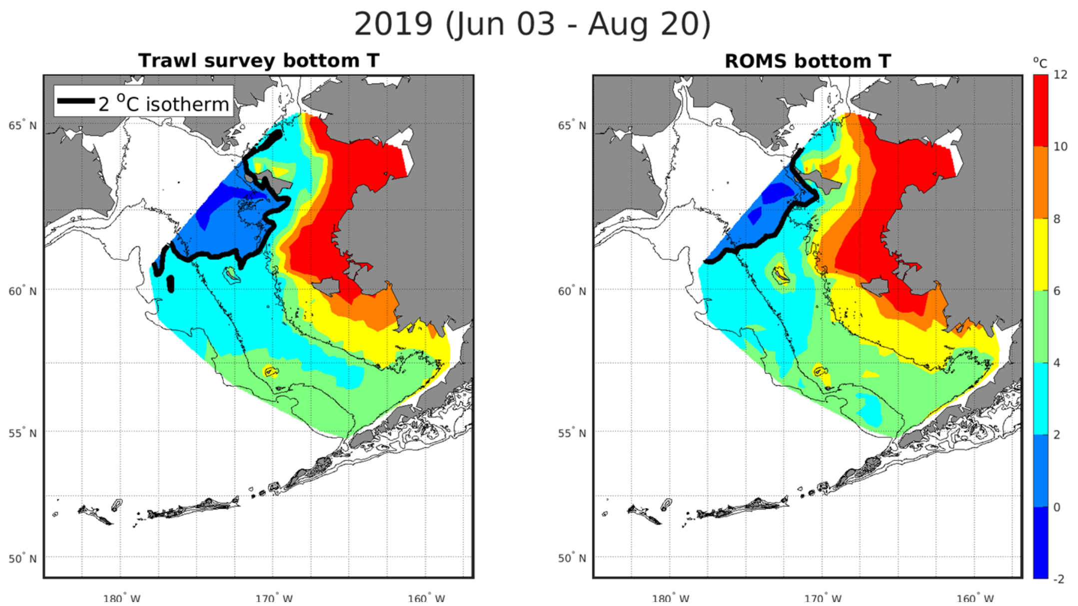
Coupled sea ice - ocean ROMS Bering Sea model captures the variability in ice concentration on the Bering Sea shelf from event to interannual time scales well.

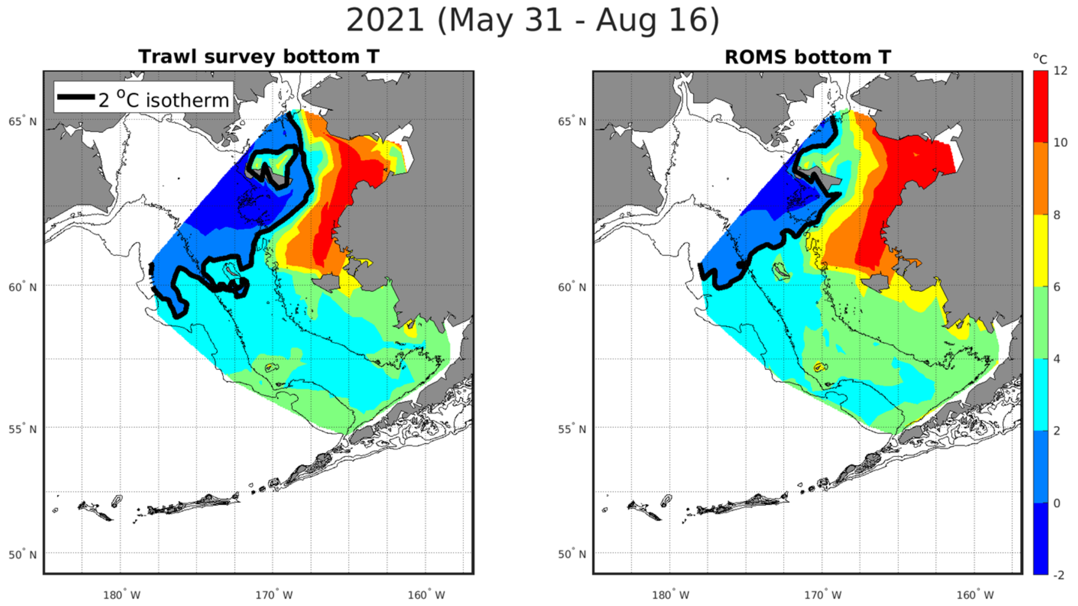
Comparison of model with ASMR-2 estimate of sea ice concentration on the eastern Bering Sea shelf



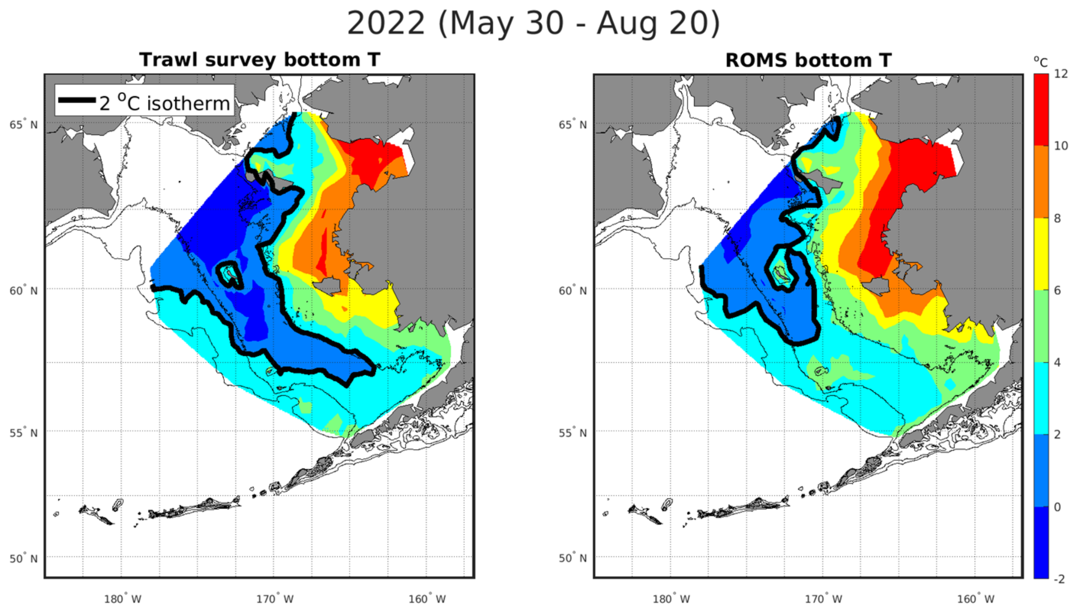
2018 2019 2020 2021 2022

ROMS/Bottom trawl survey comparison - Temperature



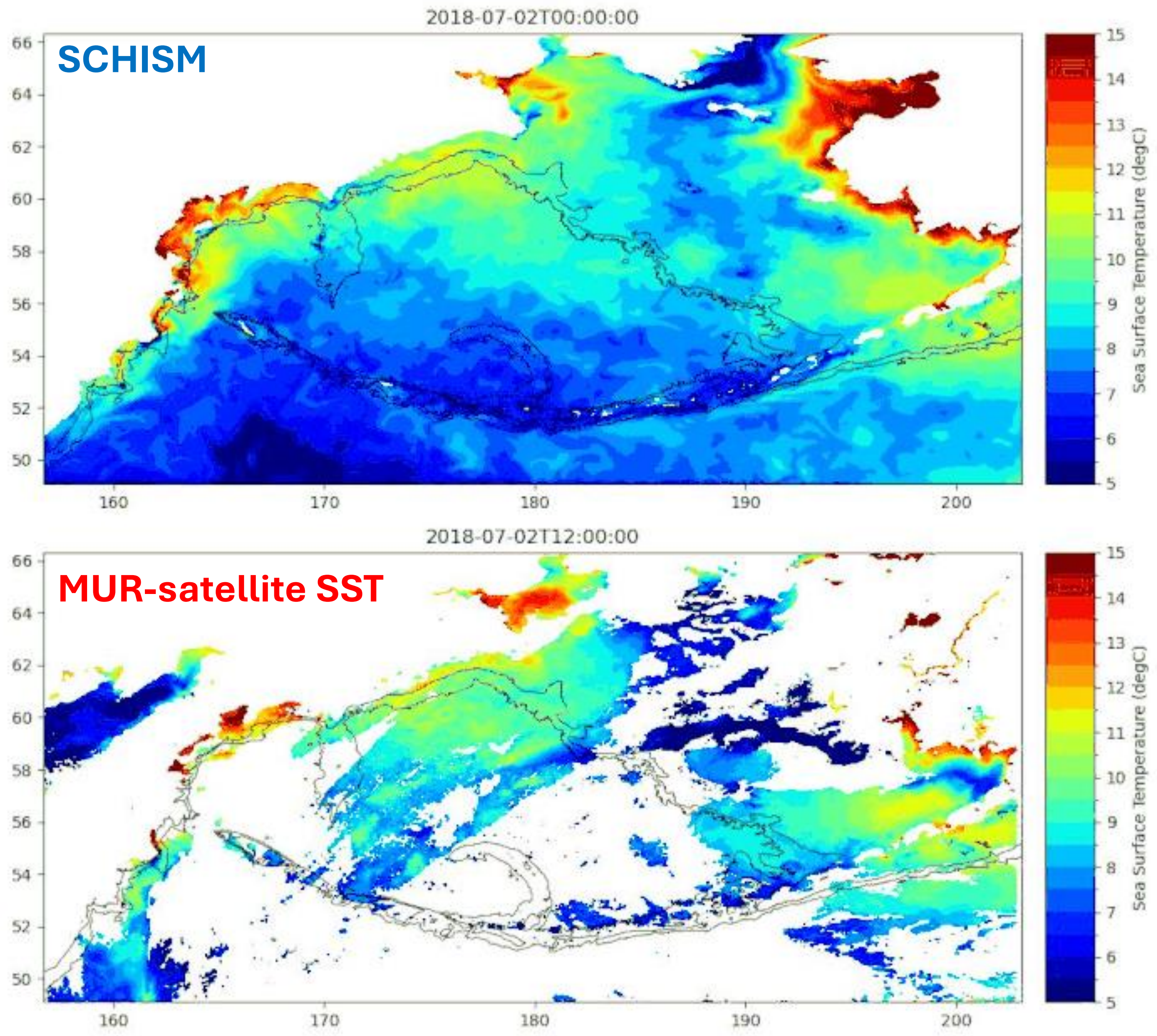


Based on comparison with bottom trawl surveys, ROMS captures interannual variability in the summer cold pool extent (as well as SST – *not pictured*)



SCHISM initial experiments demonstrate summer-fall evolution of SST

A detailed intercomparison with ROMS and observational datasets awaits further coupled modeling framework development



Extreme event in the Bering Sea - Typhoon Merbok

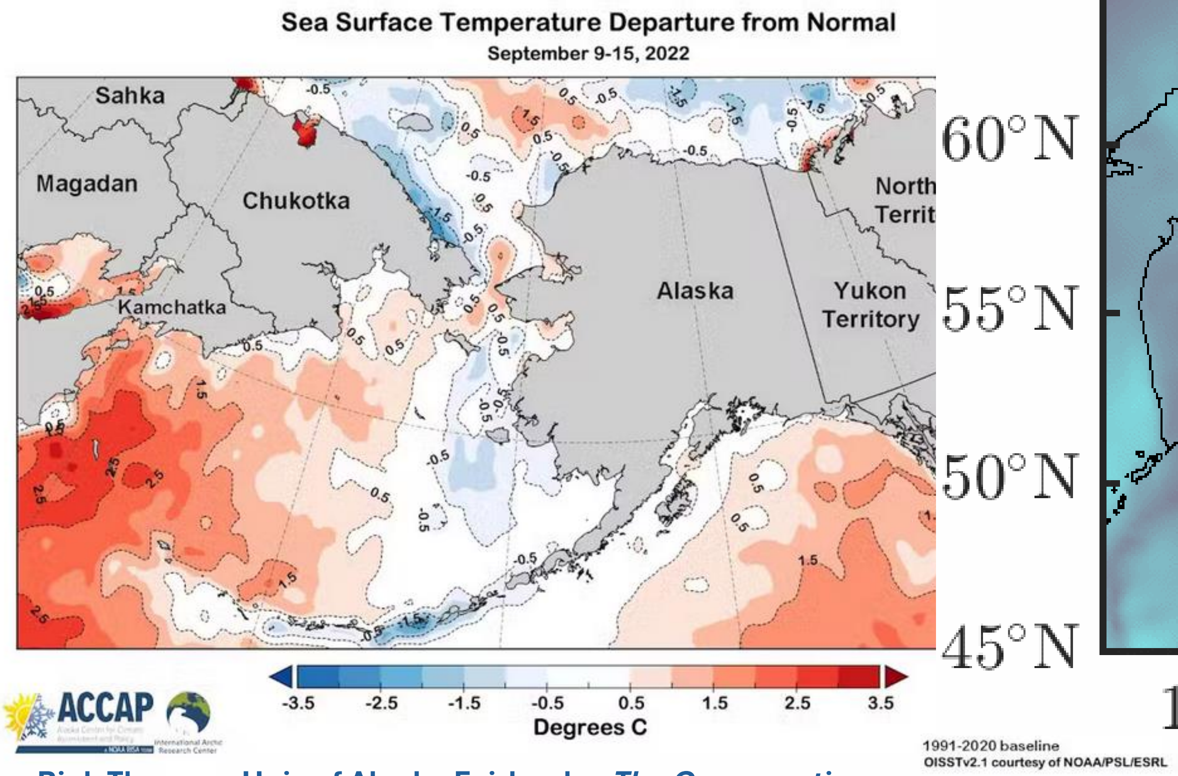
A rare occurrence happened in mid-September 2022. The remnants of a typhoon battered communities along the Bering Sea coast.

Photo by Chris Koonooka

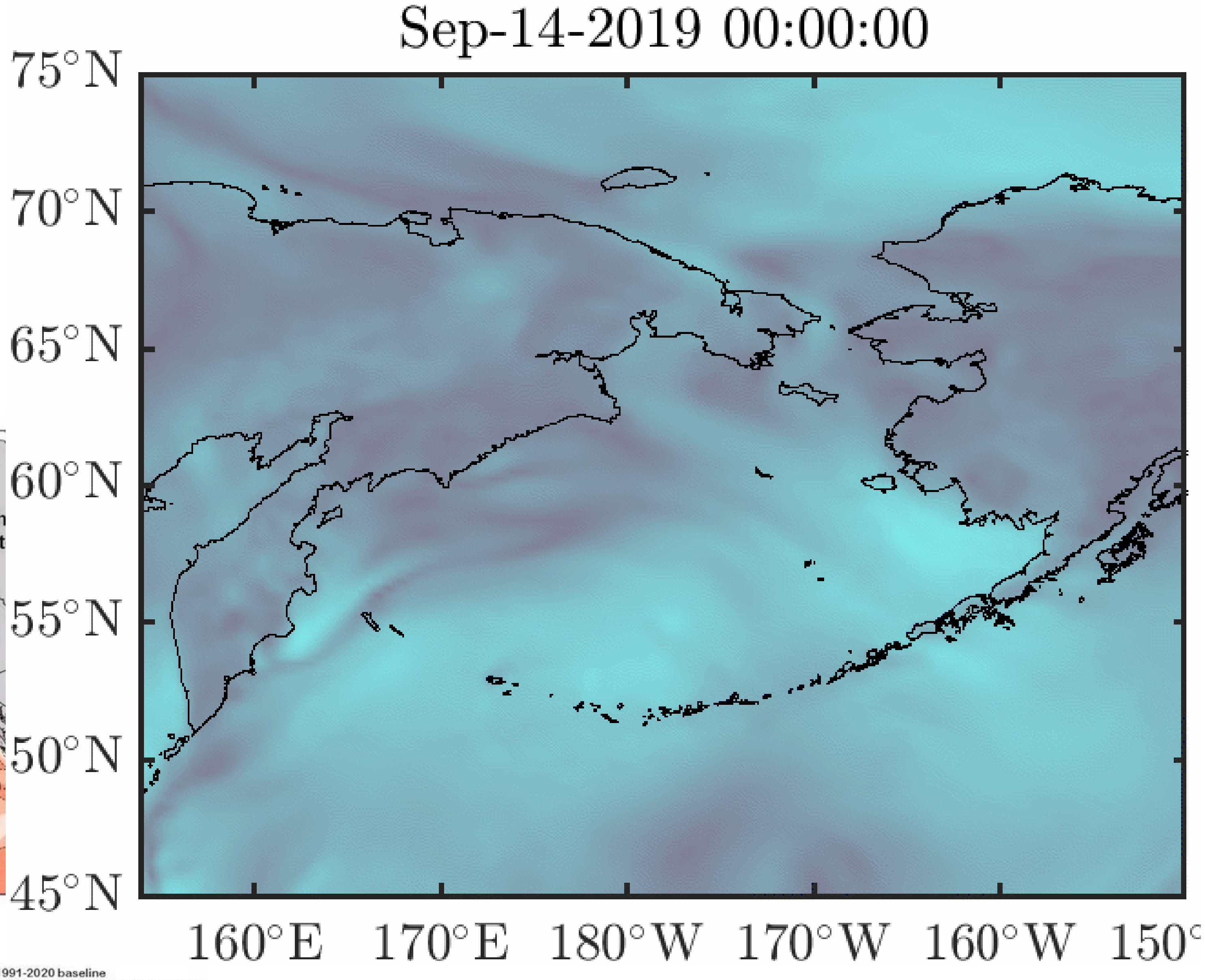
GAMBELL— Huge waves created by the ex-typhoon Merbok crashed onto West Beach near Gambell.

Test case: Typhoon Merbok

Fed by uncharacteristically warm waters in the North Pacific east of Japan, and in the Western Bering Sea. Merbok arrived on the Bering Sea shelf with 60mph+ winds typically observed only later in the fall season

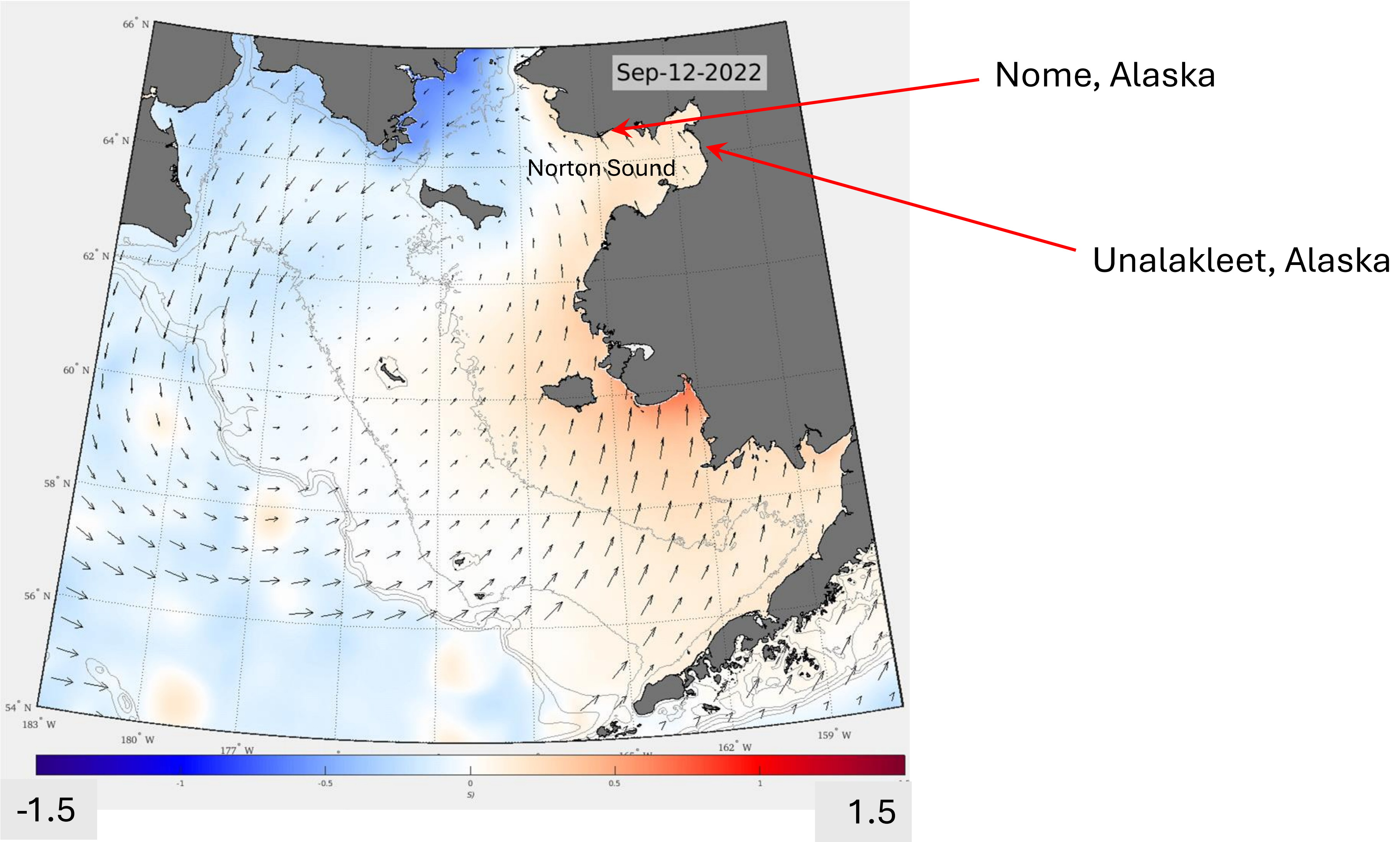


Rick Thoman, Univ of Alaska Fairbanks, *The Conversation*



Sea surface height evolution from Merbok – from ROMS simulation

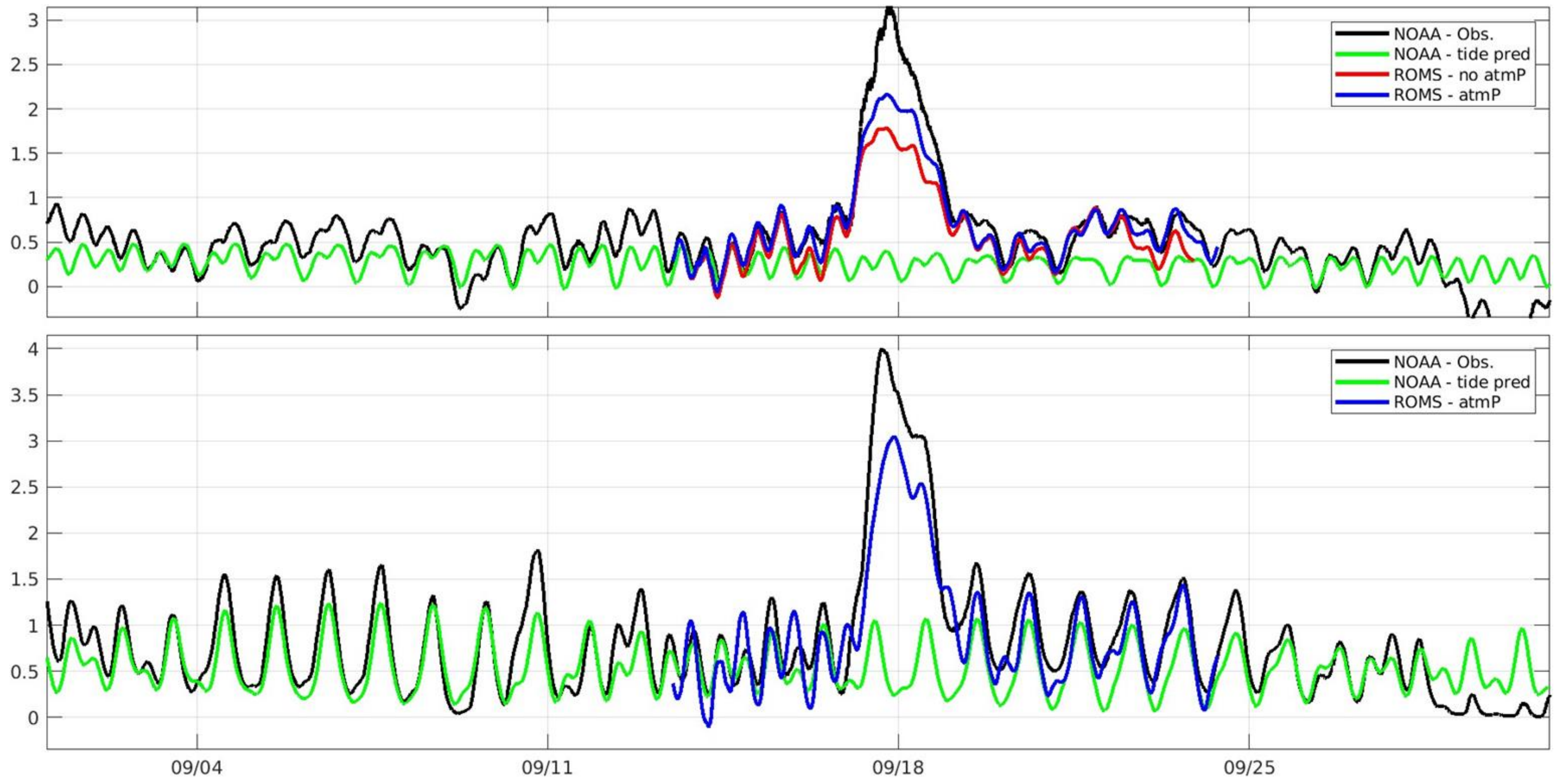
The passage of the storm is rapid, impacting Norton Sound with anomalously high SSH and the Gulf of Anadyr with anomalously low.



Daily average sea surface height with overlaid ocean surface stress vectors

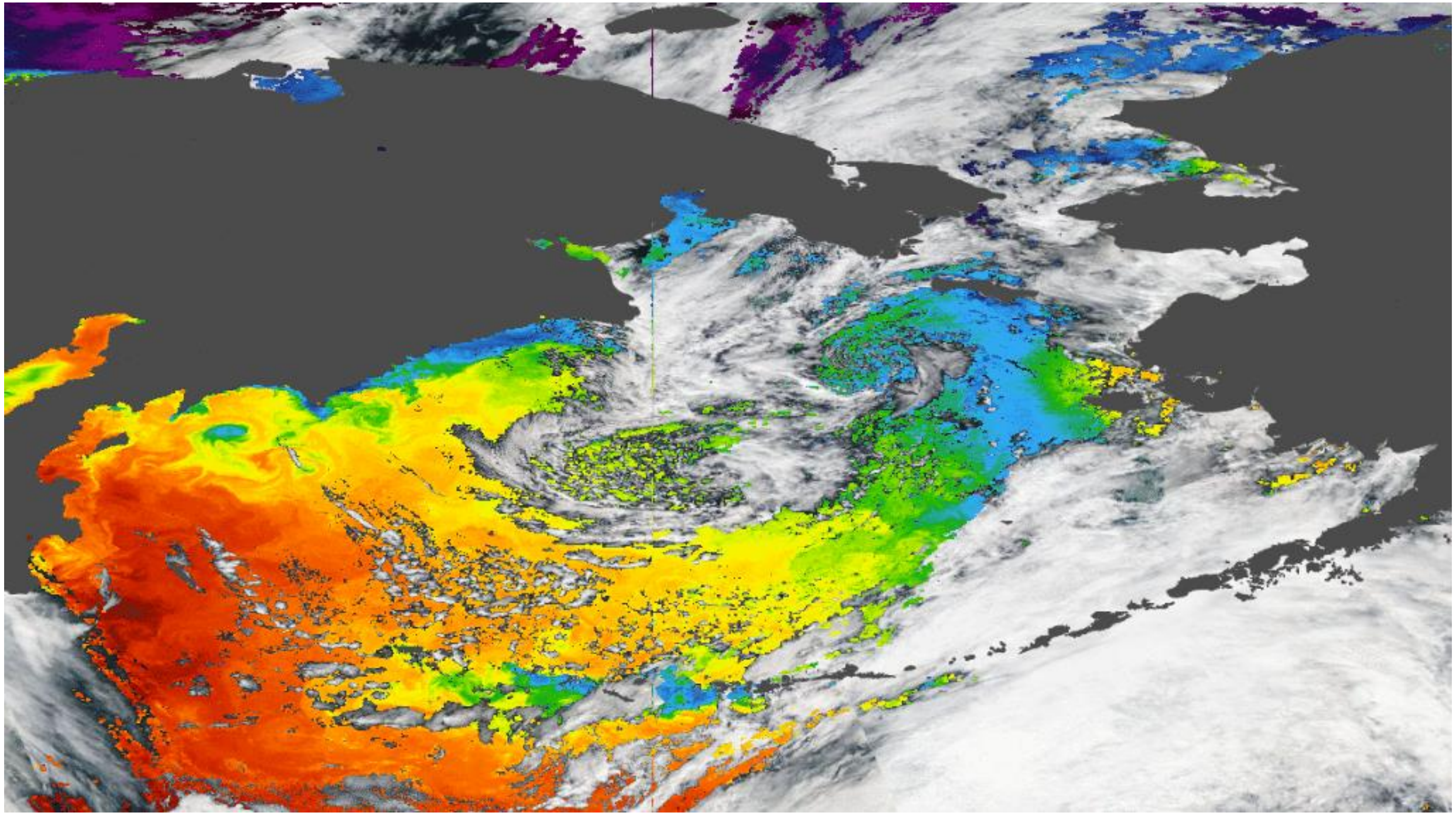
Sea surface height from coastal sea level gauges and ROMS simulations

- ROMS underestimates magnitude of coastal sea level rise from Merbok.
- Including atmospheric pressure effect improves estimate at Nome by about +40 cm.



What is the impact of Merbok on the Bering Sea Shelf?

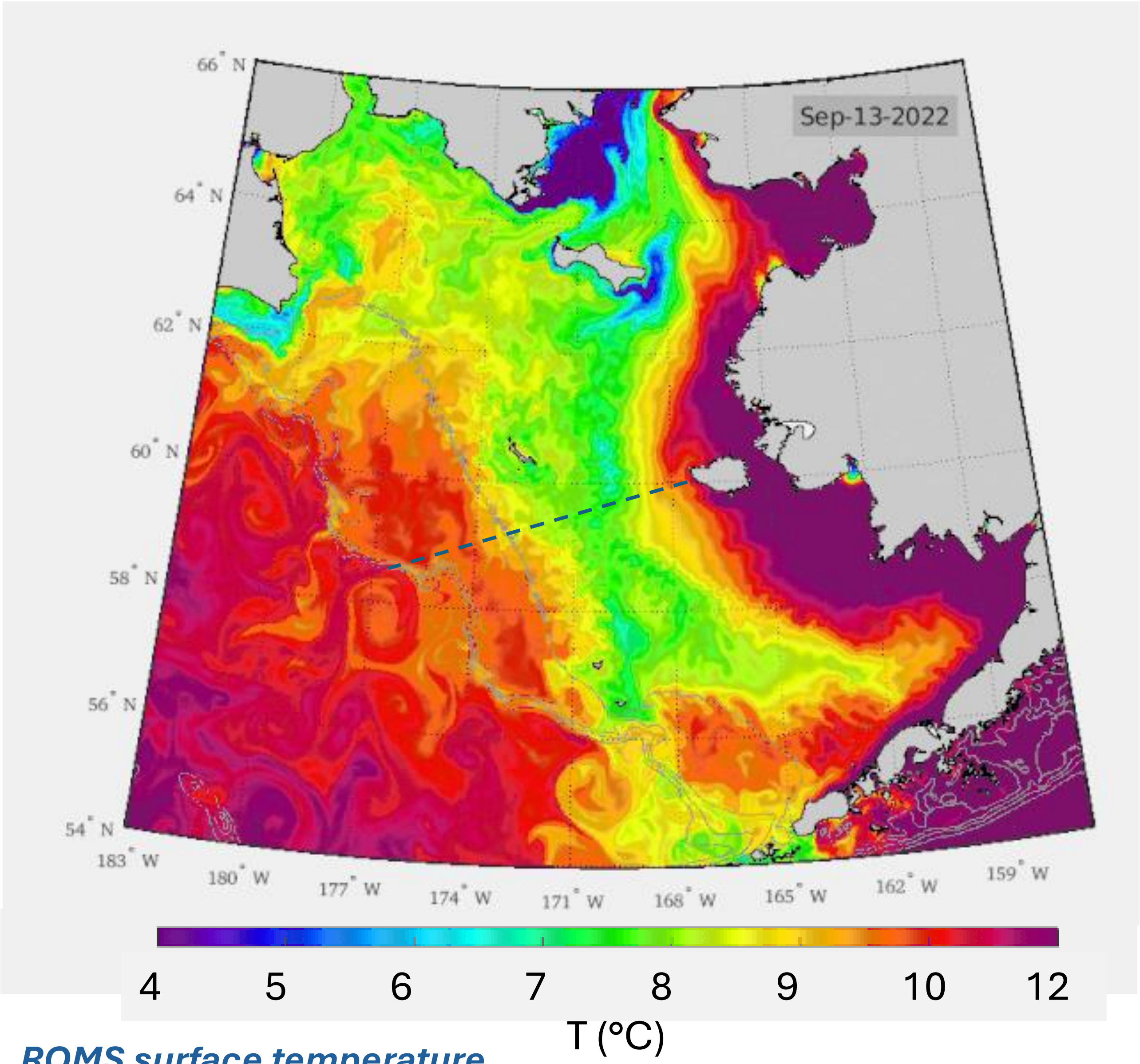
Satellite SST suggests about a 3^0 drop in ocean surface temperature over the mid-shelf in the EBS.



L2 Aquaa/MODIS Sea surface temperature on September 7th , 17th and 20th 2022.

ROMS modeled sea surface temperature during the passage of the storm

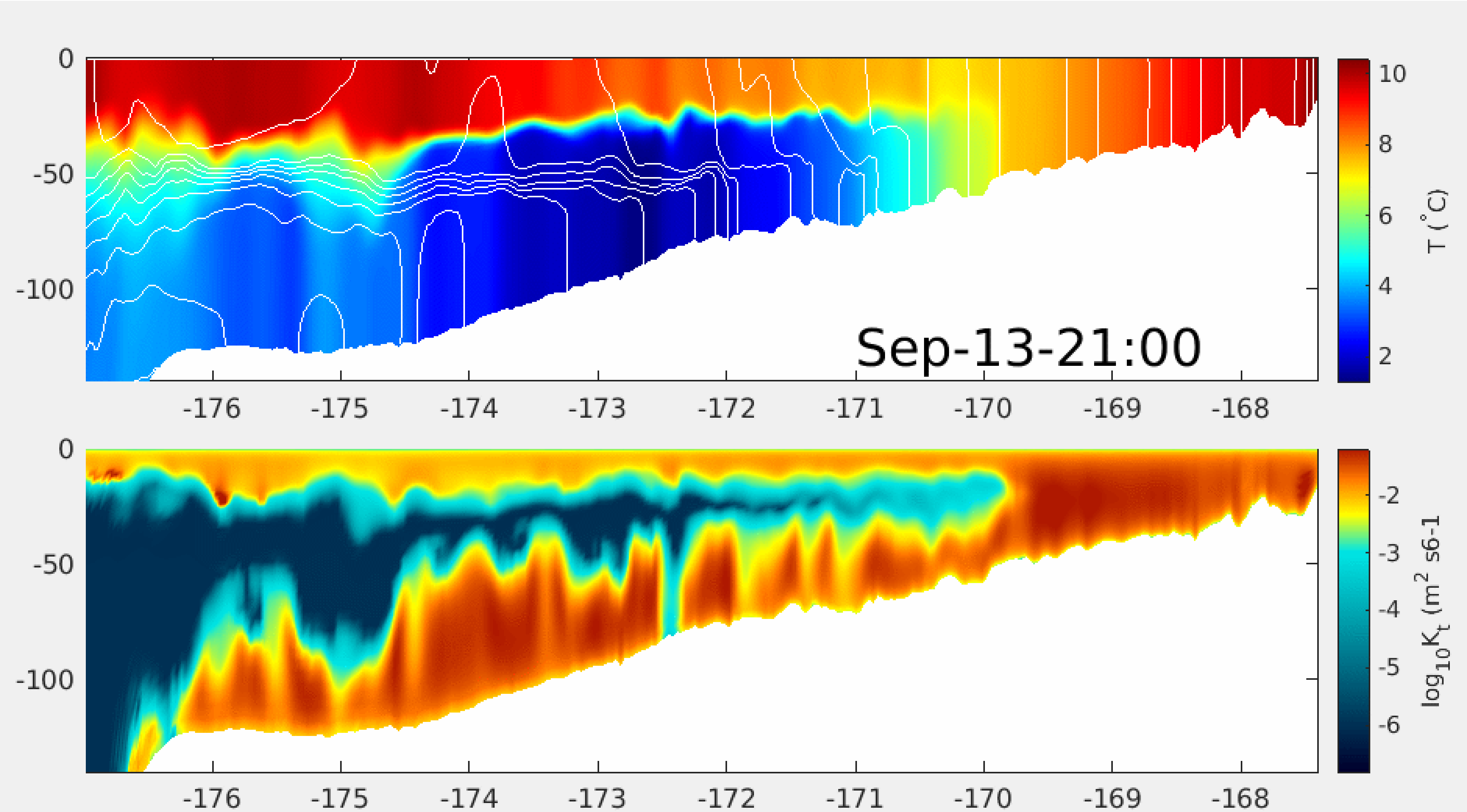
Strong wind mixing cools the ocean surface along the path of highest surface stresses, partially ventilating the cold pool and significantly deepening the mixed layer in the Bering Sea basin.
Approximately 100 km^2 of shelf sea surface drop below 6º C.



ROMS surface temperature

Section-view of partial ventilation of the cold pool

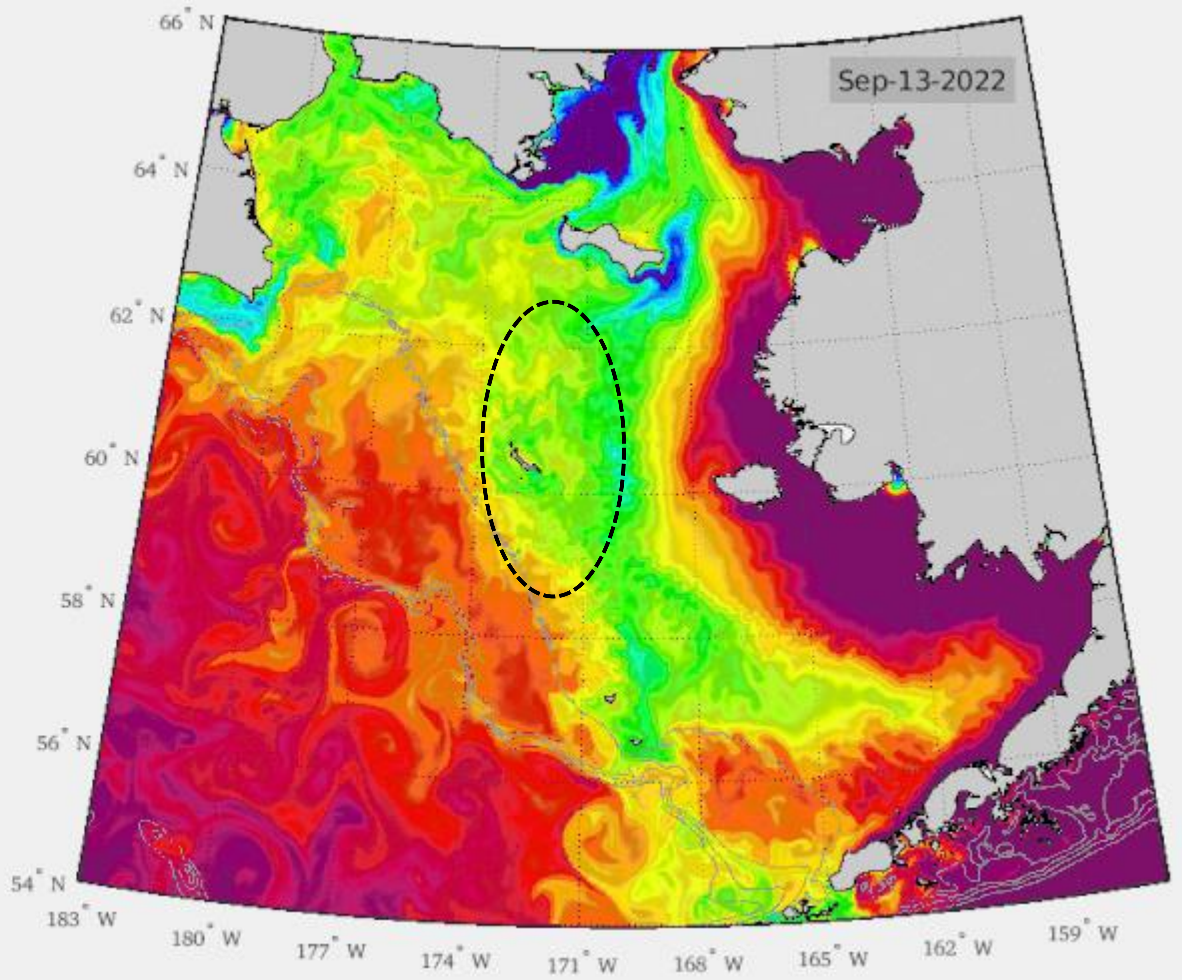
Cold pool volume is diminished as surface and bottom boundary layers interact on the mid shelf.



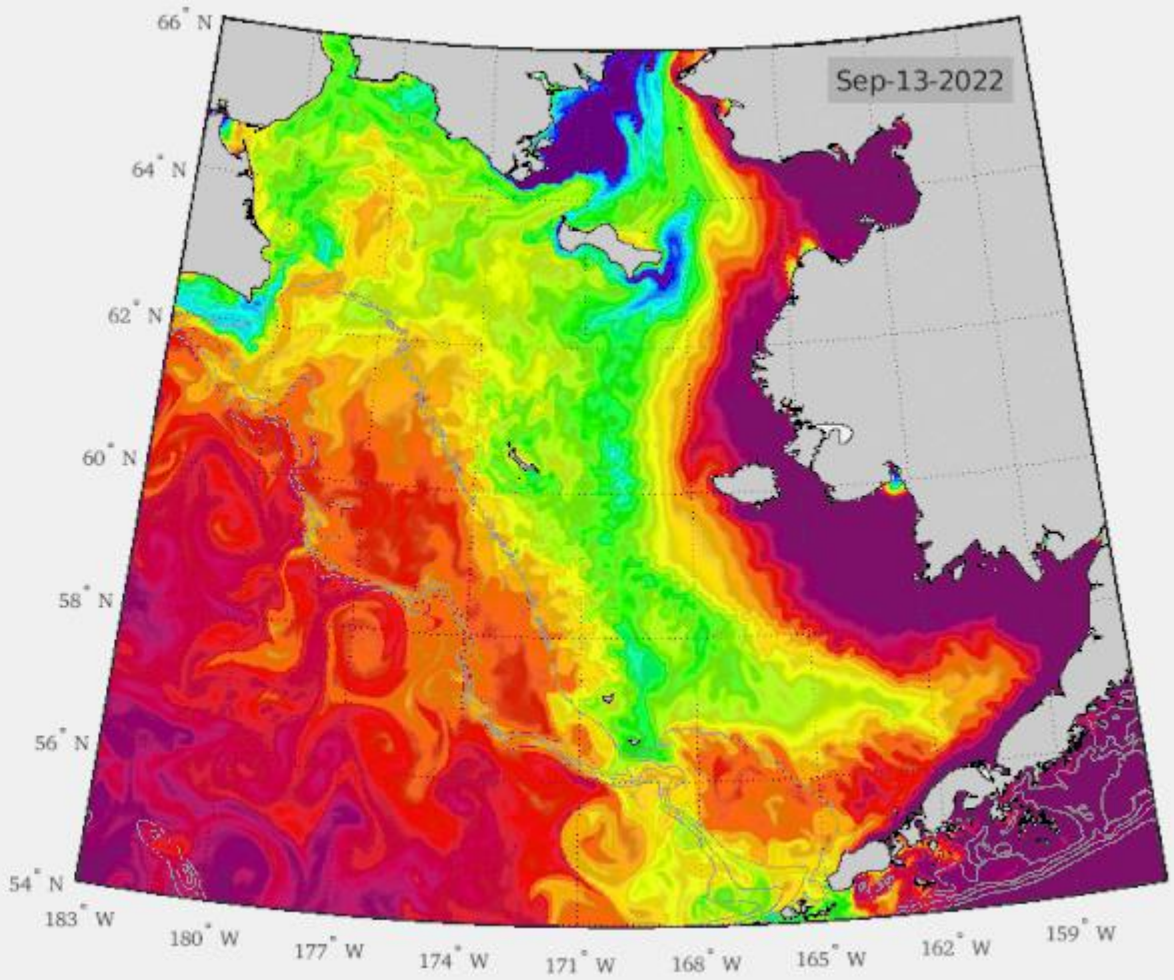
ROMS temperature (with density contour lines in white) and $log_{10}(K_T)$ along a section extending across the shelf from Nunivak island

What if …?

To gain insight into how long the storm impacts shelf stratification we can run a simulation identical to the original but with winds due to Merbok reduced 50% during its 3 day passage.



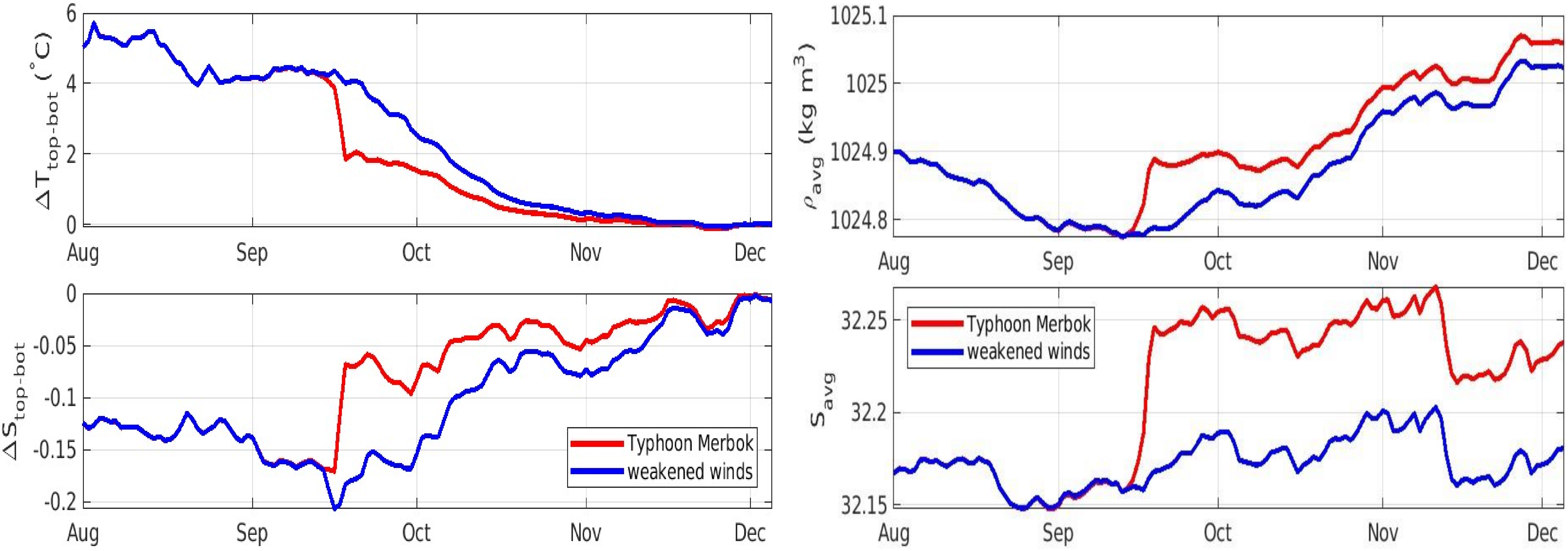
Modeled SST original ERA5 winds



Modeled SST reduced magnitude ERA5 winds

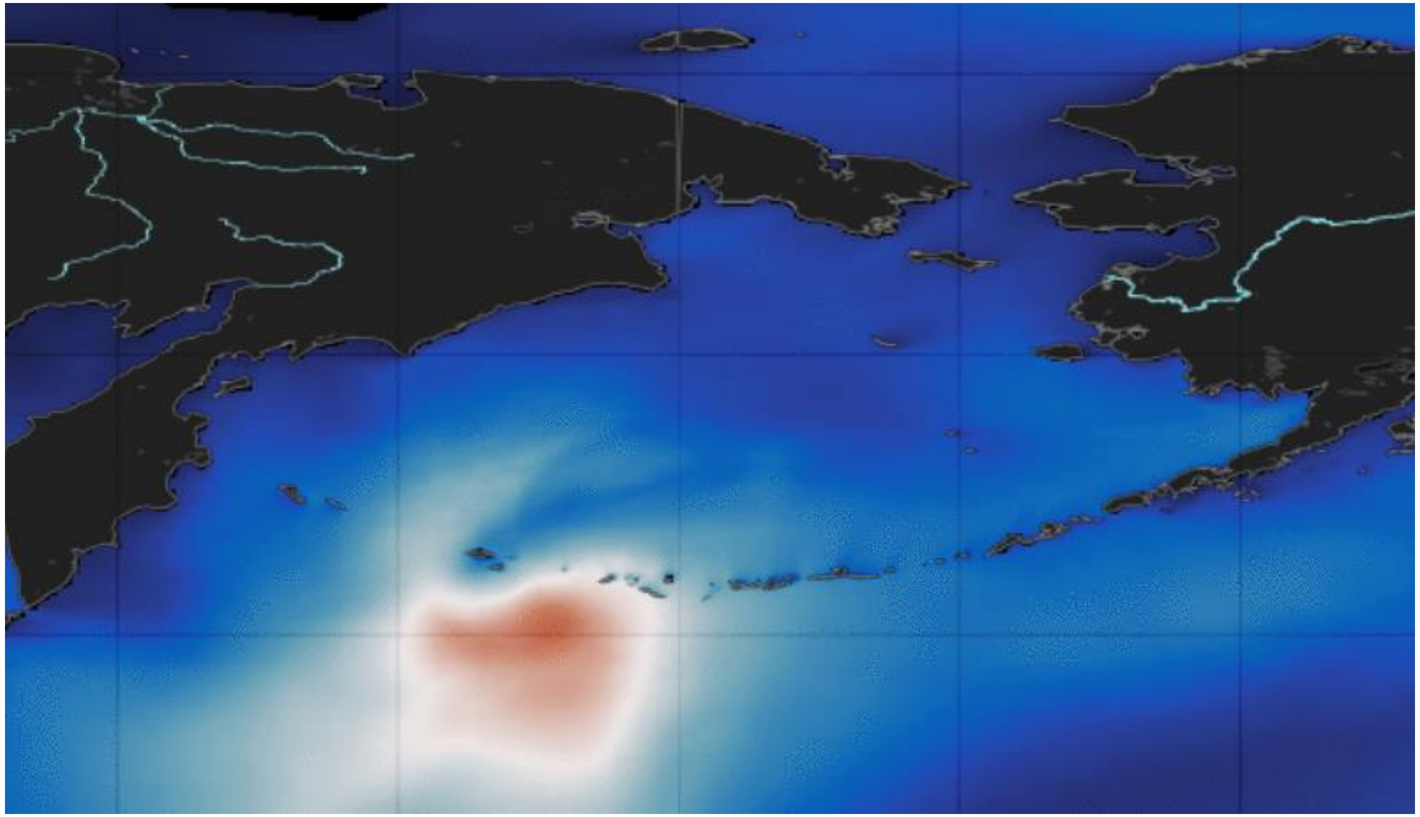
Shelf characteristics in region of partial ventilation of the cold pool

- Autumn wind mixing and atmospheric cooling erase the stratification gradually in the fall in the mid shelf region. Merbok accelerated this decrease by about 3 weeks. But by late fall freeze-up temperatures on the midshelf would have been similar with or without the storm.
- The mid shelf region remains slightly denser and saltier (in the depth average) into December 2022.



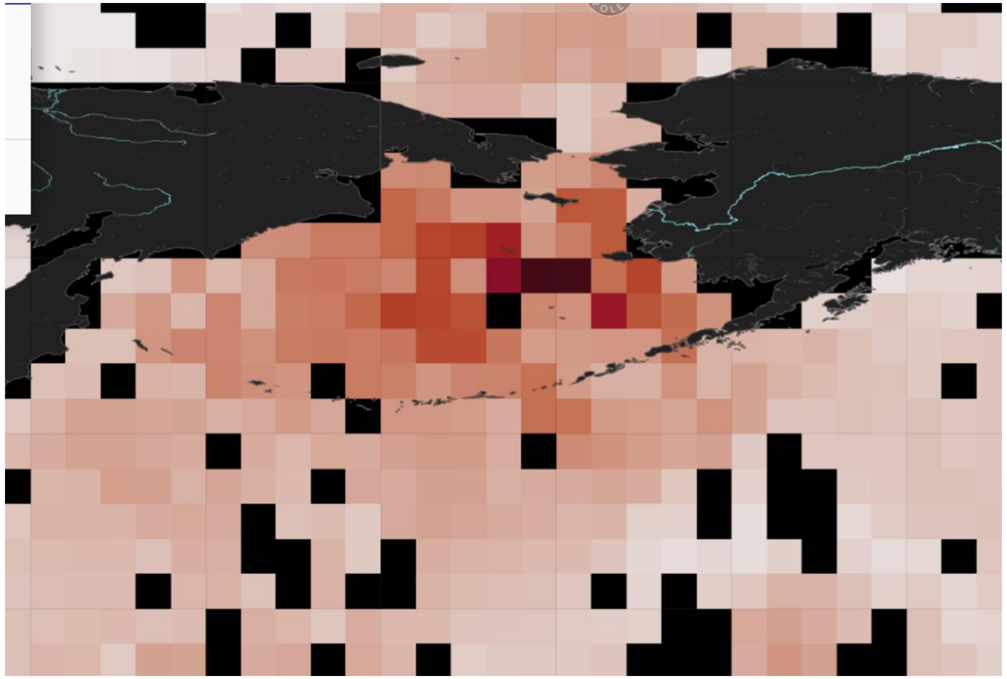
Is the model still underestimating mixing?

Analysis and measured significant wave height in the Bering Sea during the passage of Merbok show waves as large as 50m on the mid- to outer- shelf.



Significant wave height from analysis

Significant wave height from satellite altimetry



Conclusions

- The 2k- ROMS Bering Sea model captures many shelf and basin processes well, but may underestimate storm surge and neglect significant wave mixing during certain events
- Model intercomparison in the Bering Sea continues as test cases emerge that challenge the models in multiple ways
- Development of a SCHISM model for the Bering Sea as part of NOAA's STOFS system continues as steps towards CICE- and WW3- SCHISM coupling are underway
- Strong early autumn storms can ventilate the eastern Bering Sea cold pool weeks earlier than is usual, with undetermined impacts to the shelf ecosystem.