Theme B: Vertical and Alongshore Connectivity as Drivers of Ecological Change on Local to Regional Scales.

Carlos Moffat & PAL LTER Team.

PAL Mid-Term Review

Boulder, CO

October 28-30, 2024

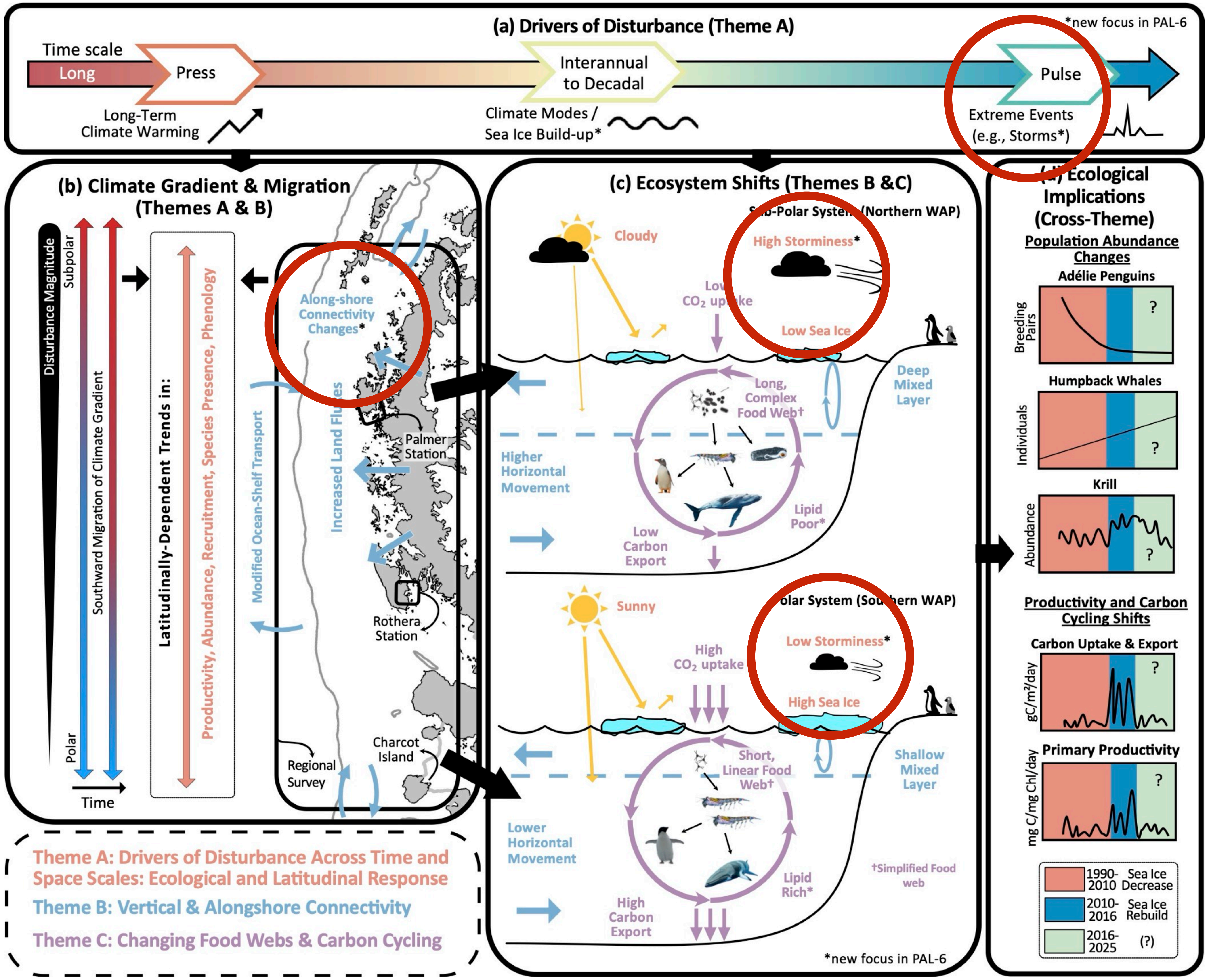
Funded by:
NSF-OPP #2224611 and previous PAL grants

Image: NASA Earth Observatory

Theme B on the PAL Conceptual Diagram

Overarching question of Theme B: How do vertical and alongshore transport and mixing dynamics along the WAP interact to modulate the distribution and variability of marine productivity, krill, and krill predators?

Sub-theme B2: Along-Shore Variability and Connectivity.

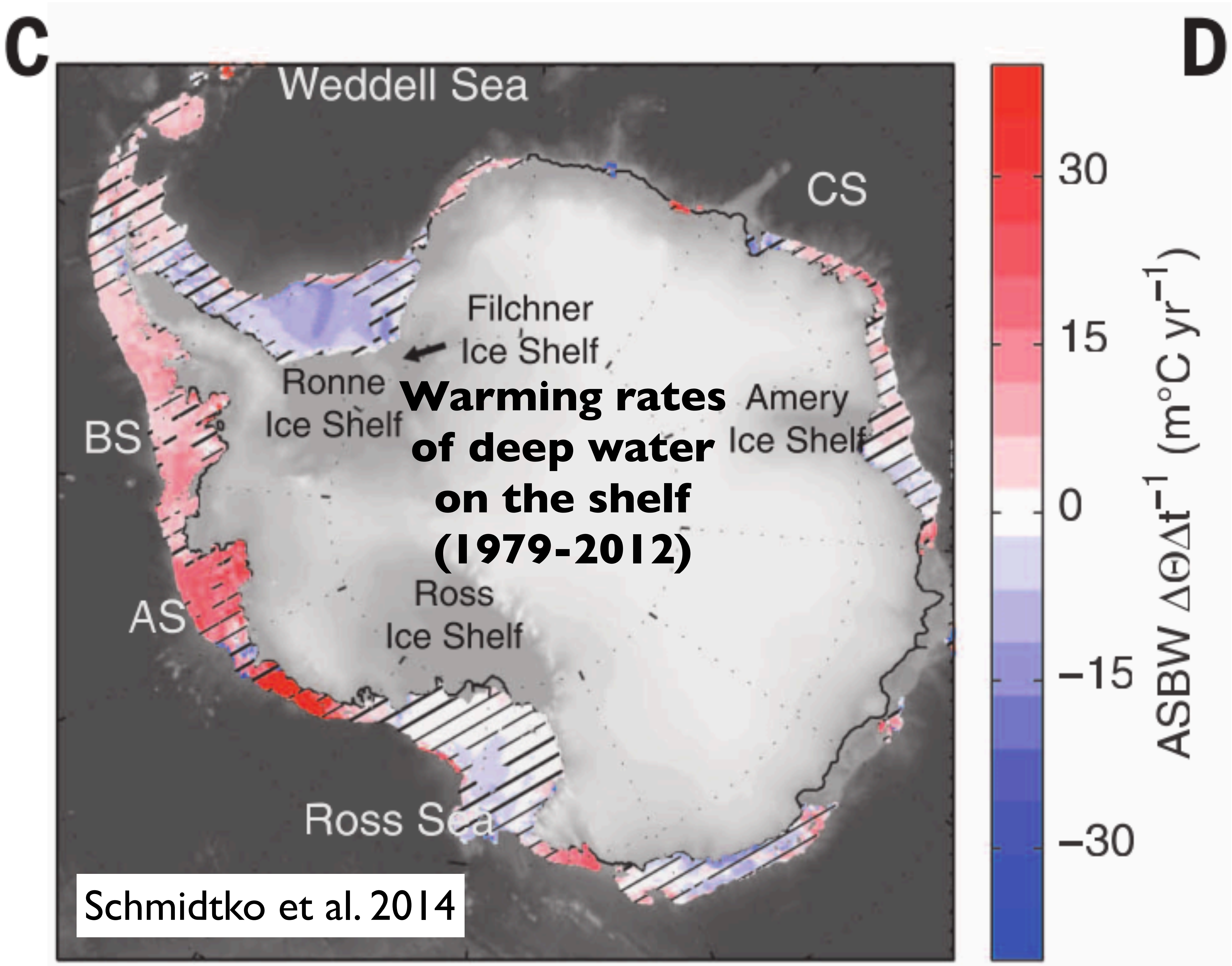


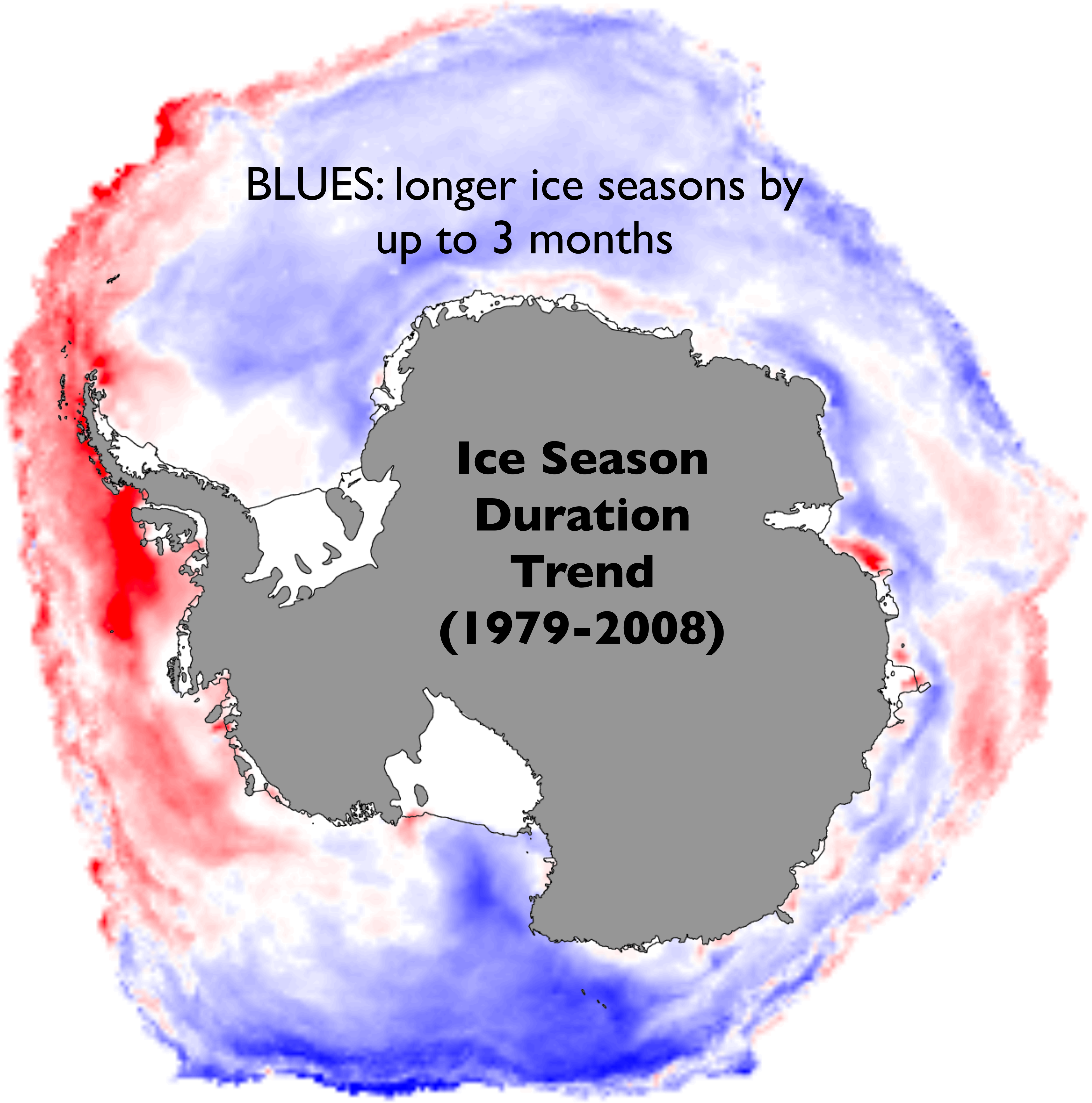
Sub-theme B1: Shifts in Upper Ocean Dynamics and Links to System Productivity.

Sub-theme B3: Response of Krill and Predators to Vertical and Alongshore Changes Driven by Storms

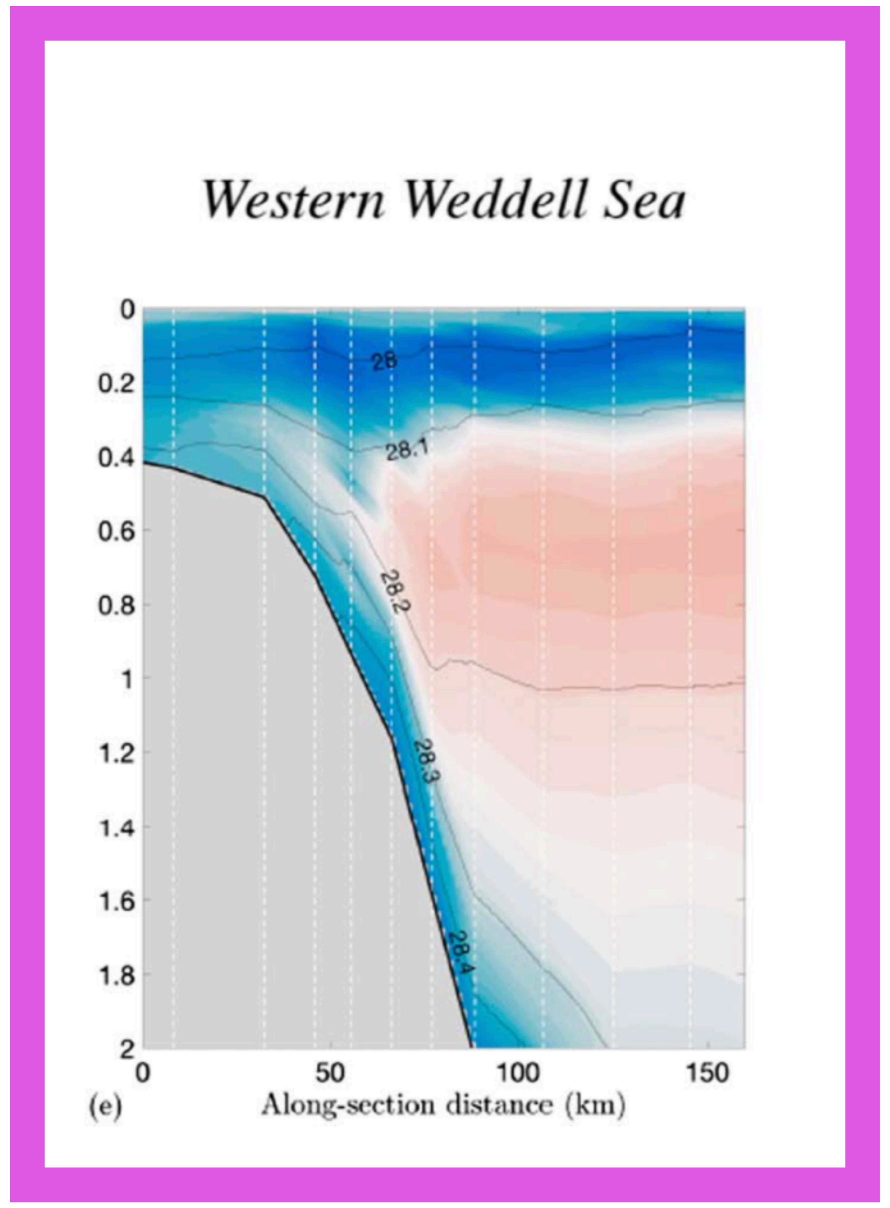
Sub-theme B2: Along-Shore Variability and Connectivity

Antarctic dynamics and long-term change are characterized by strong regional variability

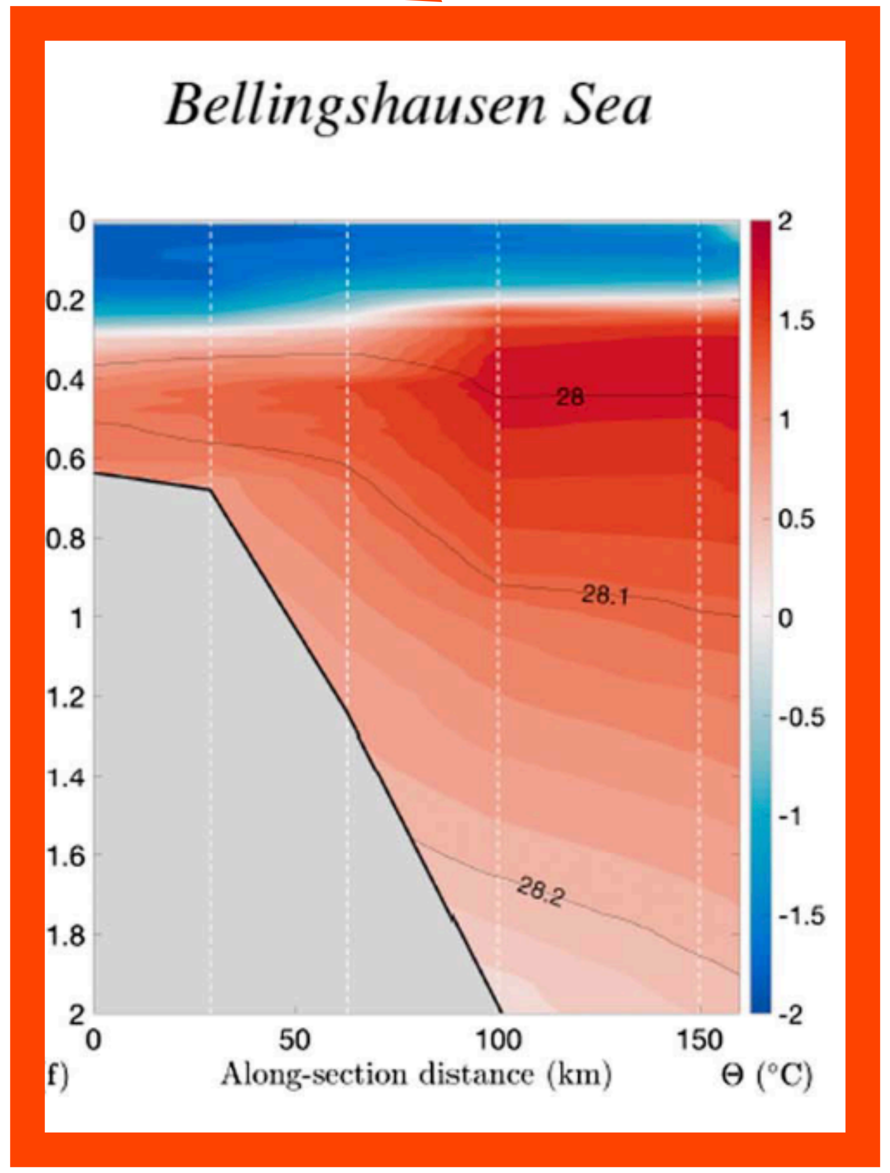


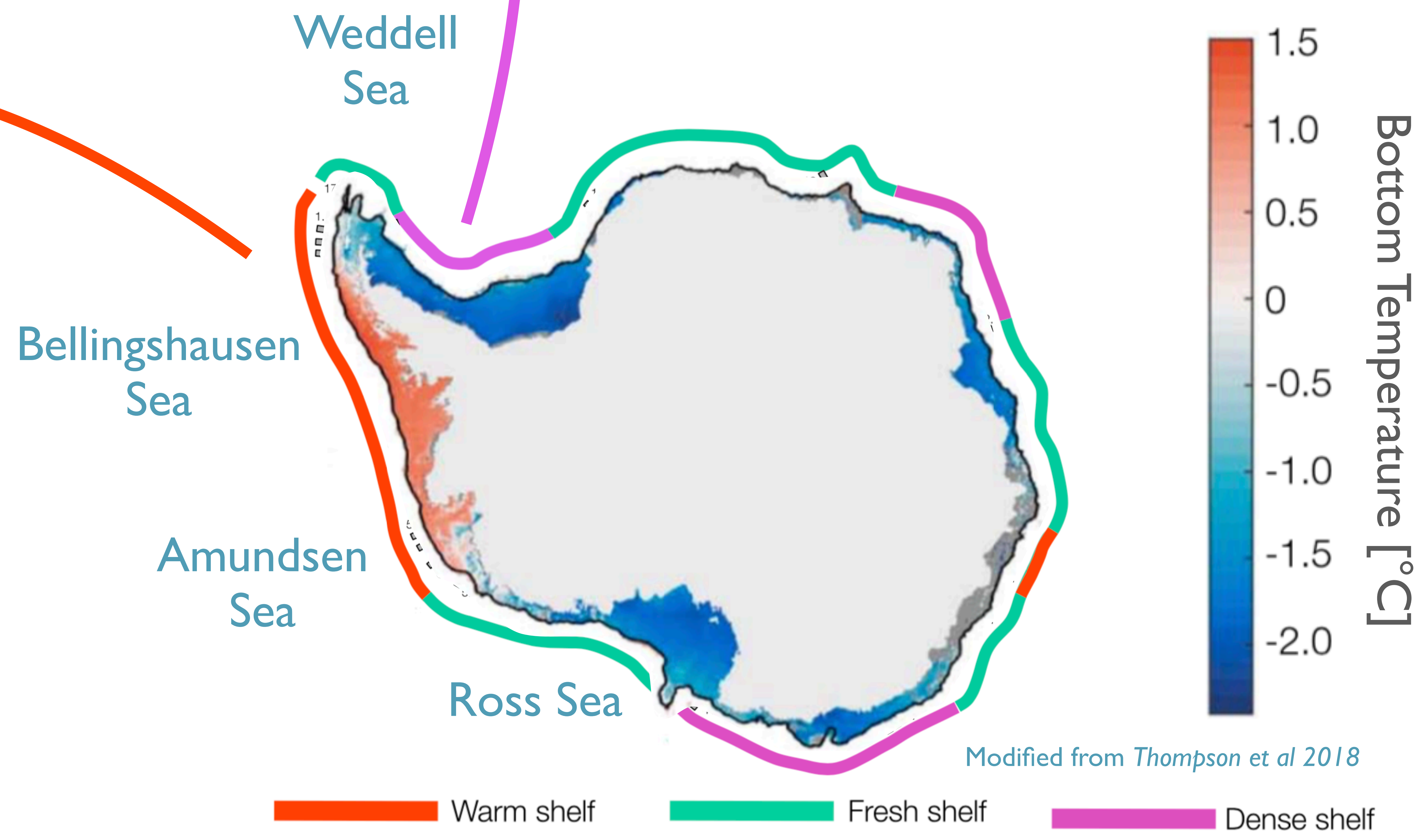


Stammerjohn & Maksym (2017, updated)



Although mostly in "warm" West Antarctica, the WAP is at a boundary of distinct Antarctic Regions



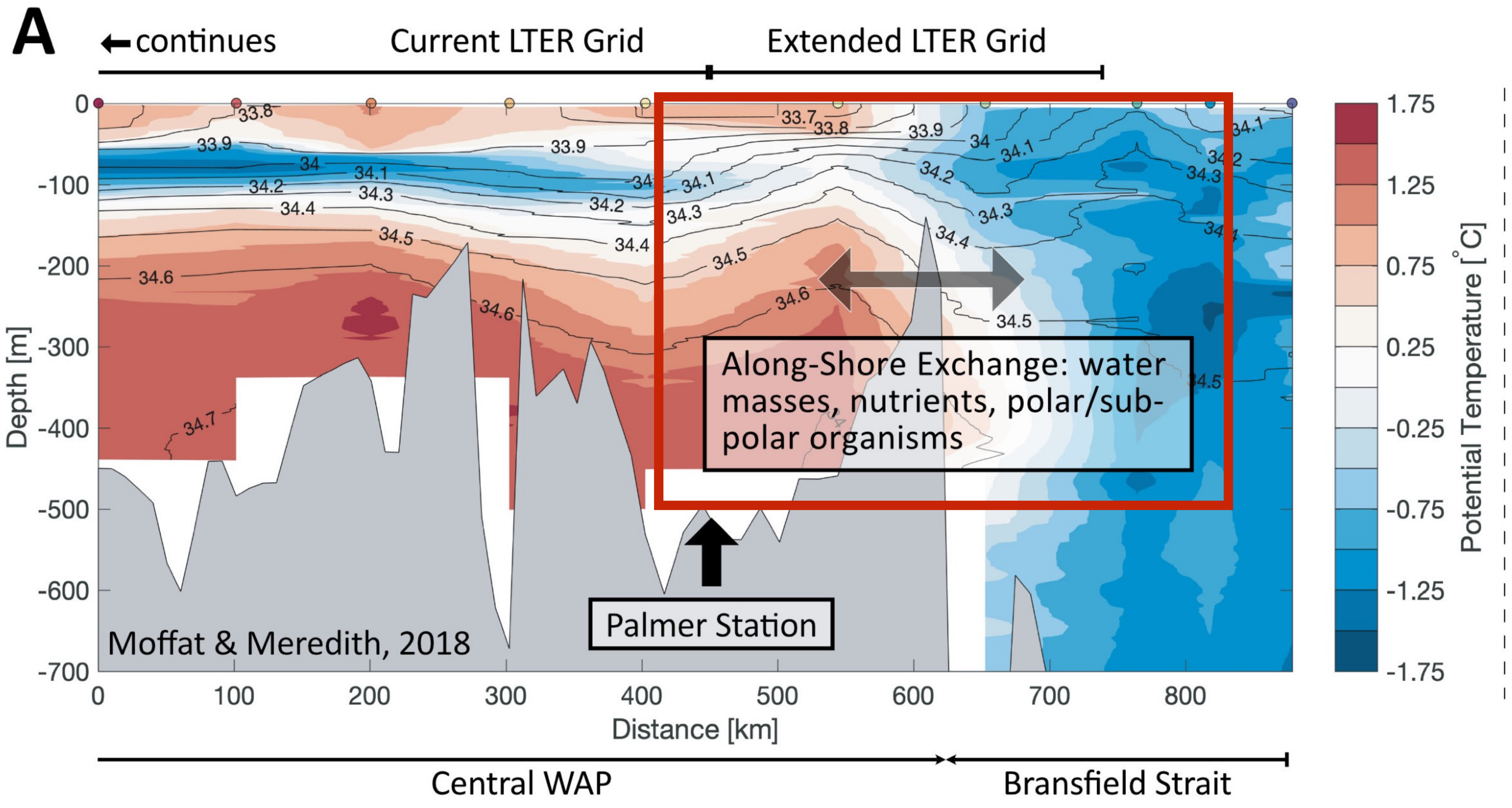


Modified from *Thompson et al 2018*

Deep shelf temperatures heavily modulate rates of continental ice loss from Antarctica.

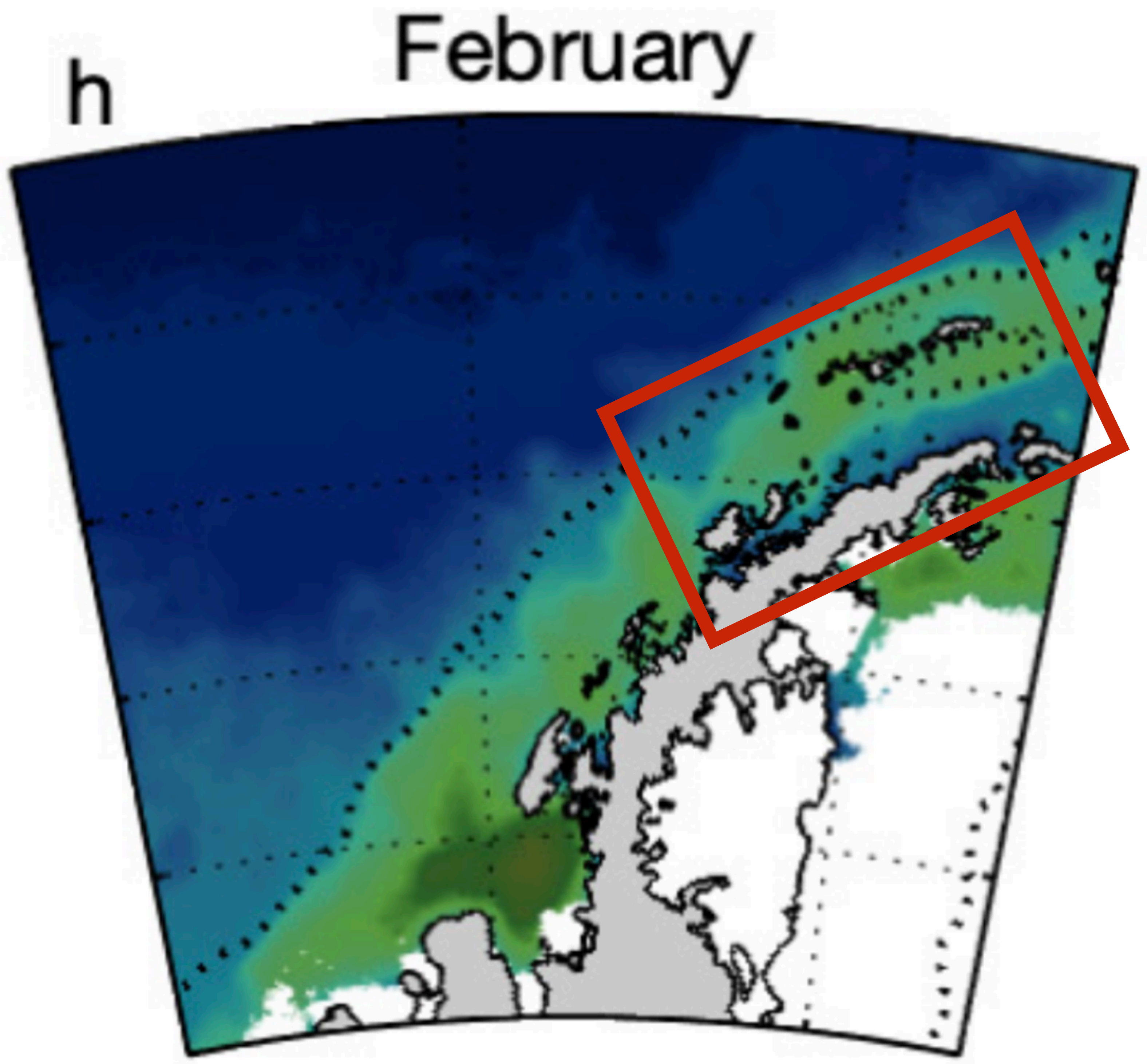
The resulting meltwater discharge to the coast is a driver of variability in upper ocean stratification and mixed layer depth.

Limited hydrographic data for this region shows a *significant* oceanographic front

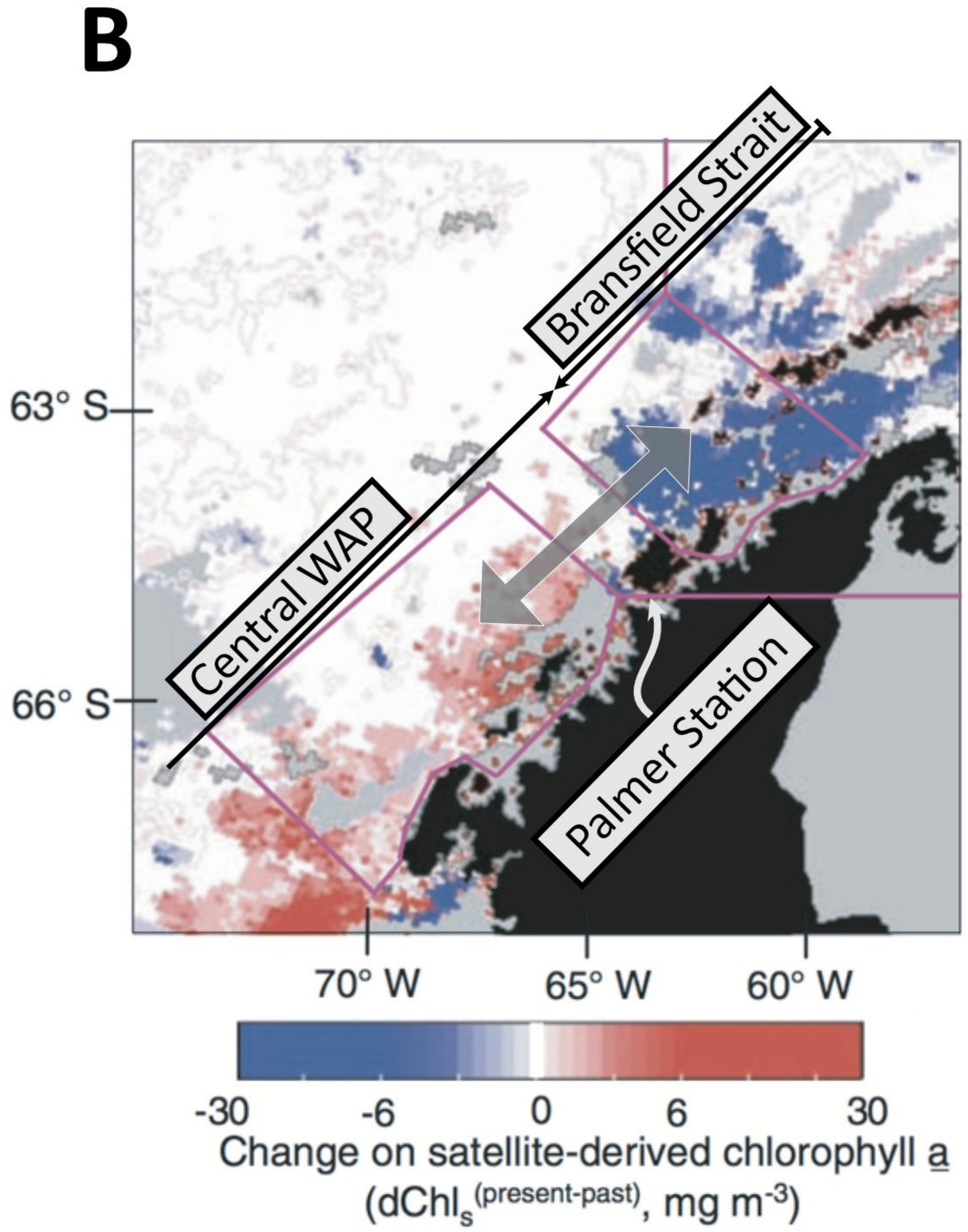


The Southern Bransfield Front

Surface Chlorophyll show significant differences across the Southern Bransfield Front



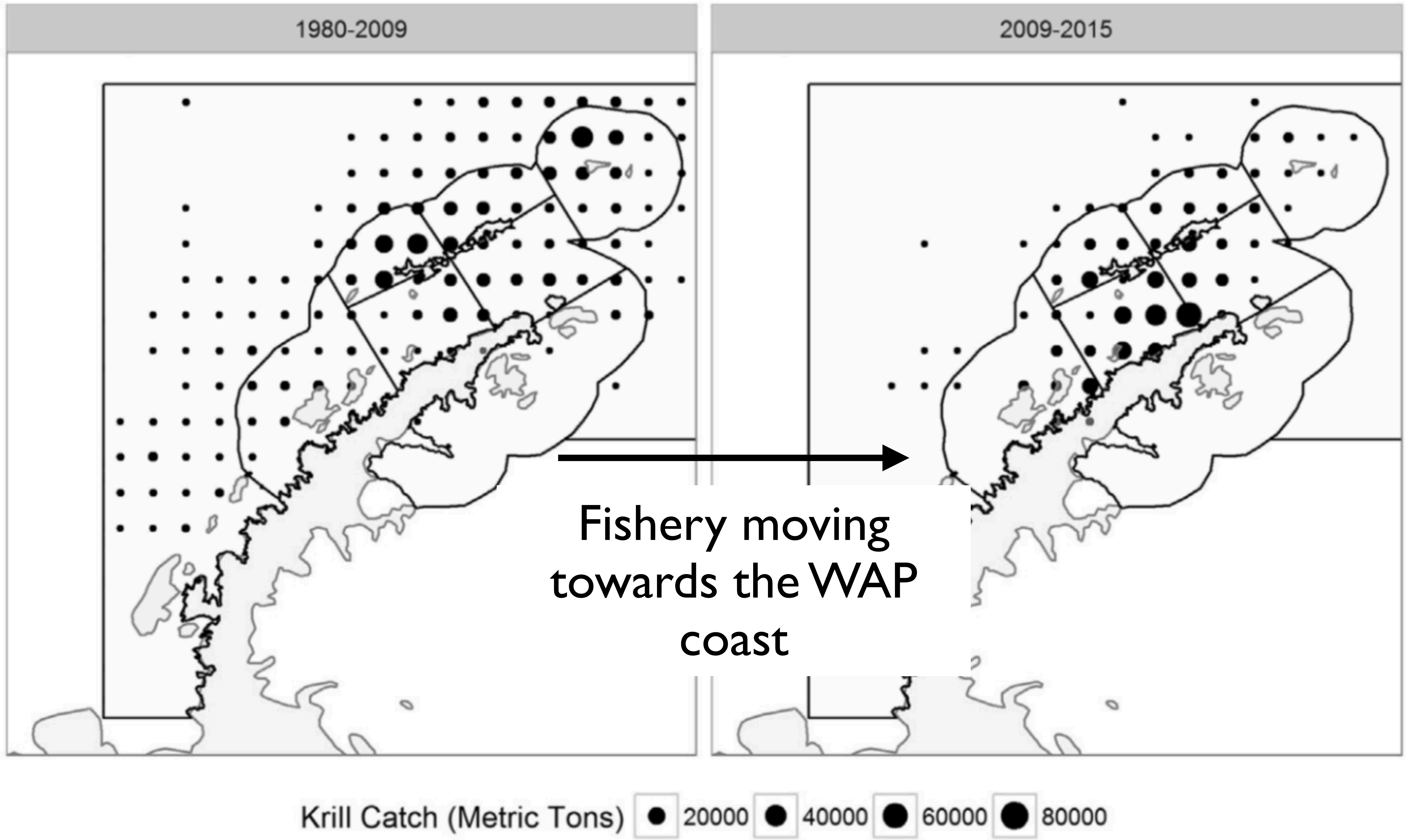
Turner et al. 2024: Climatology of Chlorophyll concentration for February (1997-2022)



Montes-Hugo et al., 2009

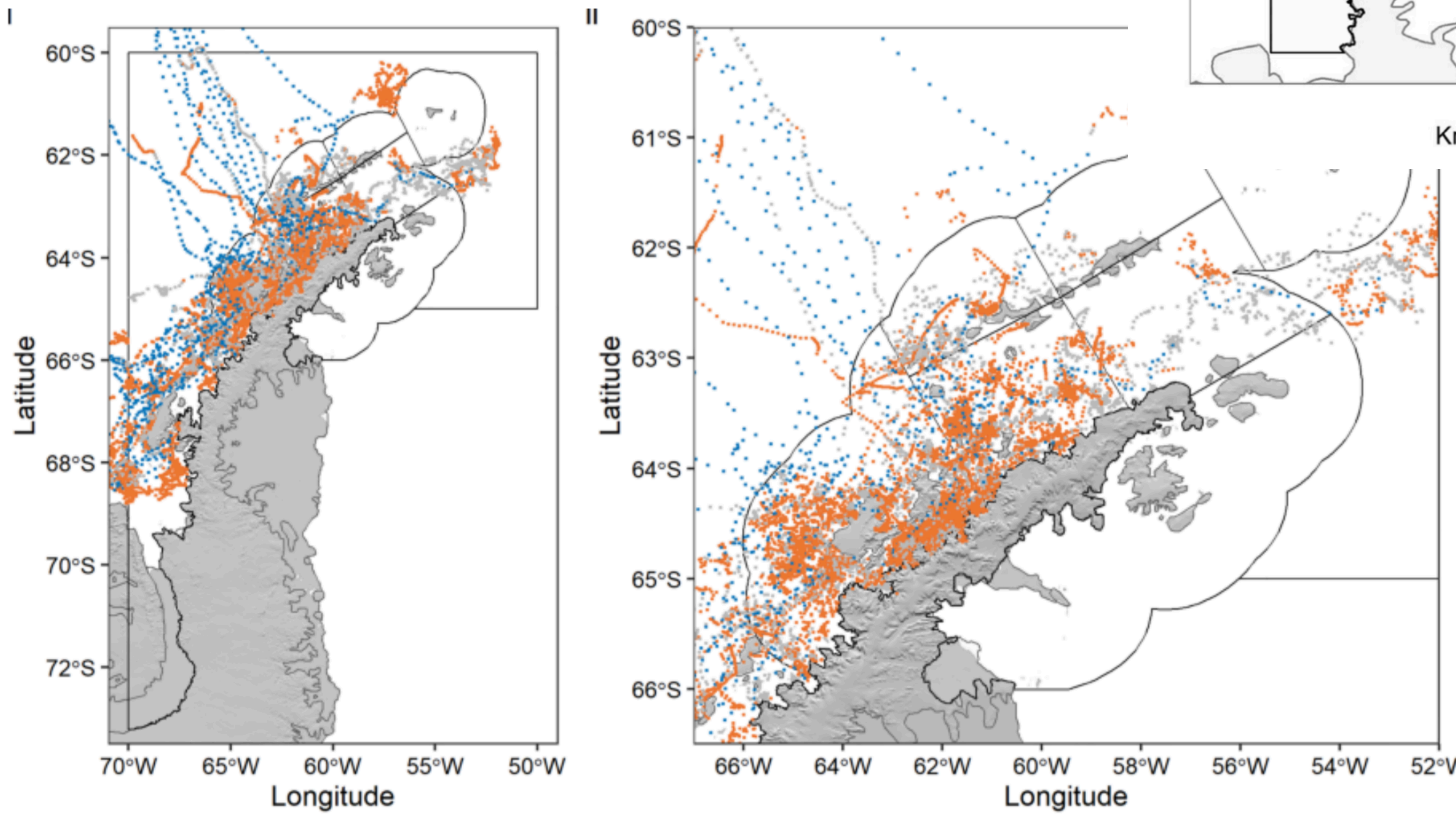
This coastal region is a key "hotspot" in the Krill fishery, and a site of high Humpback whale foraging activity

1980-2009 2009-2015



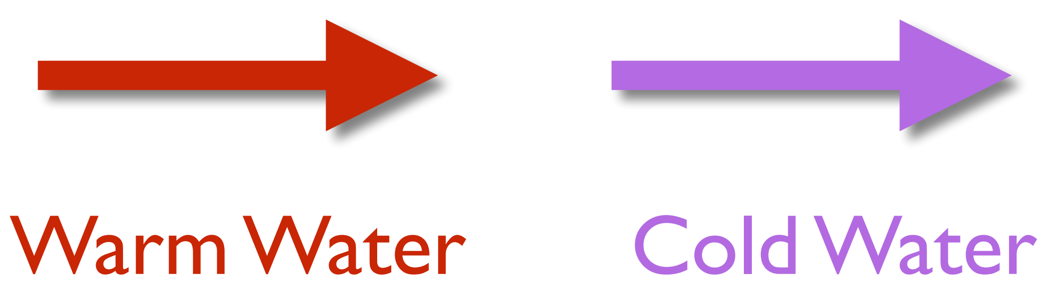
Weinstein et al. 2017

Krill catch

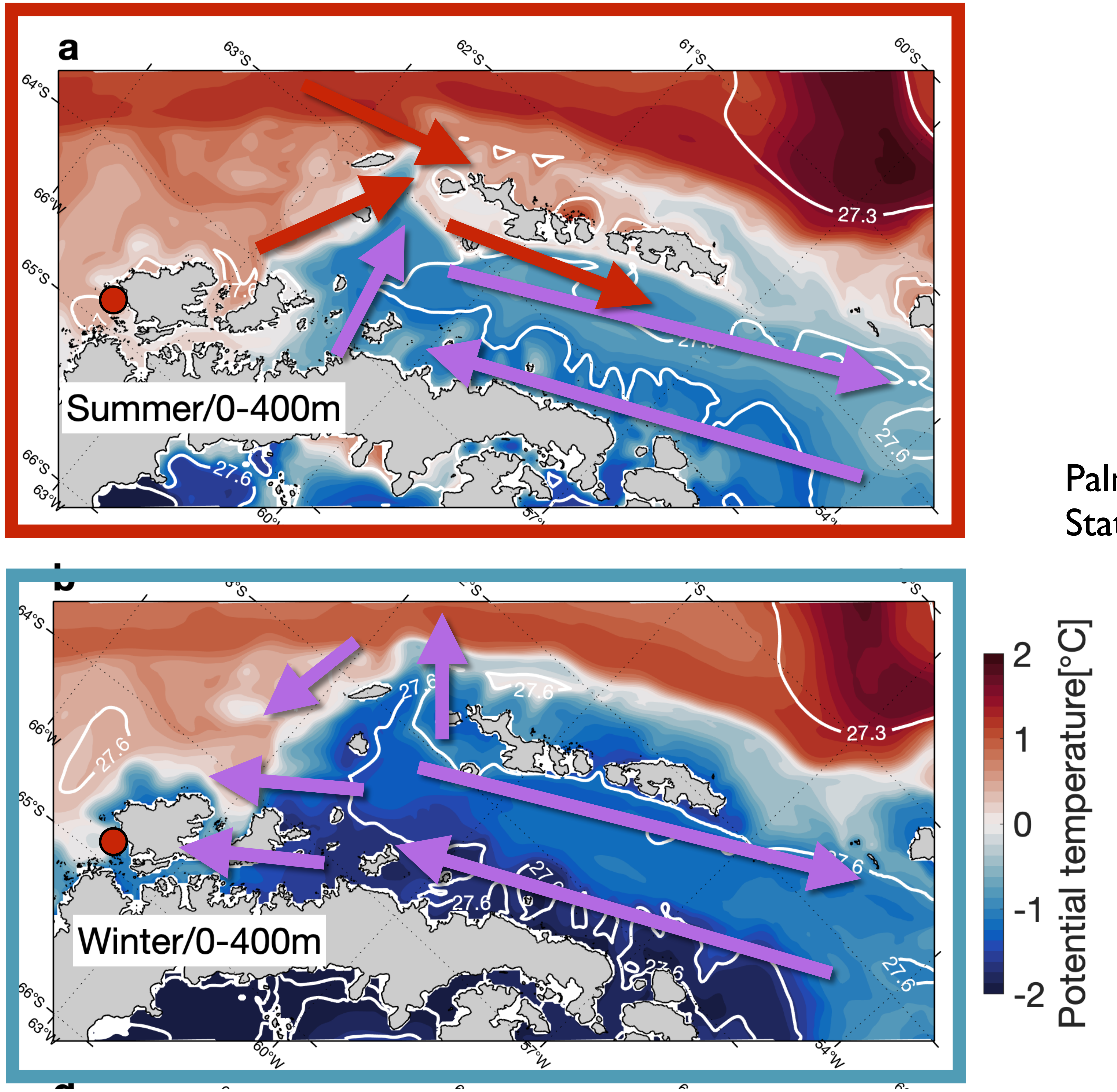


Reisinger et al. 2022

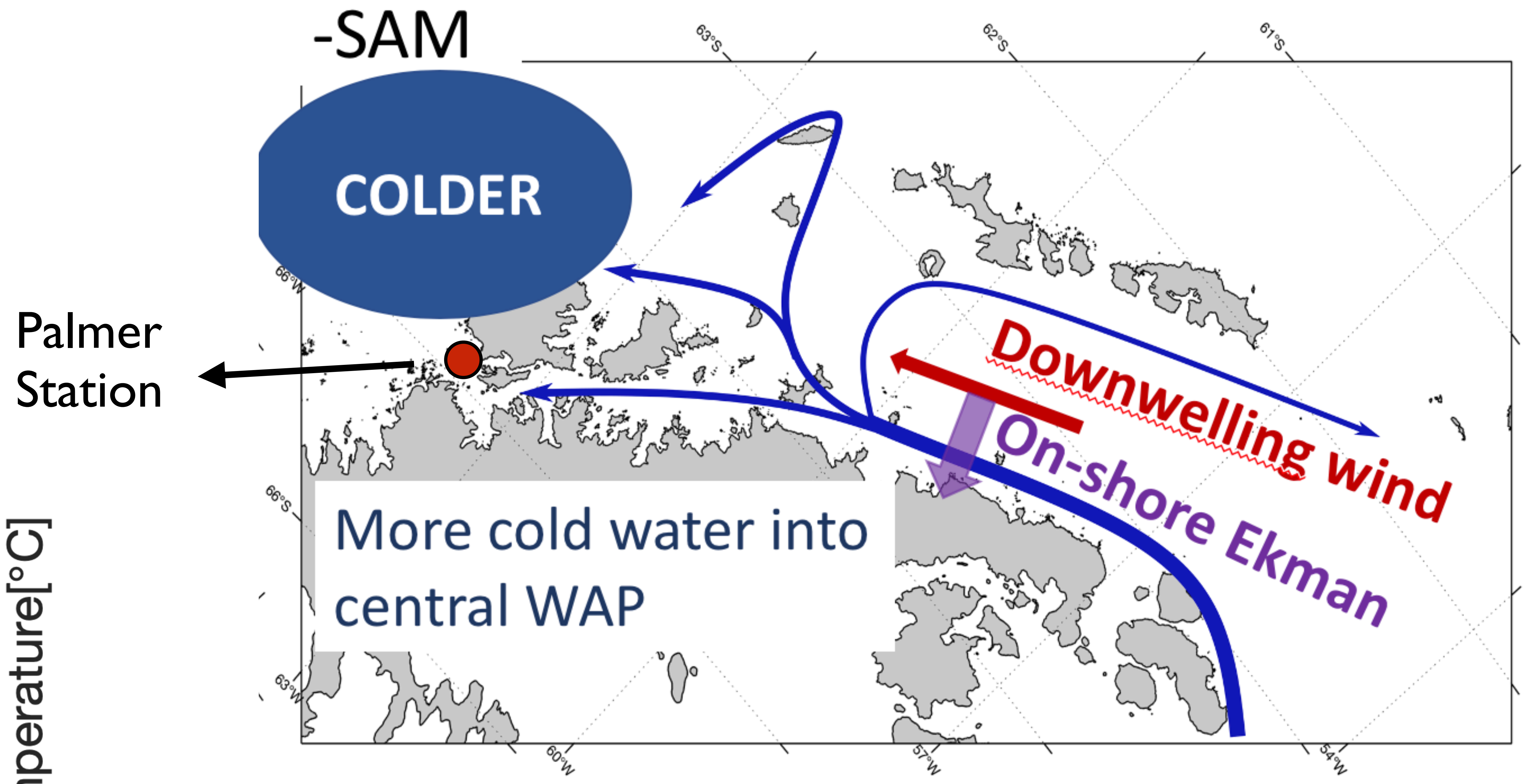
Humpback movement tracks, Antarctic Peninsula (Friedlaender's group)



Modeling Work (Wang et al. 2021) suggested significant exchange along the coast



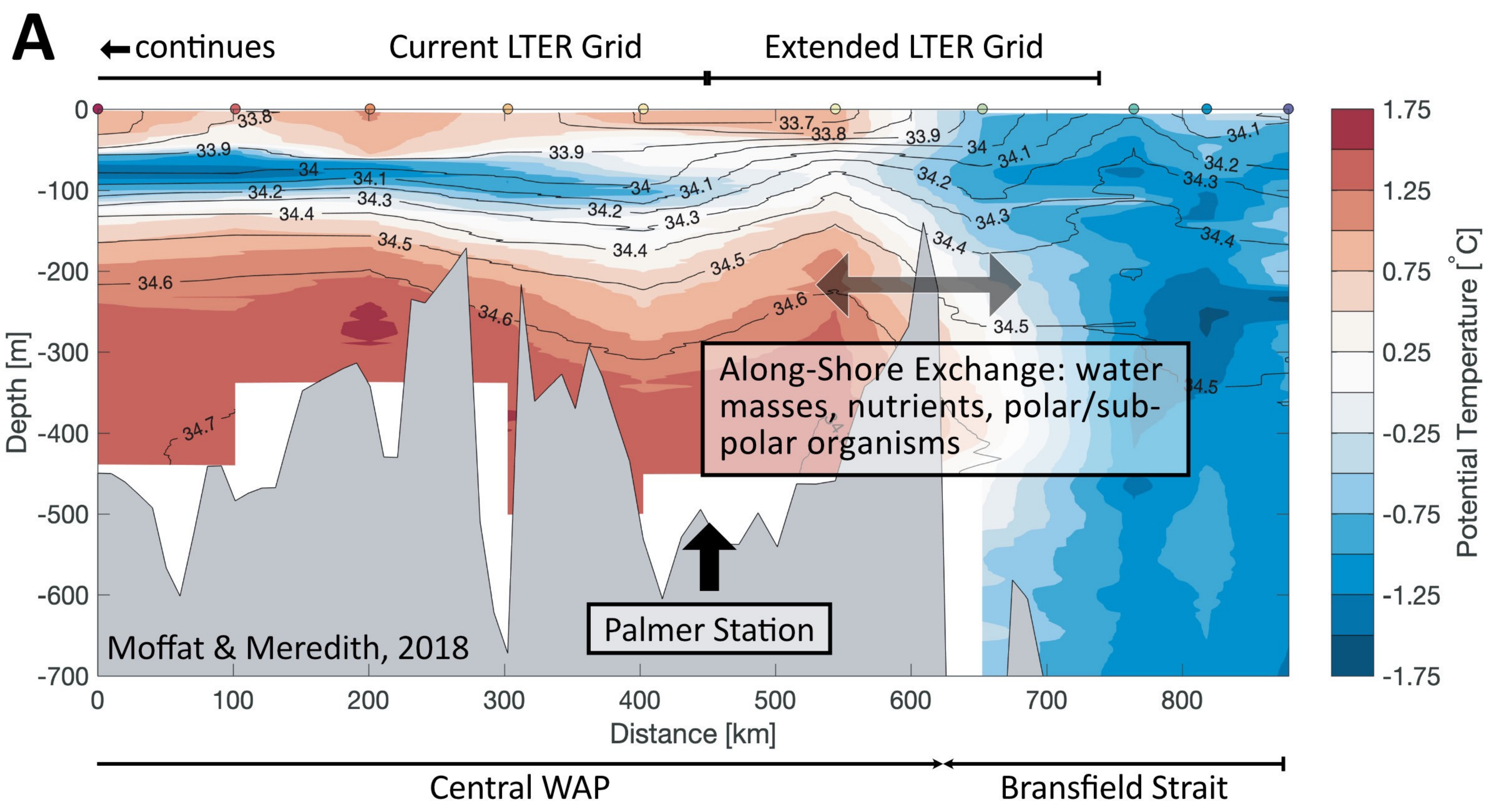
Lead: Dr. Xin Wang
(Ph.D. 2024, UDel)



Wang et al, 2022

- Model showed cold intrusions during winter.
- Interannual variability in intrusion magnitude driven by Southern Annular Mode (SAM).
- Observations of these process were non-existent.

Goals and Challenges to Address B2 Hypothesis



The Southern Bransfield Front

Hypothesis:

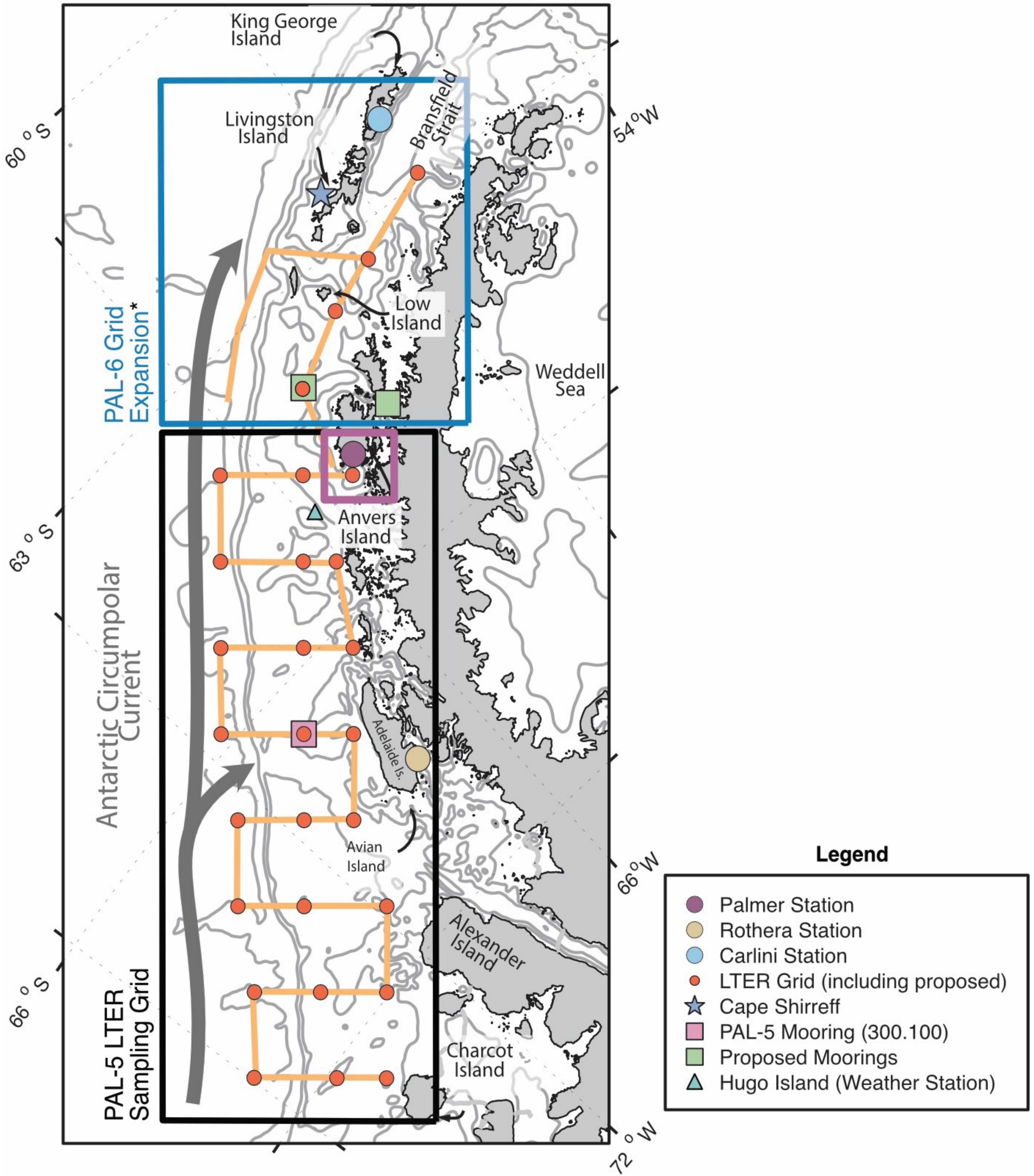
Along-shore exchange between the WAP and the Weddell Sea is a significant contributor to heat, salt, and nutrient budgets, and modulates food web productivity and structure by potentially transporting polar species (of phytoplankton, zooplankton, fish) into the northern, transitioned subpolar region.

Goals:

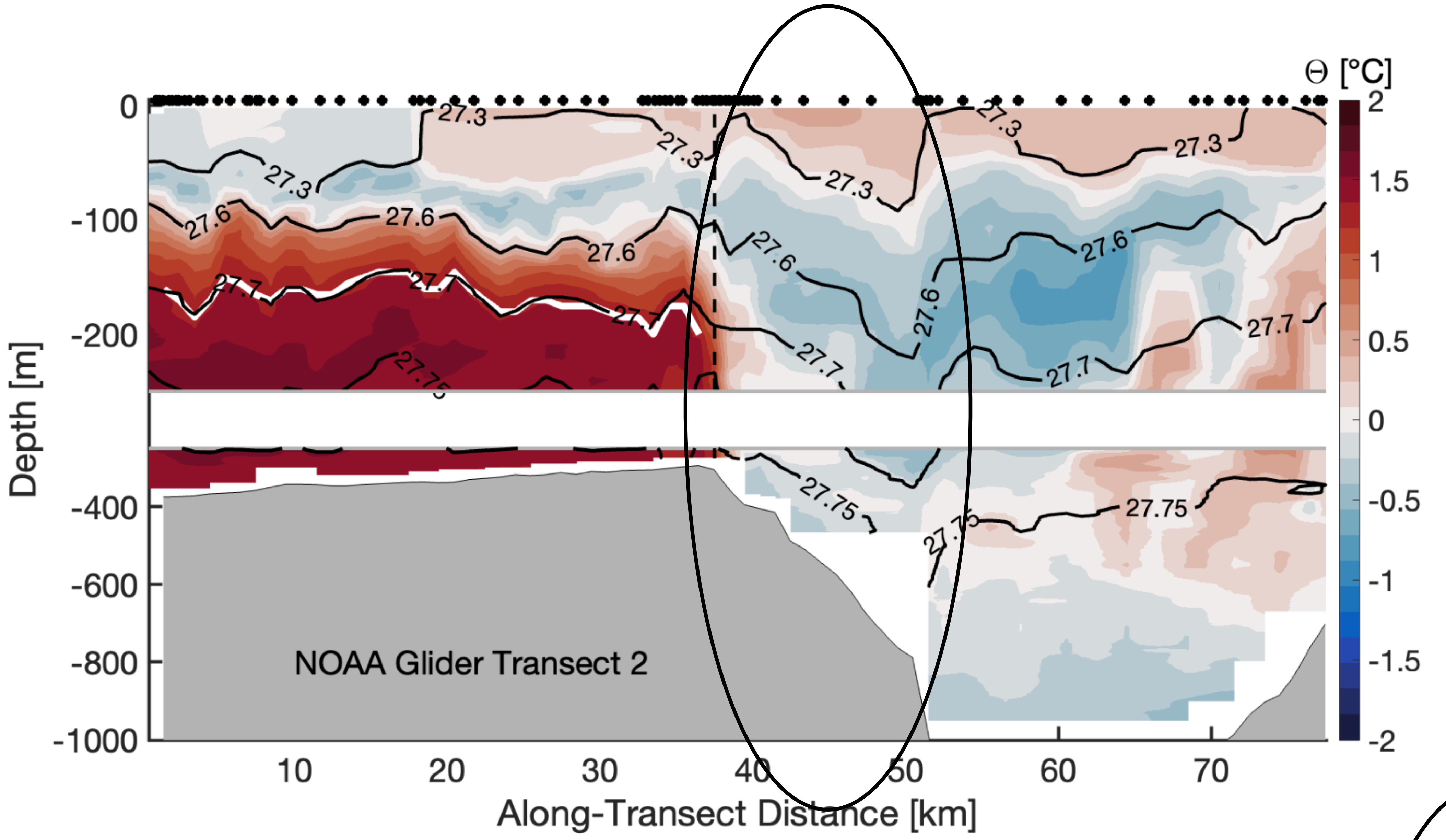
- Extend PAL cruise sampling grid to collect our usual suite of physical-biochemical observations.
- Because modeling shows ***strong seasonality,*** we need some year-round observations using new moorings.

PAL Extended Grid (2021/22-Present)

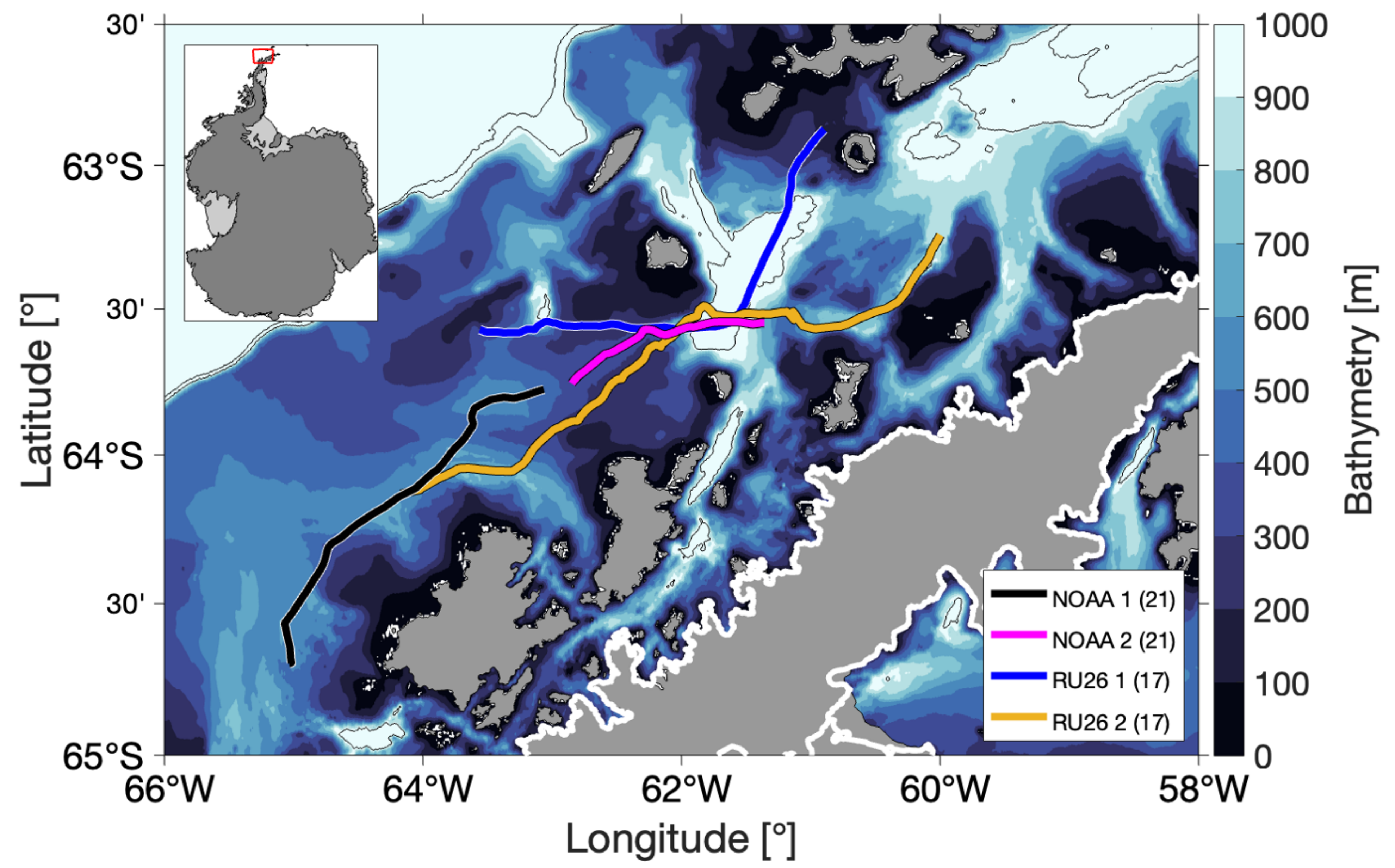
- Grid now spans ~1000 km along the coast.
  - 5 additional grid stations
  - Multiple moorings deployed
  - 2 full glider surveys
- New and expanded collaborations with:
  - NOAA's Conservation of Antarctic Marine Living Resources (CAMLR) efforts.
  - Brazilian Antarctic Program
  - UK-Ukraine project (led by the British Antarctic Survey) to understand along-shore exchange in Bransfield Strait.



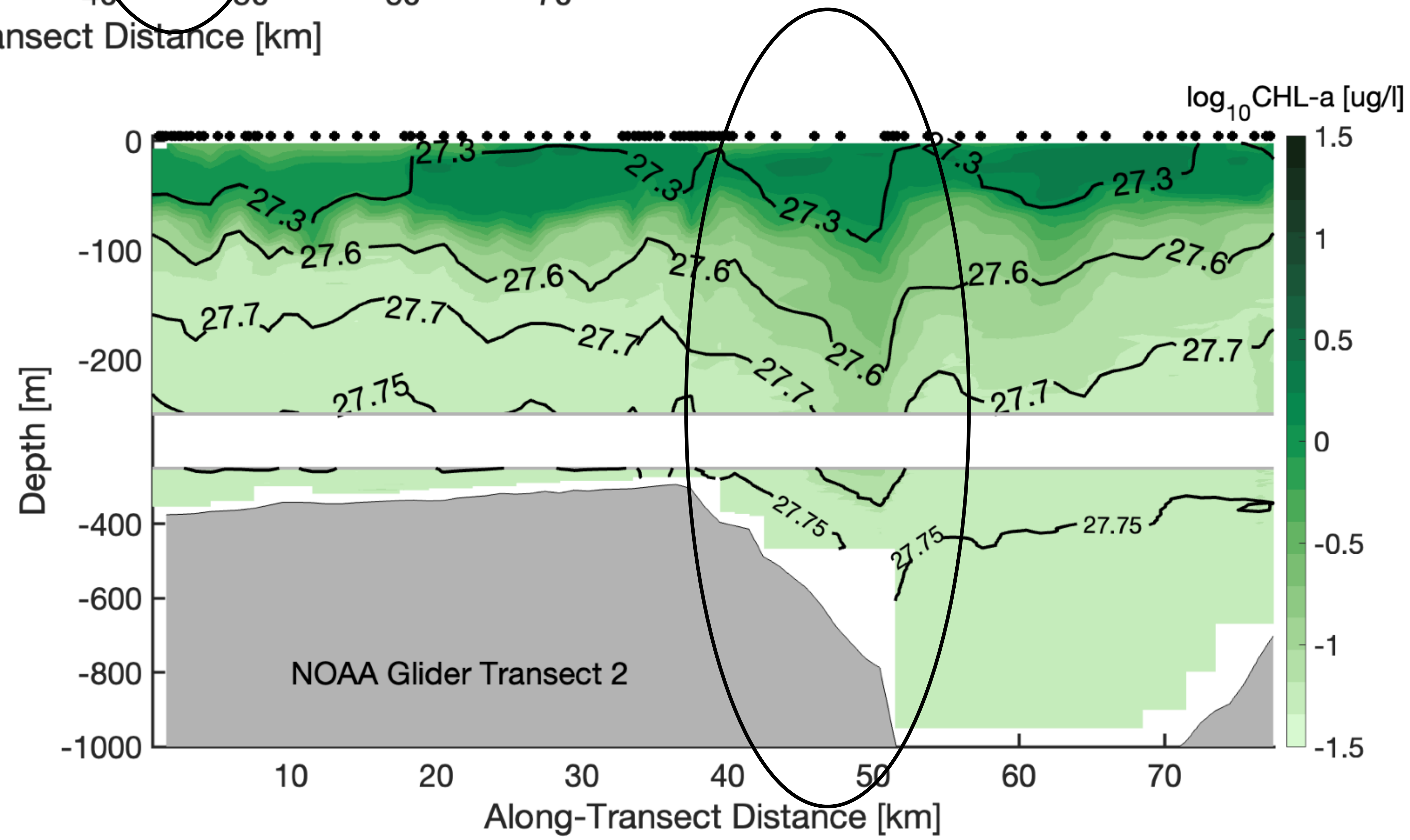
Understanding Frontal Exchange Along the WAP (in Progress)



- Glider surveys along the South Bransfield Front
- Significant gradients in temperature and Chlorophyll.



Lead: Rike Benz
(Ph.D. Student, UDel)



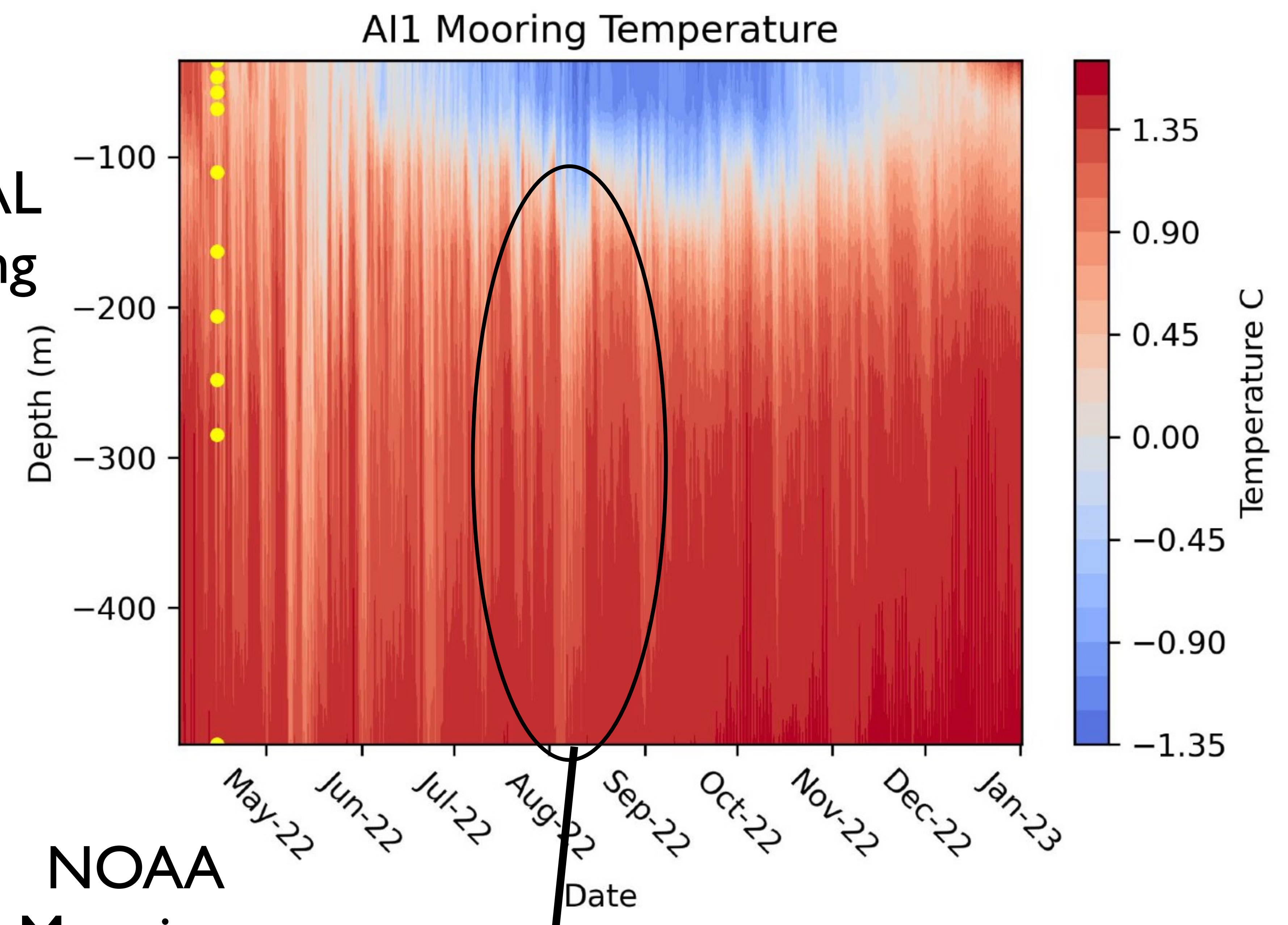
Preliminary results show:

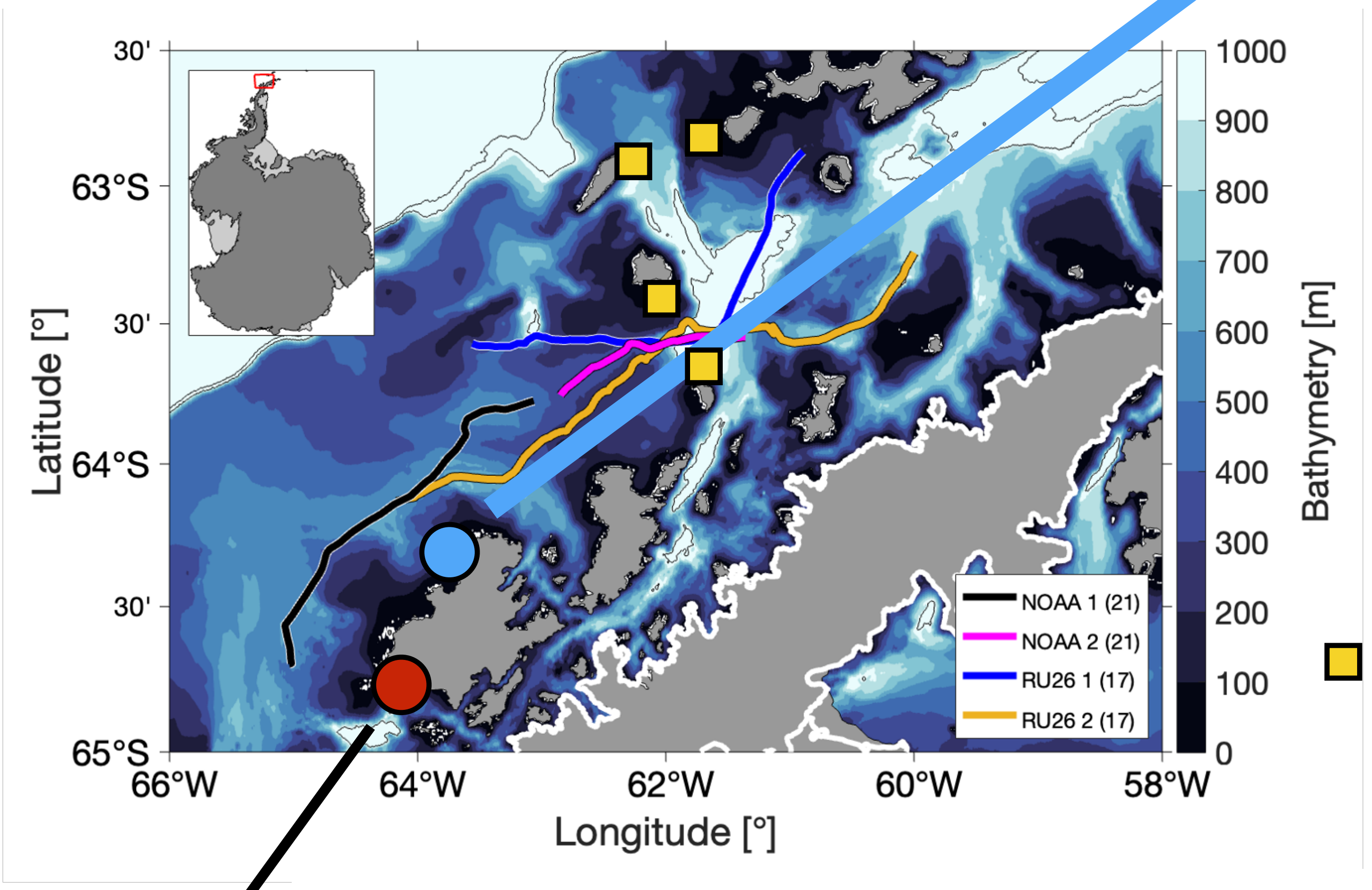
- Frontal region with velocities O(1.5 m/s). Strongest front on WAP shelf.
- Evidence of strong mixing and potential eddy generation driving exchange.

In Progress Analysis of New Mooring Records Confirm Seasonal Intrusions of Weddell Sea Water

- Mooring deployments were **coordinated and planned jointly** with NOAA.
- In 2022-2023, we deployed and recovered 6 moorings (2 LTER, 4 NOAA).
- 5 recovered in late 2023/early 2024. Analysis in progress!
- Provide first time series of frontal dynamics.

AI-1 PAL Mooring



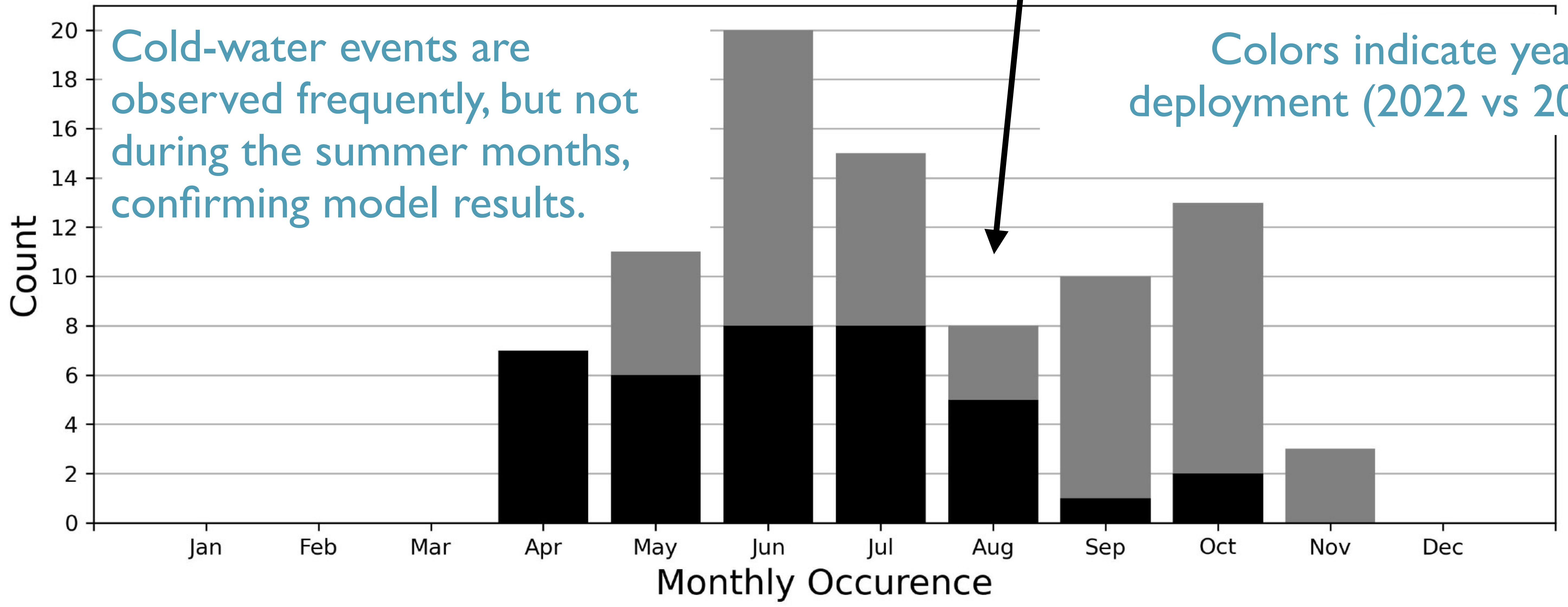


NOAA Moorings (Recovered 12/2023)

Palmer Station

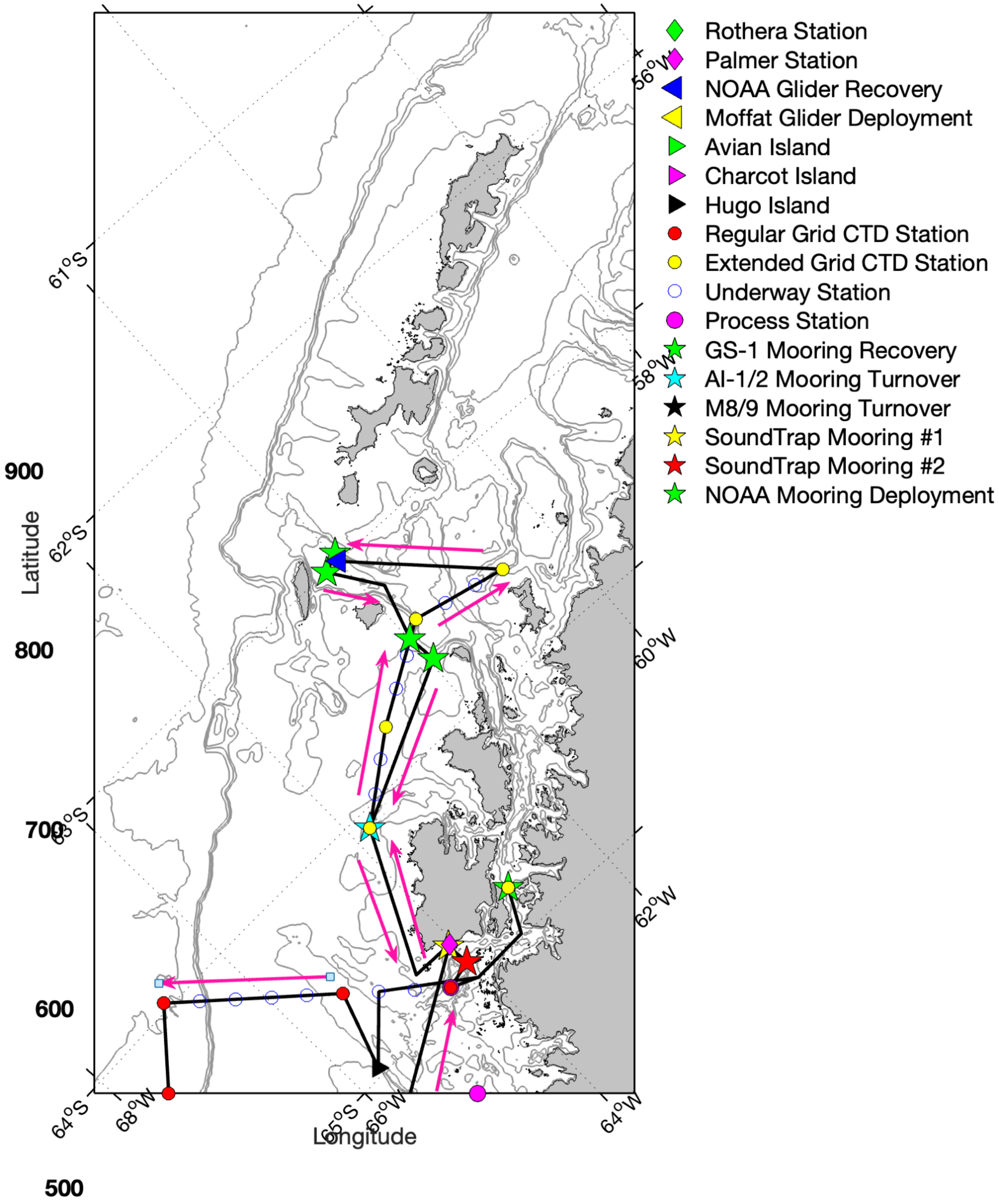
Cold-water events are observed frequently, but not during the summer months, confirming model results.

Colors indicate year of deployment (2022 vs 2023)



Lead: Jake Gessay (M.S. Student, UDel)

Map showing the plan for the January 2023 PAL Cruise



Conclusions Sub-Theme B2

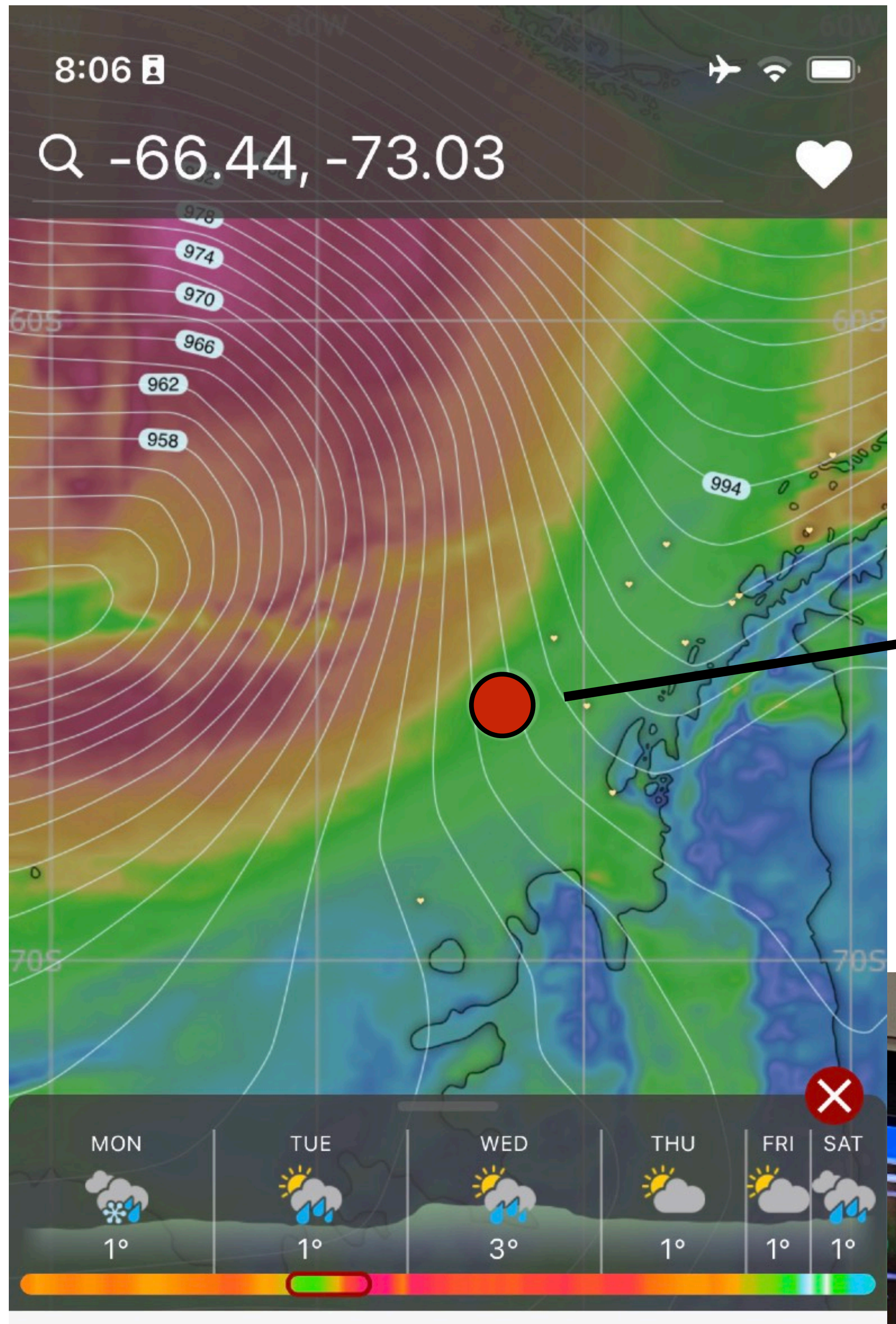
- Expansion of the PAL Grid started in 2021.
- New mooring data confirm numerical model results showing significant exchange along the coast.
- Ongoing work to understand frontal exchange and ecosystem impacts.

Sub-Theme B3: Response of krill and predators to vertical and alongshore changes driven by storms

Hypotheses:

- *B3a. Storm-induced ocean currents and turbulence change krill distribution, abundance, and aggregation structure, leading to smaller, diffuse, and deeper patches. This in turn alters krill predator foraging dynamics (deeper dives, decreased foraging efficiency) and demographics(reduced penguin chick fledging mass and whale pregnancy rates).*
- *B3b. Despite the positive and near immediate impacts of sea ice rebuild on lower trophic levels, negative storm effects dominate over any positive sea ice effects, hindering Adélie penguin population increase.*

Goals and Challenges to Address Sub-Theme B3 Hypotheses

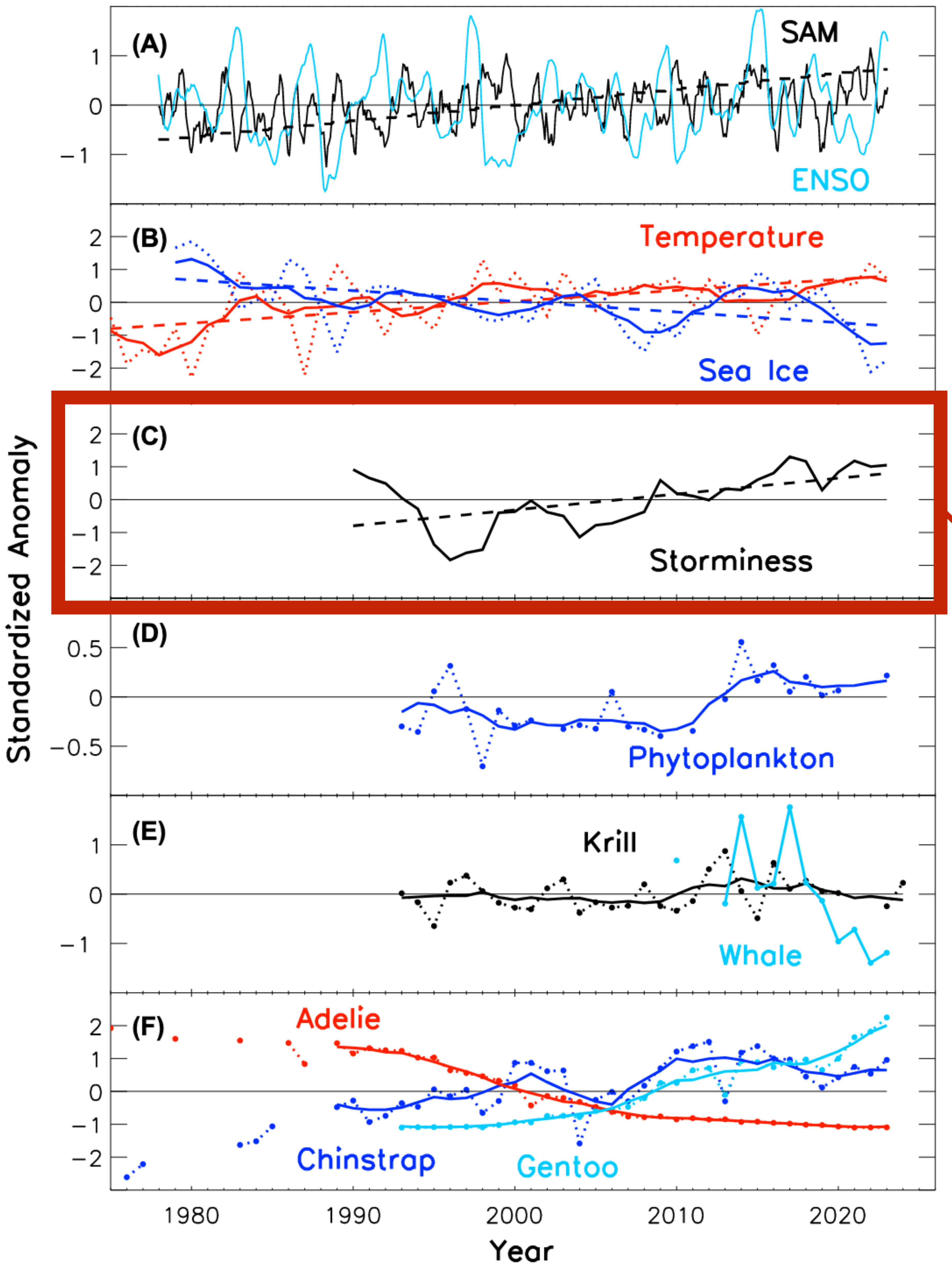


The L.M. Gould

Storminess in real life (January 16, 2023)

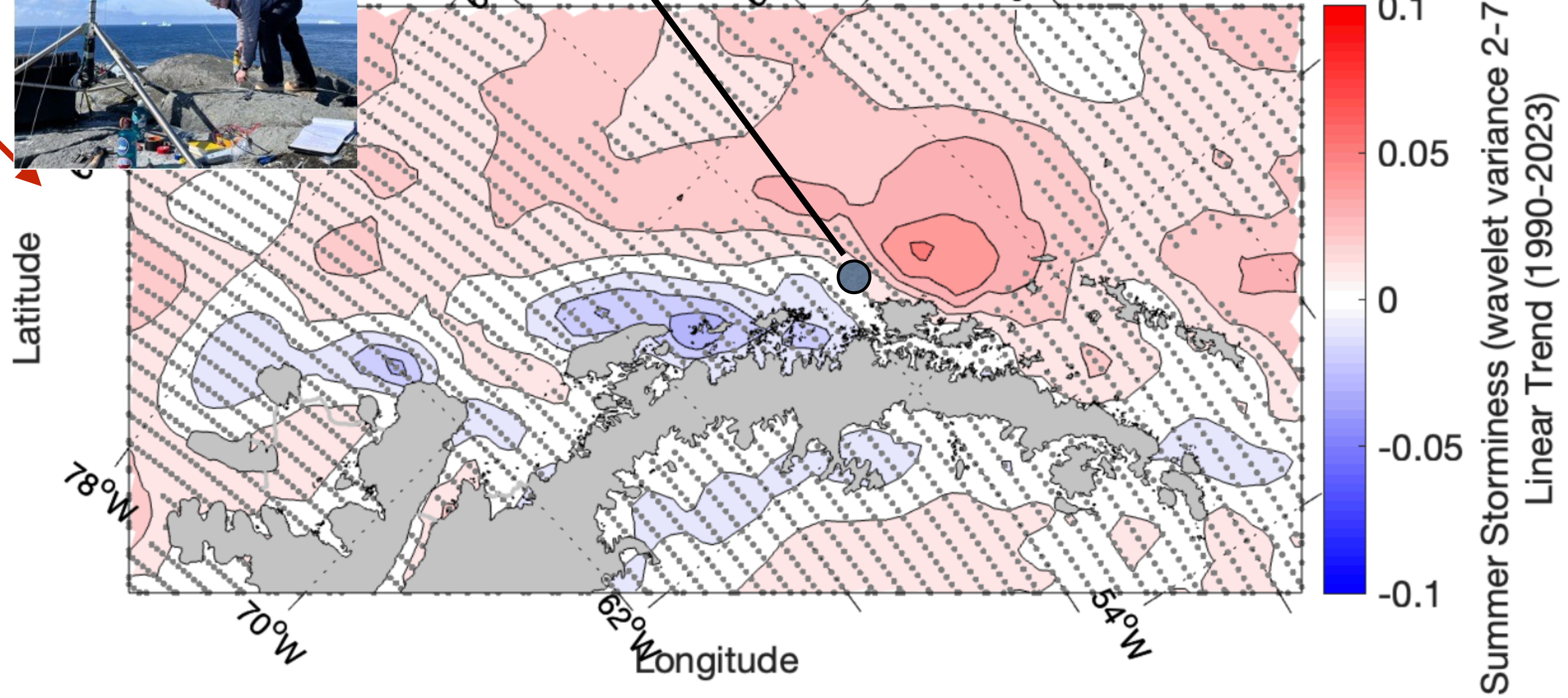
- What do we mean with "Storms" and "Storminess"? Explore metrics and understand time and space variability.
- Storm-scale variability is synoptic (e.g. days to a week or so). How do we observe critical variables in those scales?

As discussed this morning, we're using different approaches do define storminess



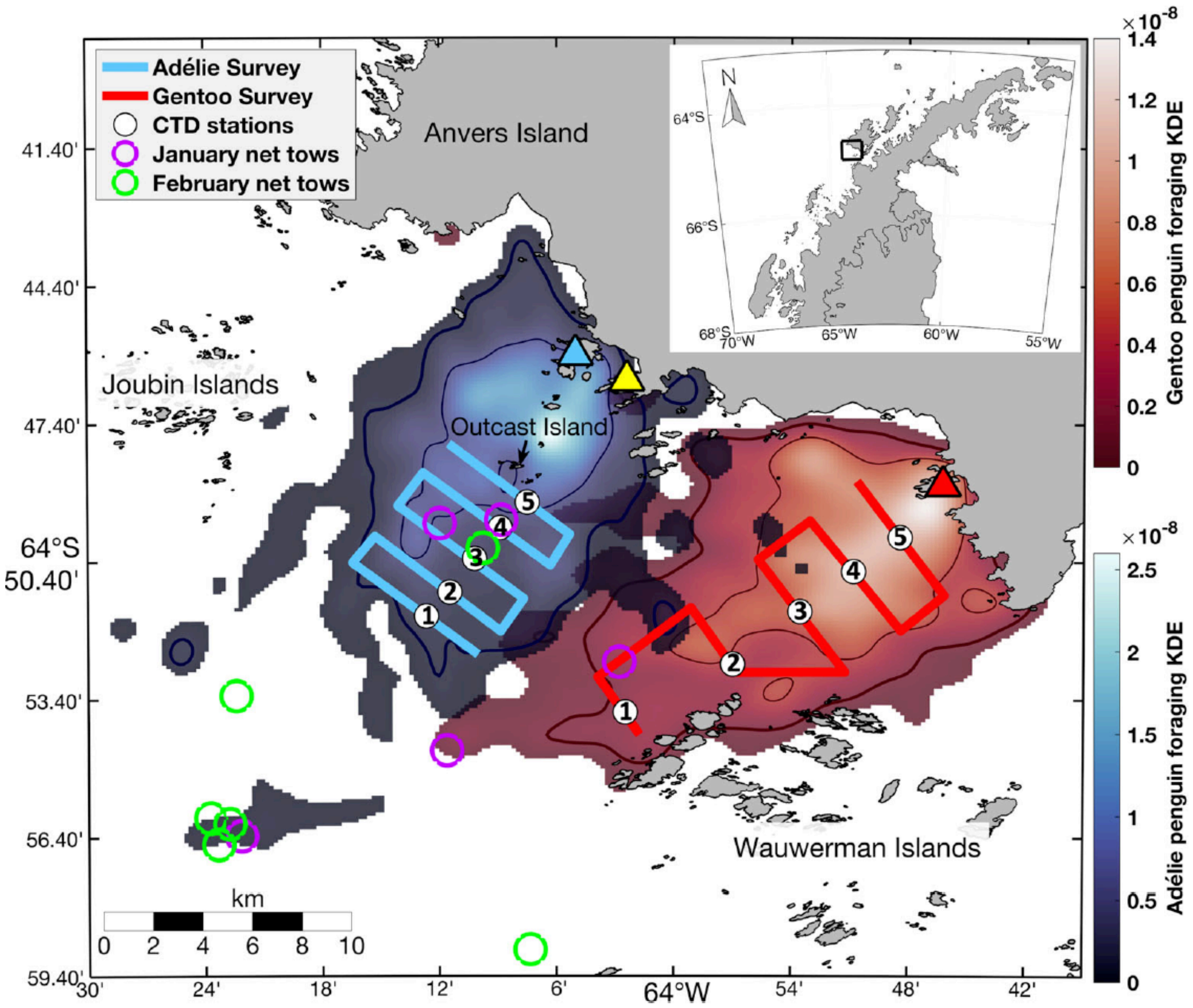
nd

New weather station
on the open shelf
(Hugo Island)

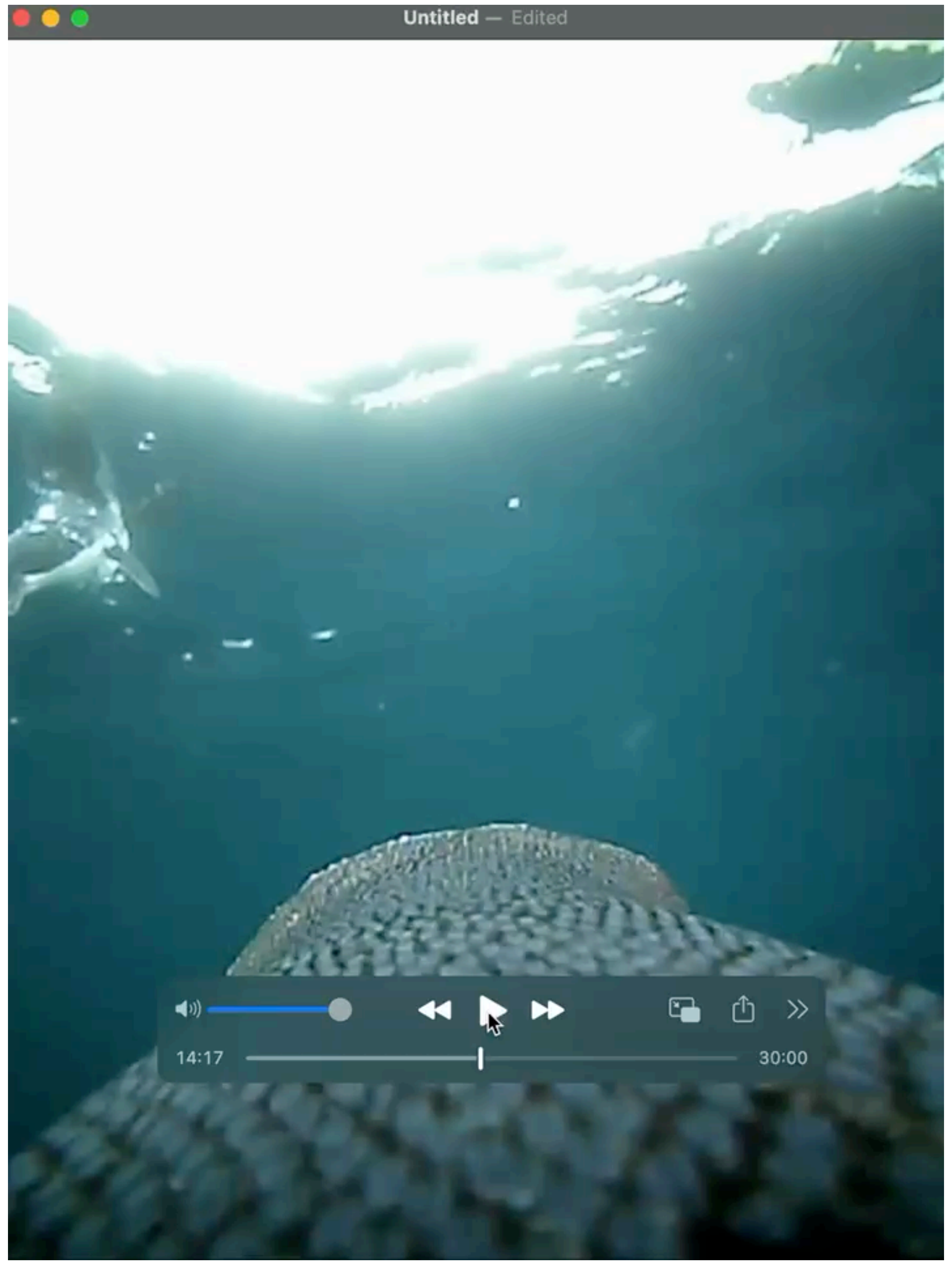


Two students (M. Stack at UVa, E. Quinter at UDel) embarked on studies of "storminess" by tracking individual storms (M. Stack) and by studying synoptic-scale wind variability (E. Quinter, above). Results reveal significant changes in storminess in different seasons.

Storm impacts on Krill & Krill Predators using Palmer Station Observations



(Nardelli et al. 2021)



Challenge: Sample environment, penguin behavior, and prey distributions in the synoptic scales (3-7 days) storms occur.

Strategy:

- Palmer station surveys using RHIB (Small boats):
  - Acoustic surveys of krill abundance
  - Complementary hydrographic surveys
- Glider surveys to sample environment during storms.
- Tags (GPS, pressure, cameras) on penguins and whales.
- Weather station data

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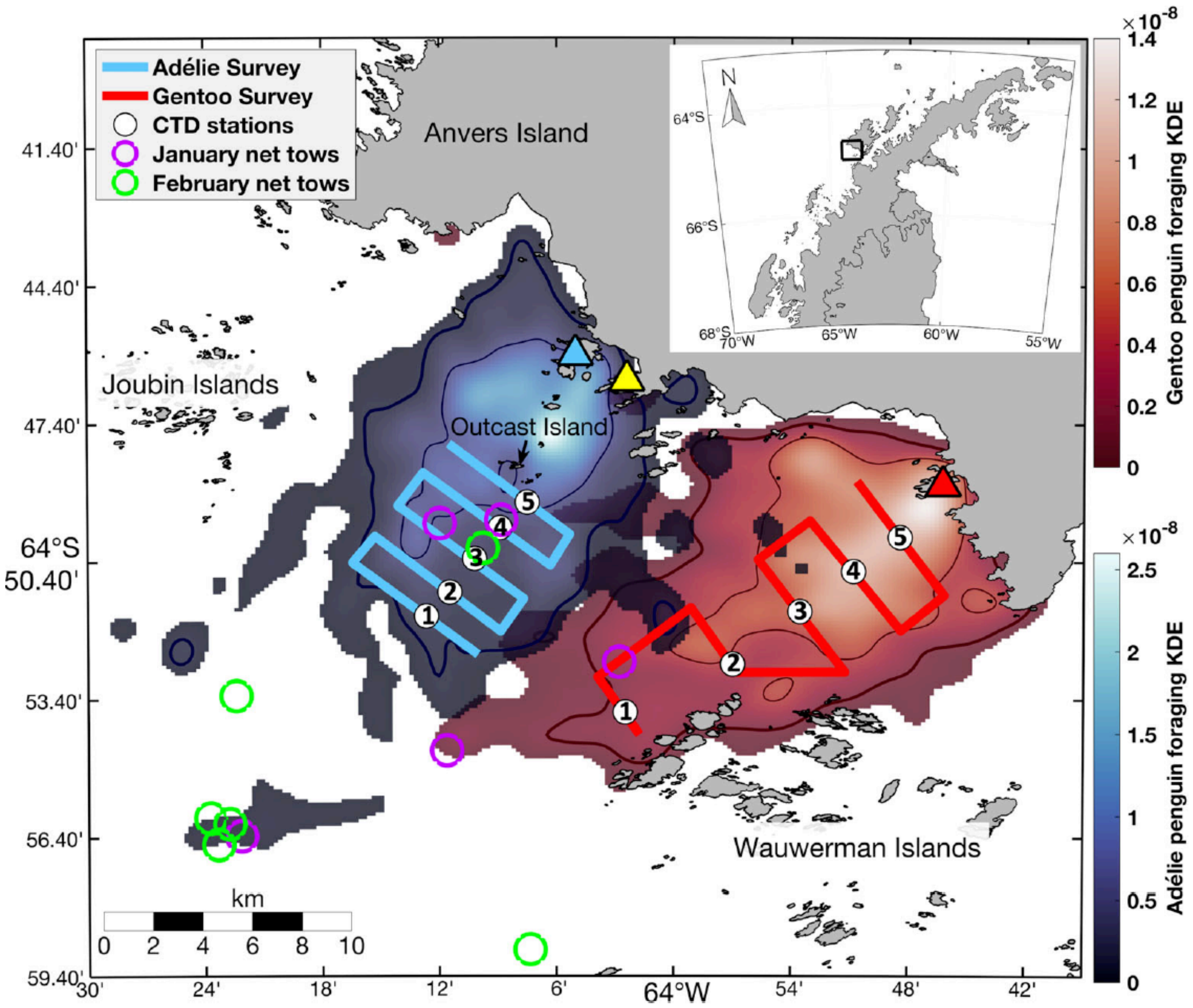

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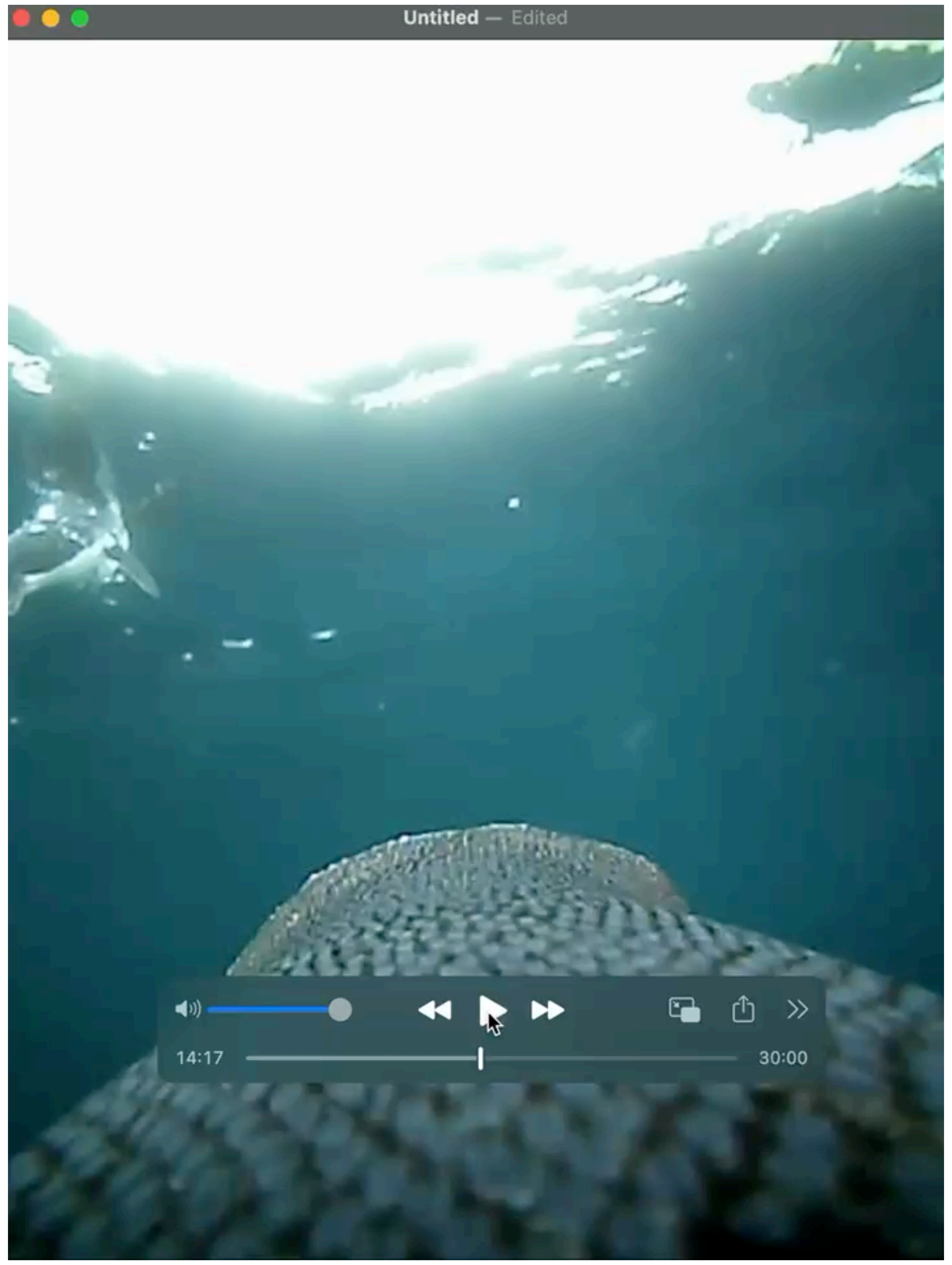

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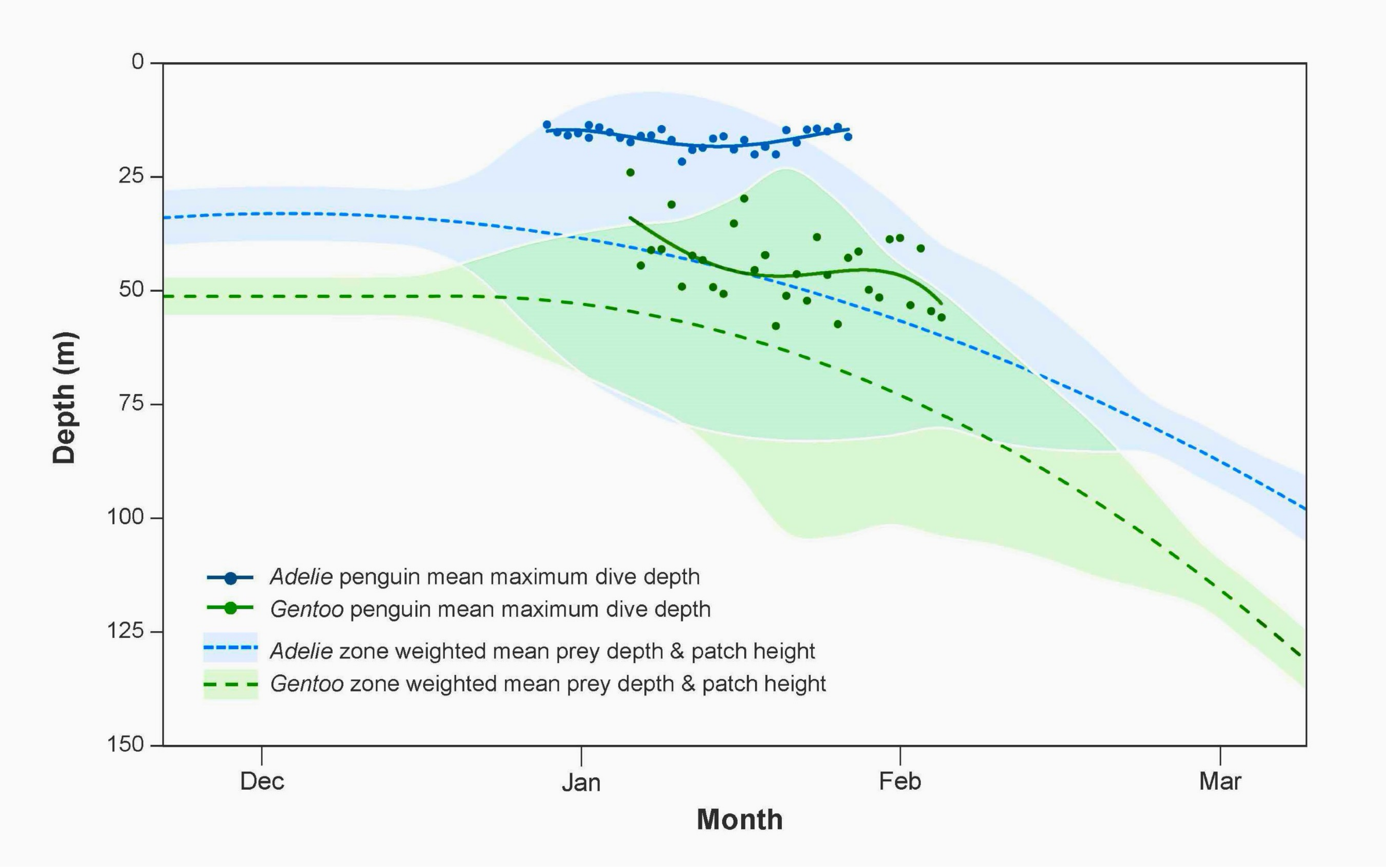
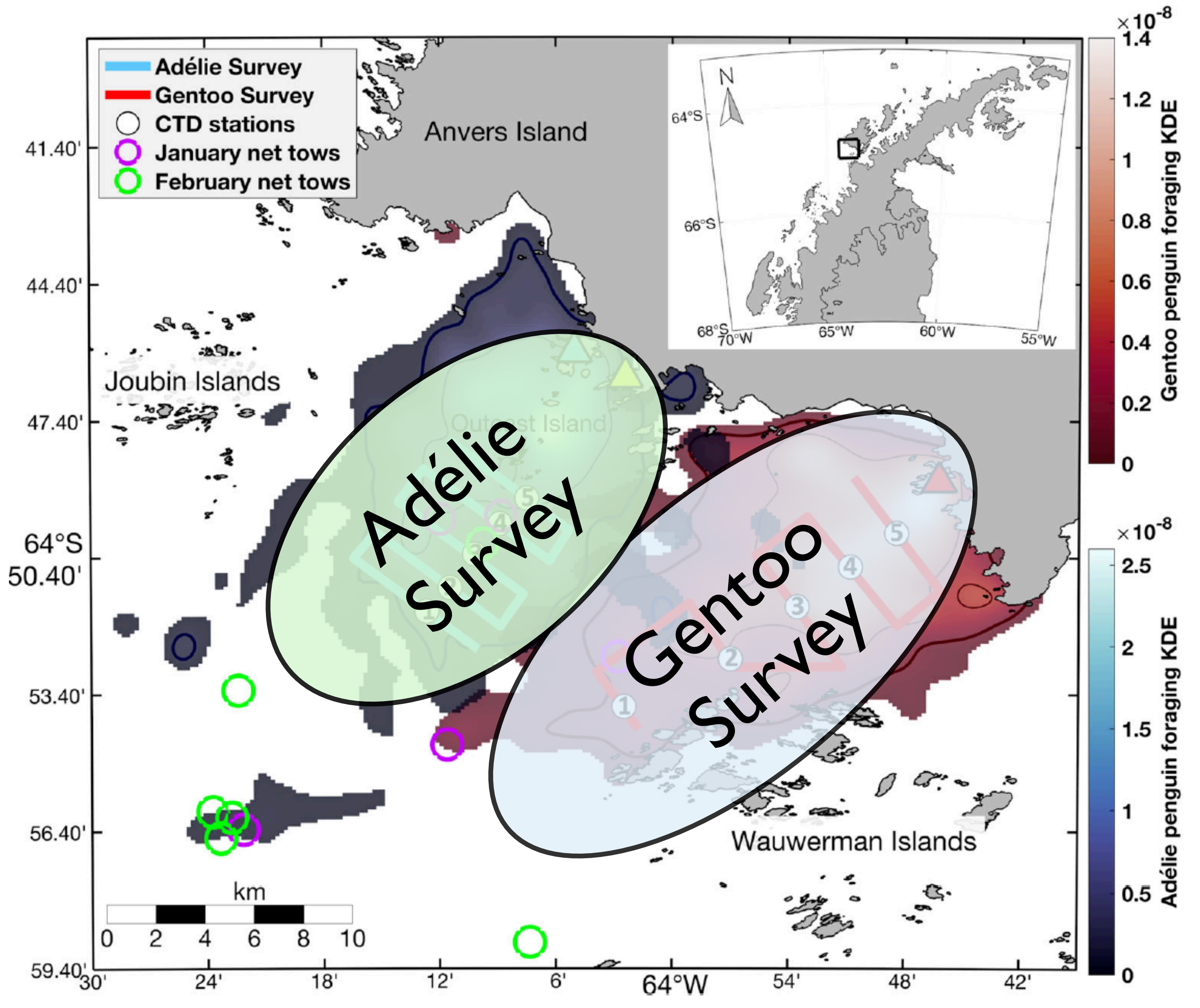
Progress in describing prey distributions





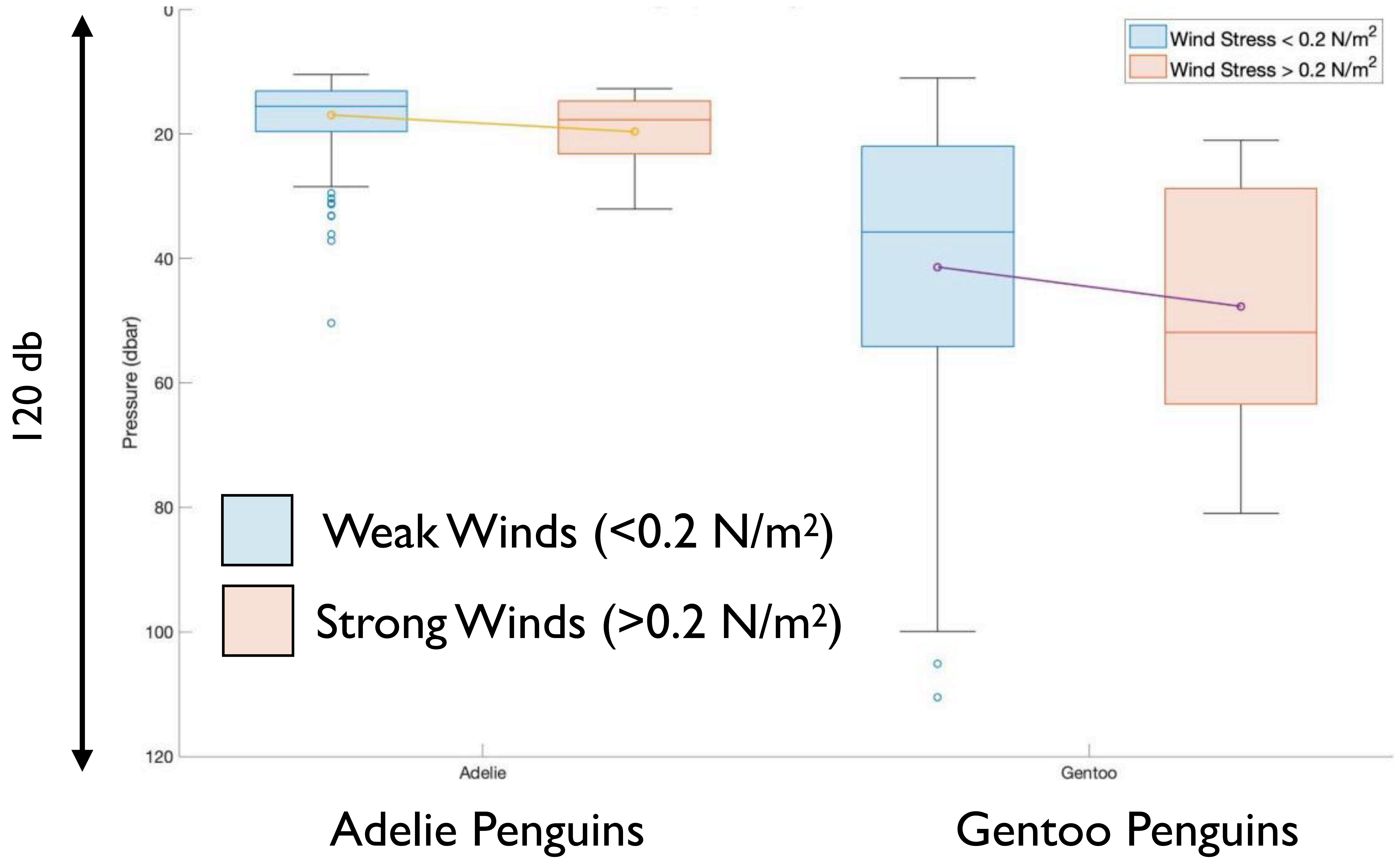
From existing acoustic surveys and penguin tags (2018-2023), clear evidence of:

- Evolving prey distribution (shading) during the season, and at each survey site.
- Gentoos and Adelies show distinct diving patterns.
- Working hypothesis is the seasonal deepening of prey & diving patterns is at least partially wind driven.

Impact of storminess on Penguin diving behavior

During strong wind stress events in 2020, Adelie and gentoo penguin maximum dive depths increased by ~13 and 36 m, and dive depths returned to pre-wind event depths within 6 to 12 hours.

In subsequent seasons, we've continued to deploy Penguin tags to track swimming behavior response to wind conditions.



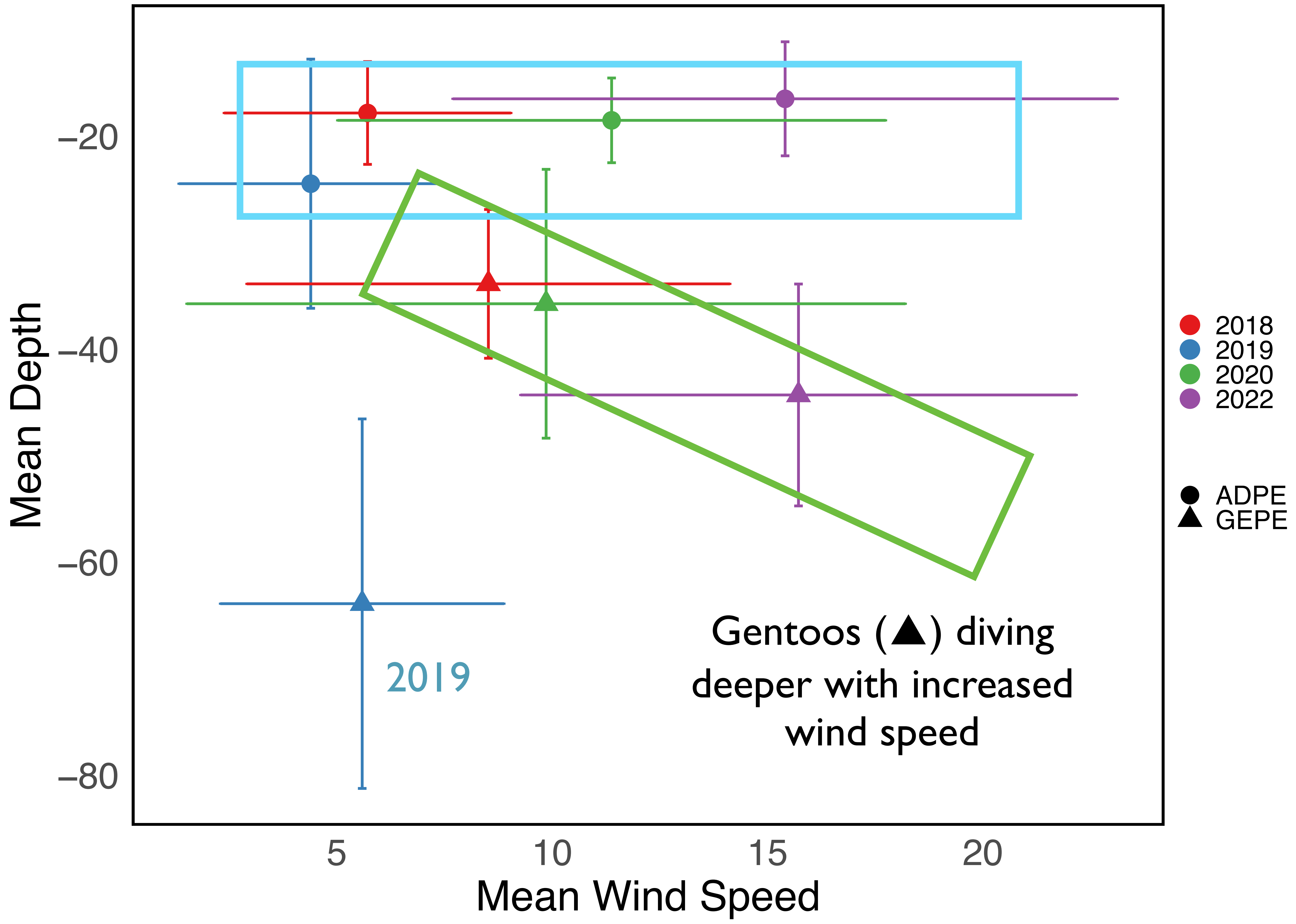
Lead: Evan Quinter (M.S., 2023, UDel)

(Quinter, 2023).

We are now expanding penguin dive analysis to multiple years

Darren Roberts, field hero.

Adelie's (●) dive depths don't show a strong response to wind increases



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An exception in 2019, where Salps were abundant in the foraging area

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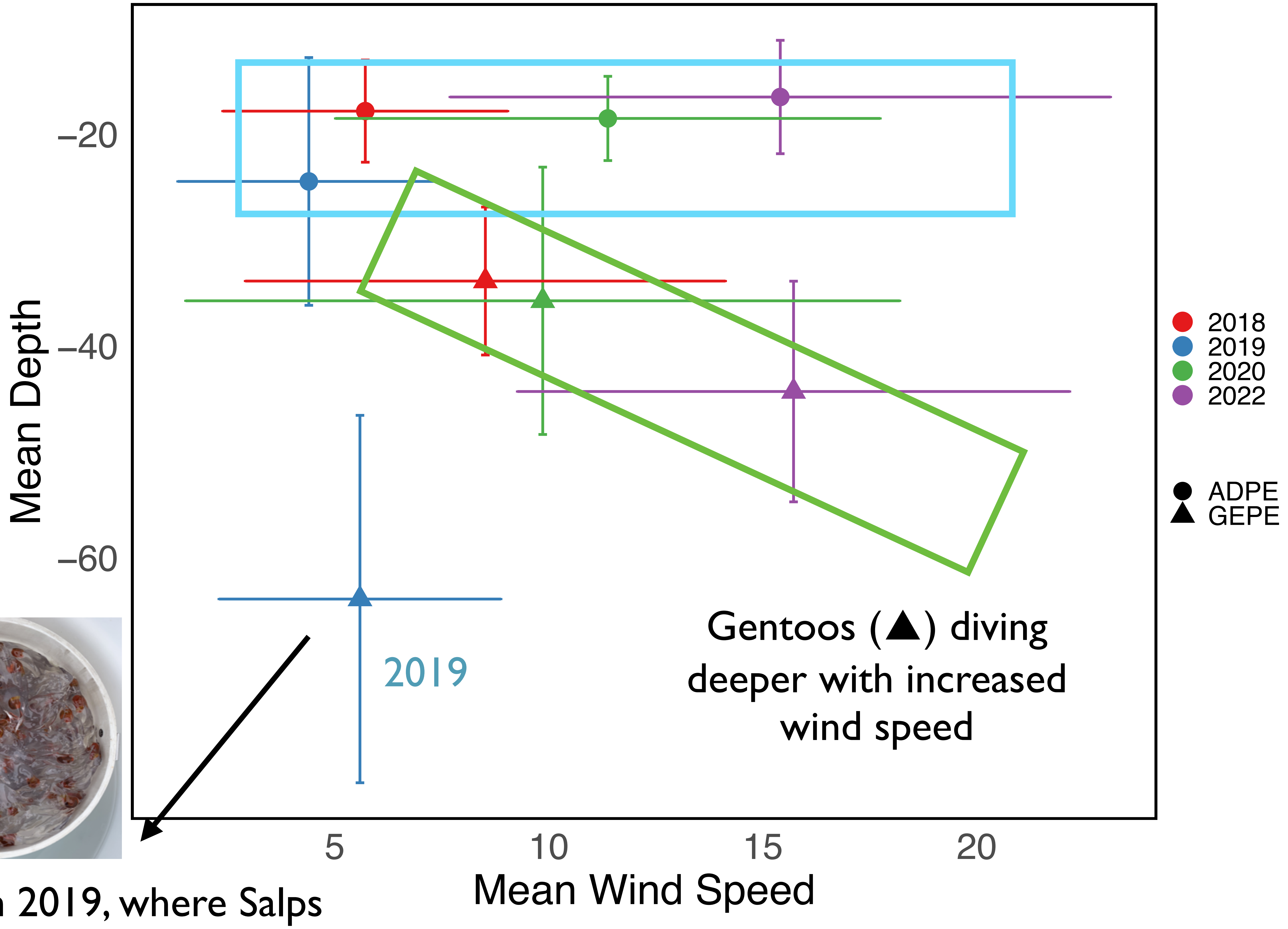


Gentoos (▲) diving deeper with increased wind speed

Conclusions Sub-Theme B3

- Observations resolving synoptic scales a big challenge!
- We are deploying a glider to Palmer Station this season.
- We are prioritizing the analysis of acoustic data for prey distribution characterization.
- More to come!

Subtheme B1. Shifts in Upper Ocean Dynamics and Links to System Productivity

Hypotheses:

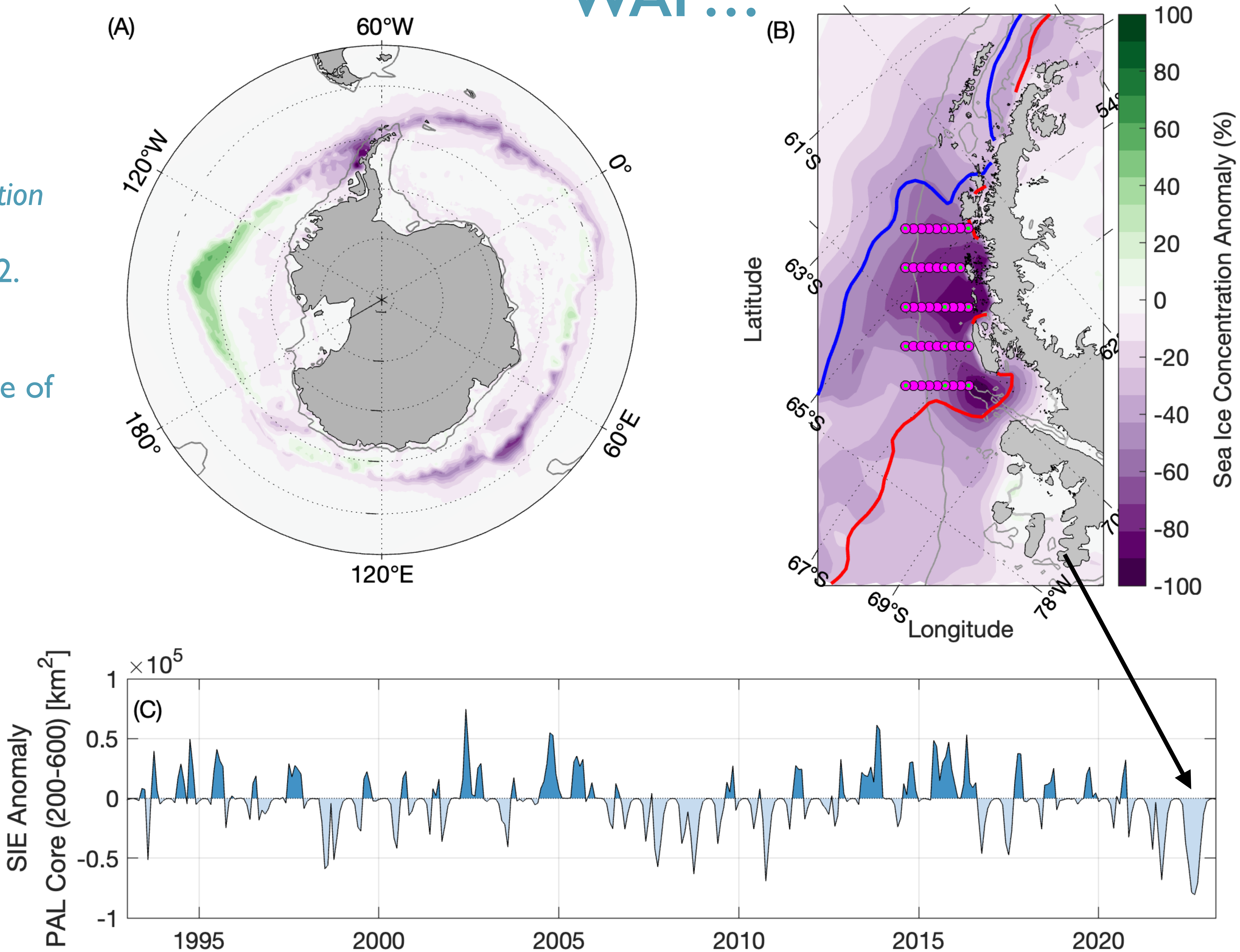
- *B1a: The competition between ice melt (from glaciers and sea-ice) and storm intensity (wind, precipitation) is a main driver of the synoptic-to-interannual variability in upper ocean structure (deep water ventilation, mixed layer depth, upper ocean stratification) along the WAP.*
- *B1b: By modulating upper ocean properties (B1a) and atmospheric forcing (cloudiness, air-sea fluxes), a climate-driven southward shift in storm activity is having a significant impact on variability of marine productivity along the WAP.*

An extreme 2022 sea ice minimum along the WAP…

Sea Ice *Concentration* Anomaly for September 2022.

Notice the circumpolar nature of the minimum.

This is the Sea Ice Extent Anomaly for the PAL "Core" Region



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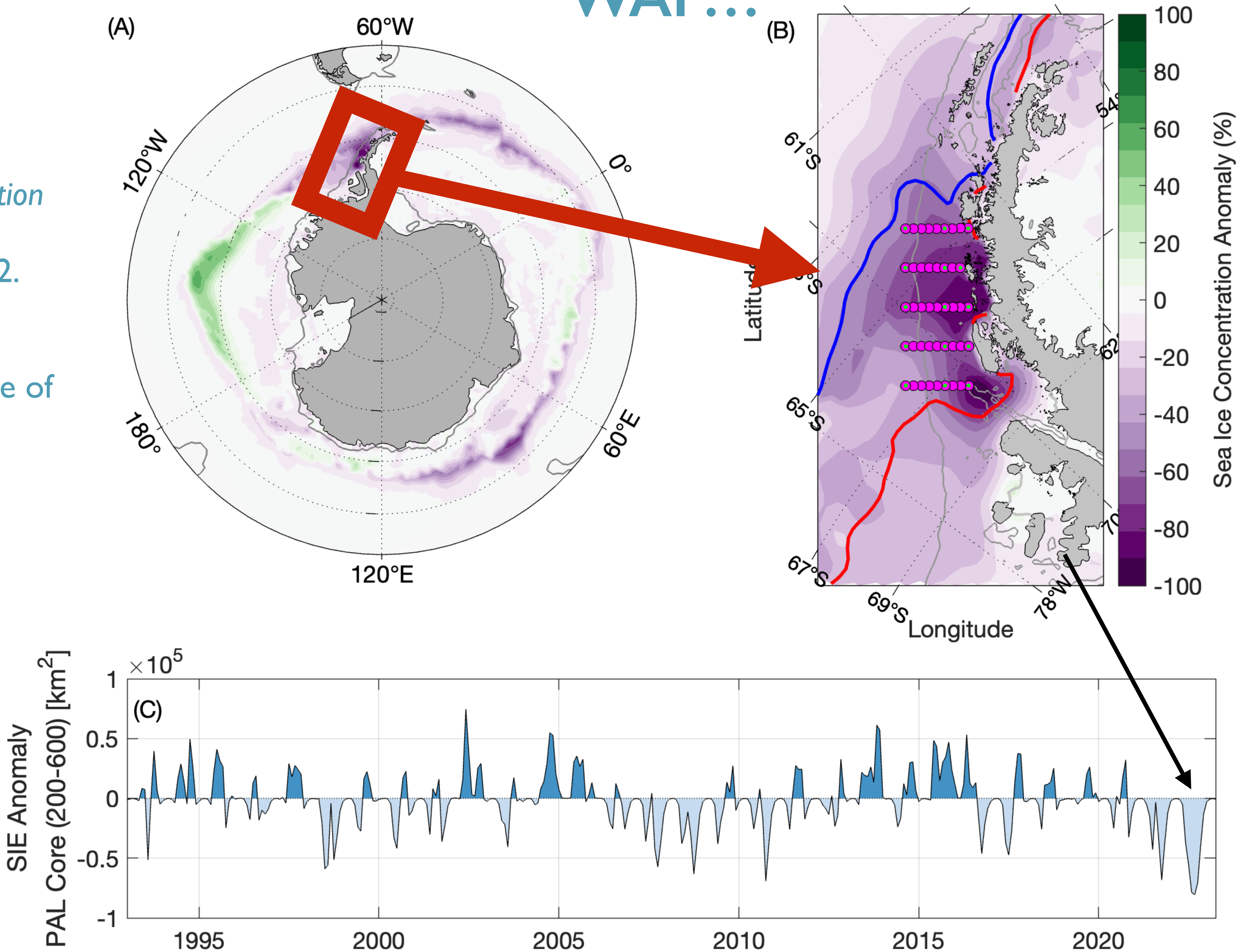
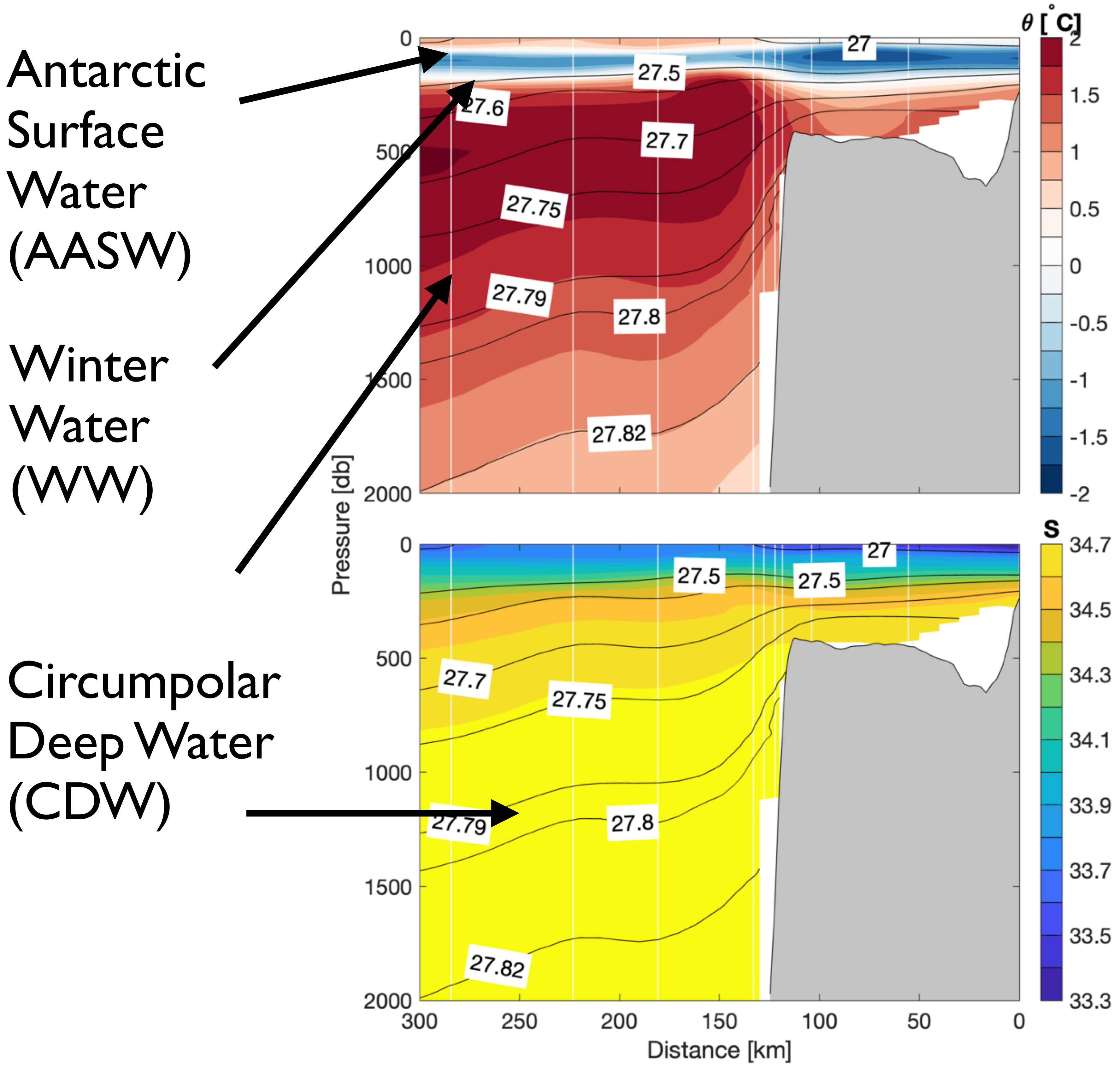
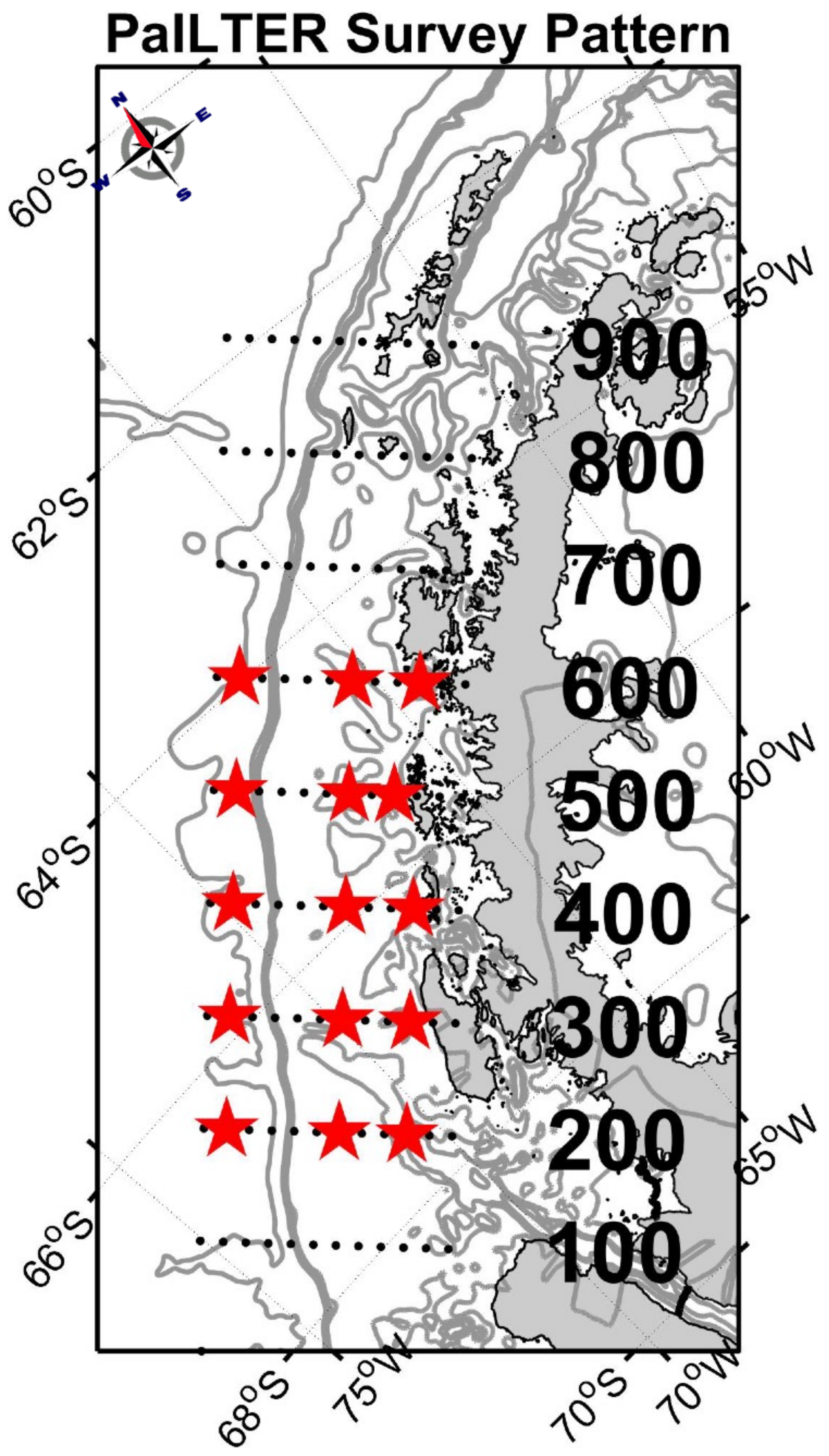
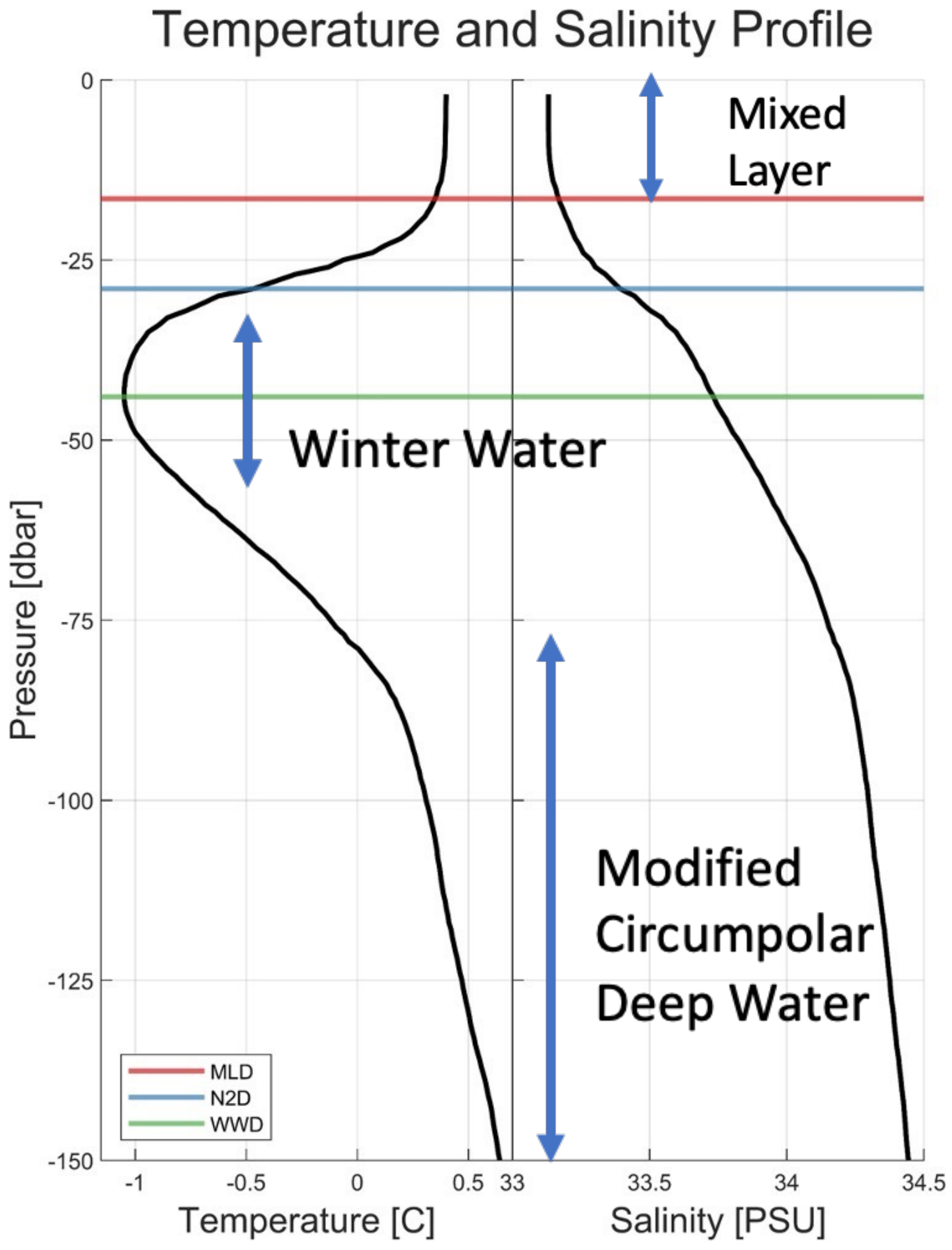


WAP Layering and Analysis



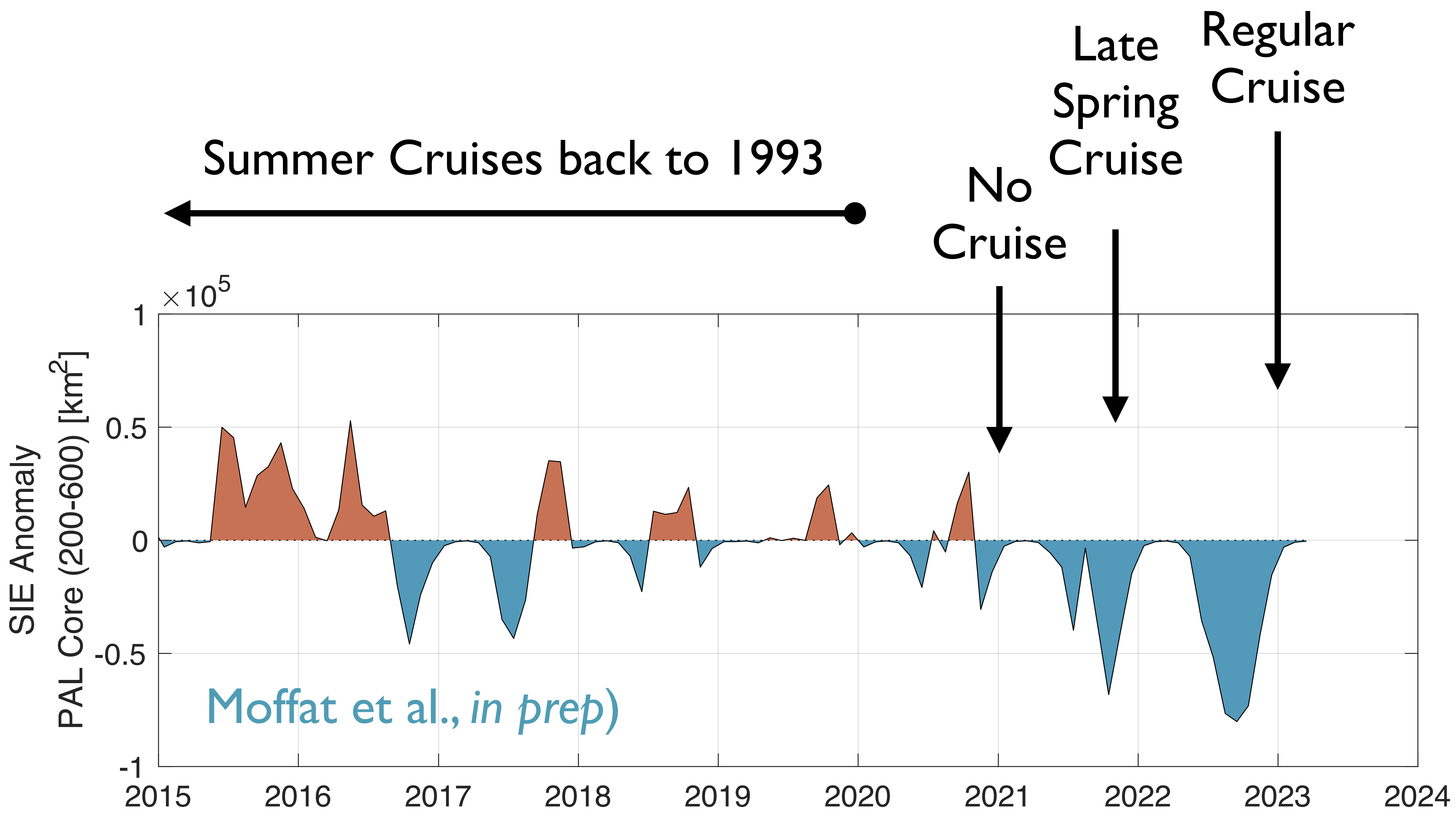




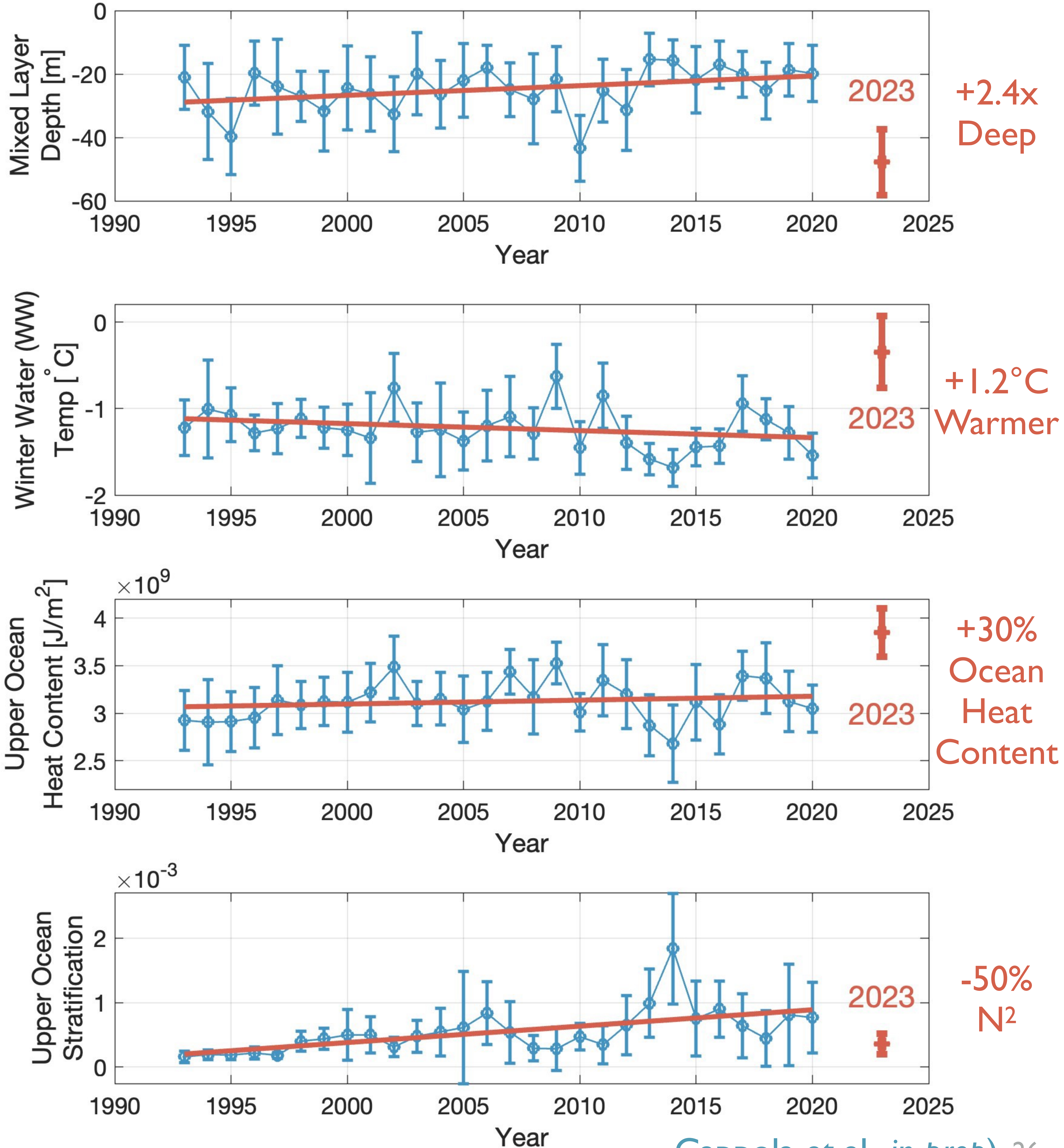
Lead: Michael Cappola (~~M.S.~~ Ph.D. Student, UDel)

- We have data going back to 1993, covering a "Core" set of stations. In PAL parlance, the 200 to 600 grid lines.
- Look at shelf-averaged bulk layer properties:
  - Mixed Layer Properties: Depth, Salinity, Temp
  - Winter Water Temperature and Depth
  - Stratification
  - Heat Content (0-300 m and "deep", below Winter Water)
  - More on this later from M. Cappola.

What happened in Summer 2023?

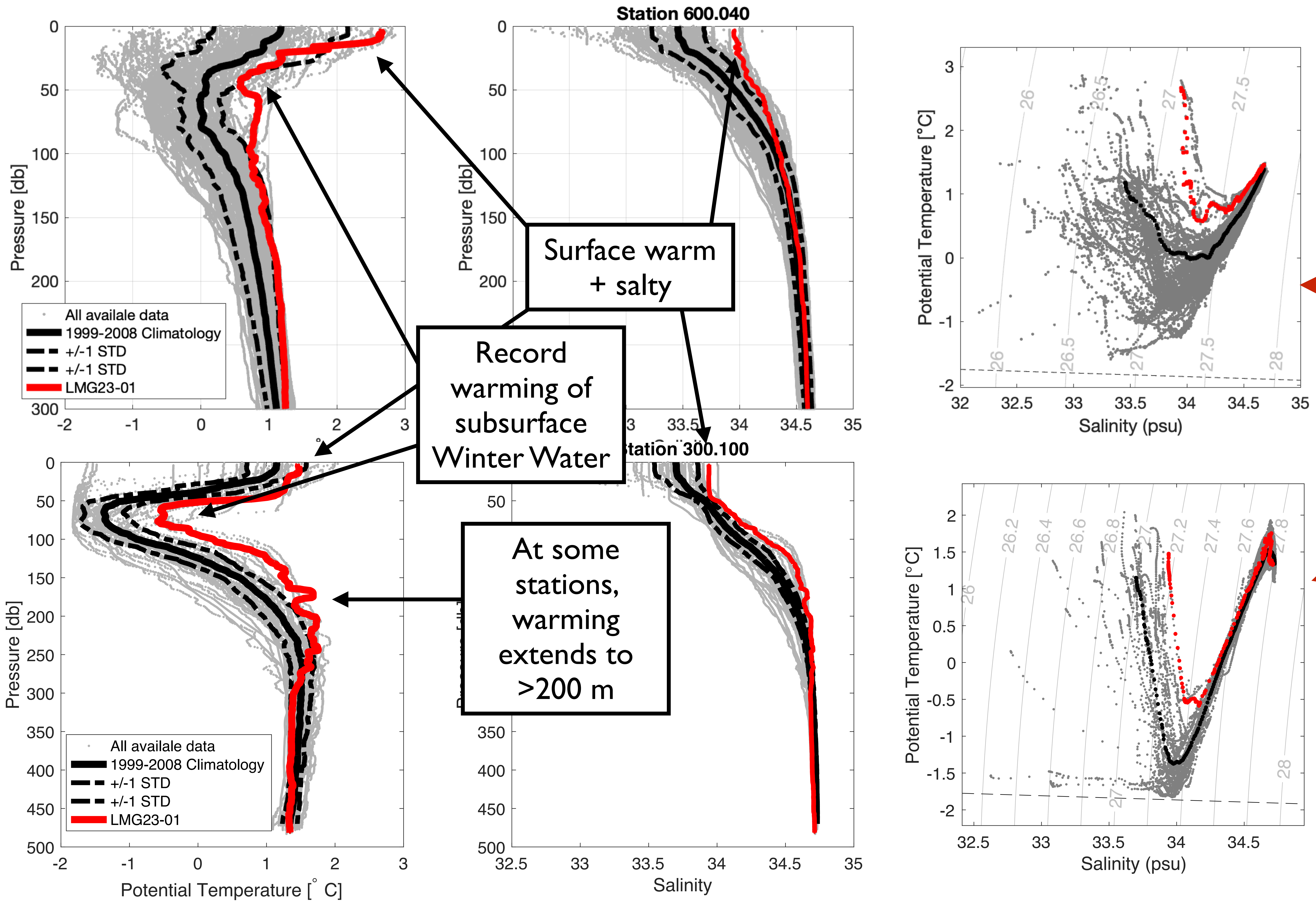


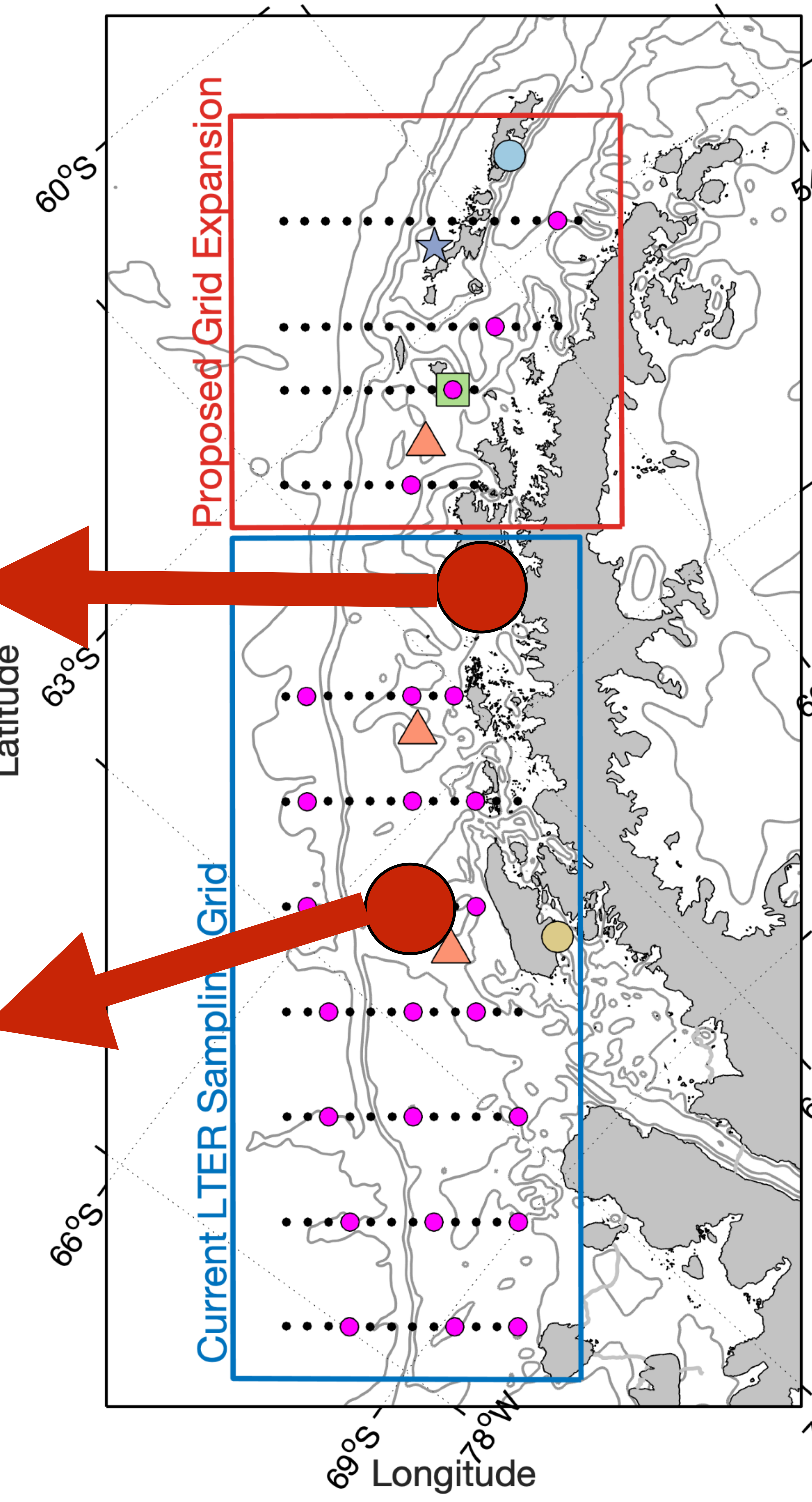
- After the record low sea ice in 2022, Summer 2023 brought record-high:
  - Ocean heat content (0-300 m)
  - Mixed-layer depth (>40 m)
  - Record-high Winter Water (subsurface water mass) temperature - a significant subsurface Marine Heat Wave.
  - …and weak stratification.



Cappola et al., *in prep*)

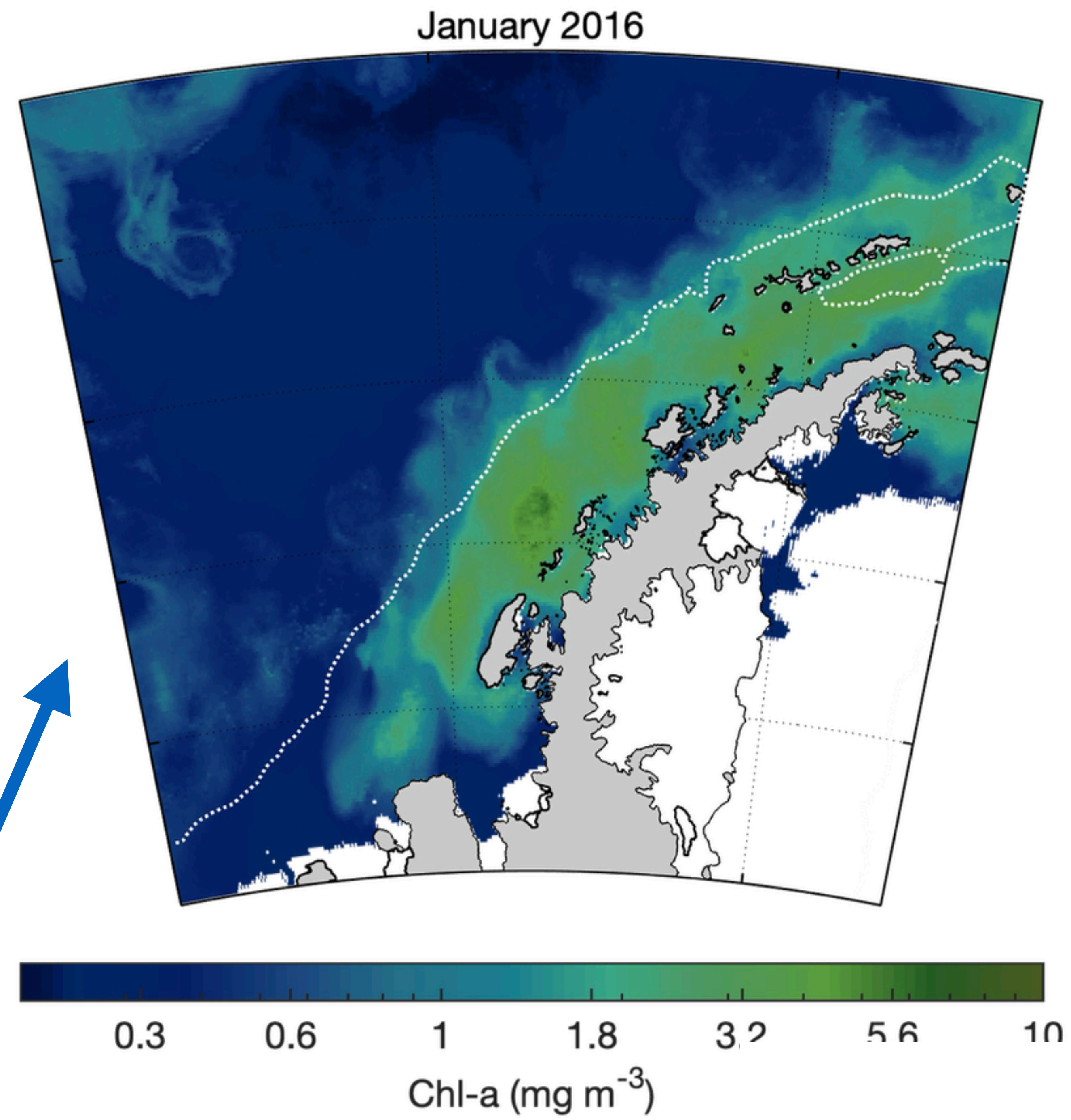
A dramatic, subsurface Marine Heat Wave in summer 2023… but how did it develop?





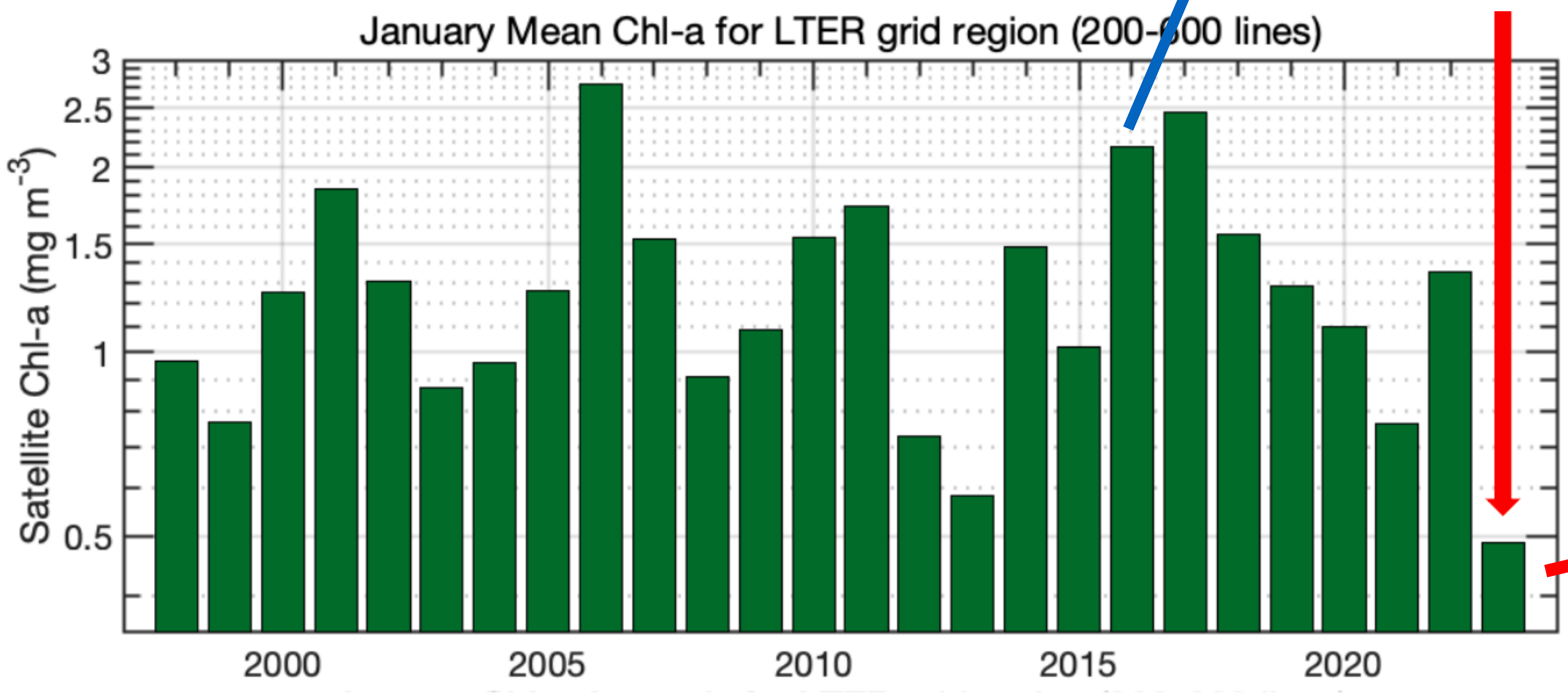
Ecosystem Impacts of 2022/23 Ice Minimum/MHW: Record low surface ChL in Jan 2023.

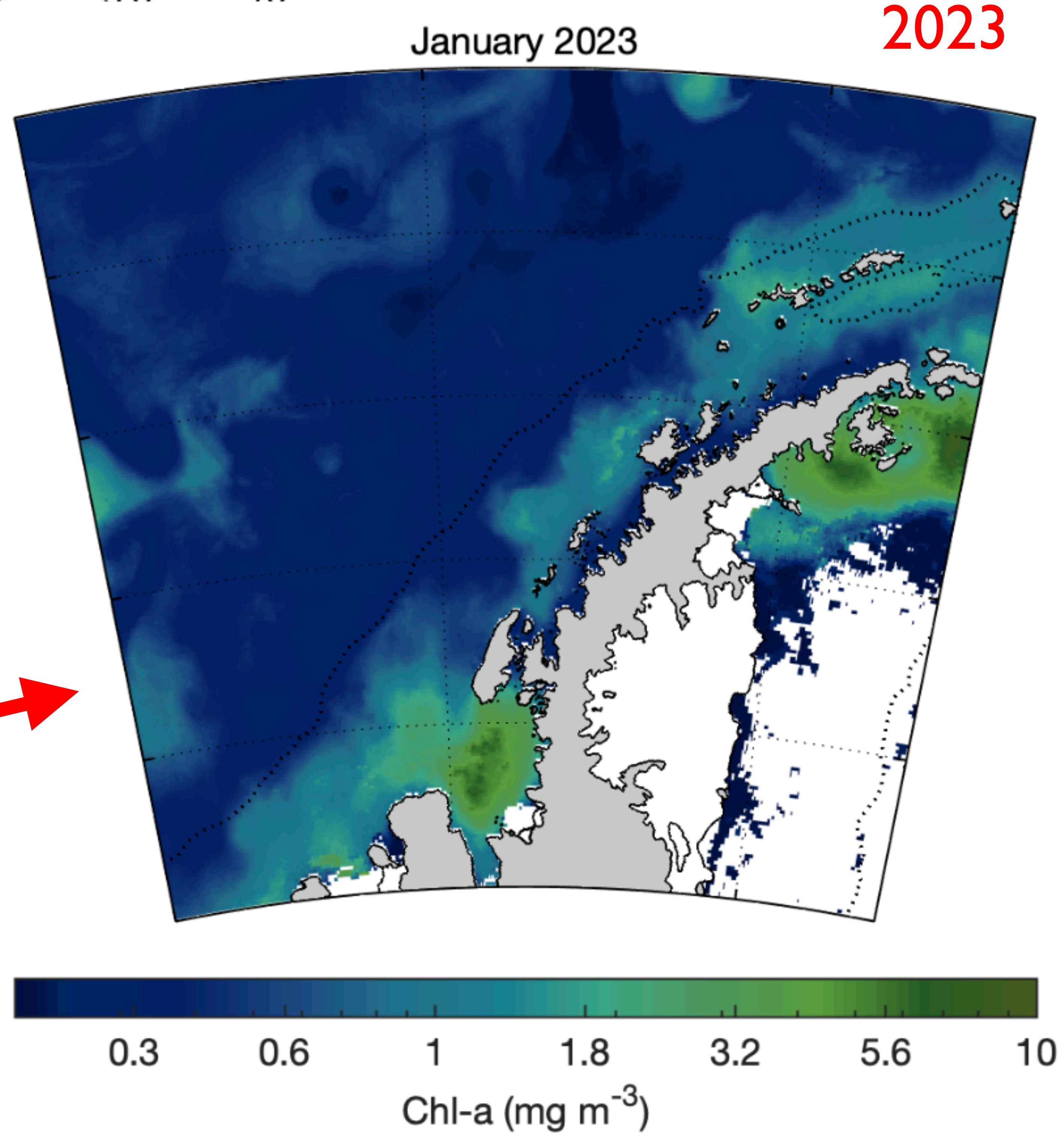
January 2016



January 2023

2023



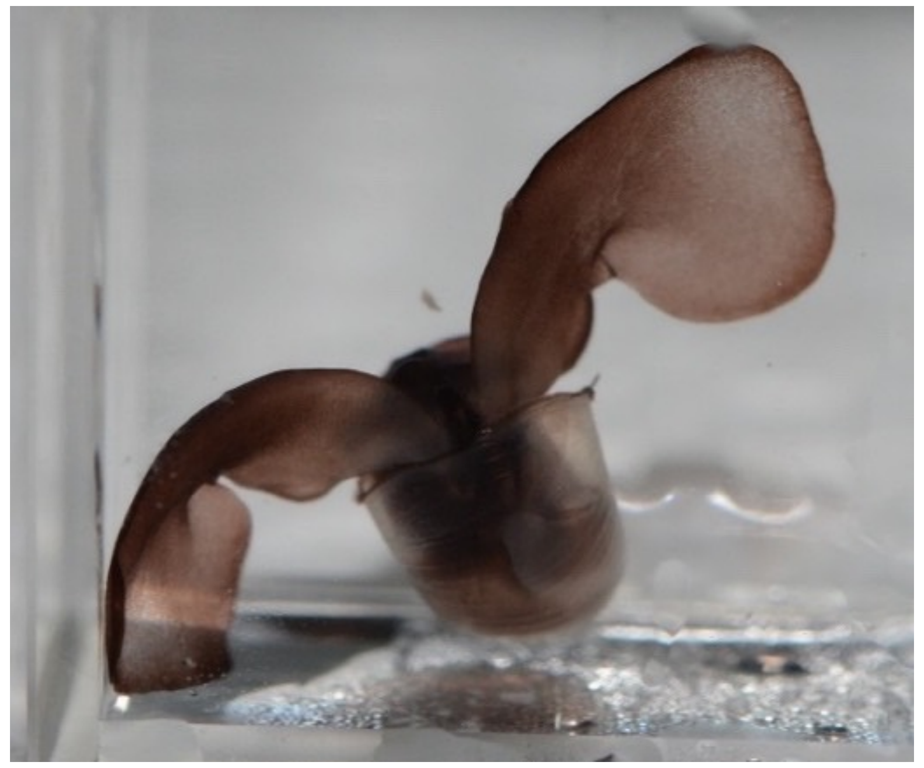


(Analysis by J. Turner, UConn)

Product: CMEMS GlobColour.

Effects of recent and unprecedented warming and low sea ice on zooplankton

Big year for pteropods in 2023!



Maya Thomas

Tricia Thibodeau

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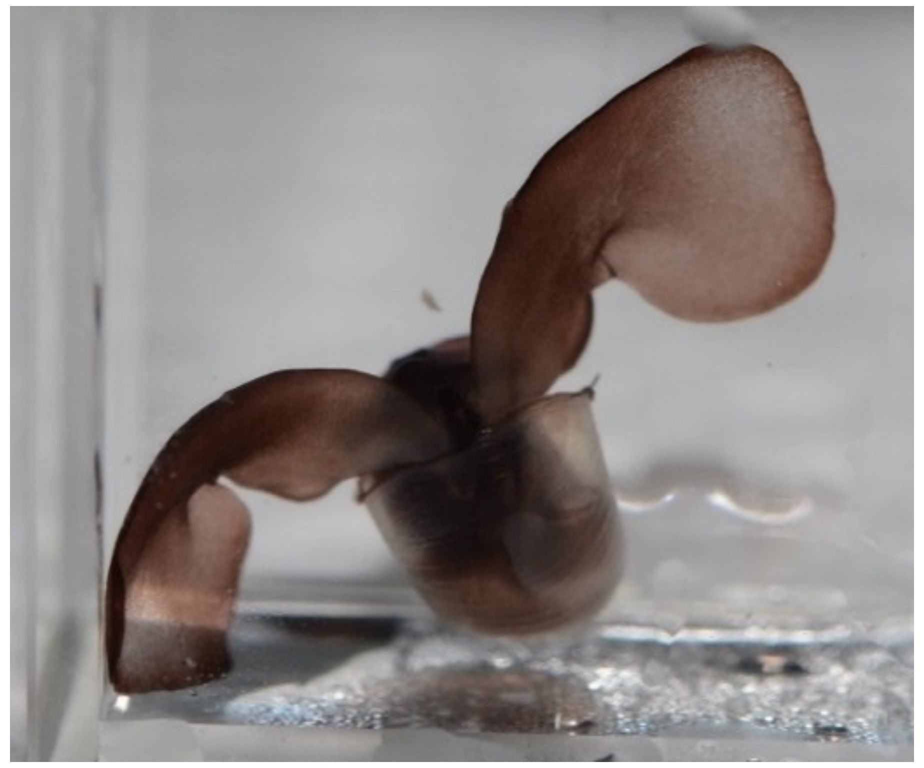

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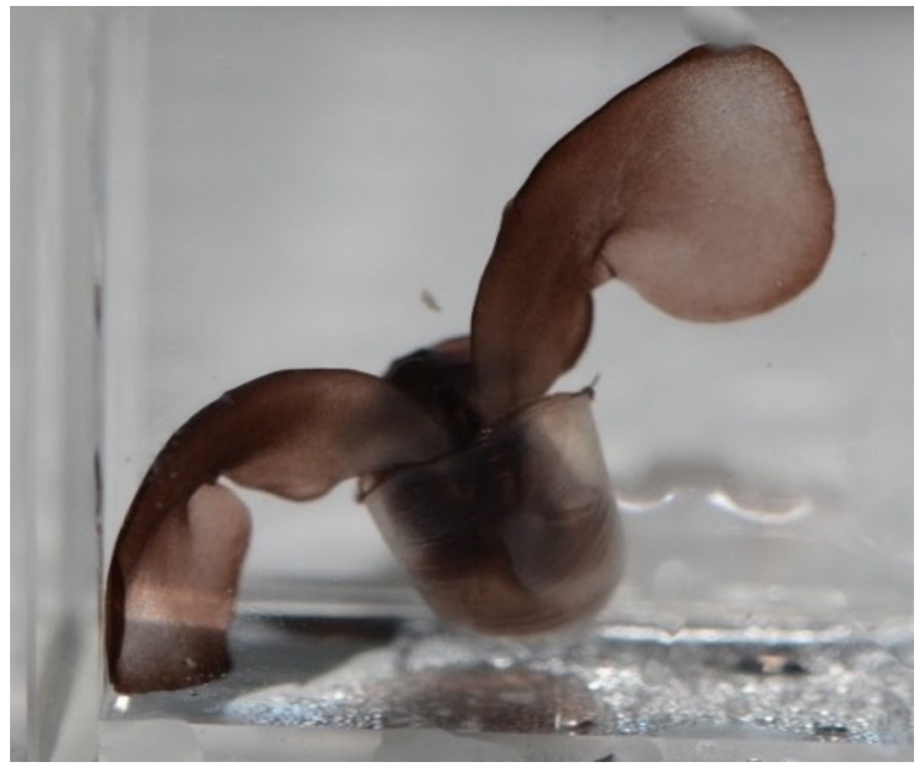
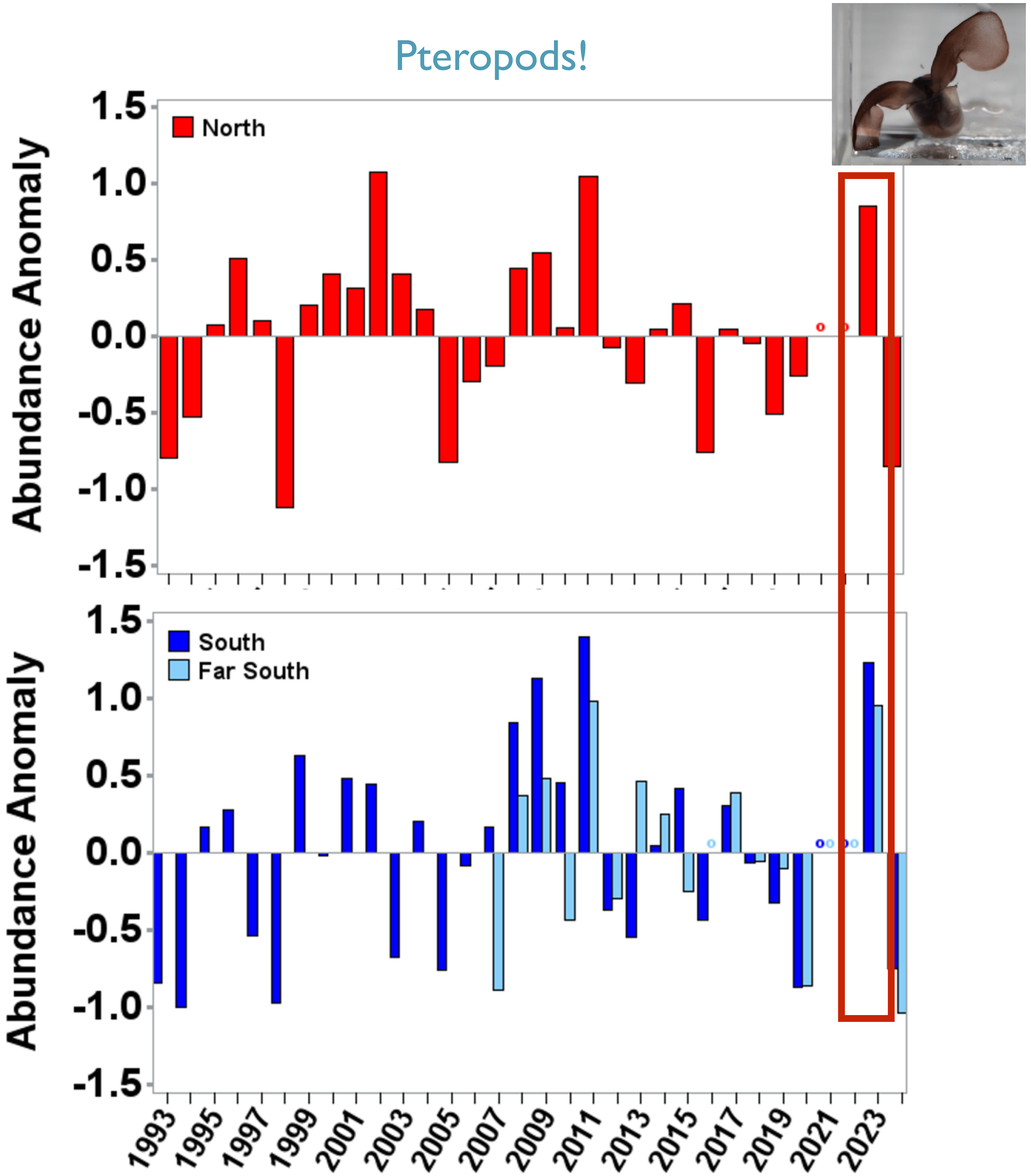
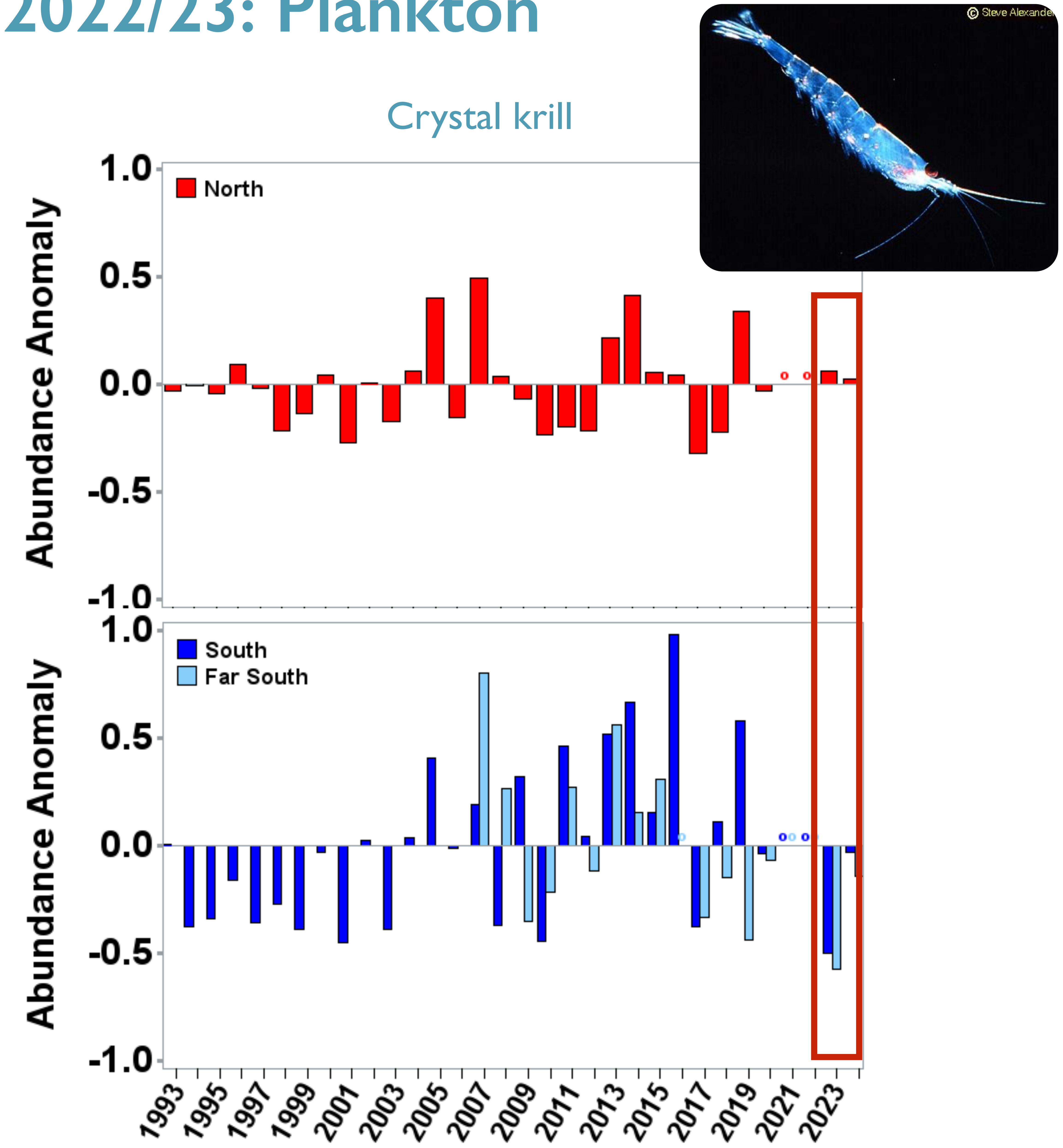


Maya Thomas

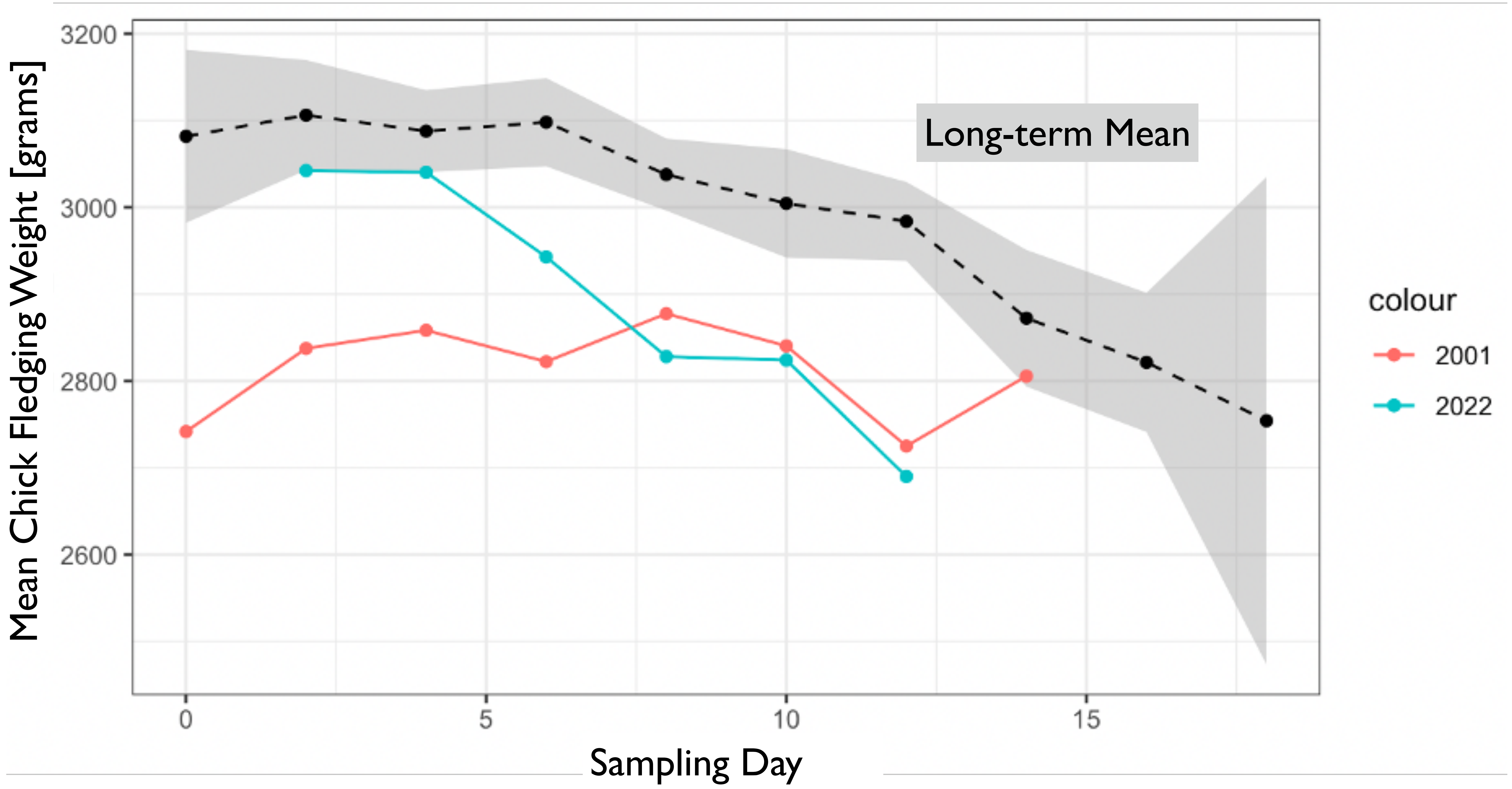
Tricia Thibodeau

Ecosystem impacts of the combined Sea Ice Minimum/ Marine Heat Wave of 2022/23: Plankton



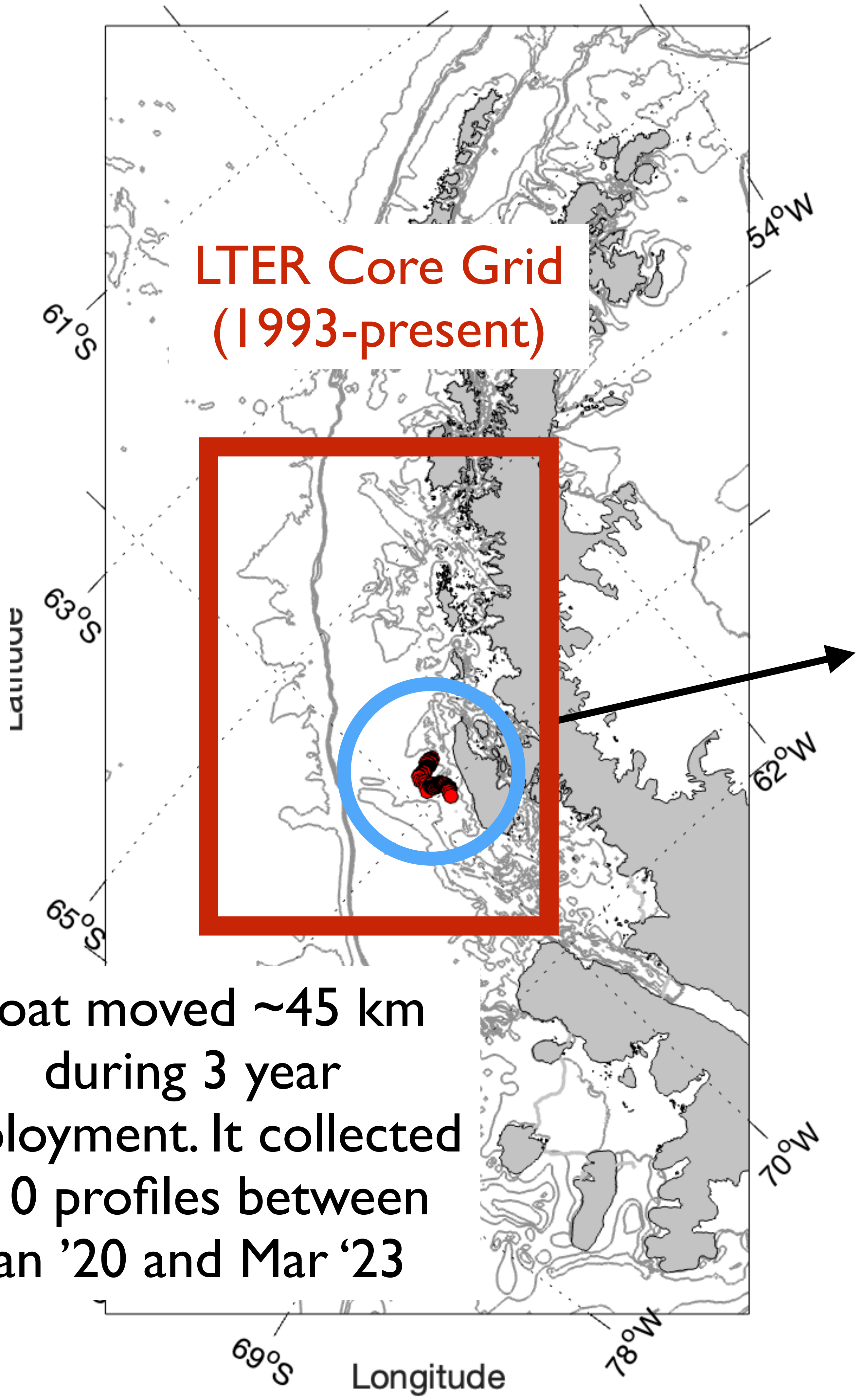


Ecosystem impacts of the combined Sea Ice Minimum/Marine Heat Wave of 2022/23: Adelie Penguins



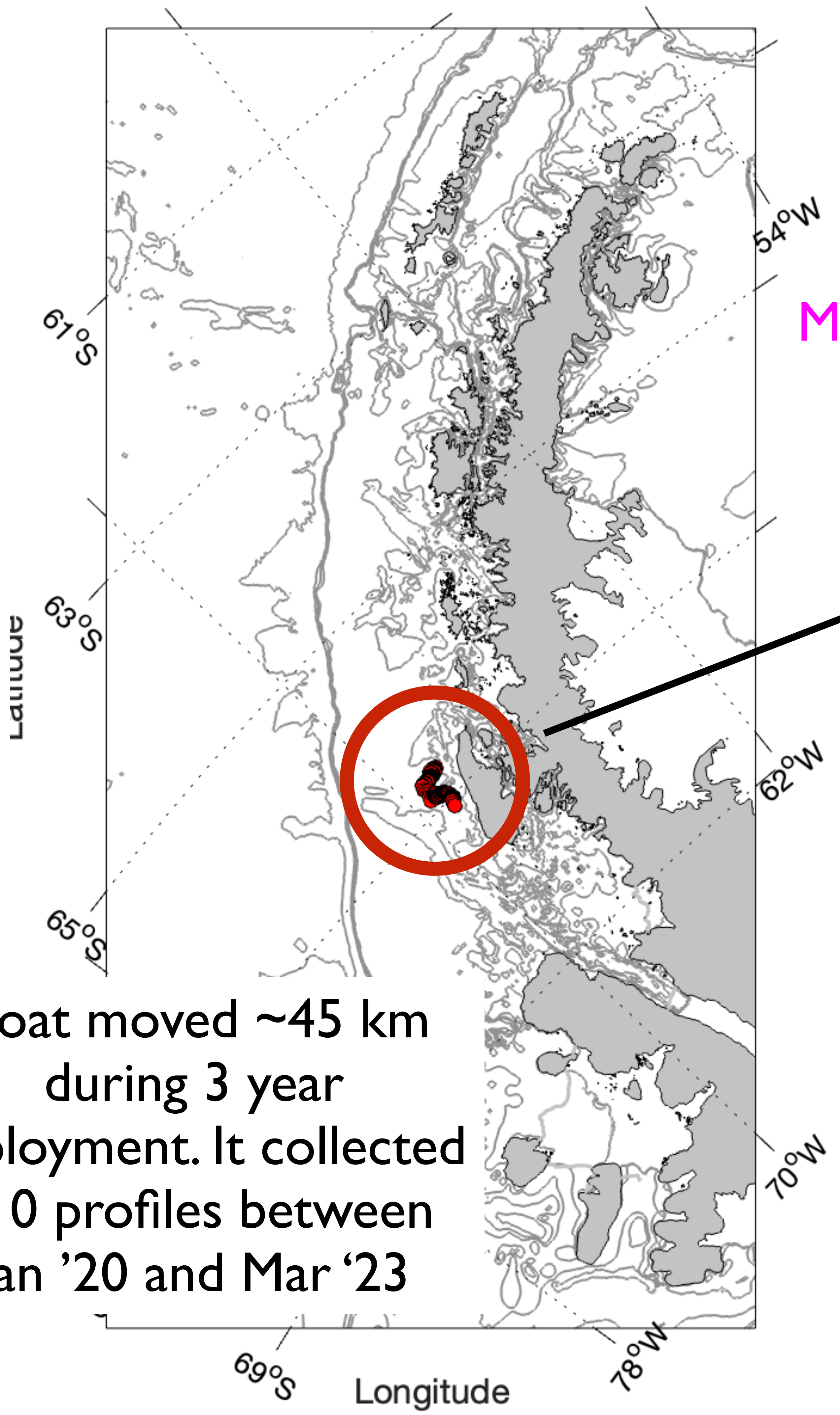
In 2022/23, Adelie penguins at Palmer Station had the **second lowest chick fledging mass since 1991.**

ARGO Float deployed near the center of the PAL Core Grid by the British Antarctic Survey (BAS)

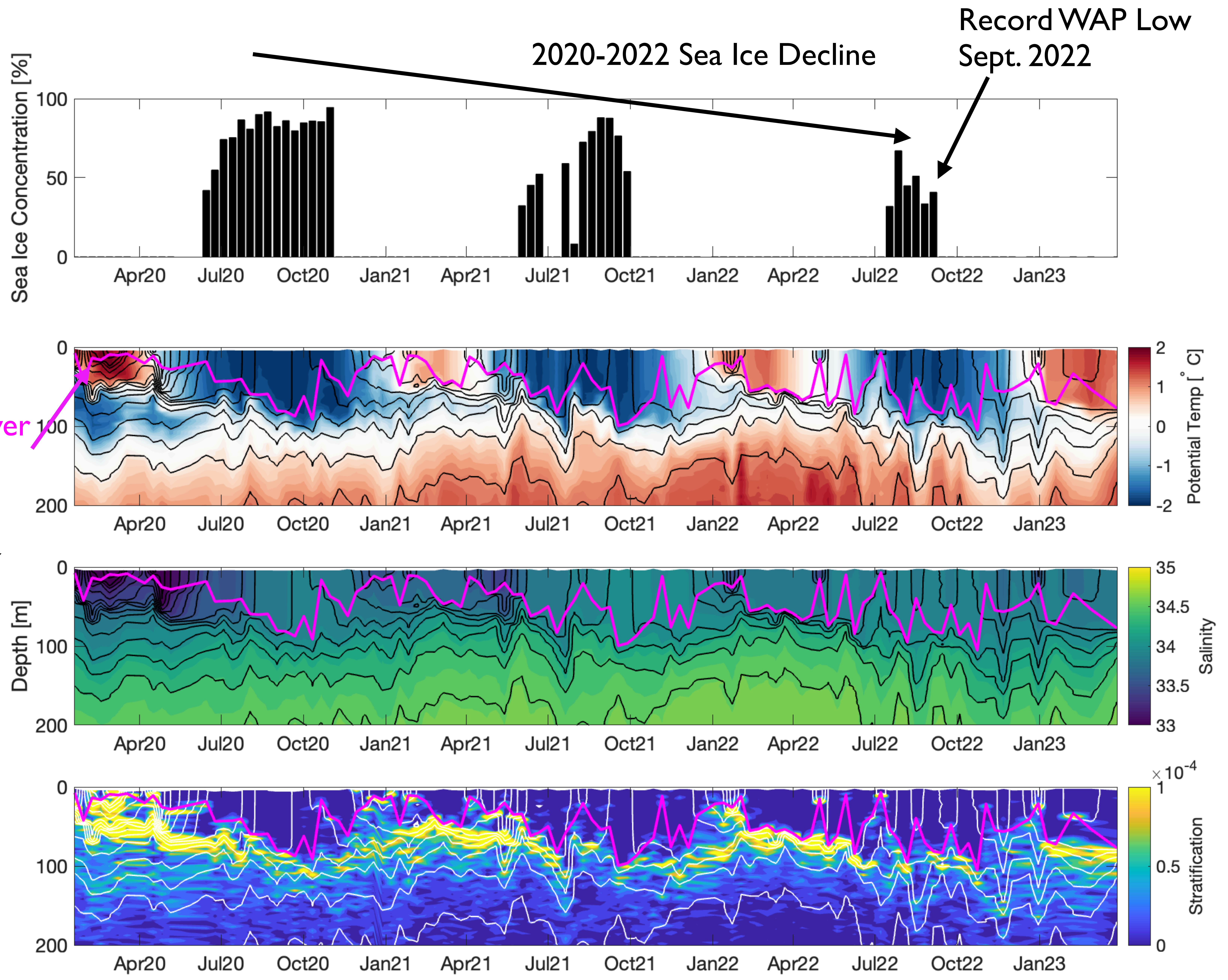


- ARGO Floats have recently been deployed to Antarctic shelves.
- A handful of successful experiments show they can be used as "virtual moorings".
- Only way to get year-round, full-depth profiles.
- A BAS float provided critical data during the "COVID Gap".

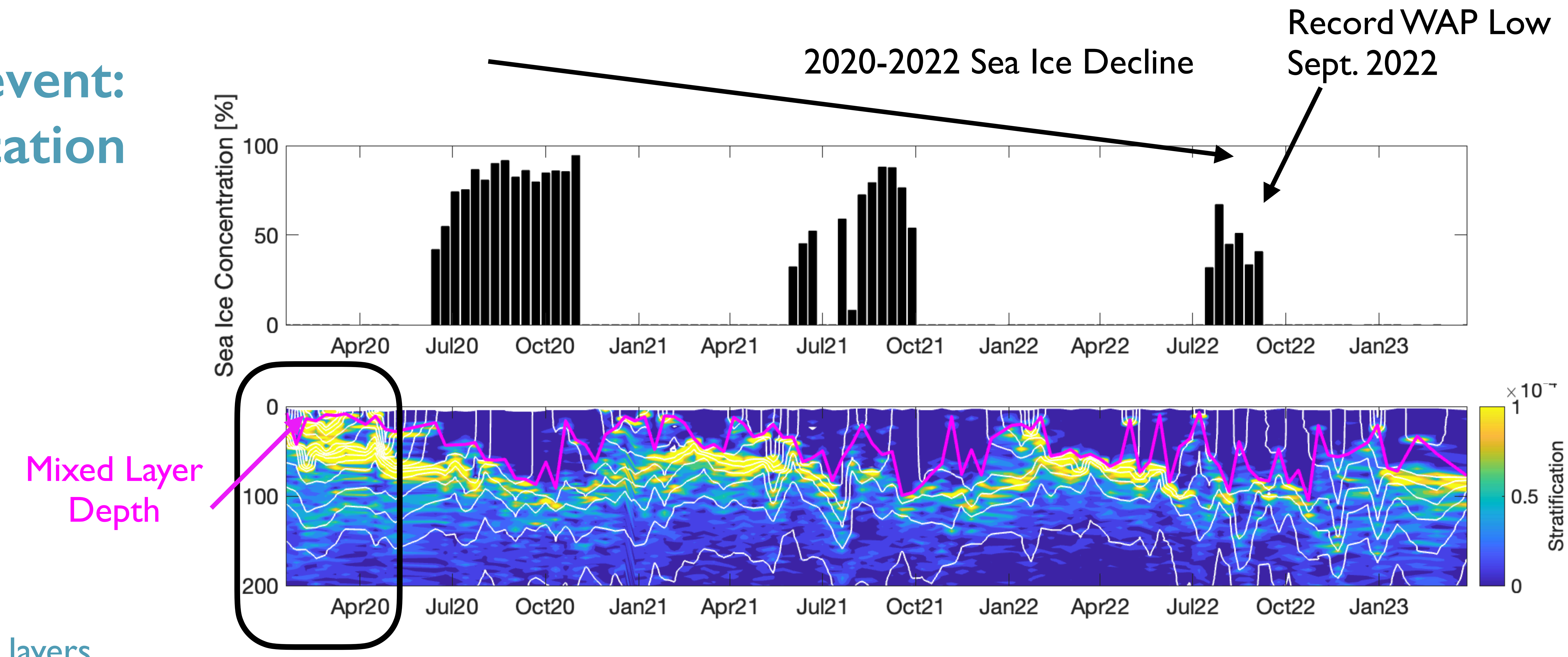
ARGO Float deployed near the center of the PAL Core Grid by the British Antarctic Survey



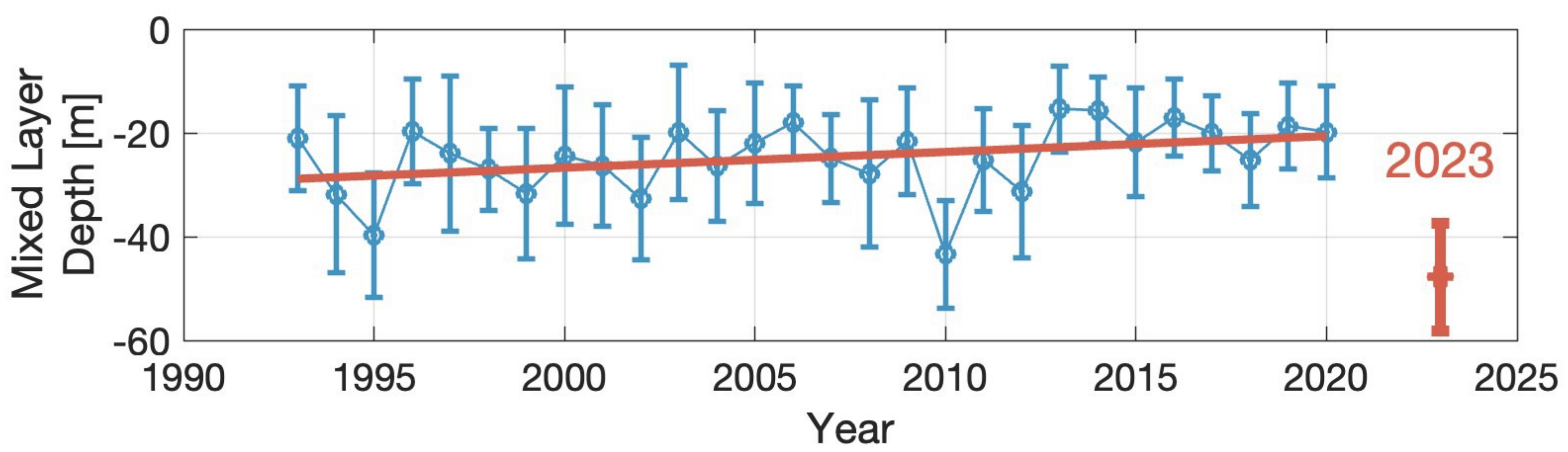
Float moved ~45 km during 3 year deployment. It collected 110 profiles between Jan '20 and Mar '23

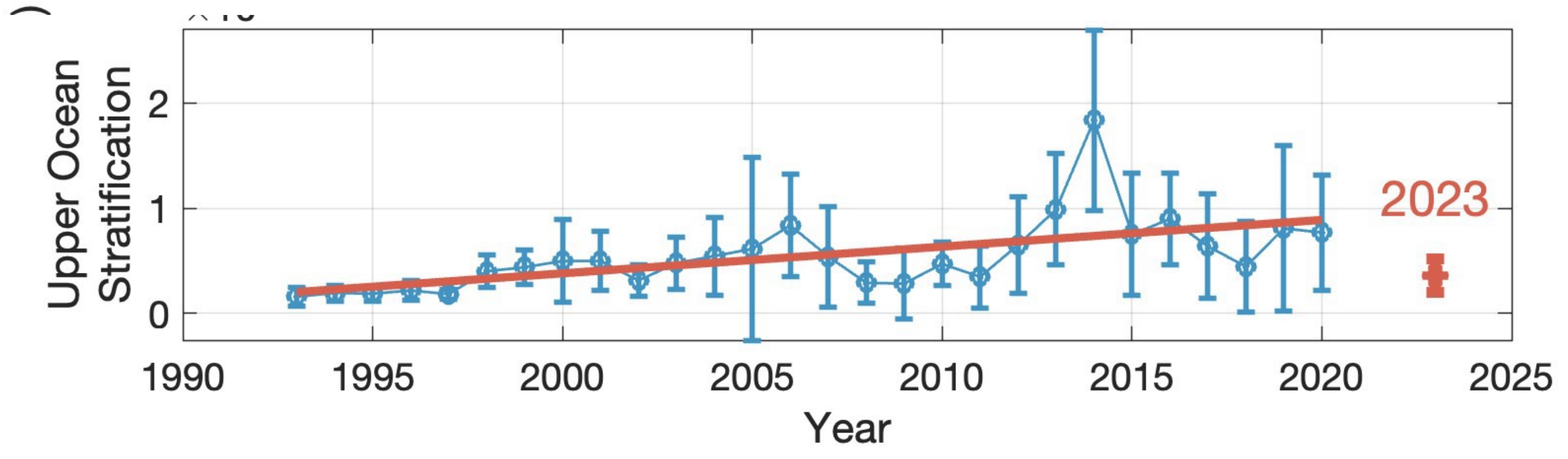


Steps to an extreme event: (I) Weakening stratification in Spring 2020



Long-term trend: shallower mixed layers and stronger stratification:





The sustained shallow mixed layer and highly stratified surface waters did not reappear in 2021 or 2022

Over the next two years, reversal of long-term trends:

- deeper mixed layers
- lower stratification
- increasingly intense events of warm deep water ventilation.

Moffat et al., *in prep*

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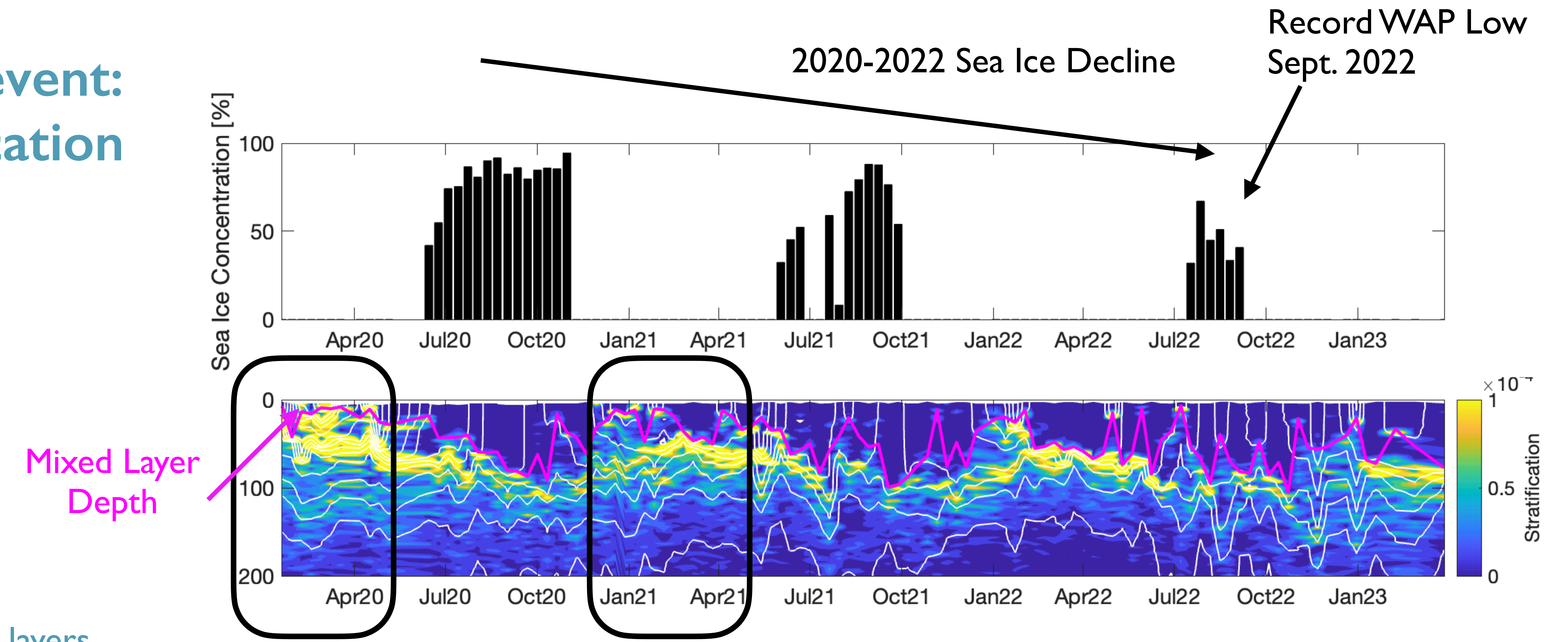

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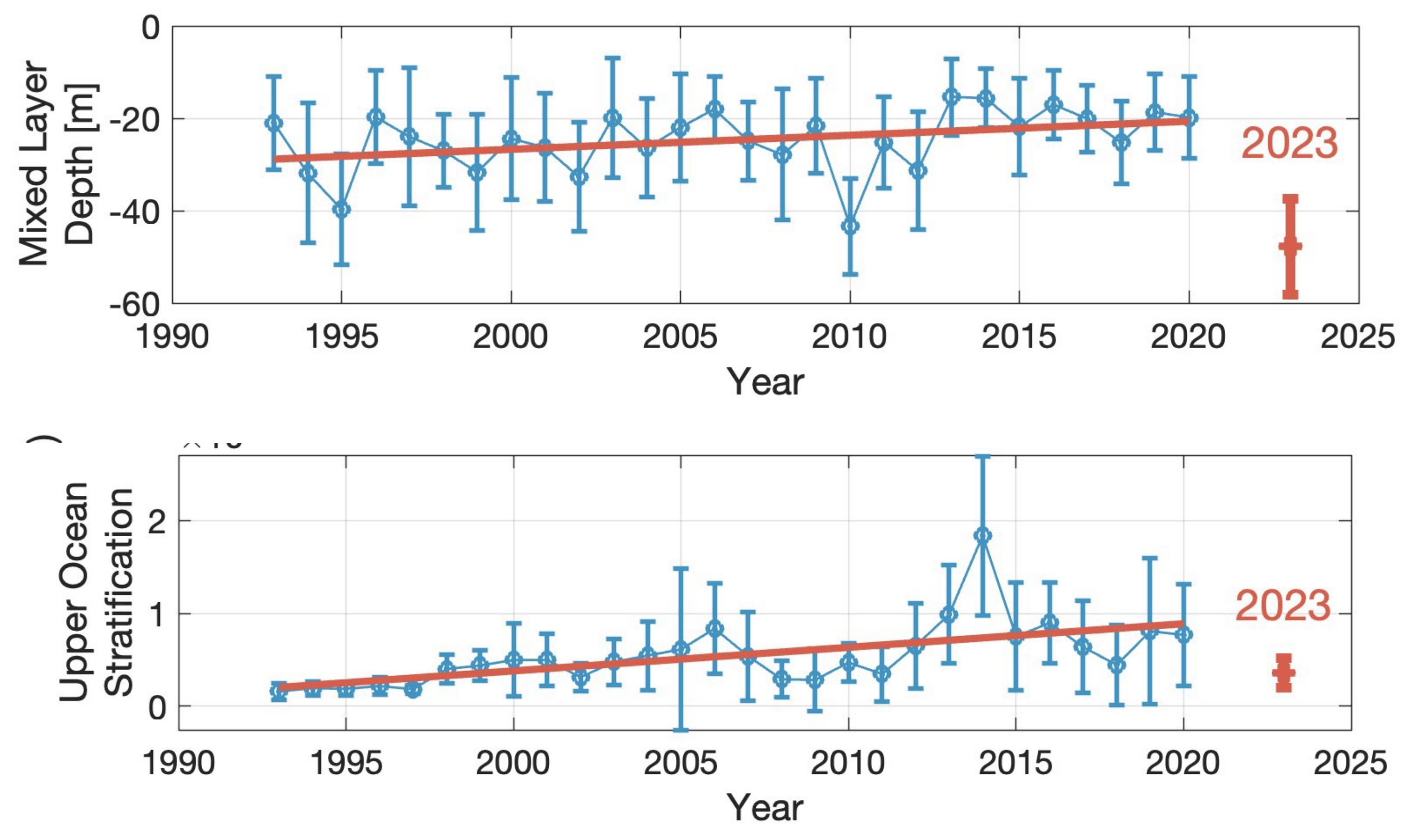

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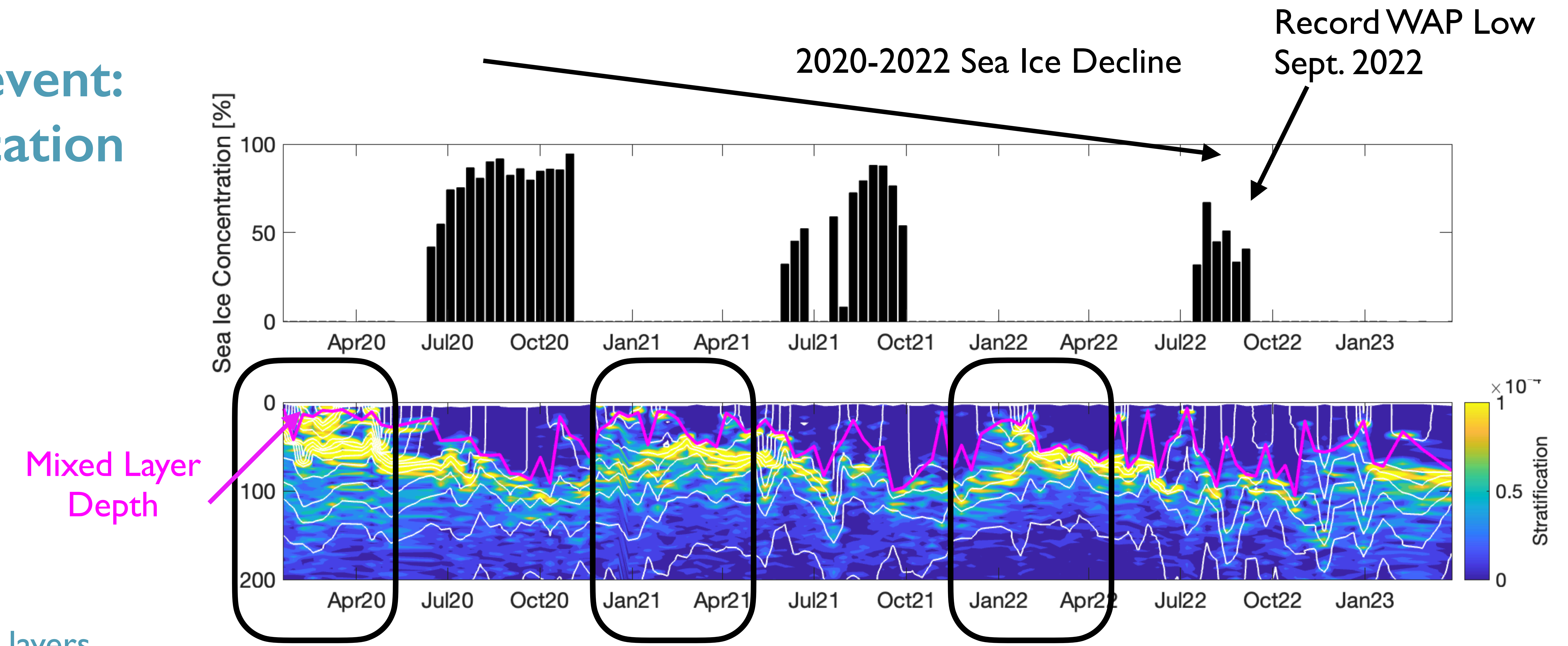

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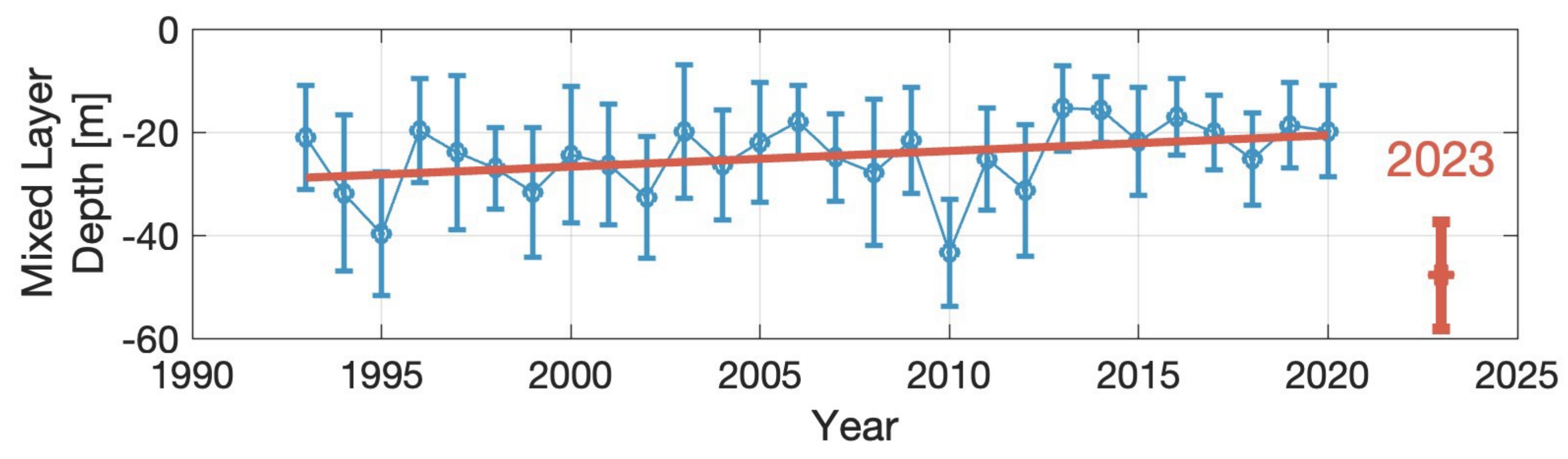

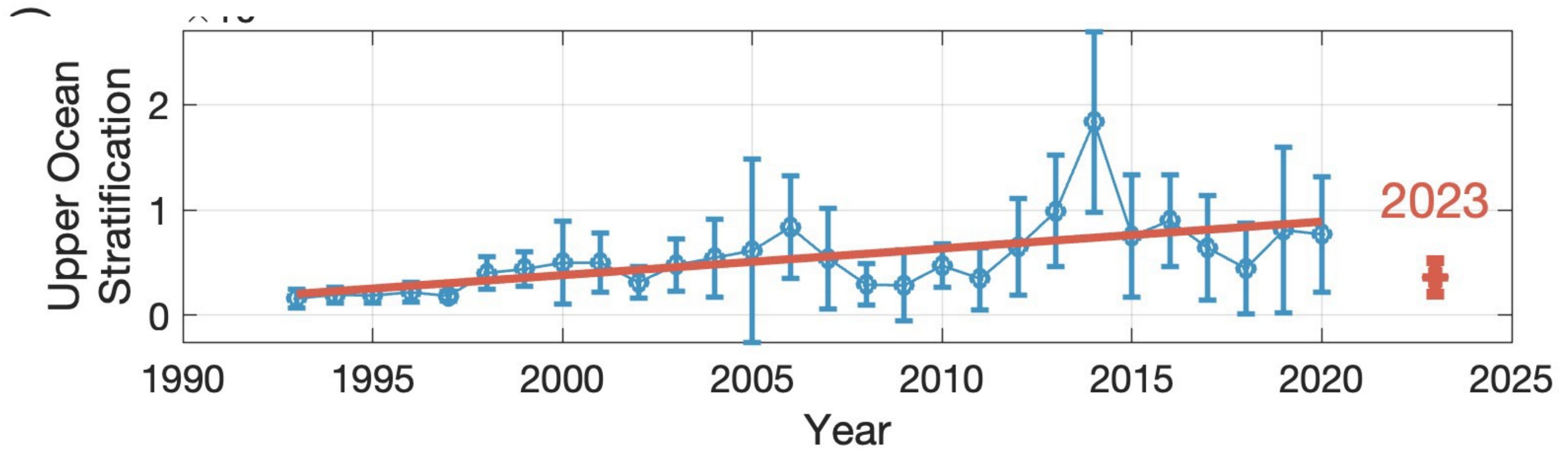

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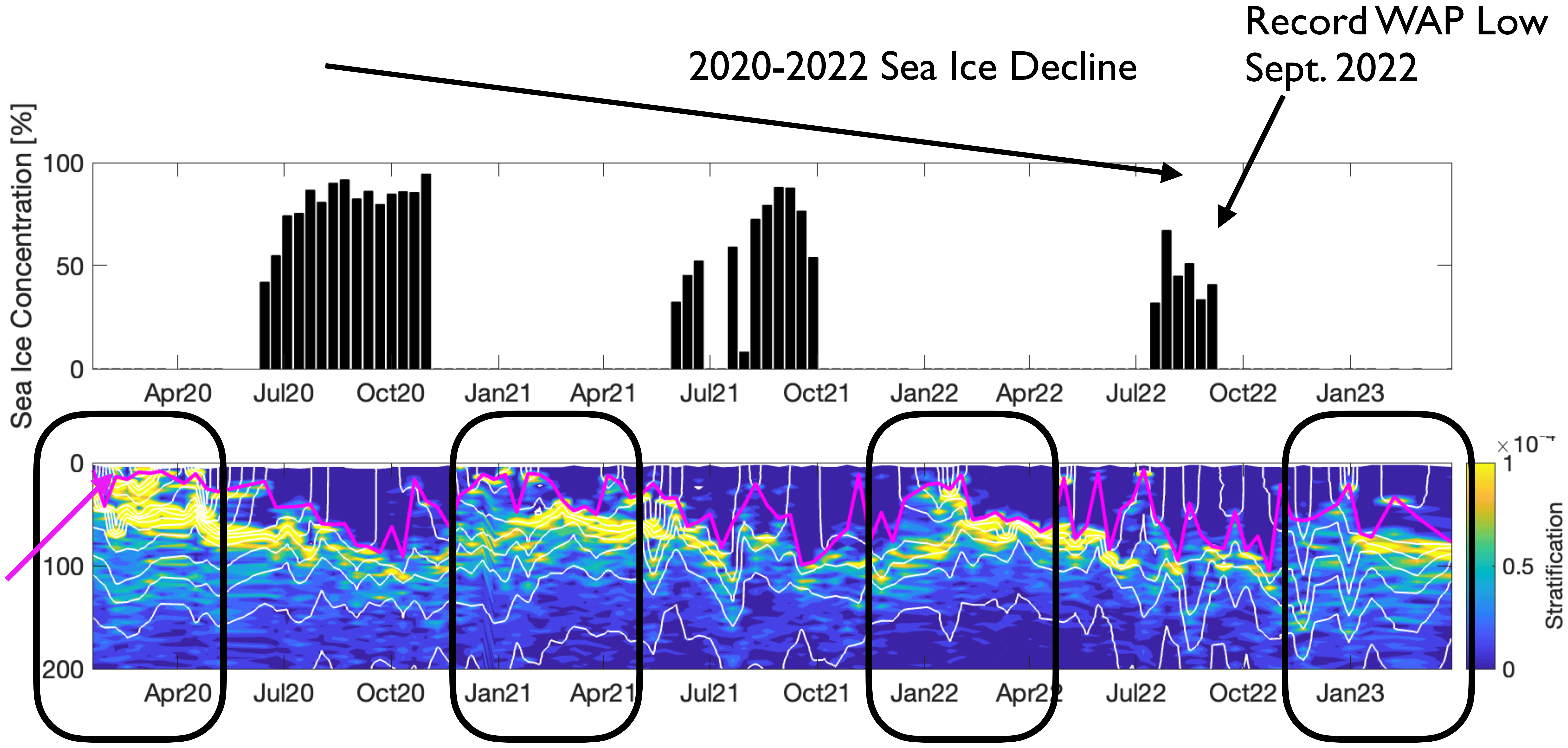

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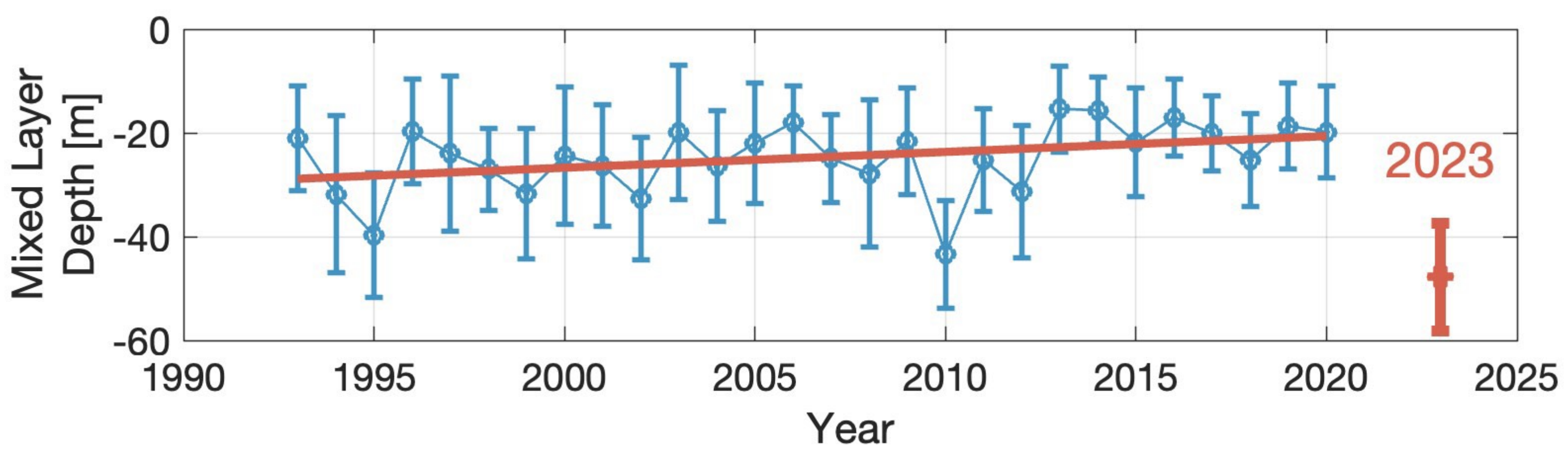

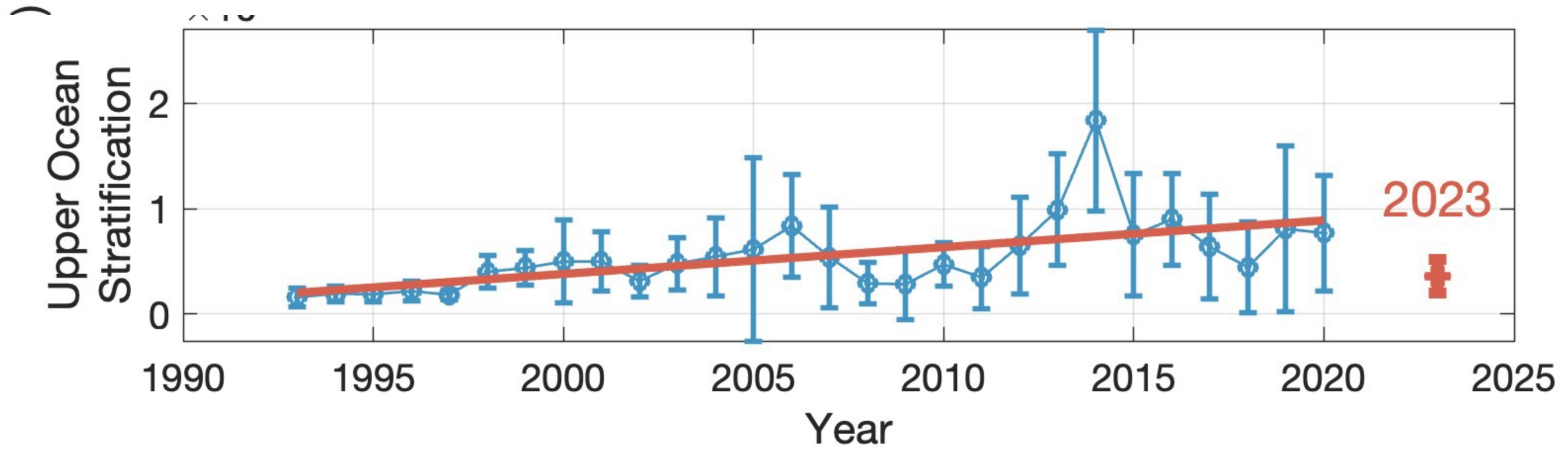

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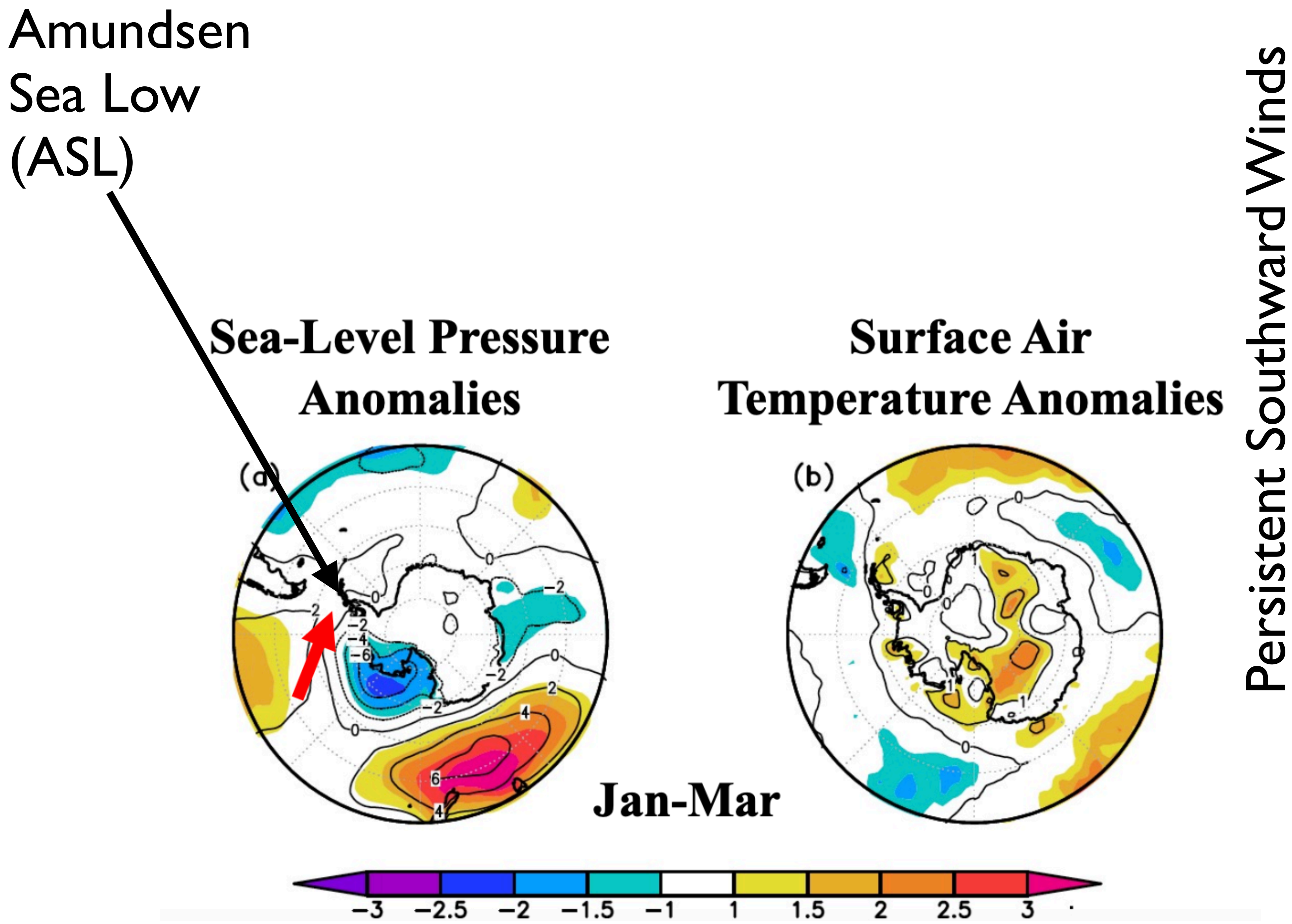
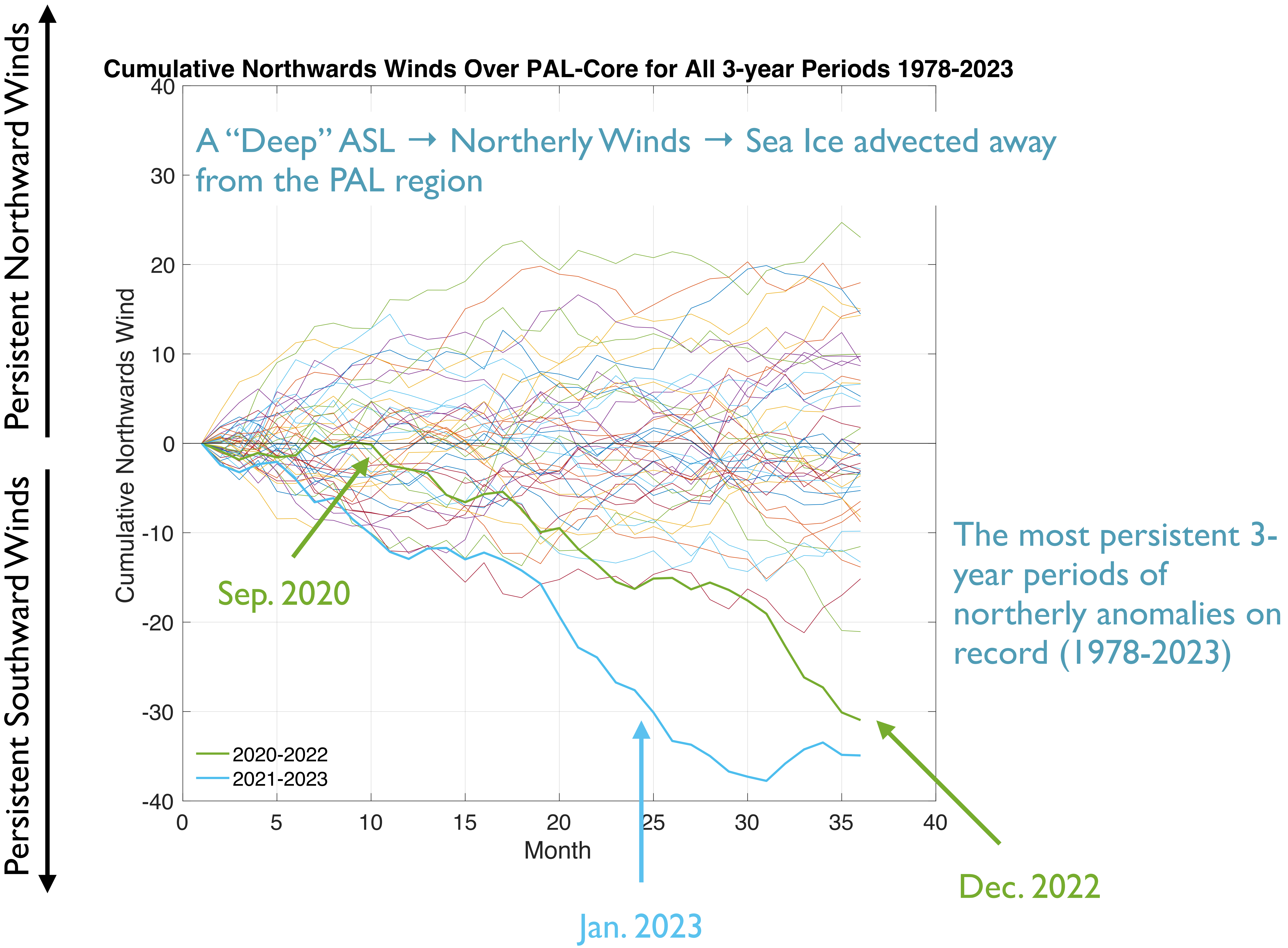
Moffat et al., *in prep*

Steps to an extreme event: (2) Winds over the WAP shelf were *persistently from the north from Spring 2020 to mid 2023**

The **most persistent 3-4 year period since 1978*

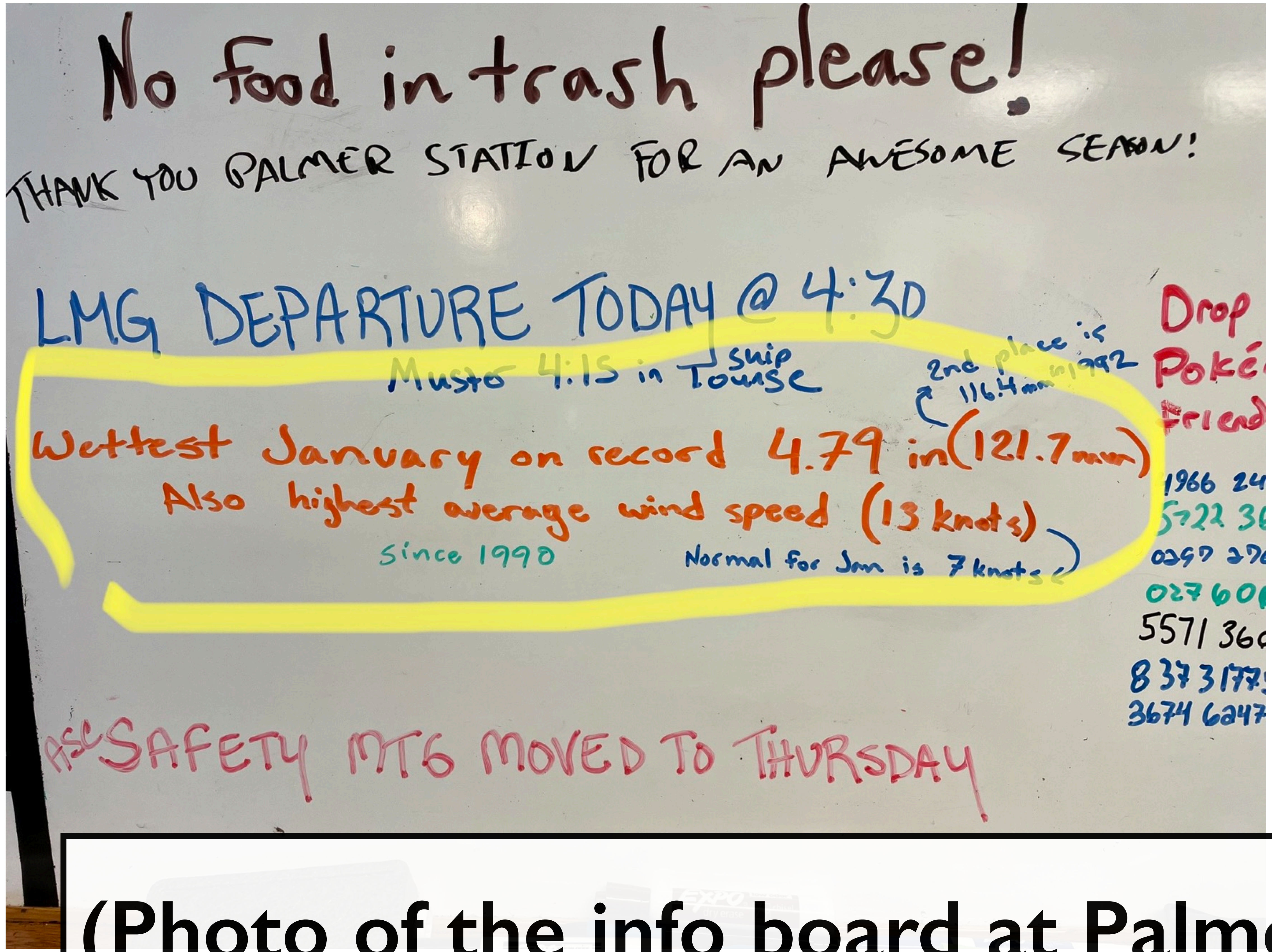




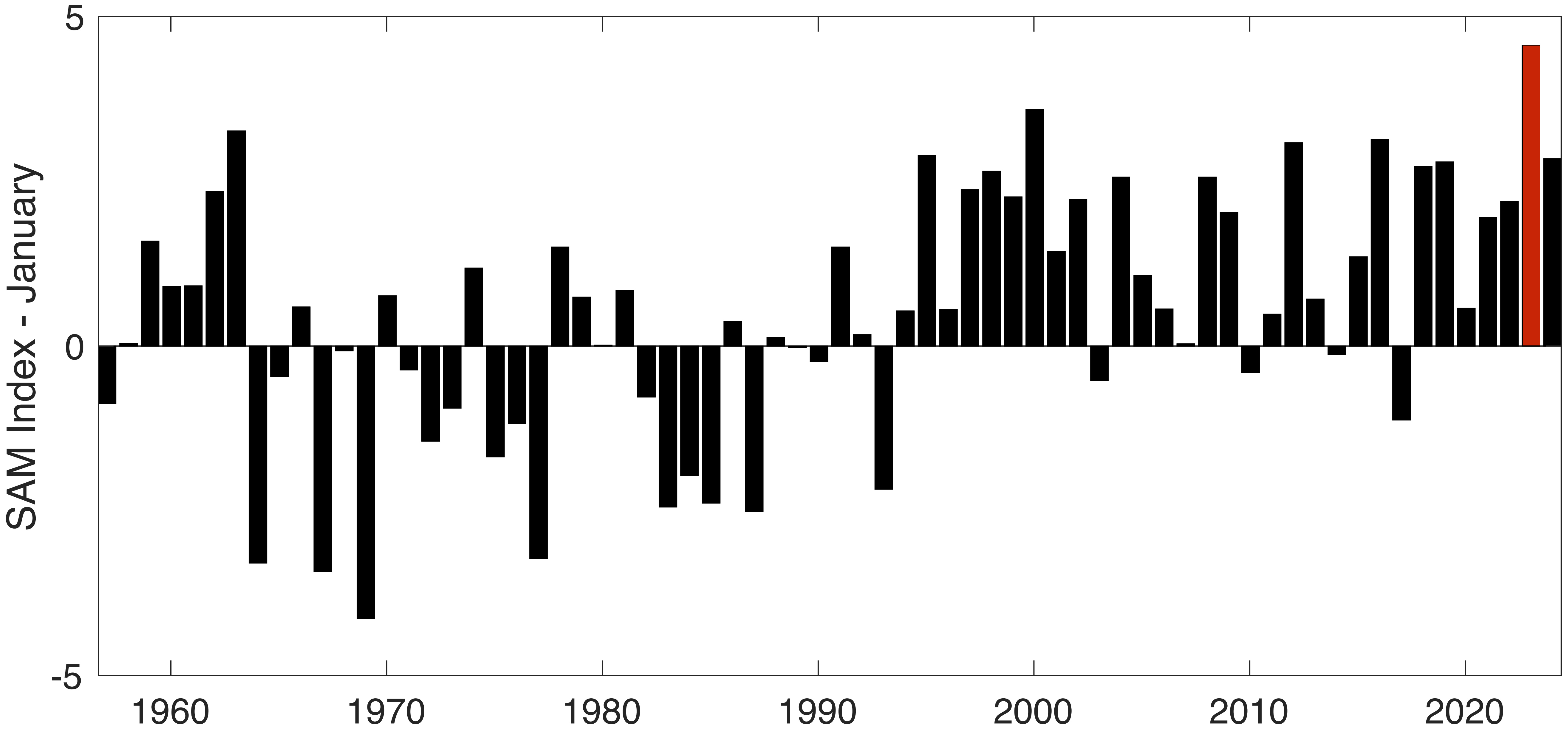
Moffat et al., *in prep*)

Steps to an extreme event:
(3) Strengthening winds culminated in a *very* stormy summer

2023: record January SAM since 1957.
(A high SAM indicates southward migration of the Westerlies+storms)



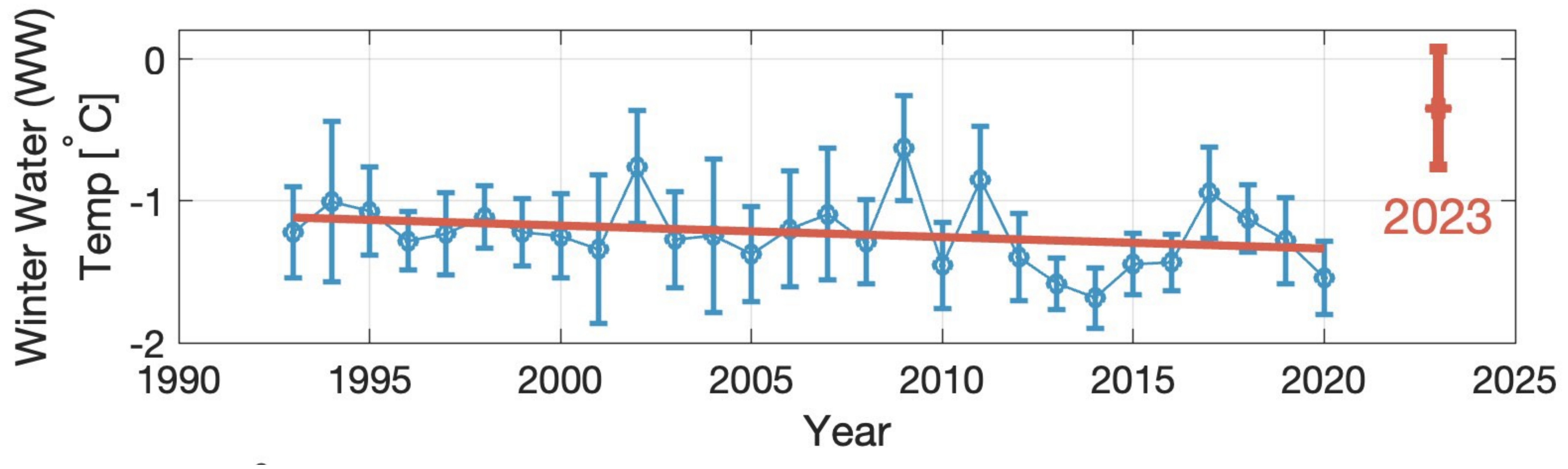
(Photo of the info board at Palmer Station, Feb 1, 2023 - end of PAL Cruise)

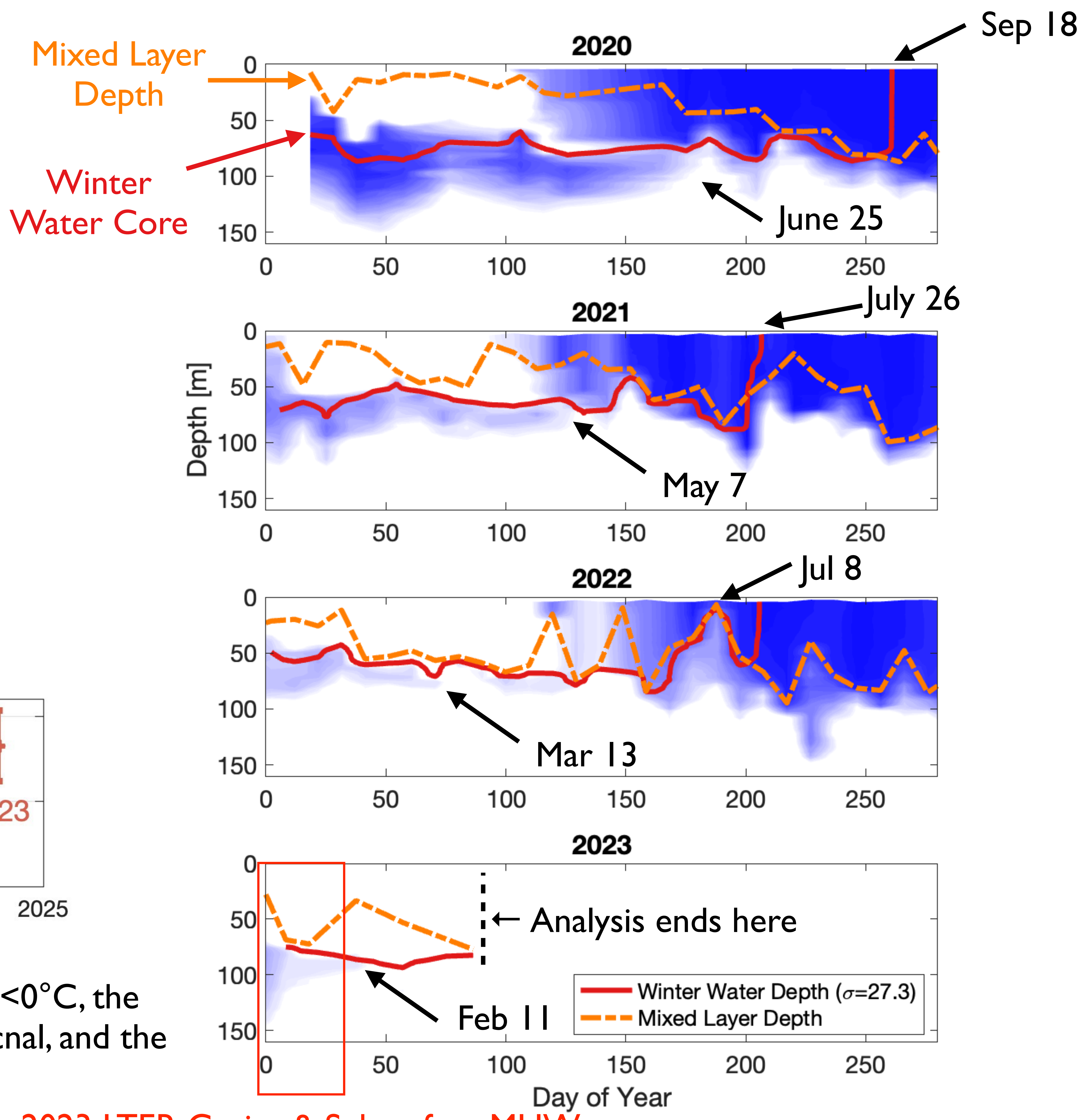


Sign reads: "Wettest January on record (4.79 in), also highest average wind speed (13 knots)" since 1990.

Steps to an extreme event: (4) Storminess + low sea ice + weaker stratification eroded subsurface *Winter Water*, leading to a Marine Heat Wave

- From summer 2020 to 2023, Winter Water virtually vanished from the shelf.
- A significant subsurface Marine Heat Wave developed.
- This "pulse" reversed a long-term cooling trend in this subsurface water.





(Plot only shows water <0°C, the depth of the 27.3 isopycnal, and the mixed layer depth)

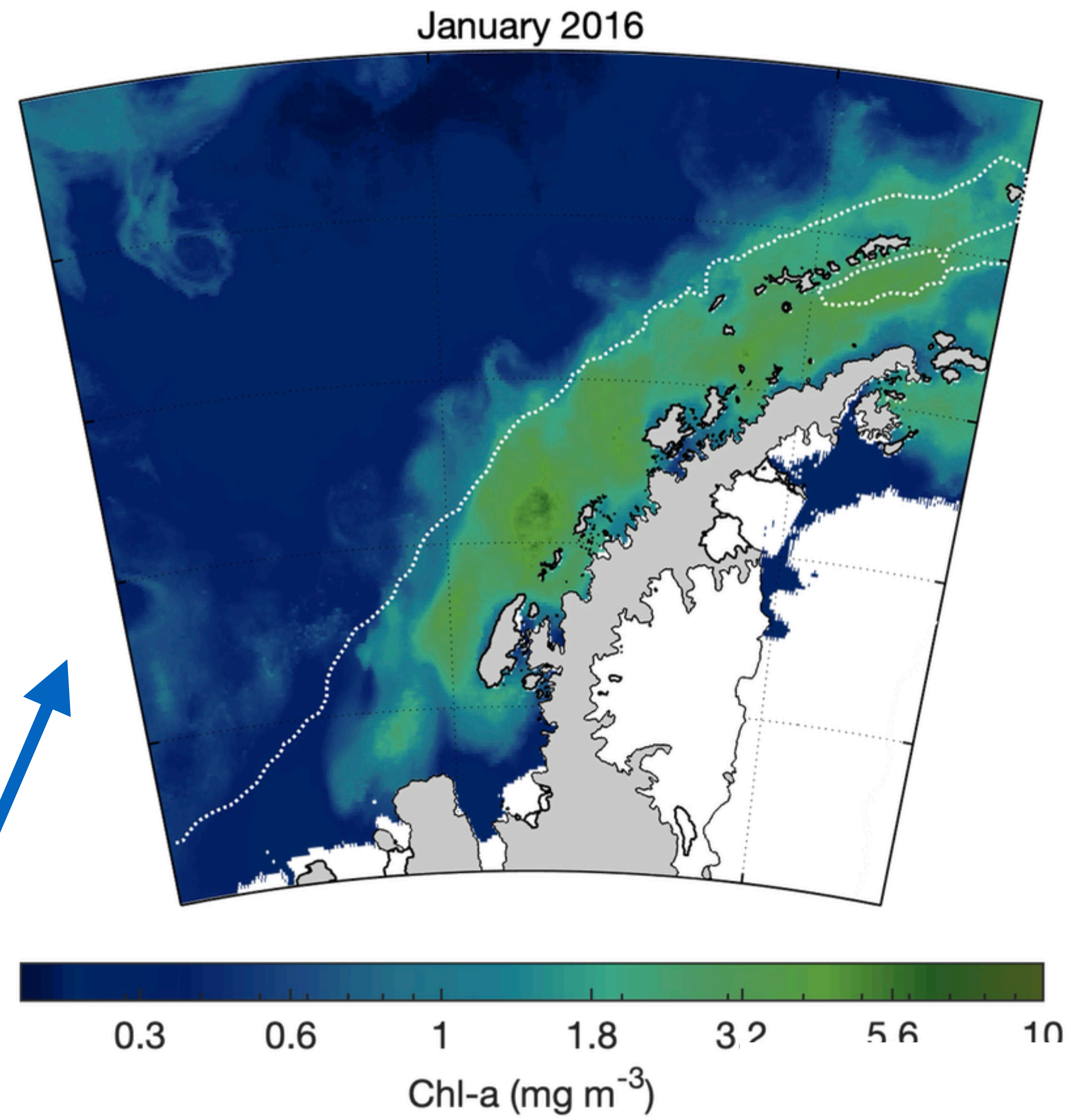
2023 LTER Cruise & Subsurface MHW

Ecosystem Impacts of 2022/23 Ice Minimum/MHW: Record low surface ChL in Jan 2023.

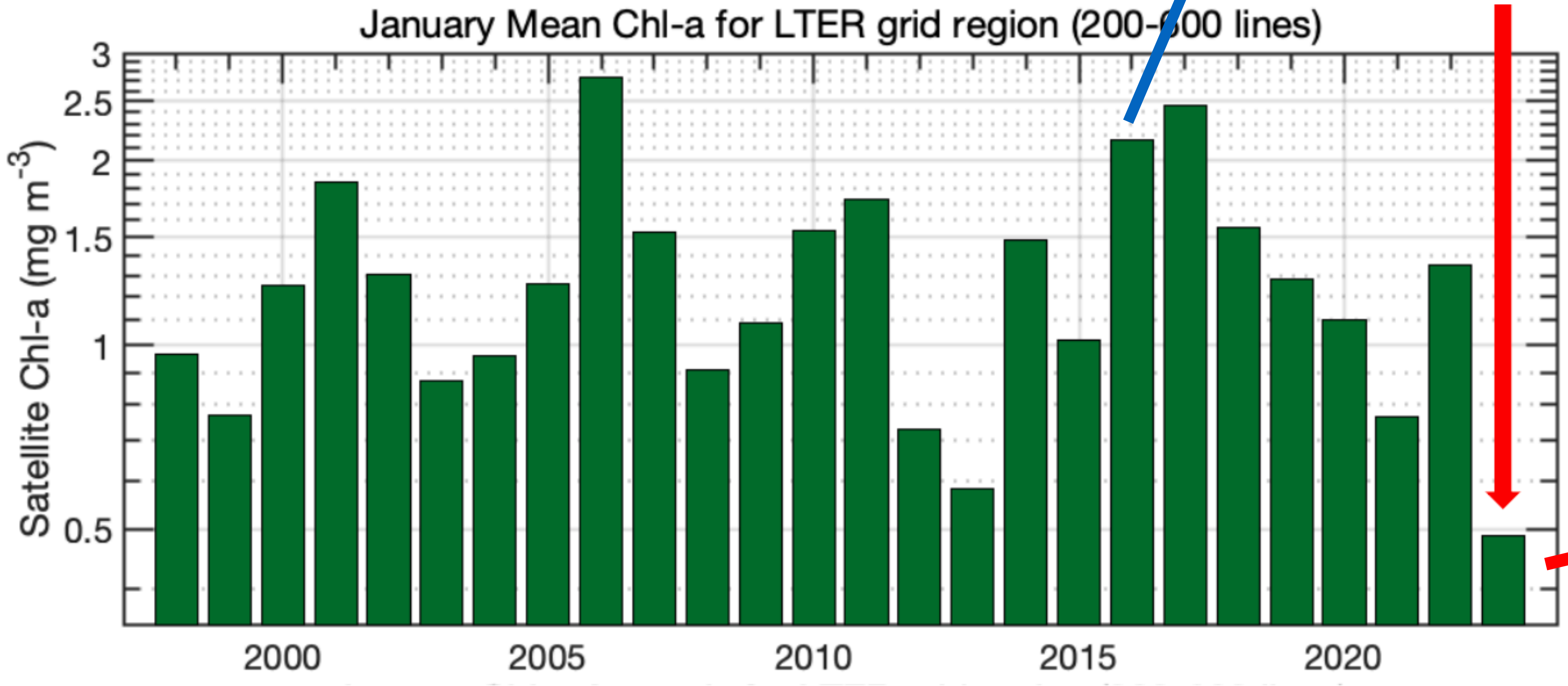
- Marine productivity on WAP shelf is primarily light limited.

persistent northerly winds + low sea ice + high storminess → low stratification + deep mixed layers → low productivity.

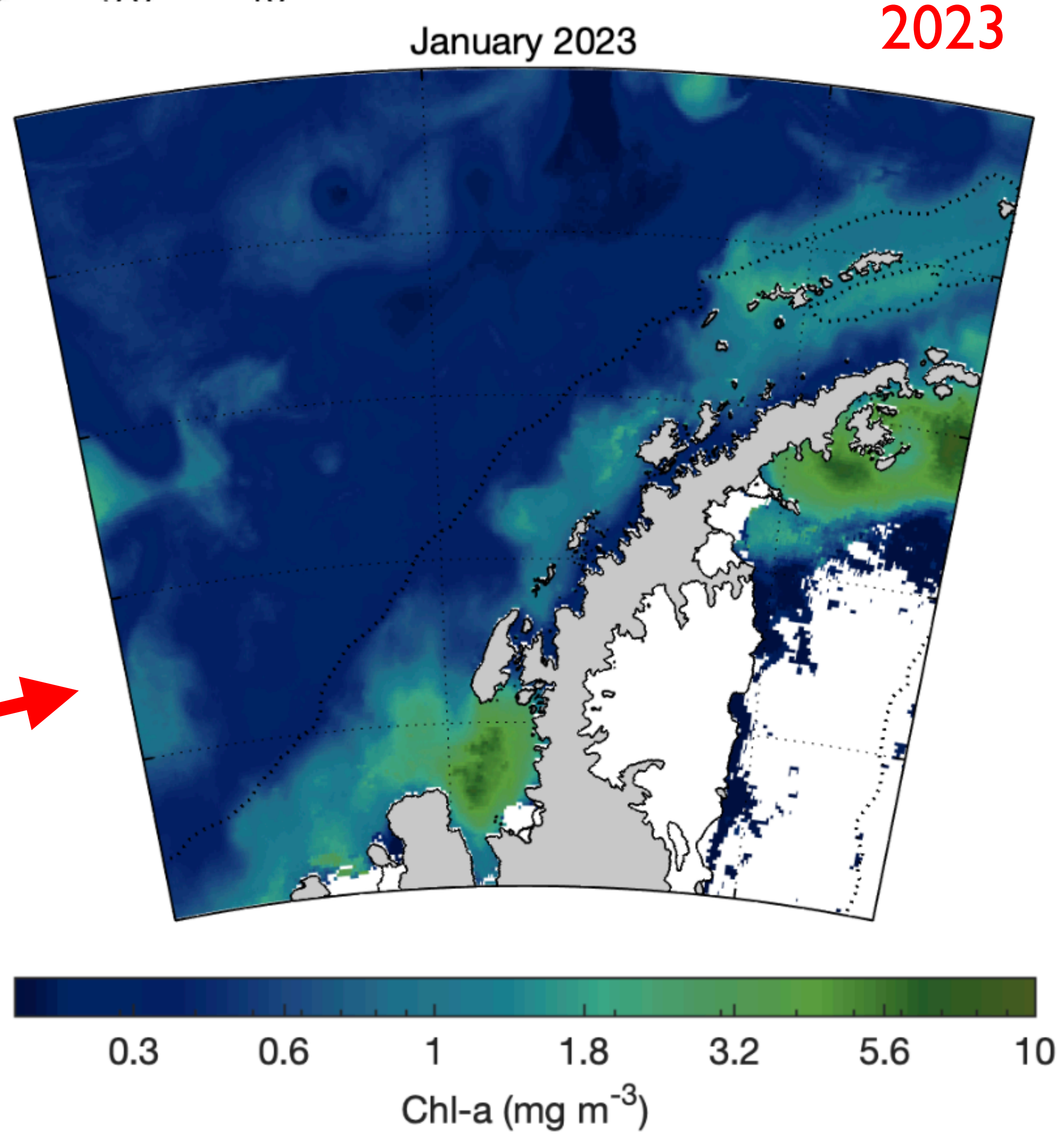
January 2016



2023



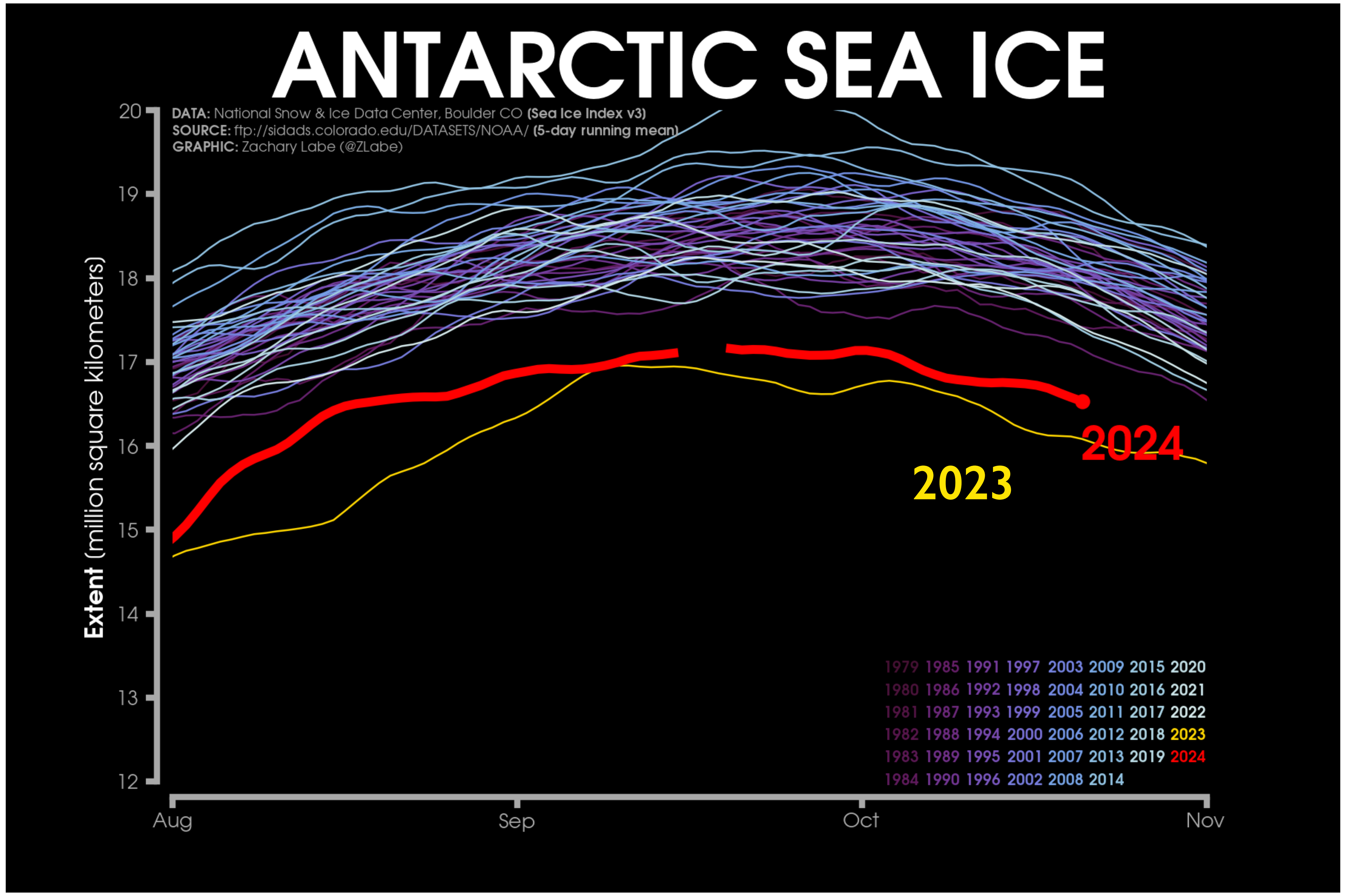
January 2023



(Analysis by J. Turner, UConn)

Product: CMEMS GlobColour.

Conclusions Sub-Theme B1



Source: Zack Labbe, NOAA GFDL (https://www.zacklabbe.com)

- A dramatic sea ice minimum/marine heat wave event in 2022/23.
- Anomalous conditions still going!
- Response observed across several trophic levels.
- Event developed over several years, and reversed long-term trends in upper ocean conditions on the WAP shelf.

- Coastal ARGO floats are a new and exciting technology for year-round, full-depth studies of coastal dynamics
- PAL planning to deploy 1-2 floats in 2024/25.

Thanks!