



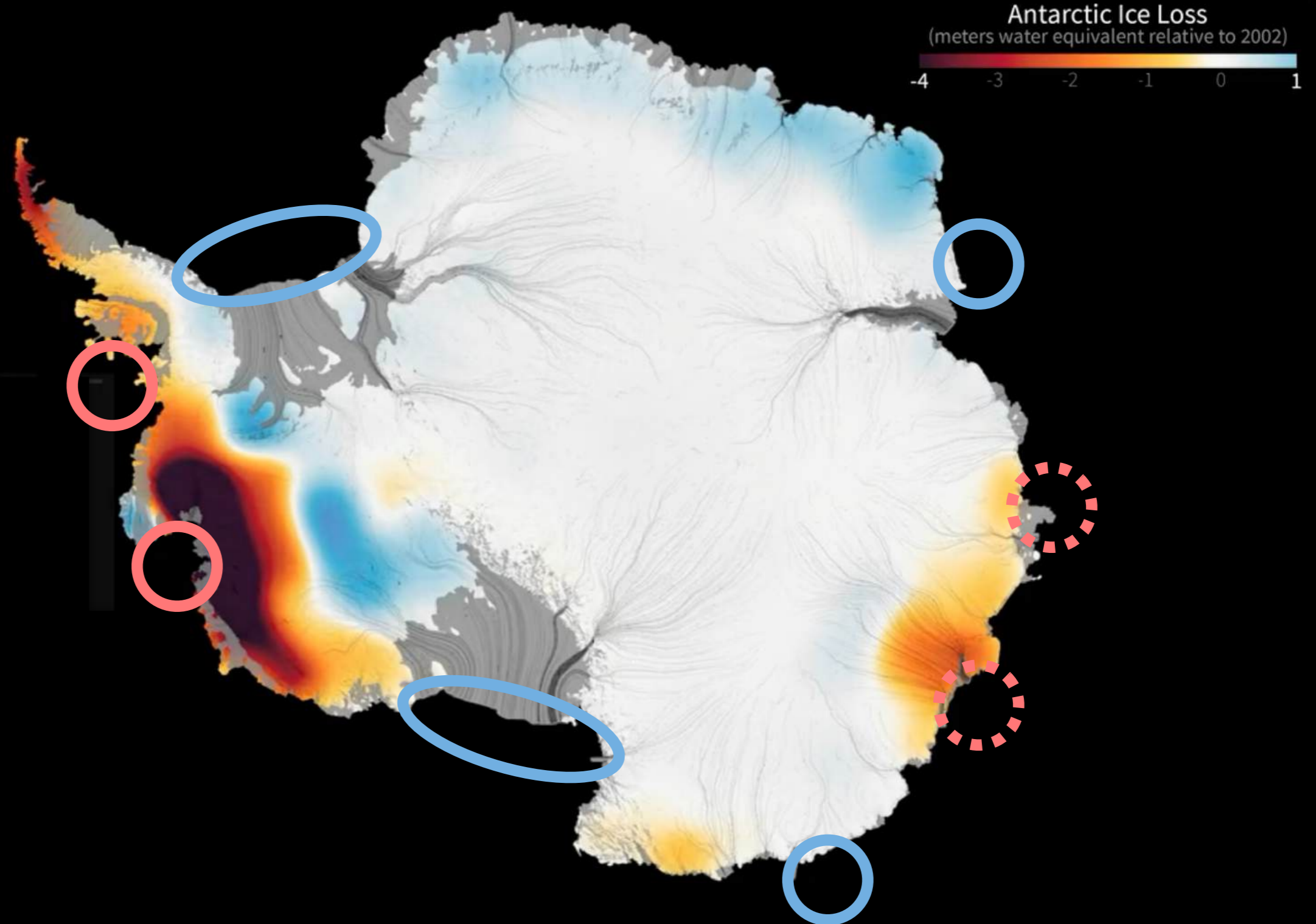
# ECCO downscaling for Antarctic coastal regions

Yoshihiro Nakayama and many collaborators

Thayer School of Engineering, Dartmouth College, Hanover, NH, USA

# ECCO downscaling for Antarctic coastal regions

- Antarctic Bottom Water (AABW) formation
- High and moderate Ice Shelf melting



# ECCO downscaling for Antarctic coastal regions

Antarctic Peninsula

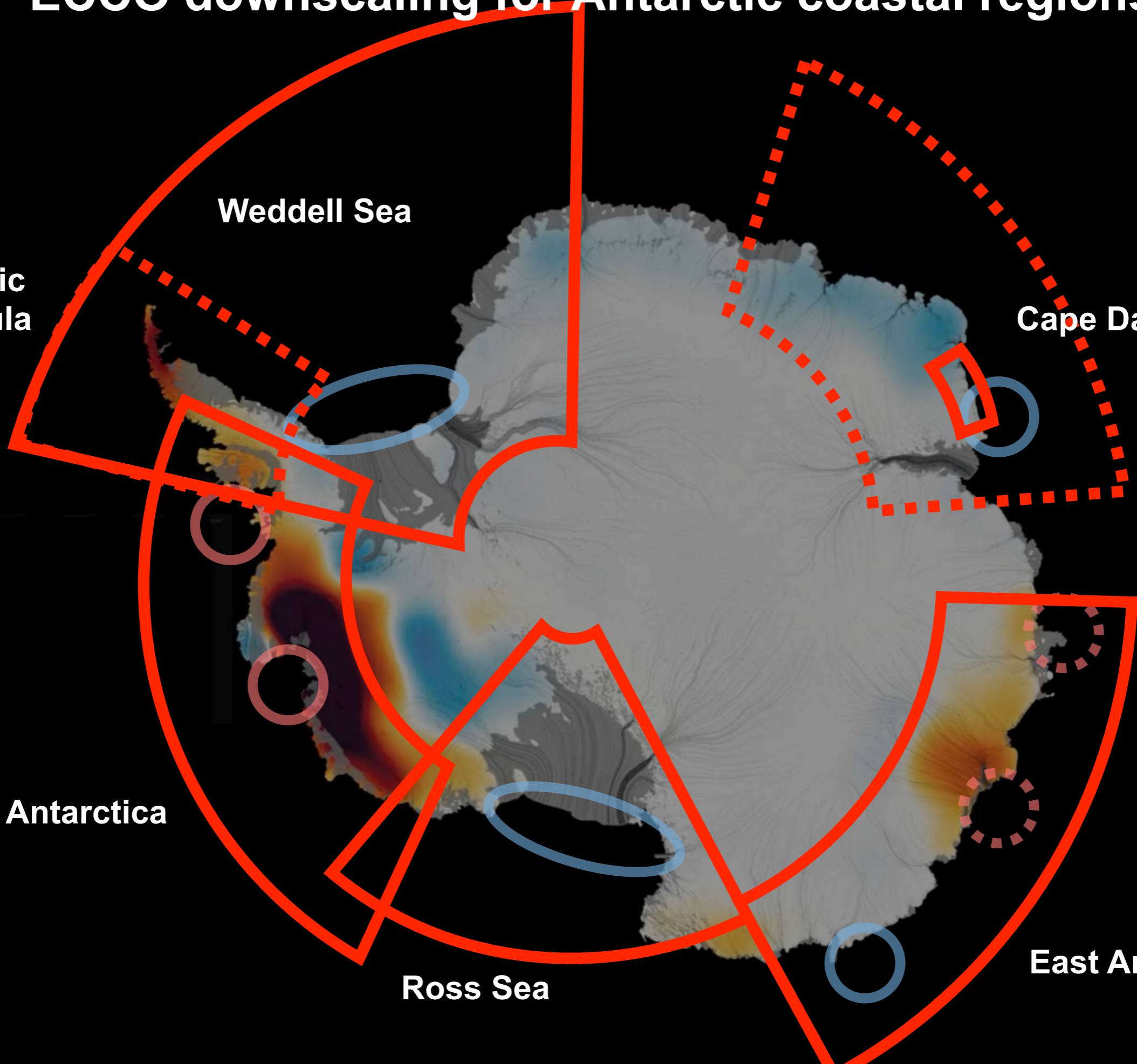
Weddell Sea

Cape Darnley

West Antarctica

Ross Sea

East Antarctica



# ECCO downscaling for Antarctic coastal regions

## ECCO downscaling

- 👁️ **Extensive model evaluation**
- 👁️ Optimize model parameters to achieve **good model-obs agreement**
- 👁️ **New mechanisms or process understanding**
- 👁️ Accessible simulated outputs and analysis scripts
- 👁️ Development towards BGC coupling



## ECCO evaluation (Nakayama et al., 2024 GMD)

- 👁️ Evaluation of ECCOv4r5, ECCO-LLC270, SOSE, and GECCO

Domain	Period	Grid	Output	Where?	BGC	Model Evaluation Publication
Amundsen/ Bellingshausen	1992-2025	3-4 km	Monthly 5-daily	NASA Earth Data	☆	Nakayama et al., 2018 (Nature Communications) Hyogo et al., 2024 (JGR Ocean) Park et al., 2024 (Nature Communications) Nakayama et al., in review (GMD)
Amundsen High-res	2010 Jan-Oct	200m	Daily/hourly	NASA Earth Data		Nakayama et al., 2019 (Scientific Report) Nakayama et al., 2021c (GRL) Shrestha et al., 2024 (GRL) Poinelli et al., 2025 (Nature Geoscience)
Ross Sea	2010-2020	2-5 km	Monthly		☆	Malyarenko et al., 2023 Taewook in prep
East Antarctic	1992-2025	4-5 km	Monthly/ daily	NASA Earth Data Zenodo	★	Nakayama et al., 2021b (GRL) Hyogo et al., in review (GRL)
Cape Darnley	2008 Jan-Dec	200m 1,2,4,8 km	Daily	Zenodo	★	Mensah et al., 2021 (Ocean Modeling) Mensa et al., In prep
Weddell Sea	1992-2025	2-5 km	Monthly	TBD		Moriyoshi et al., in prep
Antarctic Peninsula	1992-2025	TBD	Monthly	TBD	☆	Development just started



: Running with BGC

☆: Project funded for BGC

<https://sites.google.com/view/umi-nakayama/>

# Some recent updates

## 1. Amundsen Sea

- Model data agreement
- Submesoscale permitting downscaling
- Ice-ocean coupling

## 2. Cape Darnley

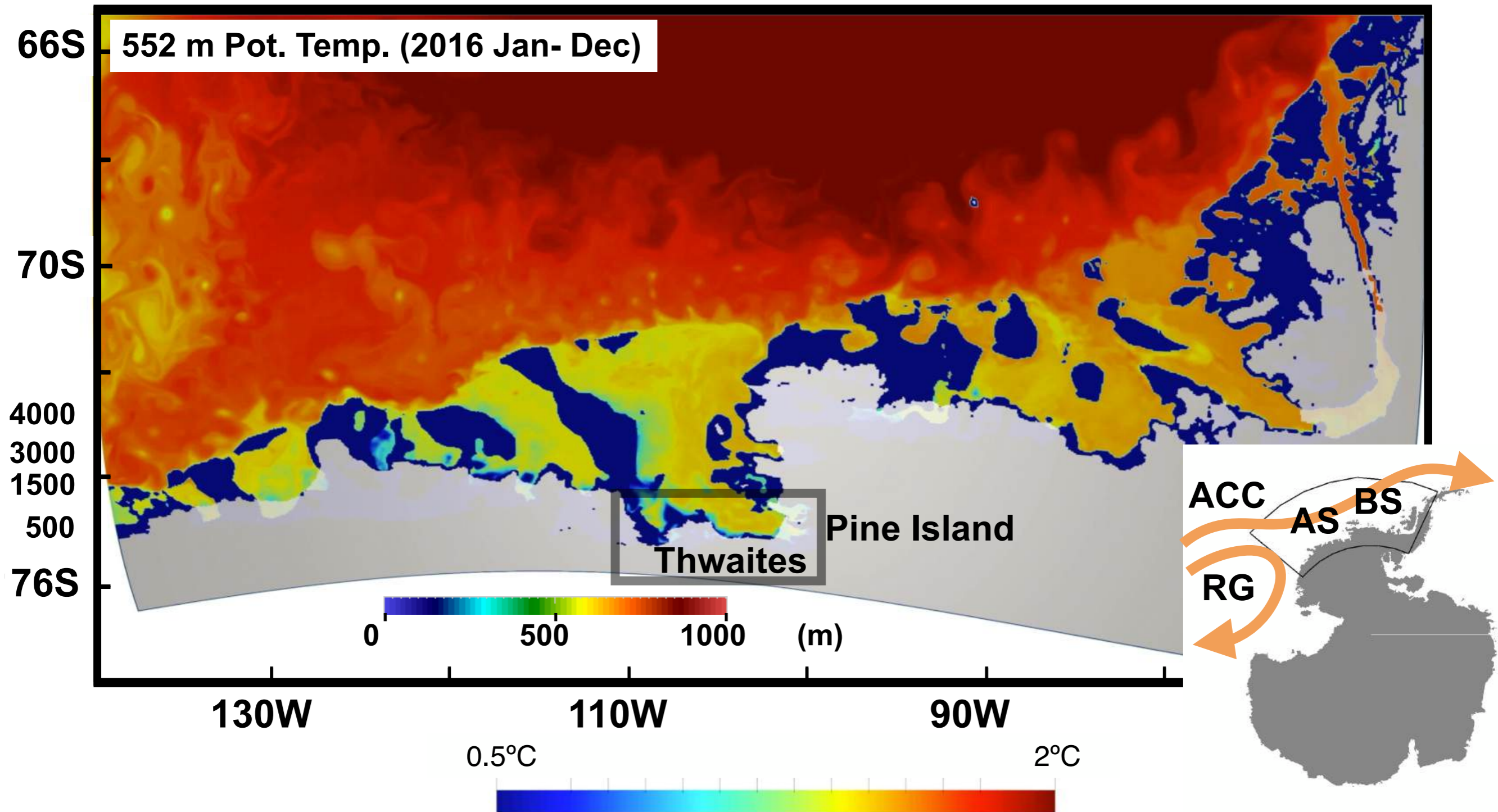
- Model data agreement
- Coupling with BGC

## 3. East Antarctica

- Model data agreement
- Why deep thermocline?

# 1. Amundsen Sea

Available between 1992-2016 (daily/monthly mean), ECCO boundary condition, ERA-interim



Nakayama et al., 2018 (Nature Communications)

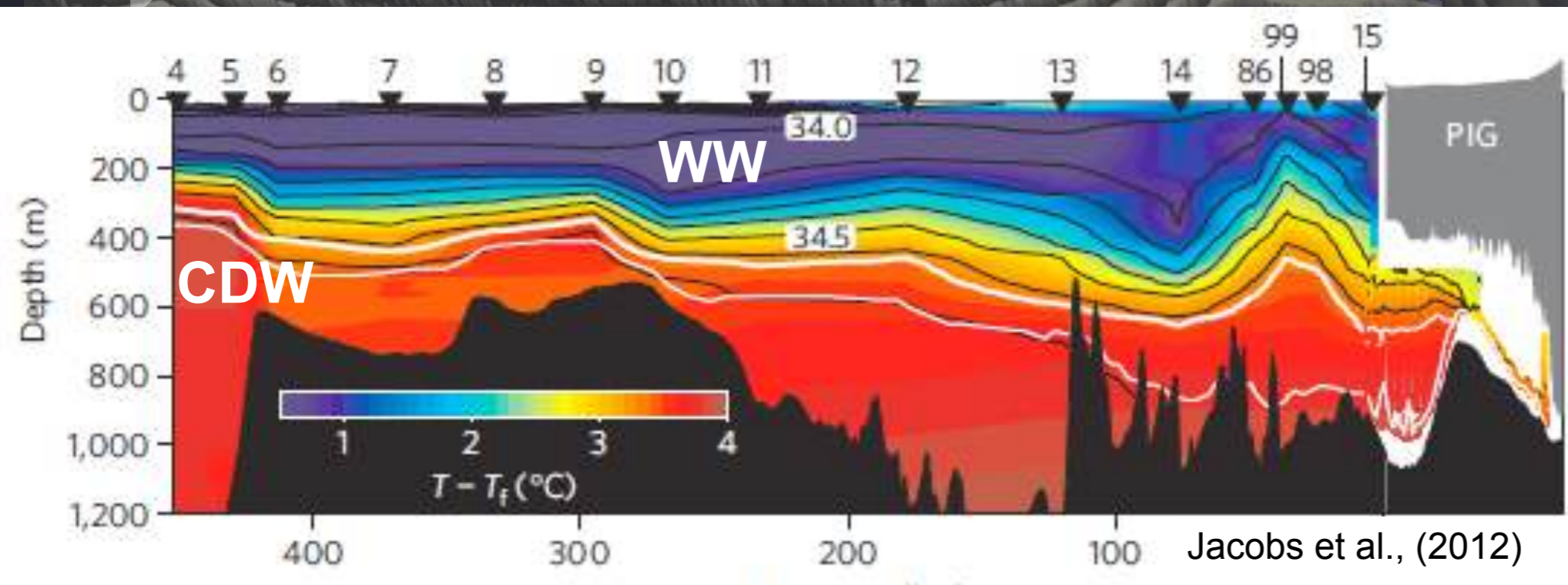
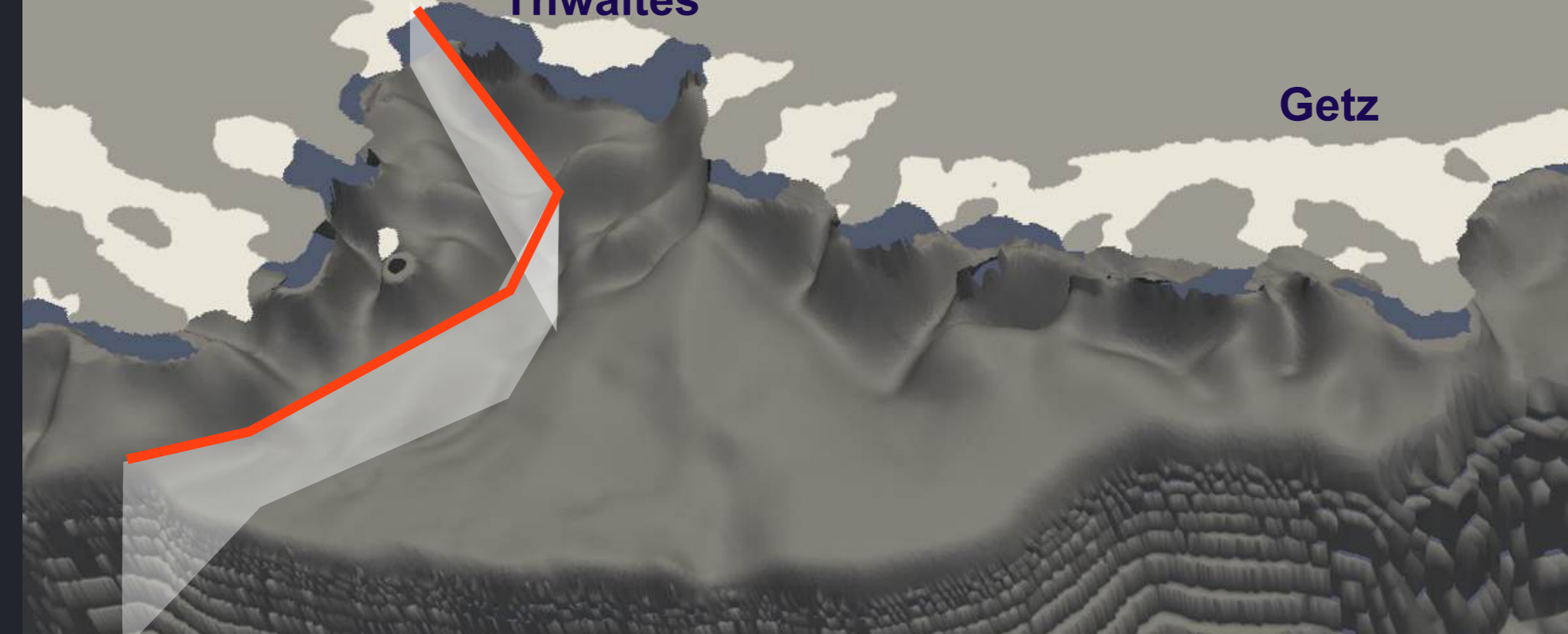
# Warm CDW intrudes into ice shelf cavities

CDW: Circumpolar Deep Water

Pine Island

Thwaites

Getz



Warm CDW and strong melting.



Ice shelf thinning



Speed up of Ice flow

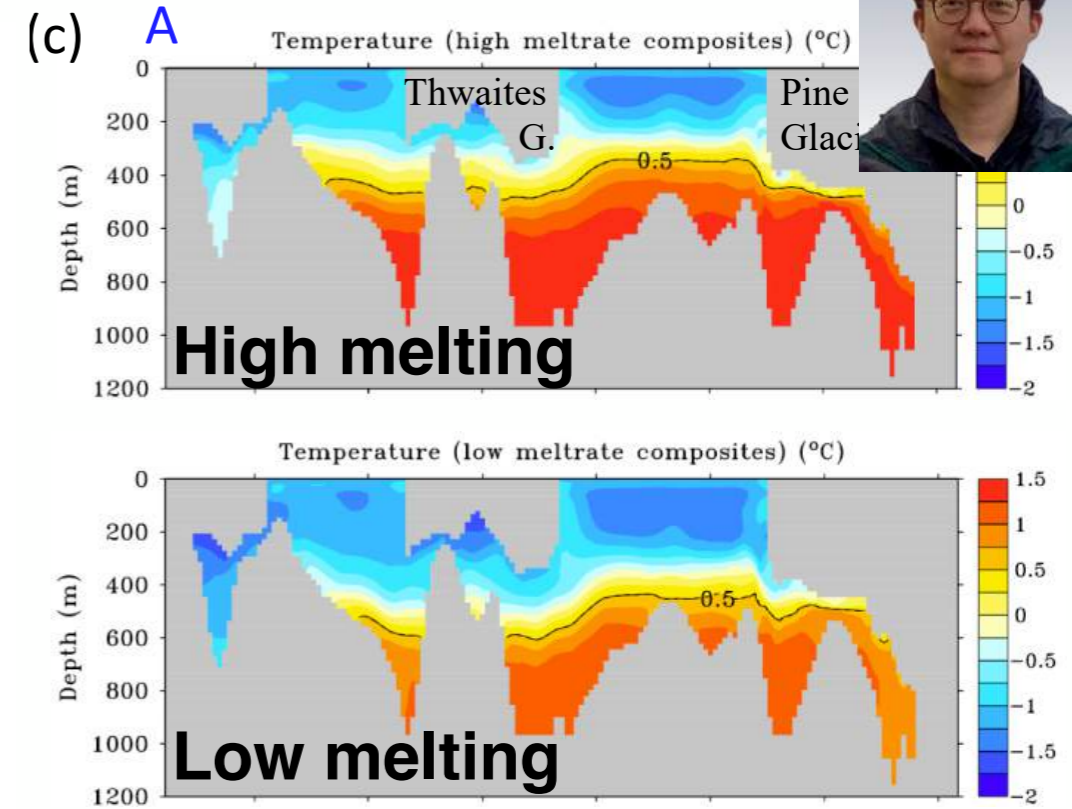
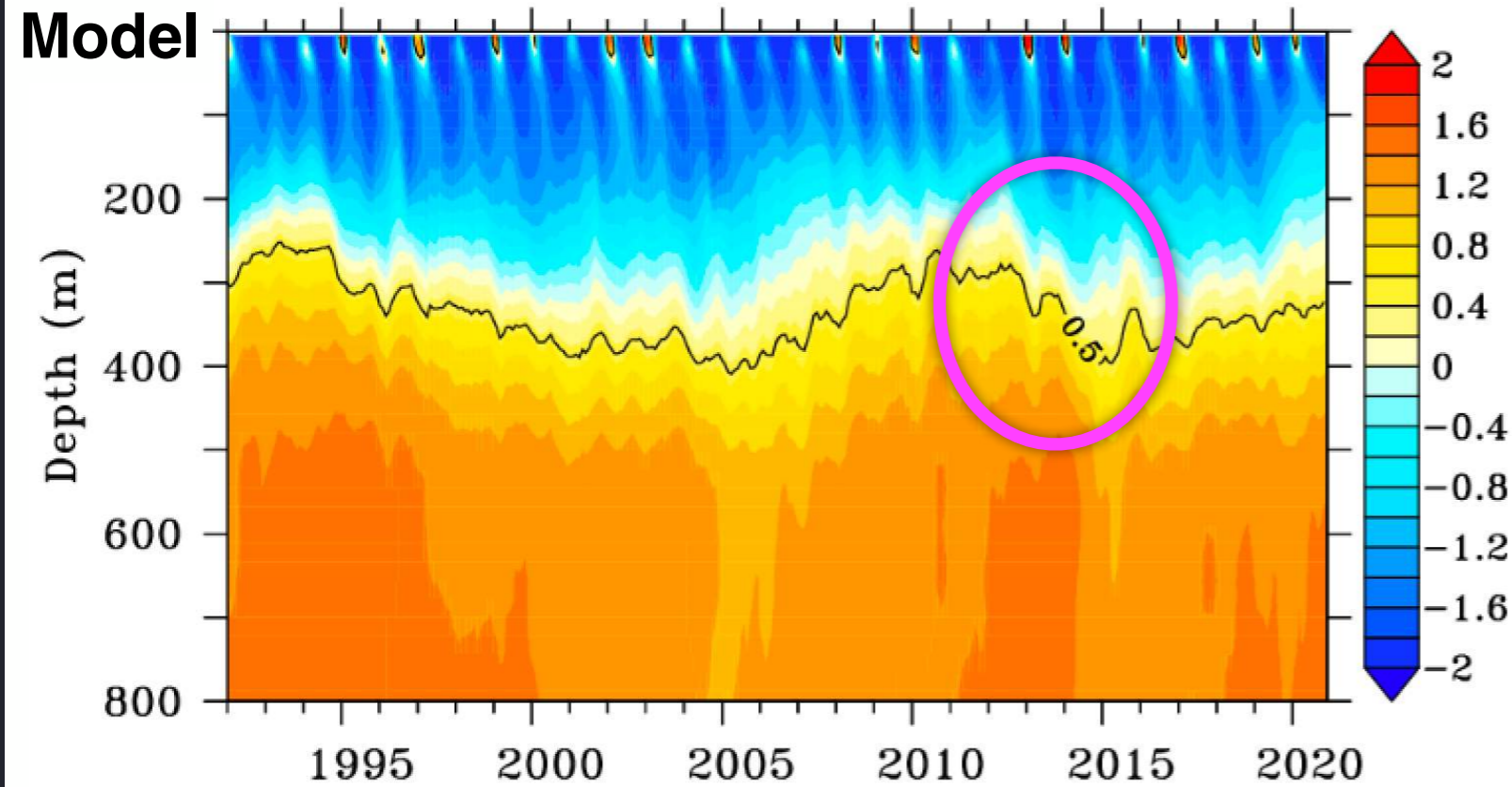
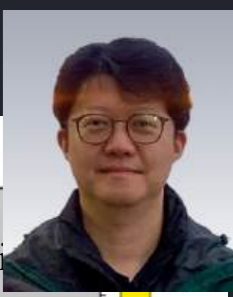


Grounded ice loss



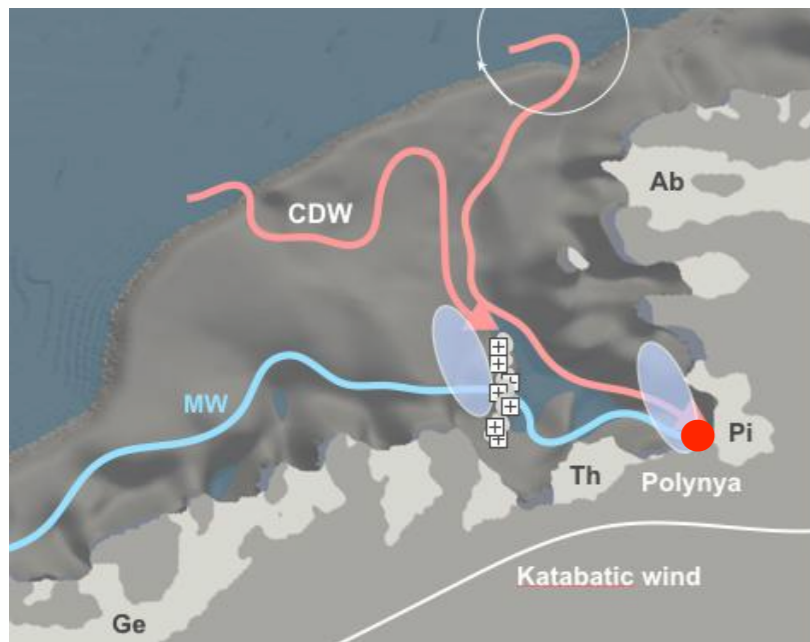
Sea level rise

# Comparison with mooring observations



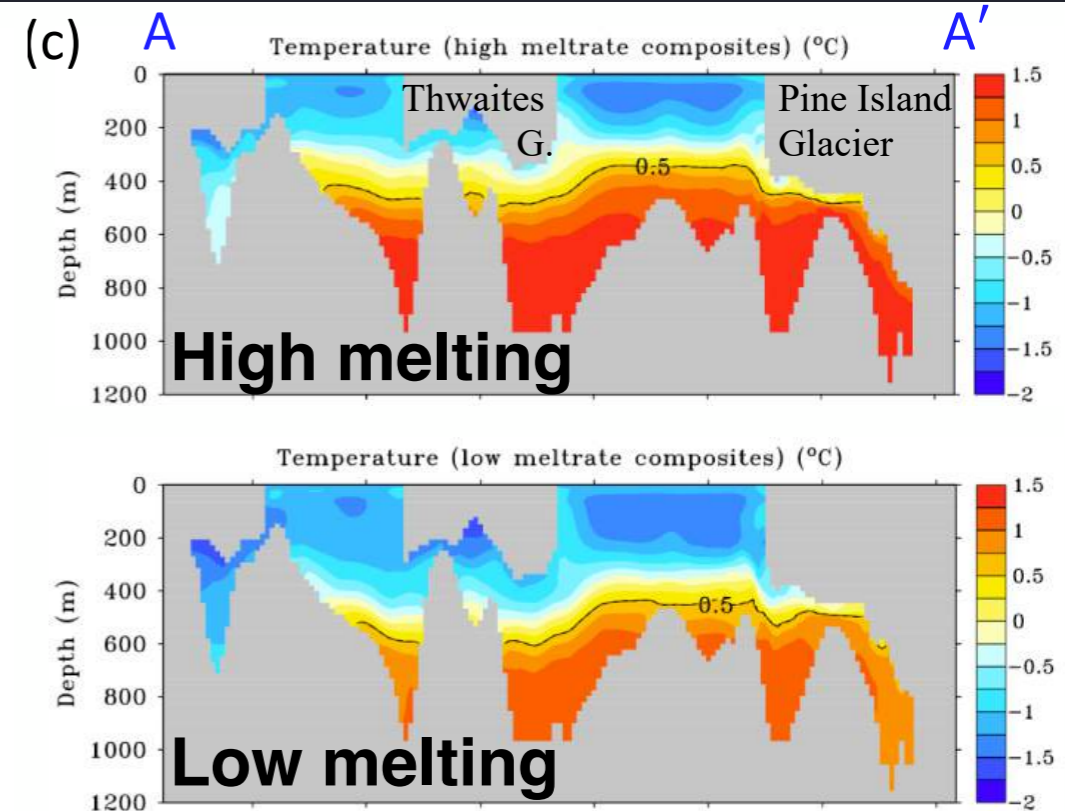
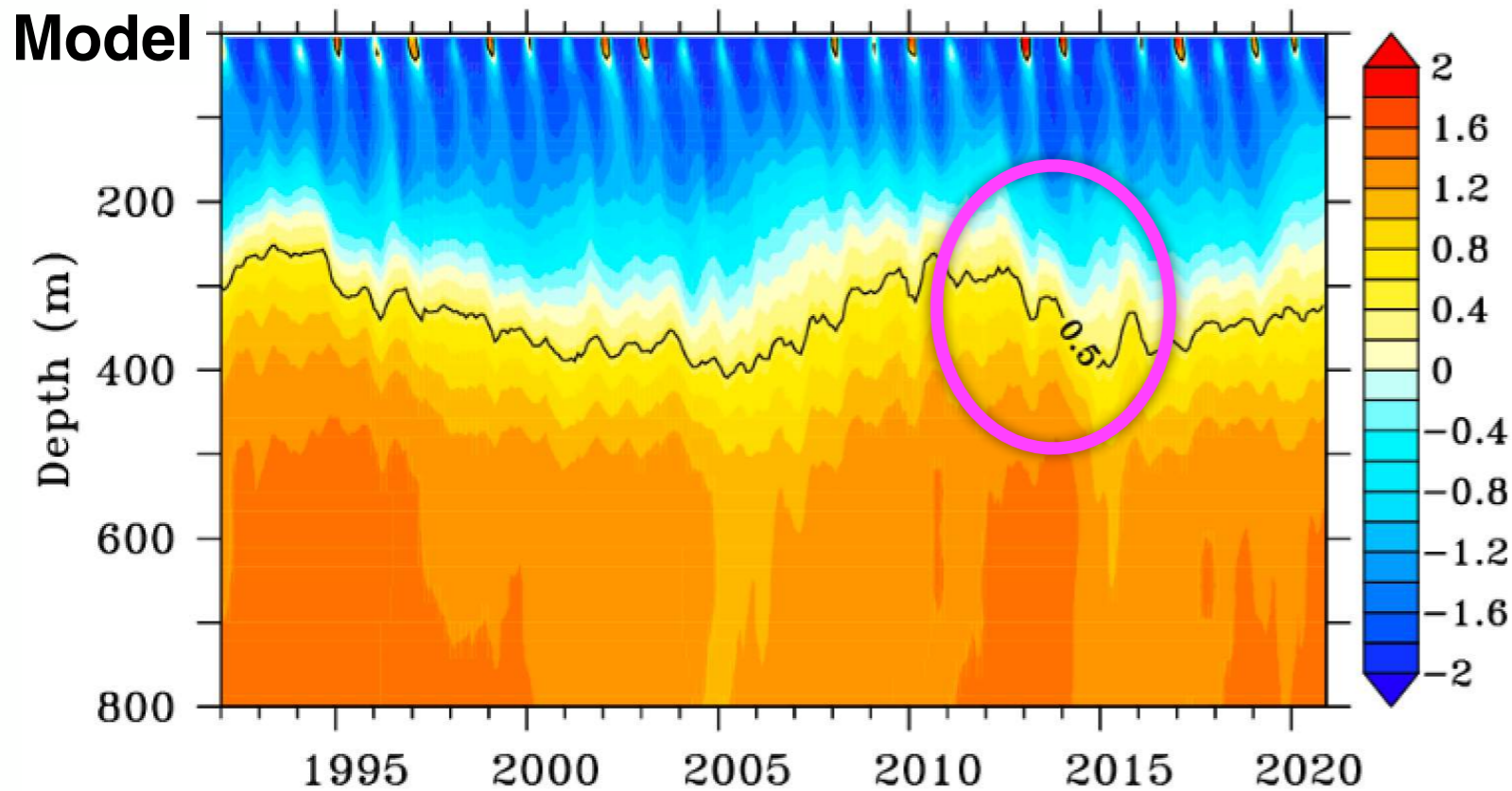
Park, Nakayama, et al., 2024 (Nature Communications)

## Observations



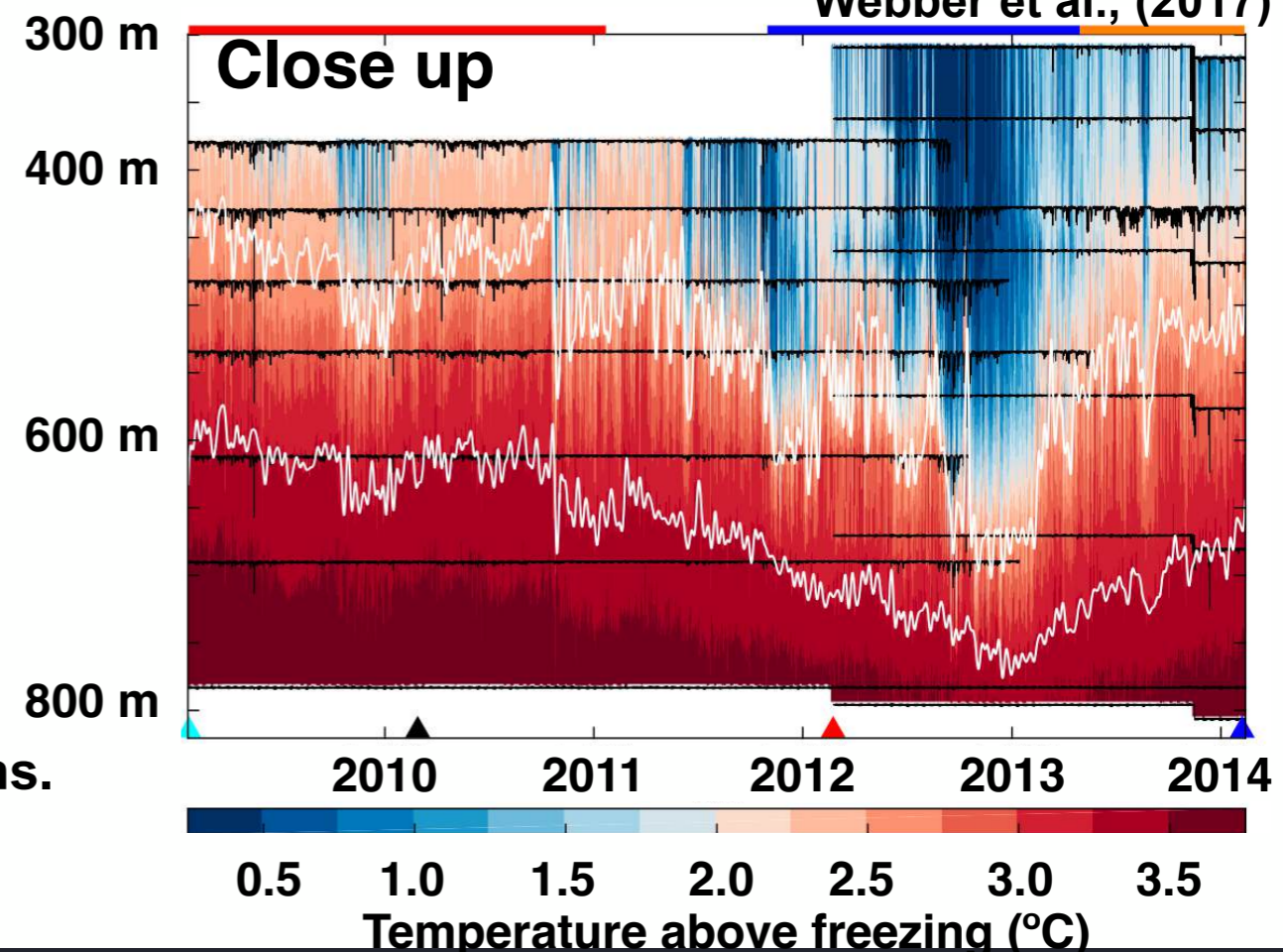
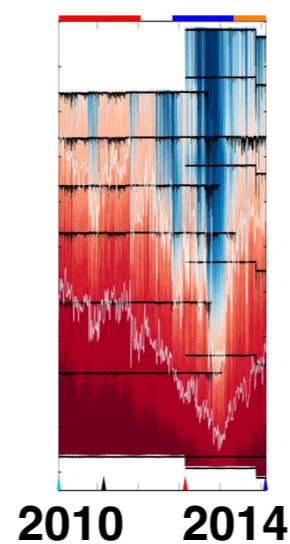
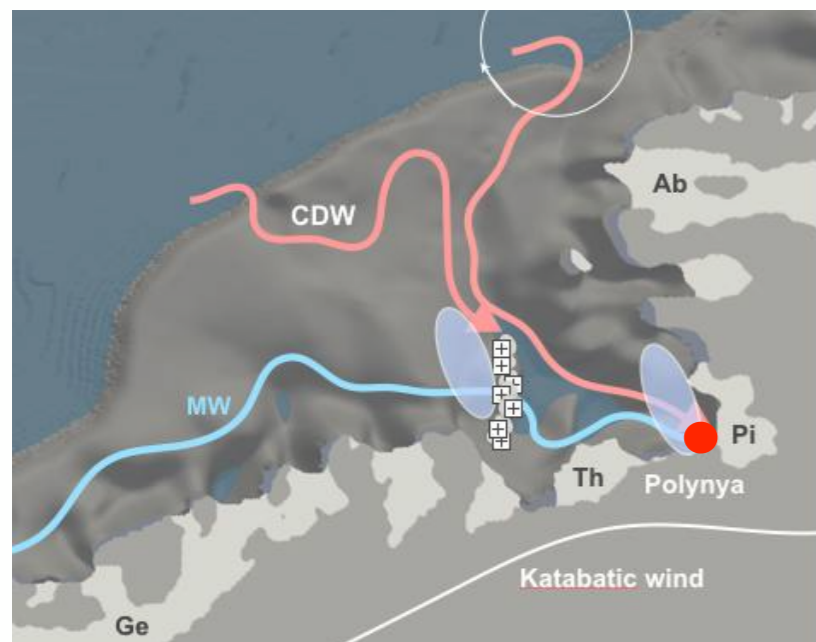
- Our simulated TD variability is similar to observations.

# Comparison with mooring observations



Park, Nakayama, et al., 2024 (Nature Communications)

## Observations



- Our simulated TD variability is similar to observations.

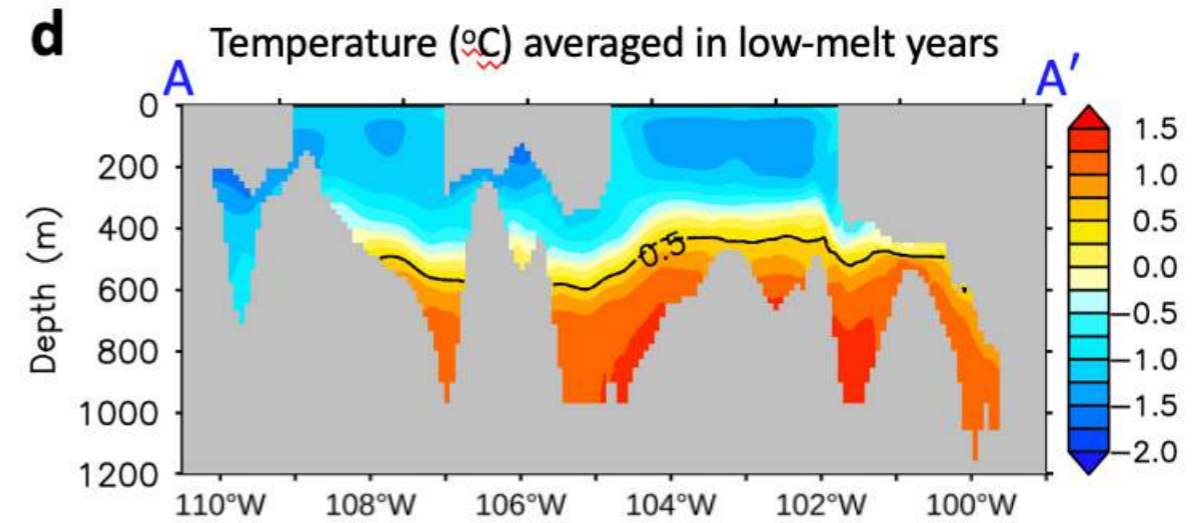
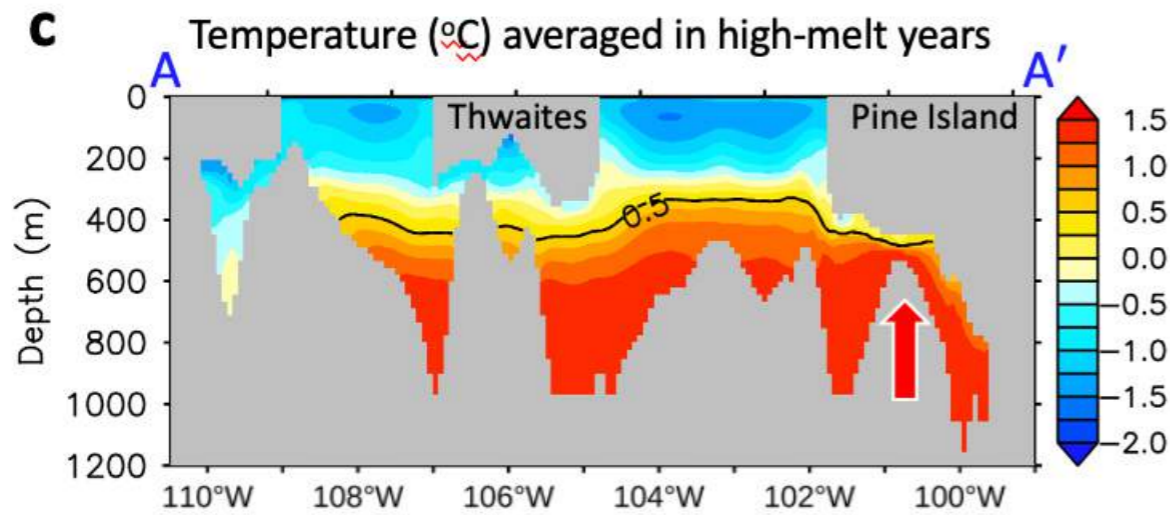
# Vertical velocity by Ocean current-bathymetry interaction

High melt composite

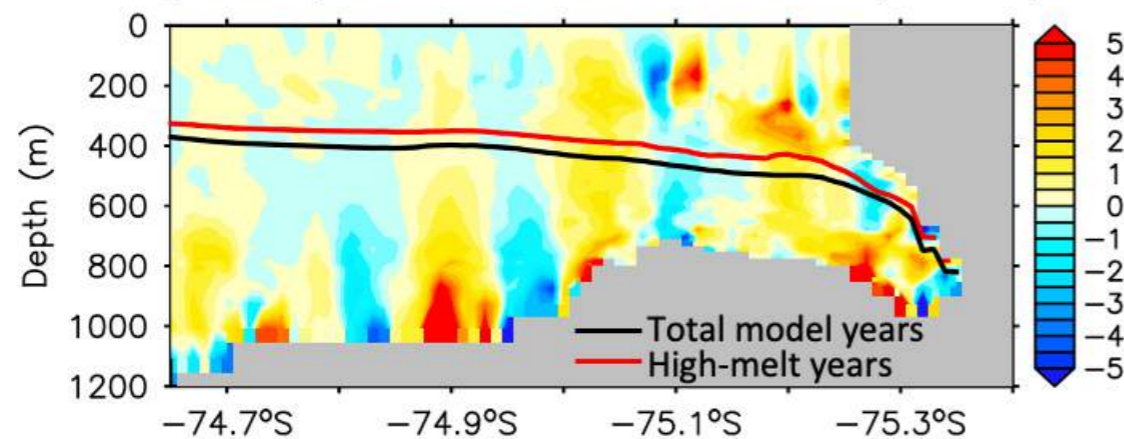
Low melt composite

Shallow thermocline

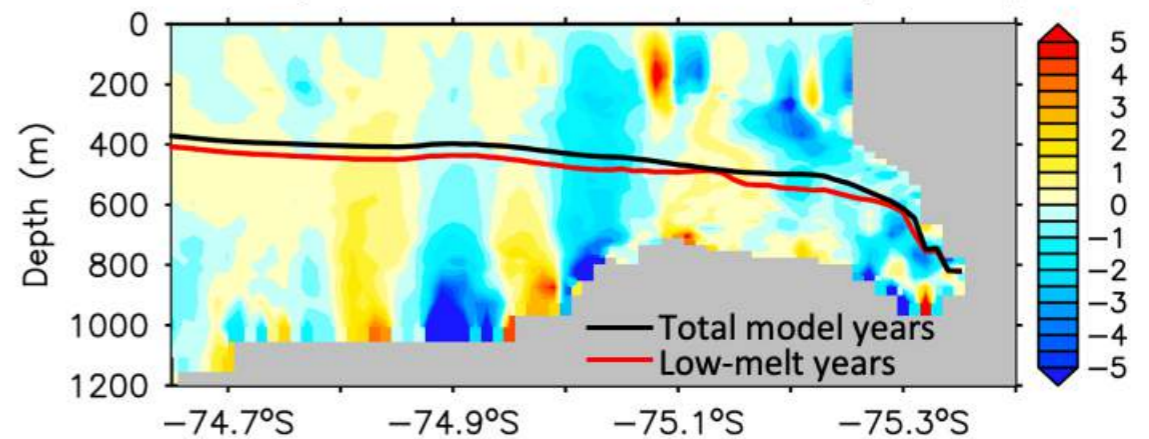
Deep thermocline



**e** Zonally-averaged vertical velocity anomaly (color shading;  $\text{m d}^{-1}$ ) in high-melt years and 0.5°C isothermal line (contour)



**f** Zonally-averaged vertical velocity anomaly (color shading;  $\text{m d}^{-1}$ ) in low-melt years and 0.5°C isothermal line (contour)



Bottom enhanced upwelling

Bottom enhanced downwelling



<https://doi.org/10.5194/egusphere-2025-5958>

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Abstract

Discussion

Metrics

03 Feb 2026



## Development of ECCO-downscaled Amundsen-Bellingshausen Sea regional simulation using MITgcm(66j)

Yoshihiro Nakayama , Shuntaro Hyogo, Yichen Lin, Taewook Park, Jinho Lee, Juistine Caillet, Gobishankar Mohan, Mattia Poinelli, Pierre Dutrieux, Kazuki Nakata, Hong Zhang, Brice Loose, and Lauren Kowalski

**Abstract.** The Amundsen and Bellingshausen Seas are among the most rapidly changing regions of the Southern Ocean, playing a pivotal role in Antarctic ice-shelf mass loss and global sea-level rise. Several ocean models have been developed to investigate these changes, revealing complex interactions among the atmosphere, ocean, sea ice, and ice shelves. However, the diversity of model configurations, parameter choices, and model versions often hampers user-friendliness, limits meaningful intercomparison, and constrains broader multidisciplinary use. Here, we present a regional ocean model configuration of the Amundsen and Bellingshausen Seas with a horizontal resolution of 2.2–3.9 km based on MITgcm, downscaled from the global ECCO-LLC270 ocean state estimate, and further optimized using regional observations. We conduct extensive model evaluation and demonstrate its applications through multiple examples and previously published analyses, with the goal of providing model configuration and their outputs – achieving good model-data agreement – to the broad scientific community. The model reproduces key hydrographic features of the region, including realistic temperature and salinity profiles and water mass distributions that closely align with local CTD and mooring observations. Simulated sea-ice concentration and extent are consistent with satellite observations, capturing the observed seasonal cycle and spatial variability. Ice-shelf basal melt rates fall within the range of available satellite and in situ estimates. The configuration also includes passive tracers for surface water, ice-shelf meltwater, and Circumpolar Deep Water, as well as Lagrangian particle-tracking capabilities that facilitate studies of water-mass transformation and tracer pathways. By providing open access to the model code, configuration, diagnostics, tracer outputs, and sensitivity experiments, we aim to support data interpretation, hypothesis testing, and observational planning across the broad scientific community.

**How to cite.** Nakayama, Y., Hyogo, S., Lin, Y., Park, T., Lee, J., Caillet, J., Mohan, G., Poinelli, M., Dutrieux, P., Nakata, K., Zhang, H., Loose, B., and Kowalski, L.: Development of ECCO-downscaled Amundsen-Bellingshausen Sea regional simulation using MITgcm(66j), EGU sphere [preprint], <https://doi.org/10.5194/egusphere-2025-5958>, 2026.

### Download

- ▶ Preprint (14302 KB)
- ▶ Metadata XML
- ▶ Supplement (32848 KB)
- ▶ BibTeX
- ▶ EndNote

### Short summary

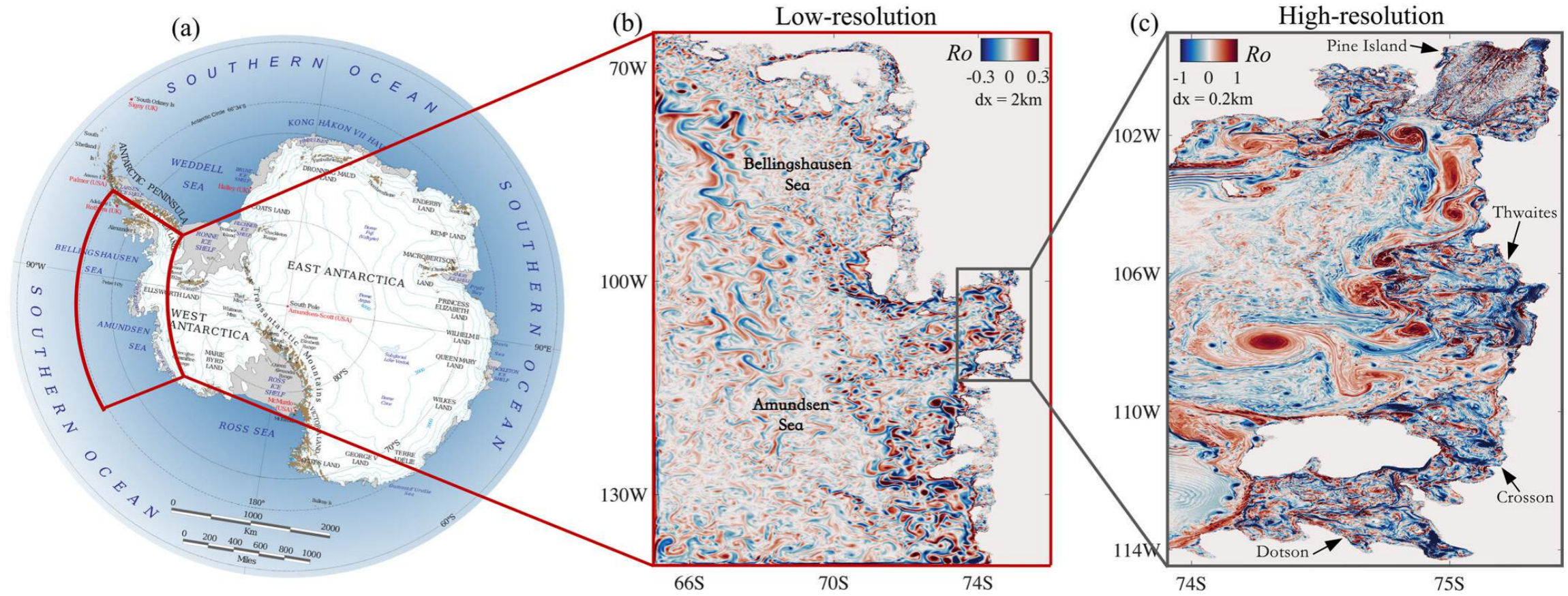
We develop a regional ocean model of the Amundsen and Bellingshausen Seas in Antarctica....

▶ Read more

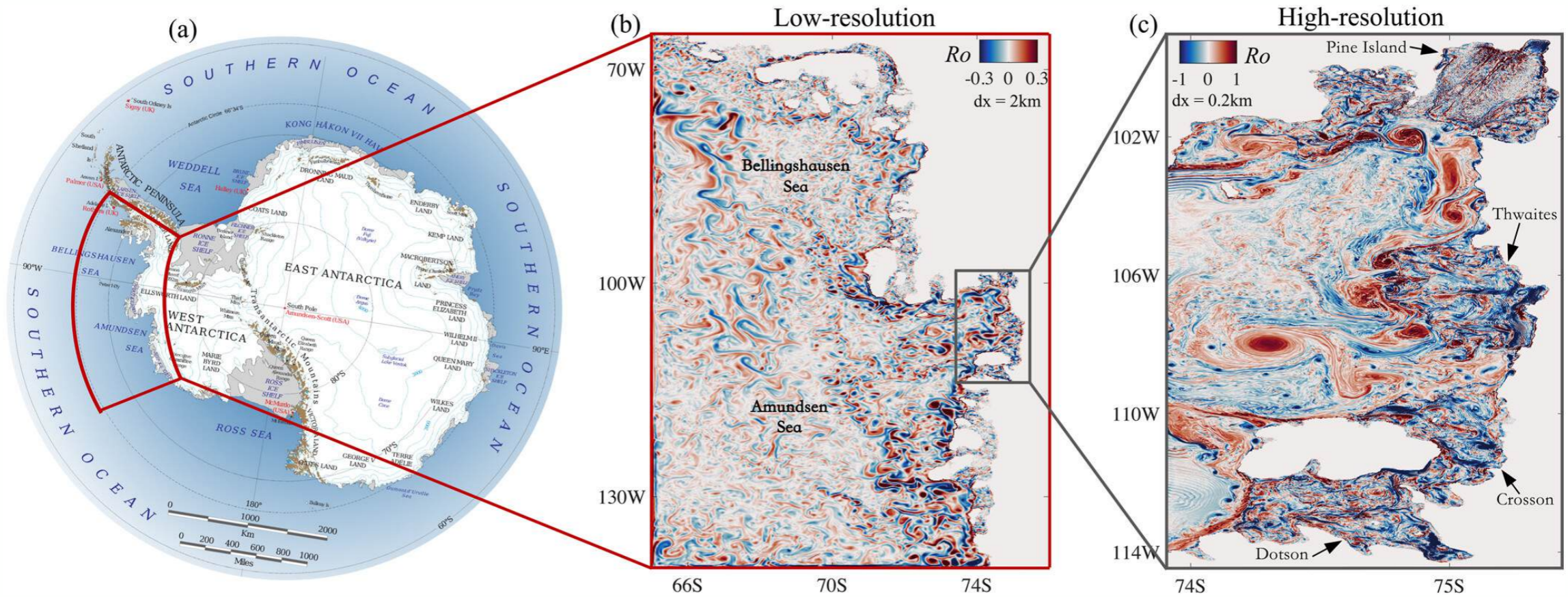
### Share



# Submesoscale permitting (200m) downscaling

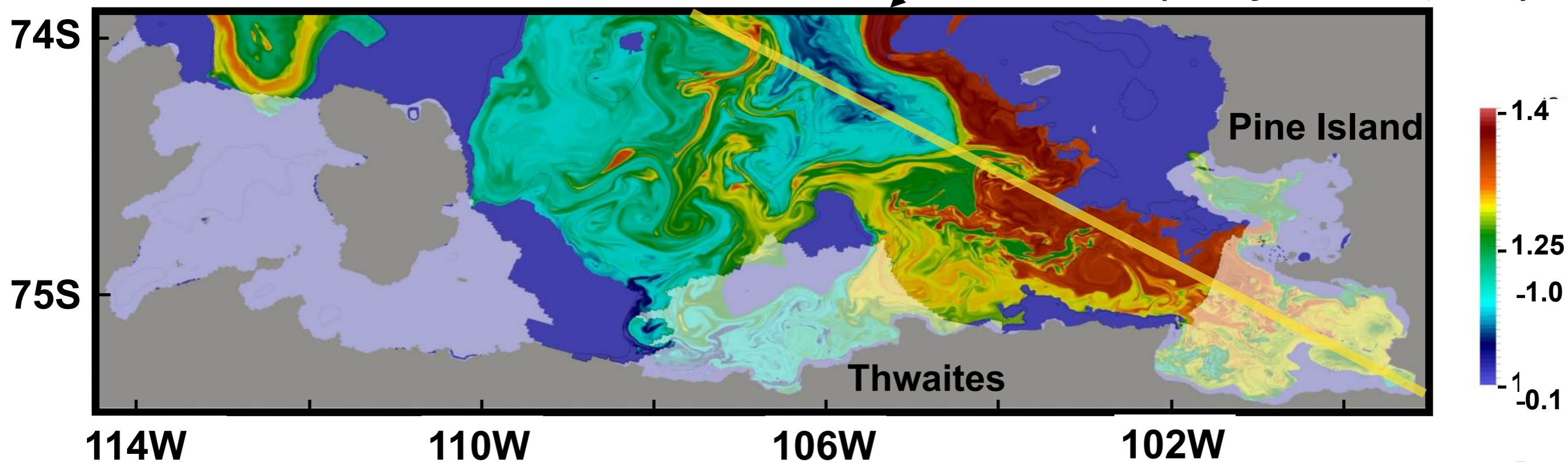


# Submesoscale permitting (200m) downscaling



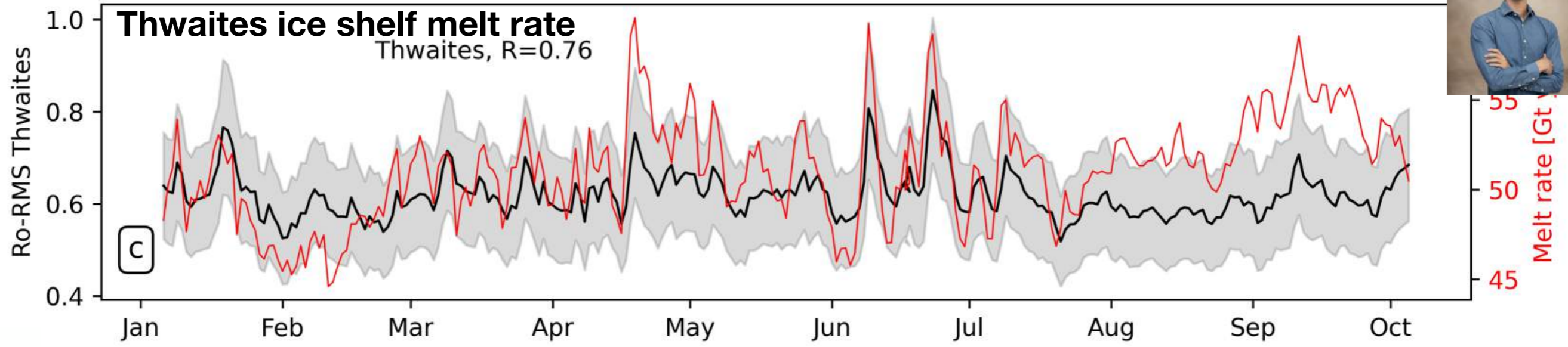
Pot. Temp. at 27.75 isopycnal surface ( $^{\circ}\text{C}$ )

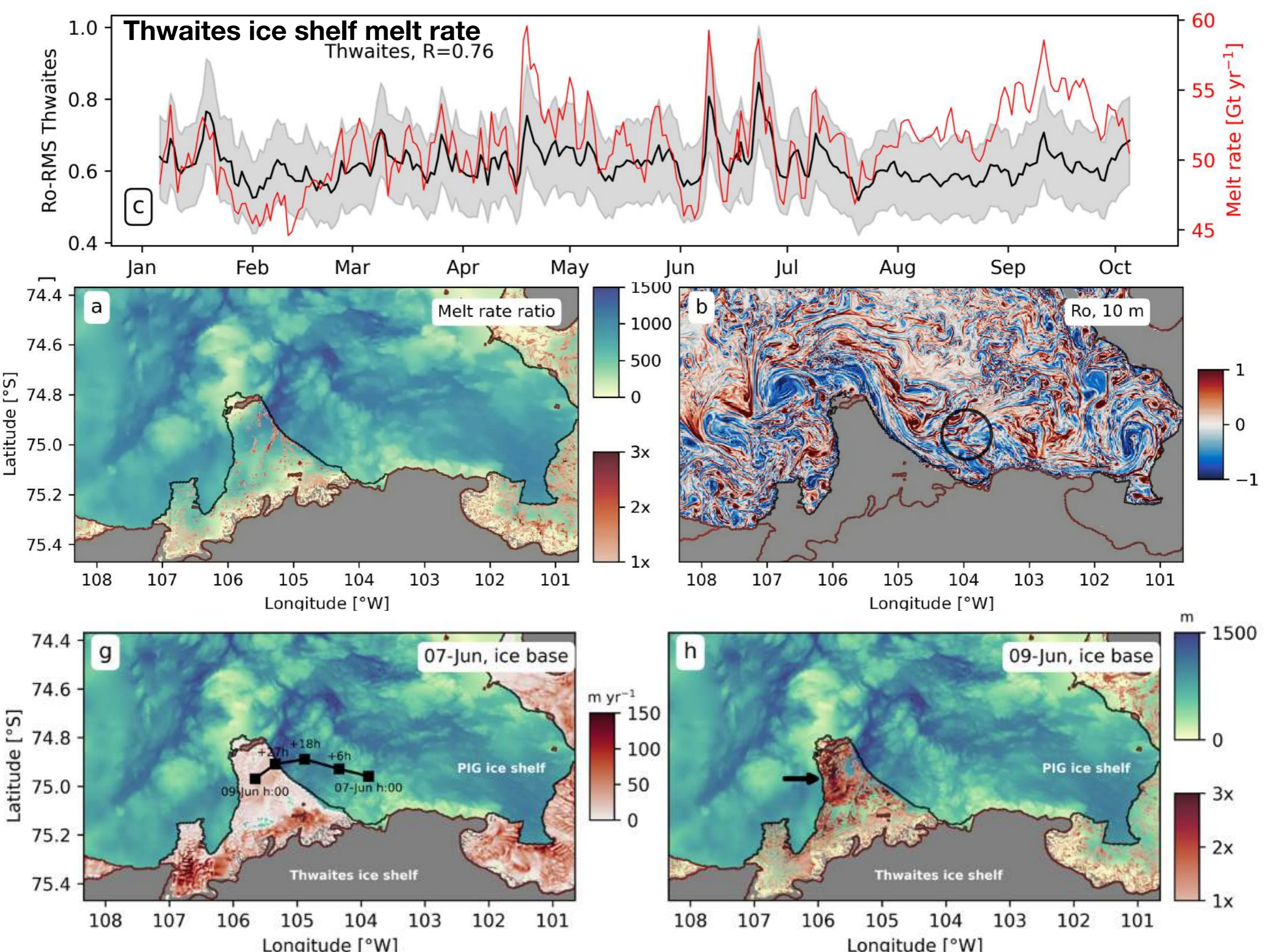
Warm water (Nakayama et al., 2019)



# Storm-like Submesoscale eddies enhances ice shelf melting

Poinelli, Sigelman, Nakayama, 2025 (Nature Geoscience)

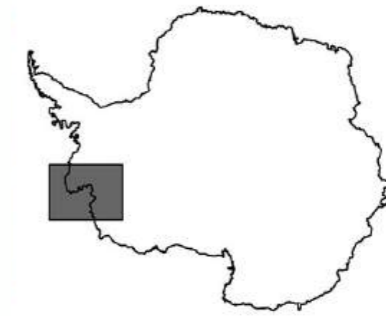




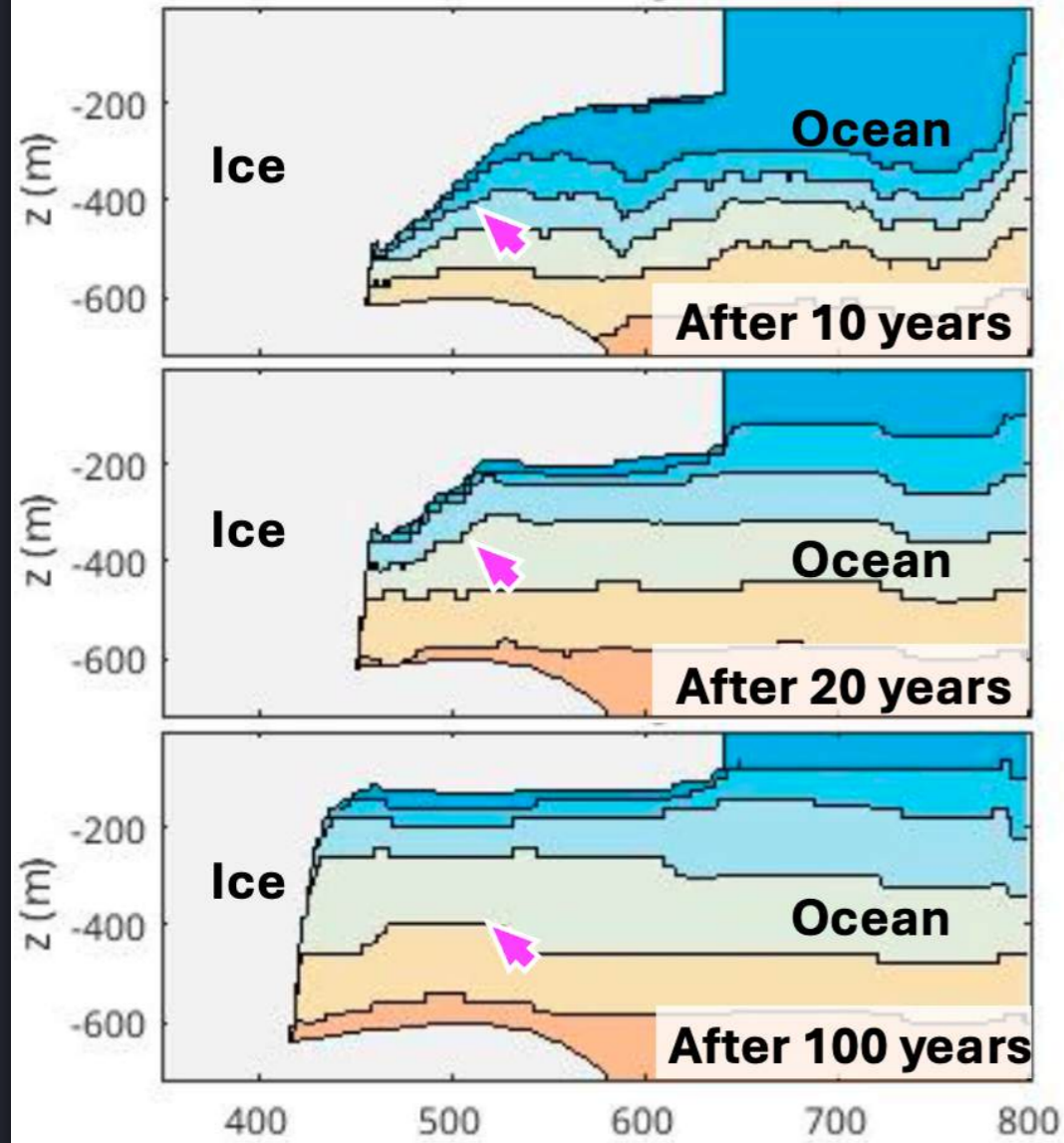
# Ice sheet ocean coupling for Amundsen and Bellingshausen Sea

## ISSM-MITgcm coupling

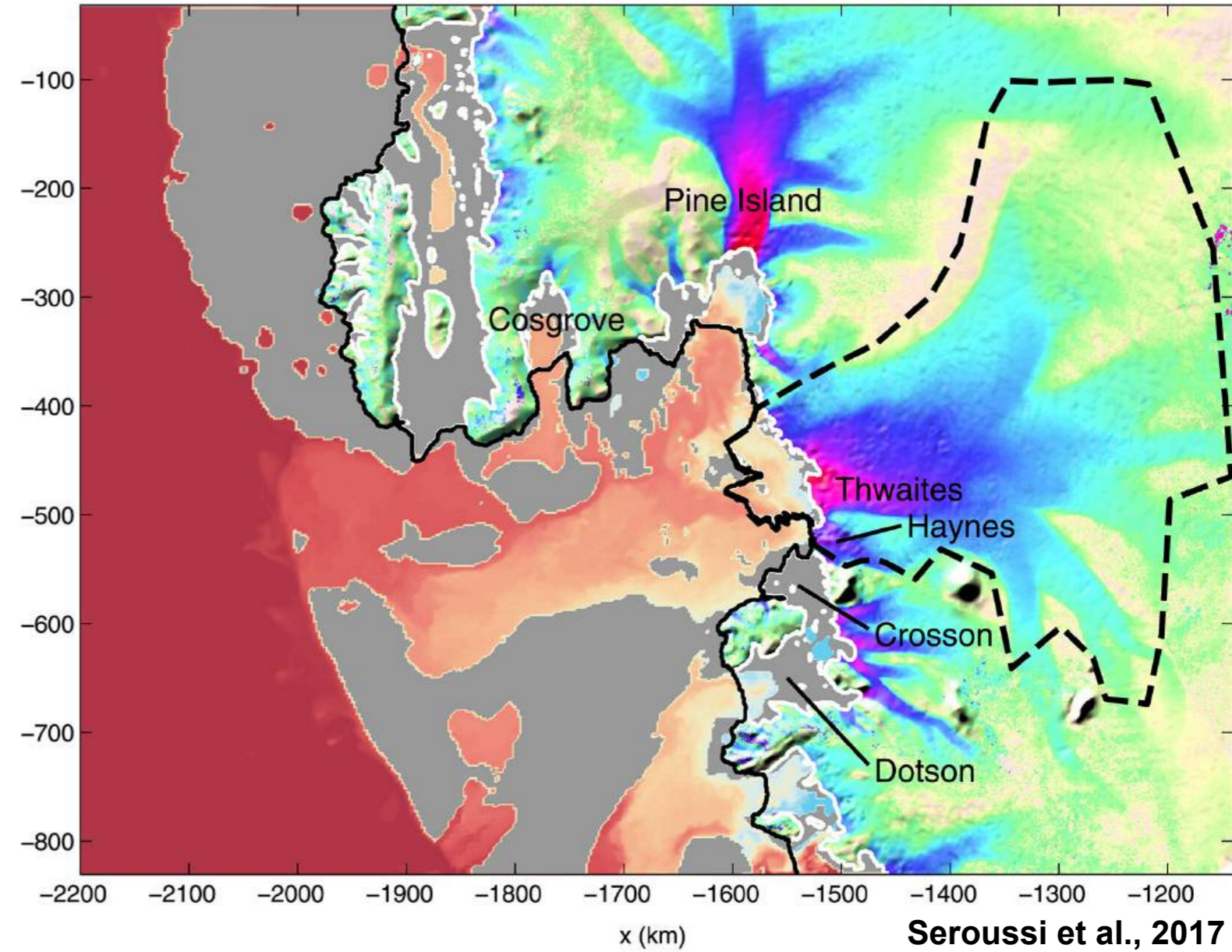
- Amundsen Sea - Thwaite ice shelf (Seroussi et al., 2017)
- East Antarctica - Totten ice shelf (Pelle et al., 2021)
- Bellingshausen Sea ice ocean coupling (Caillet et al., in prep)



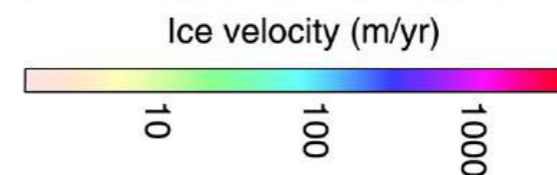
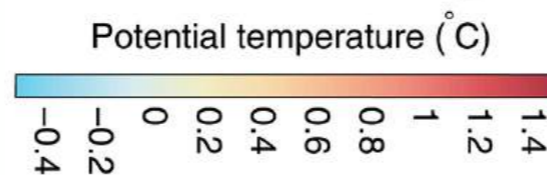
## MISOMIP preliminary results



Seroussi et al., in prep



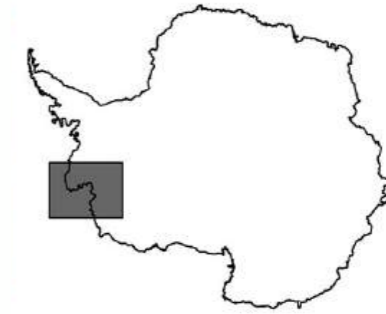
Seroussi et al., 2017



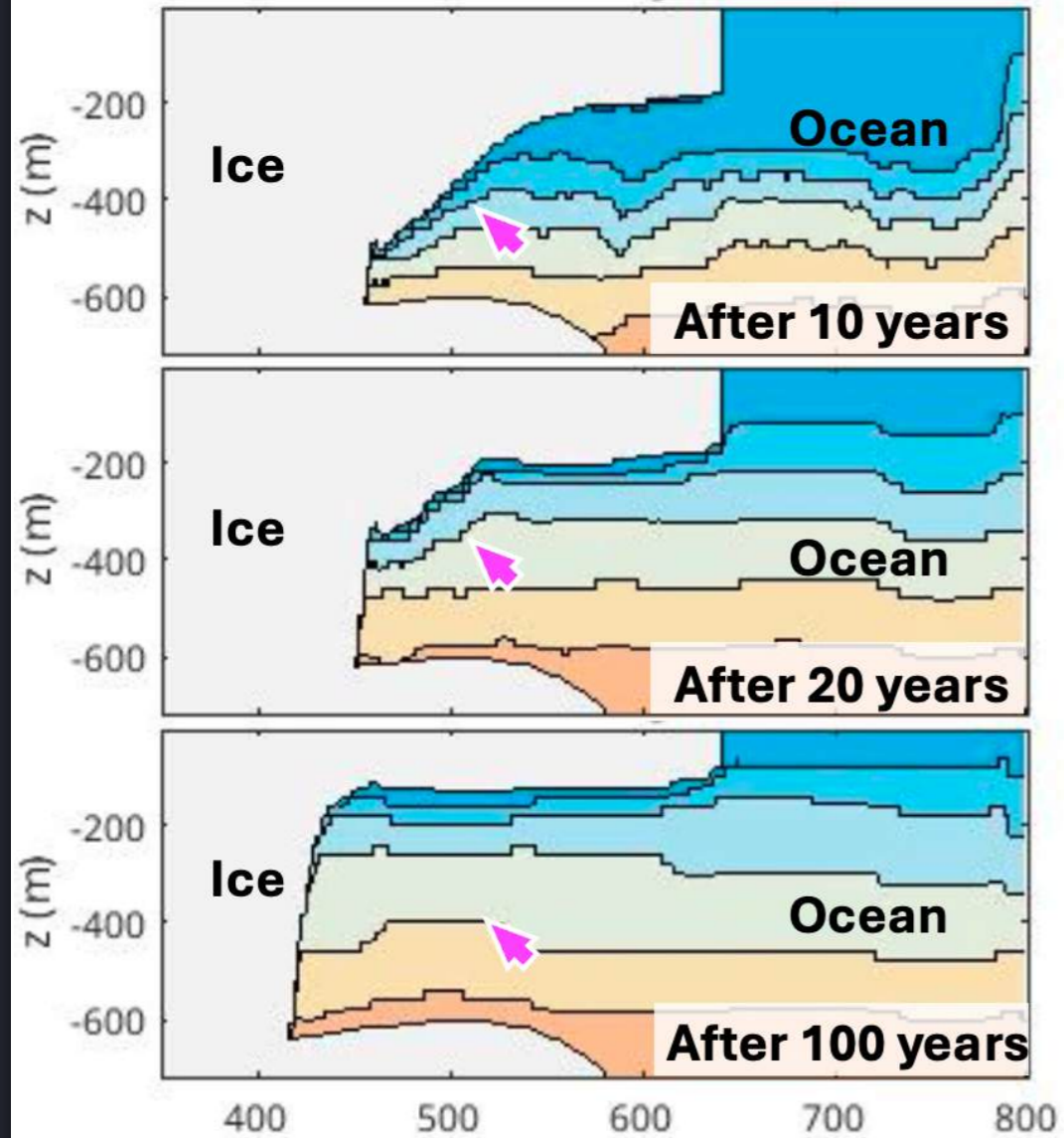
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## MISOMIP preliminary results



Seroussi et al., in prep



# Some recent updates

## 1. Amundsen Sea

- Model data agreement
- Submesoscale permitting downscaling
- Ice-ocean coupling

## 2. Cape Darnley

- Model data agreement
- Coupling with BGC

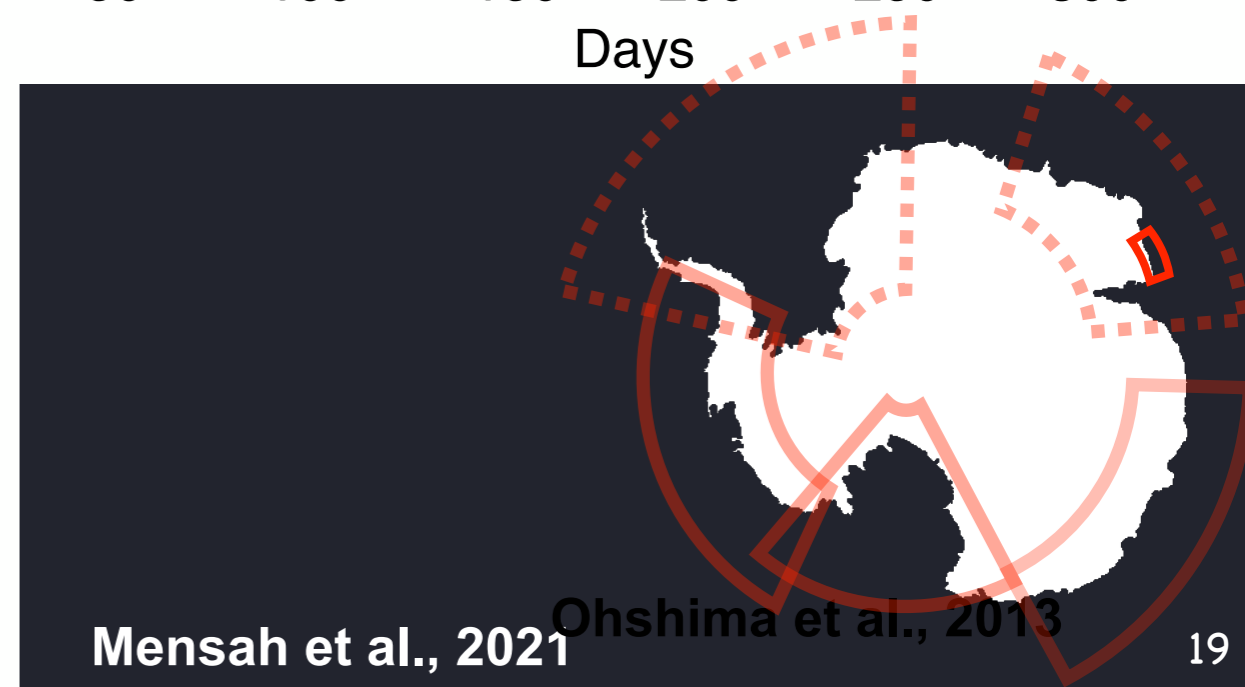
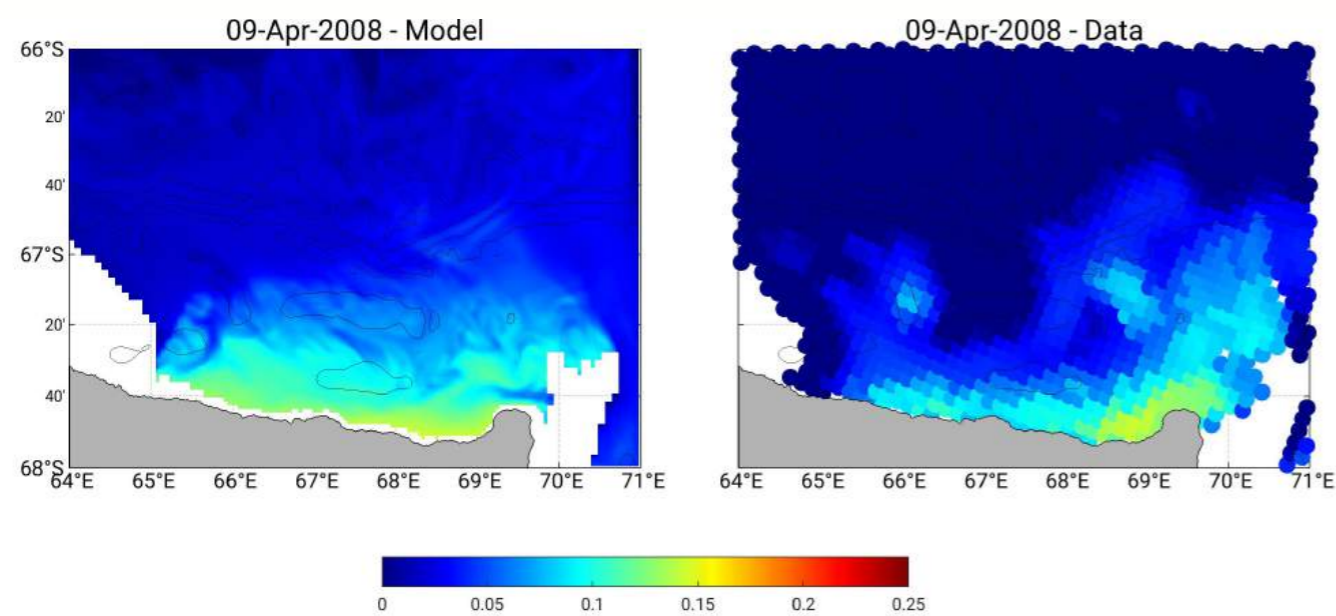
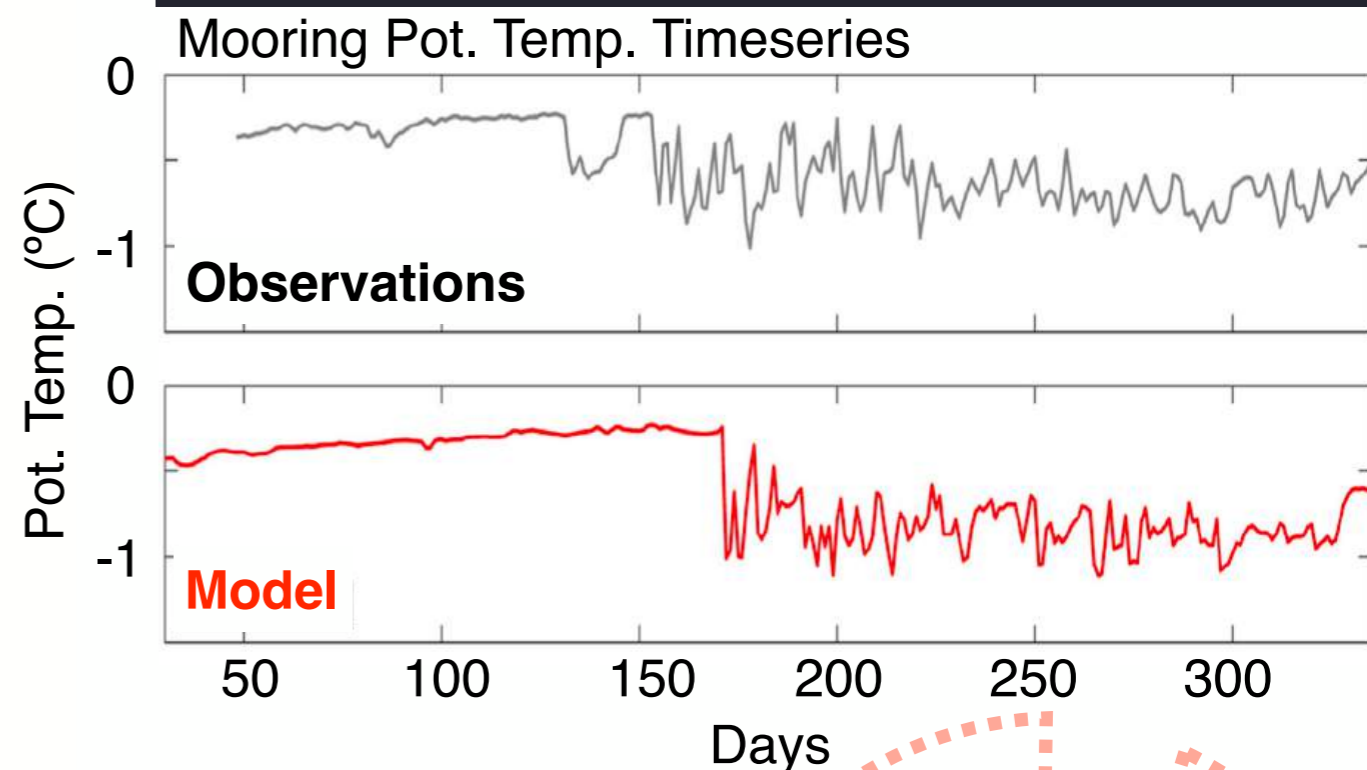
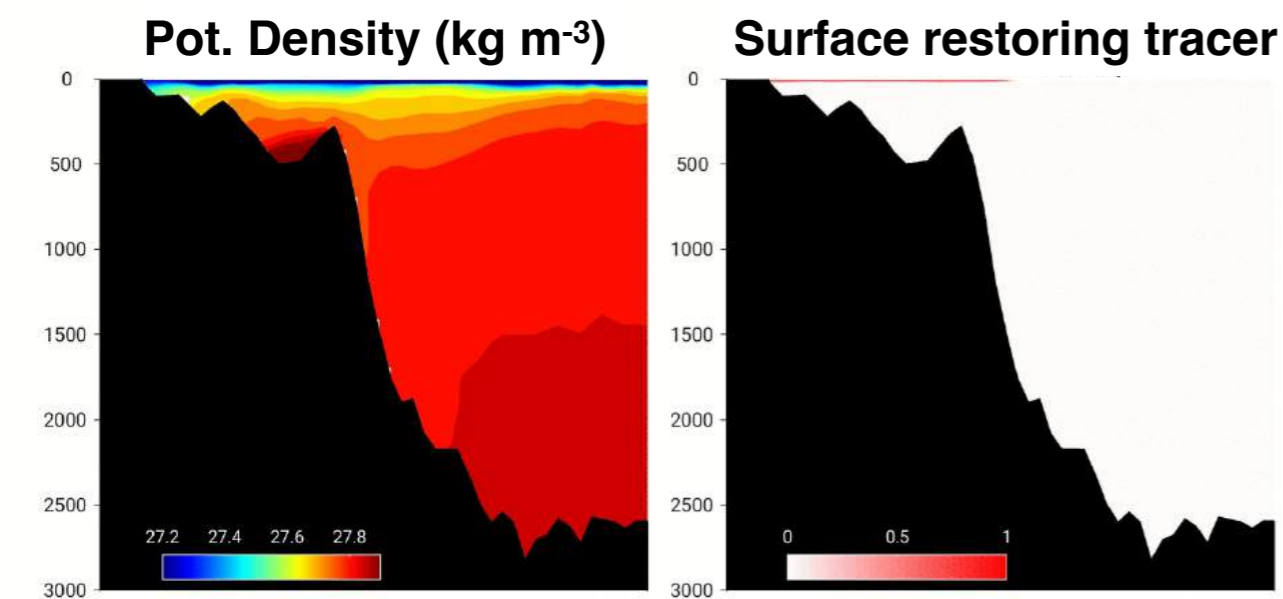
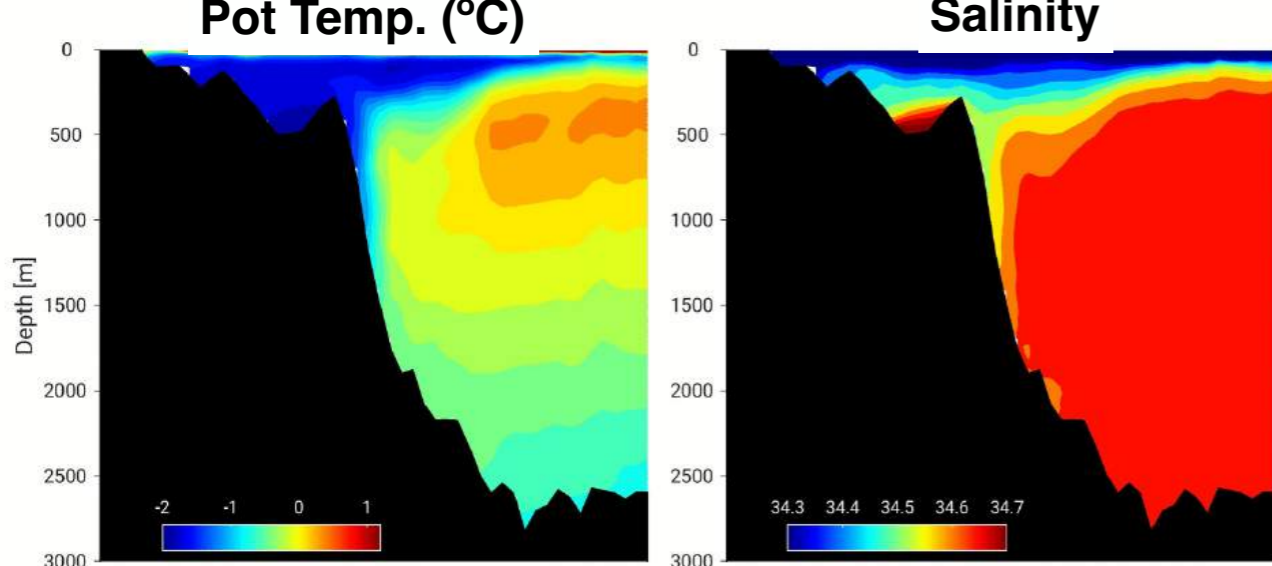
## 3. East Antarctica

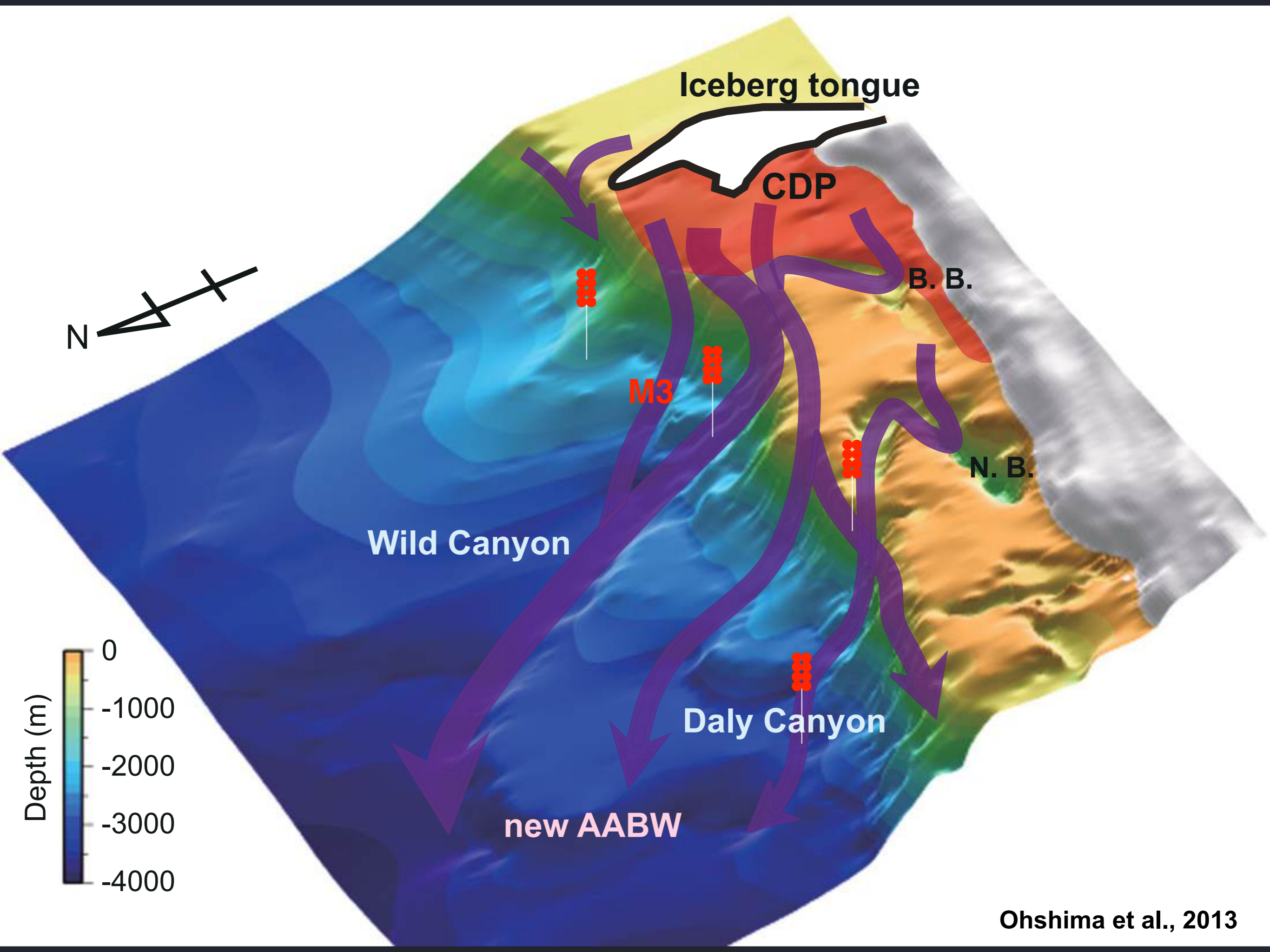
- Model data agreement
- Why deep thermocline?

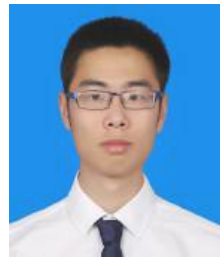


## 2. Cape Darnley Bottom Water formation

- Excellent model-data agreement for sea ice and ocean.
- Perfect test site for the development of BBL parameterization.







# Model-data agreement for BGC parameters

## Surface Chl-a

## CO<sub>2</sub> Flux

## Surface pCO<sub>2</sub>

Chl (model)

Chl (obs.)

CO<sub>2</sub> flux (model)

pCO<sub>2</sub> (model)

66°S

Nov. 67°S

68°S  
66°S

Dec. 67°S

68°S  
66°S

Jan. 67°S

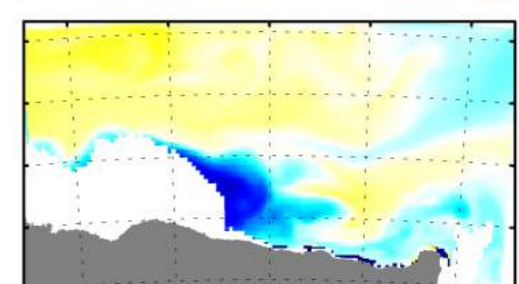
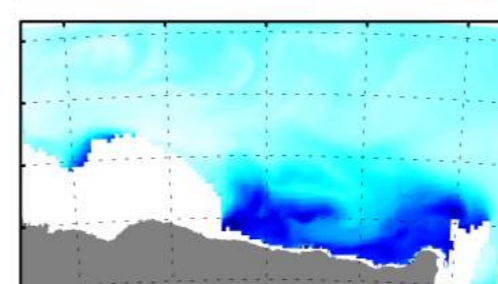
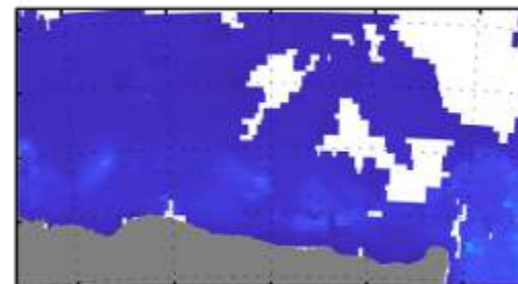
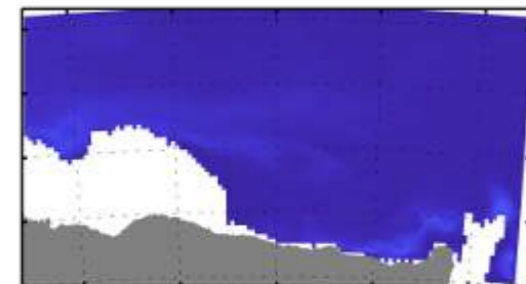
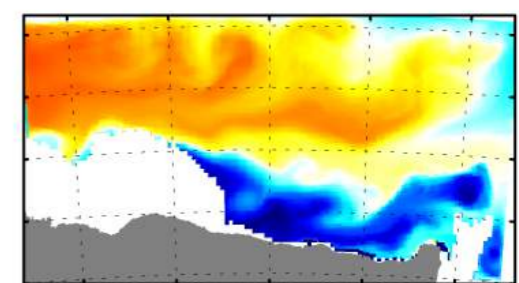
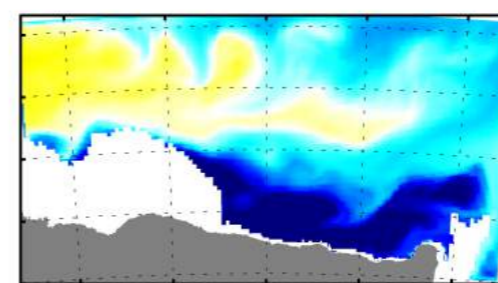
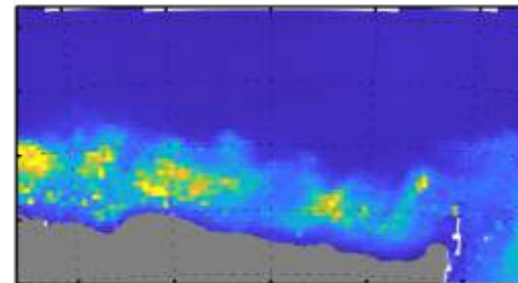
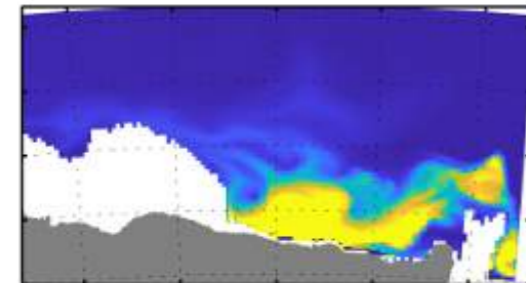
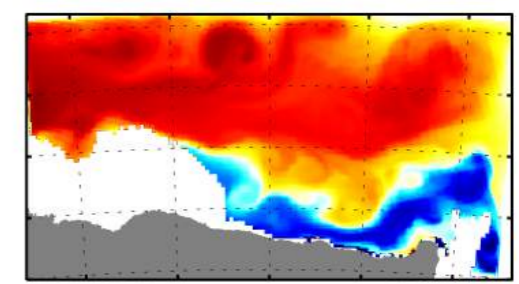
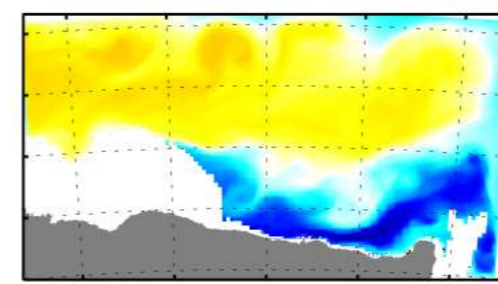
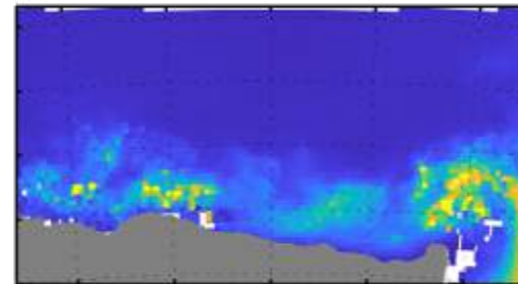
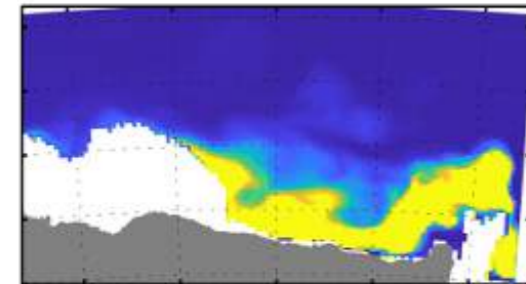
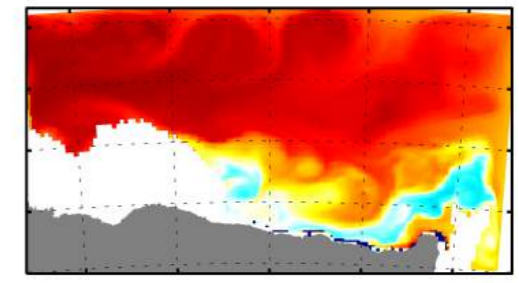
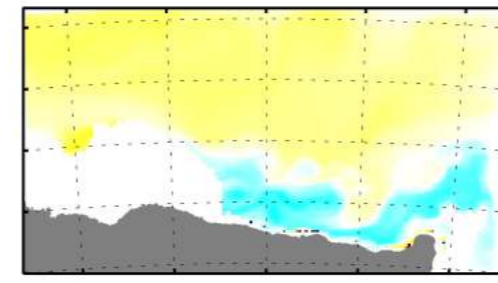
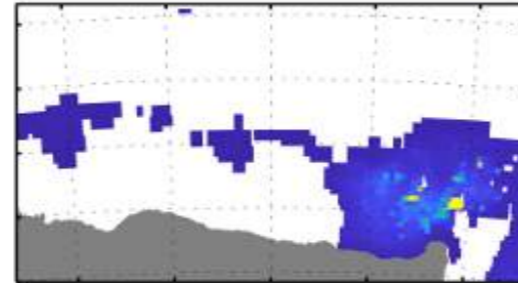
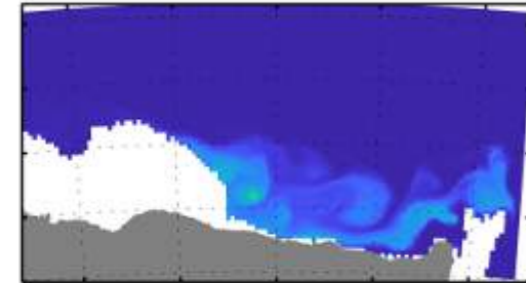
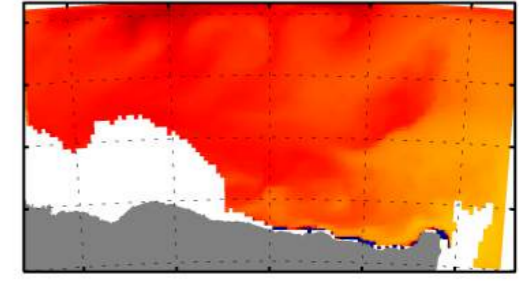
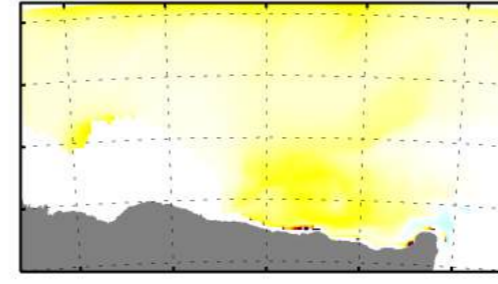
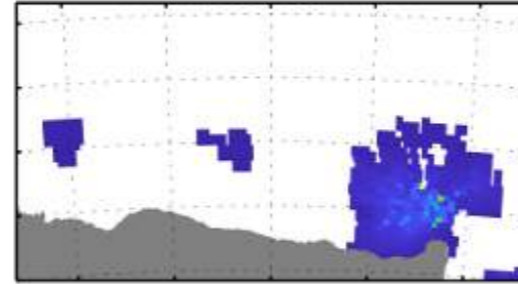
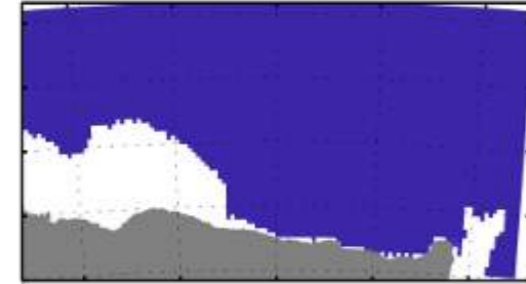
68°S  
66°S

Feb. 67°S

68°S  
66°S

Mar. 67°S

68°S



62°E 66°E 70°E

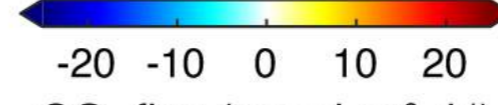
62°E 66°E 70°E

62°E 66°E 70°E

62°E 66°E 70°E



Chl-a (mg m<sup>-3</sup>)



CO<sub>2</sub> flux (mmol m<sup>-2</sup> d<sup>-1</sup>)



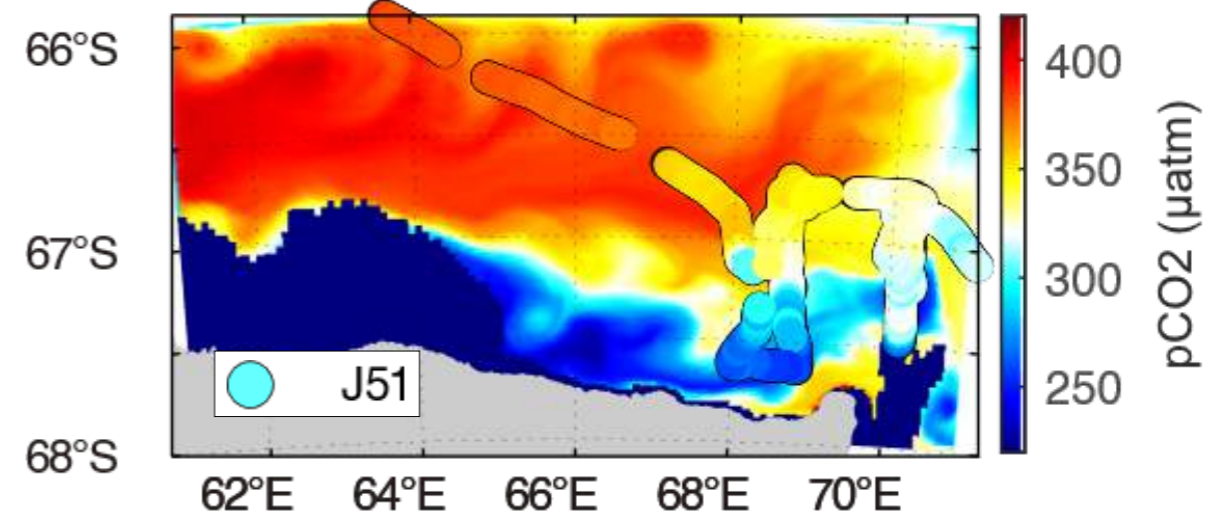
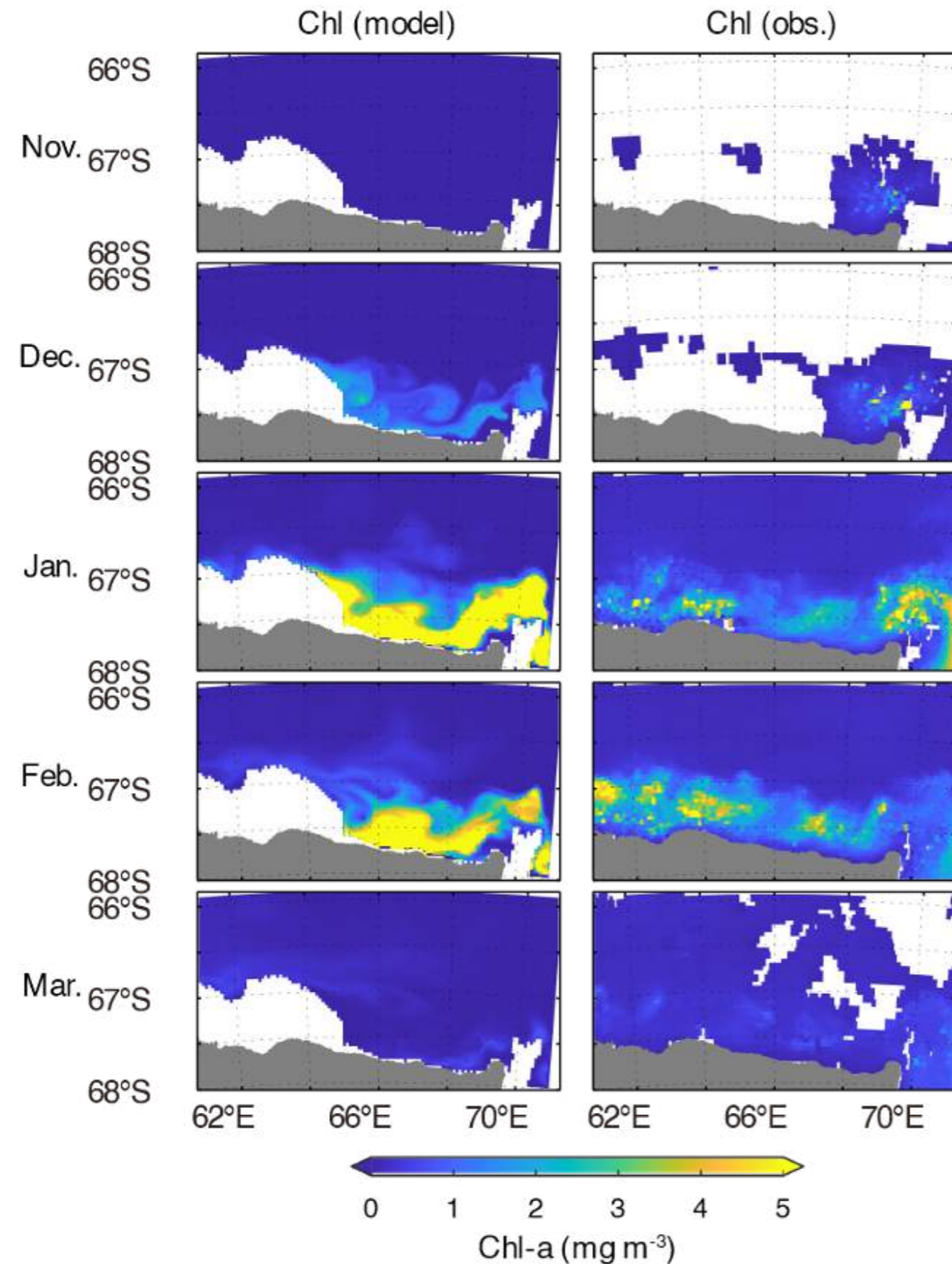
pCO<sub>2</sub> (µatm)

# Model-data agreement for BGC parameters

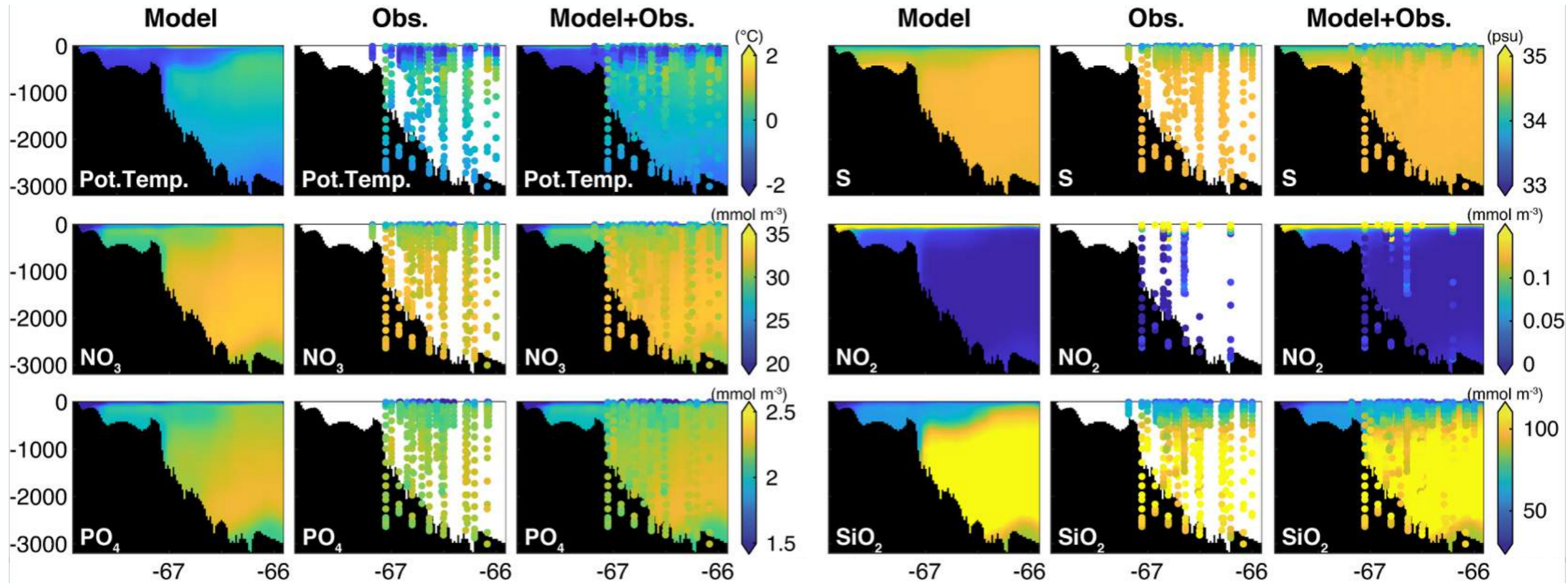
## Surface Chl-a

## Surface pCO<sub>2</sub>

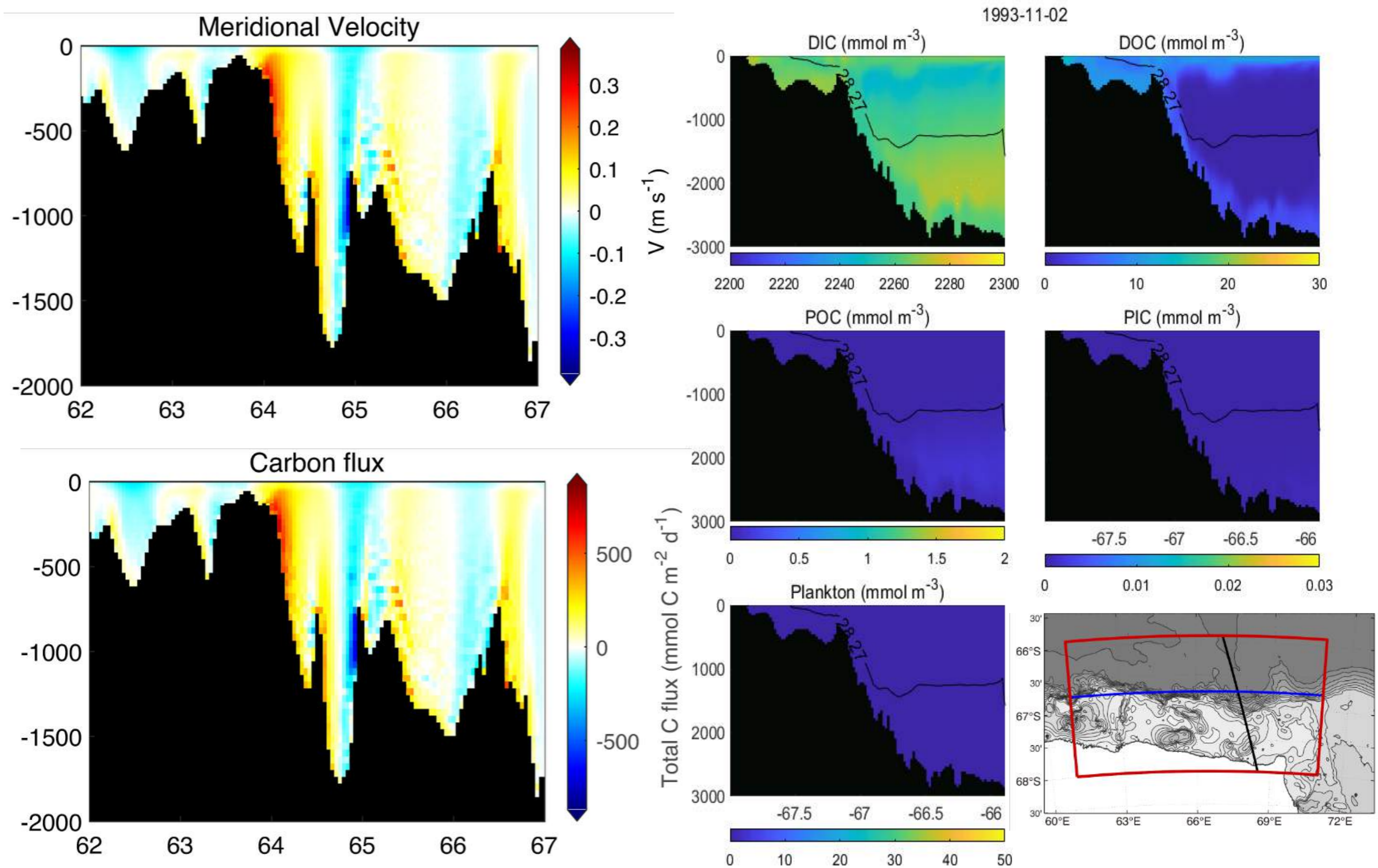
pCO<sub>2</sub> in Feb.



# Model data agreement (vertical sections)



# Transport of Carbon to deep ocean



# Some recent updates

## 1. Amundsen Sea

- Model data agreement
- Submesoscale permitting downscaling
- Ice-ocean coupling

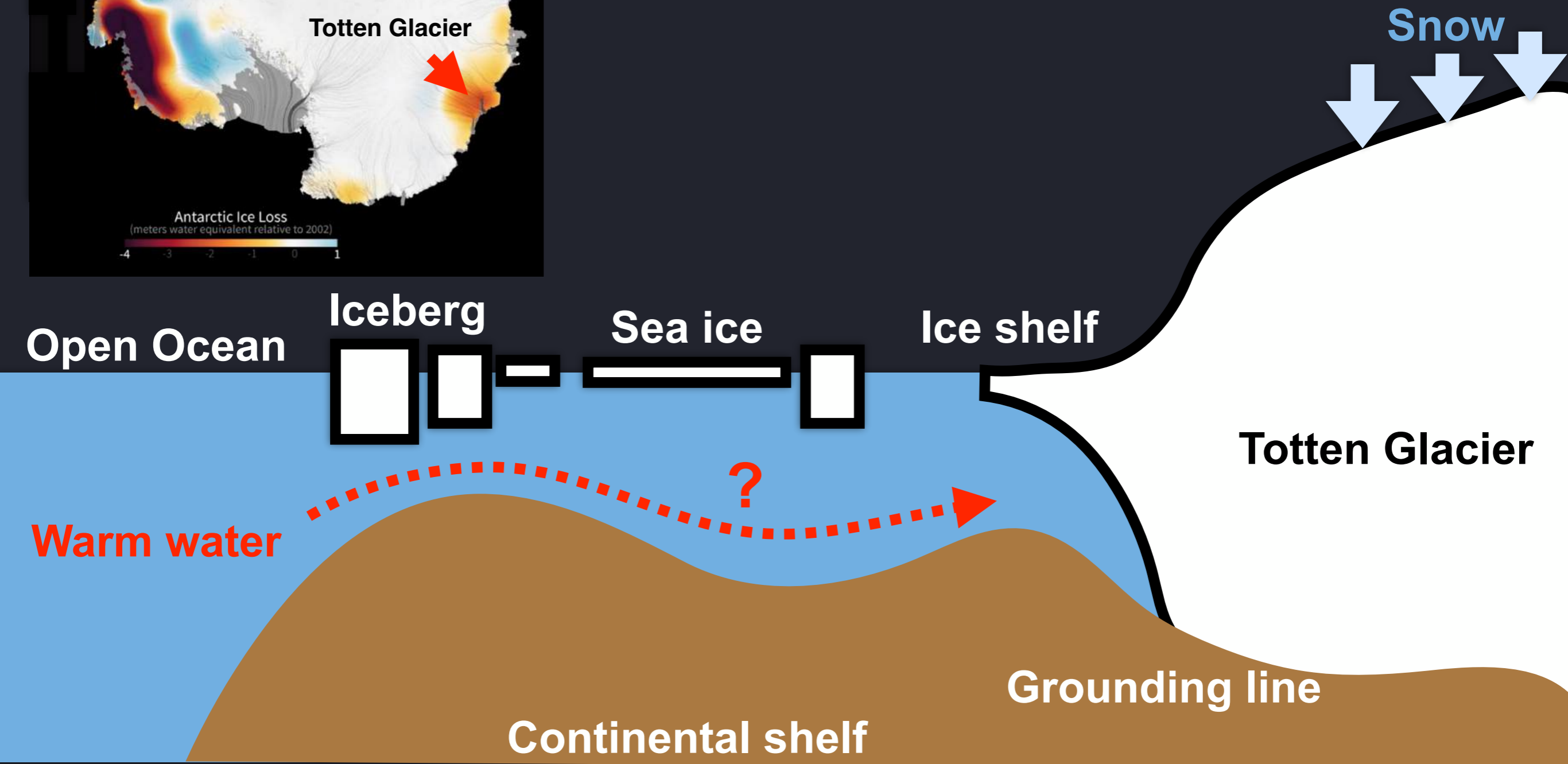
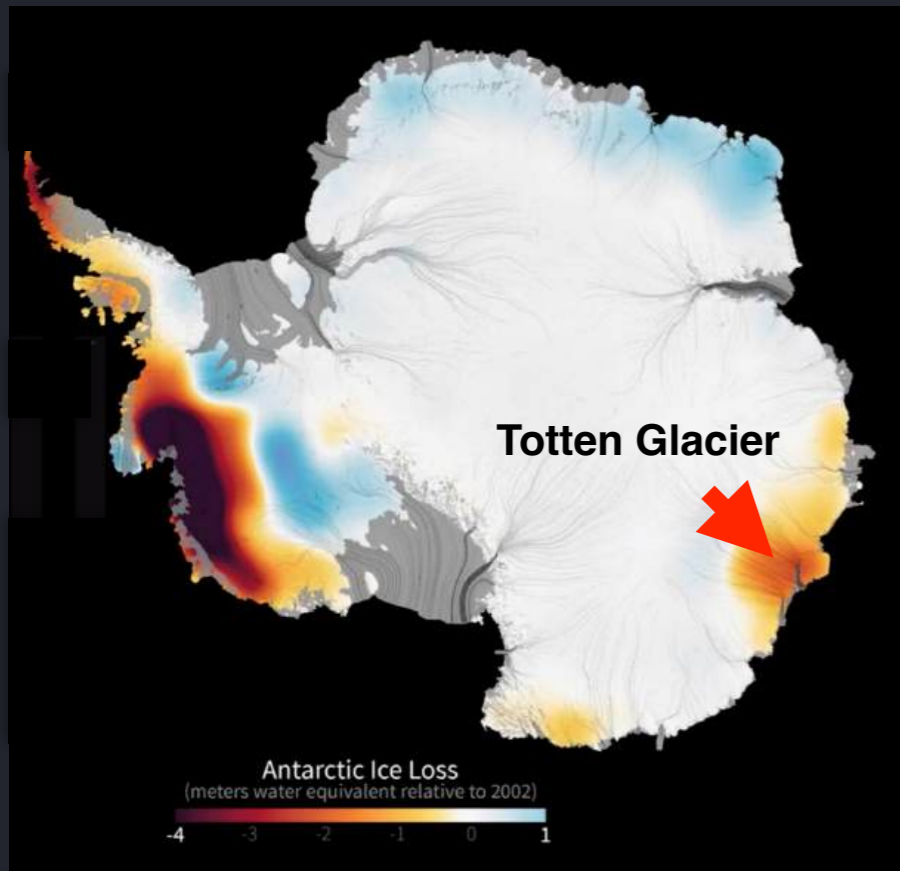
## 2. Cape Darnley

- Model data agreement
- Coupling with BGC

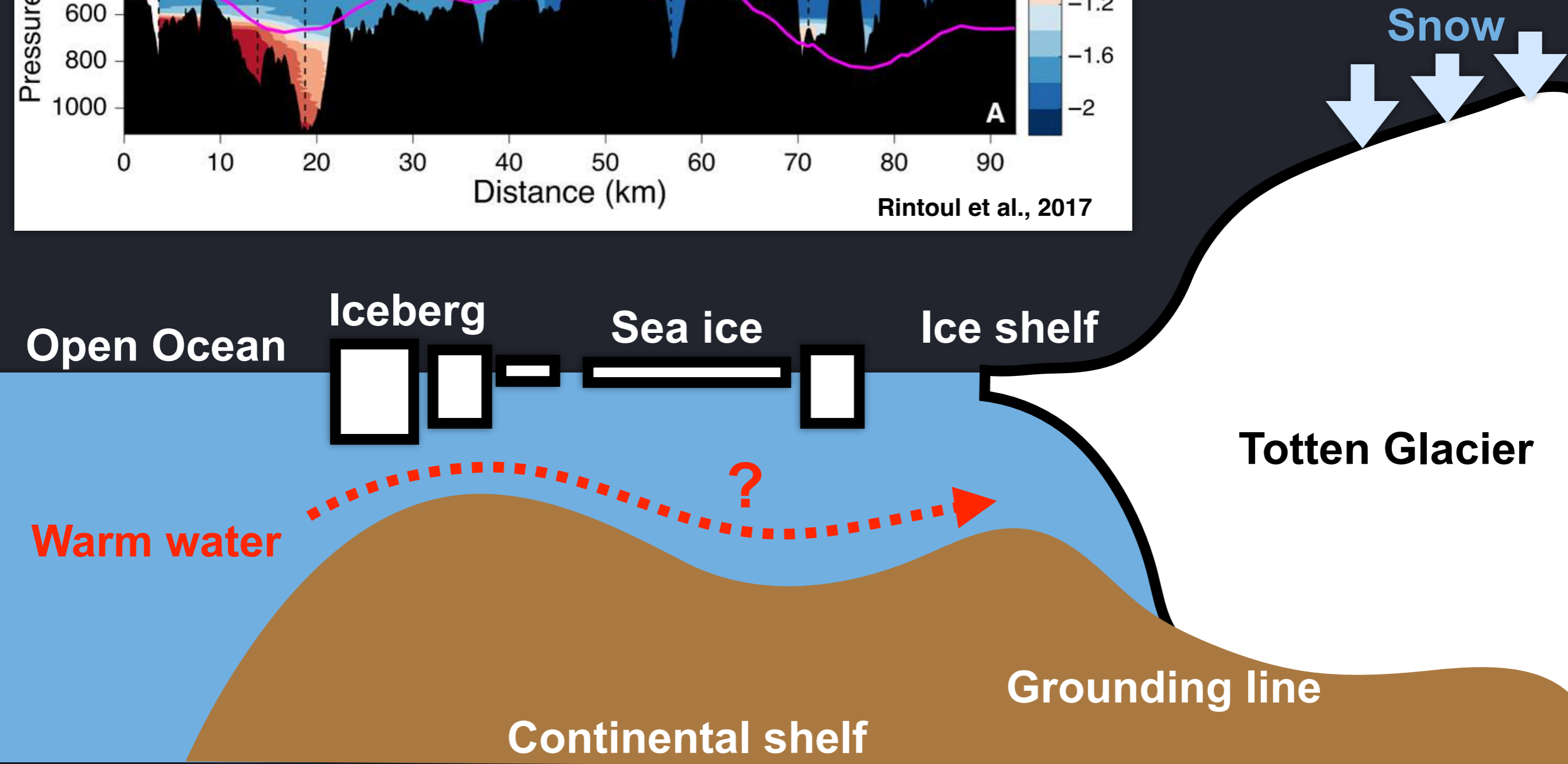
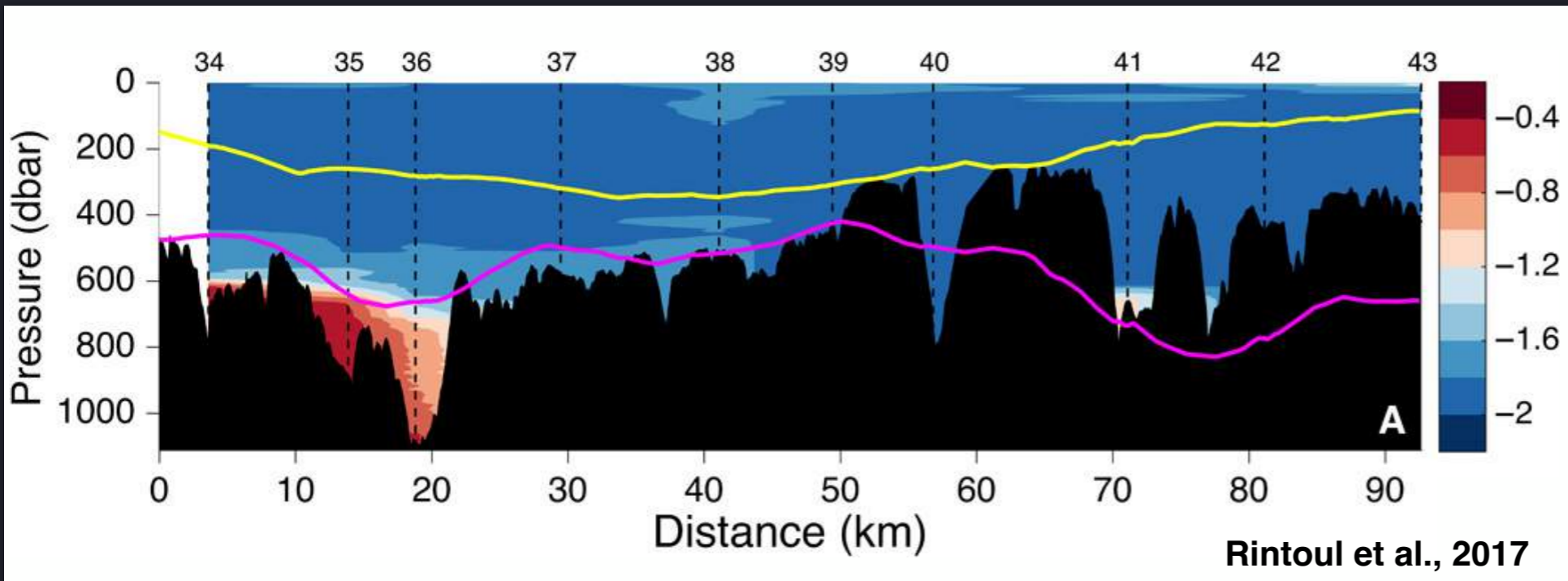
## 3. East Antarctica

- Model data agreement
- Why deep thermocline?

# Observations



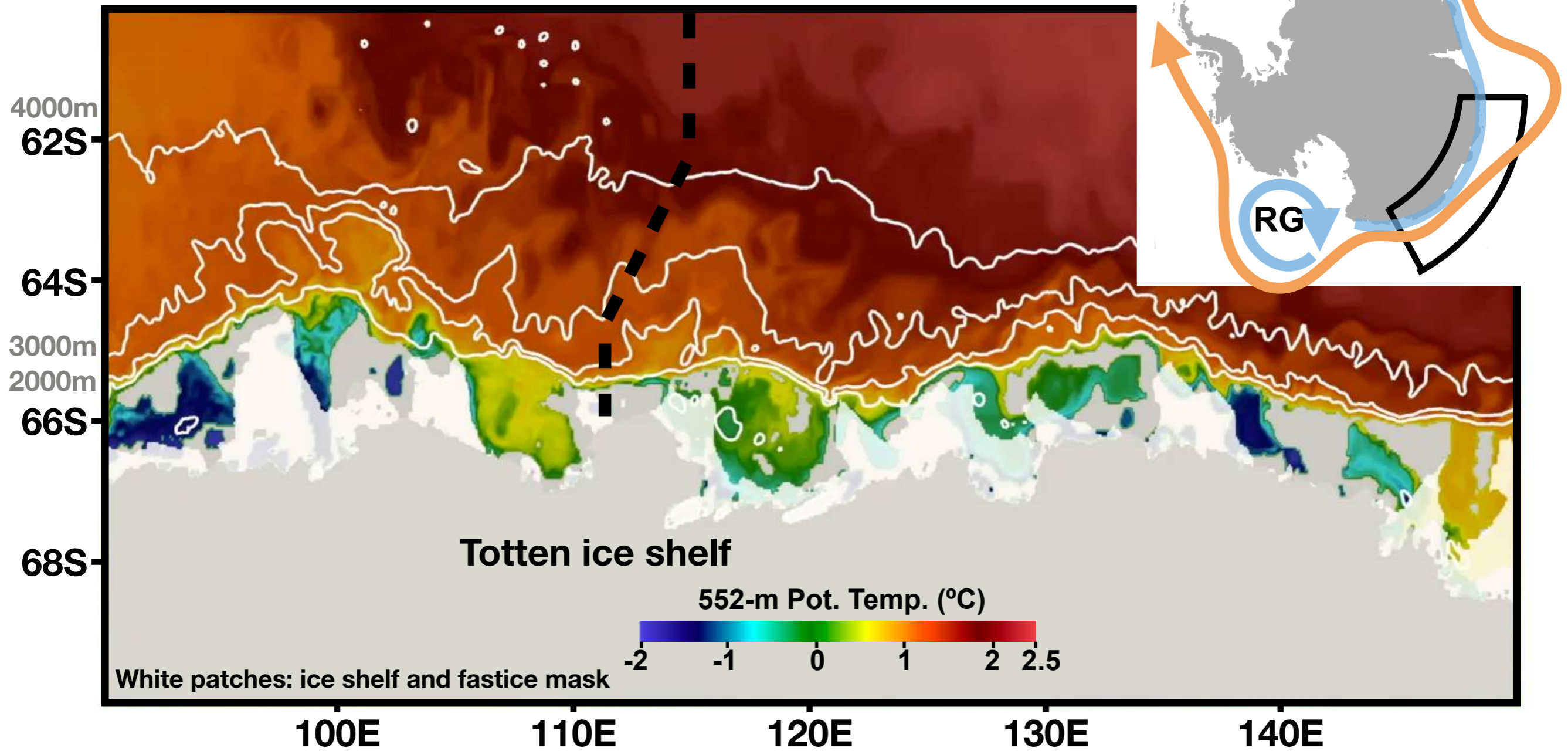
# Observations



# ECCO East Antarctic Downscaling

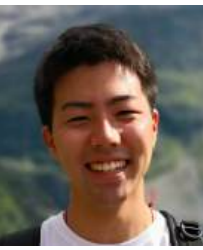
Time: 0.000000

Days since 1991/01/01



- Horizontal spacing of ~4-5 km and 50 layers vertically.
- Model simulation for 28 years from 1992 -2025.

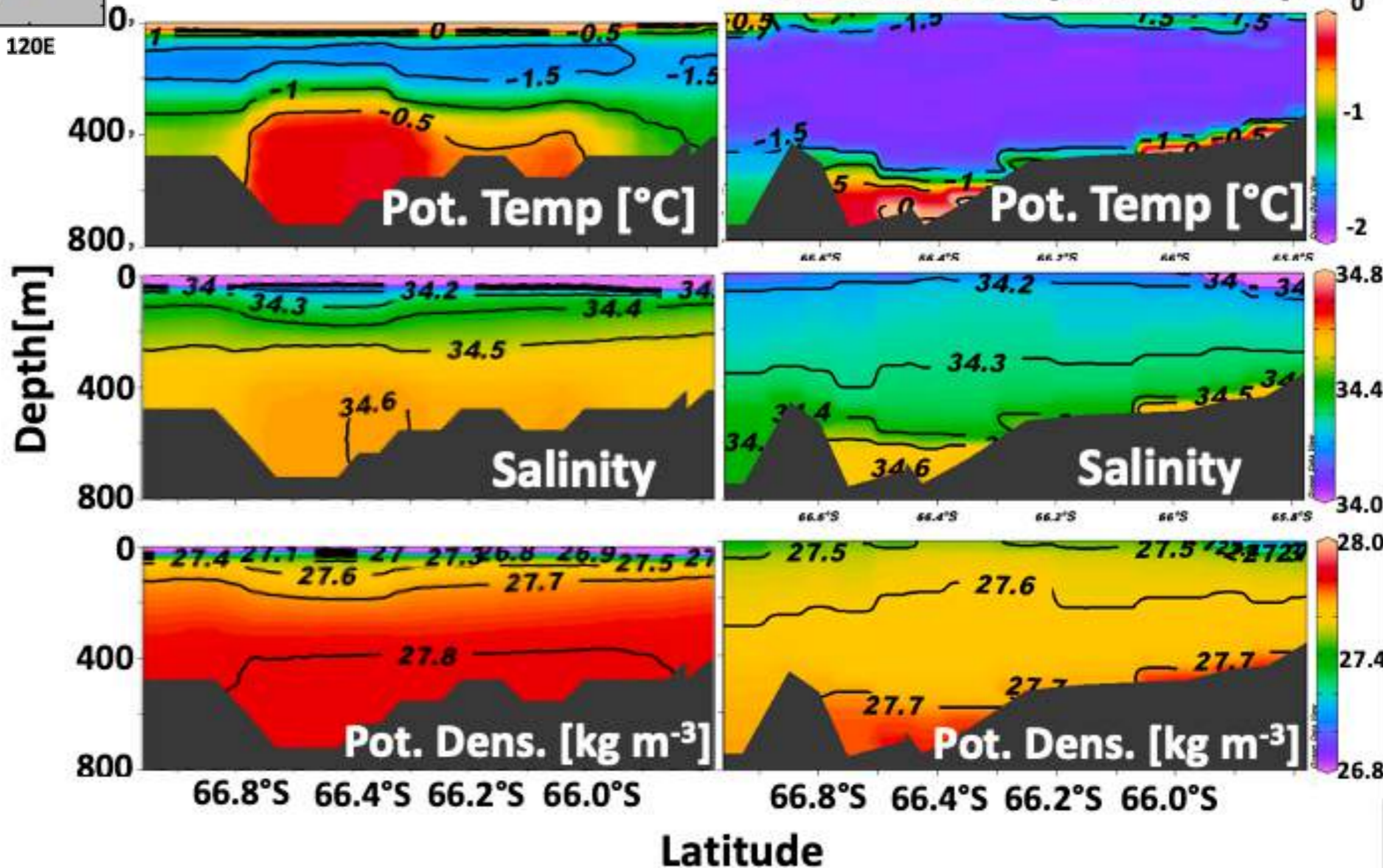
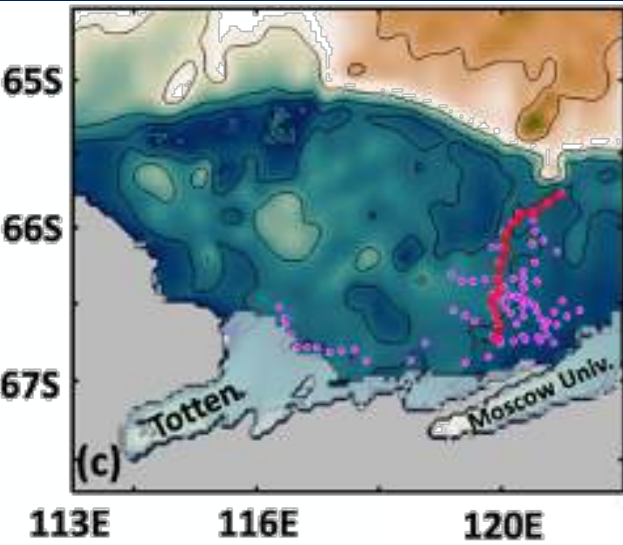
# Comparison previous model with observations



- The common problem have been reported in other modeling studies (Gwyther et al., 2014, 2018; Kusahara et al., 2024)

## Nakayama et al., 2021

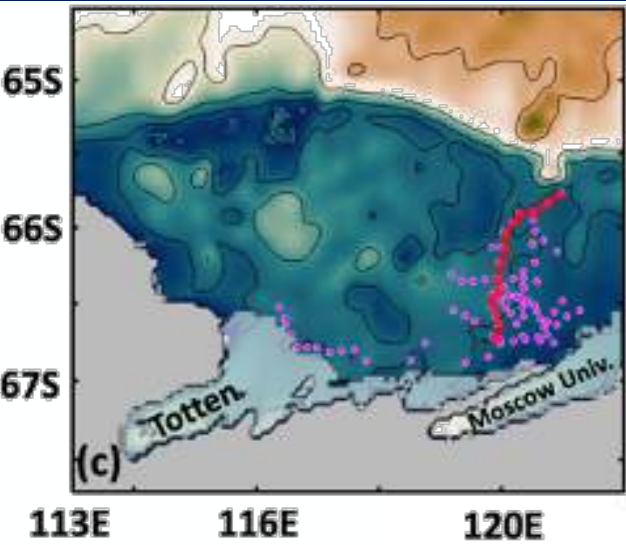
## Observation (Jan. 2015)



# Comparison previous model with observations

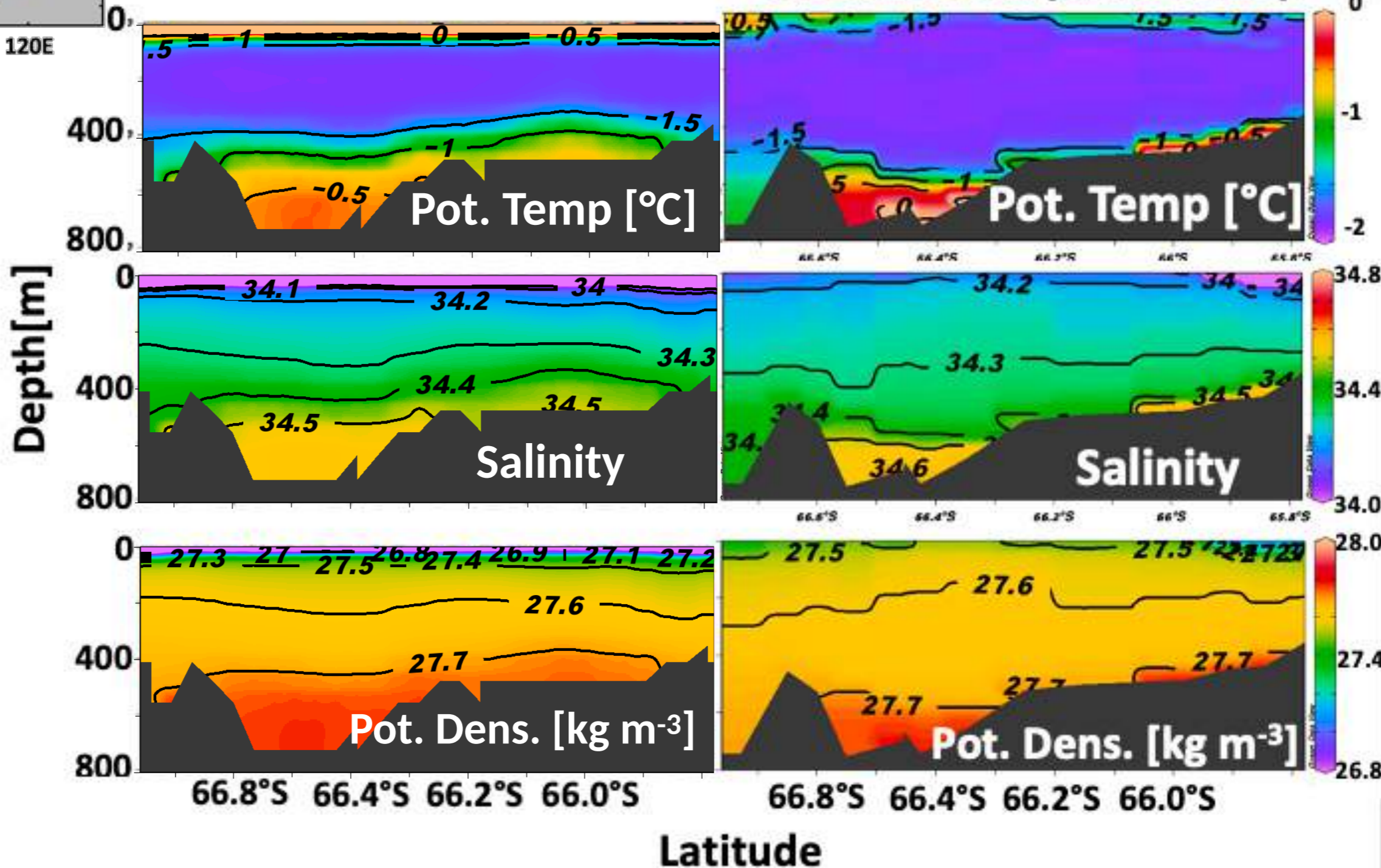


- The common problem have been reported in other modeling studies (Gwyther et al., 2014, 2018; Kusahara et al., 2024)



**New model**

**Observation (Jan. 2015)**



# ECCO downscaling for Antarctic coastal regions

## ECCO downscaling

- 👁️ **Extensive model evaluation**
- 👁️ Optimize model parameters to achieve **good model-obs agreement**
- 👁️ **New mechanisms or process understanding**
- 👁️ Accessible simulated outputs and analysis scripts
- 👁️ Development towards BGC coupling



## ECCO evaluation (Nakayama et al., 2024 GMD)

- 👁️ Evaluation of ECCOv4r5, ECCO-LLC270, SOSE, and GECCO

Domain	Period	Grid	Output	Where?	BGC	Model Evaluation Publication
Amundsen/ Bellingshausen	1992-2025	3-4 km	Monthly 5-daily	NASA Earth Data	☆	Nakayama et al., 2018 (Nature Communications) Hyogo et al., 2024 (JGR Ocean) Park et al., 2024 (Nature Communications) Nakayama et al., in review (GMD)
Amundsen High-res	2010 Jan-Oct	200m	Daily/hourly	NASA Earth Data		Nakayama et al., 2019 (Scientific Report) Nakayama et al., 2021c (GRL) Shrestha et al., 2024 (GRL) Poinelli et al., 2025 (Nature Geoscience)
Ross Sea	2010-2020	2-5 km	Monthly		☆	Malyarenko et al., 2023 Taewook in prep
East Antarctic	1992-2025	4-5 km	Monthly/ daily	NASA Earth Data Zenodo	★	Nakayama et al., 2021b (GRL) Hyogo et al., in review (GRL)
Cape Darnley	2008 Jan-Dec	200m 1,2,4,8 km	Daily	Zenodo	★	Mensah et al., 2021 (Ocean Modeling) Mensa et al., In prep
Weddell Sea	1992-2025	2-5 km	Monthly	TBD		Moriyoshi et al., in prep
Antarctic Peninsula	1992-2025	TBD	Monthly	TBD	☆	Development just started



: Running with BGC

☆: Project funded for BGC

<https://sites.google.com/view/umi-nakayama/>

**Other ongoing projects**

# Nakayama's group

- Established in April 2019
- Diverse research topics
- Model-data synthesis

D3



## Bellingshausen Sea


Collaborating with 

Hyogo, Nakayama et al., submitted

D2




## Weddell Sea

Collaborating with 

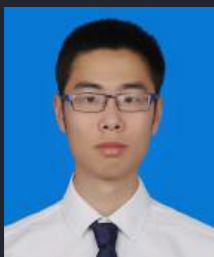
D2



## West Greenland

Collaborating with 

D3



## Cape Darnley BGC

Collaborating with 

\*\* graduated from our group

Taketo Shimada (2024)

Tsubasa Yasui (2023)

Keito Iwata (2022)

Toshiki Hirata (2022)

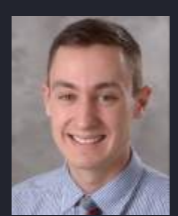
## International collaborations



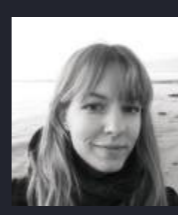
NIWA (New Zealand)  
Ross Sea simulation & Tide



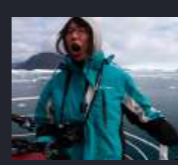
University of Washington (USA)  
1940's El Niño & Amundsen Sea



UC Irvine (USA)  
Ice-ocean coupled simulation  
Future projection of Totten Glacier  
Pelle et al., 2021



University of Bremen (Germany)  
Weddell Sea ocean state estimate

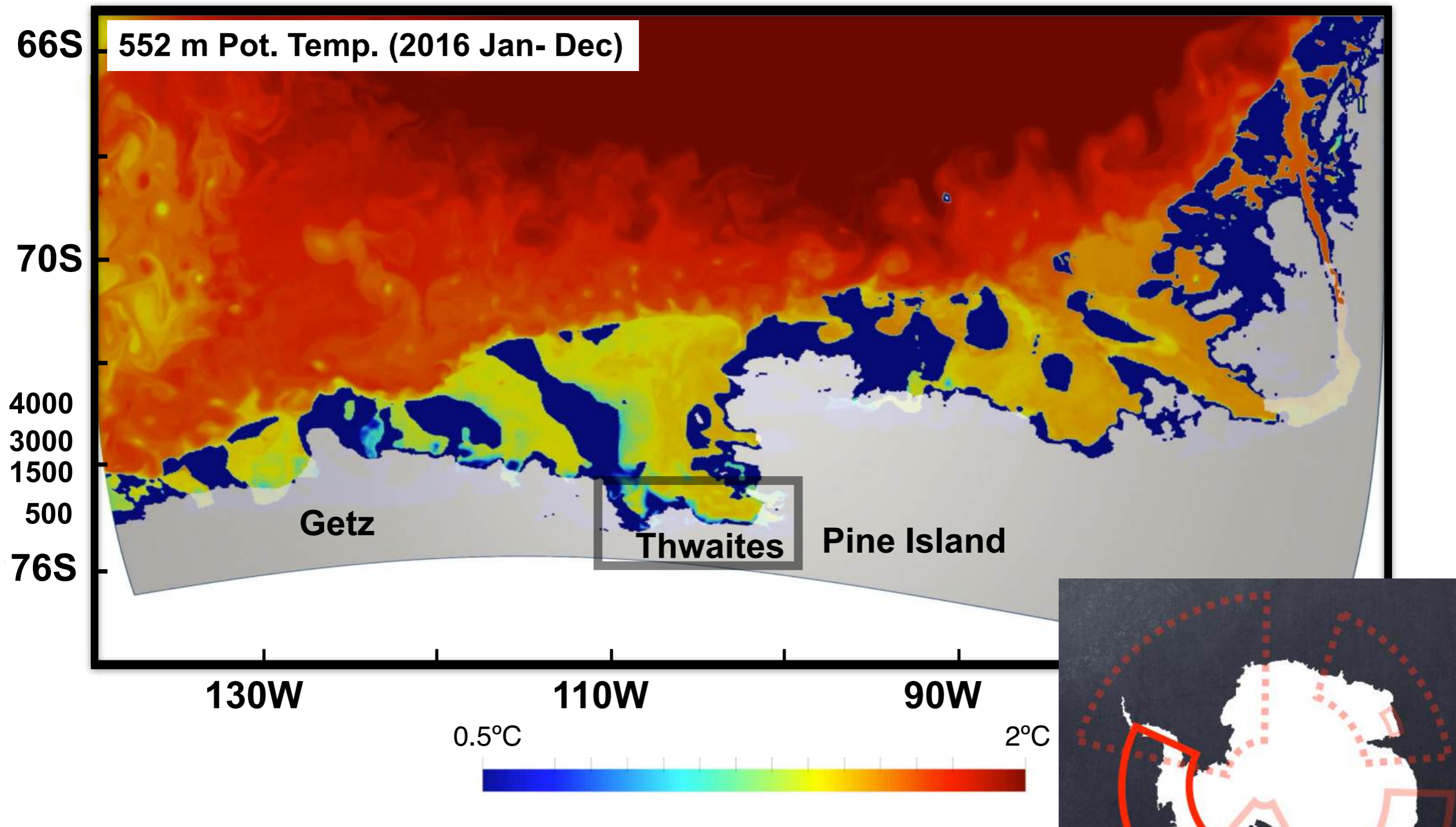


UC Irvine (USA)  
Petermann Glacier & subglacial  
freshwater runoff

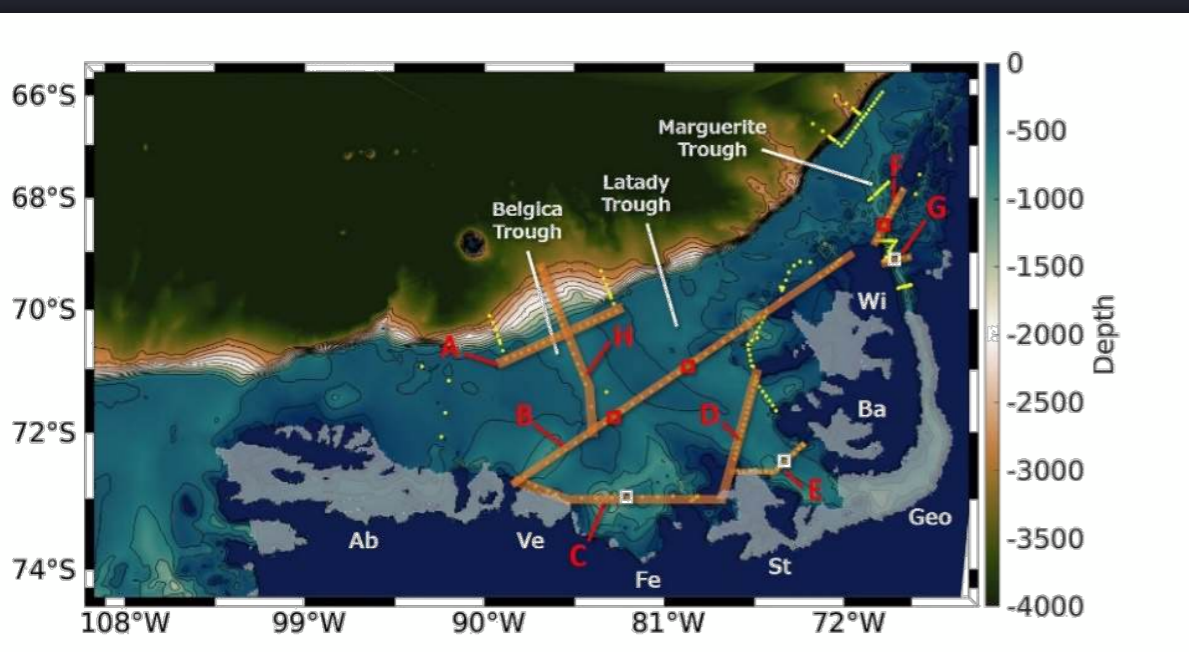
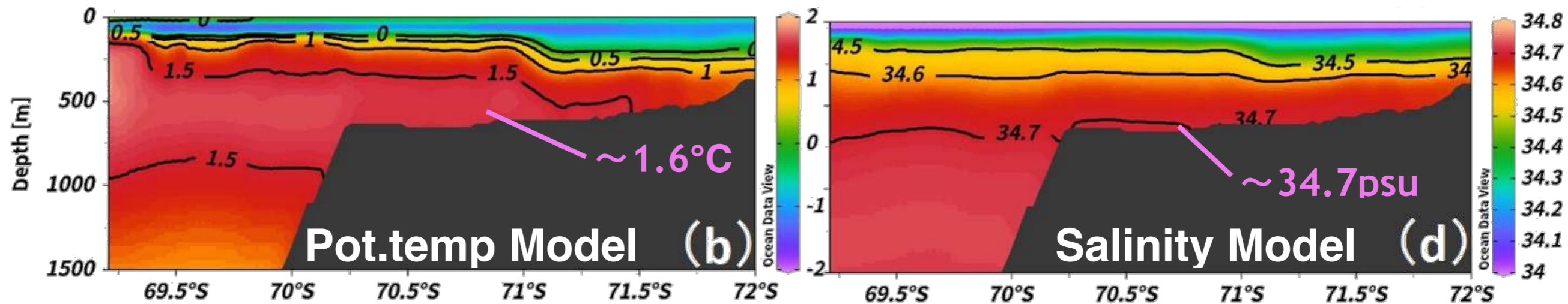
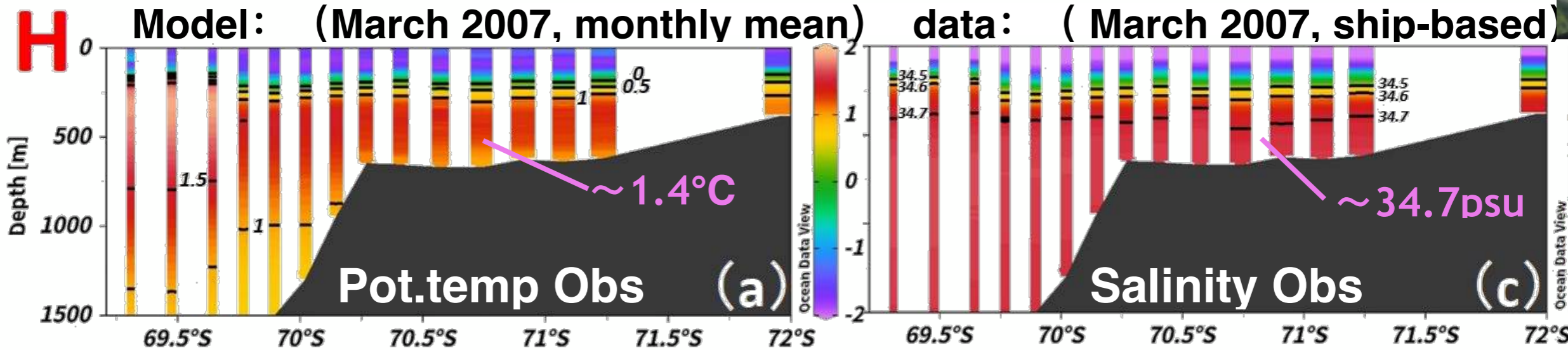
Cai et al., 2017

# Amundsen-Bellingshausen Sea configuration

Available between 1992-2020 (daily/monthly mean), ECCO boundary condition, ERA-interim

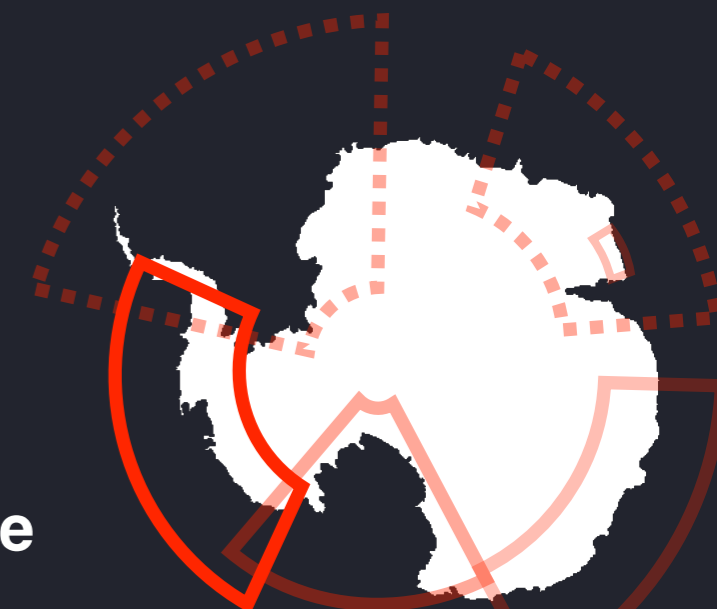


# Modeling Bellingshausen Sea

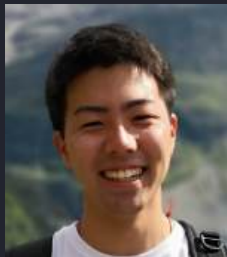


1. Simulated hydrographic structures are consistent with observations.

2. Similar mCDW pathways toward ice shelf cavities.



Hyogo et al., in prep

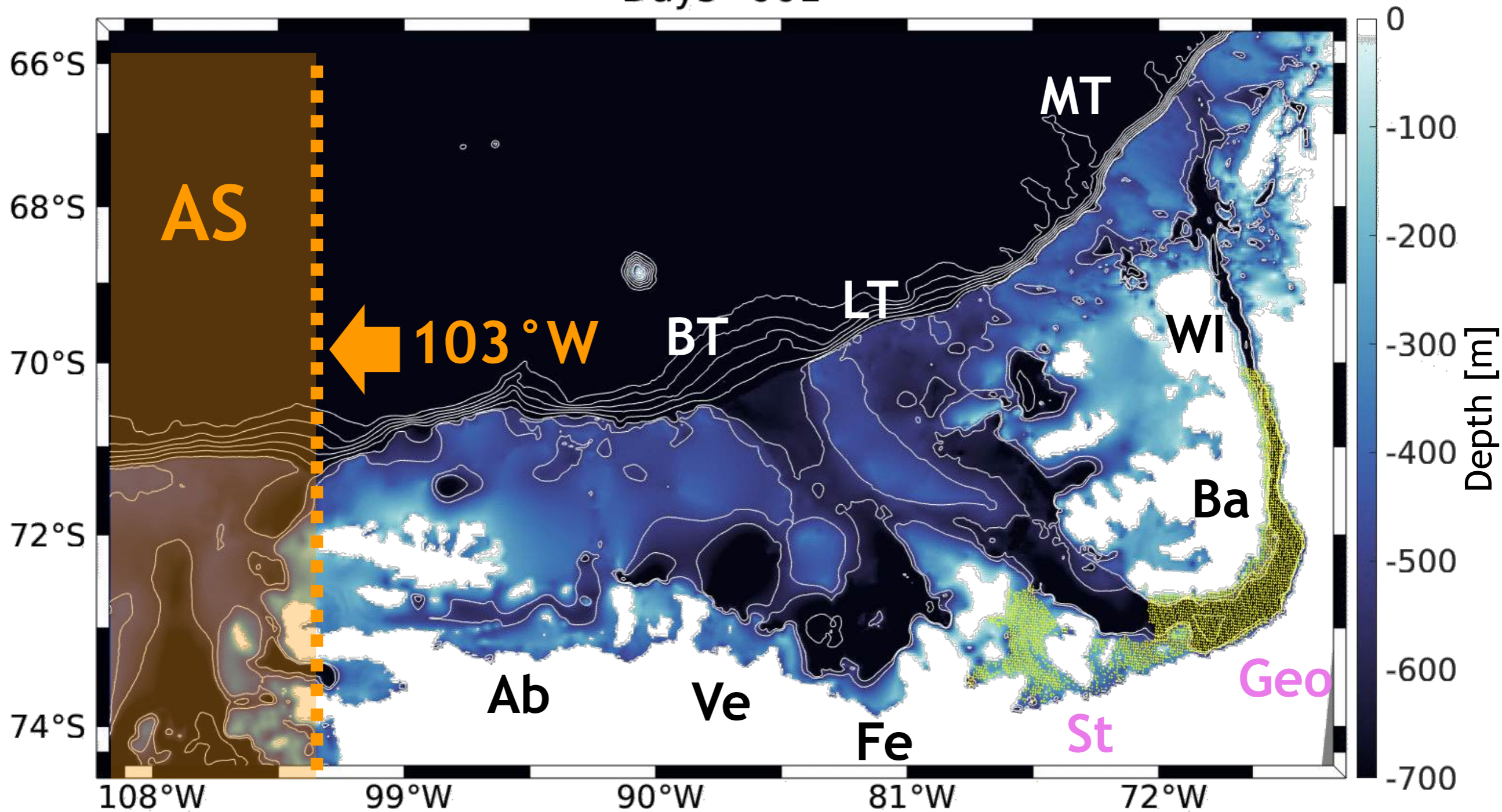


# Modeling Bellingshausen Sea



Daily locations of particles representing ice shelf meltwater

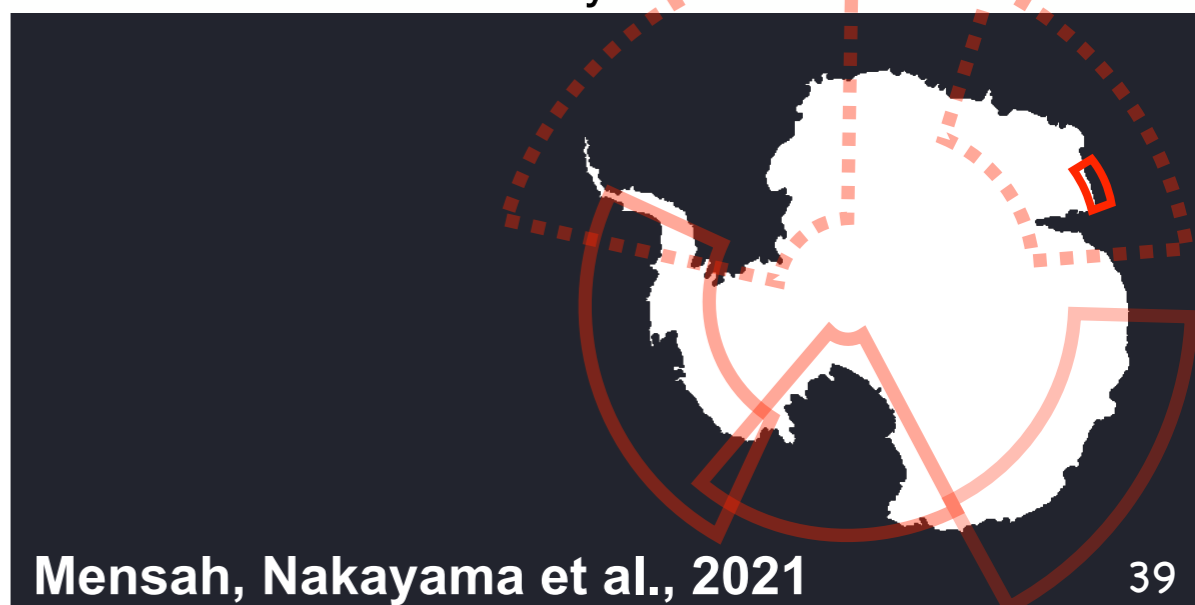
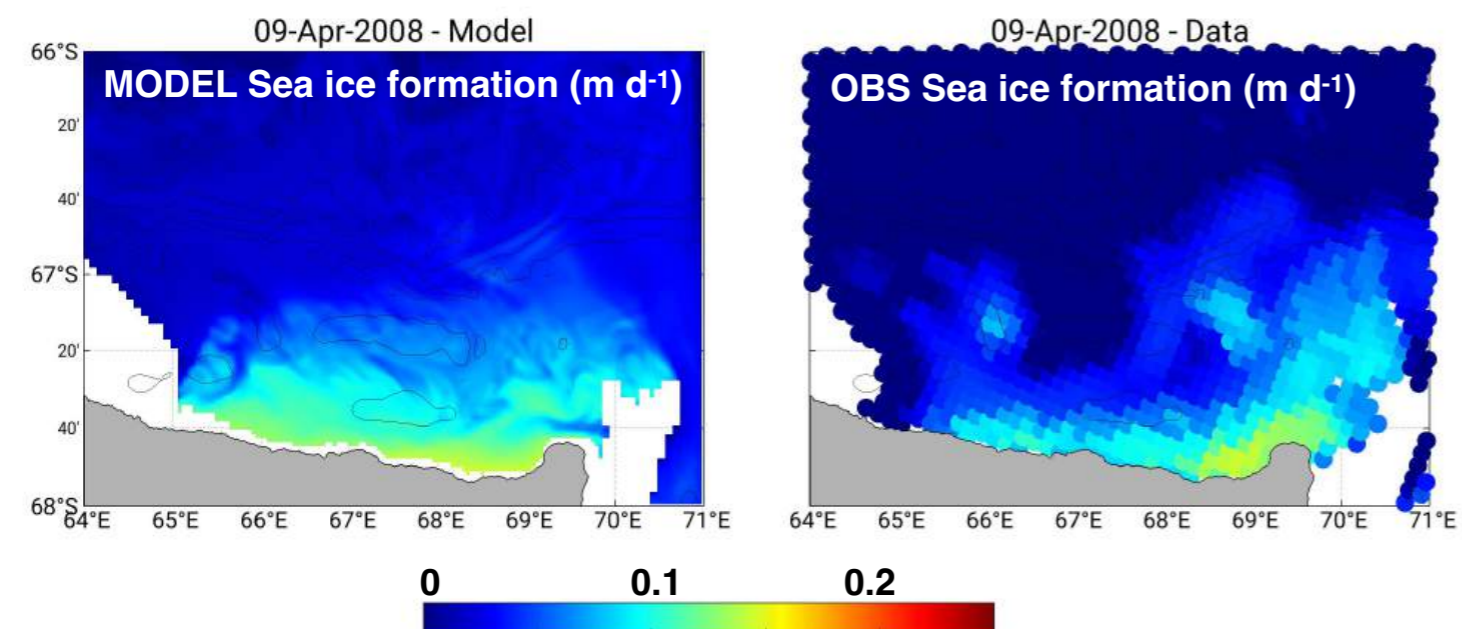
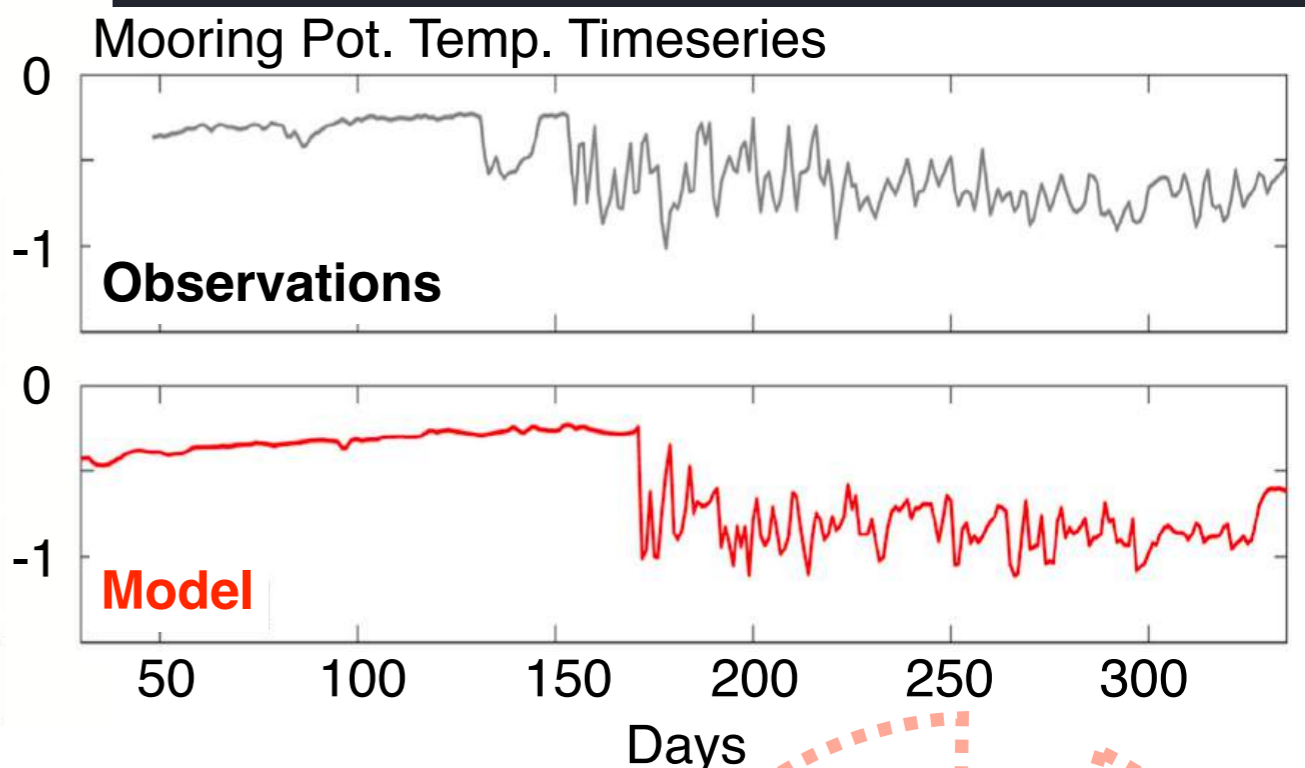
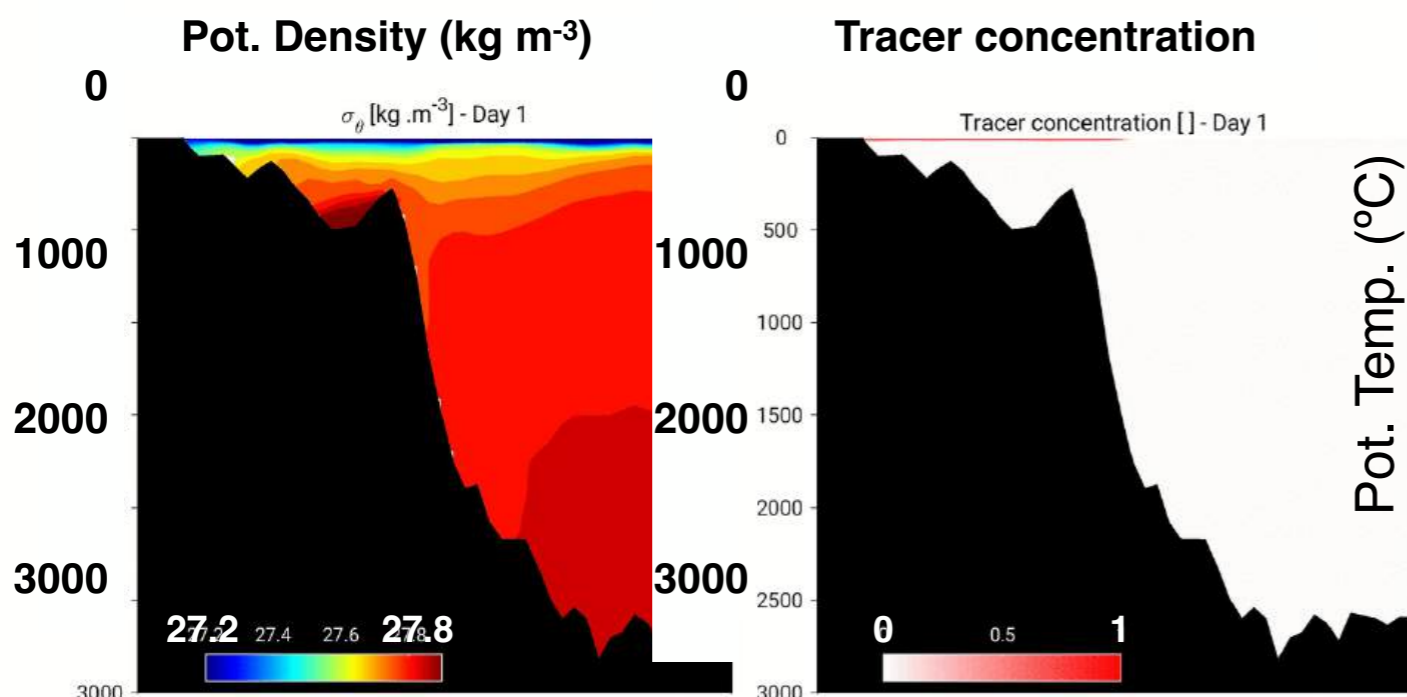
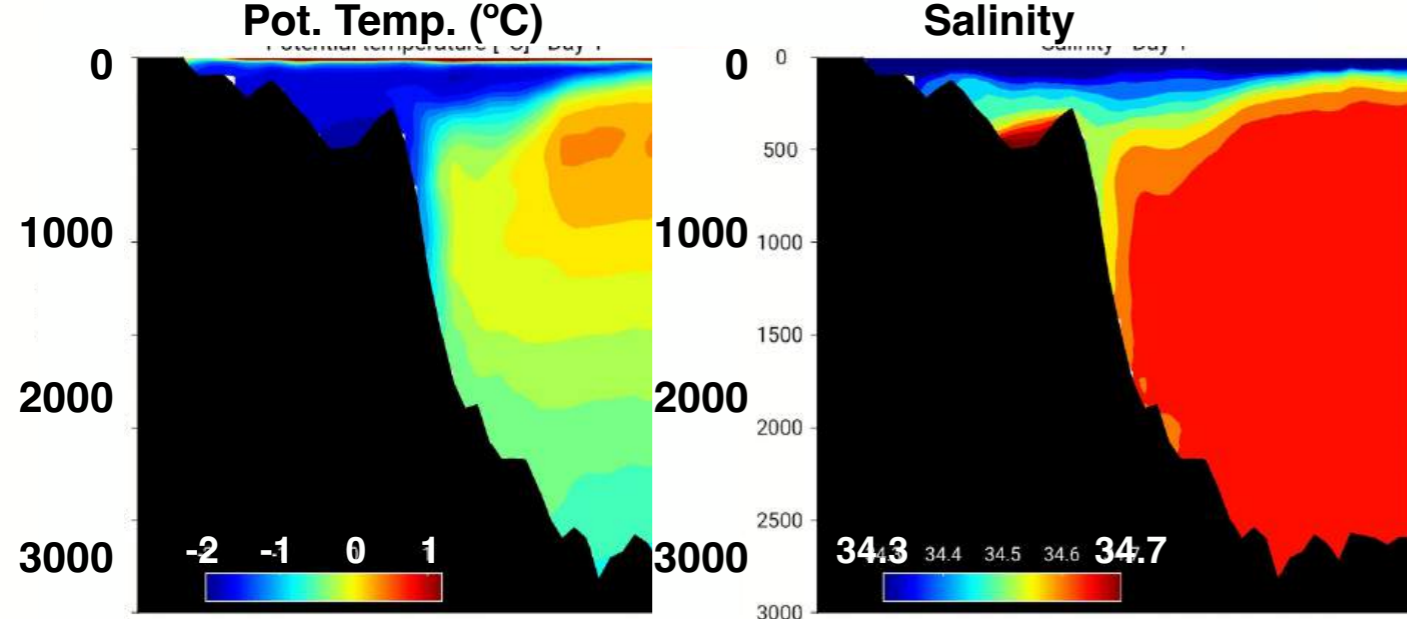
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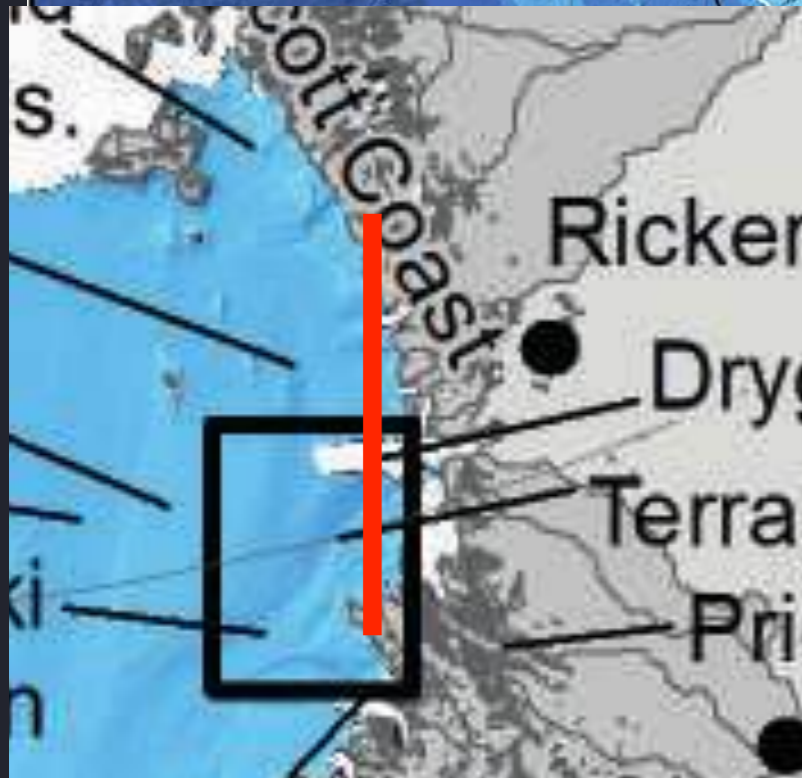
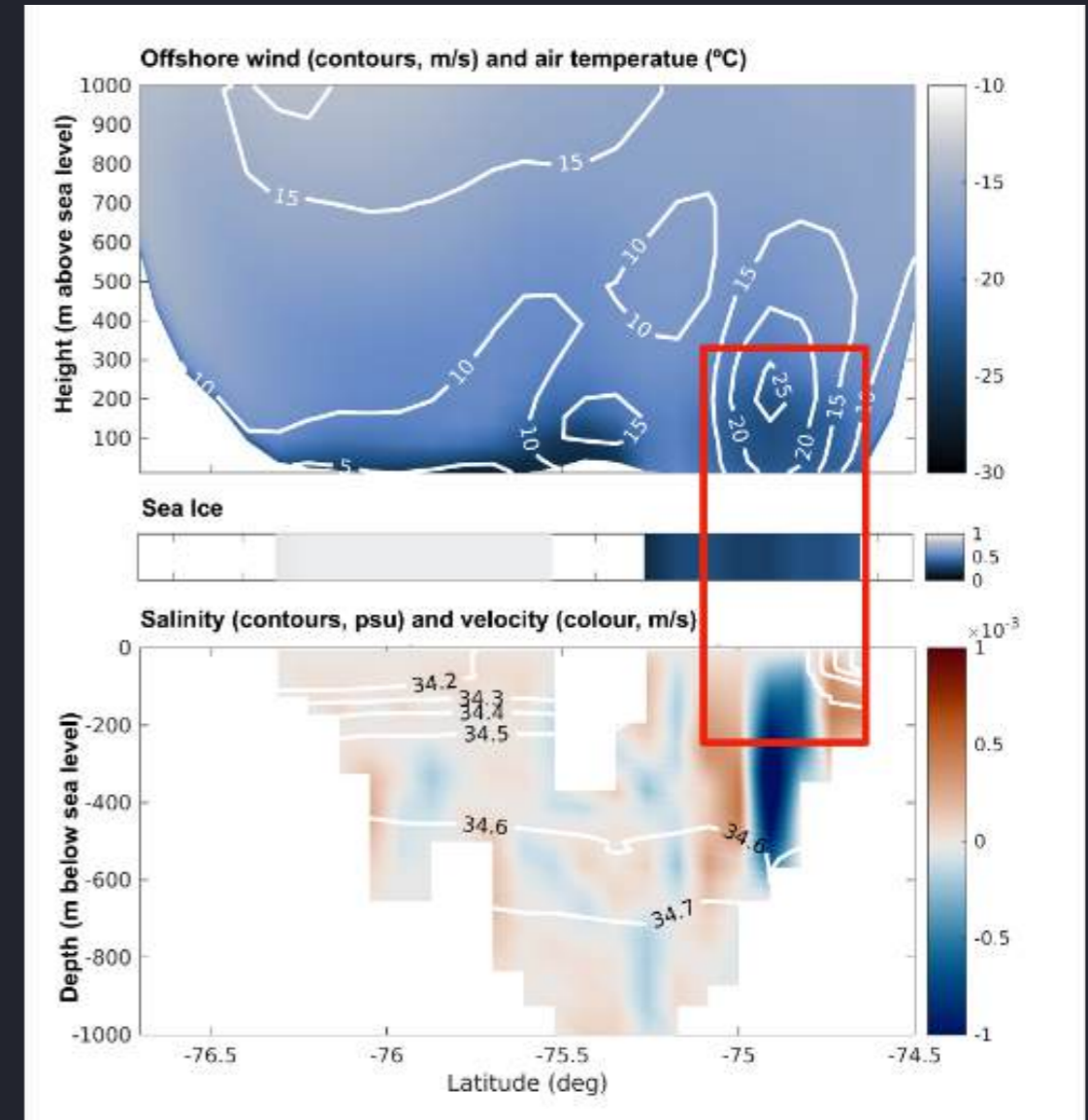
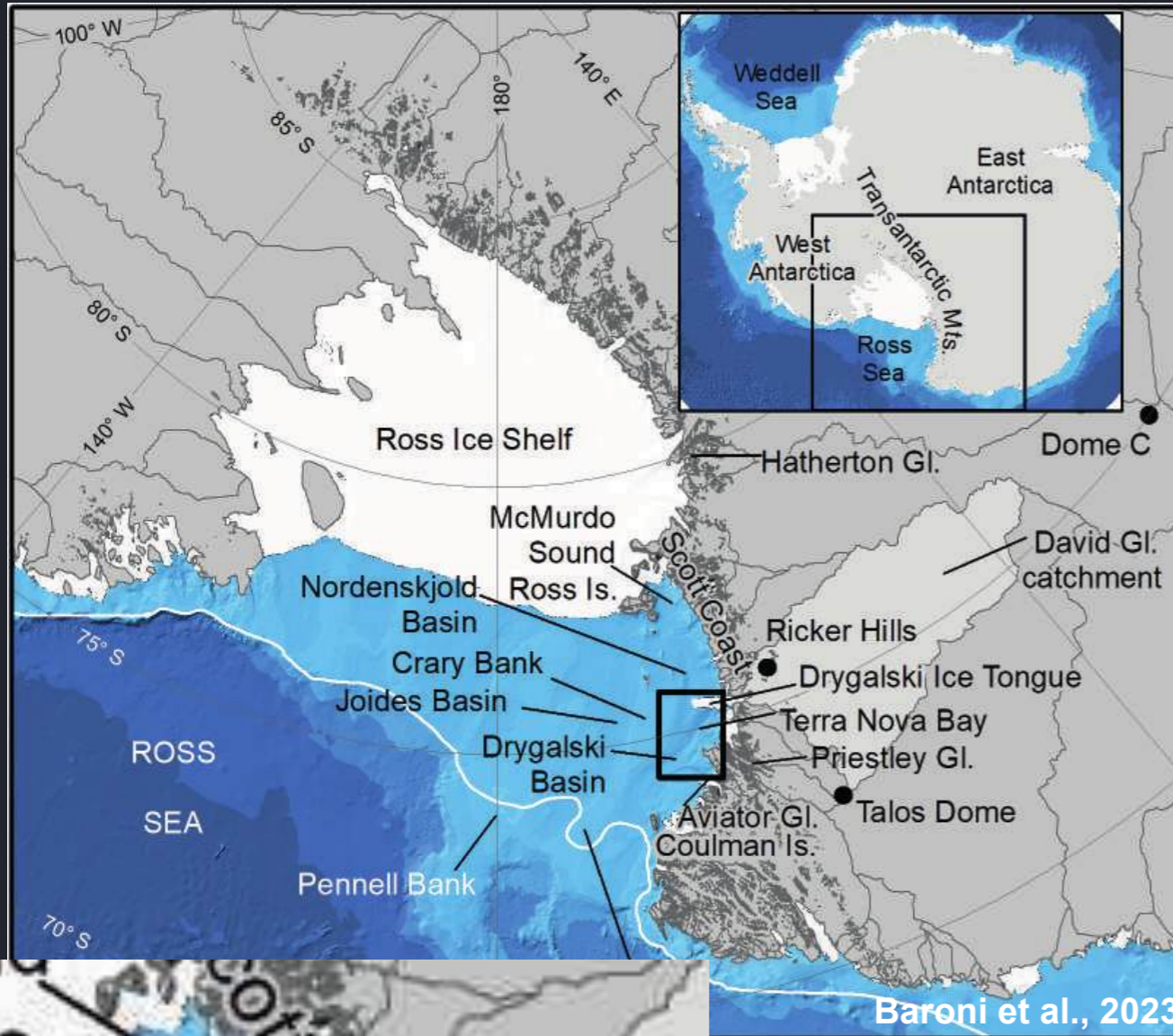




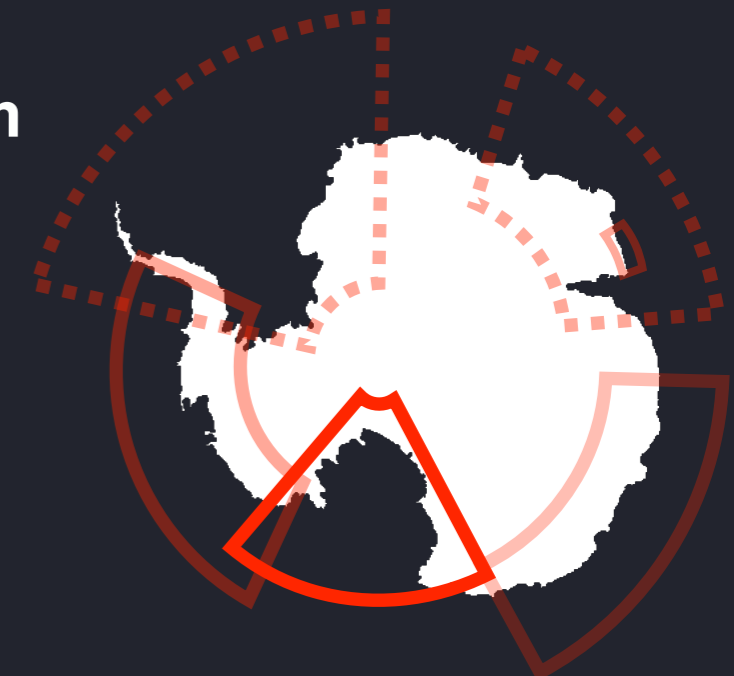
# Modeling Cape Darnley Bottom Water formation

- Excellent model-data agreement for sea ice and ocean.
- Perfect test site for the development of BBL parameterization.



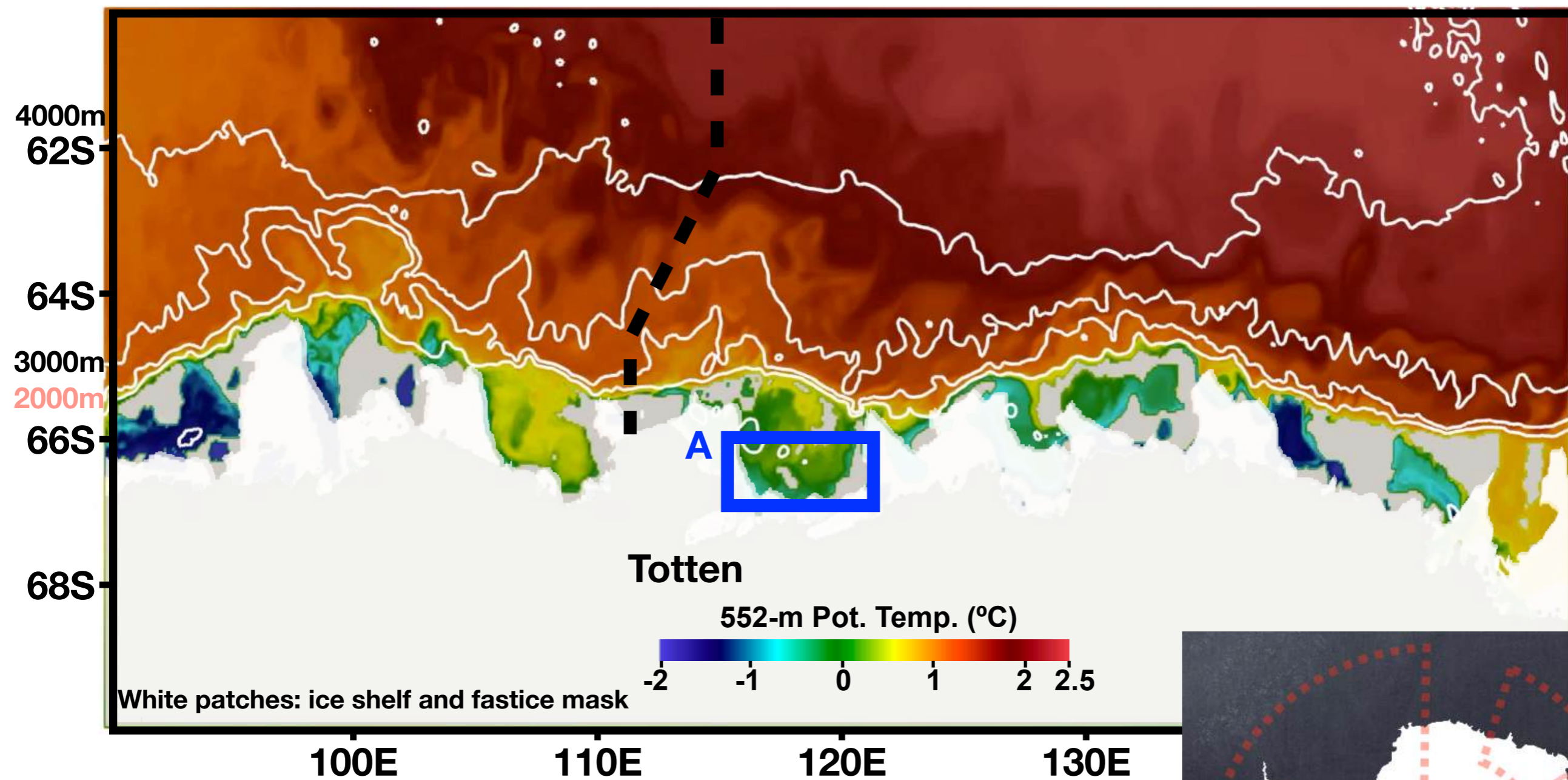


1. Katabatic wind blowing from the Antarctic continent forms sea ice and Antarctic Bottom Water.
2. Representation of both Atmosphere and ocean in the coupled setup.

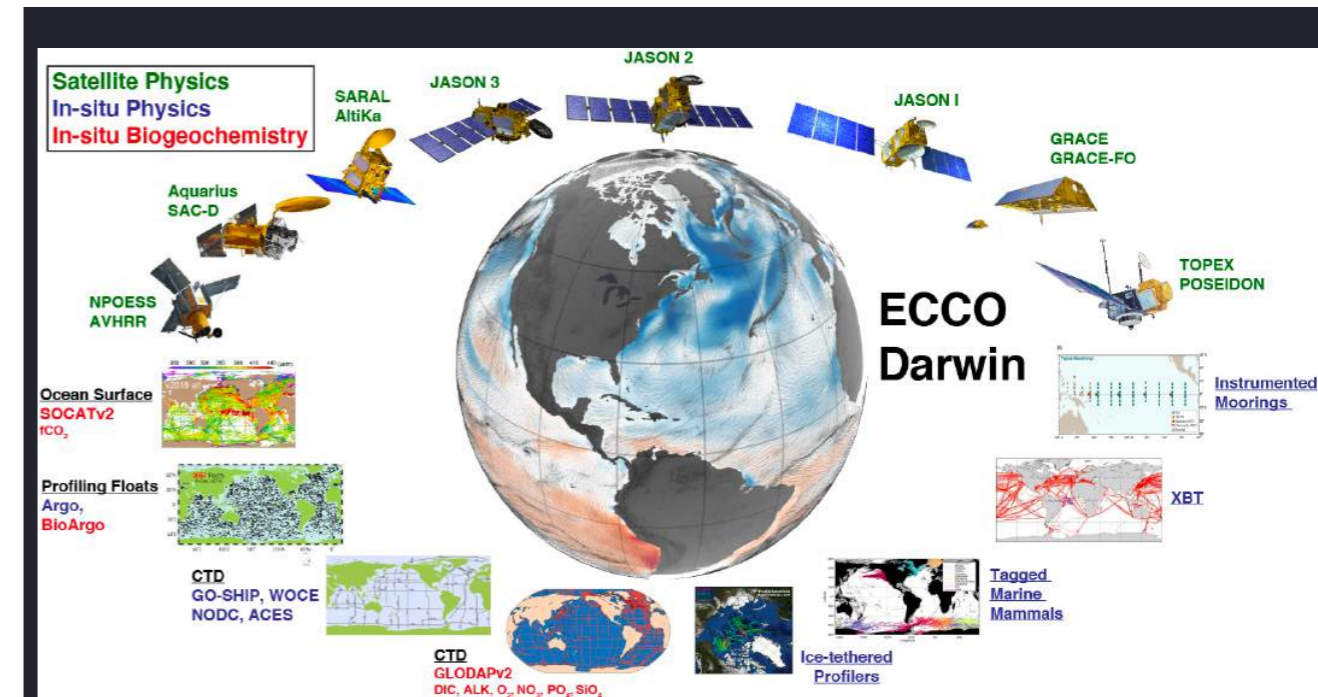
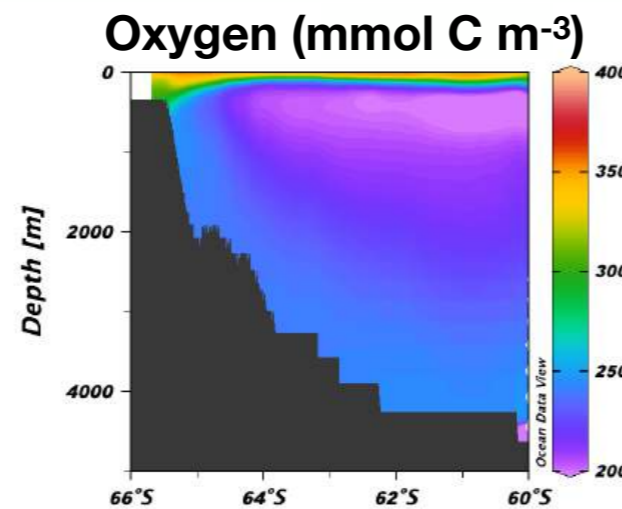
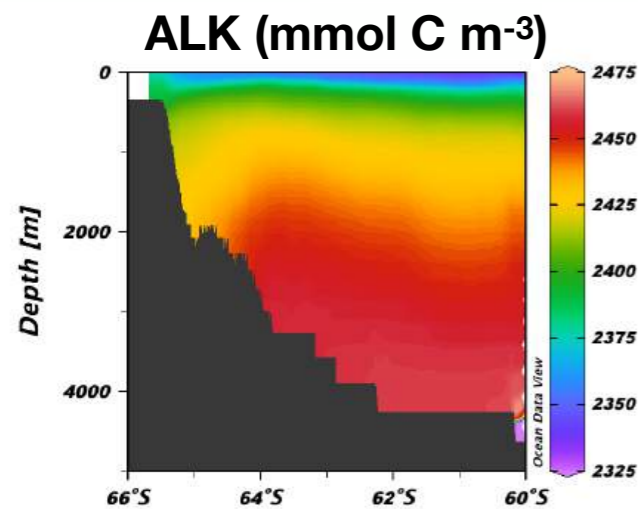
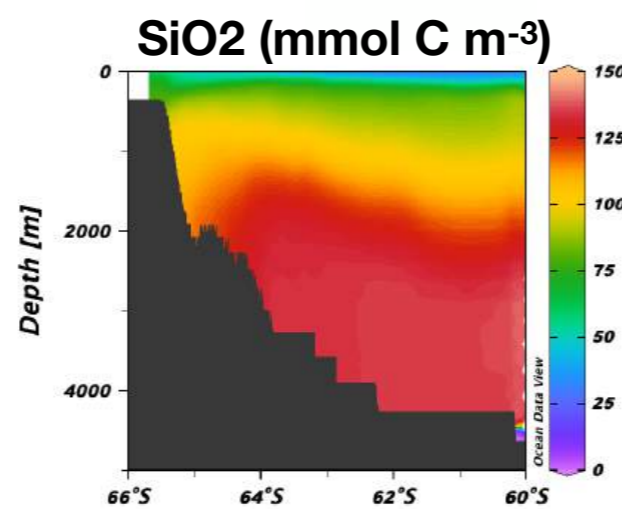
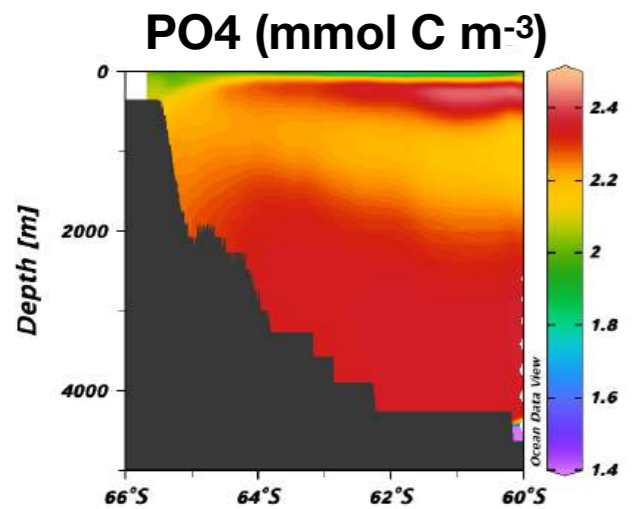
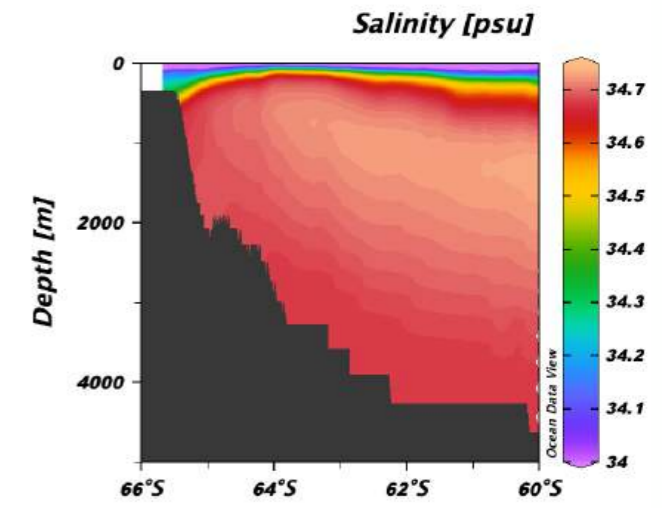
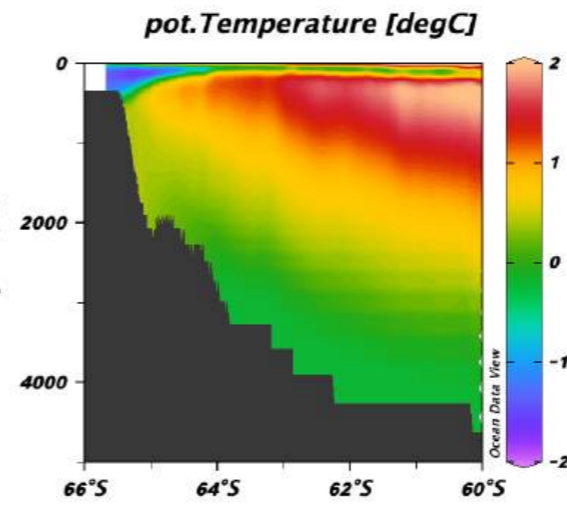
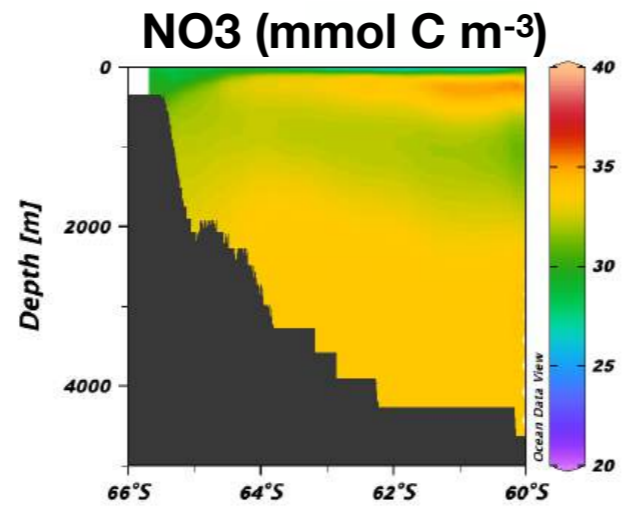
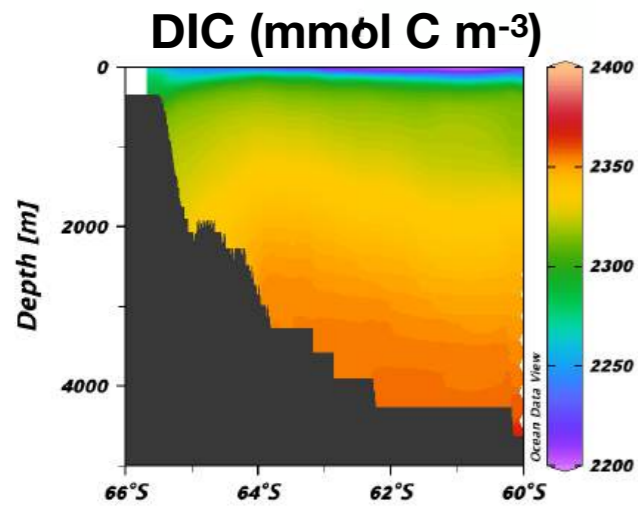


Time: 0.000000

Days since 1991/01/01



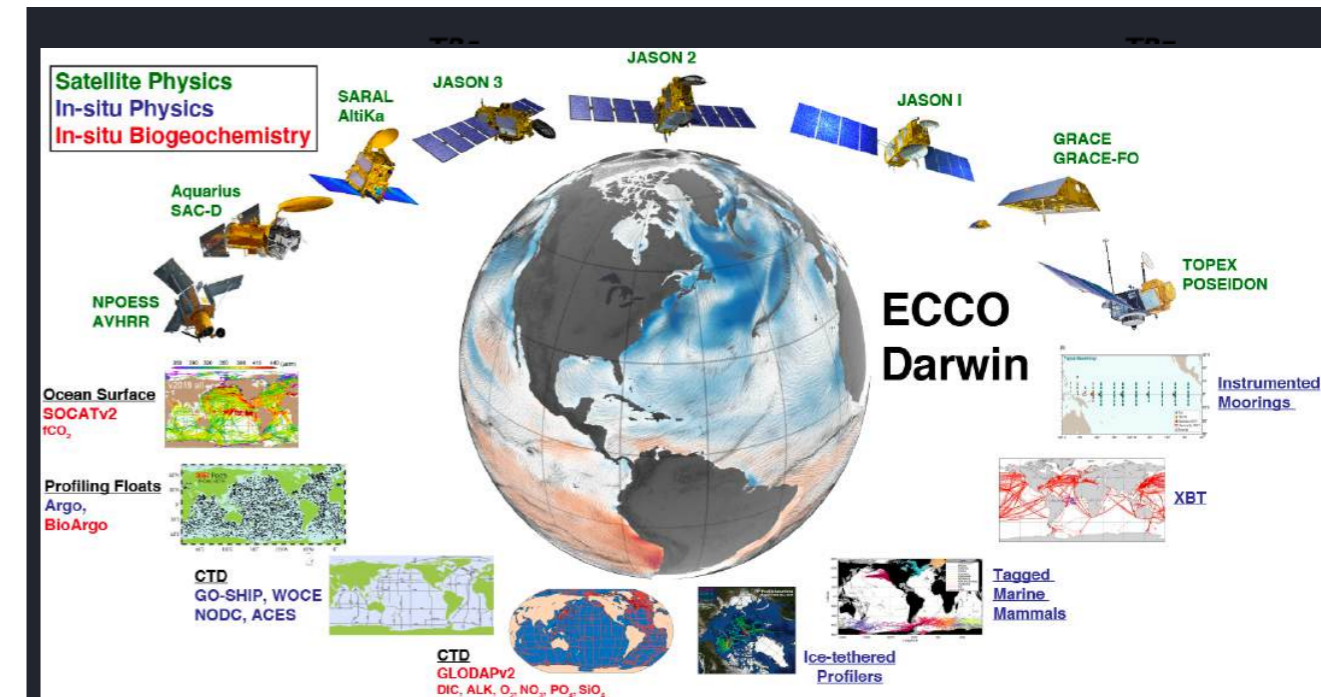
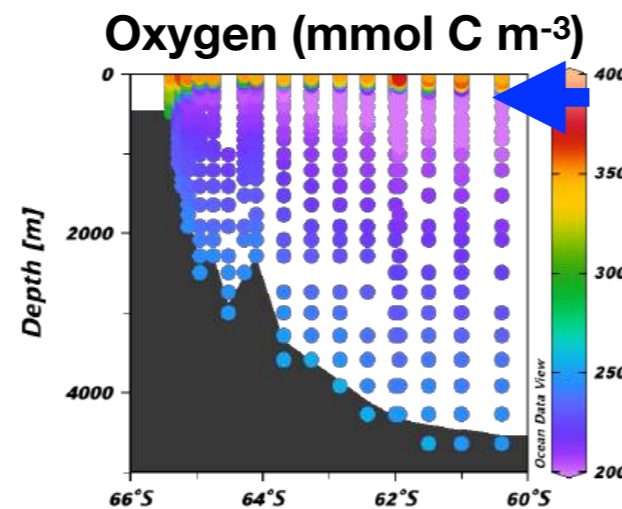
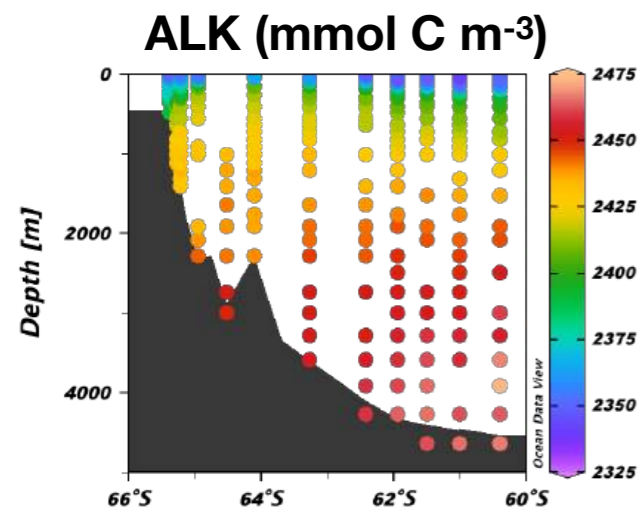
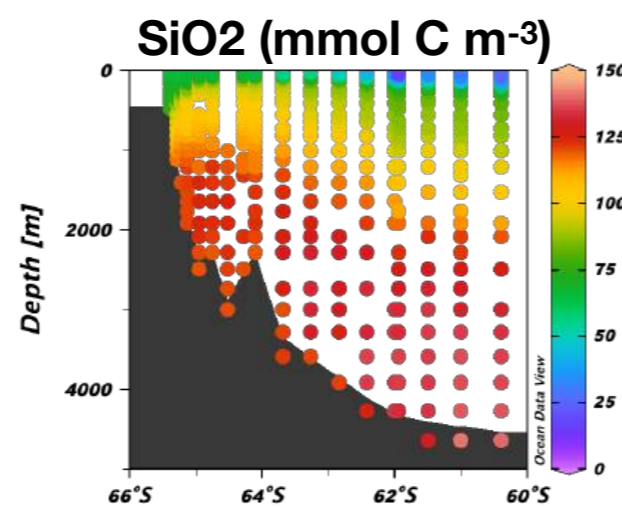
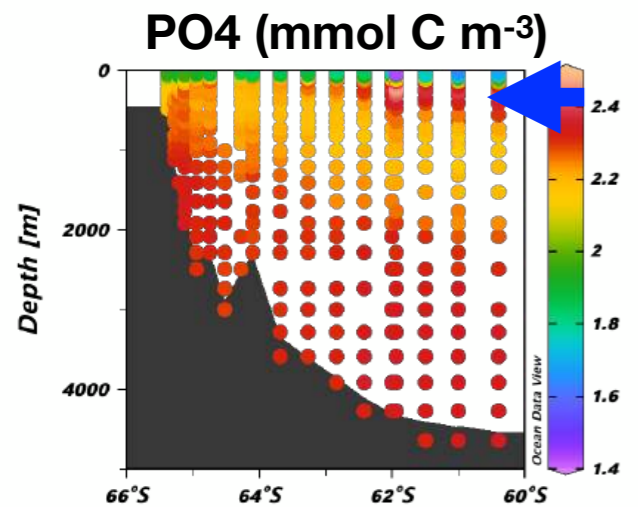
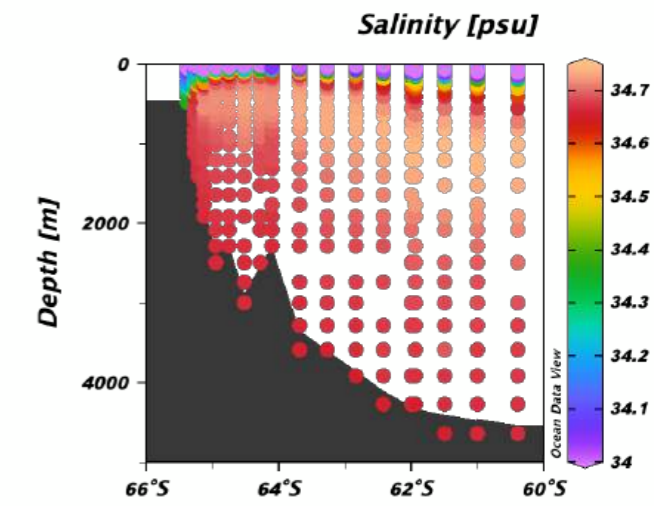
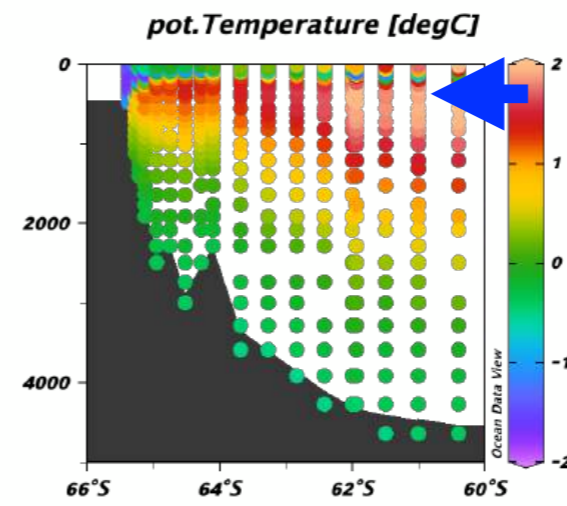
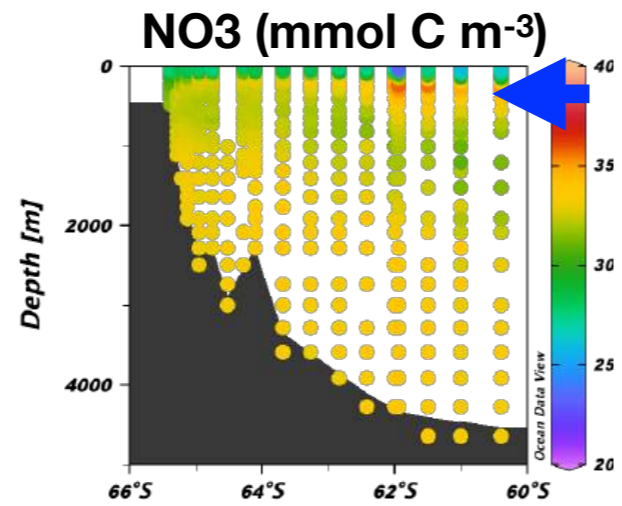
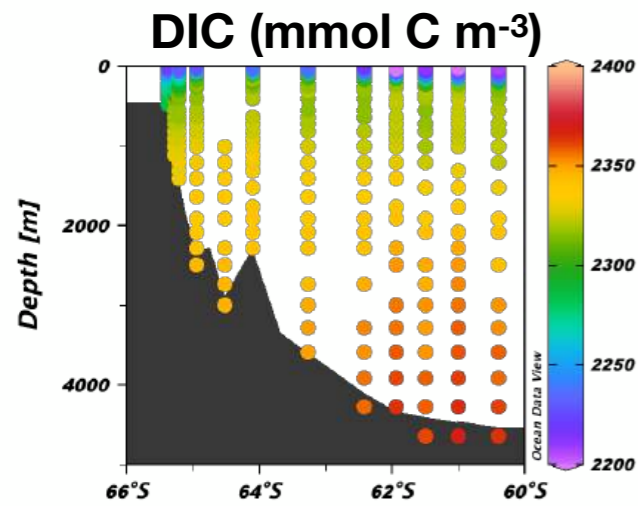
# Comparison between GLODAP and model (January mean and summer time observations (North-south section))



» Simulated distributions of DIC, NO<sub>3</sub>, PO<sub>4</sub>, SiO<sub>2</sub>, ALK, and O<sub>2</sub> are consistent with observations.

» The spatial pattern of these fields is consistent with water mass distributions (CDW & AABW), strongly controlled by ocean lateral boundary conditions.

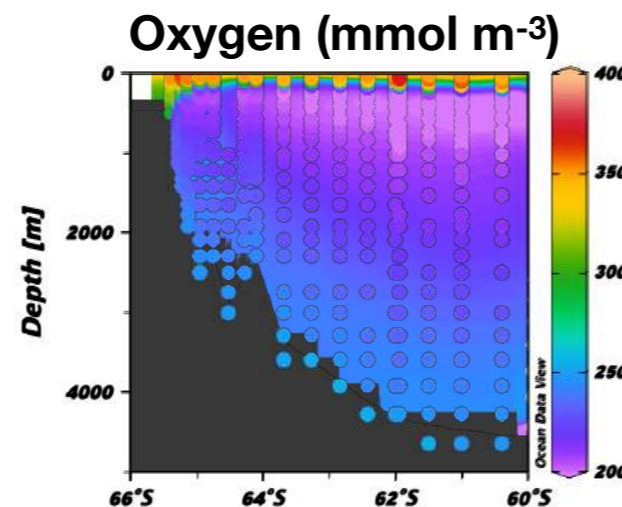
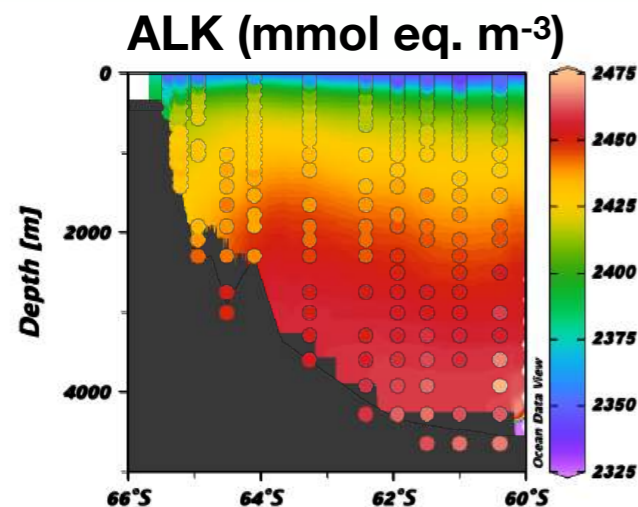
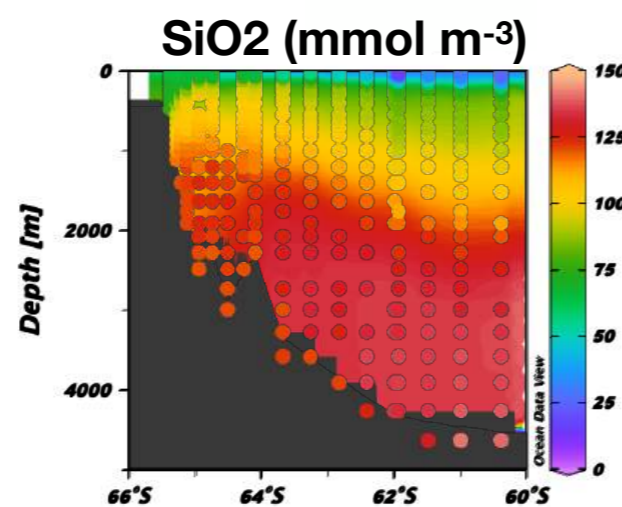
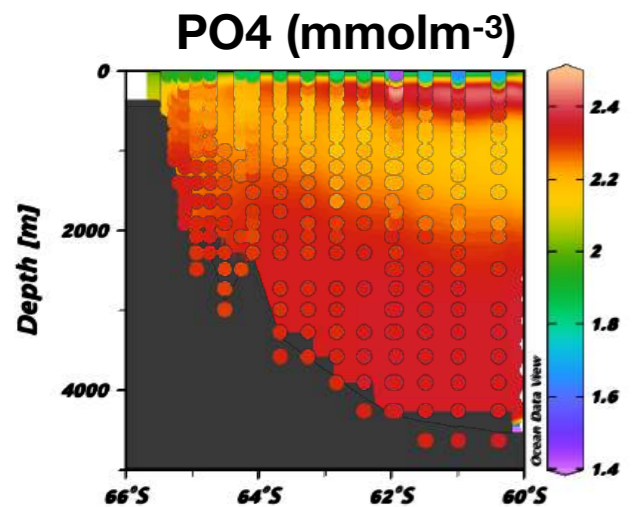
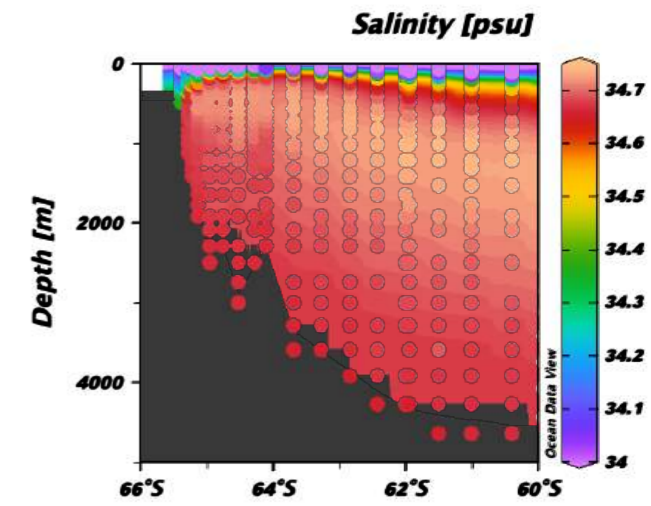
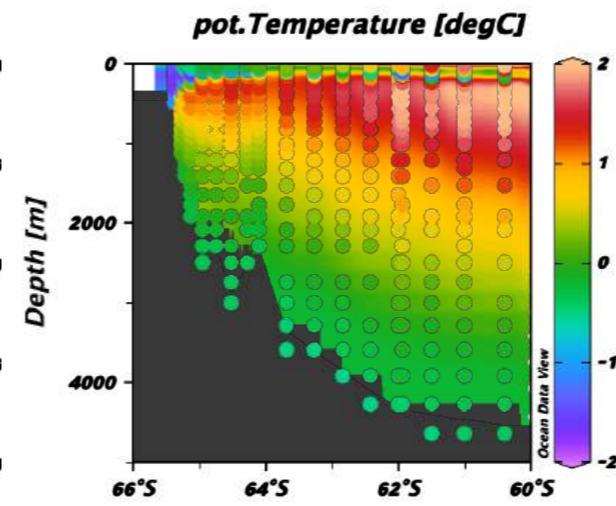
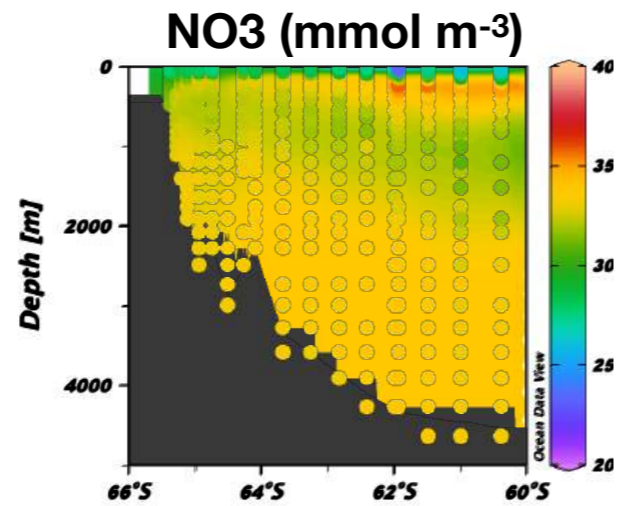
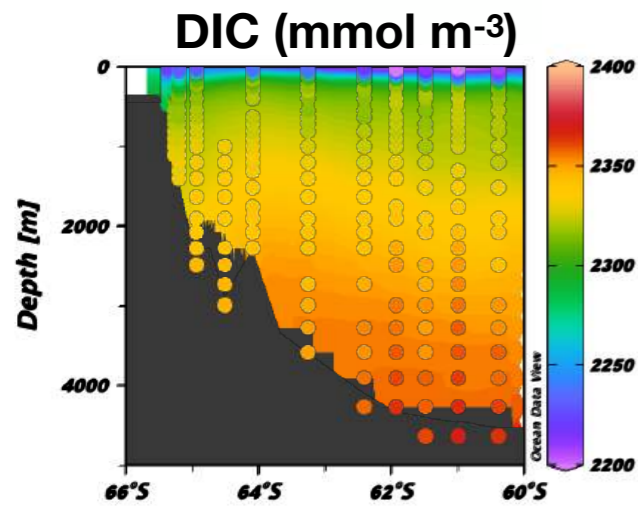
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# Comparison between GLODAP and model (January mean and summer time observations (North-south section))

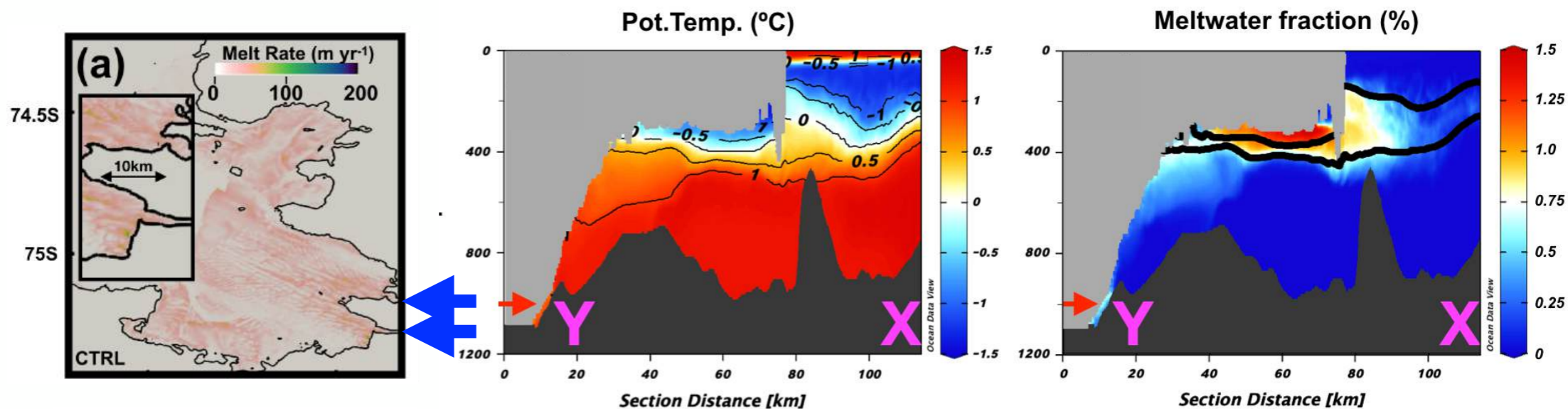


» Simulated distributions of DIC, NO<sub>3</sub>, PO<sub>4</sub>, SiO<sub>2</sub>, ALK, and O<sub>2</sub> are consistent with observations.

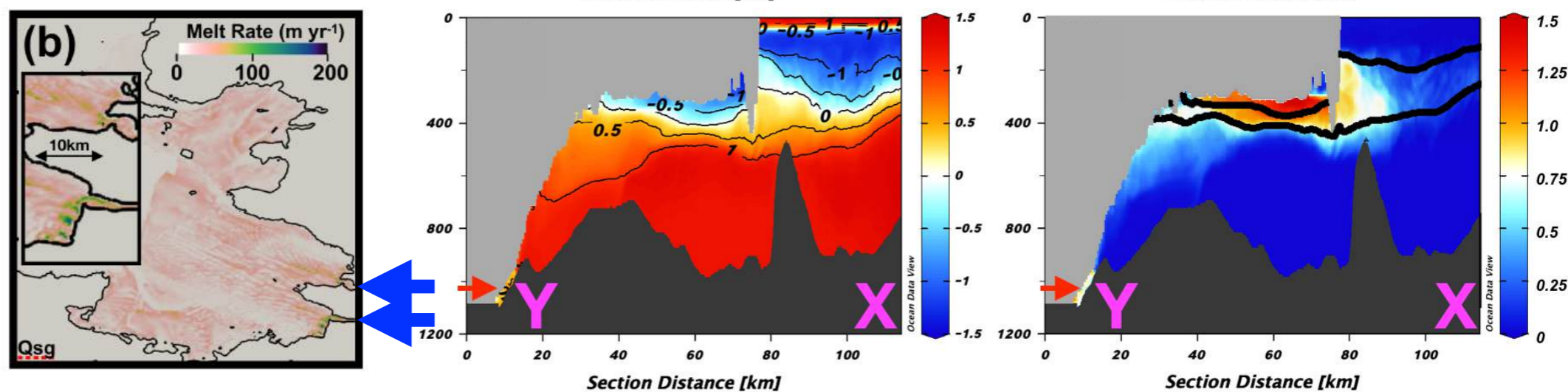
» The spatial pattern of these fields is consistent with water mass distributions (CDW & AABW), strongly controlled by ocean lateral boundary conditions.

# Modeling subglacial freshwater discharge beneath Pine Island ice shelf

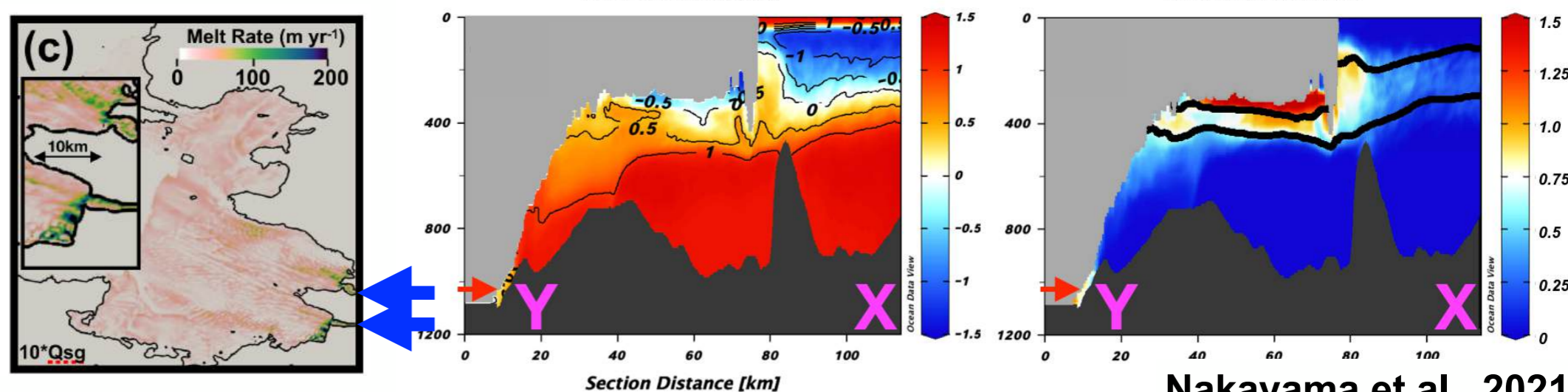
CTRL



Qsg



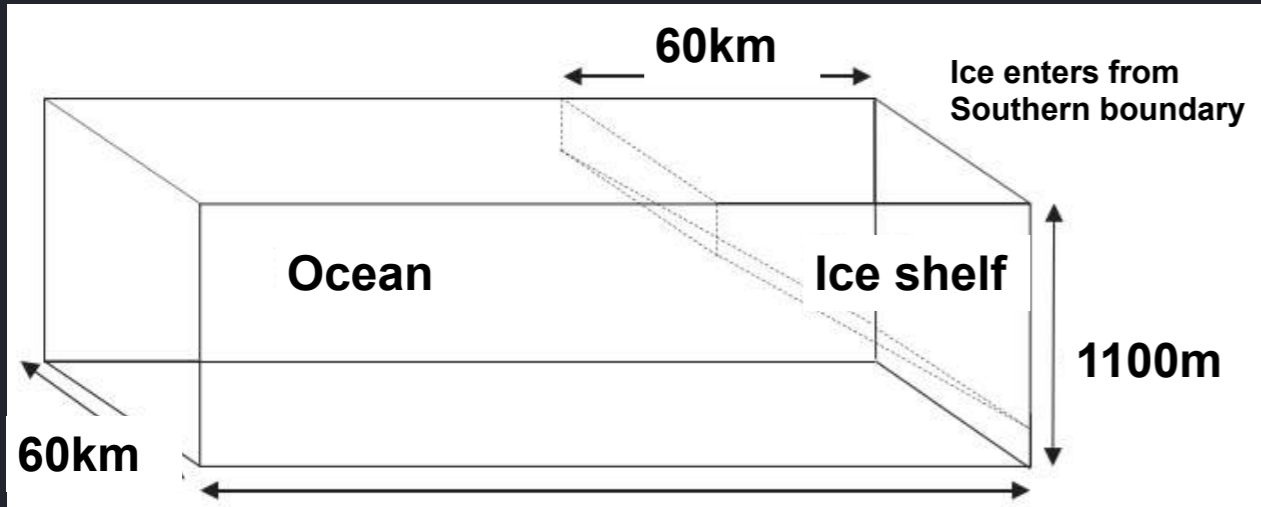
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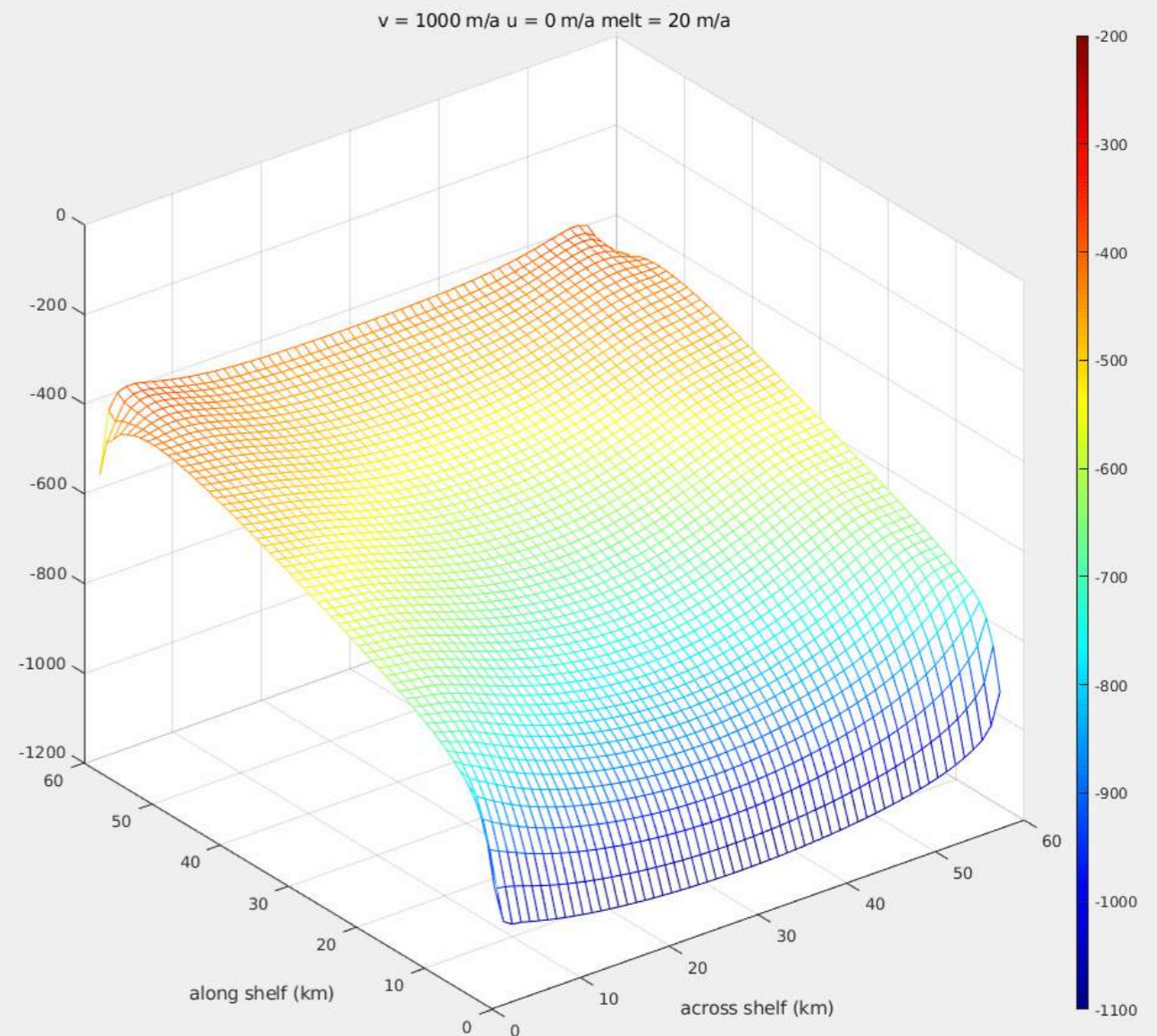
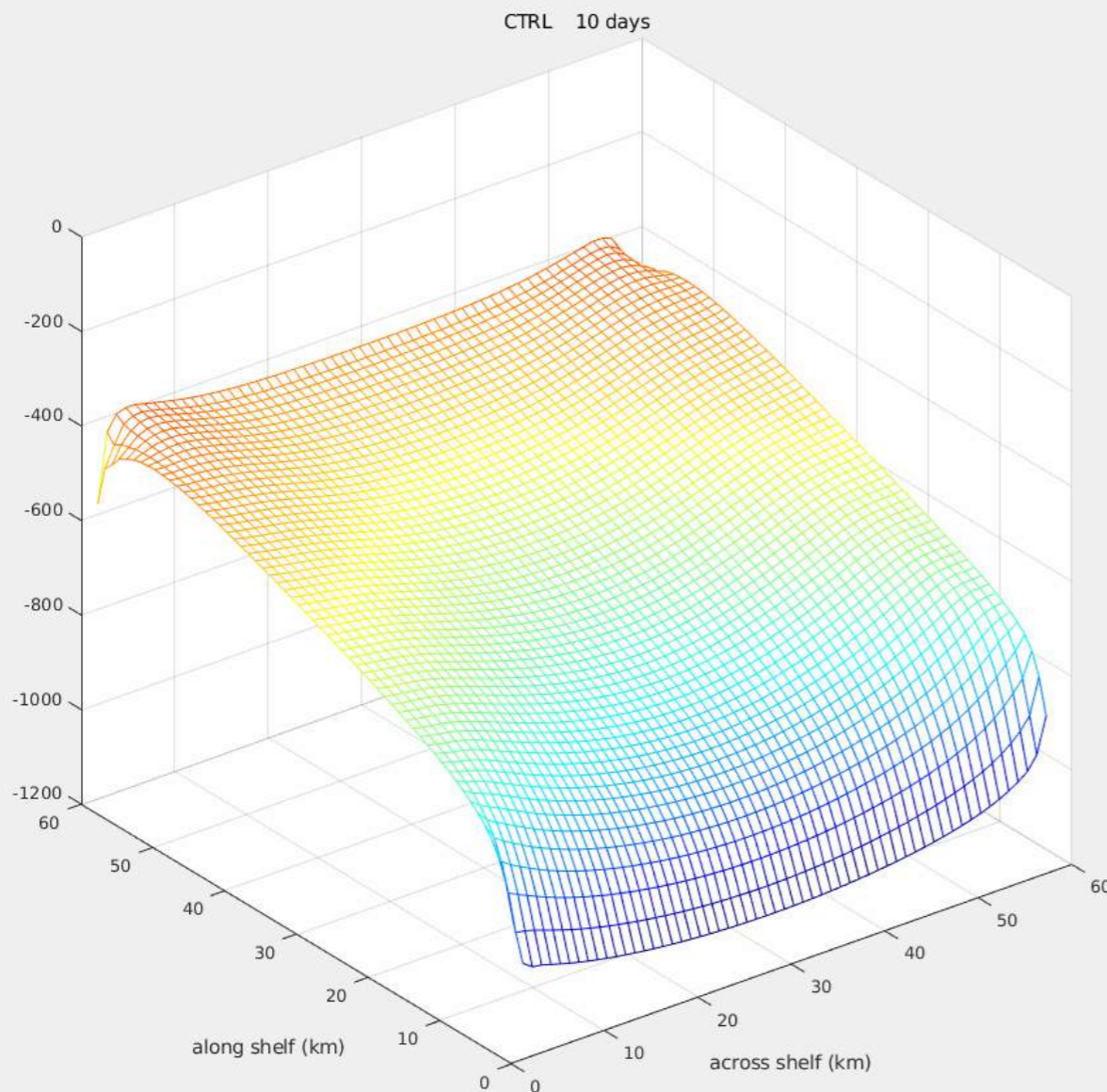
Nakayama et al., 2021

- Subglacial freshwater discharge enhances ice shelf melting locally in ocean simulations.
- Buoyant plume could rise to the surface at the ice shelf front only if very high amounts of freshwater discharge, about 50 times larger than those estimated for the current conditions.

# Processes determining ice shelf shape (idealized model)

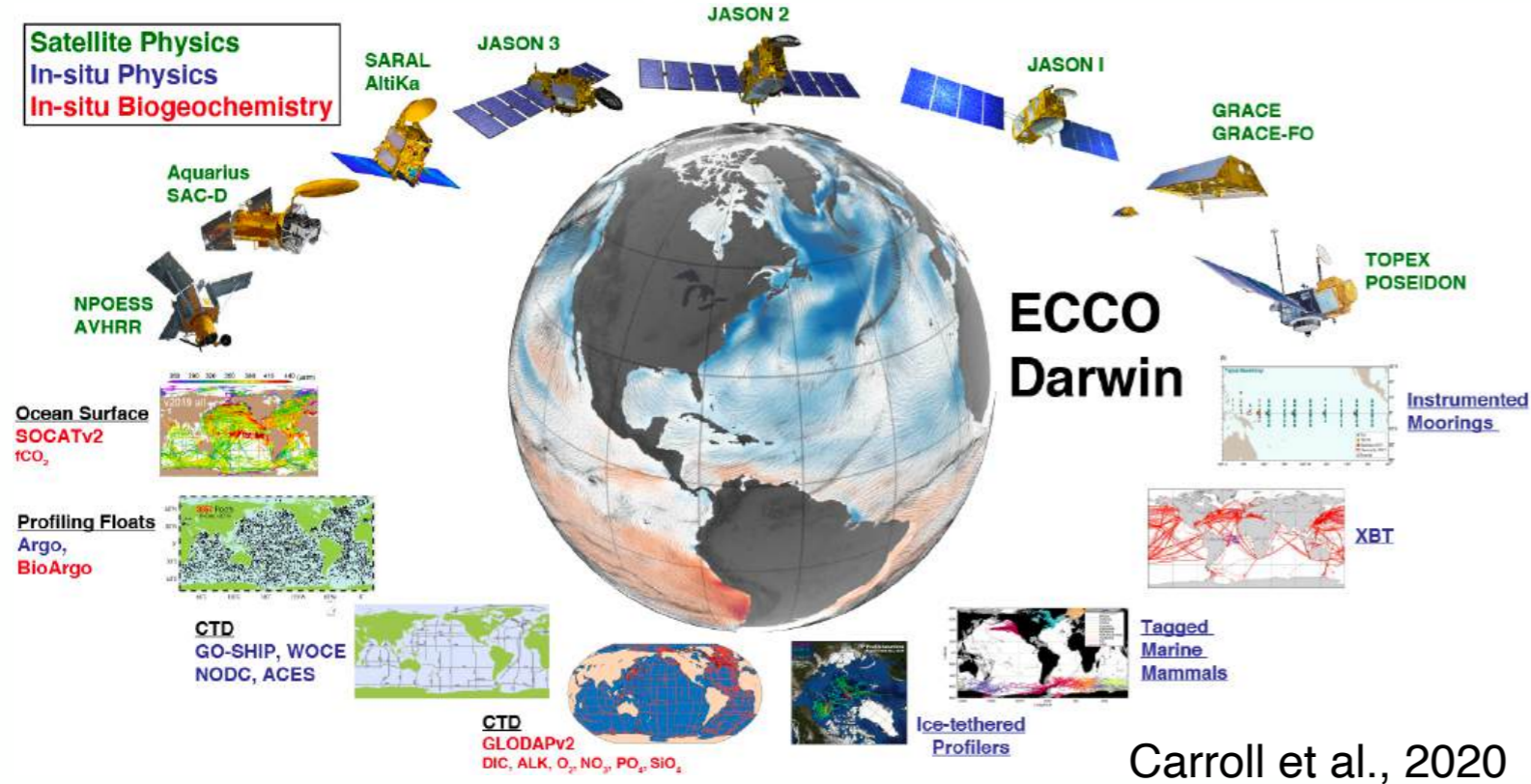


- Development of ice-ocean coupled simulations.
- We aim at understanding what determines ice shelf shape.

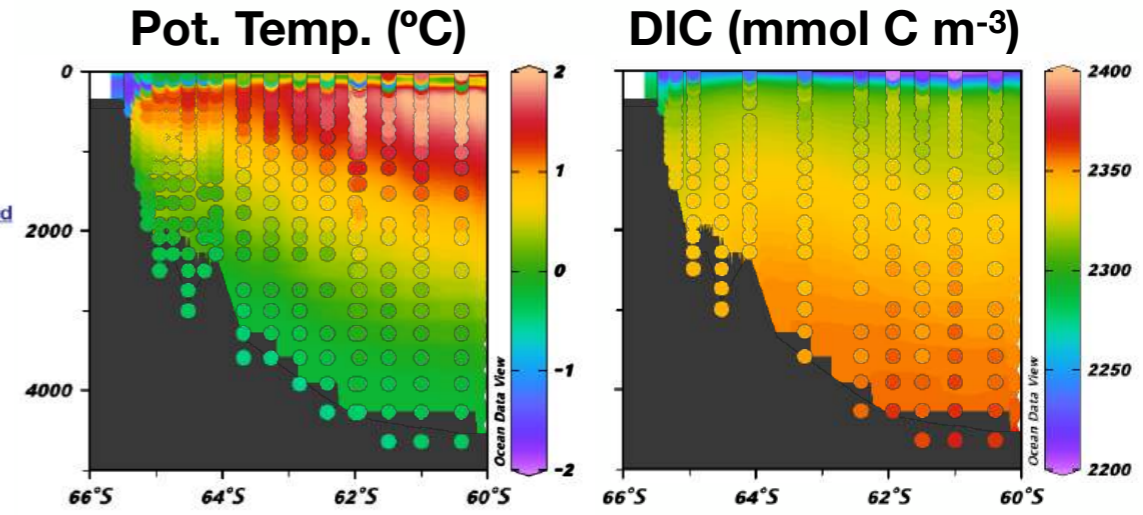


Nakayama, Hirata et al., 2022

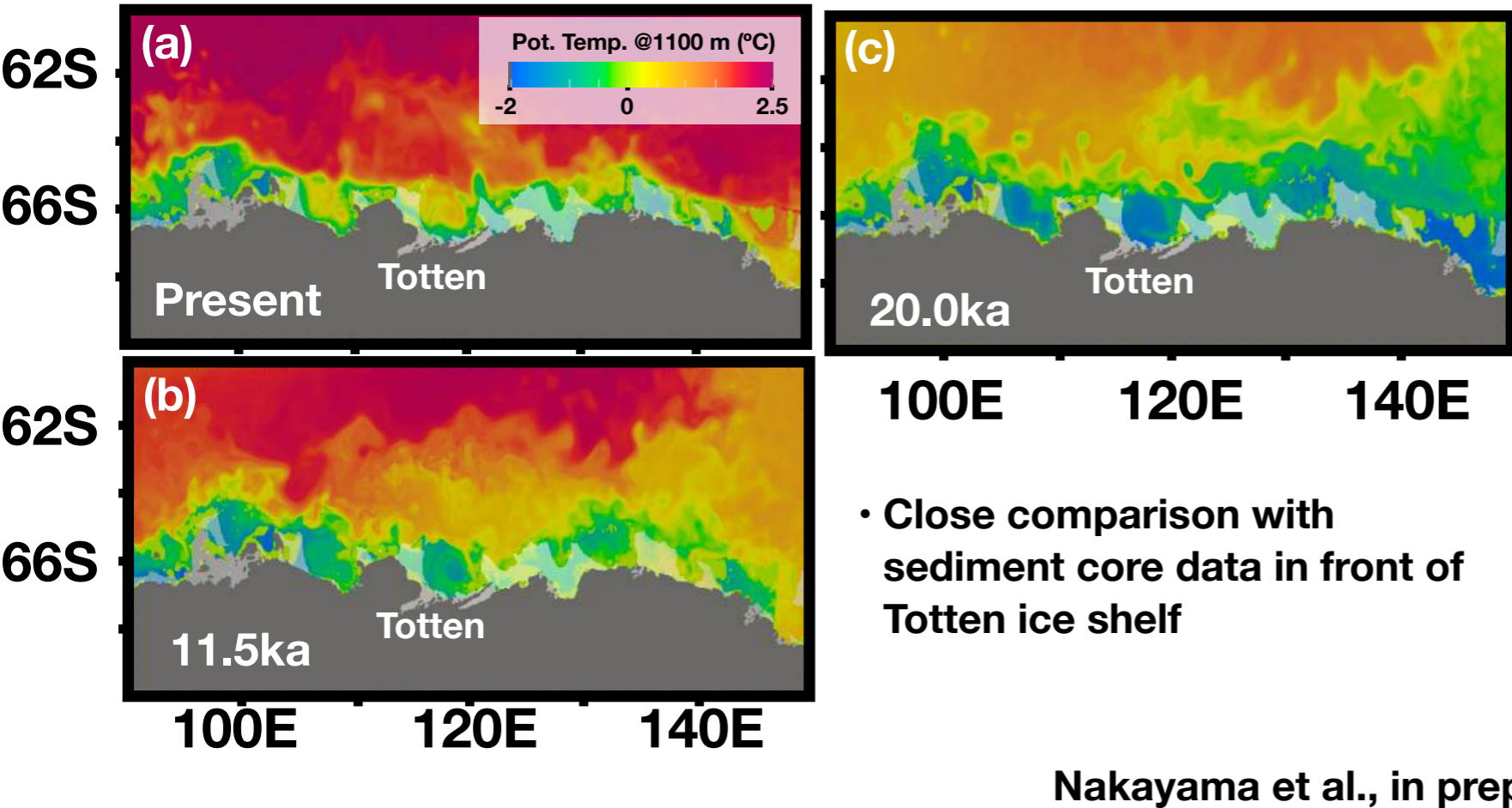
# Downscaling for ice-ocean-carbon for the Southern Ocean



## Regional ECCO-Darwin simulation for the Southern Ocean (110°E)



# Downscaling for paleo-Southern Ocean



# Greenland

