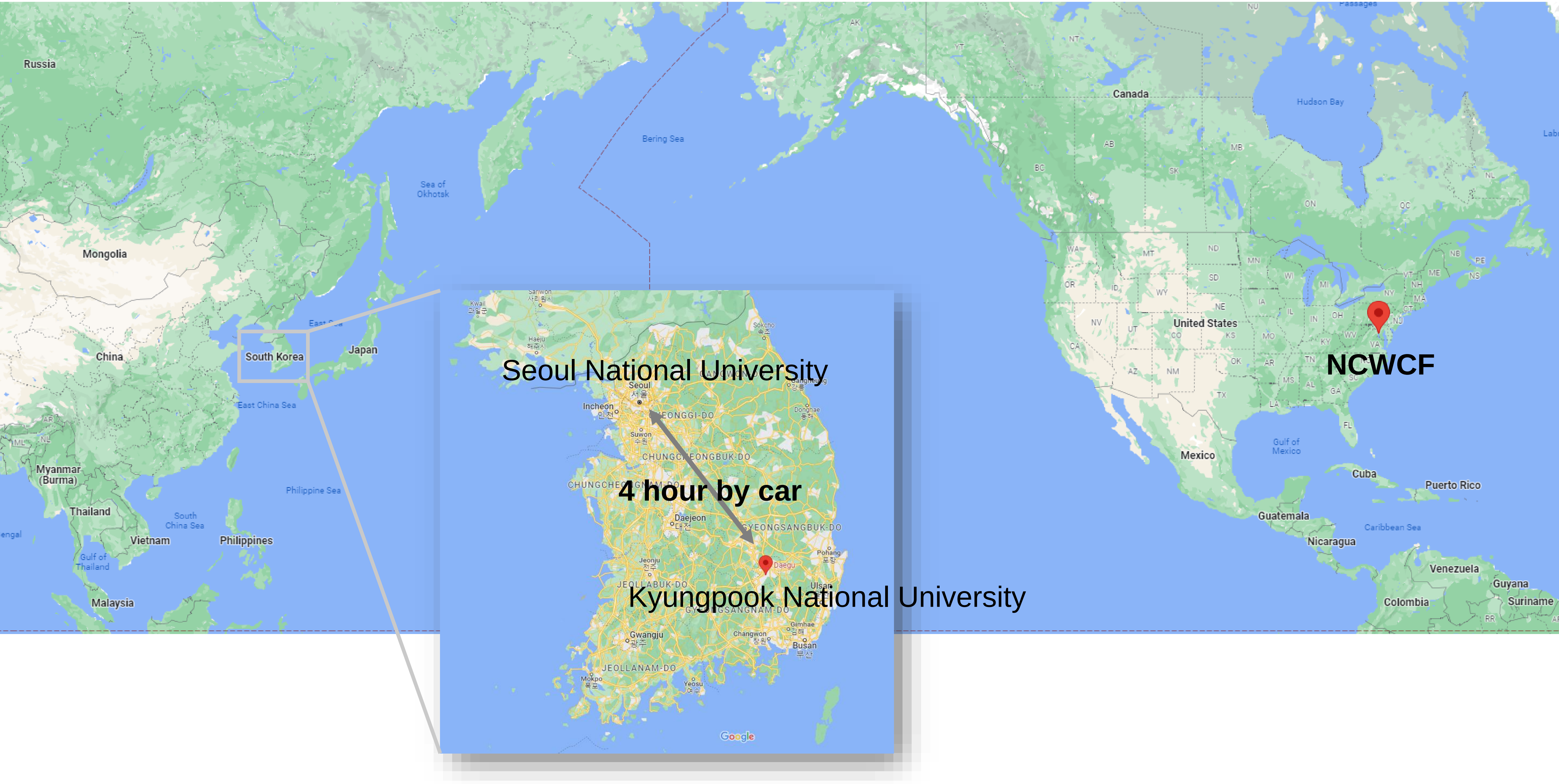
NOAA Center for Weather and Climate Prediction

Responses of the Antarctic Ocean to the climate change focusing on the Ross Sea and Amundsen Sea

Seung-Tae Yoon

Kyungpook National University
Kyungpook Institute of Oceanography

* Where do I live?



* 2023-31 JPA(Joint Project Agreement) SOUND

Southern Ocean UNDerwater studies of climate impacts (SOUND)

ROK: Won Sang Lee (Korea Polar Research Institute)
US: Robert P. Dziak (PMEL, NOAA)

❖ Purpose: **The SOUND project facilitates exchanging ideas and data sets to better understand the Southern Ocean responses and changes to global warming.**

❖ 2023 Objectives

- **Subtask T1 <Listening to climate change>** Provide long-term observation data collected by fixed (hydrophone moorings) and mobile (gliders) platforms and develop methodologies for handling massive data sets.
- **Subtask T2 <Observing the Southern Ocean in a warming world>** Exchange observation (in-situ/remote sensing) and research experiences and data sets through the JPA project to better understand physical and biogeochemical changes in the Southern Ocean in response to climate change.
- **Subtask T3 <Krill and pelagic species monitoring in MPAs>** Conduct integrated observations (acoustics) of krill and pelagic species in existing or proposed Antarctic Marine Protected Areas (MPAs), facilitating assessments of MPA effectiveness.
- **Subtask T4: <Investigating offshore geological hazards>** Assess marine geohazards such as submarine volcanic eruptions and earthquakes that may trigger significant damage to coastal research stations in the Antarctic.

* Who am I?

- **Major**

- Physical Oceanography
- Field observation expert (*14 times research cruises*)

- **Main Research Area**

- East Sea
- Southern Ocean (Ross Sea, Amundsen Sea…)

- **Research Interest**

- Ocean responses to climate change
- Air-Sea interaction
- Ice-Ocean interaction
- In-situ data QC

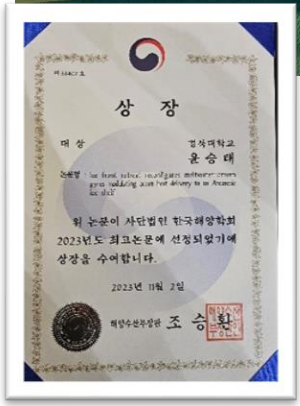
- **Career summary**

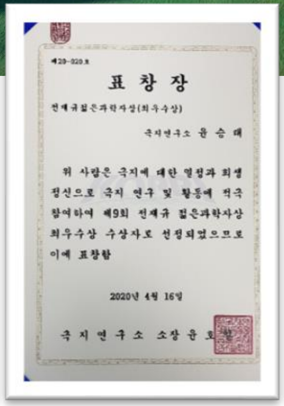
- Assistant Prof, KNU (2021.03 ~)
- Postdoc, KOPRI (2017.09 ~ 2021.02)
- Ph.D., SNU (2011 ~2017.08)
- Awarded 5 times since 2017
- **15 Publications since 2008**
  (11 SCIE papers & 4 SCOPUS papers)
- *h-index: 9*
- More than 40 times conference presentations

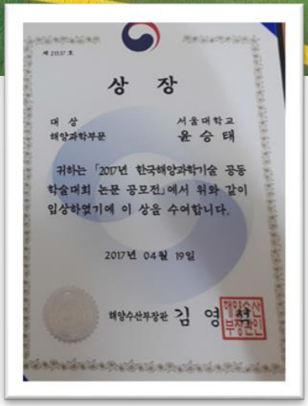

East Sea (R.V. HY2000)

K-R Joint Cruise
(R.V. Akademik Oparin)


2020. 02 Thwaites Glacier, Amundsen Sea
From Korea Polar Research Institute (KOPRI)







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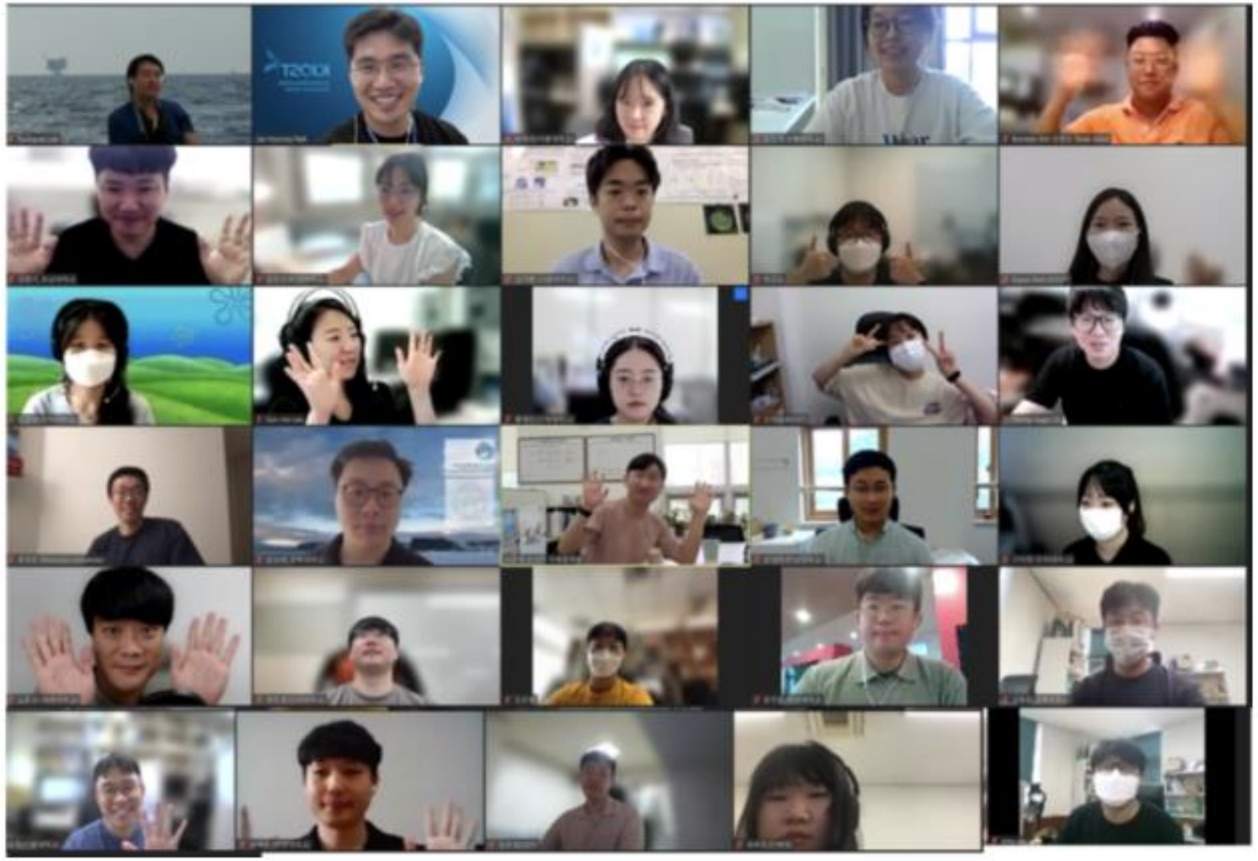
Seung-Tae Yoon 윤승태

I am an assistant professor at Kyungpook National Univer
Sciences). My major is physical oceanography, and I am m
climate change through field observations. To briefly intro
on the long-term variation of heat content and ventilation
Antarctic Ocean to climate change during my PostDoc pe
change is a very important issue not only for us but also f
oceanographers who can study and protect the Earth and
is a great honor to be part of K-ECOP. 윤승태: 저는 경북대학
니다. 제 전공은 물리 해양학이며, 해양 현장 관측을 통해 기후변화
2017년 8월 동해의 장기 변화를 주제로 박사 학위를 취득하였고
재직하면서 기후변화에 따른 남극해 반응 연구를 수행하였습니다



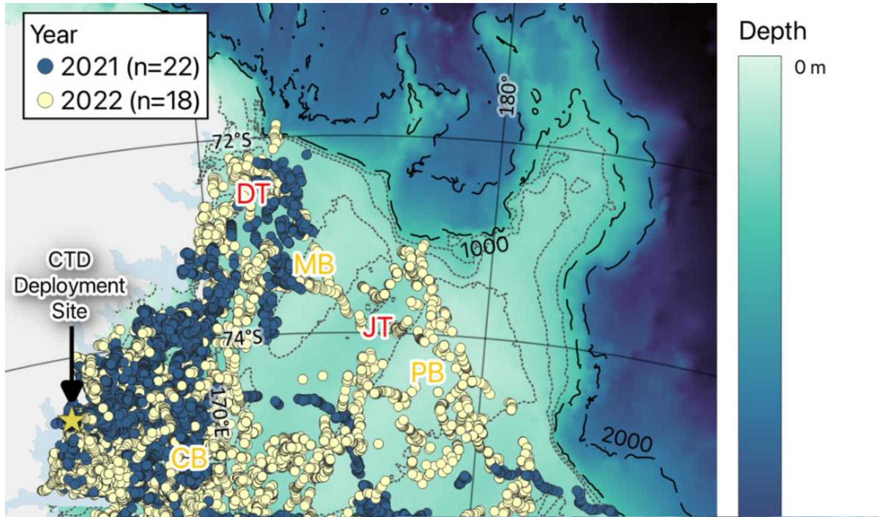
https://www.ecopdecade.org/south-korea/

* Introduce OCL (Ocean Climate Change Lab)

Since 2021.03 ~
Member: 1 PhDc, 3 Msc,
2 Undergraduate intern

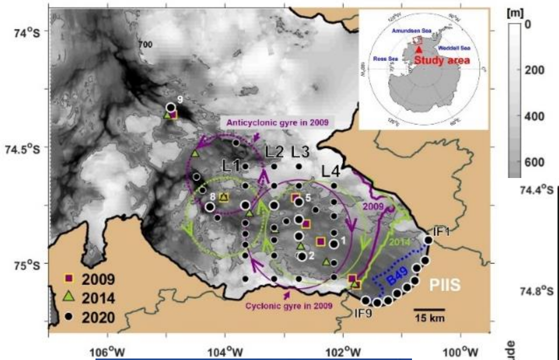
Circulation of glacial meltwater in the Ross Sea Antarctica using seal-tag hydrographic data

National Research Foundation of Korea

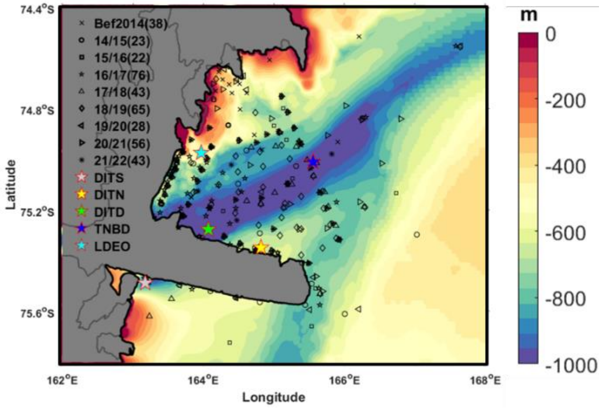


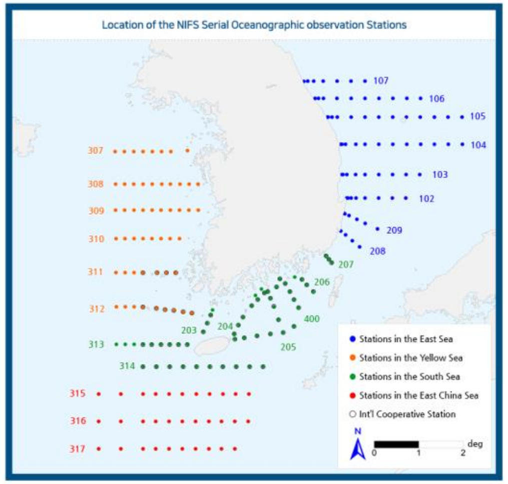
From Dr. Lee (KOPRI)

Korea Network for Observation and prediction of ice sheet and sea level changes in a Warming world (K-NOW)



KOPRI





NIFS
National Institute of Fisheries Science

Serial Oceanographic Observation line data QC (1961 ~)

※ OCL Homepage

https://app.gather.town/app/TxvSuPtuSGyw5skk/OCL

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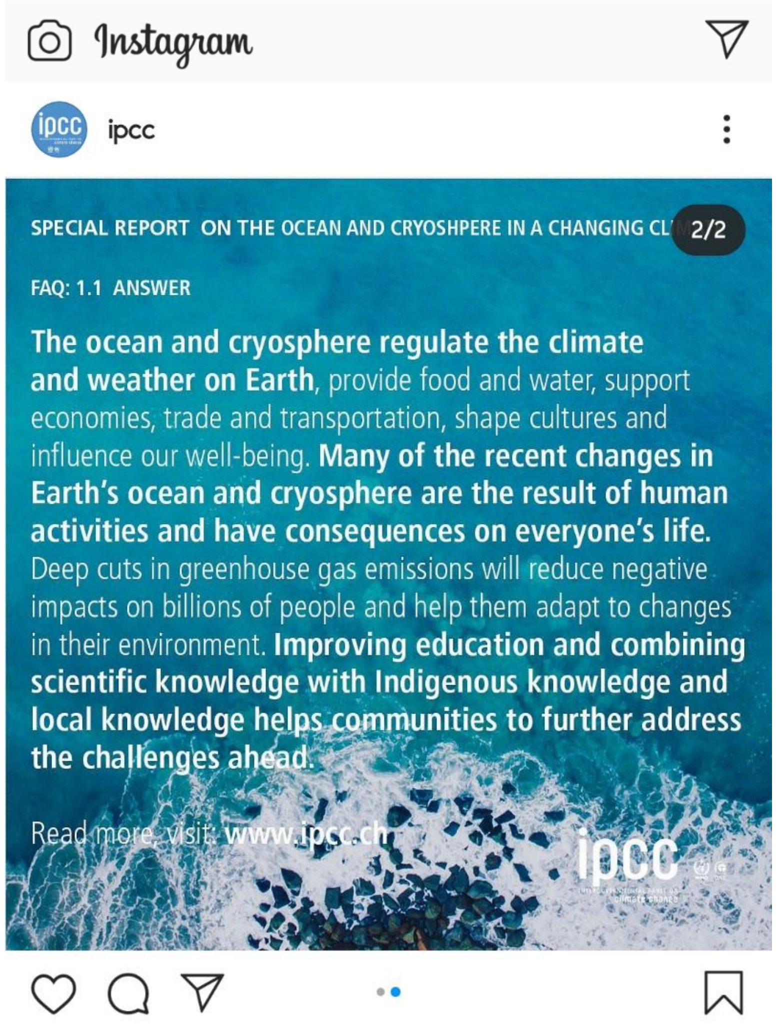
1. Introduce the Antarctic Ocean

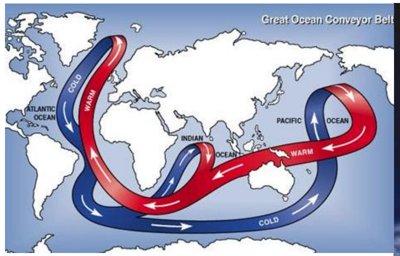
1.1. Climate Change

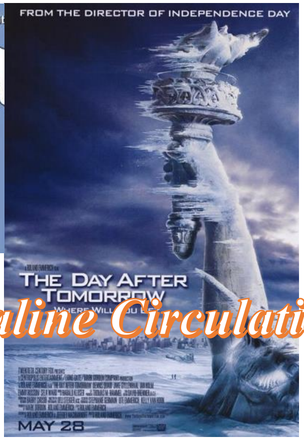
"Yes, Era of global boiling has arrived."

From IPCC Instagram

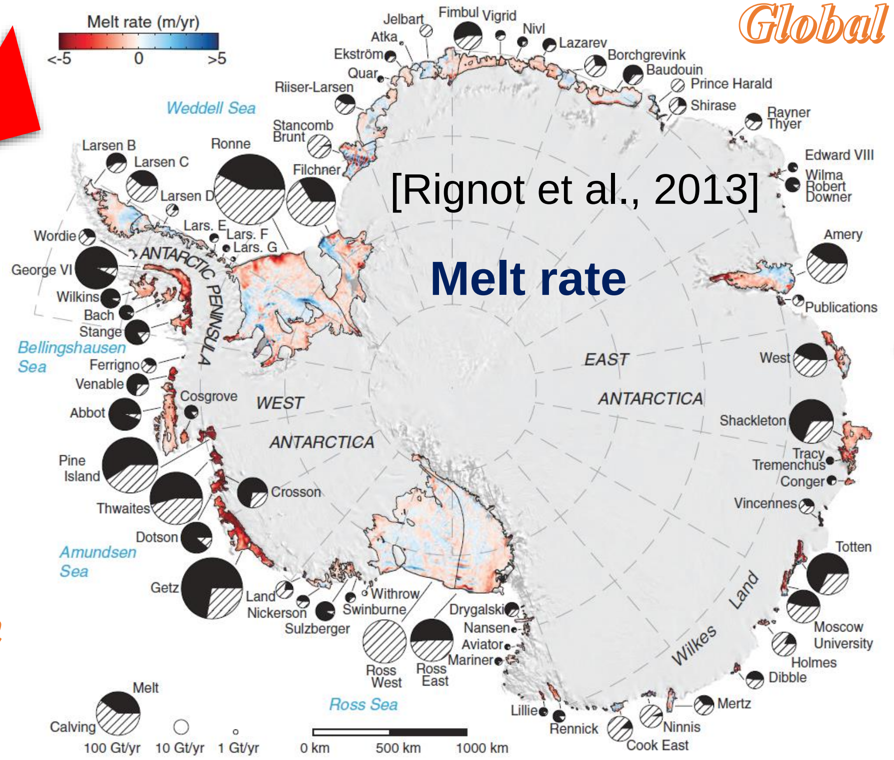


'Melting'





Global Thermohaline Circulation



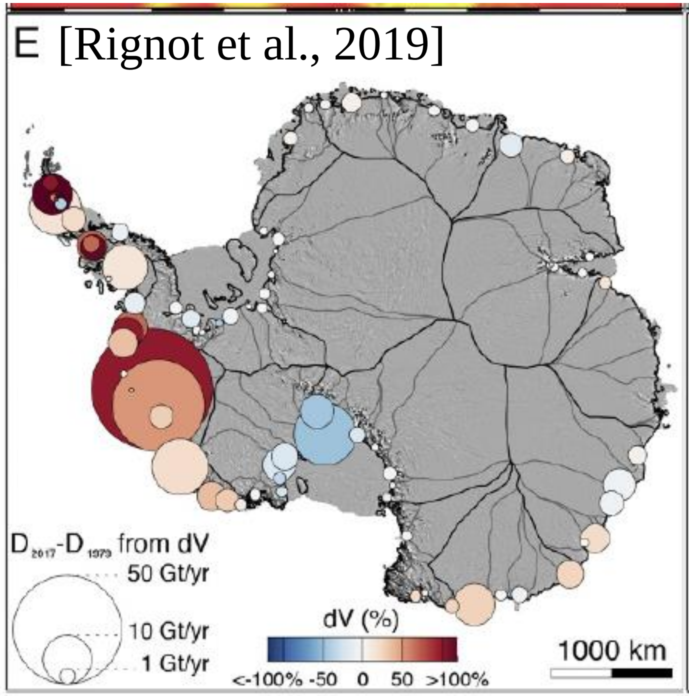
[Rignot et al., 2013]

Melt rate

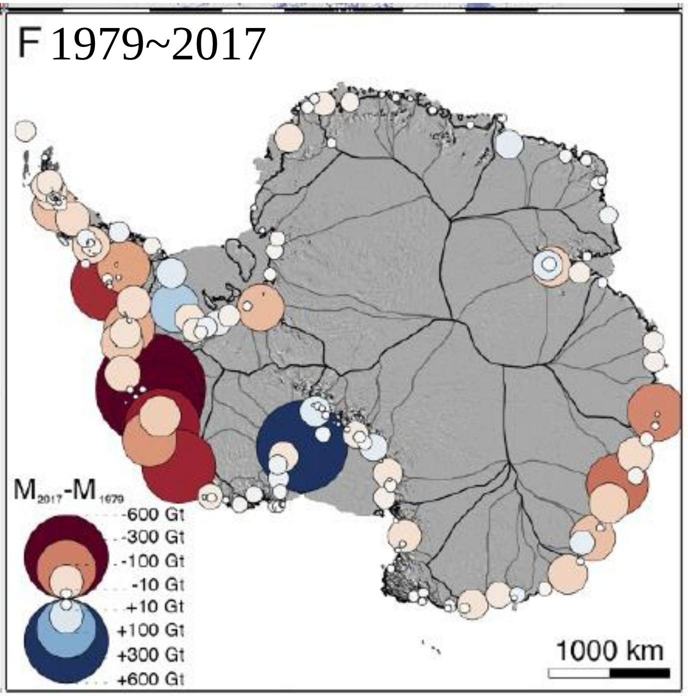
Influence on Ecosystem

1.2. Characteristics of melting

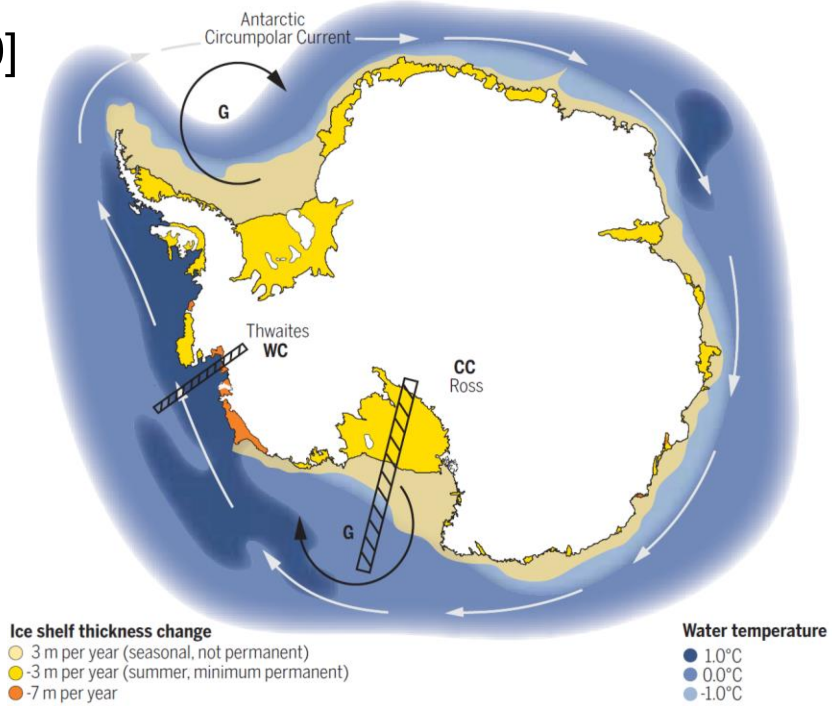
[Holland et al., 2020]



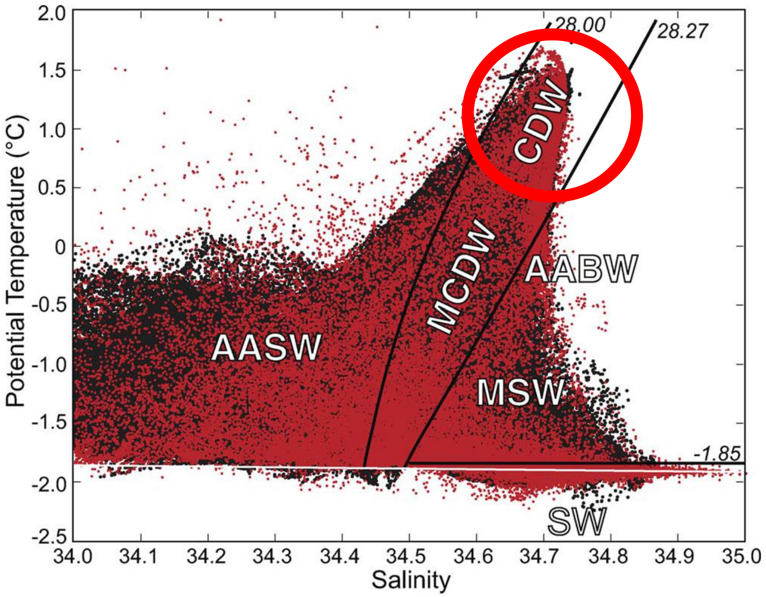
▲ Change in grounding line ice discharge
(Red: acceleration; Blue: Deceleration)



▲ Total change in mass
(Red: loss; Blue: gain)



- Relatively warm and salty Circumpolar Deep Water (CDW) is a key component of the Antarctic Circumpolar Current (ACC).

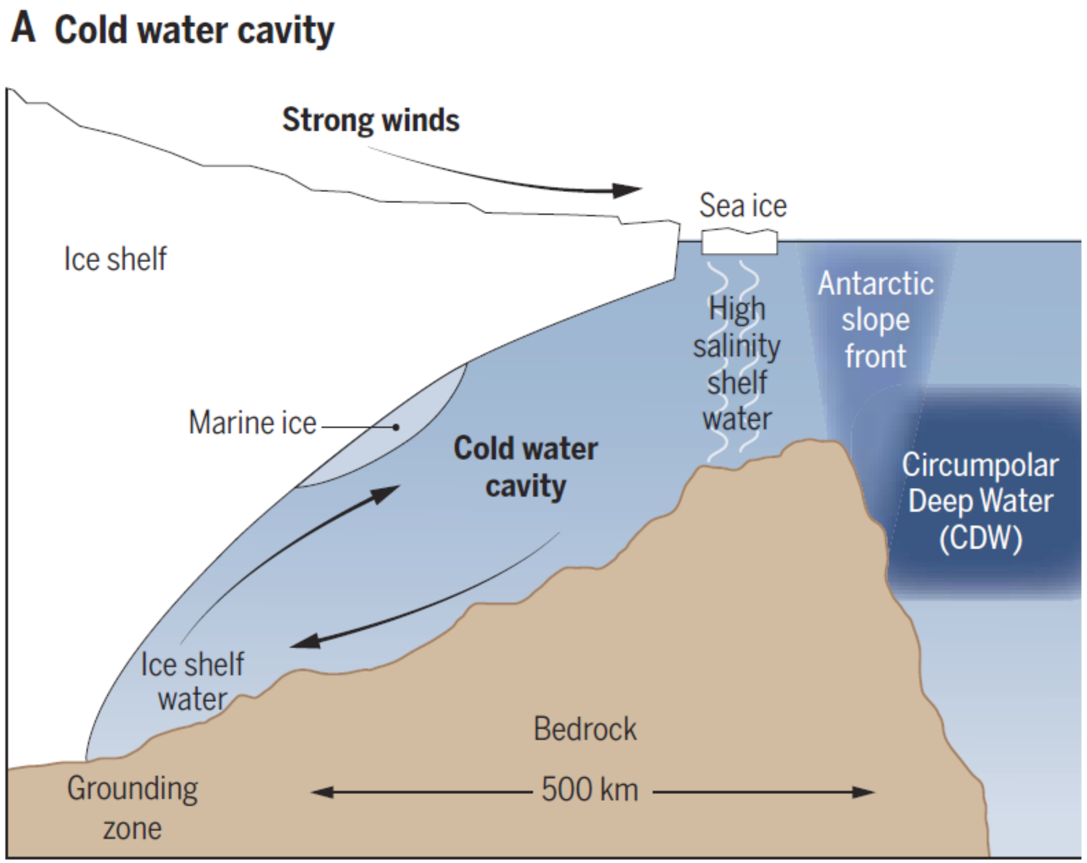


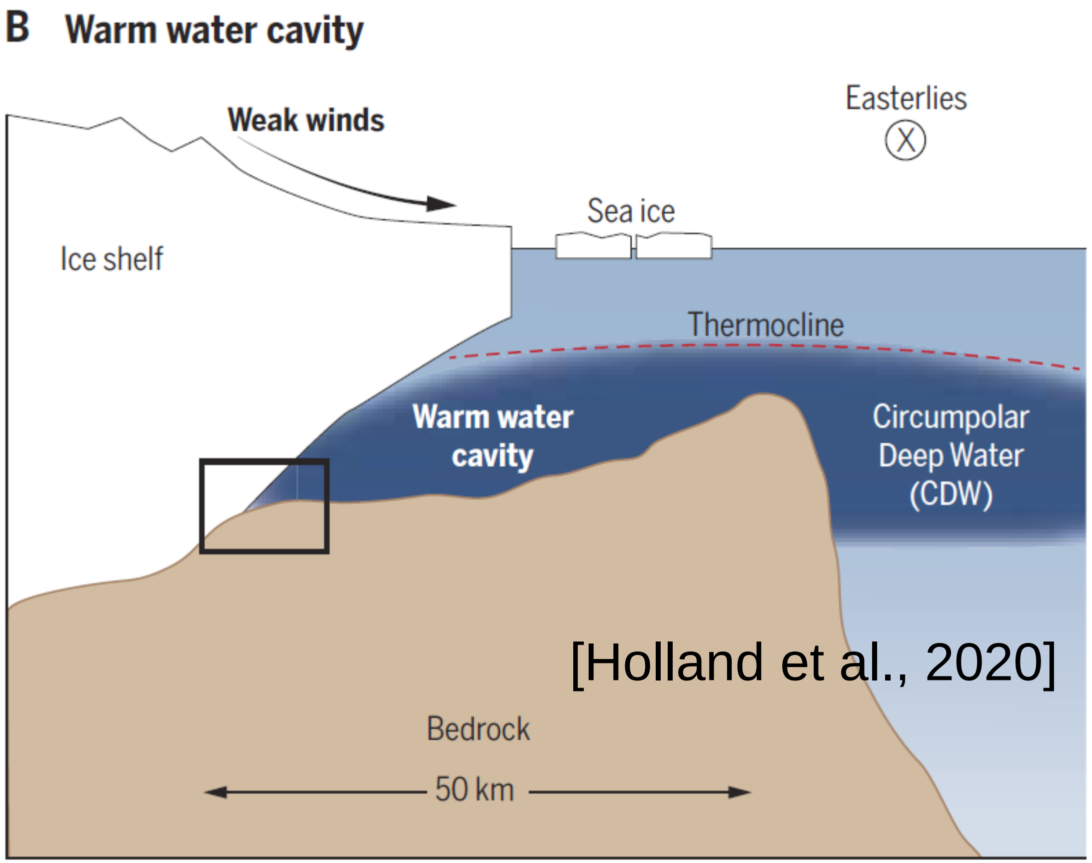
[Orsi and Wiederwohl, 2009]

- There are two types of cavity (Cold VS Warm)

Ross ice shelf
Amery ice shelf
Nansen Ice Shelf, western Ross Sea

West Antarctic ice shelves
(**Thwaites, Pine Island**, Dotson…)

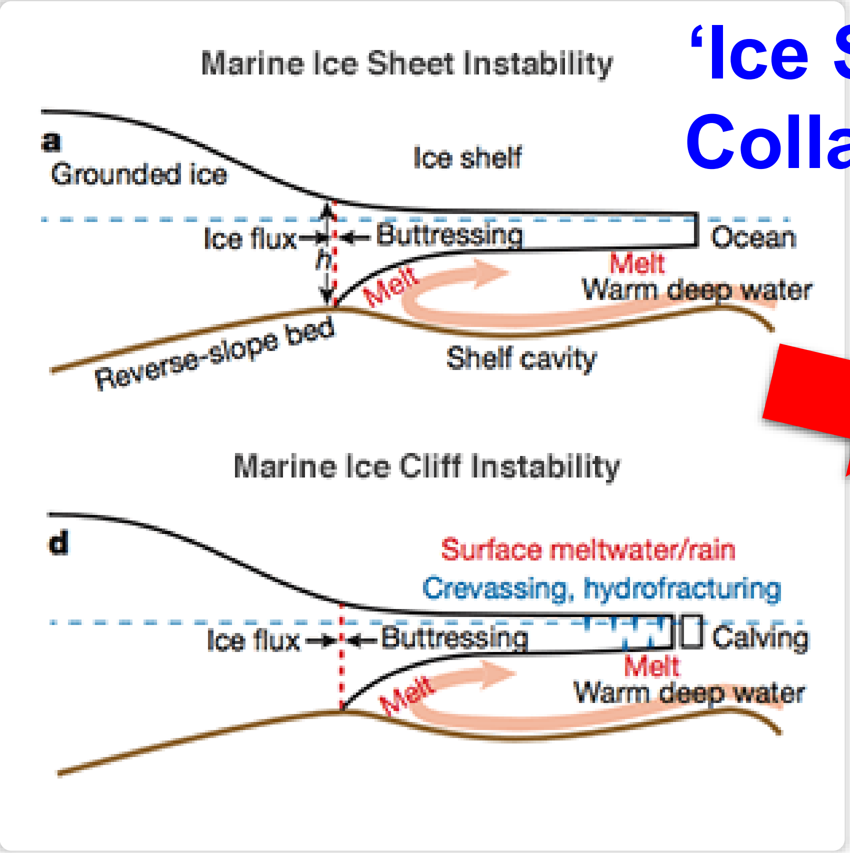




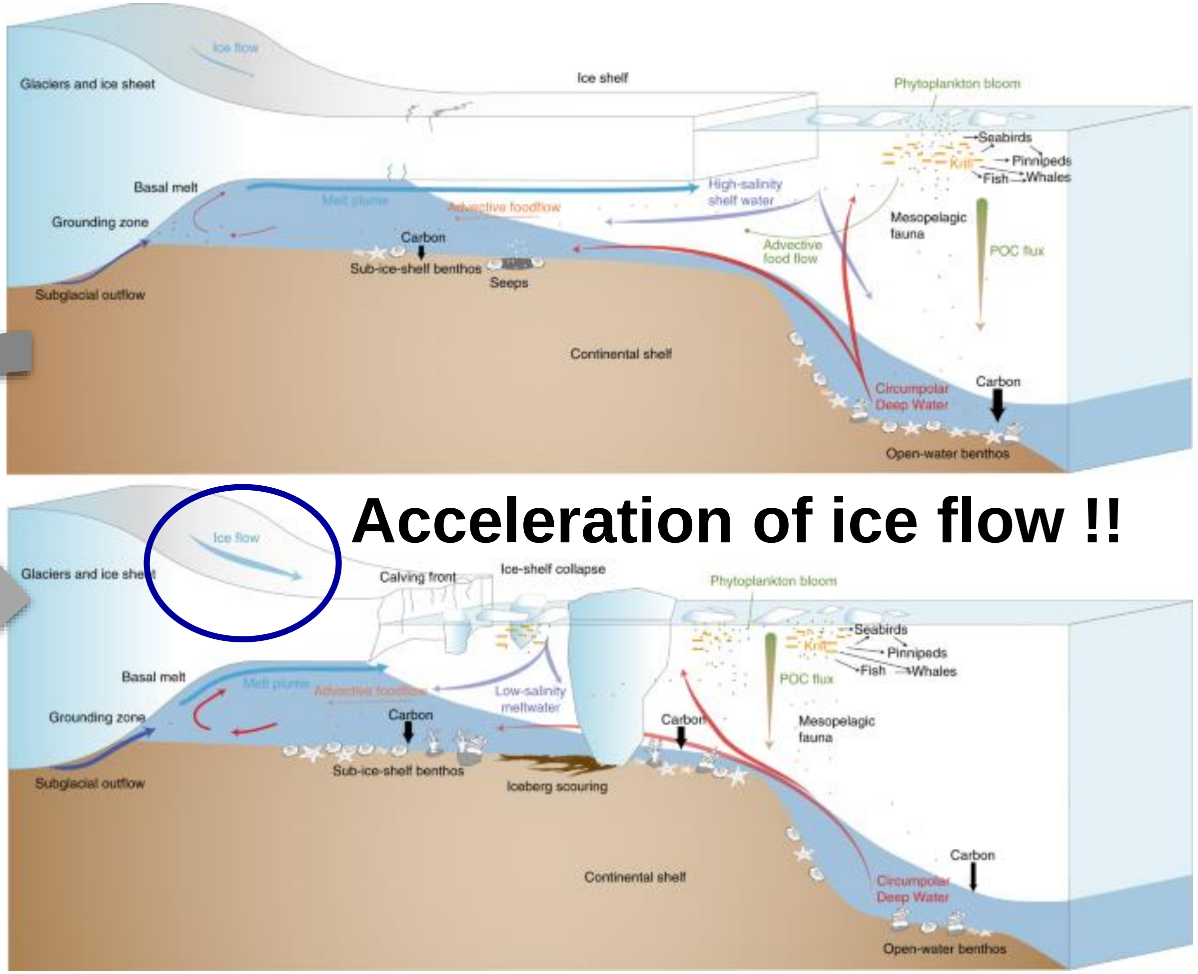
[Holland et al., 2020]

1.3. Uncertainty in Antarctica

- The Antarctic Ice Sheet is buttressed along most of its periphery by floating extensions of land ice called ice shelves and floating ice tongues.



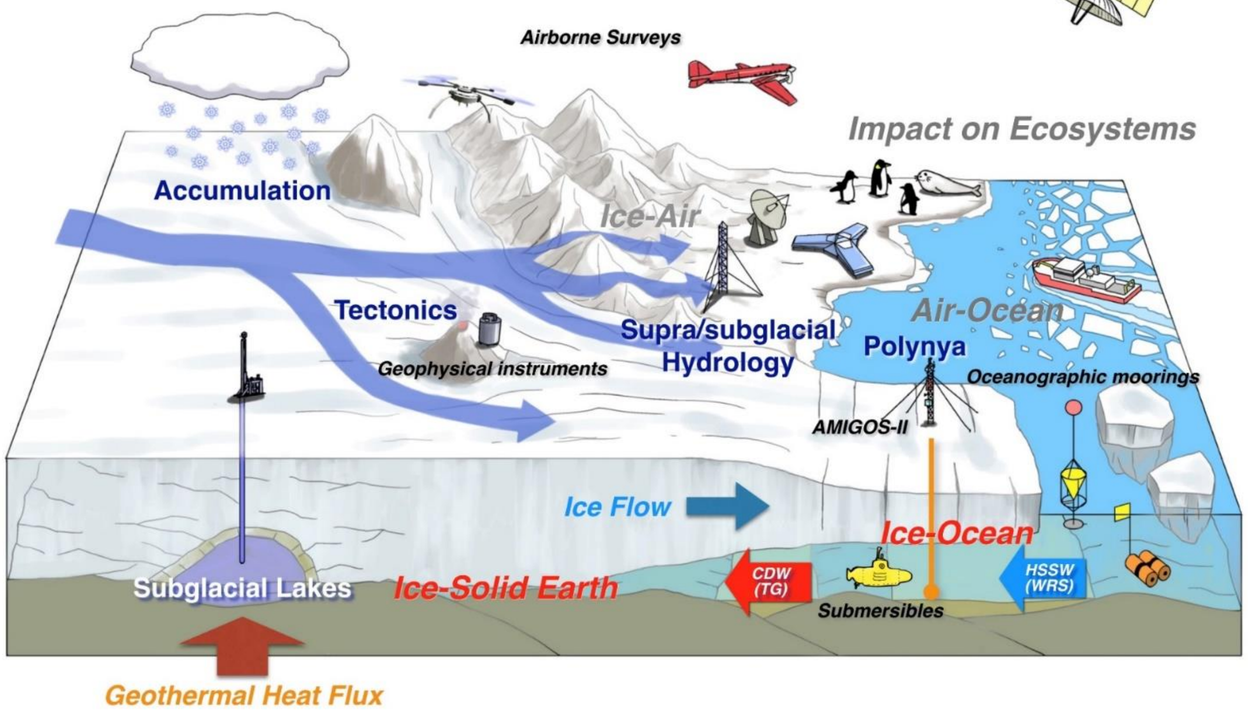
'Ice Shelf Collapse'



Acceleration of ice flow !!

2. LIONESS

Land-Ice/Ocean Network Exploration using Semiautonomous Systems



- **LIONESS-WRS (continue with K-NOW)**

: 2014. 06 ~

: Terra Nova Bay, Western Ross Sea, Antarctica (Cold water cavity)

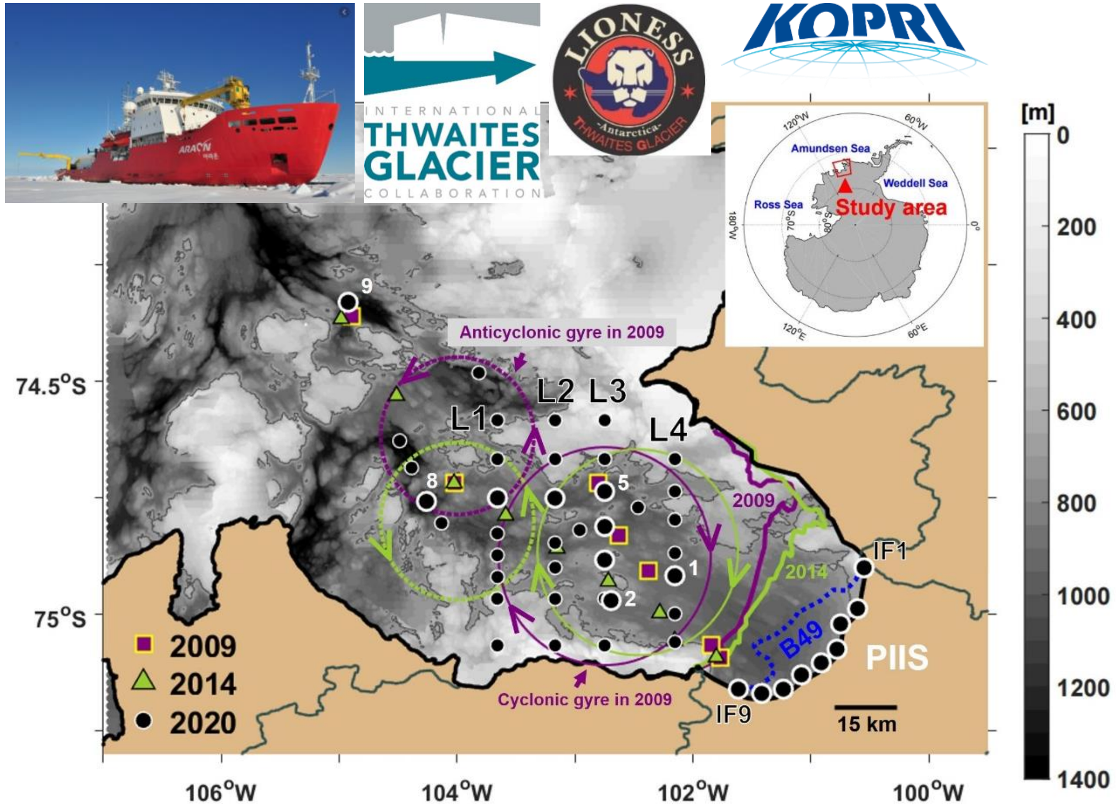
- **LIONESS-TG (continue with K-NOW)**

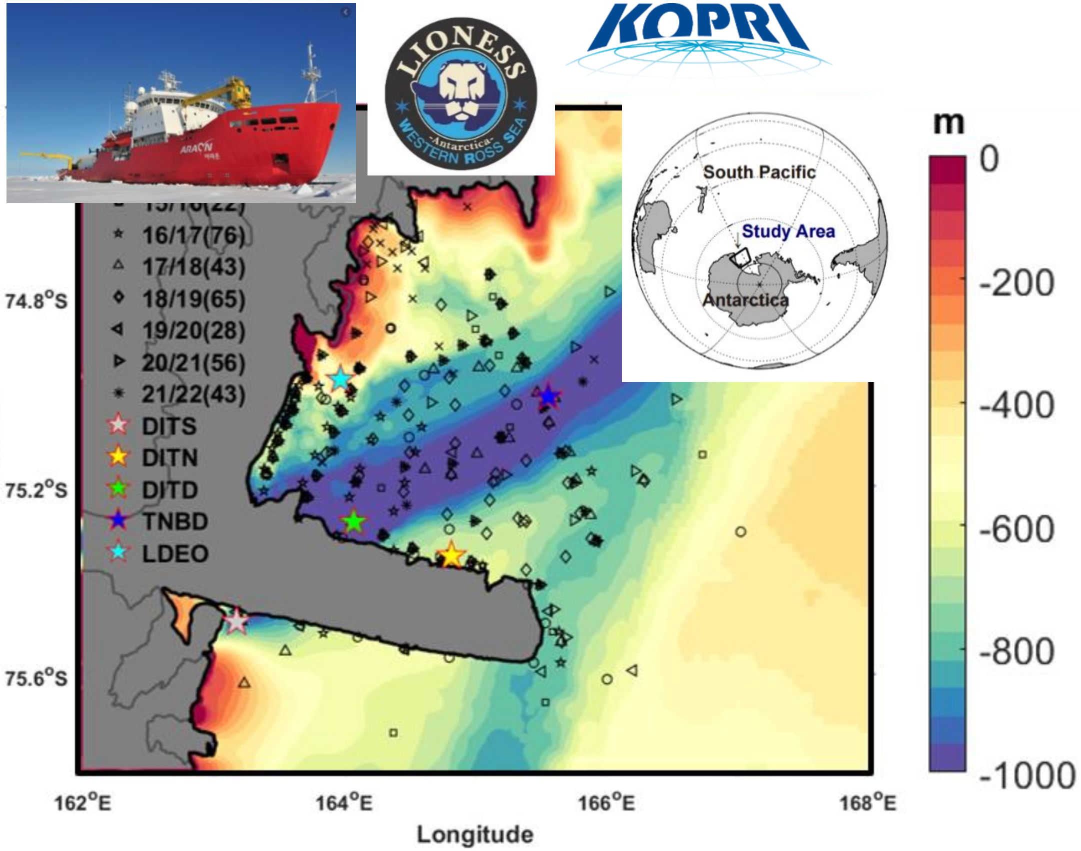
: 2019. 06 ~

: Thwaites Glacier, Amundsen Sea, Antarctica (Warm water cavity)

▲ IBRV ARAON

▲ US-UK ITGC project

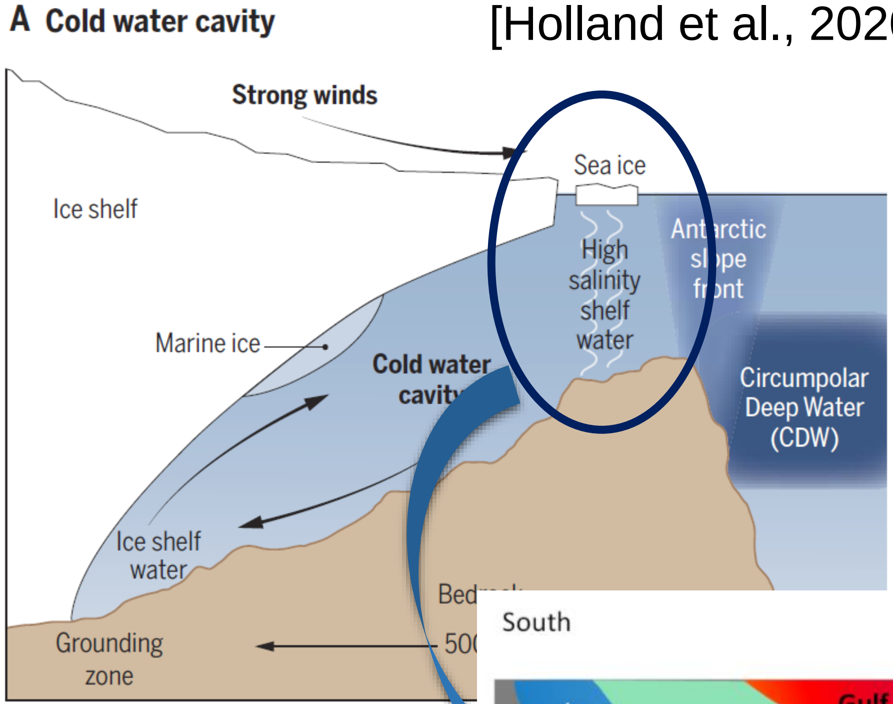




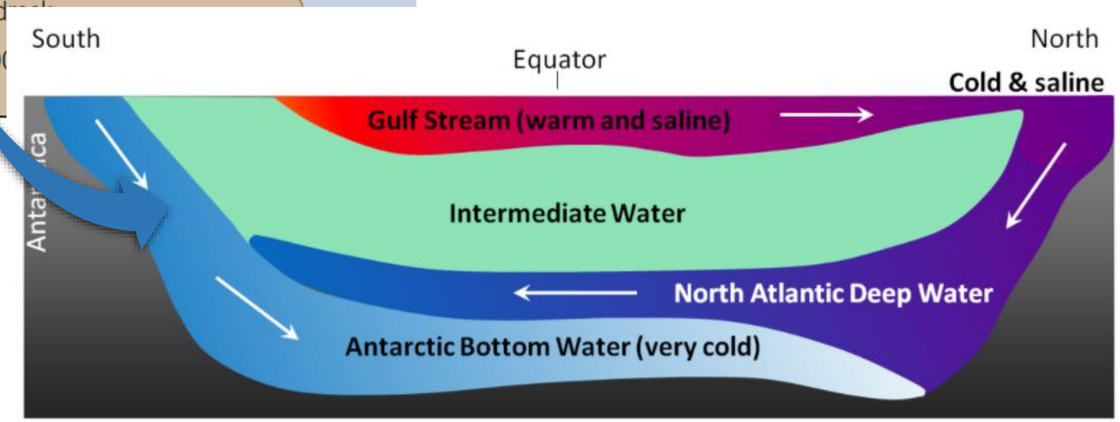
Pine Island Bay, Amundsen Sea Dotson-Getz polynya, Amundsen Sea	Terra Nova Bay, Ross Sea
• **CTD/LADCP/SADCP** (2020. 1~2) • **CTD/LADCP** (2022. 1~2) • **CTD/SADCP** (2009 & 2014)	• **9 times CTD/LADCP** (2014. 12; 2015. 12; 2017. 1~2; 2018. 3; 2019. 1; 2020. 3, 2020. 12; 2022. 3; 2022. 12) • **Mooring** (DITN(2014~2022), DITD(2017~2022), LDEO(2017~2018), TNBD(2018~2019)) • **Over 11,325 profiles from Seal-tagging (2021 & 2022 & 2023)**

※ **Mooring** (EGGTG1(2020. 1 ~), EGGTG2(2020. 1 ~))

3. Responses of the Ross Sea



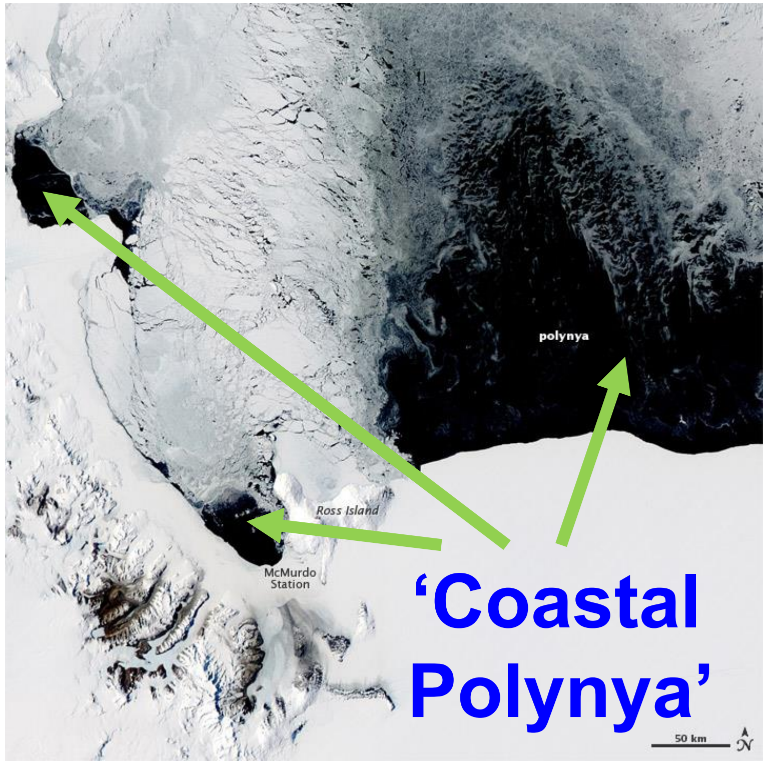
[Holland et al., 2020]

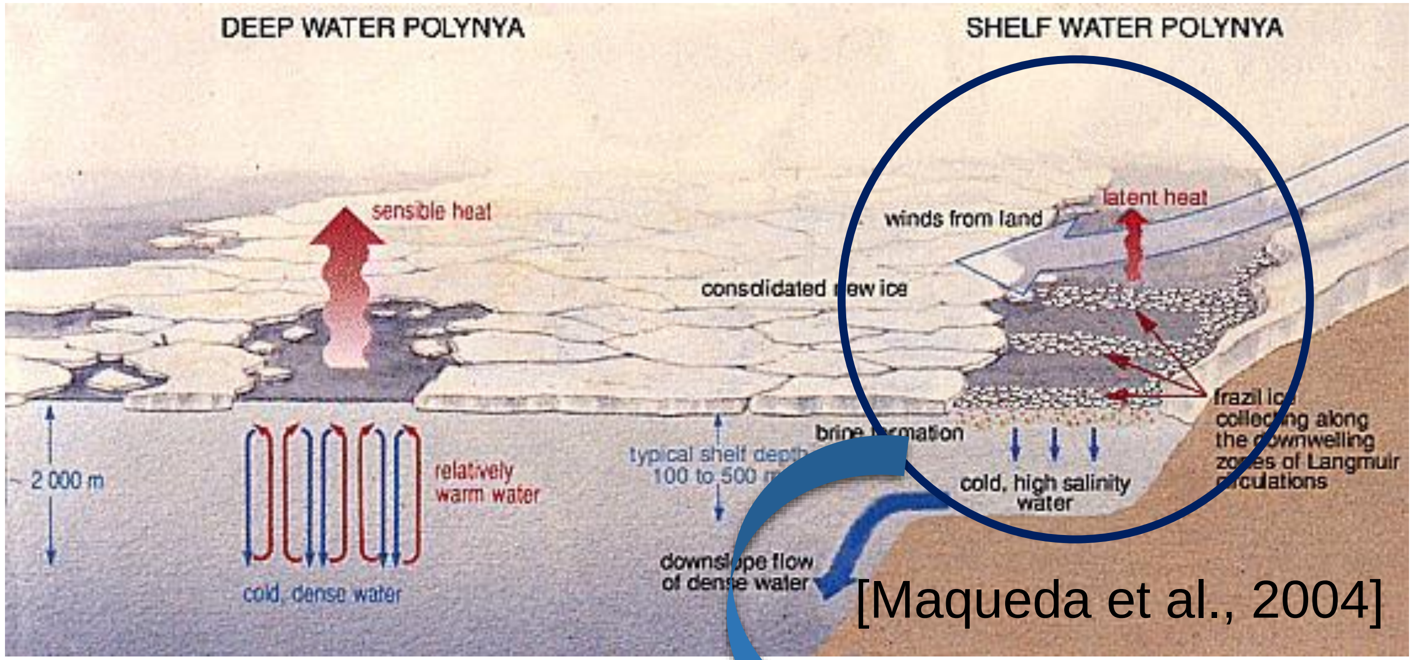


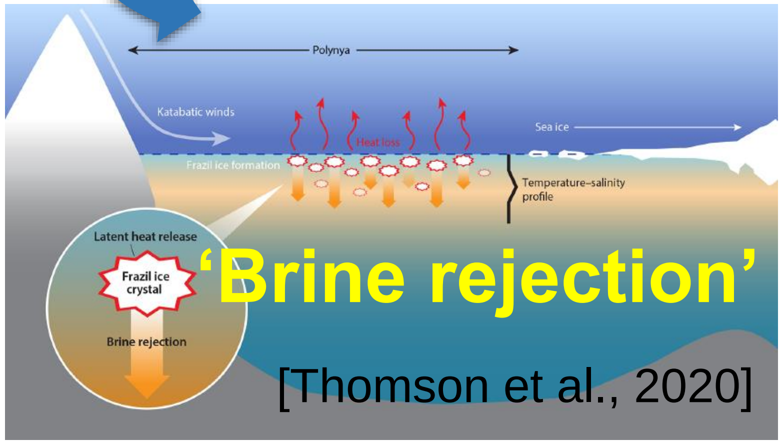
[Physical Geology - 2nd Edition by Steven Earle]

- 25 % of the Antarctic Bottom Water (AABW) formation in the Ross Sea [Orsi et al., 2002].

- Of the HSSW in the Ross Sea, 33% is produced in Terra Nova Bay [Jendersie et al., 2018].







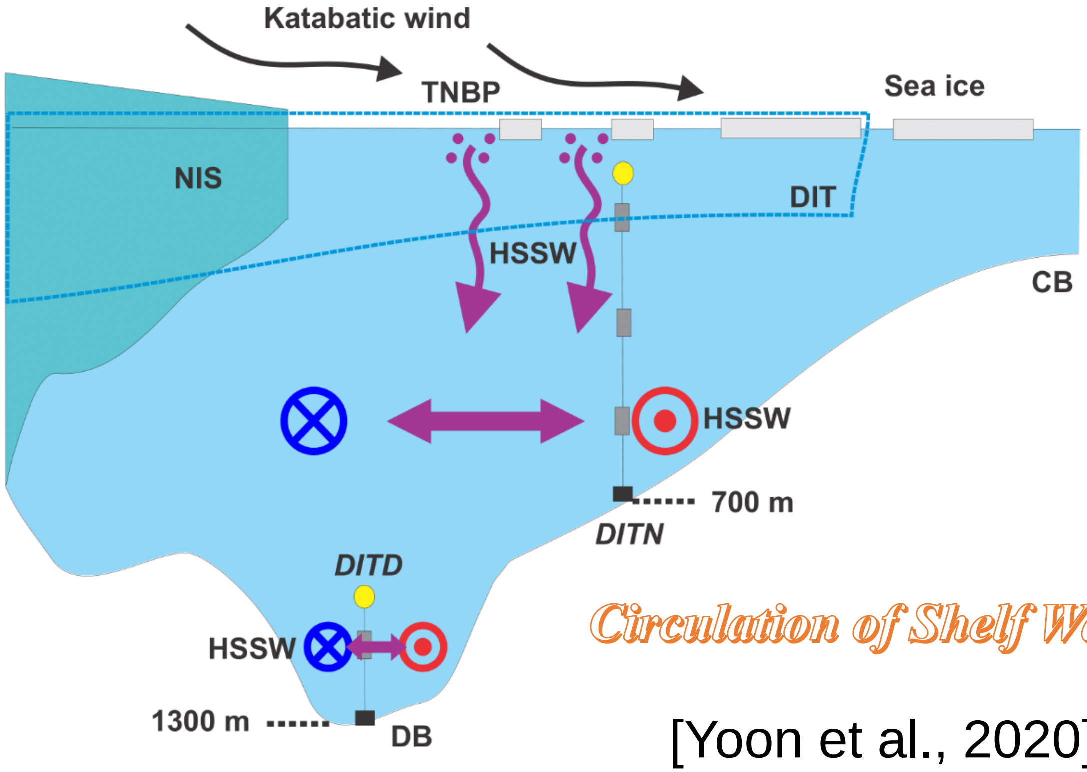
- HSSW is formed via polynya (sea-ice free area) activity [Budillon and Spezie, 2000; Gordon et al., 2009; Rusciano et al., 2013; Jendersie et al., 2018; Yoon et al., 2020].

Ocean Sci., 16, 373–388, 2020
https://doi.org/10.5194/os-16-373-2020

Ocean Science
Open Access
EGU

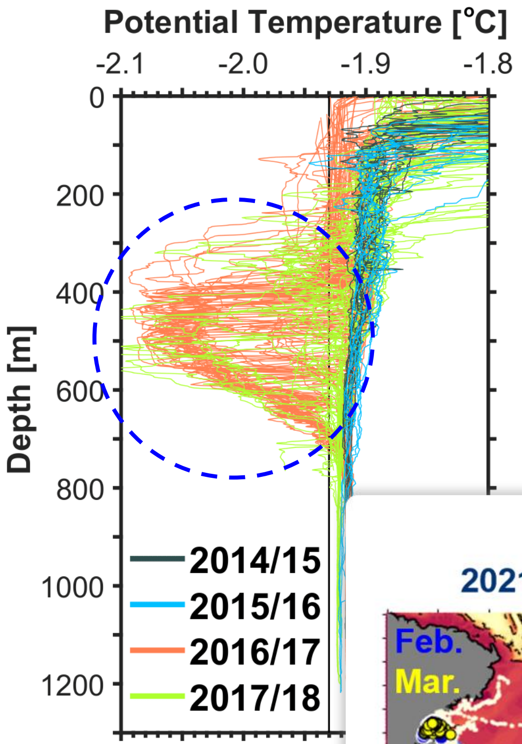
Variability in high-salinity shelf water production in the Terra Nova Bay polynya, Antarctica

Seung-Tae Yoon[1], Won Sang Lee[1], Craig Stevens[2,3], Stefan Jendersie[4], SungHyun Nam[5], Sukyoung Yun[1], Chung Yeon Hwang[1], Gwang Il Jang[1], and Jiyeon Lee[1]



Circulation of Shelf Water

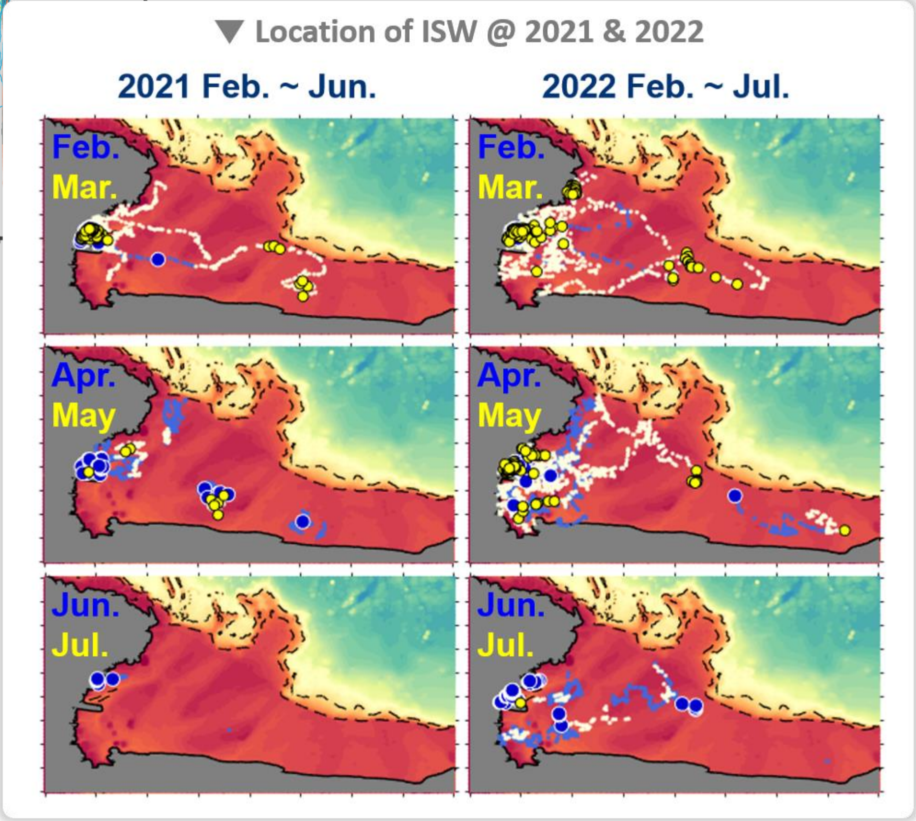
[Yoon et al., 2020]



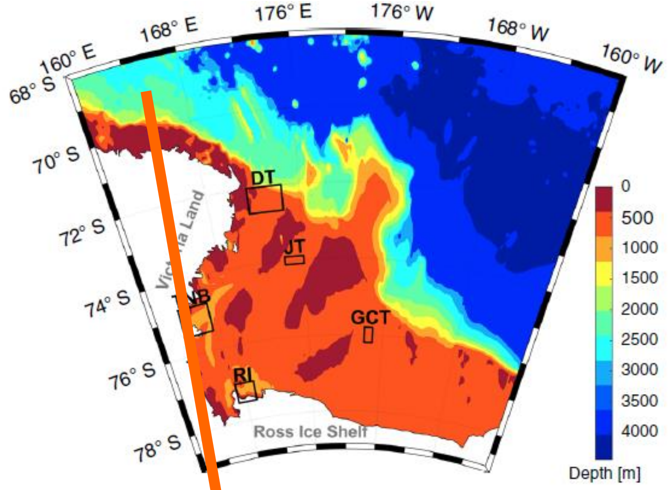
◀ **TISW**
(T < -1.93 ℃)

Impact of Ice Shelf Water

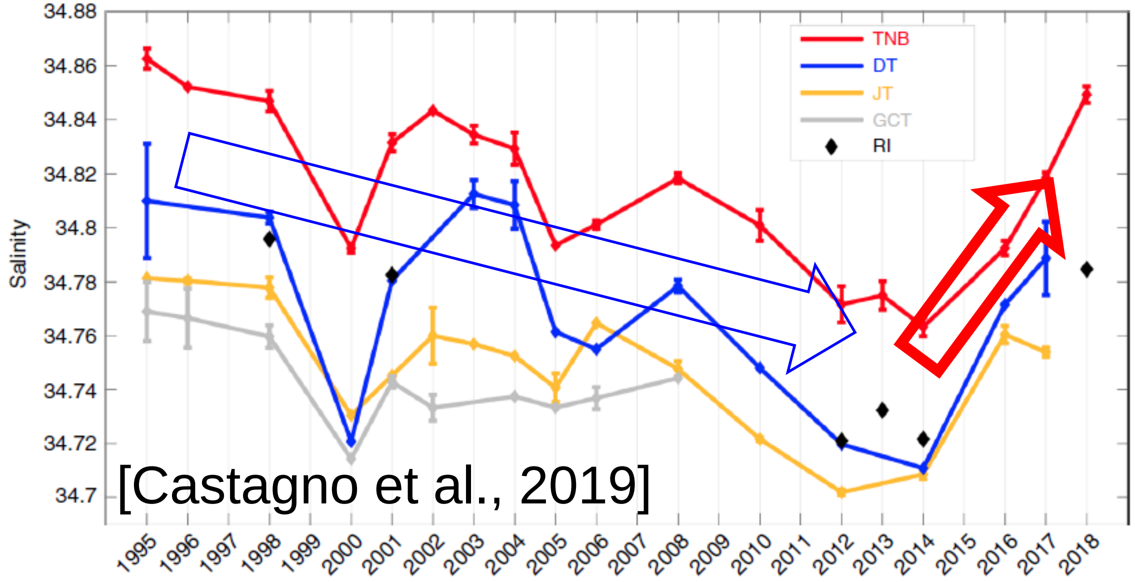
[Yoon and Lee, in prep.]



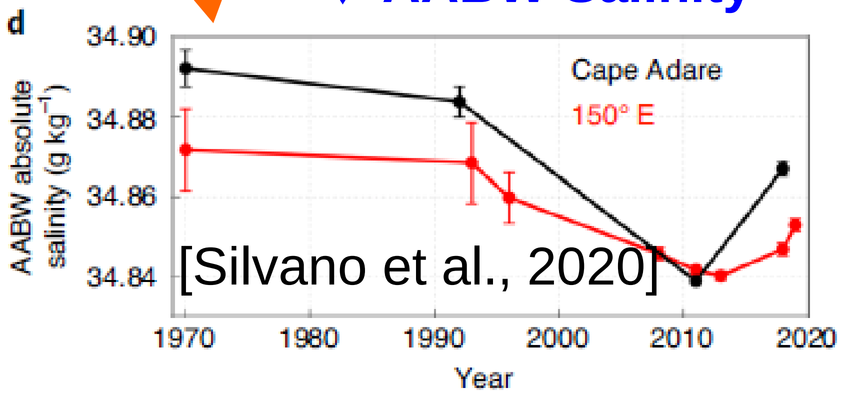
Salinity Rebound



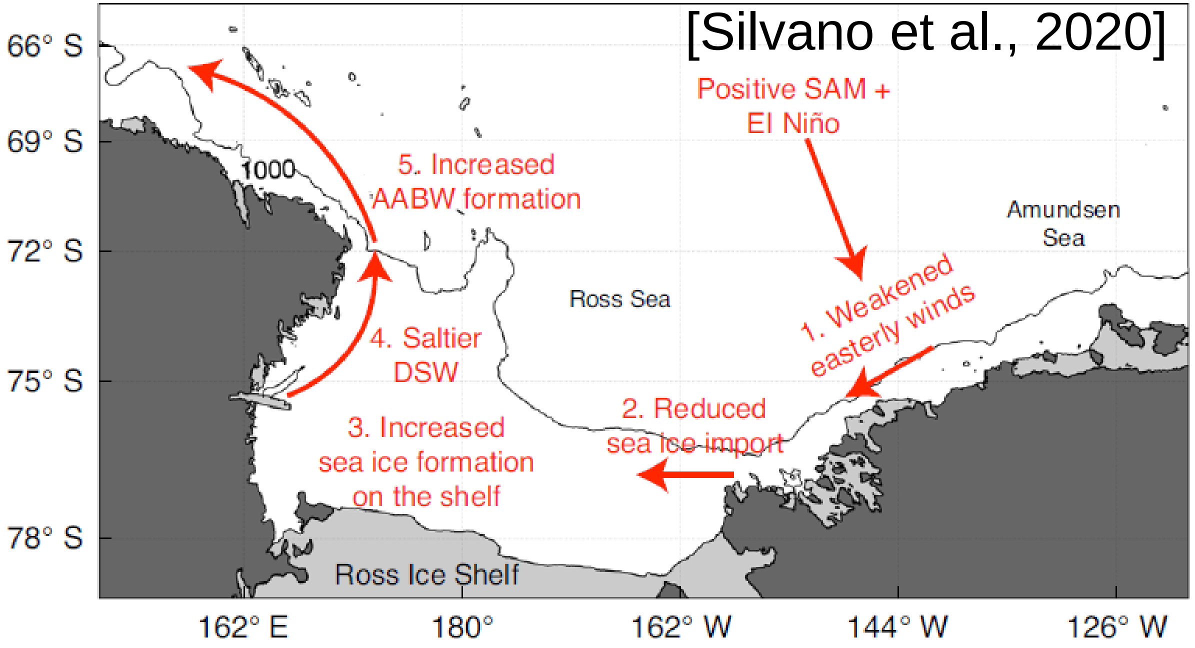
▼ HSSW Salinity



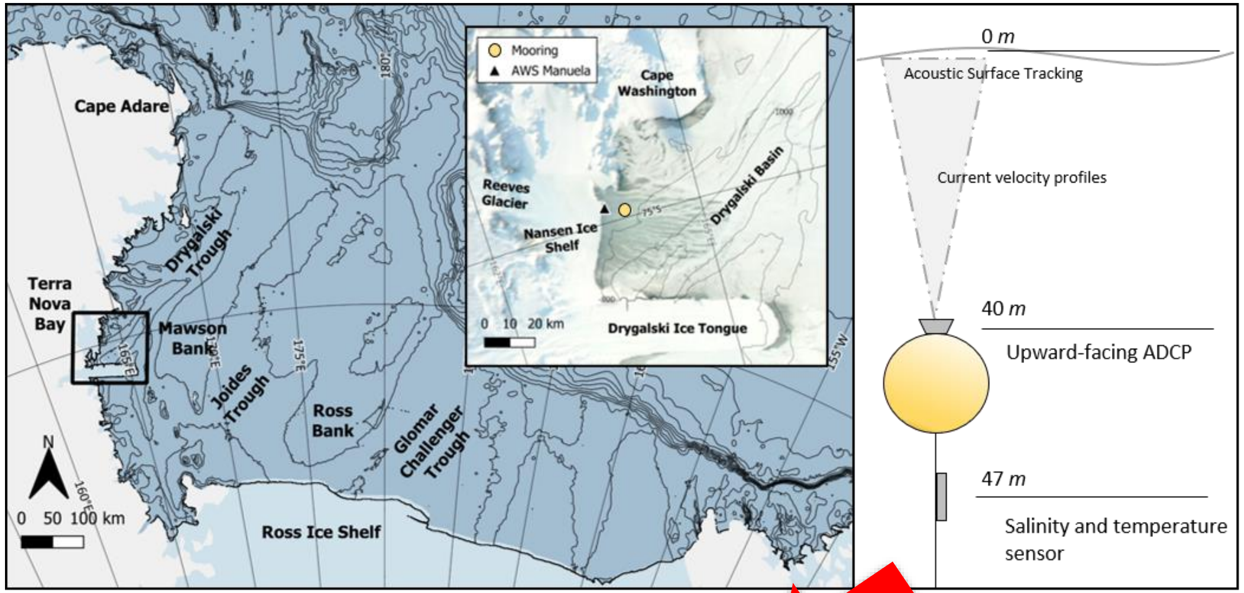
▼ AABW Salinity



Proposed mechanism for the salinity rebound! ▶



[Miller et al. will be published in NC]



HSSW production

$$m_s(t) = \int_0^H \rho S \, dz \qquad \frac{dm_s}{dt} = \frac{m_s(t_1) - m_s(t_0)}{\Delta t} \qquad P_s = \frac{dm_s}{dt} A_p$$

$$P_{HSSW} = \frac{P_s}{\rho_{HSSW}(S_{HSSW} - S_{LSSW})} \times 10^{-6}$$

Net Heat Flux

$$Q_{net} = Q_S + Q_b + Q_H + Q_E$$

$$Q_S = (1-\alpha) C_c T_r S_a cos\eta$$

$$Q_B = 4\varepsilon\sigma T_A^3 (T_A - SST) + \varepsilon\sigma T_A^4 (0.39 - 0.05\sqrt{e(T_d)})(1 - \chi C^2)$$

$$Q_H = \rho_A c_p C_H |\bar{V}| (T_A - SST)$$

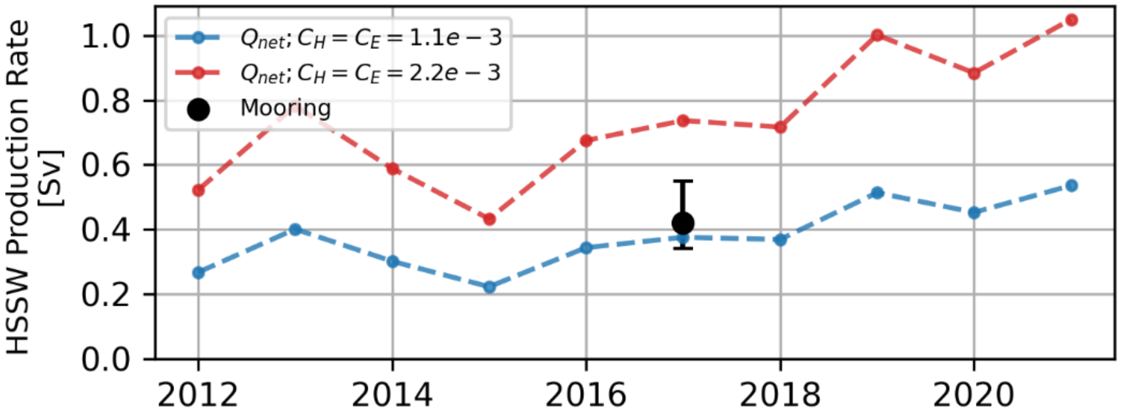
$$Q_E = \rho_A L_E C_E |\bar{V}| (q_A - q_s)$$

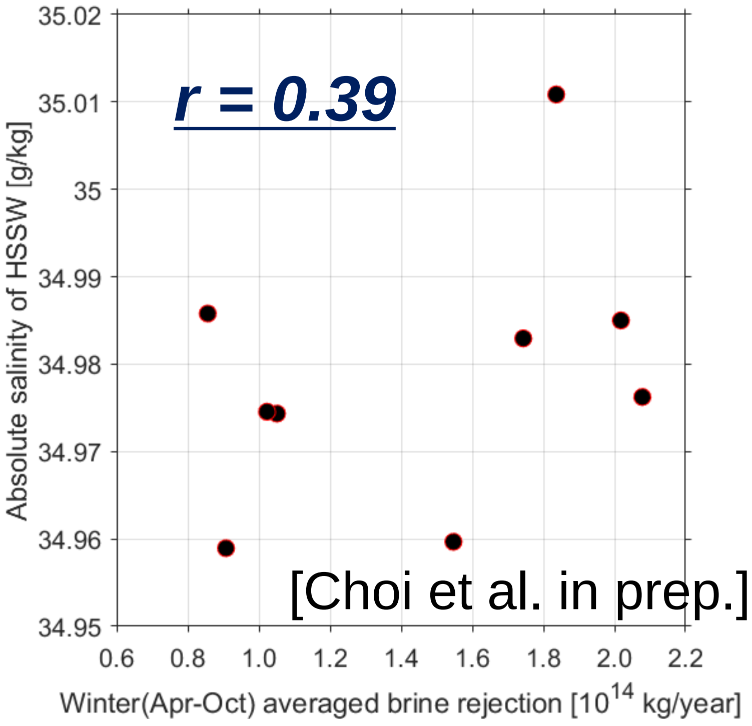
Brine rejection

$$P_i = Q_{net} / L_f \rho_i \qquad P_s = \rho_i P_i A_p (s_w - s_i)$$

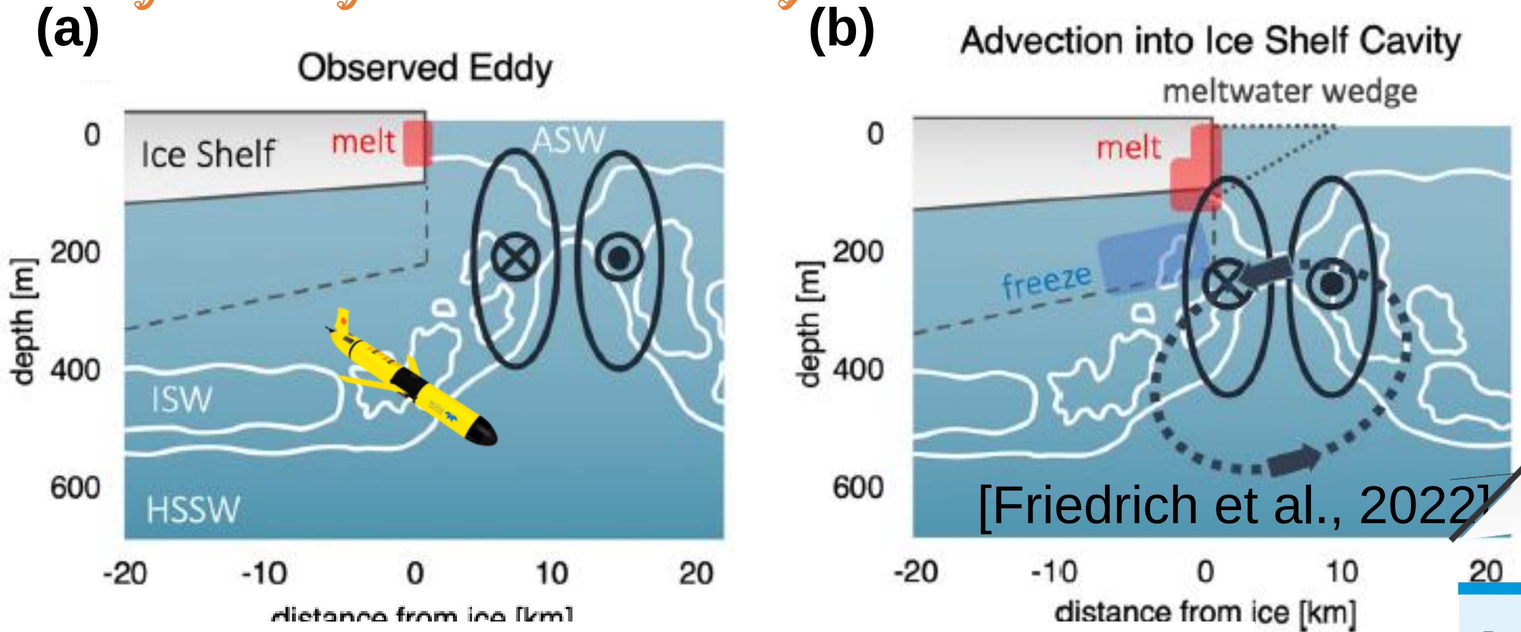
Winter Brine VS Summer Salinity

HSSW production rate



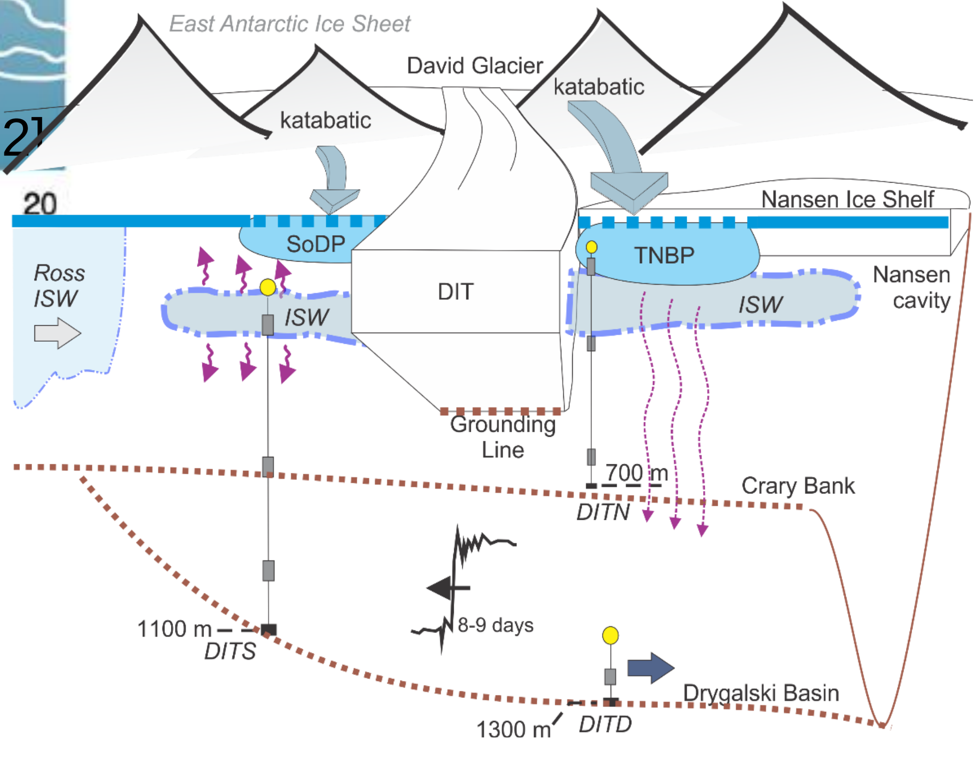


Influence of sub-mesoscale eddy

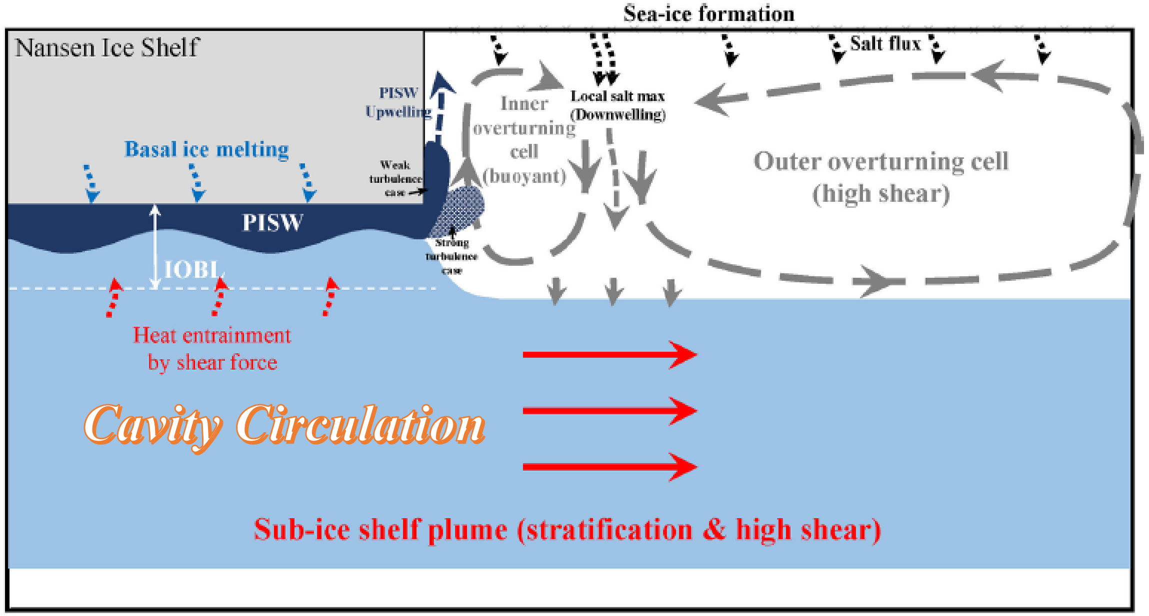


[Friedrich et al., 2022]

[Stevens et al. in prep.]



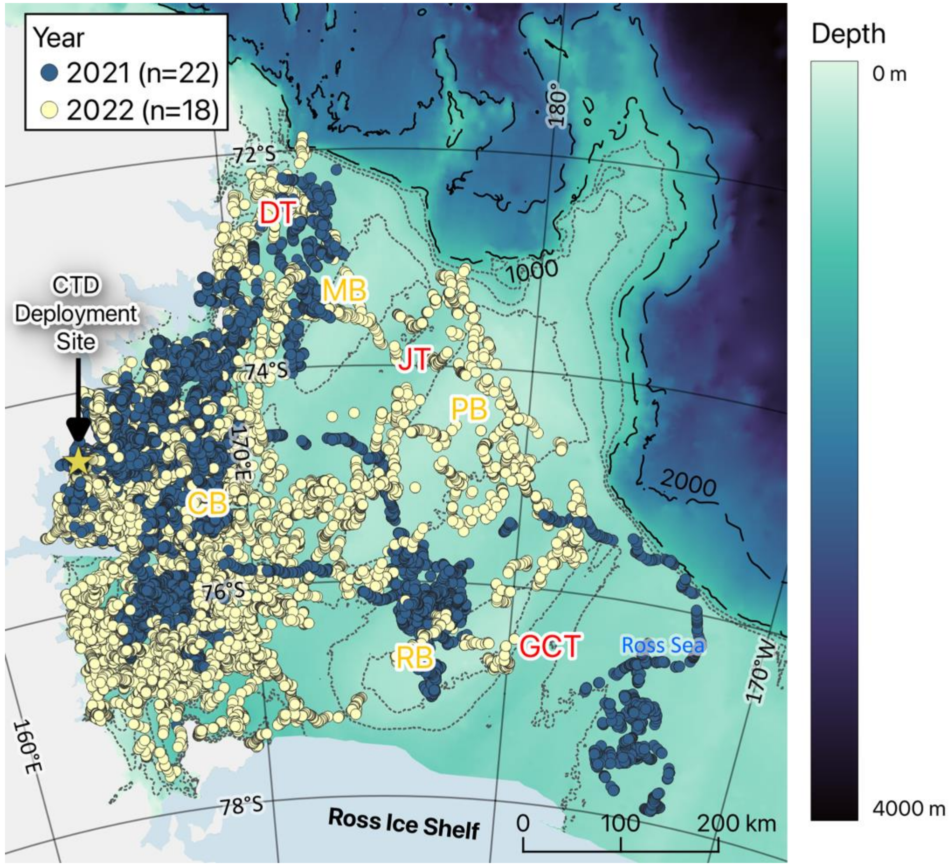
Role of Ice Tongue

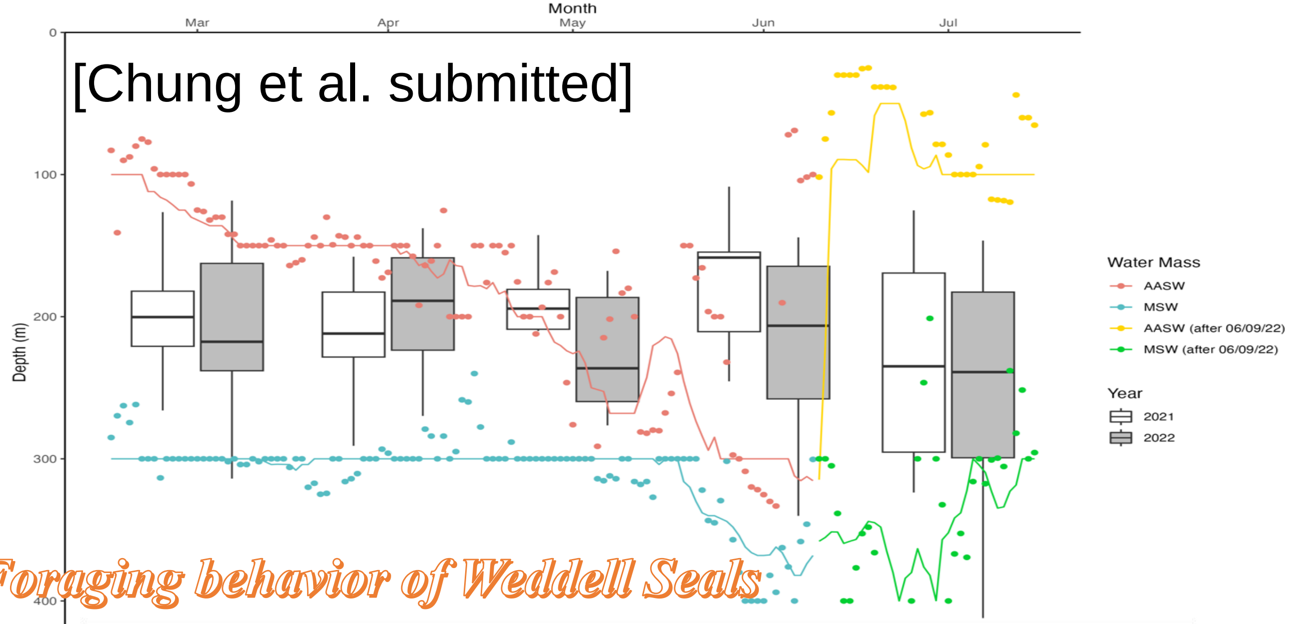


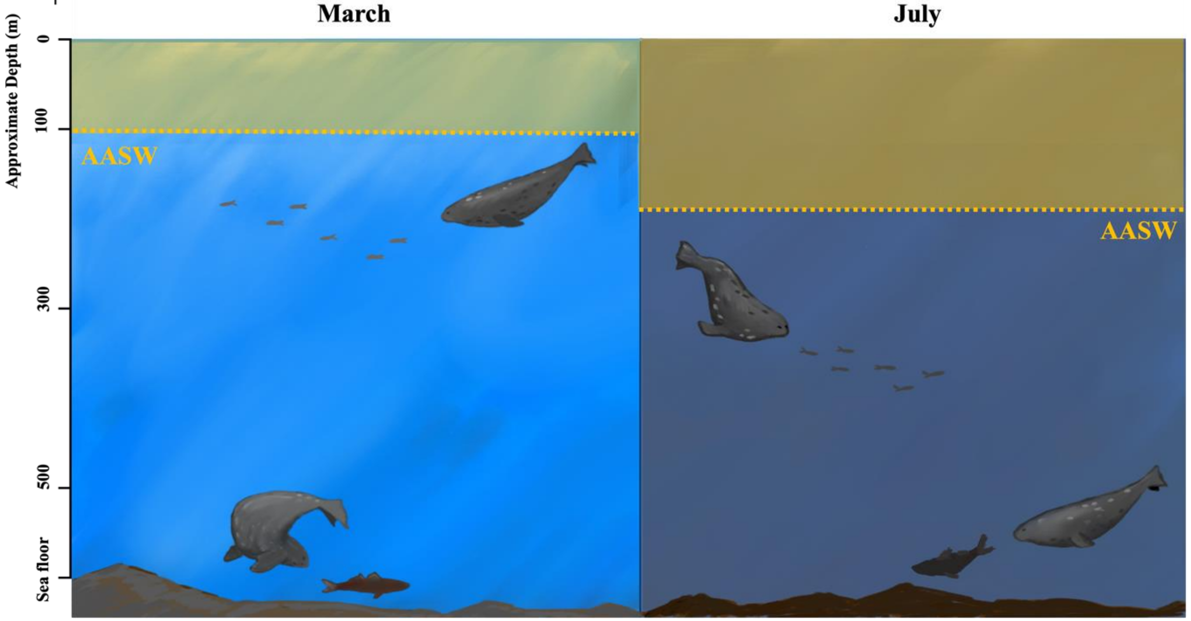
Cavity Circulation

[Na et al., 2022]

Foraging behavior of Weddell Seals

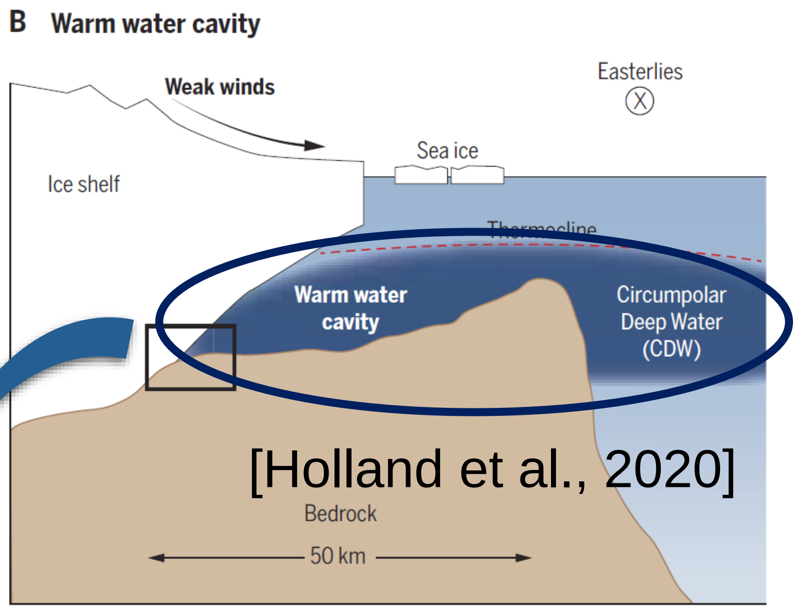




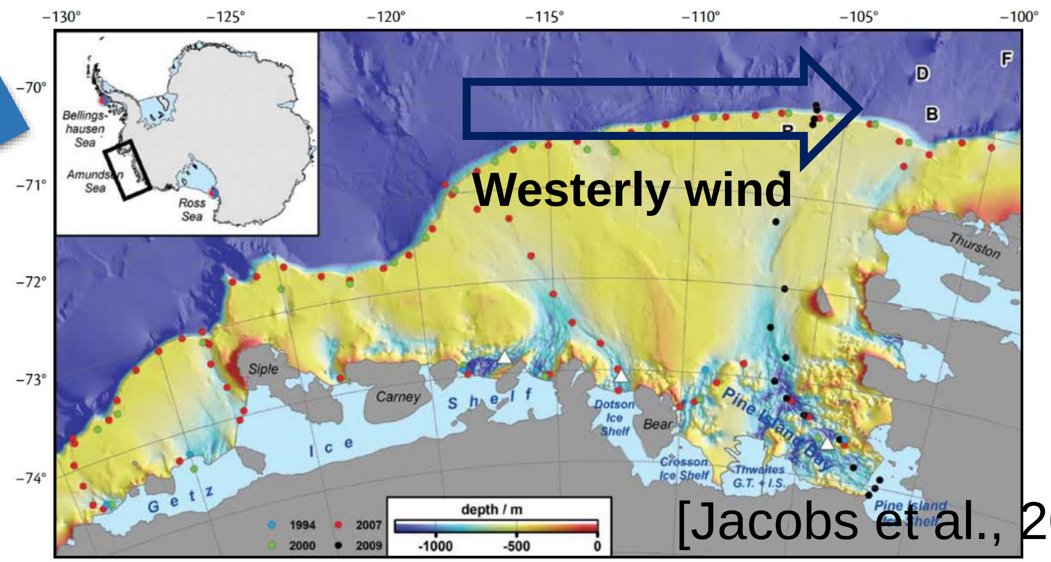


- We found that seals foraged more frequently in modified shelf water and ice shelf water compared to Antarctic surface water. This preference could be connected to greater food availability.

4. Responses of the Amundsen Sea



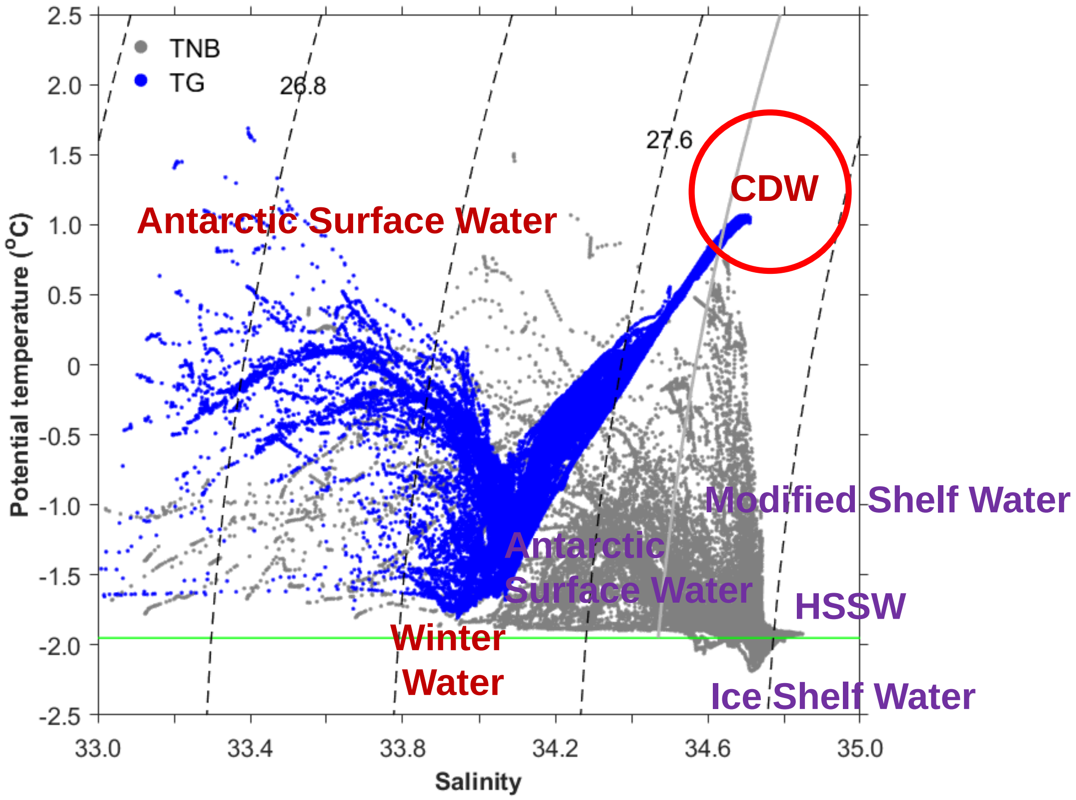
[Holland et al., 2020]

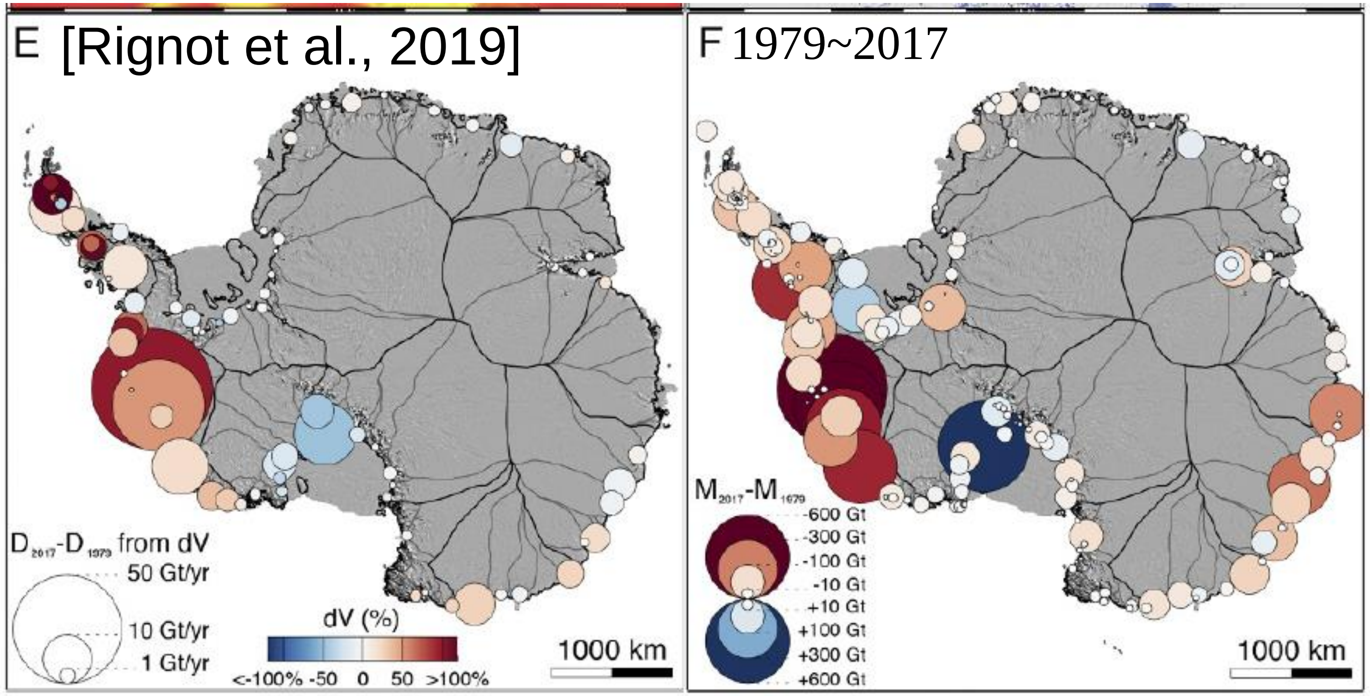


[Jacobs et al., 2012]

- Westerly wind induces equatorward Ekman transport in the continental shelf break region, increasing the flux of CDW onto the continental shelf.

- The West Antarctic ice shelves have been greatly influenced by the CDW.

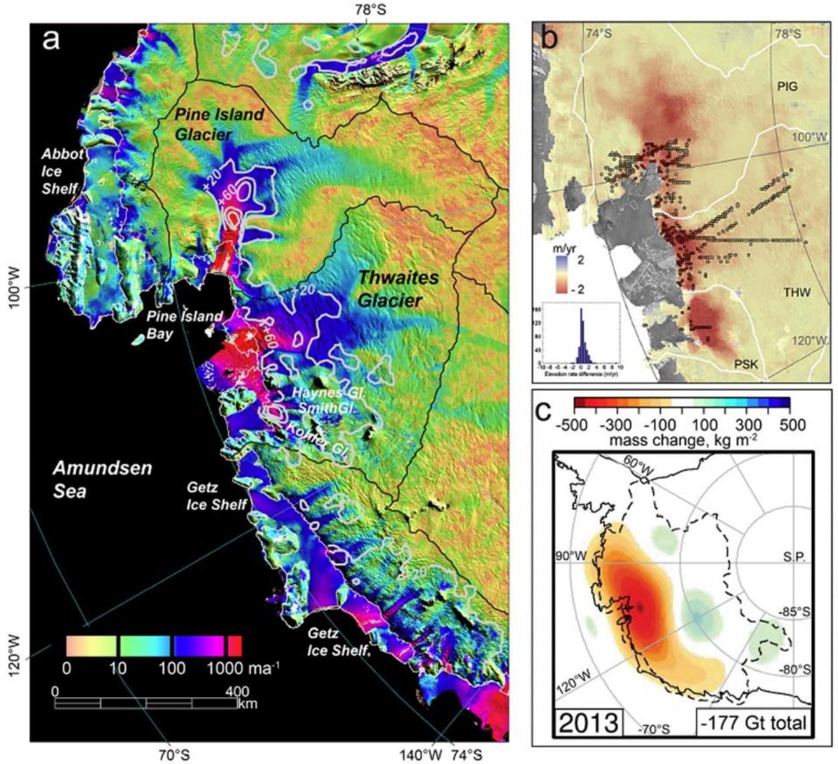




▲ Change in grounding line ice discharge (Red: acceleration; Blue: Deceleration)

▲ Total change in mass (Red: loss; Blue: gain)

[Scambos et al., 2017] ▼ Recent significant increases in mass loss



- The West Antarctic ice shelves have experienced extensive melting together with the rapid grounding line retreat in recent decades. The primary driver of the melting is an increased input of ocean heat into the sub-ice-shelf regions.

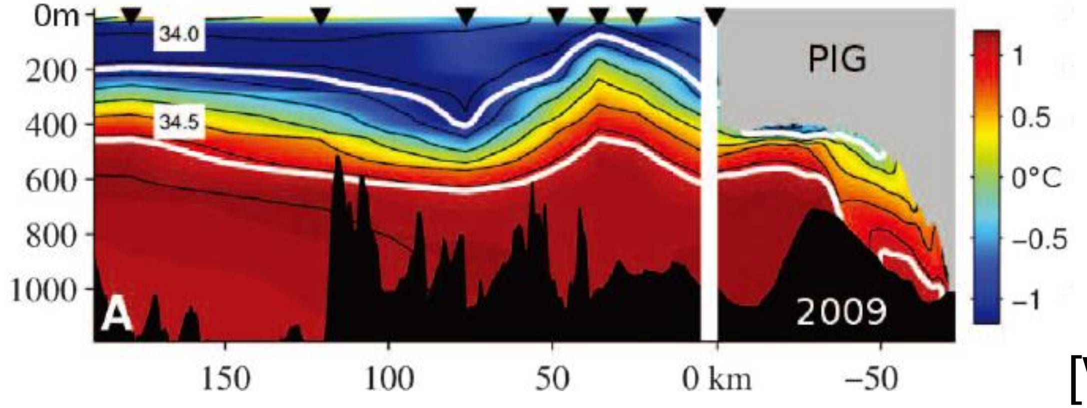
- The most apparent mass loss occurs in the Thwaites and Pine Island Glaciers.

US-UK ITGC project

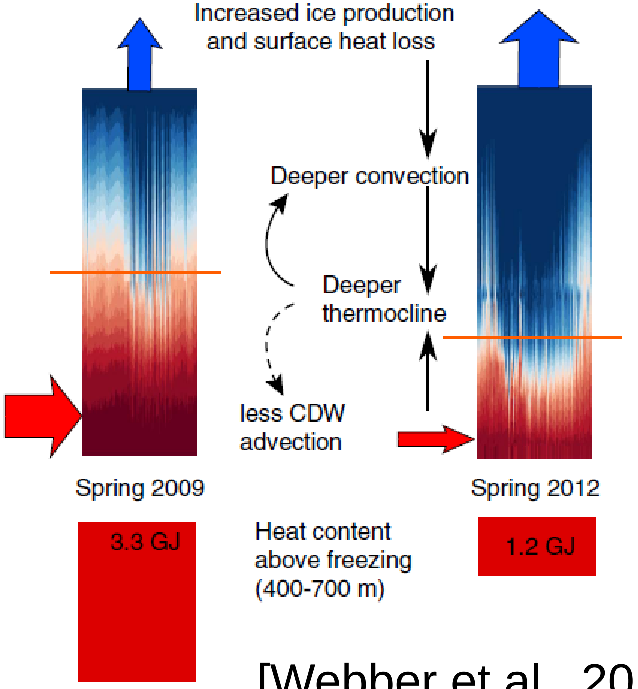
INTERNATIONAL THWAITES GLACIER COLLABORATION

LIONESS -Antarctica- THWAITES GLACIER

Dynamics for heat supply to the sub-ice shelf

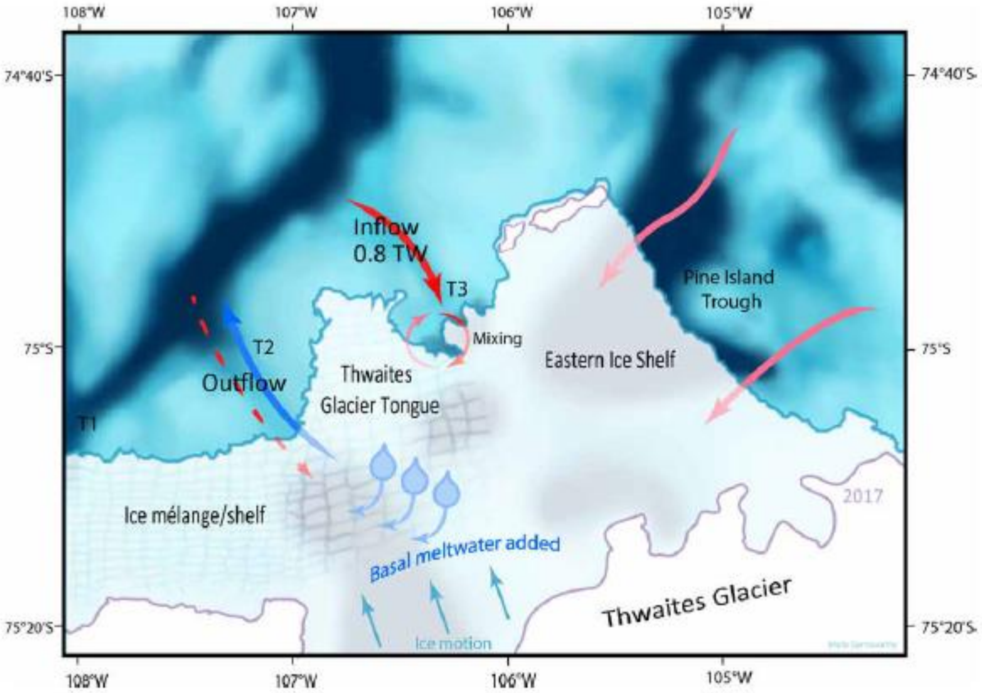


[Dutrieux et al., 2014]

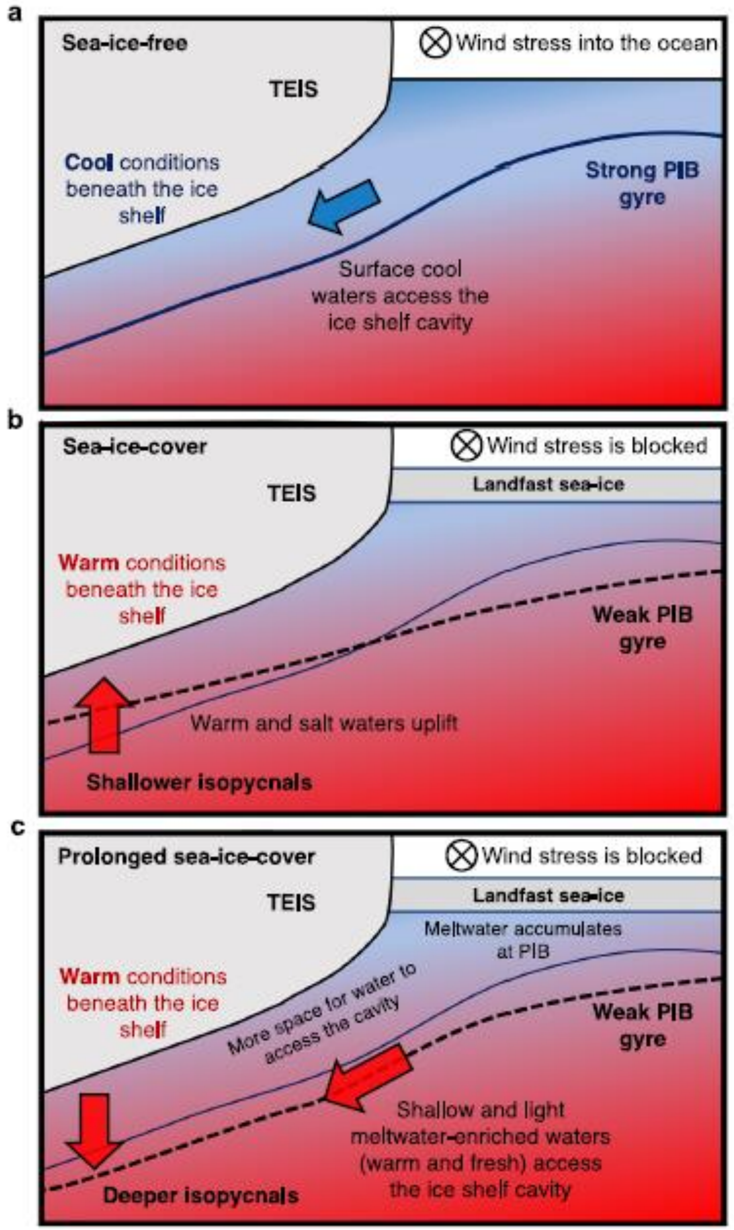


[Webber et al., 2017]

[Wahlin et al., 2021]



[Dotto et al., 2022]



Meltwater influence from other ice shelves

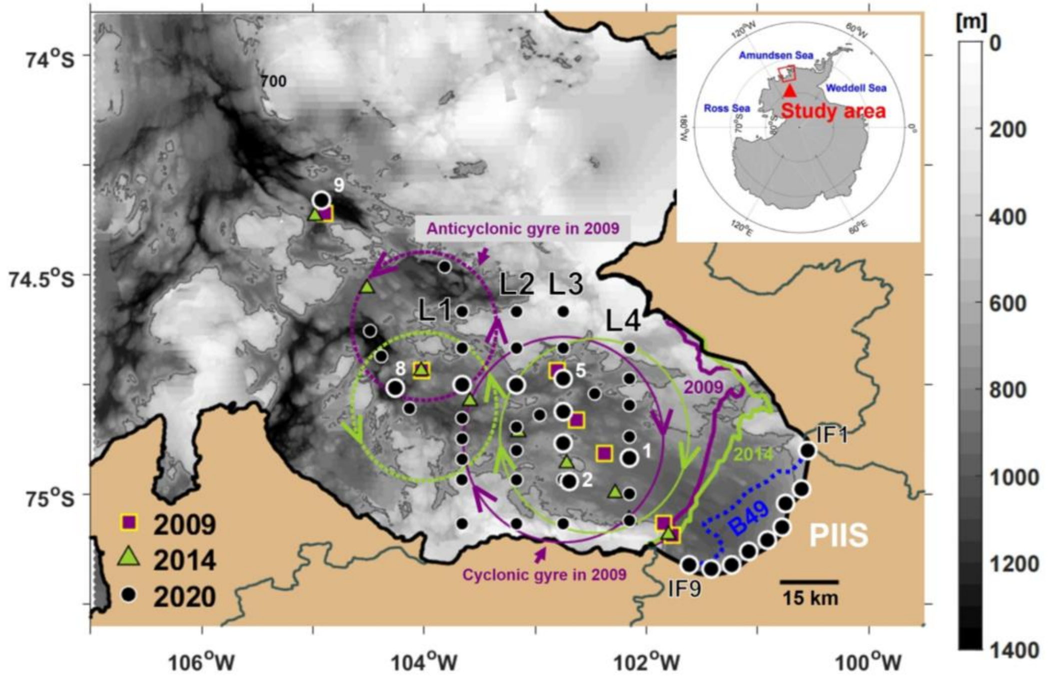
nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-022-27968-8 OPEN

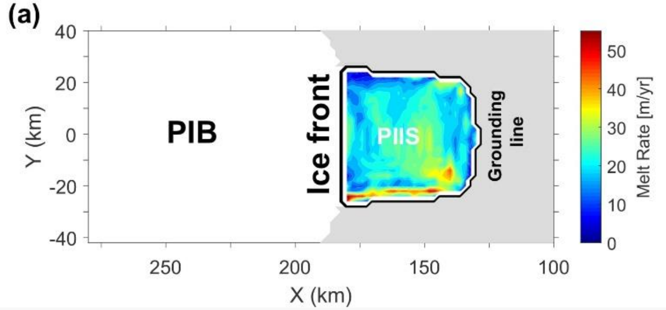
Ice front retreat reconfigures meltwater-driven gyres modulating ocean heat delivery to an Antarctic ice shelf

Seung-Tae Yoon[1], Won Sang Lee[2✉], SungHyun Nam[3✉], Choon-Ki Lee[2], Sukyoung Yun[2], Karen Heywood[4], Lars Boehme[5], Yixi Zheng[4], Inhee Lee[6], Yeon Choi[3], Adrian Jenkins[7], Emilia Kyung Jin[2], Robert Larter[8], Julia Wellner[9], Pierre Dutrieux[8] & Alexander T. Bradley[8]

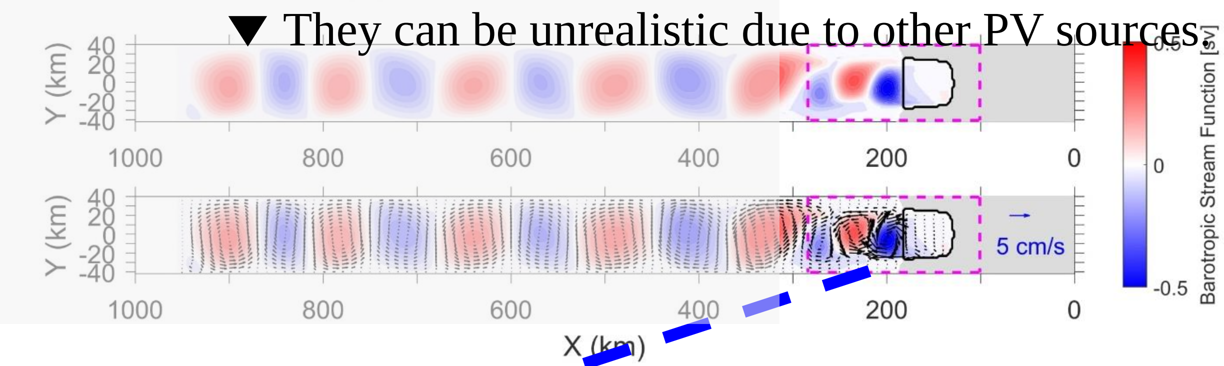


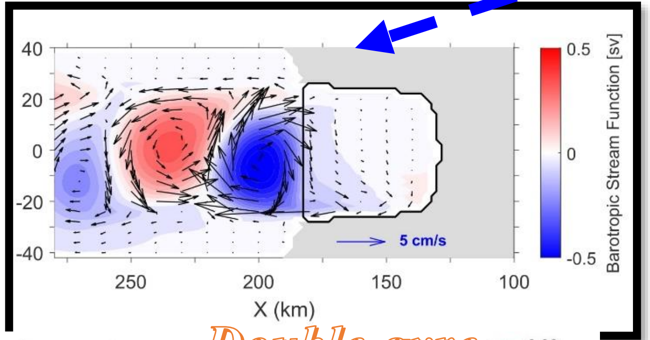
MITgcm (only melting)

[Yoon et al., 2022]

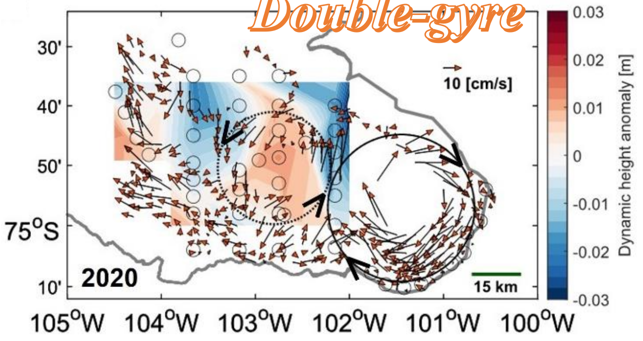


▼ They can be unrealistic due to other PV sources

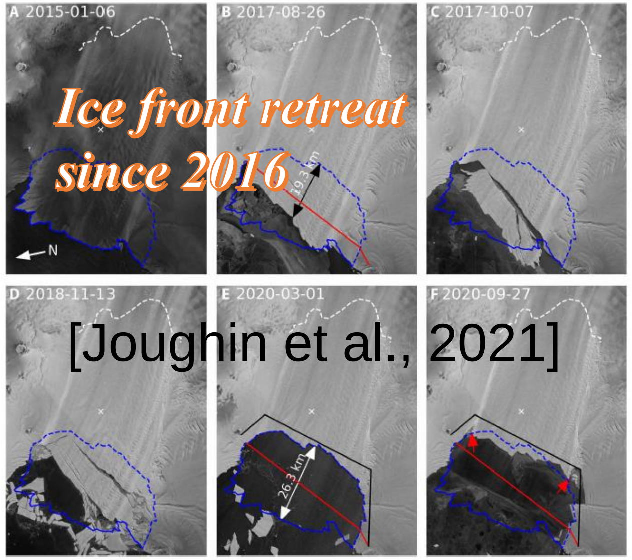




Double-gyre

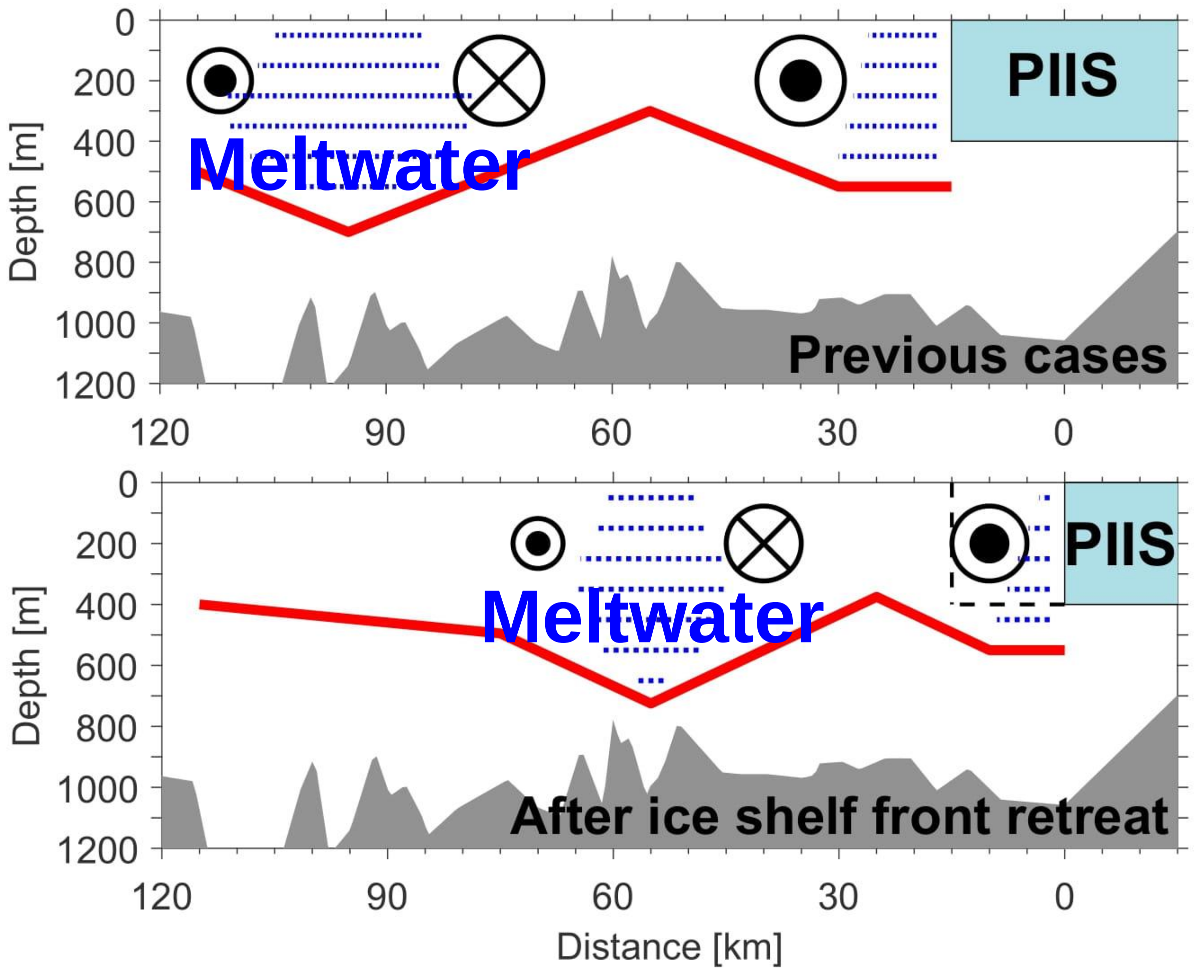


Ice front retreat since 2016



[Joughin et al., 2021]

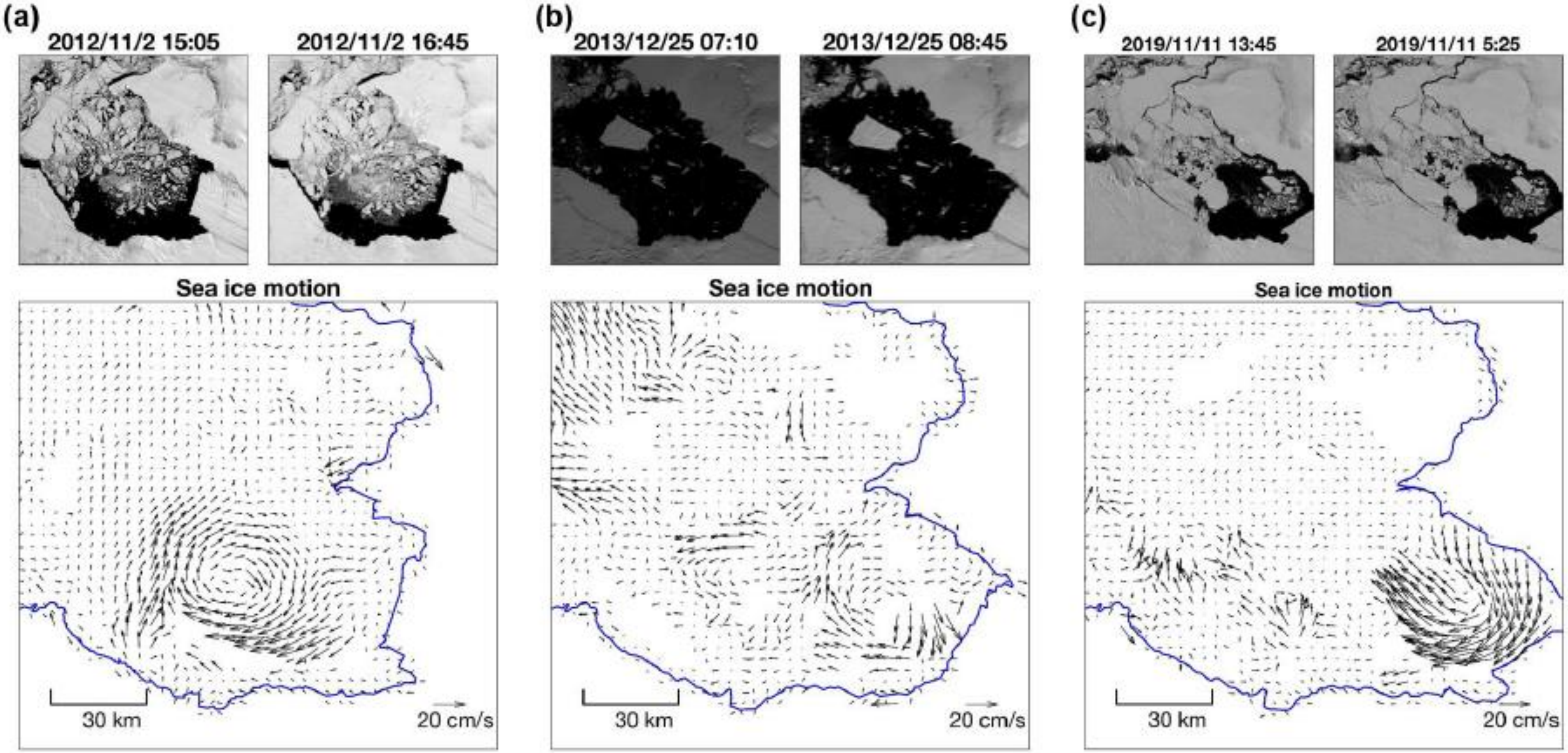
Meltwater feedback



[Yoon et al., 2022]

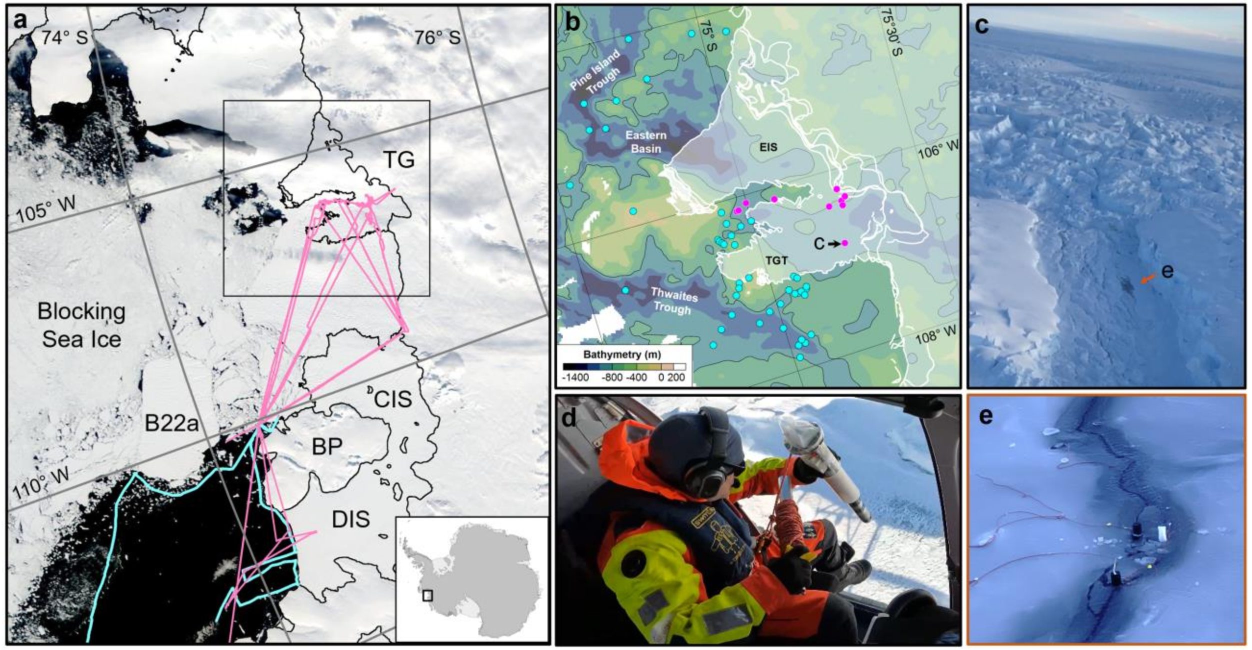
- A feedback loop is suggested as follows,

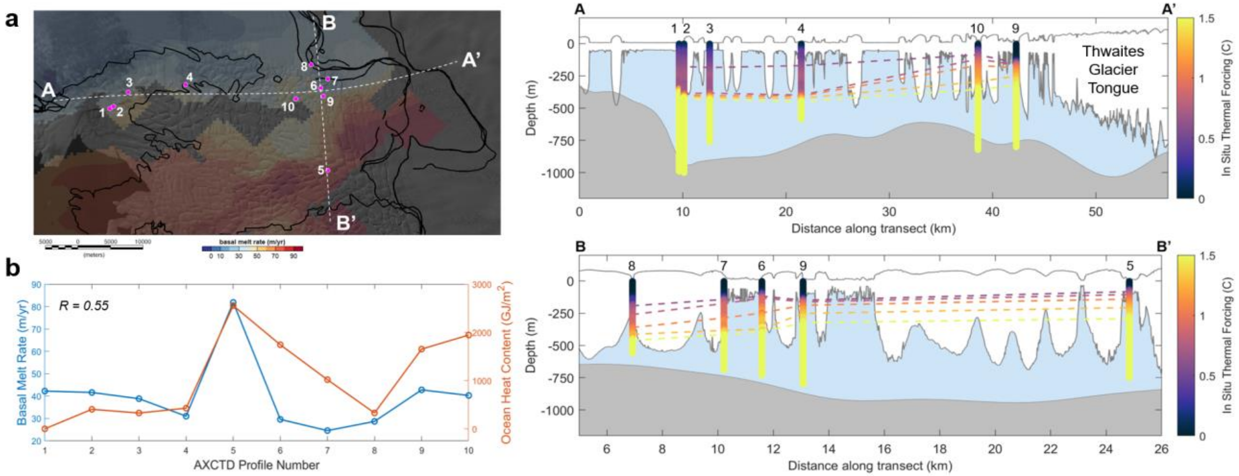
(i) increase in PIIS melting
caused
(ii) an increase in meltwater outflow
(iii) strengthening the anticyclonic gyre and increasing the meltwater accumulation within the gyre
(iv) decreasing the available OHC delivered towards PIIS by a deeper convex downward thermocline depth
(v) resulting in a reduction in the PIIS melt rate



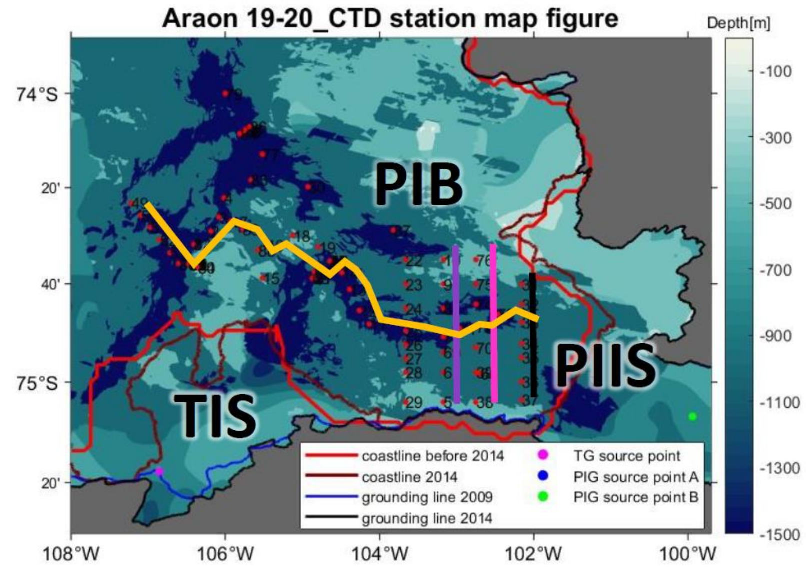
Supplementary Fig. 2. Sea ice motion derived from sea ice images (YYYY/MM/DD HH:MM). (a) Sea ice motion derived from MODIS imagery on 2 November 2012. **(b)** Same as in **(a)** but for 25 December 2013. **(c)** Same as in **(a)** but for 11 and 12 November 2019.

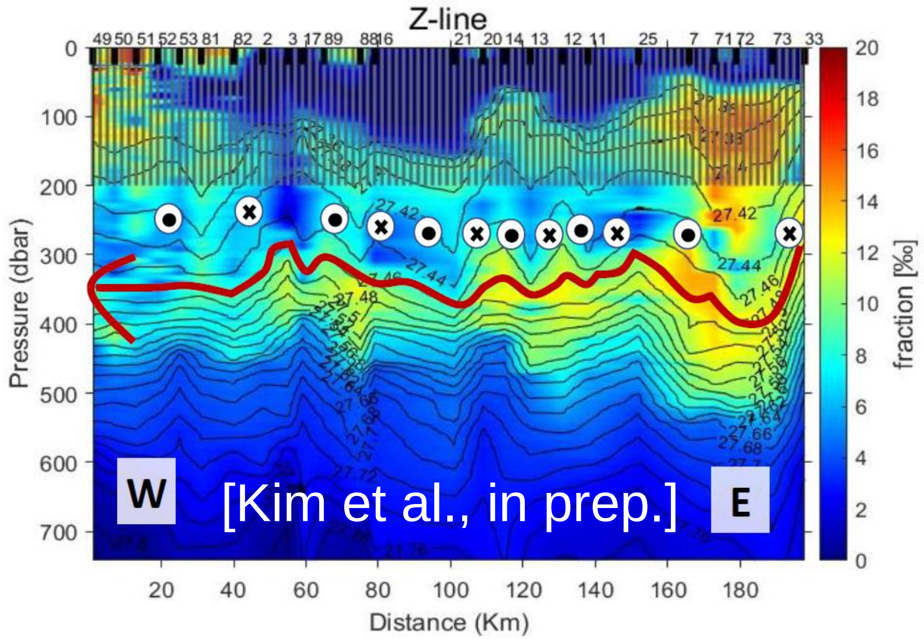
Meltwater distribution





[Greenbaum et al., in prep.]

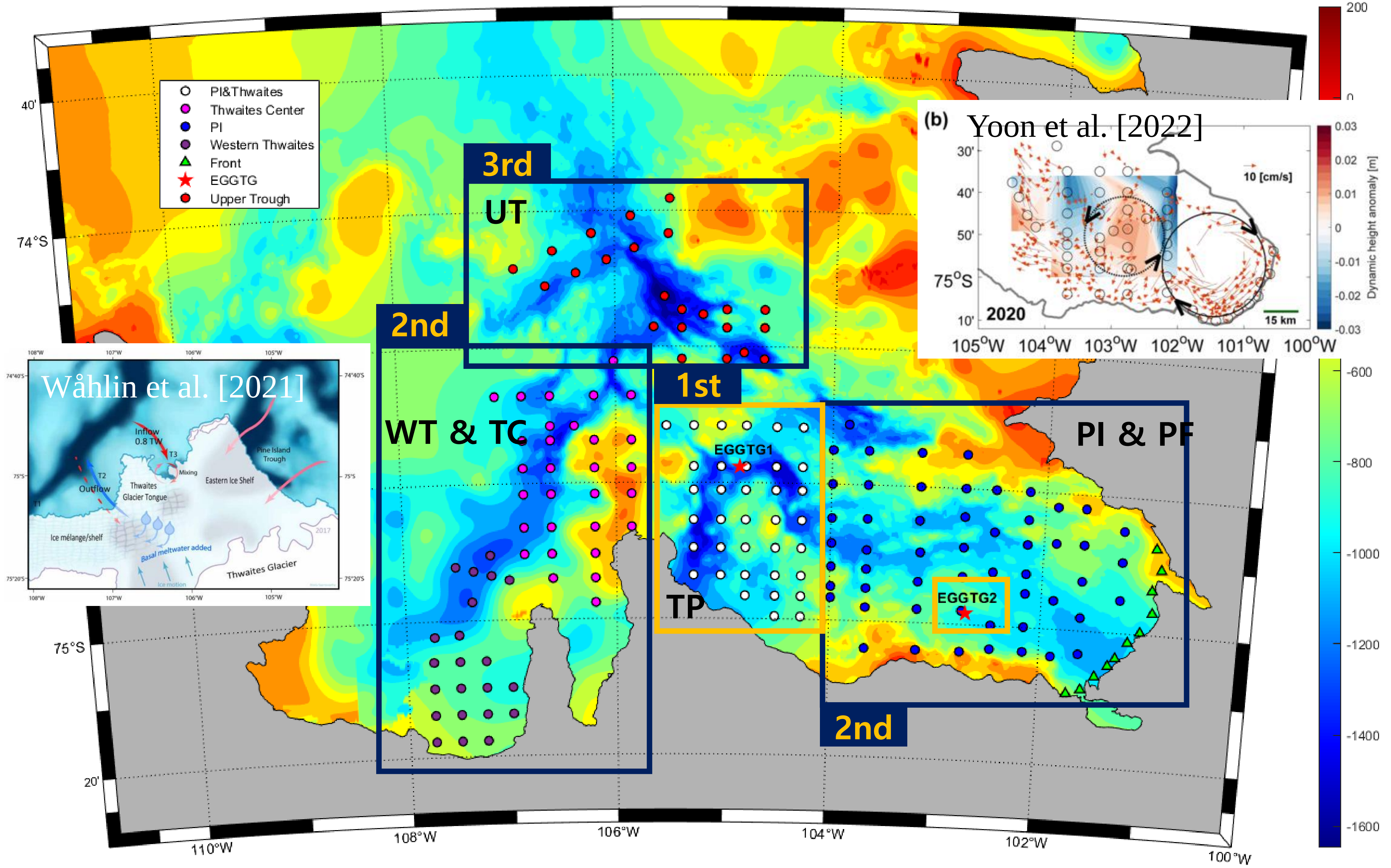




[Kim et al., in prep.]

AXCTD observation under sea ice

Upcoming season's observation plan - CTD

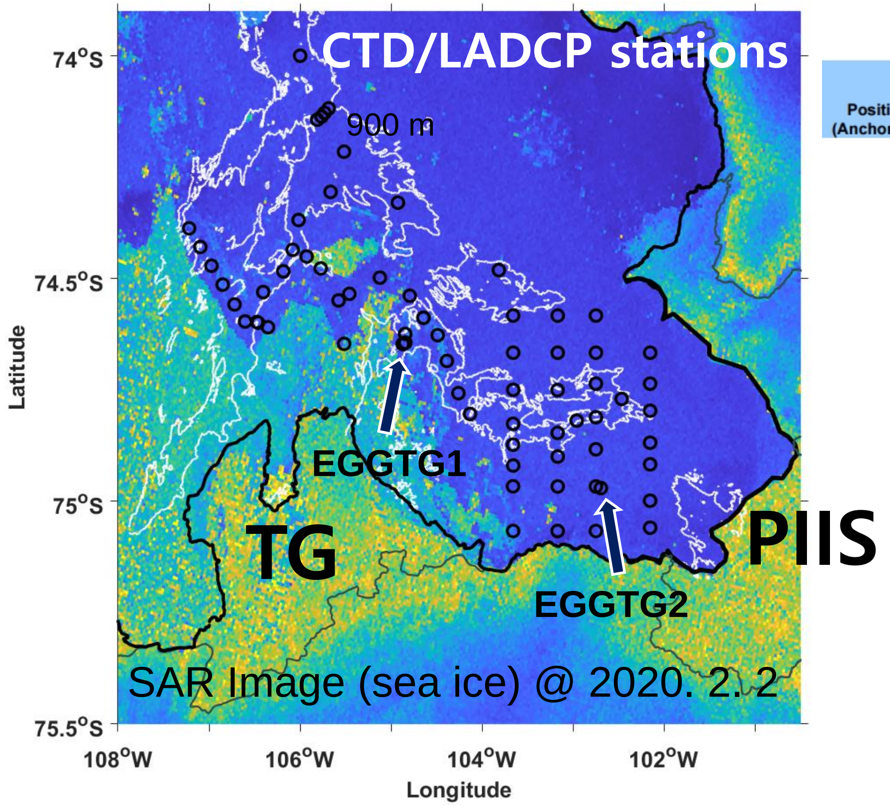


1st (TP lines):
PIIS influence on TG

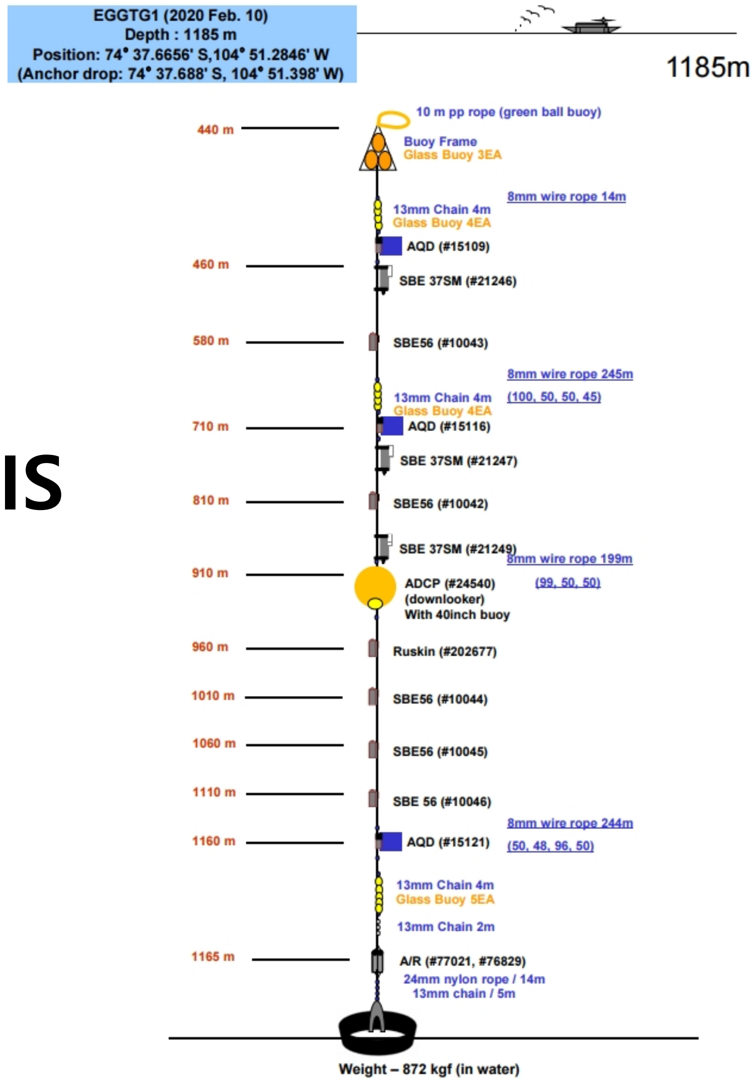
2nd (WT, TC, PI, PF lines):
PIB & TG

3rd (UT lines):
PITT (Pine Island – Thwaites Trough)

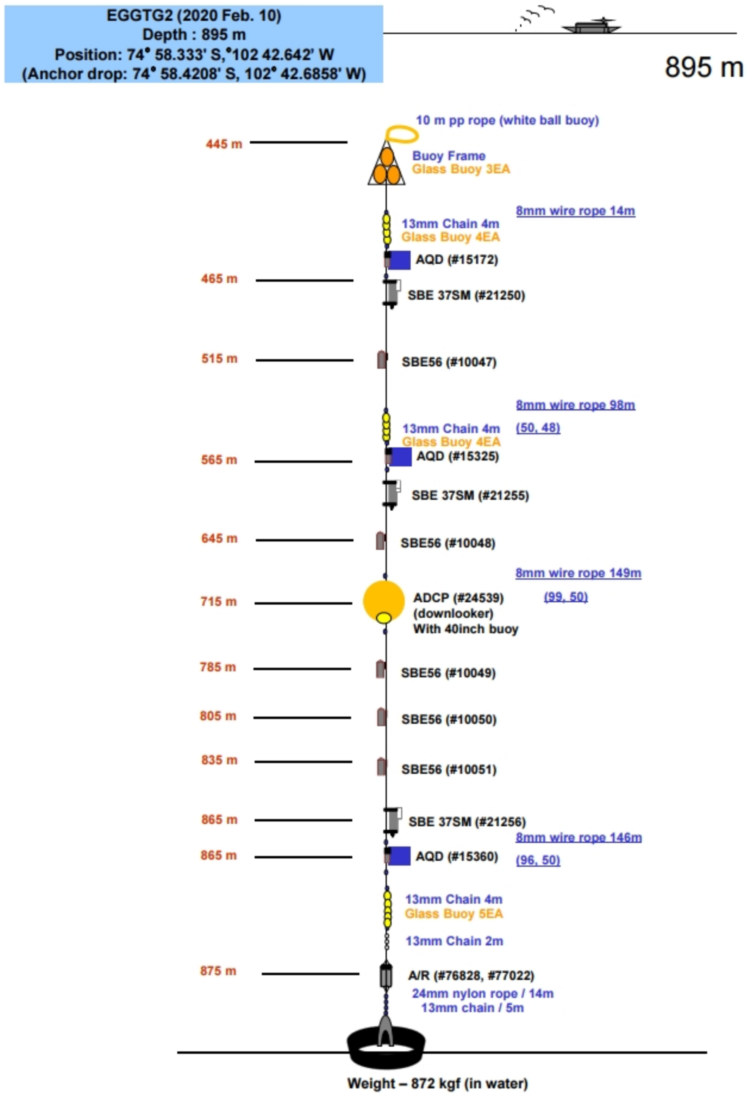
Upcoming season's observation plan - Mooring (plan A)



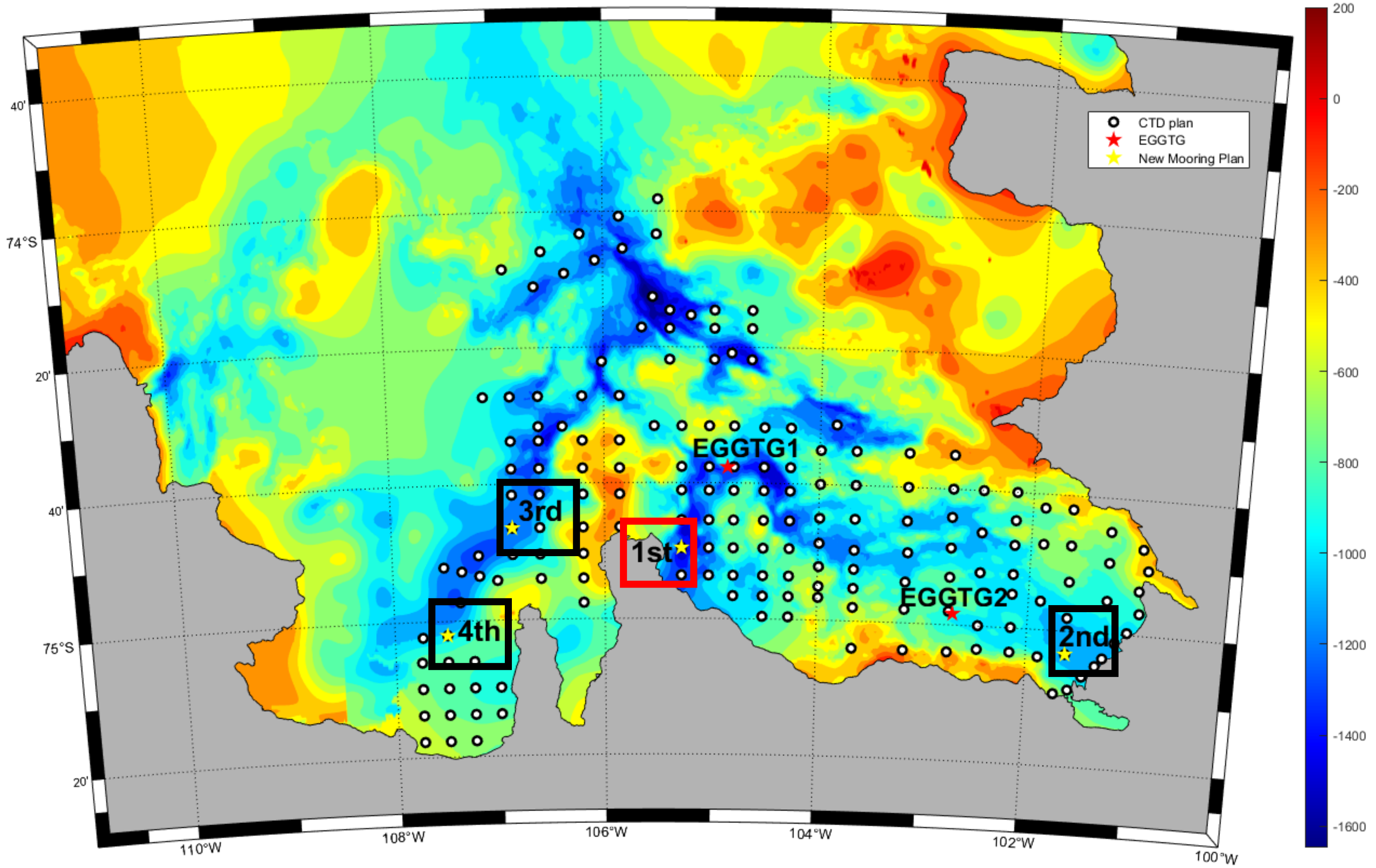
▼PIIS influence on TG

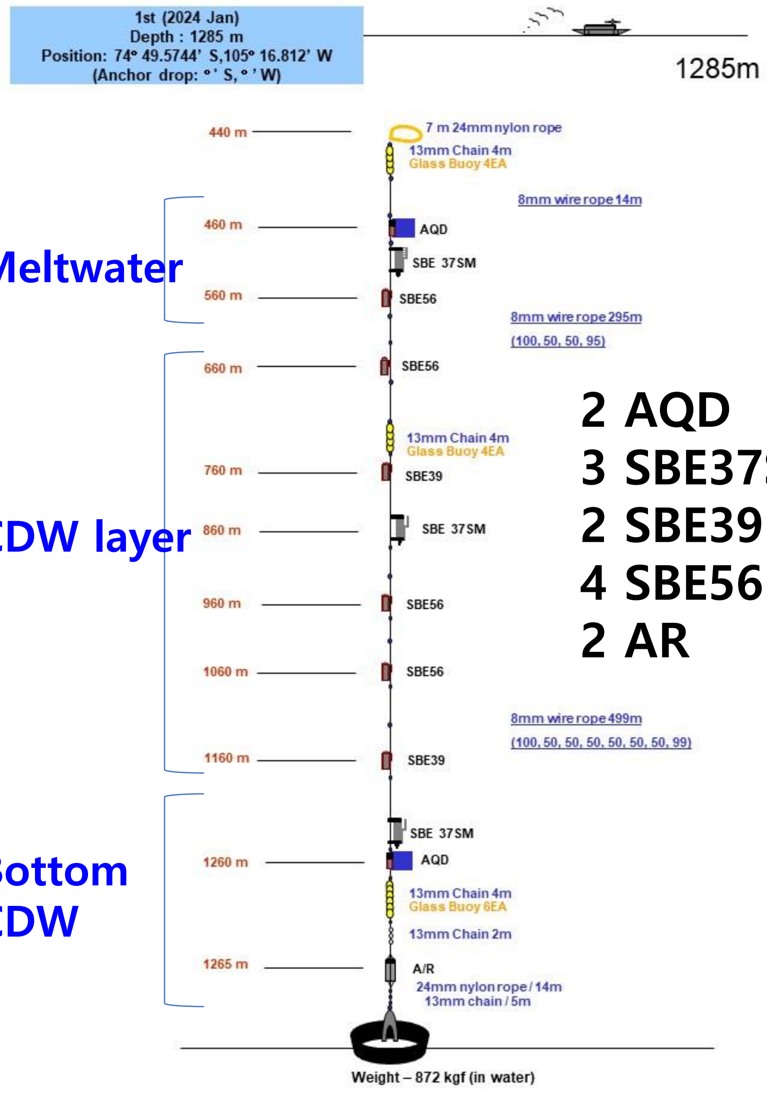


▼ PIB circulation & CDW



Upcoming season's observation plan - Mooring (plan B)





Meltwater

CDW layer

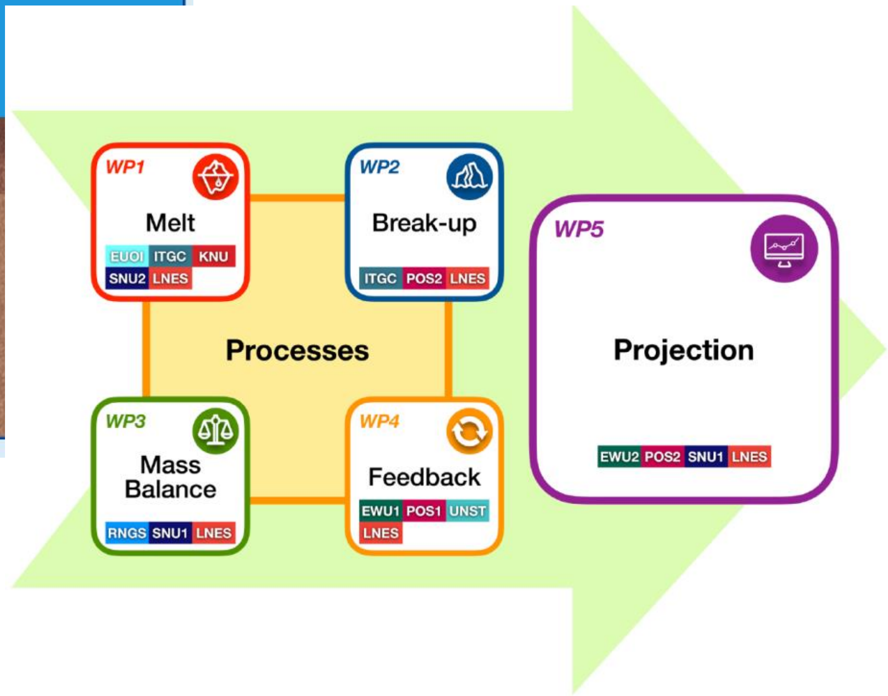
Bottom CDW

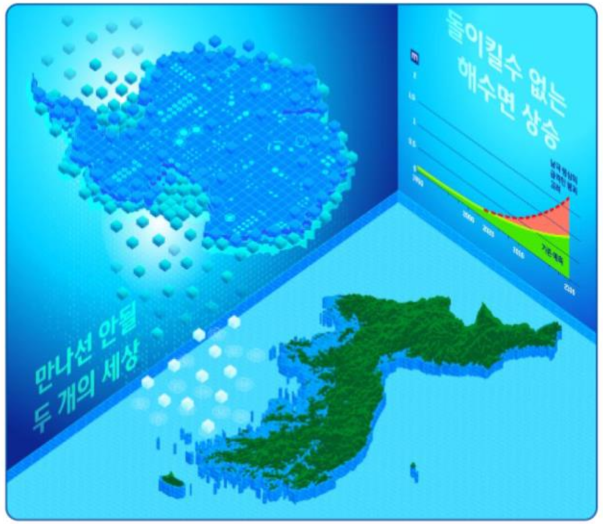
2 AQD
3 SBE37SM
2 SBE39
4 SBE56
2 AR

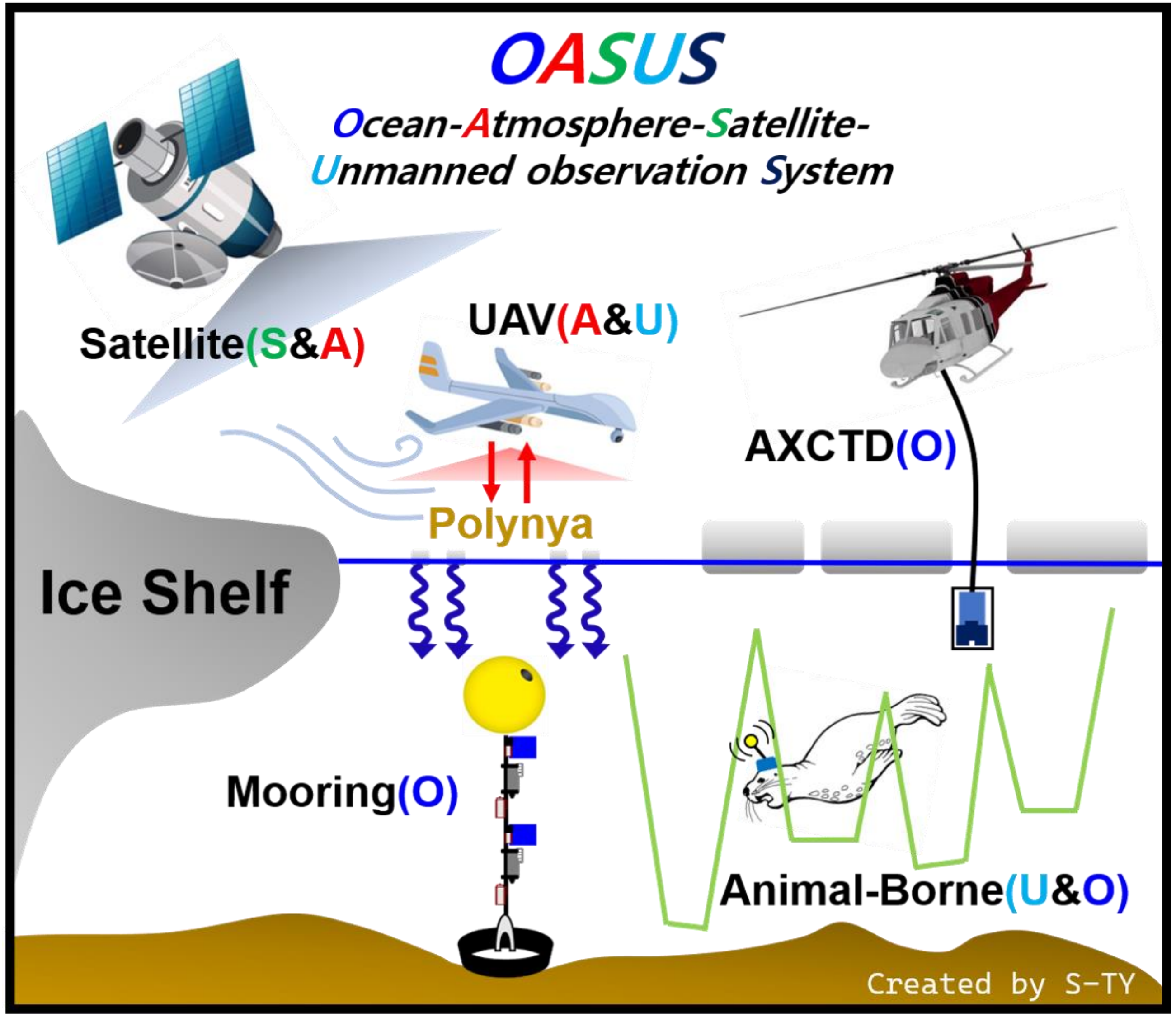
5. Future plan

"Korea Network for Observation and prediction of ice sheet and sea level changes in a Warming world (K-NOW)"

2023 – 2031

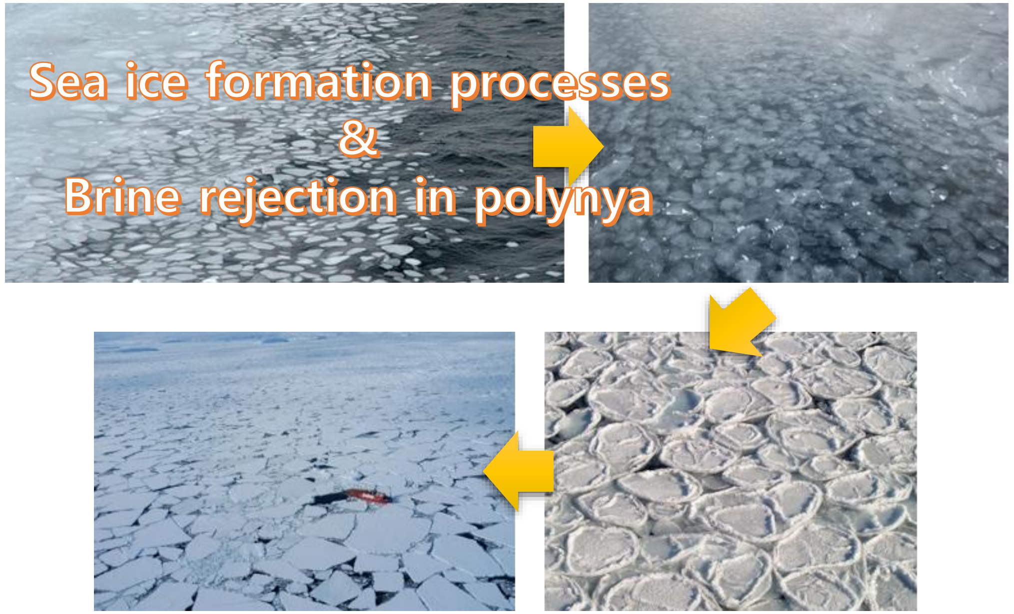






"Development of Polynya Research Technology based on OASUS"

2025 (?) ~



Hope a further cooperation with NOAA !!

Thank you for listening :)

Acknowledgement

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