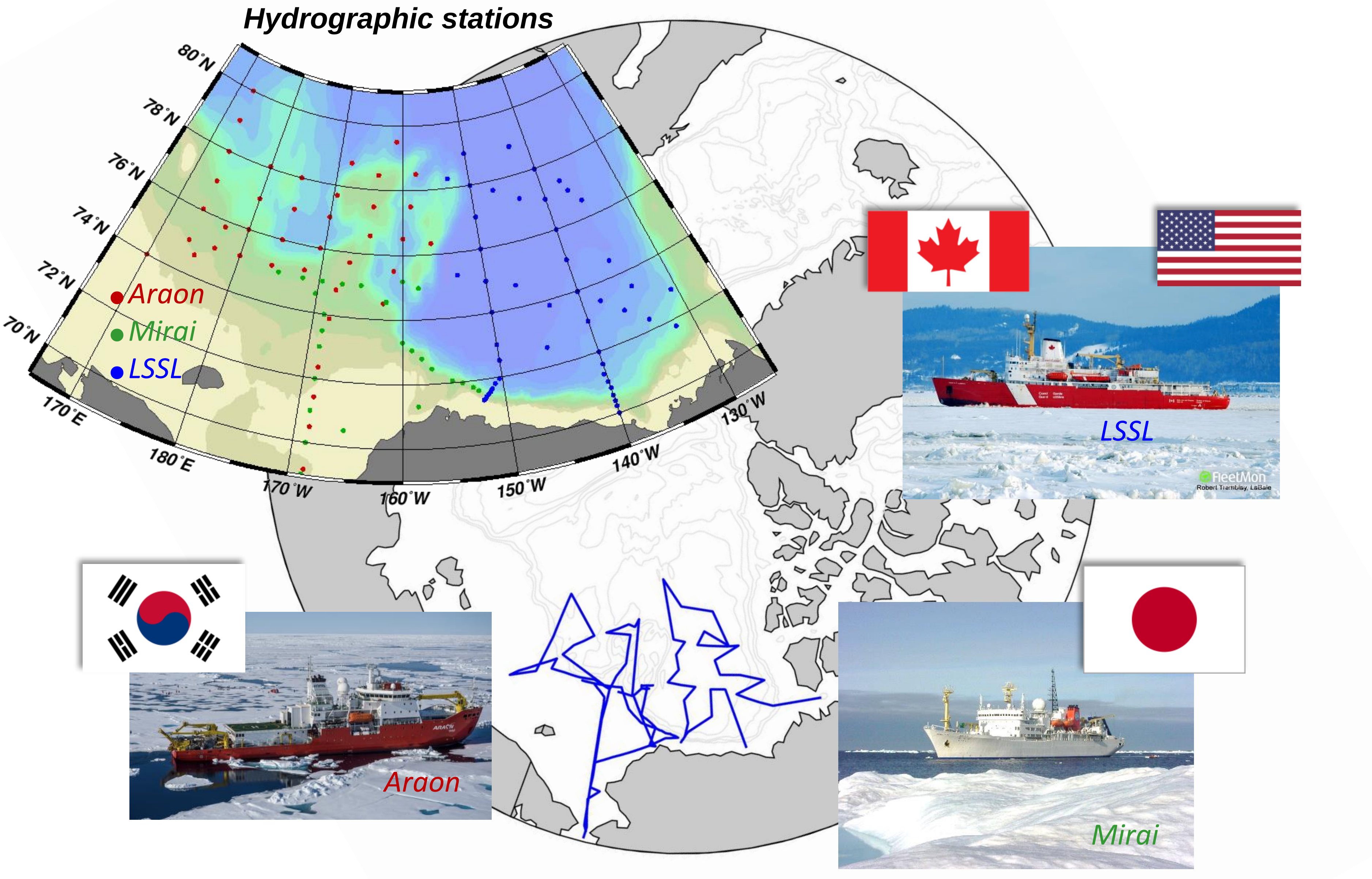
Synoptic Arctic Survey

International SAS Synthesis Workshop
7–9 June 2023
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts, USA

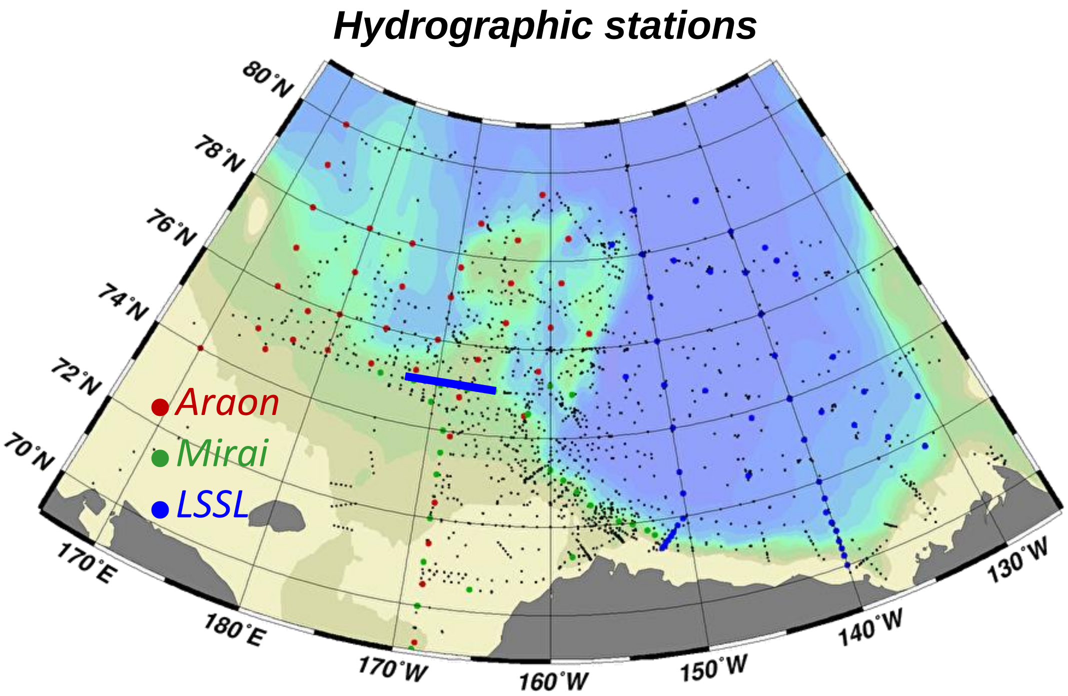
Beaufort Gyre shrinkage and Atlantification induced an anomalous biogeochamical event in the western Arctic Ocean

Shigeto Nishino, Jinyoung Jung, Kyoung-Ho Cho, William J. Williams, Amane Fujiwara, Akihiko Murata, Motoyo Itoh, Eiji Watanabe, Michio Aoyama, Michiyo Yamamoto-Kawai, Takashi Kikuchi, Eun Jin Yang, Sung-Ho Kang

SAS collaborative cruises in 2020
by Korea, Japan, and Canada/US

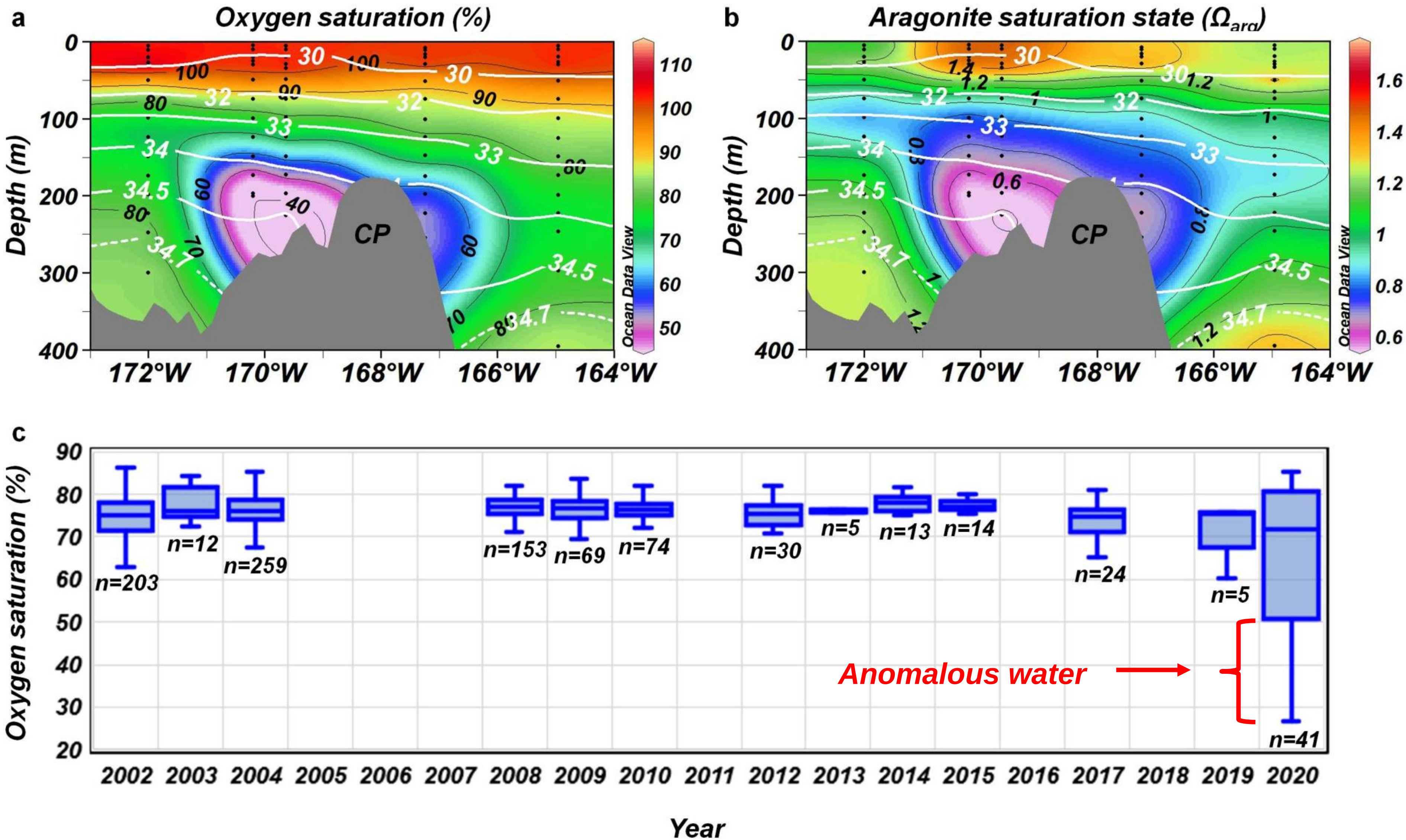


Data collected between 2002 and 2020



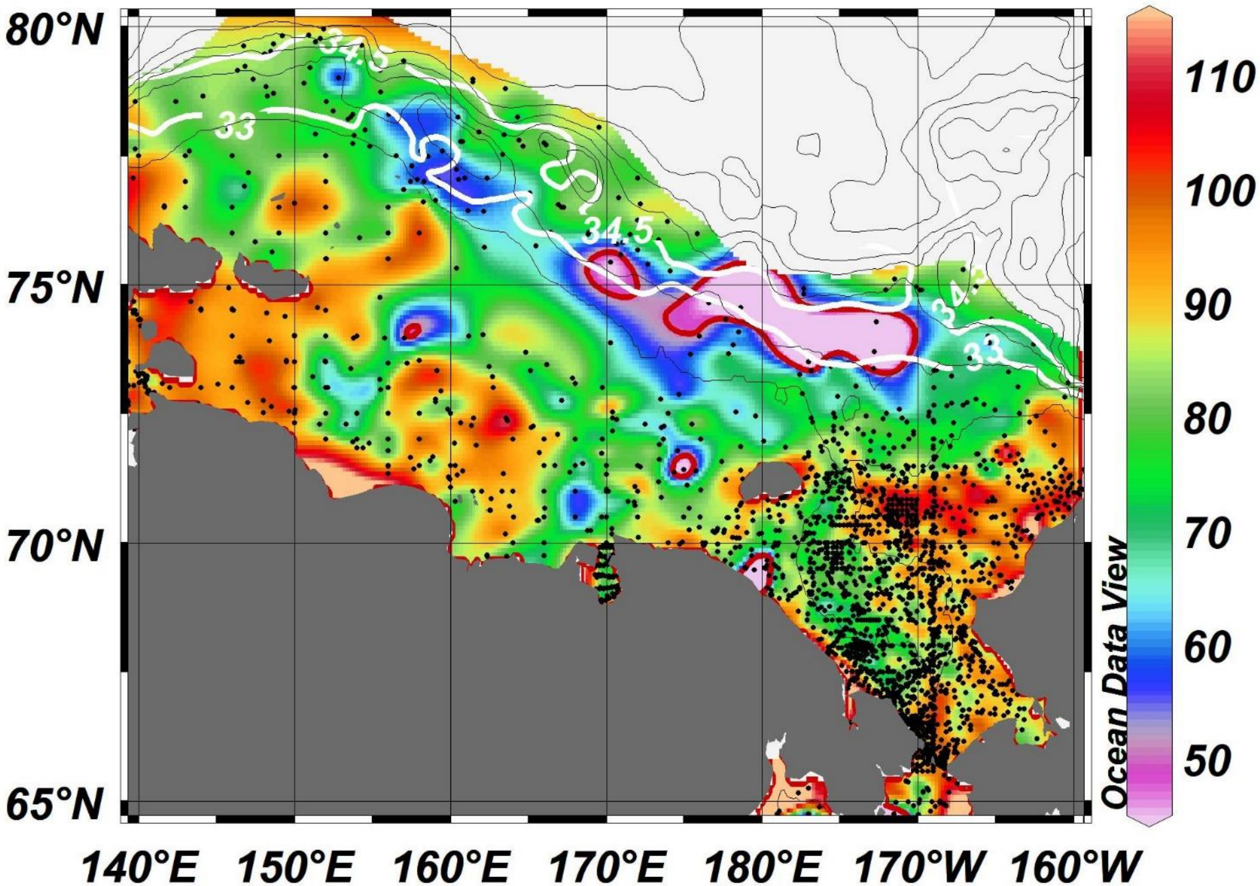
Expeditions	Data sites
Araon 2020	https://kpdc.kopri.re.kr/search/694ee19e-1c0b-4a44-8fd6-e83c94992731
Mirai 2002-2020	http://www.godac.jamstec.go.jp/darwin/e
BGEP 2003-2020	https://www2.whoi.edu/site/beaufortgyre/data/ctd-and-geochemistry/
CBL 2002	http://psc.apl.washington.edu/HLD/CBL/CBL.html
ISSS 2008	https://cchdo.ucsd.edu/cruise/90JS20080815

Low Oxy and highly acidified water on the Chukchi Plateau



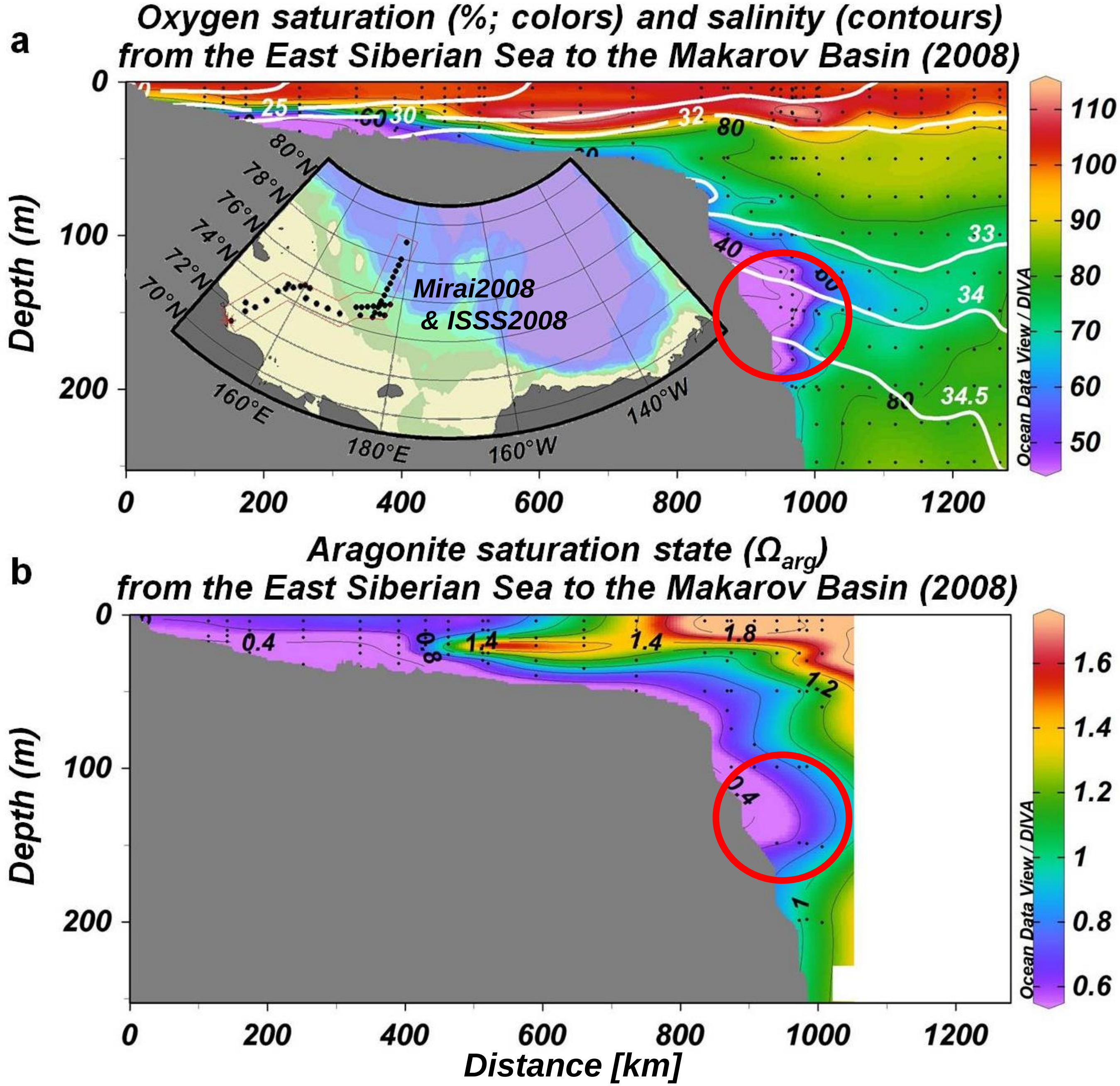
Possible origin of the low Oxy and highly acidified water

Bottom oxygen saturation (%)



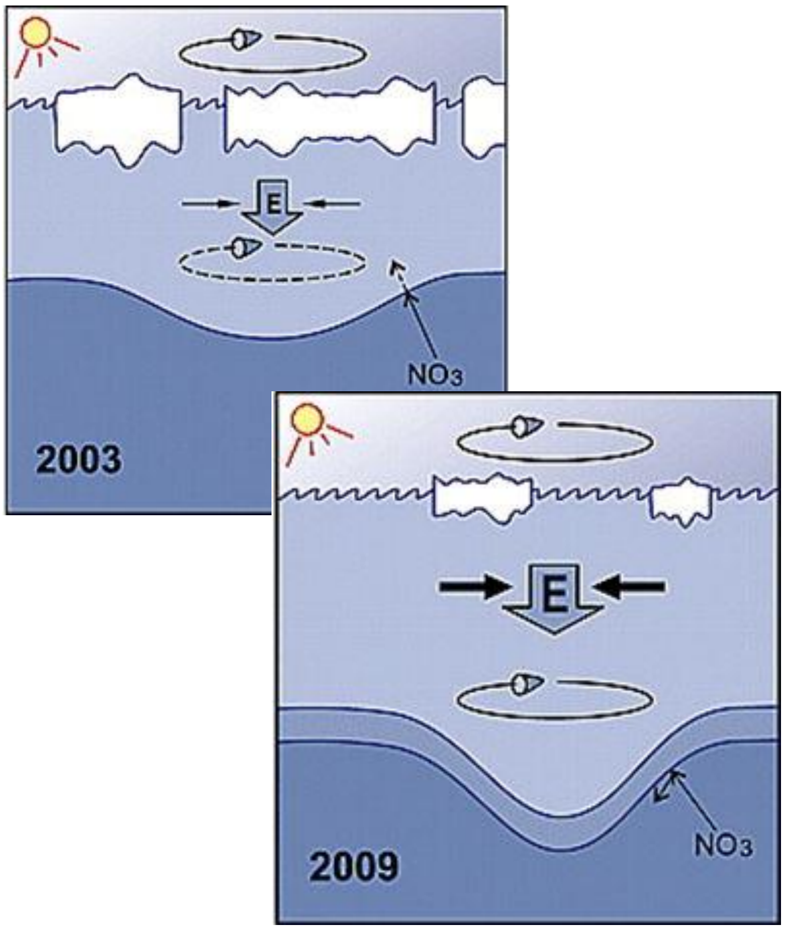
Hydrochemical Atlas of the Arctic Ocean

Possible origin of the low Oxy and highly acidified water



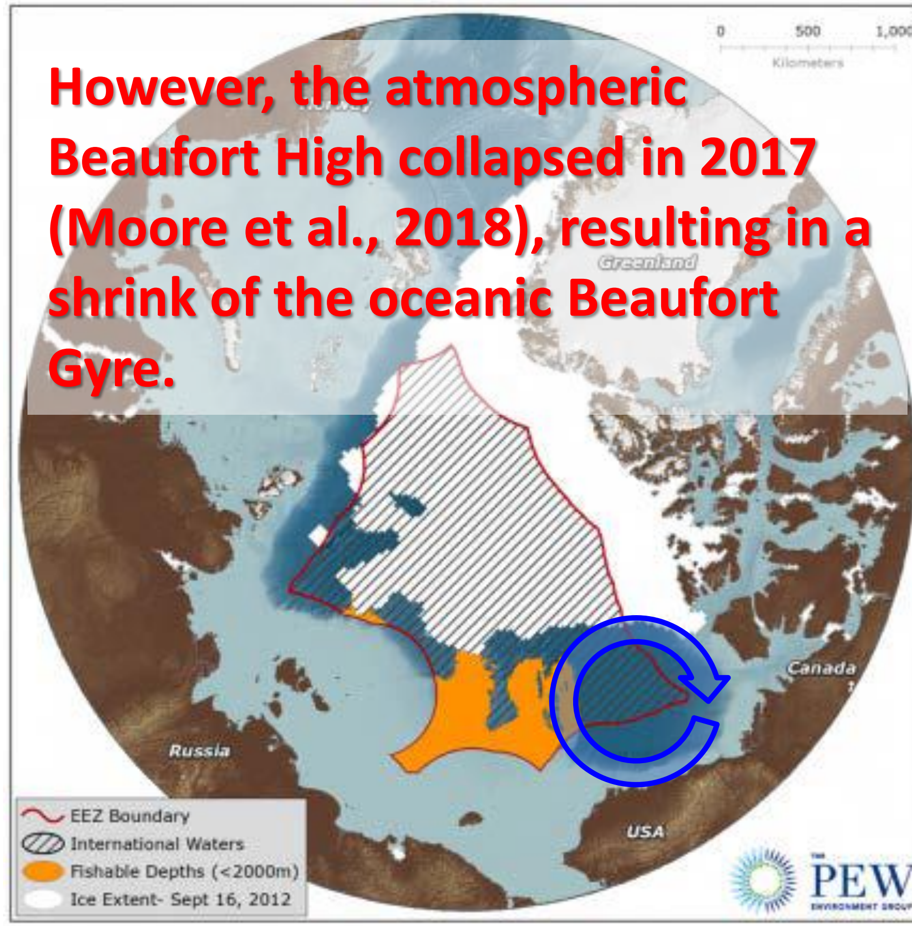
Enhancement of the Beaufort Gyre due to the sea-ice loss

The Beaufort Gyre has recently become enhanced because the melting of thick, solid multiyear ice has produced fragmented and mobile sea ice, which allows the wind to more efficiently drive the ocean circulation.

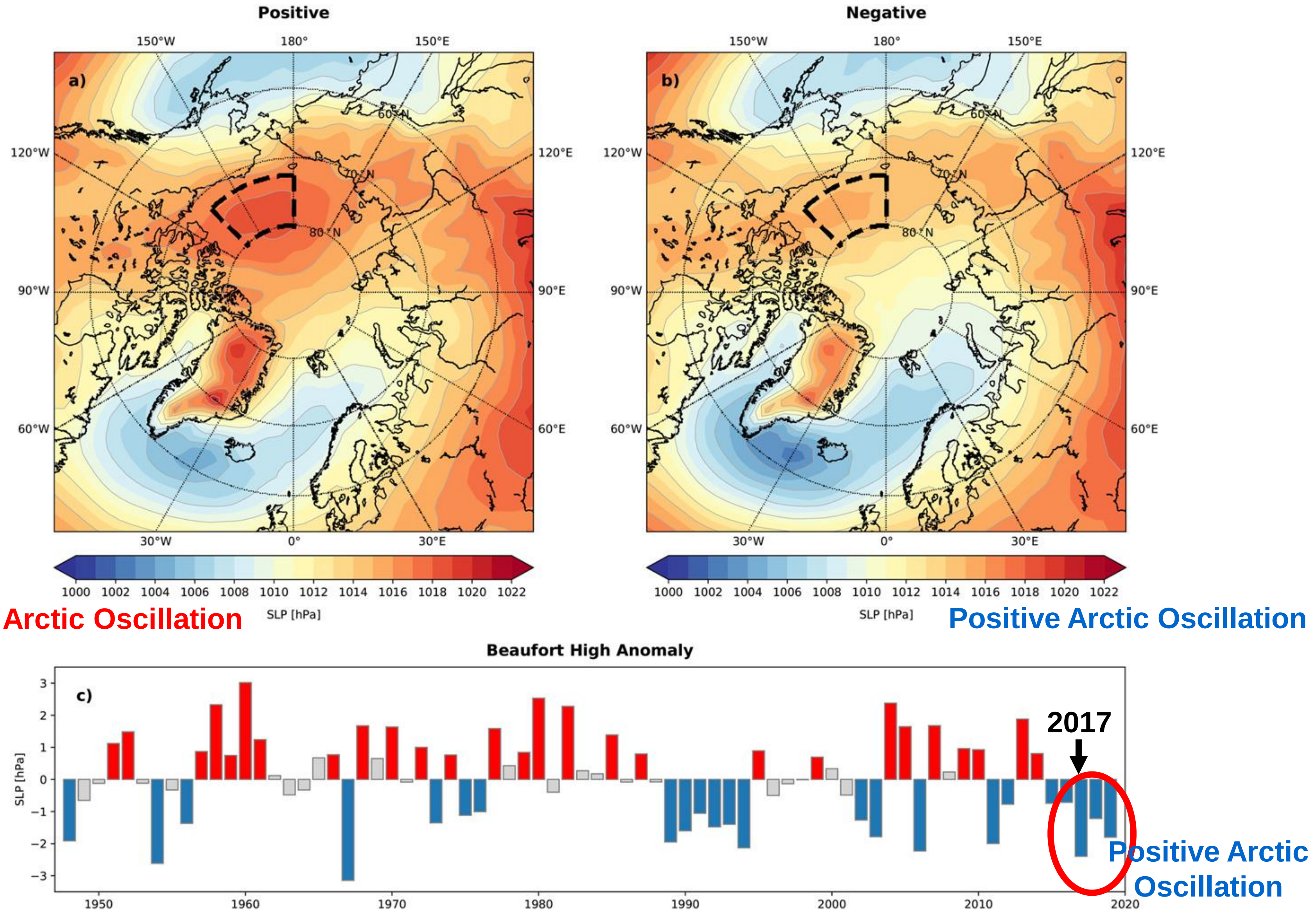


[McLaughlin and Carmack, 2010]

However, the atmospheric Beaufort High collapsed in 2017 (Moore et al., 2018), resulting in a shrink of the oceanic Beaufort Gyre.



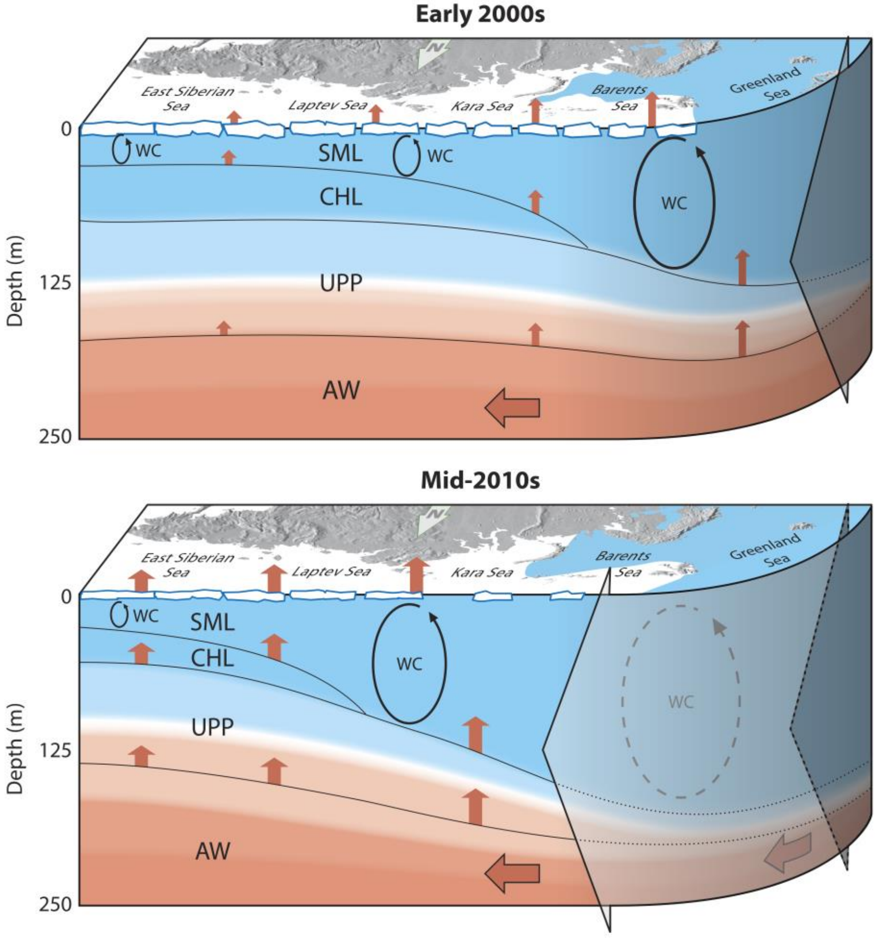
Increased cyclone activity and an accompanying weakening of the Beaufort High were also observed after the mid-2010s

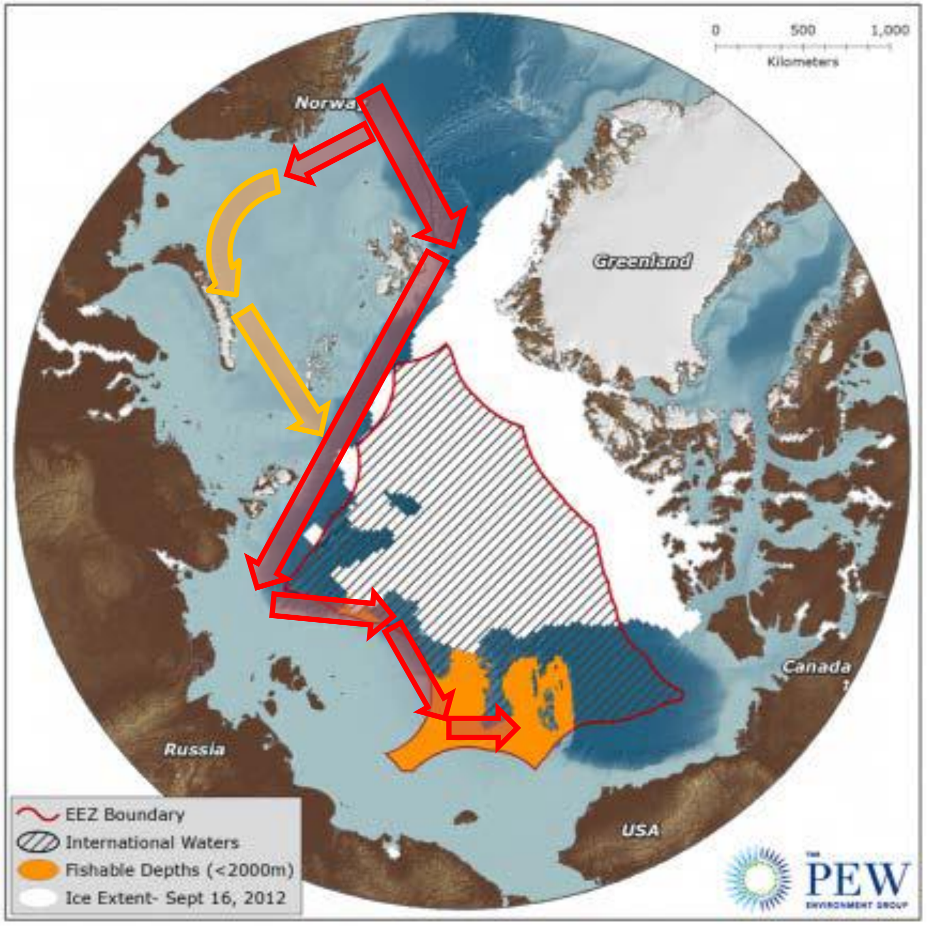


[Kenigson and Timmermans, 2021]

Atlantification

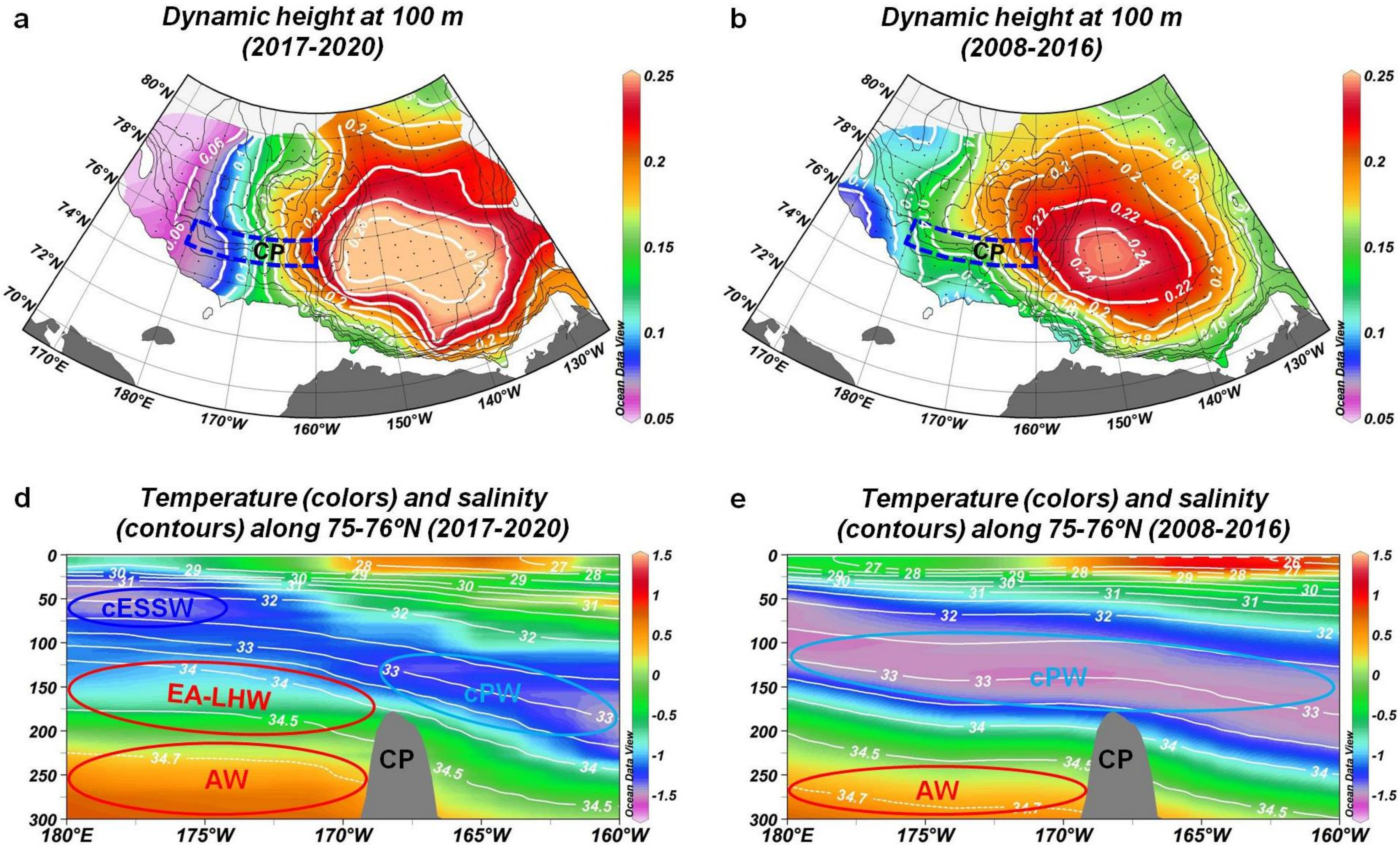
Atlantification accompanies salinification, shoaling of the AW layer, weakening of the ocean stratification, uplifts of nutrient-rich water, and a possible increase in phytoplankton biomass.





[Polyakov *et al*., 2017]

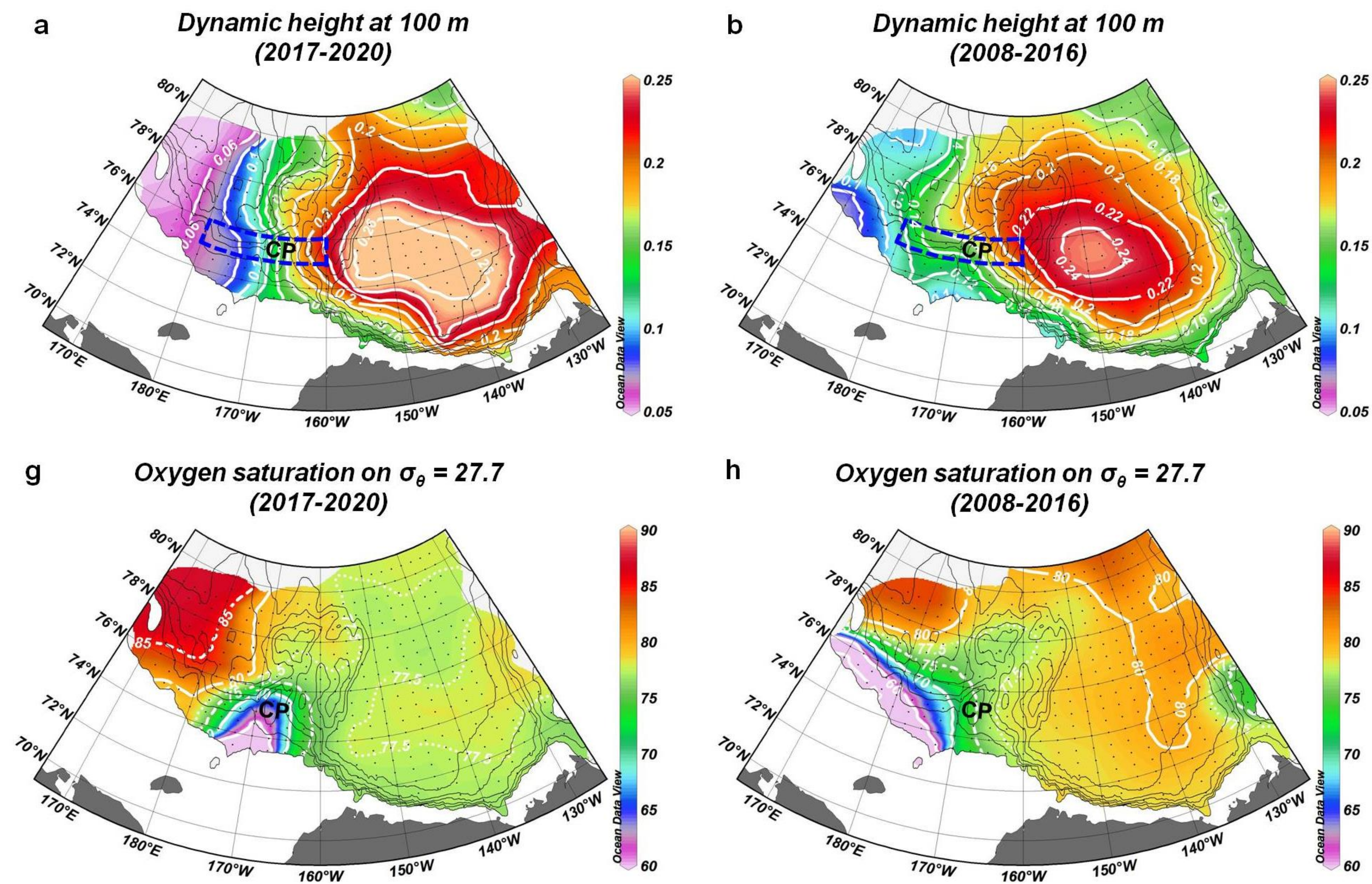
Beaufort Gyre extent and Atlantification determine Oxy distribution



- *cPW and EA-LHW/AW encountered over CP*
- *A frontal structure appeared over CP*
- *A frontal northward flow was formed along CP*

- *cPW overshot CP toward the west*
- *A frontal structure disappeared from CP*
- *A frontal northward flow was not formed*

Beaufort Gyre extent and Atlantification determine Oxy distribution



- *Low Oxy water was washed by high Oxy EA-LHW*
- *A frontal northward flow carried the low Oxy water toward the north along CP*
- *Low Oxy water occupied outside BG (shadow zone)*
- *Low Oxy water was not ventilated by cPW and EA-LHW*

Pan-Arctic Sea Ice-Ocean Model

[COCO]

Center for Climate System Research Ocean Component Model version 4.9

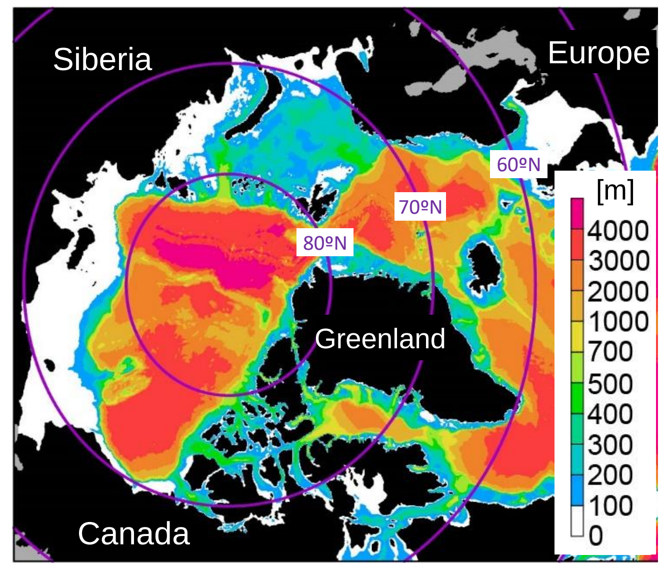
Sea Ice Part
- 1 layer thermodynamics [Lipscomb et al., 2001]
- EVP rheology [Hunke and Duckwicz, 1997]
- 7 thickness category [Bitz et al., 2001]

Ocean Part
- free surface general circulation model
- UTOPIA/QUICKEST advection scheme
- turbulence closure scheme [Noh and Kim, 1999]

(for eddy-resolving configuration)
- Smagorinsky harmonic viscosity [Griffies, 2000]
- Enstrophy preserving scheme [Ishizaki and Motoi, 2001]

Model Bathymetry

Bering Strait



Experimental Design
- NCEP/CFSR atmospheric daily forcing
- AOMIP river water discharge
- Pacific water inflow at Bering Strait
- Sponge layer in Atlantic side
- Passive tracer (ESS shelf-slope)

EARTH SIMULATOR

Spin up exp. 1979 forcing — 10 yrs

Decadal exp. 1979 – 2001 — 22 yrs

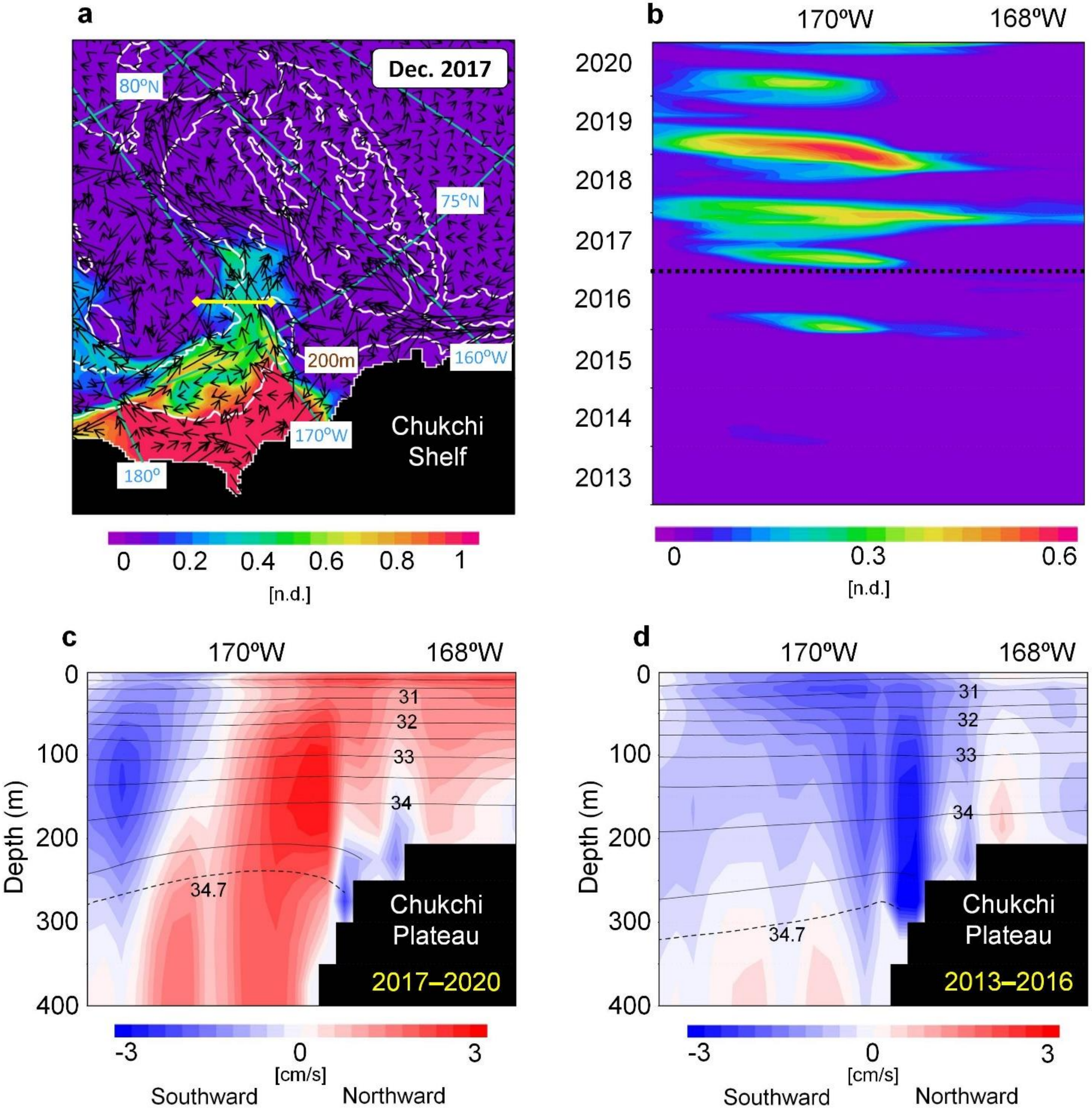
25 km — 280 x 200 x 28 grids

Interannual exp. 2001 – 2020 — 20 yrs

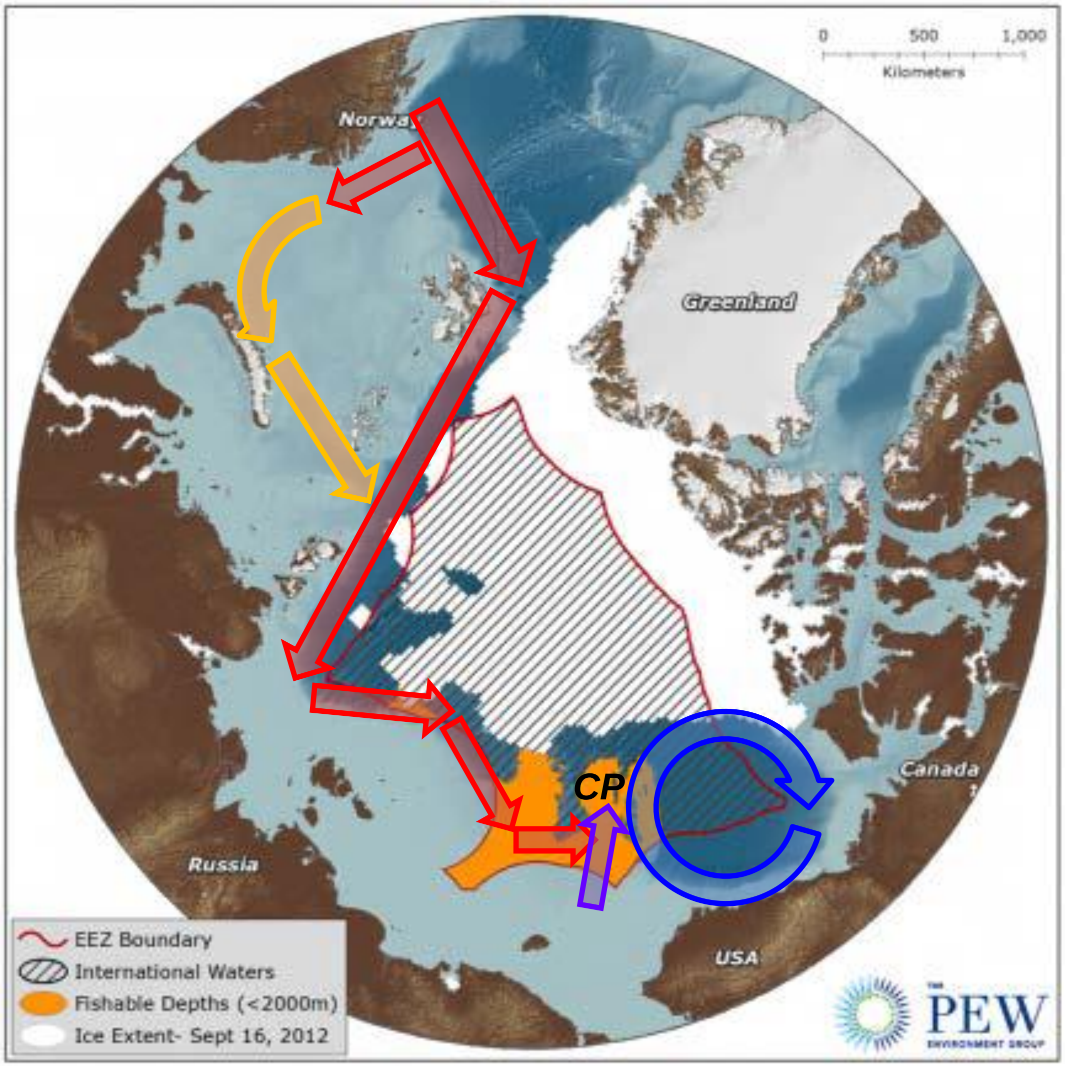
5 km — 1280 x 1024 x 42 grids

[Watanabe et al., 2022]

Simulated ocean velocity and tracer distributions



Shrink of a gyre in the Pacific Arctic and Atlantification open a door of low Oxy water spreading from the ESS shelf slope to the CP



- In the future, the bottom oxygen uptake rate in the ESS might increase due to increased organic matter inputs from rivers, coastal erosion, and biological production, resulting in the formation of the low Oxy water more quickly and widely.
- Moreover, the appearance of the frontal northward flow along the Chukchi Plateau might increase with the sea-ice reduction.
- Consequently, the anomalous event of low oxygen and acidification on the Chukchi Plateau could occur more frequently in the future. It may further impact the marine ecosystem around the plateau.

Two important cod species in Arctic marine food webs

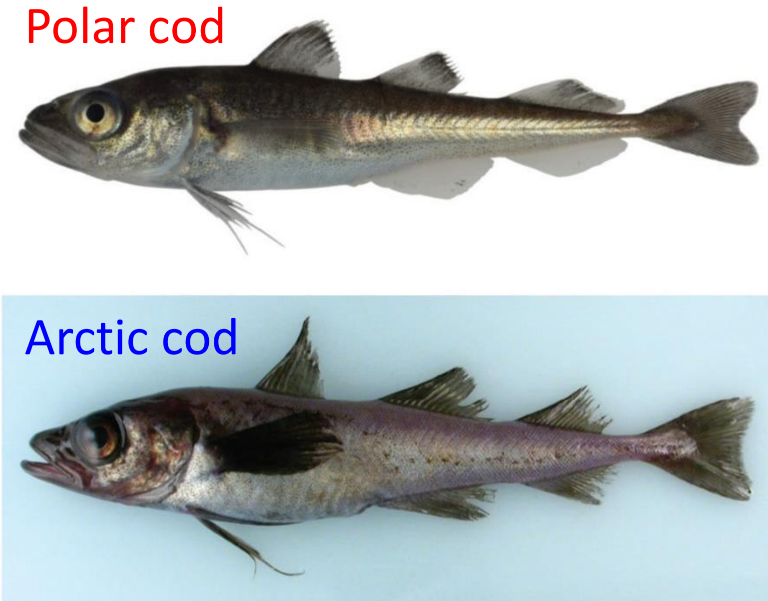


Figure 8.7. (Upper) Polar cod (*Boreogadus saida*) and (lower) Arctic cod (*Arctogadus glacialis*). Note the relatively large eyes which indicate that the species live in low-light environments. Photos: Samuel P. Iglesias and Catherine W. Mecklenburg.

Two fish species recorded in the CAO that may be of commercial interest

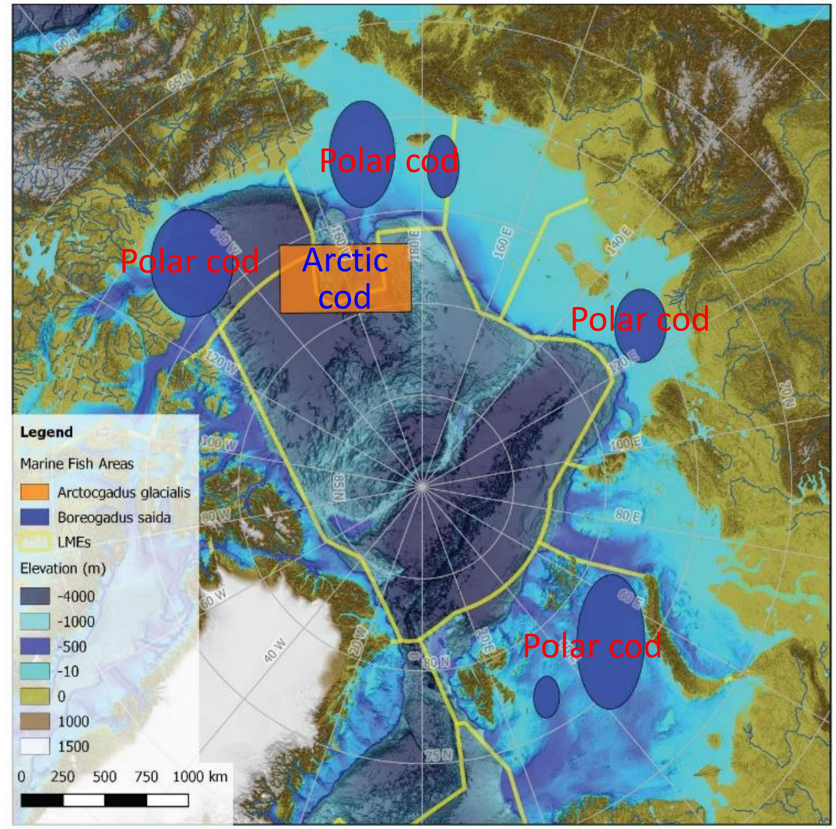


Figure 8.8. Known and tentative migratory populations or stocks of polar cod (*Boreogadus saida*) on the shelves surrounding the CAO. See the text for more information and sources for the geographical stocks or potential stocks. Also indicated is the location of a potential spawning area for Arctic cod (*Arctogadus glacialis*).

Potential distribution map of two fishes

- When introducing appropriate ecosystem-based management under the central Arctic Ocean fisheries agreement, it will become important to monitor the marine environment and ecosystem in the Chukchi Borderland region under a framework of such as DBO, especially across the Chukchi Plateau where anomalous events of low oxygen water and acidification are expected to increase in the future, such decadal changes may be observed by the SAS II project.


Japan's first research icebreaker for Arctic science
delivered in 2026
The Arctic region is facing many difficult challenges including environmental changes that have led to the loss of sea ice, and learning how to balance the increased economic activities that have resulted from these changes. The effects of these environmental changes are far-reaching and are often witnessed as extreme weather systems outside of the Arctic region - one example of this being extreme snowfall occurring in Japan. As such, the changing Arctic environment is really a global concern. It is our responsibility as a world leading nation, that is also directly affected by these changes, to form a commitment to scientific investigations into the changing environment of the Arctic. In order to fulfill these commitments, Japan has decided to build an Arctic research vessel with icebreaking capabilities and world-class scientific facilities. This research vessel will be harnessed to promote the importance of Arctic science and to work towards sustainable development of the Arctic region. Furthermore, Japan remains committed to raising the next generation of scientists and engineers and plans to utilize this research vessel to further develop collaborations with international partners.
Weather balloon carrying atmospheric instruments
Measure atmospheric variables such as, air pressure, temperature, and humidity.
Rainfall/snowfall observations using a meteorological radar
Measure variables such as wind speed, speed and size of raindrops and snowflakes inside the clouds by radiating electric waves over the Arctic ocean.
Sea-ice observation using autonomous on-ice and under-ice vehicles
Non-destructive observation above and below the sea ice to i) measure ice thickness and floe shape, and ii) observe the marine environment under the ice.
JAMSTEC
Monitoring the hull structure of the ship
Collect data on the ice load experienced by the ship for continued operation and maintenance.
Deep sea water sampler
Measure variables such as temperature, salinity, and pressure in the deep sea, which enable us to better characterize the ongoing changes in the Arctic Ocean.
Fish finding echo sounder
Piston corer
Collect seafloor sediment cores without disrupting the sediment layers.
Fixed point observation by moorings
Continue to maintain our moorings, which monitor physical and biological changes in the Arctic Ocean.
Survey of bathymetry and biological resources using echo sounders
Conduct bathymetric and biological surveys of the Arctic Ocean.
Seafloor survey using ROV/AUV
Operate autonomous underwater vehicles for data collection.