The Pacific Arctic Gateway: Connecting the marine ecosystems of shelf/slope regions to the Central Arctic Ocean

Jackie M. Grebmeier
Chesapeake Biological Laboratory
University of Maryland Center for Environmental Science,
Solomons, MD, USA

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(INVITED-RECORDED)

WORKSHOP VW4 SB Topic Workshop: How does the Pacific Arctic gateway affect the marine system in the Central Arctic Ocean (CAO)? Victoria, BC, Canada#(HOST group)

Introduction

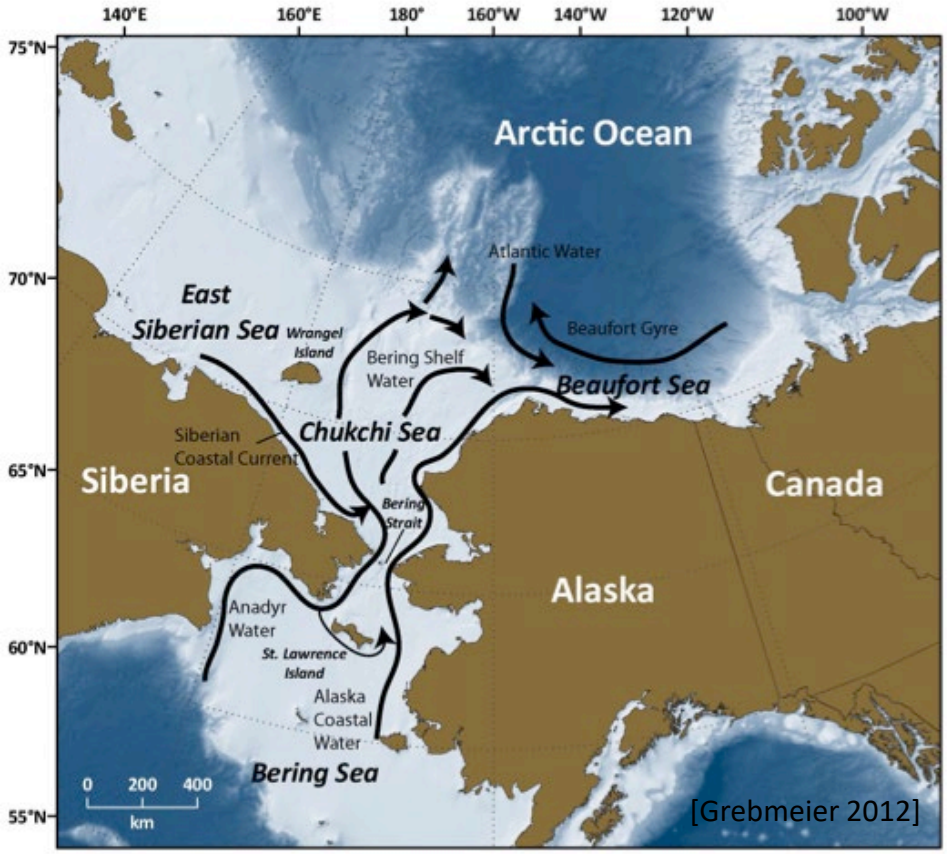
- Key environmental drivers that influence ecosystem dynamics of the Central Arctic Ocean (CAO) and surrounding shelf-basin interactions
  - Decrease in sea ice extent and duration
  - Seasonal warming seawater temperatures
  - Change in prey concentrations
  - Northward movement of some lower to upper trophic level species, including commercial fish species and subarctic upper trophic level marine mammals

- These changes have regional to global implications related to climate change, light penetration and availability, productivity, northward migration of biological organisms and biodiversity, and future development of commercial fisheries

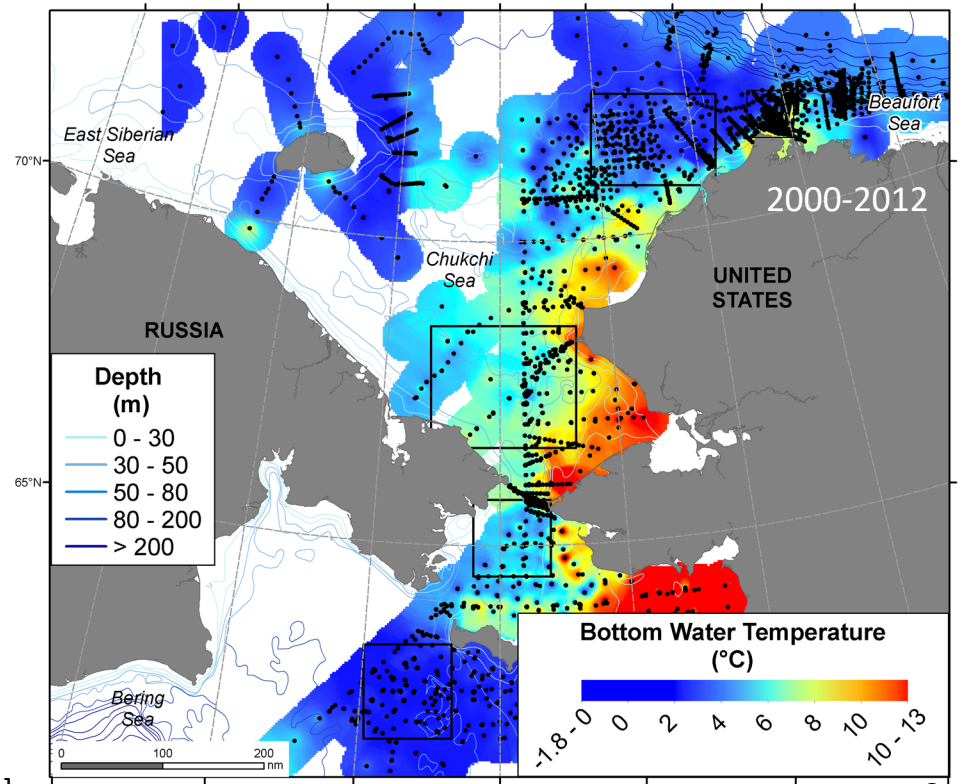
- In 2015, the five Arctic coastal states (Canada, Denmark/Greenland, Norway, Russia, Federation, USA) signed the Oslo Declaration, pledging not to fish in CAO until there is sufficient scientific information; invited five distant-water fishing jurisdictions (the European Union, Iceland, Japan, People's Republic of China, Republic of Korea) to join further negotiations to develop an international agreement ("5+5" partners)

- 2018 October the "5+5" partners approved an international "Agreement to prevent high seas fisheries in the Central Arctic Ocean" and agreed on the need to monitor and regulate potential fisheries that could develop in the CAO beyond national boundaries

Current flow and bottom water temperatures from March-October

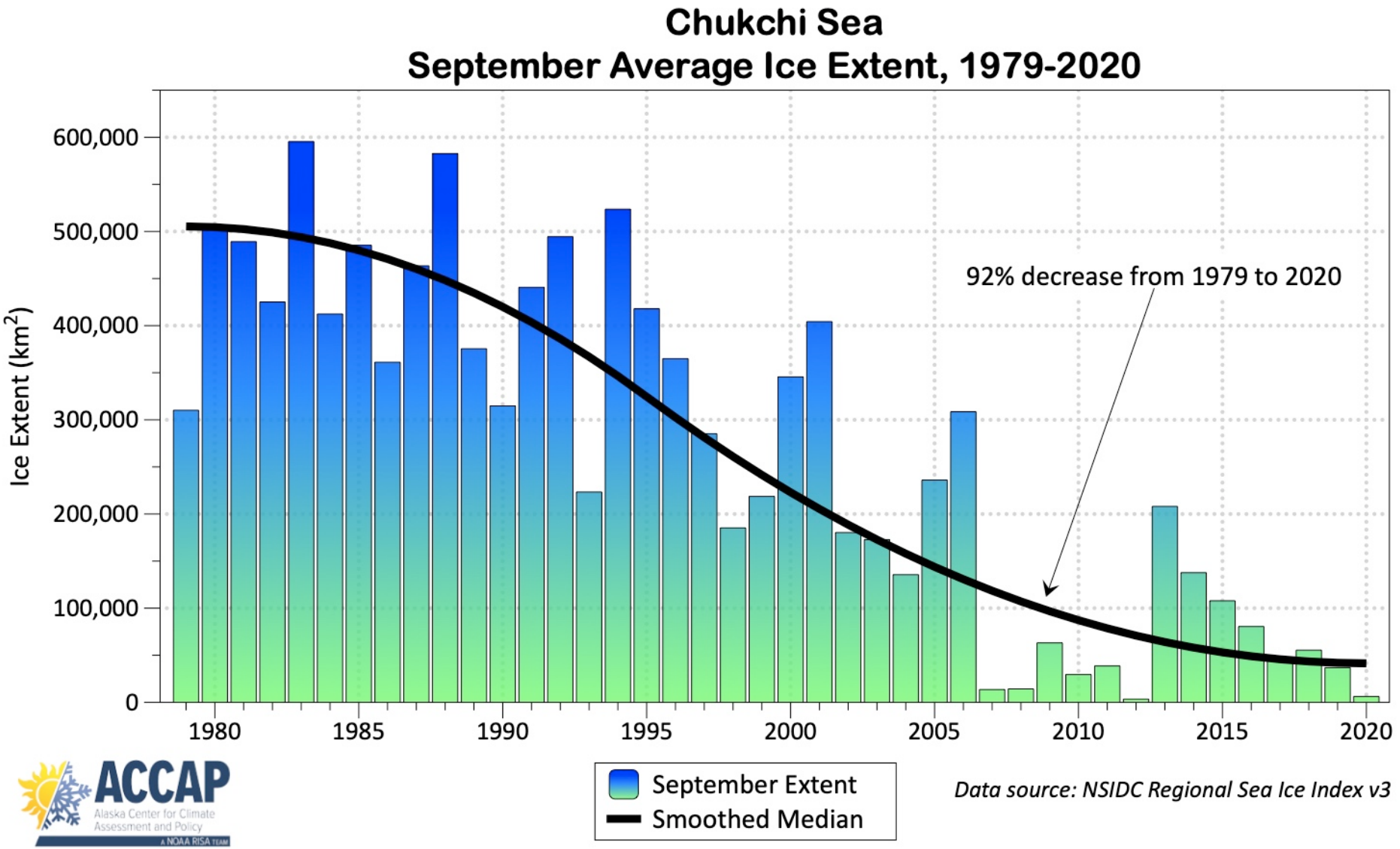


- Advective regime
- High nutrients western side
- Increasing volume of warm Pacific water through Bering Strait in recent years (Woodgate 2018]

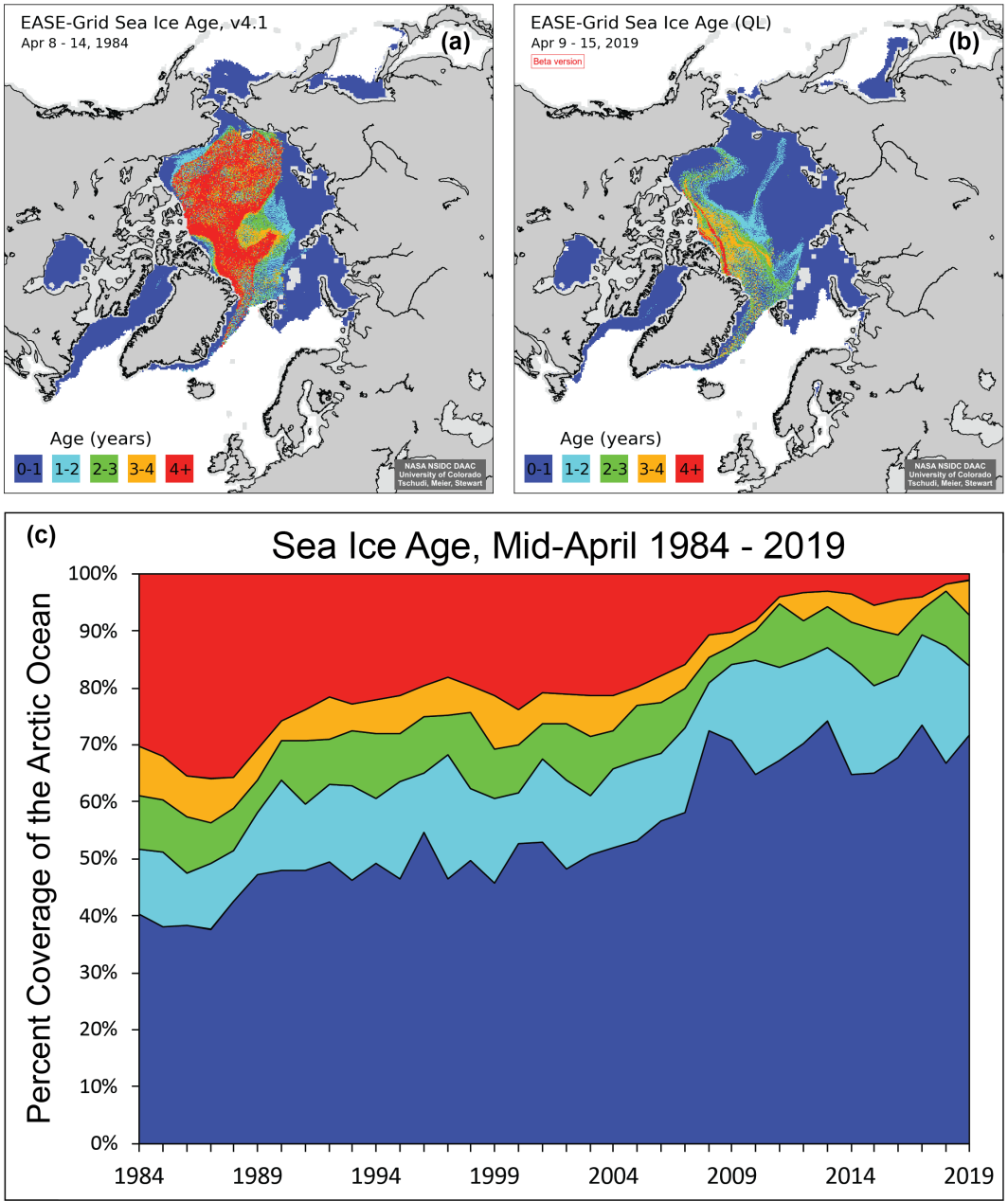


- Latitudinal warming bottom water temperatures
- Coldest: Northern Bering Sea south of St. Lawrence Island & Northeast Chukchi Sea, plus downslope western Chukchi Sea

[Grebmeier+17 co-authors, 2015 SOAR Prog. Oceangr.]

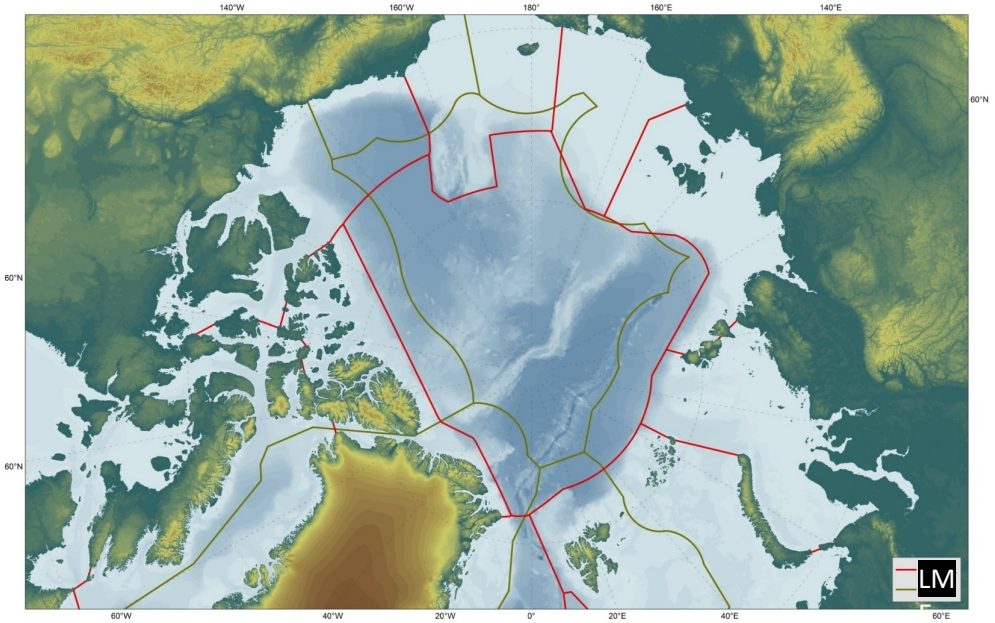

Chukchi Sea
September Average Ice Extent, 1979-2020
Ice Extent (km²)
600,000
500,000
400,000
300,000
200,000
100,000
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
92% decrease from 1979 to 2020
September Extent
Smoothed Median
Data source: NSIDC Regional Sea Ice Index v3
ACCAP
Alaska Center for Climate Assessment and Policy
A NOAA RISA TEAM

Arctic Sea Ice Age Maps Comparing April 1984 to 2019



[Walt Meier, NASA]

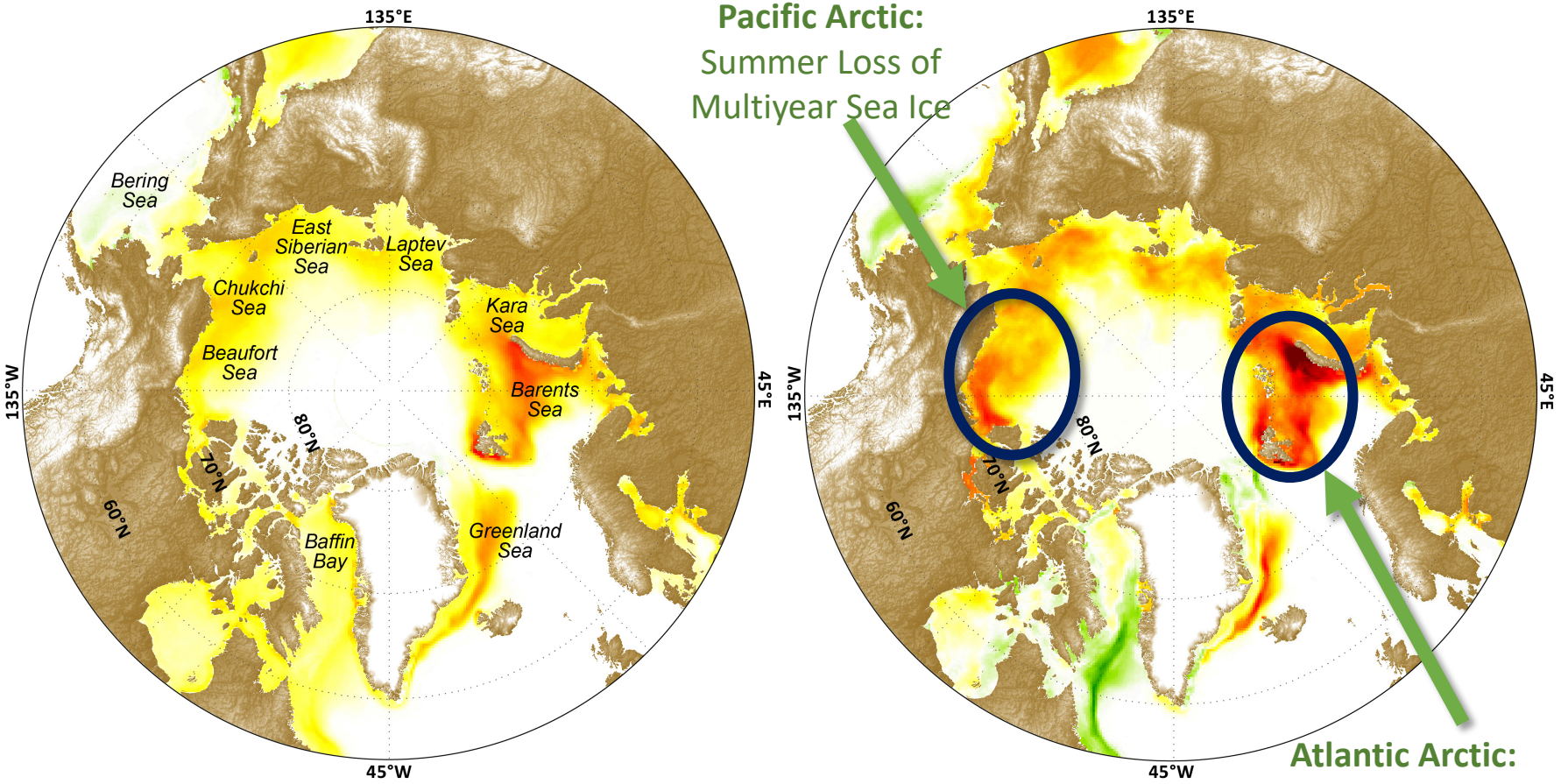
International Science Organizations Involvement in Central Arctic Ocean Evaluation



Large Marine Ecosystems (red) and **Territorial Boundaries (green)** of the Central Arctic Ocean

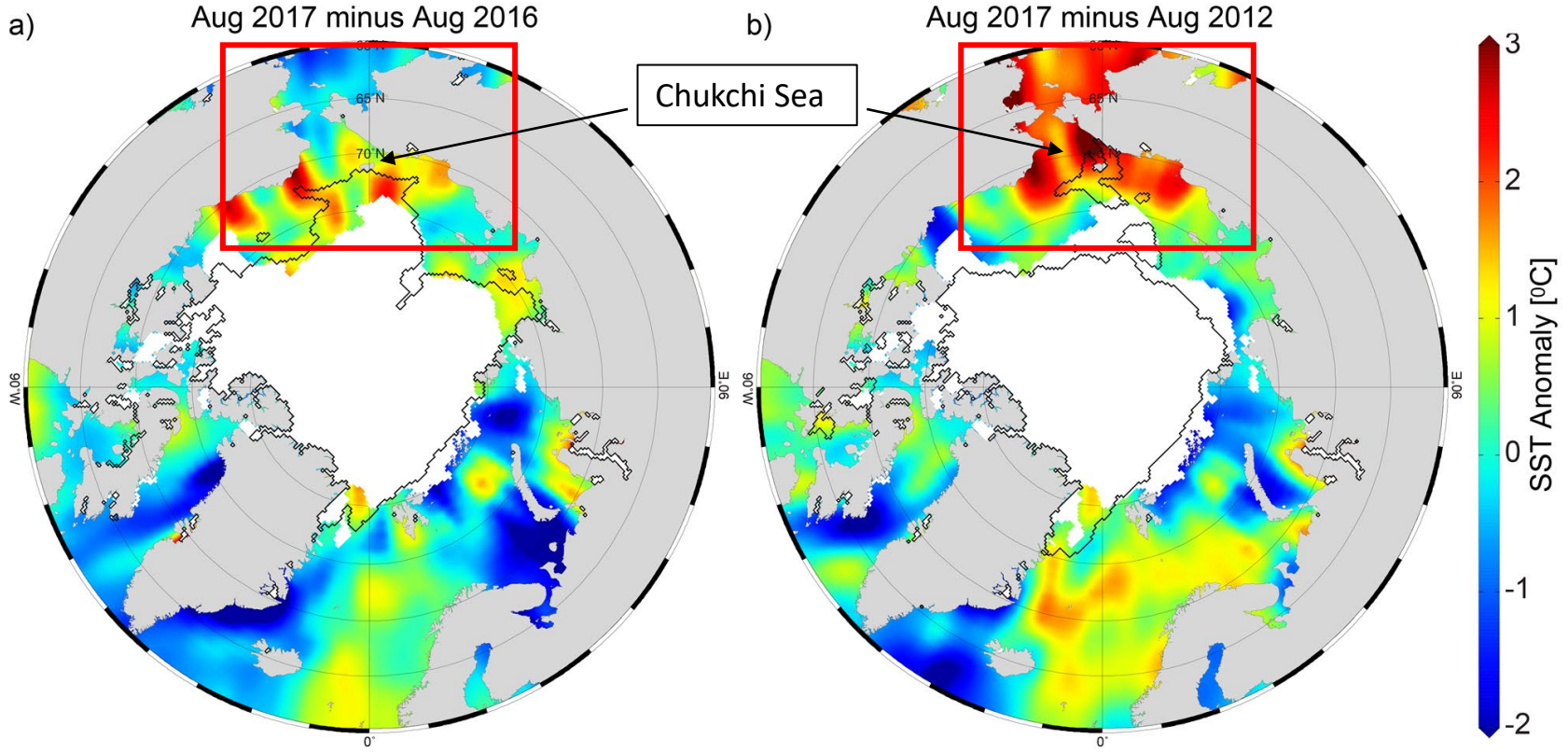
- **International Council for the Exploration of the Sea (ICES),** the **North Pacific Marine Science Organization (PICES)** and the **Arctic Council's Protection of the Arctic Marine Environment (PAME)** and **Conservation of Arctic Flora and Fauna (CAFF)** representatives in the **Working Group on Ecosystem Assessment of the Central Arctic Ocean (WGICA; 2020 report online)**
- **Scientific Experts on Fish Stocks in the Central Arctic Ocean (FiSCAO)-**agreement at 5th FiSCAO meeting, Ottawa, Canada, October 2017; recognized value Indigenous Knowledge
- **CAFF Circumpolar Biodiversity Monitoring Program (CBMP Marine)-**recent "State of the Arctic Marine Biodiversity Report, 2017"

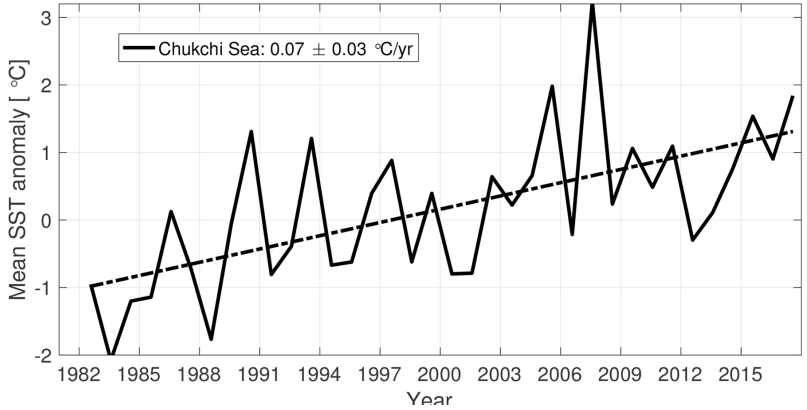
Pan-Arctic Trends in Annual Sea Ice Persistence 1979-2017



[courtesy K. Frey]

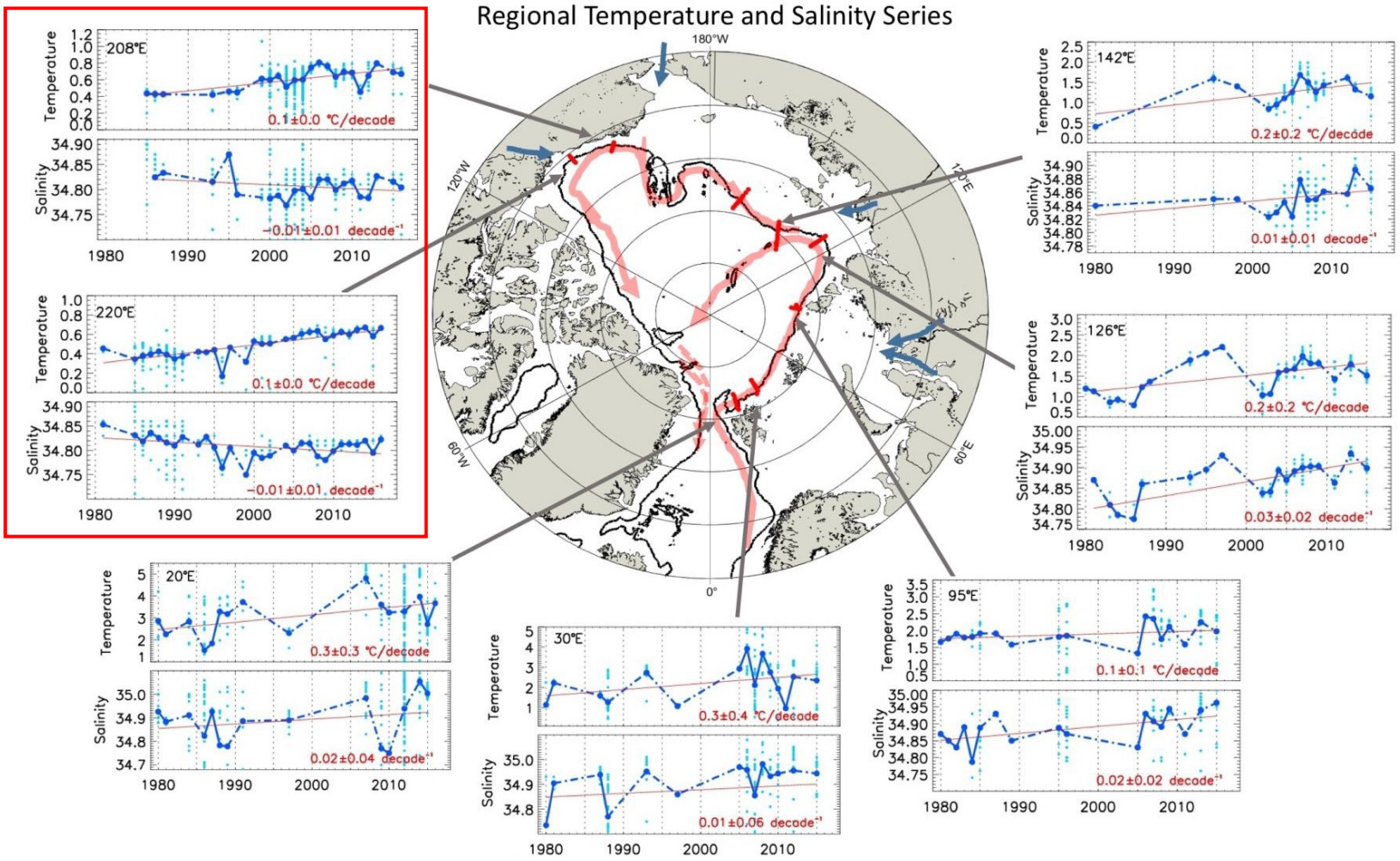
Arctic Ocean Sea Surface Temperature Change





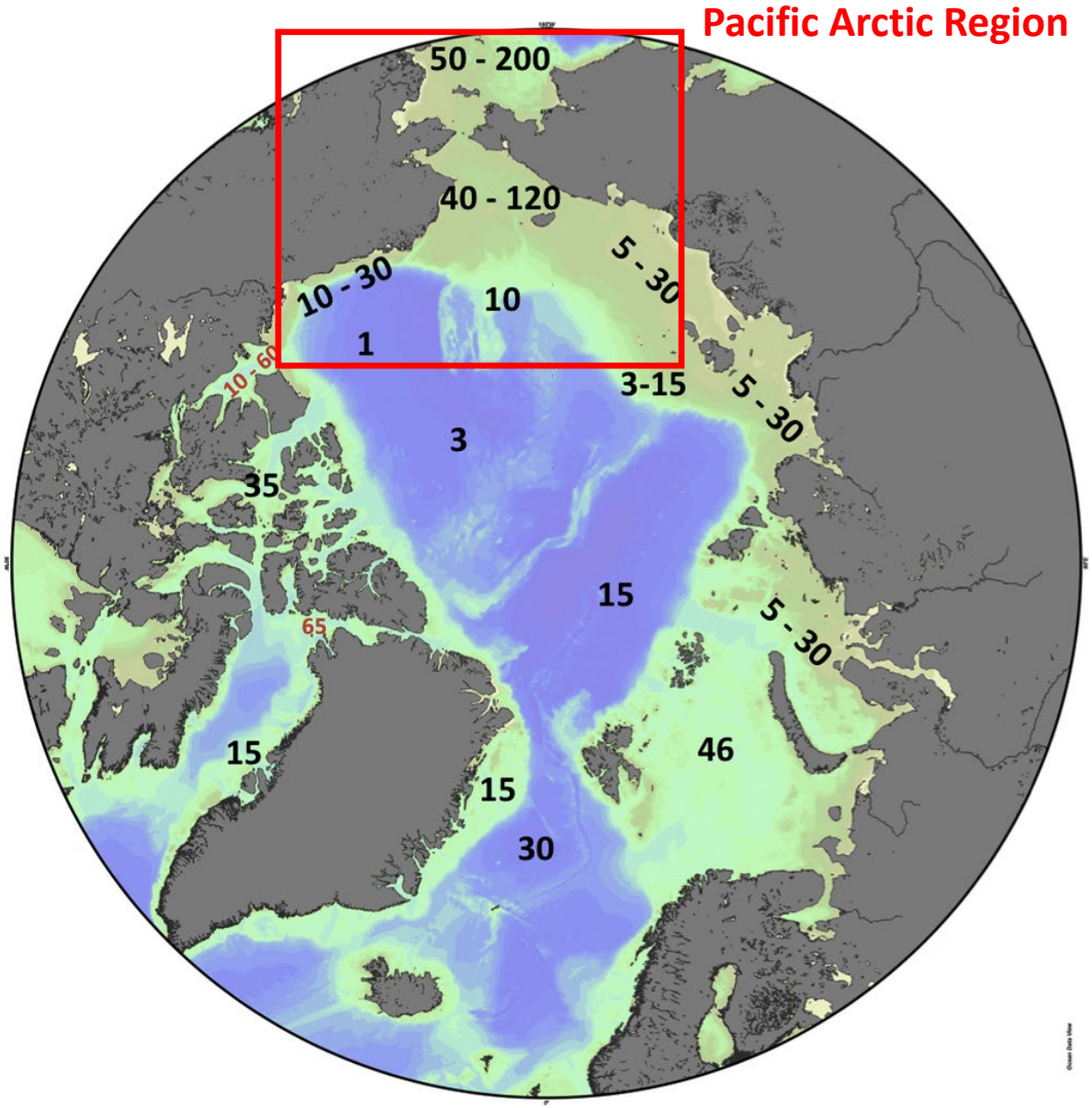
[Timmermans et al. 2017]

Towards: pan-Arctic change



[Polyakov et al. 2020, Frontiers in Marine Science]

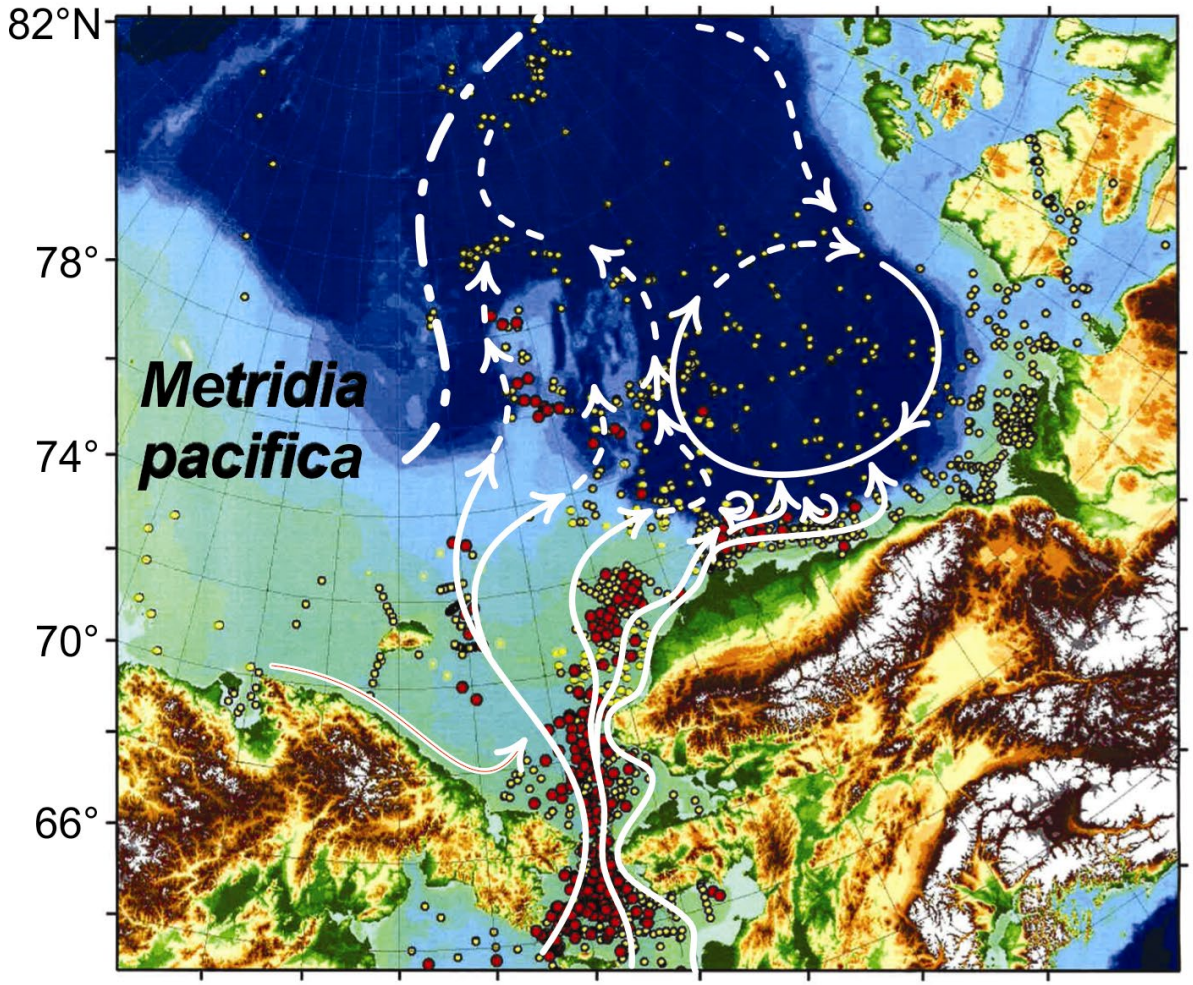
Coarse spatial distribution of annual NCP (g C yr^{-1}) across different sectors of the Arctic Ocean



Coarse spatial distribution of annual NCP (g C yr1) across different sectors of the Arctic Ocean based on the estimations of Codispoti et al. (2013, black numbers) and additional data from Tremblay et al. (2002a, 2008) and Forest et al. (2011) (red numbers).

[Tremblay et al. 2015]

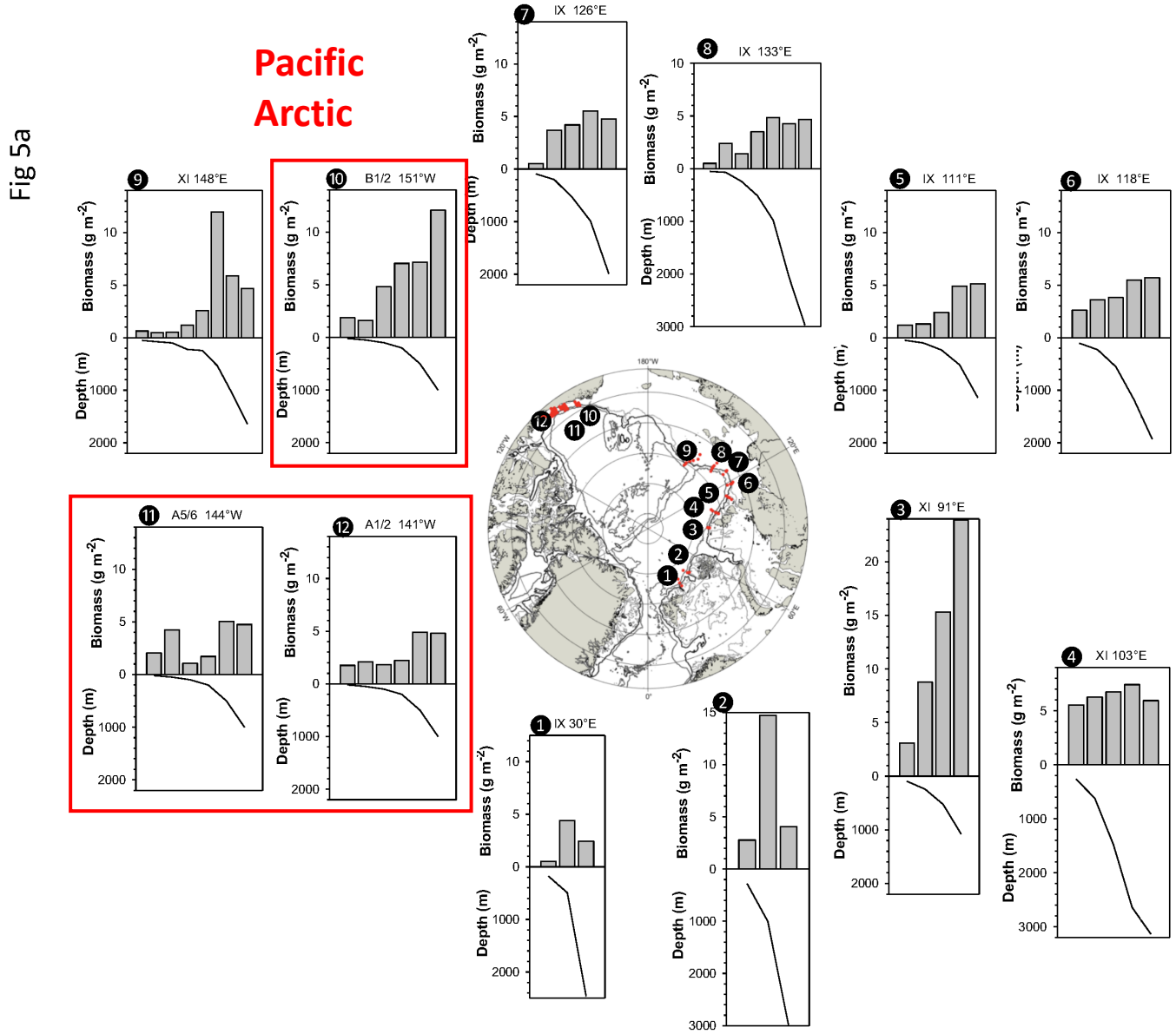
Zooplankton in the Pacific Arctic



Mesozooplankton biomass in the central Arctic is dominated at most locations and depths by the large copepod *Calanus hyperboreus*, with lesser contributions (> 5% of biomass) by the copepods *C. glacialis*, *Microcalanus* spp., *Metridia longa*, and *Paraeuchaeta glacialis* and the chaetognaths, based on representative data from the Canada Basin [*Kosobokova and Hopcroft*, 2010].

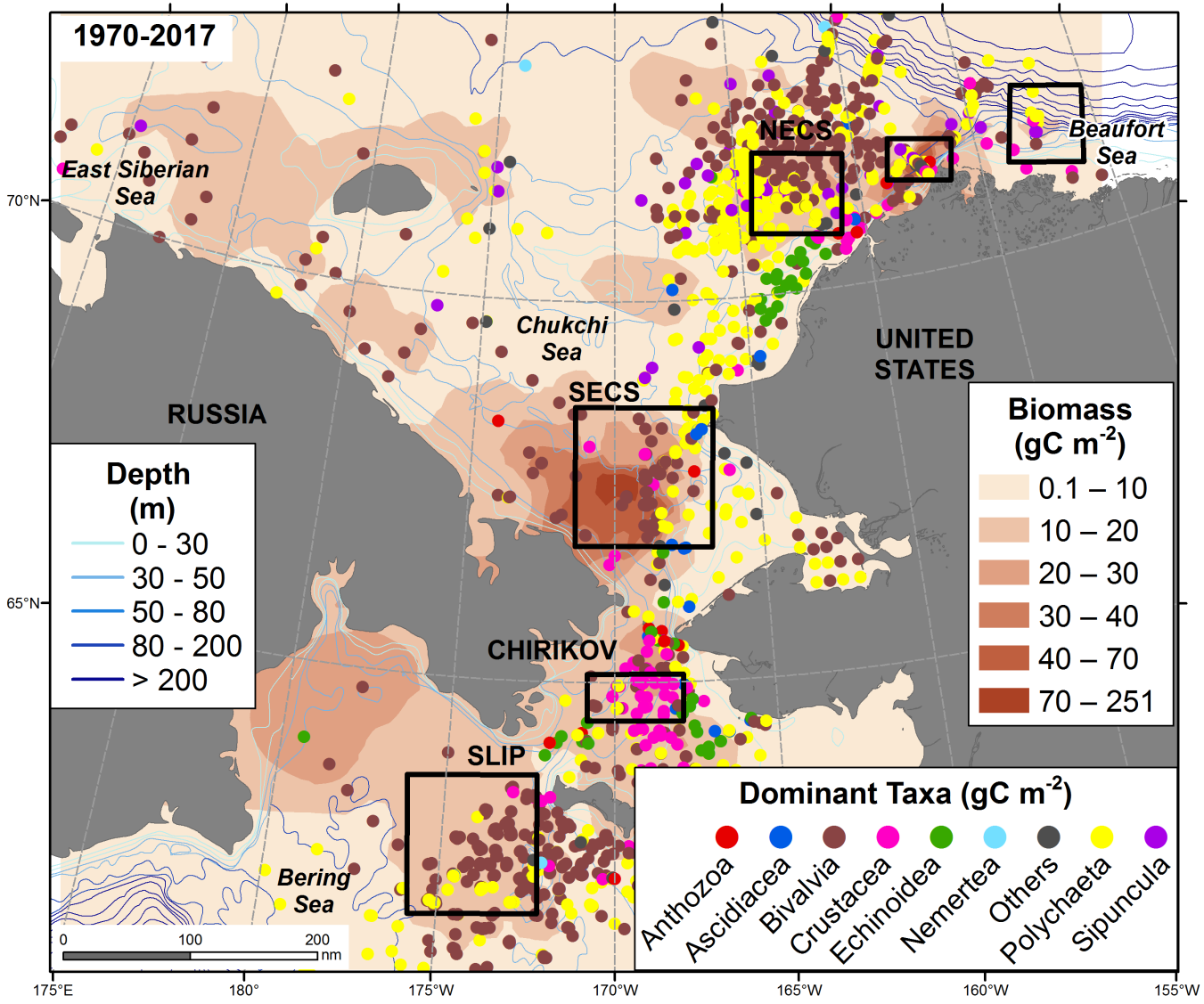
[modifed from Nelson et al. 2014]

Mesozooplankton biomass with depth over a pan-Arctic slope region



[Bluhm et al. 2020, Frontiers in Marine Science, in press]

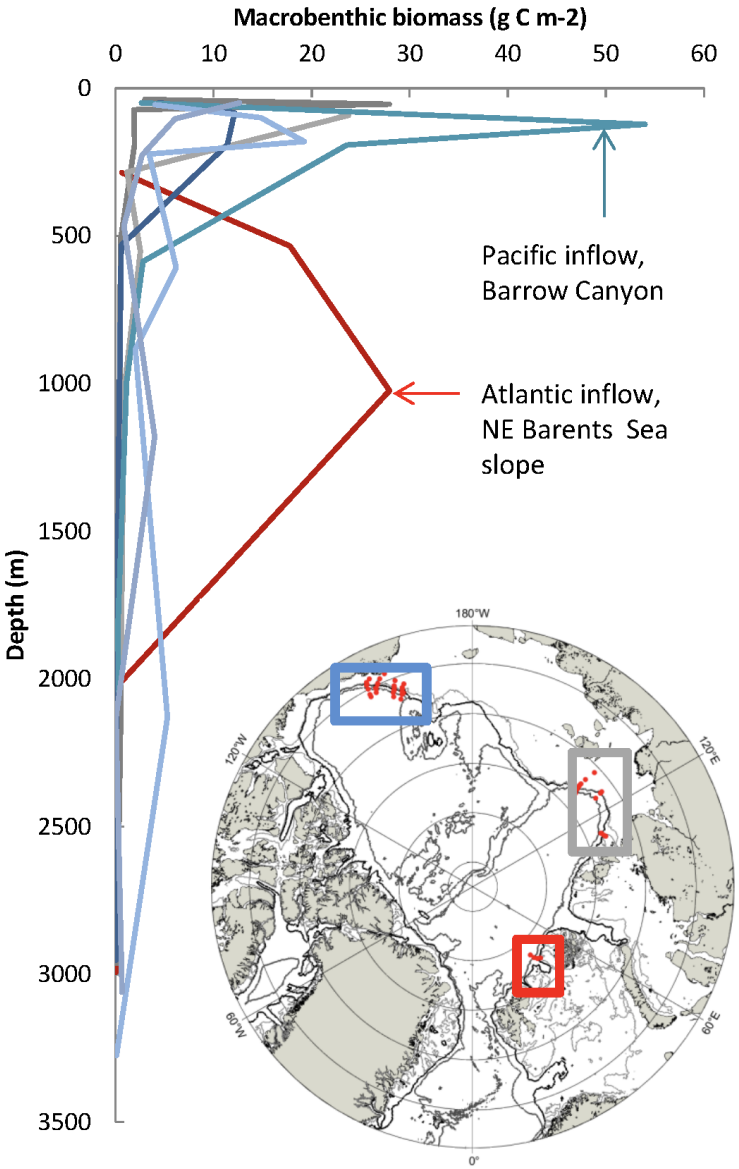
Rich benthic communities on the western side of the Bering/Chukchi Sea system 2000-2017



- **"foot prints"** of high benthic biomass reflect pelagic-benthic coupling and export of carbon to sediments
- infauna dominated by amphipods, bivalves, polychaetes, and sipunculids

[modified from Grebmeier et al. 2015, Prog. Oceangr.]

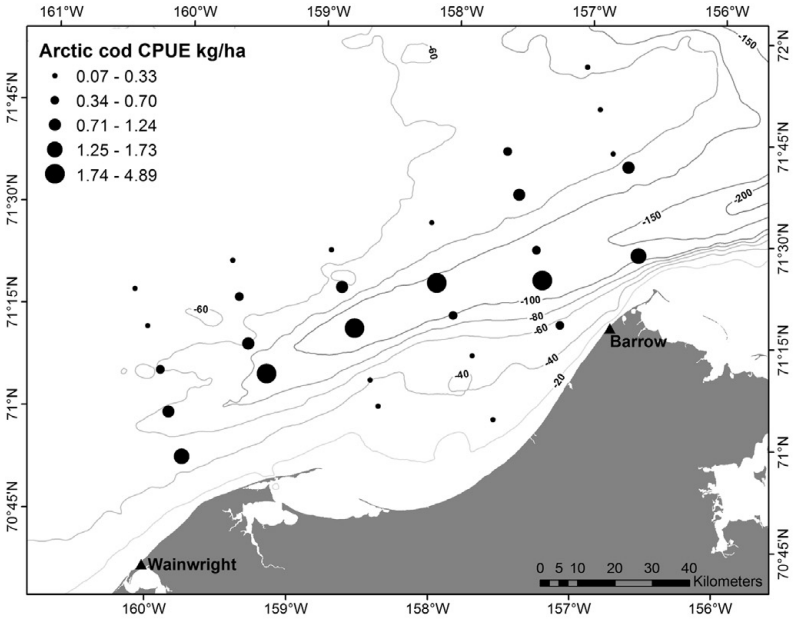
Macrofaunal Benthic Biomass in the Pacific and Atlantic Arctic

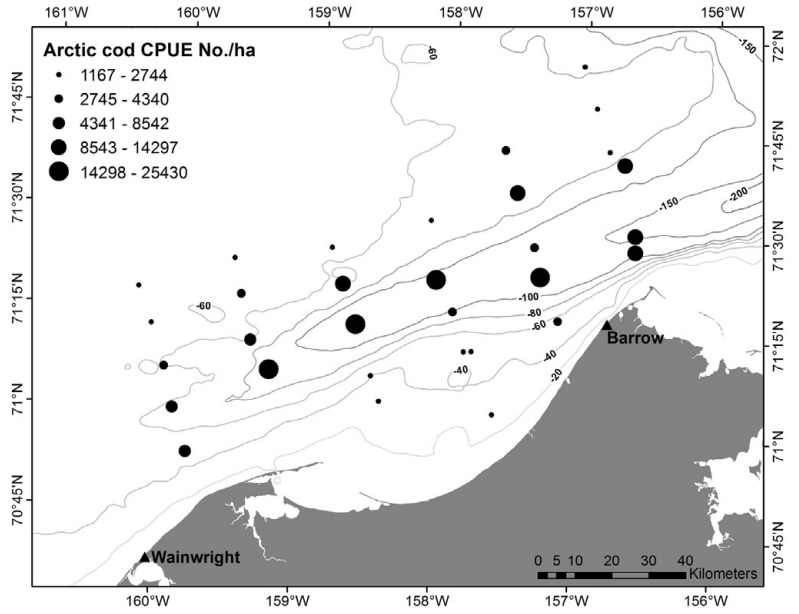


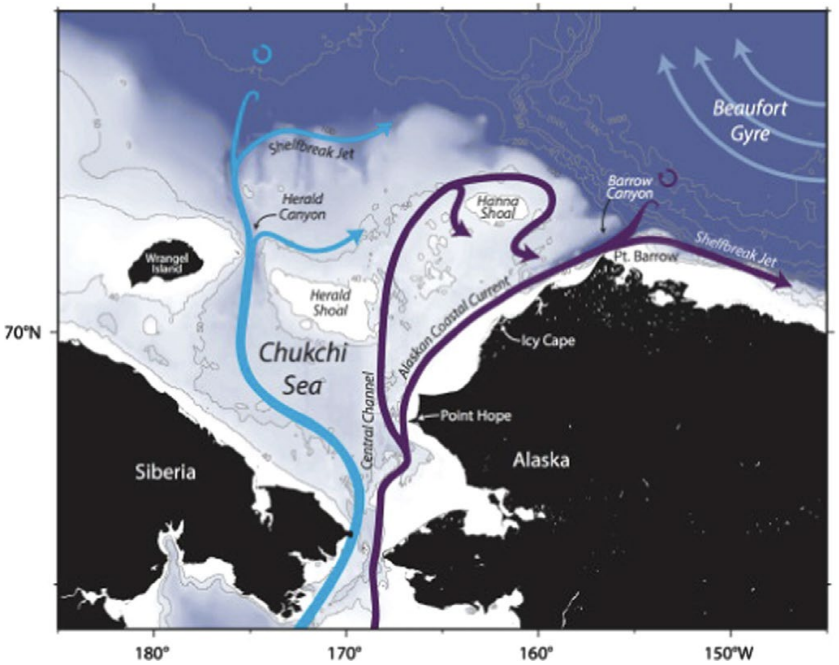
- Macrofaunal biomass highest on upper slope (200m) downstream of Barrow Canyon within Pacific Arctic inflow to Arctic Basin
- By comparison, macrofaunal biomass highest on the lower NE Barents Sea slope of Atlantic inflow to Arctic Basin (1000m), yet 50% less than in the Pacific Arctic

[Bluhm et al. 2020, in press]

Arctic cod in the Barrow Canyon region, Chukchi Sea





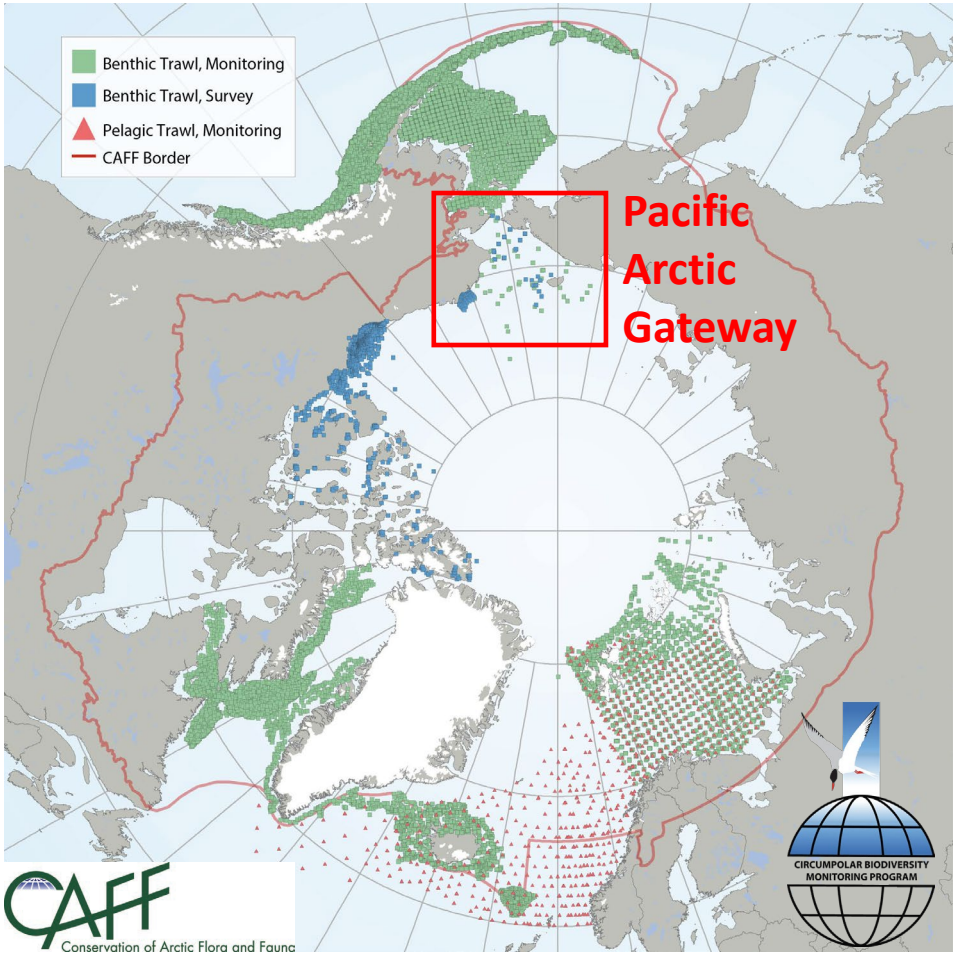


[from Gong and Pickart, 2015]

Catch-per-unit-effort (CPUE) by biomass (kg/ha) and number (No./ha) for the most abundant fish species, Arctic cod. Depth contours in meters.

[Logerwell et al. 2018 SOAR2 DSR]

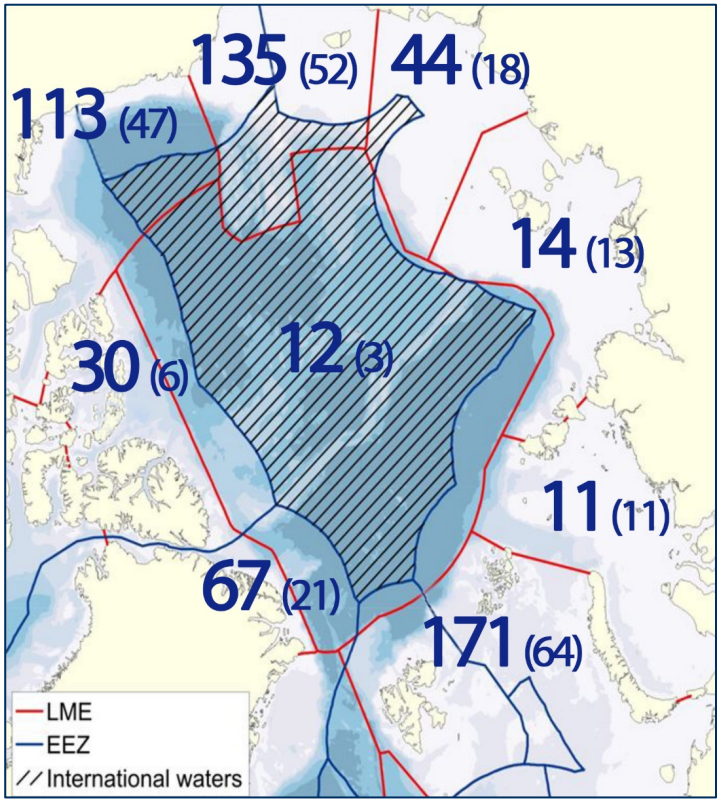
Fish stock monitoring in the High Seas of the CAO



[SAMBR 2017]

- Fish communities in waters below 1,500 m as well as mid-water realm are poorly known due to a lack of commercially important species

Pacific Arctic



[Data: FiSCAO Synthesis, 2018]

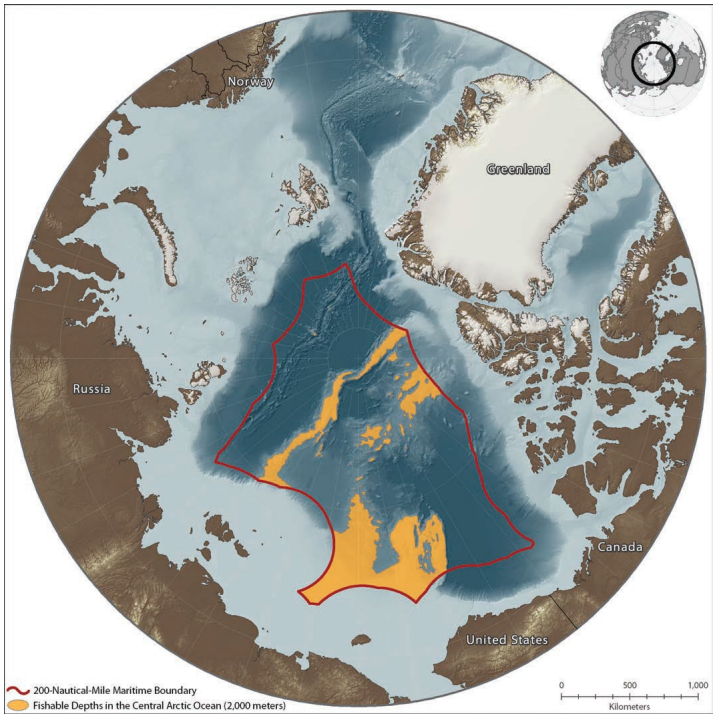
Fish species diversity (shelf seas 339 species, High Seas 12 BUT many uncertainties!)

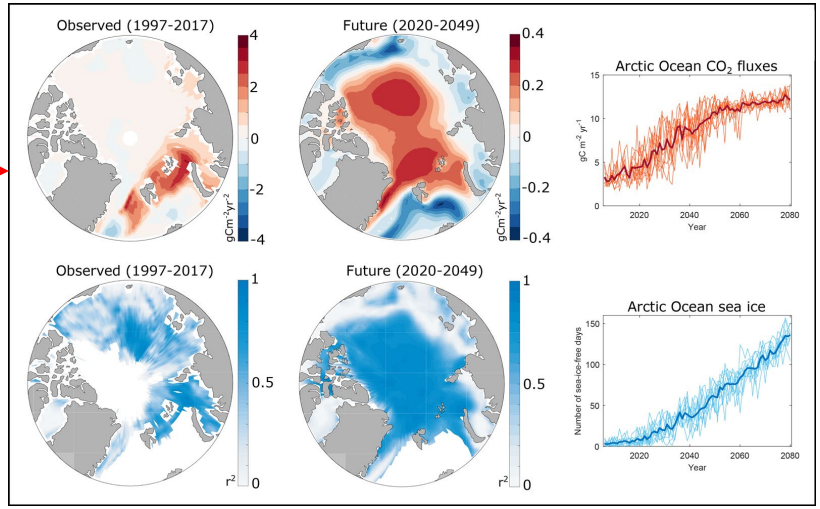
Addressing Arctic Challenges Requires a Synoptic Ocean Survey

A coordinated effort involving trailblazing science—and icebreaking ships—from many nations is needed to fill gaps in our understanding of the Arctic Ocean and how it's changing.

In this 2007 photo, the Swedish icebreaker *Oden* (left) runs a seismic cable in the wake of the Russian nuclear-powered icebreaker *50 Let Pobedy*, which is plowing through heavy ice north of Greenland. The Synoptic Arctic Survey team plans to launch a coordinated multinational campaign using icebreaker ships to gather data in the Arctic Ocean beginning in 2020. Credit: Leif Anderson

Fishable depths were derived from IBCAO v3 bathymetry (www.ngdc.noaa.gov/mgg/bathymetry/arctic/).



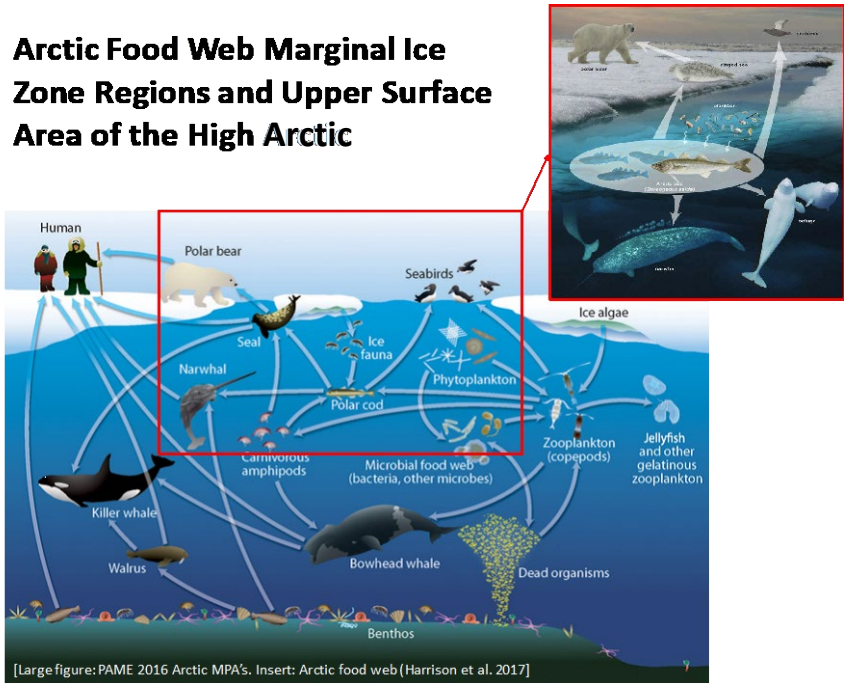


[Paasche et al. 2019 Eos, Nov]

Synoptic Arctic Survey (SAS): Physical, Chemical and Biological Studies on the slope and high regions of the Central Arctic Ocean

Synoptic Arctic Survey

Arctic Food Web Marginal Ice Zone Regions and Upper Surface Area of the High Arctic



[Large figure: PAME 2016 Arctic MPA's. Insert: Arctic food web (Harrison et al. 2017]

- evaluate shelf-basin exchange of biological and chemical component connected to the Central Arctic Ocean


In a boon for fish stocks, the Barents Sea last year saw a steep rise in photosynthesis by phytoplankton (blue-green bloom above) and other organisms.

CLIMATE CHANGE

Nations put science before fishing in the Arctic

Historic fishing ban gives scientists time to probe ecology as northern waters warm

By Hannah Hoag

Nine nations and the European Union have reached a deal to place the central Arctic Ocean (CAO) off-limits to commercial fishers for at least the next 16 years. The pact, announced last week, will give scientists time to better understand the region's marine ecology—and the effects of climate change—before receding sea ice opens the way to widespread fishing.

"There is no other high seas area where we've decided to do the science first," says Scott Highleyman, vice president of conservation policy and programs at the Ocean Conservancy in Washington, D.C., who was part of the U.S. delegation involved in the negotiations. "It's a great example of putting the precautionary principle into action."

The deal to protect 2.8 million square kilo-

gobbled up by Arctic cod, which in turn are hunted by animals higher up the food chain, including seals, polar bears, and humans. Some parts of the Arctic Ocean's adjacent seas, such as the Barents Sea (off the northern coasts of Russia and Norway), saw steep increases in primary production—photosynthesis by plankton and other organisms—in 2016, approaching 35% above the 2003 to 2015 average, according to the U.S. National Oceanic and Atmospheric Administration.

Farther north, the state of fish stocks in the CAO is unknown, but existing international law does not prohibit fishing there. Some researchers, environmental groups, and policymakers fear unregulated commercial fishing in the CAO could harm the fragile and rapidly changing marine ecosystem. In the late 1980s, fishing trawlers from Japan, China, and elsewhere crowded the international waters in the Bering Sea between

fishing until there was enough science and management in place," says David Balton, deputy assistant secretary for oceans and fisheries at the U.S. Department of State in Washington, D.C., who has chaired the negotiations since 2015. The deal will stand for 16 years, and will renew automatically every 5 years after that unless a country objects or until science-based fisheries quota and rules are put in place.

In addition to closing the area to fishing, the delegations have agreed to a research and monitoring program to identify species, their abundance, predator-prey relationships, and the pressures they face, including climate change. It hasn't been worked out yet how the program would be funded and managed, Balton says.

For now, reaching the CAO to study its marine ecology requires significant icebreaker capacity, says Peter Harrison, an Arctic

Harrison argues that the signatories collected, and provide advice on the state of the CAO's fish stocks. "If you see commercial

SCIENCE sciencemag.org

9 DECEMBER 2017 • VOL 358 ISSUE 6368 1235

November 2017: Agreement between USA, Canada, Russia, Norway, Denmark, China, Japan, South Korea, Iceland & the EU: No commercial fishing in the High Sea in the coming 16 years and scientific cooperation; signed Oct 2018

http://www.synopticarcticsurvey.info/splan.html; https://web.whoi.edu/sas2019/

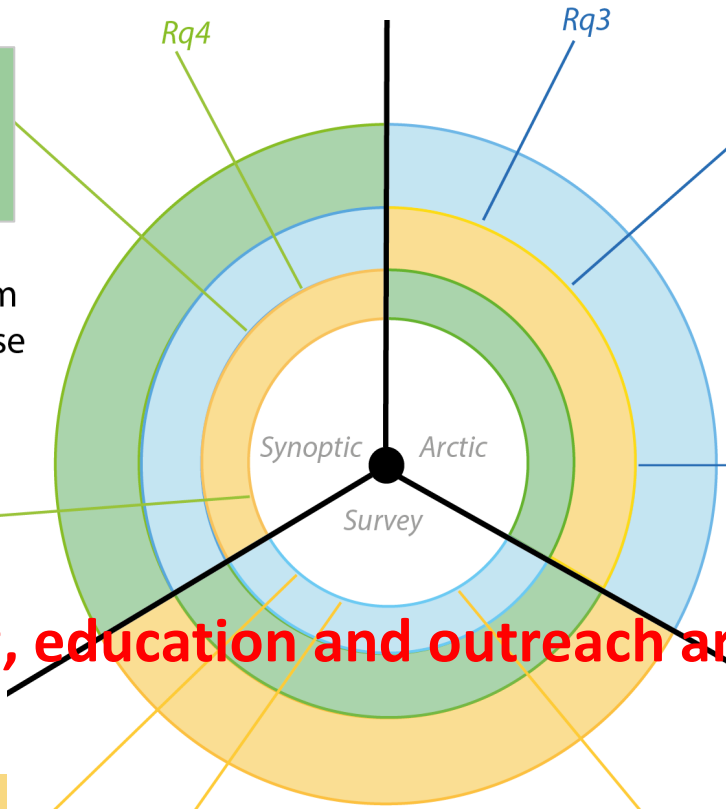
What are the present state and major ongoing transformations of the Arctic marine system?

How does primary production and associated availability of nutrients vary between Arctic regions?

What are the changes in water mass sources, sinks and transformations?

Does northward range expansion of subarctic species vary regionally and are any of these species likely to establish permanent populations in Arctic regions?

What are the states of, and changes in, heat and freshwater budgets in the Arctic regions?



How does biomass flow vary across regional ecosystems of the Arctic?

How are Arctic Ocean water masses and circulation responding to changes in sea ice properties, and atmospheric, advective and freshwater forcing?

Training, education and outreach are integral

What is the contribution of the Arctic Ocean to maintaining the global ocean carbon dioxide reservoir and uptake?

What are the magnitude, drivers, and impacts of Ocean Acidification in the different regions of the Arctic Ocean?

What are the input and fate of terrestrial and subsea carbon to the Arctic Ocean?

Recommended Set of Measurements

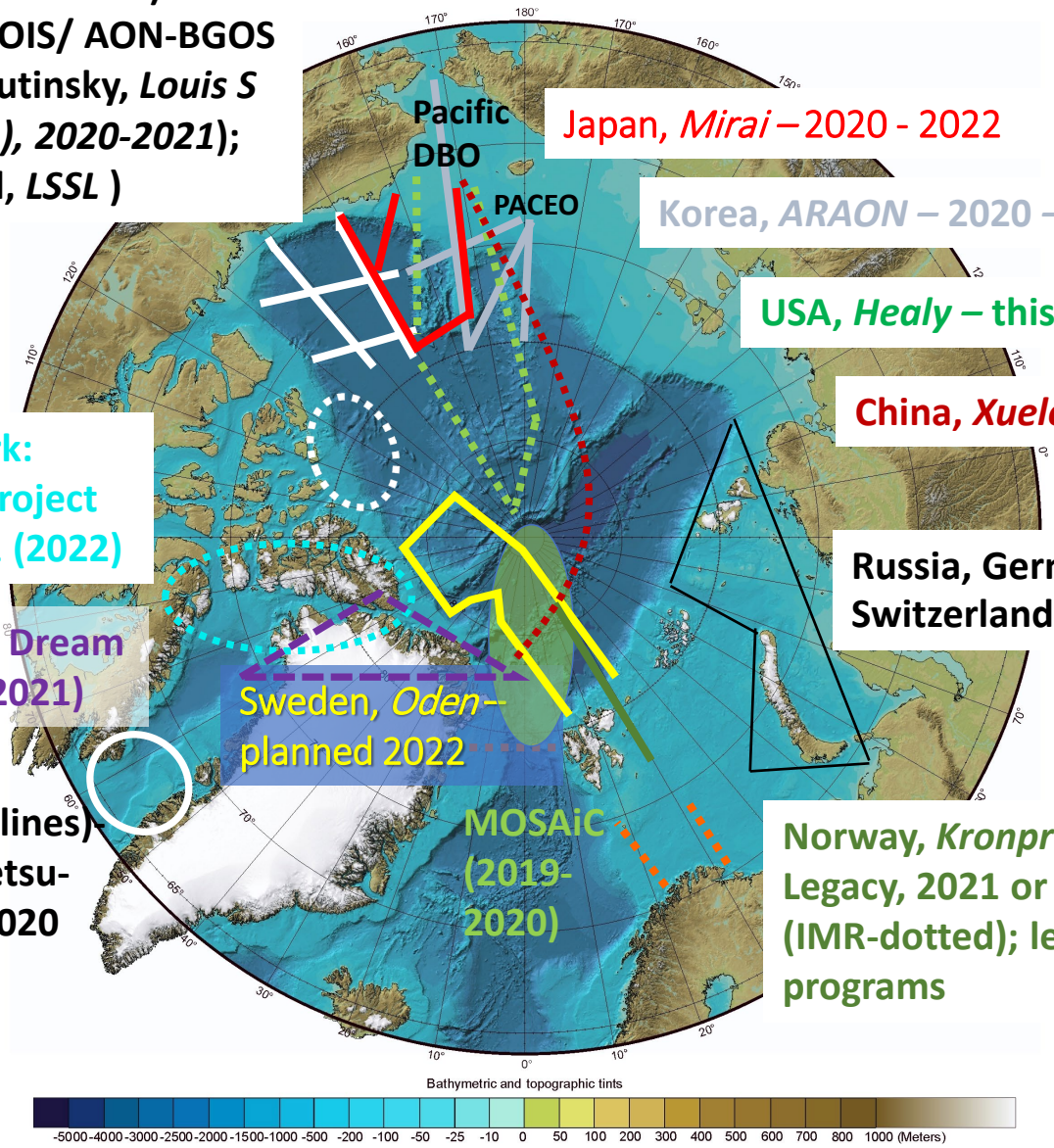
Variable	Sampling
Physical and chemical measurements	
Pressure	CTD
Temperature	CTD
Salinity	CTD + Niskin
Dissolved Oxygen	CTD + Niskin
Nutrients (NO_3/NO_2, PO_4, SiO_3)	Niskin
CFCs and SF_6	Niskin
Dissolved Inorganic Carbon	Niskin
Total Alkalinity	Niskin
pH	Niskin
$\delta^{18}O$ of H_2O	Niskin
Methane	Niskin
Dissolved Organic Carbon (DOC)	Niskin
Particulate Organic Carbon (POC)	Niskin
Water column ecosystem measurements	
Chlorophyll	Niskin
Primary production	Incubation
Viruses	Niskin
Bacteria	Niskin
Phytoplankton composition	Niskin
Microzooplankton	Niskin
Meso-and Macro- zooplankton	Bongo nets, Multinet, Optical Instruments, Acoustics
Icthyoplankton	Aluette or Tucker Trawls, Acoustics
Fish	Trawls, Acoustics
Marine mammals	Passive acoustics, Visual observations
Other Carbon transformation rates	Selected process studies (e.g., grazing, reproduction, sinking, respiration)
Benthic measurements	
Meio- and Macro- fauna	Box Core or Multicore or other corers
Epifauna	Benthic camera, Beam trawl
Other Carbon transformation rates	Selected process studies (e.g., grazing, reproduction, sinking, respiration)
Other	
Epontic Communities	Under-ice imaging, ice cores, sub-ice sampling
Seabirds	Visual Observations

- Physics, carbon chemistry, nutrients, and oxygen following standard protocols
- Add basic atmospheric measurements from ships
- Include ecosystem measurements
- Tailored to Arctic science

***fish connected to CAO ecosystem status and trends studies**

Confirmed and Planned SAS cruises during 2020-2022

Canada, USA (white lines) - collaborations: JOIS/ AON-BGOS (Williams/Proshutinsky, *Louis S St. Laurent (LSSL), 2020-2021*); LIA-MPA (Michel, *LSSL*)



Japan, *Mirai* – 2020 - 2022

Korea, *ARAON* – 2020 – 2022

USA, *Healy* – this proposal 2022

China, *Xuelong – 2020, 2021?*

Canada/Denmark: Pikialasorsuaq Project and BBOS - 2021 (2022)

Russia, Germany, Switzerland – 2021

Denmark: Polar Dream Project (*Dana*, 2021)

Sweden, *Oden*– planned 2022

MOSAiC (2019-2020)

Canada, USA (white lines)- Davis Strait (Lee/Azetsu-Scott, *Armstrong),* 2020 (2021)

Norway, *Kronprins Haakon* (Nansen Legacy, 2021 or 2022-solid), *G.O. Sars* (IMR-dotted); leveraging existing programs

[updated B. Williams and J. Grebmeier, Sept 2020]

Summary and Future Directions

- Northern sections of Pacific Arctic shelf seas and deeper into the Arctic Basin becoming accessible during the late summer and fall months with earlier sea ice retreat, atmospheric changes, and northward advection of warming Pacific water into the region

- Opening of area can change primary production with increasing solar radiation and light penetration in surface waters; impact character primary production in marginal ice zone

- Unknown consequences for carbon cycling and the biodiversity of zooplankton and benthic organisms as few studies on high Arctic food webs; also uncertain impacts fate of export fluxes over Arctic shelves vs. over the deep Arctic Ocean

- Need coordinated, multi-national and interdisciplinary program, such as the Synoptic Arctic Survery (SAS), to provide an framework fo interannual time series suite of ecosystem and fisheries data from shelf-to-basin and in central Arctic Ocean that allow for joint analysis and assessment via approved mechanisms and management goals

Thank you for your attention. Questions?

Support provided by the US national and ongoing international science partners in the Pacific Arctic Group and national funding agencies. Additional support for science planning activities through the International Arctic Program of the PEW Charitable Trusts and international host academic and research institutions.