Shifts in the Pacific Arctic and implications for ecological timing and structure

Trends in Ocean Systems, PICES Annual Science Meeting, Victoria Canada

Matthew Baker[1], **Kirill Kivva[2]**, Jordan Watson[3], Maria Pisareva[4], Julia Selivanova[2, 4]

[1] North Pacific Research Board, 1007 West Third Avenue, Anchorage, AK, 99501 USA

[2] VNIRO, Russian Federal Research Institute of Fisheries and Oceanography, 17 V. Krasnoselskaya, Moscow 107140 Russia

[3] NOAA, Alaska Fisheries Science Center, Auke Bay Laboratories 17109 Pt. Lena Loop Road, Juneau AK 99801 USA

[4] P.P.Shirshov Institute of Oceanology of the Russian Academy of Sciences, 36 Nakhimovsky Prospekt, Moscow 117997 Russia

PICES Data Sharing Workshops RUS-US

PICES North Pacific Ecosystem Status Report

International Collaboration

- Bering-Chukchi complex is complicated by the political boundary
- area of active research for many Arctic states
- international marine research and management organizations

  Arctic Council, International Arctic Science Committee (IASC), Intergovernmental Consultative Committee (ICC), ESSAS, PAG, PICES

RUS-US Collaboration

- coordinated cruise transects (BERPAC, 1988-1995; RUSALCA, 2004-2011)
- joint mooring deployments (Woodgate, 2015)
- US-Russian cooperative surveys in NBS and Gulf of Anadyr (1990, 1994)
- Bering Aleutian Salmon International Surveys
- NPRB Arctic IERP (2017-2019)

Our Research

- integrate data from US-RUS scientific surveys/moorings and satellite data
- highlight recent trends relative to historical baseline conditions
- investigate potential mechanisms and implications for shifts in physics in Pacific-Arctic gateway

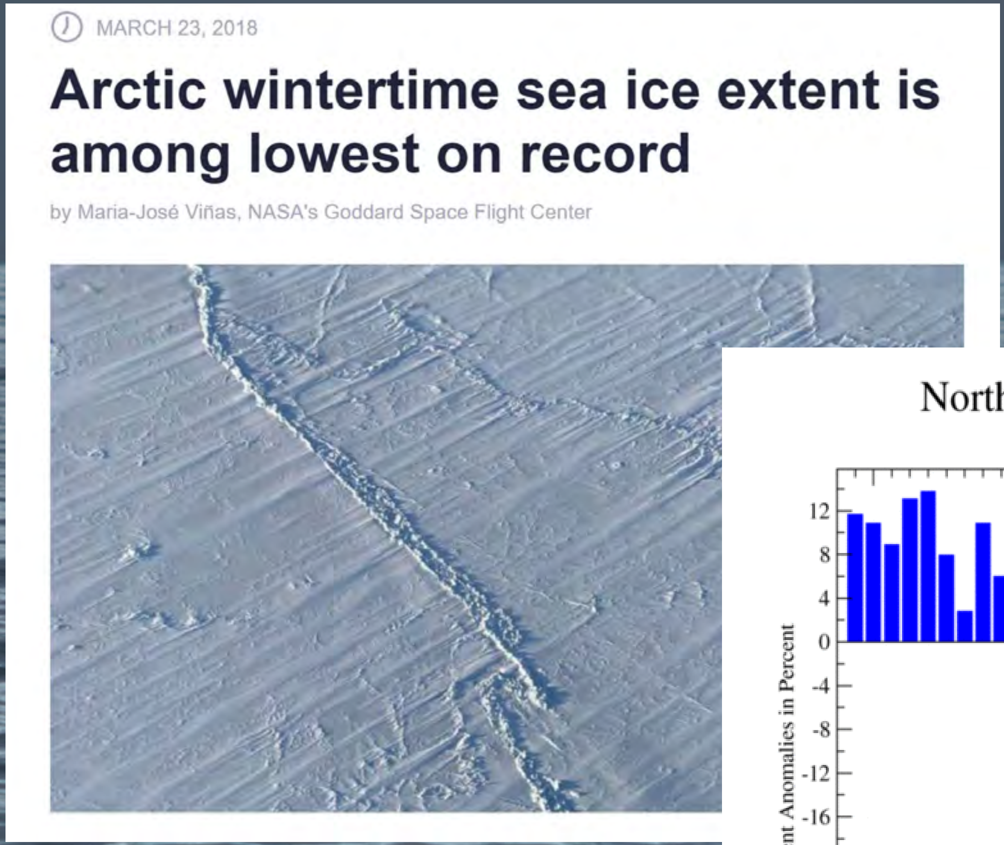
Photo: B. Smith

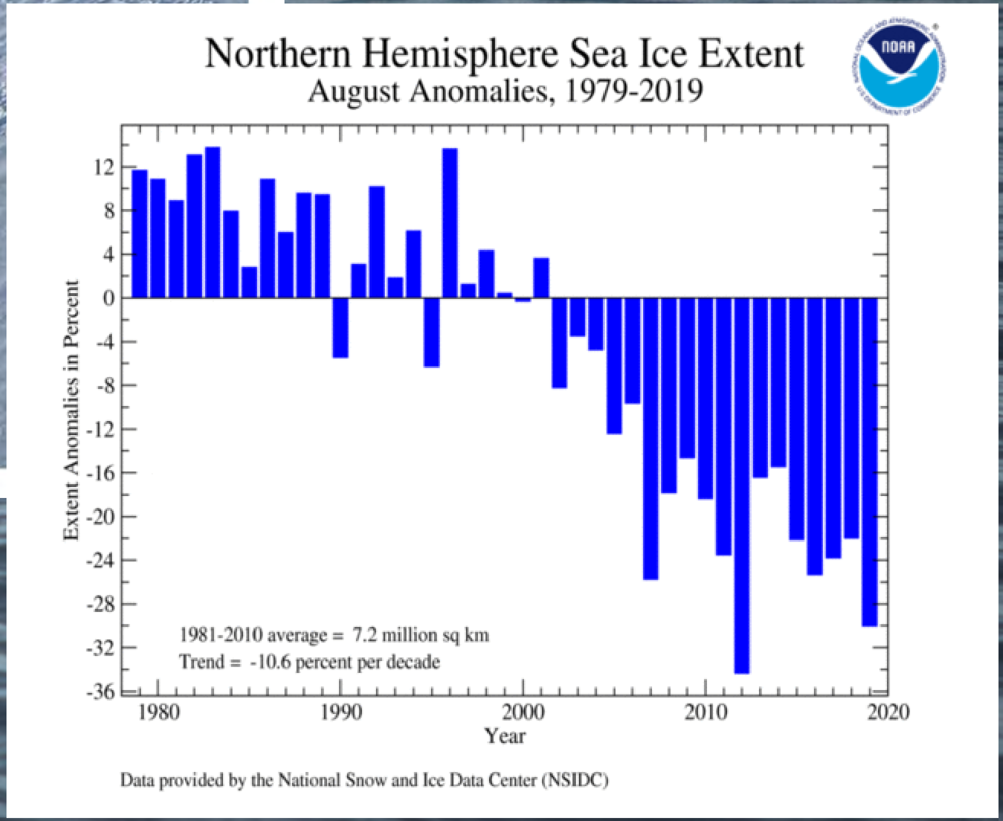
Arctic Change

Loss of Sea Ice

- reductions in extent, concentration and duration
- multiple factors
    - rising air temperature
    - increased flux of warm water into the Arctic
    - advection of ice out of the Arctic
    - positive feedback

Arctic Change

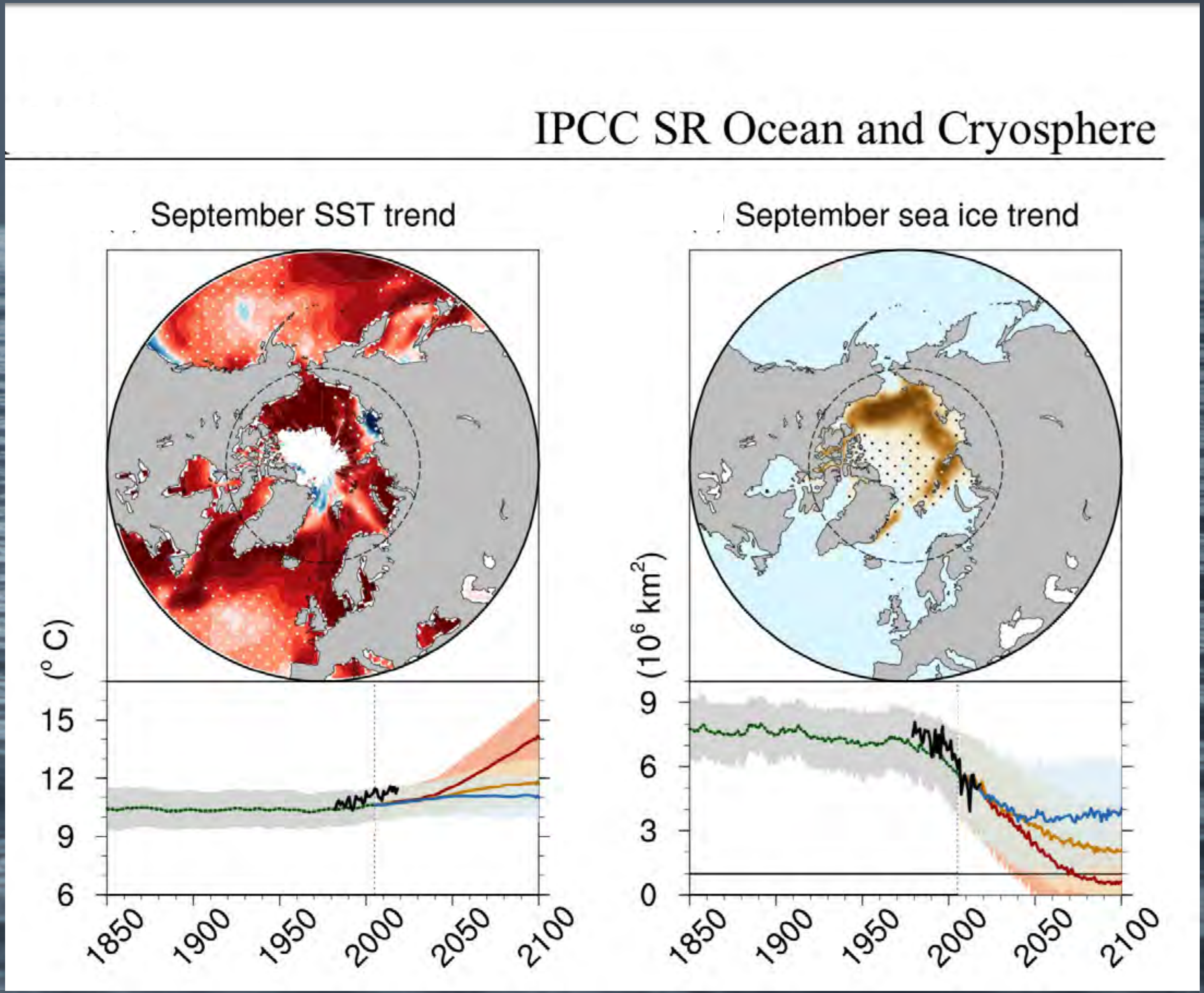




Transformation of the Arctic

- 1979-2019 Arctic Ocean experienced unprecedented and accelerating sea-ice loss

Arctic Change



Transformation of the Arctic

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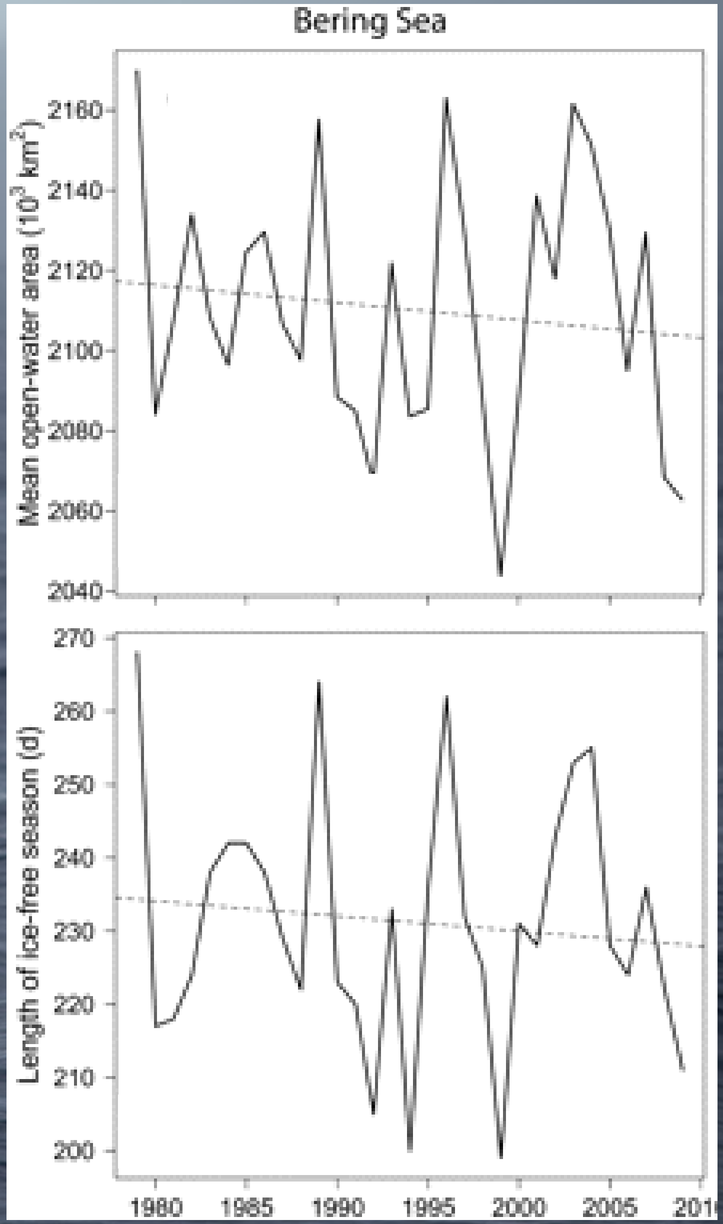
Shifts in the Pacific Arctic

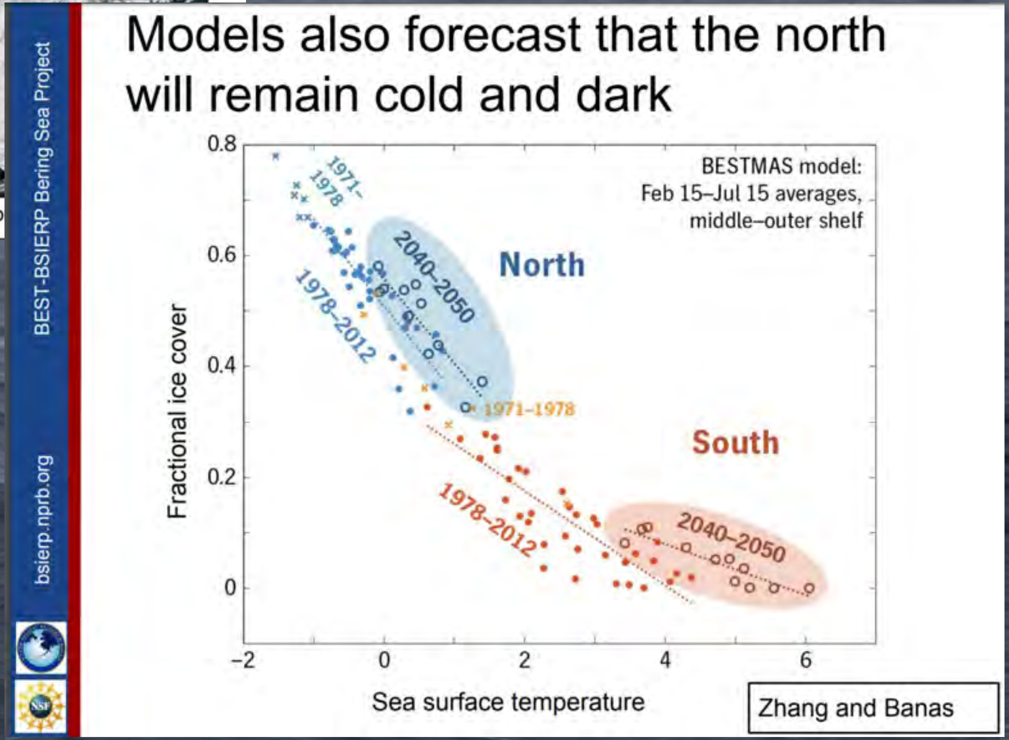


Brown and Arrigo 2012

Until recently processes appeared absent in the Pacific Arctic

- No significant trend in sea ice extent in Bering Sea

Shifts in the Pacific Arctic



Until recently processes appeared absent in the Pacific Arctic

- BEST/BIERP - assumed seasonal sea ice would form in high latitudes of NBS

Recent Trends

Oceanographic conditions in 2017-2019 are unprecedented

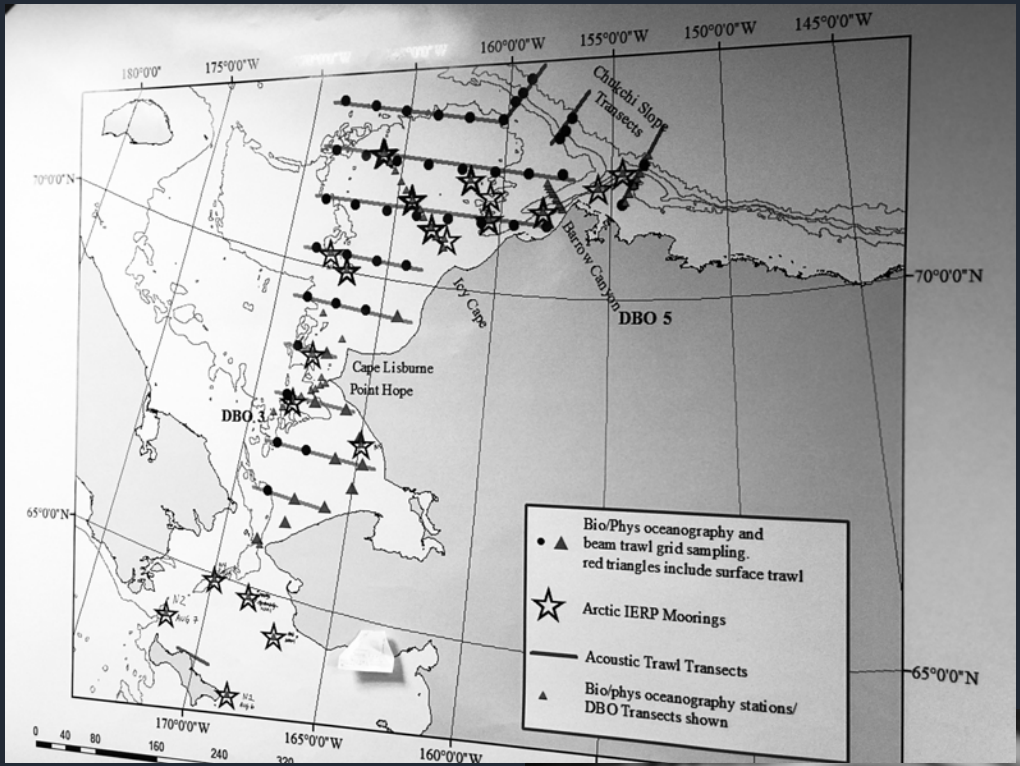
- near-complete lack of sea ice in winters 2017-2018, 2018-2019
- lowest sea ice cover on record in NBS
- first recorded absence of the cold pool separating the EBSS and NBSS
- massive primary productivity blooms
- northward movement of groundfish stocks
- decline in Arctic cod stocks in the region
- marine bird mortality events

Implications

- progressively later date of sea ice formation
- thinner winter ice less stable and shorter duration

Pressing Questions

- phase shift?
- how will processes and properties vary on interannual/decadal scales?
- mechanisms?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Chukchi Slope Transects
70°0'0"N
70°0'0"N
Barrow Canyon
Icy Cape
DBO 5
Cape Lisburne
Point Hope
DBO 3
65°0'0"N
65°0'0"N
Bio/Phys oceanography and beam trawl grid sampling. red triangles include surface trawl
Arctic IERP Moorings
Acoustic Trawl Transects
Bio/phys oceanography stations/ DBO Transects shown
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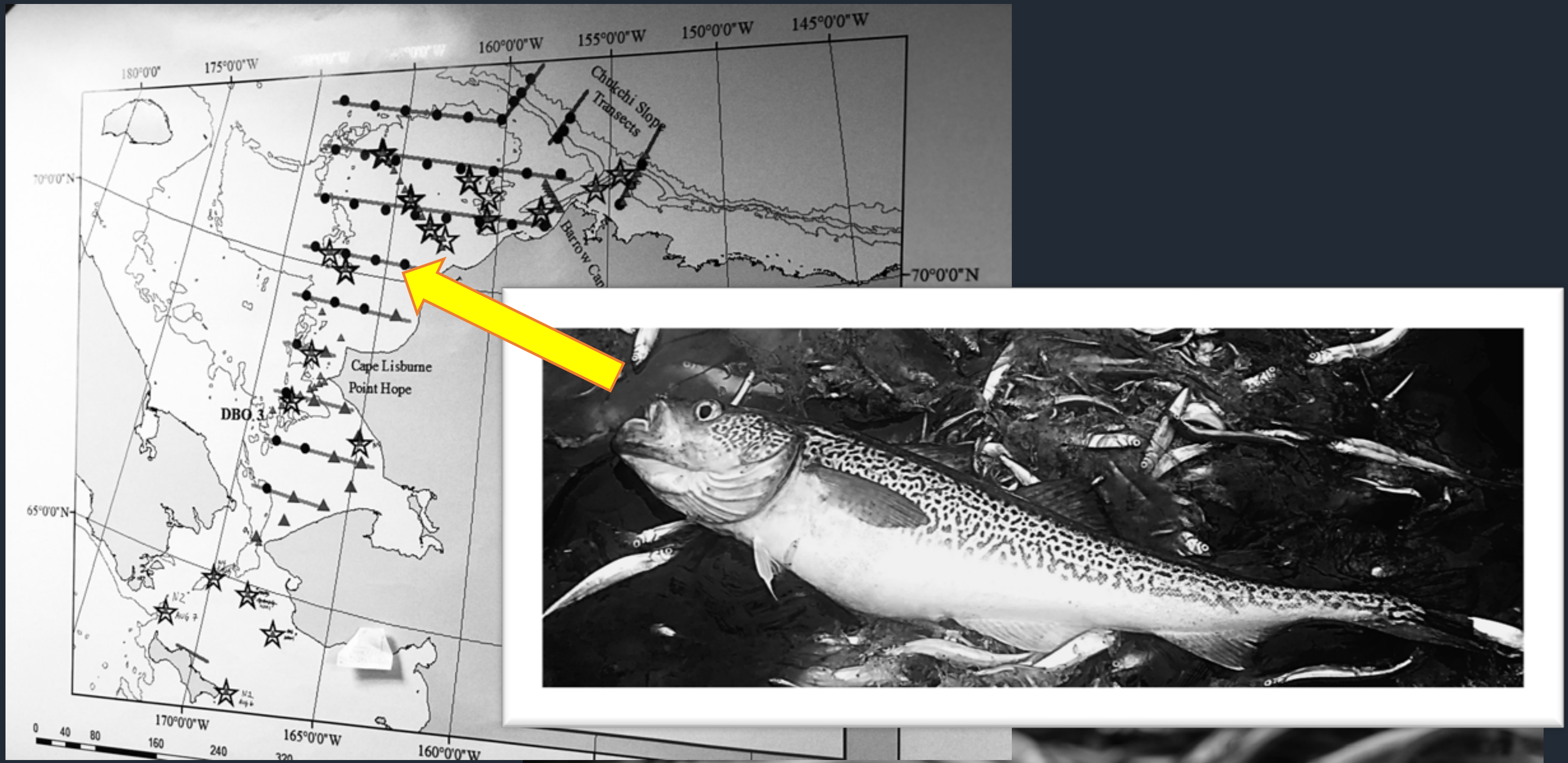
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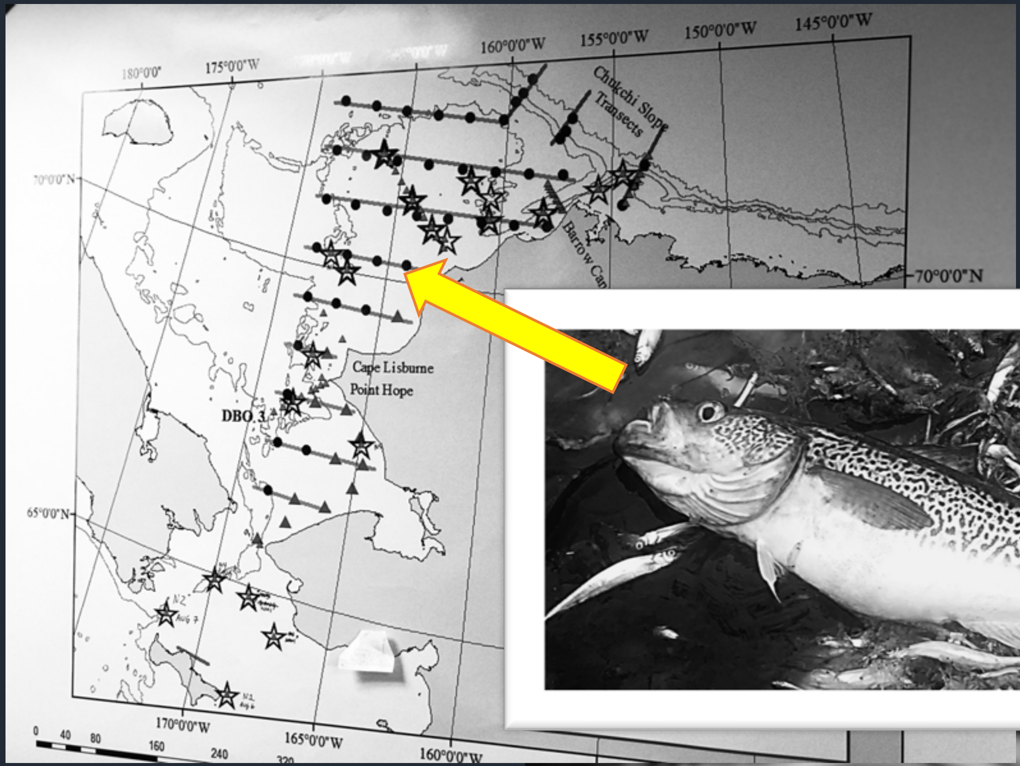
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Levi's

Our Motivation

- Need to integrate data and perspectives from eastern and western Pacific
- Opportunity for international collaboration

- Discussions and exchange at PICES workshops, data sharing in NBS (2016-2017)
- Discussions in NPSER (2016-2019)

POC Workshop (W9): The role of the northern Bering Sea in modulating Arctic environments: towards international interdisciplinary efforts

Co-sponsor: North Pacific Research Board (NPRB)

Convenors:
Lisa Eisner (USA)
Matthew Baker (USA)
Kirill Kivva (Russia)

Invited Speakers:
Seth Danielson (University of Alaska Fairbanks, USA)
Kirill Kivva (Russian Federal Research Institute of Fisheries and Oceanography (VNIRO), Russia)
Alexander Zavolokin (North Pacific Fisheries Commission (NPFC))

W1: MONITOR/TCODE Workshop
The role of the northern Bering Sea in modulating the arctic II: International interdisciplinary collaboration

Co-sponsor: NPRB

Convenors:
Matthew Baker (USA)
Lisa Eisner (USA)
Kirill Kivva (Russia)

Invited Speakers:
Maria Pisareva (Polar Oceanography Group, P.P. Shirshov Institute of Oceanology (IO) RAS, Russia)

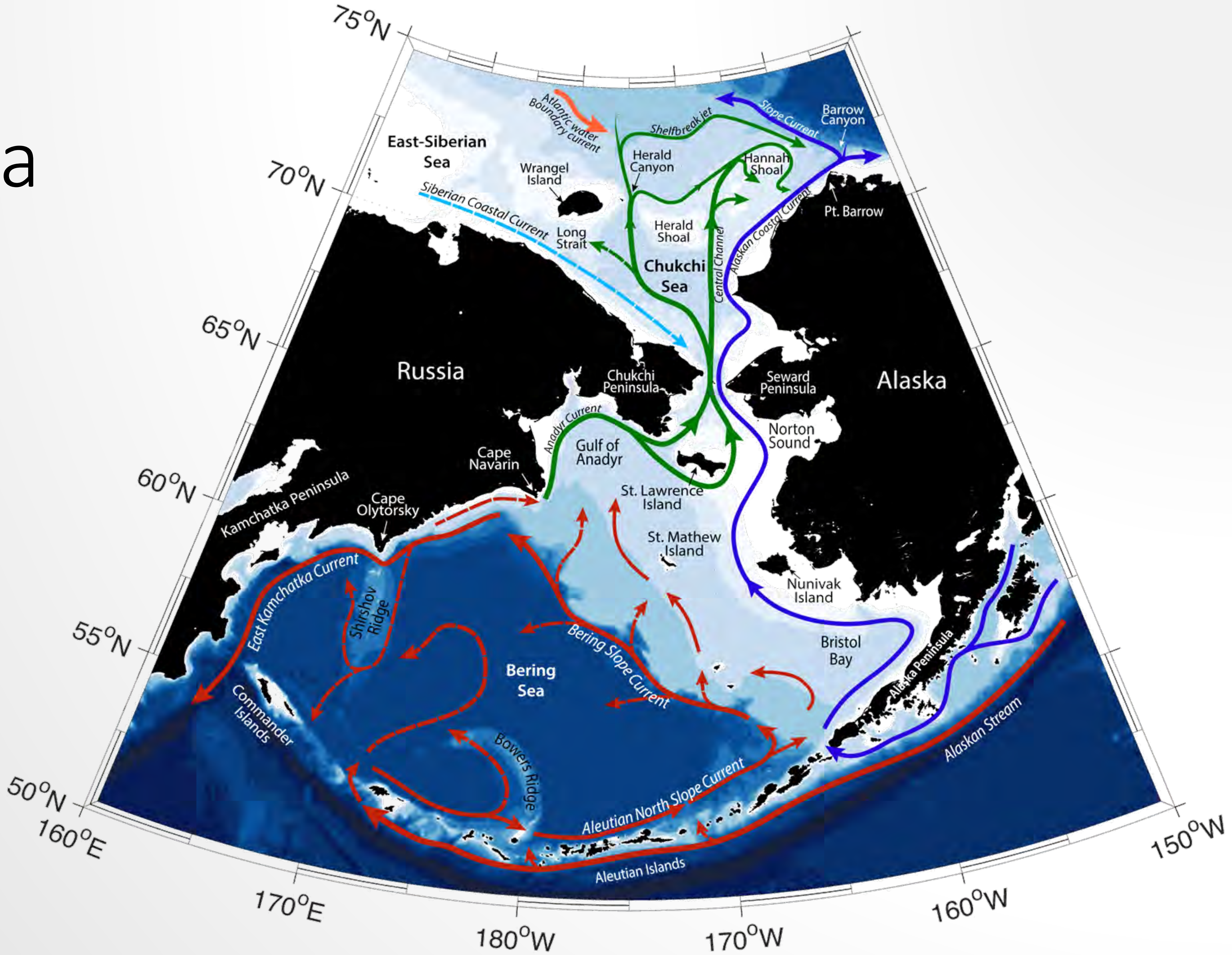
Our Data

- Sea Ice concentration
  - NSIDC SSMIS
- Bering Sea cold pool
  - NOAA surveys
- SST (Bering Sea)
  - NASA High Resolution Level 4
  - CoastWatch ERDDAP, MEaSUREs
- SST (Bering-Chukchi)
  - NOAA Optimal Interpolation
- Wind
  - European Centre for Medium-Range Weather Forecasts ERA5 reanalysis data

Our Approach

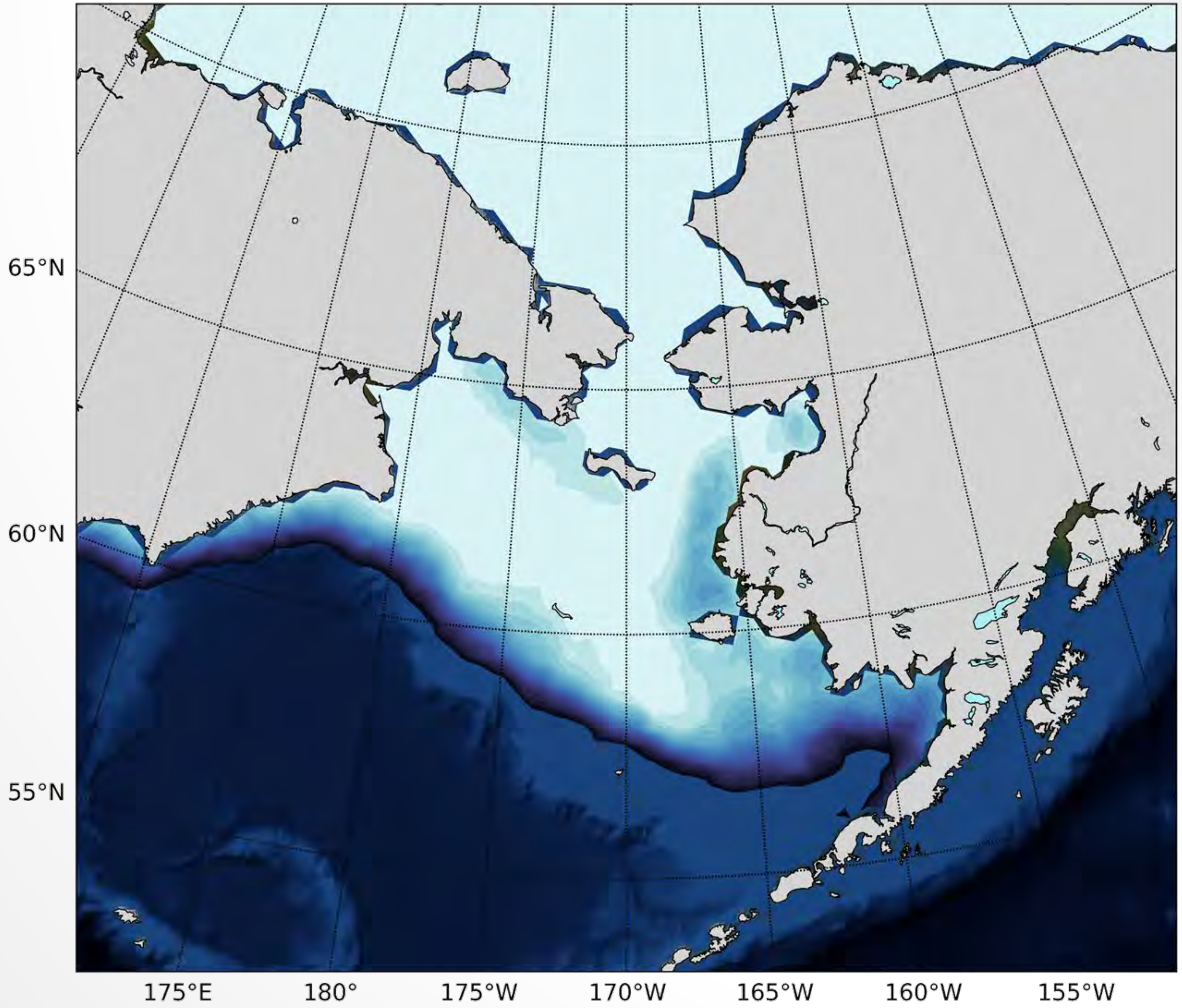
- Integrate remote sensing and in situ data
- Consider data at various resolutions and spatial scales
- Compare Bering and Chukchi ecosystems
- Examine east-west gradients within BS/CS
- Use patterns in SST to identify:
  - areas of convergence and differentiation
  - sub-regional patterns in the shelf-basin
  - how regional properties influence system-scale processes.

Research Area



Sea Ice Extent

Sea ice extent at the approximate point of season maximum, March 15 (1980)

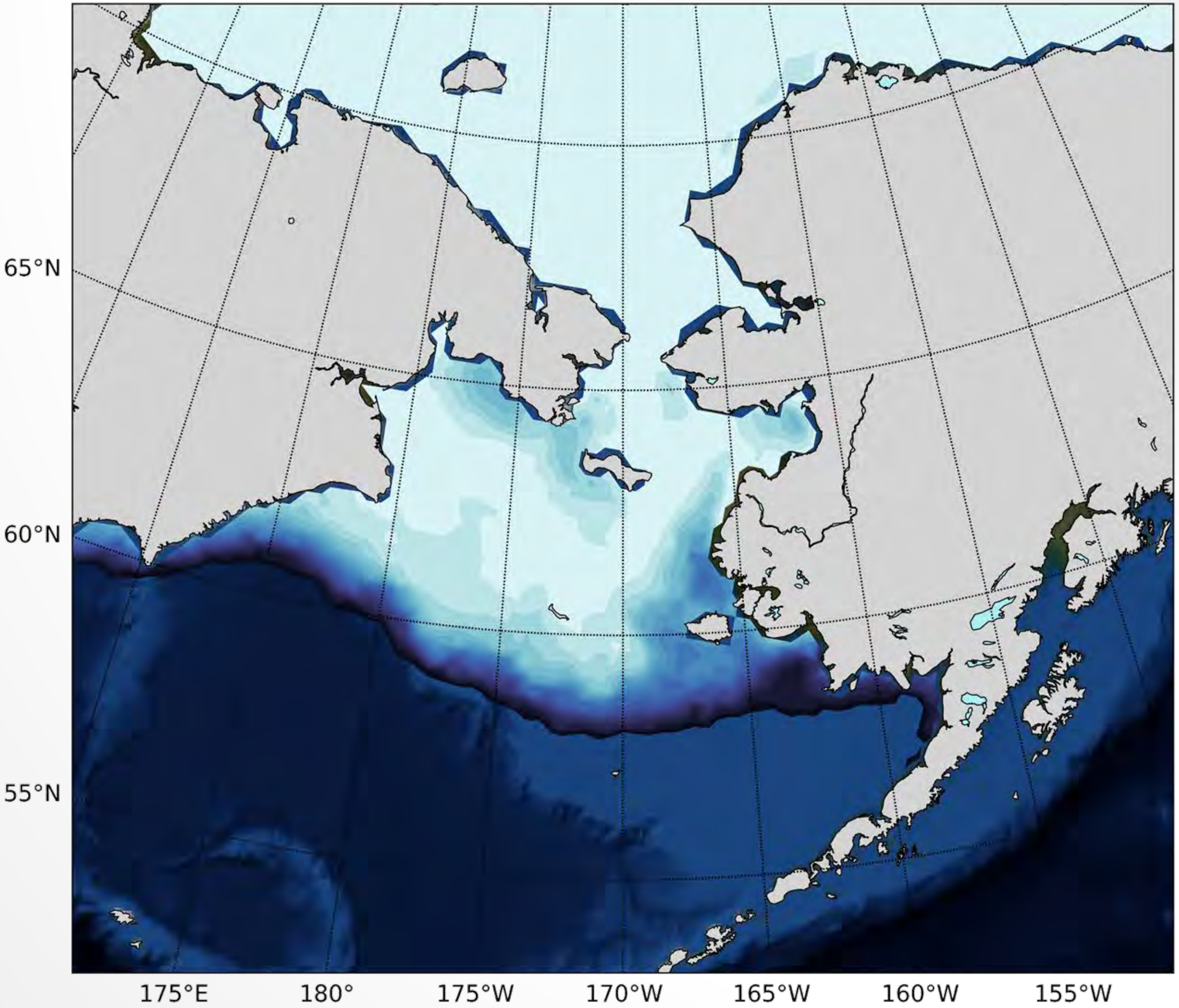


Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

polar stereographic grid of nominal resolution 25 × 25 km.

Sea Ice Extent

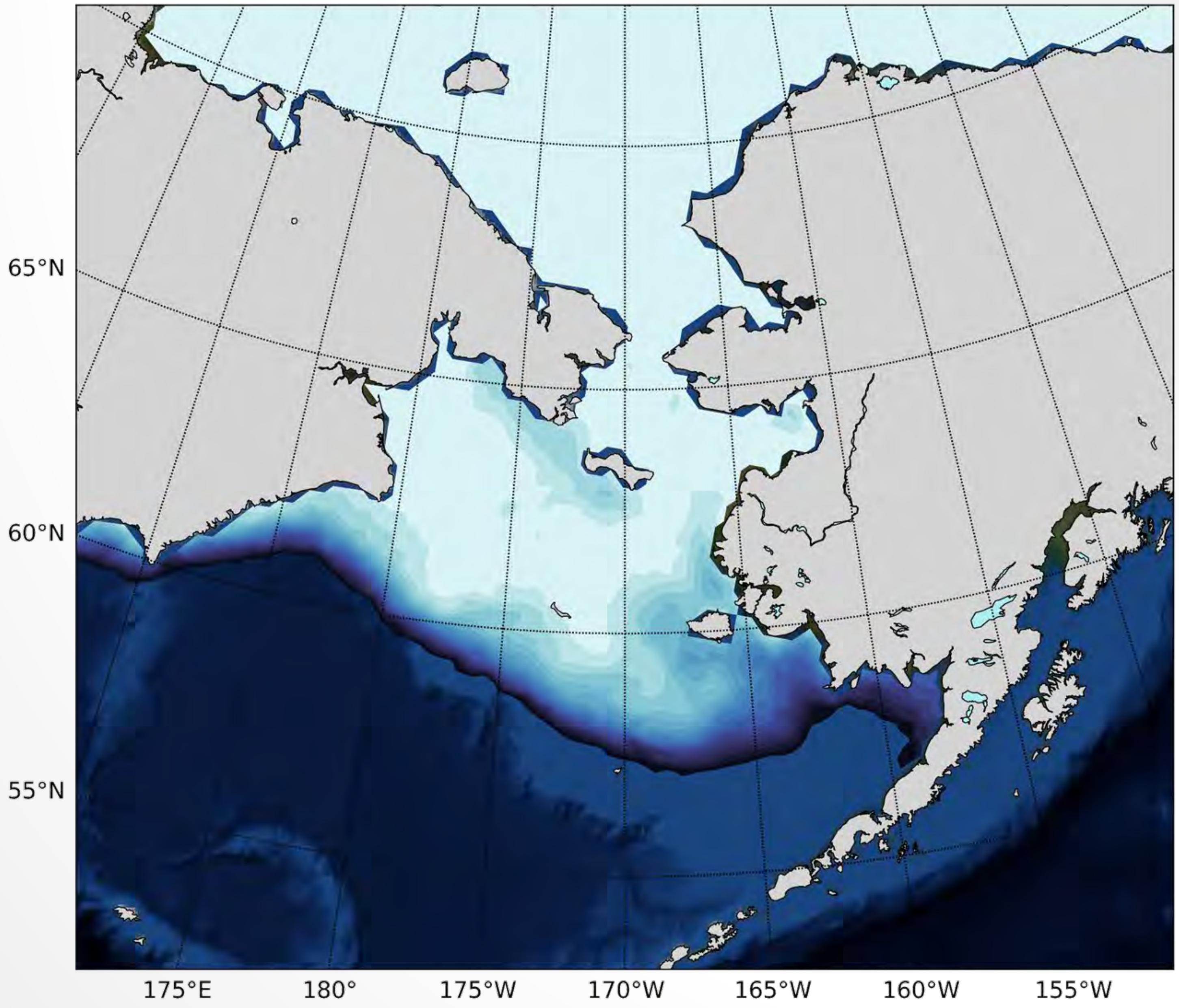
Sea ice extent at the approximate point of season maximum, March 15 (1981)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

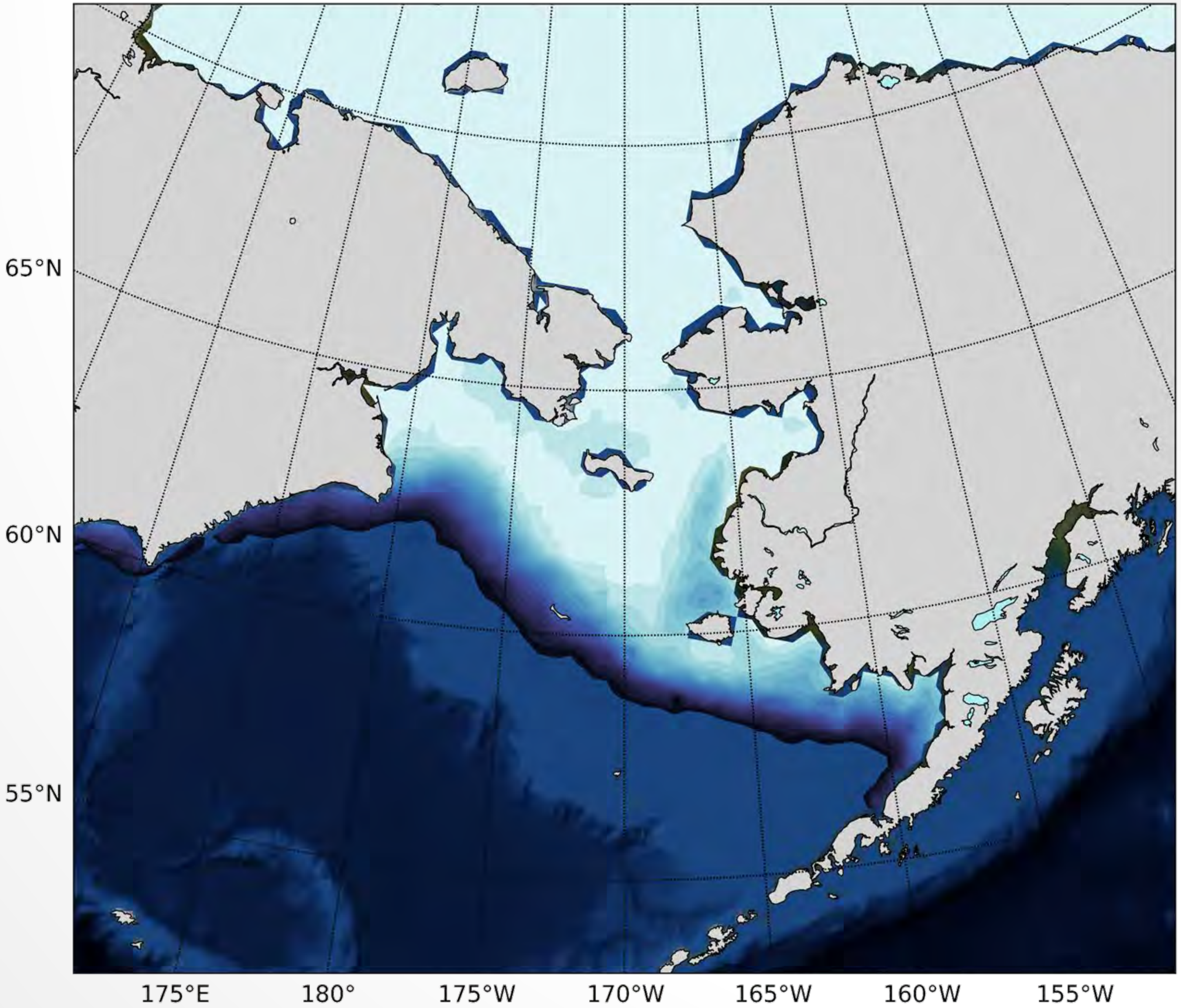
Sea ice extent at the approximate point of season maximum, March 15 (1982)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

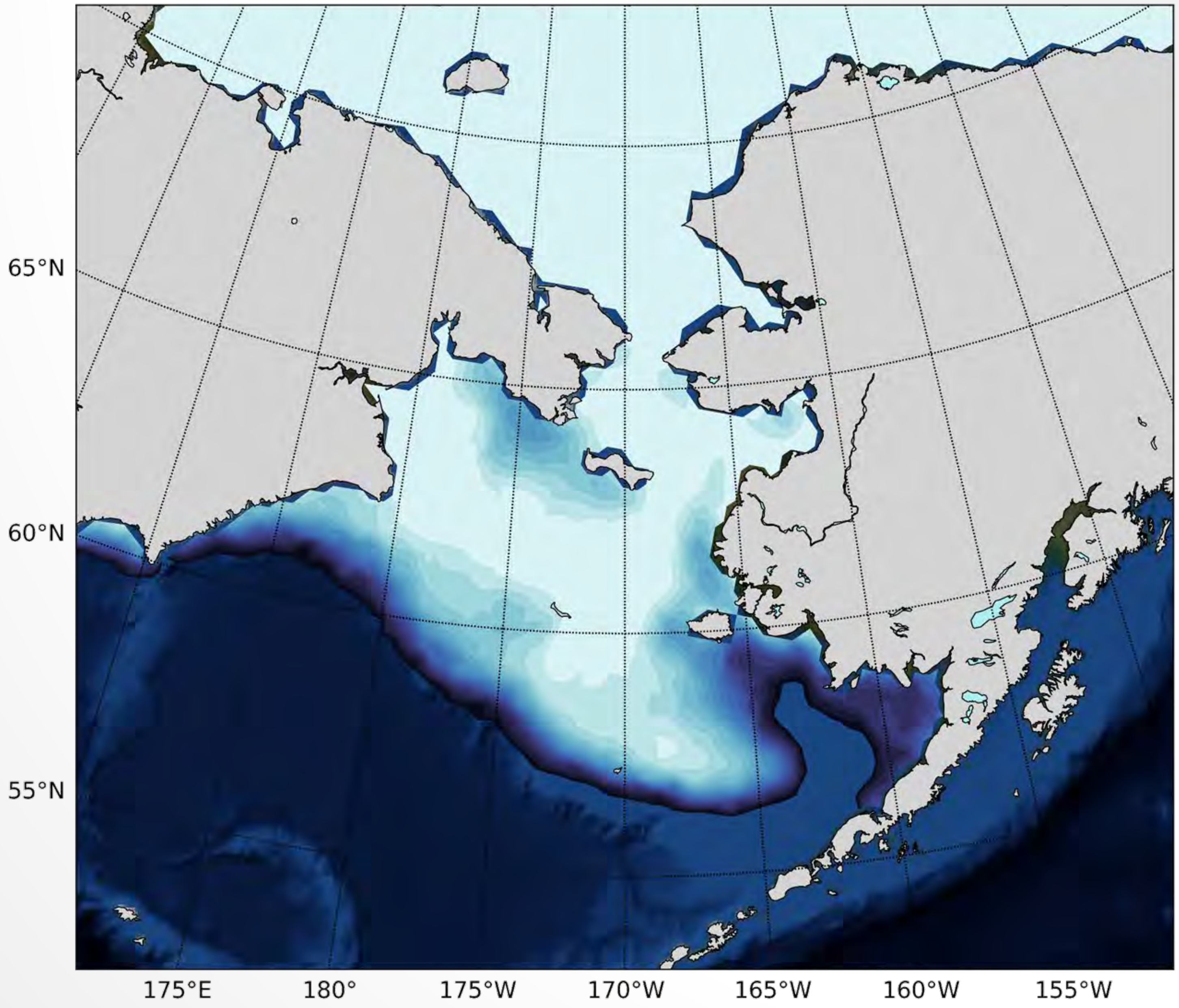
Sea ice extent at the approximate point of season maximum, March 15 (1983)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

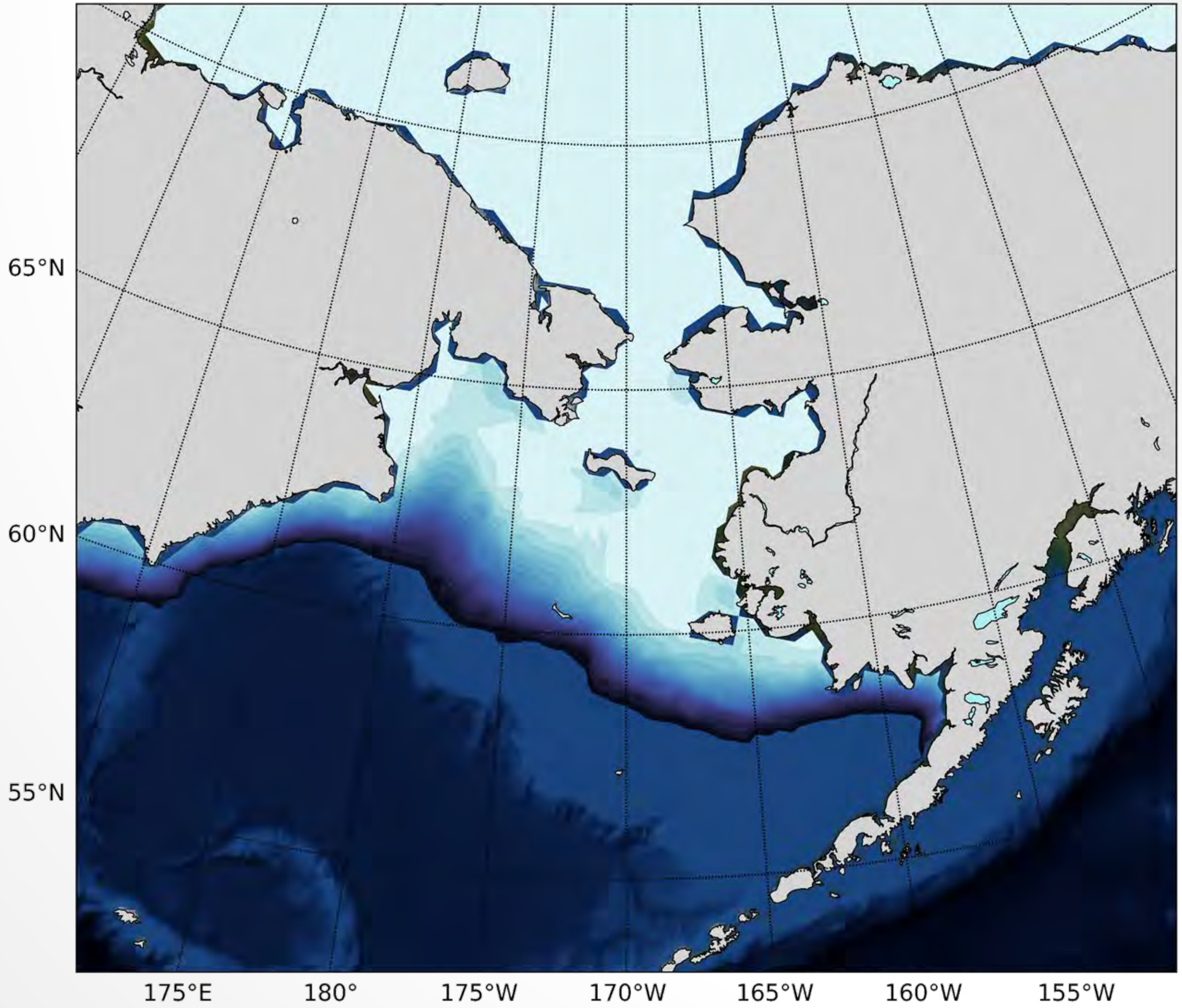
Sea ice extent at the approximate point of season maximum, March 15 (1984)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

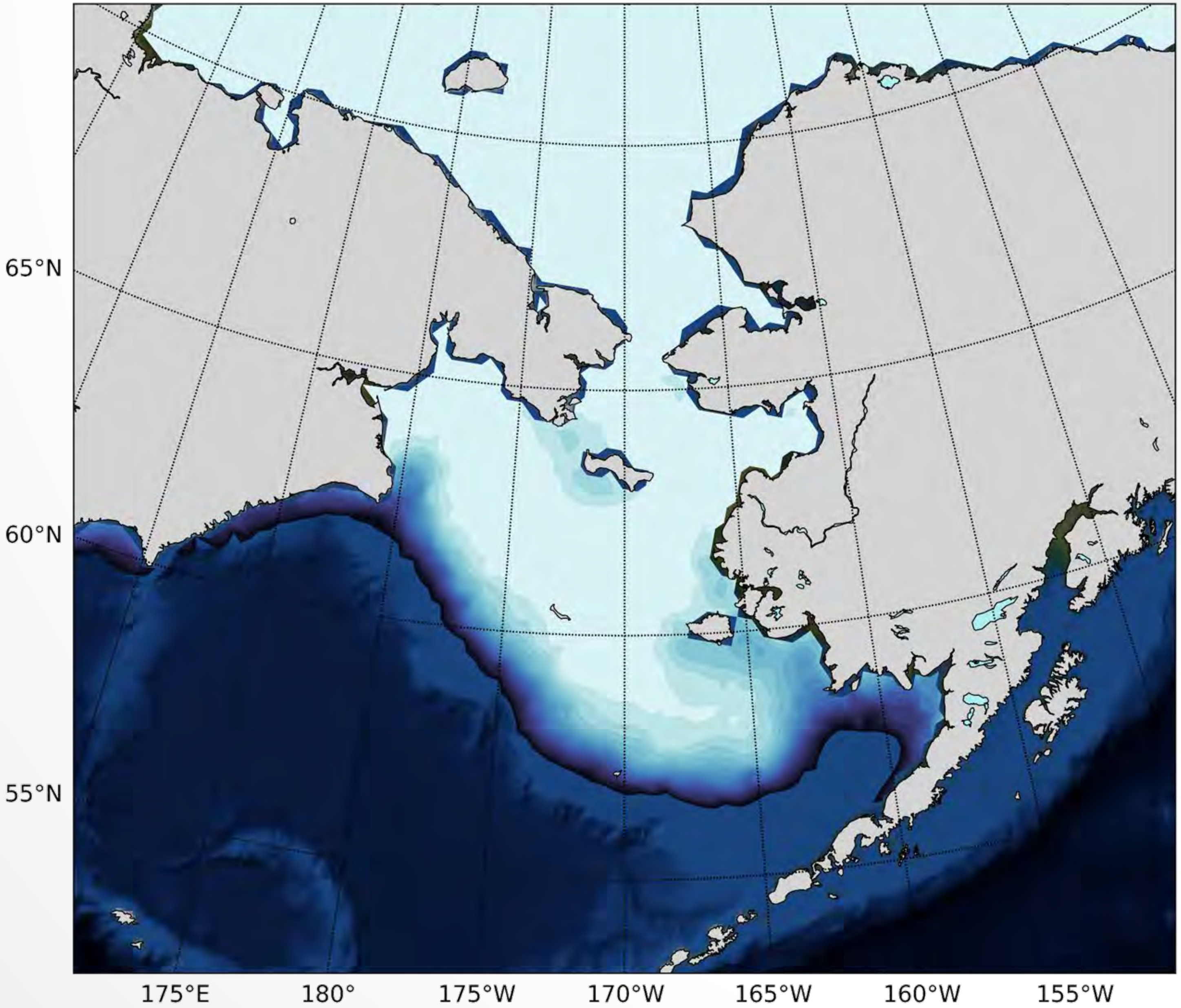
Sea ice extent at the approximate point of season maximum, March 15 (1985)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

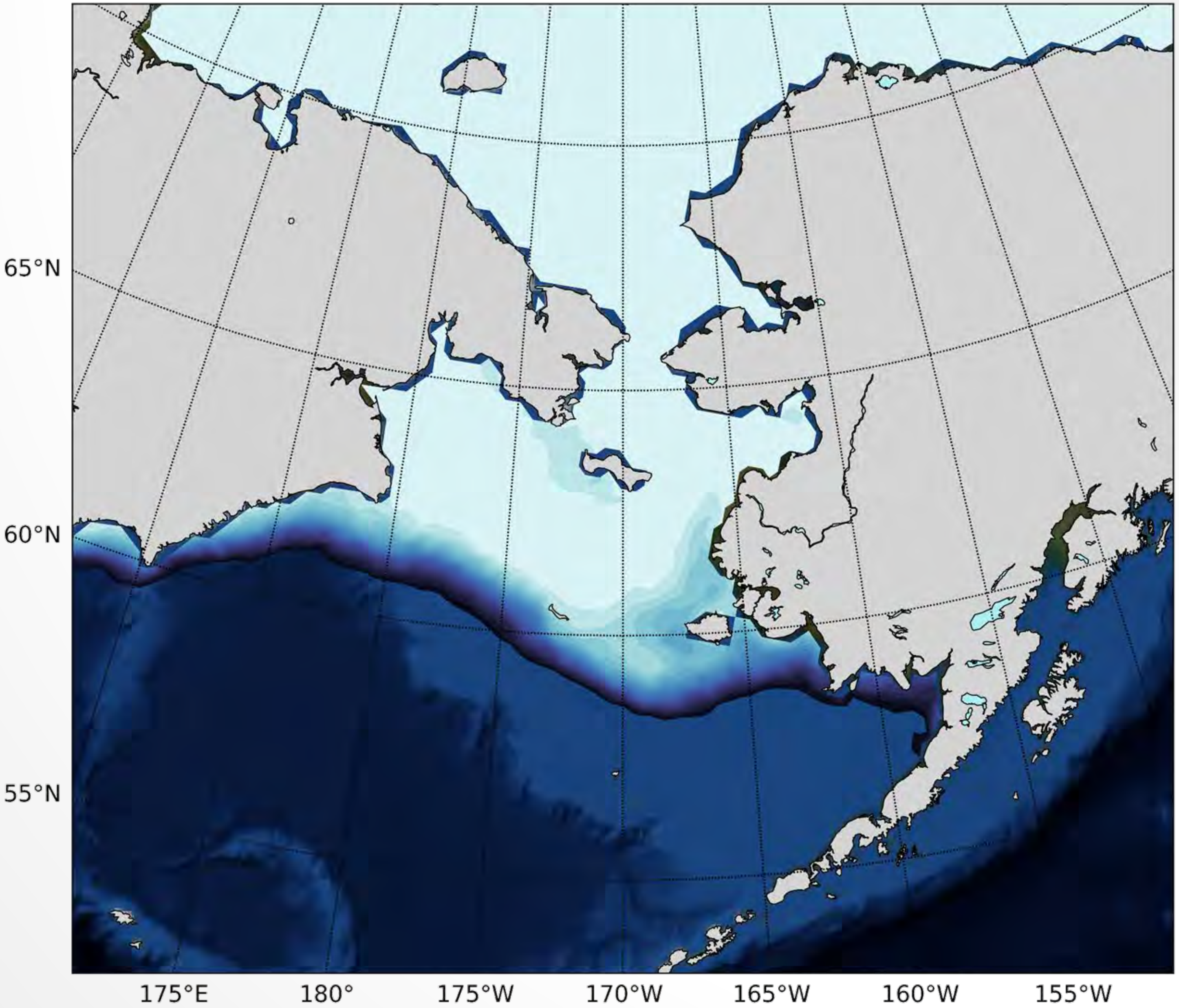
Sea ice extent at the approximate point of season maximum, March 15 (1986)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

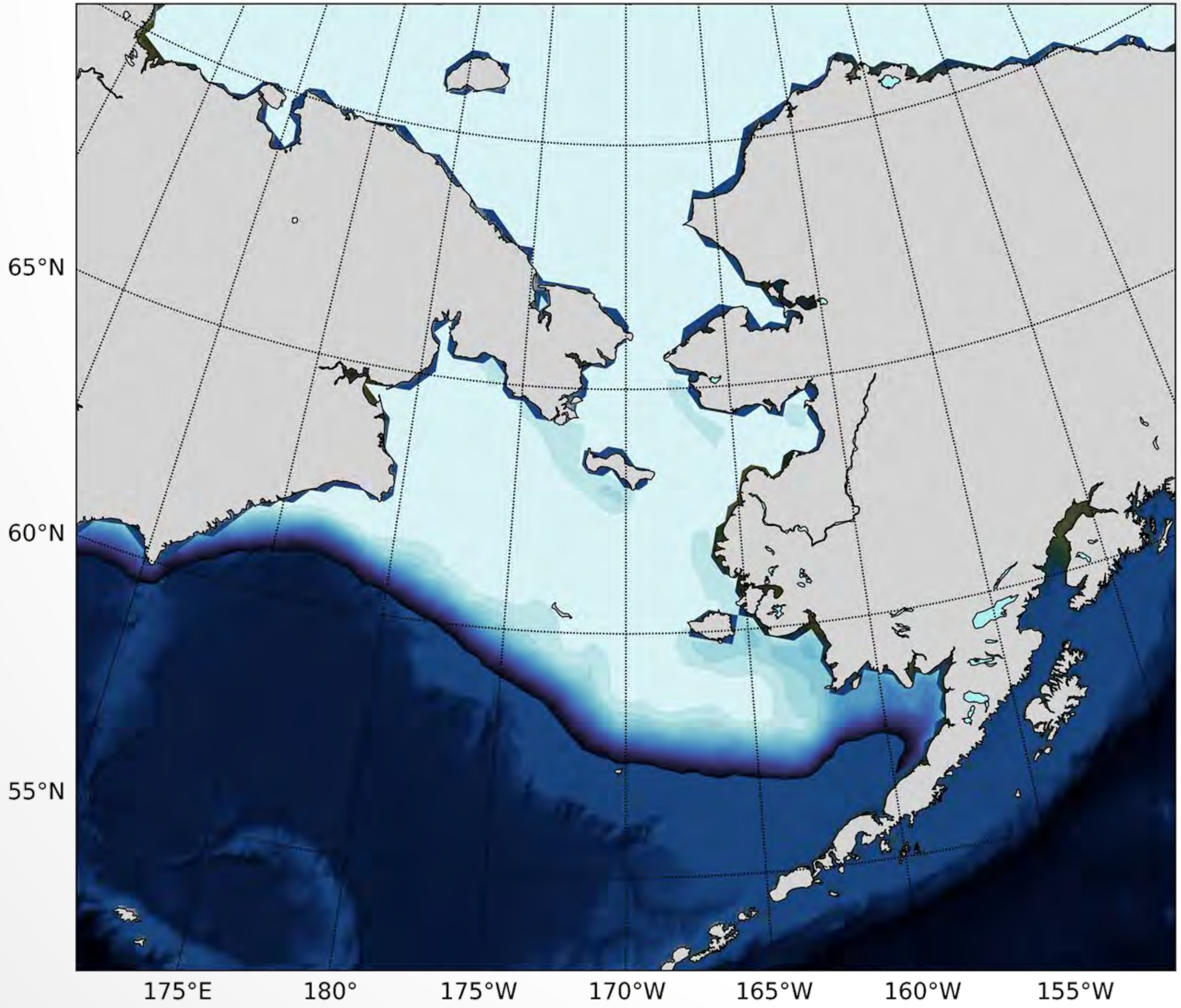
Sea ice extent at the approximate point of season maximum, March 15 (1987)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

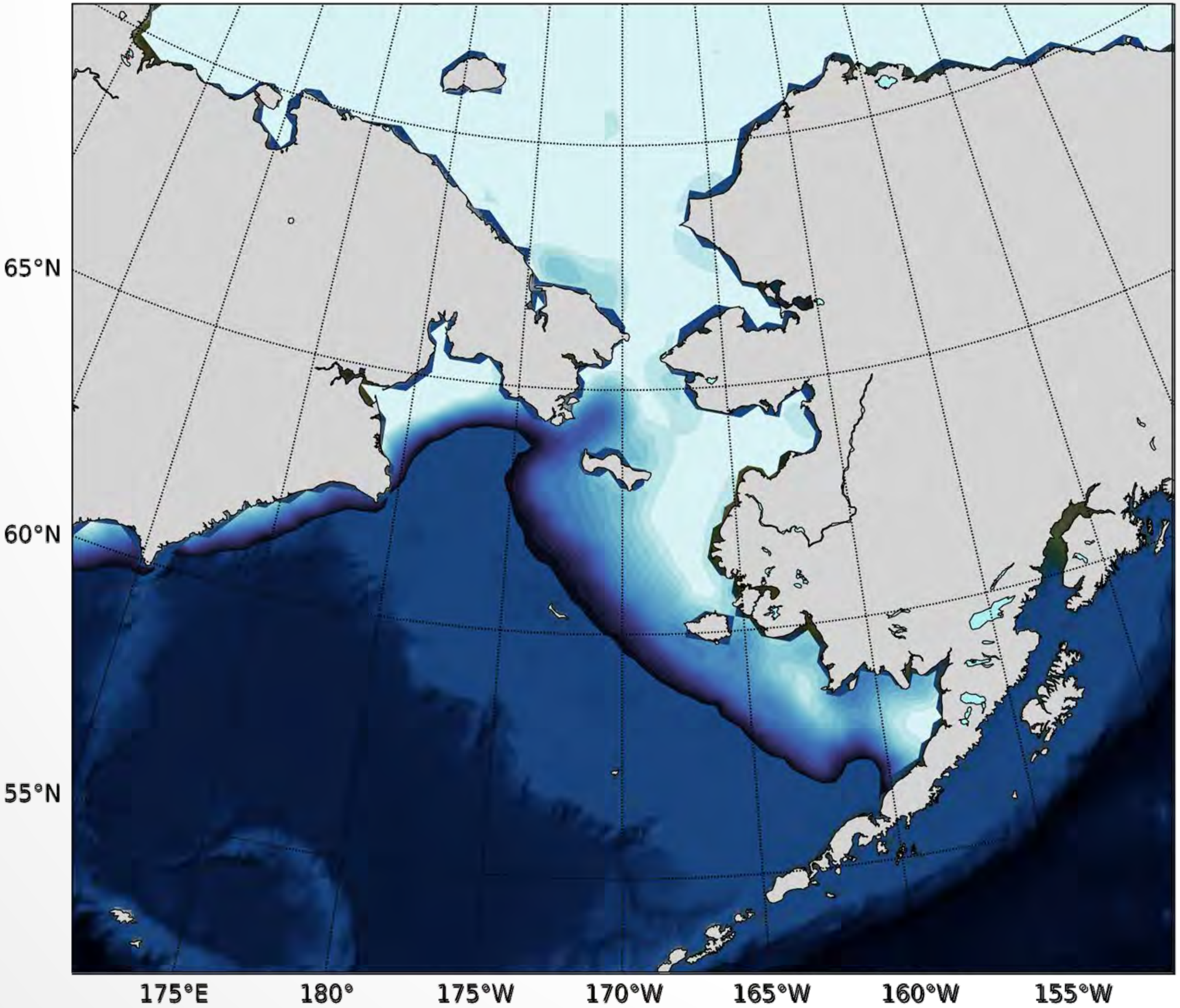
Sea ice extent at the approximate point of season maximum, March 15 (1988)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

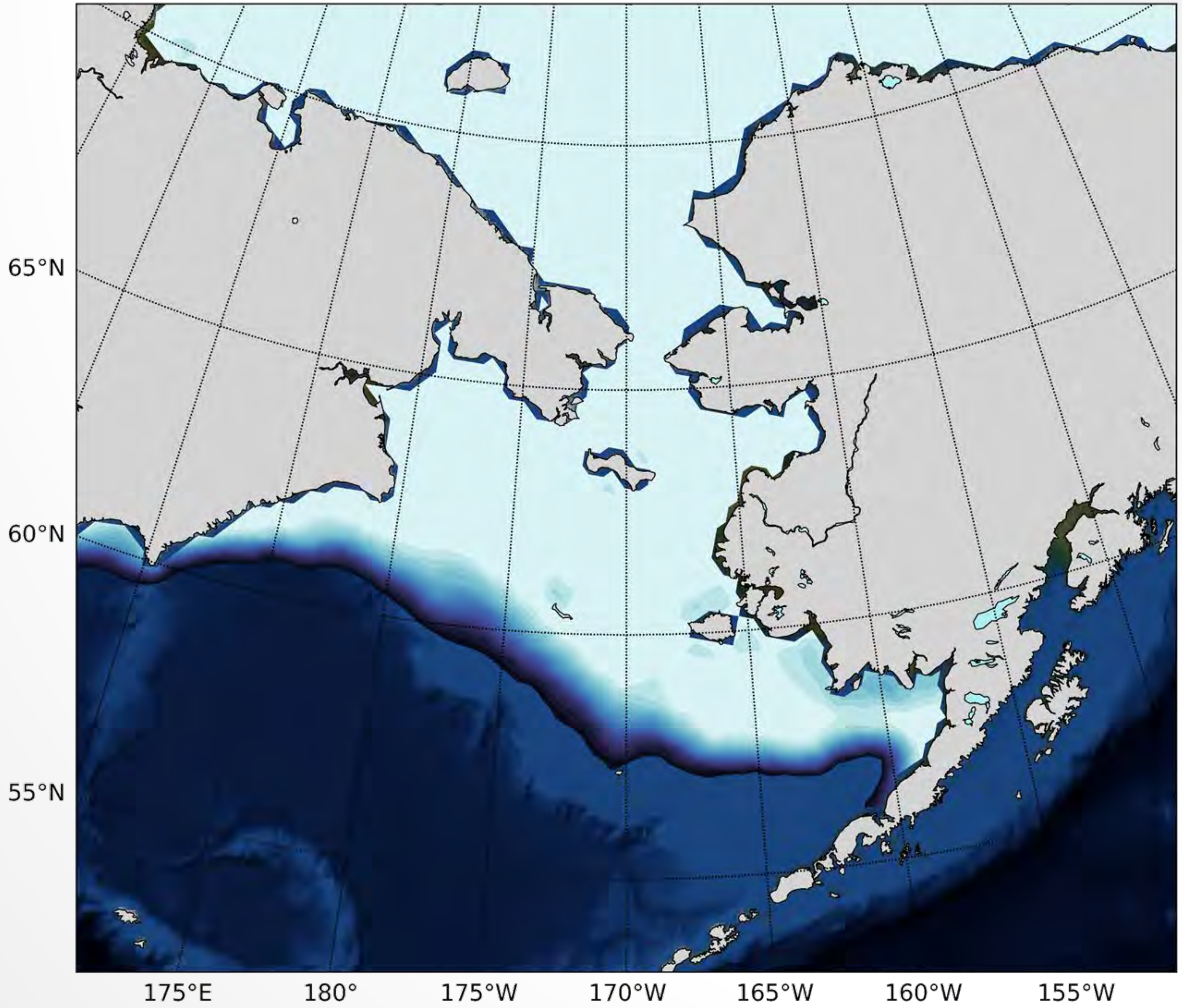
Sea ice extent at the approximate point of season maximum, March 15 (1989)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Sea Ice Extent

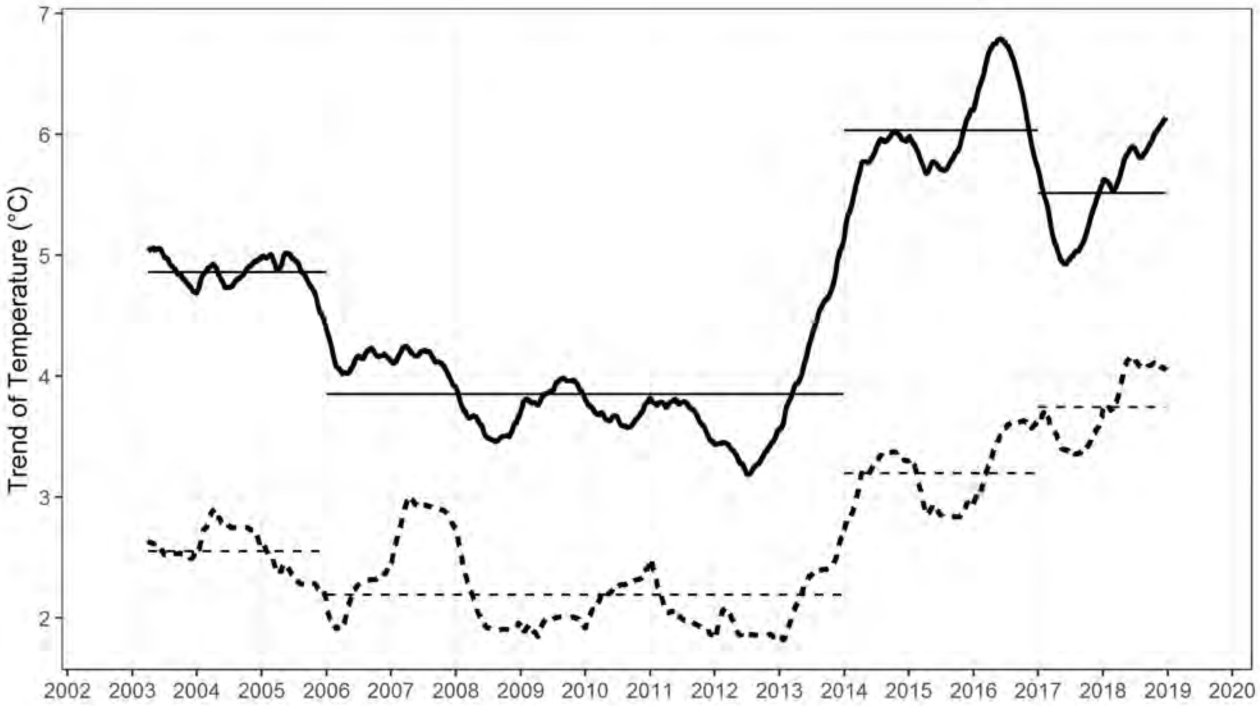
Sea ice extent at the approximate point of season maximum, March 15 (1990)



Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)

Data for the BS shelf were derived from NASA aggregated via the NOAA CoastWatch West Coast Node ERDDAP

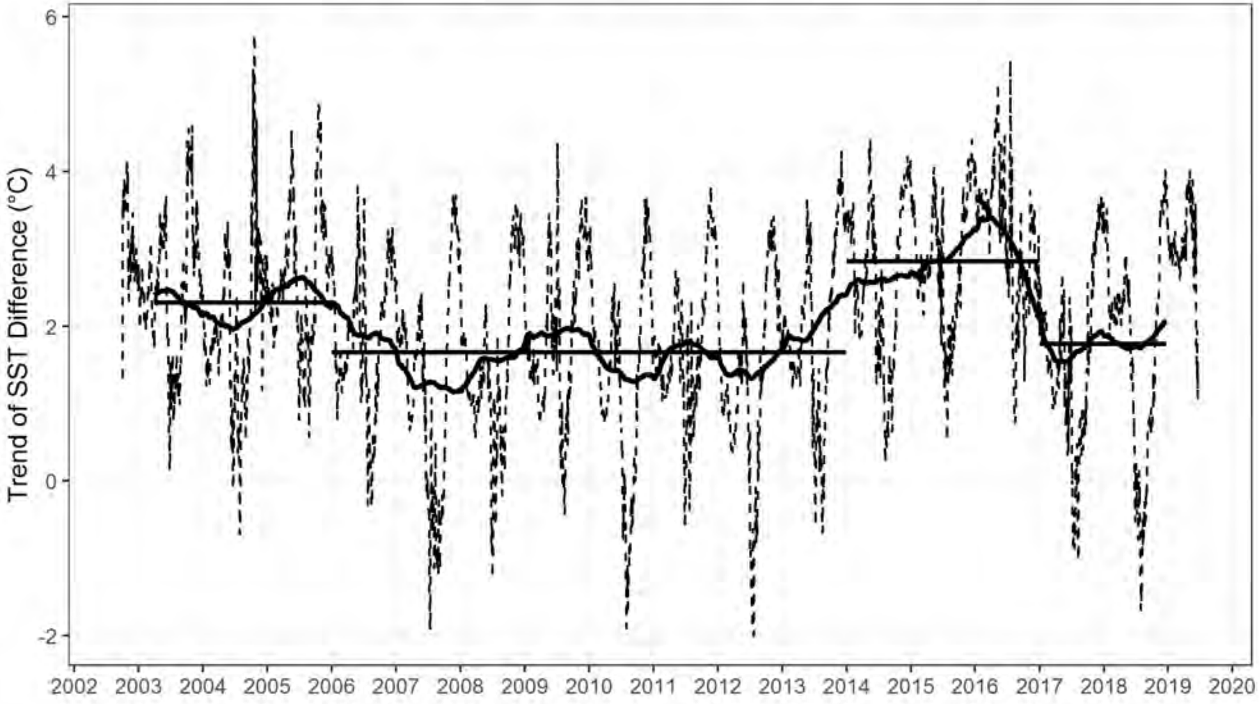
- o EBSS data south of 60°N (–)
- o NBSS data between 60°N and 65.5°N (…)



Time series trend (–)

EBS and NBS temperature difference (…)

- o positive values indicate > temp in EBS



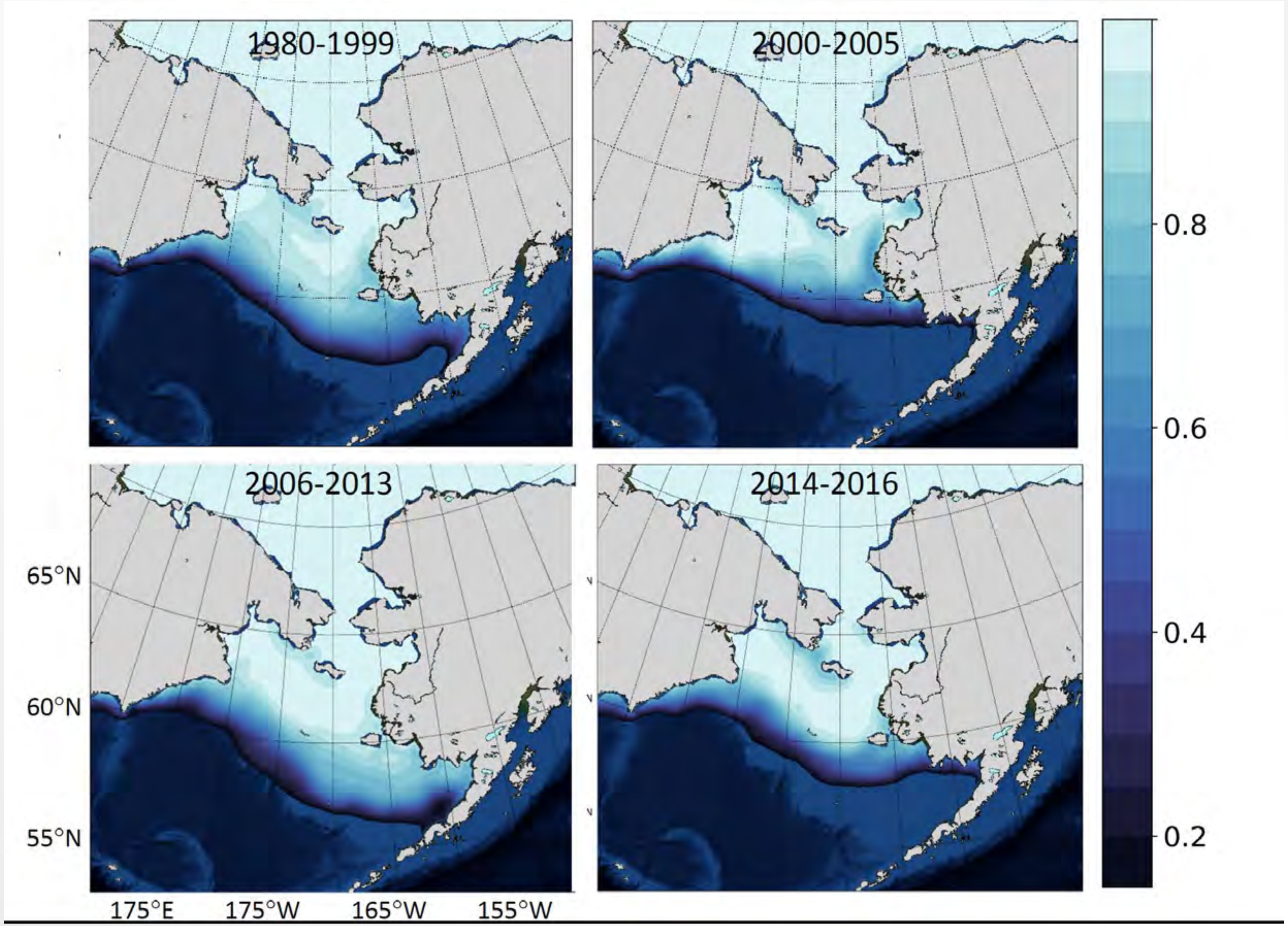
NASA Group for High Resolution Sea Surface Temperature Level 4 analysis, JPL MUR MEaSUREs

Our Research

Mean sea ice extent at the approximate point of season maximum, March 15, compiled in discrete temperature phases,

1980-1999 (high variability)
2000-2005 (warm)
2006-2013 (cold), bottom right
2014-2016 (warm), bottom

Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)



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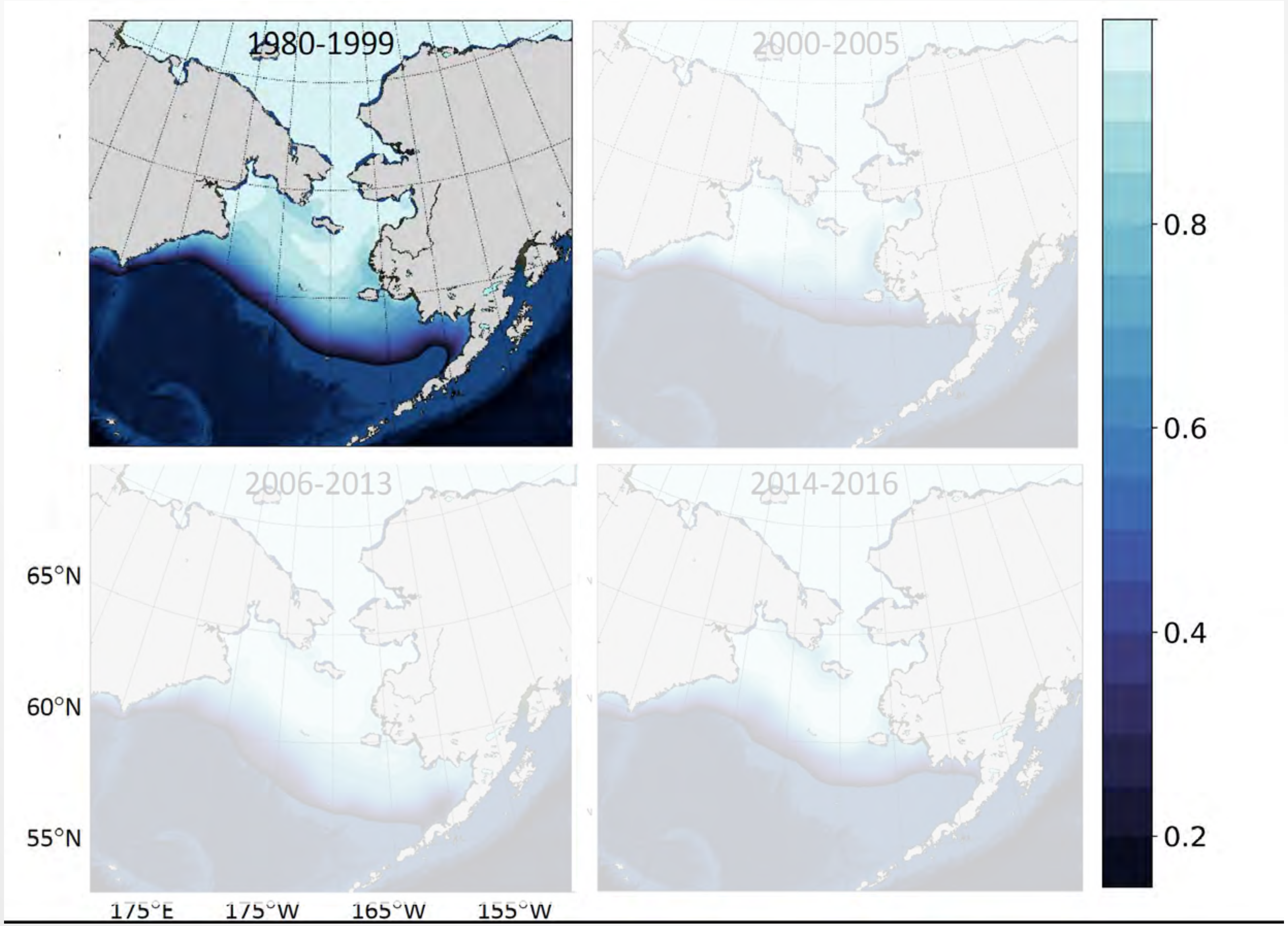

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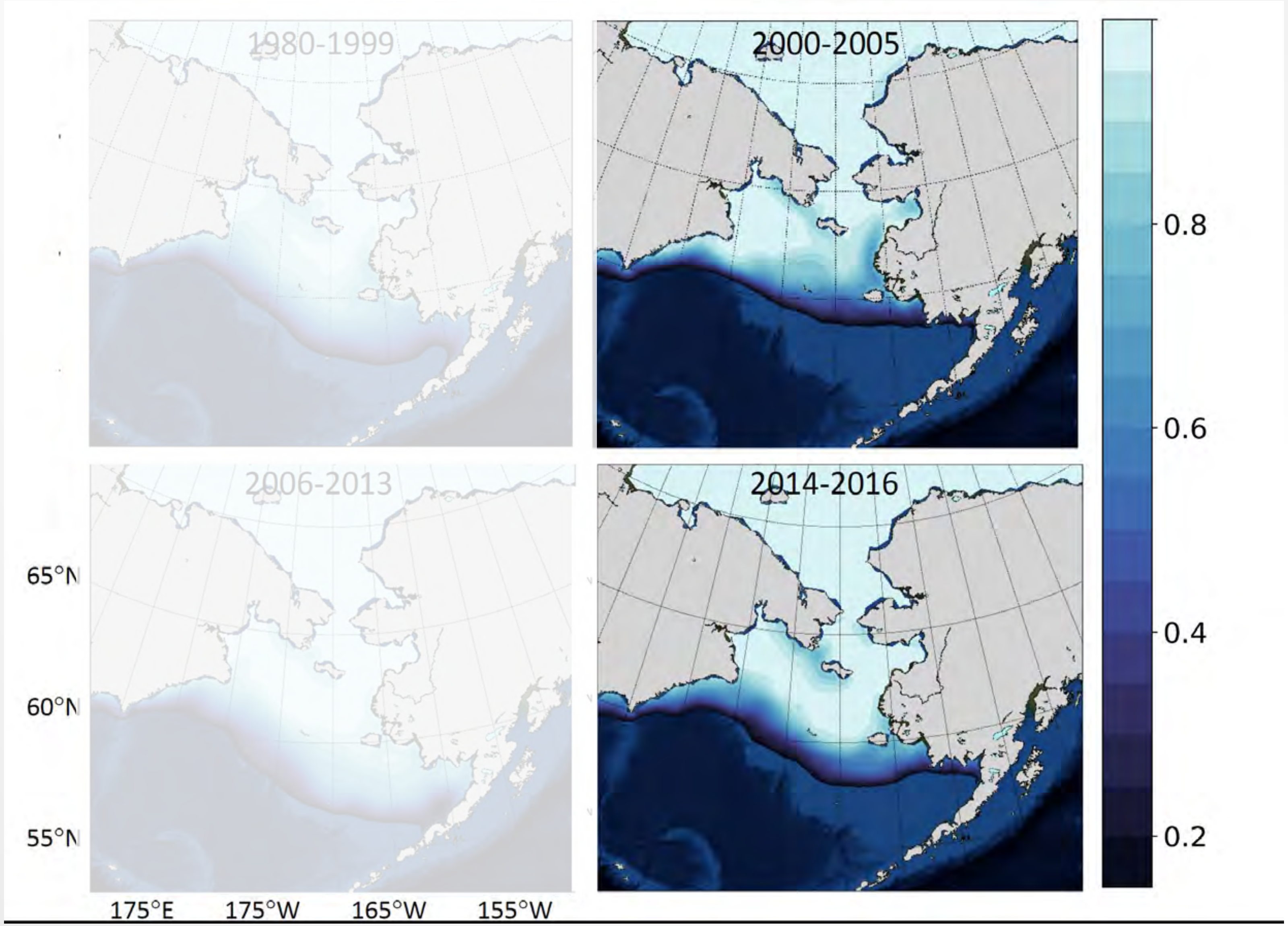

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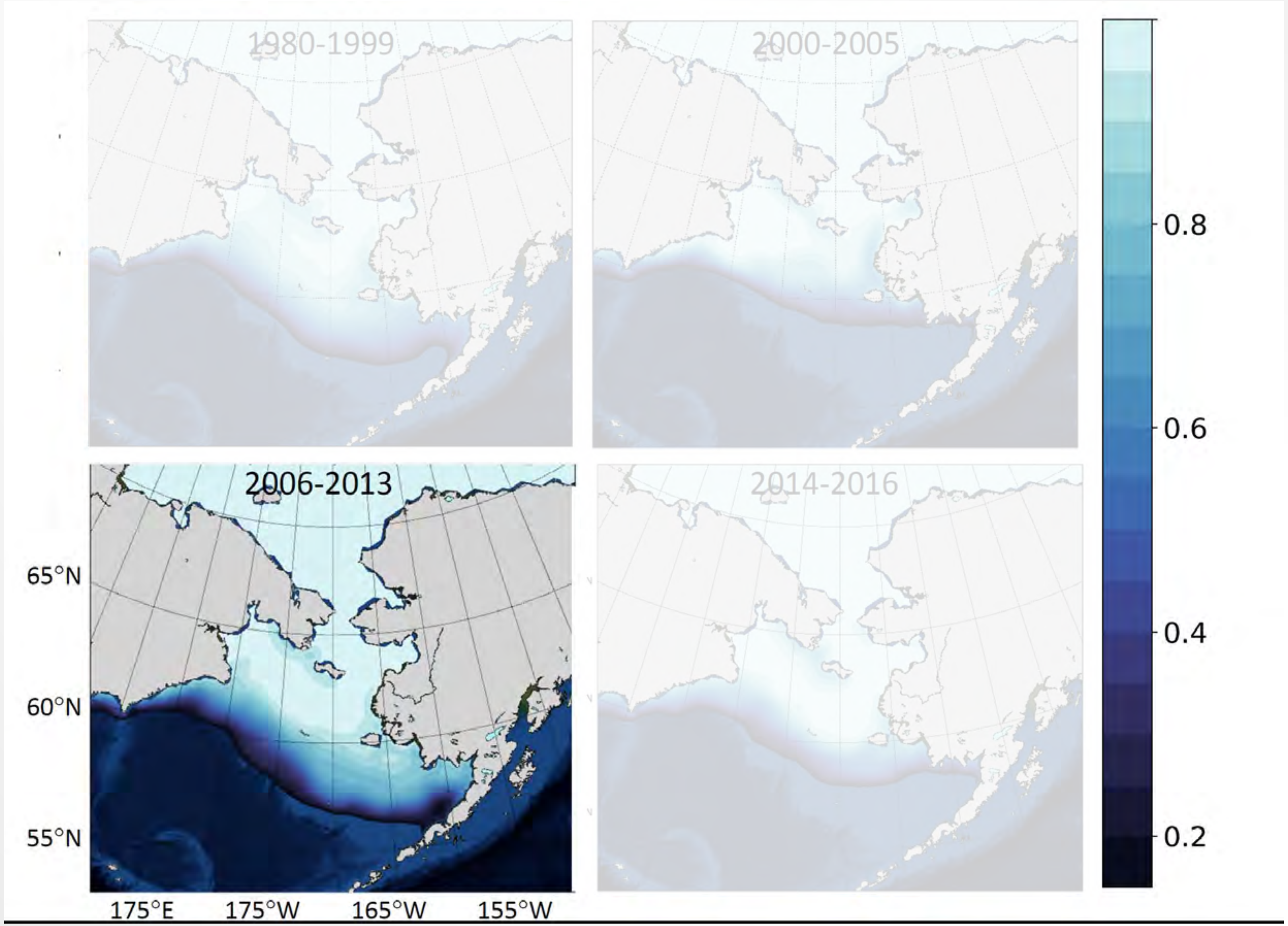
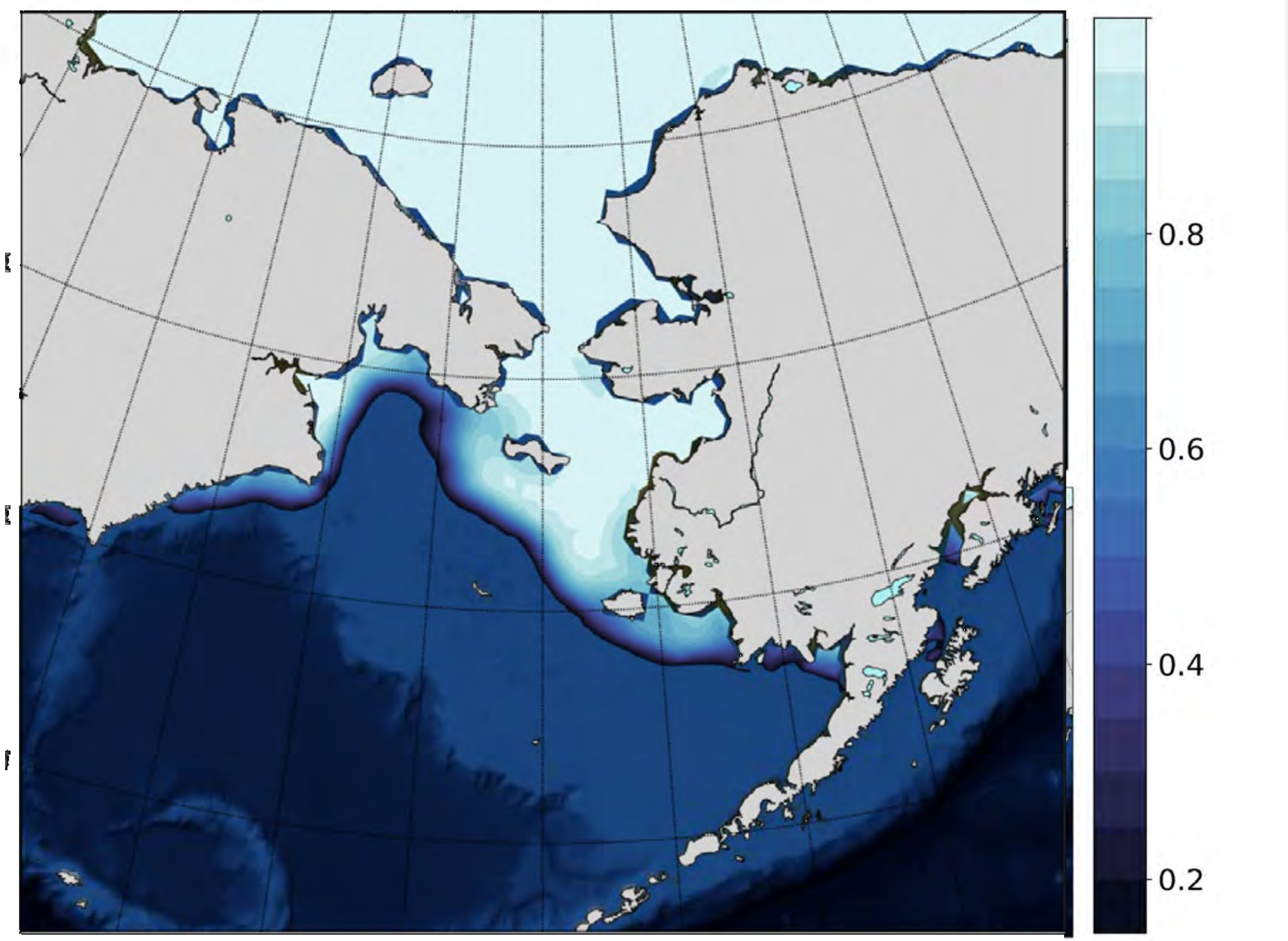


Our Research

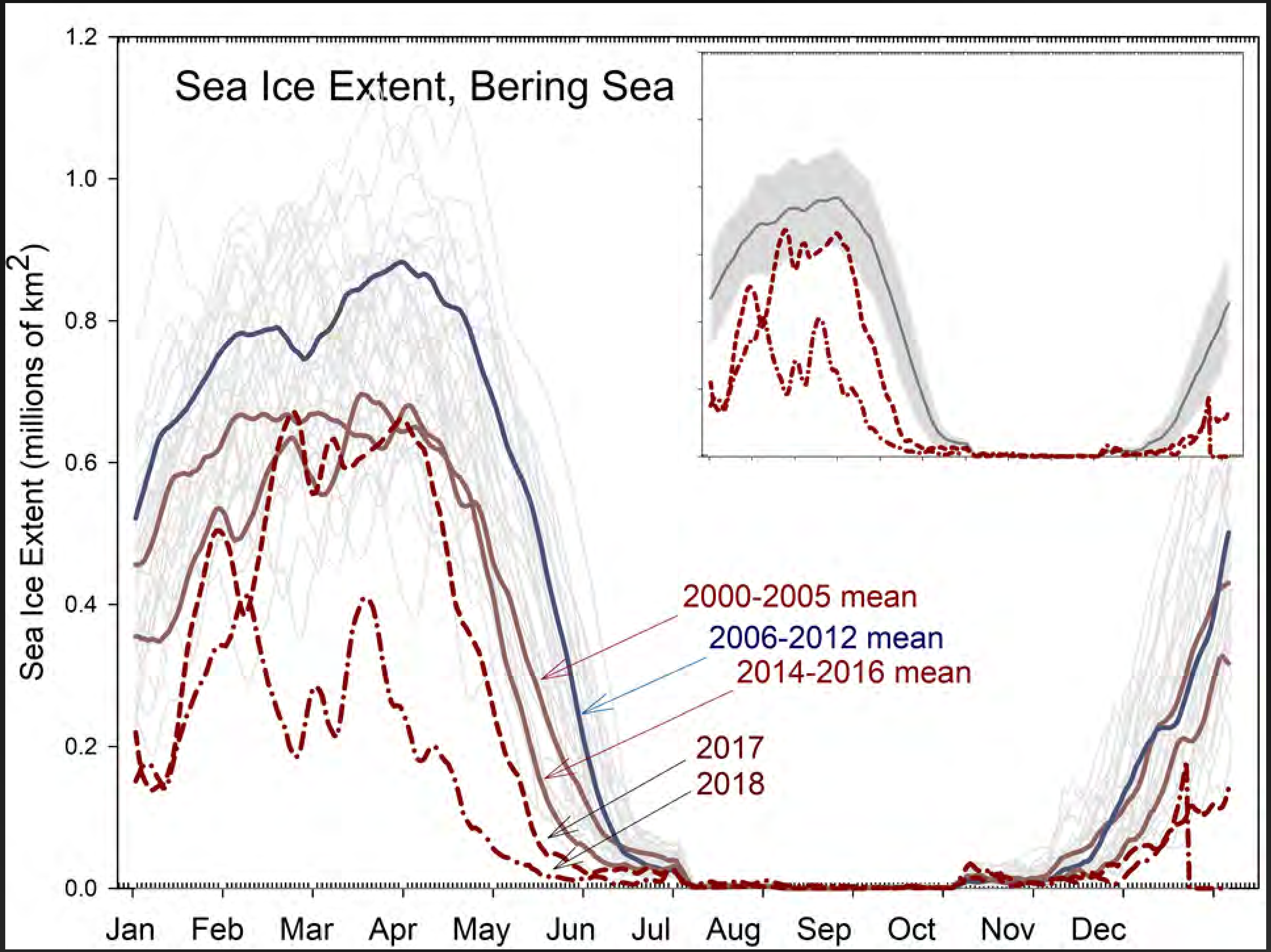
2017-2018 (anomalously warm)

Sea ice concentration - NSIDC Special Sensor Microwave Imager and Sounder (1979-2018)



Sea Ice Extent

- Differences in annual areal extent and duration in identified stanzas



Sea Ice Index Regional 270 Monthly Data G02135_v3.0].

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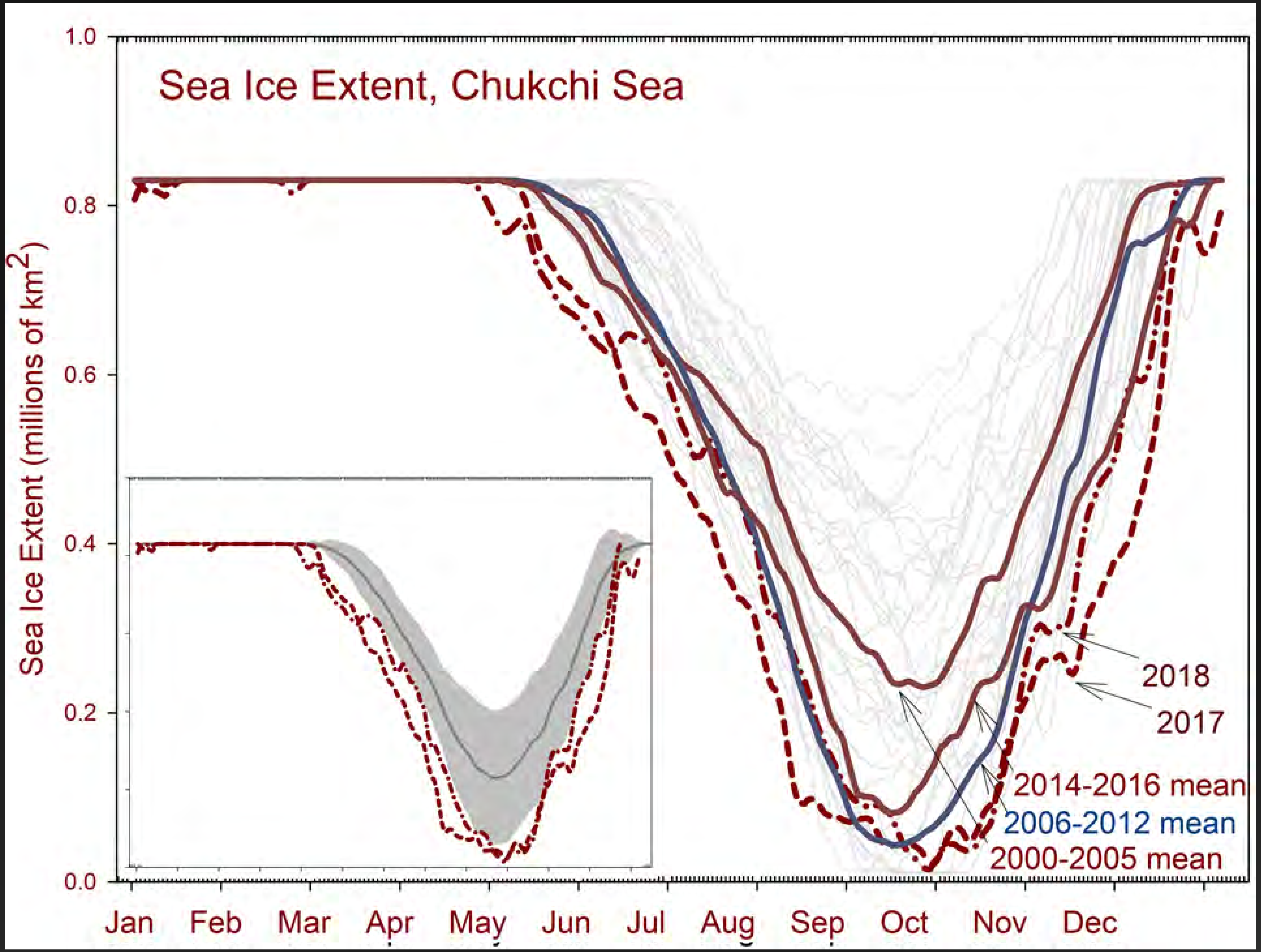


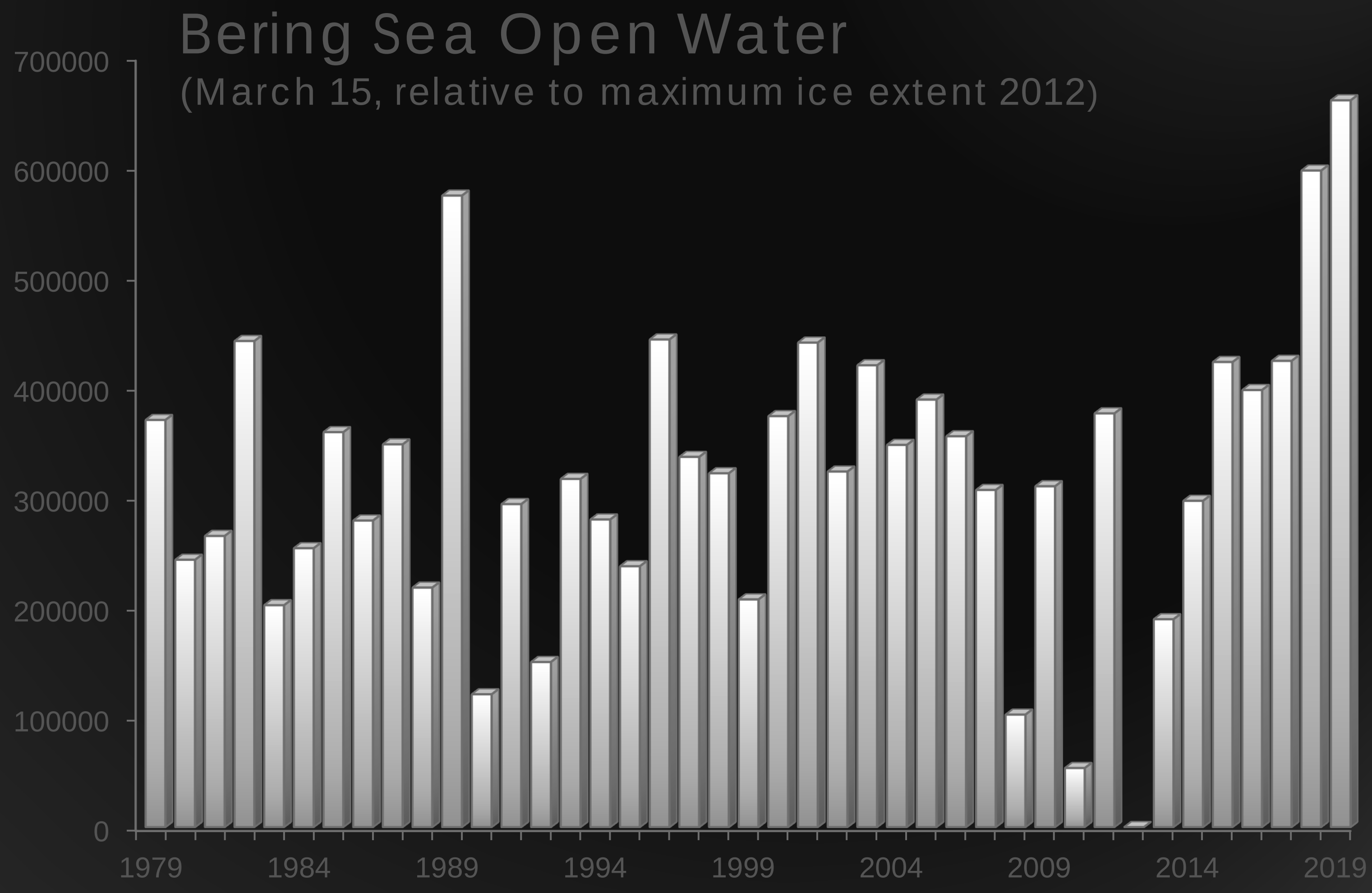
Sea Ice Index Regional 270 Monthly Data G02135_v3.0].

Open Water

In Bering Sea, our index of interest was extent of sea ice coverage.

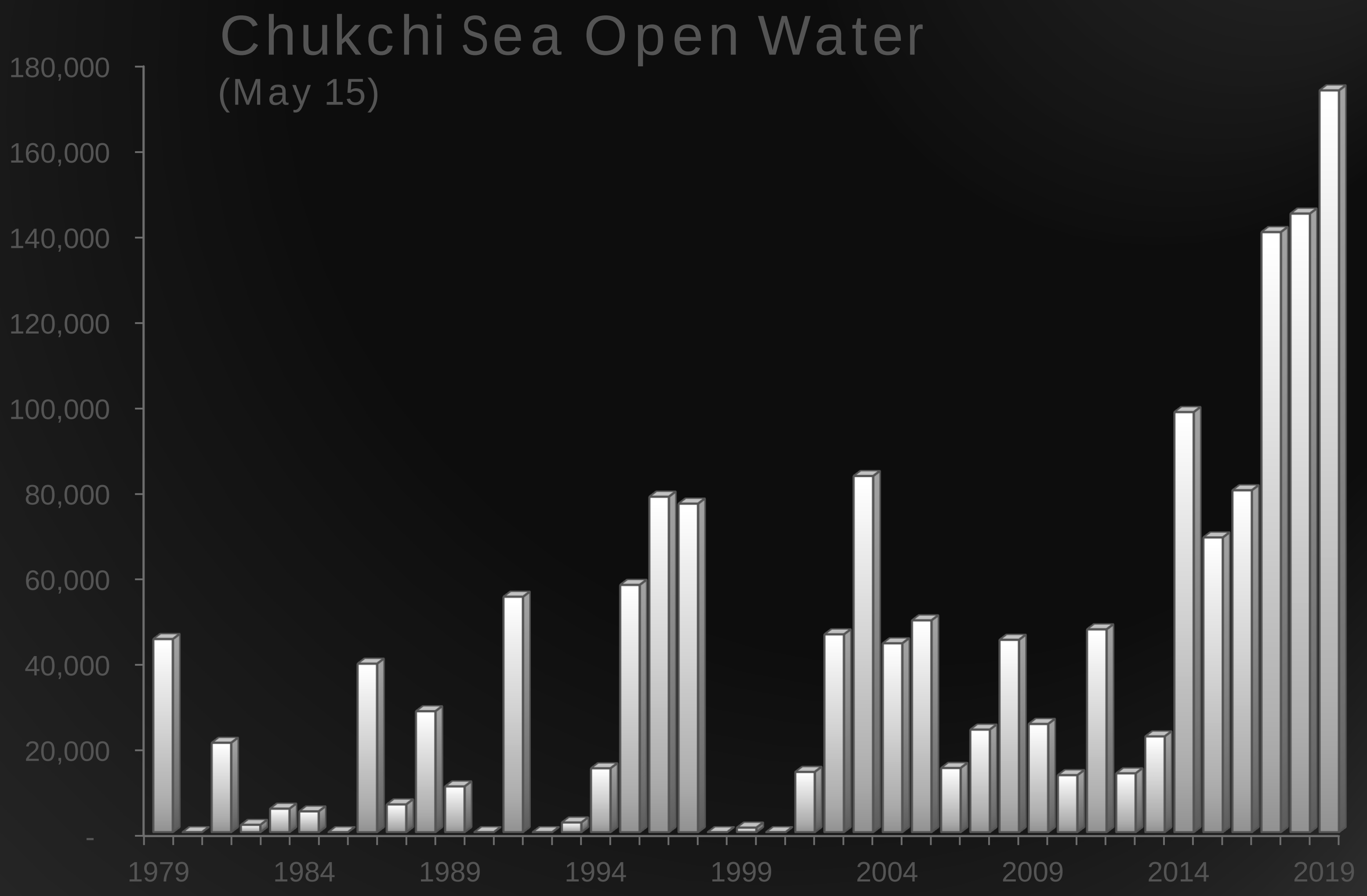
We measured at approximate maximal ice extent (March 15).

We calculated open water as the deviation from maximum sea ice extent (2012, 817,752 km2)



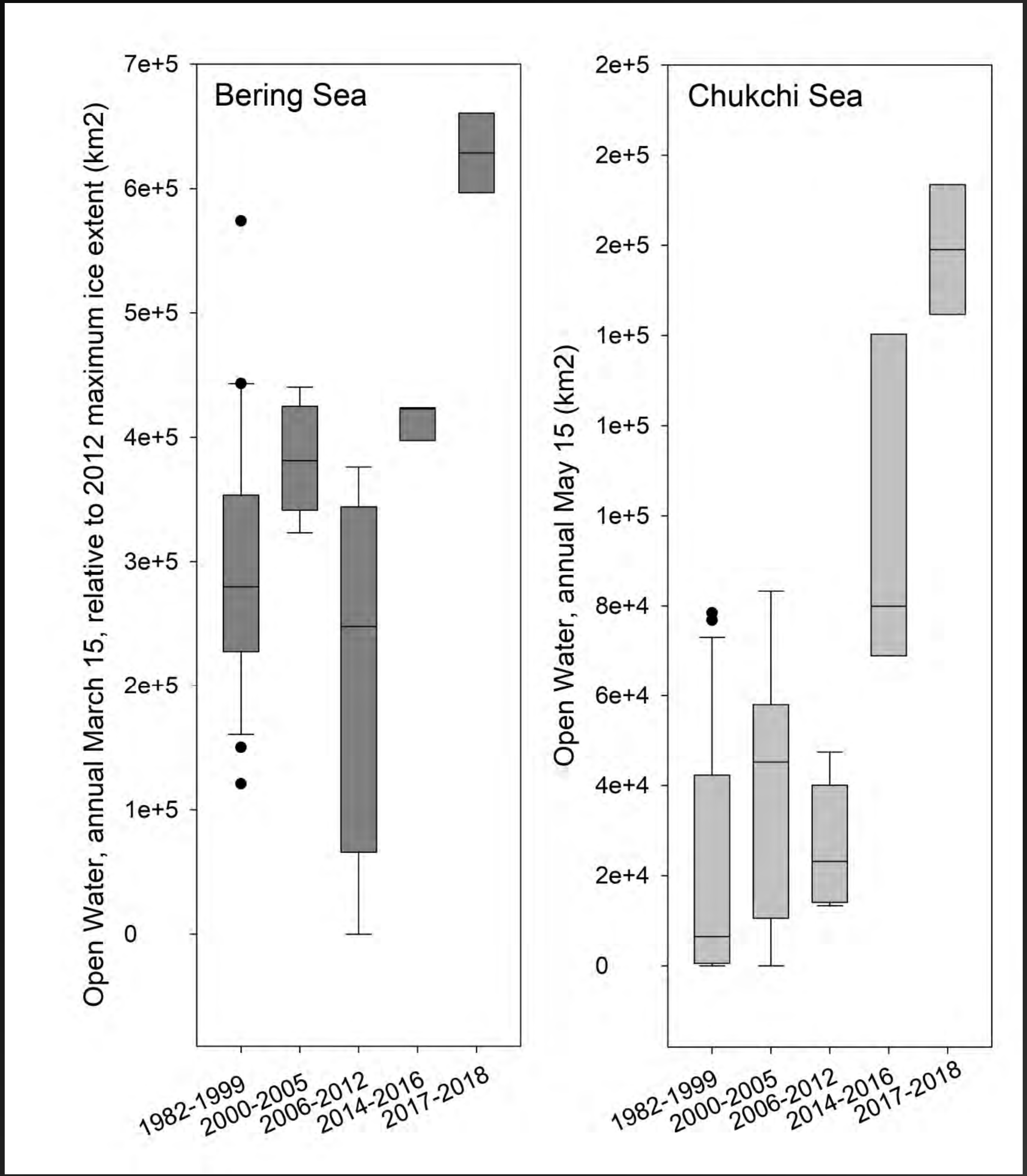
In Chukchi Sea, our interest was in spring melt and the location of ice edge at peak primary production.

We used a standard date of May 15 and calculated open water as the areal extent of Chukchi Sea (800,000 km2) minus the areal extent of sea ice in that region on May 15



Areal extent of open water at the approximate peak of ice extent in the Bering Sea (March 15) and at approximate point of maximal seasonal flux in Chukchi Sea (May 15) varied considerably.

Differences in the extent of open water were noted across identified climatic stanzas in both regions ($P<0.001$).

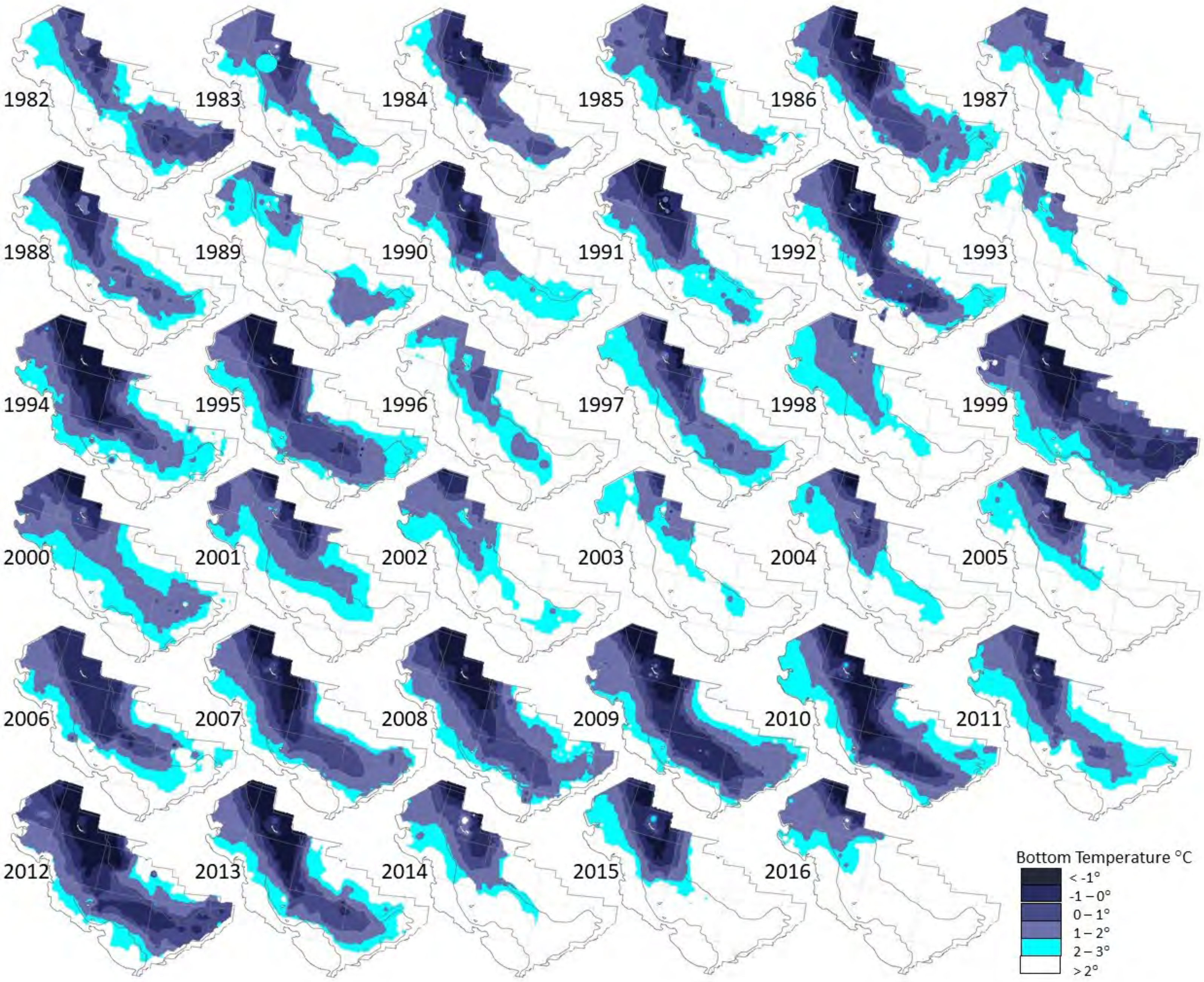


Cold Pool

Annual areal extent of cold pool (< 2°C), varied between climatic stanzas (P=0.001). Post Hoc tests noted significant differences in warm (2000-2005, 2014-2016) and cold (2006-2013) years.

Differences in the mean areal extent in climatic stanzas were significant at all other temperature intervals (1°C, 0°C,-1°C, -2°C; P<0.046)

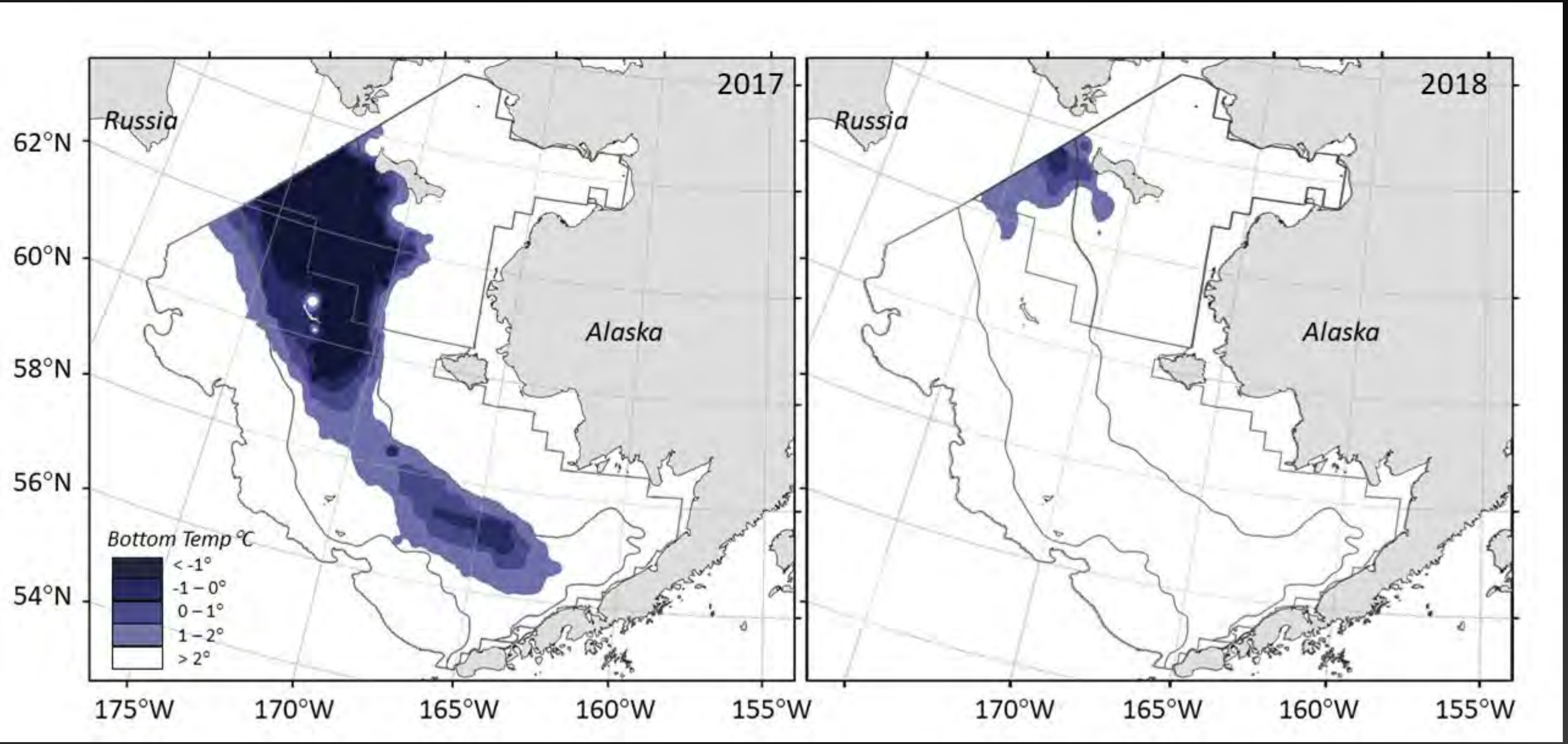
annual NOAA bottom trawl surveys EBSS/NBSS in summer 1982-2016



2018 significantly different from cold, 2006-2012 (*P*=0.013) and variable period, 1982-1999 (*P*=0.038)

Cold pool area (as % of total survey area) declined 38.7% (1982-2018) → 1.4% (2018)

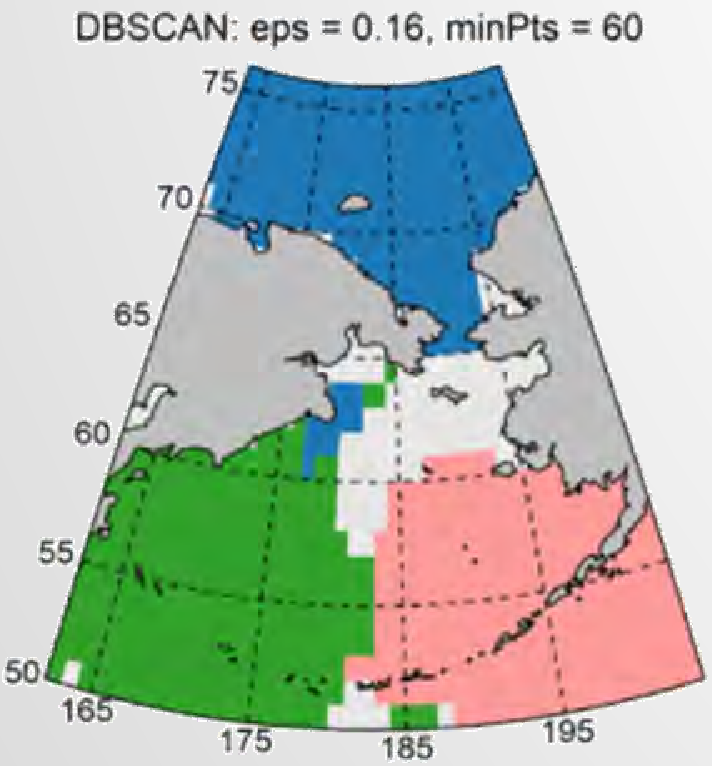
No area in 2018 survey had bottom temperature < 0°C,



annual NOAA bottom trawl surveys
EBSS/NBSS in summer 1982-2016

Regional Delineation

- To identify regional boundaries according to patterns in mean monthly SSTA, varied input parameters to choose the best spatial organization of clusters and minimize noise. Further reduction in eps values resulted in the separation of the Chukchi-Siberian cluster with an increase in noise.



NOAA Optimum Interpolation Sea-Surface Temperature V2 monthly data

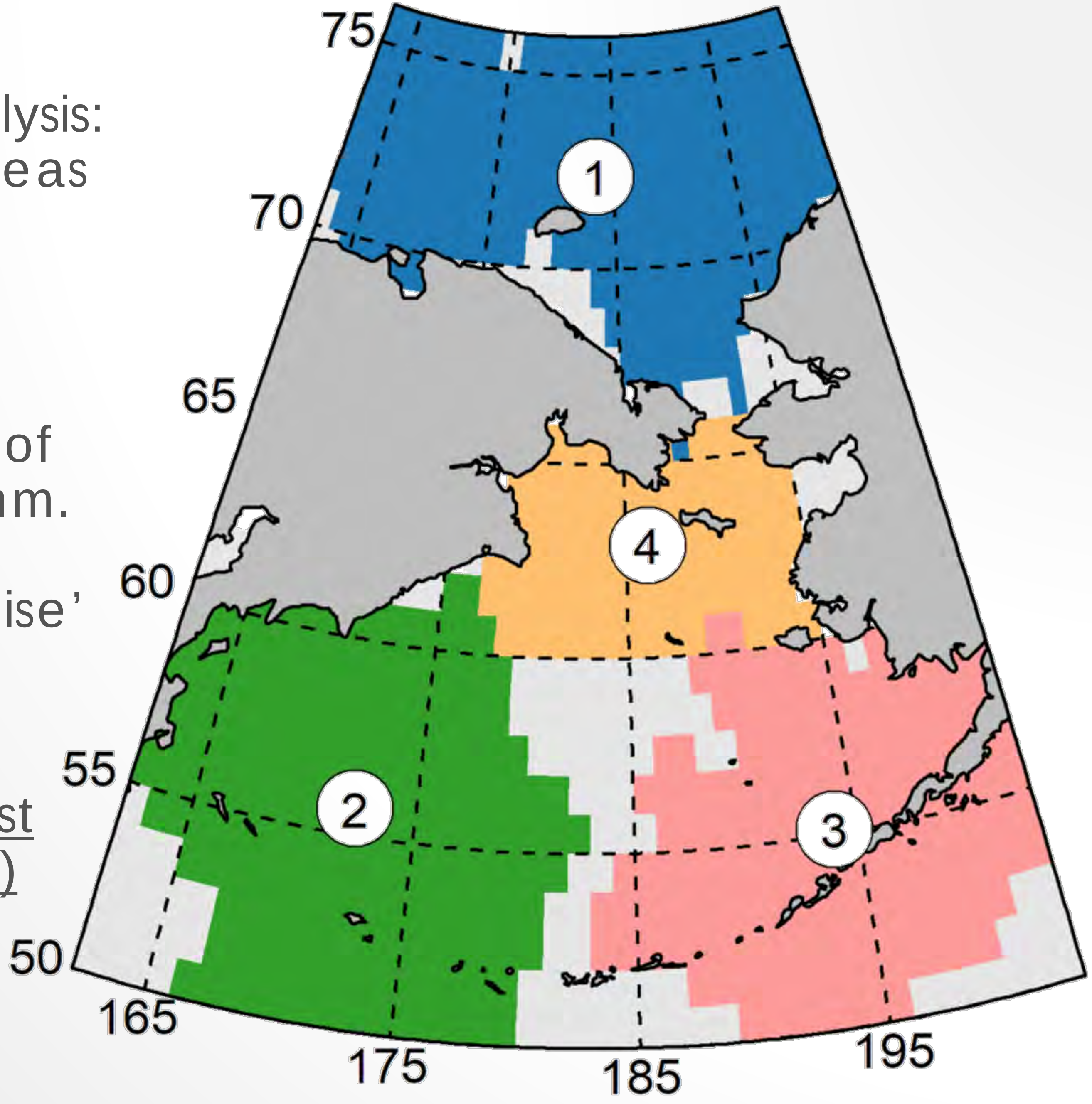
Regions used in SSTA time-series analysis:

- Region 1 – Chukchi, East Siberian Seas
- Region 2 – western Bering Sea
- Region 3 – eastern Bering Sea
- Region 4 – northern Bering Sea

Regions 1-3 are based on clustering of annual mean SSTA, DBSCAN algorithm.

Region 4 is remaining grid nodes 'noise'

Results of cluster analysis confirm past analyses that distinguish NBS (> 60°N) from other regions of Bering Sea.



NOAA Optimum Interpolation Sea-Surface Temperature V2 monthly data

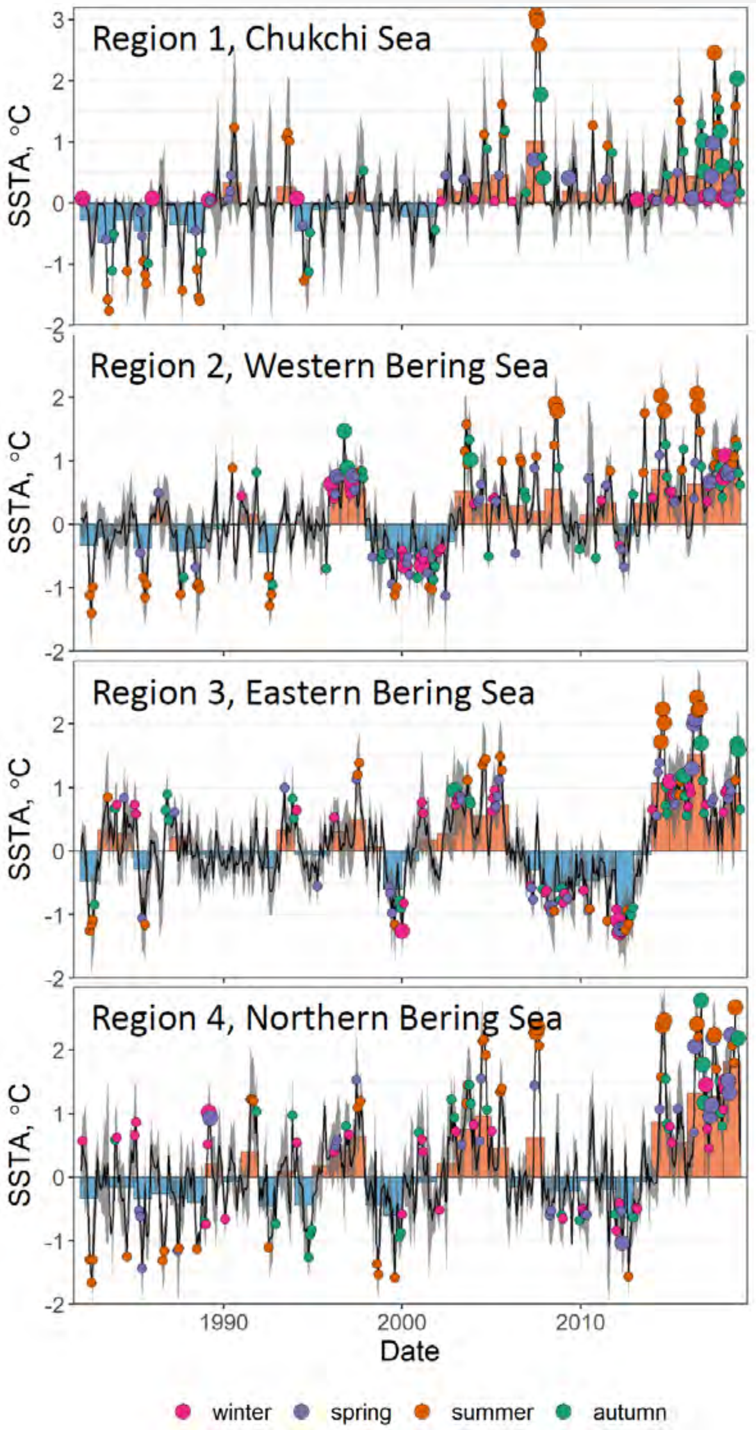
Regional patterns in SST

Sea surface temperature anomalies
(relative to mean,1982-2019)

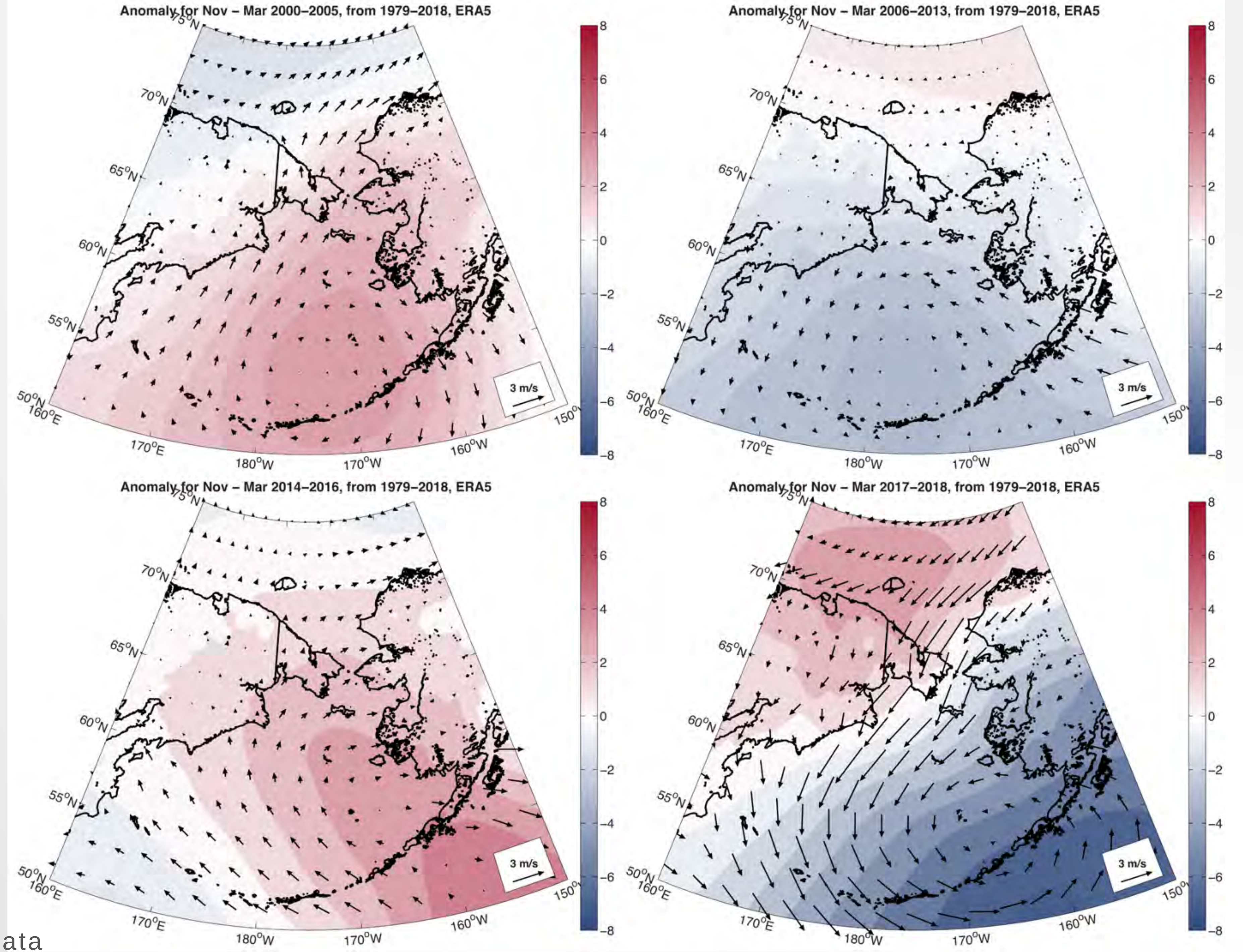
Solid black line = monthly regional mean SSTA
Grey shading = monthly regional std

Cold periods relative to time series mean=blue, warm=red

Dots denote months with absolute SSTA values > 1 standard deviation (color-coded according to seasons)



Winds and Atmospheric Forcing

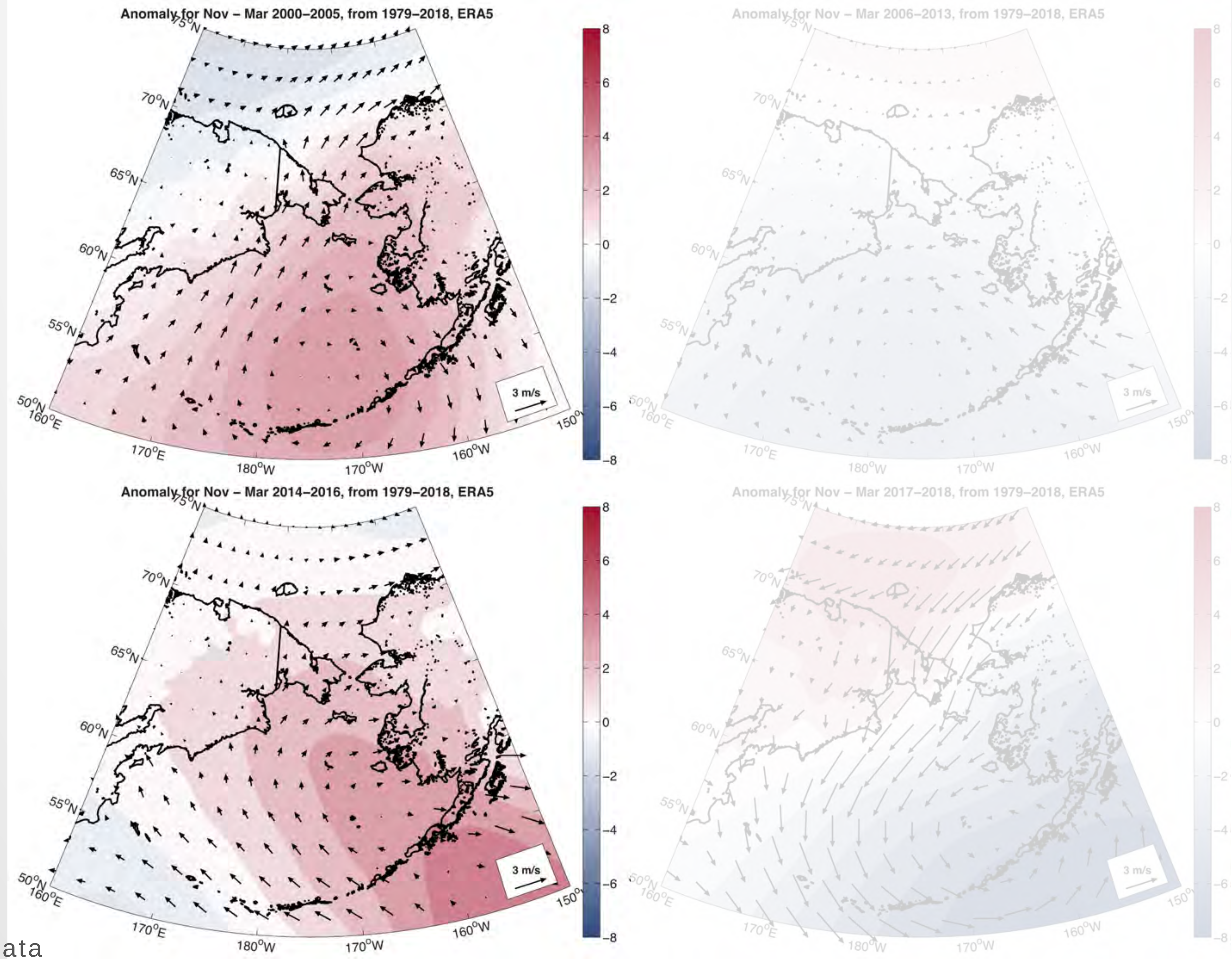


Maps of mean sea level pressure (mb, color) and 10-m winds (m/s, vectors) for months with ice coverage (Nov-Mar)

European Centre Medium- Range Weather Forecasts ERA5 reanalysis data

In the warm periods (2000-2005, 2014-2016) both the Aleutian Low and the high-pressure system of Beaufort High and Siberian High were strong, with Aleutian Low located over the Aleutian Islands.

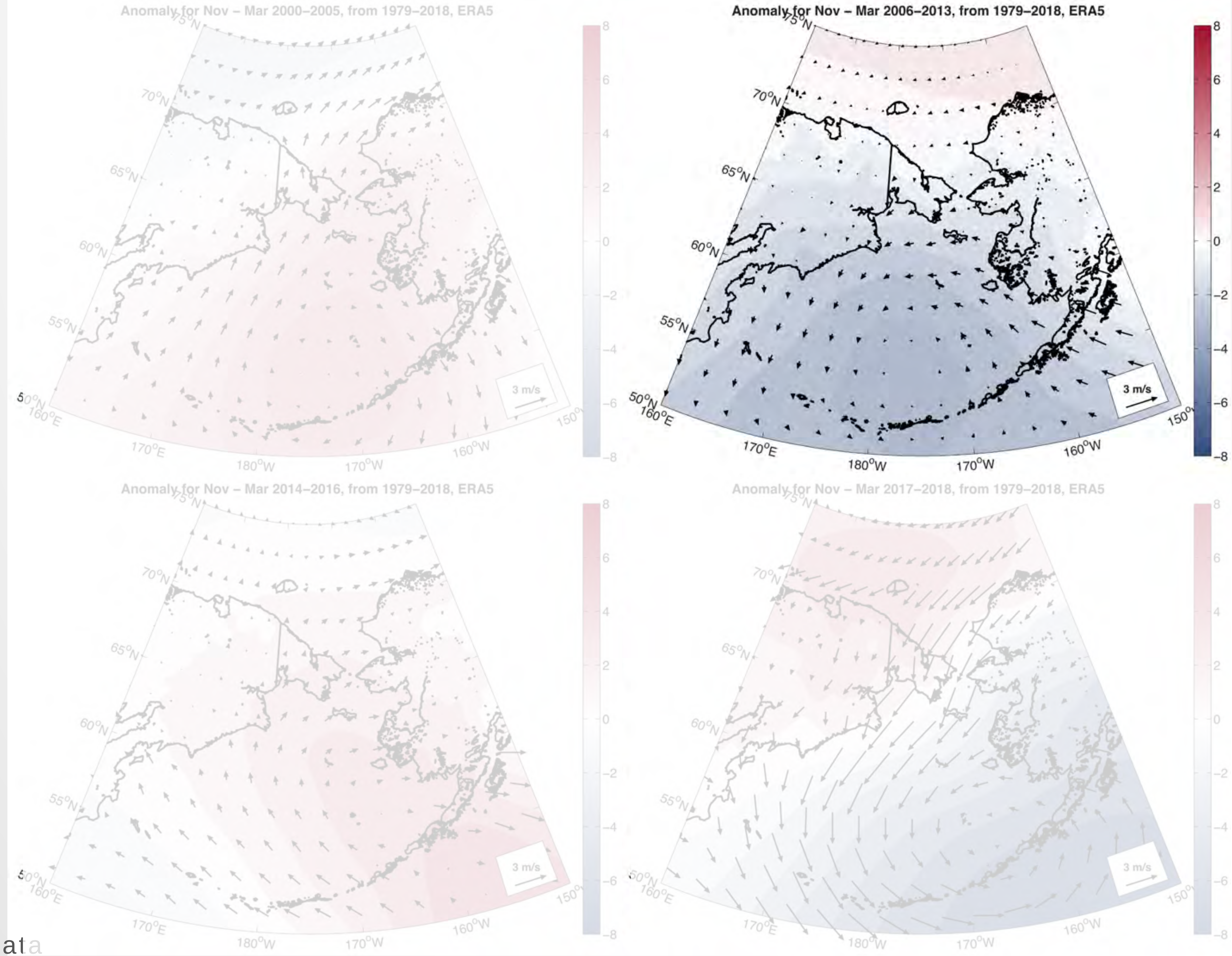
These time intervals also exhibited slightly enhanced winds.



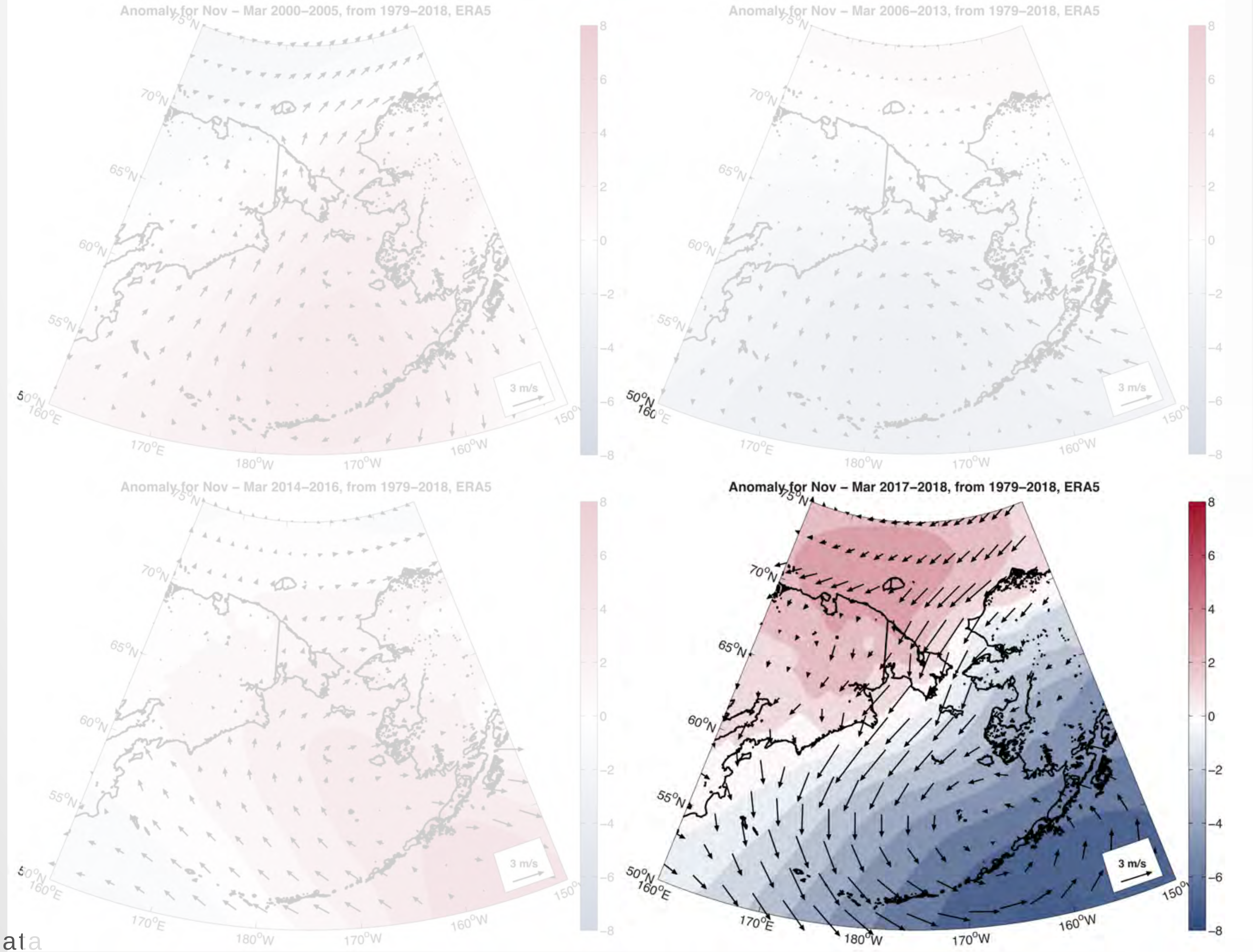
European Centre Medium- Range Weather Forecasts ERA5 reanalysis data

In the cold phase (2007-2013), the Aleutian Low was much weaker, with two centers - one in the Gulf of Alaska, another close to Russia.

This resulted in weaker winds over the central part of the Bering shelf.



European Centre Medium- Range Weather Forecasts ERA5 reanalysis data



In the most recent period of anomalous warming (2017-2018), there was a significant weakening and shift of the Aleutian Low towards Russia.

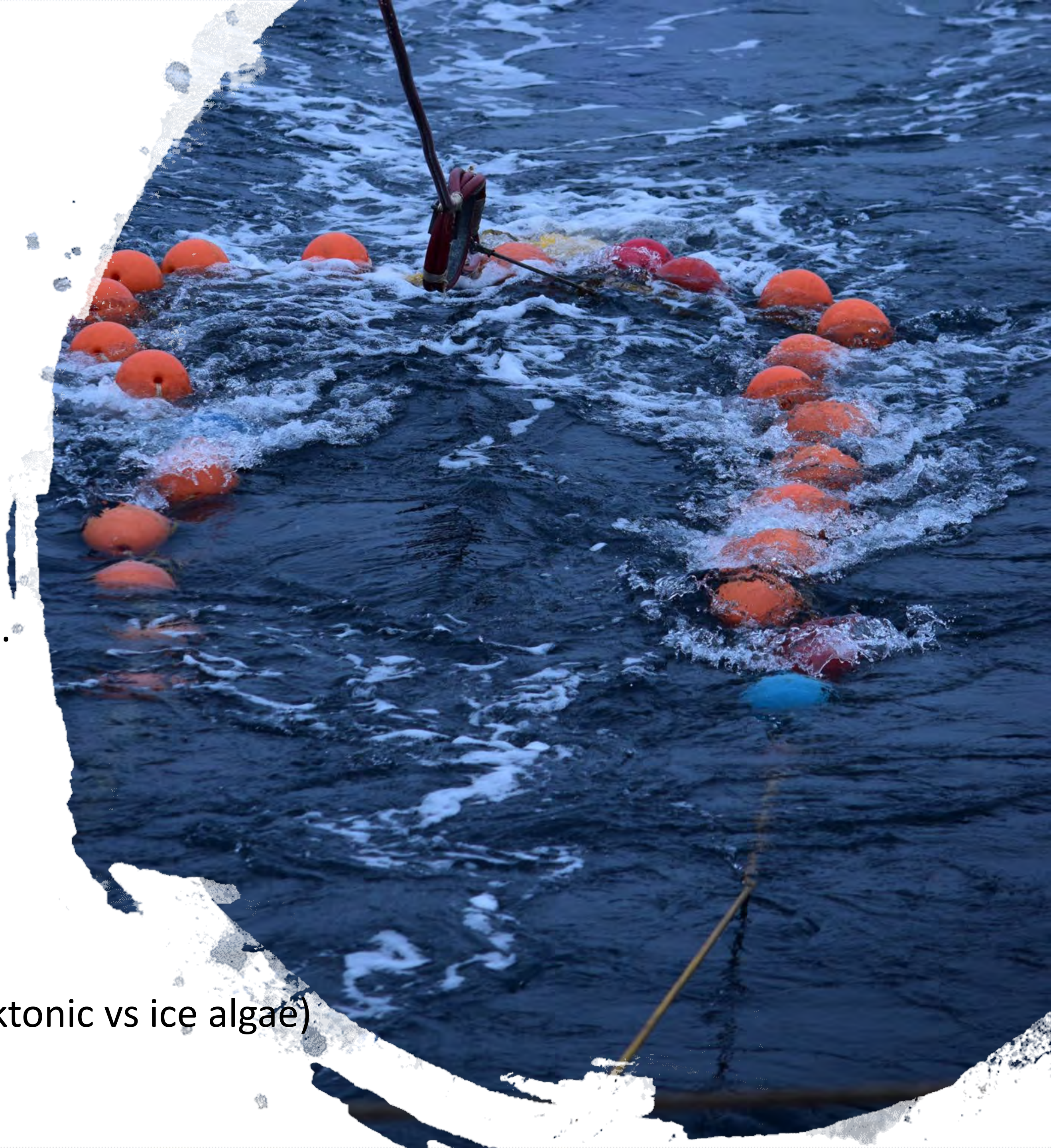
European Centre Medium- Range Weather Forecasts ERA5 reanalysis data

Regional distinctions

Cluster analysis confirm past analyses that distinguish NBS from other regions in BS

This distinction may be less evident absent sea ice.

- Important implications for:
  - atmospheric-oceanic interactions
  - wind mixing
  - wave activity
  - salinity and stratification
  - phenology and primary productivity (planktonic vs ice algae)



Regional distinctions

Attributes that are changing:

- —vertical hydrographic, temp/salinity profiles (Goes et al. 2014)
- —distinct patterns in stratification (Ladd and Stabeno, 2012)
- —ROMS results SST, ice cover, wind stress (Hermann et al., 2016)

Attributes at 60N that will remain constant and may permanently distinguish NBS:

- —Bering Slope current diverges west (Ladd, 2014)
- —Intensified flow in Anadyr Current Kinder et al., 1986)
- —Geostrophic velocity vectors and circulation patterns diverge (Cokelet et al., 2016; Hollowed et al., 2012).
- —Intensified northward flow at Bering Strait (Woodgate and Aagaard, 2005)
- —Differences in bottom and surface velocities (Zhang et al., 2012).

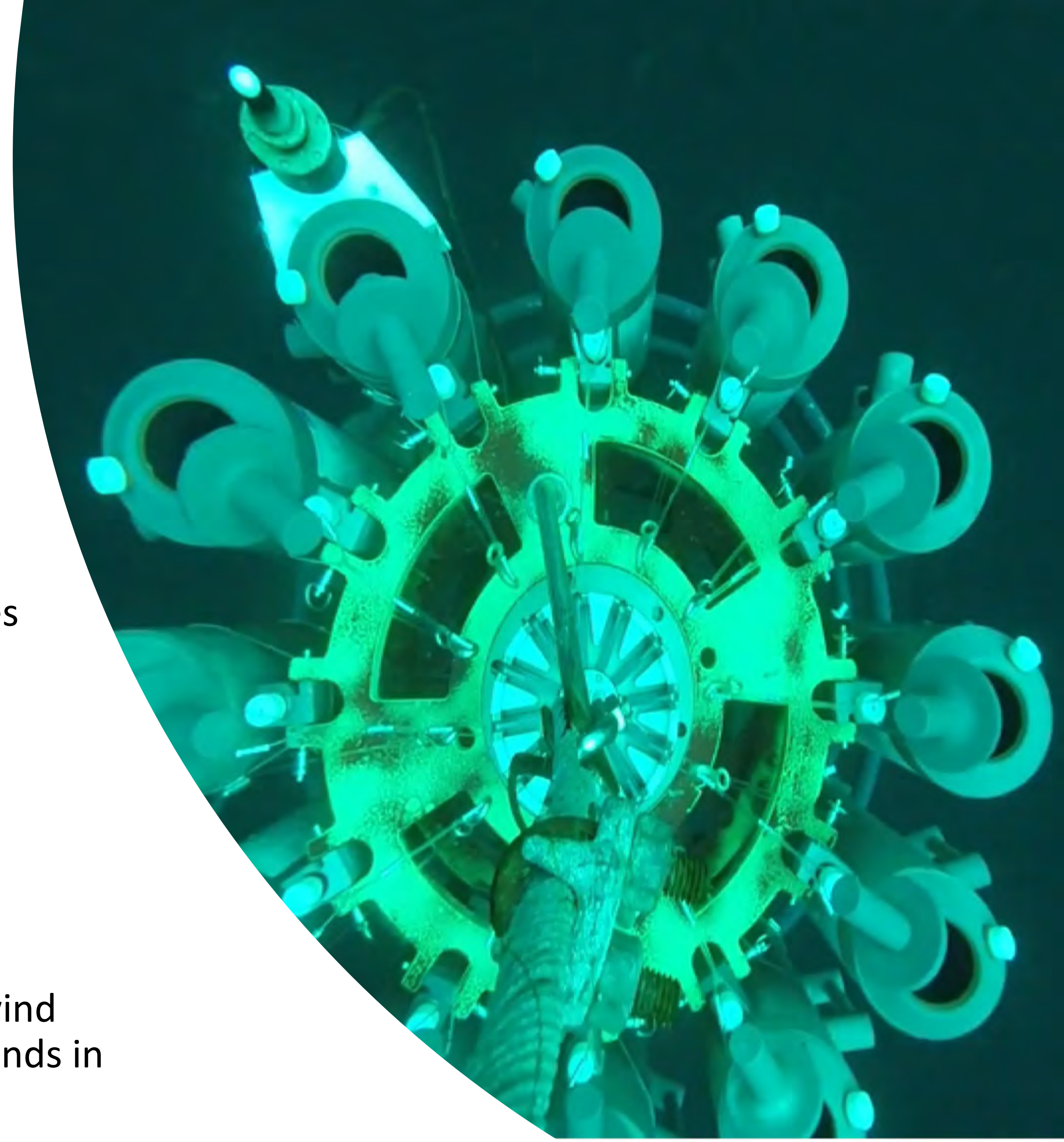
Mechanisms for reduced sea ice

While trends seem clear, mechanisms and interactions are complicated. Physical conditions are governed by:

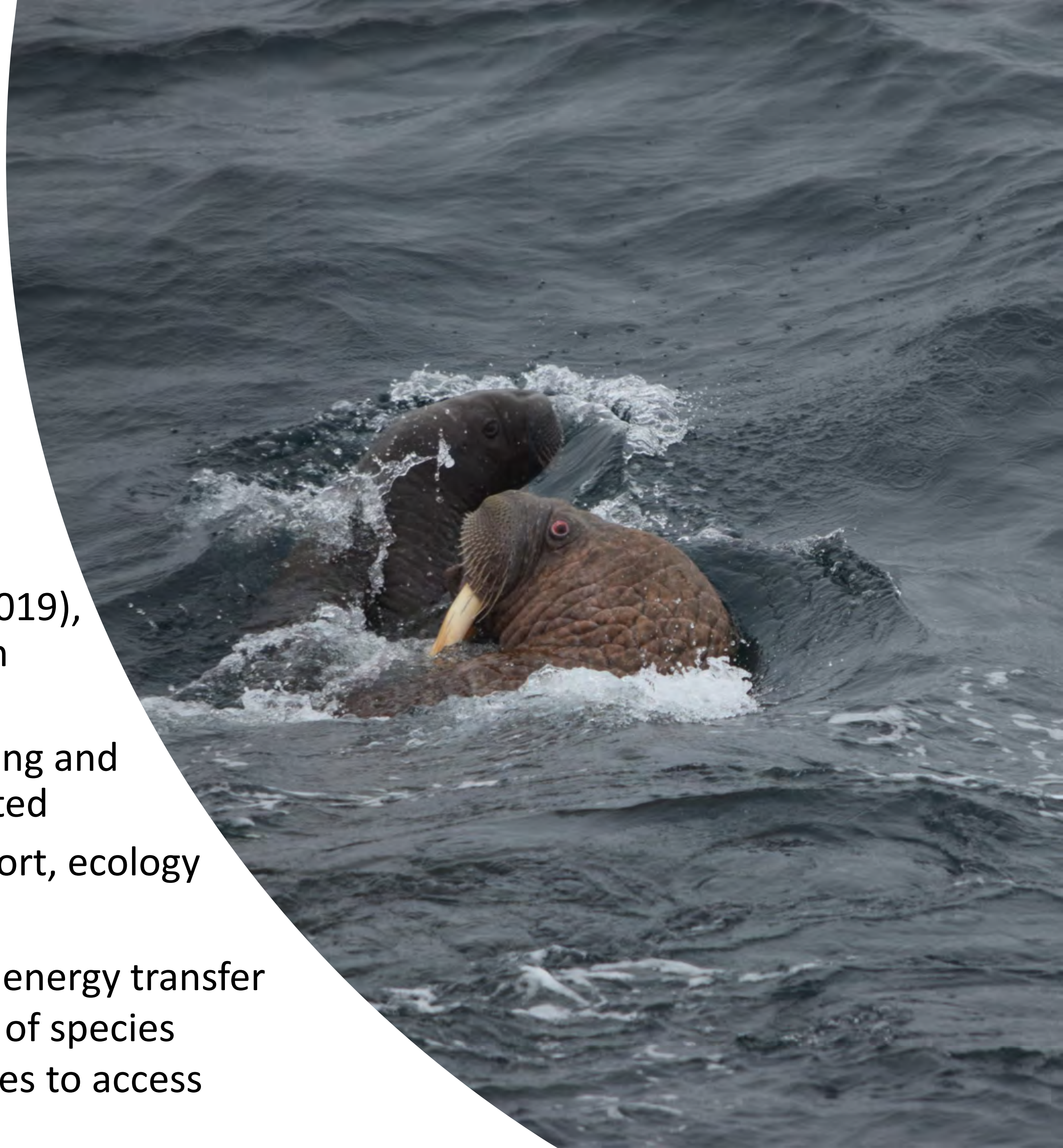
—exchange of Pacific-Arctic ocean and air masses
—advection from the Pacific to the Arctic
—formation and retreat of sea ice
—stratification and mixing dynamics

Chukchi Sea: heat flux through the Bering Strait influences distribution and thickness of sea ice

Bering Sea: winter sea ice extent influenced by wind and air temperature, with persistent northerly winds in winter and spring leading to extensive sea ice



New state of the Pacific Arctic



- Decline in Arctic ice in satellite observations the most visible signs of climate change.
- Until recently Pacific Arctic appeared exempt
- Including more recent data (2014-2018, 2017-2019), models and observations note reduced duration and extent of sea ice
  - thermal barriers previously evident in the Bering and Chukchi eroded and thermal gradient has shifted
  - implications Pacific-Arctic connectivity, transport, ecology
    - primary production and phenology
    - benthic-pelagic coupling and carbon and energy transfer
    - abundance, distribution and interactions of species
    - increased opportunity for subarctic species to access and ultimately transform these systems

Prospects for increased international collaboration

- Ability to access and visualize data in a unified portal is limited
- Data sharing often dependent on personal correspondence
- An integrated Arctic Ocean Observing System has emerged to complement regional networks, but none are comprehensive.
- International institutions (PICES) and regional networks (PAG) are instrumental in standardization and information sharing
- Continued efforts to integrate data and perspectives across national boundaries are increasingly necessary

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