Modeling Tools for Designing for Resilience – Connectivity Under Changed Conditions

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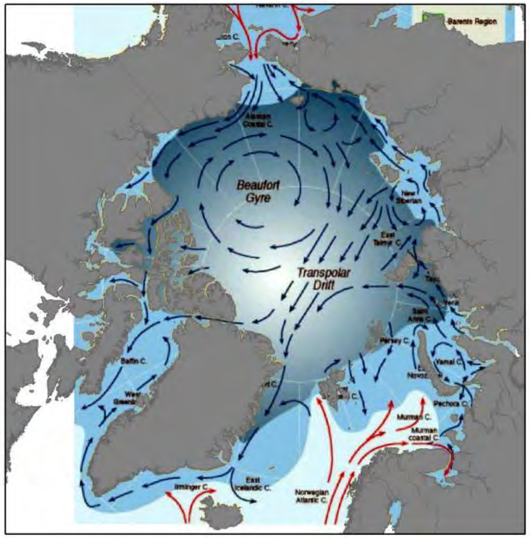


ARCTIC COUNCIL/PAME WORKSHOP

Science and Tools for Developing Arctic MPA Networks:

Understanding MPA Networks as Tools for Resilience in a Changing Arctic

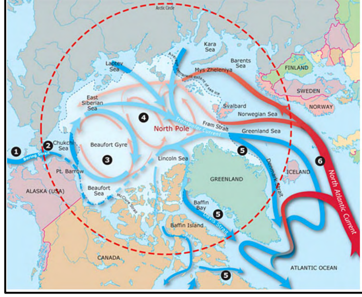
Copenhagen, Denmark

February 3, 2017

Marine Geospatial Ecology Lab

Duke University

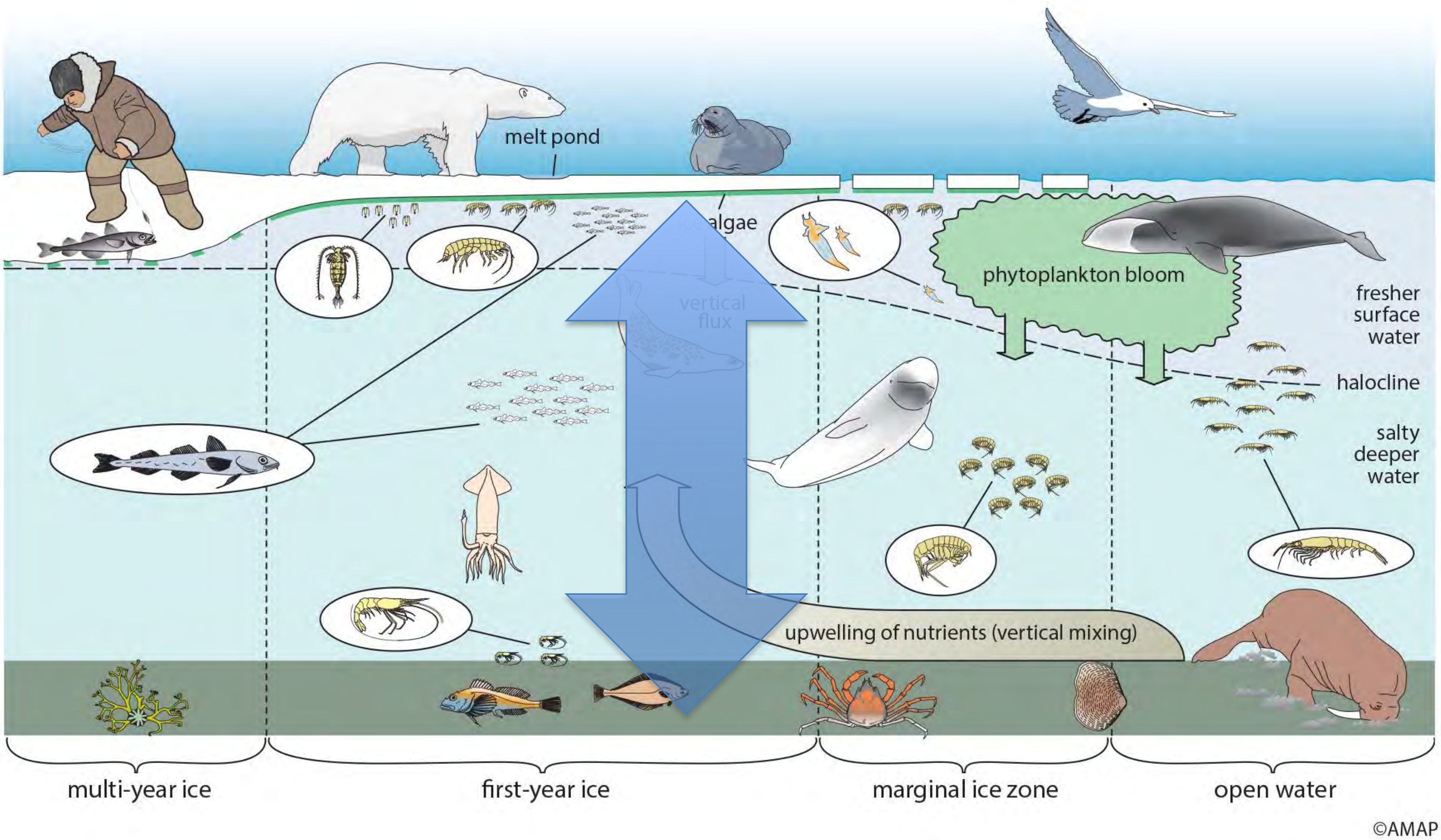
THE UNIVERSITY OF MELBOURNE



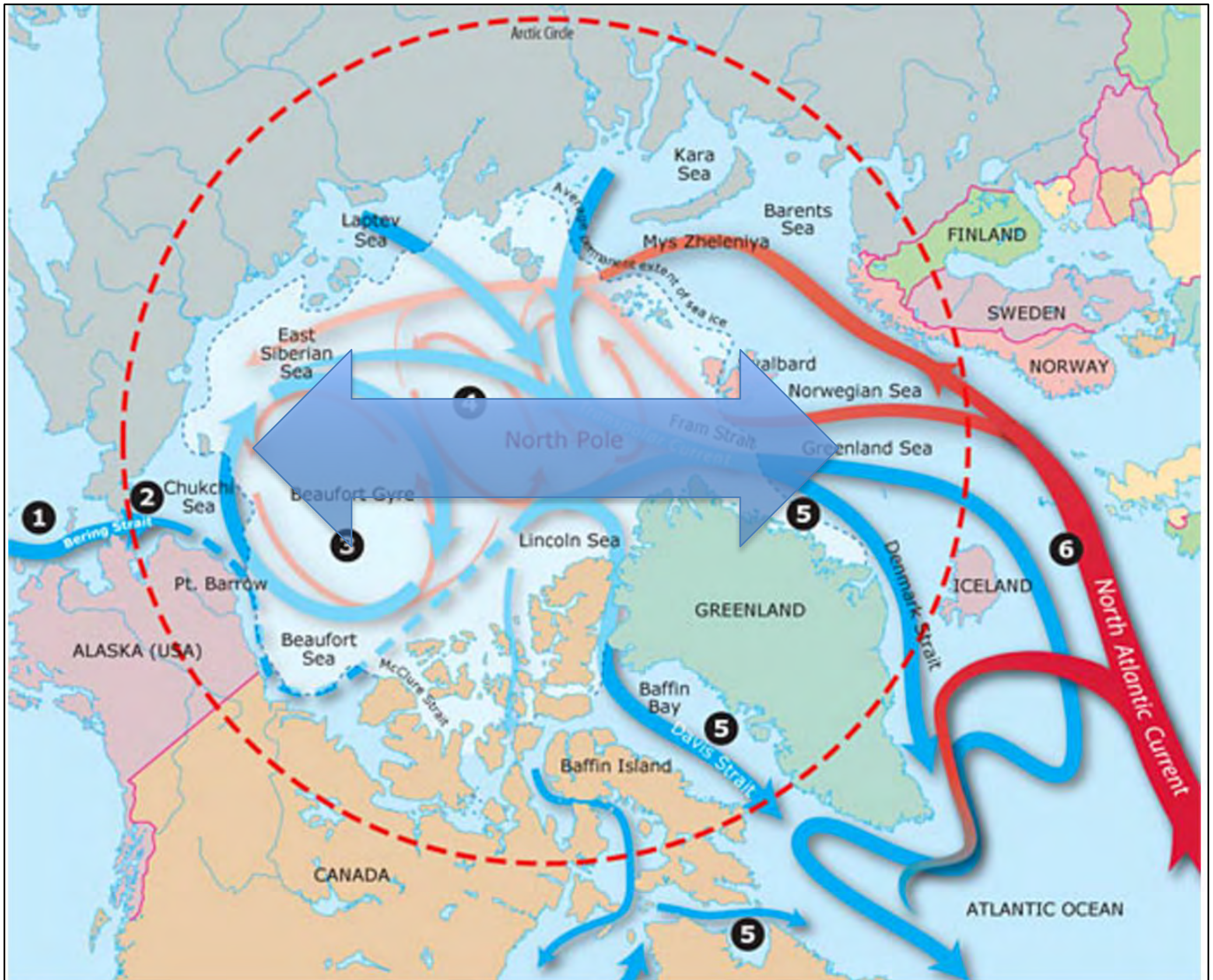
Topics:

- The Arctic context
- Connectivity modeling framework
- Arctic connectivity pilot studies
- Conclusions

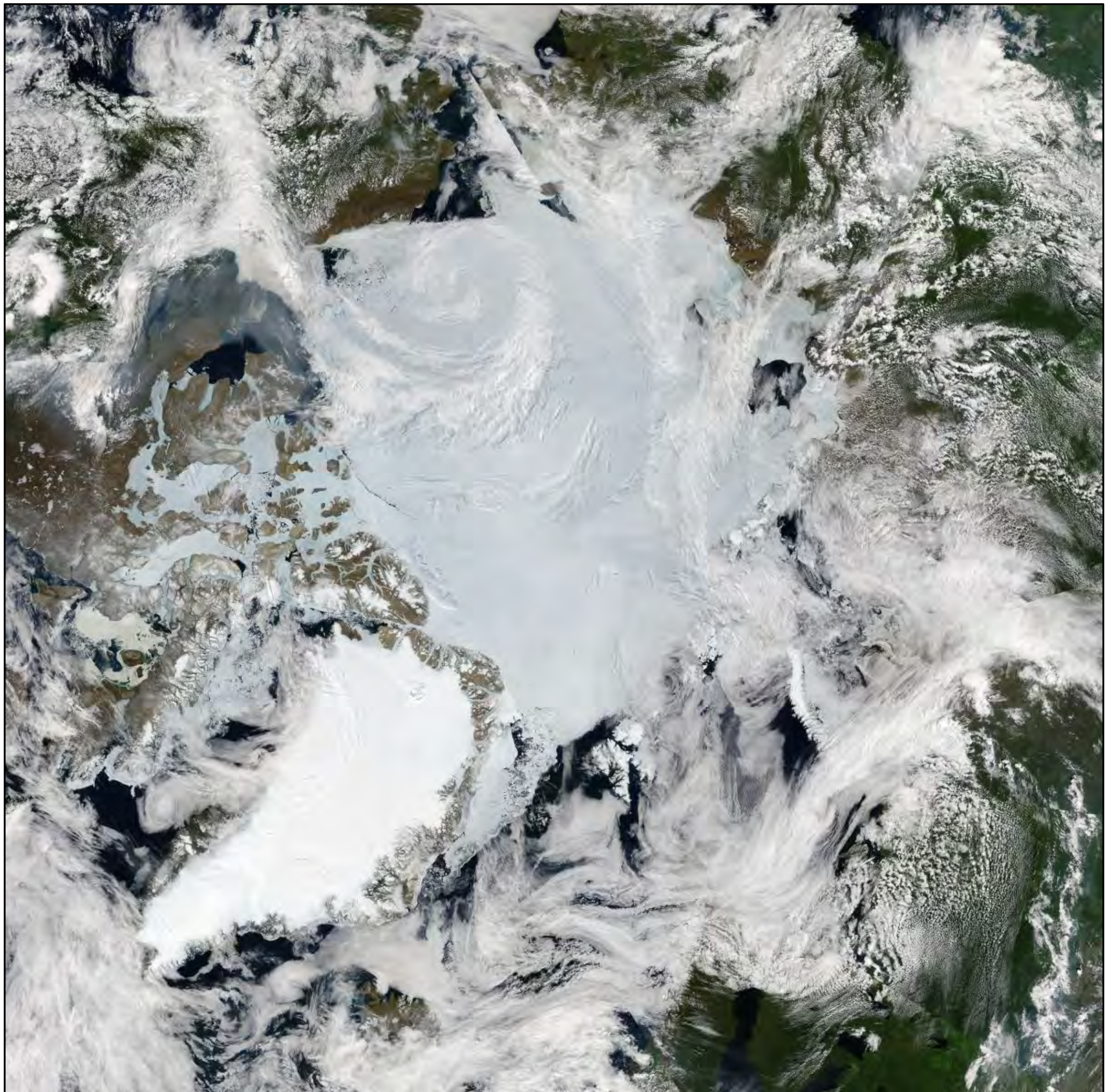
We tend to view Arctic marine ecosystems in terms of ***vertical connections*** across seasonal ice conditions…



…but there is significant ***horizontal connectivity*** in the Arctic that controls the distribution of species, habitats and exchanges of resources

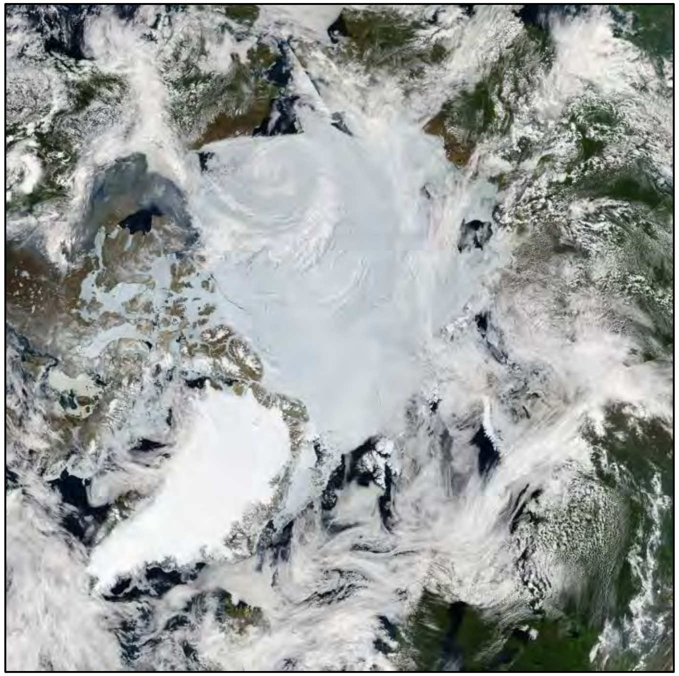


Movement and connectivity in the Arctic is highly dynamic at multiple spatial and temporal scales…



Physical factors effecting marine connectivity

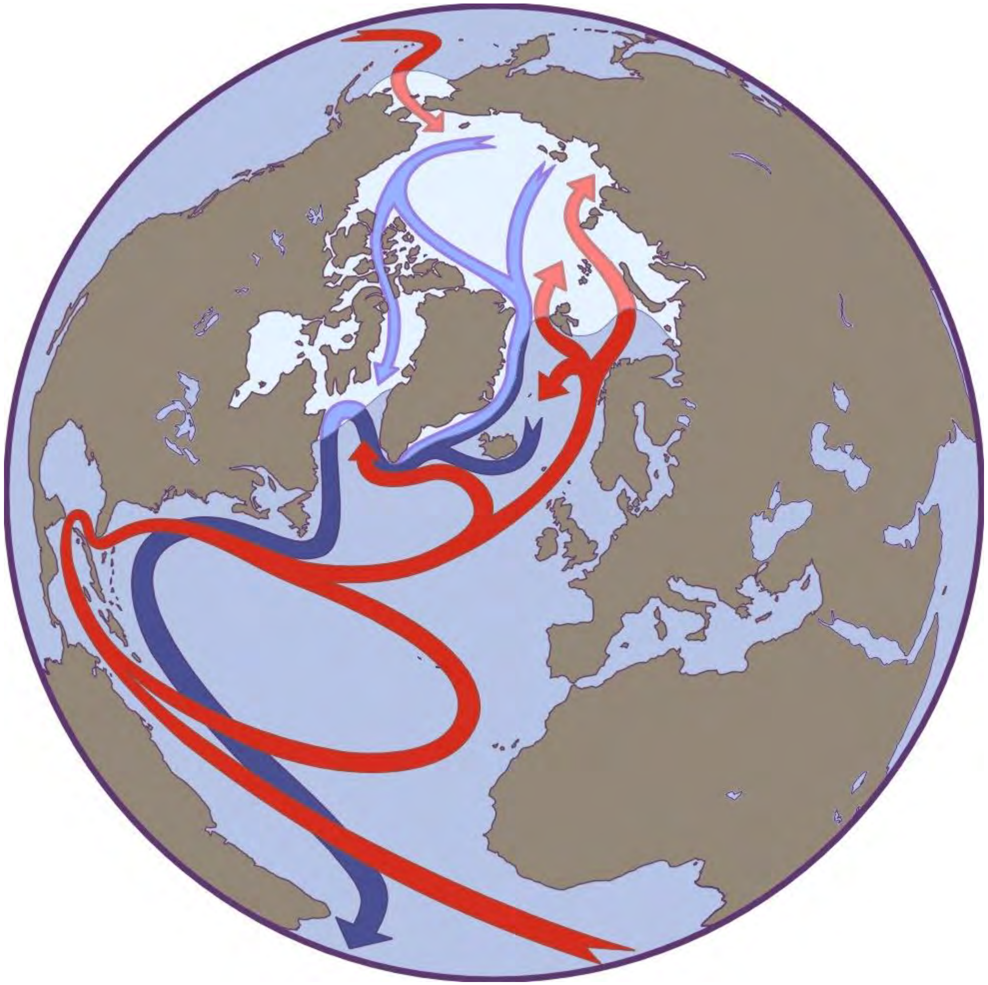
- Ocean currents (surface & sub-surface)
- Water mass properties (temperature, salinity…)
- Surface wind
- Sea ice
- Seasonality



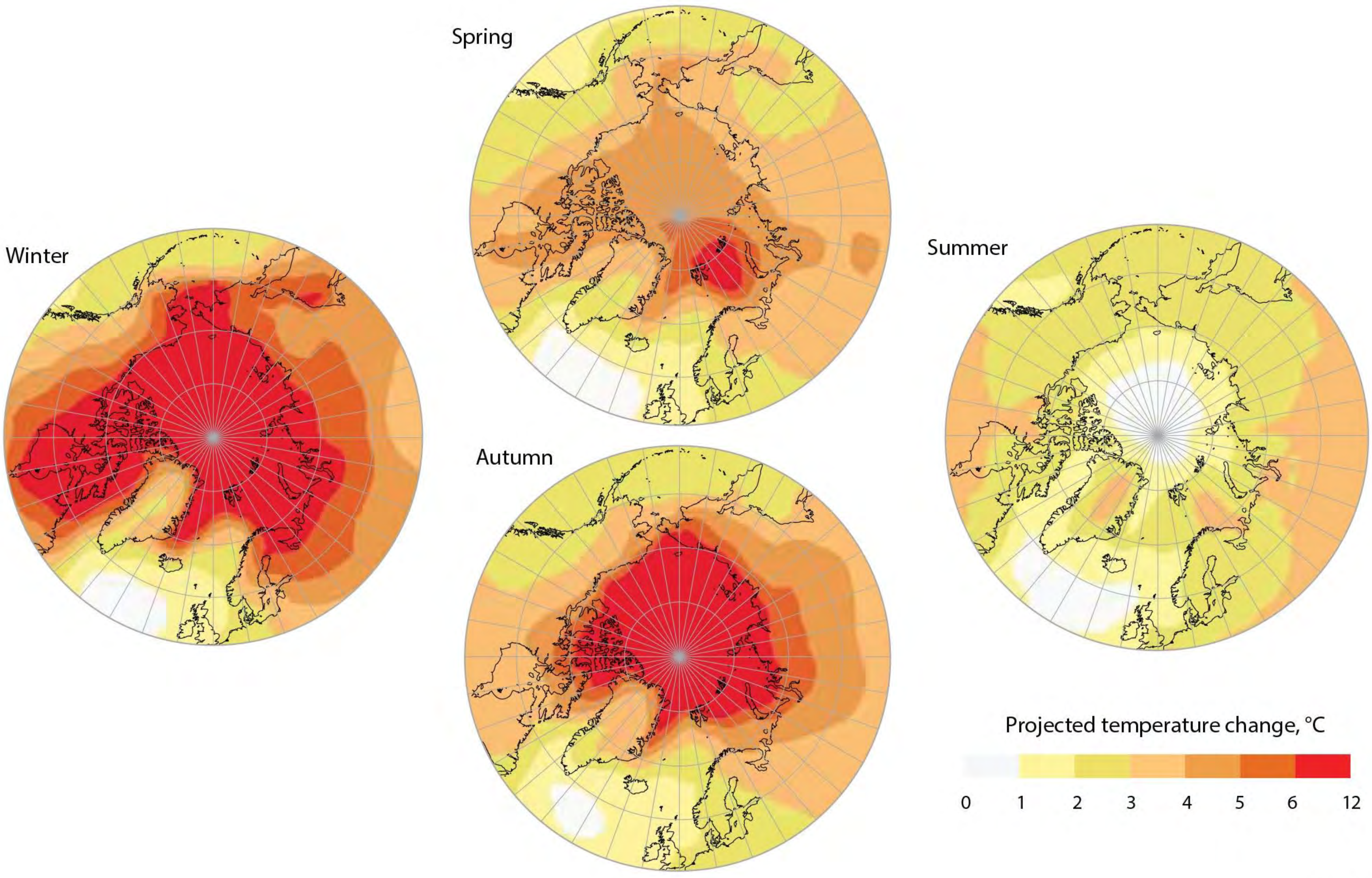
All of these factors are changing…

Changing currents

Potential changes to the oceanographic regimes at multiple depths

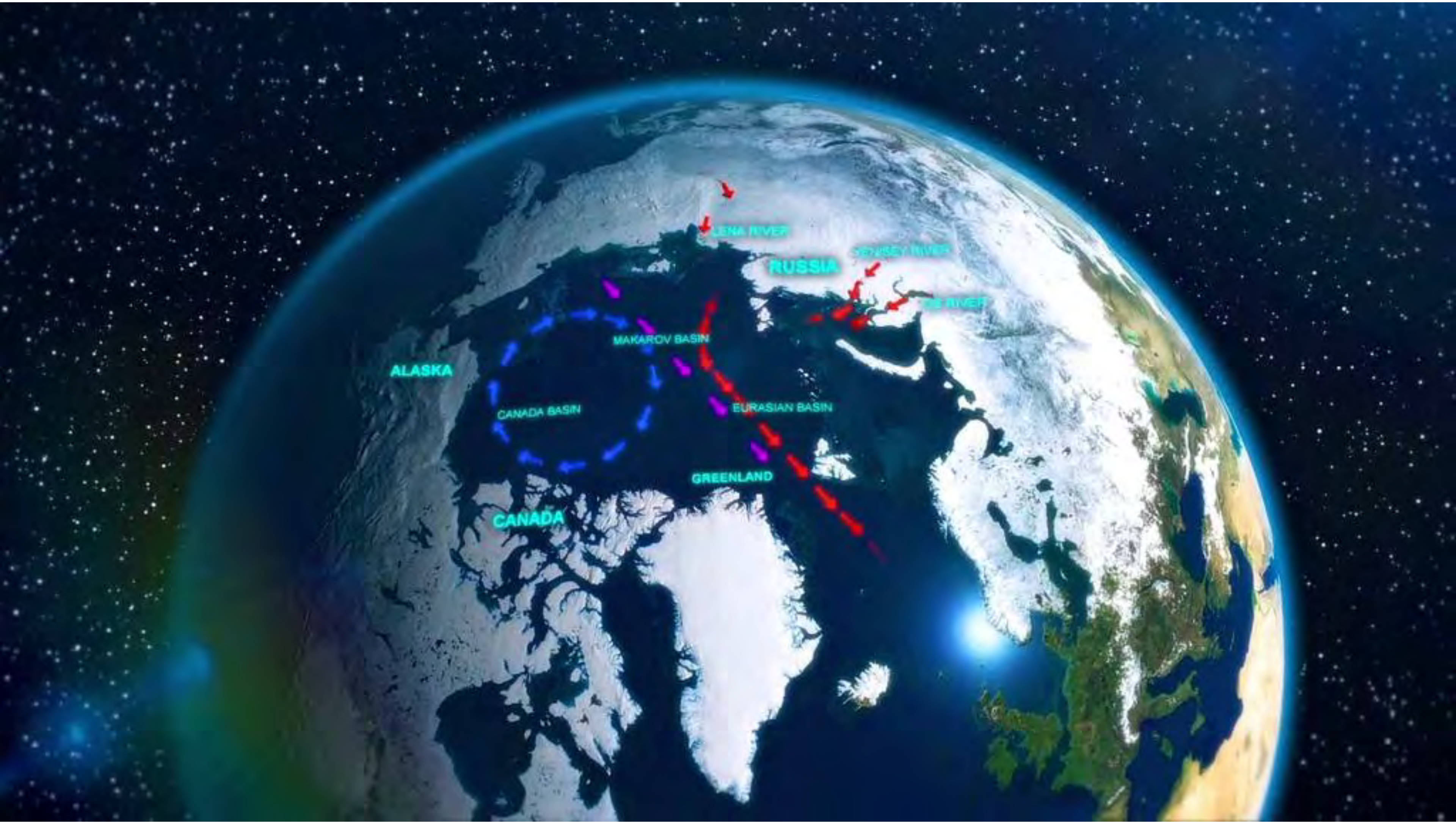


Changing surface temperature



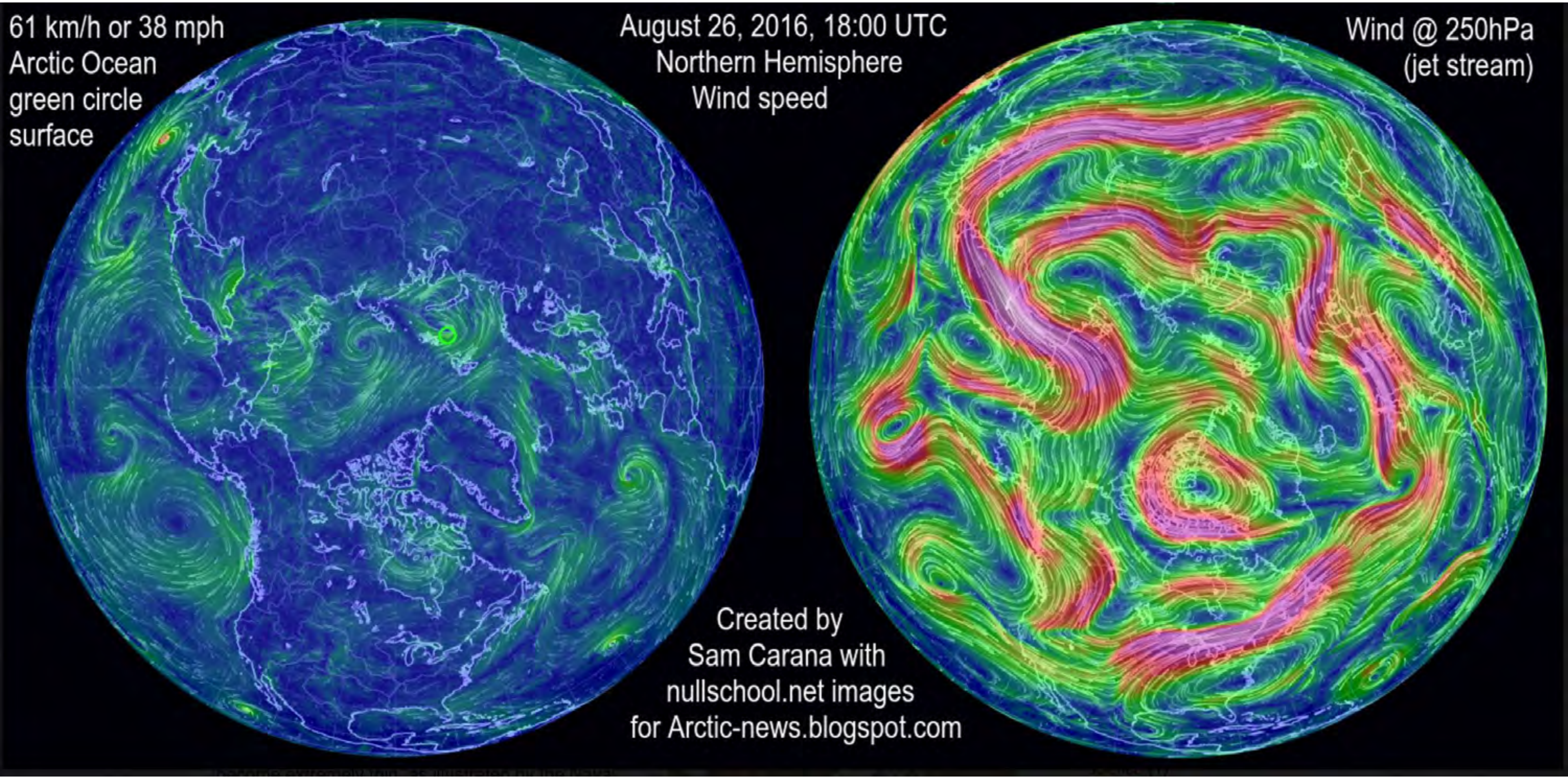
Changing freshwater circulation

Russian runoff “freshening” Canadian waters…

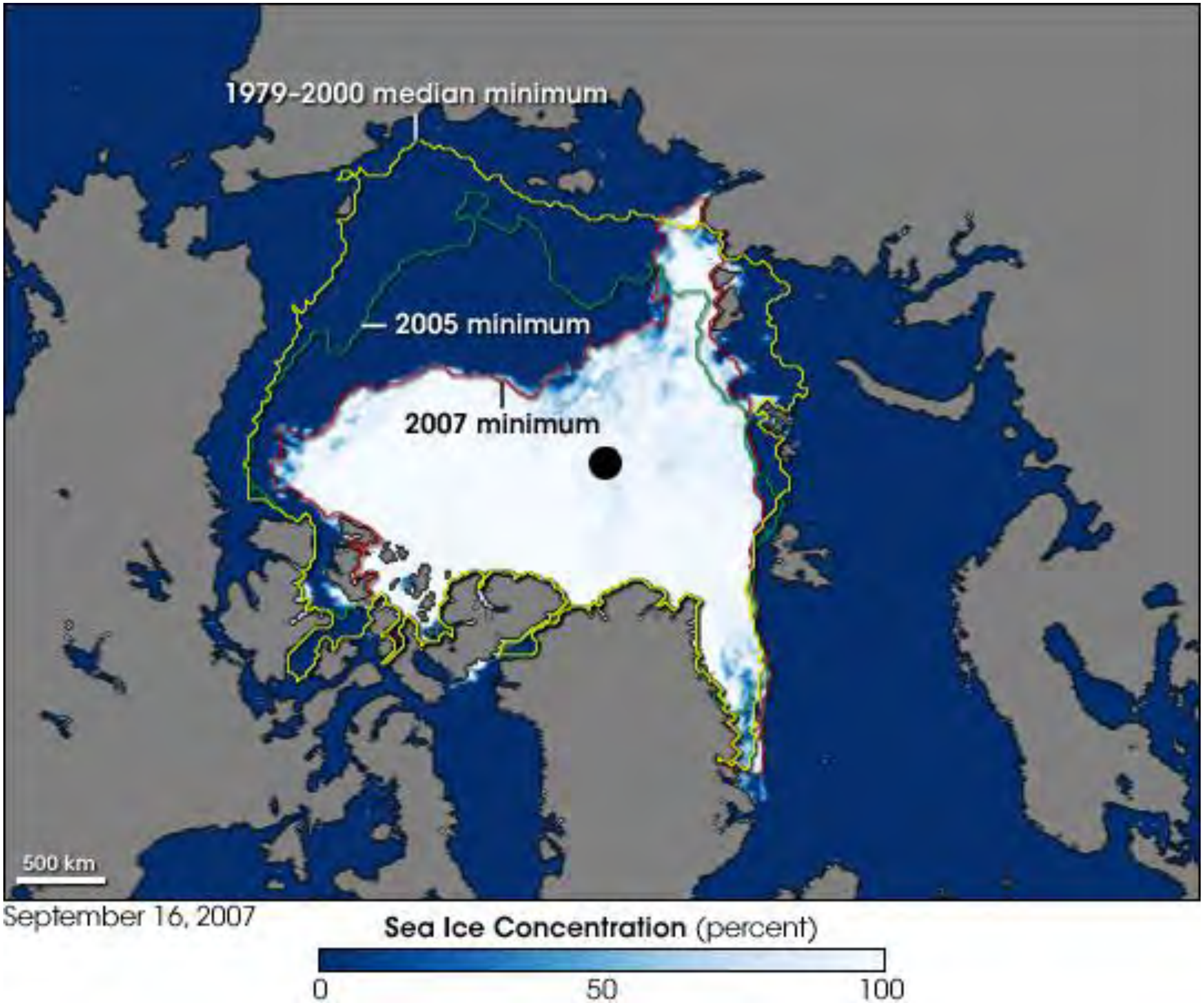


http://svs.gsfc.nasa.gov/vis/a010000/a010800/a010889/

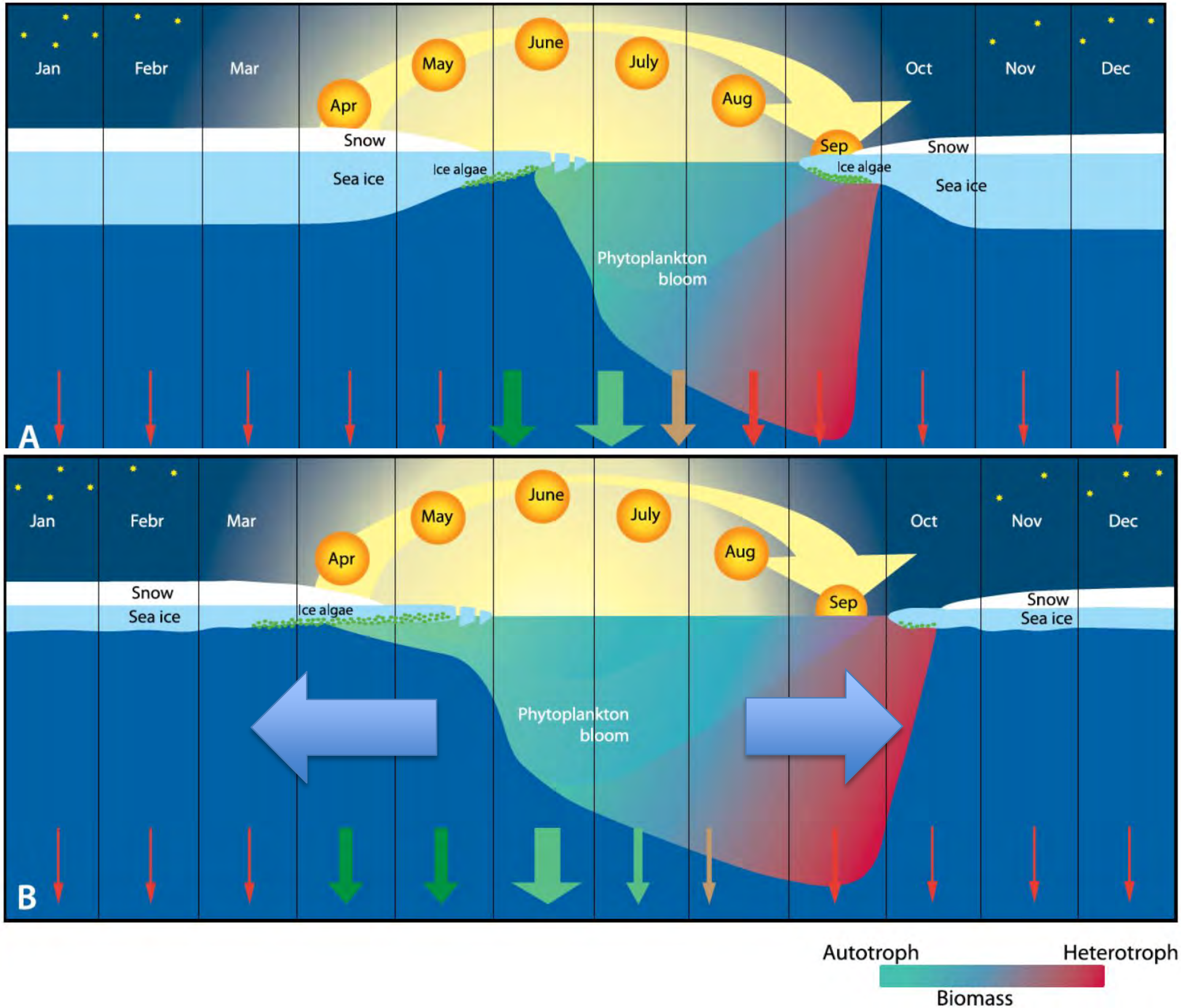
Changing wind regimes



Changing sea ice



Changing seasonality/phenology



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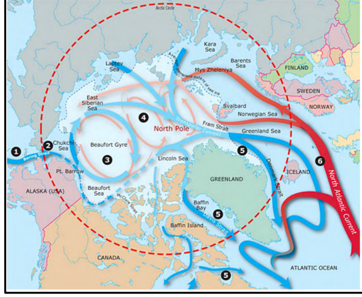

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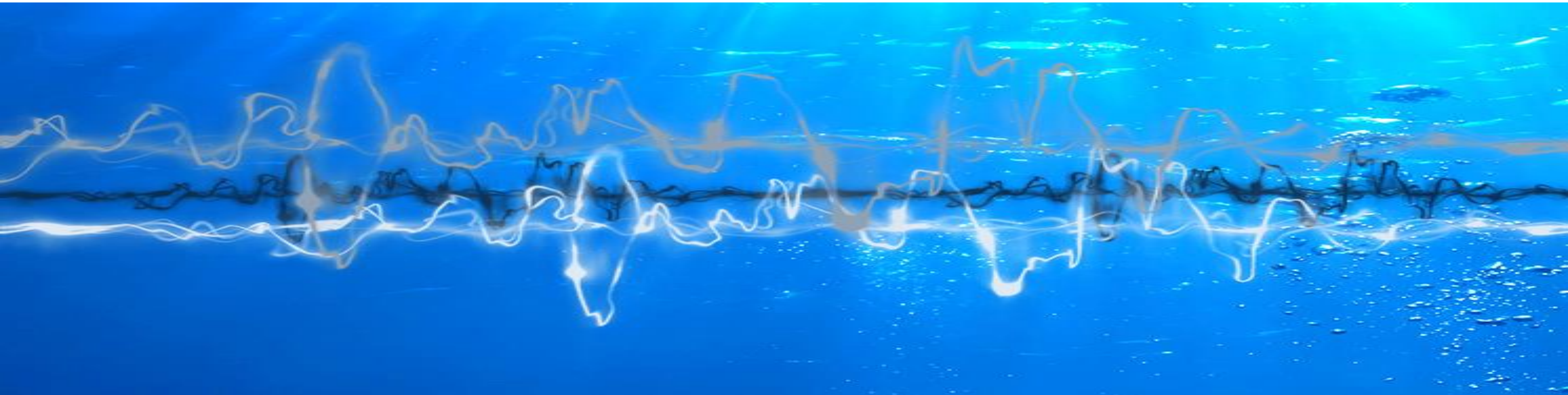
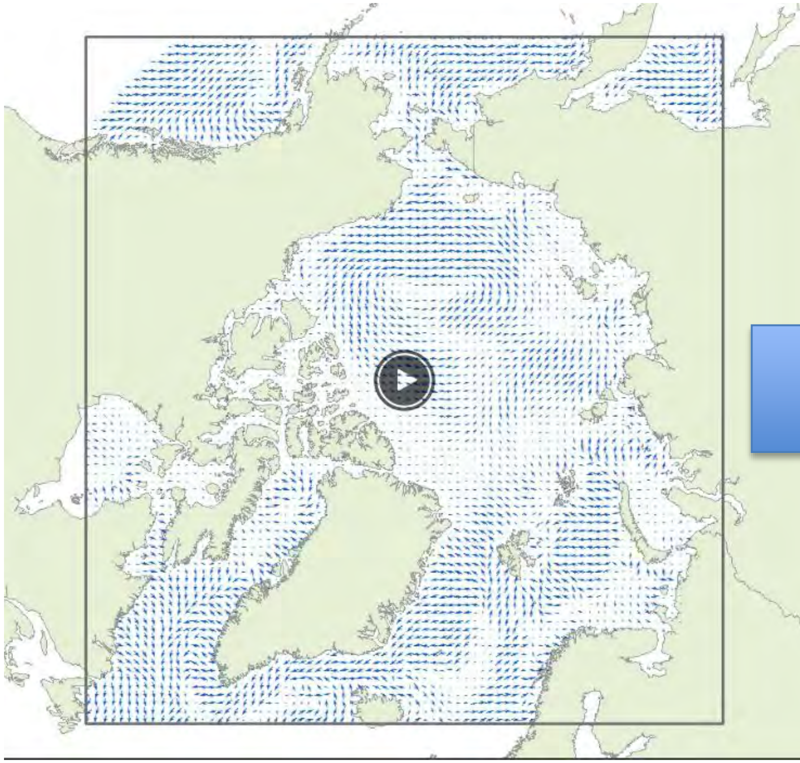
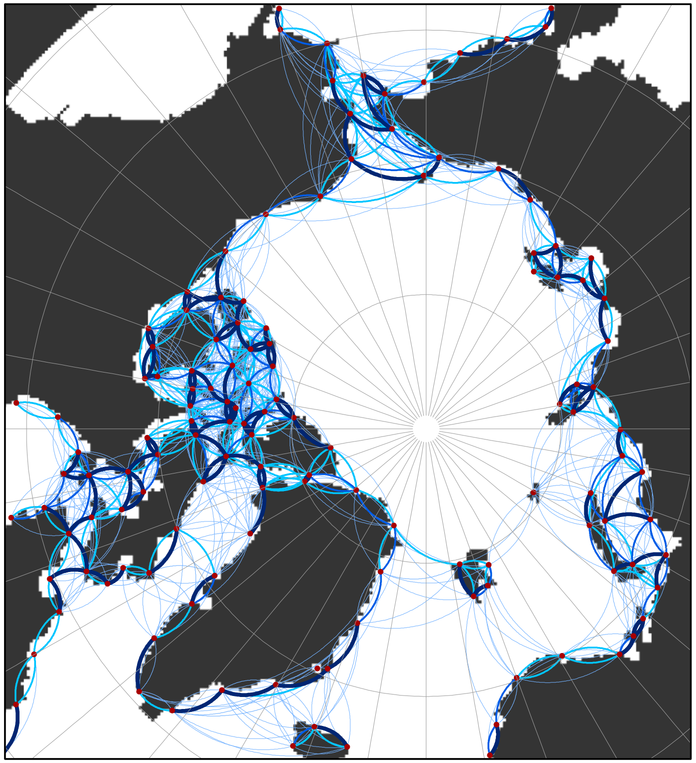


Arctic connectivity analysis framework

Models of surface currents



Network Models



How do we represent physical and ecological processes of connectivity…

How do we ask questions about connectivity…

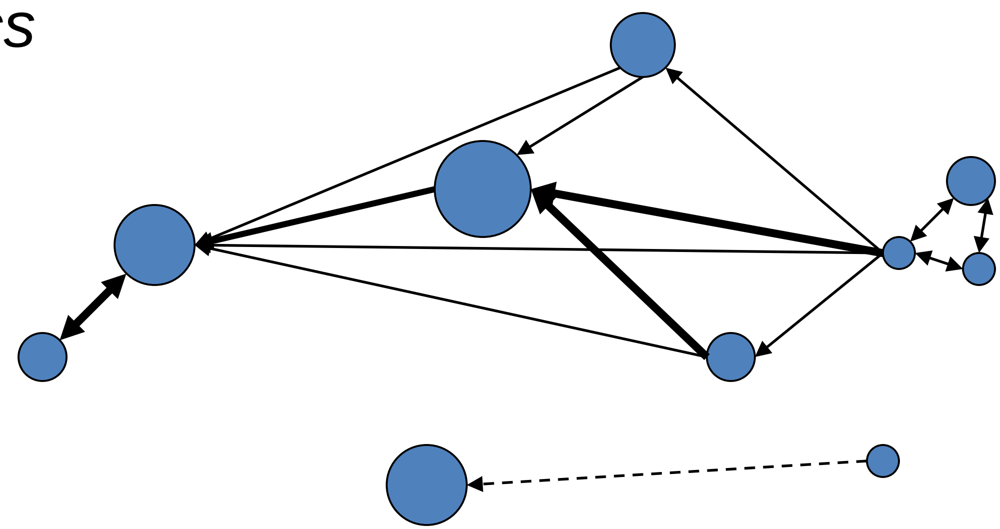
Marine Connectivity
via Larval dispersal

Connectivity

- Recruitment/recovery from disturbances
- Source/sink implications
- Flow of genetic information
- Range expansion
- Biogeographic and phylogeographic patterns

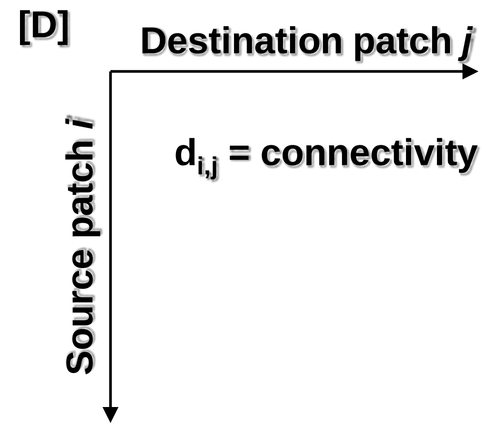
Driven by hydrodynamics

- Sub-networks
- Stepping stones
- Betweeness



Modeling Connectivity

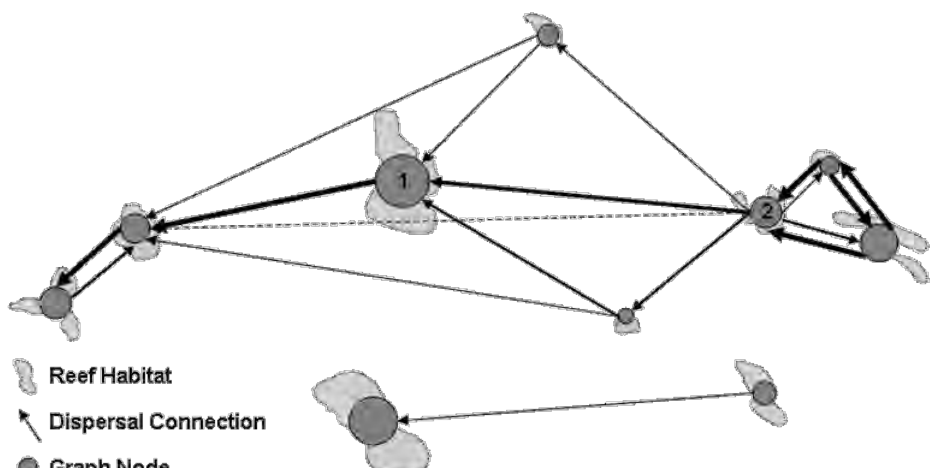
Data Structure



Data model

- Connectivity matrix [D]
  - Drifting days **
  - Probability
  - Geographic distance

- Location matrix (patch id, longitude, latitude)
- Habitat properties (area, density, quality, etc)



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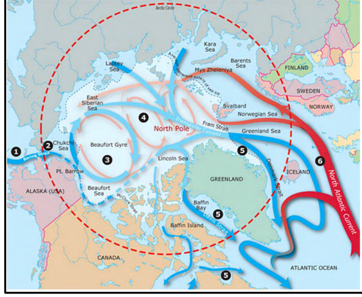
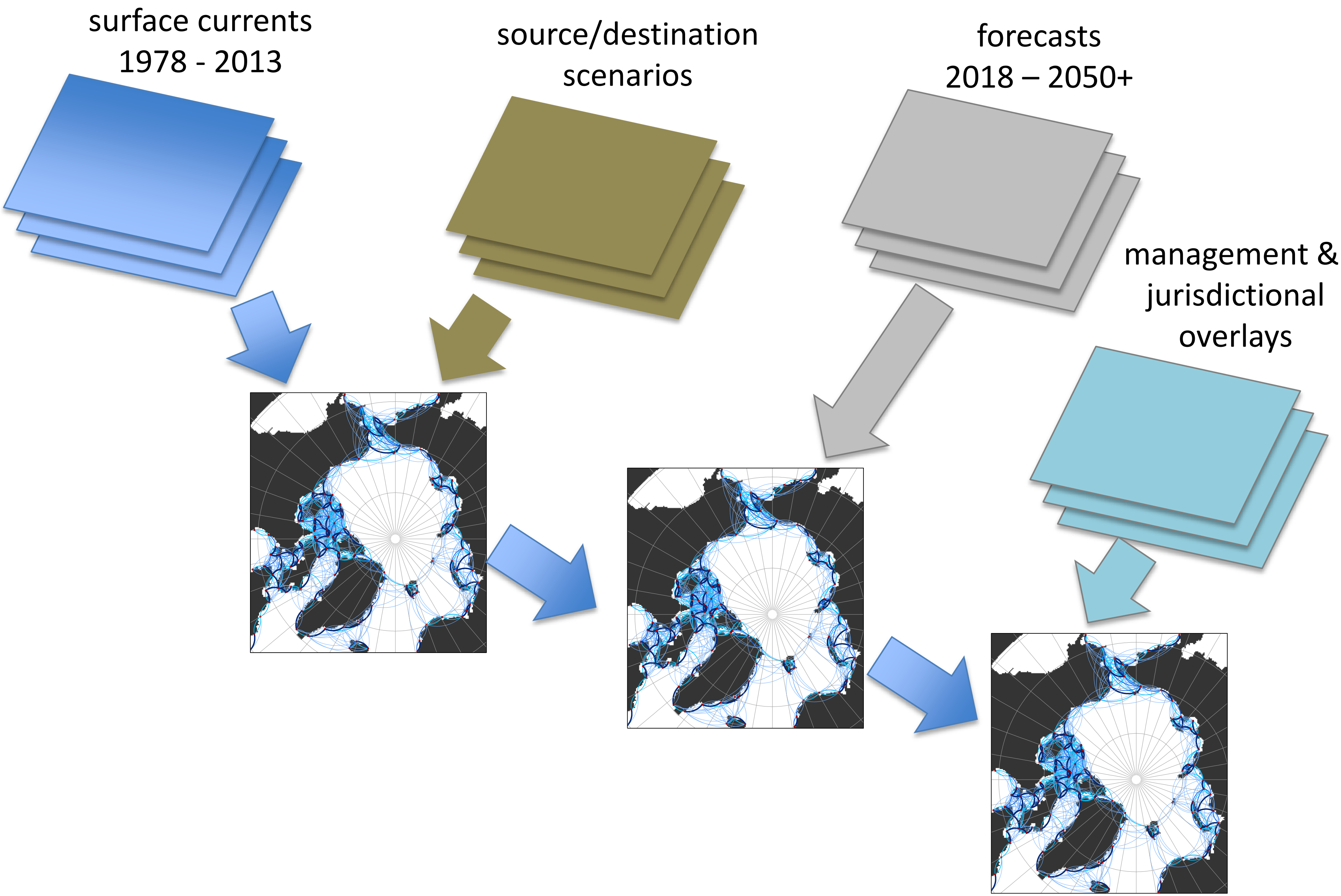


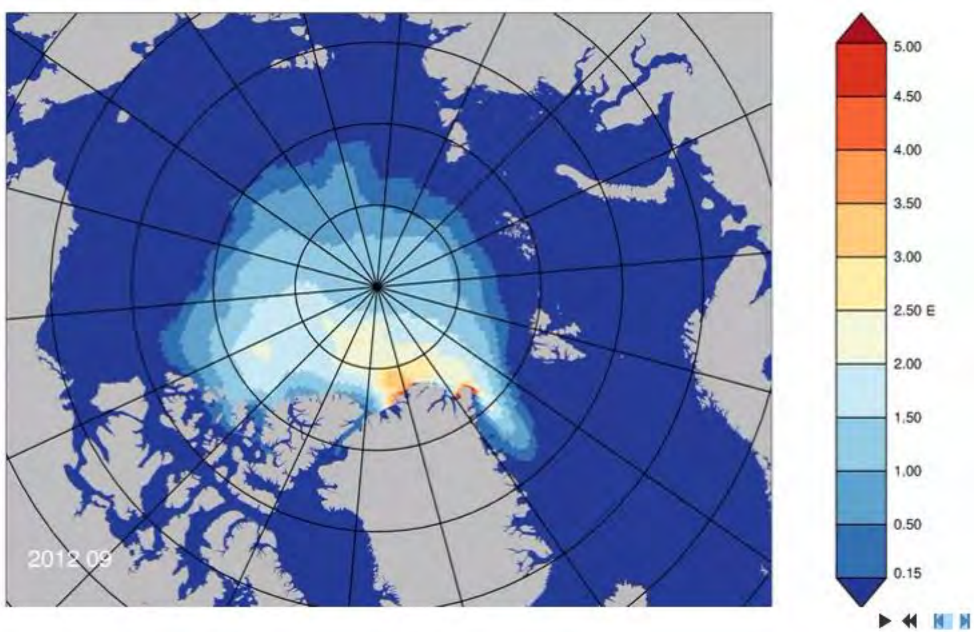
Arctic connectivity pilot analysis



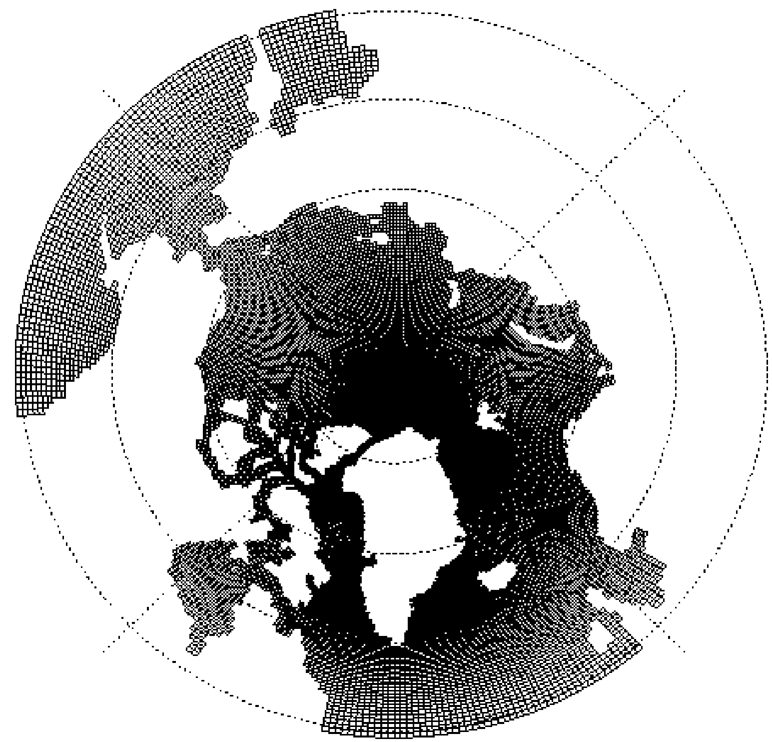
Arctic connectivity pilot analysis

Surface Currents:

Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, version 2.1), Zhang and Rothrock (2003)



Monthly Ice Thickness from 1979-2015

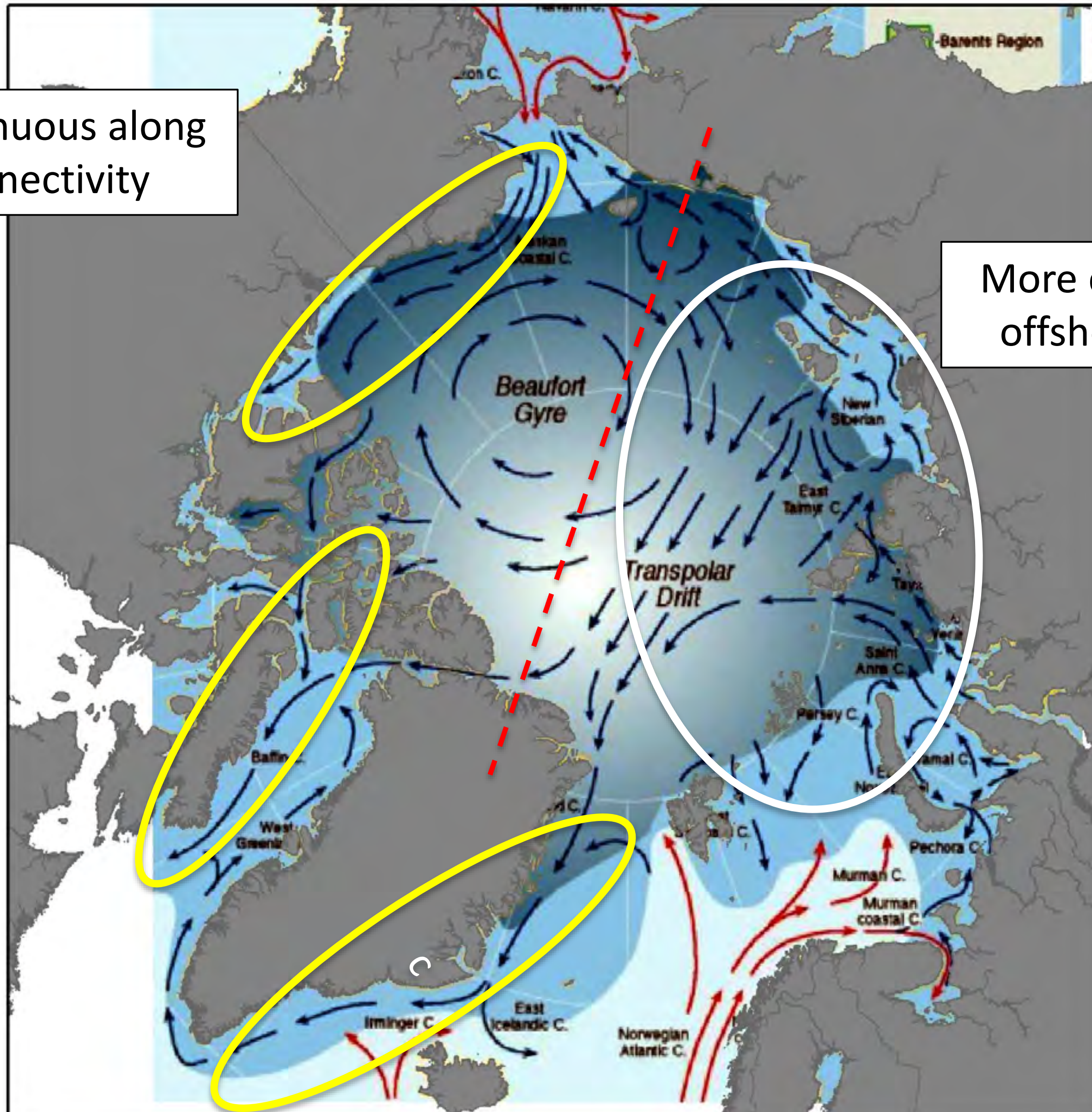


Monthly data, 1978 – 2013
partially-coupled, data assimilative

General surface currents

Longer continuous along shore connectivity

More complex shore to offshore connections

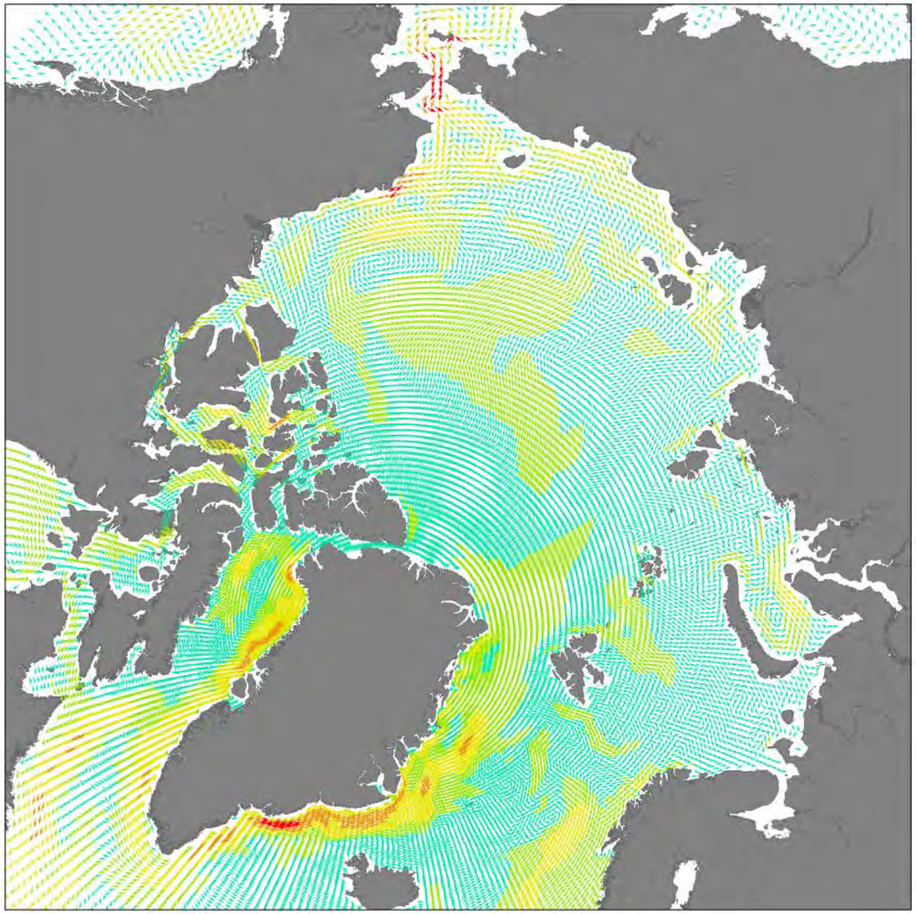


Surface Current Schematic

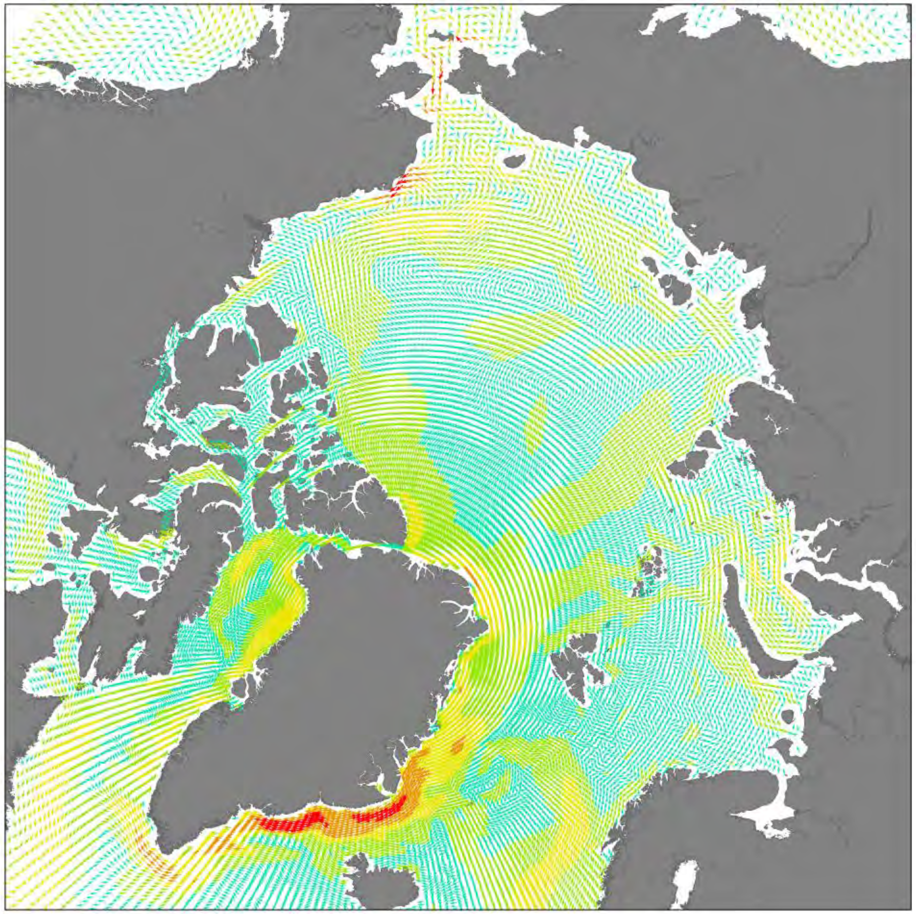
Arctic connectivity pilot analysis

Surface Currents velocities:

Forecast 2018



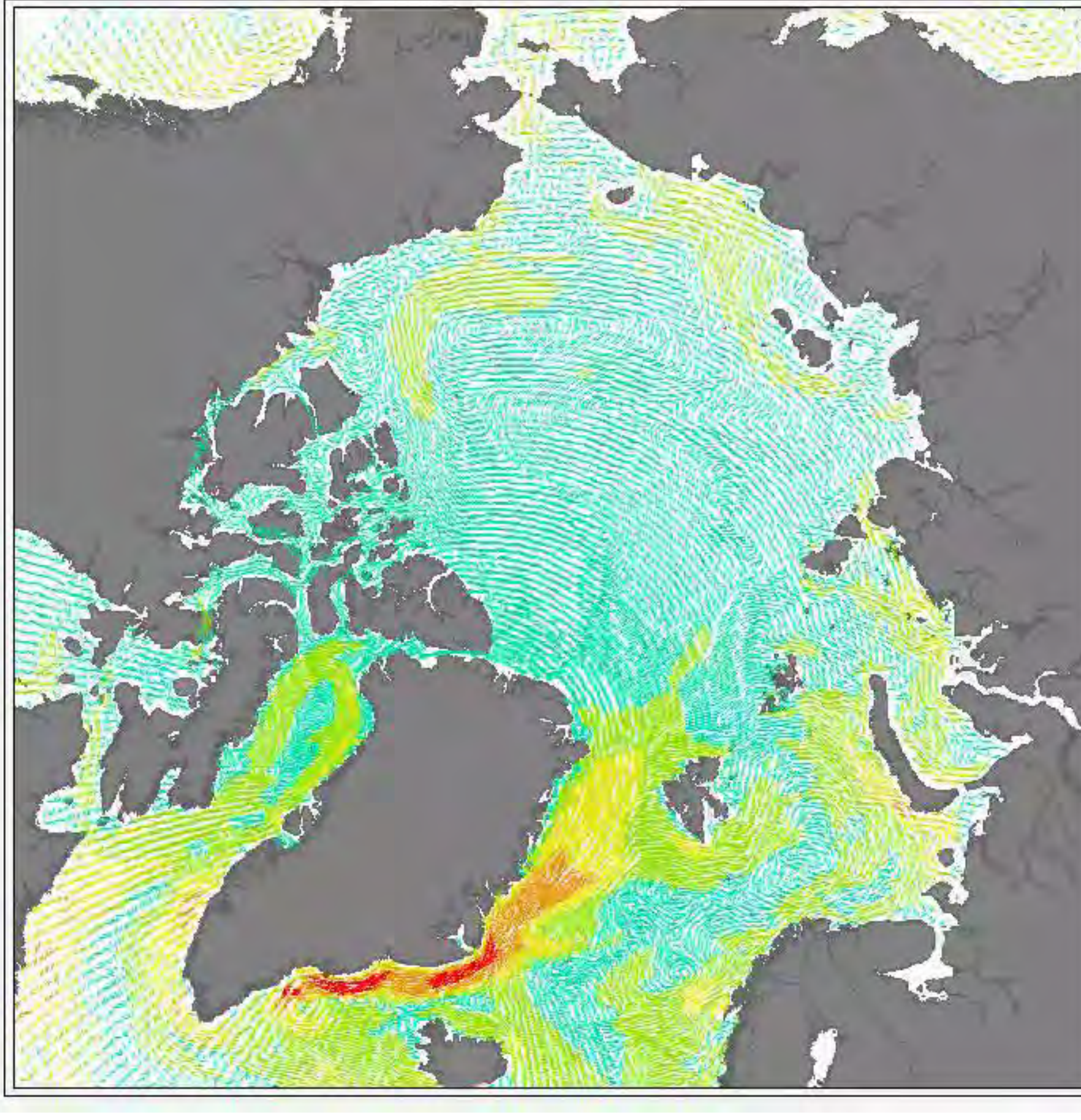
Forecast 2050



From models after: Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, version 2.1), Zhang and Rothrock (2003)

Surface Current Velocities:

Forecast **2018**



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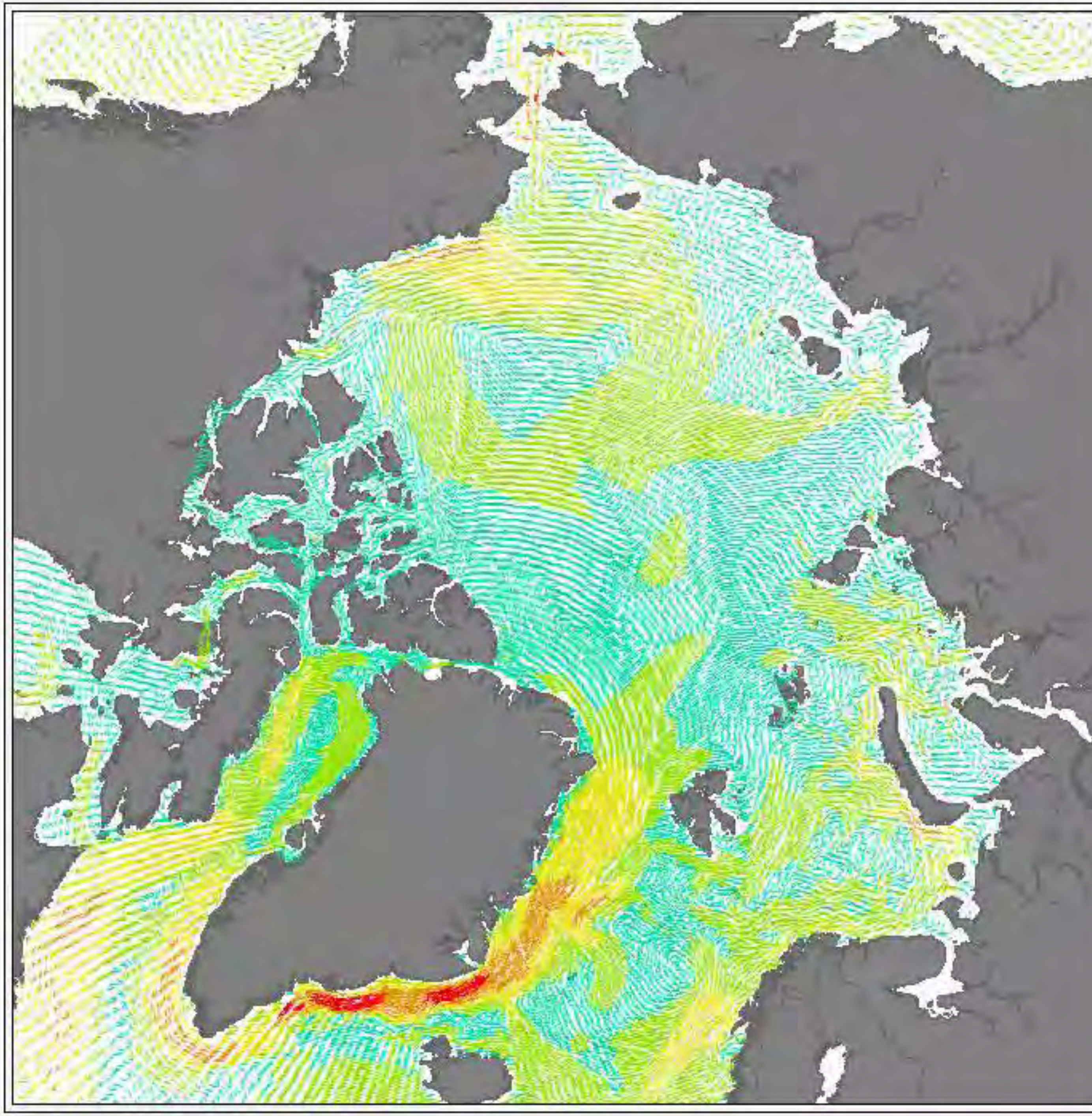
Surface Current Velocities:

Forecast **2050**

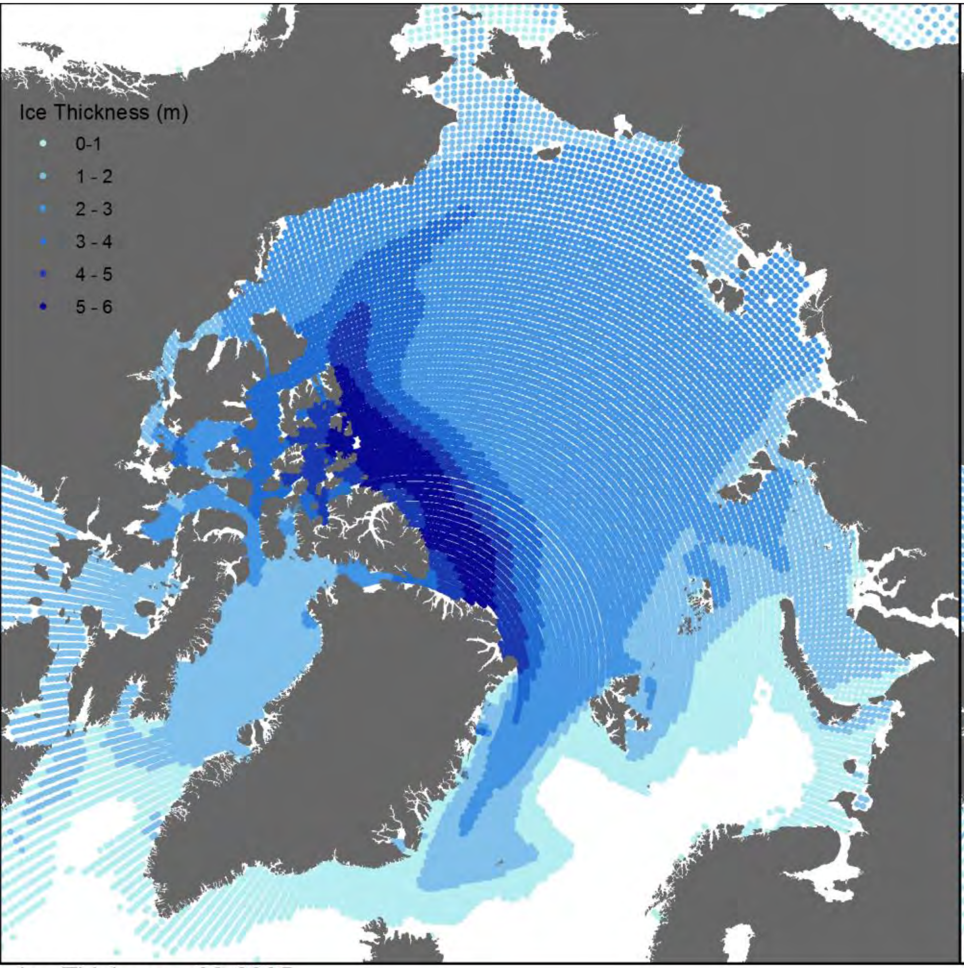


From models after: Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS, version 2.1), Zhang and Rothrock (2003)

Arctic connectivity pilot analysis

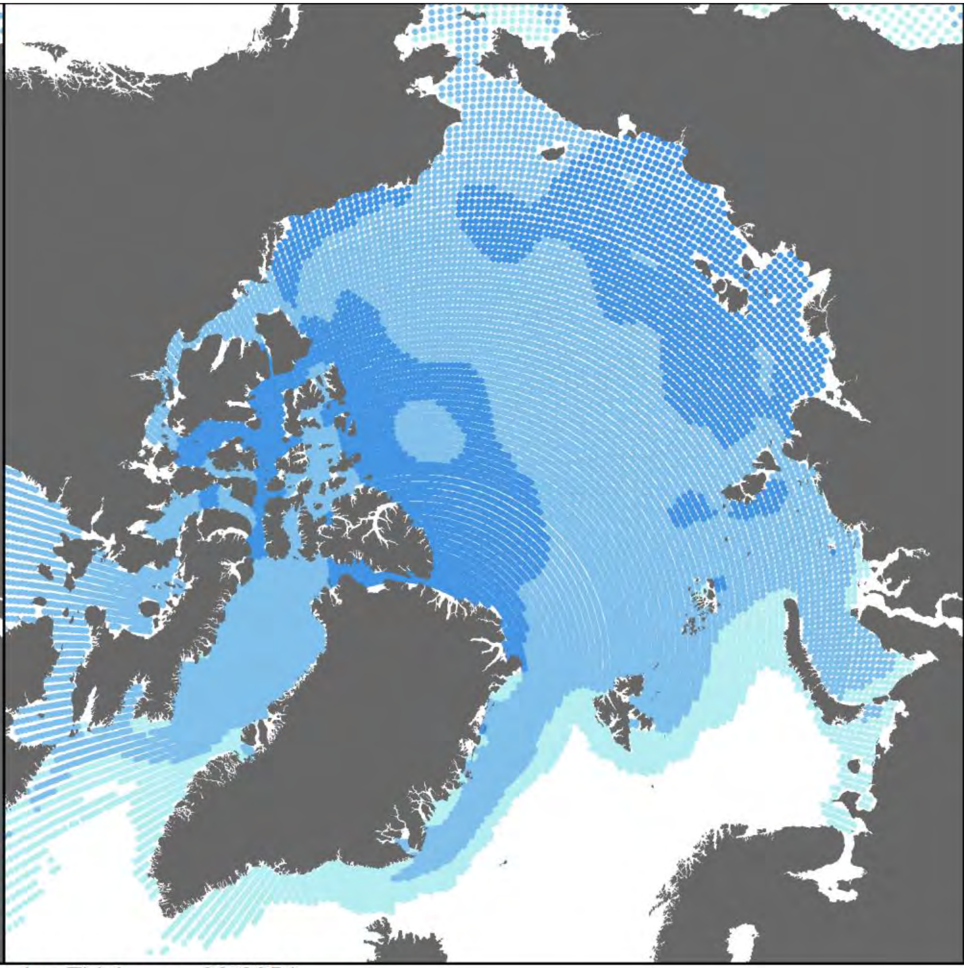
Ice Thickness: **Winter**

2005



Ice Thickness, 02-2005

2051



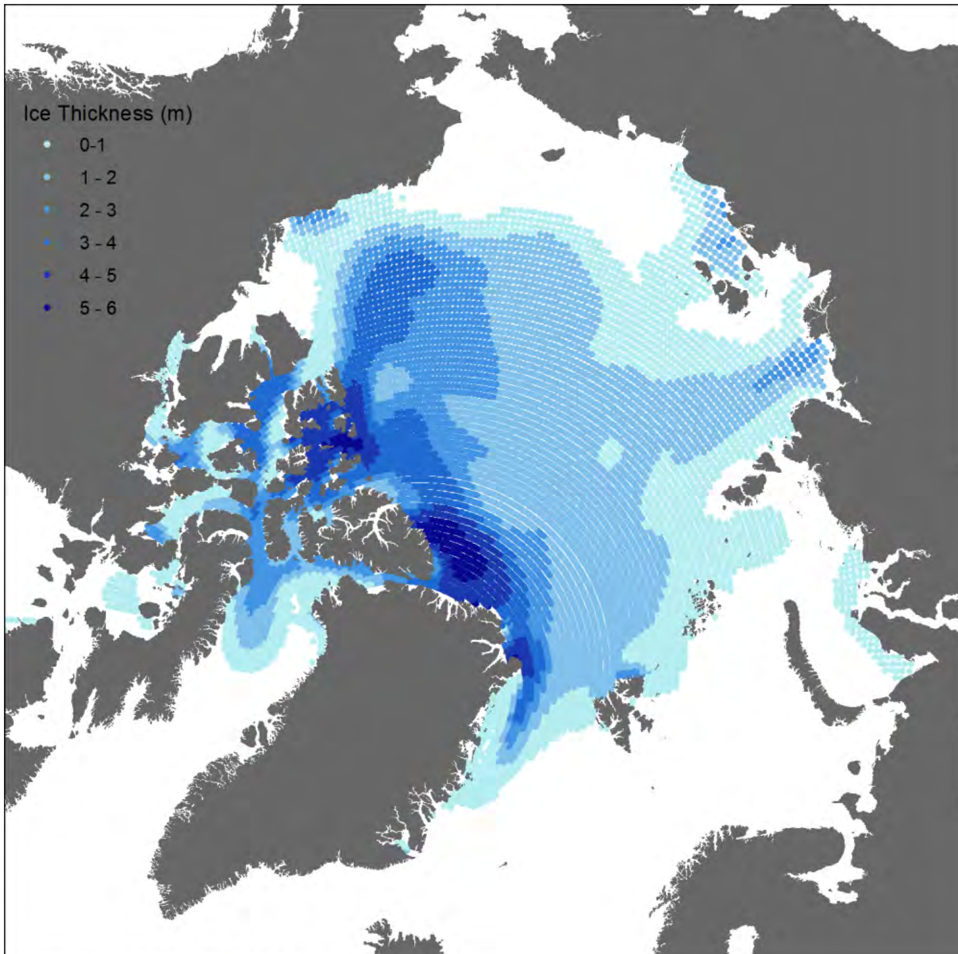
Ice Thickness, 02-2051

PIOMAS Projections of an Ice-Diminished Arctic Ocean, Zhang and Rothrock (2003)

Arctic connectivity pilot analysis

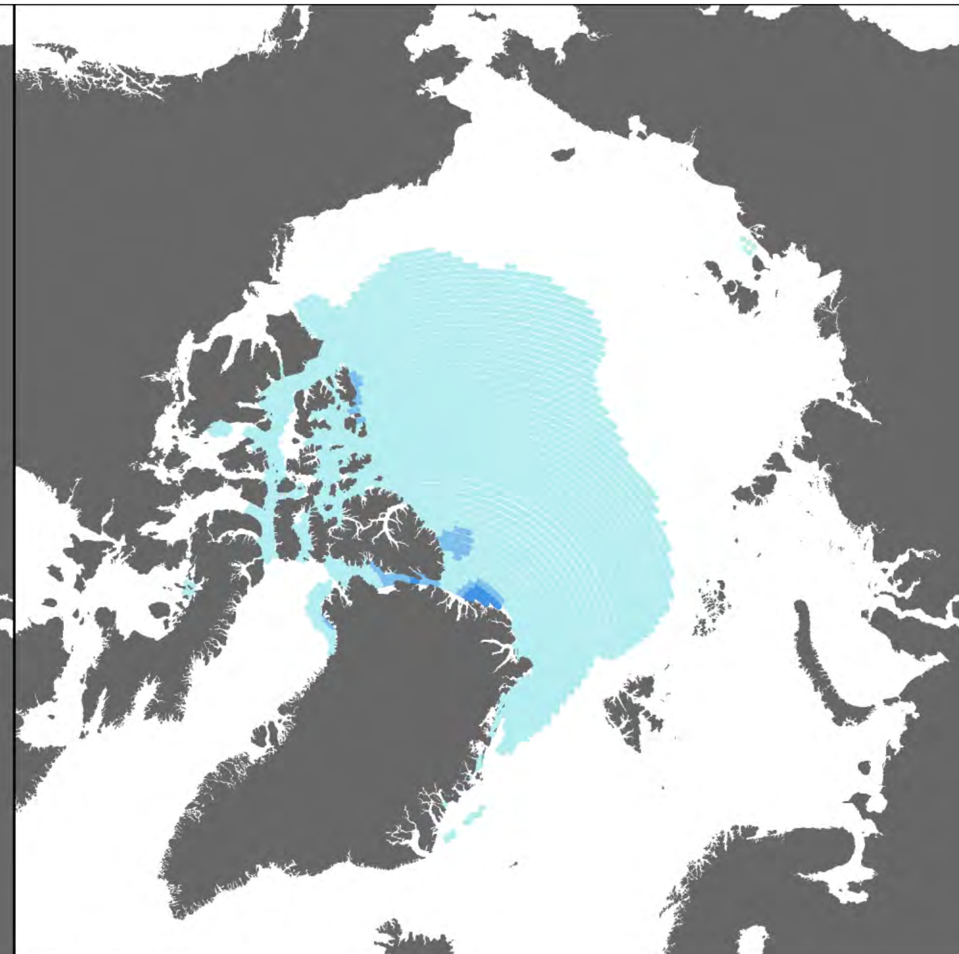
Ice Thickness: **Summer**

2005



Ice Thickness, 09-2005

2051



Ice Thickness, 09-2051

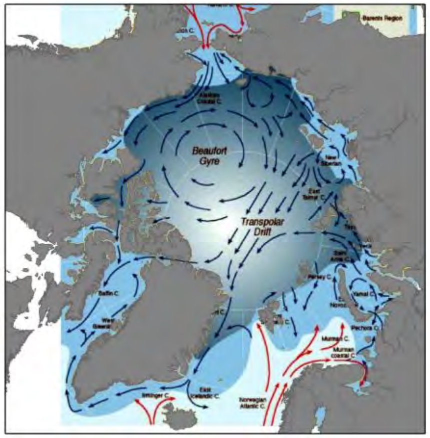
PIOMAS Projections of an Ice-Diminished Arctic Ocean, Zhang and Rothrock (2003)

Arctic connectivity pilot analysis

Potential pilot scenarios

3 x 2 x 2 = 12 initial pilot scenarios

Source / destination targets	**“normal” ice year**		**“low” ice year**	
Coastal areas (500km regions)	winter	summer	winter	summer
Fish spawning areas	winter	summer	winter	summer
Important feeding grounds	winter	summer	winter	summer



Arctic connectivity pilot analysis

Potential pilot scenarios

Source / destination targets	"normal" ice year		"low" ice year	
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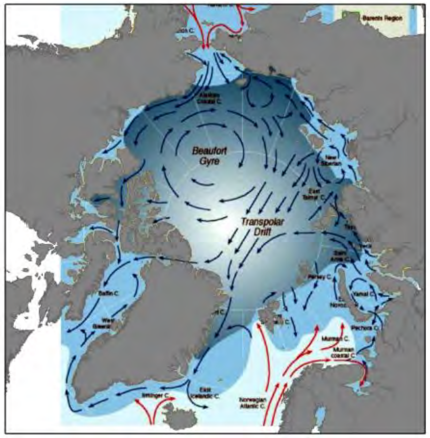
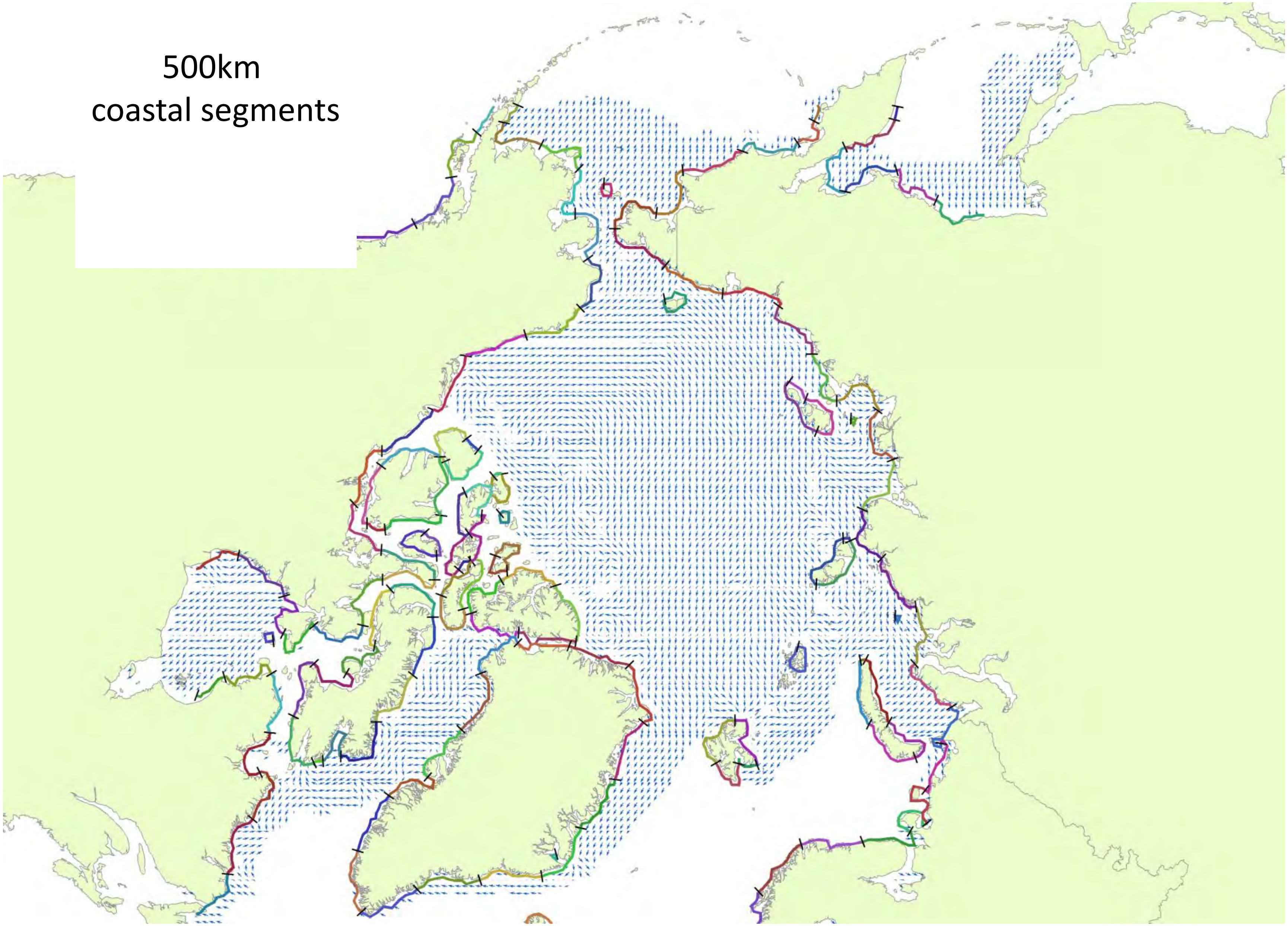


Arctic connectivity pilot analysis



Arctic connectivity pilot analysis

Surface Currents:

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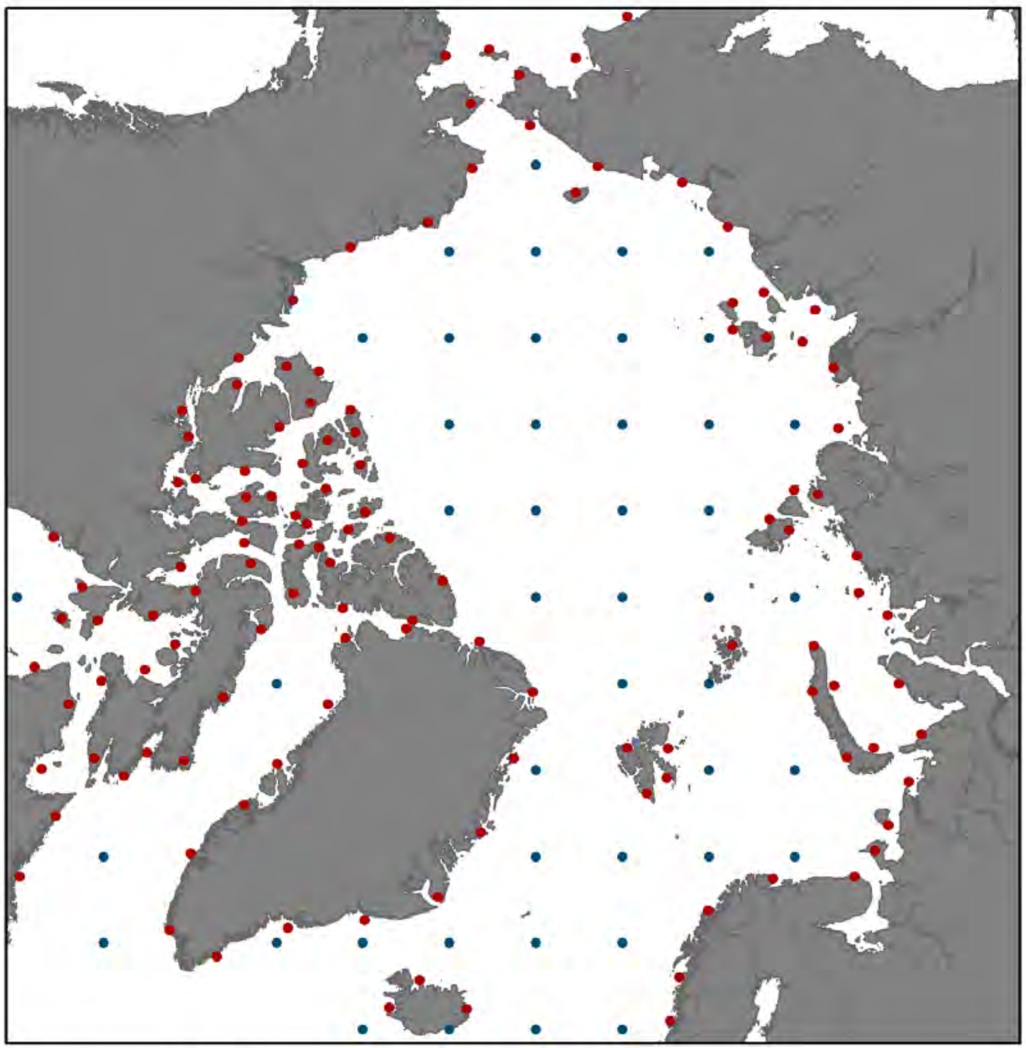
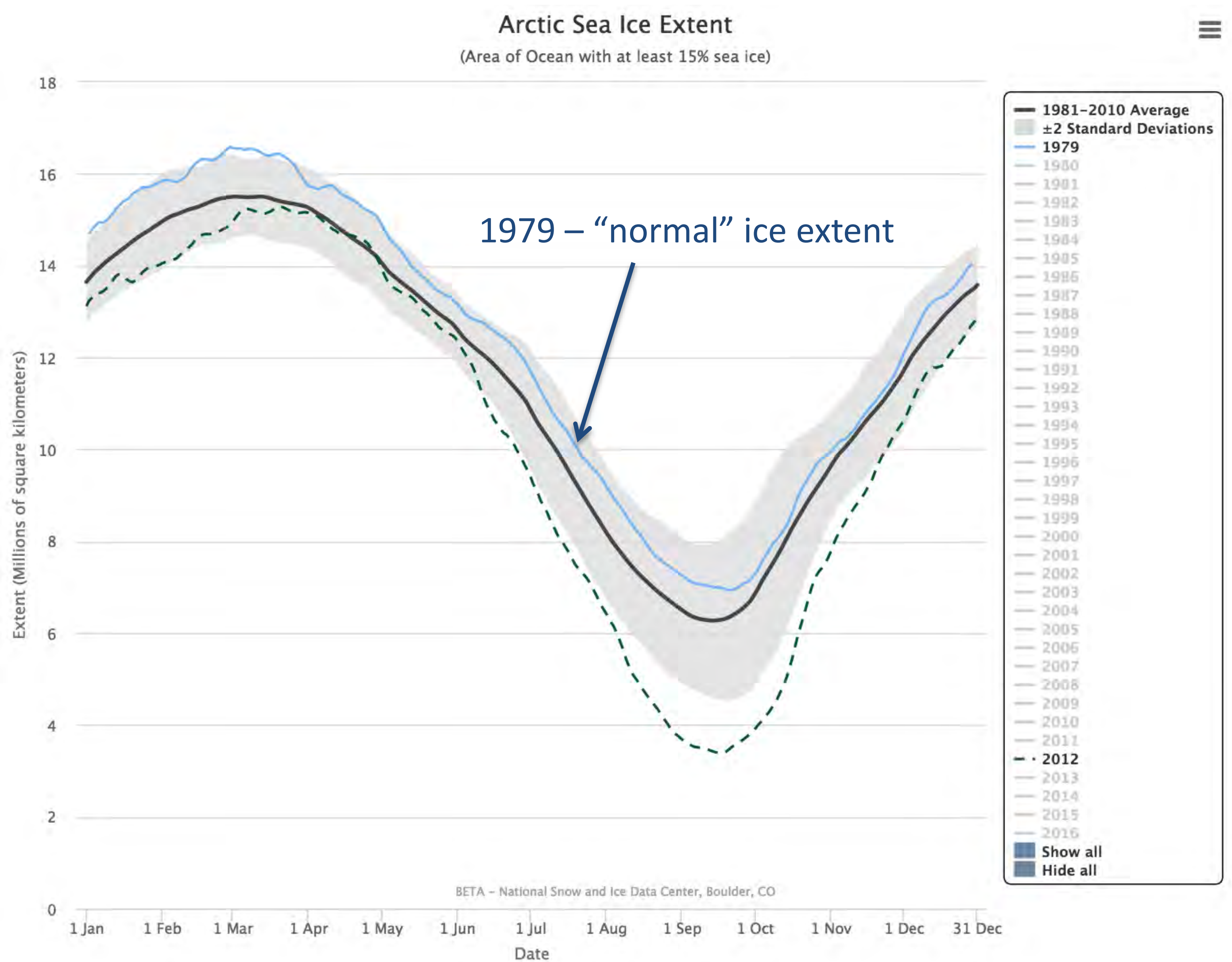


Shoreline and Offshore Grid

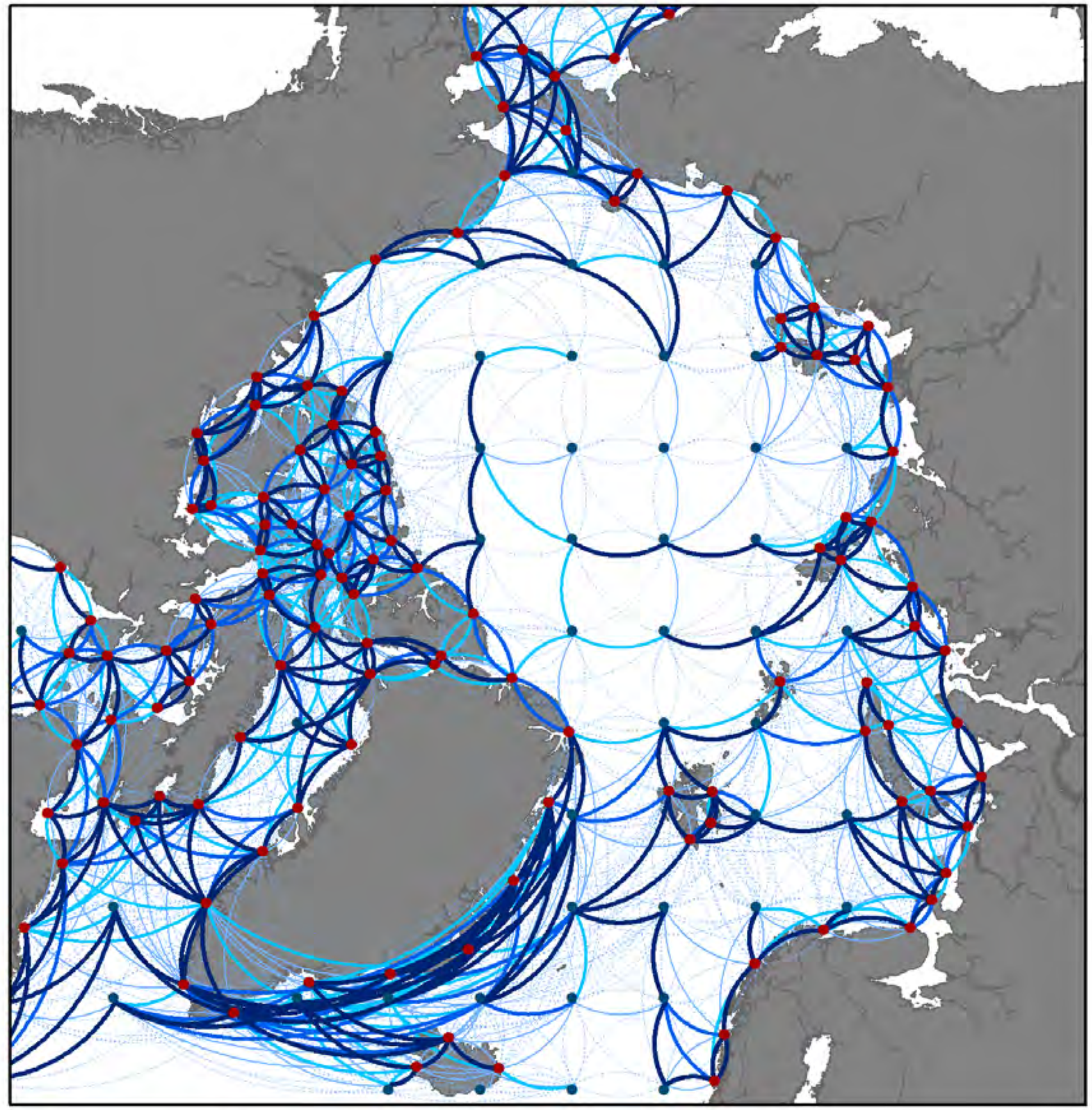
Arctic connectivity pilot analysis



Arctic connectivity pilot analysis

Summer
September 1979 connectivity
500km coastline regions

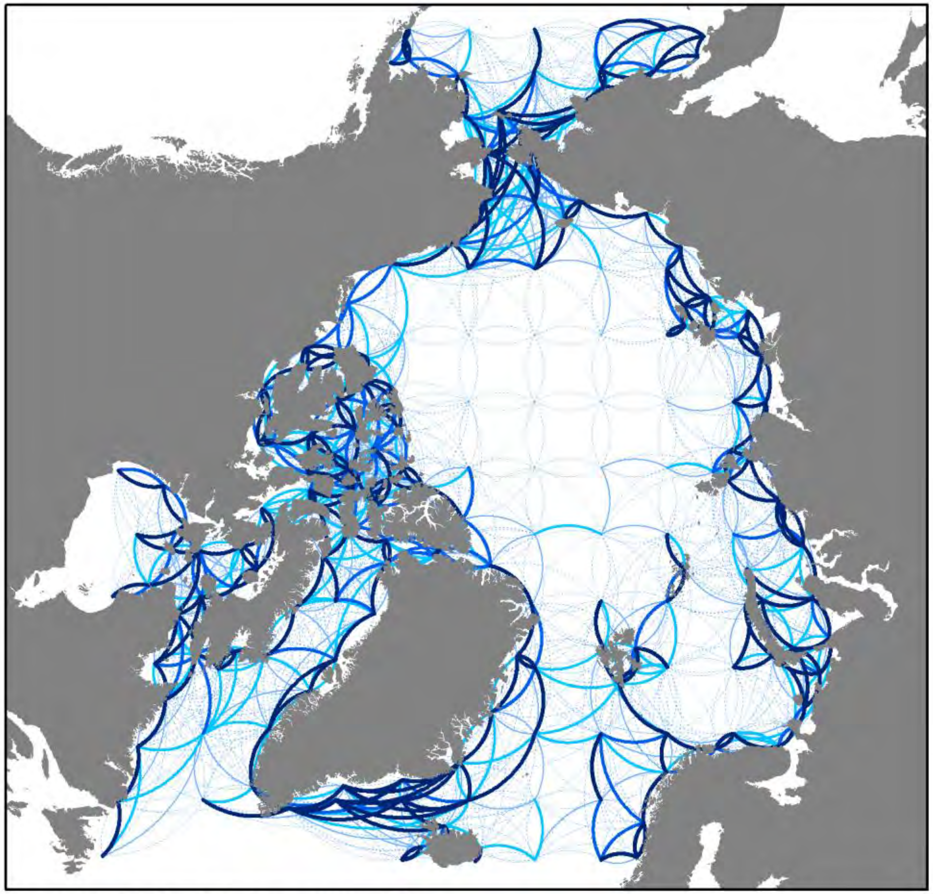
Connectivity
What coastal areas are connected to other coastal areas on a 100 day period



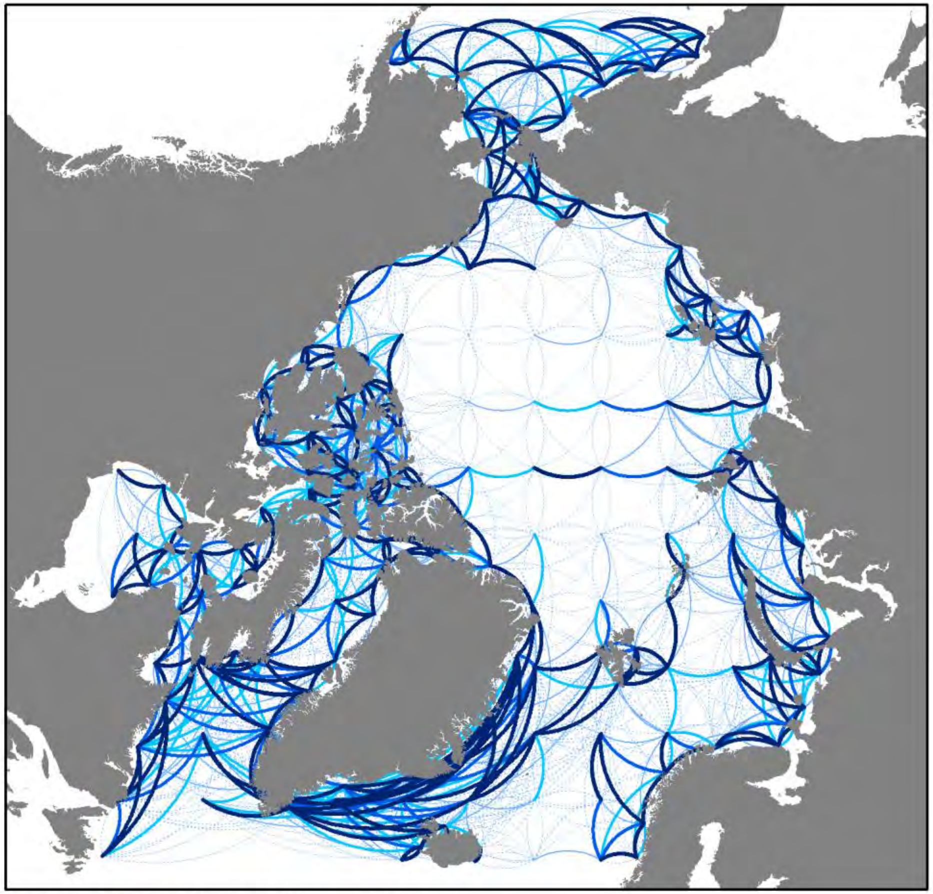
Shoreline and Offshore Grid

Coastal water connectivity

summer vs. winter normal year (1979)



Summer 1979, 100 day connectivity



Winter 1979, 100 day connectivity

Arctic connectivity pilot analysis

Potential pilot scenarios

Source / destination targets	"normal" ice year		"low" ice year	
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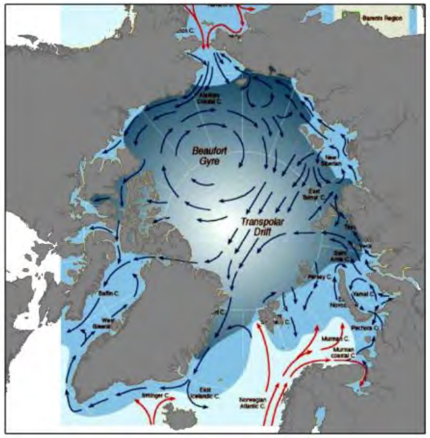
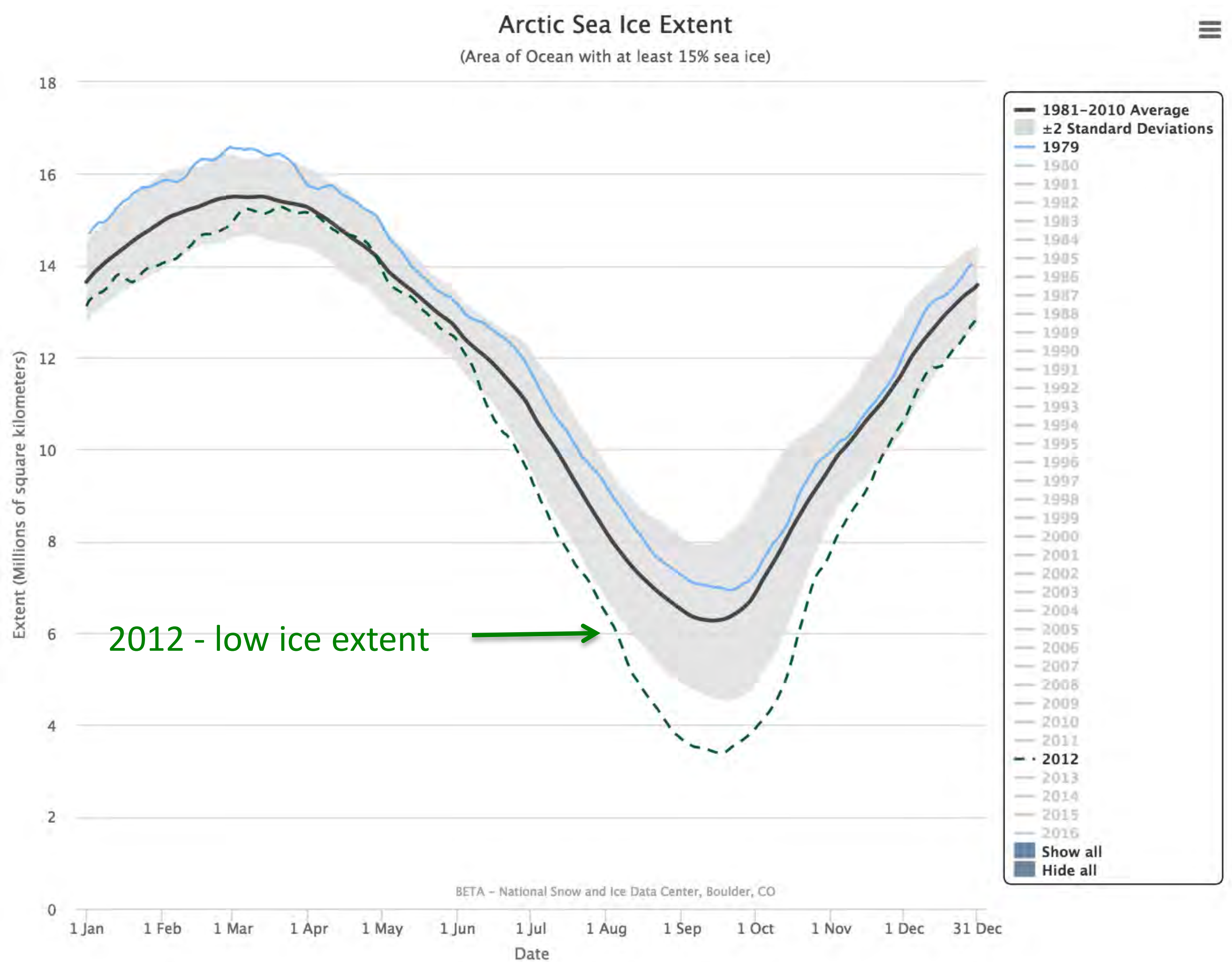


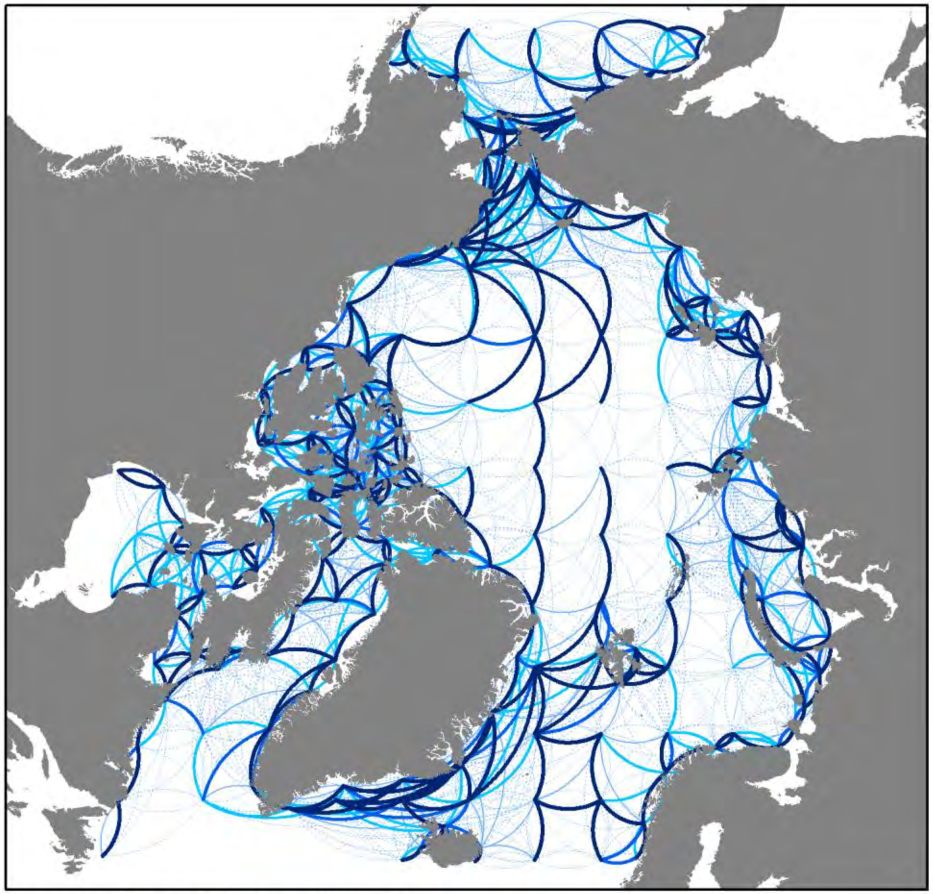
Arctic connectivity pilot analysis



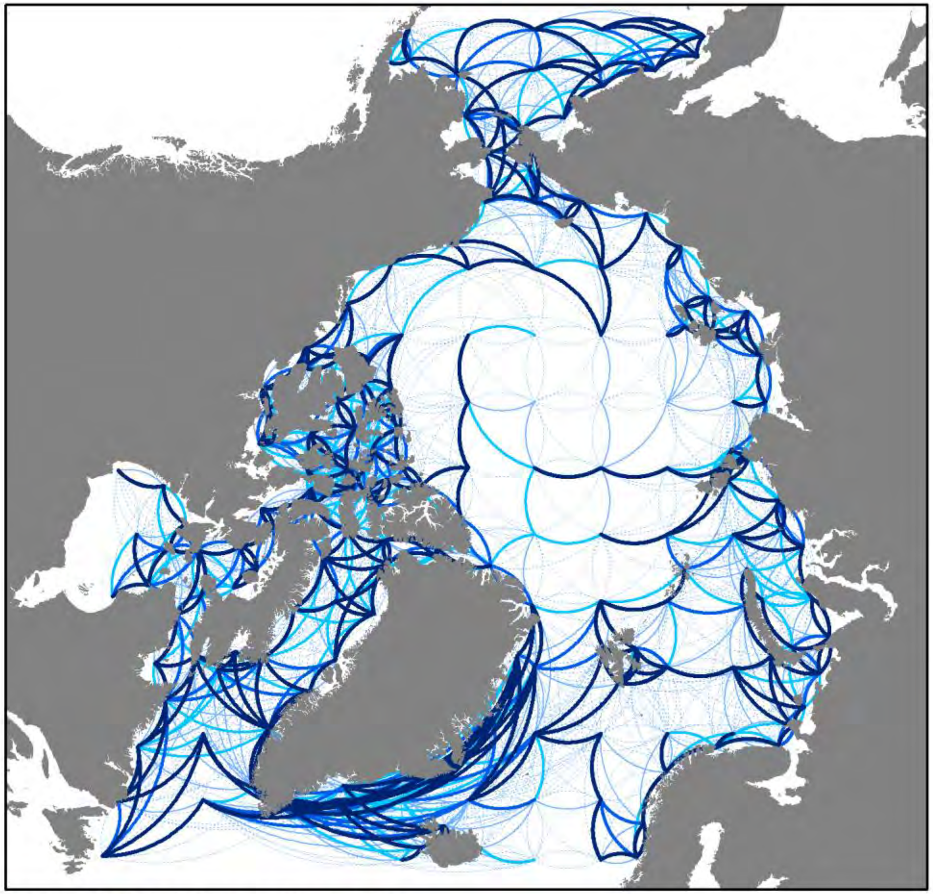
Arctic connectivity pilot analysis

summer / winter comparison

2012



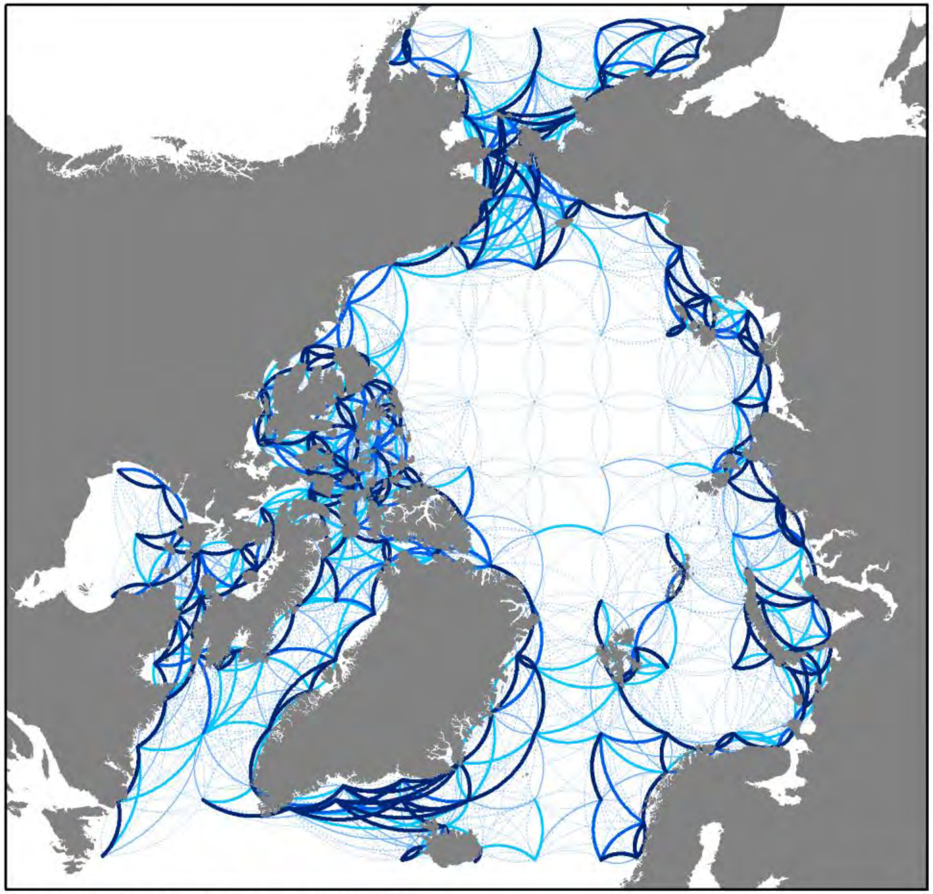
Summer 2012, 100 day connectivity



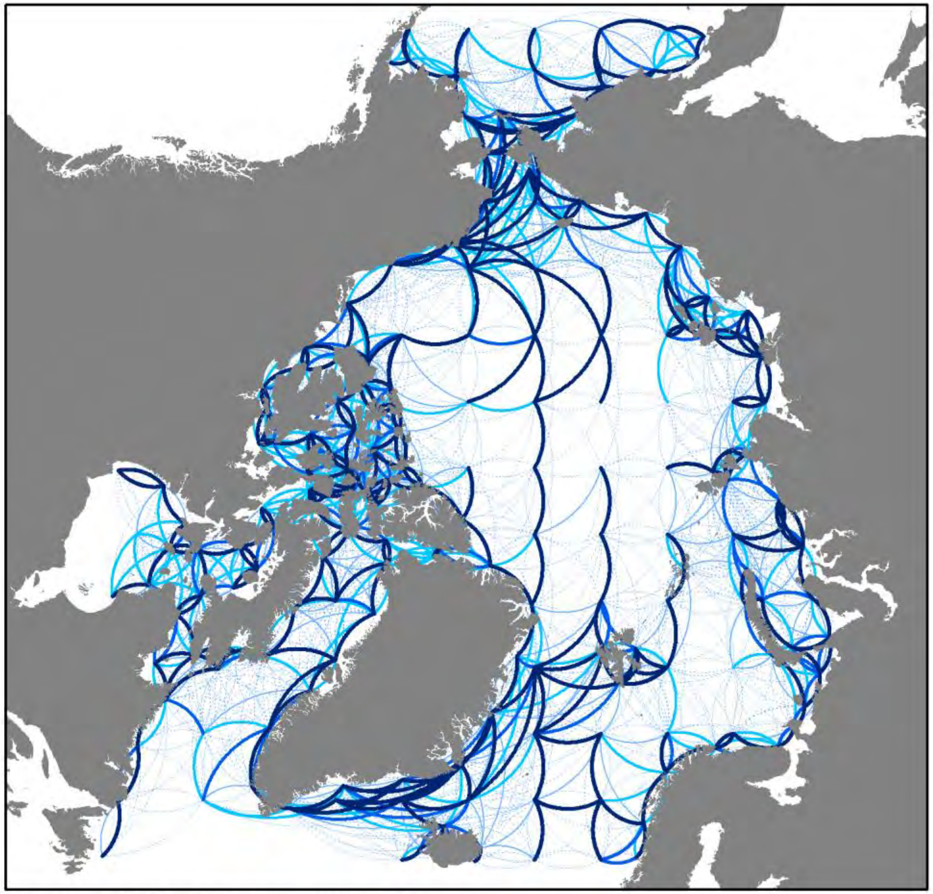
Winter 2012, 100 day connectivity

Arctic connectivity pilot analysis

Summer 1979 (normal) vs. 2012 (low ice)



Summer 1979, 100 day connectivity

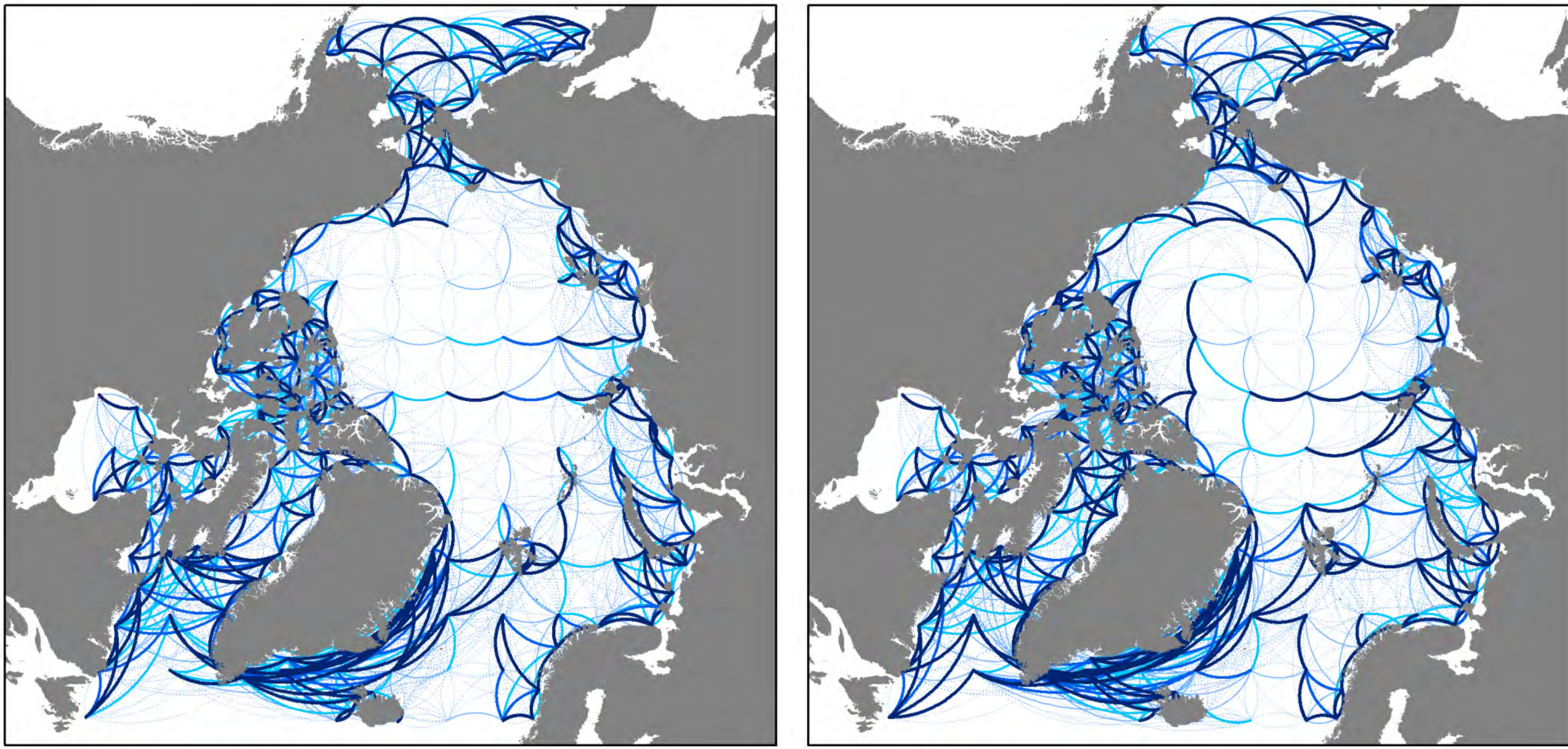


Summer 2012, 100 day connectivity

More longer distance & offshore connections

Arctic connectivity pilot analysis

Winter 1979 (normal) vs. 2012 (low ice)

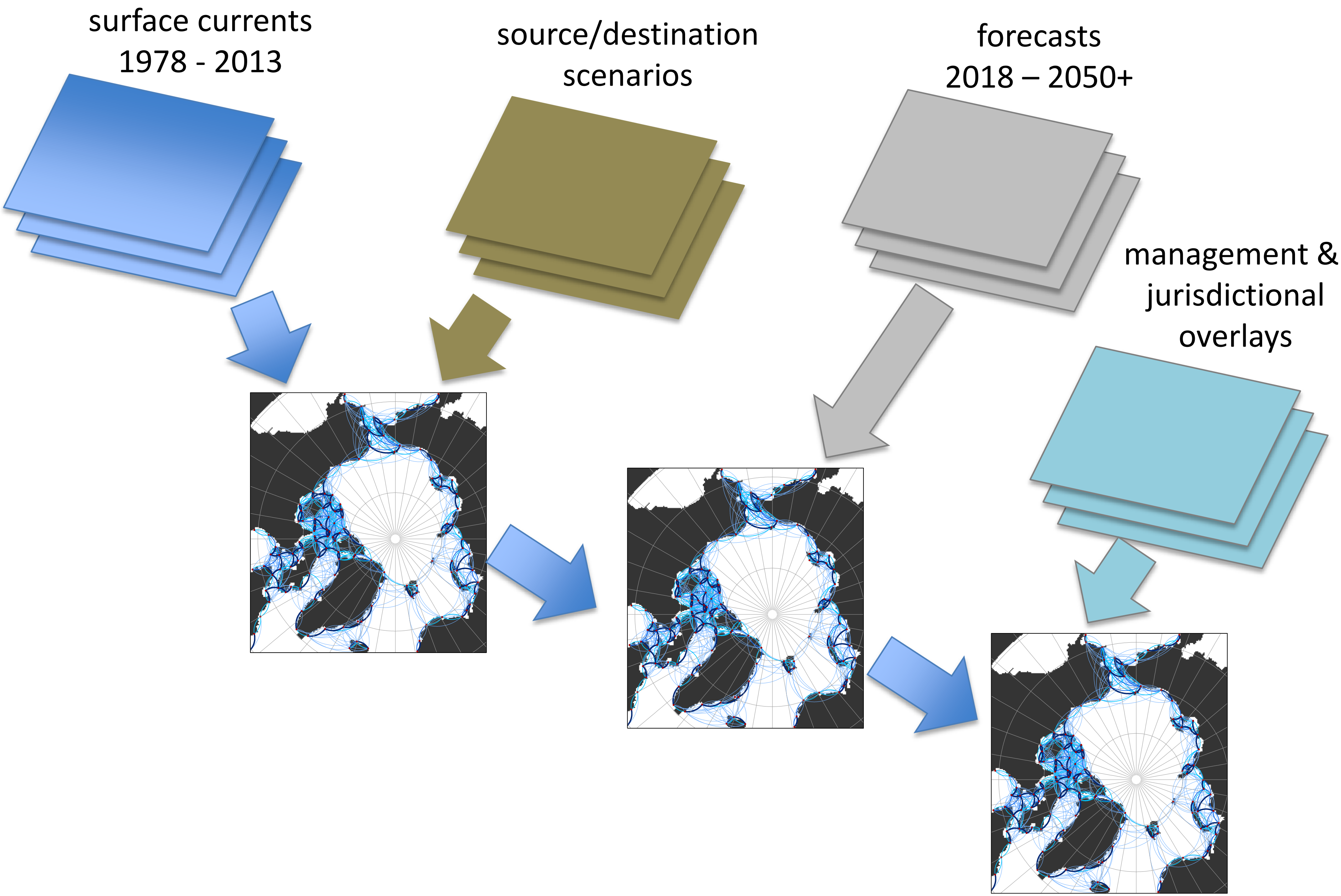


Winter 1979, 100 day connectivity

Winter 2012, 100 day connectivity

More offshore connections

Arctic connectivity pilot analysis



Arctic connectivity pilot analysis

Potential pilot scenarios

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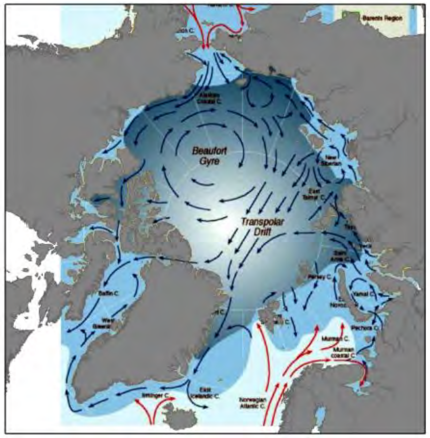
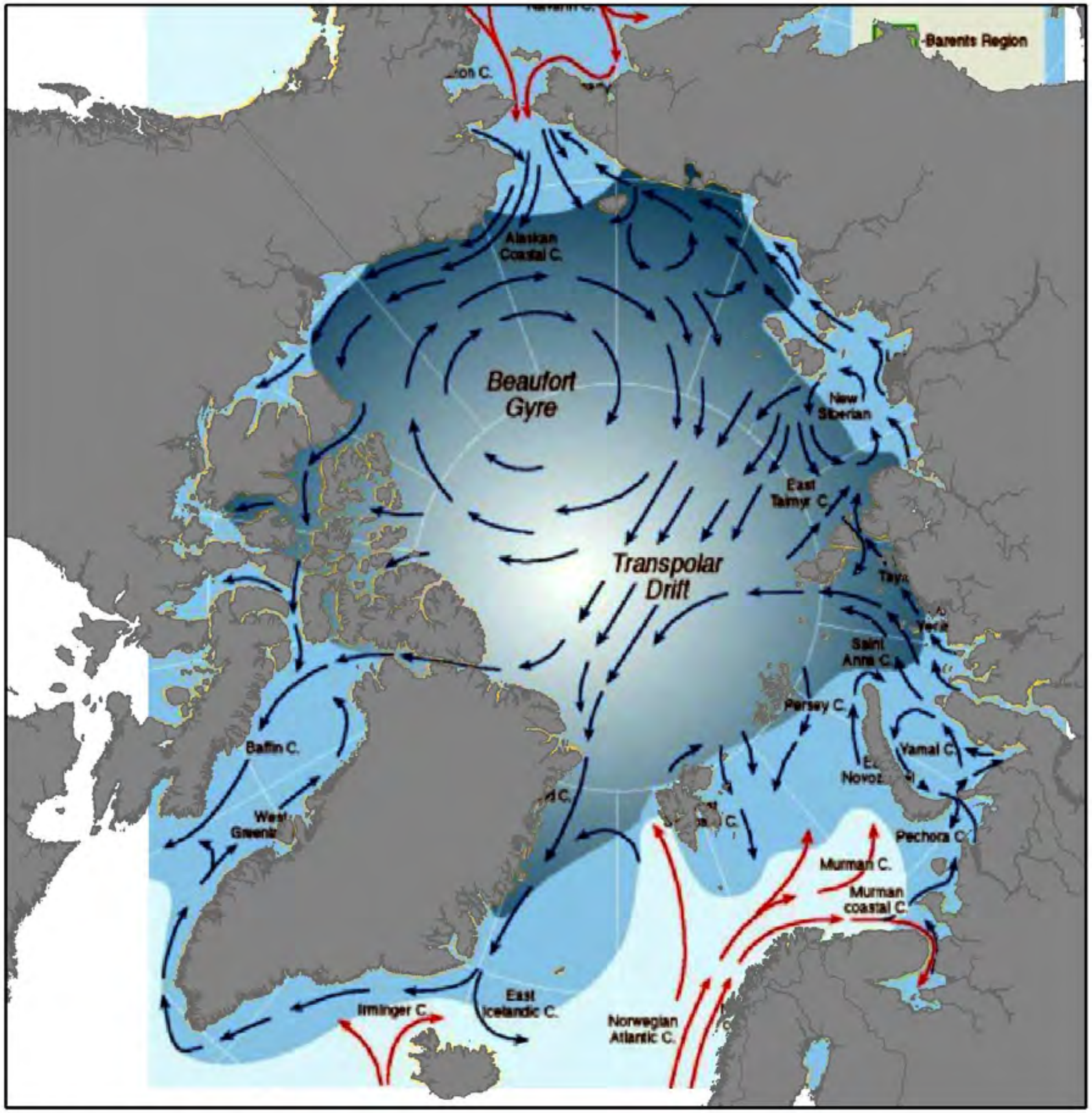


Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc
(multiple types)

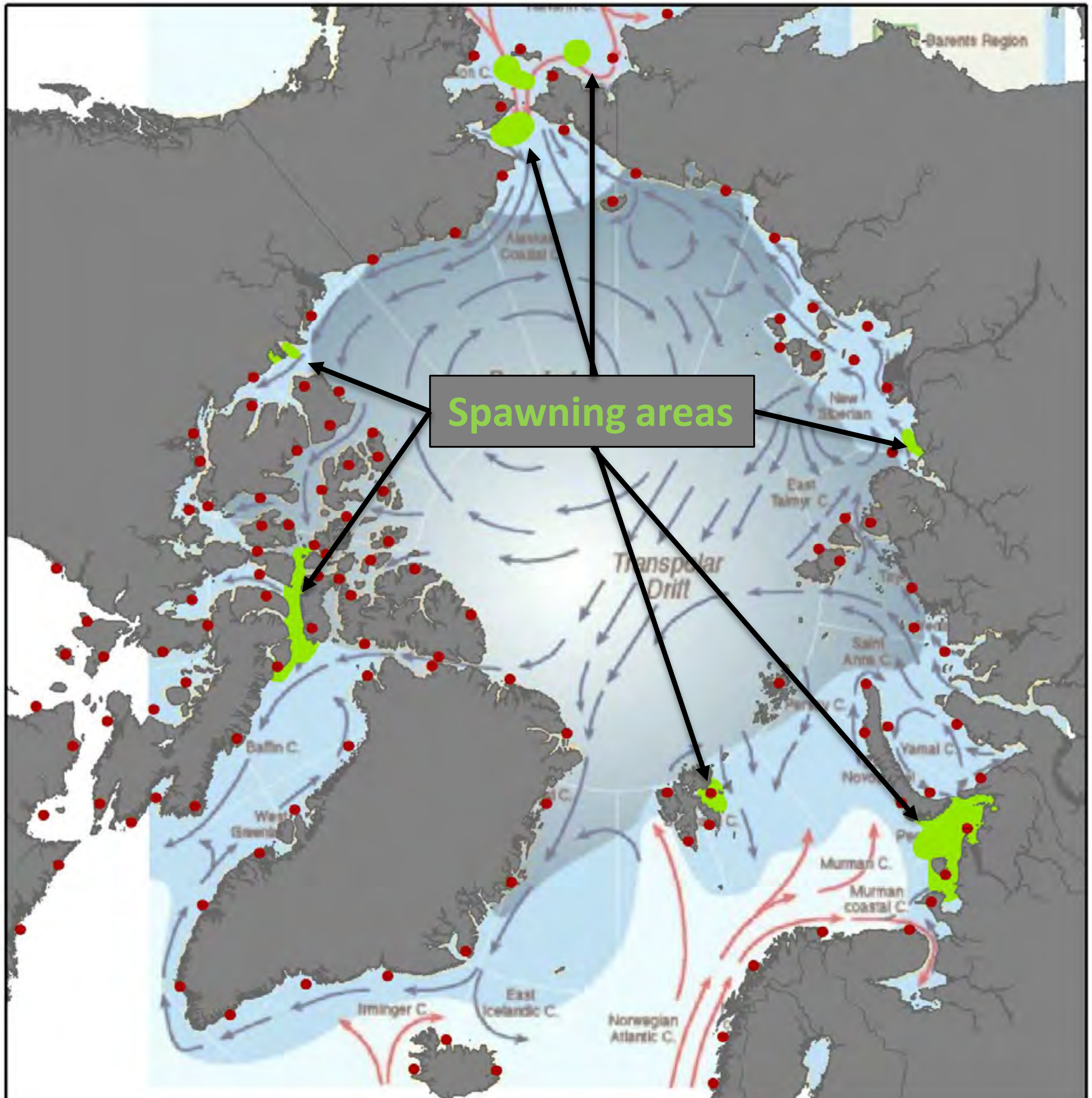


Surface Current Schematic

Arctic connectivity pilot analysis

Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

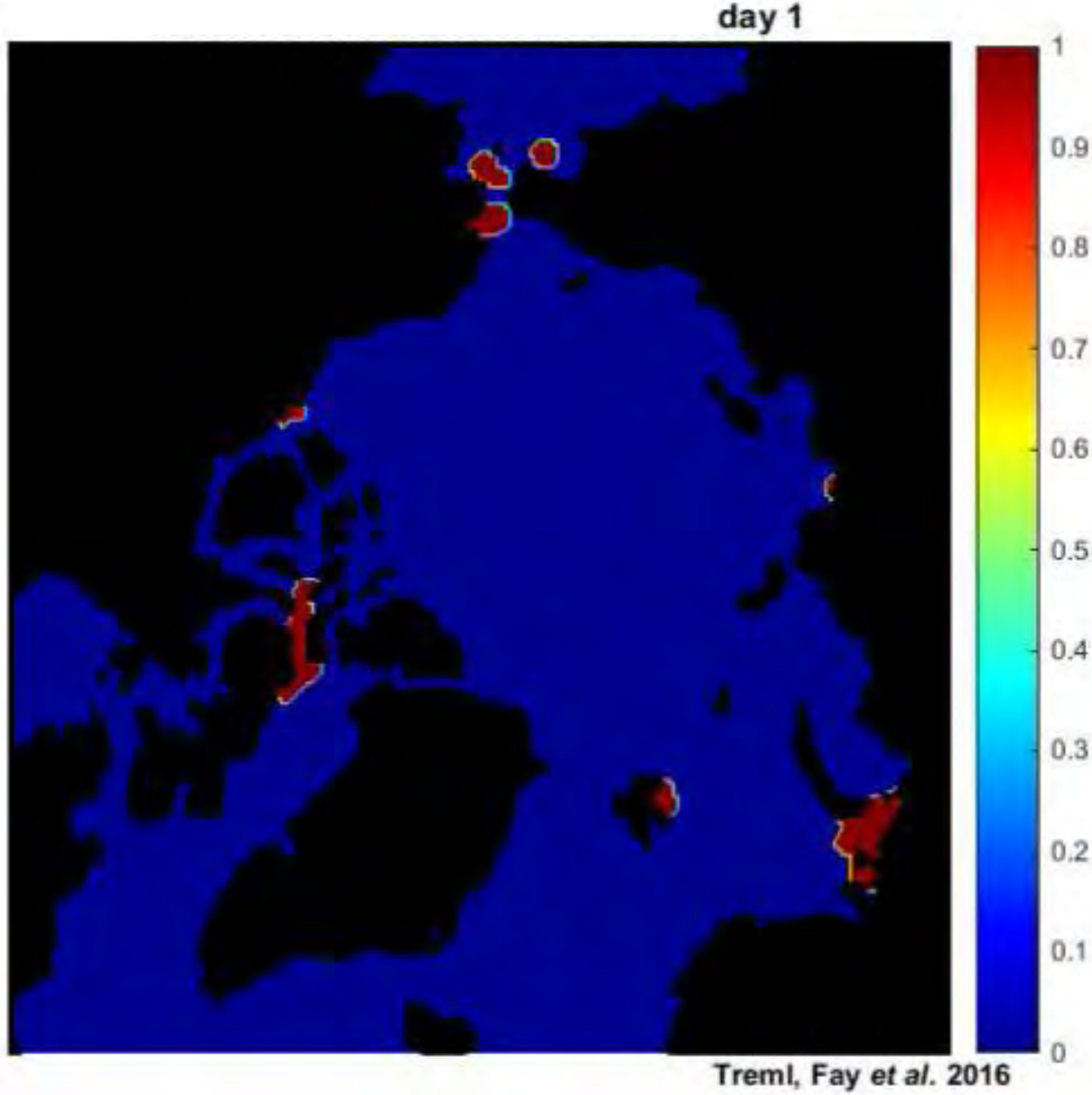


Surface Current Schematic - Polar Cod Spawning

Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

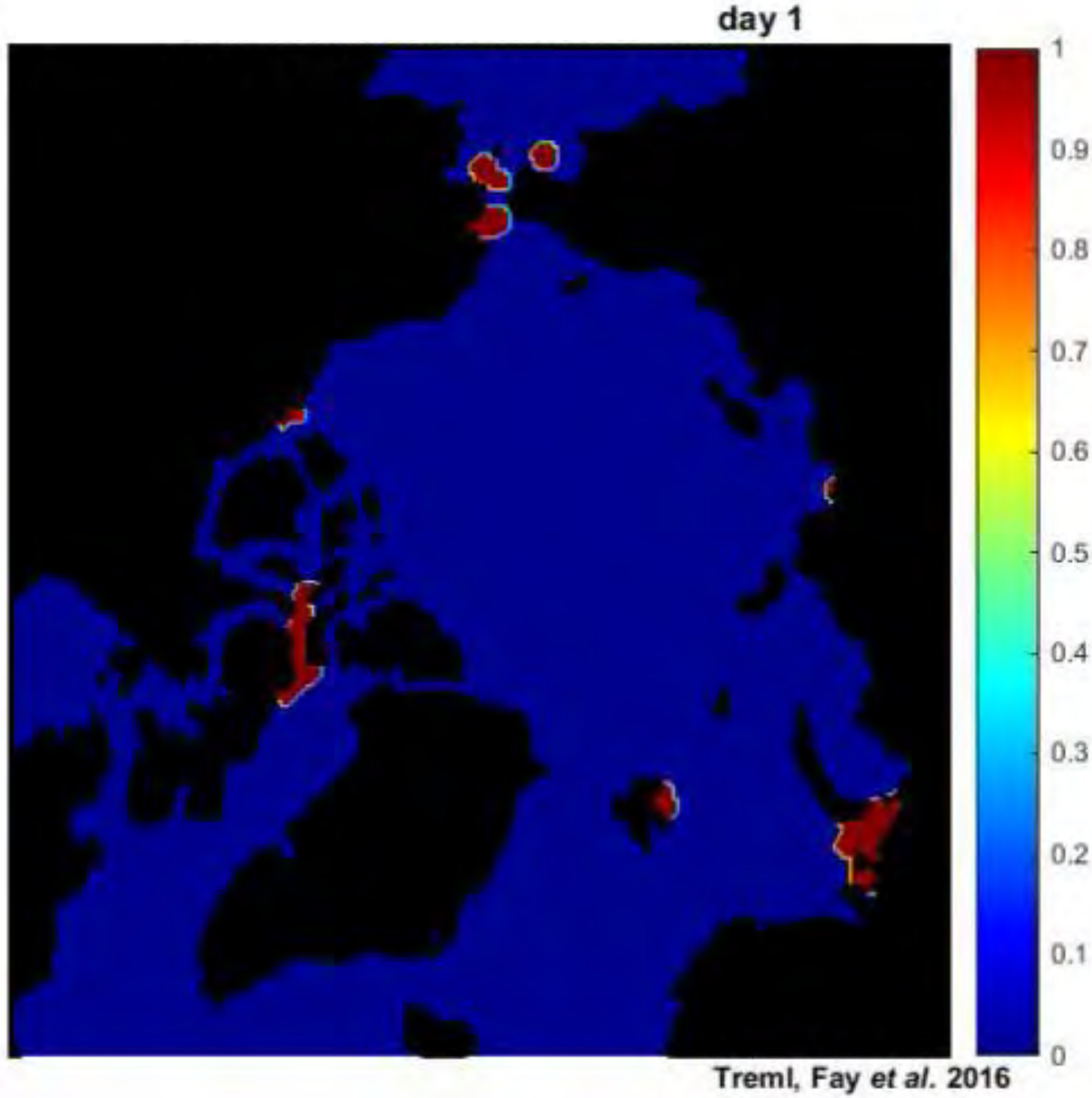
Winter 1979
“normal” ice
year



Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

Winter 2012
“low” ice year

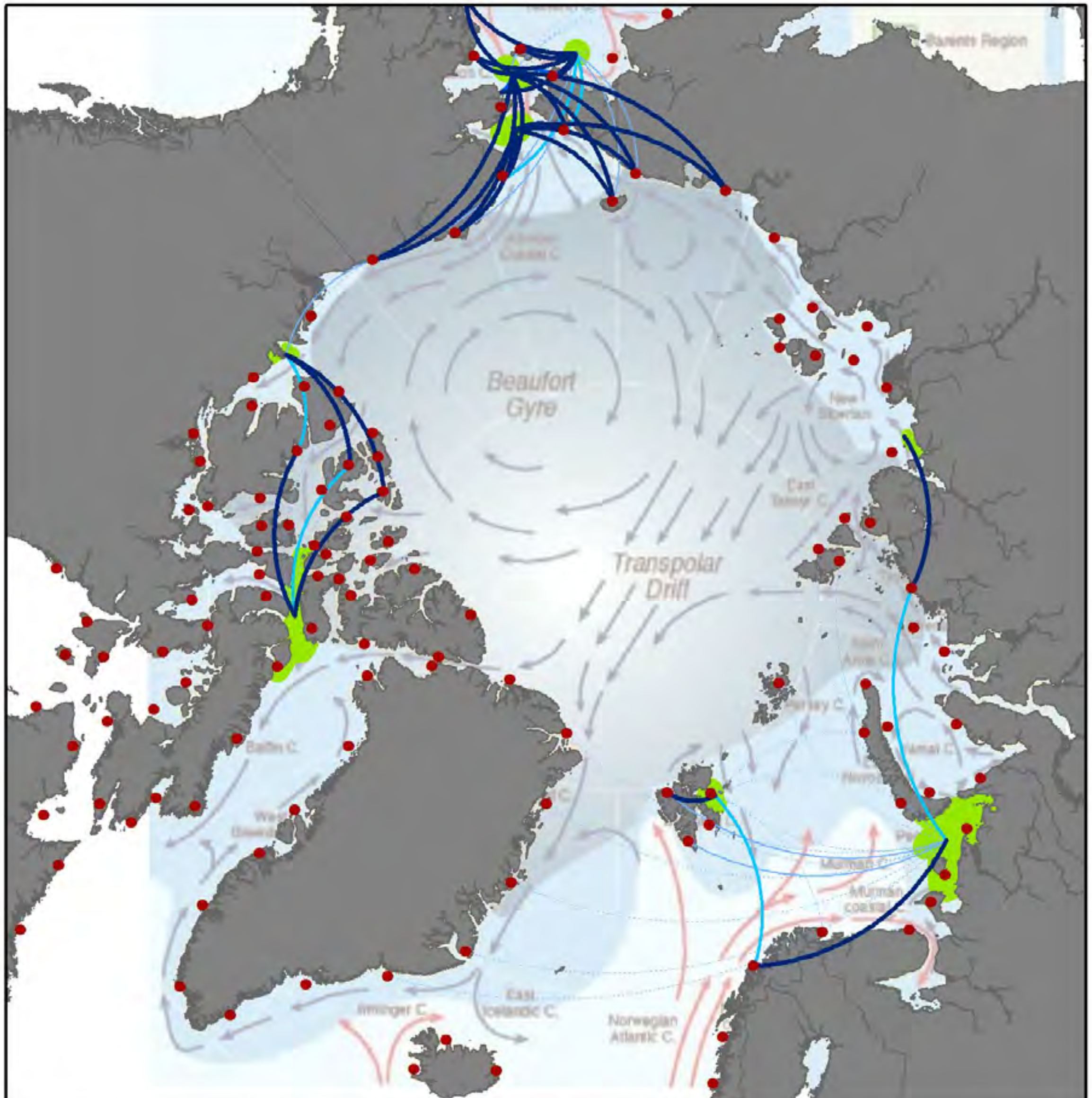


Arctic connectivity pilot analysis

Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

connectivity
winter 1979
“normal” ice year



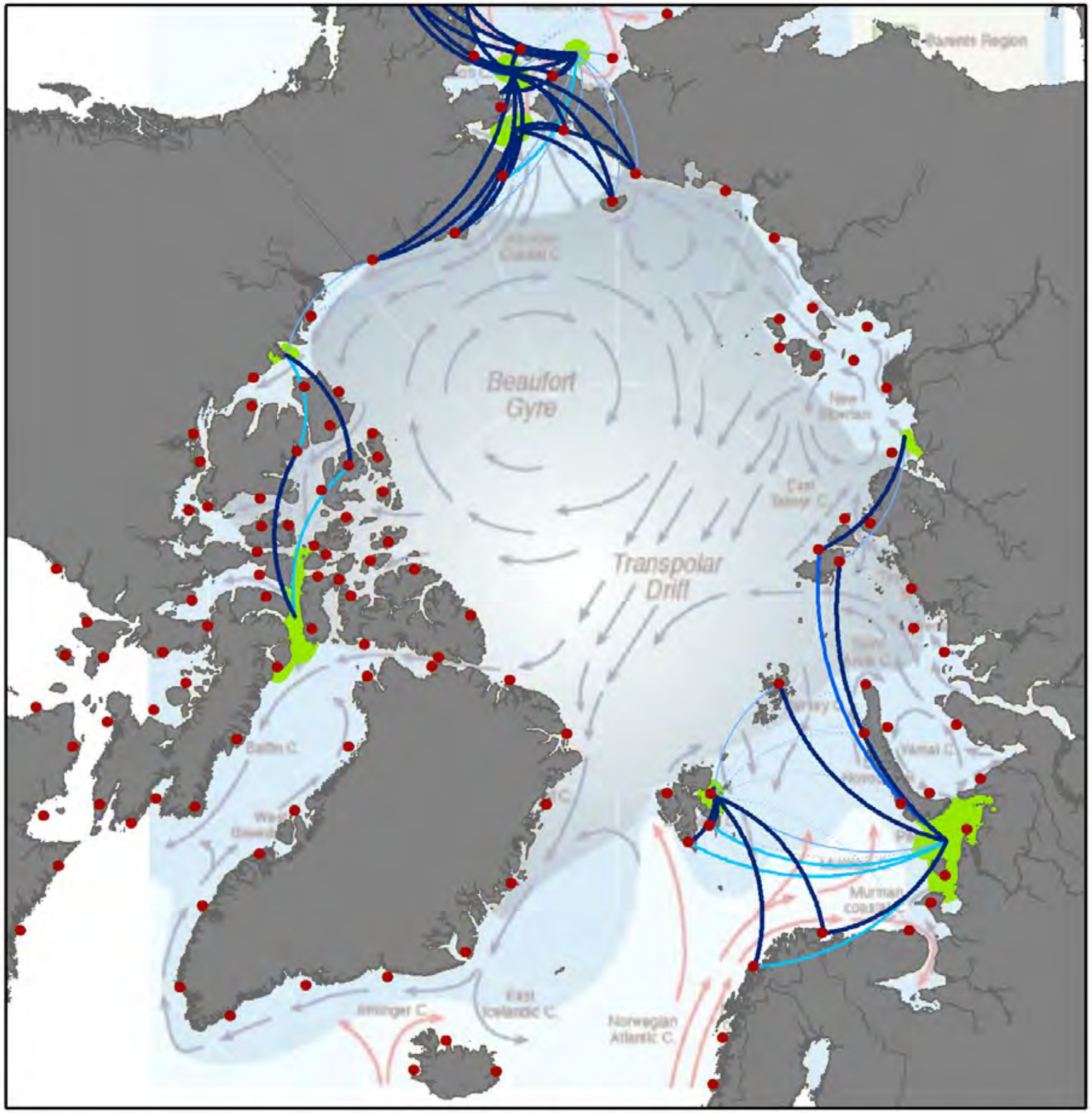
Surface Current Schematic - Polar Cod Spawning Connectivity (1979)

Arctic connectivity pilot analysis

Polar cod
Boreogadus saida
Spawning areas

From: AMSA-IIc

connectivity
winter 2012
“low” ice year



Surface Current Schematic - Polar Cod Spawning Connectivity (2012)

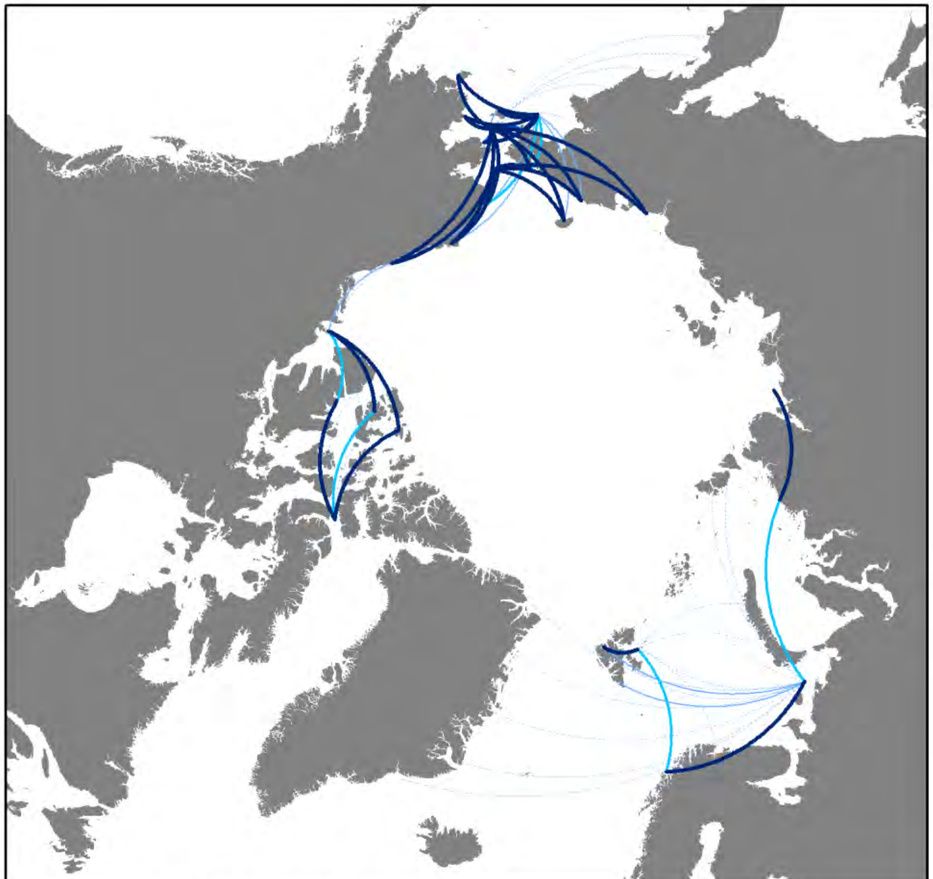
Arctic connectivity pilot analysis

connectivity winter 1979 - 2012

Polar cod *Boreogadus saida* Spawning areas

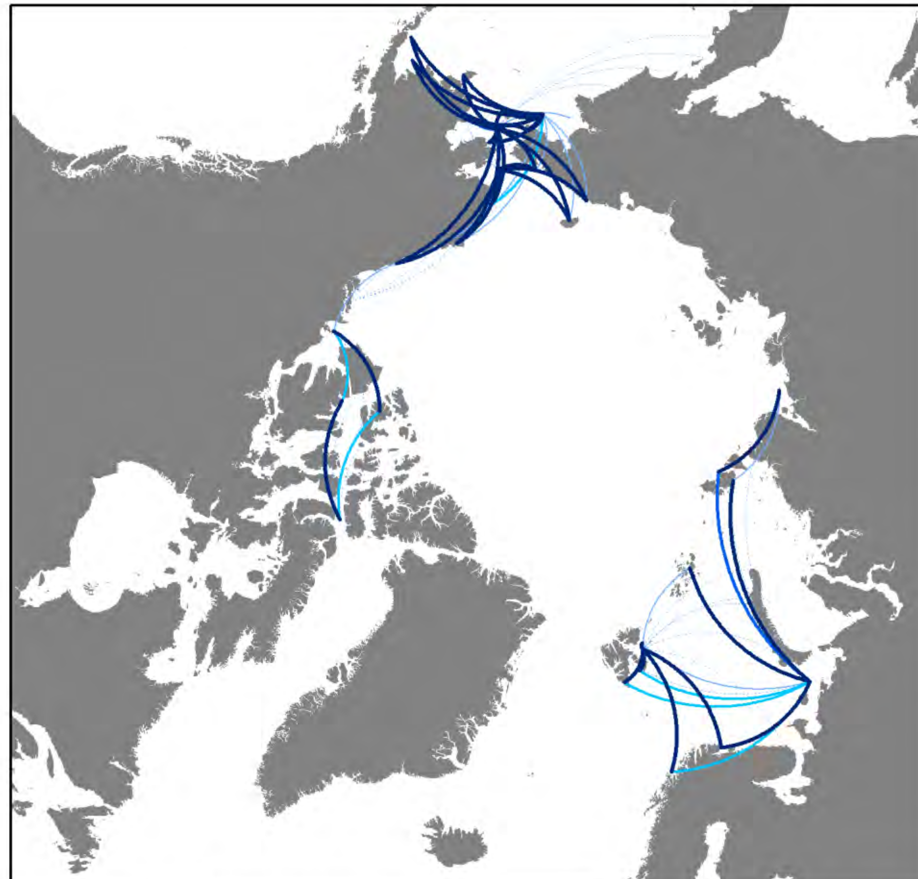
From: AMSA-IIc

Winter 1979 (normal ice year)



Winter 1979, 275 day connectivity

Winter 2012 (low ice year)



Winter 2012, 275 day connectivity

Arctic connectivity pilot analysis

Polar Biol
DOI 10.1007/s00300-015-1774-0

CrossMark

ORIGINAL PAPER

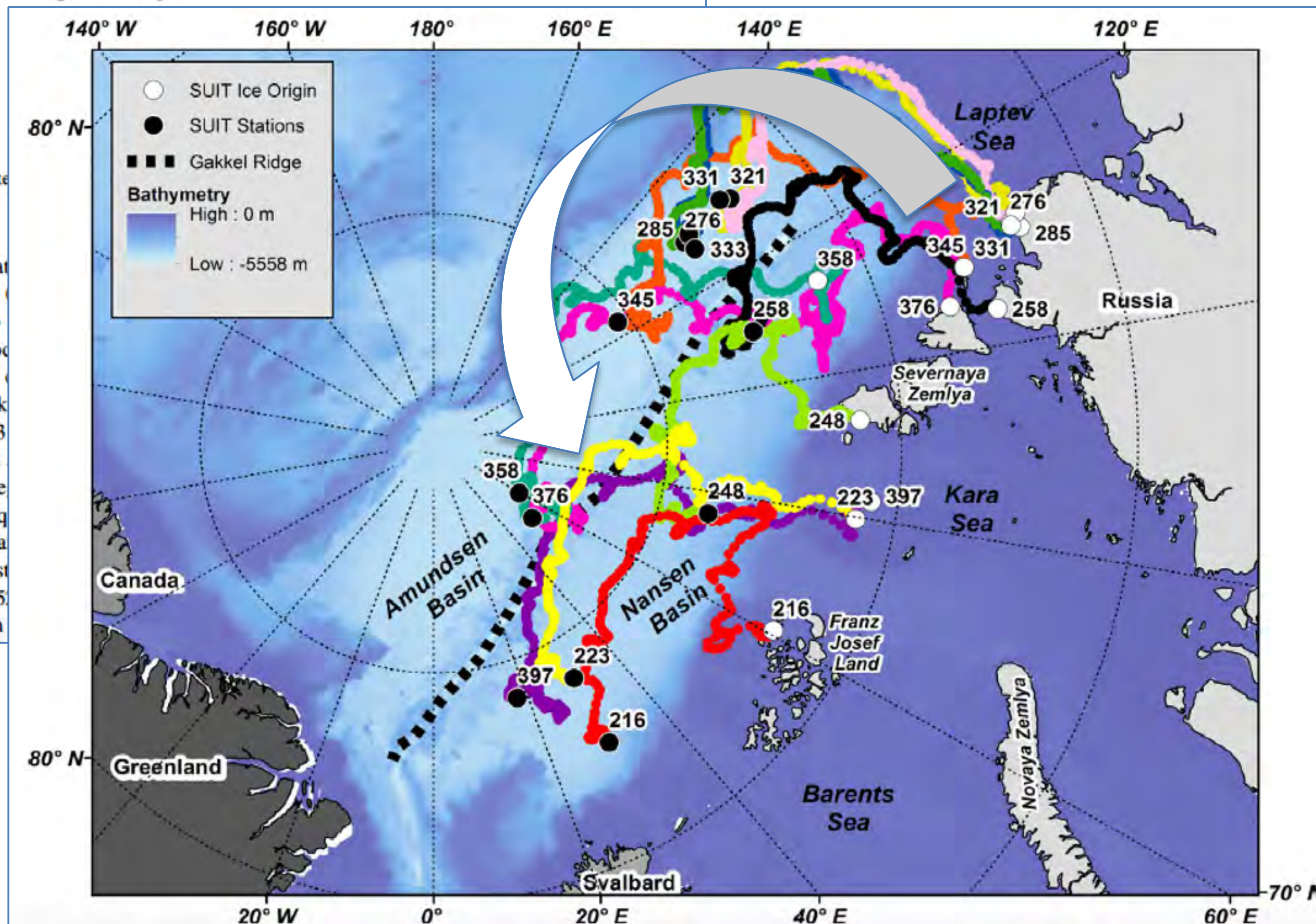
Under-ice distribution of polar cod *Boreogadus saida* in the central Arctic Ocean and their association with sea-ice habitat properties

Carmen David[1,2] · Benjamin Lange[1,2] · Thomas Krumpen[1] · Fokje Schaafsma[3] · Jan Andries van Franeker[3] · Hauke Flores[1,2]

Received: 28 February 2015 / Revised: 16 July 2015 / Accepte

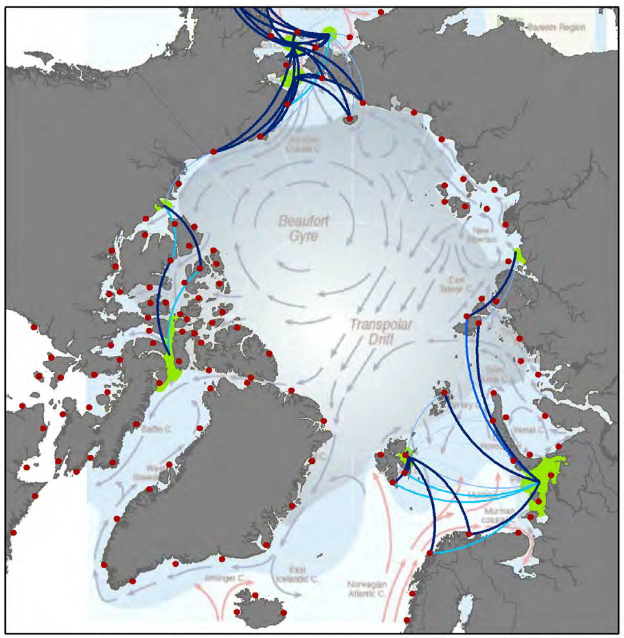
Abstract In the Arctic Ocean, sea-ice habitat
undergoing rapid environmental change. Polar cod (
ogadus saida) is the most abundant fish known to
under the pack-ice. The under-ice distribution, assoc
with sea-ice habitat properties and origins of polar
the central Arctic Ocean, however, are largely unk
During the RV *Polarstern* expedition ARK XXVII/3
Eurasian Basin in 2012, we used for the first time in
waters a Surface and Under Ice Trawl with an inte
bio-environmental sensor array. Polar cod was ubiq
throughout the Eurasian Basin with a median abunda
5000 ind. km^{-2}. The under-ice population consist
young specimens with a total length between 5
140 mm, dominated by 1-year-old fish. Higher fish

Need to compare & validate models to empirical observations

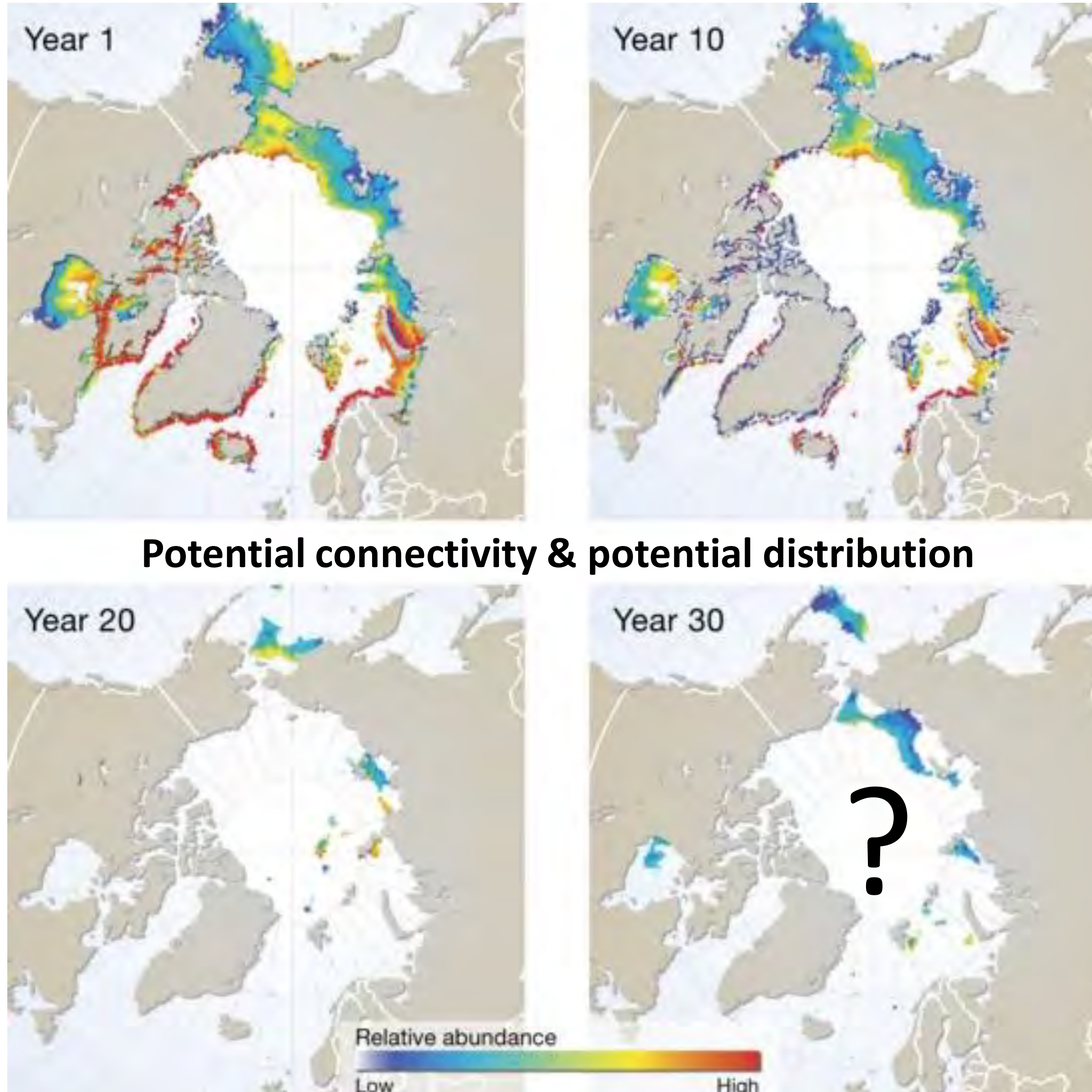


Arctic connectivity pilot analysis

Simulated projections for Polar cod distribution with global warming



Surface Current Schematic - Polar Cod Spawning Connectivity (2012)

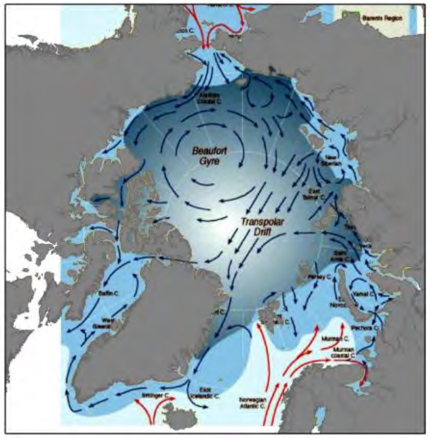


http://www.grida.no/graphicslib/detail/simulated-projections-for-polar-cod-distribution-with-global-warming_5c5a#

Arctic connectivity pilot analysis

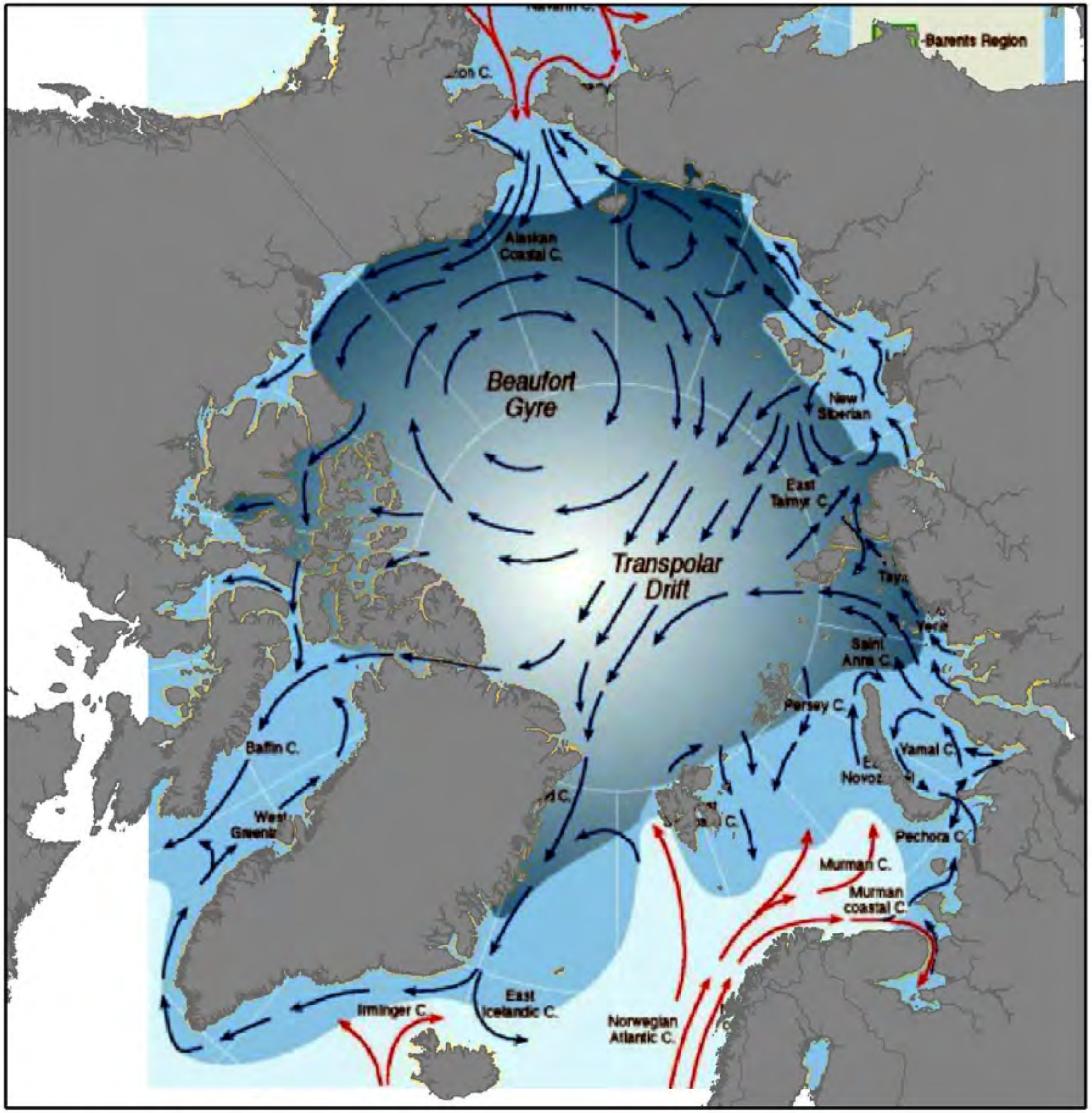
Potential pilot scenarios

Source / destination targets	“normal” ice year		“low” ice year	
Coastal areas (500km regions)	winter	summer	winter	summer
Fish spawning areas	winter	summer	winter	summer
Important feeding grounds	winter	summer	winter	summer



Arctic connectivity pilot analysis

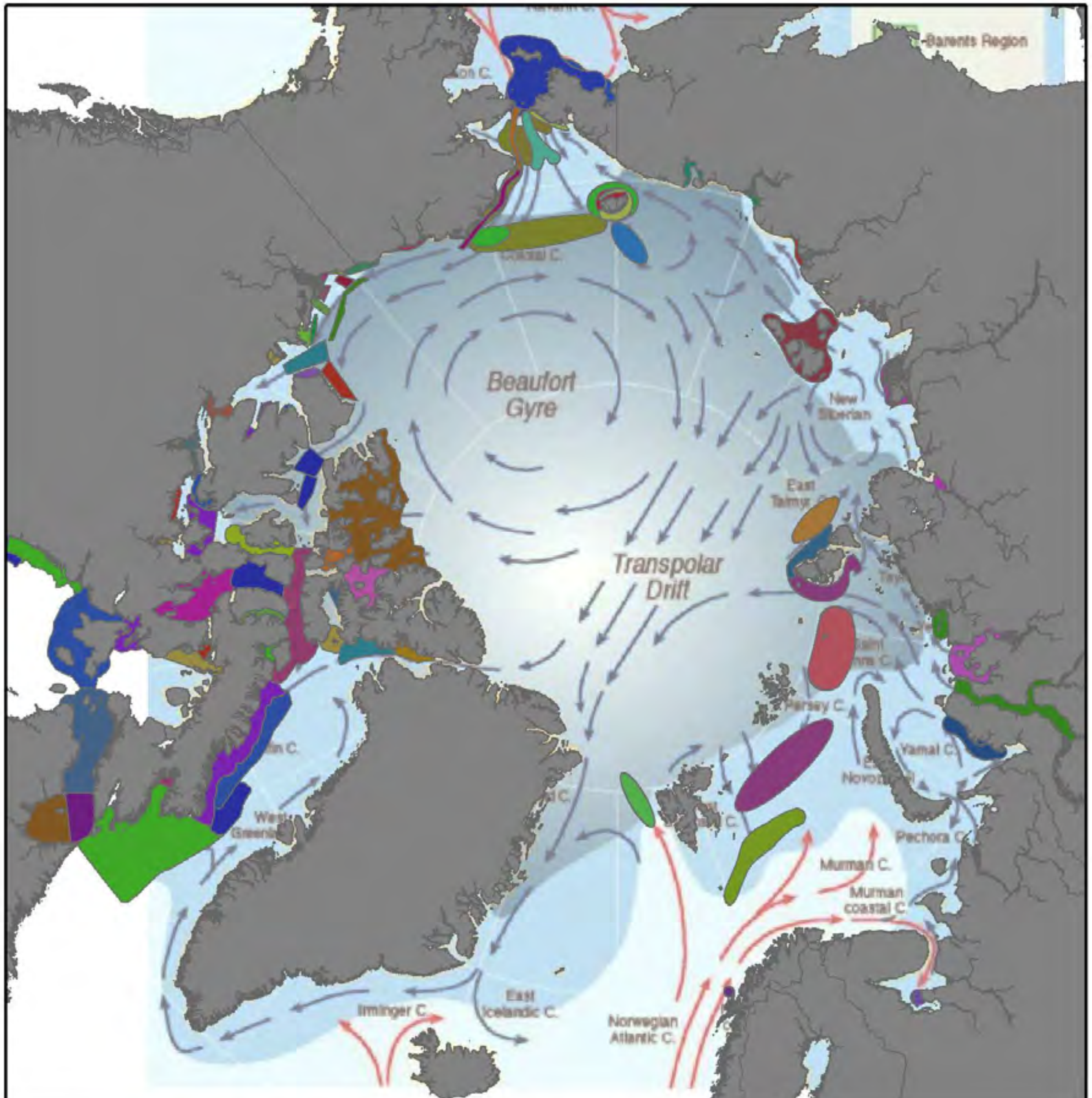
Foraging areas
AMSA-IIc
(multiple types)



Surface Current Schematic

Arctic connectivity pilot analysis

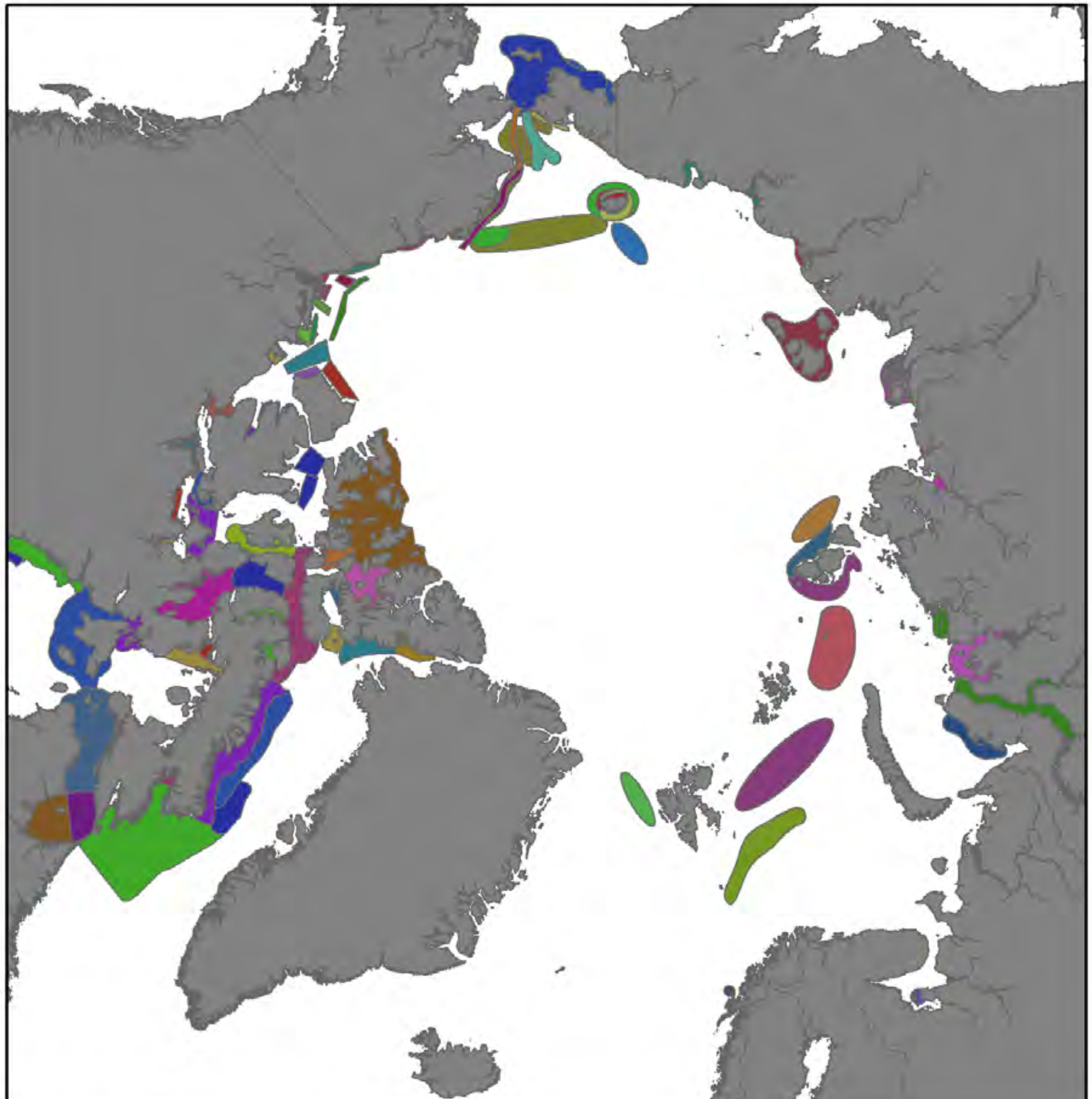
Foraging areas
AMSA-IIc
(multiple types)



Surface Current Schematic - AMSA IIC Feeding Areas

Arctic connectivity pilot analysis

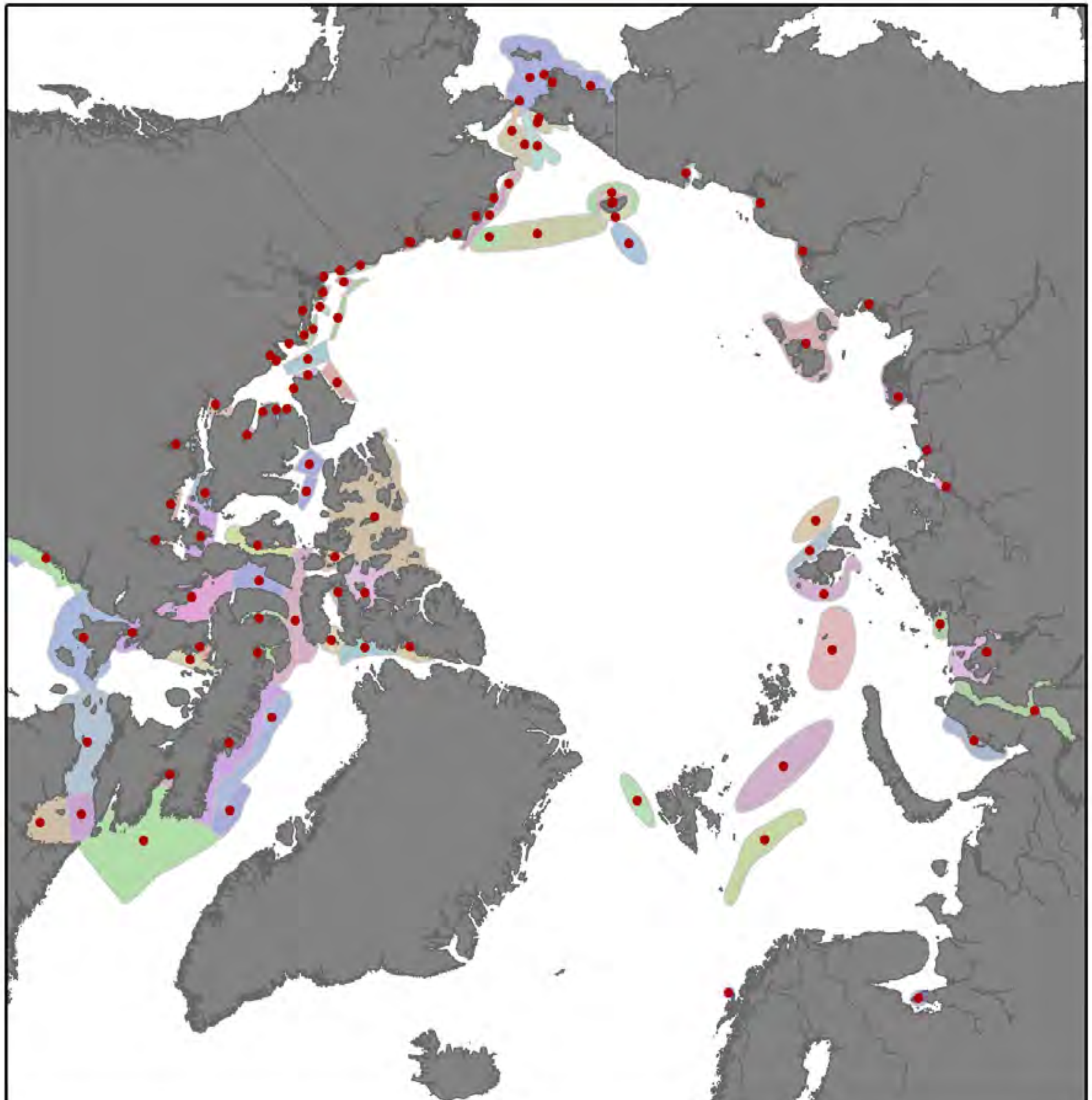
Foraging areas
AMSA-IIc
(multiple types)



AMSA IIC Feeding Areas

Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc
(multiple types)

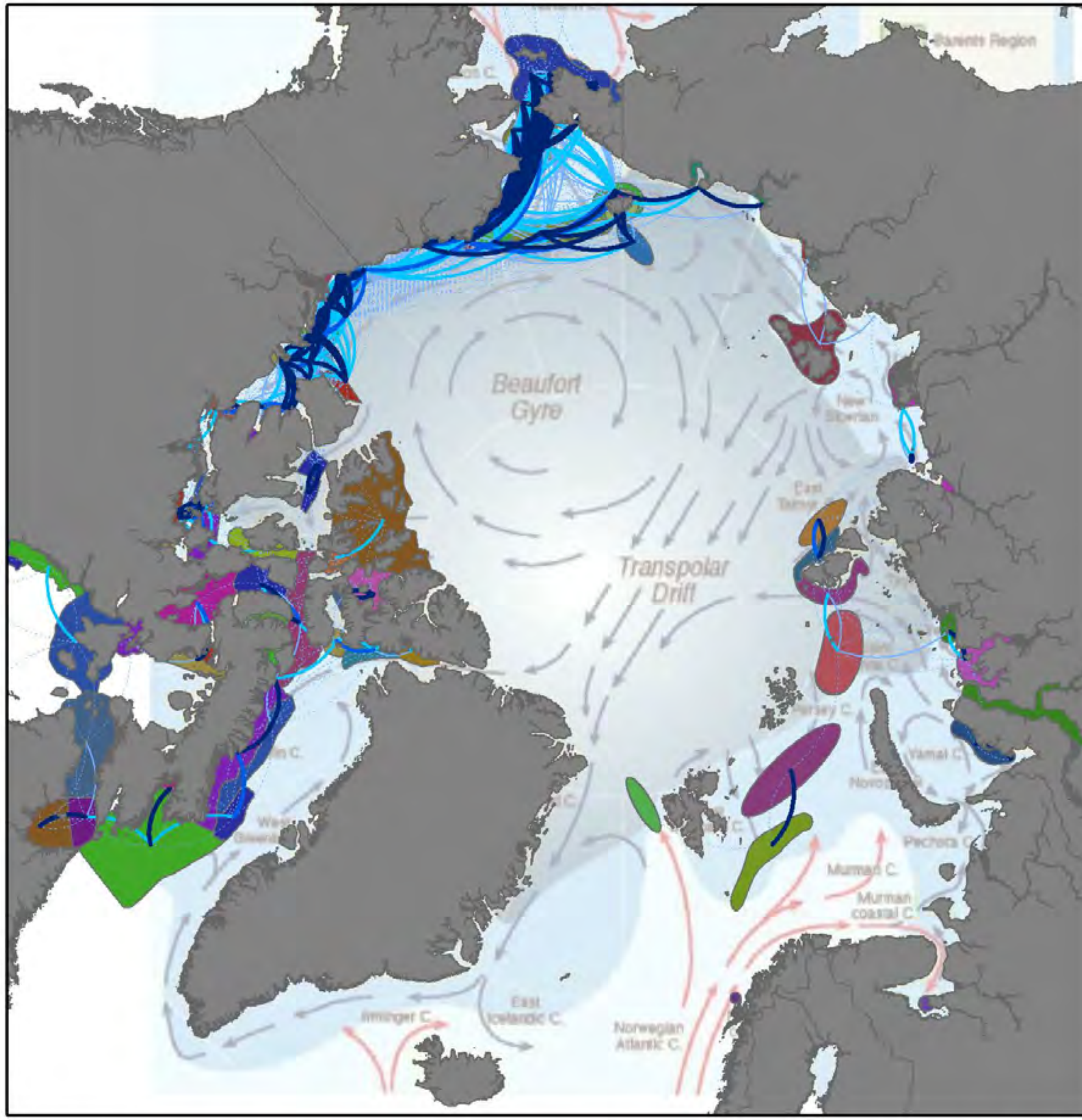


AMSA IIC Feeding Areas

Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc
(multiple types)

Summer 2012
(representative low ice year)

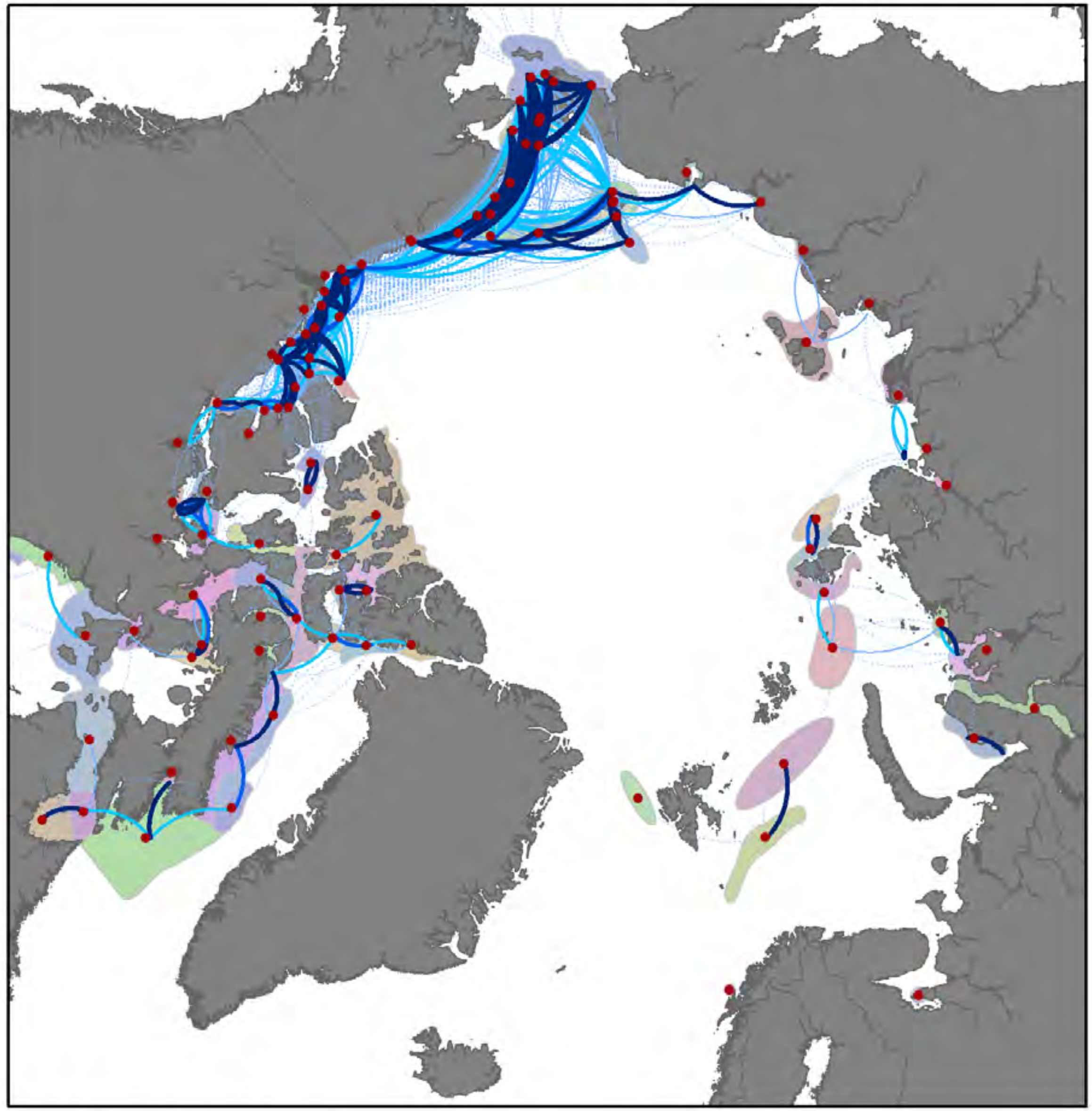


Surface Current Schematic - AMSA IIC Feeding Connectivity (Summer 2012)

Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc
(multiple types)

Summer 2012
(representative low ice year)

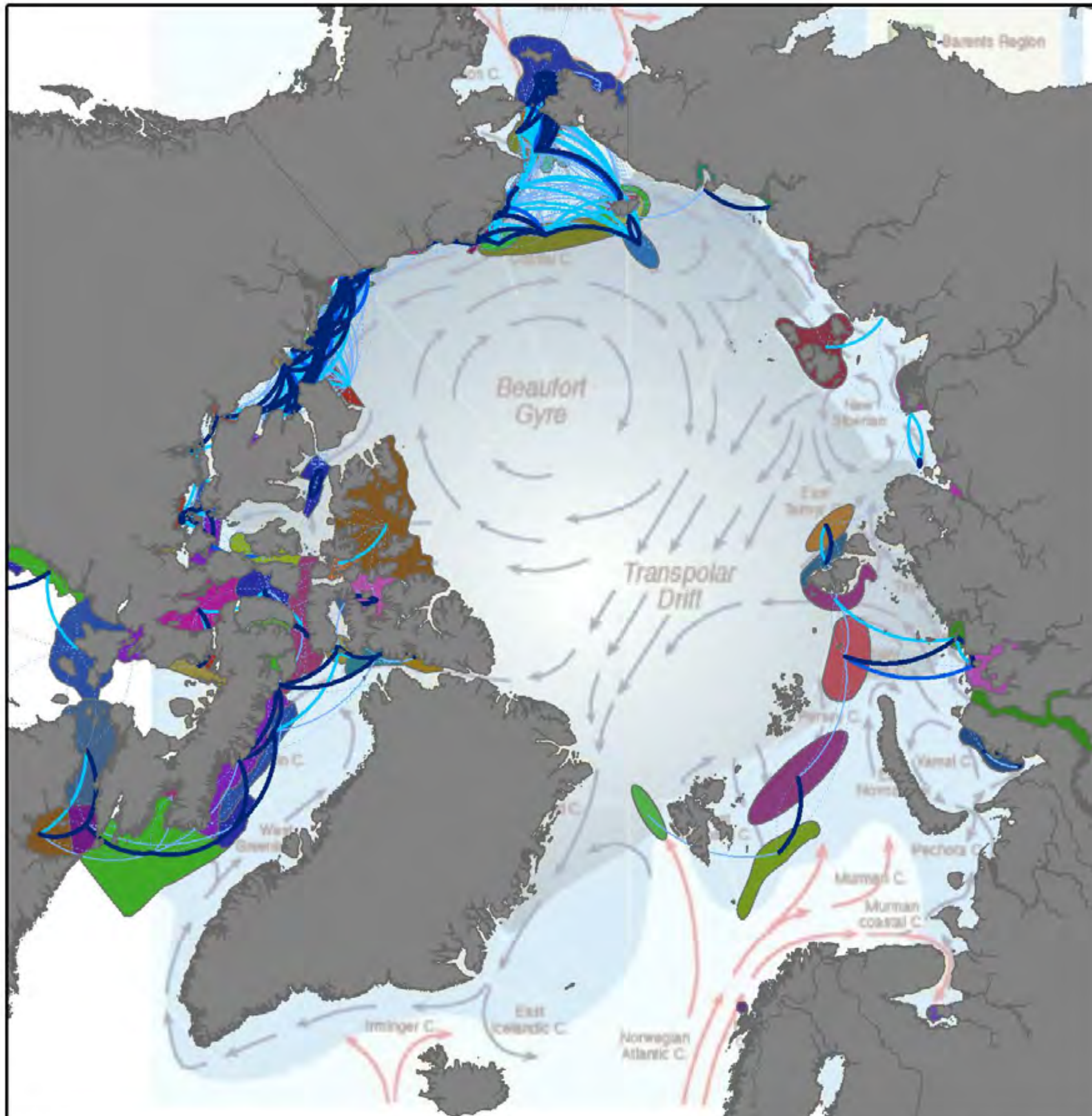


AMSA IIC Feeding Areas

Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc
(multiple types)

Winter 2012
(representative low ice year)



Surface Current Schematic - AMSA IIC Feeding Connectivity (Winter 2012)

Arctic connectivity pilot analysis

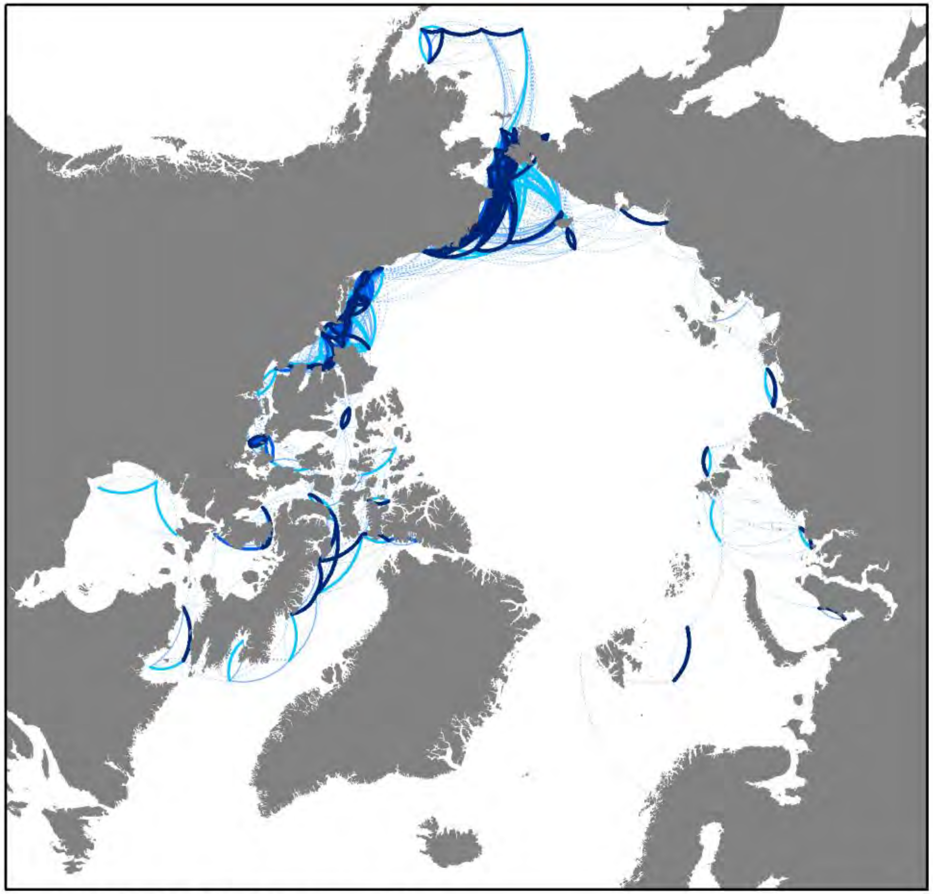
Foraging areas

AMSA-IIc (multiple types)

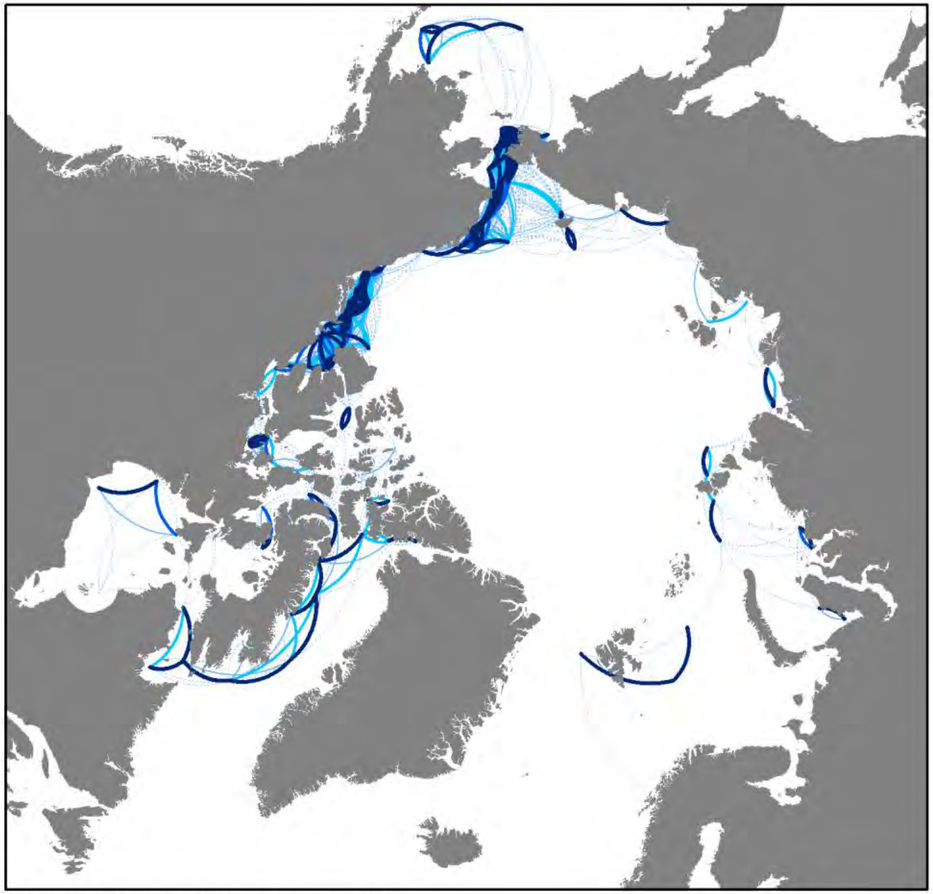
"normal" ice year (1979)

summer

winter



Summer 1979, 100 day connectivity



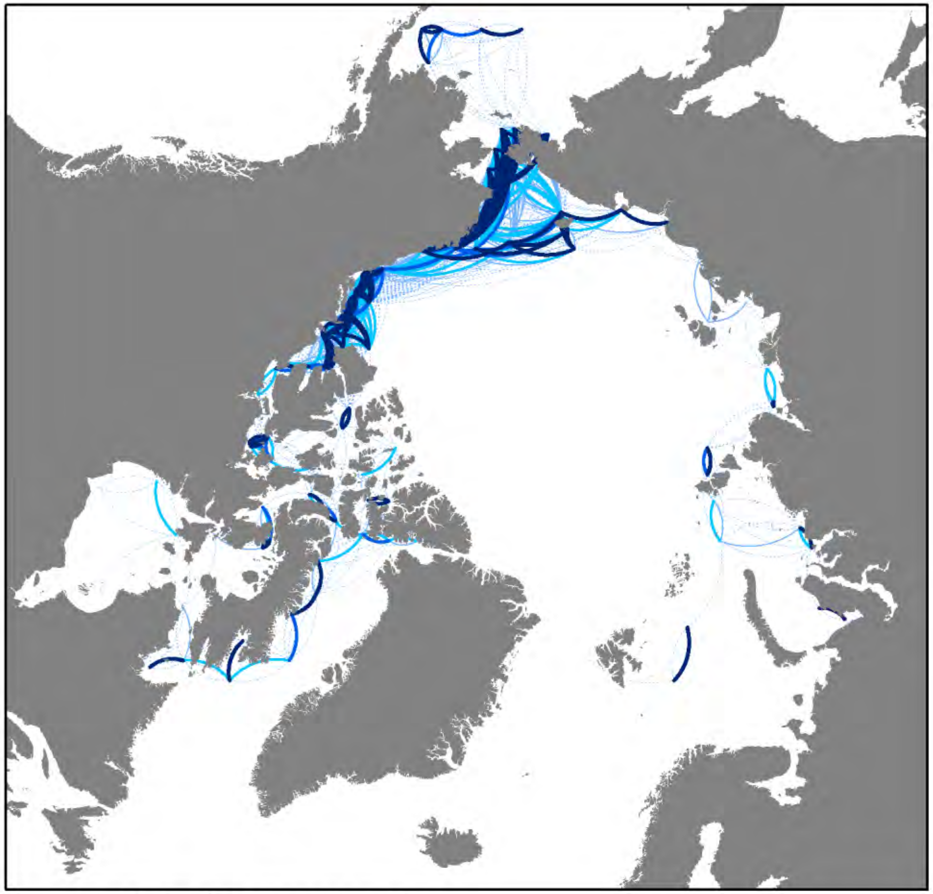
Winter 1979, 100 day connectivity

Arctic connectivity pilot analysis

Foraging areas
AMSA-Iic (multiple types)

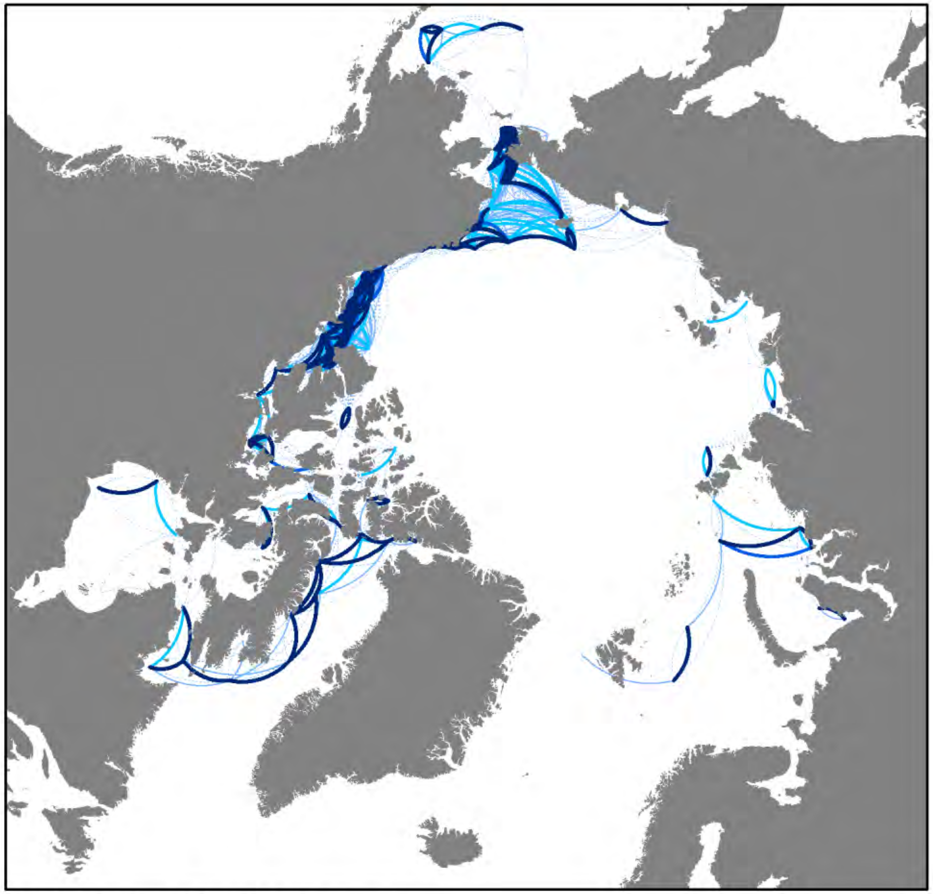
low ice year (2012)

summer



Summer 2012, 100 day connectivity

winter

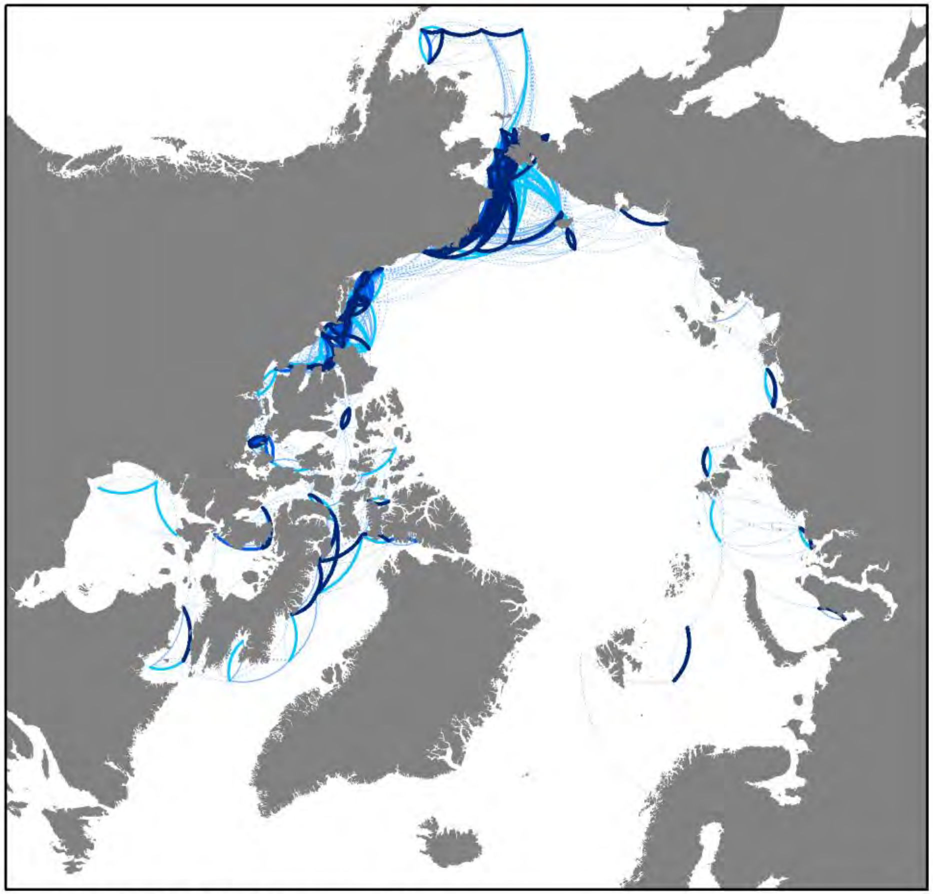


Winter 2012, 100 day connectivity

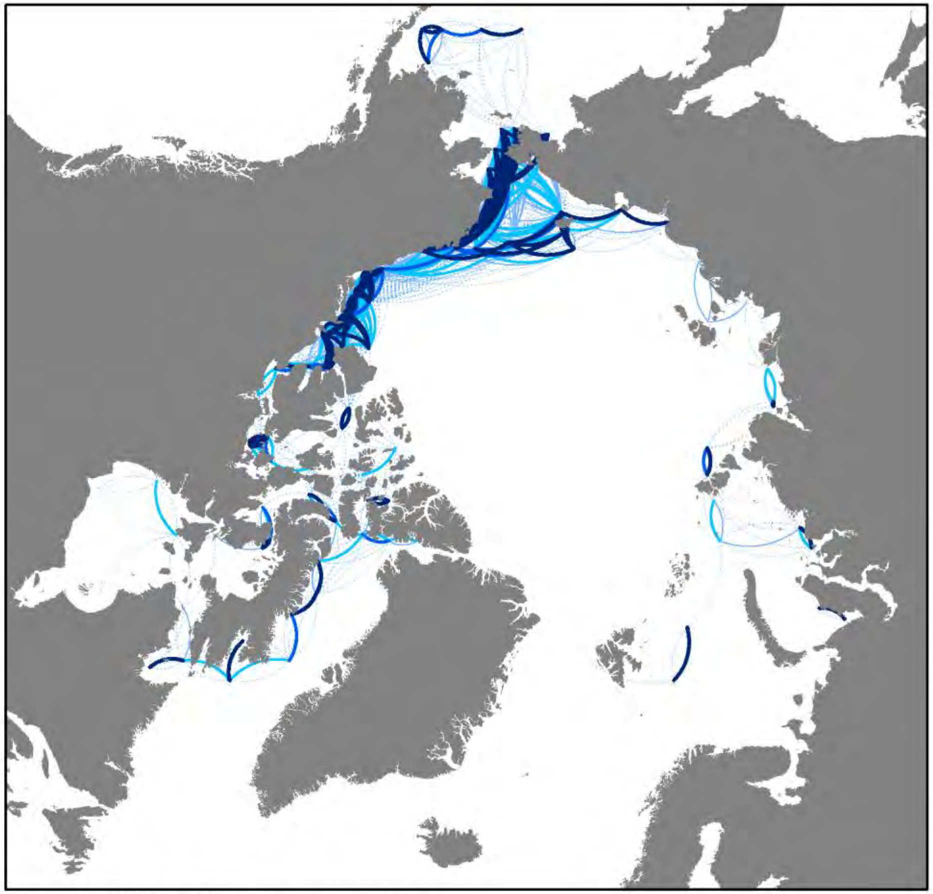
Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc (multiple types)

summer normal ice year (1979) vs. summer low ice year (2012)

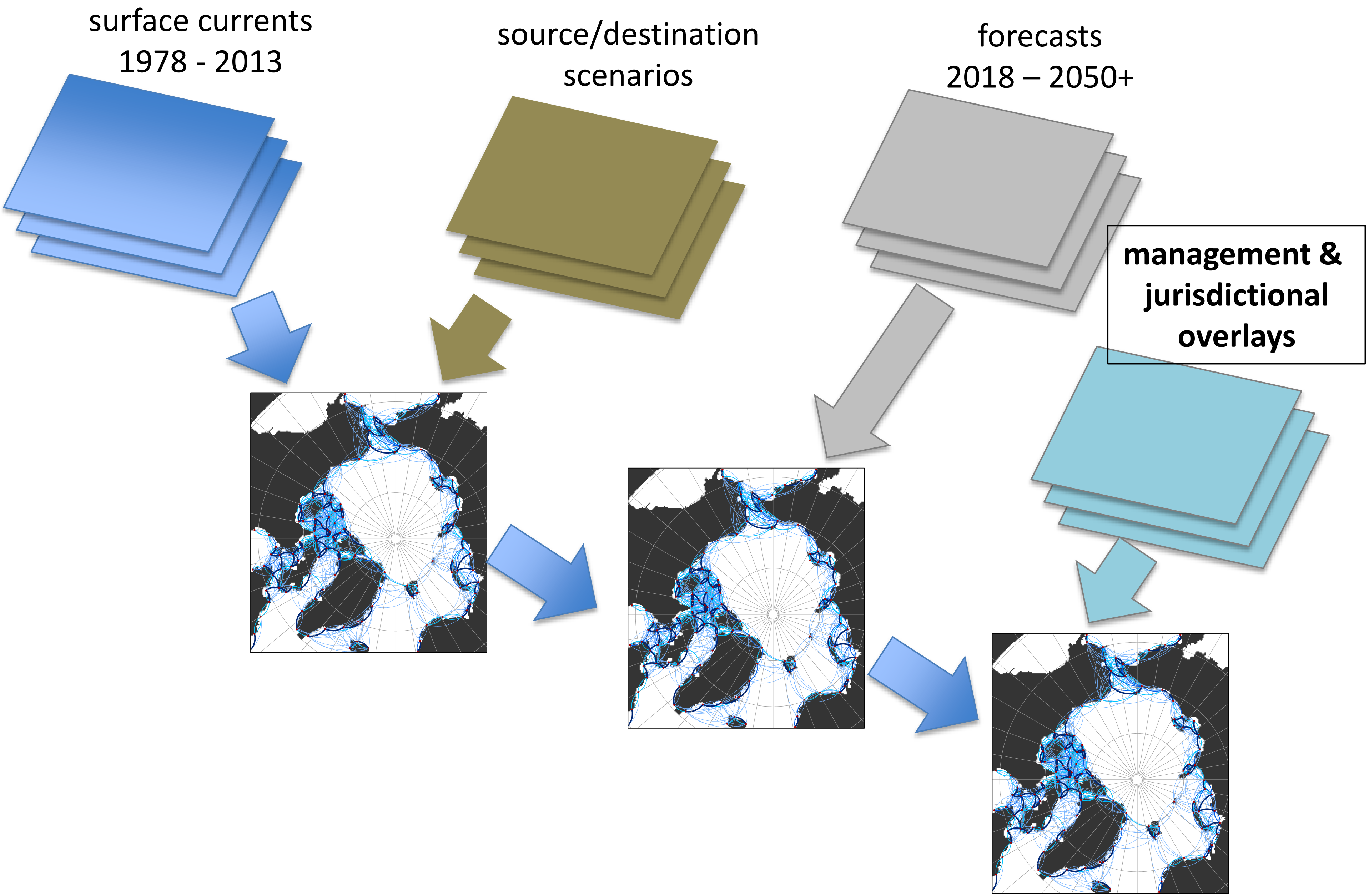


Summer 1979, 100 day connectivity



Summer 2012, 100 day connectivity

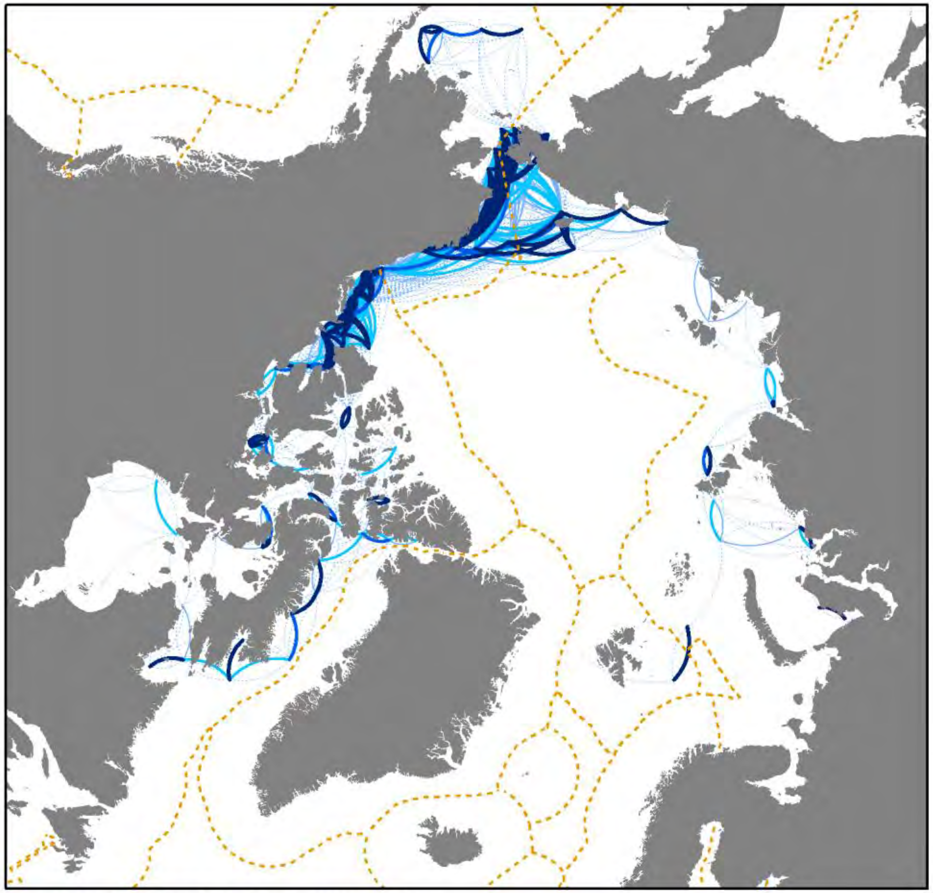
Arctic connectivity pilot analysis



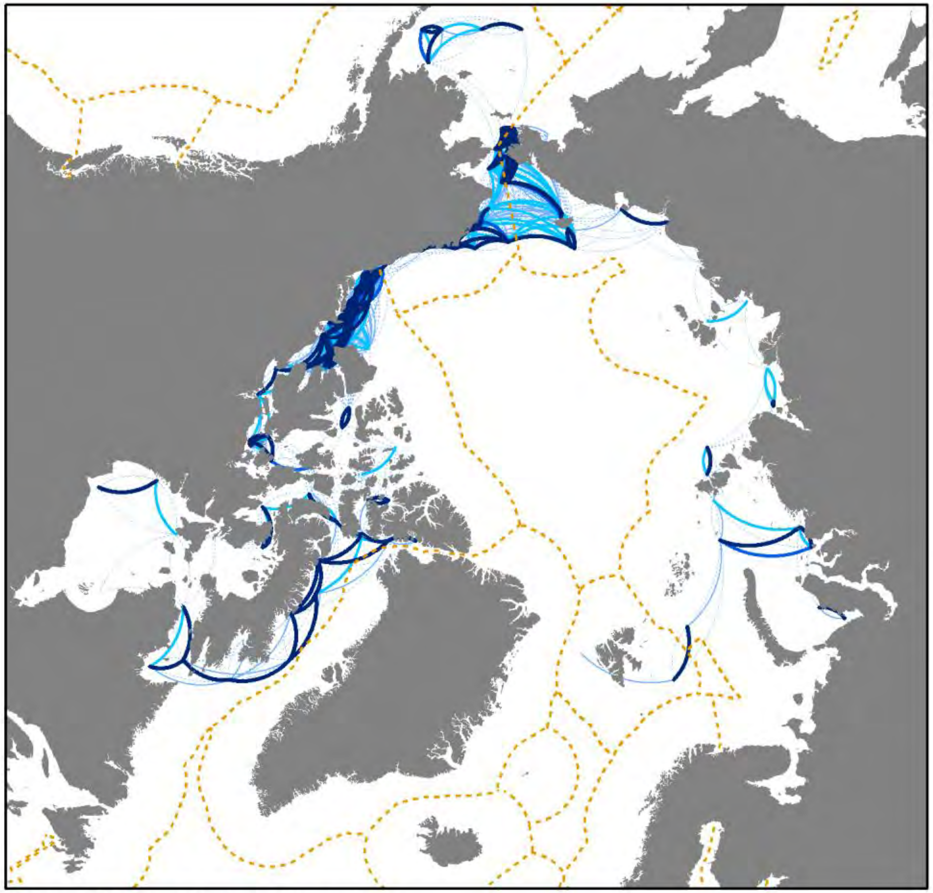
Arctic connectivity pilot analysis

Foraging areas
AMSA-IIc (multiple types)

Foraging area connectivity across EEZ boundaries



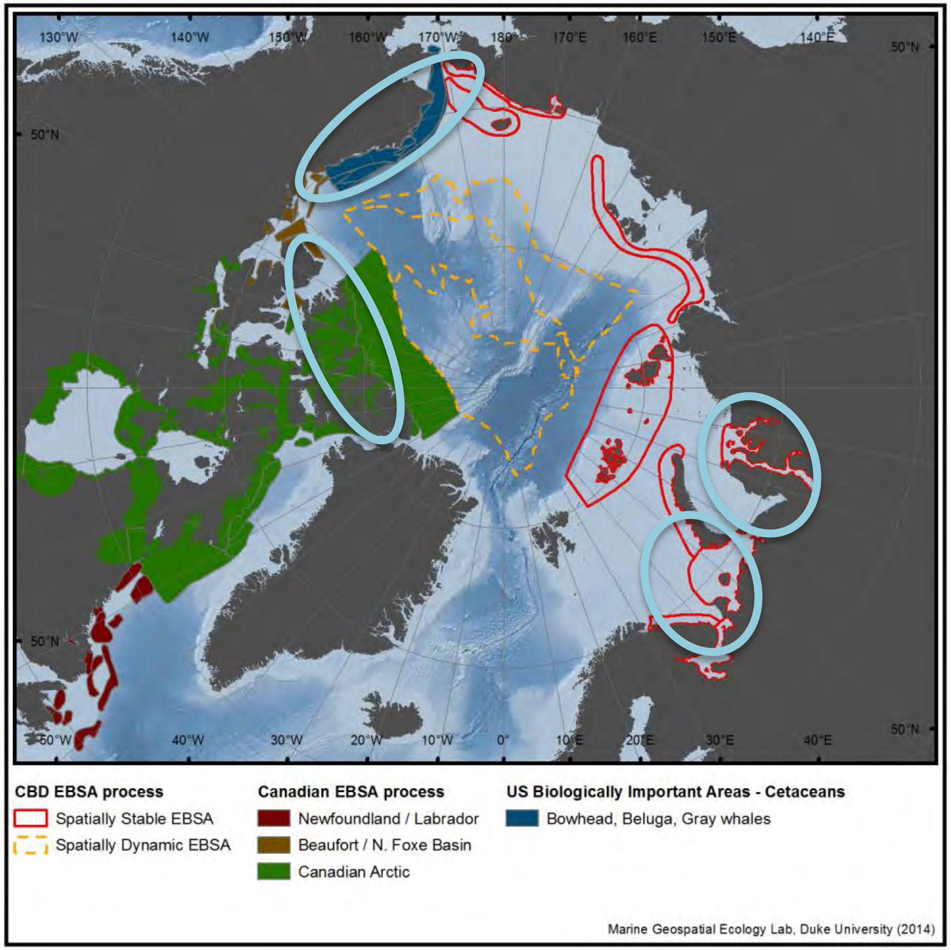
Summer 2012, 100 day connectivity



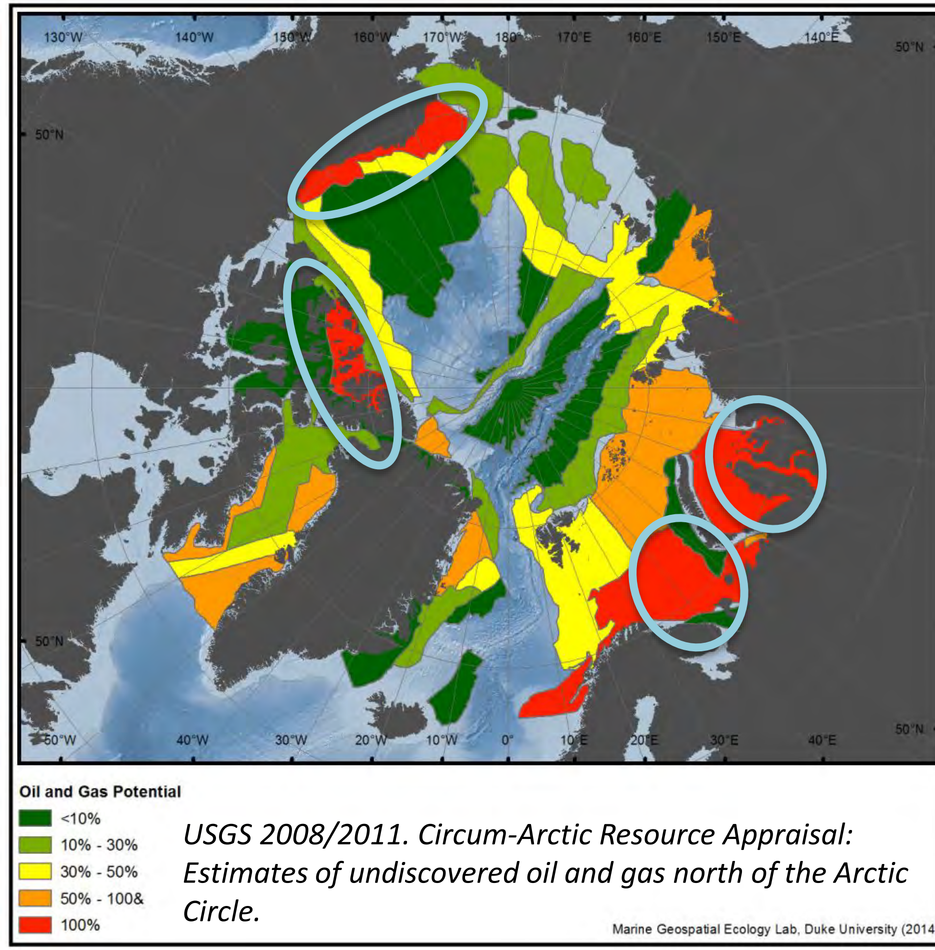
Winter 2012, 100 day connectivity

Areas of oil & gas potential *vs.* ecological importance

Ecologically or Biologically Important Areas

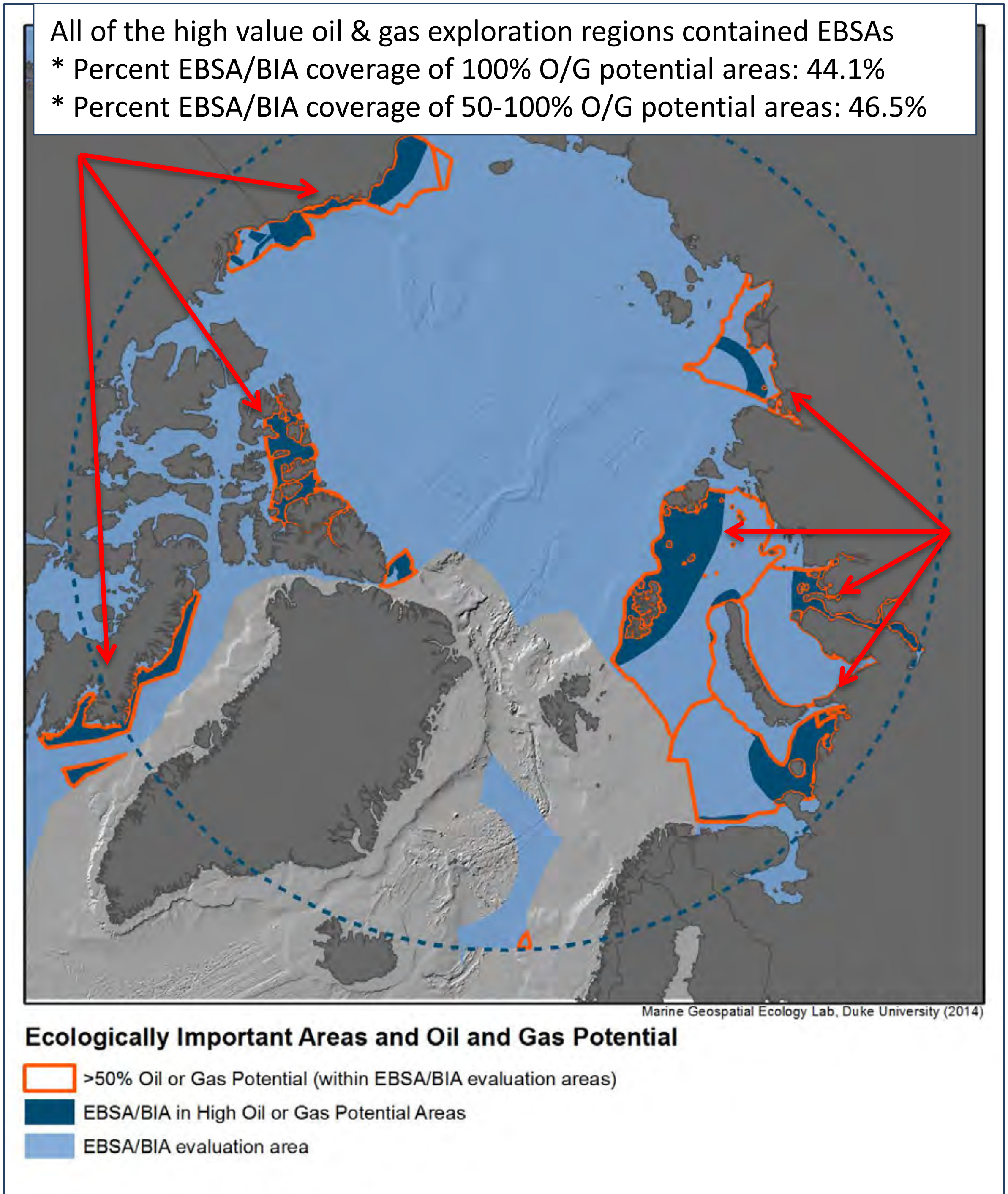


Oil & Gas Potential

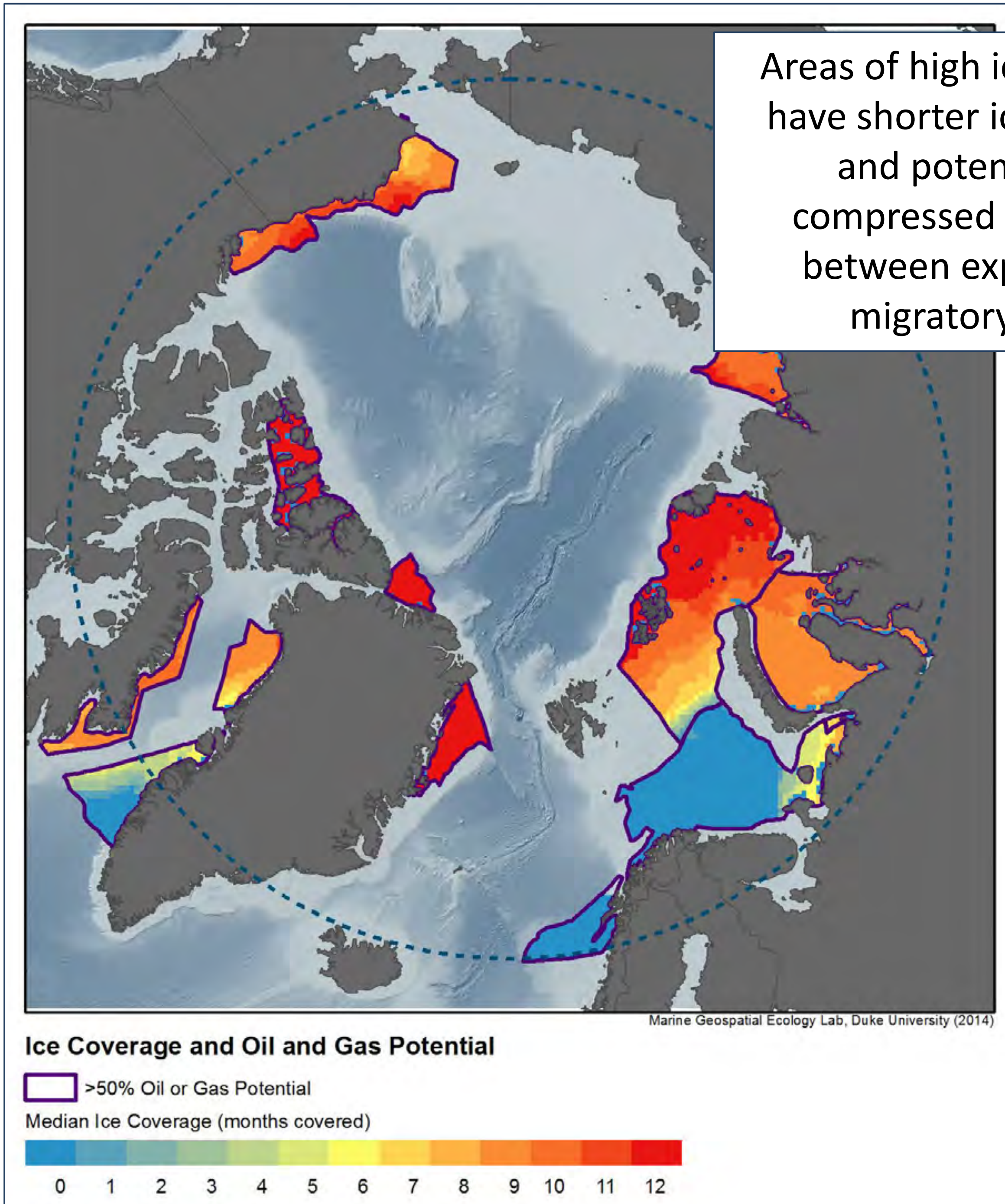


"Assessment units (AUs) in the Circum-Arctic Resource Appraisal (CARA) color-coded by assessed probability of the presence of at least one undiscovered oil and/or gas field with recoverable resources greater than 50 million barrels of oil equivalent (MMBOE).

Areas of oil & gas potential *vs.* ecological importance



Ice months vs. oil & gas potential

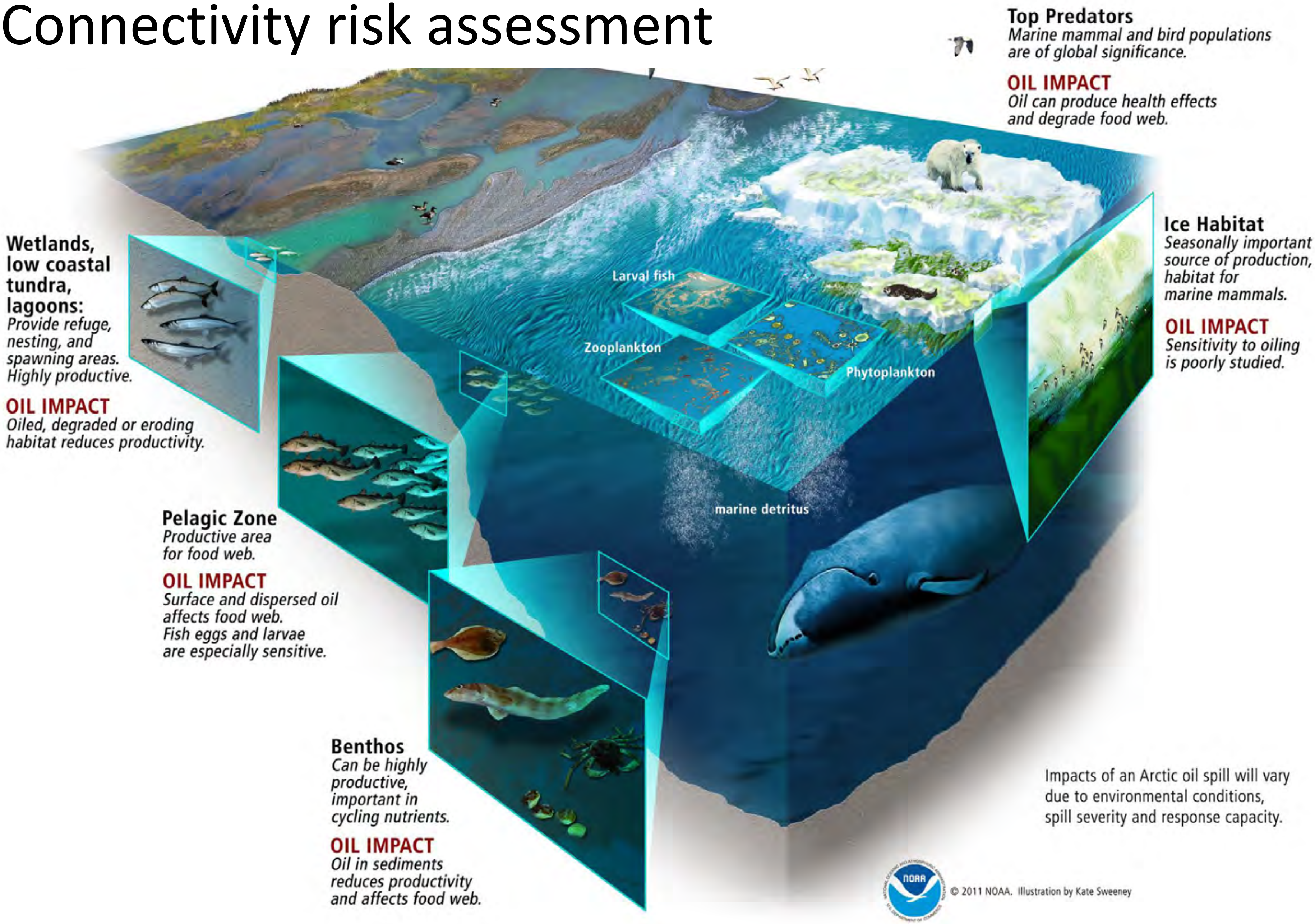


Areas of high ice coverage will have shorter ice-free seasons and potentially more compressed time overlaps between exploration and migratory species...

EBSAs *vs.* oil & Arctic shipping routes

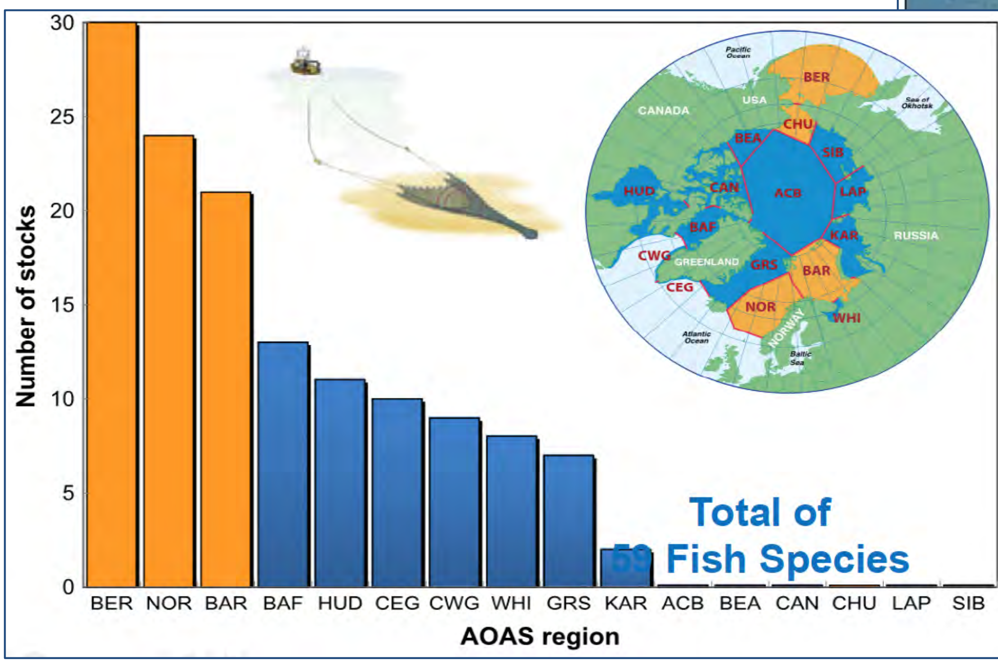
Emerging arctic shipping lanes will pass through identified EBSA areas…

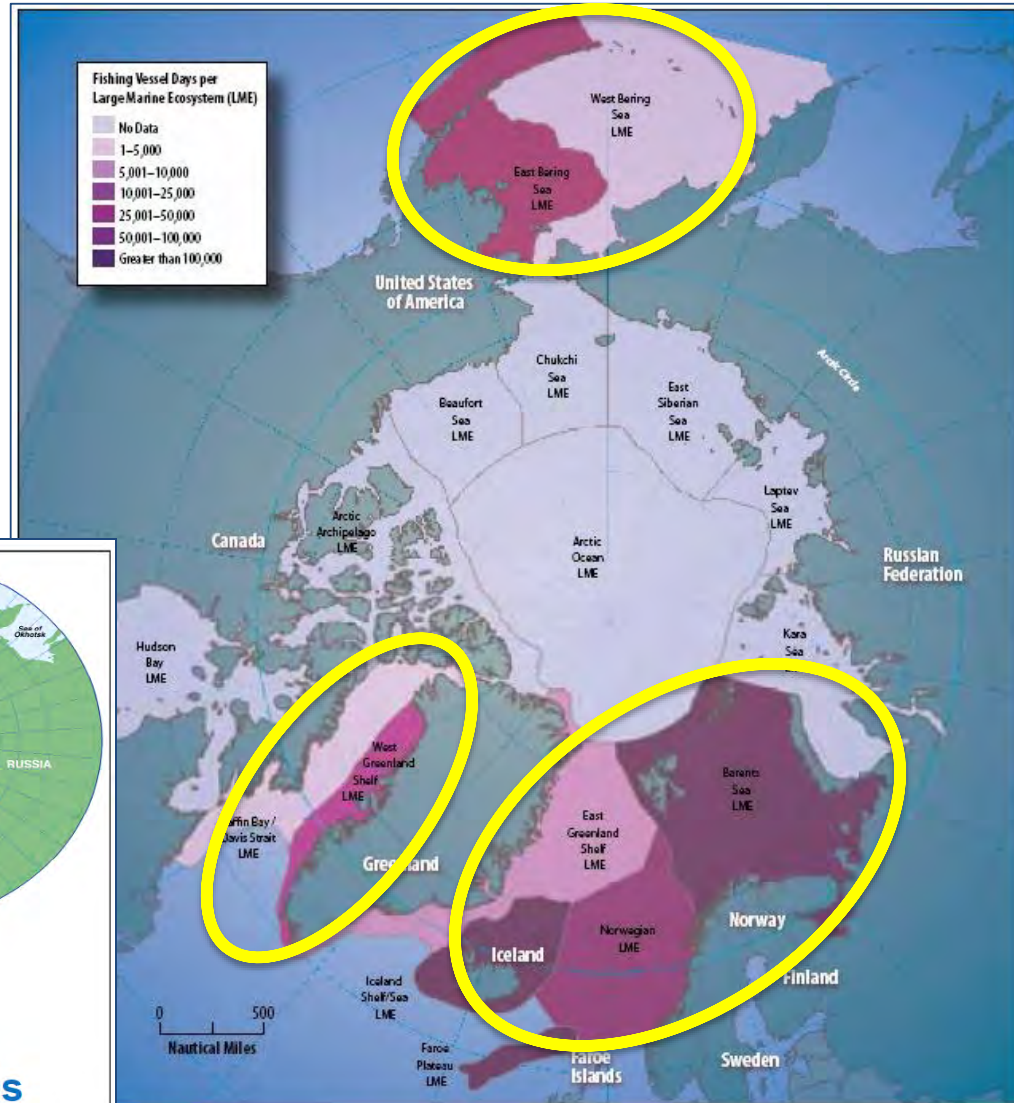
Connectivity risk assessment



http://usresponserestoration.files.wordpress.com/2011/05/arctic-food-webs-oil-impacts-illustration_noaa_katesweeney.jpg

Fishing activity by Large Marine Ecoregions (LME) & AOAS regions



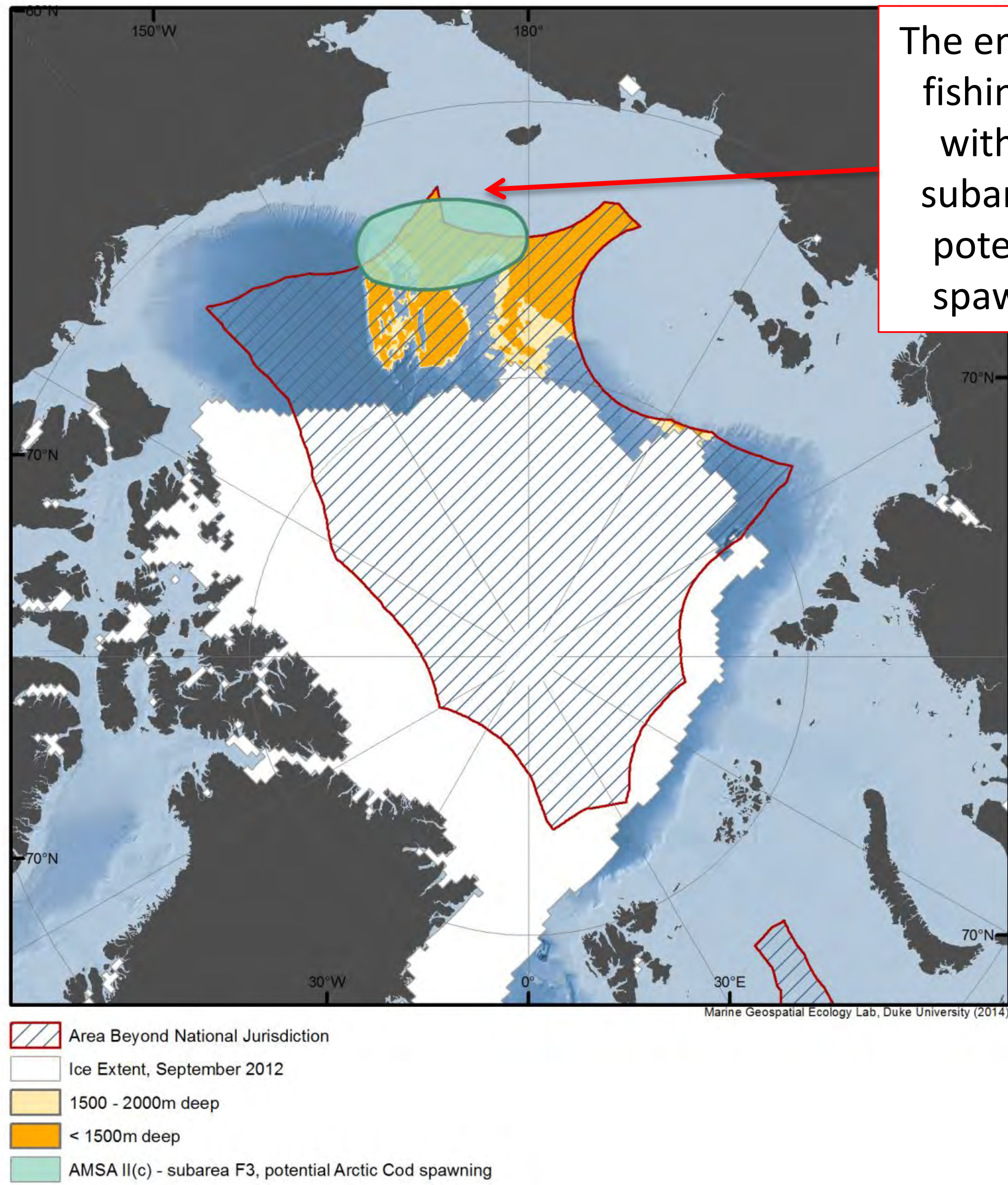


Fishing vessel activity. *Source: AMSA*

Harald Loeng: Arctic fisheries: present and future perspectives , Bergen June 2014

Potential deep sea fishing areas

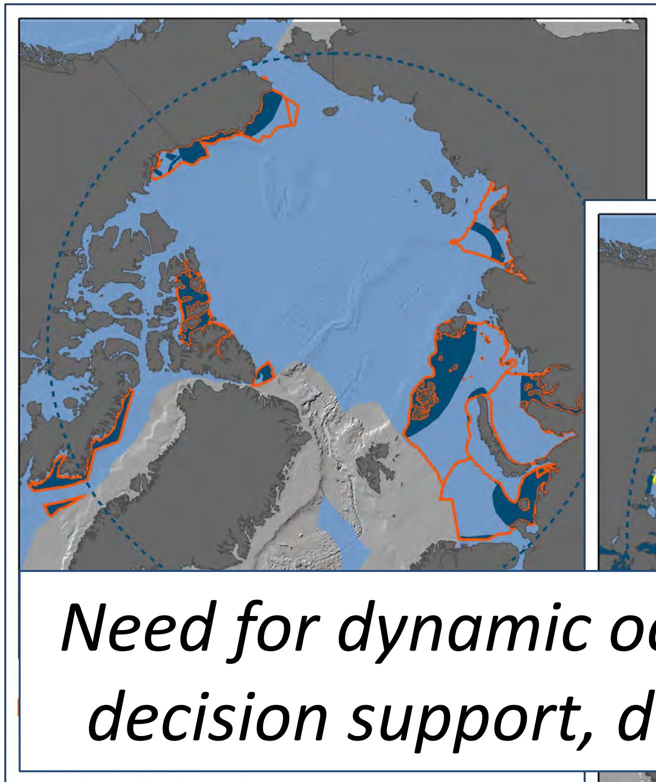
Potential Arctic cod *(Arctogadus glacialis)* spawning area



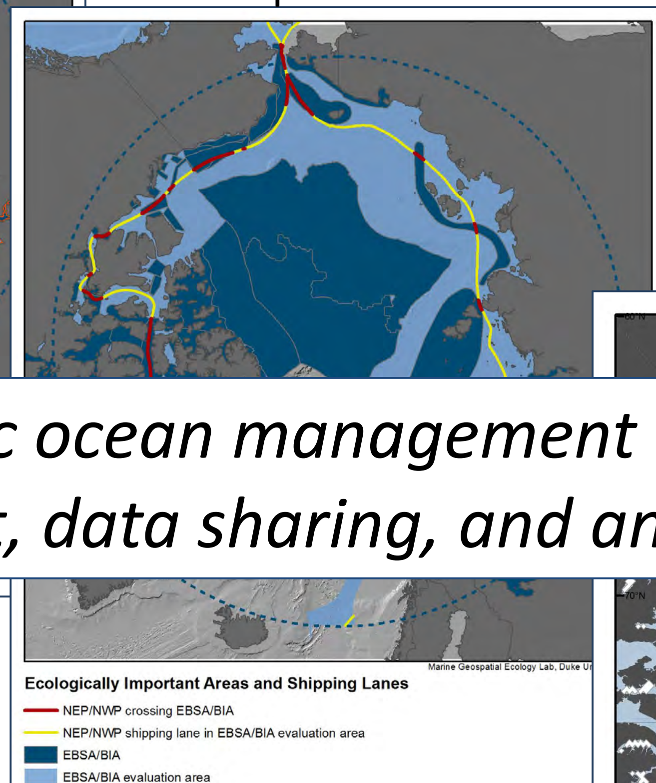
The emerging deep sea fishing area overlaps with an AMSA-II(c) subarea identified as potential Arctic cod spawning habitat …

Potential space & time overlaps

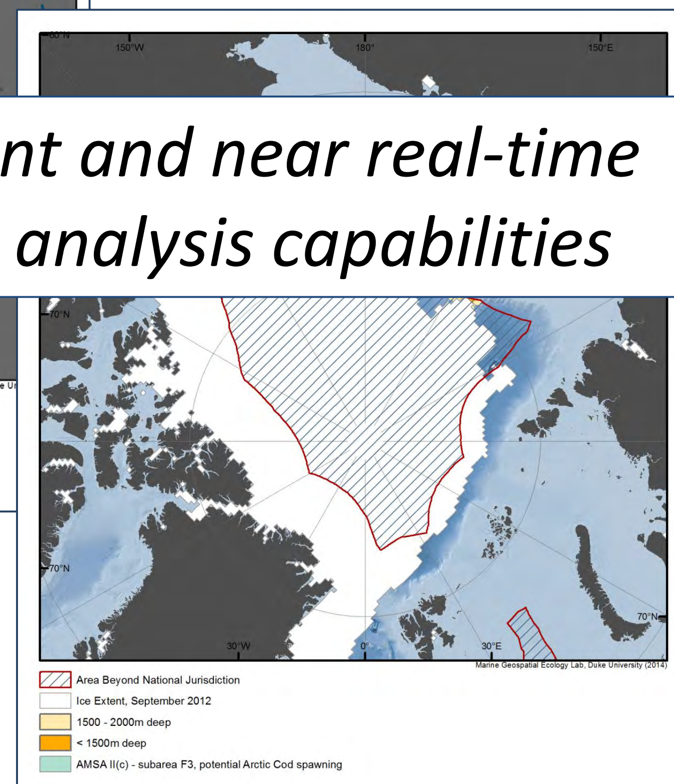
Oil & gas vs. ecological importance



Shipping vs. ecological importance

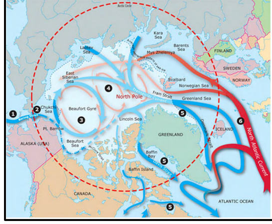


New fisheries vs. ecological importance



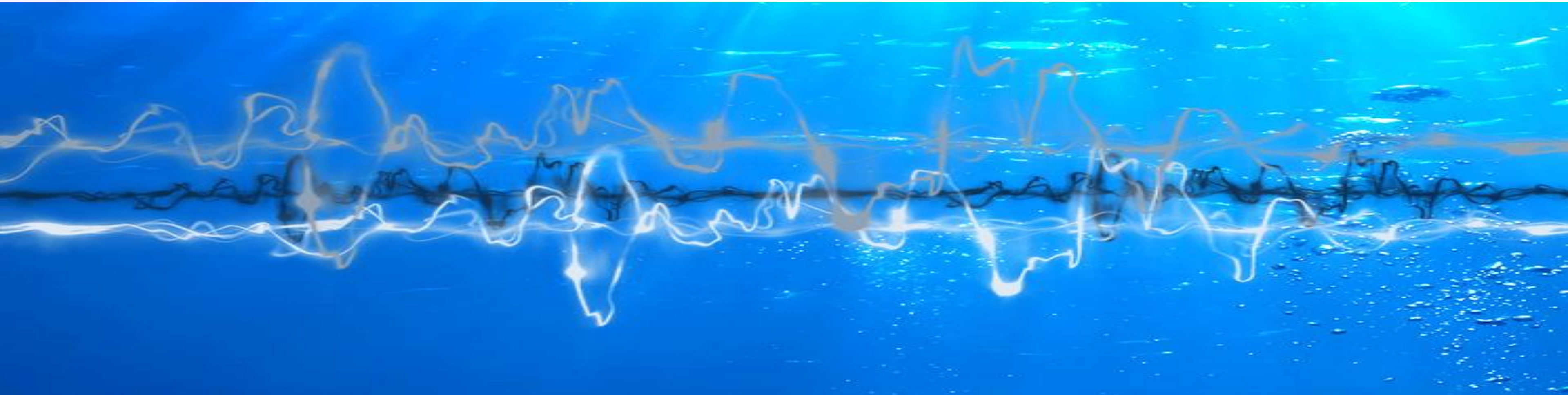
Need for dynamic ocean management and near real-time decision support, data sharing, and analysis capabilities

General comment: *The arctic is noteworthy for having resources use and ecological importance compressed in space & time.*

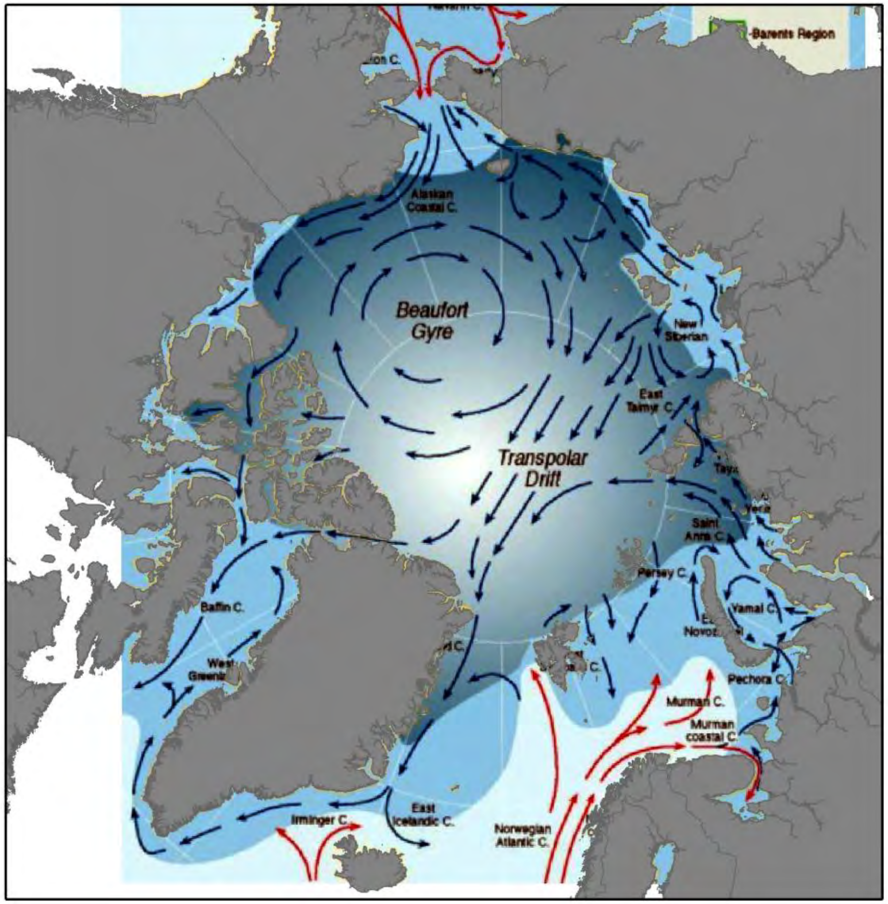


Conclusions:

- Patterns of physical connectivity in the Arctic are ***not uniform*** and are ***rapidly changing***;
- Assessments of connectivity need to be tied to specific cases (***species***, ***processes*** or ***functions***);
- Connectivity needs to be assessed in ***space and time*** across ***multiple scales***;
- Connectivity cannot be assessed in isolation from ***human uses in space and time***.



Discussion


Barents Region
Alaskan Coastal C.
Beaufort Gyre
New Siberian
East Taimyr C.
Transpolar Drift
Saint Anna C.
Persey C.
Vamal C.
Baffin C.
West Greenl
Pechora C.
Murman C.
Murman coastal C.
Irminger C.
East Icelandic C.
Norwegian Atlantic C.