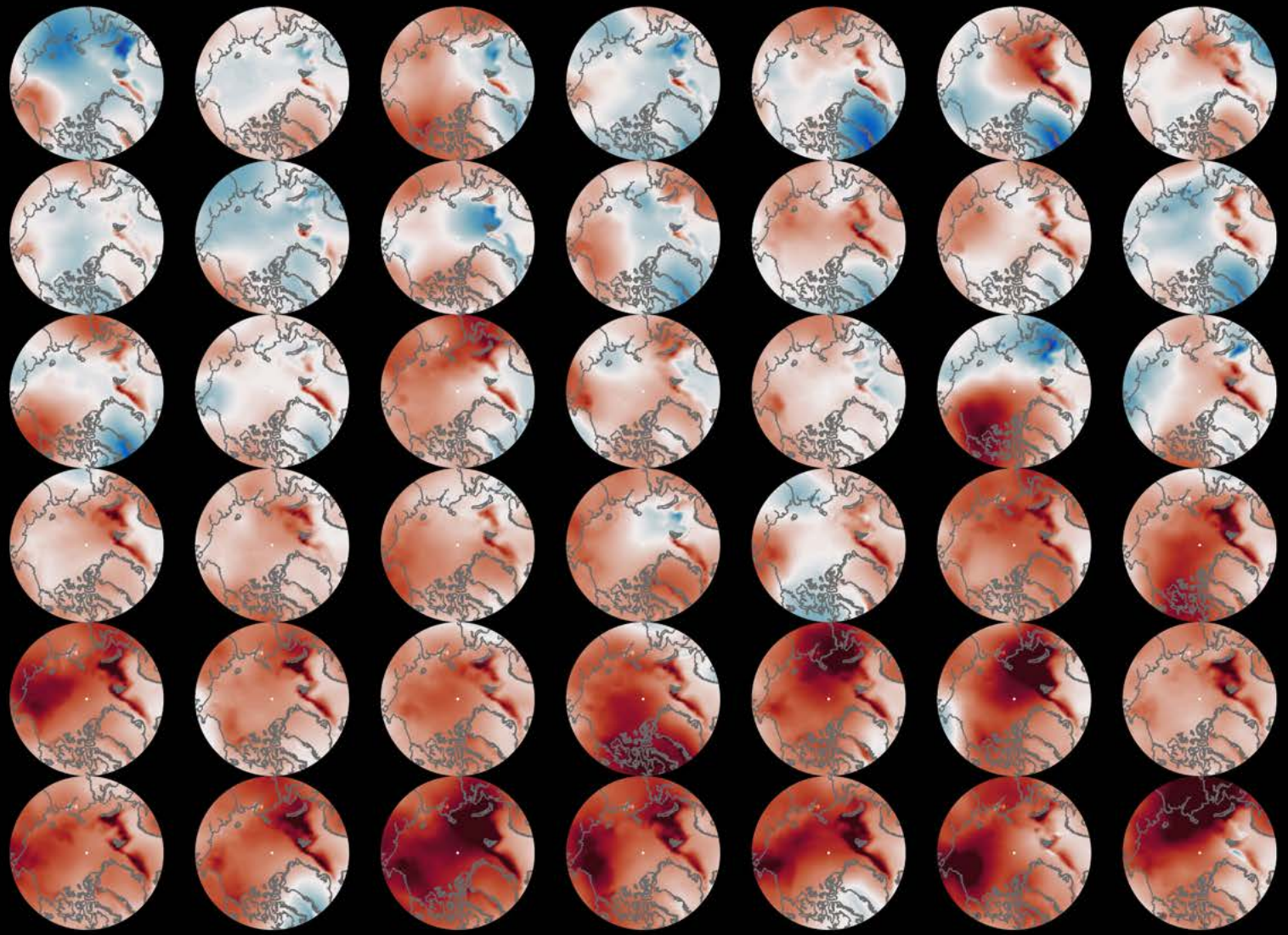
The Pan-Arctic Impacts of Thinning Sea Ice

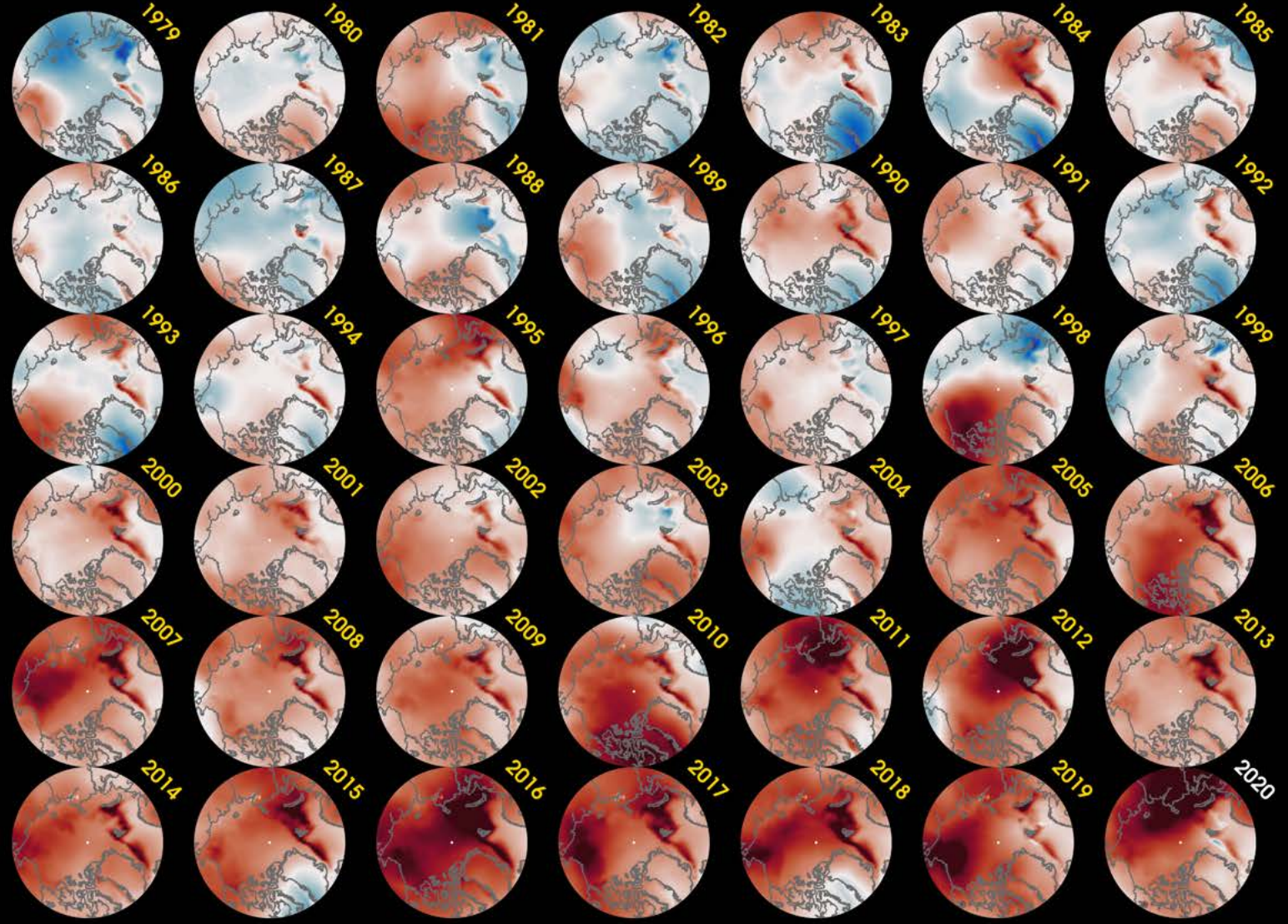
Zachary Labe
Colorado State University

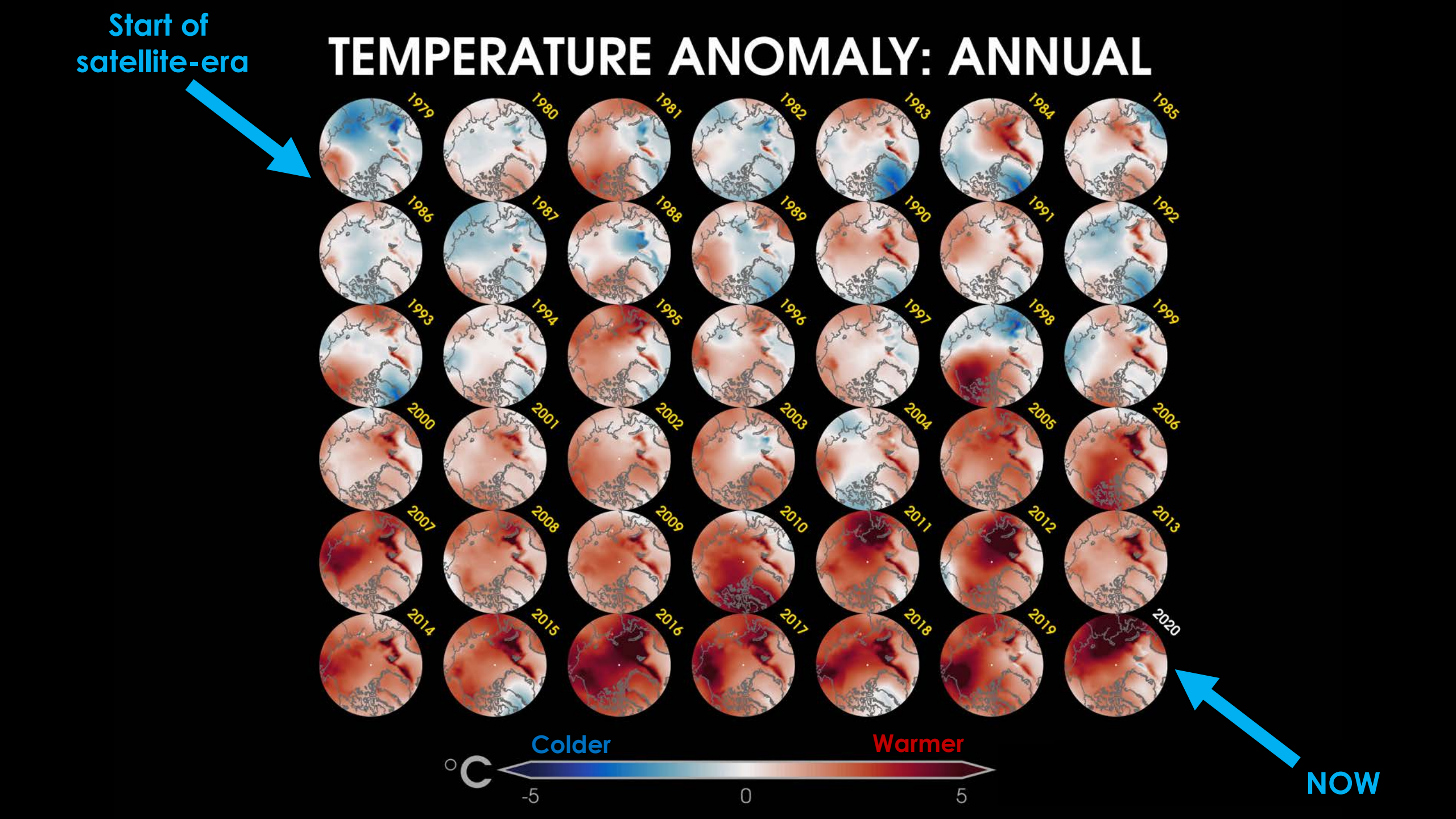
26 January 2021
Alaska Native Tribal Health Consortium (ANTHC)

Alaska LEO Network Webinar



TEMPERATURE ANOMALY: ANNUAL




Start of satellite-era
TEMPERATURE ANOMALY: ANNUAL
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Colder
Warmer
°C
-5
0
5
NOW

Explore changes in the temporal and spatial variability of Arctic sea-ice thickness over the satellite-era and 21st century

1. **Compare satellite, submarine, and simulated** ("reanalysis") **sea-ice thickness products**

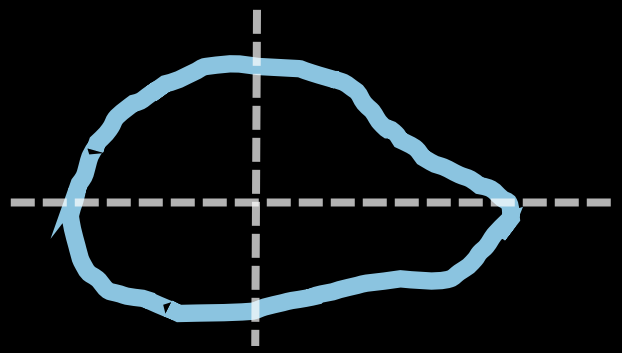
2. **Analyze changes in the variability of sea-ice thickness using a reanalysis product and a global climate model**

3. **Quantify future projections (21st century) of Arctic sea-ice thickness and volume using a regional approach**


The Arctic.

Sea Ice Extent

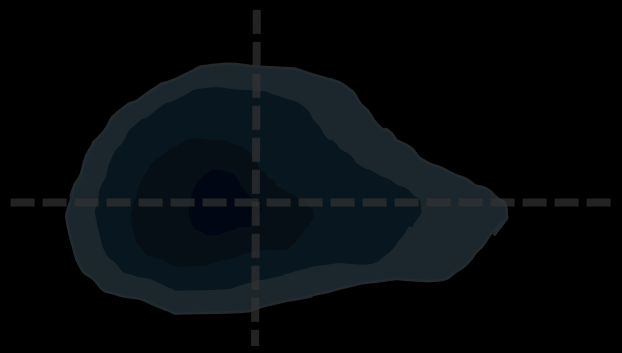
Area of seawater covered by any amount of ice (>15%)



[SIE]

Sea Ice Concentration

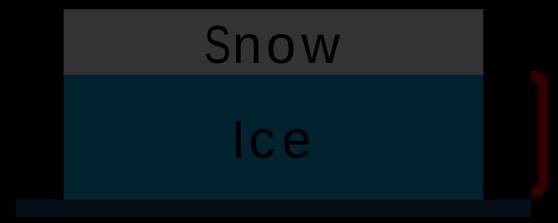
Fraction (%) of seawater covered by ice



[SIC]

Sea Ice Thickness

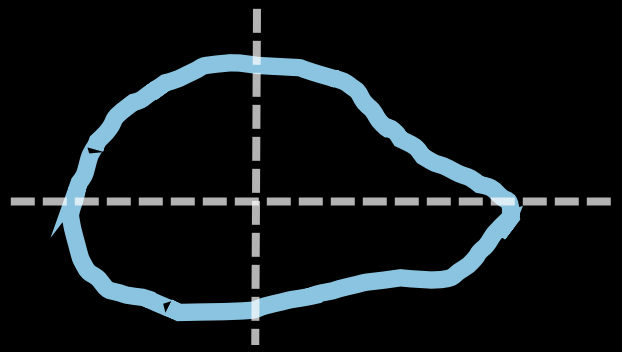
Depth between sea surface and ice/snow layer



[SIT]

Sea Ice Extent

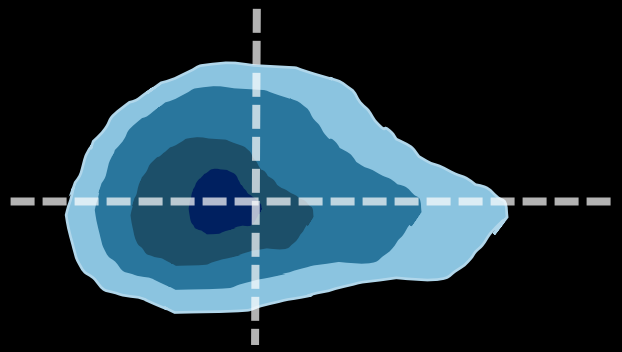
Area of seawater covered by any amount of ice (>15%)



[SIE]

Sea Ice Concentration

Fraction (%) of seawater covered by ice



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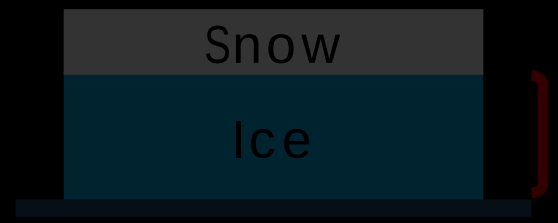

[SIT]

Sea Ice Extent

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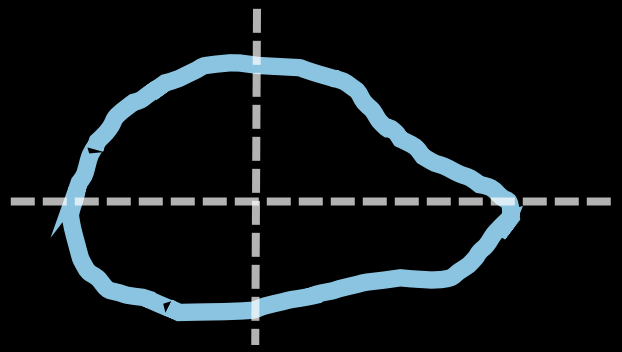
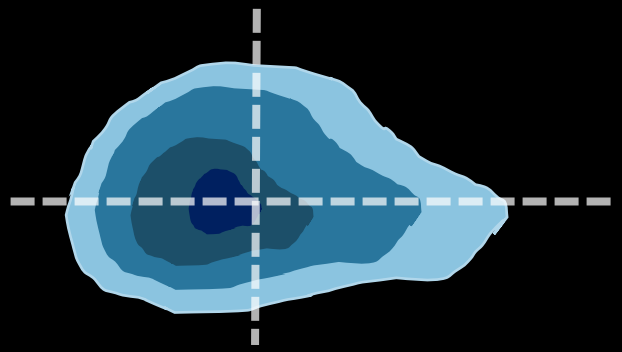


[SIE]

Sea Ice Concentration

Fraction (%) of seawater covered by ice



[SIC]

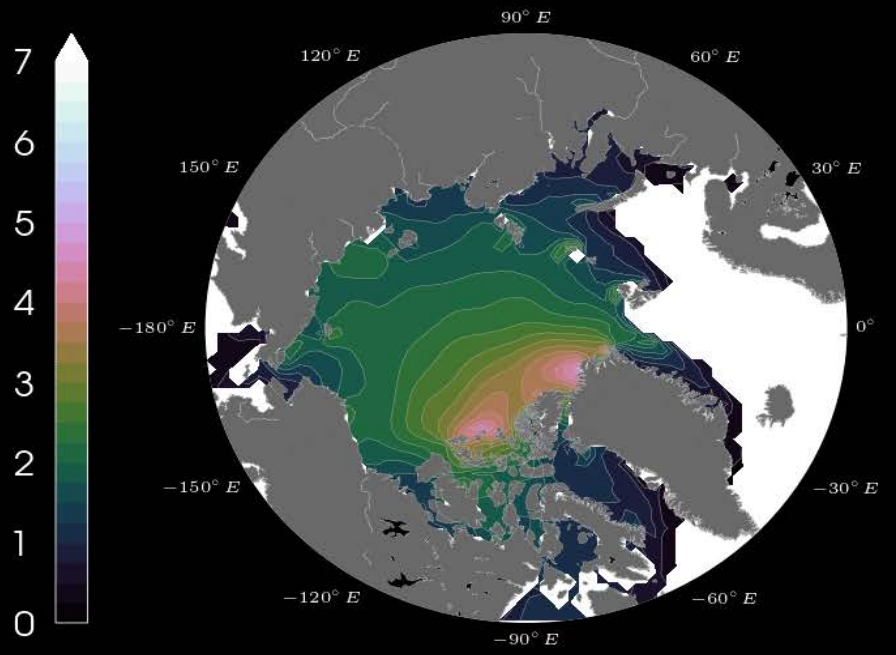
Sea Ice Thickness

Depth between sea surface and ice/snow layer

[SIT]

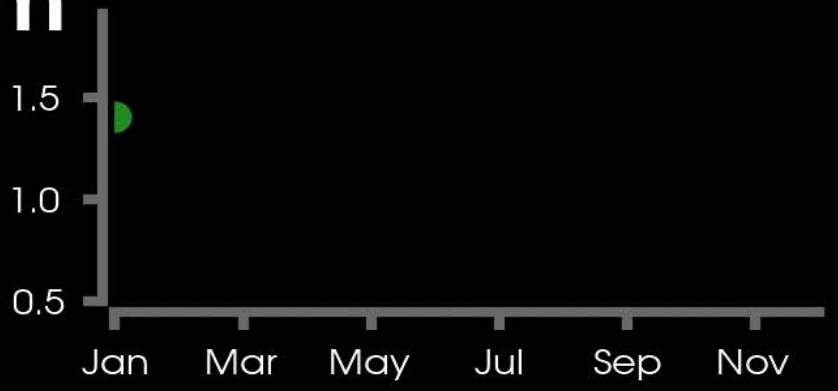
Jan

SIT


90° E
120° E
60° E
150° E
30° E
−180° E
0°
−150° E
−30° E
−120° E
−60° E
−90° E

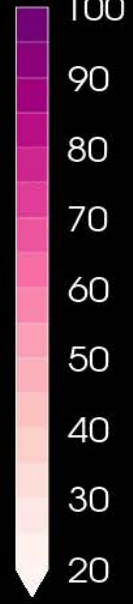
7
6
5
4
3
2
1
0

m

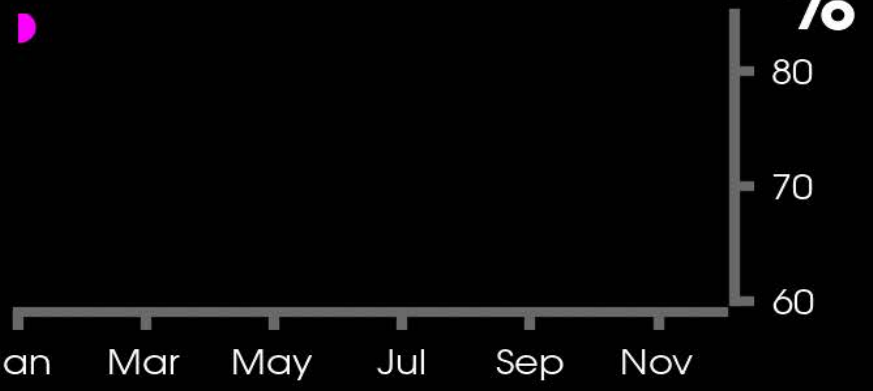

1.5
1.0
0.5
Jan
Mar
May
Jul
Sep
Nov

SIC


90° E
120° E
60° E
150° E
30° E
−180° E
0°
−150° E
−30° E
−120° E
−60° E
−90° E

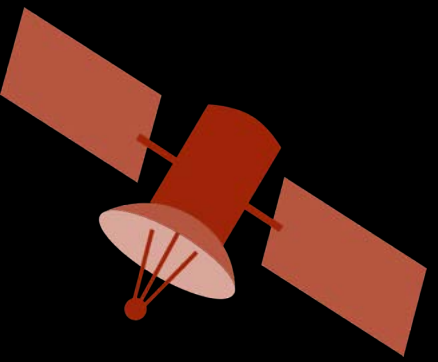

100
90
80
70
60
50
40
30
20

%


80
70
60
Jan
Mar
May
Jul
Sep
Nov

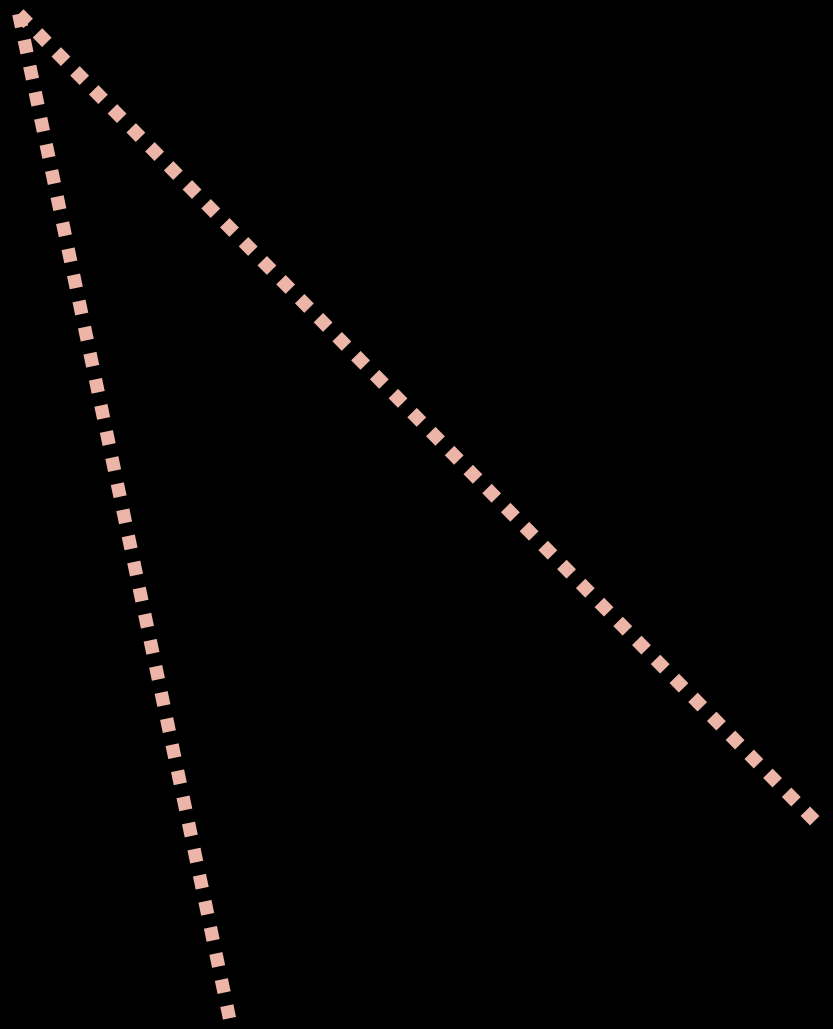

Observing ice.

SEA-ICE EXTENT



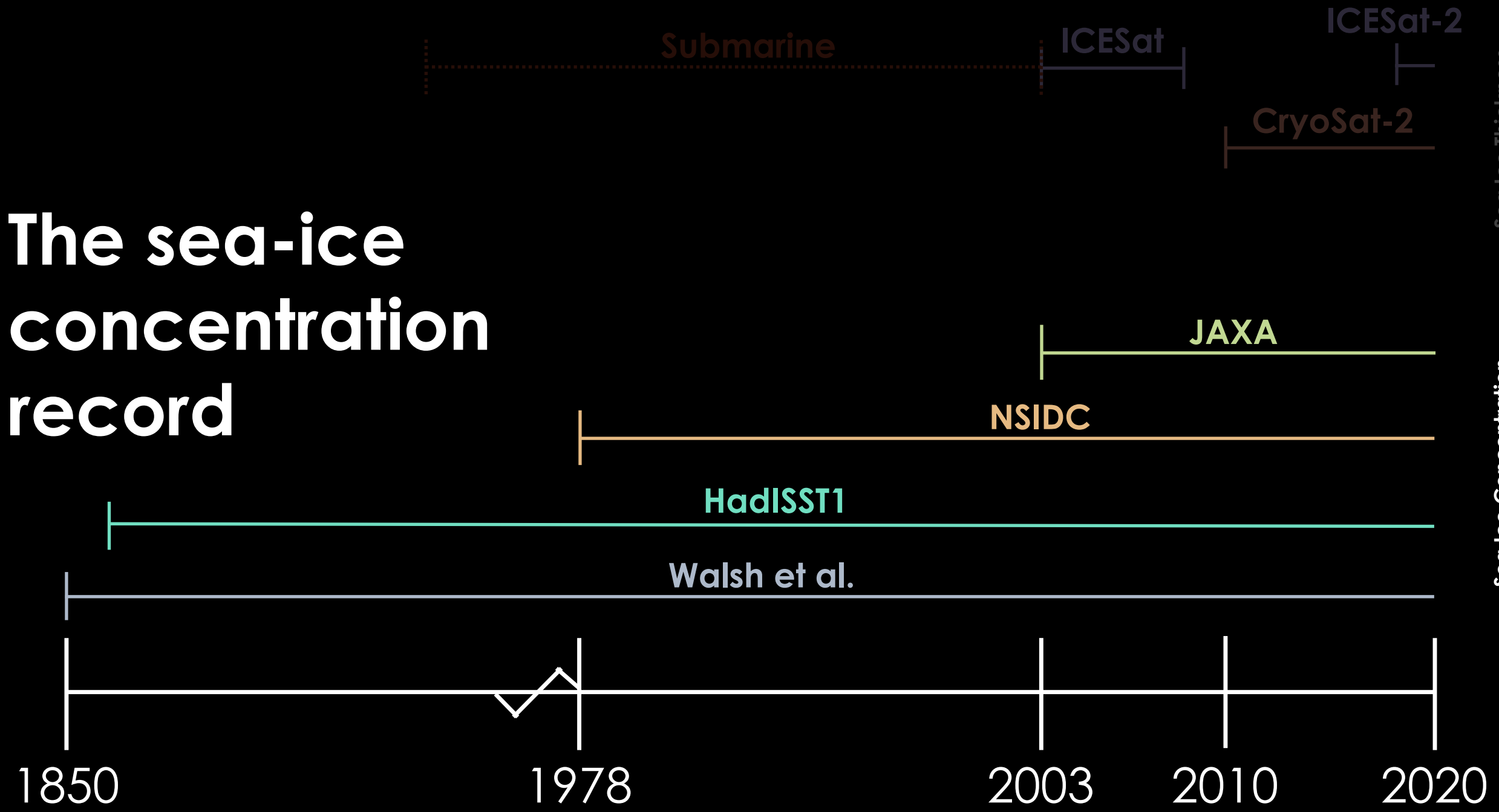
2 km

SEA-ICE THICKNESS

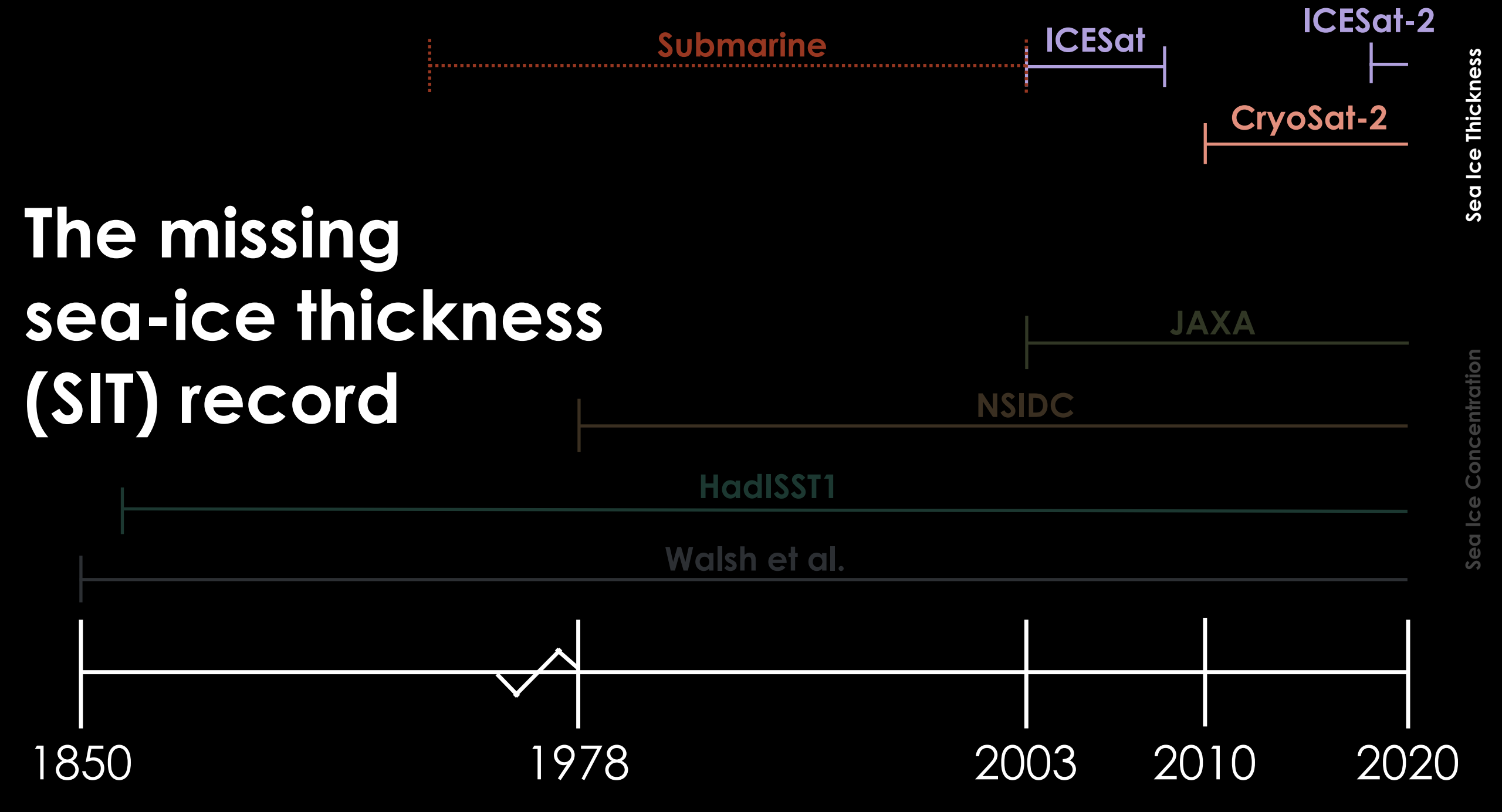


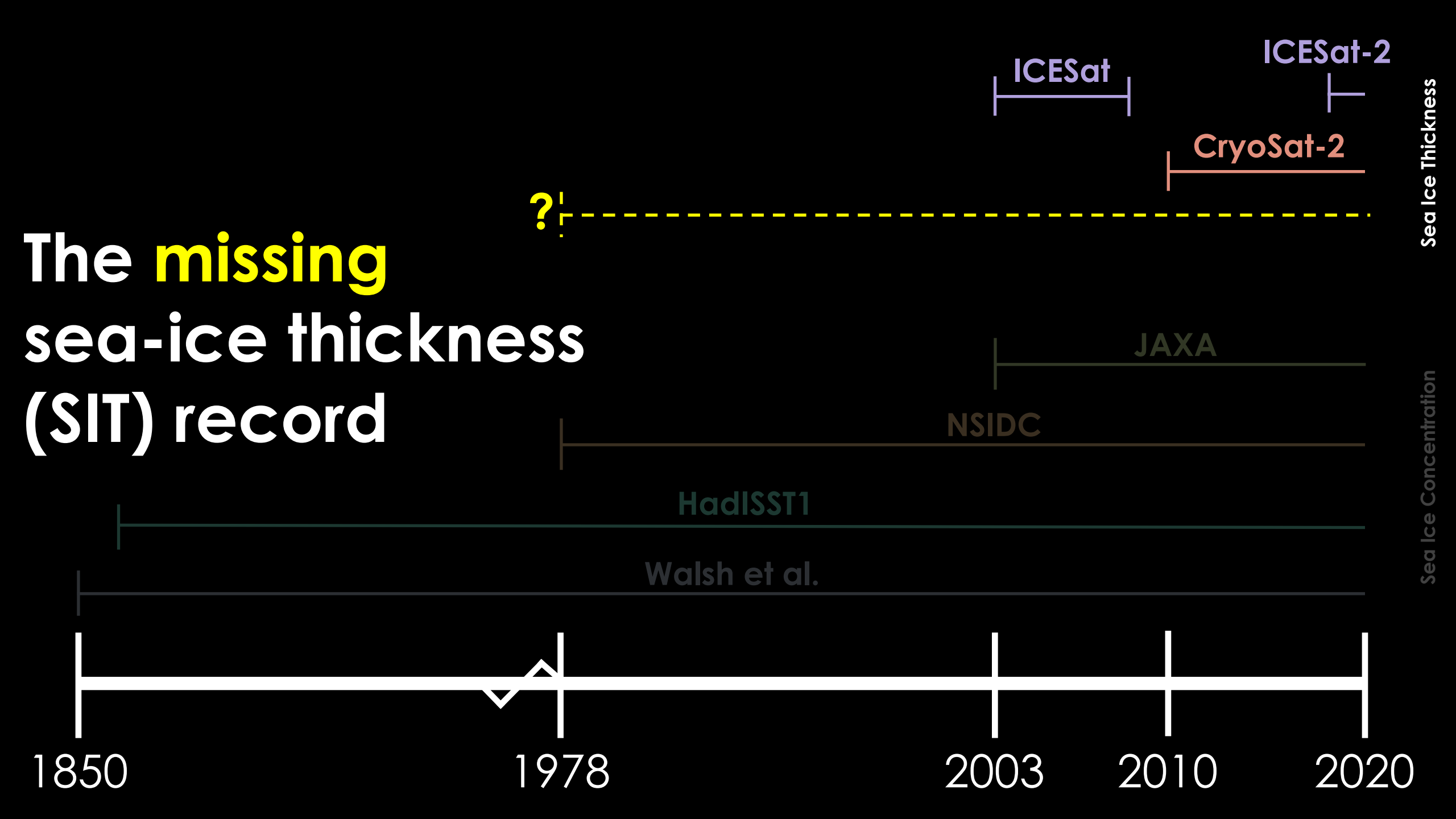
1.5 m

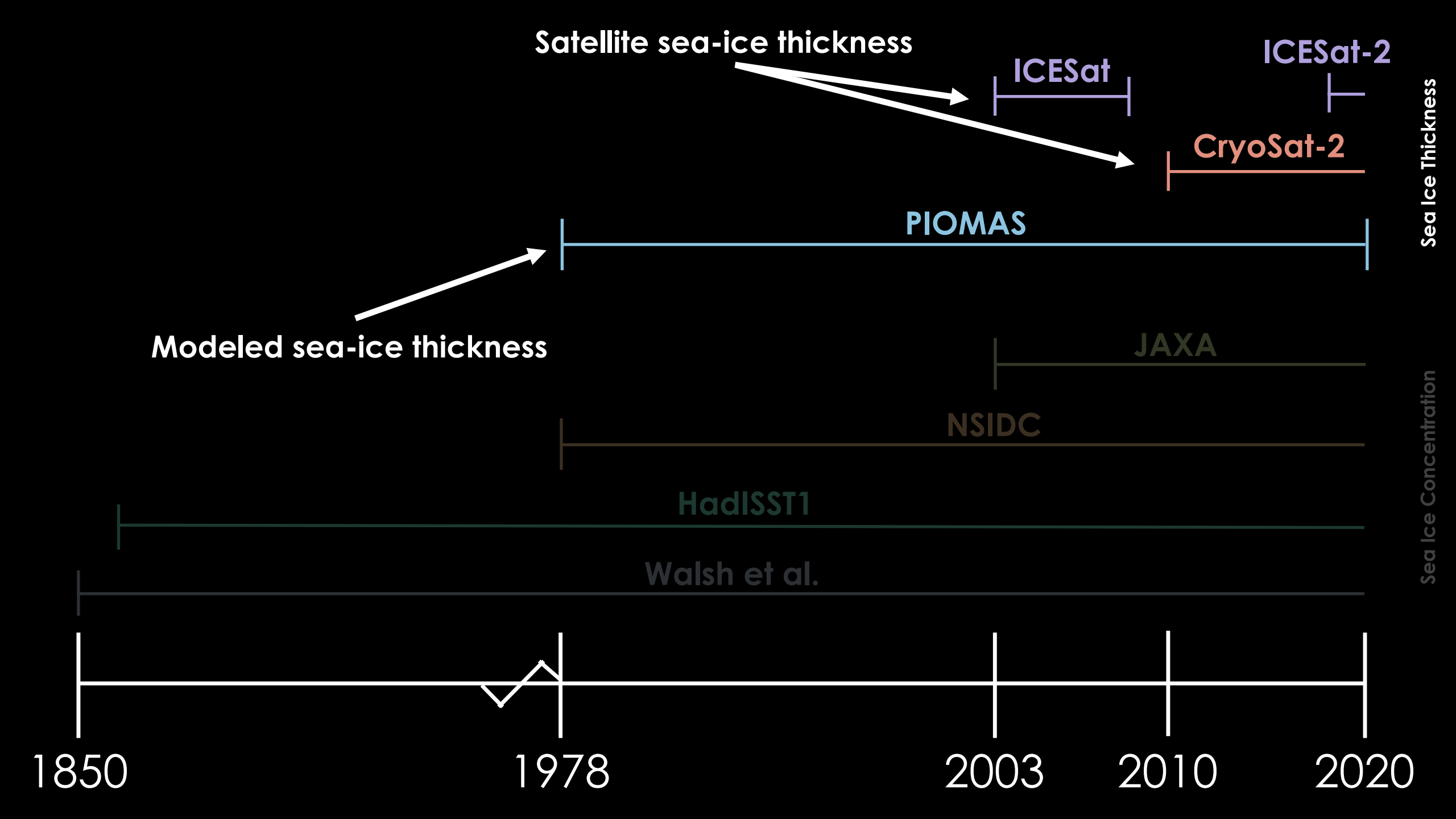
The sea-ice concentration record



The missing sea-ice thickness (SIT) record

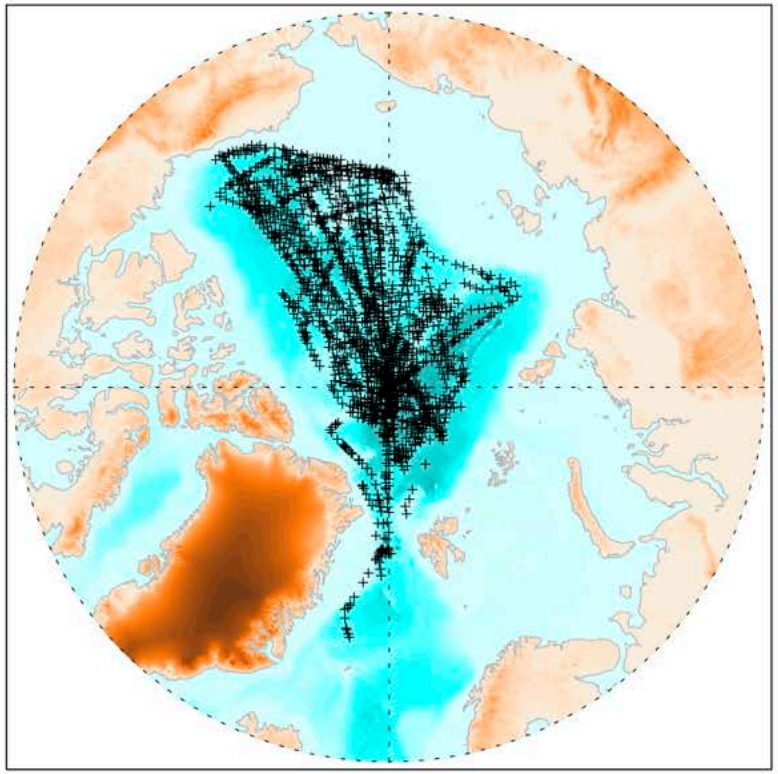



ICESat
ICESat-2
CryoSat-2
?
Sea Ice Thickness
The missing sea-ice thickness (SIT) record
JAXA
NSIDC
HadISST1
Walsh et al.
Sea Ice Concentration
1850
1978
2003
2010
2020

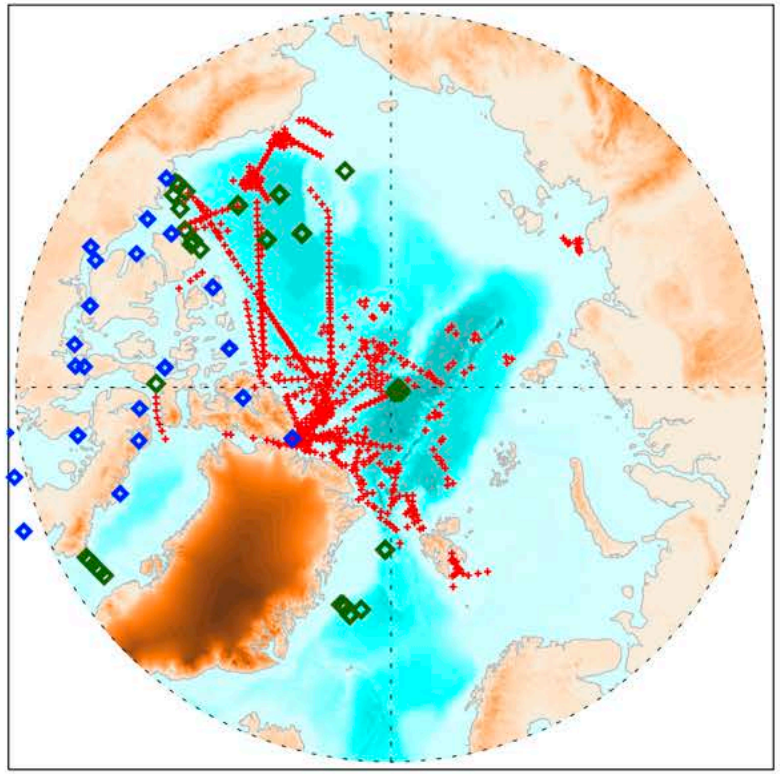

Satellite sea-ice thickness
ICESat
ICESat-2
CryoSat-2
PIOMAS
Modeled sea-ice thickness
JAXA
NSIDC
HadISST1
Walsh et al.
Sea Ice Thickness
Sea Ice Concentration
1850
1978
2003
2010
2020

CHANGING DATA

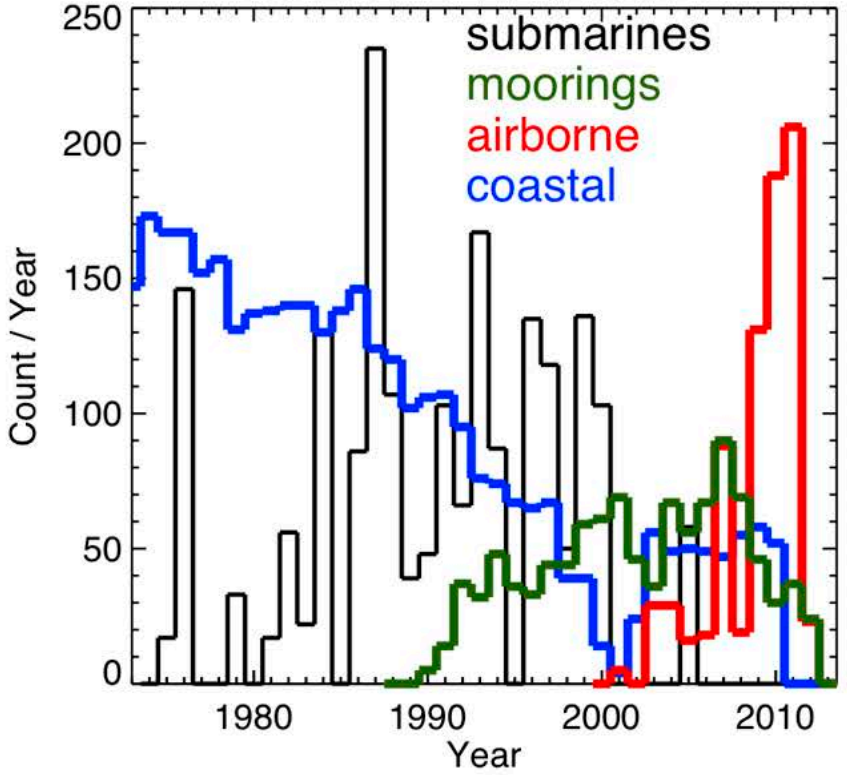
Submarines



Moorings, Airborne and Coastal



Number of Observations



LINDSAY 2010, *EOS*

SEA ICE DATA SETS

	TIME	SPATIAL DOMAIN
PIOMAS	1979 - present	pan-Arctic
Submarine	1986 - 1993	upward looking sonar (narrow)
ICESat	2004 - 2009	ICESat domain
CryoSat-2	2011 - present	pan-Arctic
ICESat-2	2018 - present	pan-Arctic

SEA ICE DATA SETS

PIOMAS

Submarine

ICESat

CryoSat-2

ICESat-2

DOMAIN

Arctic

Sonar (narrow)

Domain

Arctic

Arctic

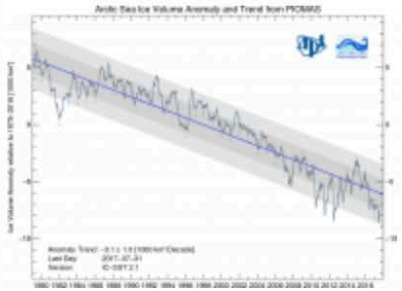
https://climatedataguide.ucar.edu/climate-data/sea-ice-thickness-data-sets-overview-comparison-table

NCAR UCAR | ClimateDataGuide

CLIMATE DATA | ANALYSIS TOOLS | MODEL EVALUATION | EXPERT CONTRIBUTOR

SEA ICE THICKNESS DATA SETS: OVERVIEW & COMPARISON TABLE

Summary | Expert Guidance | Metadata | Get Data (External) | References



While satellite observations of sea ice extent and concentration are available from 1979, long-term high quality (daily and high spatial resolution) observations of sea ice thickness remain limited as a result of few satellite and in situ observations. Reconstructions using numerous observational sources show a 65% decline in annual mean sea ice thickness in the central Arctic since the 1970s (*Lindsay and Schweiger* , 2015). Existing observations of sea ice thickness can differ through spatial and temporal coverage, measurement uncertainties, and methods of estimation. (excerpted from Zachary Labe's expert-user guidance).

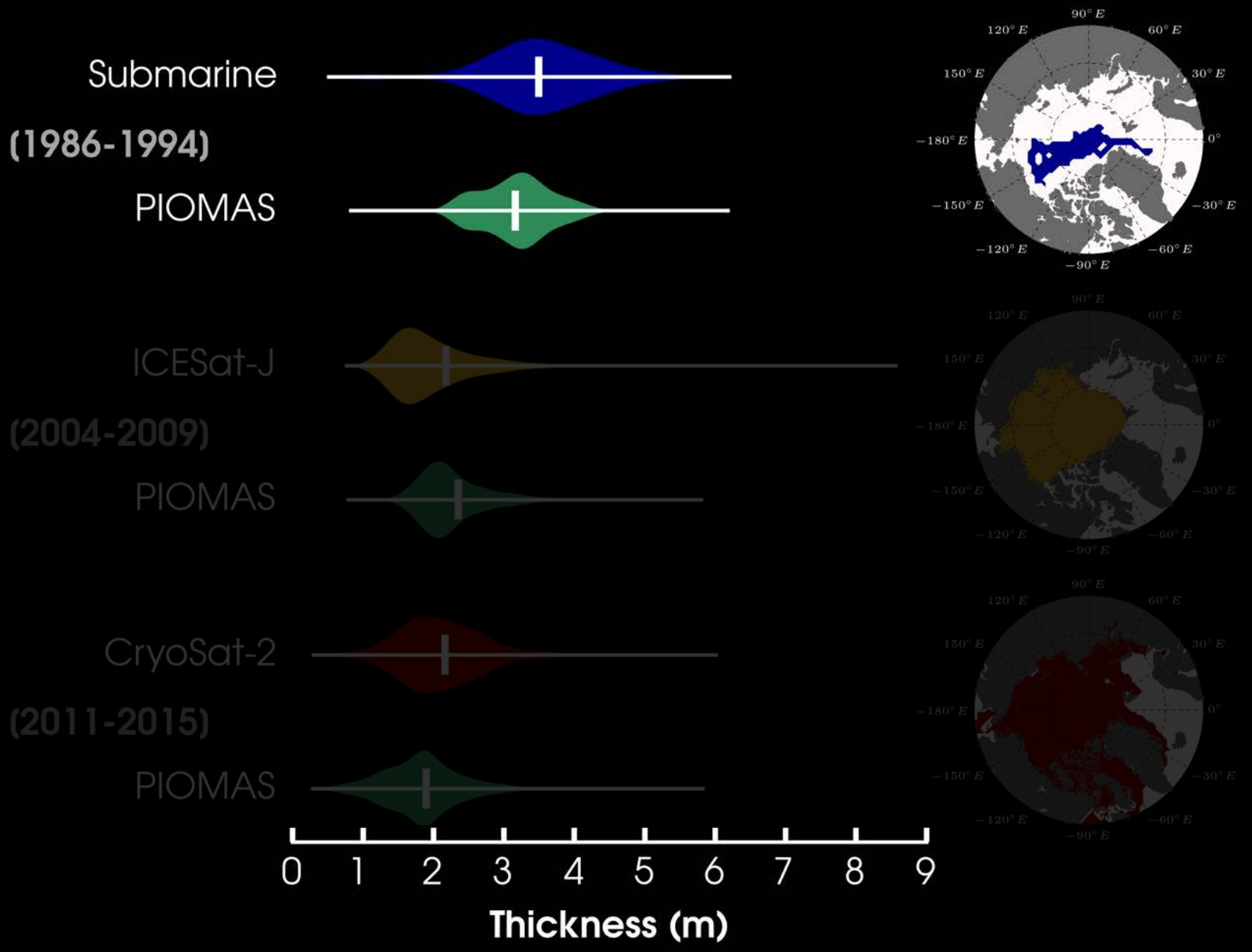
KEY STRENGTHS:

- Sea ice thickness data is necessary for assessing sea ice mass balance, the surface energy budget, seasonal and annual sea ice prediction, and changes in the polar climate system
- Total sea ice volume can be estimated through sea ice thickness and sea ice concentration

KEY LIMITATIONS:

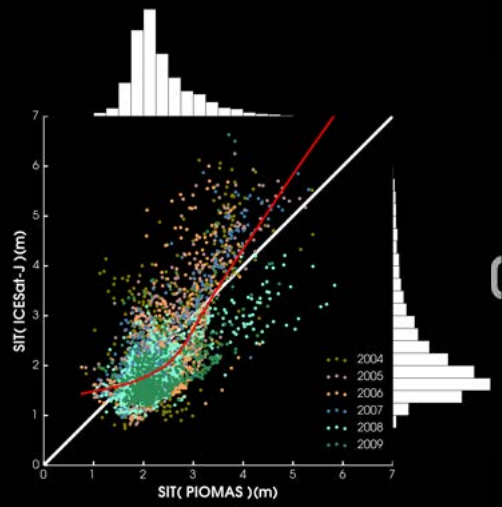
- Numerous uncertainties as a result of different methods, assumptions, and data sources
- Major limitations in the spatial and temporal coverage of sea ice thickness, which prevent a consistent record of long-term change and variability
- Methods for assessing snow depth on top of the sea ice (i.e. use of climatology) may lead to biases in sea ice thickness estimates

DATA COMPARISON



LABE ET AL. 2018, JCLI

DATA COMPARISON



Submarine

(1986-1994)

PIOMAS

ICESat-J

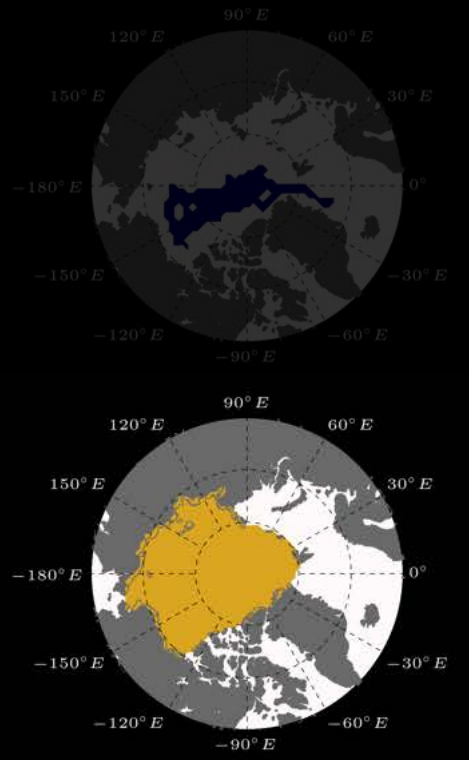
(2004-2009)

PIOMAS

CryoSat-2

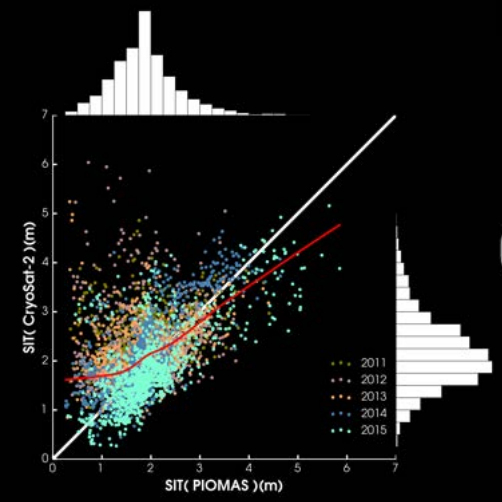
(2011-2015)

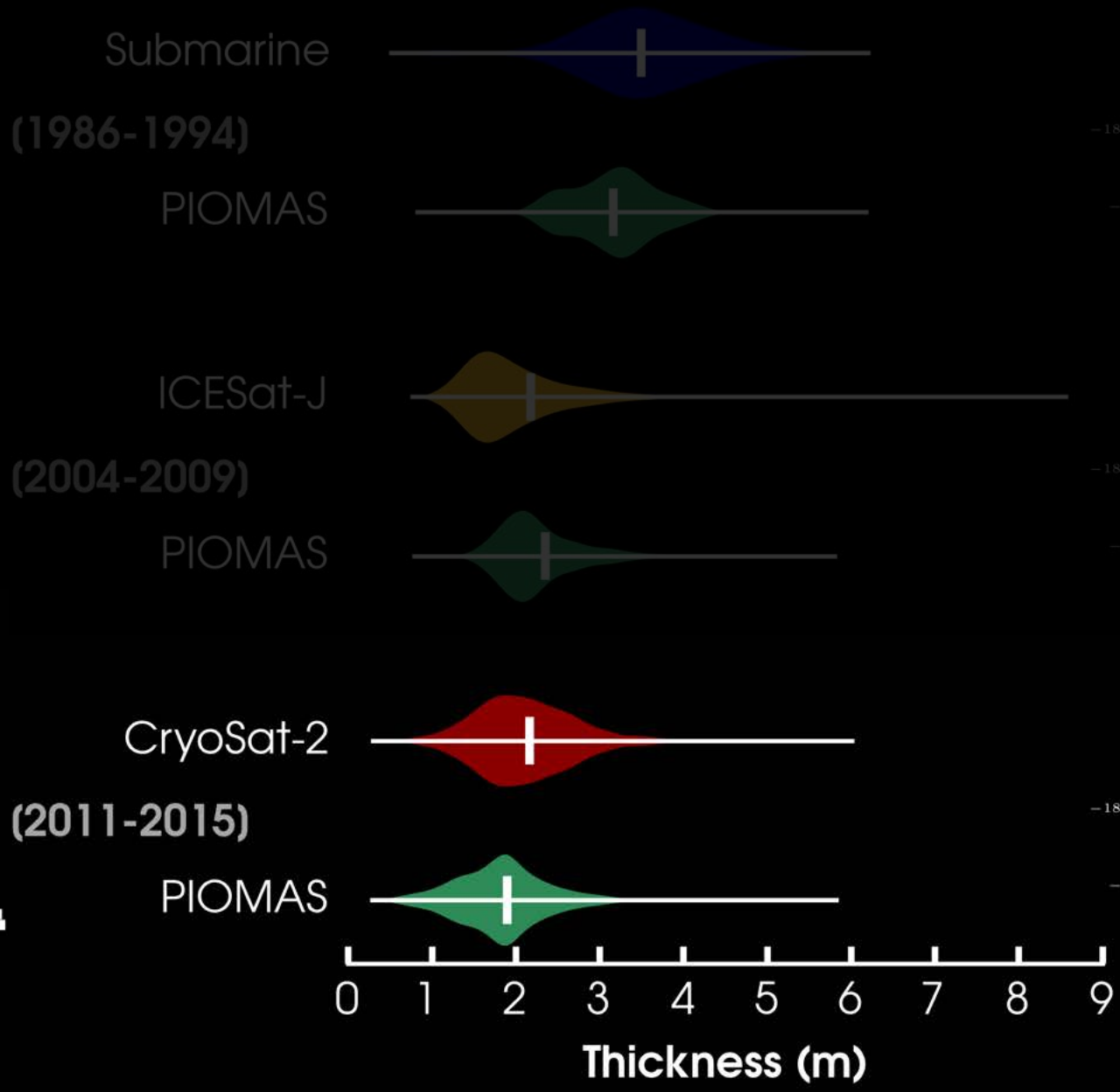
PIOMAS

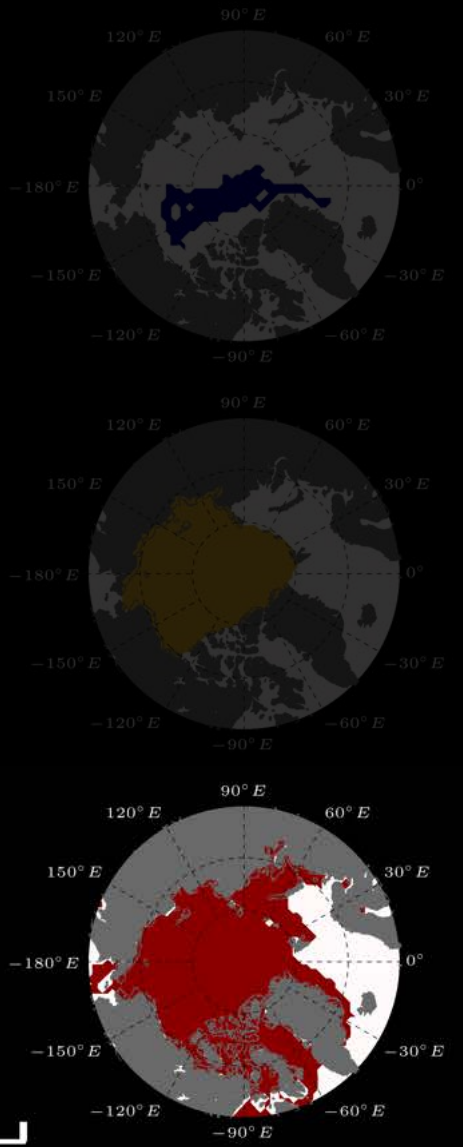


LABE ET AL. 2018, JCLI

DATA COMPARISON







LABE ET AL. 2018, JCLI


Trends &
Variability.

Trends

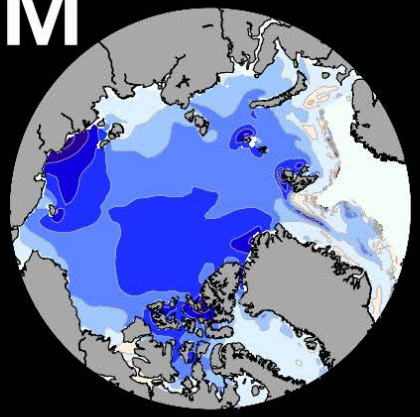
Variability

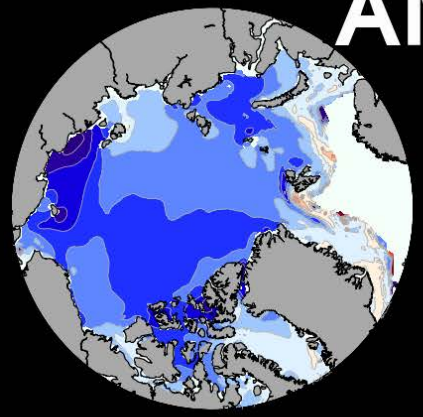
JFM

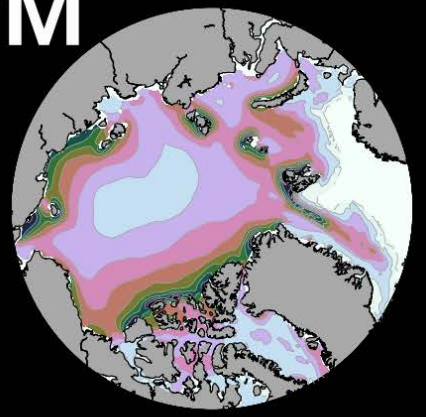
AMJ

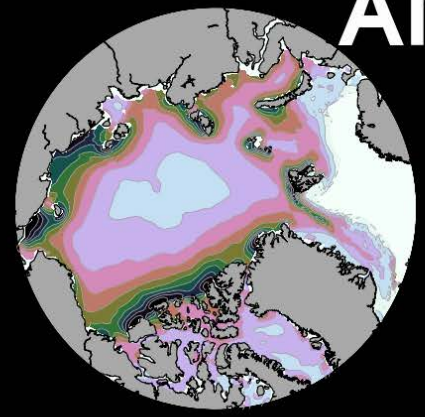
JFM

AMJ







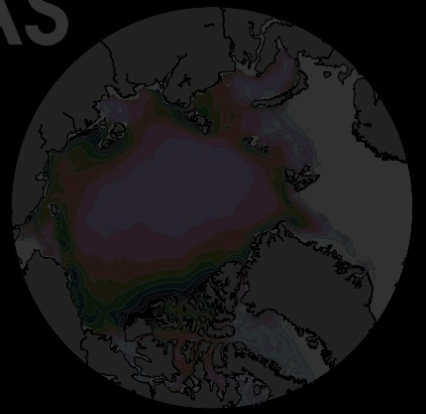


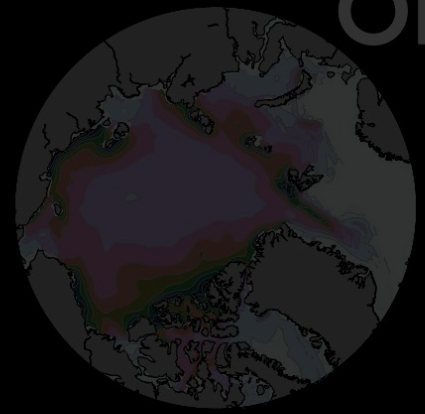
JAS

OND

JAS

OND





Less ice

More ice

-0.6 -0.3 0.0 0.3 0.6

SIT(m decade^{-1})

More variability

0.0 0.5 1.0

Thickness (meters)

LABE ET AL. 2018, JCLI

Trends

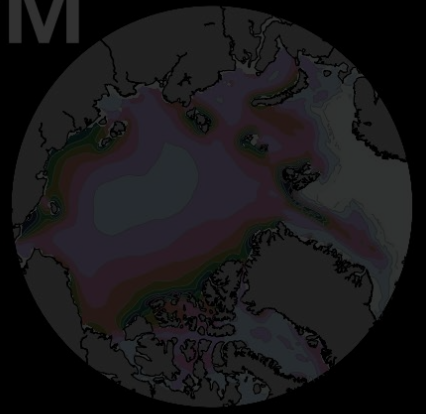
Variability

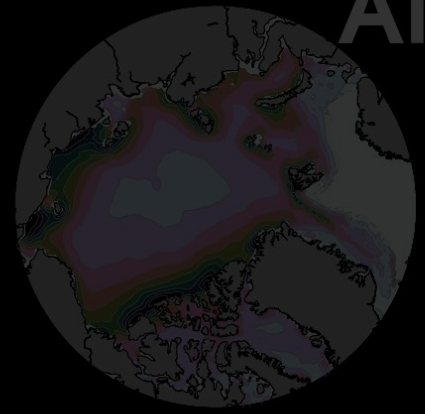
JFM

AMJ

JFM

AMJ



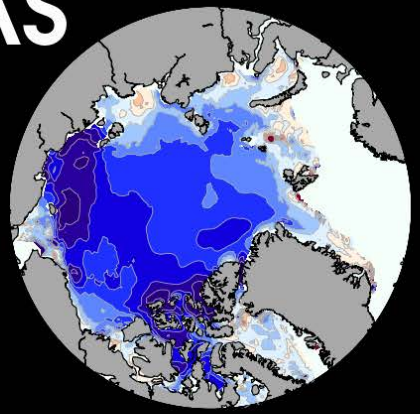


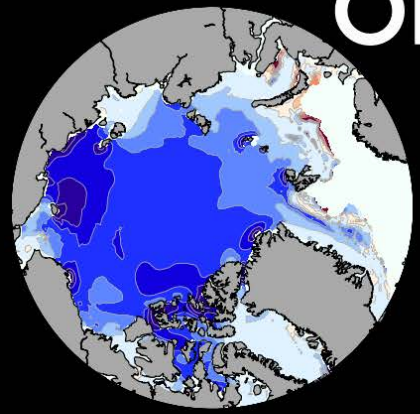
JAS

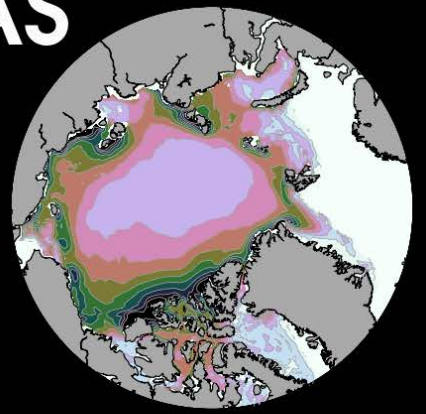
OND

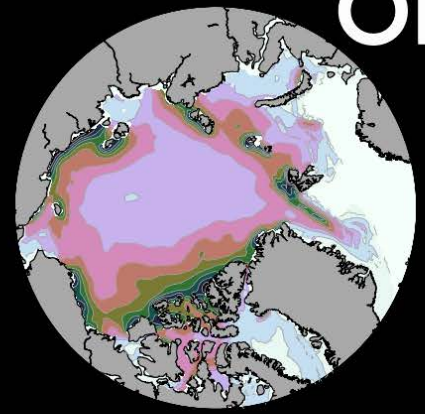
JAS

OND



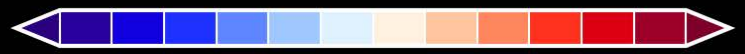






Less ice

More ice



-0.6 -0.3 0.0 0.3 0.6

SIT(m decade^{-1})

More variability

0.0 0.5 1.0

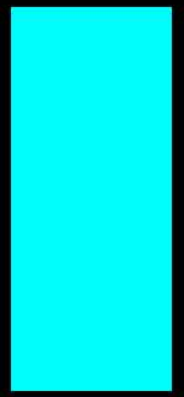
Thickness (meters)

LABE ET AL. 2018, *JCLI*

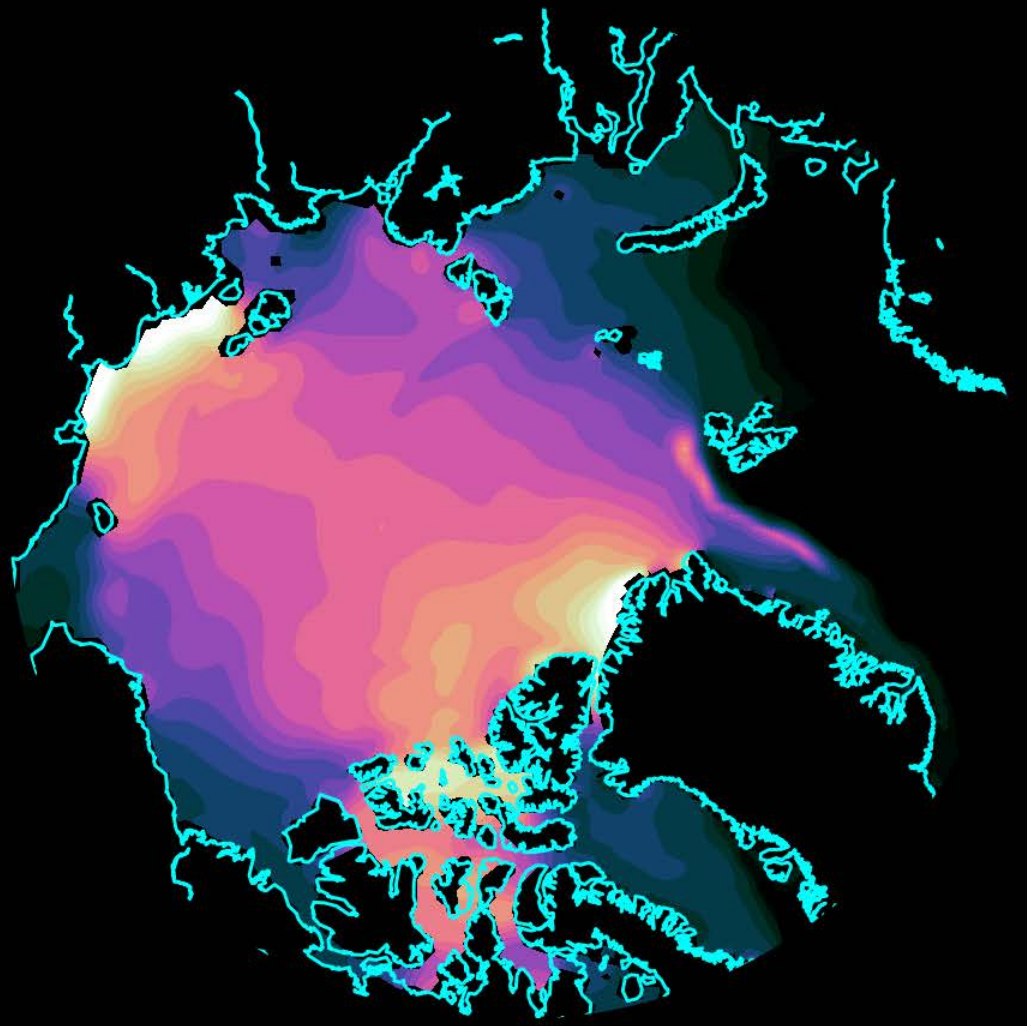
DECEMBER

1979

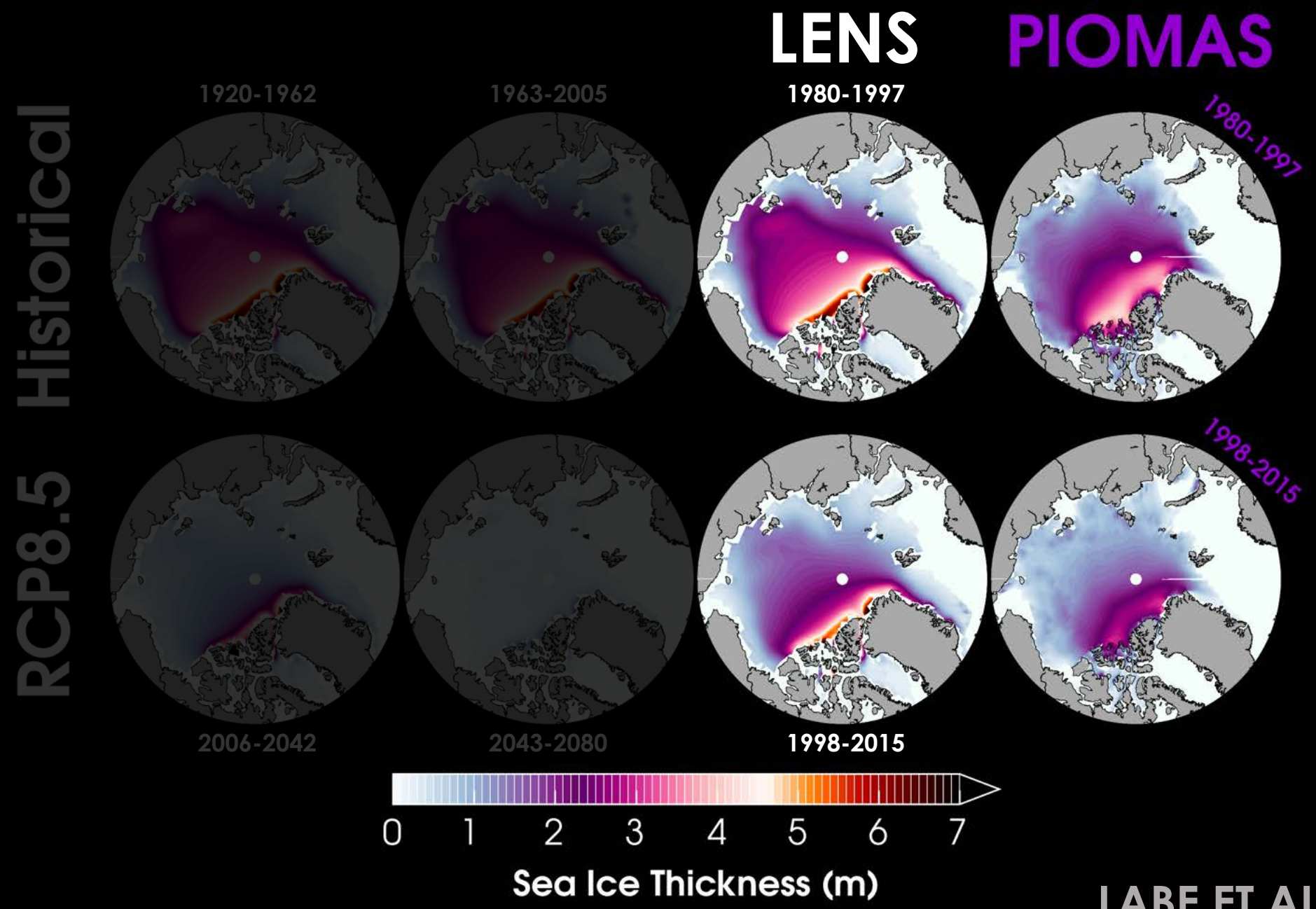
23,201



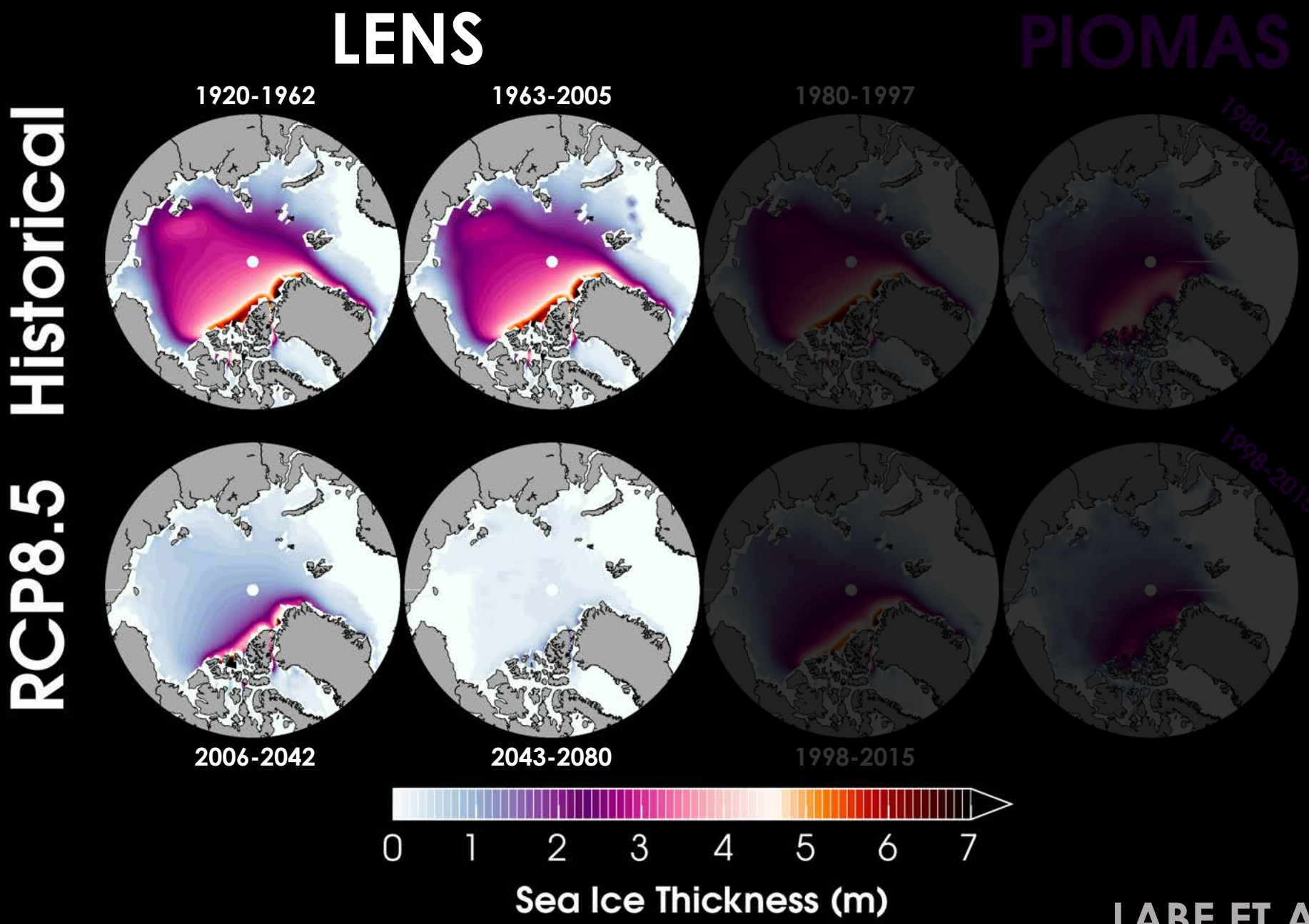
SEA ICE VOLUME (km^3)



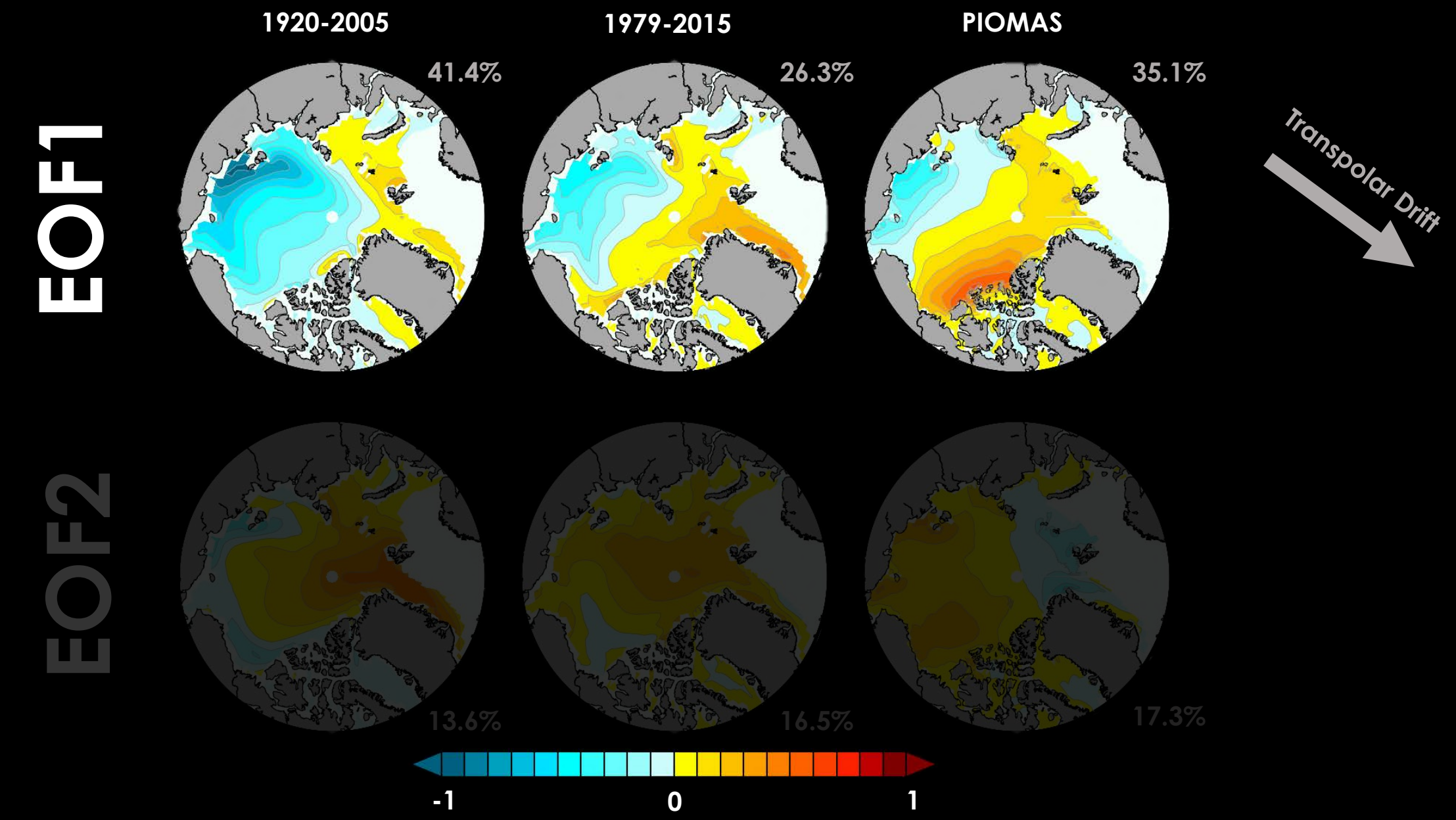
SEA ICE THICKNESS (m)



LABE ET AL. 2018, *JCLI*



LABE ET AL. 2018, *JCLI*



Patterns of sea-ice variability

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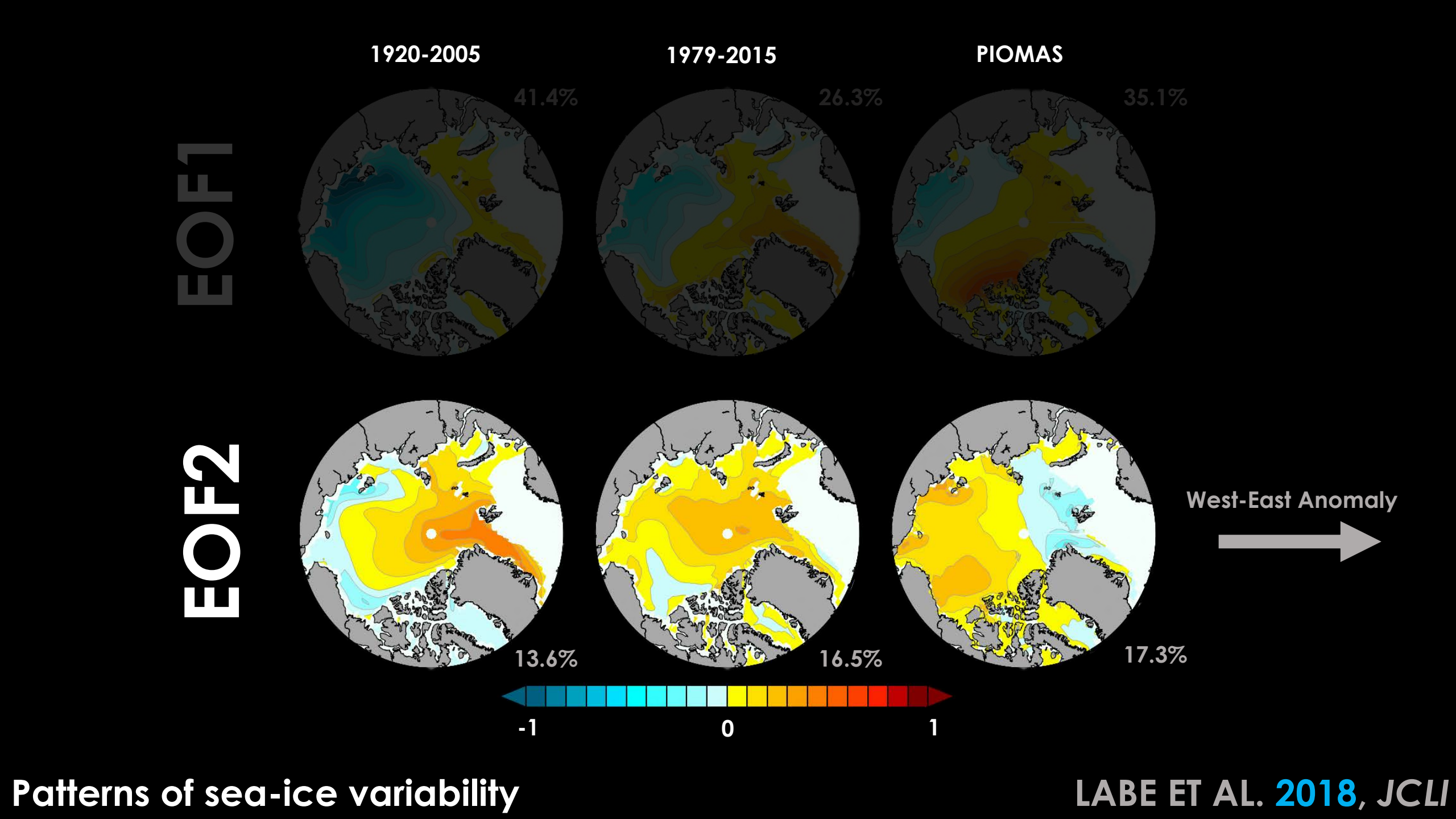
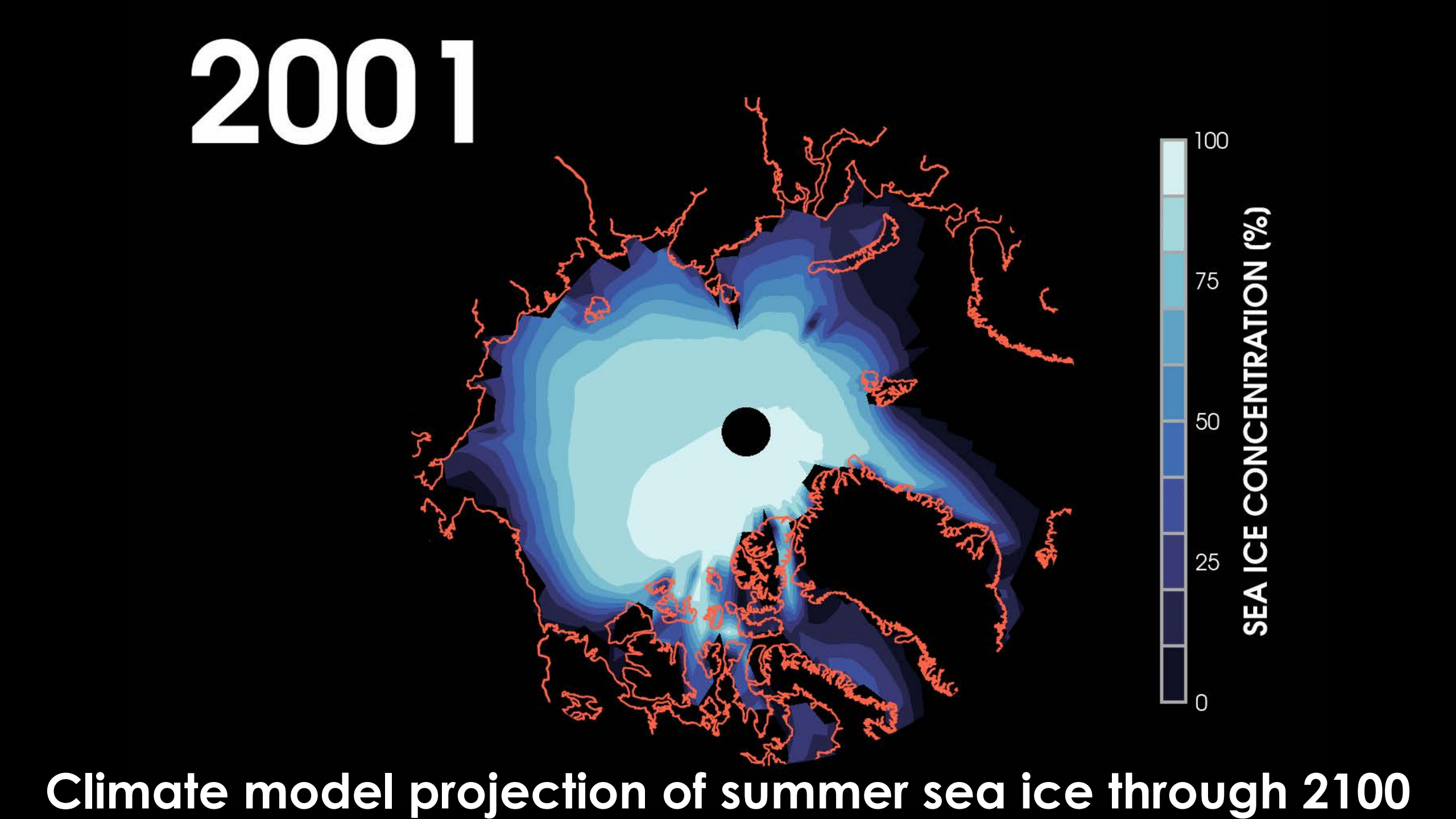


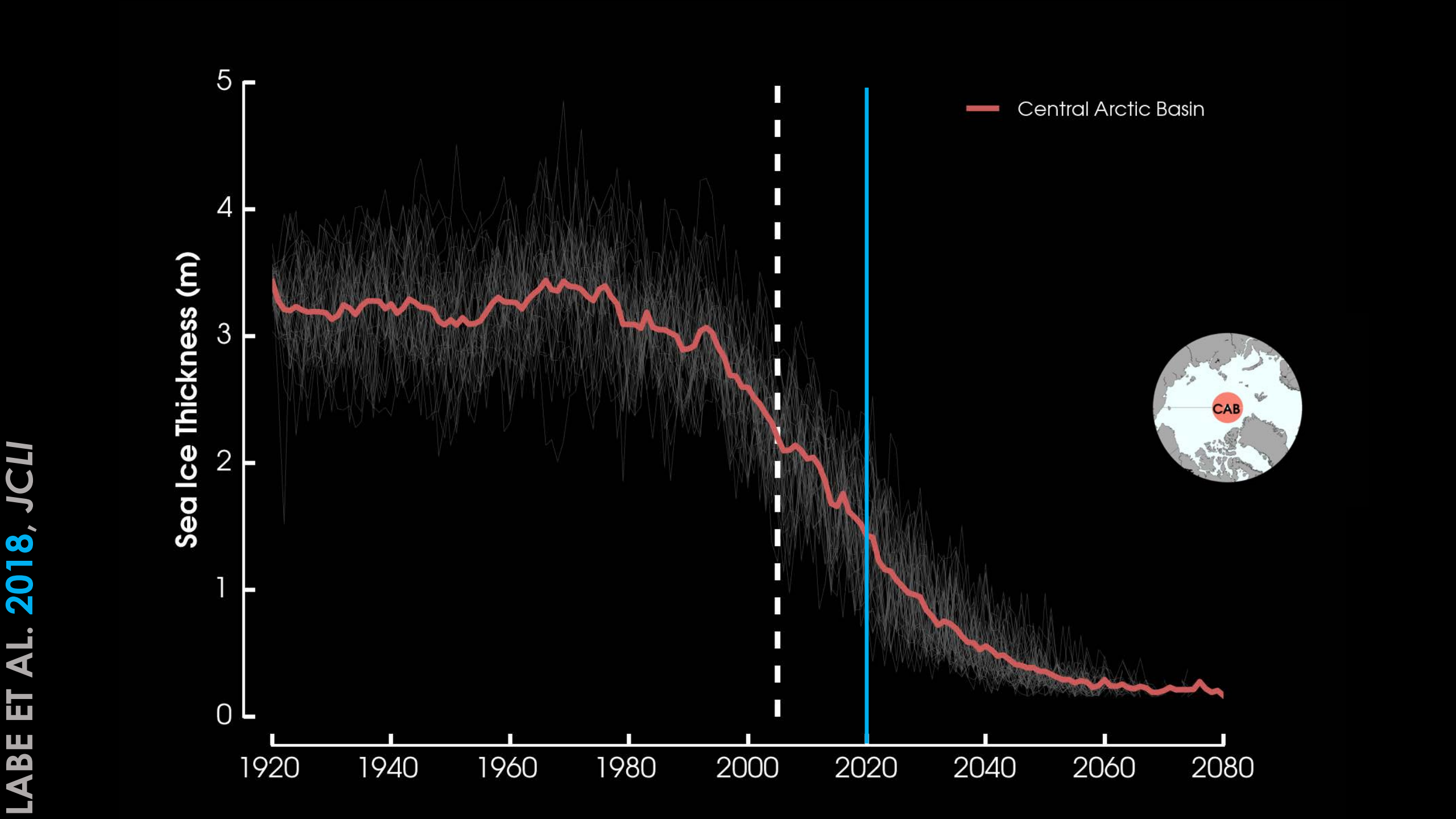
Patterns of sea-ice variability

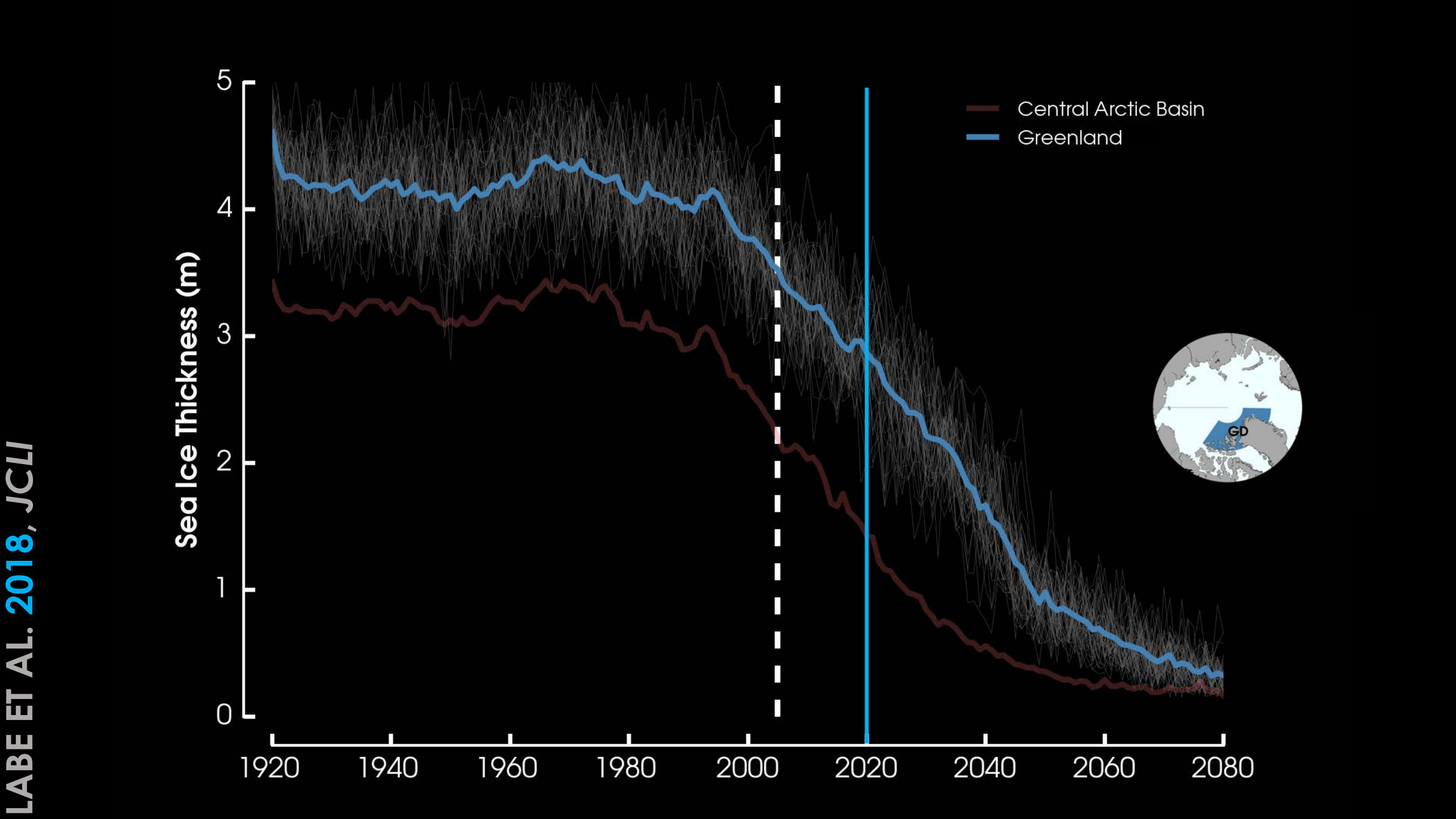
LABE ET AL. 2018, *JCLI*

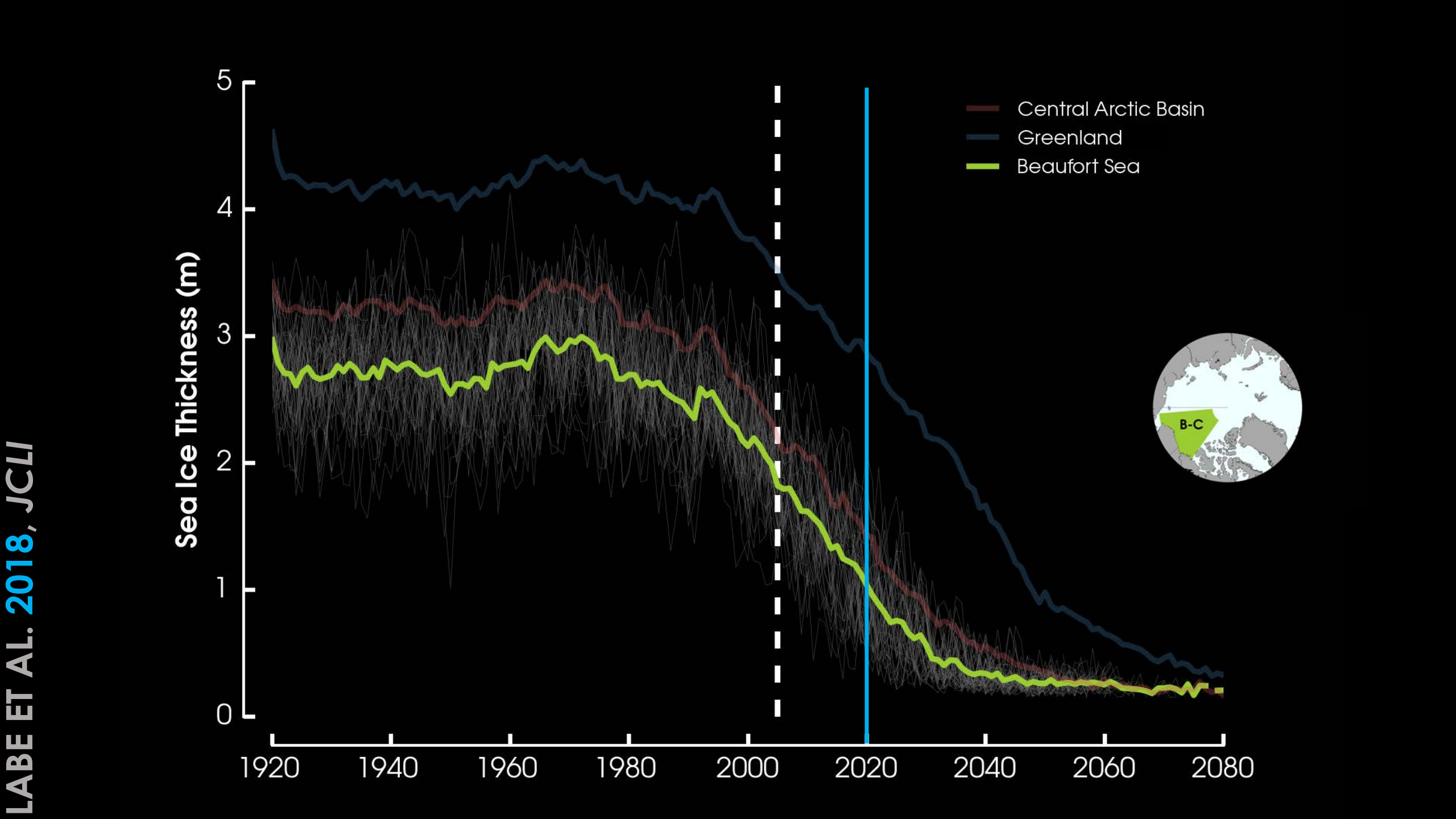

Future projections.

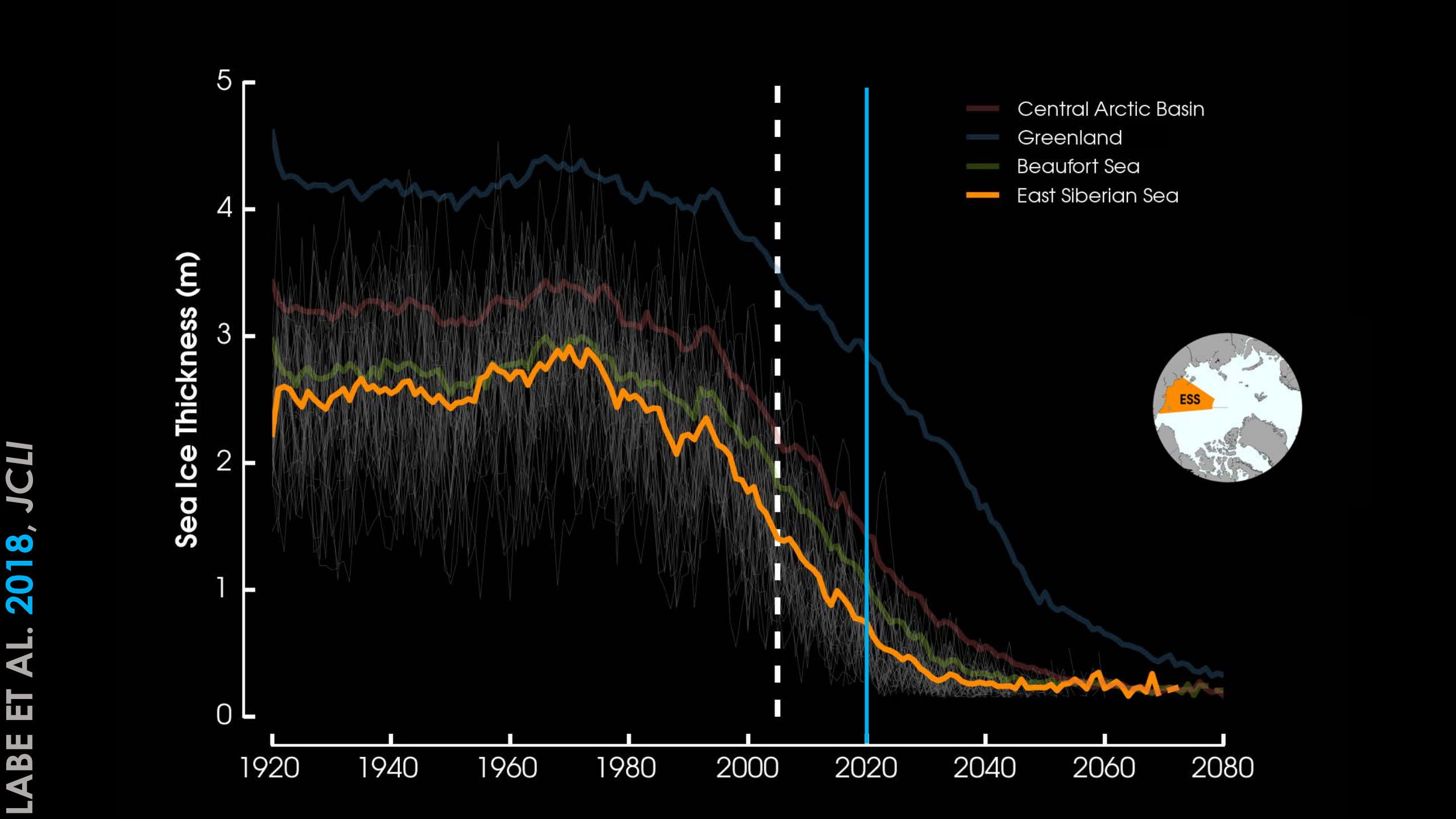


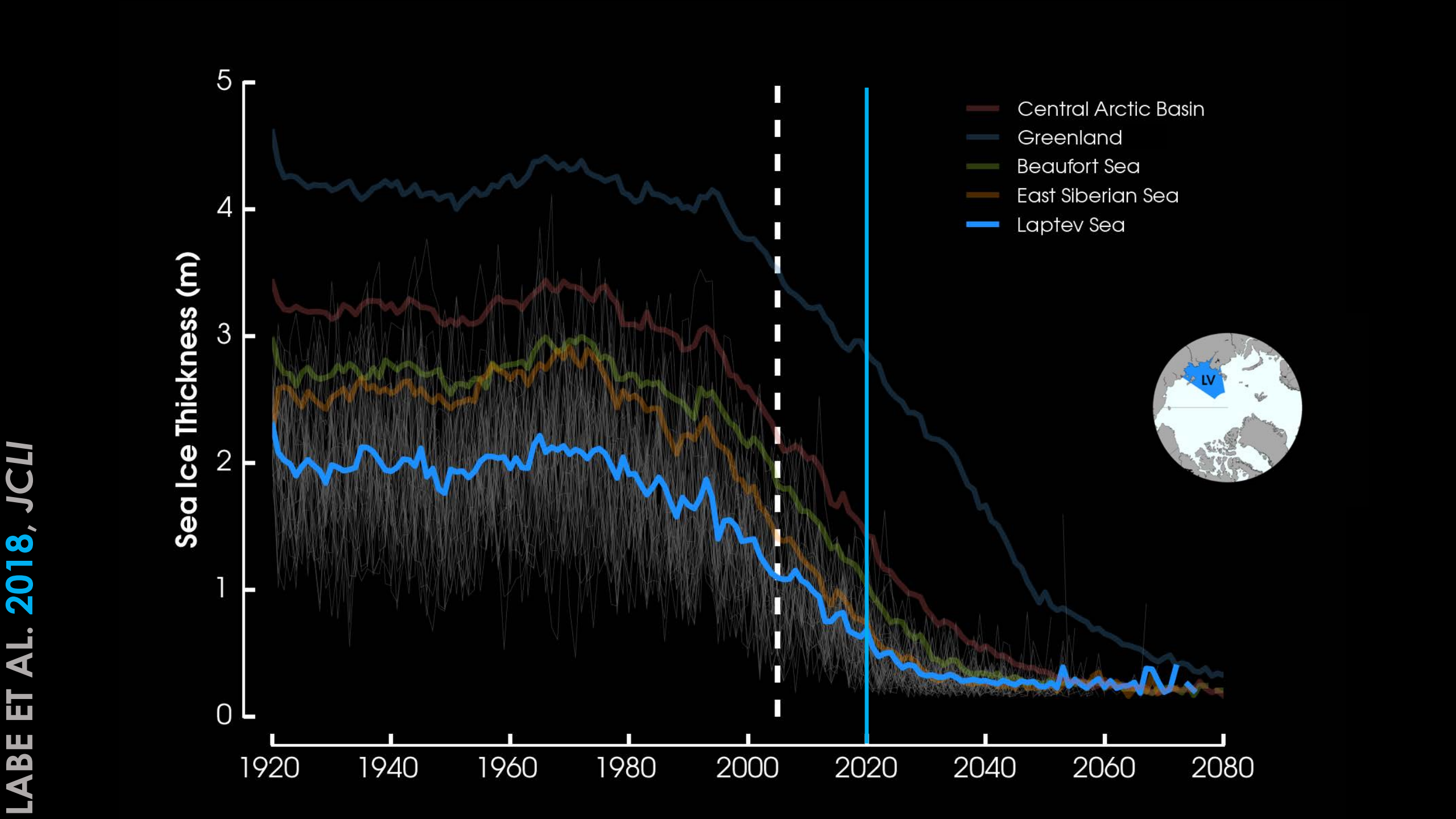
Climate model projection of summer sea ice through 2100

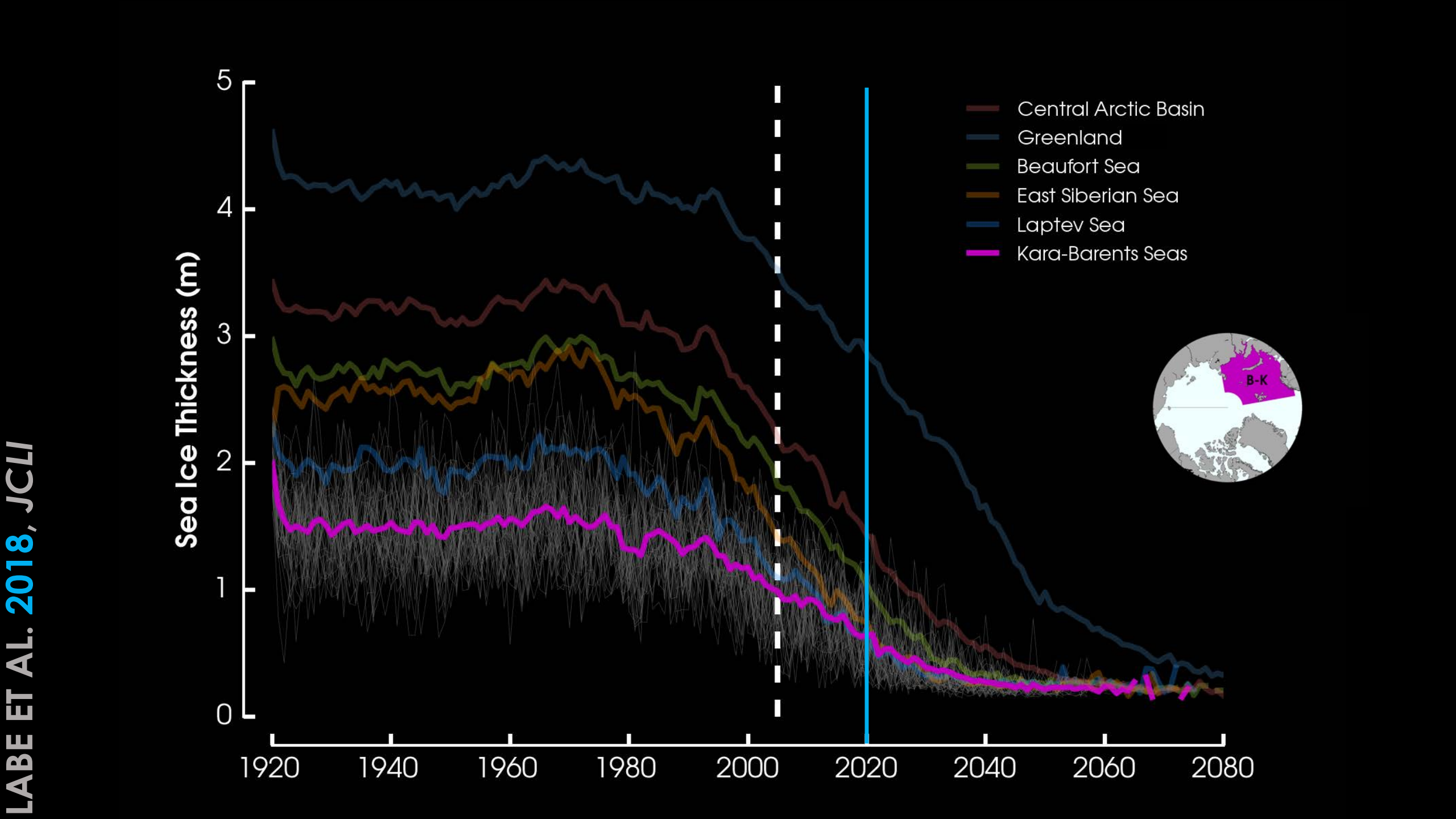

Central Arctic Basin
Sea Ice Thickness (m)
0
1
2
3
4
5
1920
1940
1960
1980
2000
2020
2040
2060
2080
CAB
LABE ET AL. 2018, JCLI


Central Arctic Basin
Greenland
Sea Ice Thickness (m)
0
1
2
3
4
5
1920
1940
1960
1980
2000
2020
2040
2060
2080
GD
LABE ET AL. 2018, JCLI


Central Arctic Basin
Greenland
Beaufort Sea
Sea Ice Thickness (m)
0
1
2
3
4
5
1920
1940
1960
1980
2000
2020
2040
2060
2080
B-C
LABE ET AL. 2018, JCLI

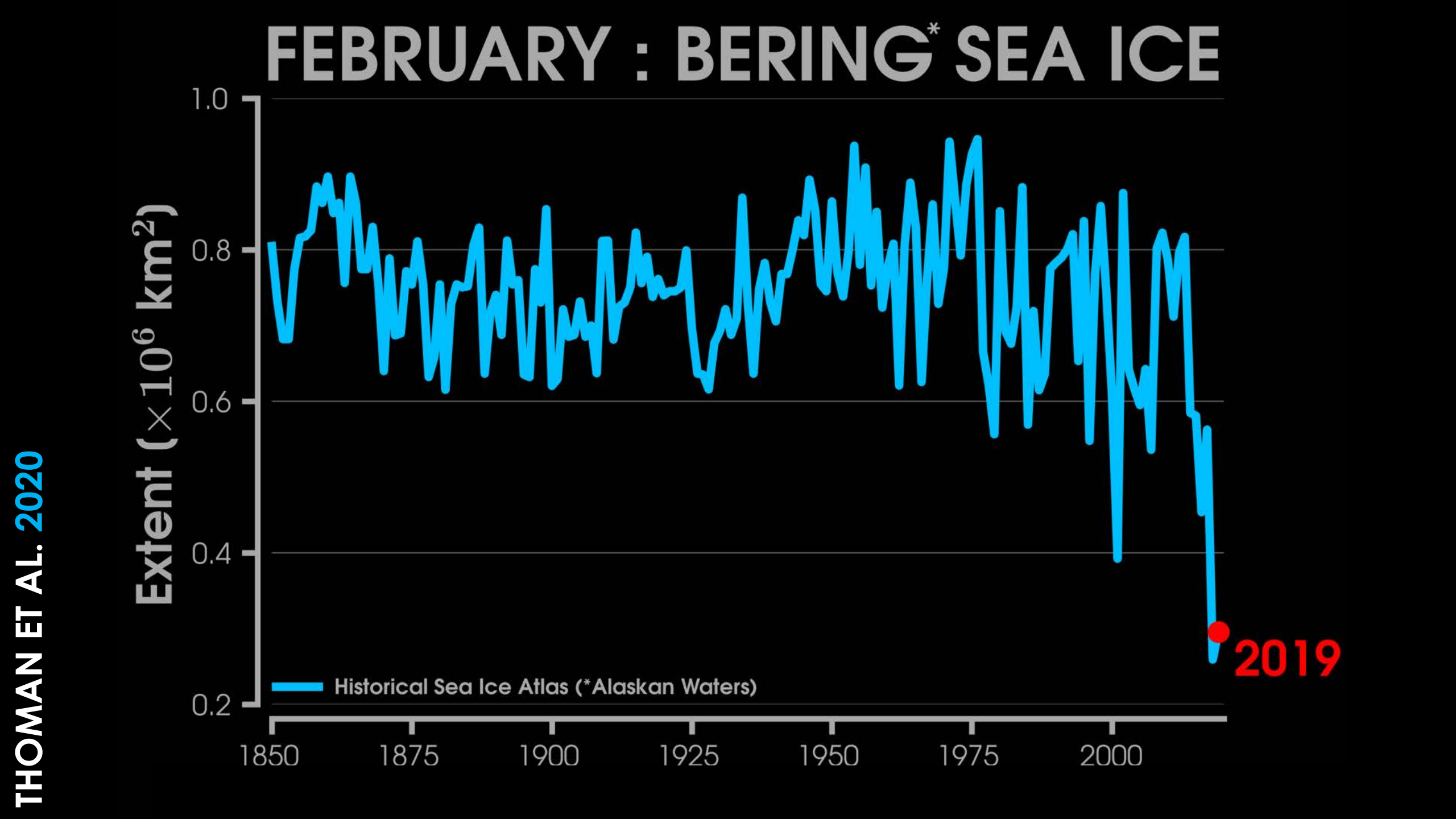

Sea Ice Thickness (m)
0
1
2
3
4
5
1920
1940
1960
1980
2000
2020
2040
2060
2080
Central Arctic Basin
Greenland
Beaufort Sea
East Siberian Sea
ESS
LABE ET AL. 2018, JCLI

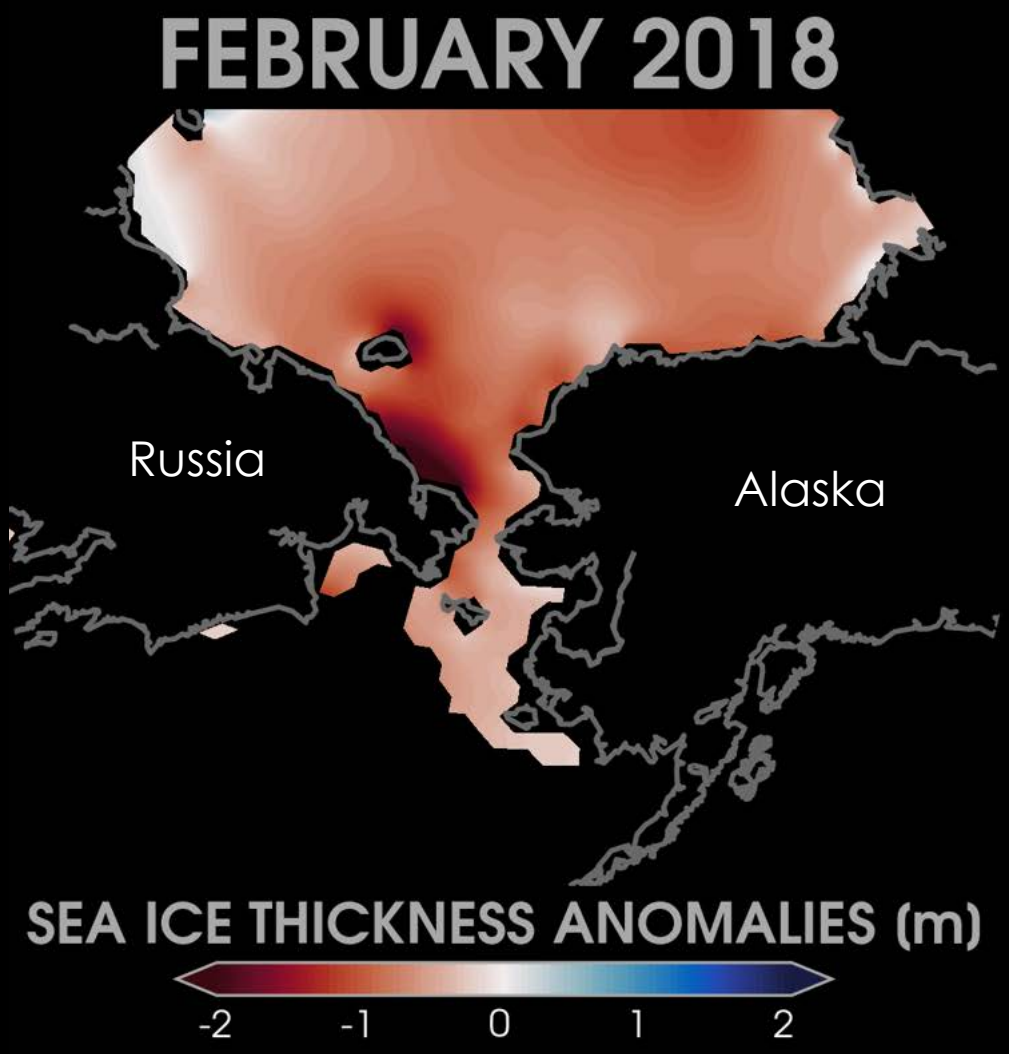

Sea Ice Thickness (m)
0
1
2
3
4
5
1920
1940
1960
1980
2000
2020
2040
2060
2080
Central Arctic Basin
Greenland
Beaufort Sea
East Siberian Sea
Laptev Sea
LV
LABE ET AL. 2018, JCLI



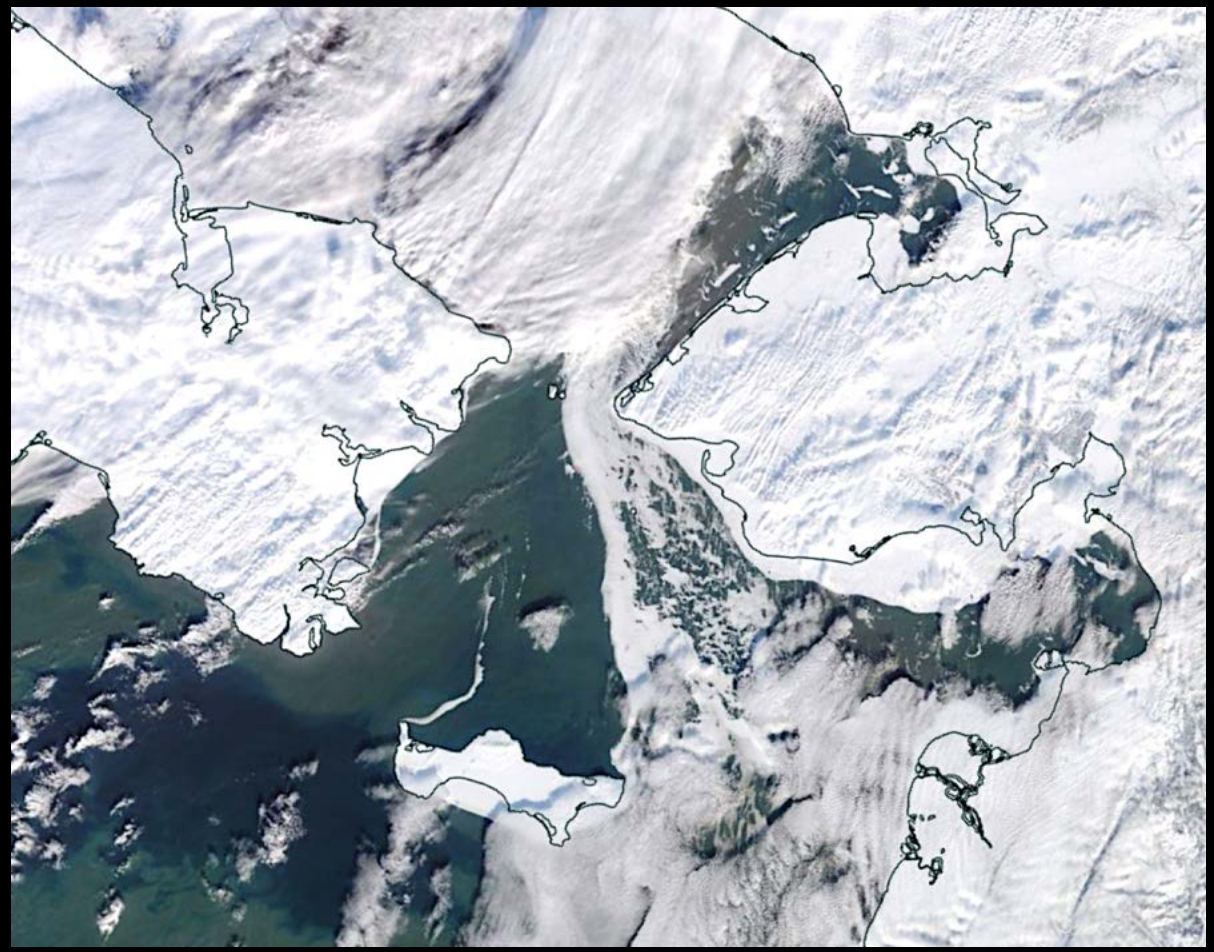
LABE ET AL. 2018, *JCLI*


Regional impacts.


FEBRUARY : BERING* SEA ICE
Extent (×10^6 km^2)
1.0
0.8
0.6
0.4
0.2
1850
1875
1900
1925
1950
1975
2000
2019
Historical Sea Ice Atlas (*Alaskan Waters)
THOMAN ET AL. 2020



MODIS (Terra) Satellite on 20 February 2018



RUSSIA'S ARCTIC OBSESSION

As global warming melts Arctic ice, Moscow hopes to resurrect the historic Northern Sea Route between Europe and Asia. But the challenges — and the costs — are immense. For a special FT feature and film, *Kathrin Hille* reports from one of the world's most inhospitable places. Photographs by *Davide Monteleone*

ON MELTING ICE

INUIT STRUGGLE AGAINST OIL AND GAS IN THE ARCTIC

Your carbon footprint destroys 30 square metres of Arctic sea ice a year

New research calculates the impact of the average westerner's carbon emissions to help people understand their own contribution to climate change

Arctic Ocean shipping routes 'to open for months'

By Jonathan Amos
BBC Science Correspondent

New research calculates the impact of the average west
to help people understand their own contribution to climate change

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Route
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INUIT STRUGG

avide Monteleone

Arctic Ocean shipping ro
months'

By Jonathan Amos
BBC Science C

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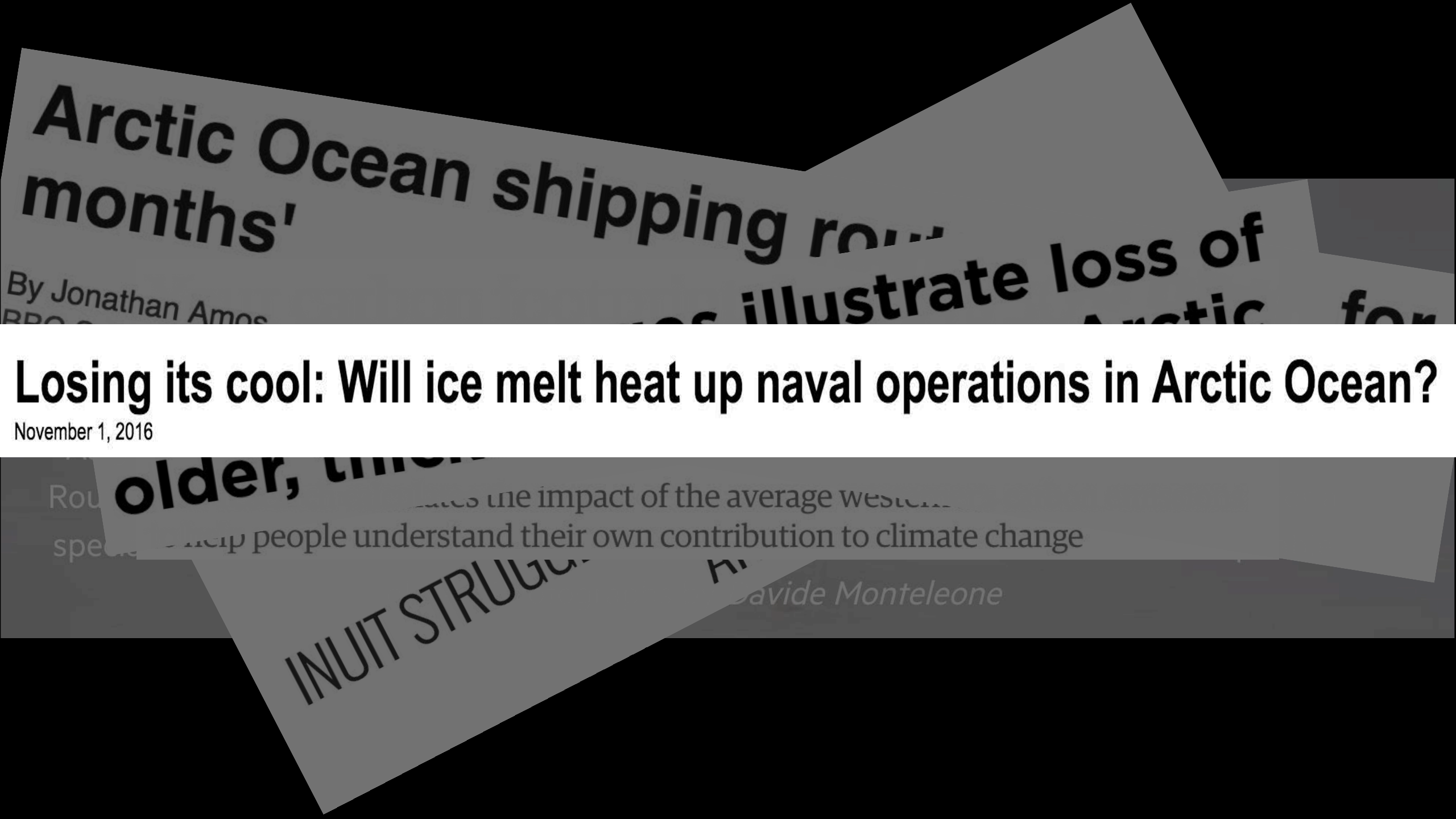
Time-lapse images illustrate loss of older, thicker ice in warming Arctic

ates the impact of the average weste
help people understand their own contribution to climate change

Davide Monteleone



Losing its cool: Will ice melt heat up naval operations in Arctic Ocean?

November 1, 2016

Arctic Ocean shipping ro... months'

By Jonathan Amos

...s illustrate loss of Arctic for

Losing its cool: Will ice melt heat up naval operations in Arctic Ocean?

November 1, 2016

Energy and Environment

Climate change is turning into a race between politics and physics


Arctic Ocean shipping ro
months'
By Jonathan Amos
illustrate loss of
Arctic's Melting Permafrost Problem Is Slowly Destroying Russian Cities
Energy and Environment
Climate change is turning into a race between politics and physics


Arctic Ocean shipping
months'
By Jonathan Amos
Arctic's Melting
Russian Cities
Energy and Environ
Climat
a race
between politics and physics
ALEC LUHN SCIENCE 10.20.16 7:00 AM
ARCTIC CITIES CRUMBLE AS CLIMATE CHANGE THAWS PERMAFROST

Changing Sea Ice Thickness

MELIA ET AL., 2016

"Sea ice Decline and 21st century trans-Arctic shipping routes"

POST ET AL., 2013

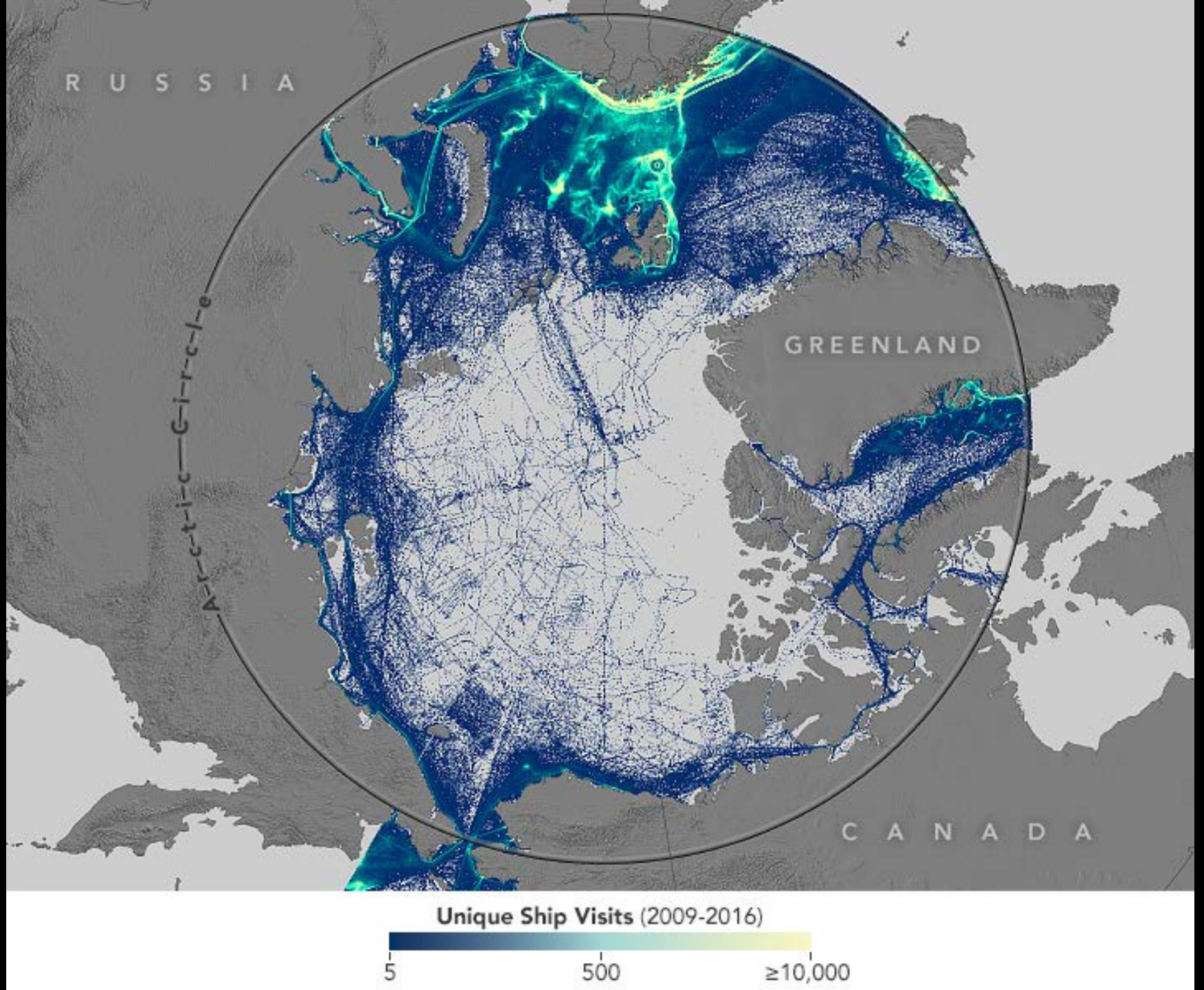
"Ecological consequences of sea-ice decline"

PIZZOLATO ET AL., 2016

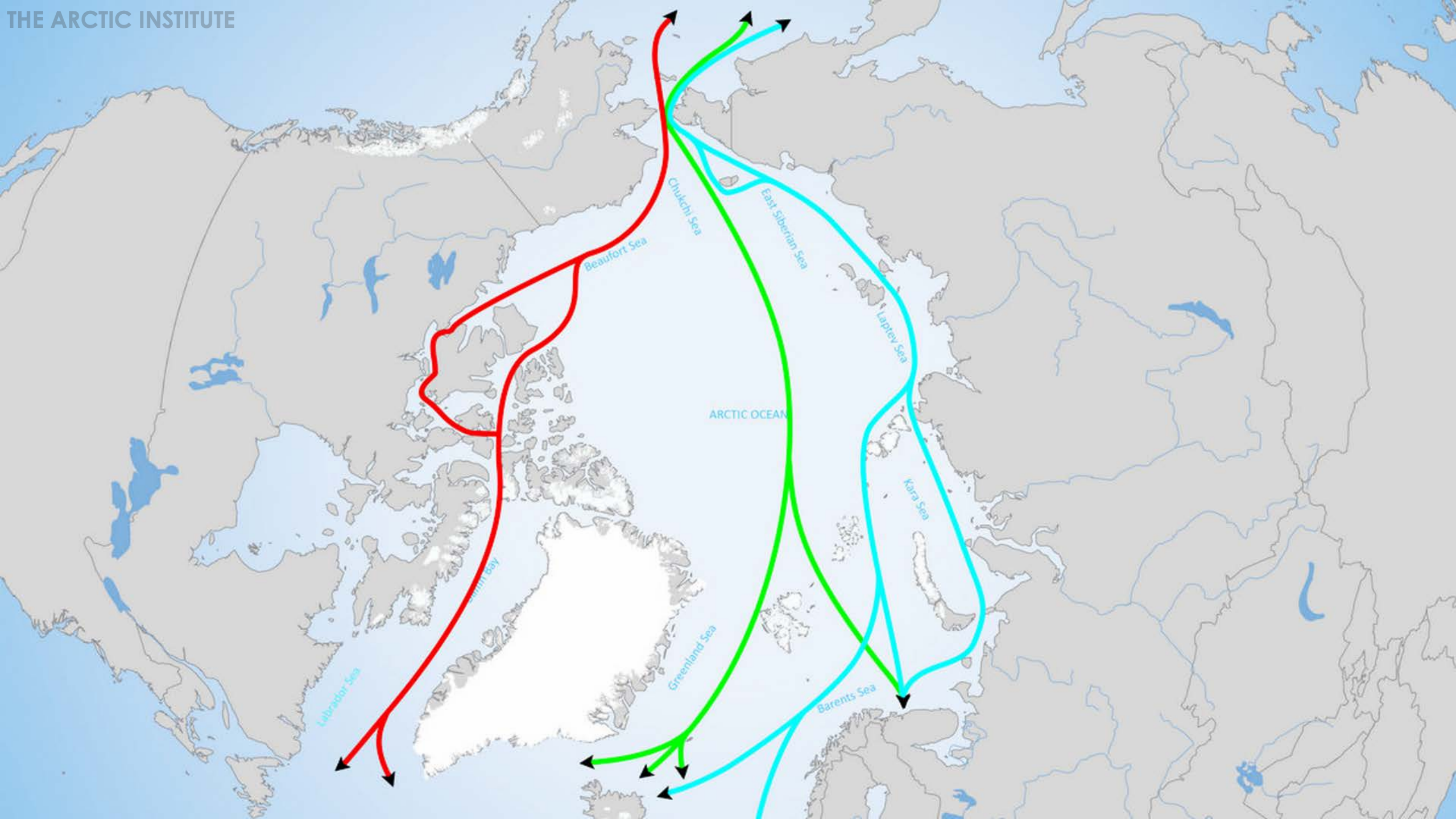
"The influence of declining sea ice on shipping activity in the Canadian Arctic"

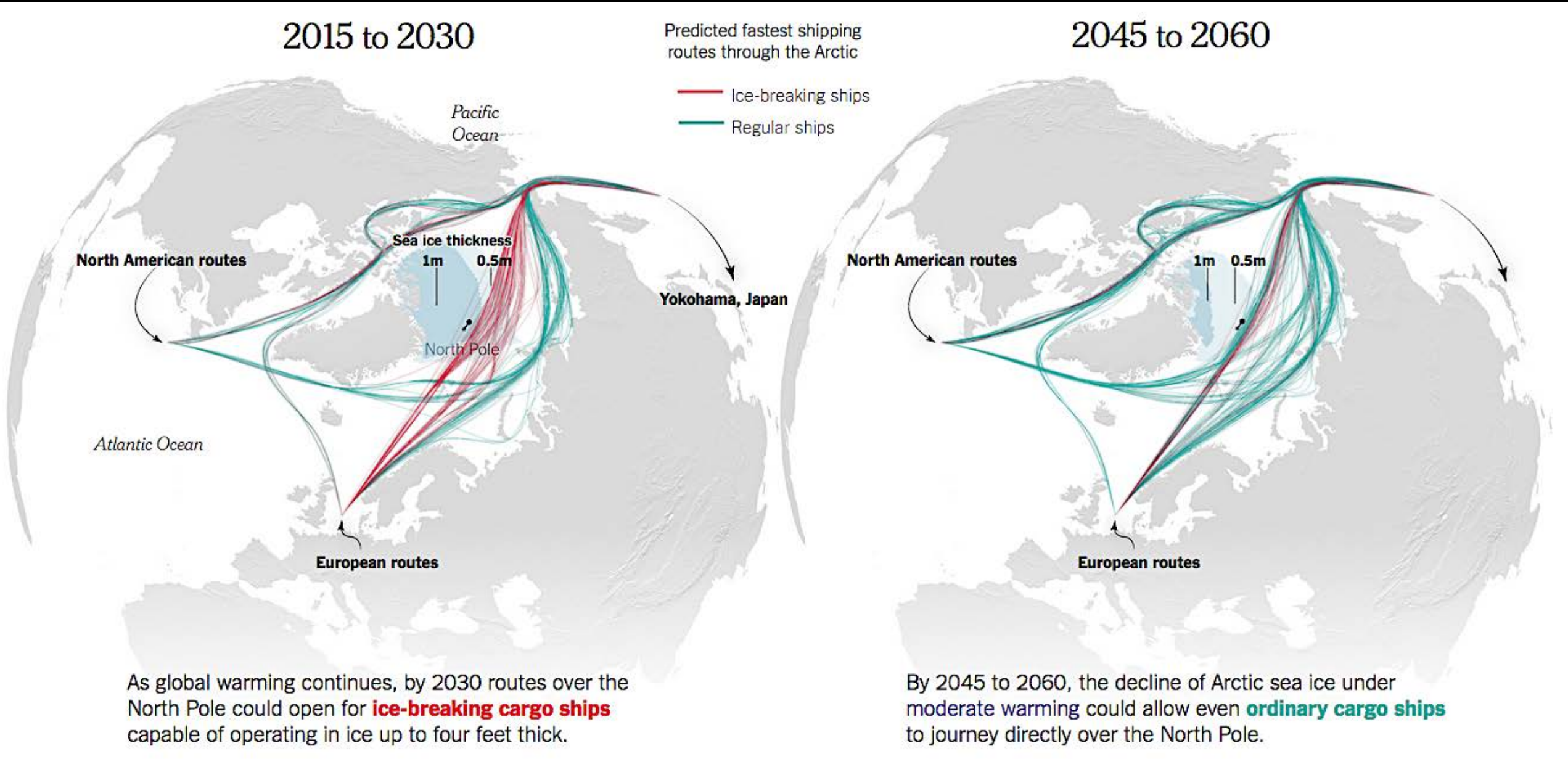
LANG ET AL., 2016

"Sea ice thickness and recent Arctic warming"



Visualization by Paul Arthur Berkman and Greg Fiske

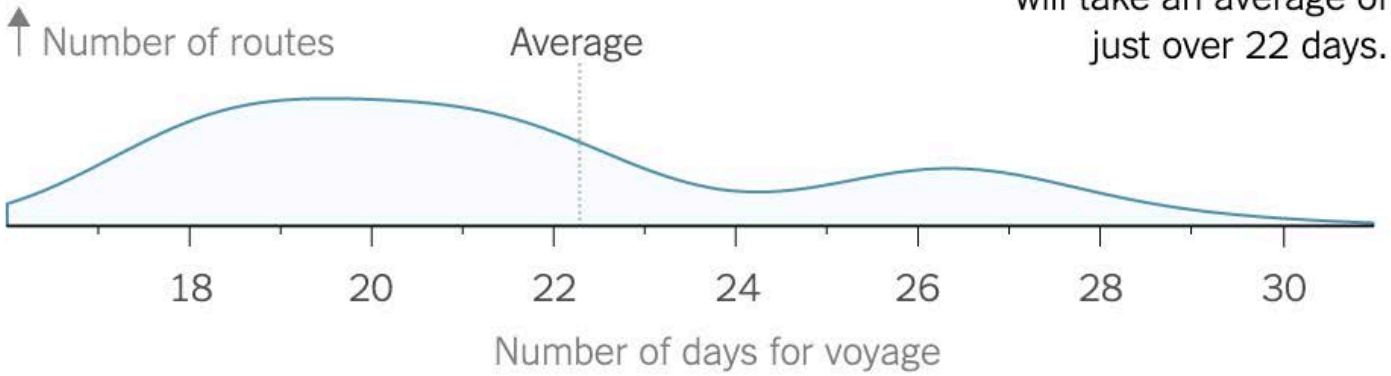

Chukchi Sea
East Siberian Sea
Beaufort Sea
Laptev Sea
ARCTIC OCEAN
Kara Sea
Baffin Bay
Greenland Sea
Barents Sea
Labrador Sea



Visualization by The New York Times

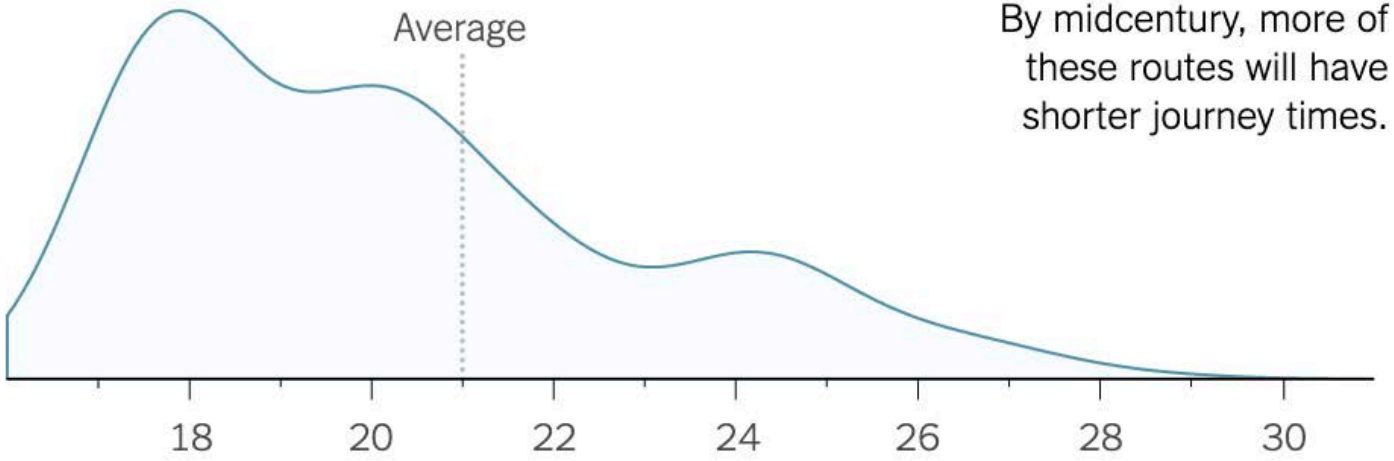
2015 to 2030

Through 2030, routes connecting North America and Europe with Japan will take an average of just over 22 days.



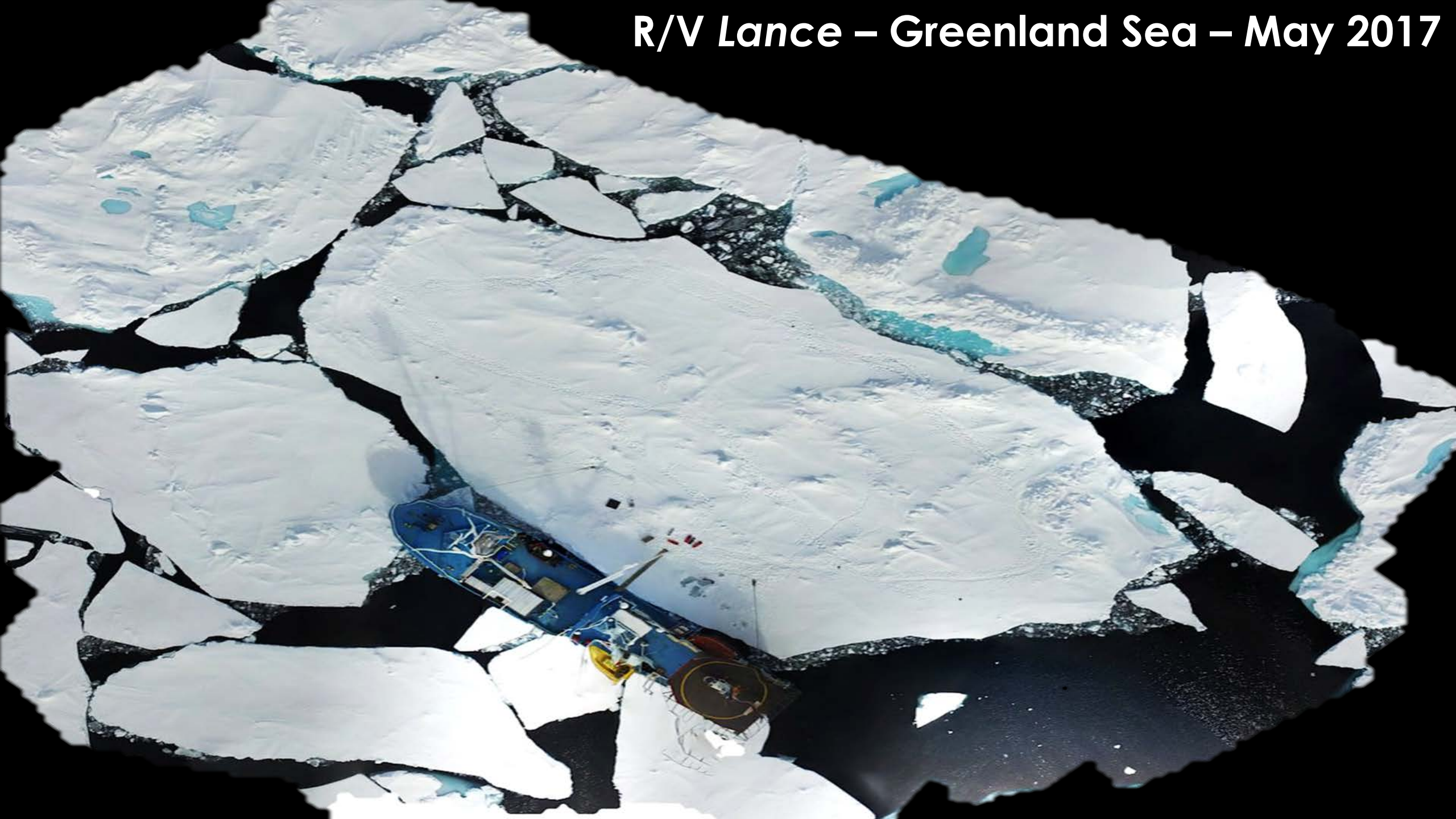
2045 to 2060

By midcentury, more of these routes will have shorter journey times.

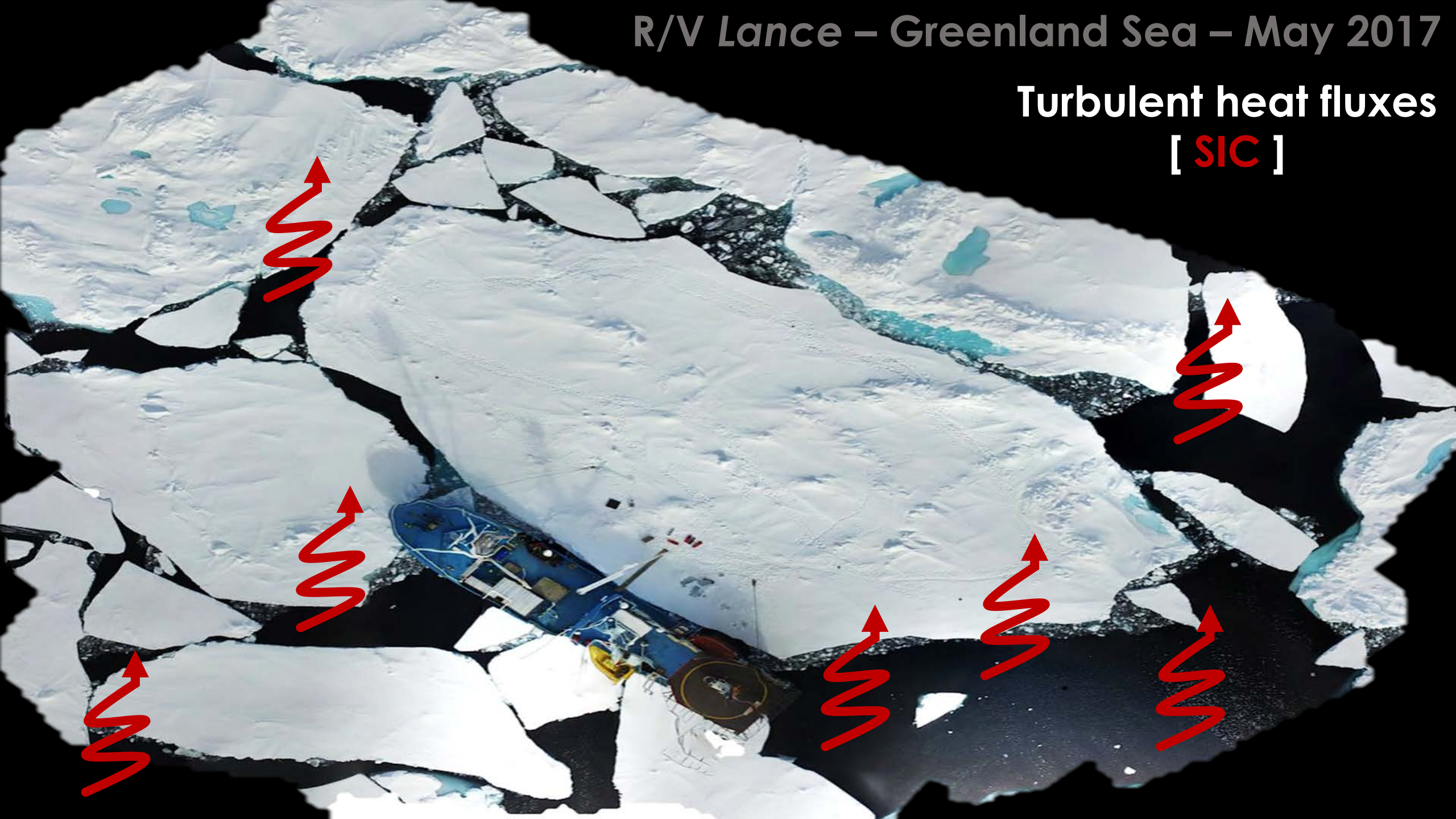


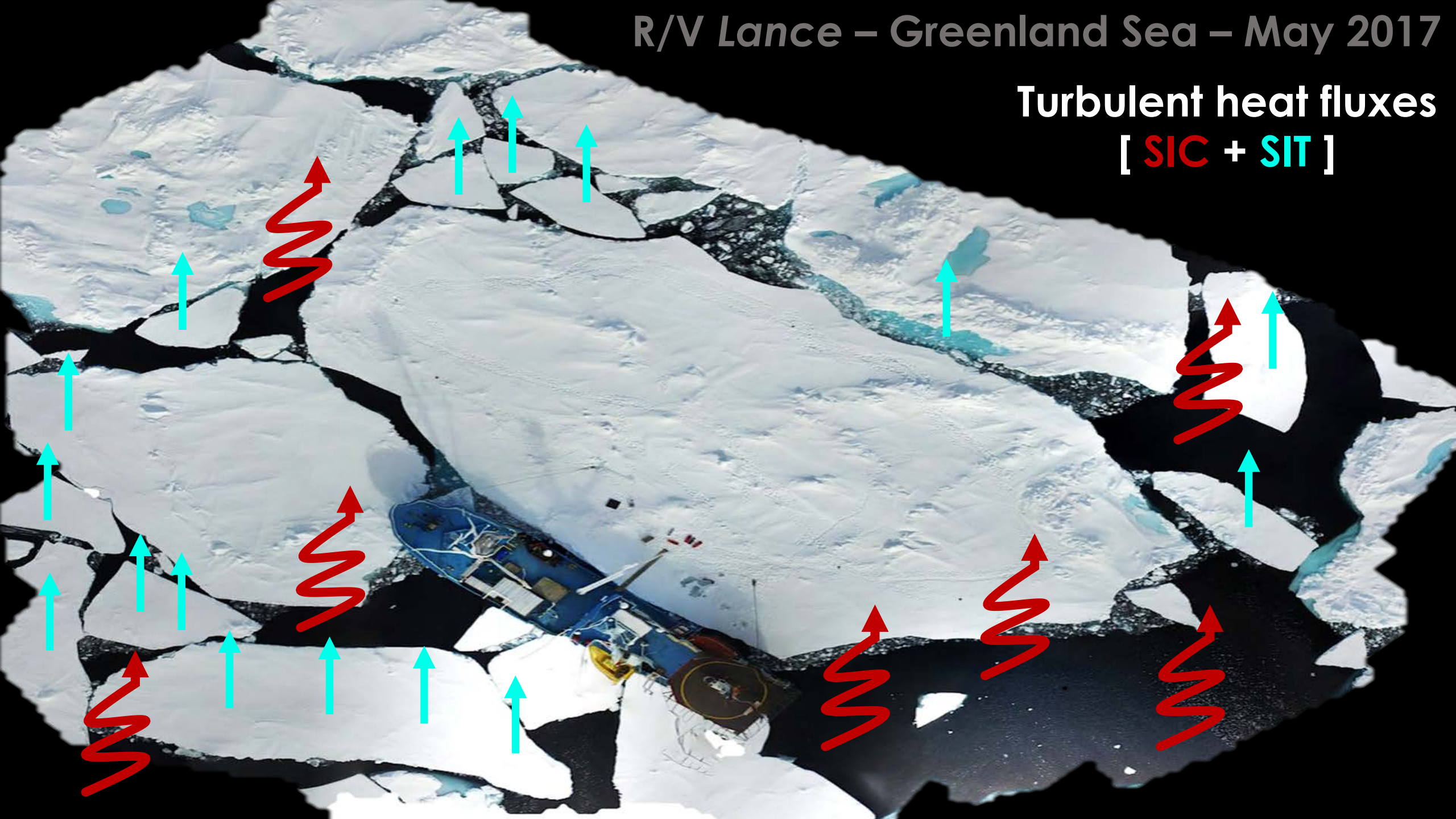
Visualization by The New York Times

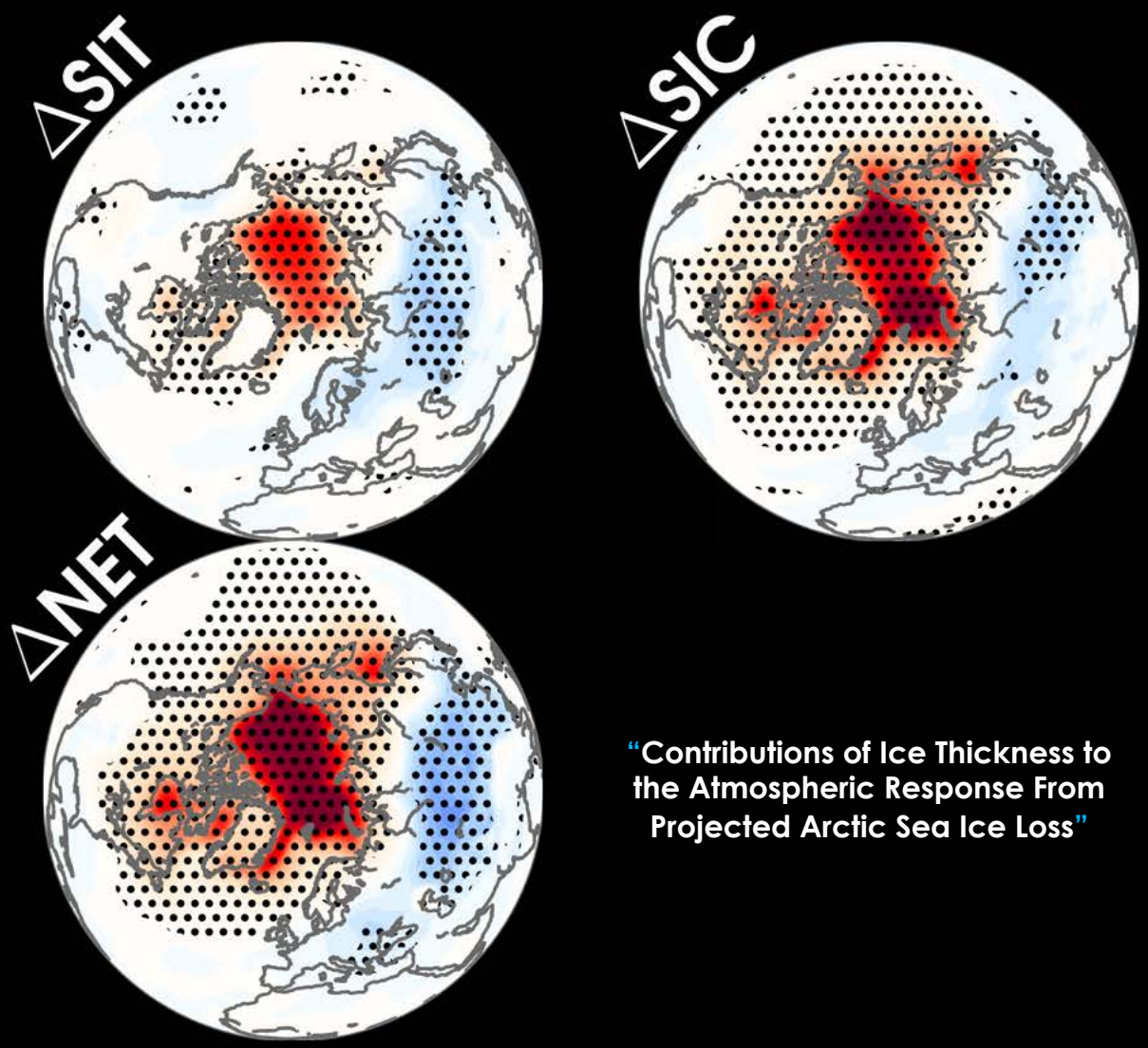

Changes to
weather.



R/V *Lance* – Greenland Sea – May 2017


R/V *Lance* – Greenland Sea – May 2017
Turbulent heat fluxes
[SIC]


R/V Lance – Greenland Sea – May 2017
Turbulent heat fluxes
[SIC + SIT]



"Contributions of Ice Thickness to the Atmospheric Response From Projected Arctic Sea Ice Loss"

Future Arctic

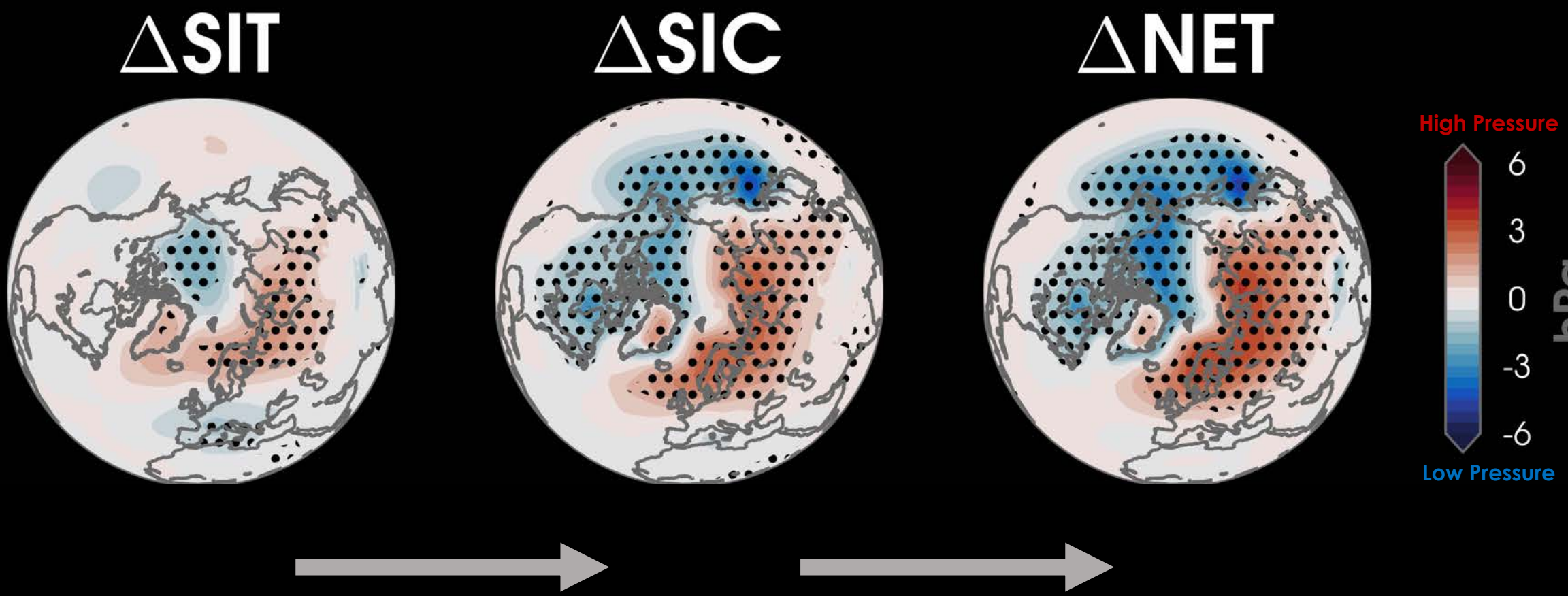
How does sea-ice thickness decline influence the large-scale atmospheric response?

Significant warming response over Arctic Ocean

Weakening of jet stream

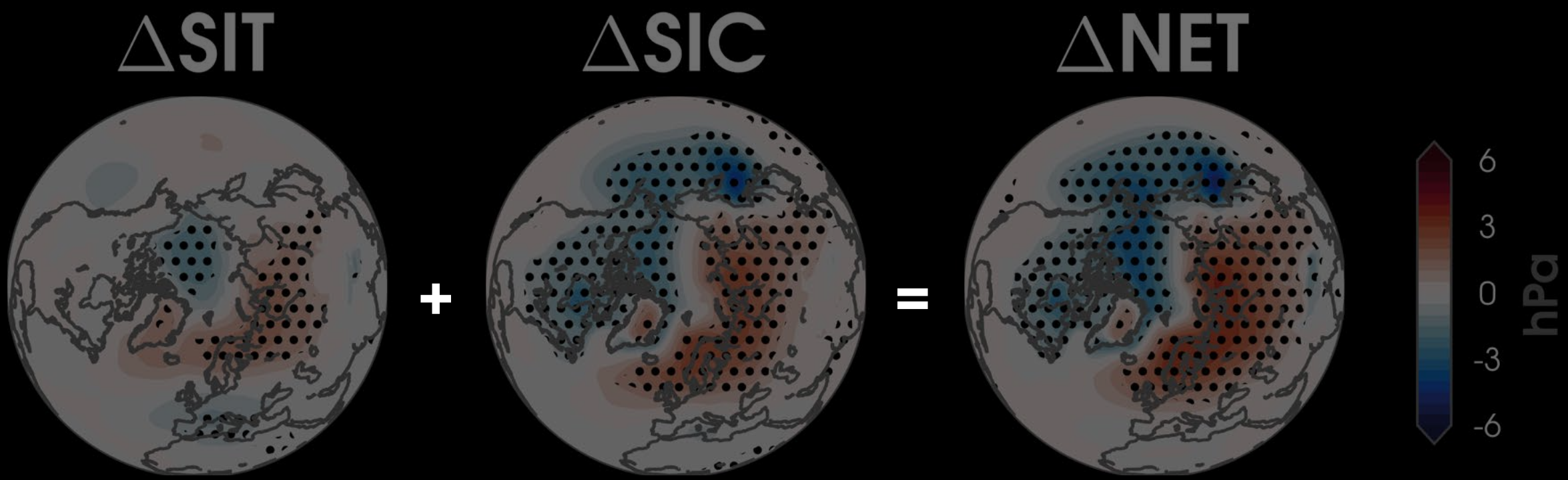
LABE ET AL. 2018, *GRL*

Sea Level Pressure (SLP)



LABE ET AL. 2018, *GRL*

Sea Level Pressure (SLP)

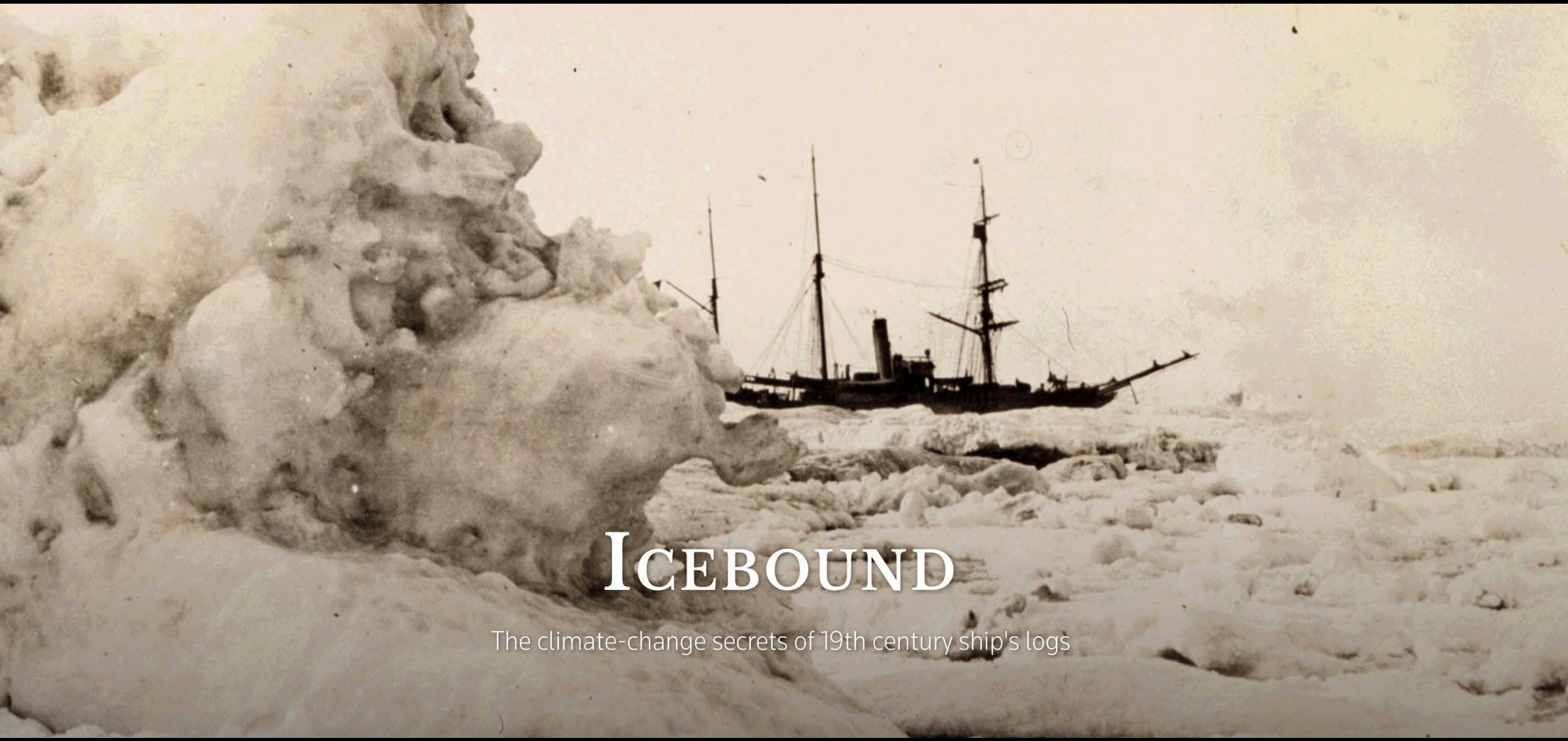


Loss of sea-ice thickness reinforces large-scale atmospheric response

LABE ET AL. 2018, *GRL*


Longer records.

https://www.reuters.com/investigates/special-report/climate-change-ice-shiplogs/



"The Bear spent its most illustrious years in the treacherous waters of the Arctic in the U.S. Revenue Cutter Service. Photo courtesy of the Alaska and Polar Regions Collections, Elmer E. Rasmuson Library, University of Alaska Fairbanks."

https://www.oldweather.org/

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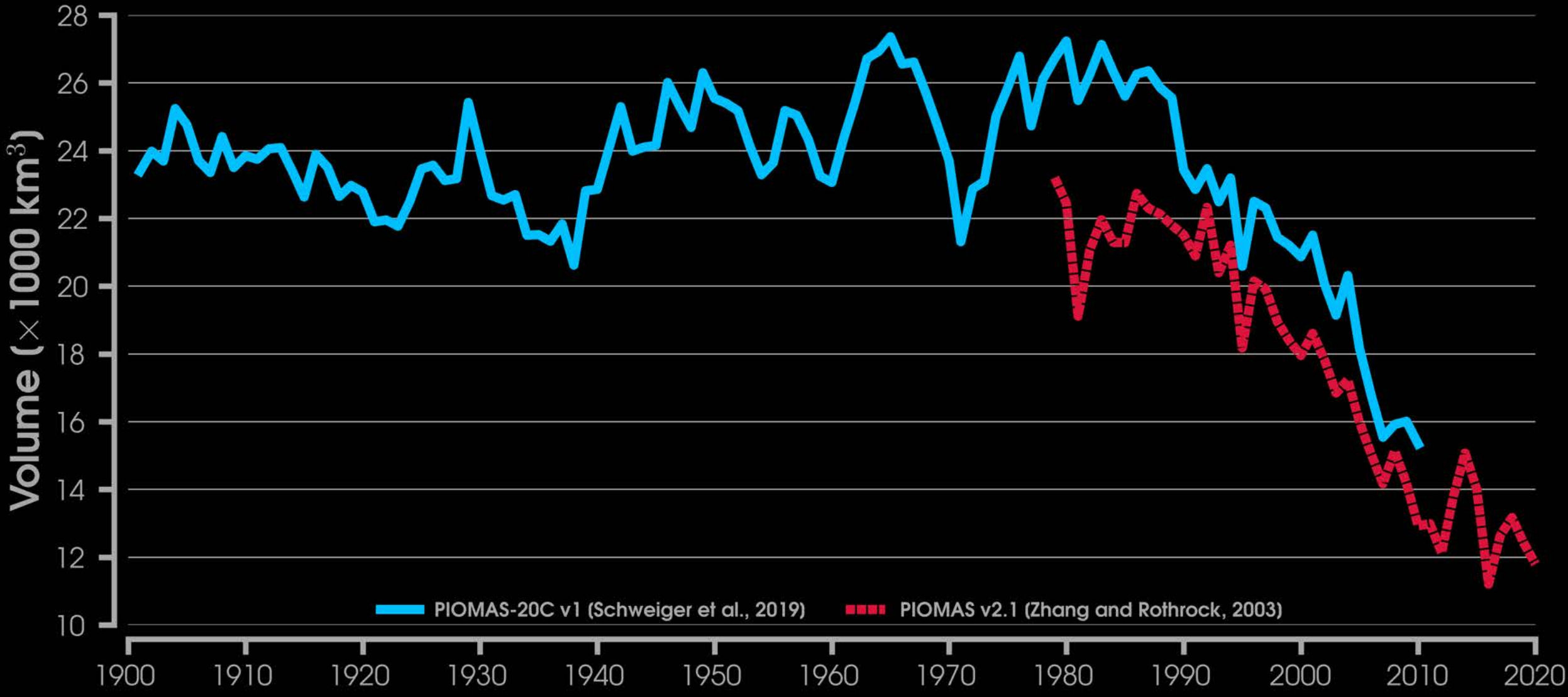
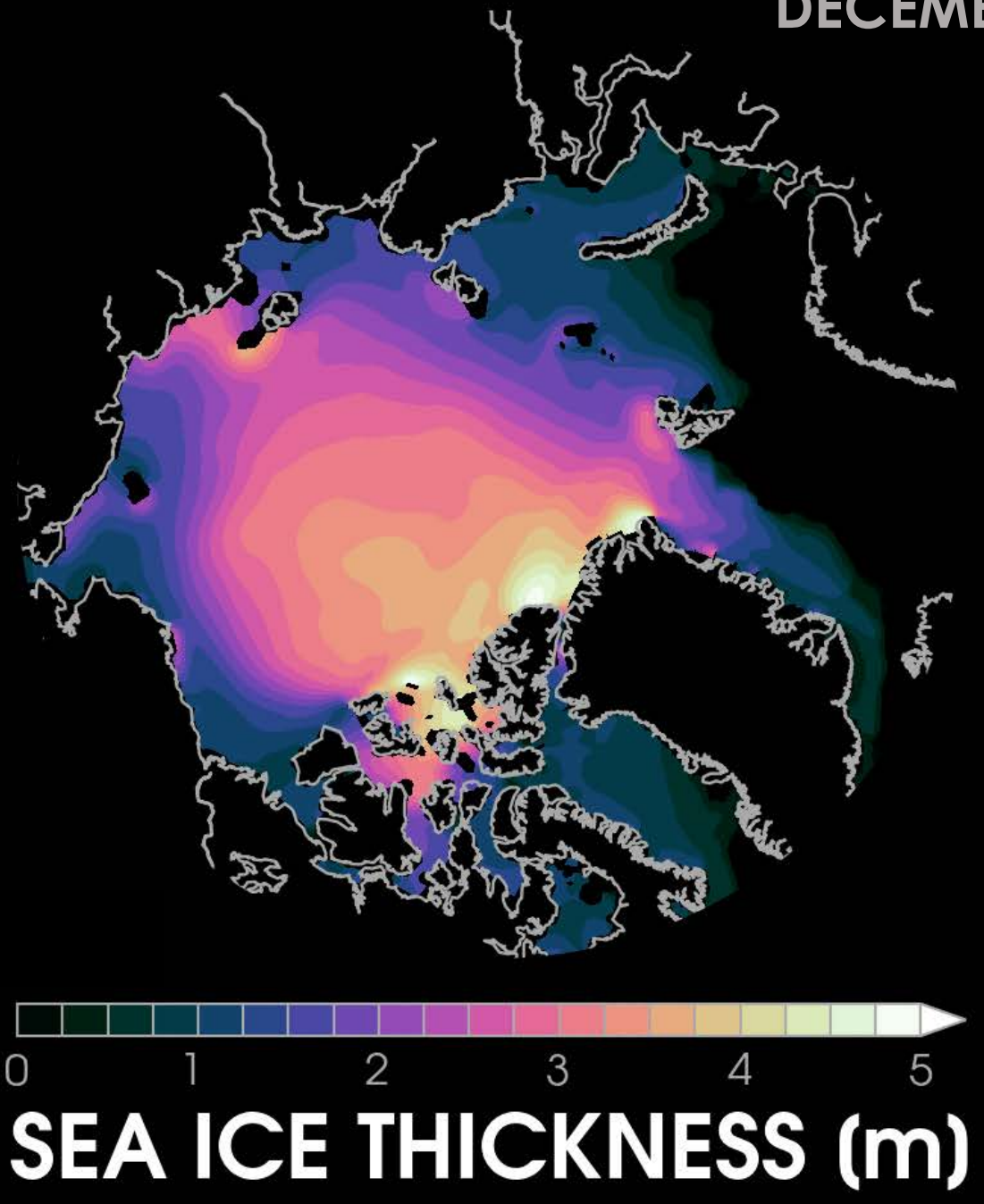
DECEMBER – ARCTIC SEA ICE

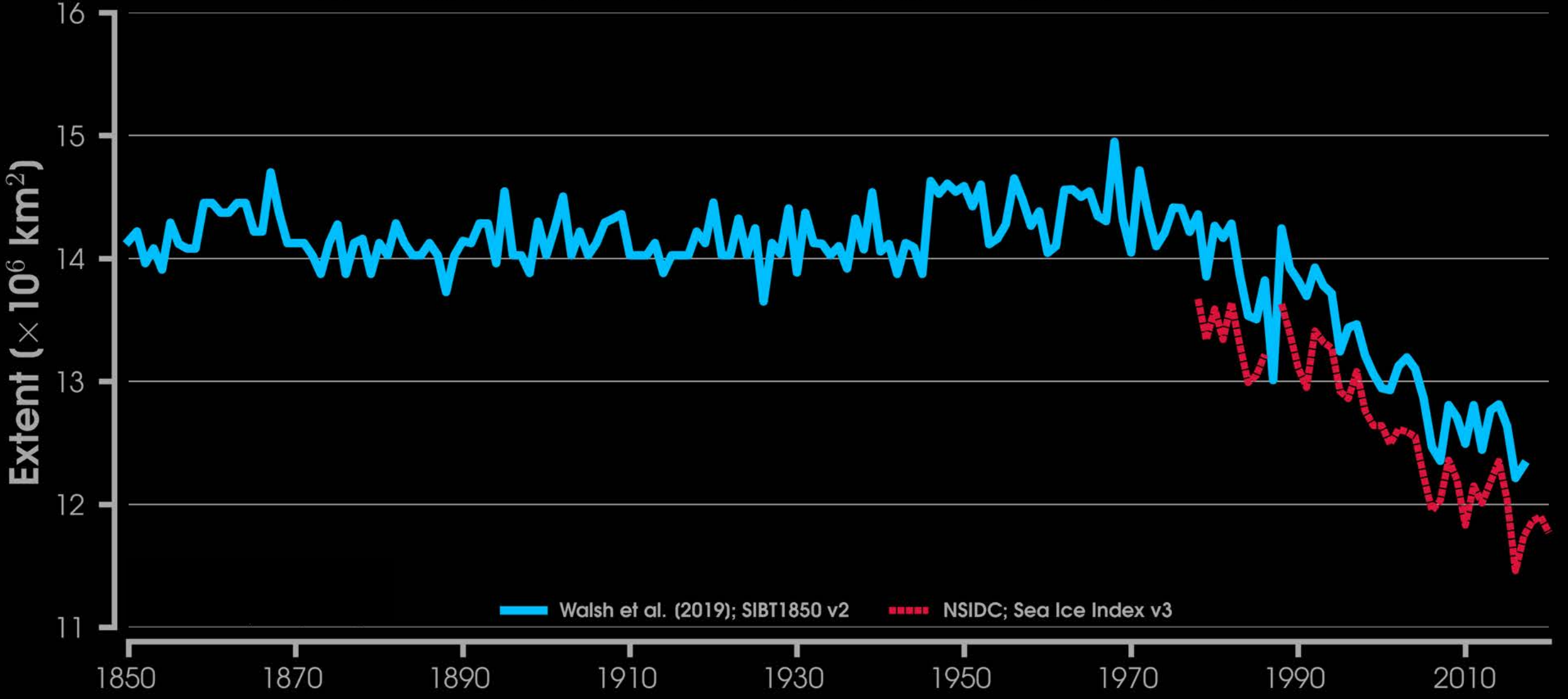


1901

DECEMBER – PIOMAS-20C



DECEMBER – ARCTIC SEA ICE



Large regional and internal variability of sea-ice thickness
Need for longer ("consistent") satellite record
Atmosphere sensitive to changes in Arctic sea-ice thickness

Zachary Labe

zmlabe@rams.colostate.edu
@ZLabe

QUESTIONS…

Large regional and internal variability of sea-ice thickness
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Zachary Labe

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