Arctic sea-ice change and potential societal impacts from the large-scale to the local level: A perspective from Alaska

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& collaborators, incl. Matt Druckenmiller, Amy Lovecraft, Don Perovich

- Introduction
- The Arctic sea-ice cover: Observations
- The Arctic sea-ice cover: Predictions
- Societal impacts: An Alaska perspective
- Conclusions

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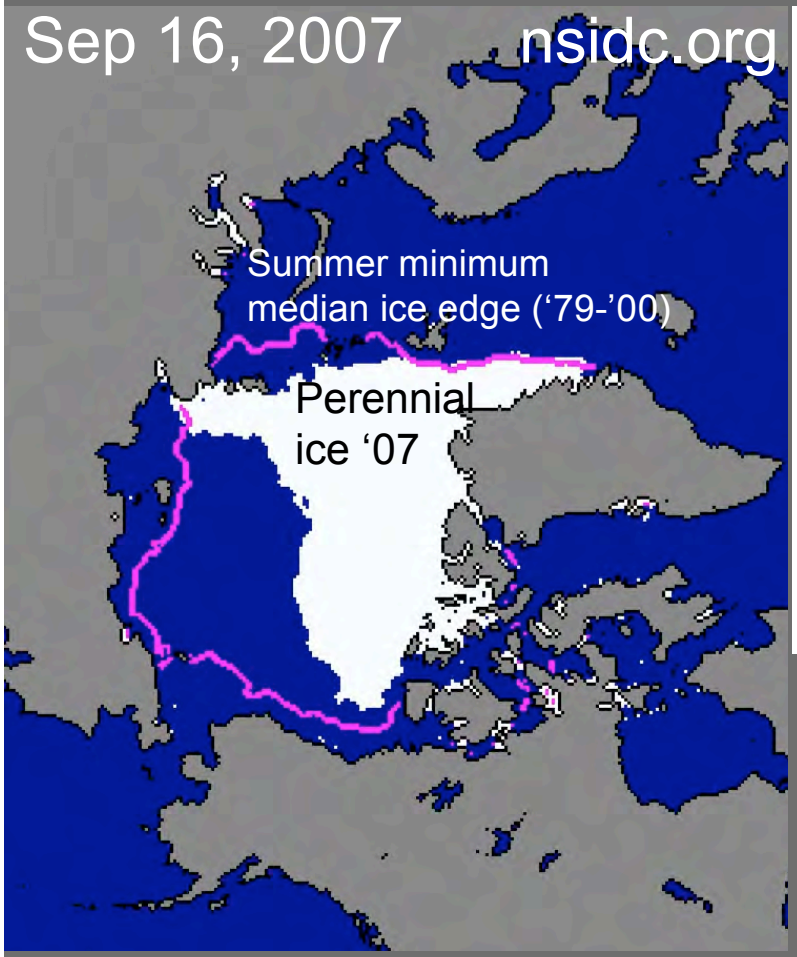
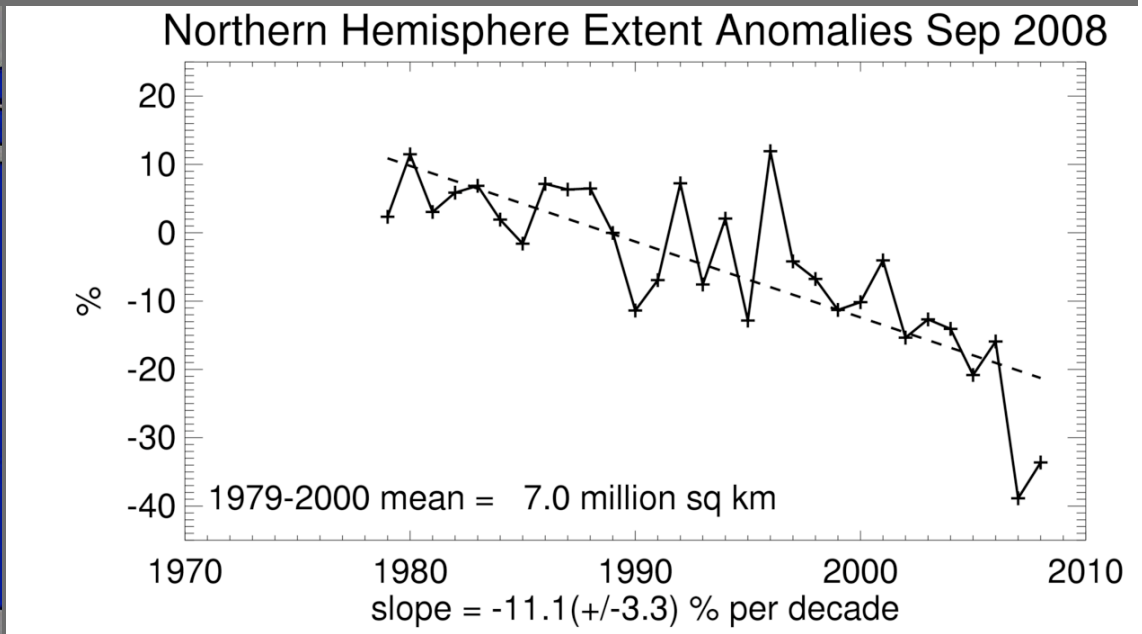
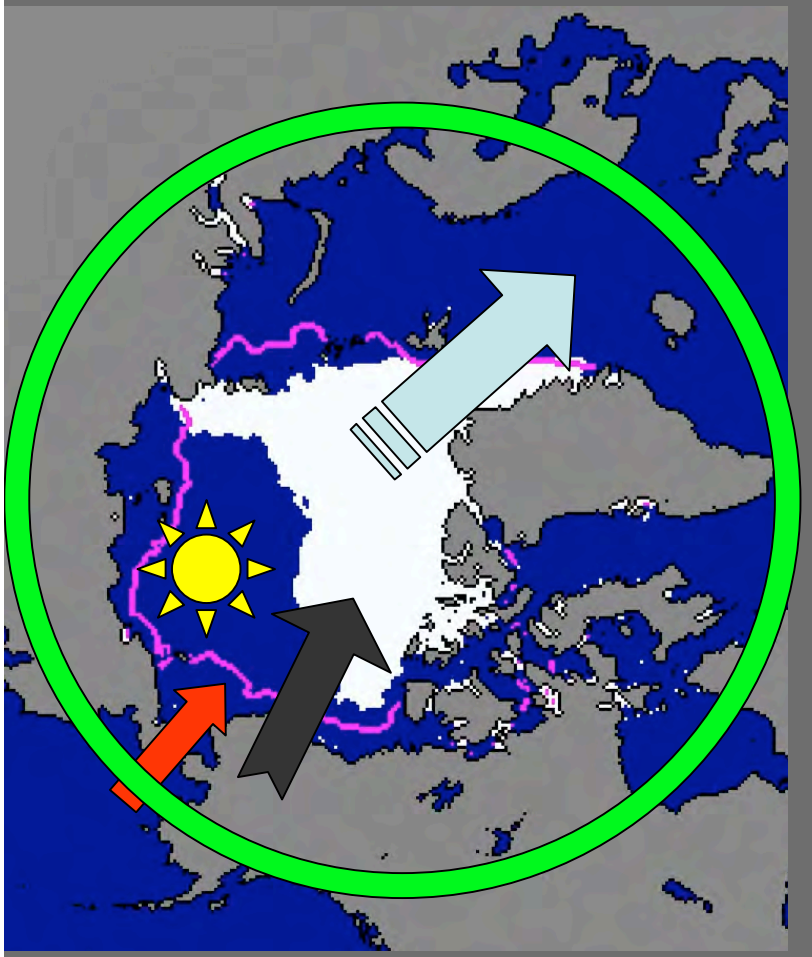
Arctic sea-ice summer extent





- 2007 record sea-ice minimum, almost one quarter less in extent than previous record minimum in 2005
- 2008 also with greatly reduced summer ice extent
- Winter ice extent is decreasing but at much slower rate: More seasonal ice

Explaining the 2007 record minimum Arctic sea-ice summer extent



(1) Unusual weather pattern with persistent southerly winds brought warm air and moved ice towards North Pole in 2007

(2) Longer-term ice thinning in line with Arctic warming driven by impact of greenhouse gases on longwave radiation balance

(3) Thinner, more mobile ice cover more susceptible to episodes of extreme summer retreat

(4) Warming of water north of Alaska as a result of thinned & reduced ice cover melts back ice from below in summer (>2 m of summer bottom melt north of Alaska!); less clouds in 2007

(5) Warm inflow of water through Bering Strait (?)

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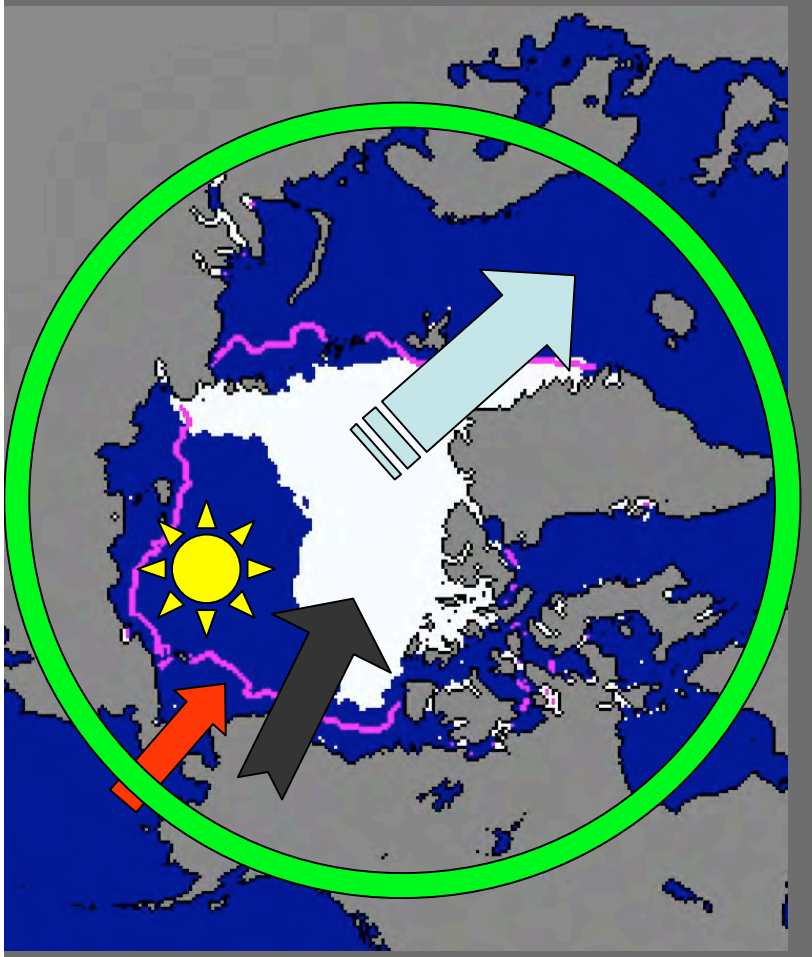

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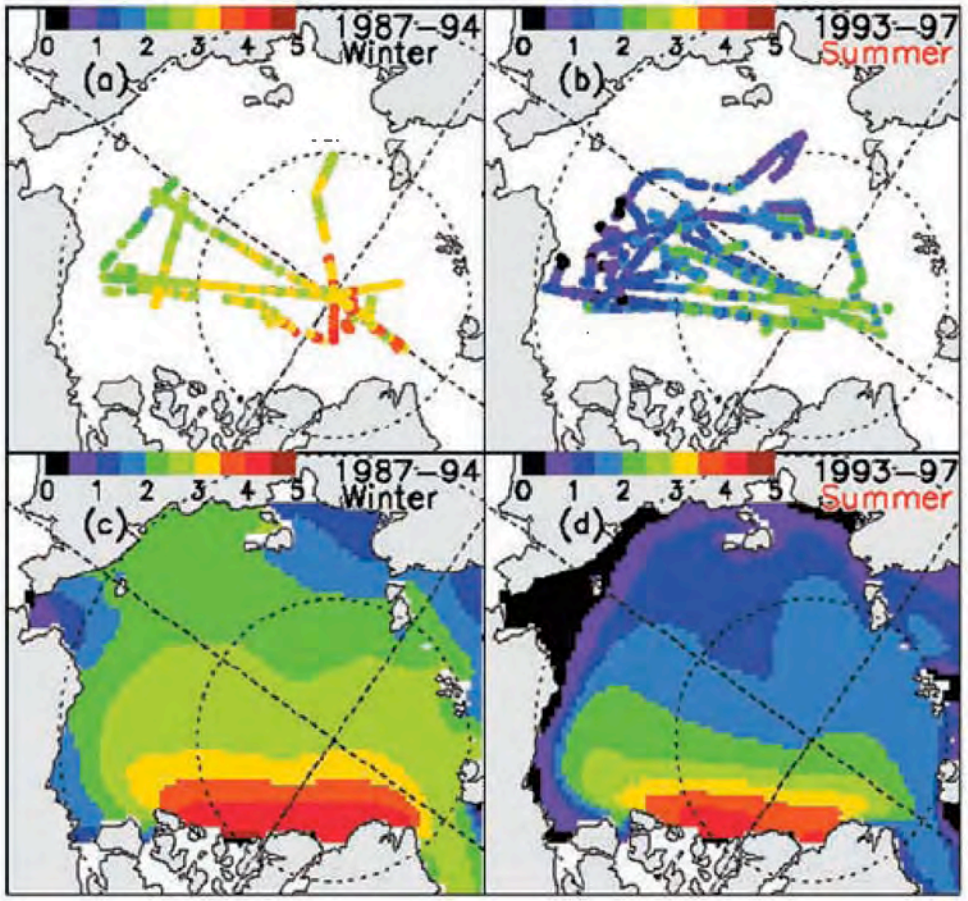


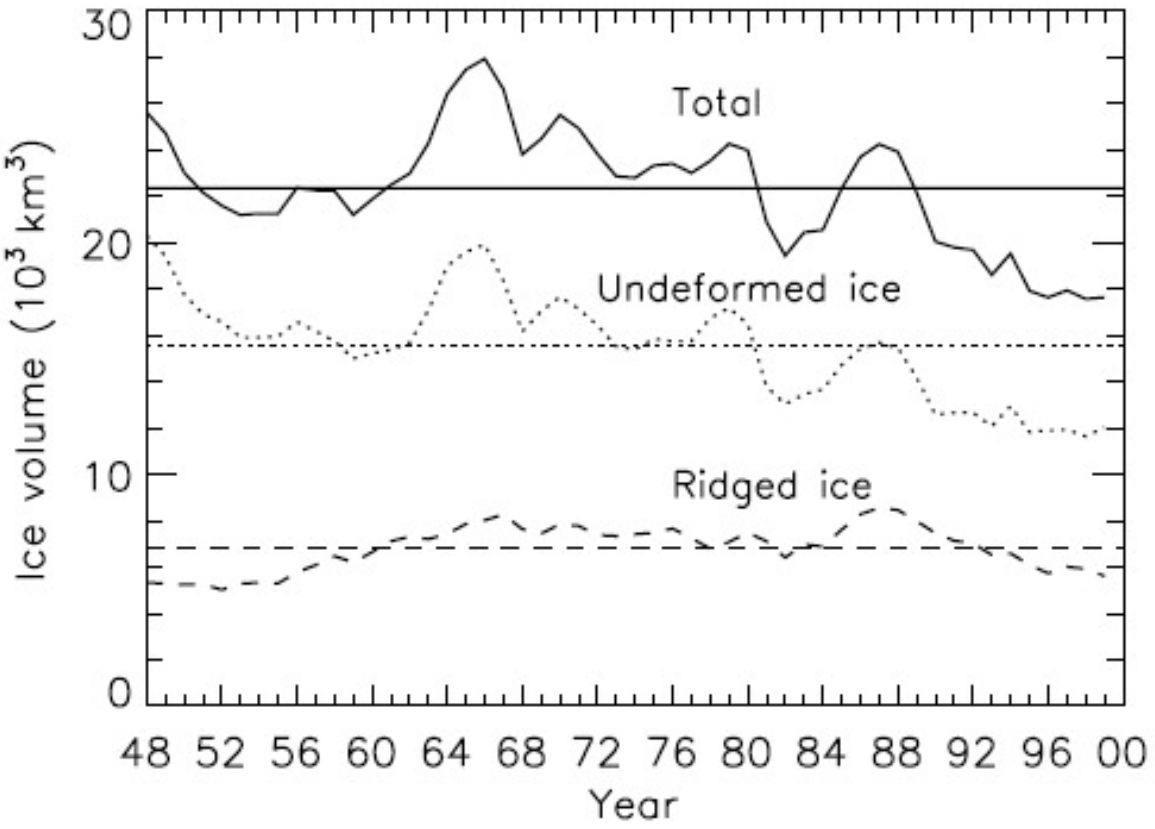
Figure 8. Composite of mean draft for winter (a) and for summer (b) cruise tracks. Model mean draft for period of winter cruises (c) and of summer cruises (d).

Long-term thinning of the Arctic ice cover

- Submarine data indicate 40 % reduction in ice thickness between 1950s and 1990s
- Limited coverage and timing of cruises
- Broader assessment of Arctic sea-ice change through ice-ocean model simulations, assimilating observed ice concentration fields

Rothrock et al., 2003

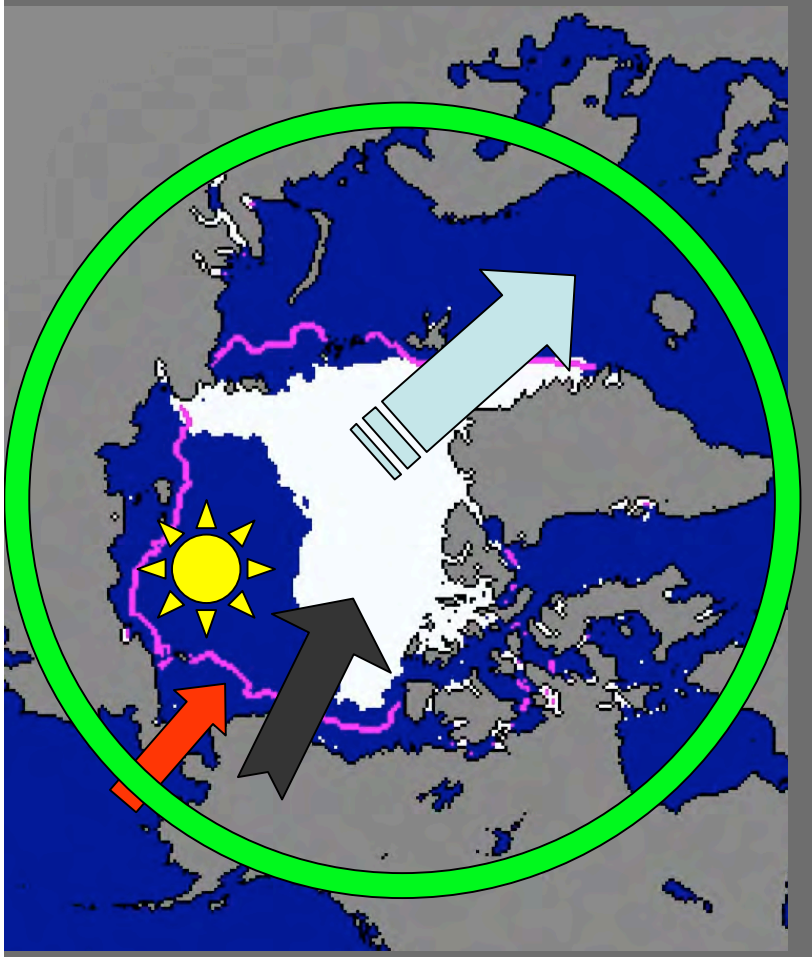
Long-term thinning: Deformed vs. undeformed ice



Rothrock & Zhang, 2005

- Thickness changes over past few decades mostly result of reduction in undeformed ice
- Undeformed ice reduction in turn driven largely by thermal forcing (increased melting/reduced ice growth)

Explaining the 2007 record minimum Arctic sea-ice summer extent



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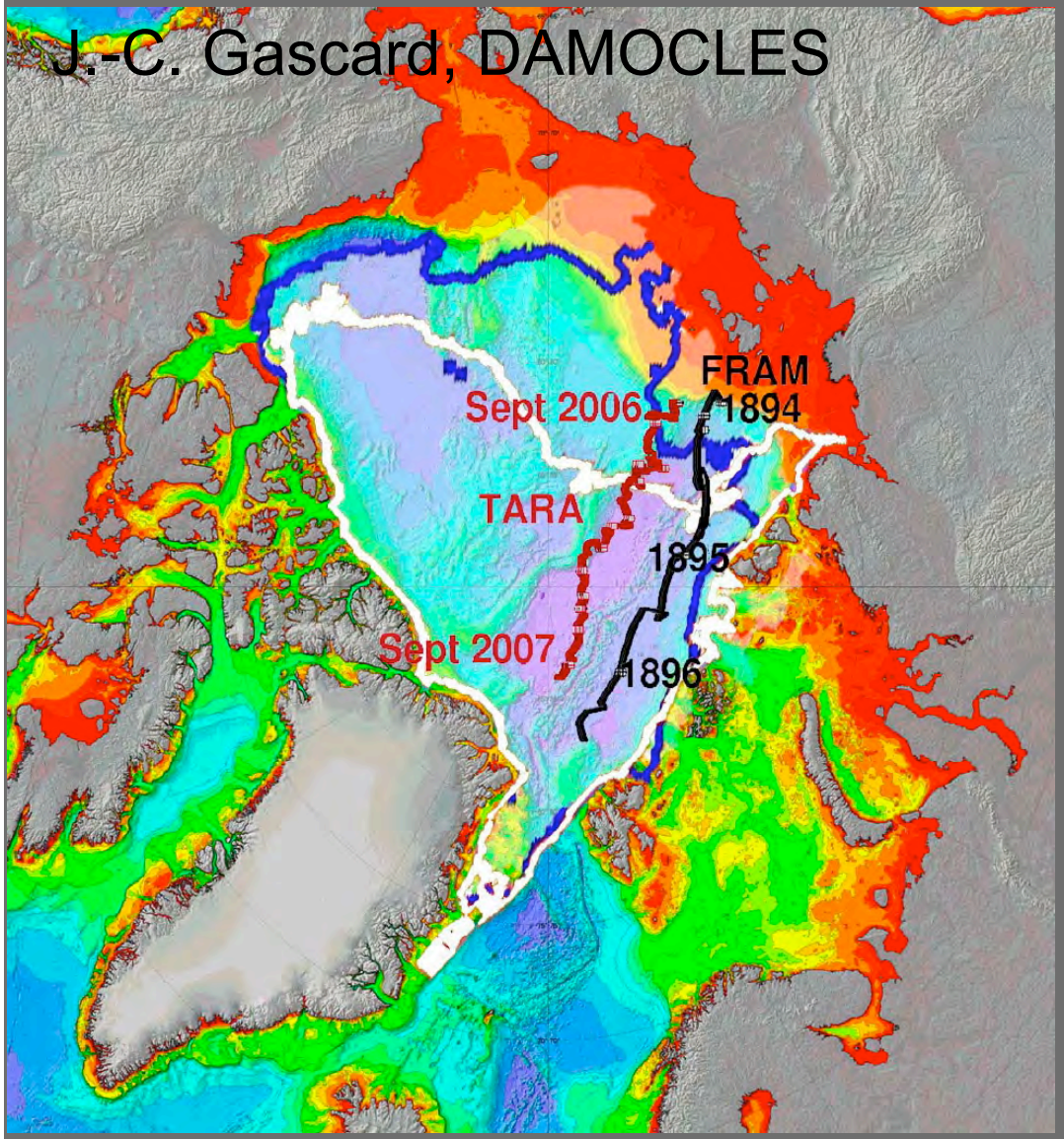
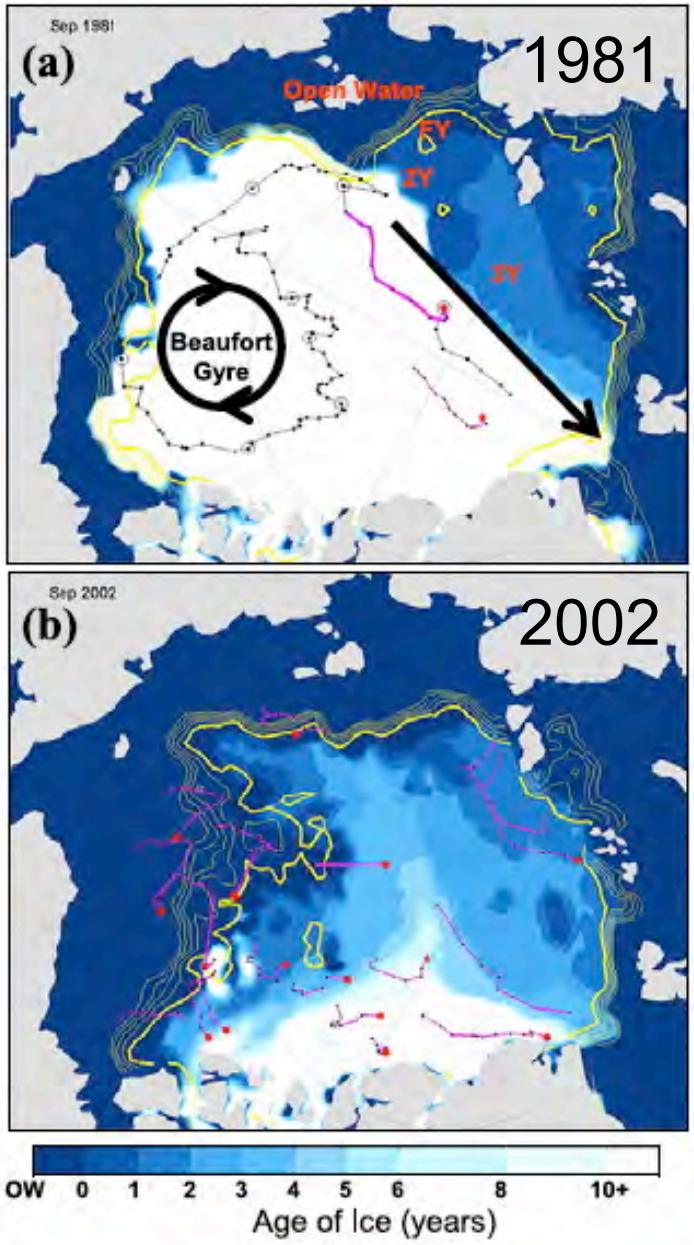
A thinner, more mobile ice cover

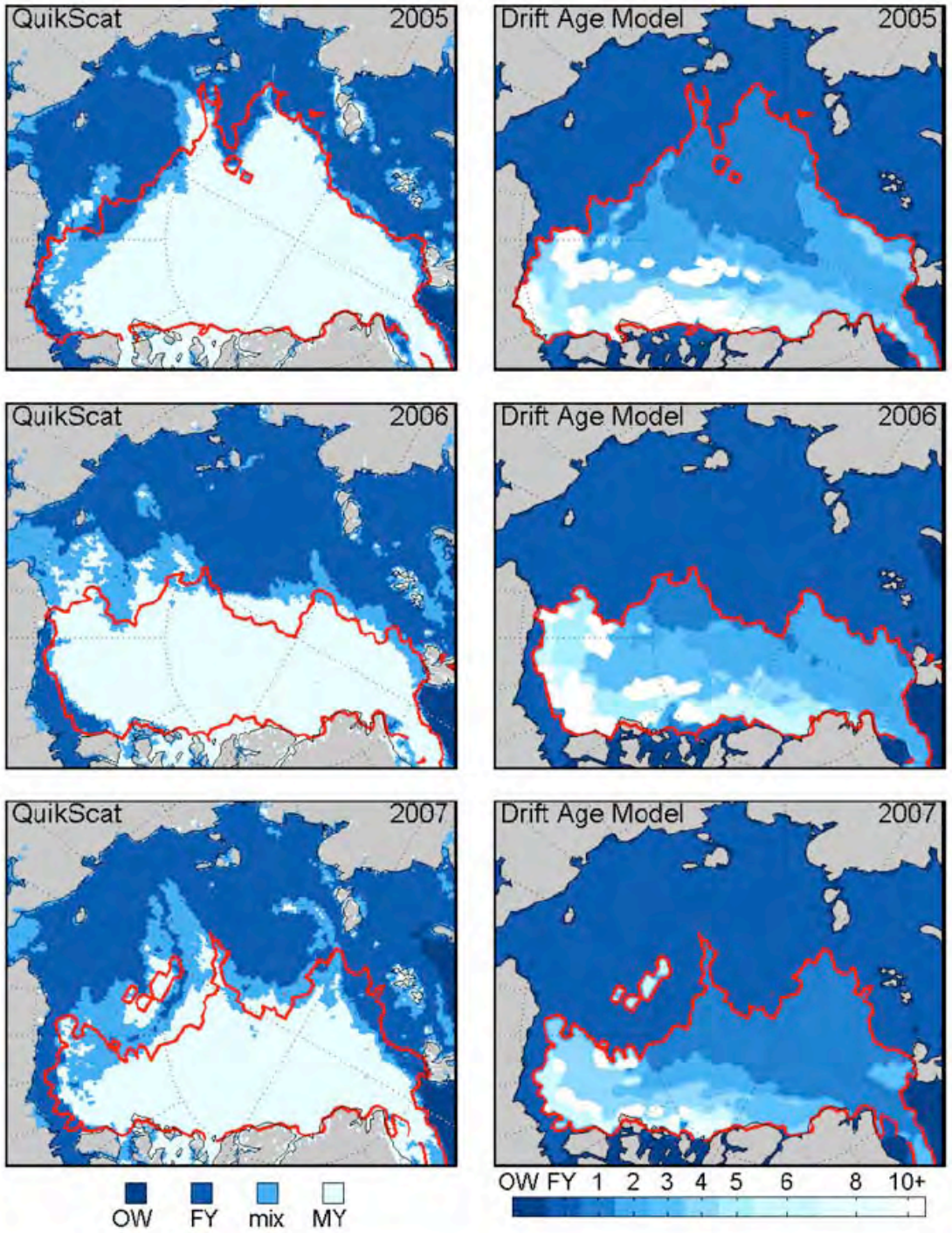


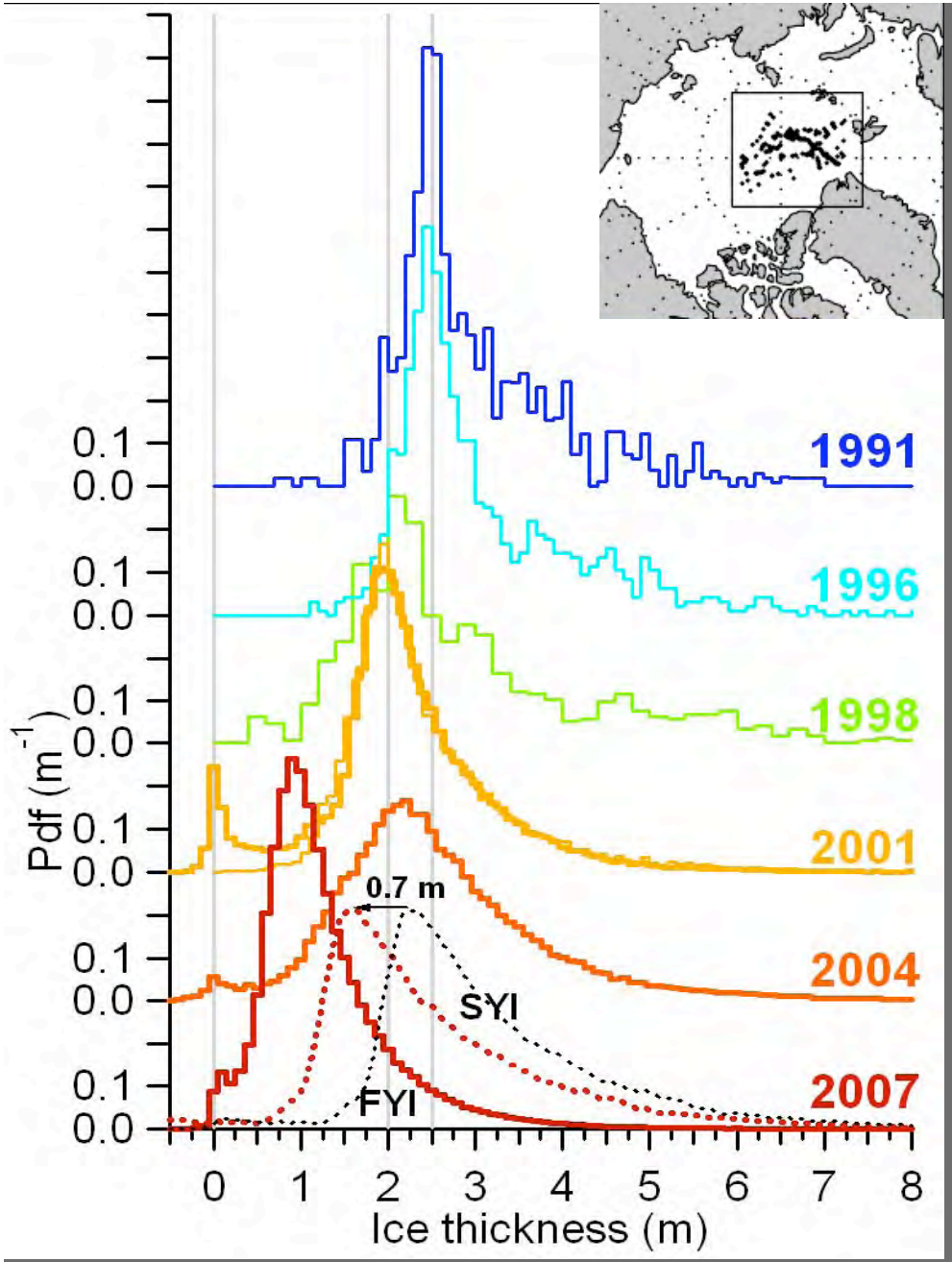
- Ice drift speed has increased in Transpolar Drift and Beaufort Gyre
- Implications of reduced residence time on age structure of Arctic sea ice and ice properties?

Rigor et al., 2004

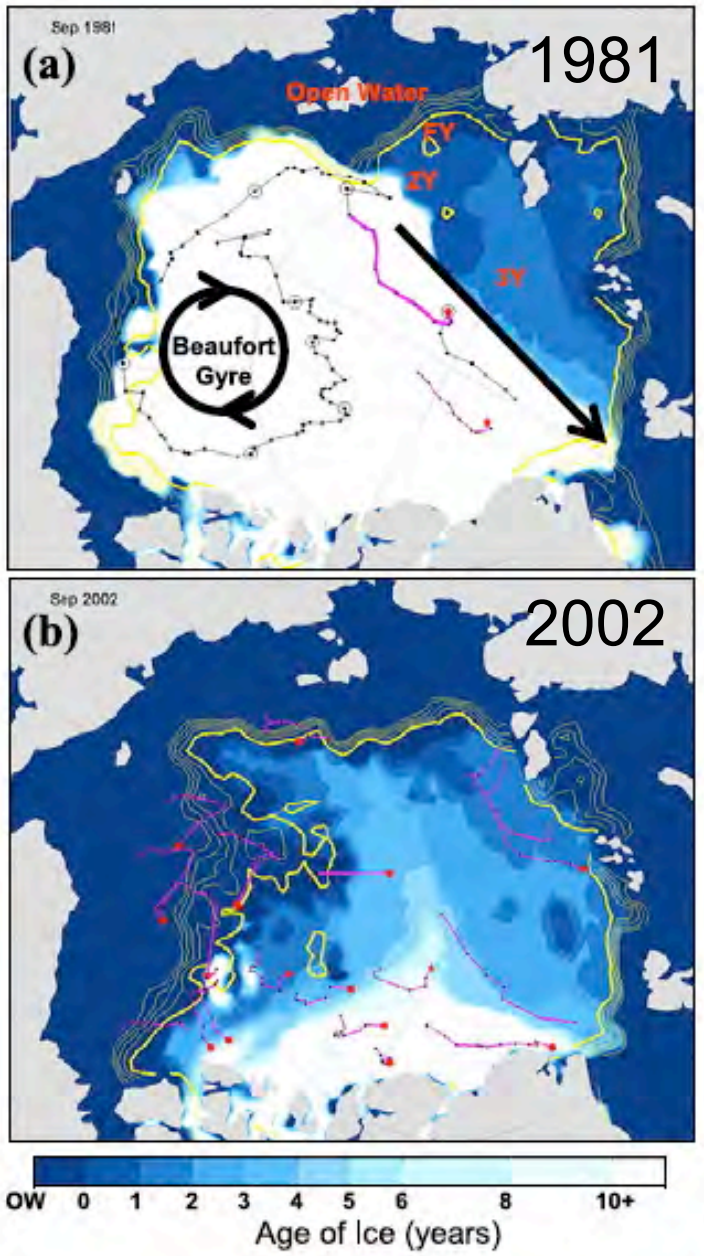
Nghiem et al., GRL, 2007







Haas et al. (2008)



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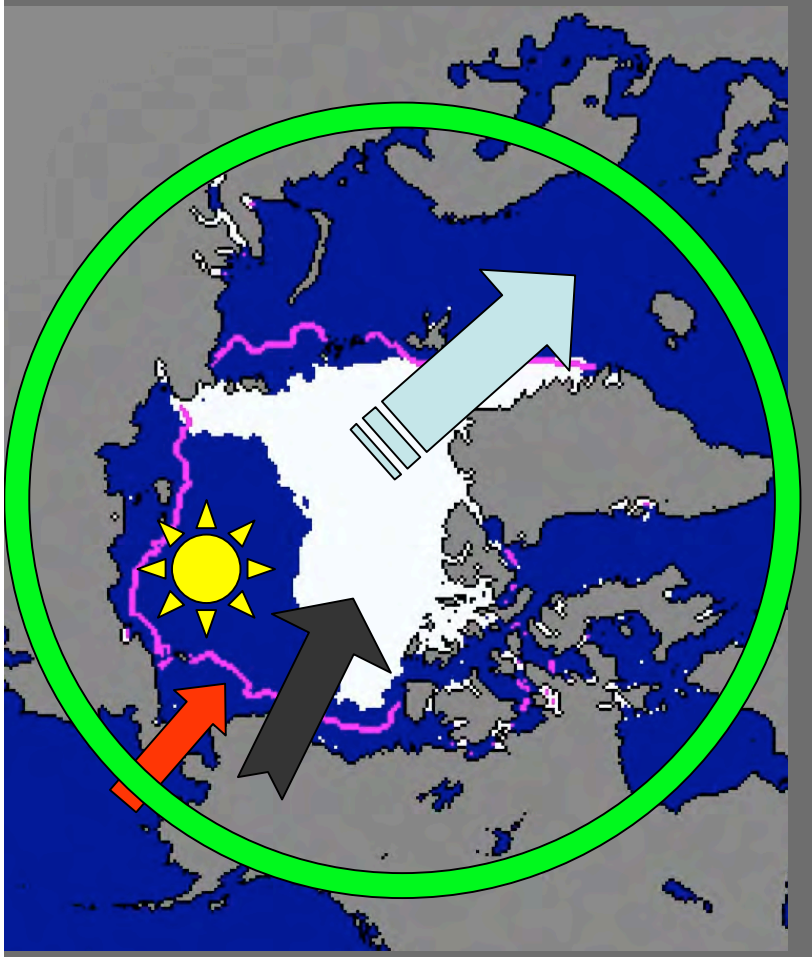

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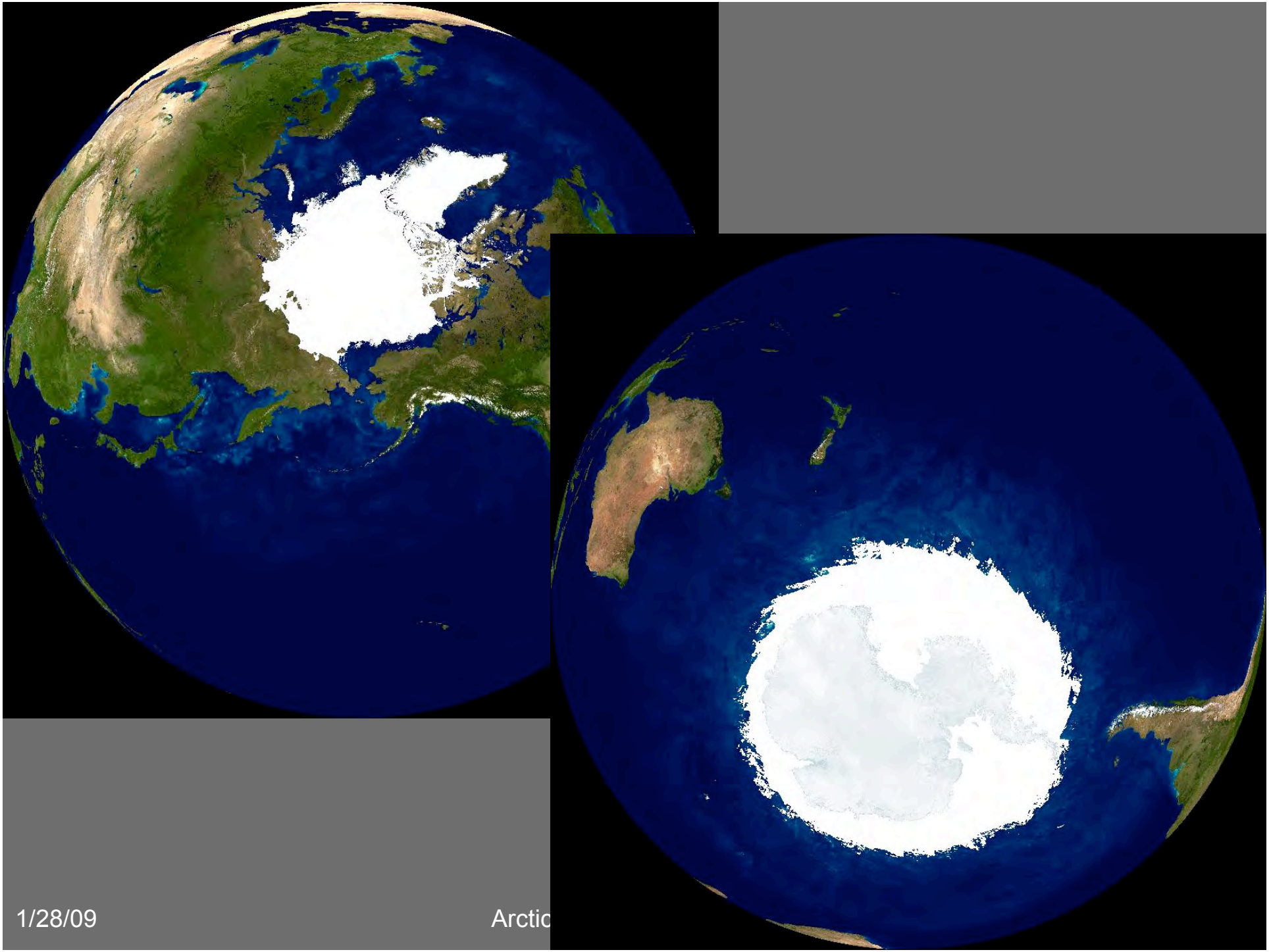
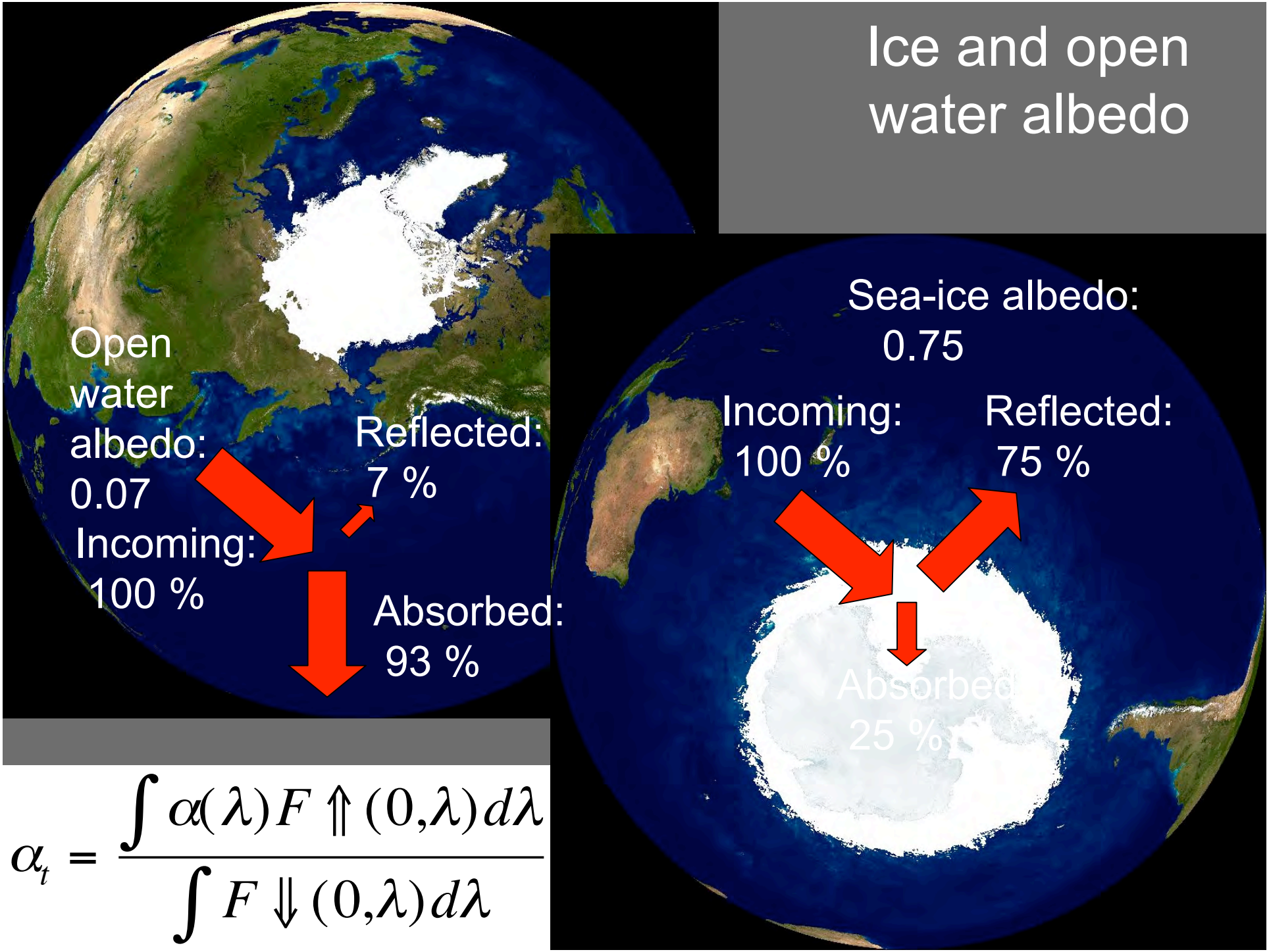

1/28/09
Arctic

Ice and open water albedo

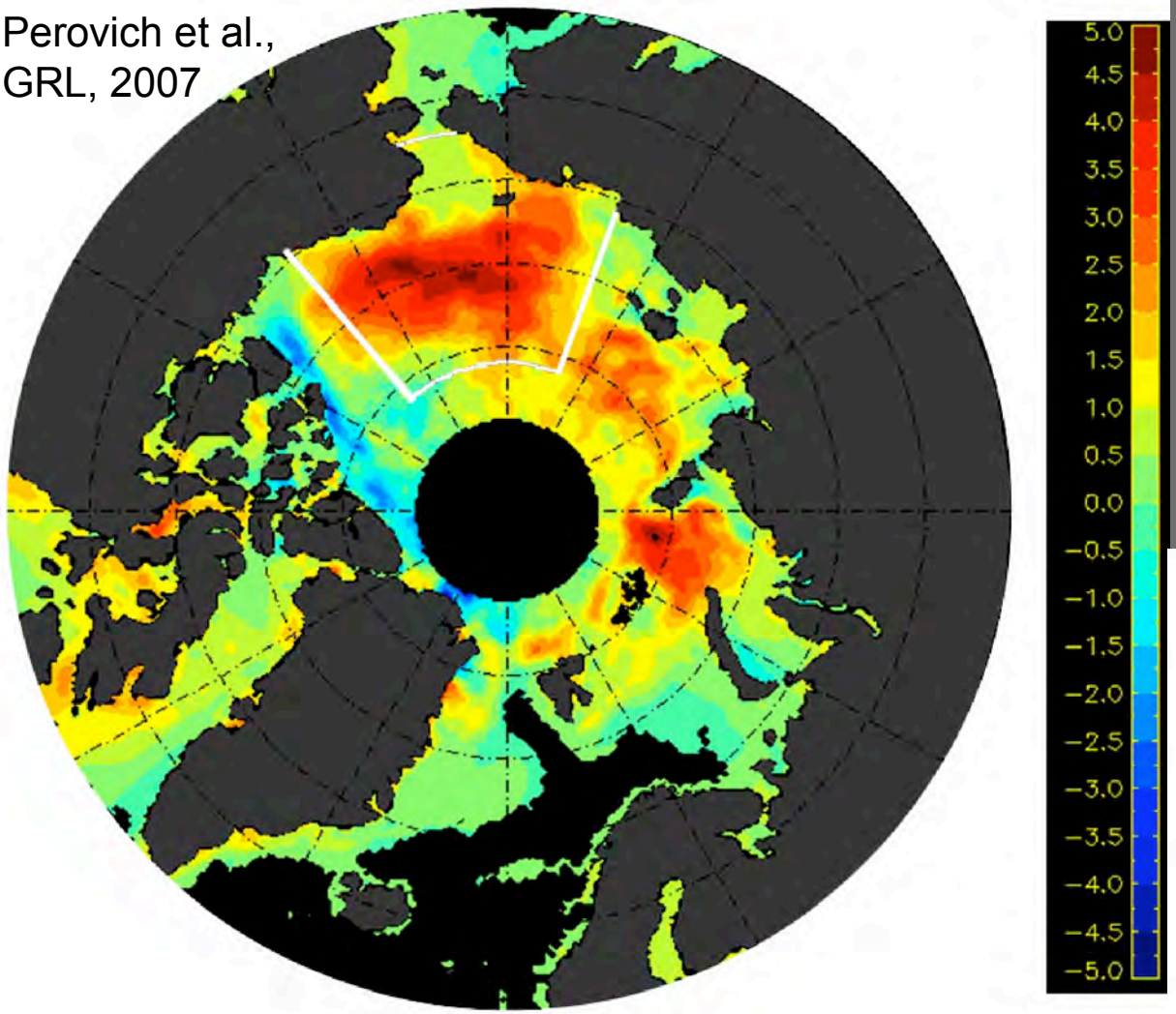


$$\alpha_t = \frac{\int \alpha(\lambda) F \Uparrow (0,\lambda) d\lambda}{\int F \Downarrow (0,\lambda) d\lambda}$$

Solar heating of surface waters in pack ice

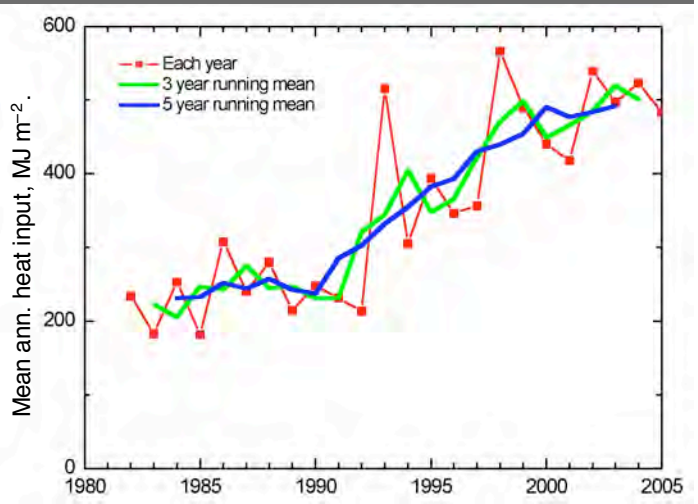
Solar heating linear trend (% yr^{-1})

Perovich et al., GRL, 2007

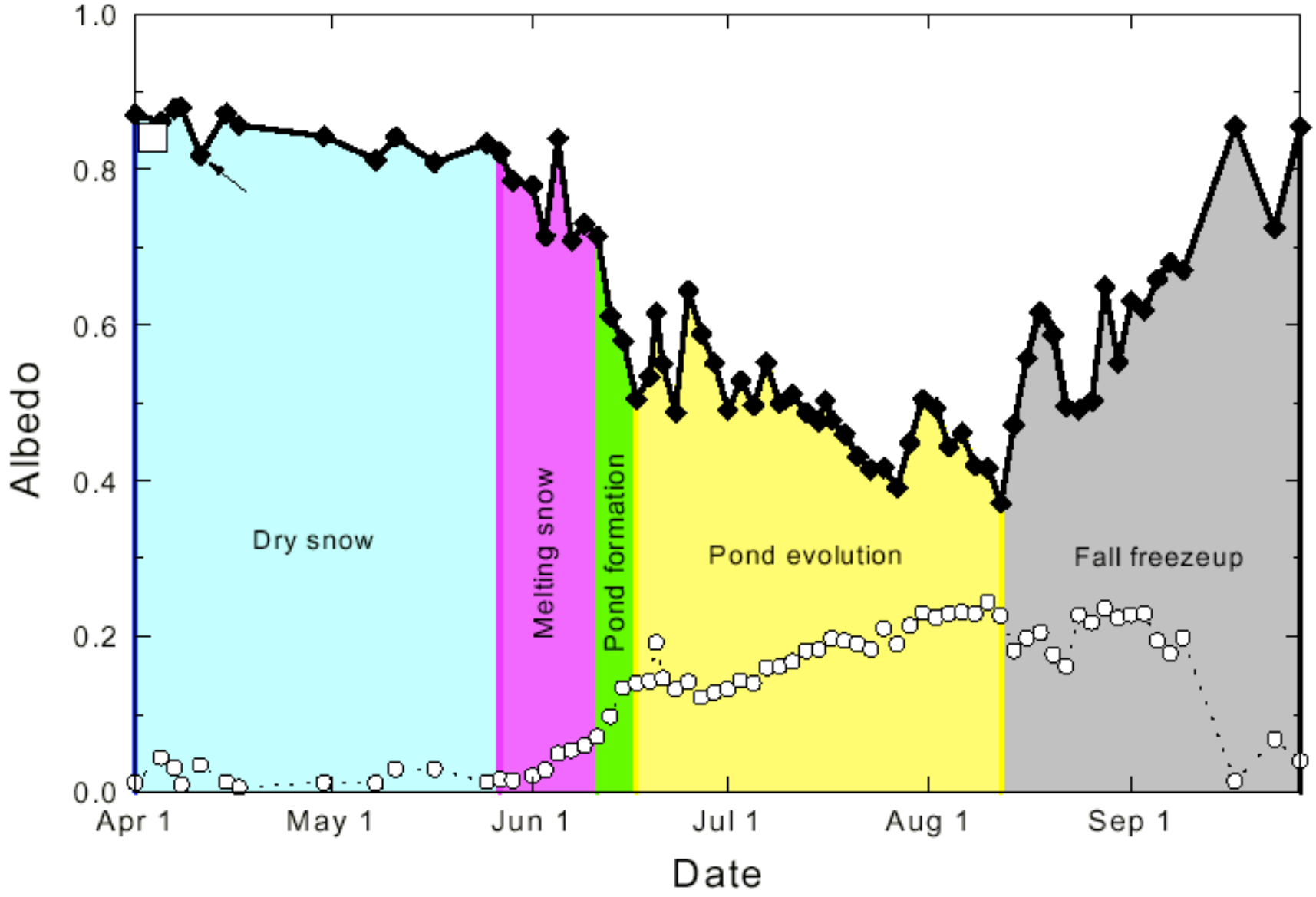


- Oceans north of Alaska have received at least twice as much heat from sun in recent years compared to 1980s

Solar heat input at 75˚N 165˚W



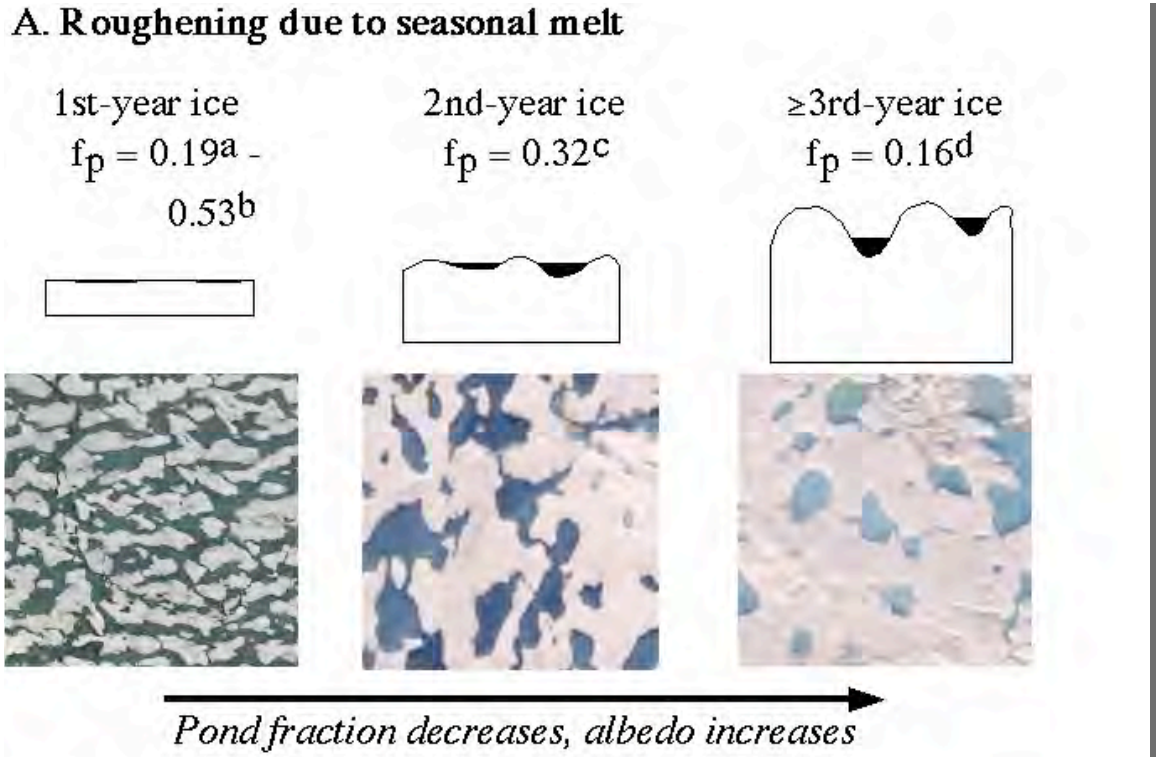
Changes in Arctic summer ice albedo



Perovich et al., 2003

Seasonal reduction of ice albedo

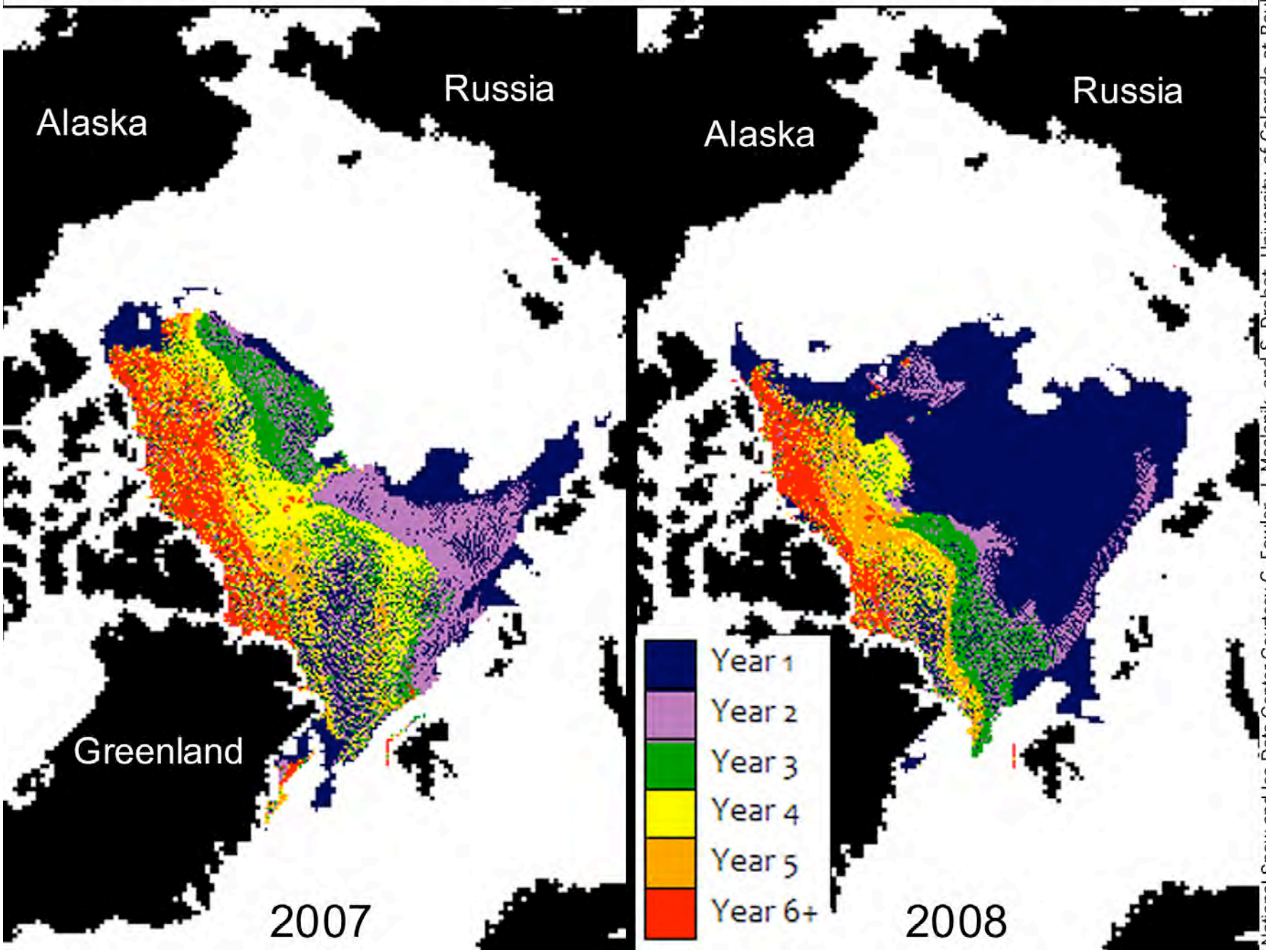
- Surface consists of bare, white ice and melt ponds
- White ice surface shows stable albedo
- Areal fraction (and type) of meltpond determine large-scale ice albedo



Ice roughness and ponding

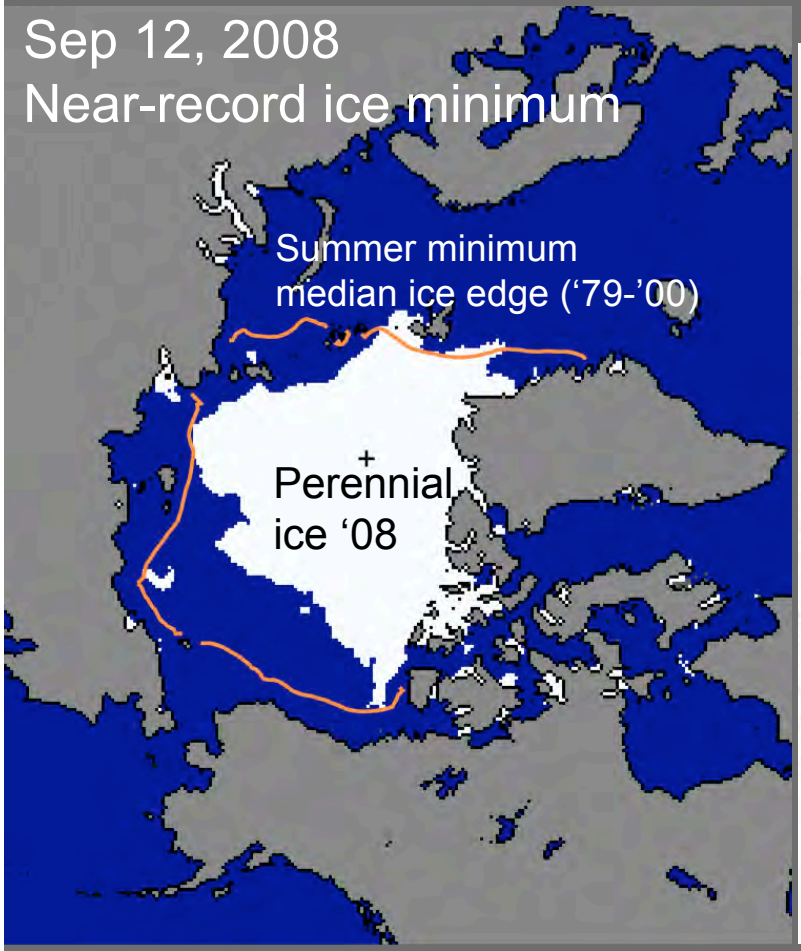
- Pond shrinkage and albedo increase with age: Is the Arctic darkening?
- Pond shrinkage and albedo increase with roughening through deformation: Is the Arctic whitening?

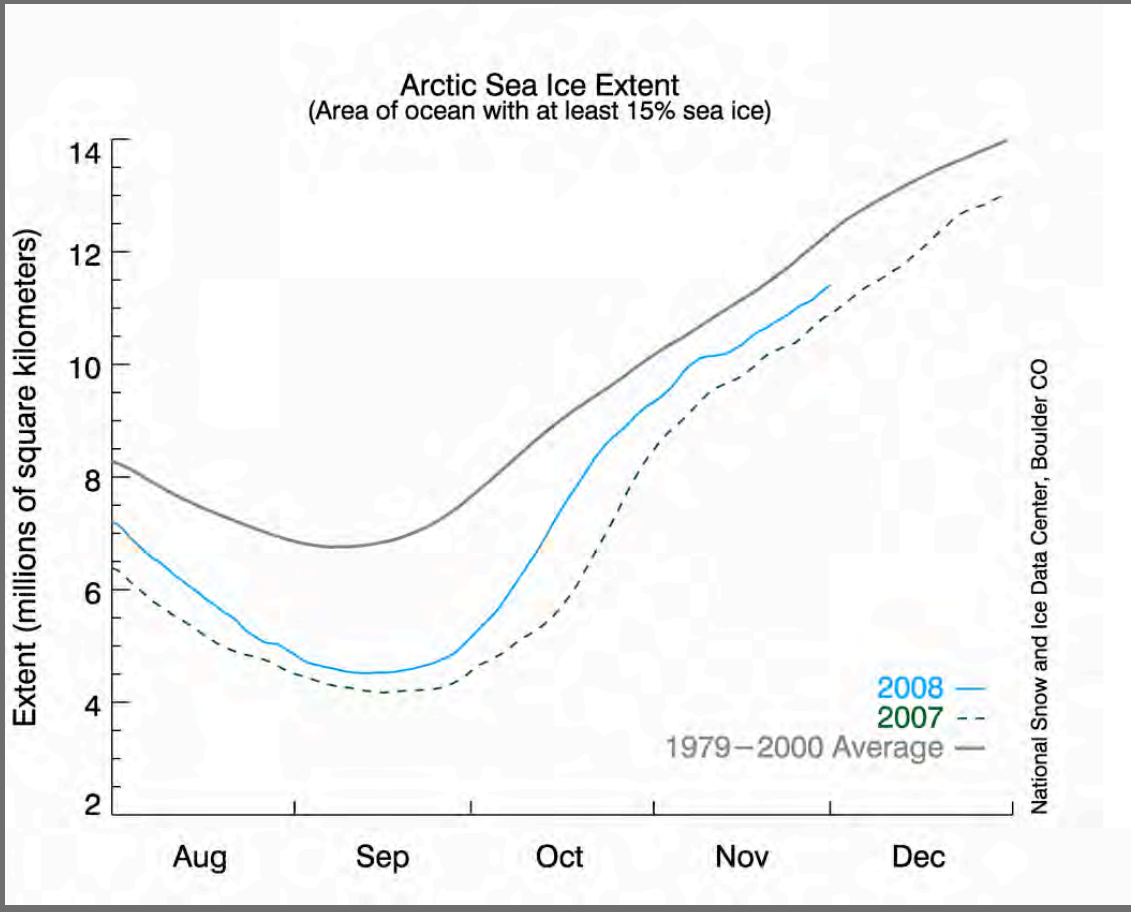
Ice age at the end of the 2007 and 2008 melt seasons



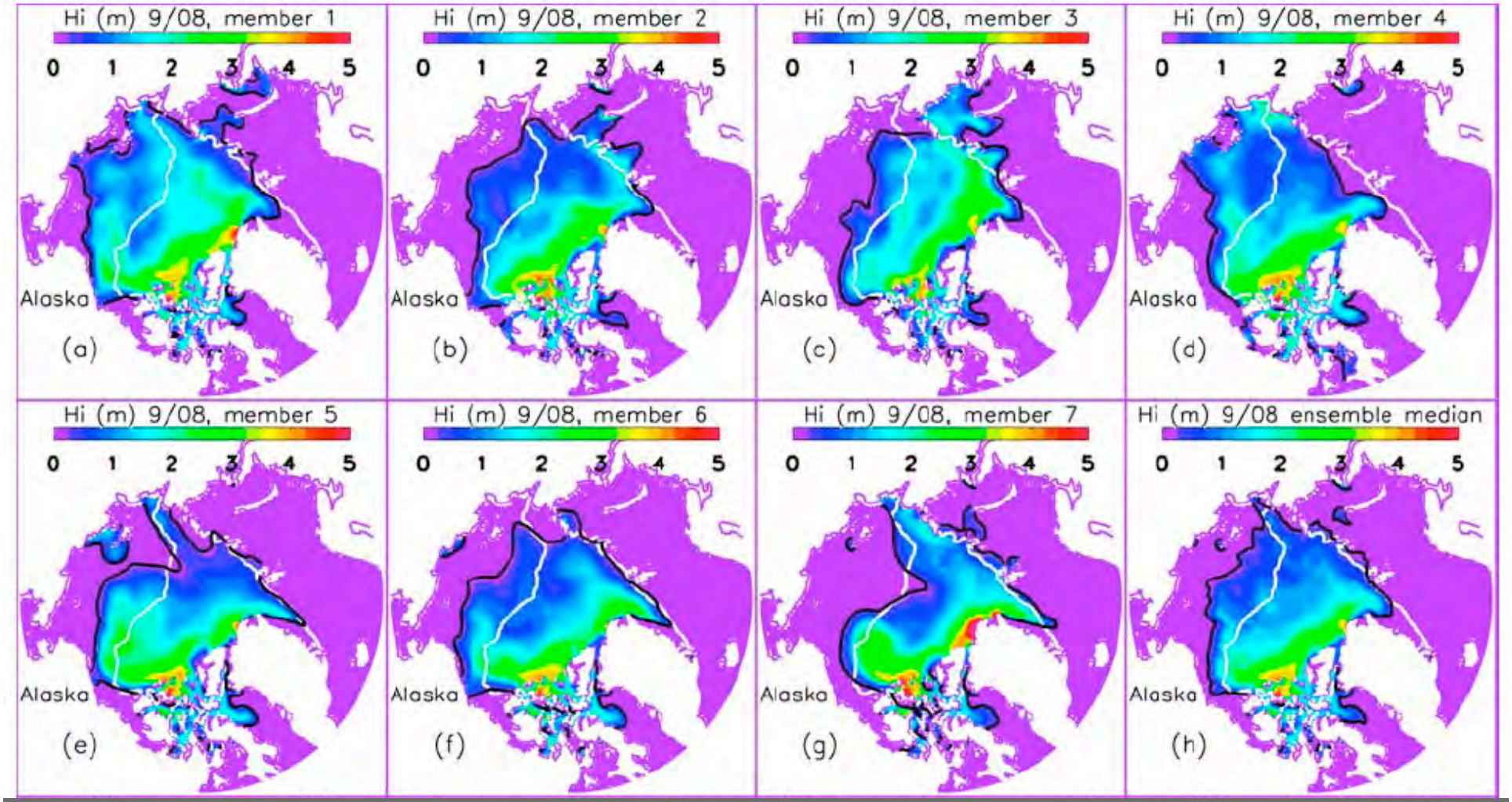
National Snow and Ice Data Center Courtesy C. Fowler, J. Maslanik, and S. Drobot, University of Colorado at Boulder

2008 sea-ice summer extent





- Ice conditions in 2008 governed by disproportionate fraction of first-year ice (2007 minimum) and average summer weather

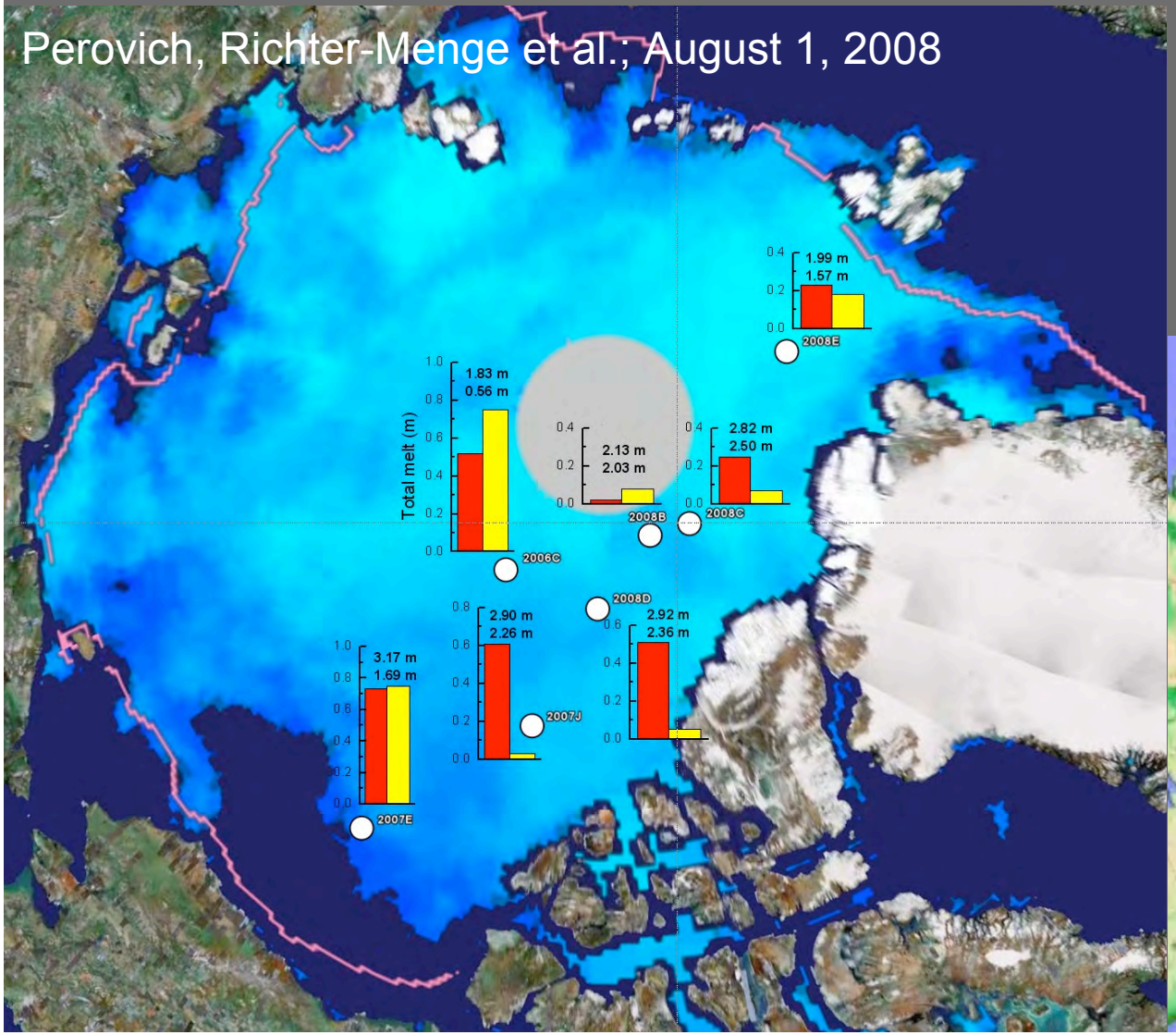


Zhang et al, 2008

- 2008 Arctic sea-ice outlook, www.arcus.org/search/seaiceoutlook

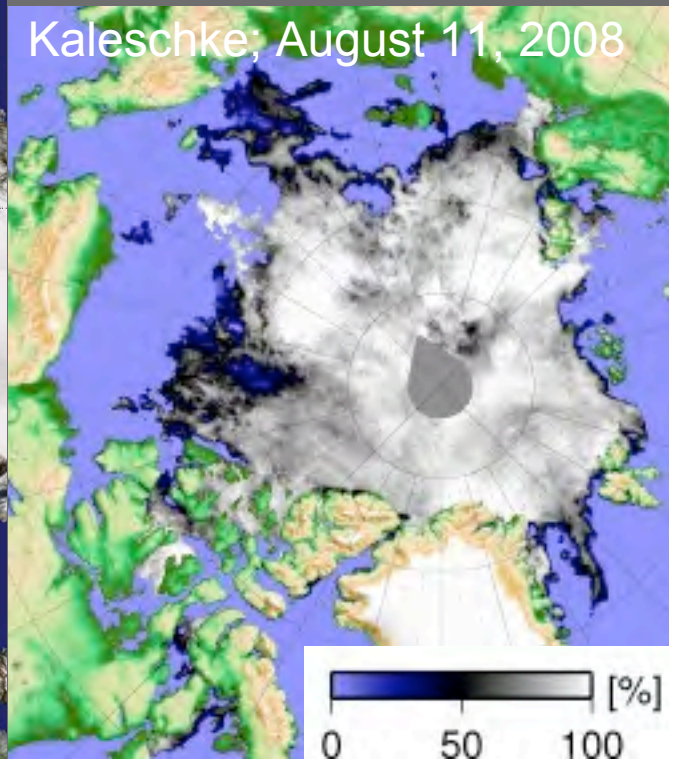
A nascent Arctic Observing Network (AON)

- Anomalously high bottom melt rates persisted into 2008



- Key observations & insights from AON

cdp.ucar.edu/cadis



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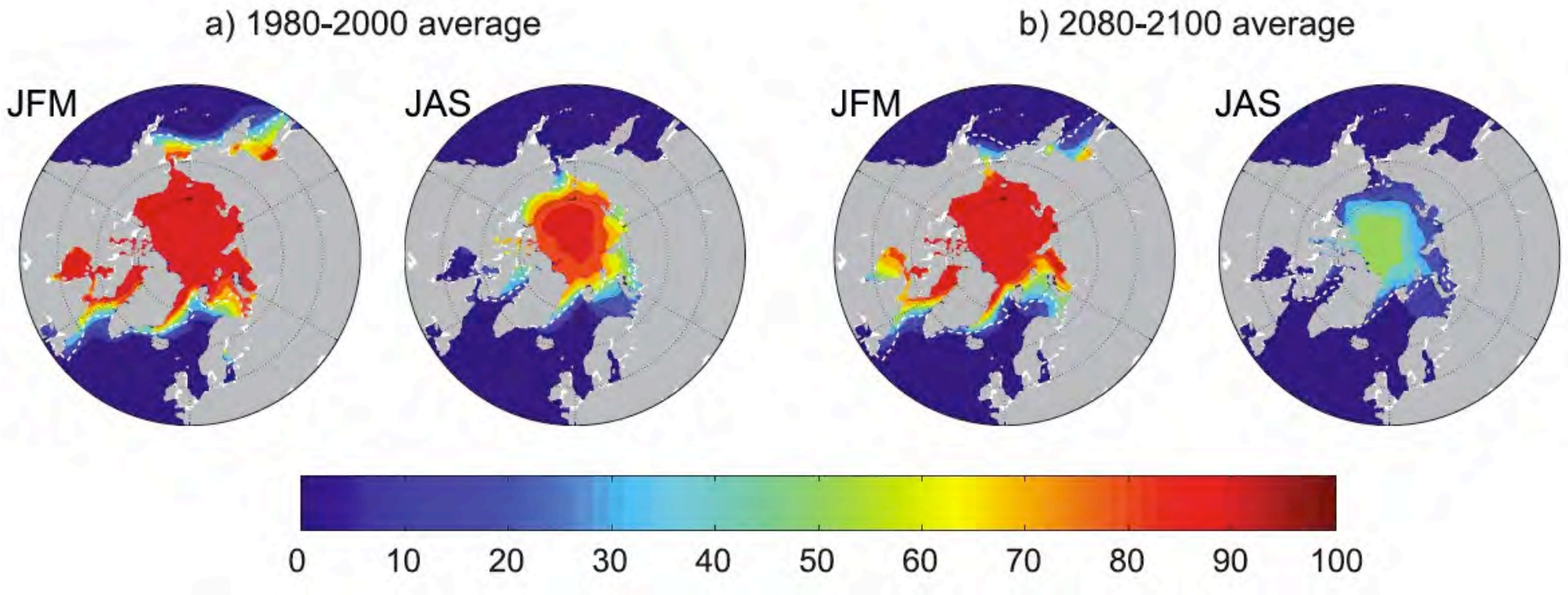
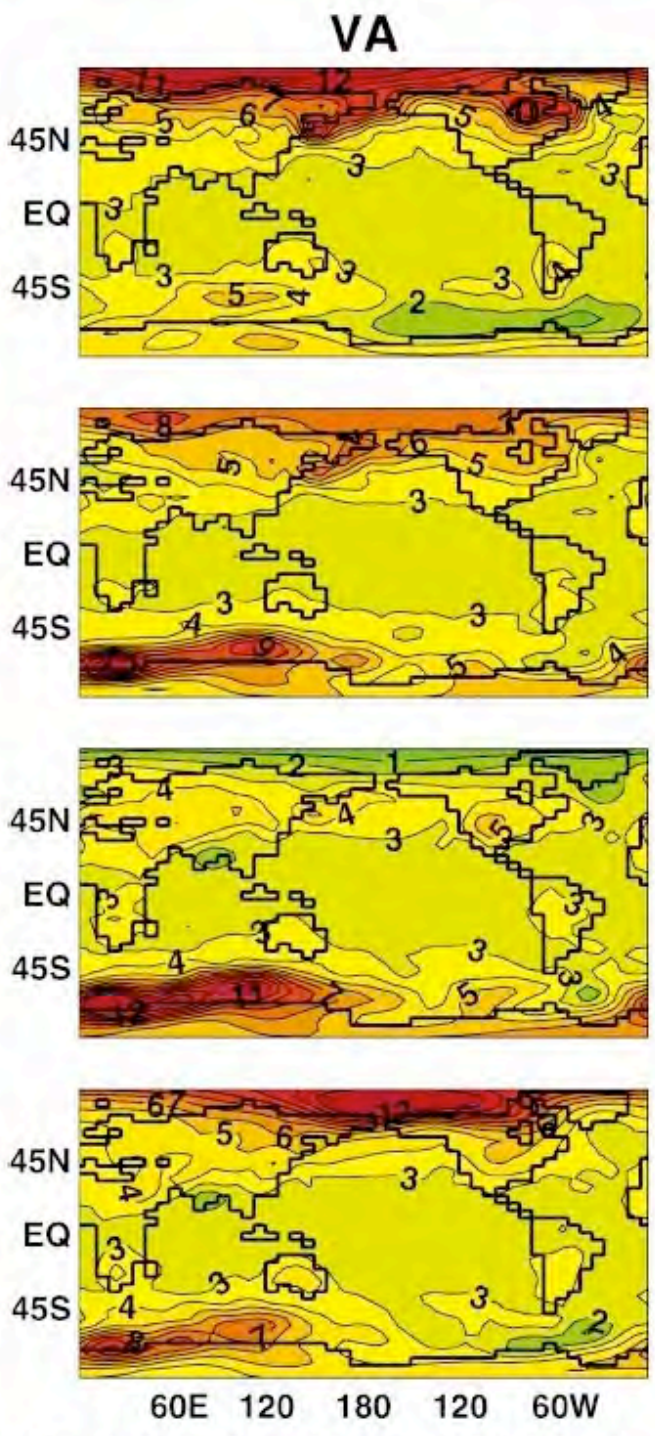
The Arctic sea-ice cover: Model projections

Meehl et al., 2007

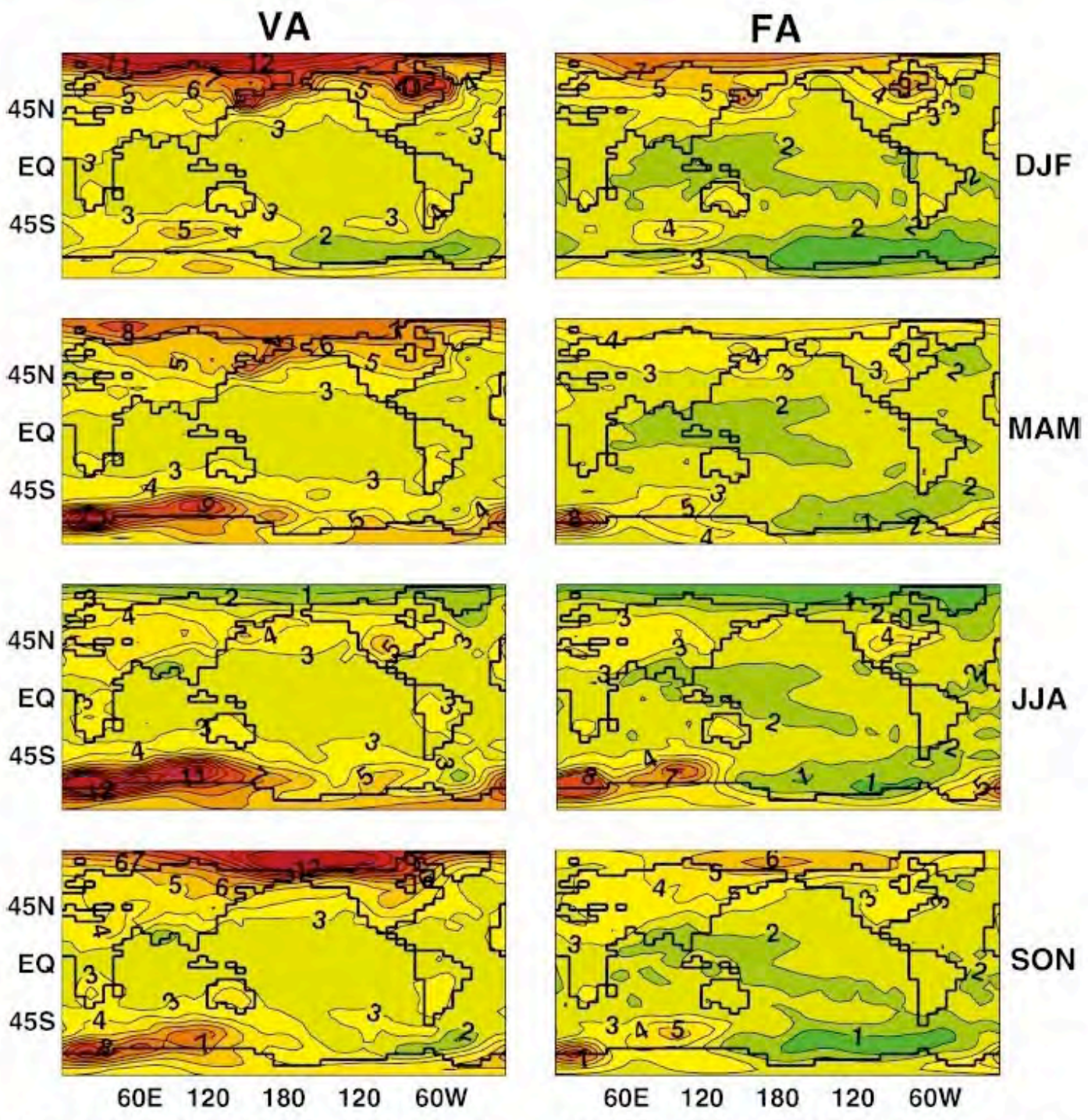




Global & Arctic Warming

- Models consistently show amplified warming in polar regions, in particular the Arctic ("polar amplification of climate change"; shown here are simulations with GFDL GCM by Hall, 2004, for doubling of CO_2)
- Such enhanced warming is generally attributed in large part to ice-albedo feedback

Hall, 2004

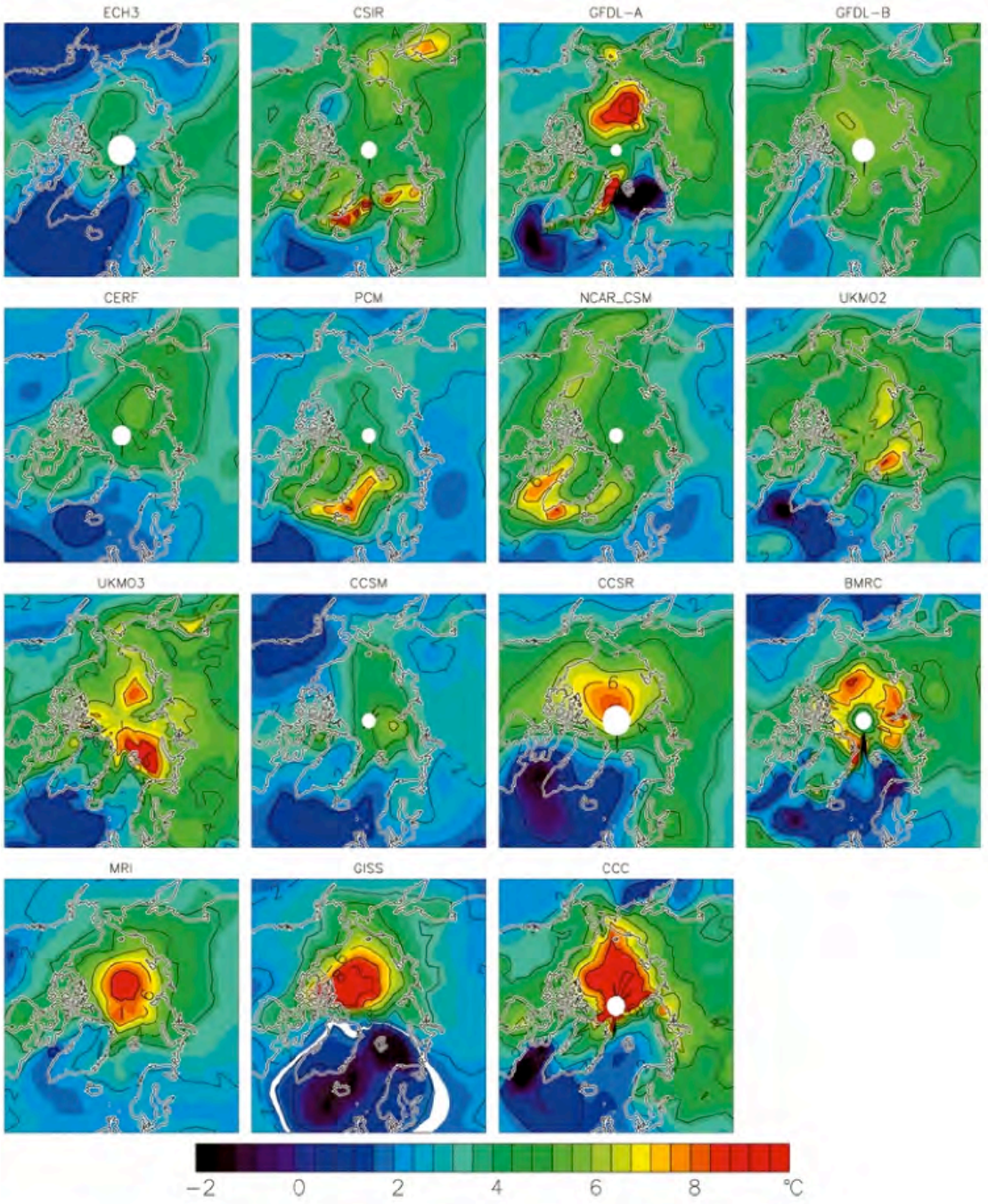


- Variable (VA) vs. fixed (FA) albedo GCM simulations indicate extent of albedo contribution to warming
- FA sets surface albedo at present-day climatological mean (w/ seasonal evolution)

Hall, 2004

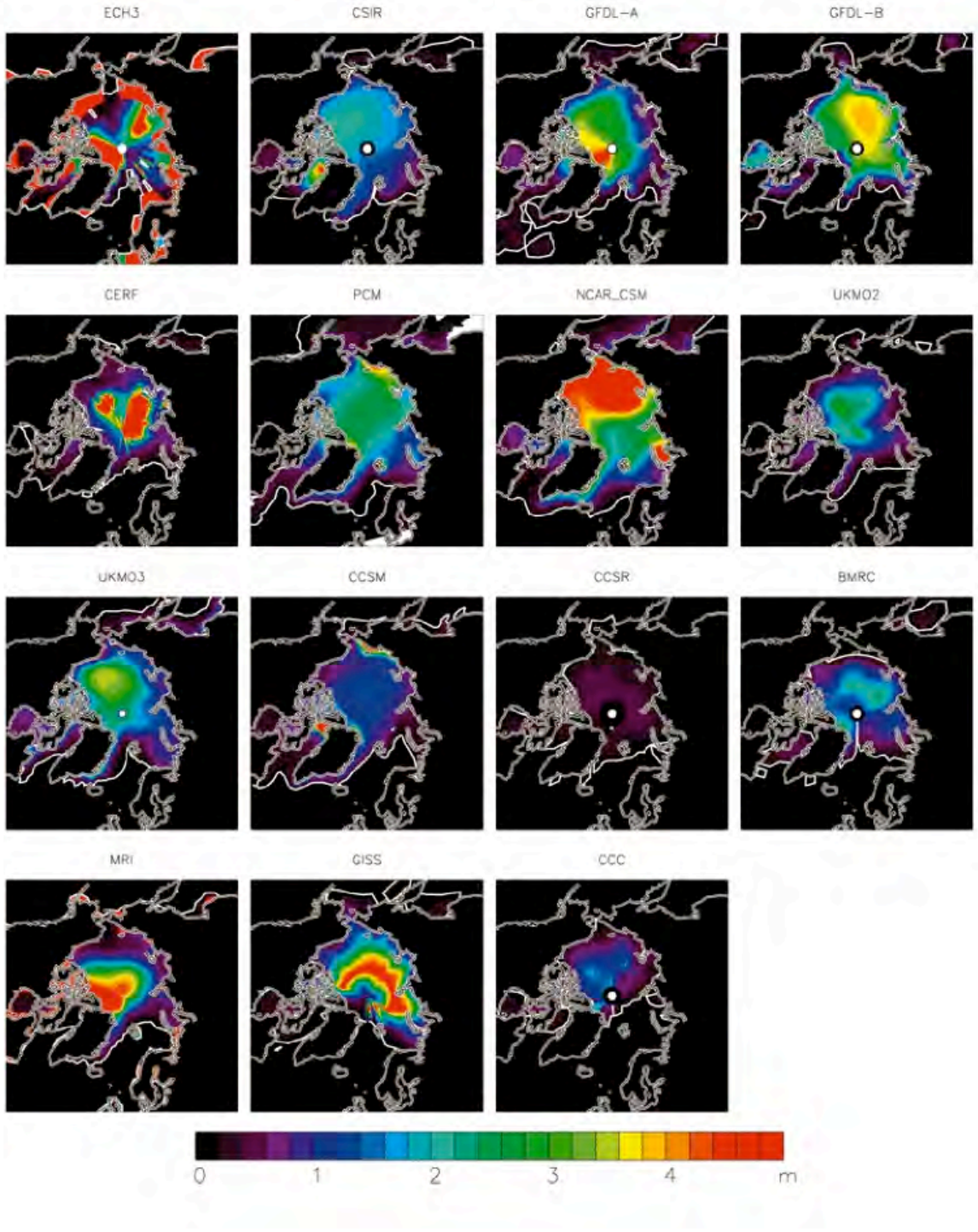
Fig. 2 The temperature change for 2×CO_2 conditions normalized by the global average air temperature change

2 X CO_2: 2000-2080



Polar (Arctic) amplification of global T rise: 1.5 to 4.5

Holland & Bitz, 2003

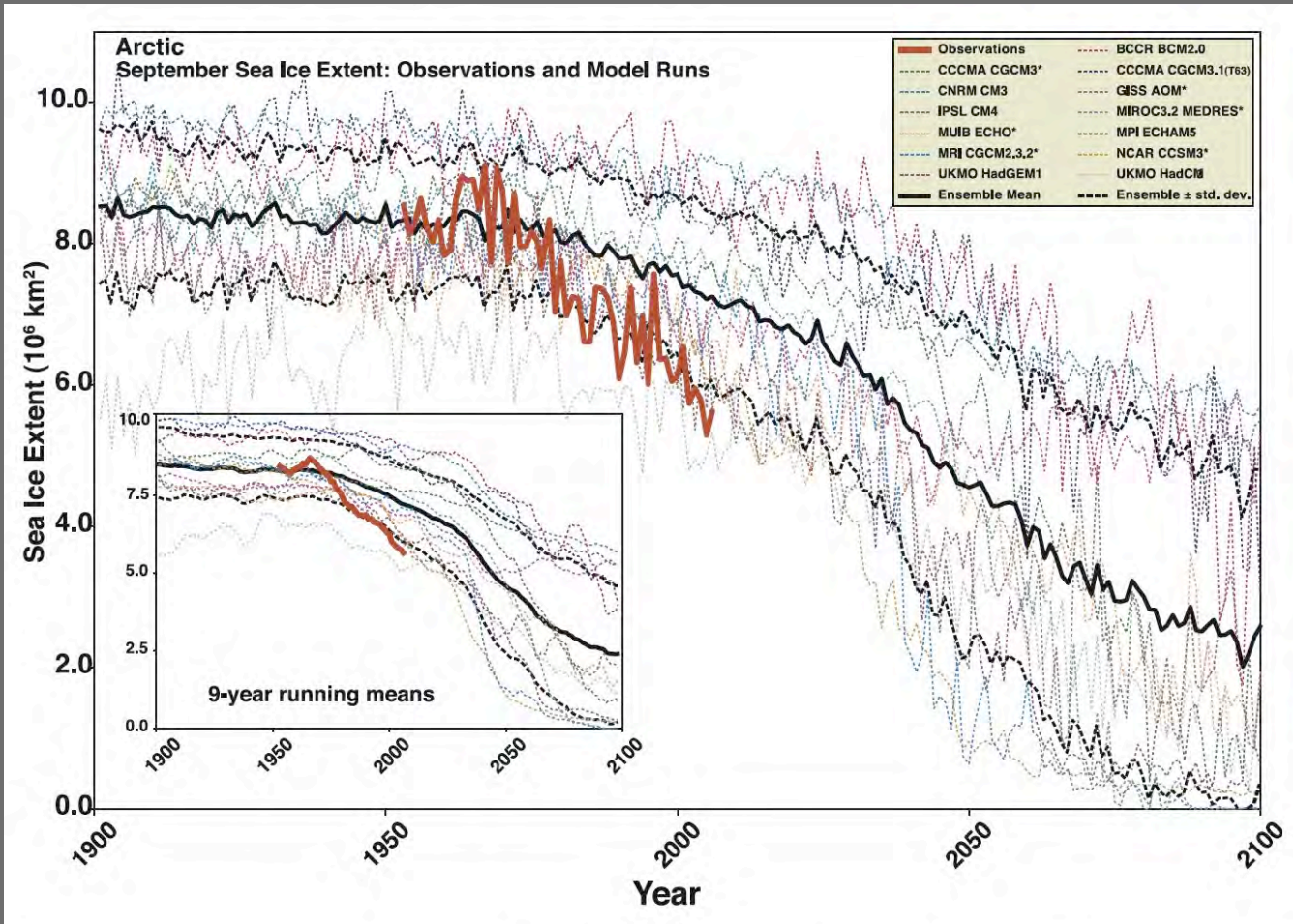


- Simulated mean Arctic sea-ice thickness under present-day conditions varies considerably, both in magnitude and regional patterns
- What is the impact of deviations from observed mean field on predictions of sea-ice retreat and warming?

Holland & Bitz, 2003

The Arctic sea-ice cover: Model projections

- Recent summer reductions somewhat faster than models predict
- Several plausible explanations, related to how albedo, ice thickness and other factors are simulated



Stroeve et al., 2007

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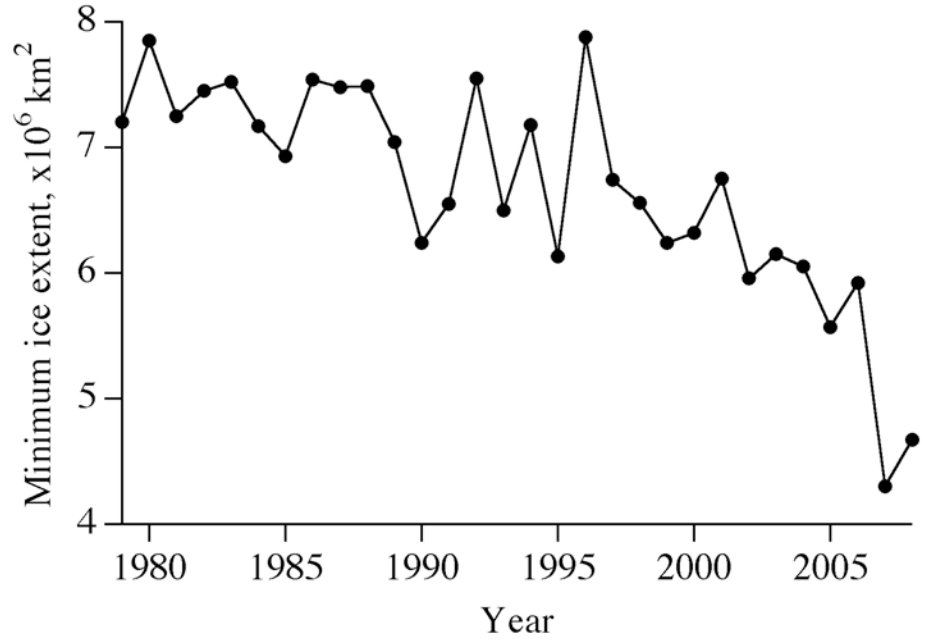
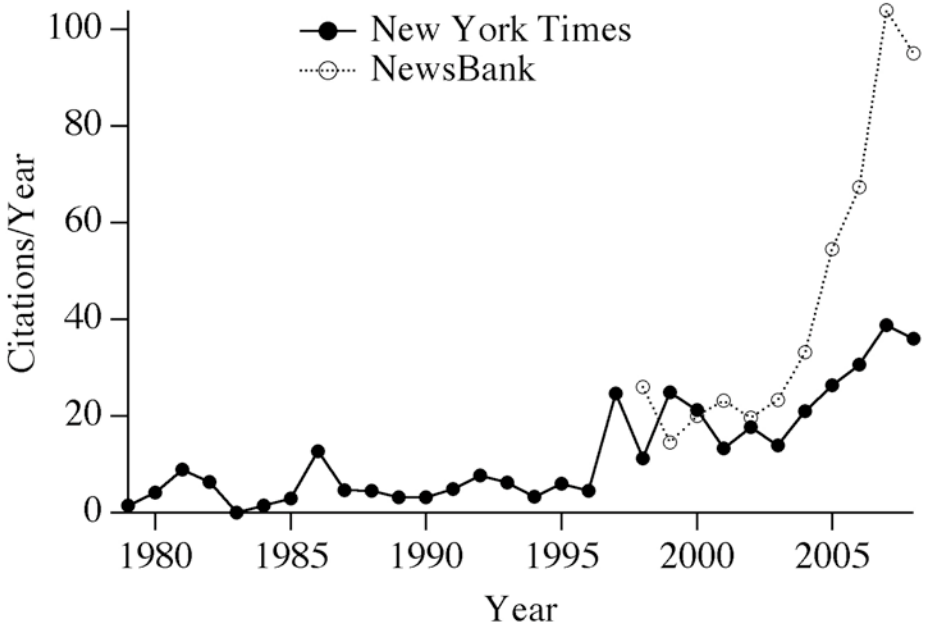




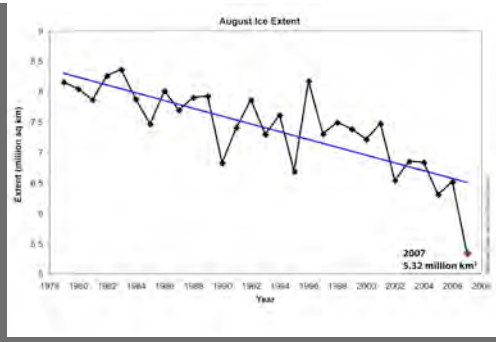
Gauging societal relevance

- Citations (normalized) of “sea ice” in news media related to coverage of climate change, polar bears, access to the Arctic

A changing North

Barrow Whaling camp
(Photo: Bill Hess)

Regime shifts in climate and the environment that are about to exceed range of past variability and change

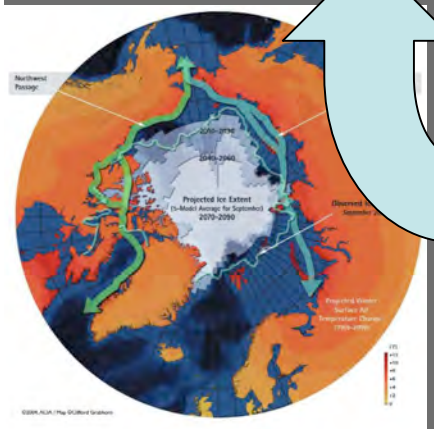


NSIDC

Increasing inter-dependence between the Arctic region and global processes

Sweeping impacts of change on Northern populations and cultures

ACIA

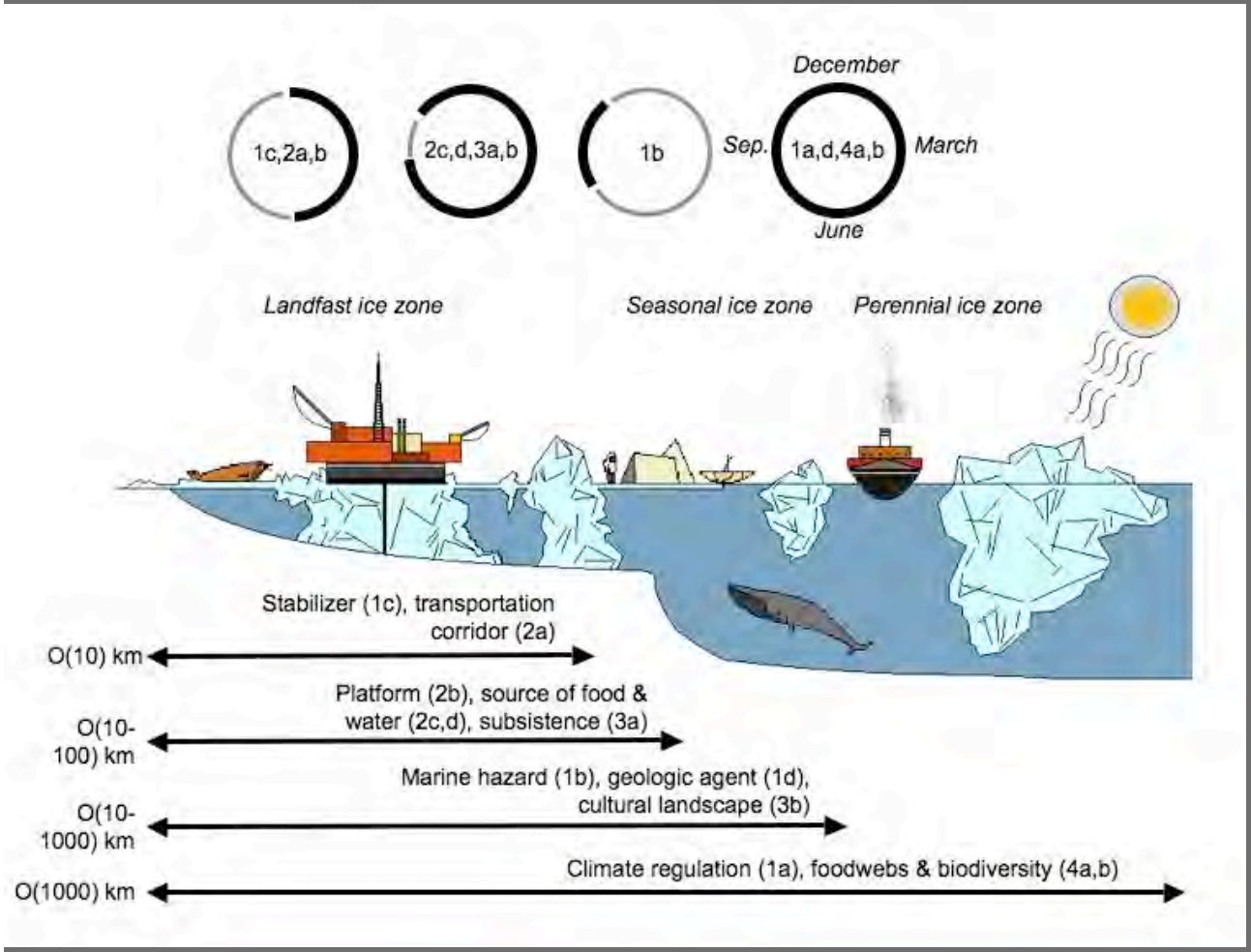


Expansion of global geopolitical and economic interests into the North

BP Northstar
Photo: BP

Arctic Sea Ice Change

Sea-ice system services (or: What has sea ice done for me lately?)



- New, potentially overlapping or conflicting uses of sea ice
- Management regimes need to adapt to rapid environm'l change & variability
- Information needed at local scale relevant to sea-ice users

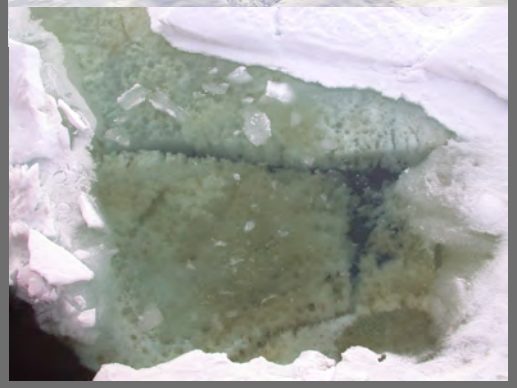
Eicken et al., *Arctic*, in press

Sea-ice system services

- Regulating
  - Climate regulator
  - Marine & coastal hazard
  - Stabilizing element in coastal zone
  - Geologic agent (ice rafting of sediments, bottom interaction)
- Provisioning
  - Transportation corridor
  - Platform (industry & subsistence)
  - Freshwater source
  - Source of food
- Cultural
  - Subsistence activities
  - Ice as part of cultural & spiritual landscape (incl. tourism)
- Supporting
  - Ice-based foodwebs
  - Reservoir and driver of biological diversity (e.g., extremophiles)

(1) Icescape

(2) Platform & Hazard

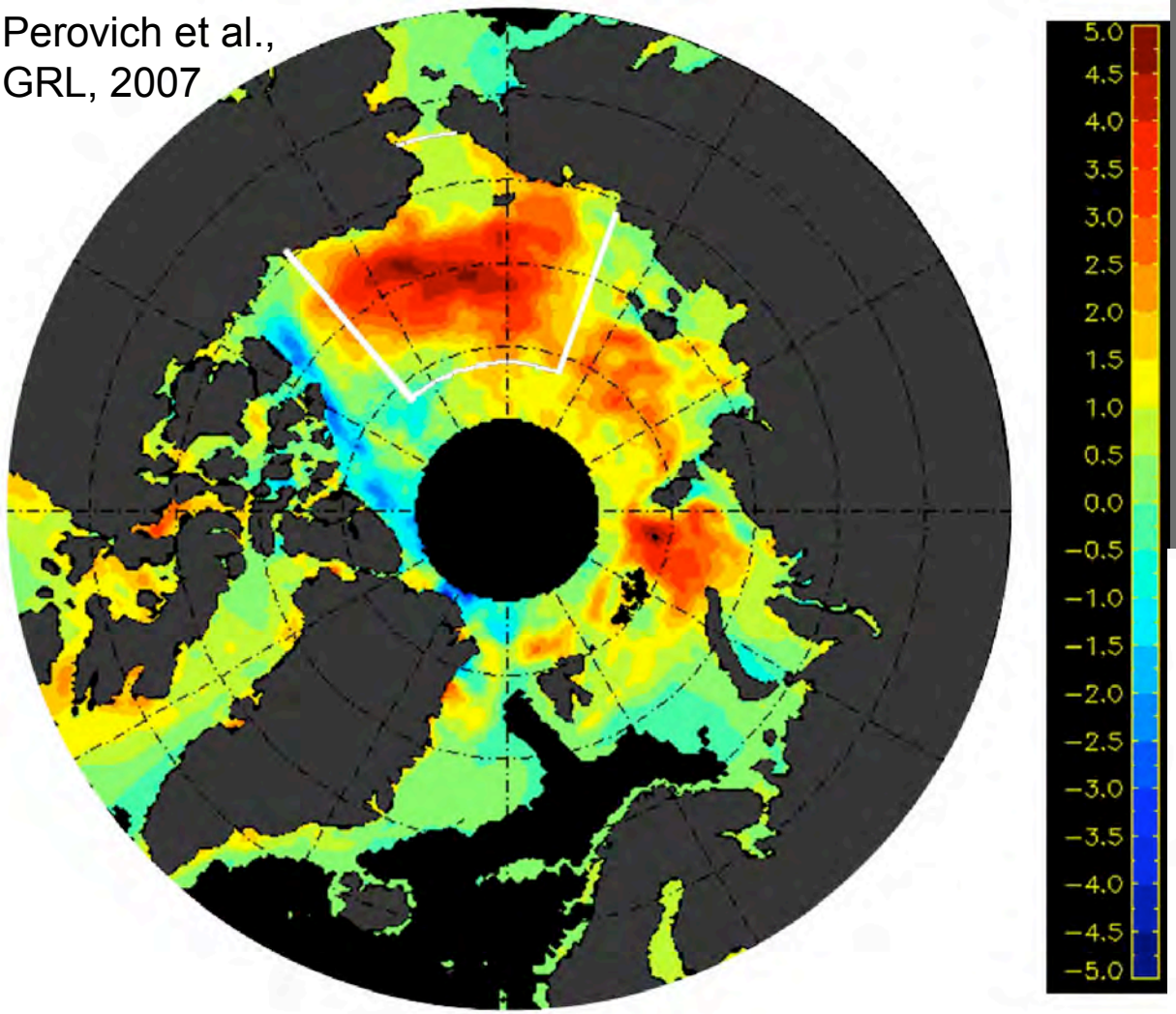


(3) Habitat

Solar heating of surface waters in pack ice

Solar heating linear trend (% yr^{-1})

Perovich et al., GRL, 2007



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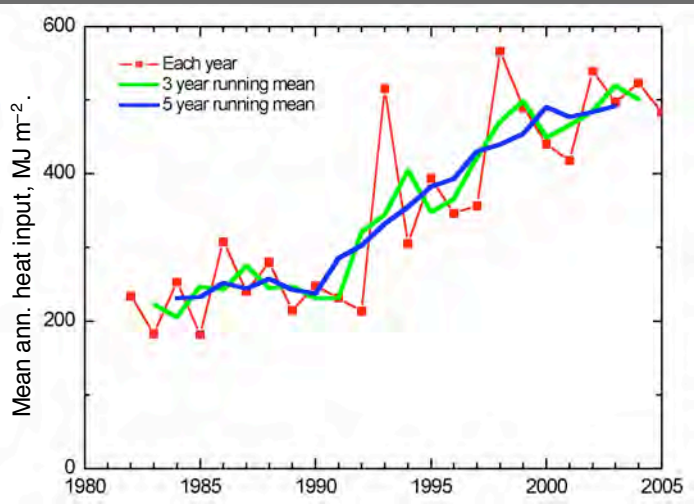
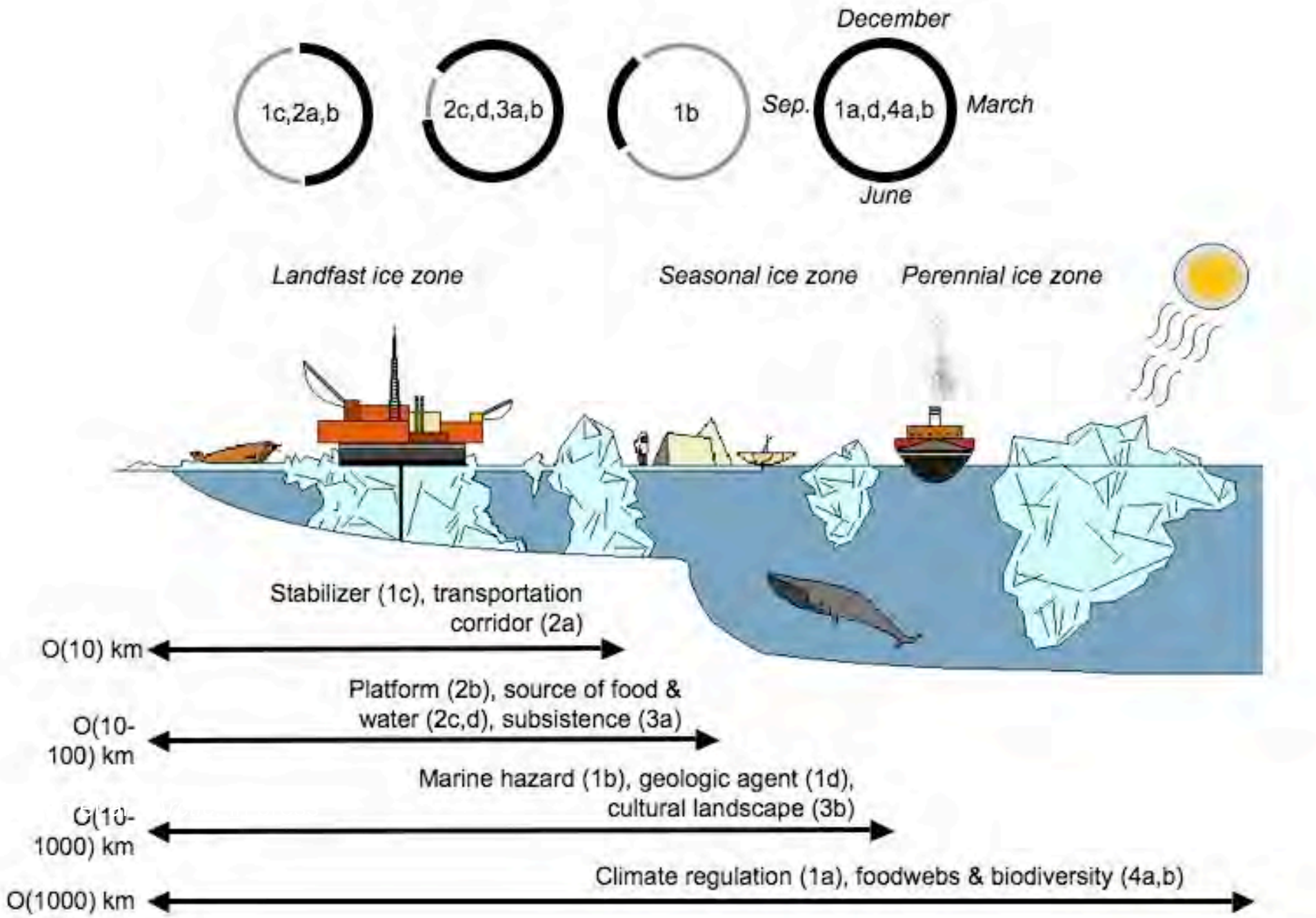
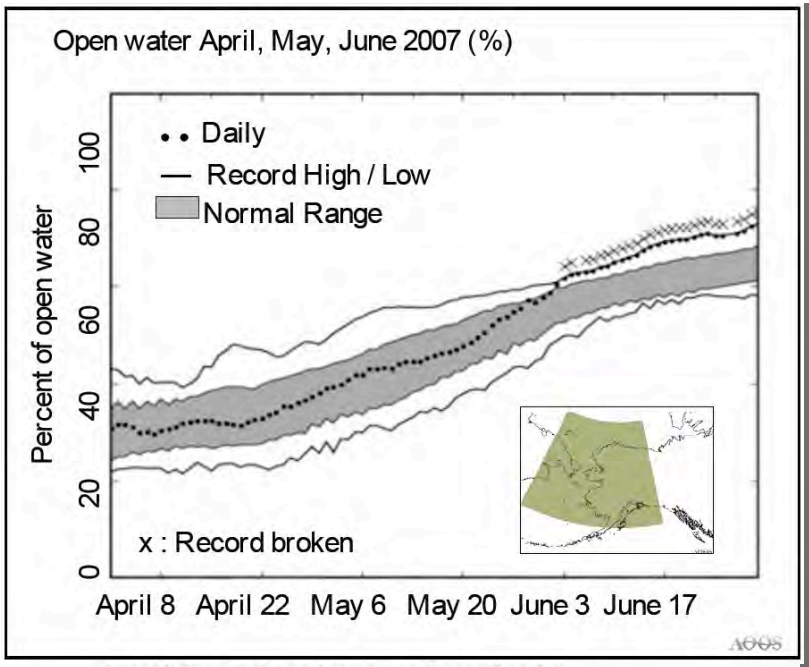
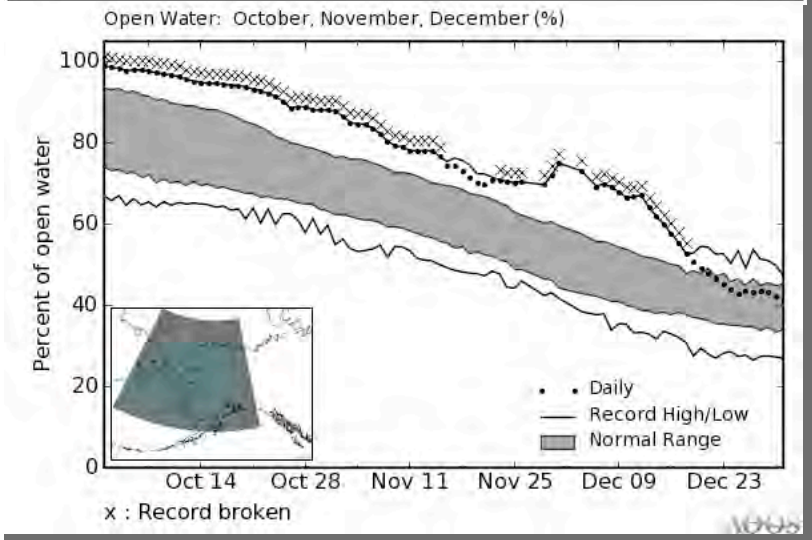
Solar heat input at 75˚N 165˚W

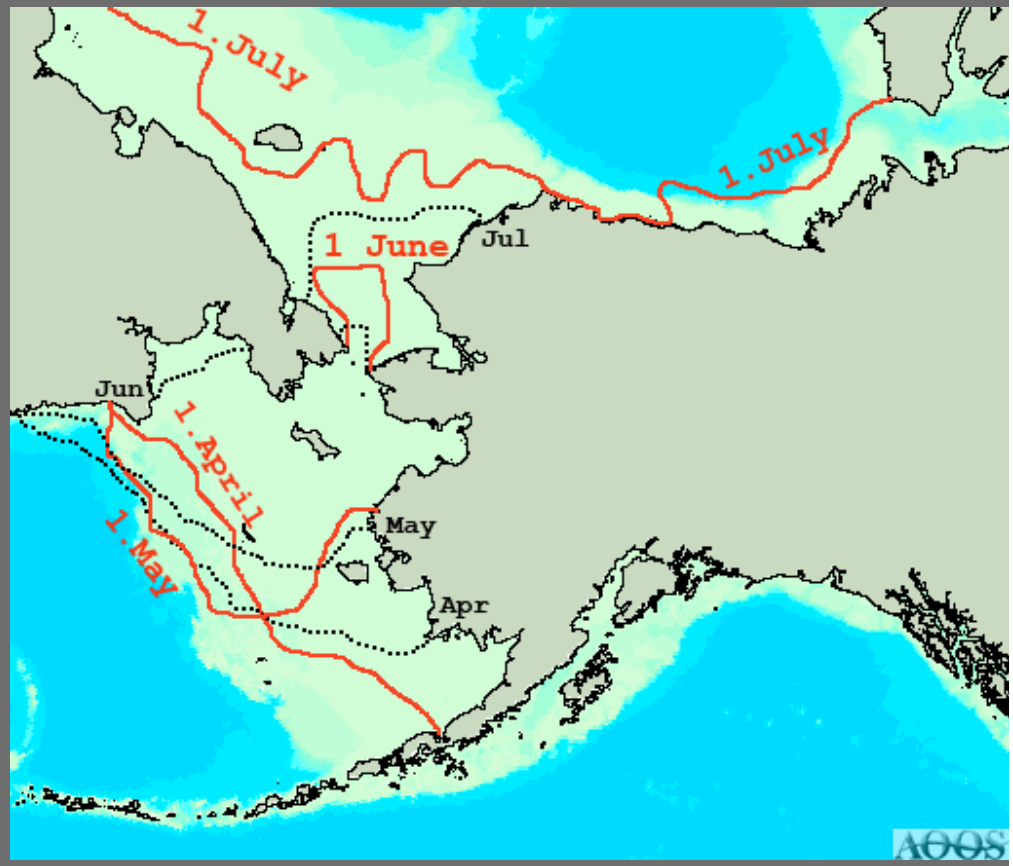



December
1c,2a,b
2c,d,3a,b
1b
Sep.
1a,d,4a,b
March
June
Landfast ice zone
Seasonal ice zone
Perennial ice zone
Stabilizer (1c), transportation corridor (2a)
O(10) km
Platform (2b), source of food & water (2c,d), subsistence (3a)
O(10-100) km
Marine hazard (1b), geologic agent (1d), cultural landscape (3b)
O(10-1000) km
Climate regulation (1a), foodwebs & biodiversity (4a,b)
O(1000) km

2007: Record ice year in Alaska

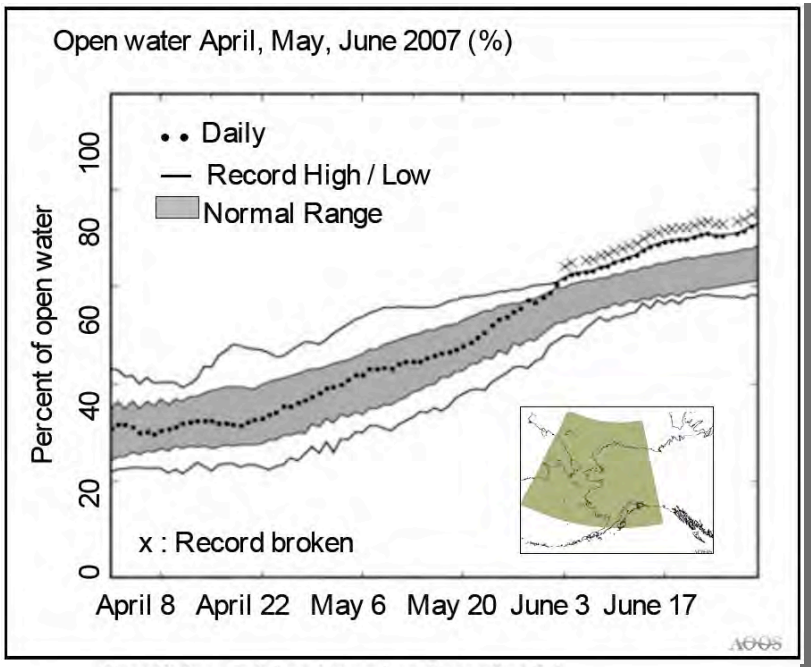


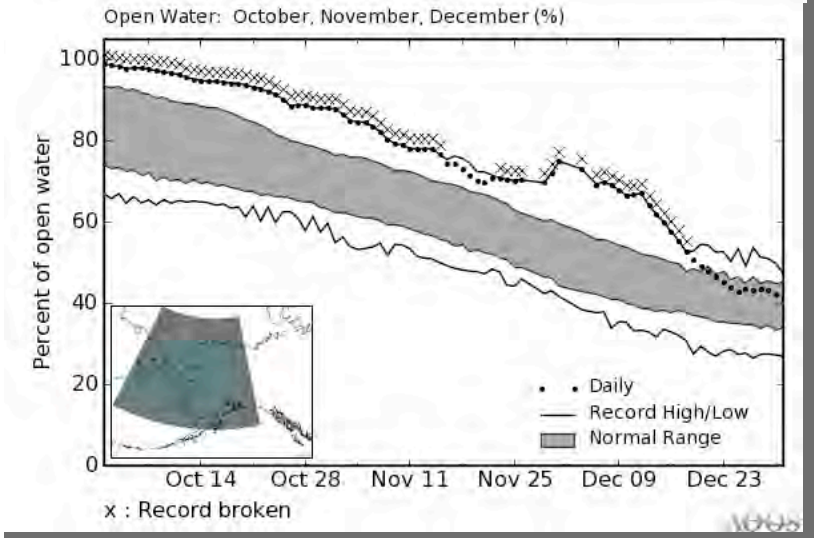


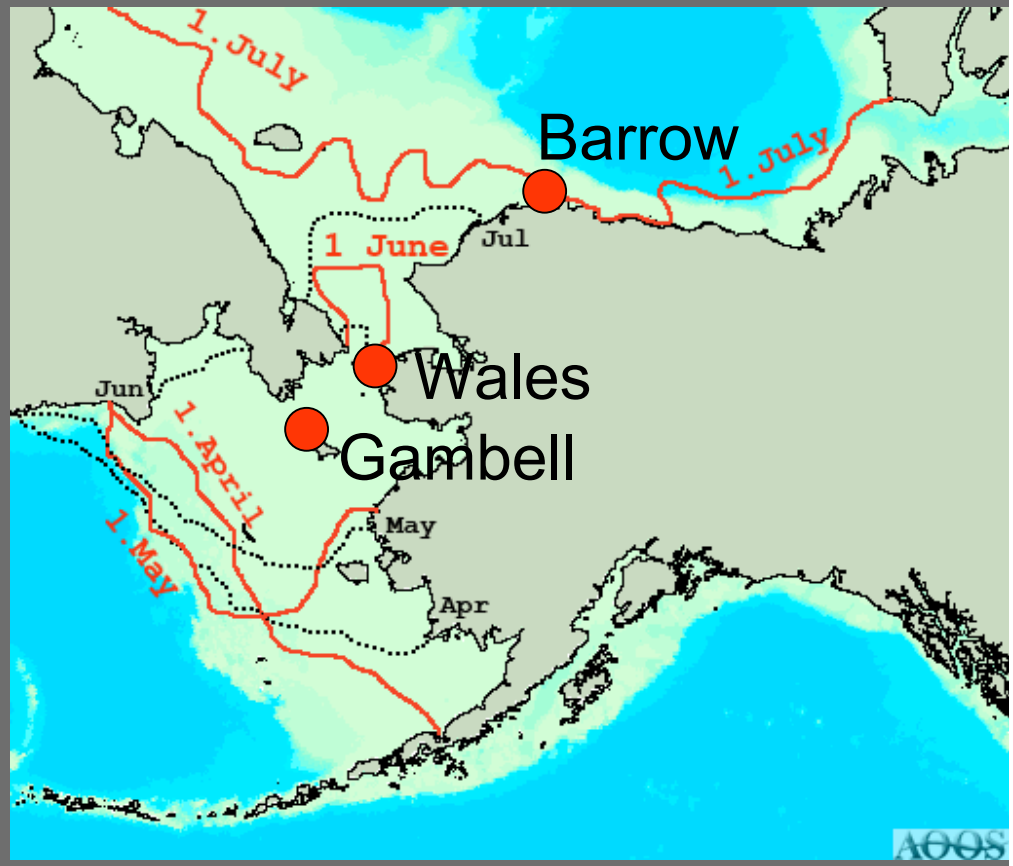


- From June 2007, amount of open water at record high through November 2007
- Poor subsistence hunting conditions for coastal communities, vulnerability to erosion
- Greatly reduced ice hazard for marine shipping

2007: Record ice year in Alaska







- From June 2007, amount of open water at record high through November 2007
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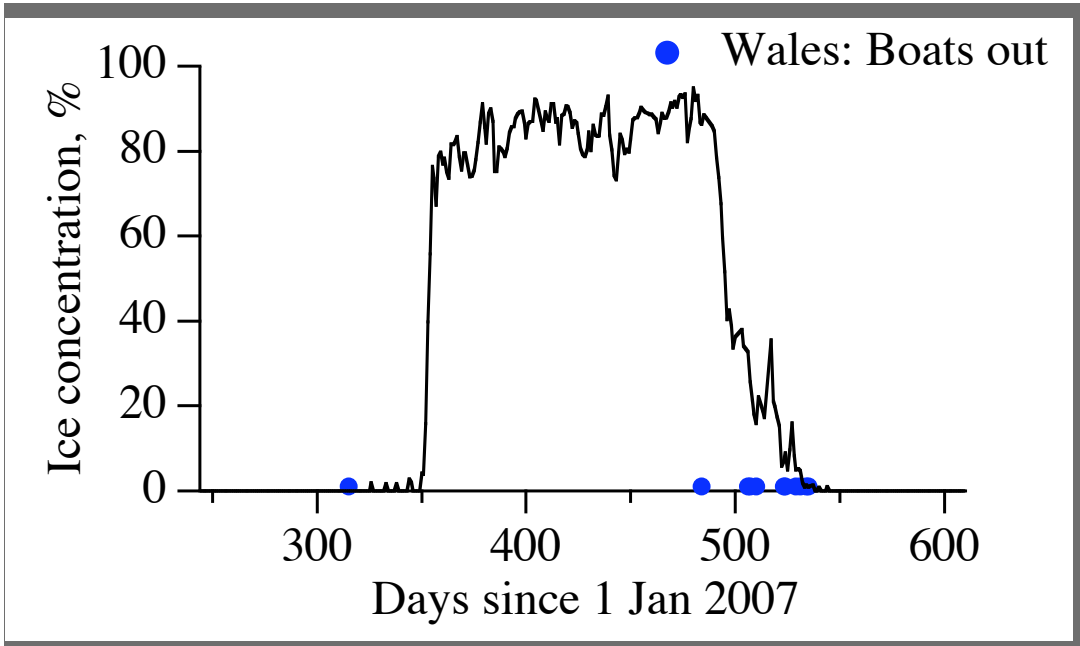
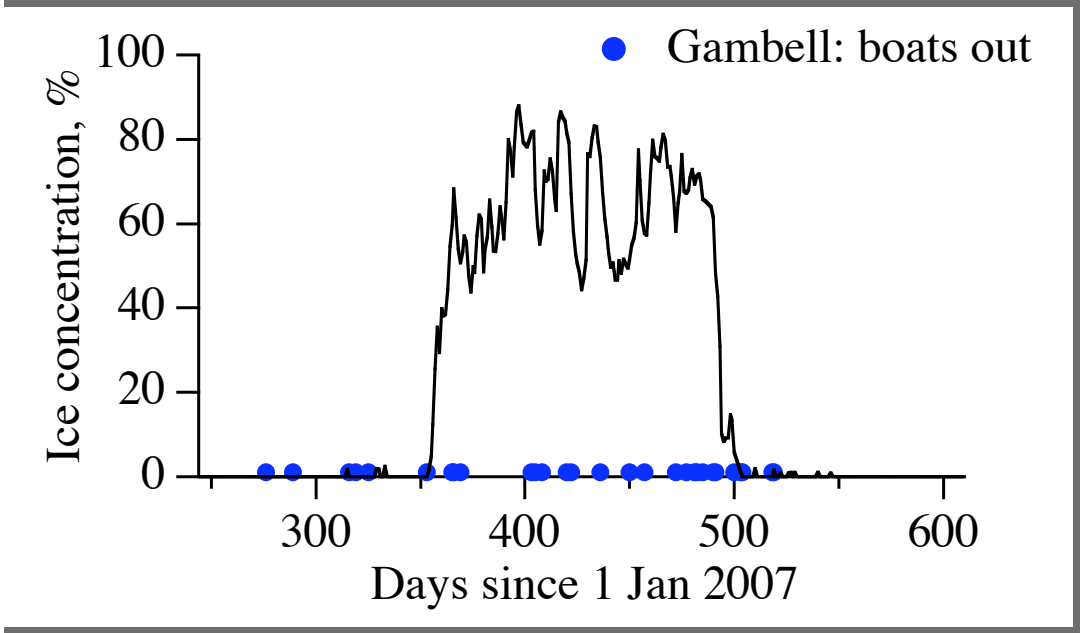
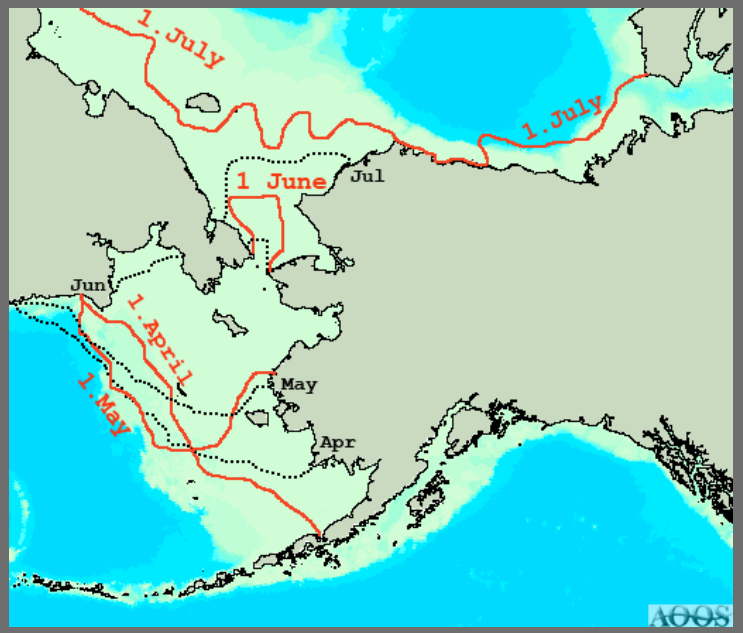
Photos: Winton Weyapuk Jr.

- Use of sea ice as platform by marine mammals (walrus, seals)
- Use of sea ice as a platform for hunting by Iñupiaq & Siberian Yupik hunters



- Observations by ice experts L. Apangalook, W. Weyapuk Jr., and J. Leavitt indicate that access to walrus and bearded seal has increased on St. Lawrence Island and decreased in Bering Strait and Barrow due to changing ice conditions





Integrated sea-ice observations at Barrow, AK

- *Remote sensing* (km-scale)
- *Coastal radar* (sub-km scale)
- *Thickness and topography* (sub-km)
- *Ice mass-balance* site (10s m-scale)
- *Local Iñupiaq ice observations* (J. Leavitt, A. Brower Sr. and others)

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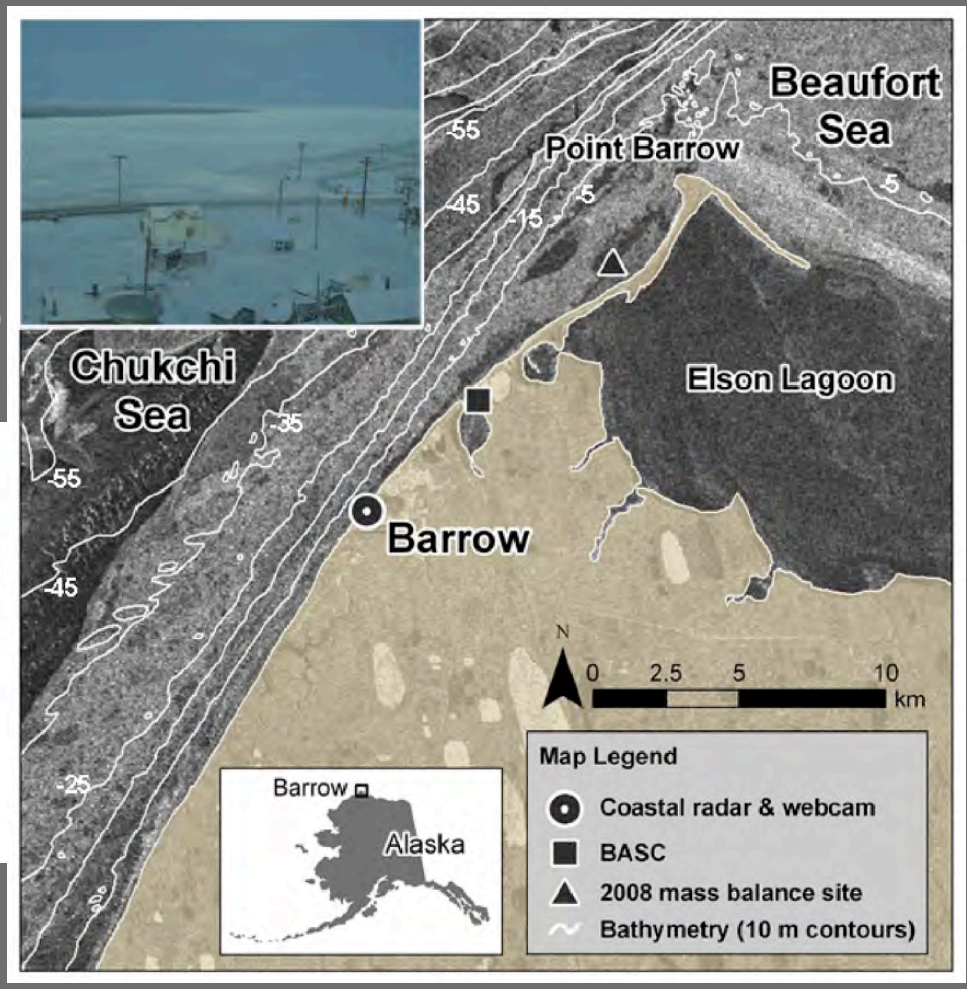
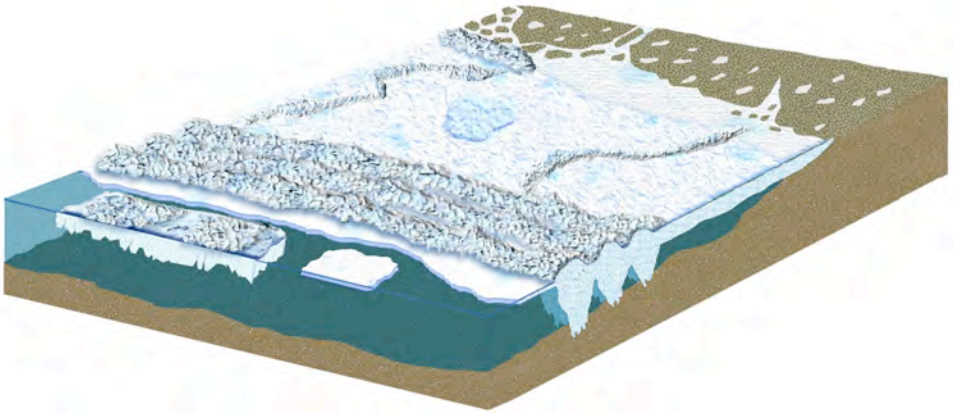


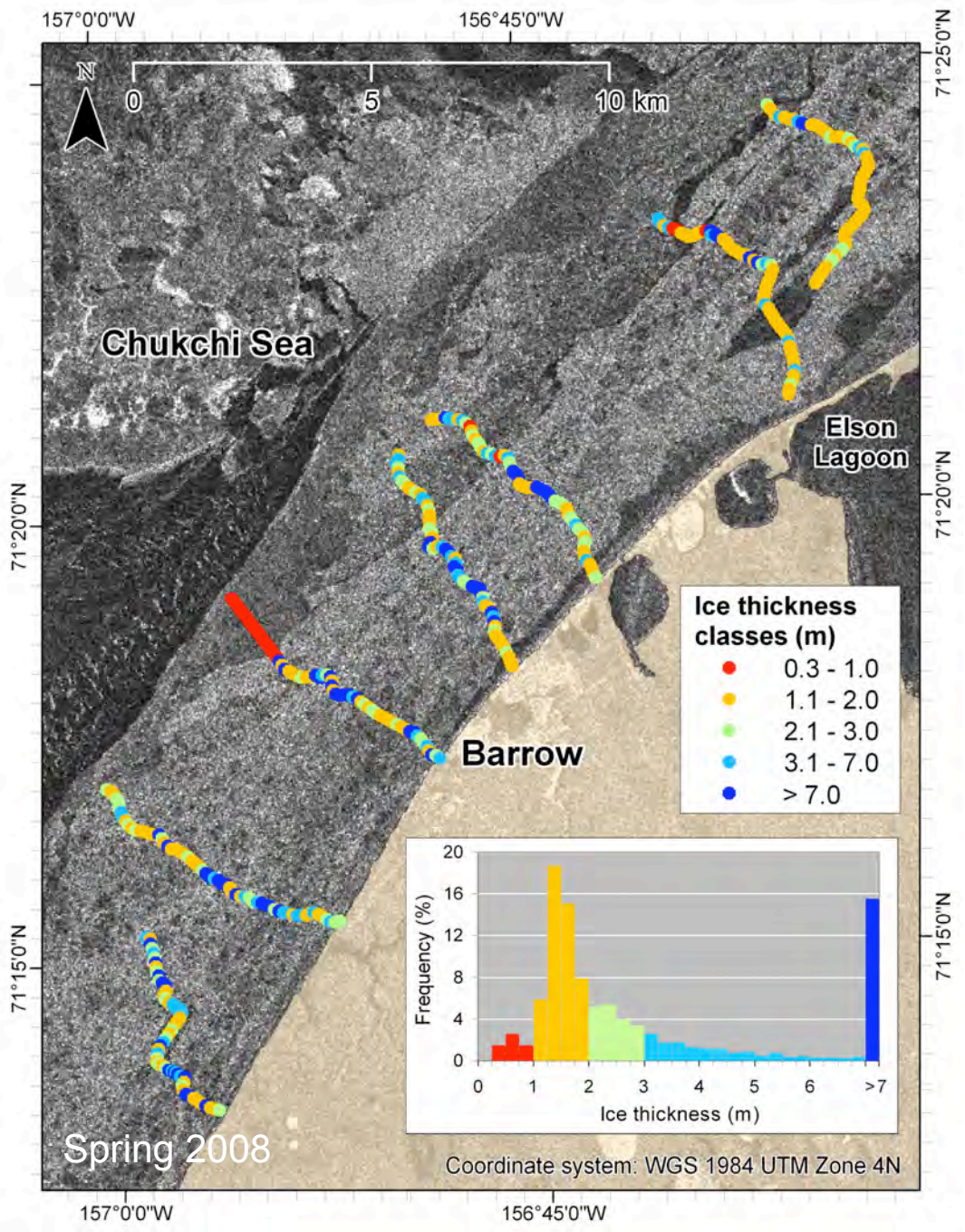


- *Seasonal Ice Zone Observing Network (SIZONet)*
  IPY Project with support from NSF-AON and NOAA AK Ocean Observing System

M. Druckenmiller et al.

Tracking ice use & ice stability

- Trails for hunting camps established annually
- Thickness (EMI) & surf. elevation (DGPS) data collected trail on system
- Interviews with hunters

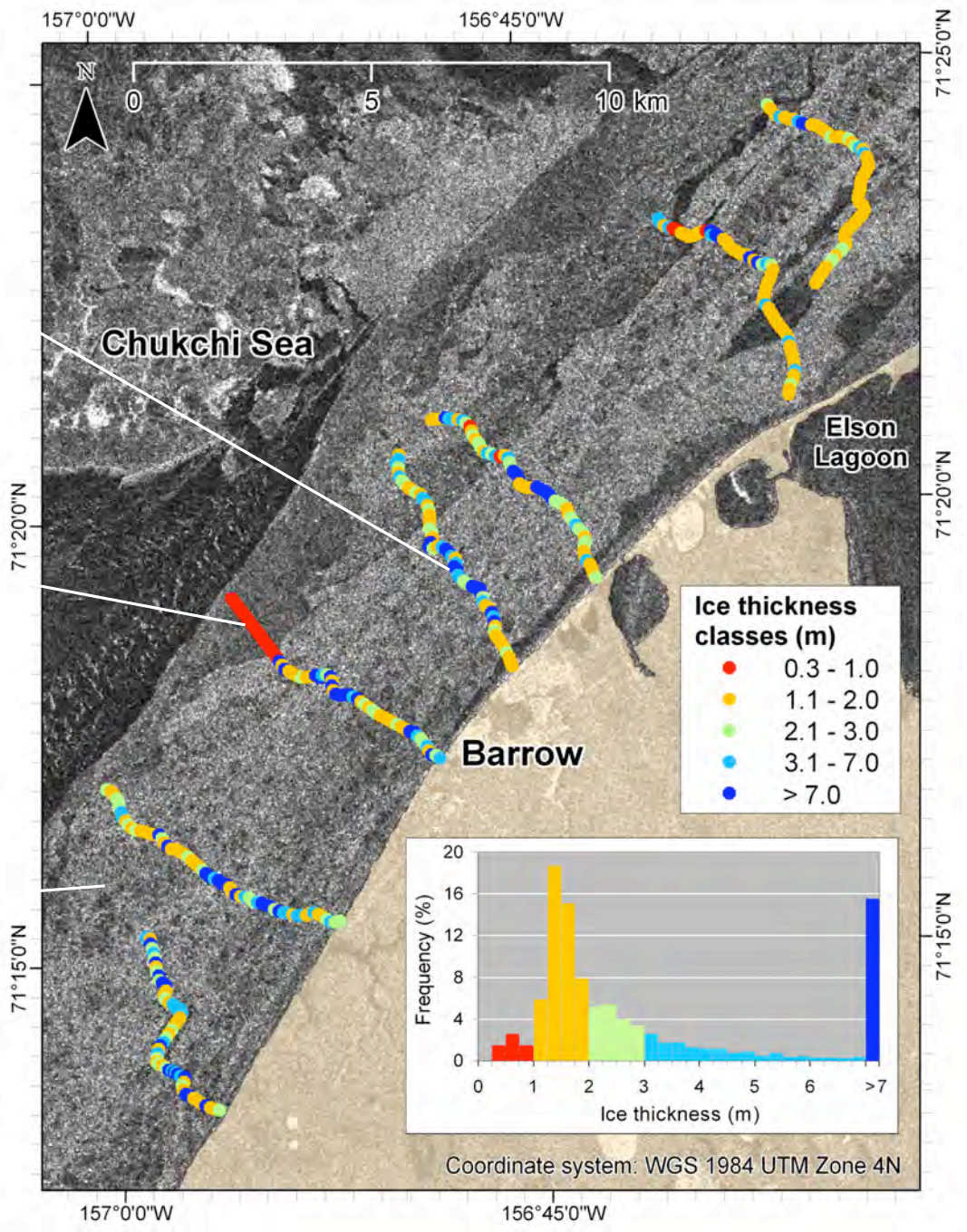


Coastal sea-ice change during past two decades

Ice is rougher with fewer pressure ridges, reducing landfast ice stability

Thinner ice impacts load-bearing capacity & harvesting of whales

Lack of multiyear ice & more dynamic ice pack reduce landfast ice stability and impact access to marine mammals

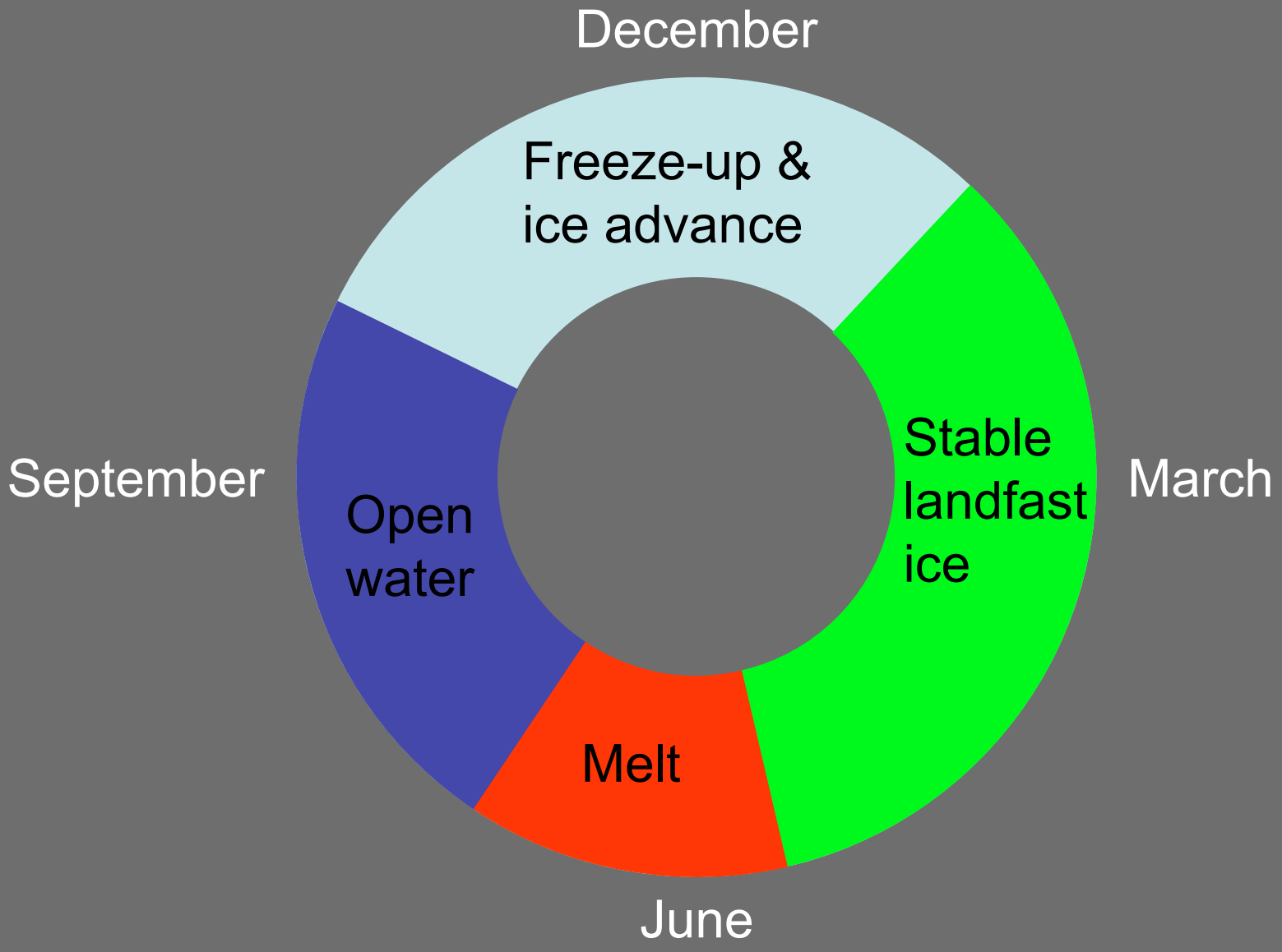


Local environmental, indigenous knowledge

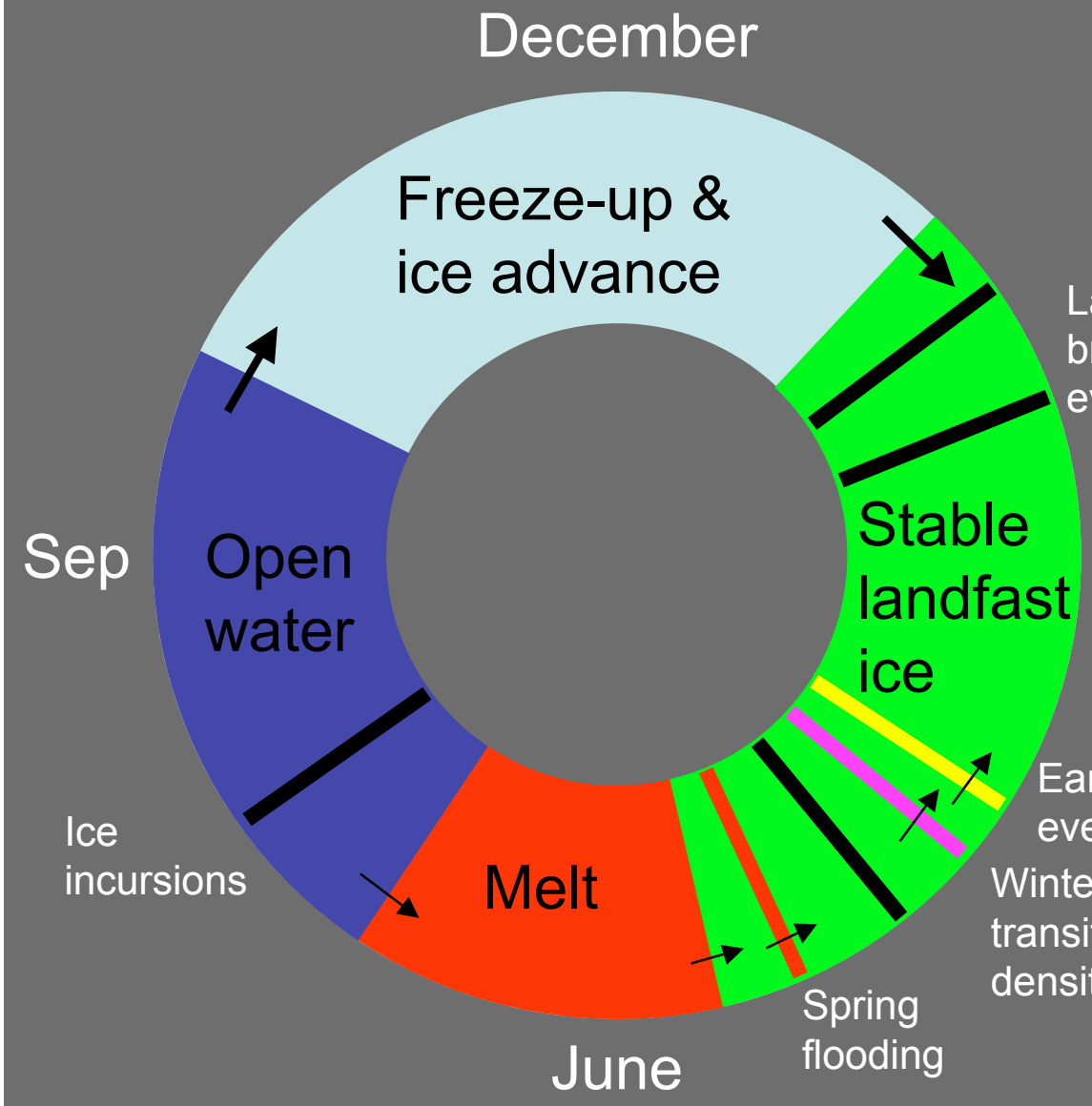
- Sea-ice stability
- Broad assessment & monitoring of range of variables
- Need for quick decisions

Animation: Miho Aoki, ARSC

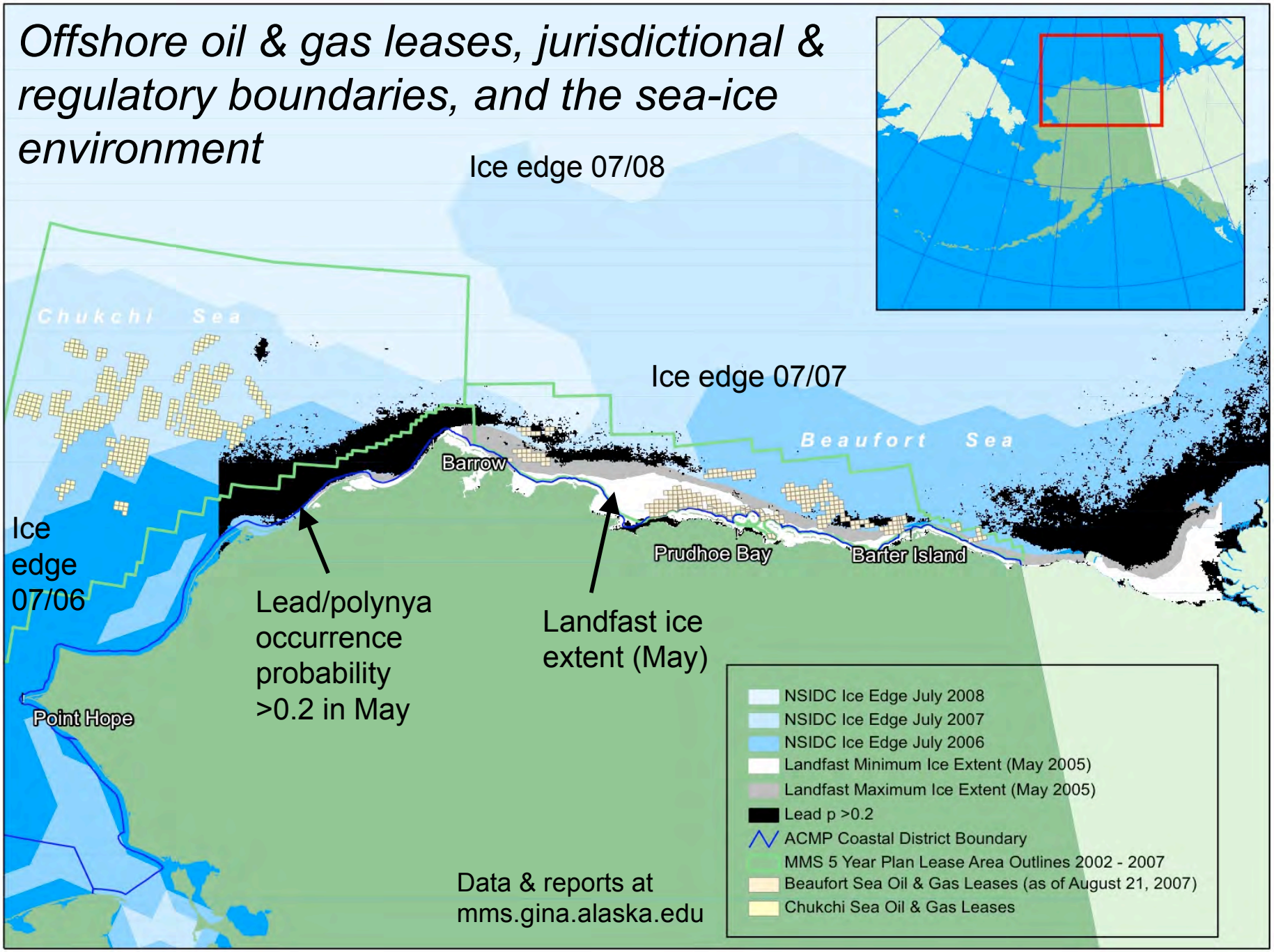
Annual sea-ice cycle & operational windows



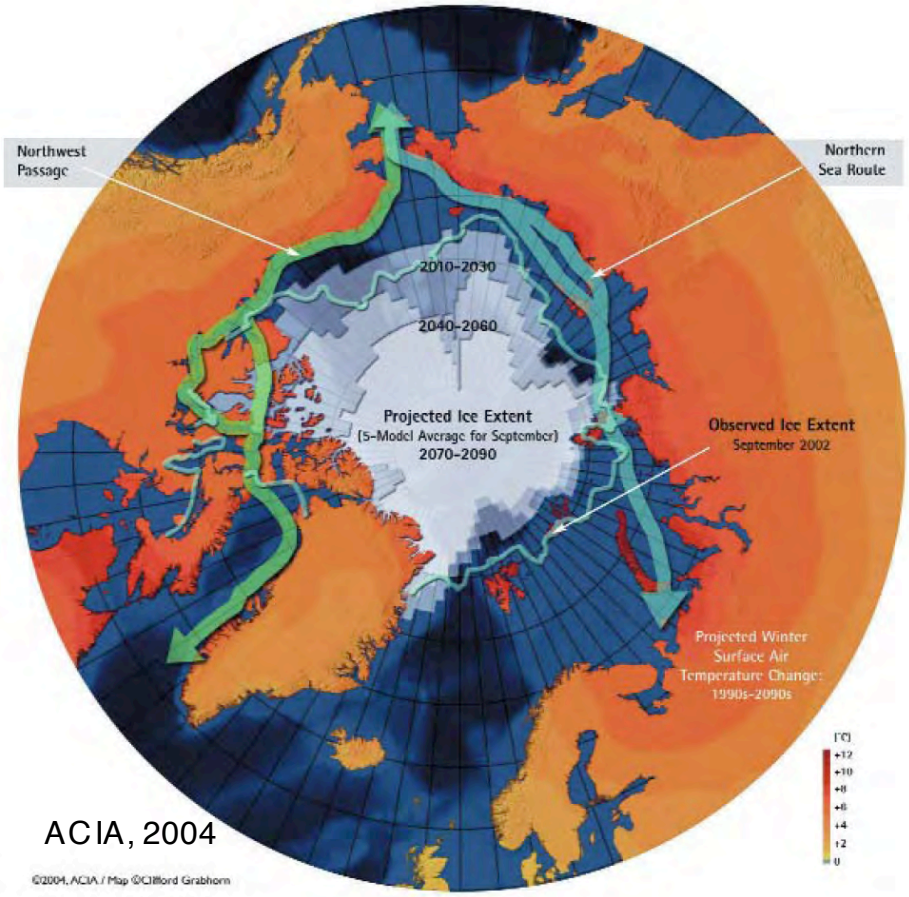
Annual sea-ice cycle & operational windows



- Open-water operations regime longer, potential for ice incursions
- Landfast-ice operations regime shorter, potential for break-outs
- Coastal & offshore ice regime more variable in time & space
- Highly specific to a given location

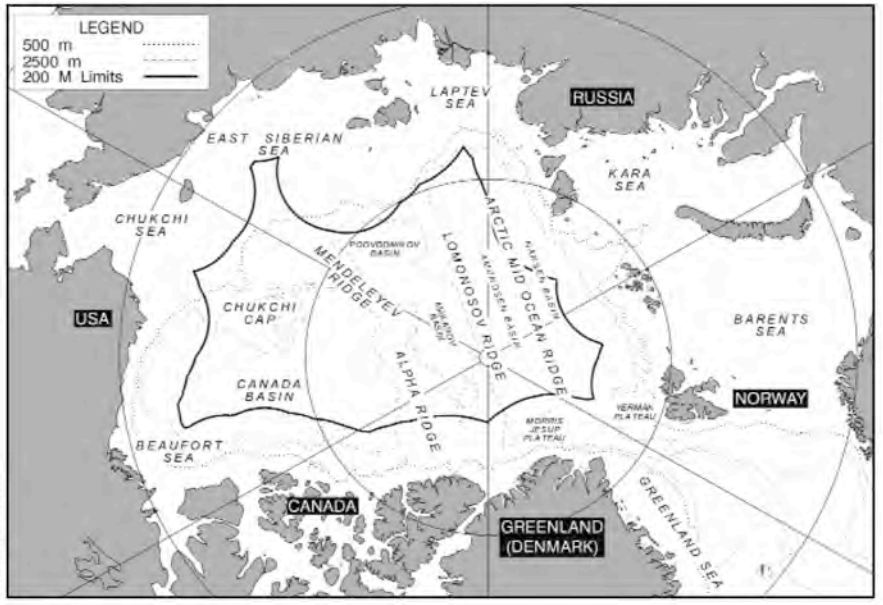

Offshore oil & gas leases, jurisdictional & regulatory boundaries, and the sea-ice environment
Ice edge 07/08
Ice edge 07/07
Ice edge 07/06
Chukchi Sea
Beaufort Sea
Barrow
Prudhoe Bay
Barter Island
Point Hope
Lead/polynya occurrence probability >0.2 in May
Landfast ice extent (May)
Data & reports at mms.gina.alaska.edu
NSIDC Ice Edge July 2008
NSIDC Ice Edge July 2007
NSIDC Ice Edge July 2006
Landfast Minimum Ice Extent (May 2005)
Landfast Maximum Ice Extent (May 2005)
Lead p >0.2
ACMP Coastal District Boundary
MMS 5 Year Plan Lease Area Outlines 2002 - 2007
Beaufort Sea Oil & Gas Leases (as of August 21, 2007)
Chukchi Sea Oil & Gas Leases

"Reduced sea ice is very likely to increase marine transport and access to resources."



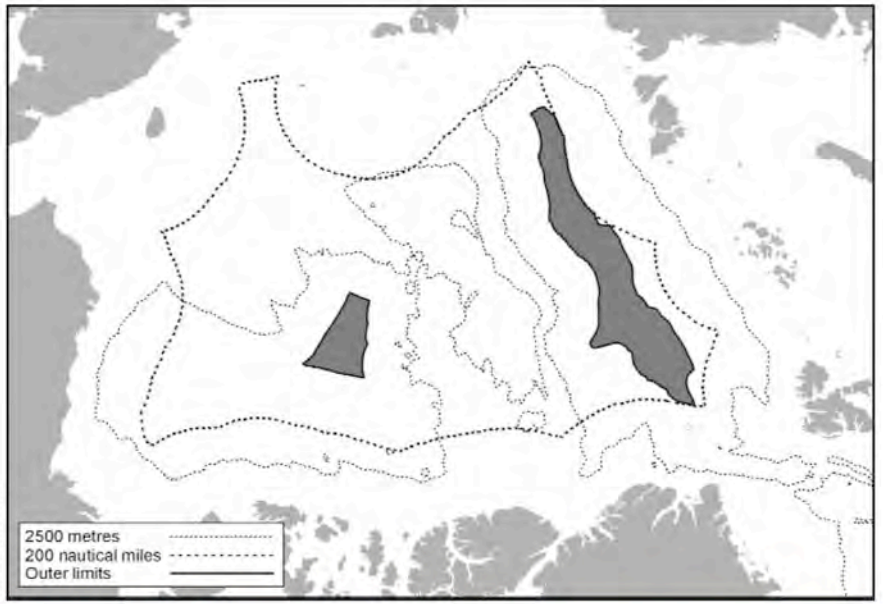
ACIA, 2004

Arctic Research Commission, 2004



Ron Macnab

Map showing the coastal Arctic states, their joint Exclusive Economic Zones (EEZs), and the natural prolongations of their land territories.



Ron Macnab

Response to changing conditions:

Reexamination of EEZ/territorial claims in the context of marine transportation and resource extraction (Russia, Denmark/Greenland, Canada)

Conclusions

- Arctic sea-ice cover has been declining in volume for past three decades, recent, extreme reductions in summer ice extent driven by atmospheric warming, more mobile ice cover and ice-albedo feedback
- Key Arctic sea-ice processes (such as ponding and impact on albedo) still need improved representation in large-scale models; climate model utility for regional assessments needs to be carefully examined
- Sea ice provides services to broad range of ice users; changing Arctic results in increasing overlap of such uses
- Increasing conjoined sea-ice use requires careful planning based on useful data & information, a voice for local expertise and new partnerships

Support by NSF, NOAA, University of Alaska and numerous people and organizations in northern Alaska gratefully acknowledged.