Recent Arctic climate change: Observations, drivers and impacts

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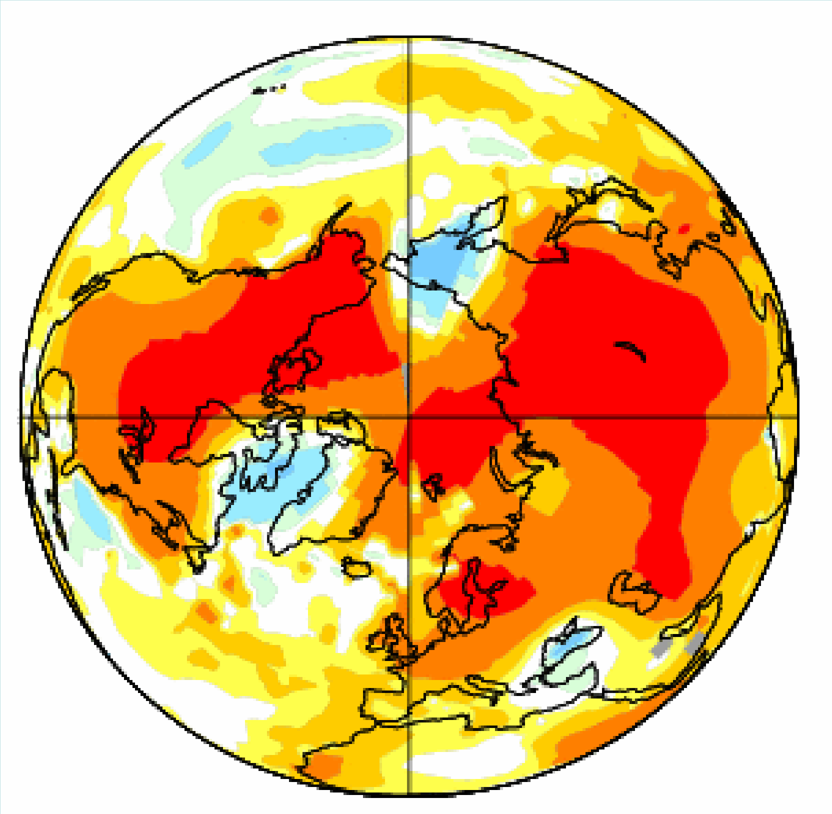
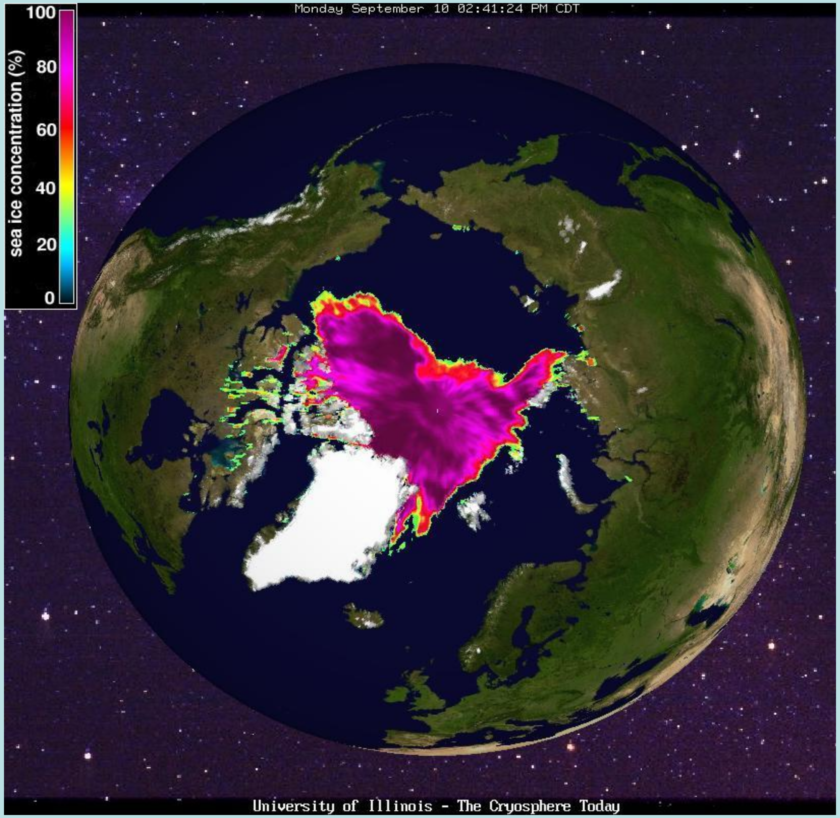




Outline

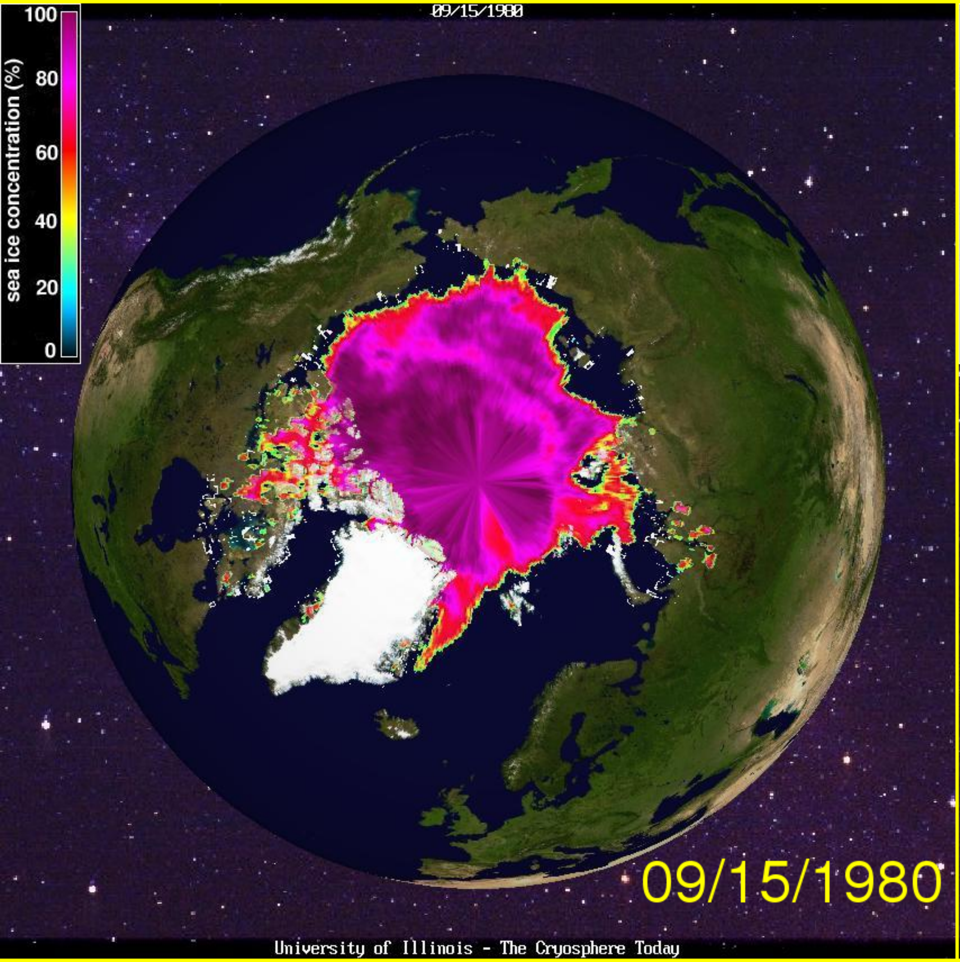
- **Recent Arctic changes**
  -- focus on sea ice, ocean, hydrology

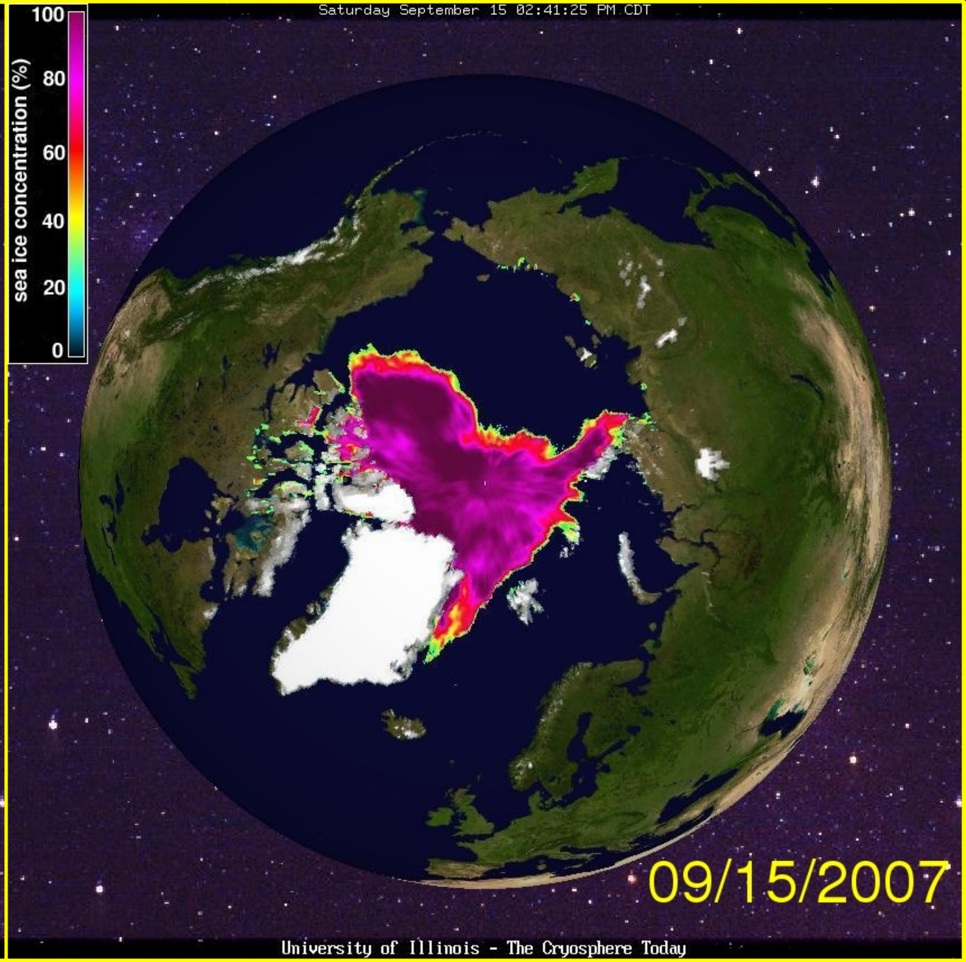
- **Drivers of recent Arctic changes**
  -- global linkages

- **Impacts on Alaska**
  -- from: Global Climate Change Impacts in the U.S. (2009)

Arctic sea ice concentrations

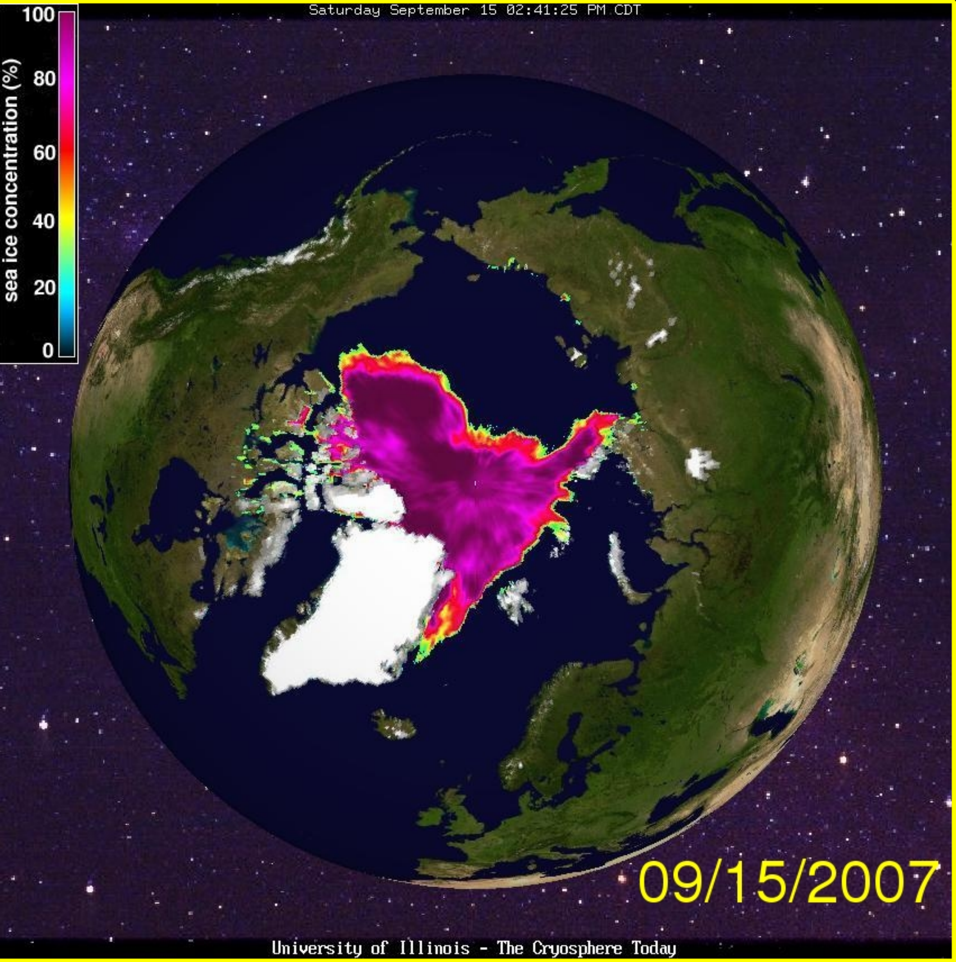
Sep. 15, 1980 **Sep. 15, 2007**



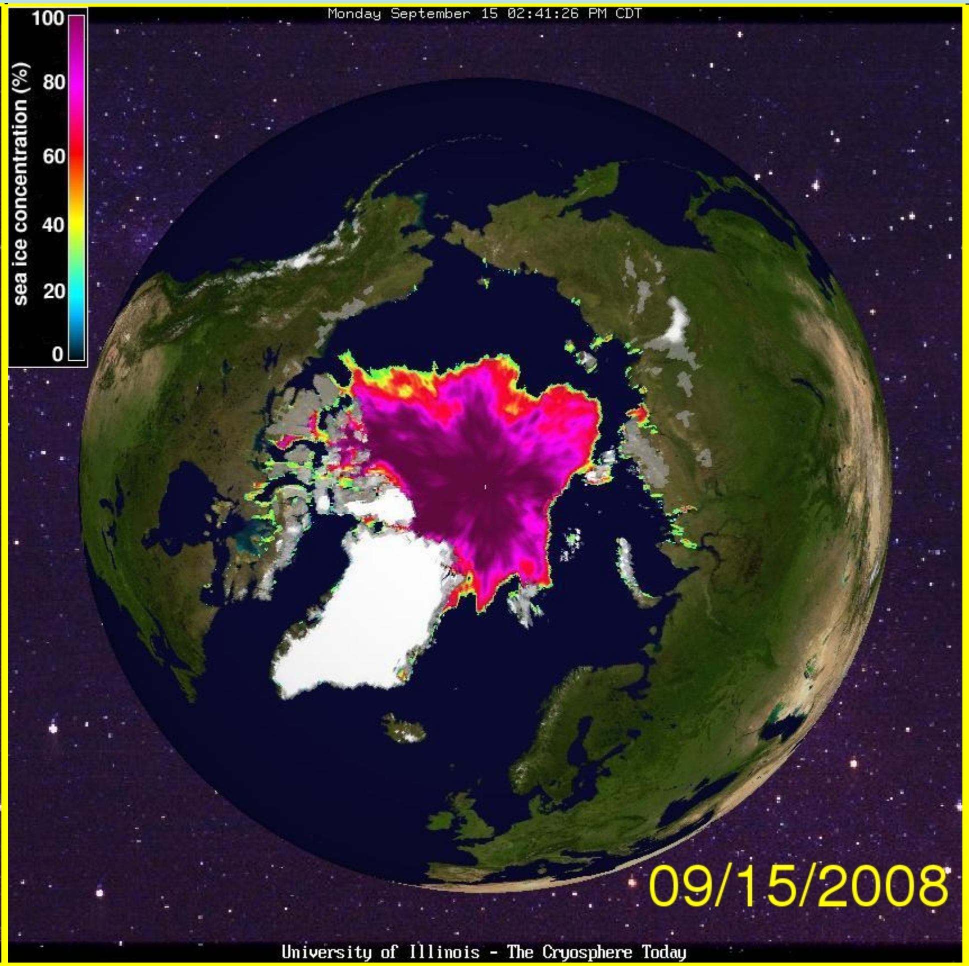


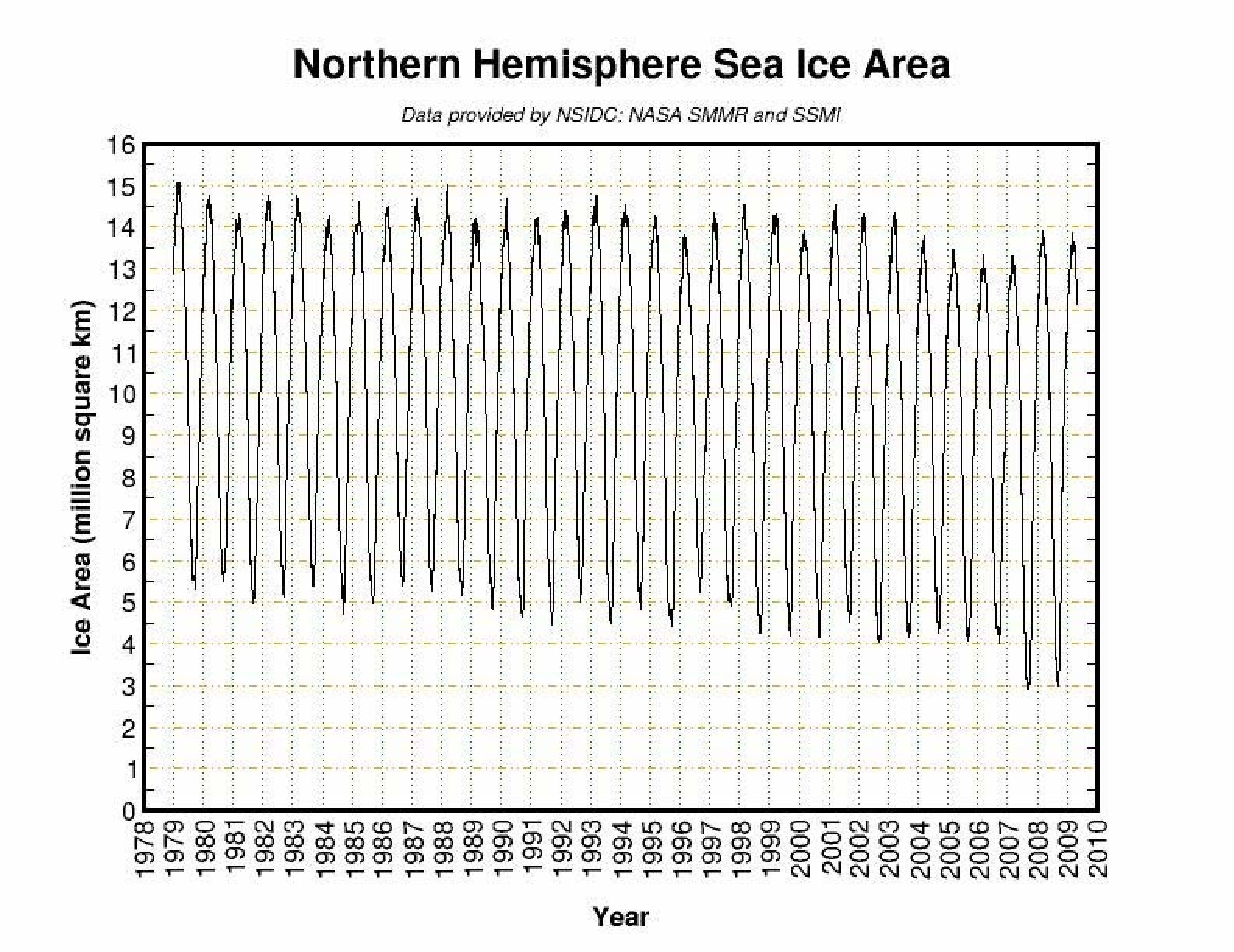
Arctic sea ice concentrations

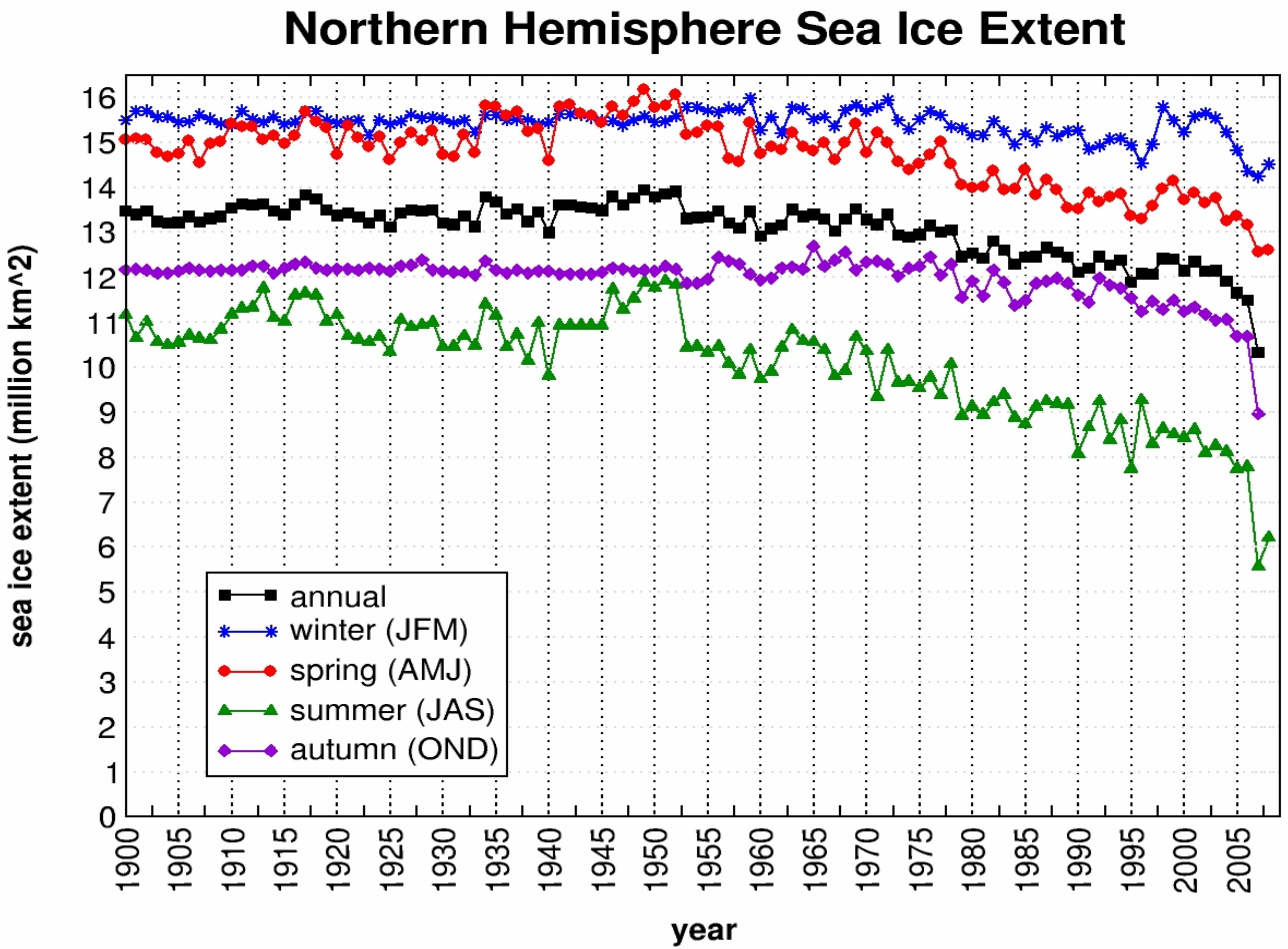
Sep. 15, 2007



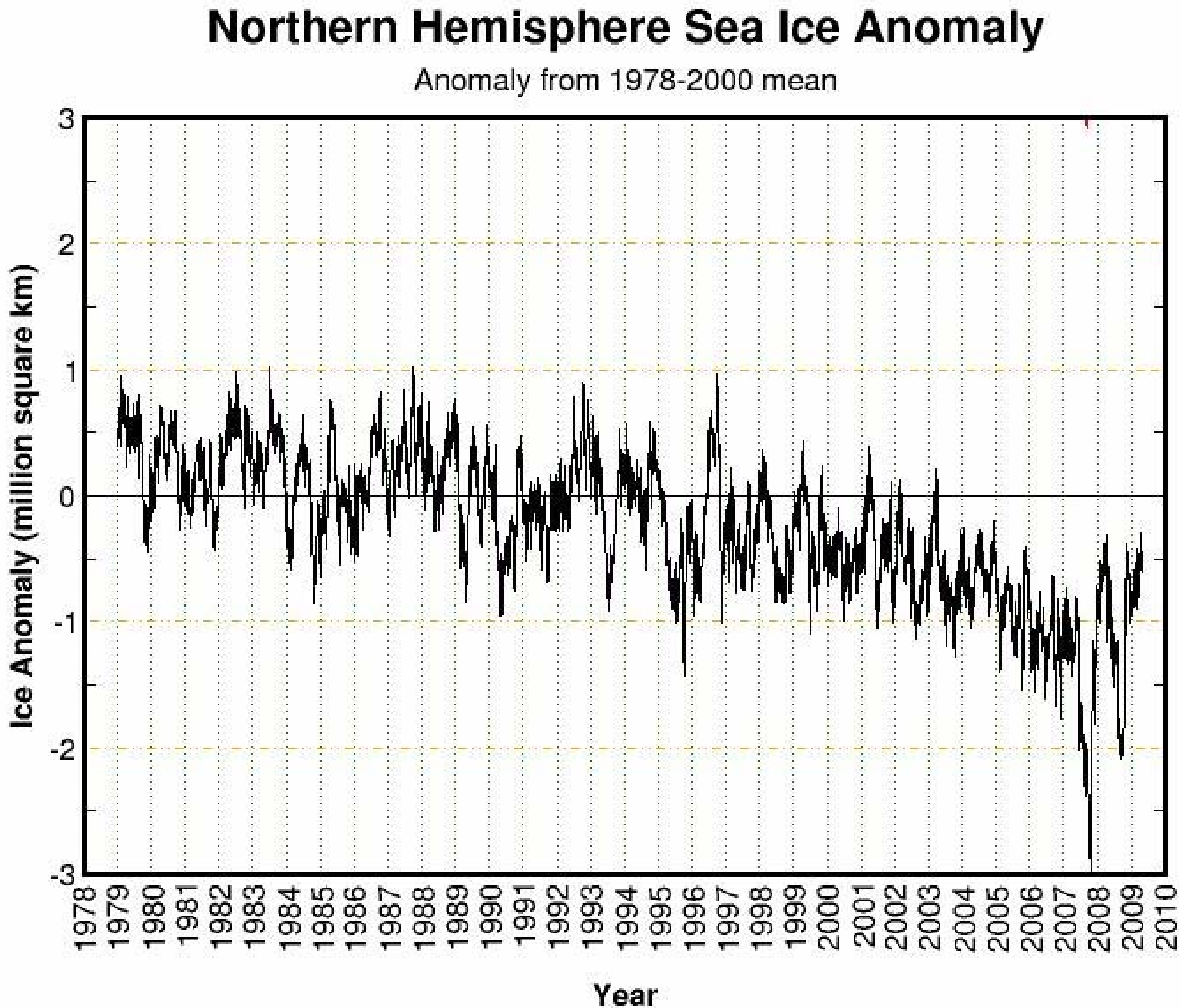
Sep. 15, 2008




Northern Hemisphere Sea Ice Area
Data provided by NSIDC: NASA SMMR and SSMI
Ice Area (million square km)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
1978
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
Year



Northern Hemisphere Sea Ice Extent
sea ice extent (million km^2)
year
annual
winter (JFM)
spring (AMJ)
summer (JAS)
autumn (OND)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005



Northern Hemisphere Sea Ice Anomaly
Anomaly from 1978-2000 mean
Ice Anomaly (million square km)
3
2
1
0
-1
-2
-3
1978
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
Year

Why the extreme retreat of sea ice in 2007 and 2008?

- Preconditioning
  -- warmer intermediate-level ocean water
  -- export of older, thicker ice in previous years
- Favorable winds
- Solar heating (albedo-temperature feedback)

Three sources of Arctic Ocean water temperatures

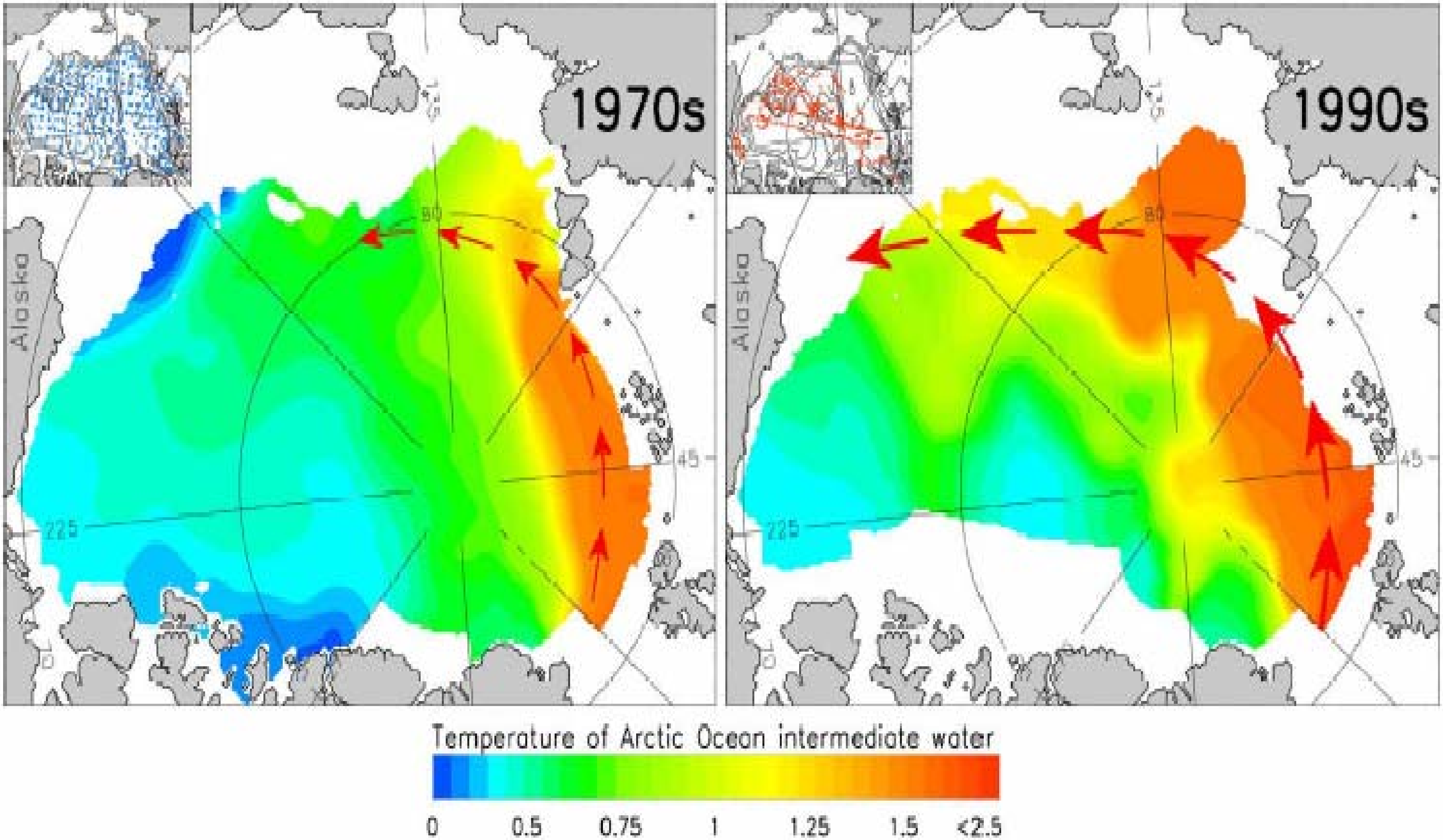
- **Historical records (esp. Russian measurements)**
  -- decadal climatologies

- **IARC cruises, 2002-2008**
  -- Nansen-Amundsen Basin Observing System, NABOS)

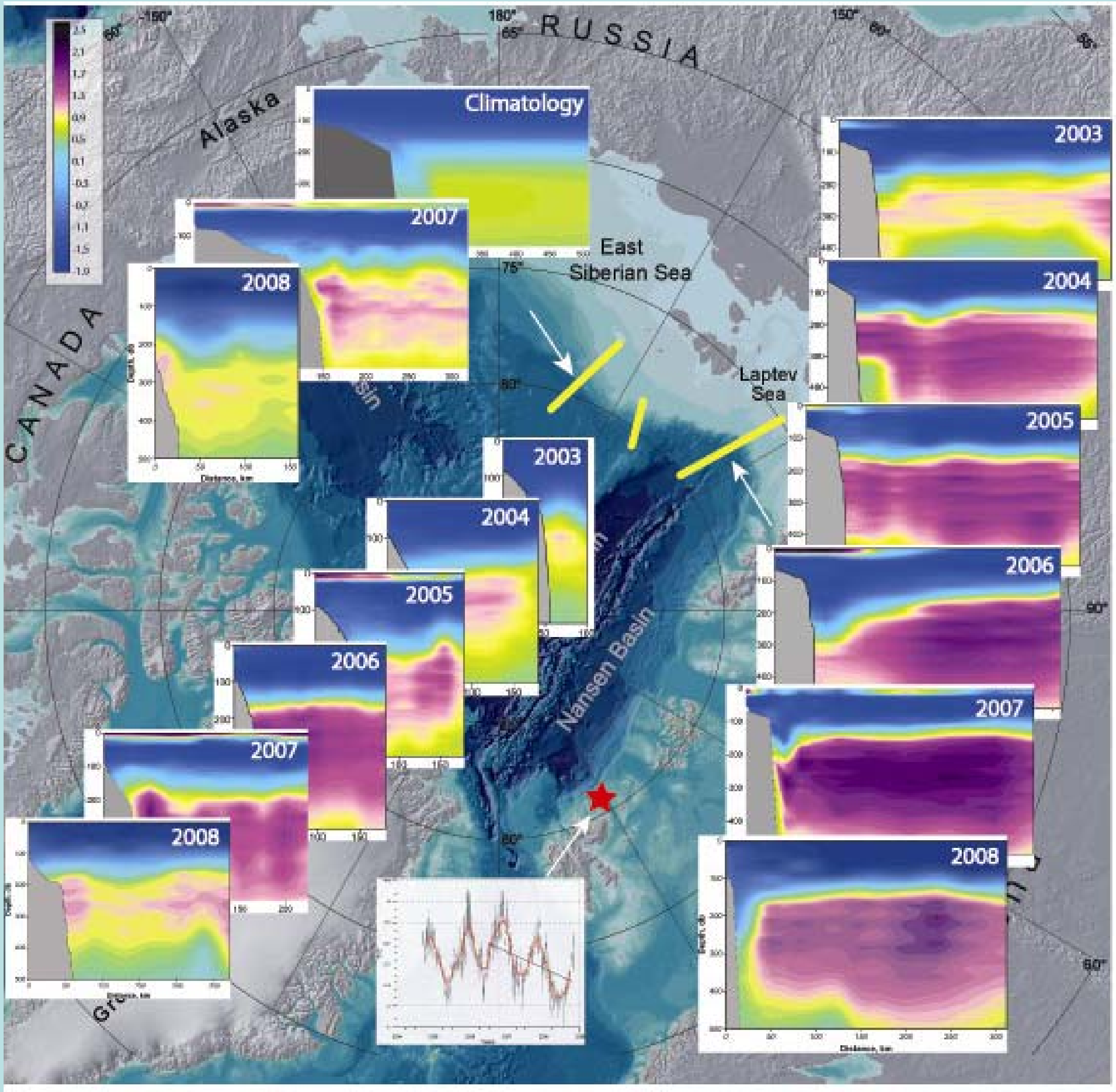
- **IPY intensive observations, 2007-2008**

Temperature change of Arctic Ocean intermediate water

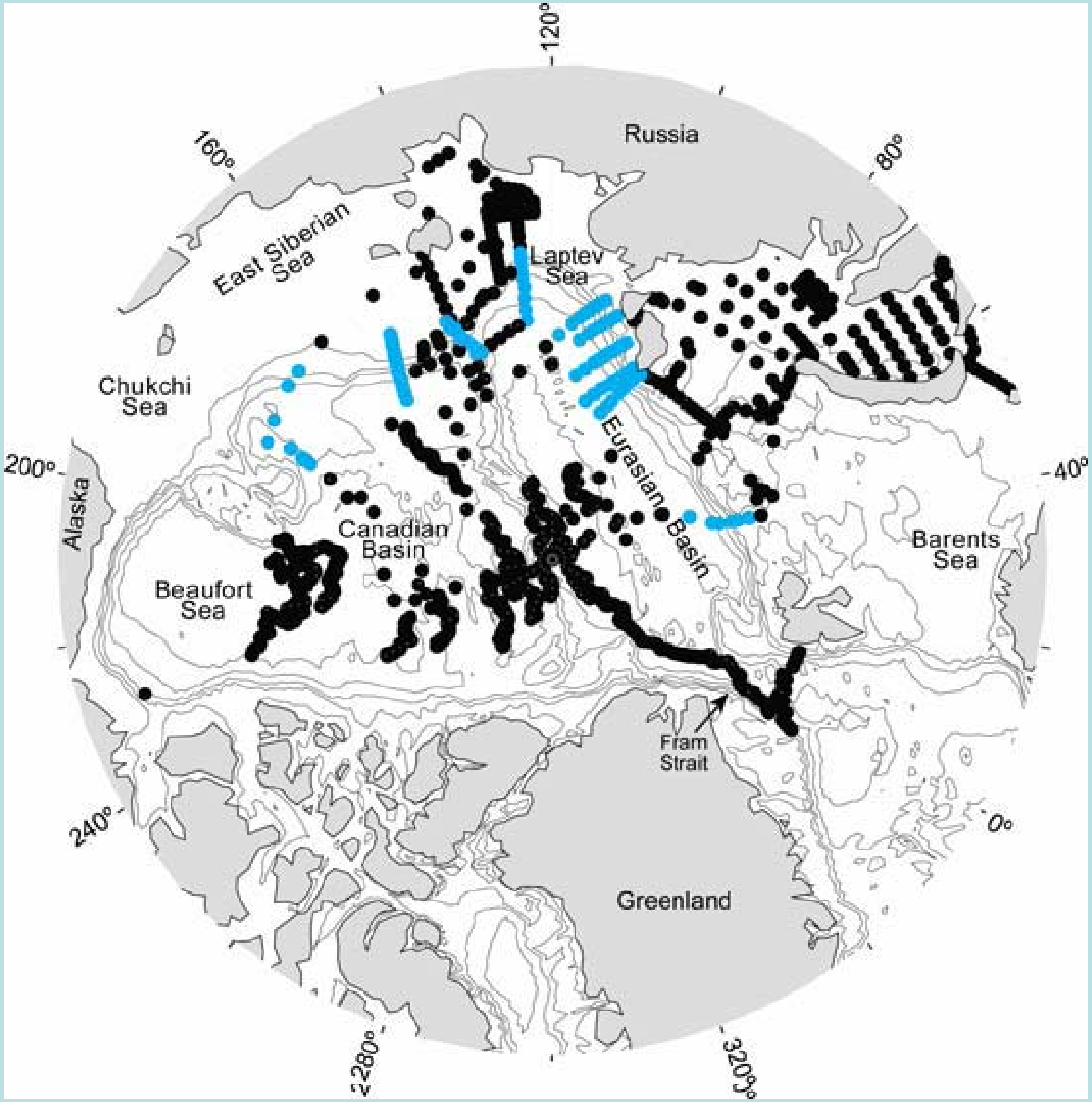
[from Polyakov et al., 2004]



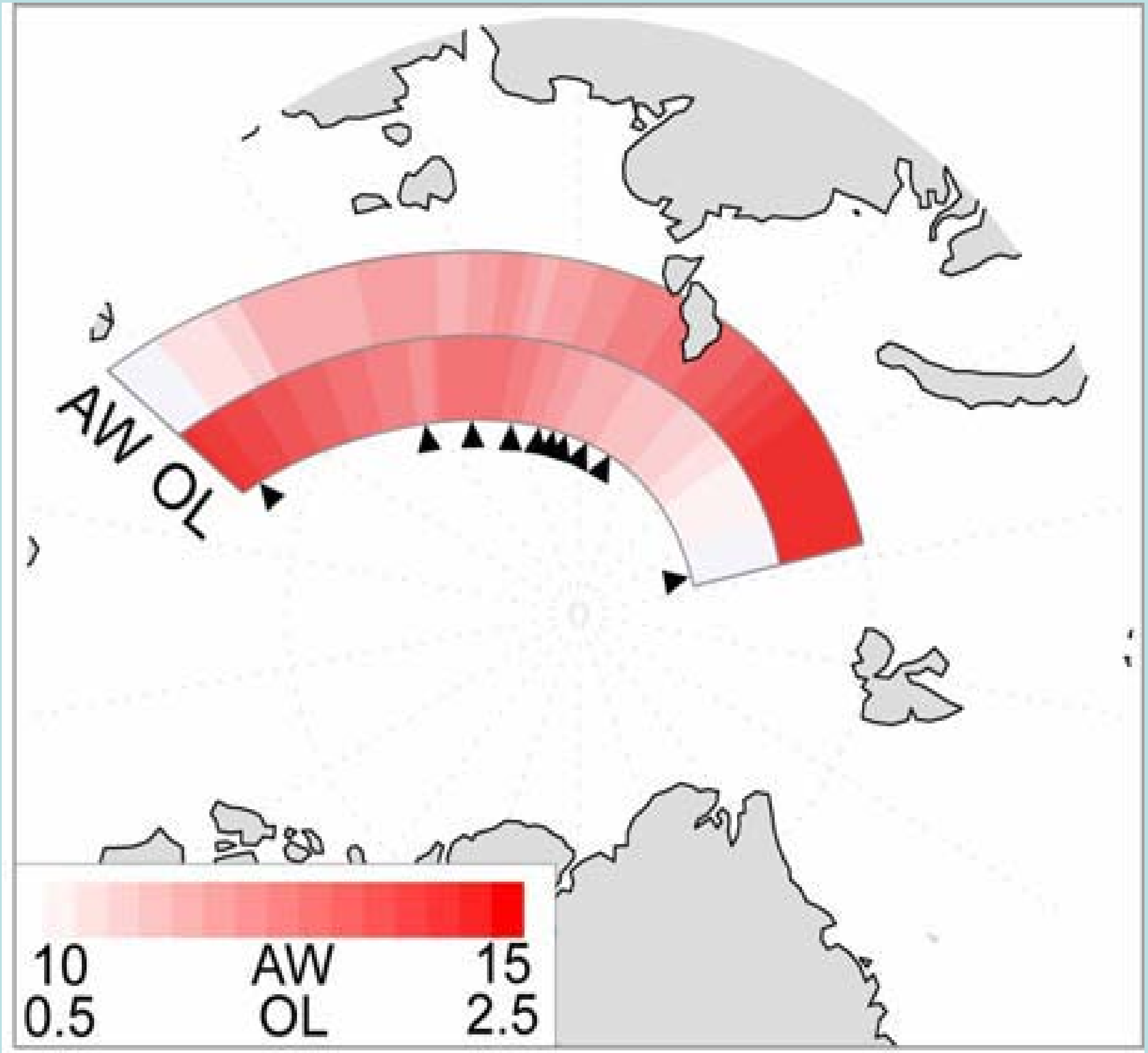
2008 NABOS cruise results:
Cross-sections of Arctic Ocean temperature



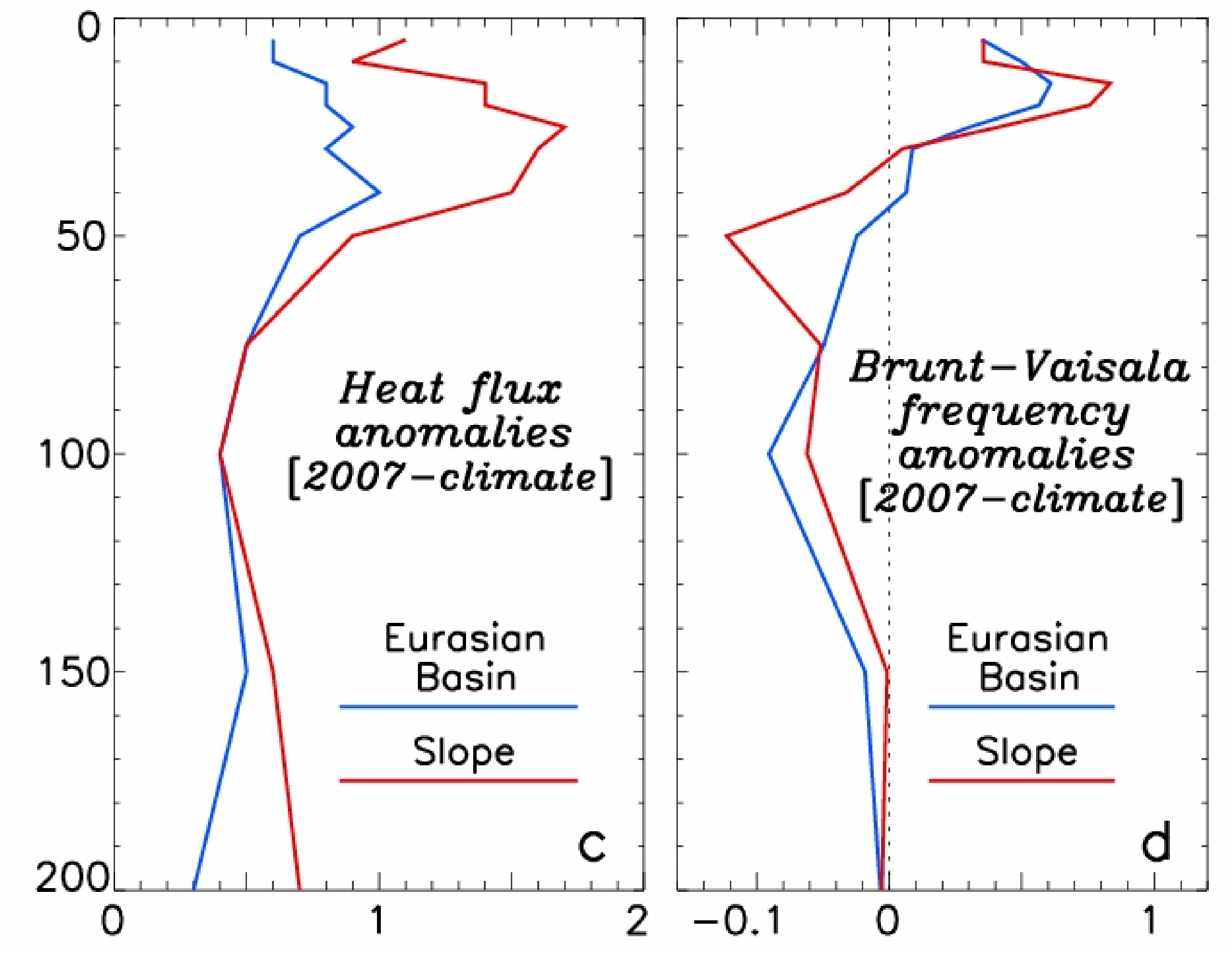
Arctic Ocean stations during 2007 (IPY)



2007 Arctic Ocean heat anomalies:
AW = Atlantic Water, OL = Overlying Layer
[Polyakov et al., 2009]

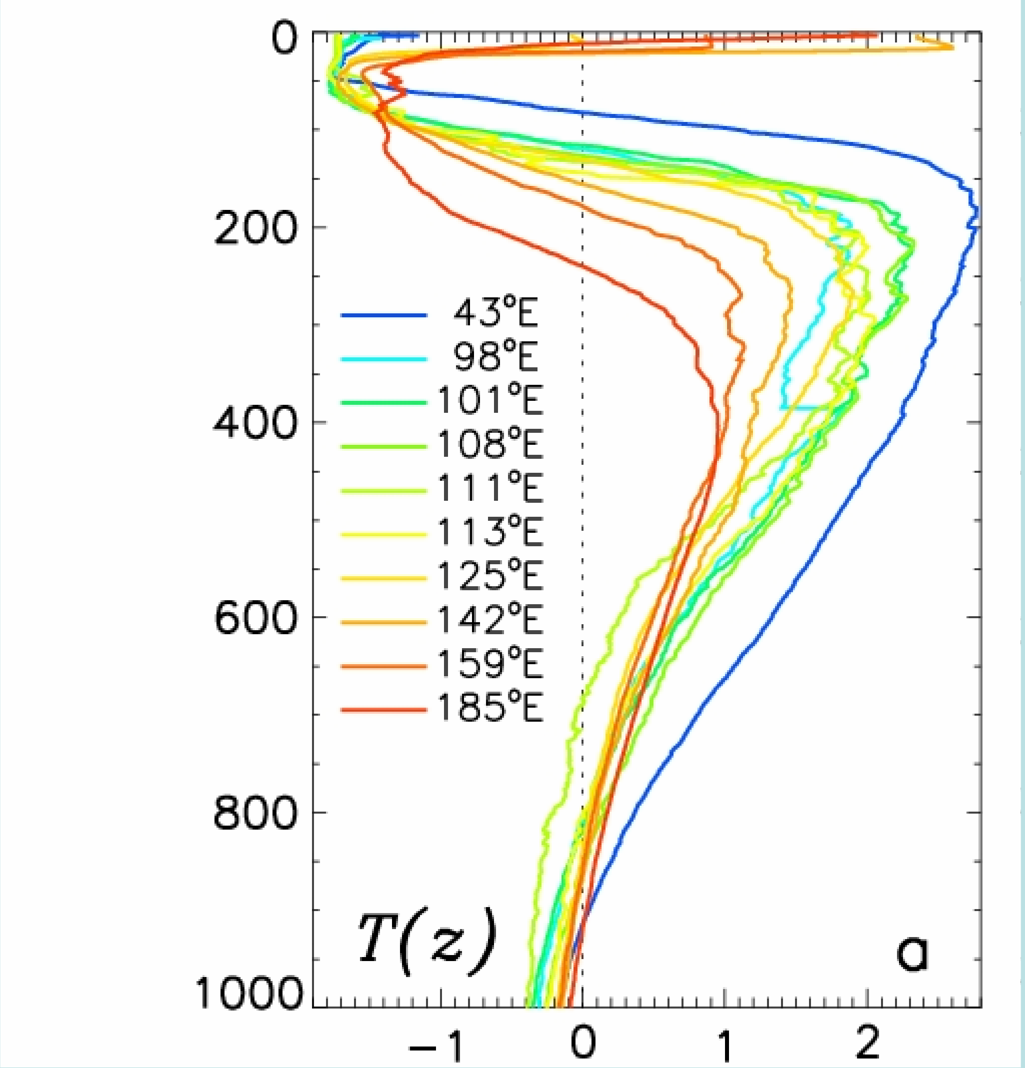


2007 anomalies of vertical heat flux, stability
[Polyakov et al., 2009]



2007 Arctic Ocean temperatures vs. depth – longitudes

[from Polyakov et al., 2009]



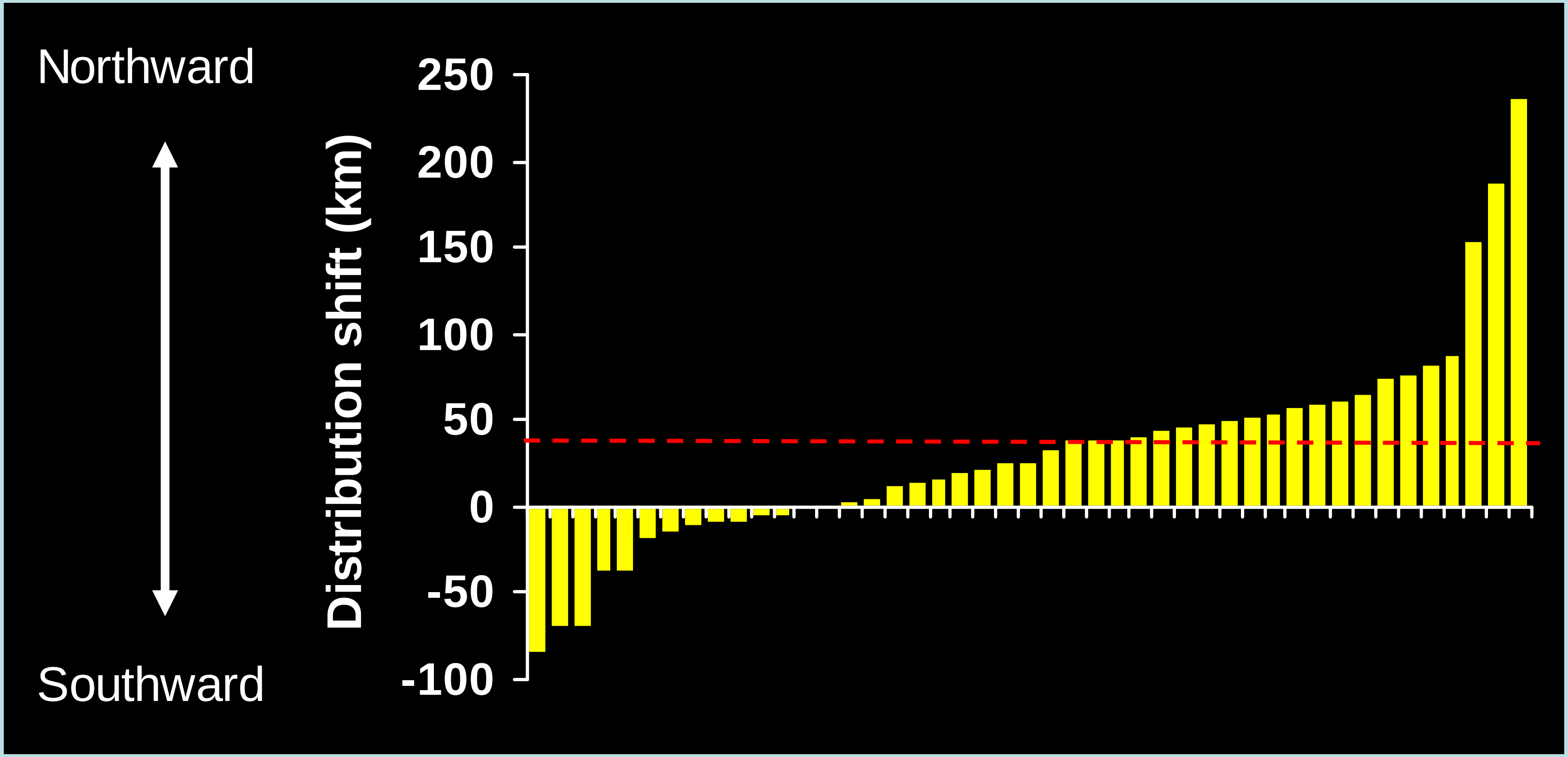
Conclusion

- **Atlantic Water warming, reduced stratification have increased upward heat flux by ~ 0.5 W/m2**

- **Corresponding ice thickness reduction: 24-35 cm**

  [vs. ~30 cm loss due to surface melt]

Shifts in center of distribution for 45 taxa in SE Bering Sea, 1982-2006

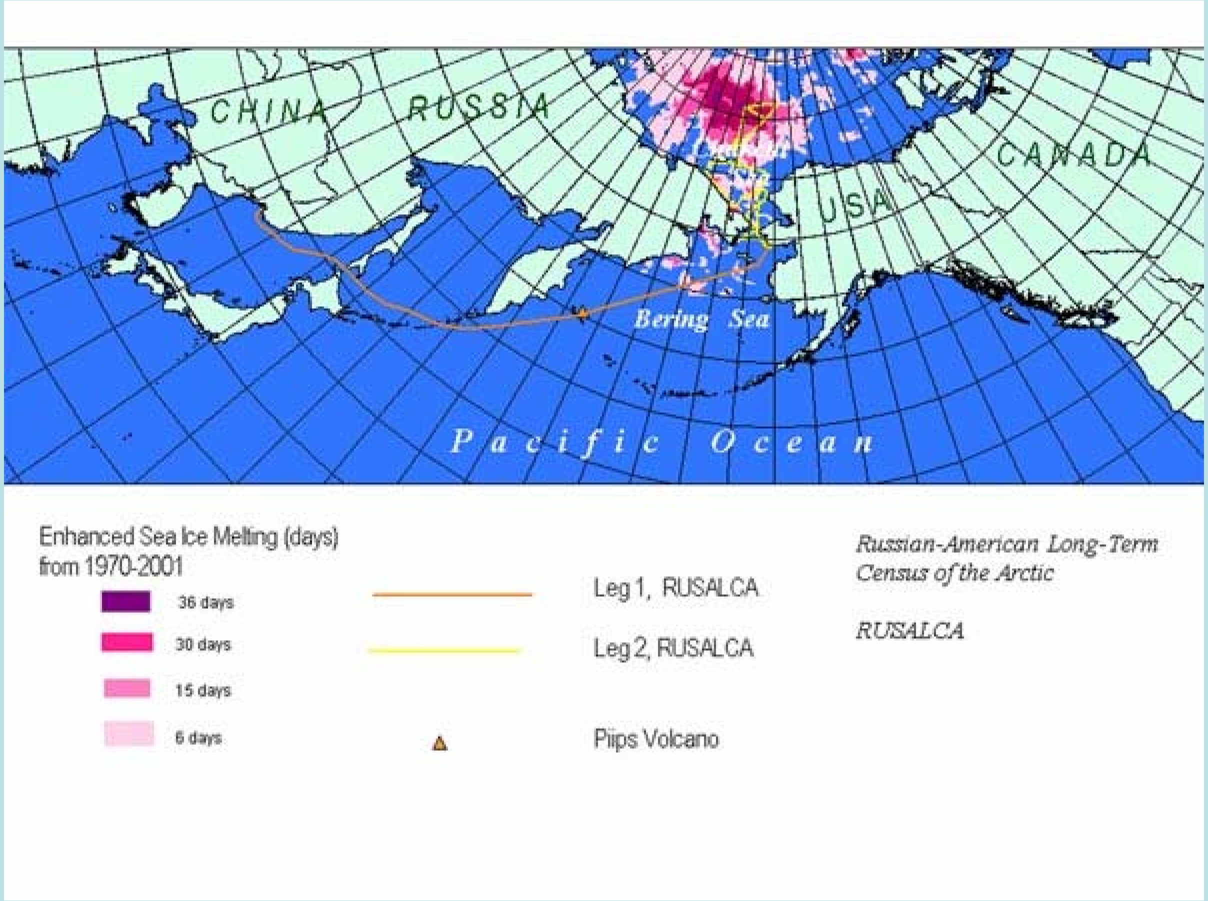


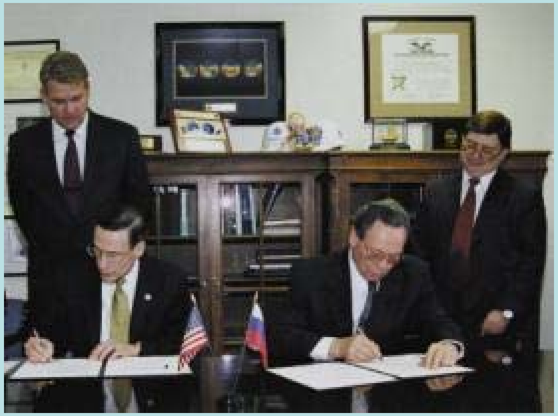
Rate similar to North Sea (Perry et al. 2005)

2-3 times faster than terrestrial mean (Parmesan and Yohe 2003)

RUSALCA (Russian-American Long-term Census of the Arctic)

Major cruises: 2004, 2009





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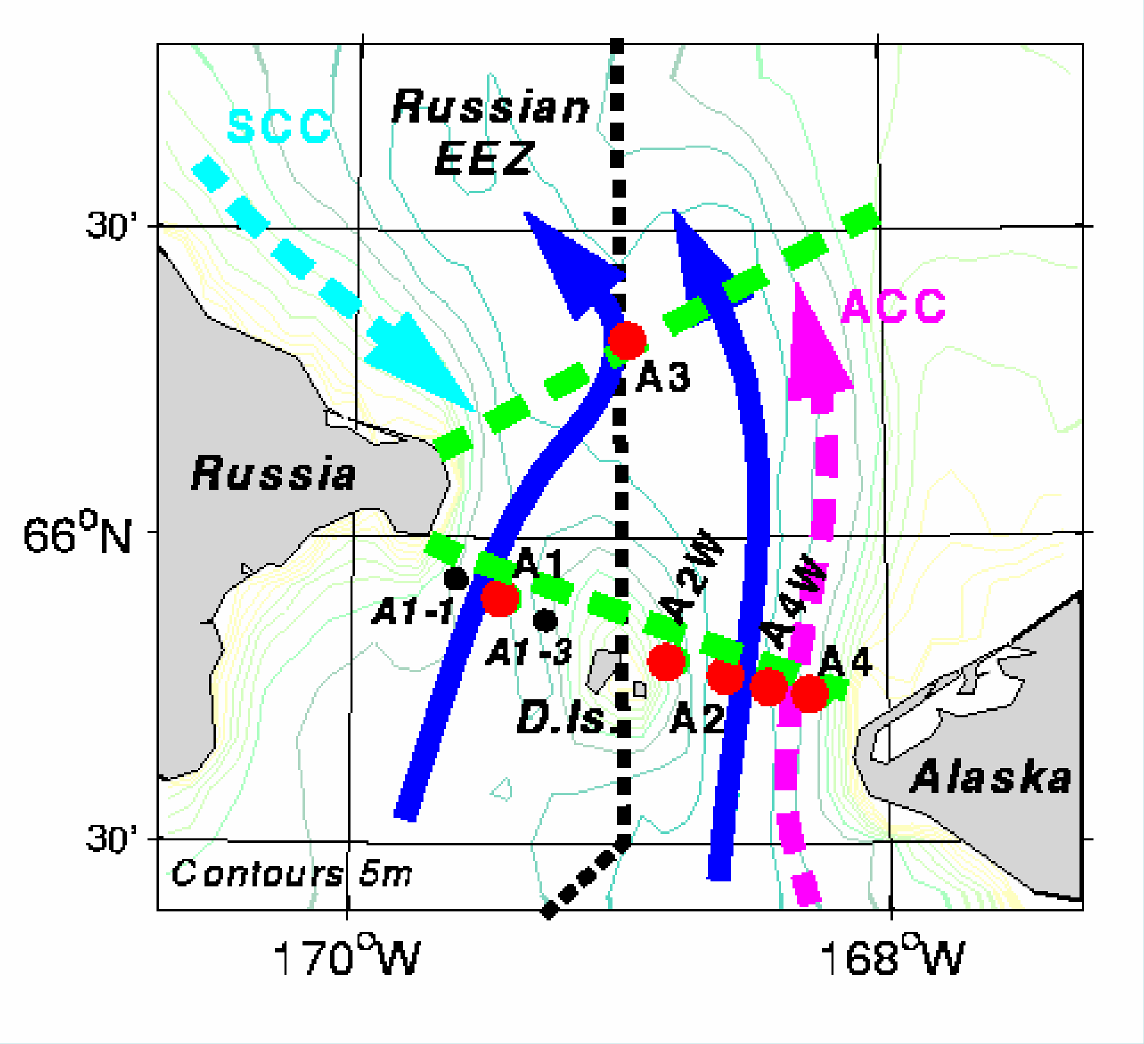
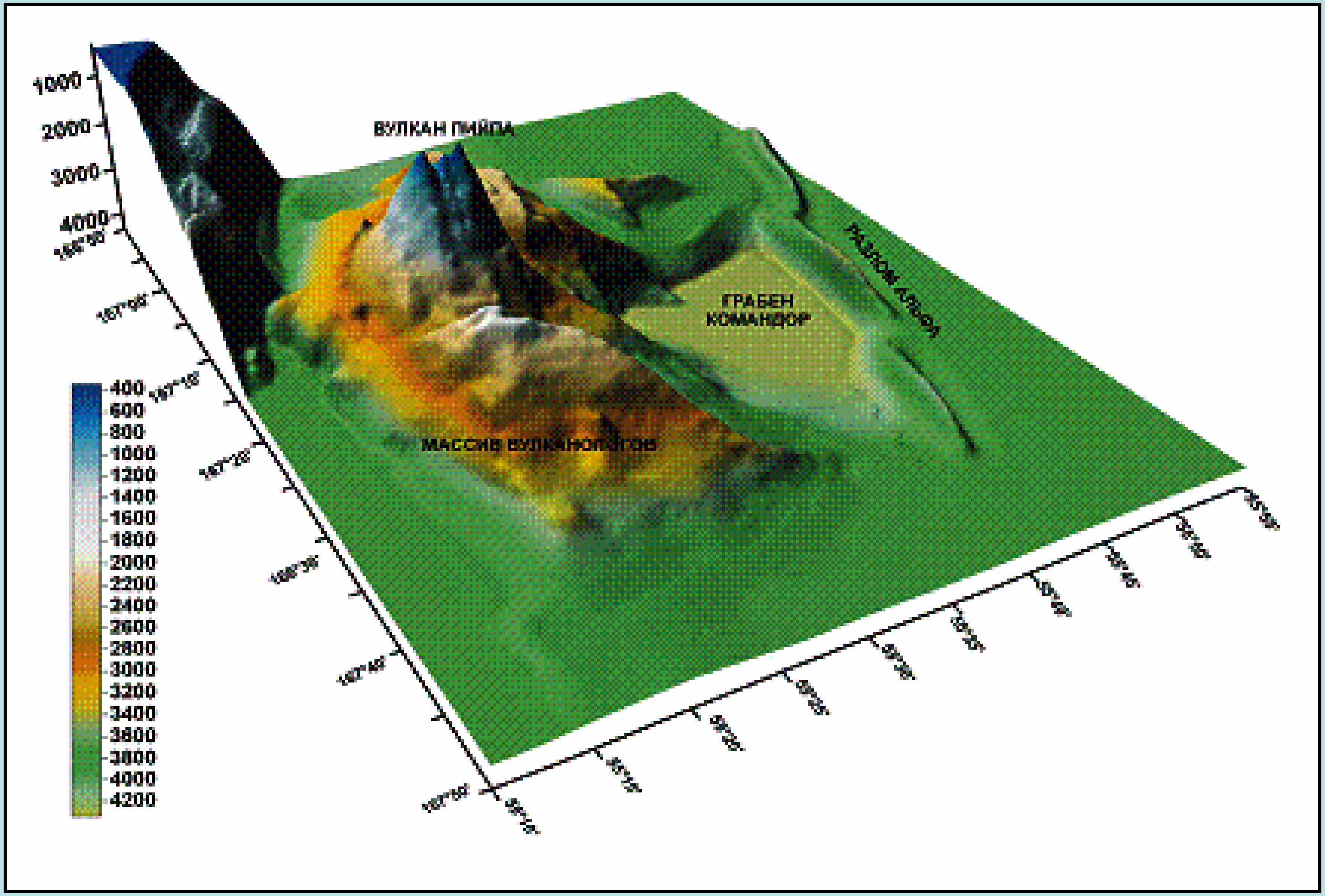


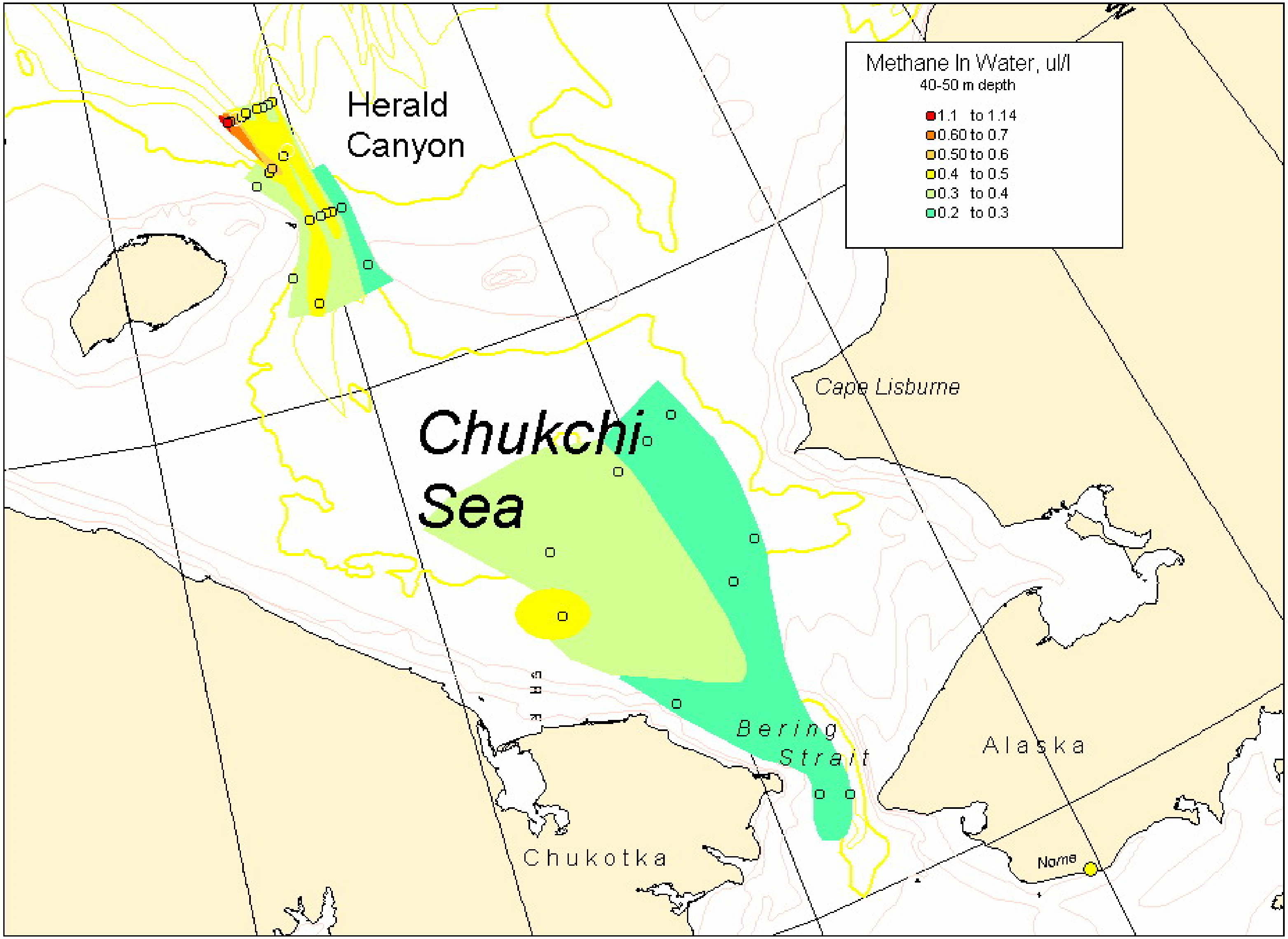
RUSALCA 2004:
Sampling of hydrothermal vents (undersea volcanoes)



RUSALCA 2004 cruise

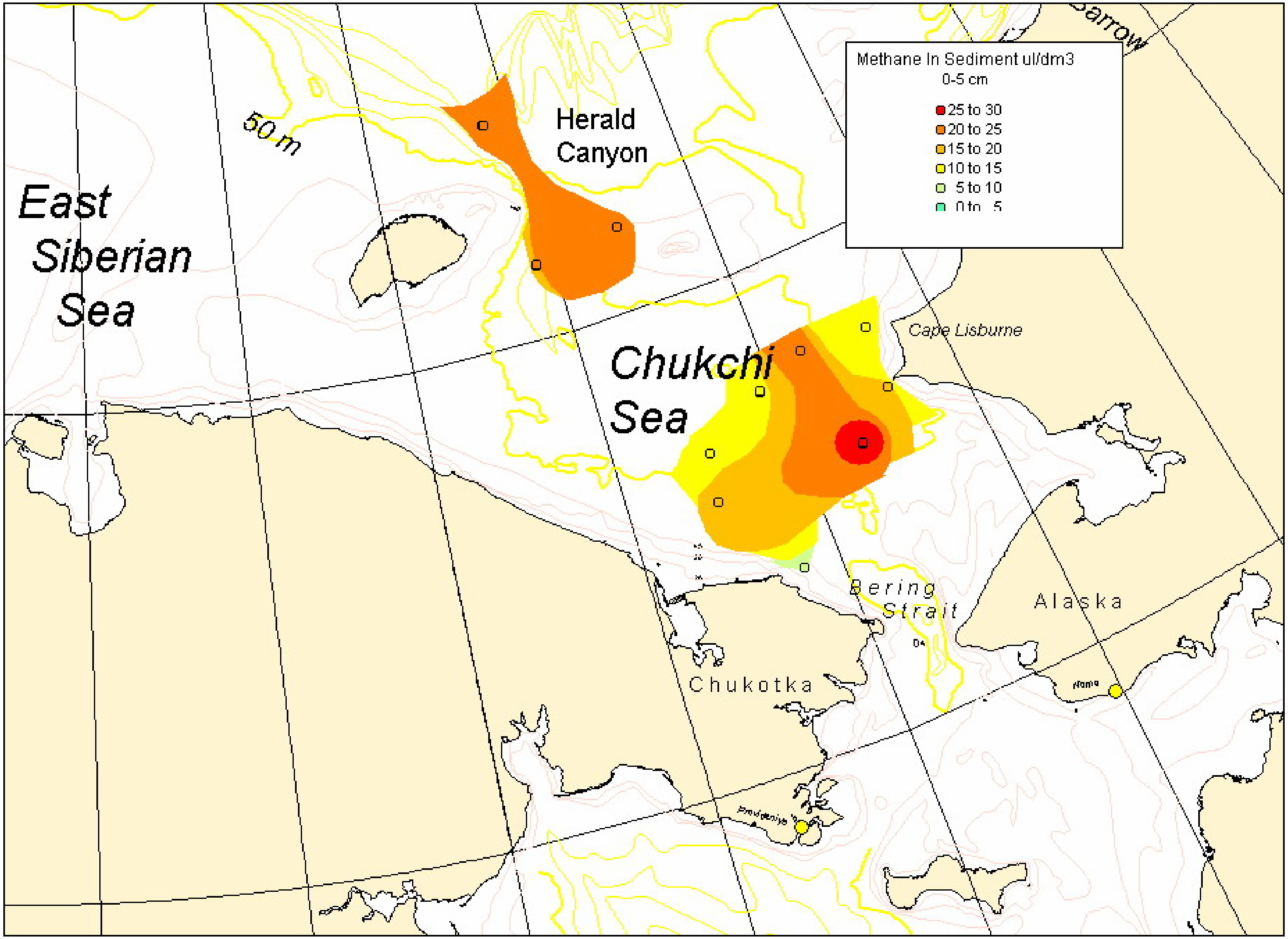
RUSALCA 2004

RUSALCA 2004: Methane concentrations in water



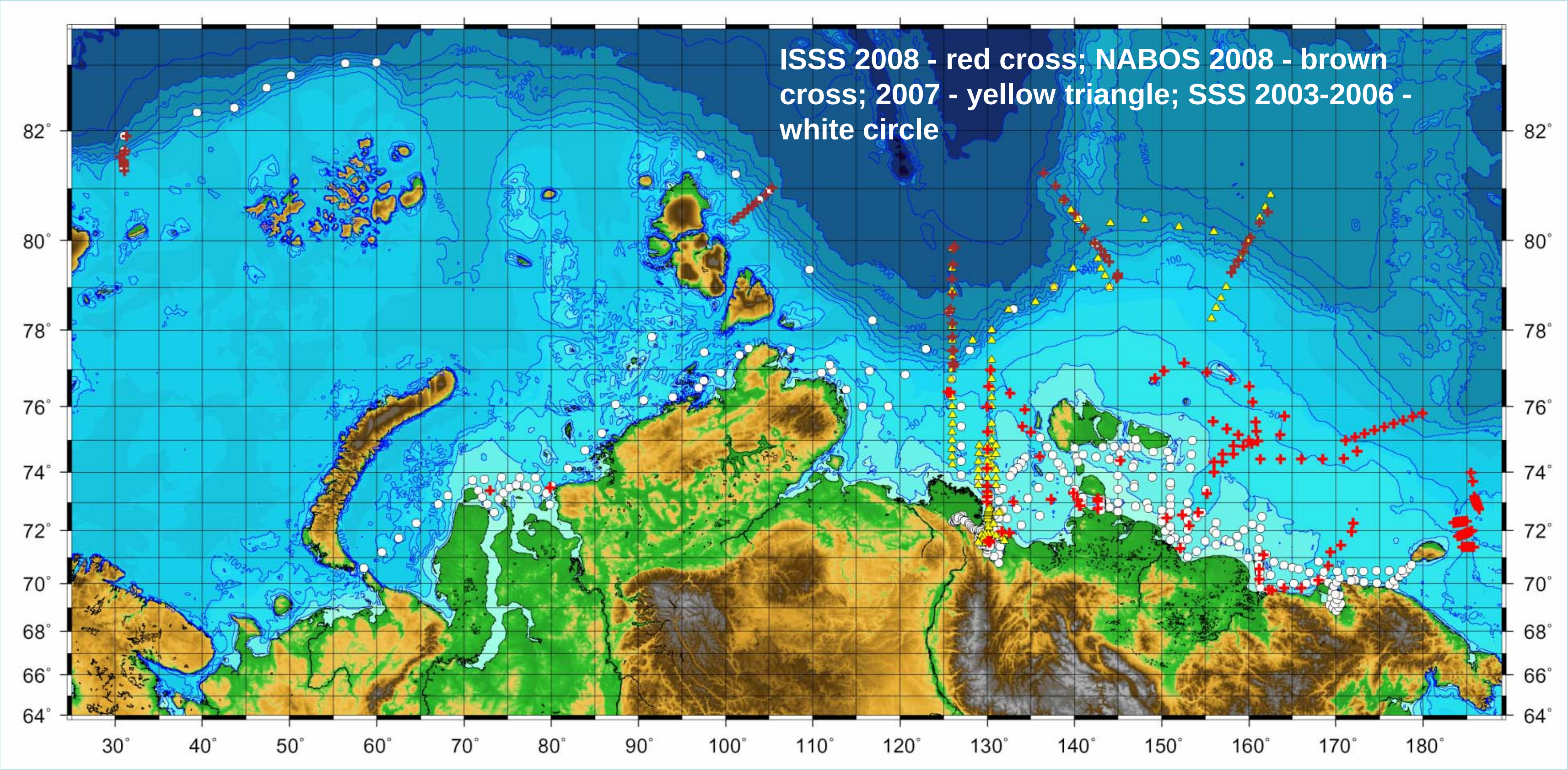
A. Savvichev, I. Rusanov and K. Crane, 2004

RUSALCA 2004: Methane concentrations in sediments



A. Savvichev, I. Rusanov and K. Crane, 2004

Siberian Shelf Study: (2003-08)



The overall *goal* of the project is to provide a quantitative, observationally-based assessment of the dynamics of different components of the East Siberian Arctic Shelf (ESAS) carbon cycle under conditions of changing climatic and environmental conditions

Key Objective is to quantify the area-scaled ESAS contribution of CH4 and CO2 to the atmosphere.

Semiletov, Shakhova

Significant release of methane from seabed deposits (Fig. 2a,b) to the water column -atmosphere was obtained. Bubble clouds of methane were discovered over large areas of venting fields. At few locations such clouds were associated with geophysical gas-chimney (CH) structures (Fig. 2b). It is likely that the ESAS may contribute to atmospheric CH4.

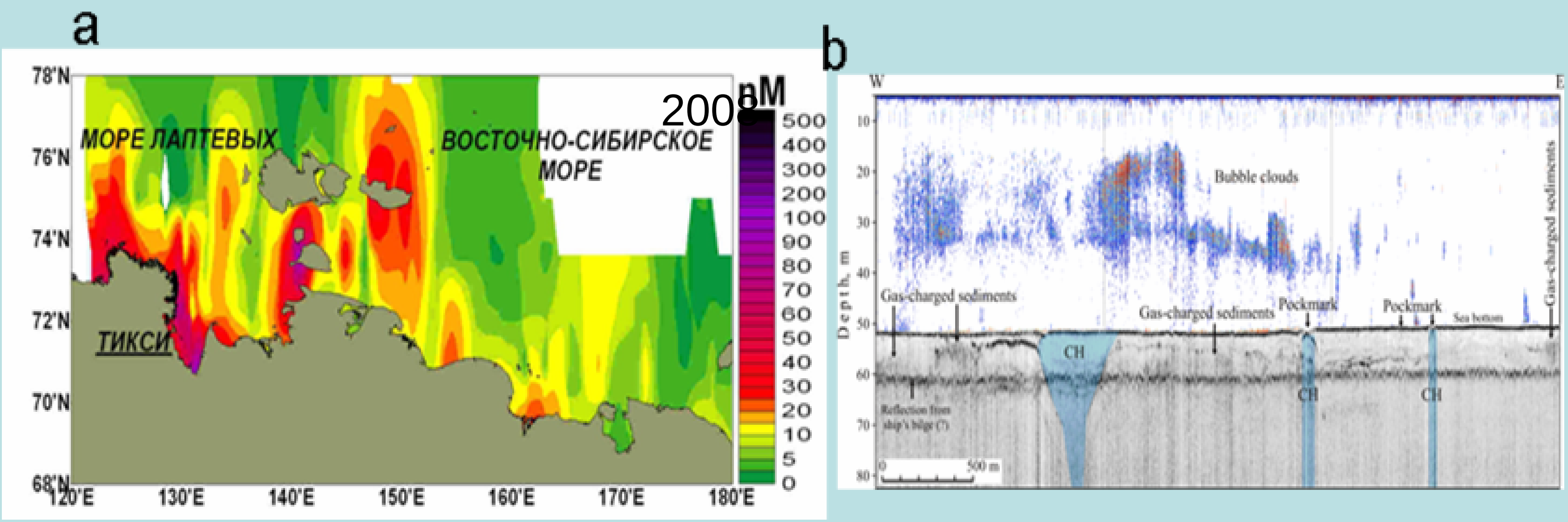


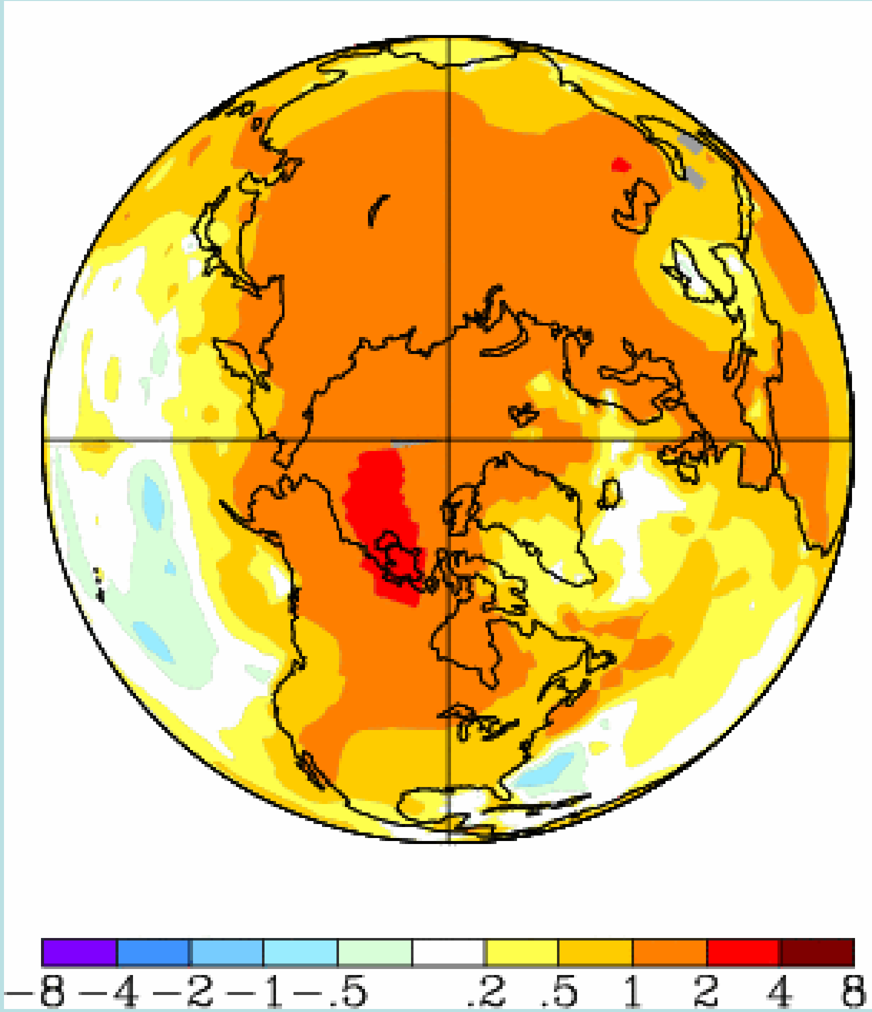
Fig. 2. Distribution of aqueous methane in the surface water on the ESAS (**a**, Shakhova et al. 2008); clouds of methane bubbles within the water column in the East Siberian Sea (**b**, Shakhova et al., 2009, in preparation

Shakhova, Semiletov

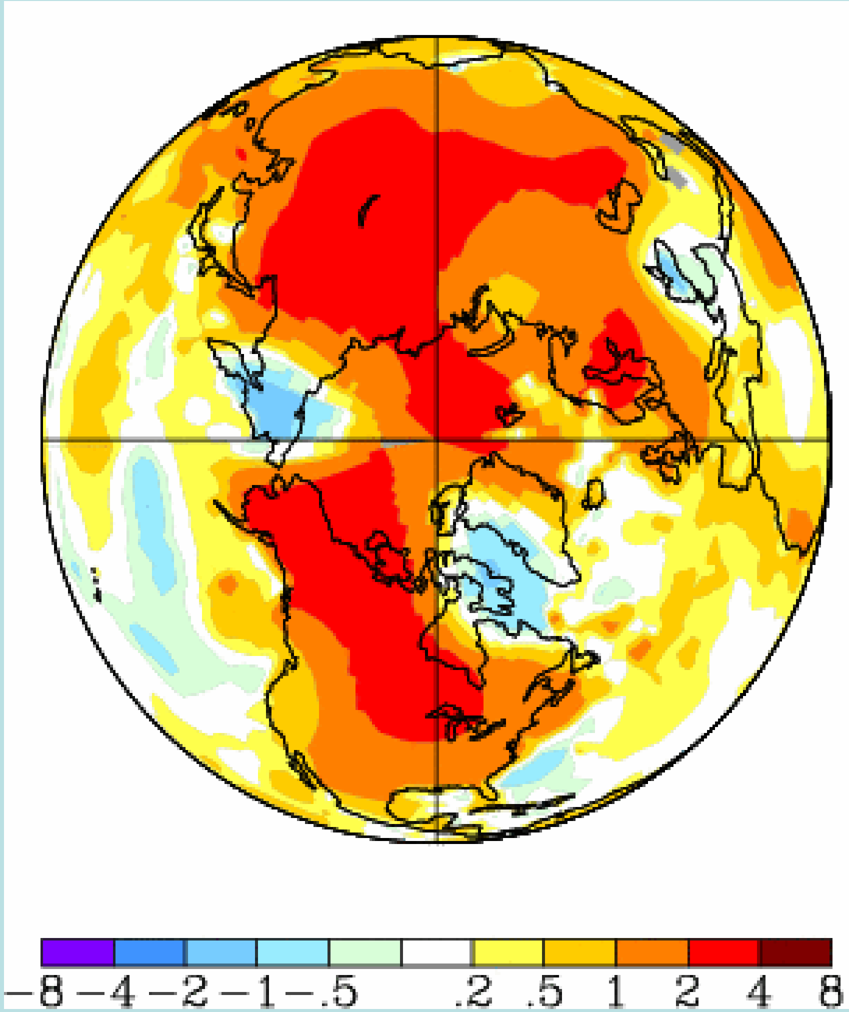
Change in surface air temperature (°C), 1957-2006

[from NASA GISS]

Annual

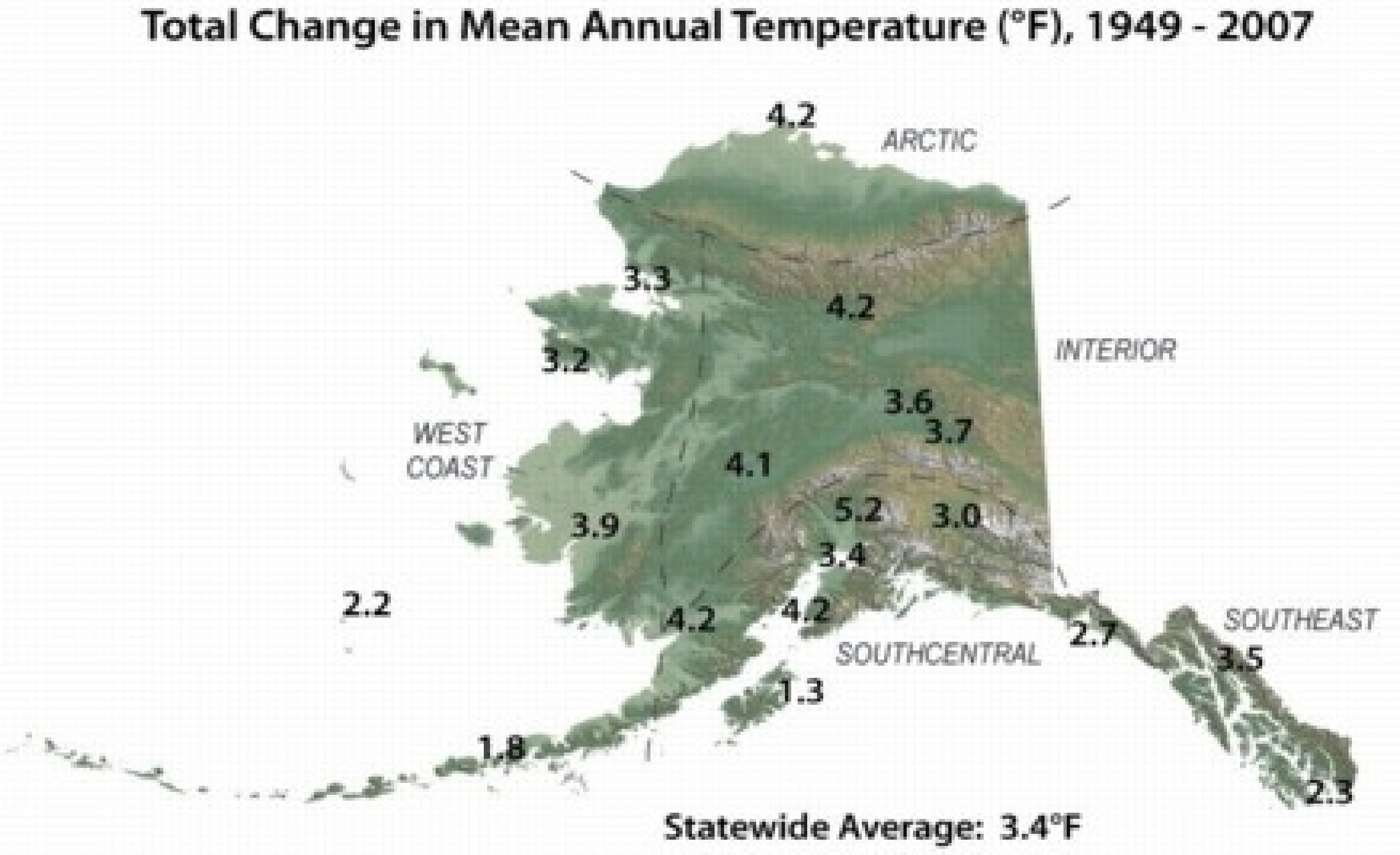


Winter



Temperature change in Alaska, 1949-2007

[from Alaska Climate Research Center]

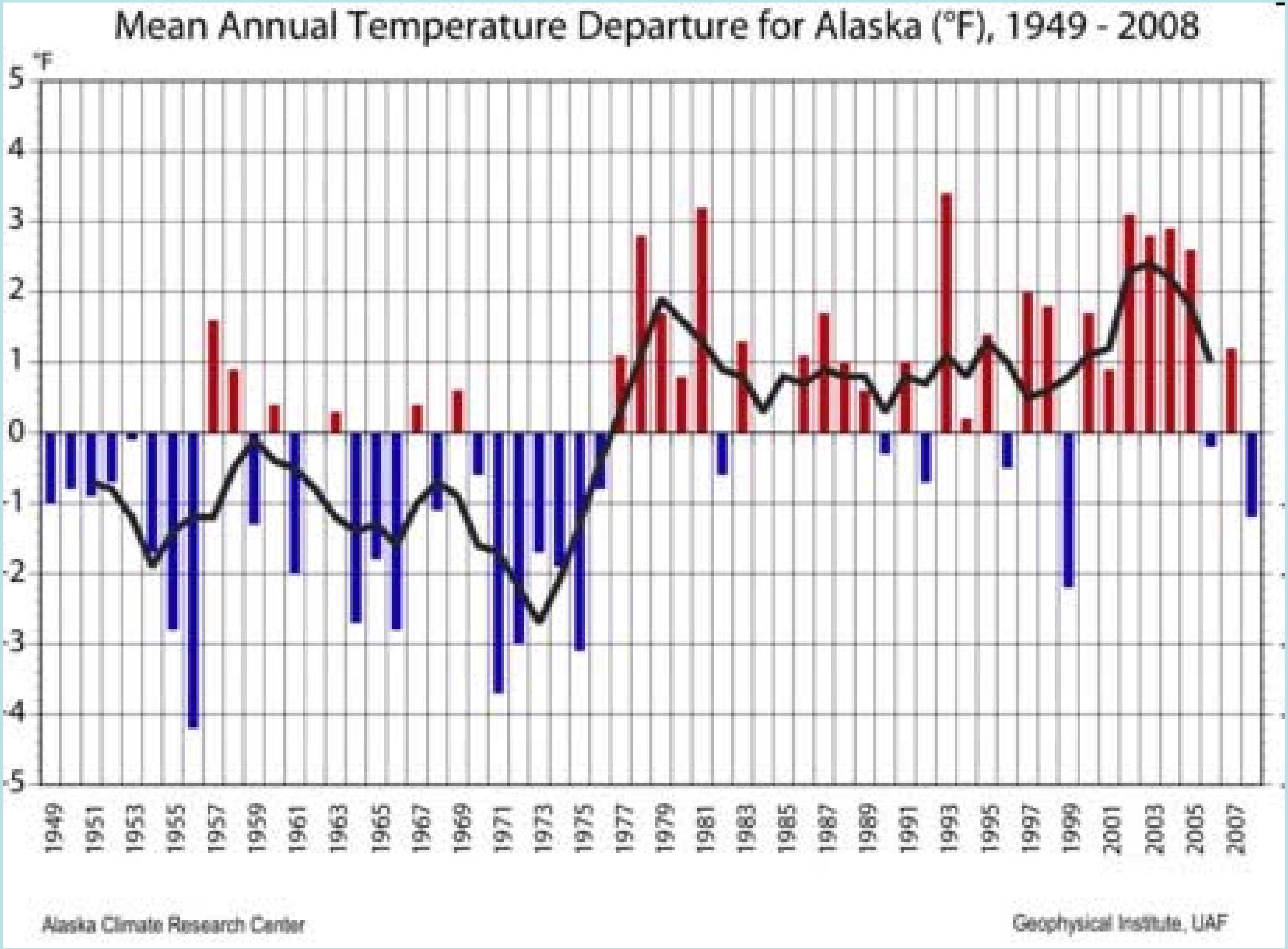


Changes of annual and seasonal temperatures in Alaska: 1949-2006

Location	Annual	Spring	Summer	Autumn	Winter
	Total change, °F (1949 - 2006)				
Arctic					
Barrow	3.8	4.2	2.5	2.1	6.1
Interior					
Bettles	4.0	4.8	1.8	0.9	8.5
Big Delta	3.7	3.9	1.3	0	9.7
Fairbanks	3.6	4.2	2.2	-0.2	8.1
Gulkana	3.0	2.7	1.0	-0.3	8.3
McGrath	4.0	5.0	2.8	0.6	7.6
West Coast					
Bethel	3.7	5.3	2.4	0.3	6.9
Cold Bay	1.9	2.6	2.1	1.1	2.0
King Salmon	4.3	5.5	2.0	0.7	9.2
Kotzebue	3.2	2.1	2.4	1.4	6.8
Nome	3.0	4.0	2.5	0.7	4.9
St. Paul	2.3	3.3	3.2	1.5	1.5
Southcentral and Southeast					
Anchorage	3.4	4.1	2.0	1.0	7.2
Annette	2.4	2.9	1.9	0.3	4.1
Homer	4.3	4.6	3.7	1.8	7.0
Kodiak	1.5	3.1	2	-0.1	1.5
Juneau	3.6	3.5	2.4	1.4	6.8
Talkeetna	5.3	5.7	3.3	2.2	9.3
Yakutat	2.8	3.5	2.0	0.2	5.1
Average	*3.4*	*3.9*	*2.3*	*0.8*	*6.3*

Color code:	*-1 - 0*	*0 - 1*	*1 - 3*	*3 - 5*	*5 - 7*	*7 - 9*	*> 9*

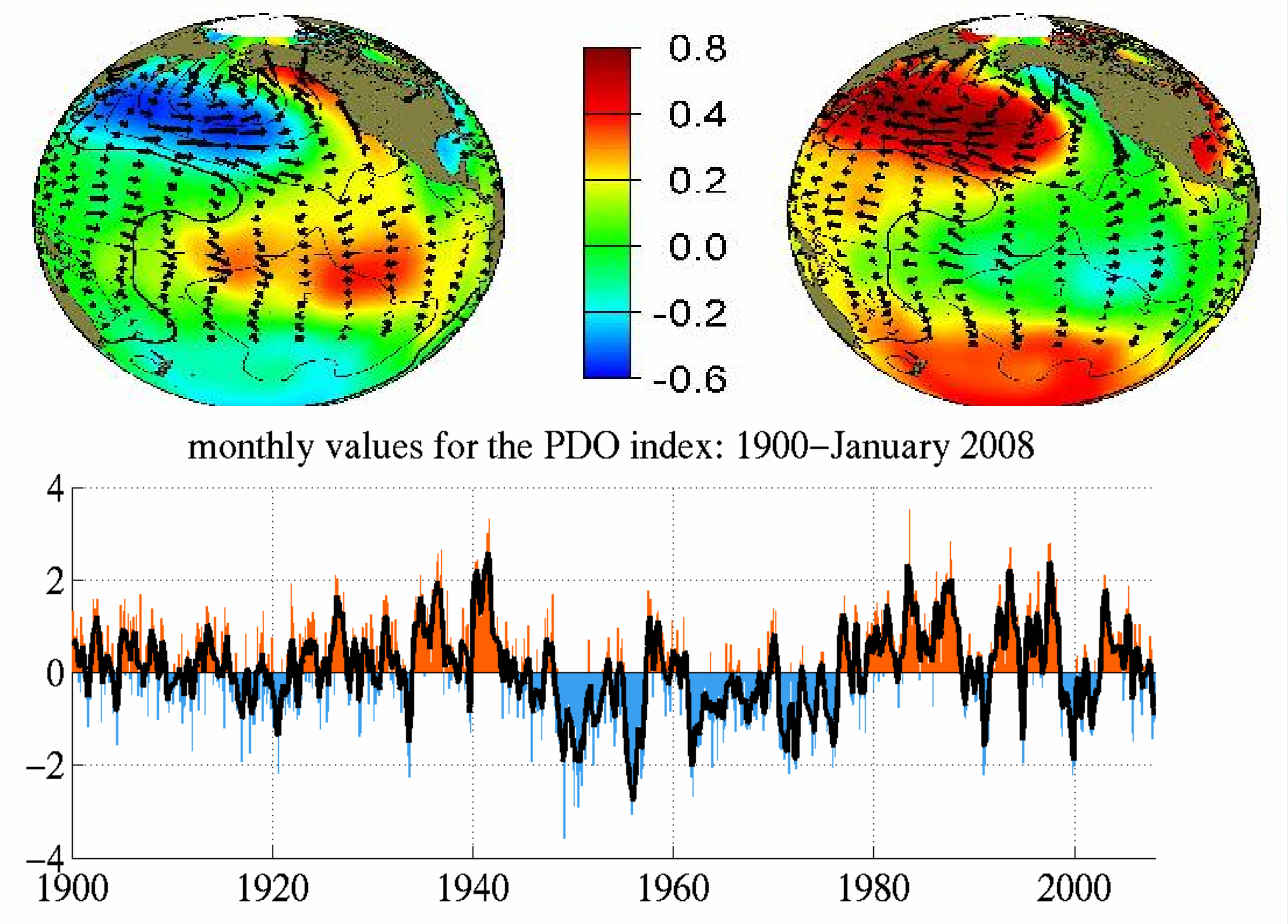
Alaska statewide temperature anomalies: 1949-2008



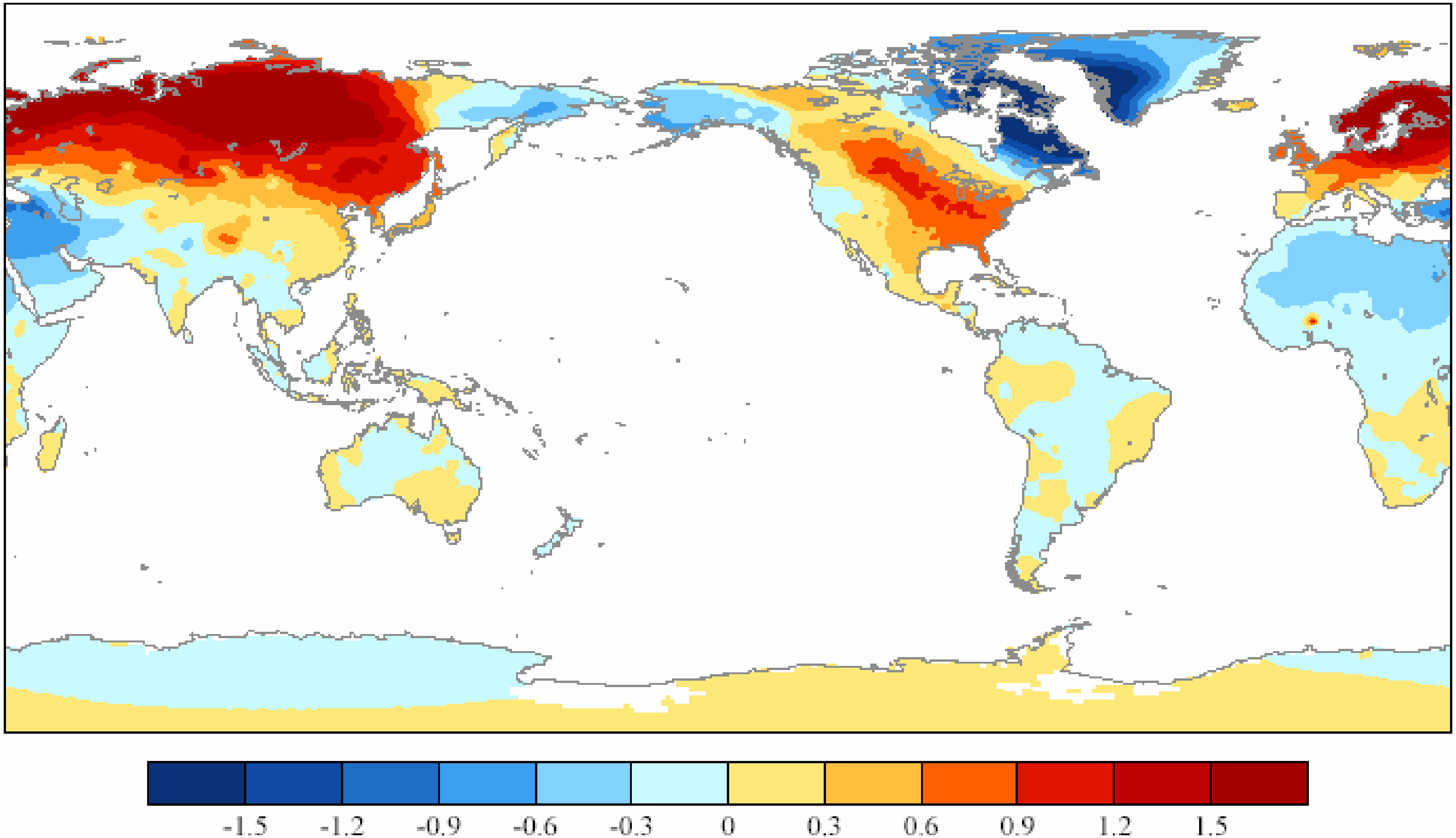
The Pacific Decadal Oscillation

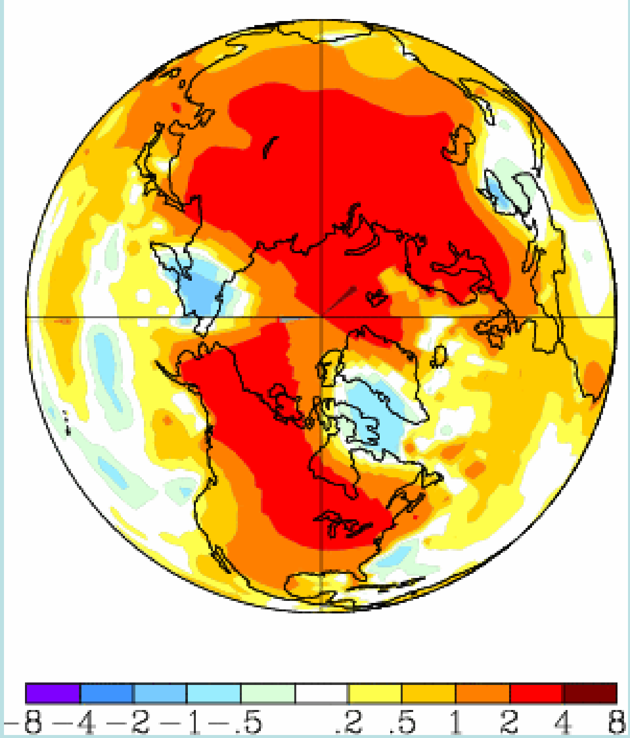
[from JISAO, Univ. Of Washington]

Alaska warm phase **Alaska cold phase**



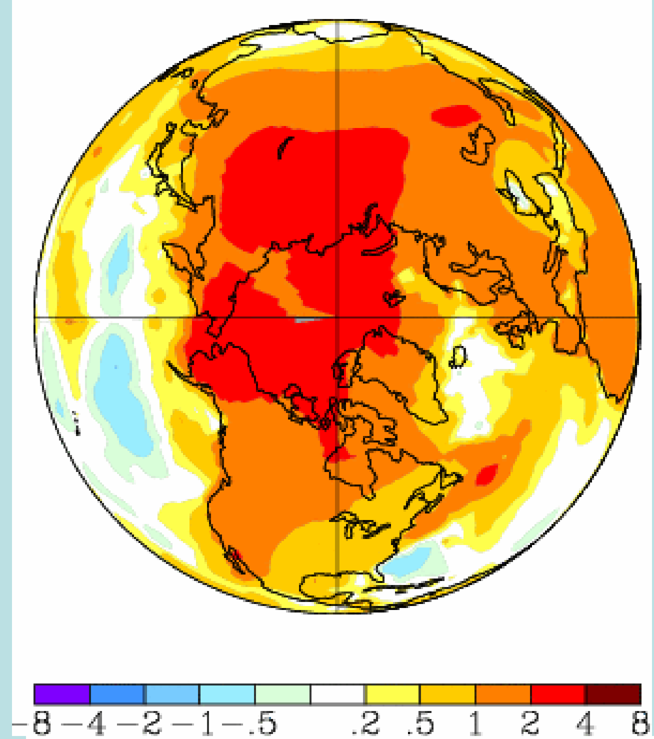
Arctic Oscillation's contribution to recent winter temperature changes (from D. Thompson)

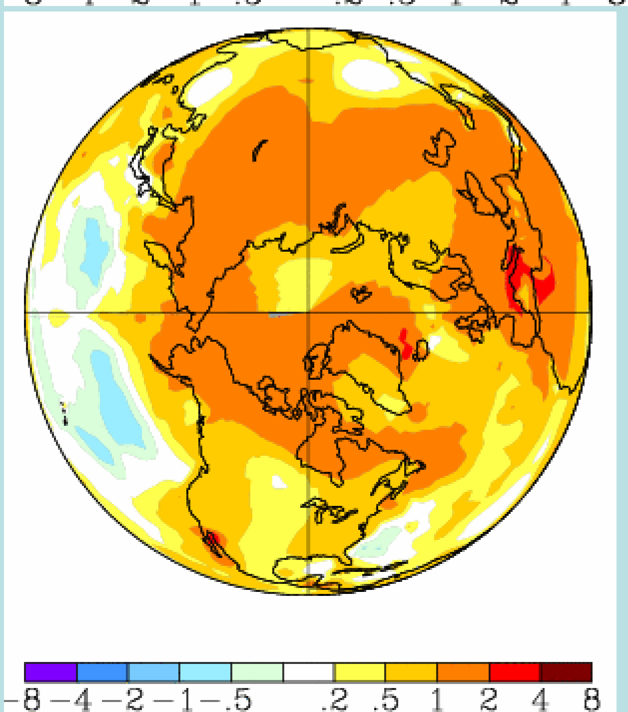




← winter

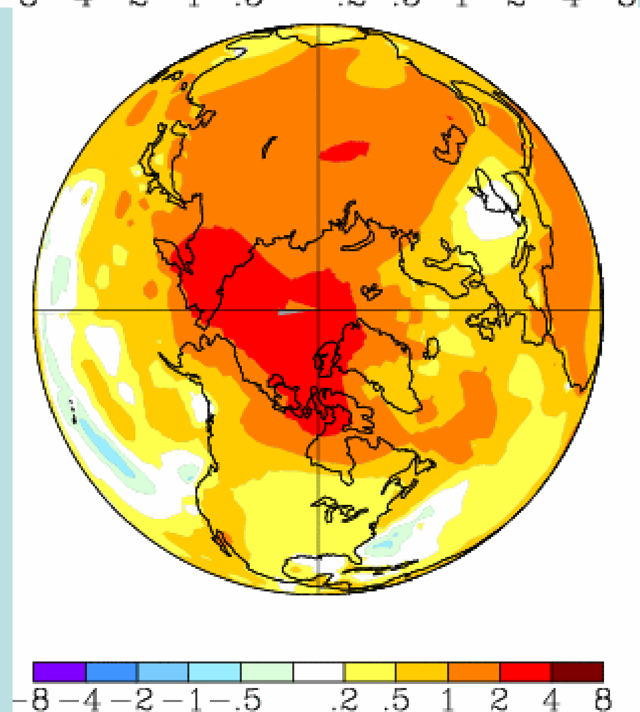
spring →





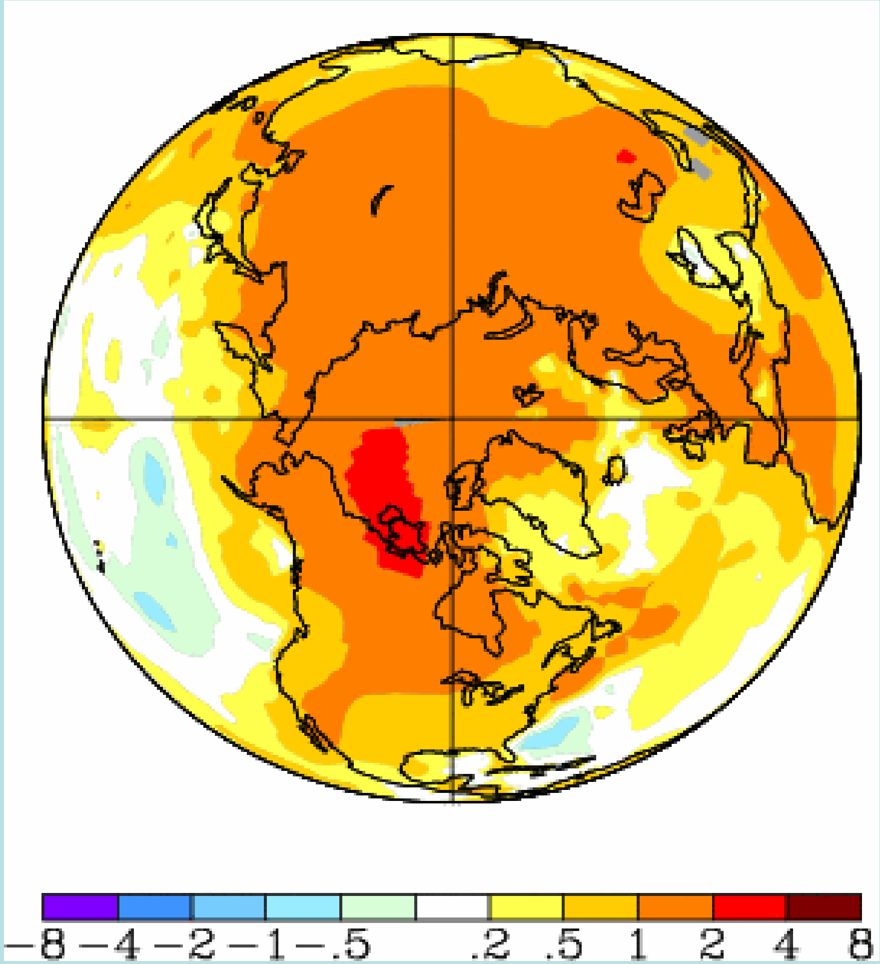
← summer

autumn →

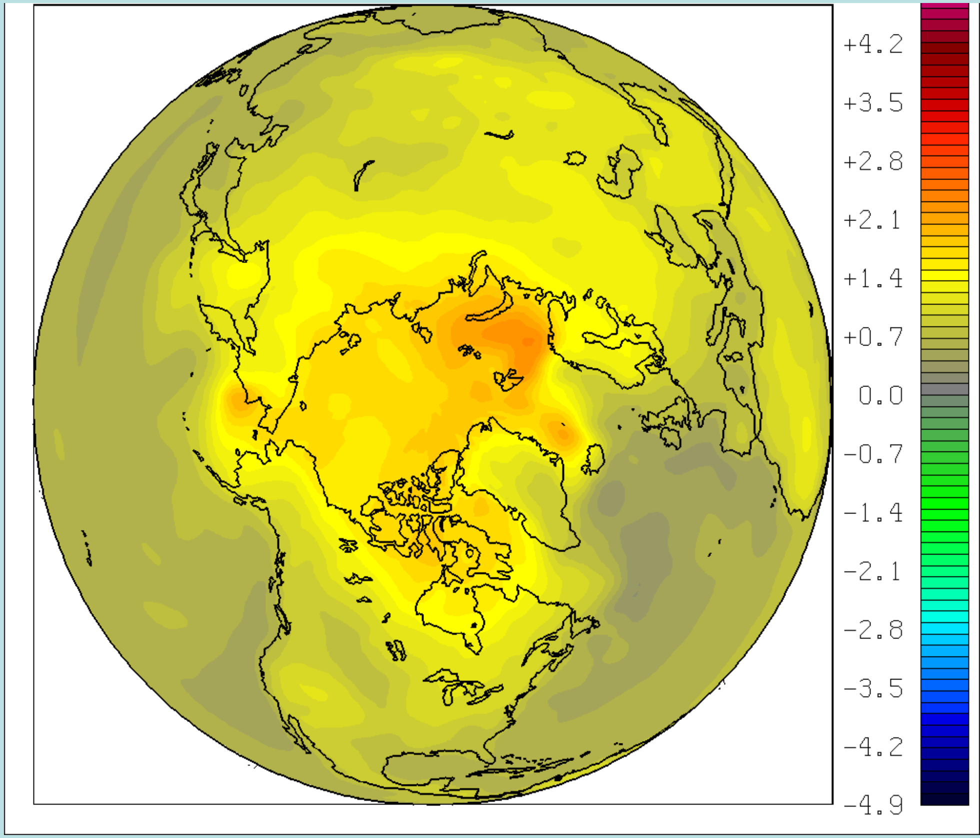


Change in *annual* surface air temperature, 1957-2006

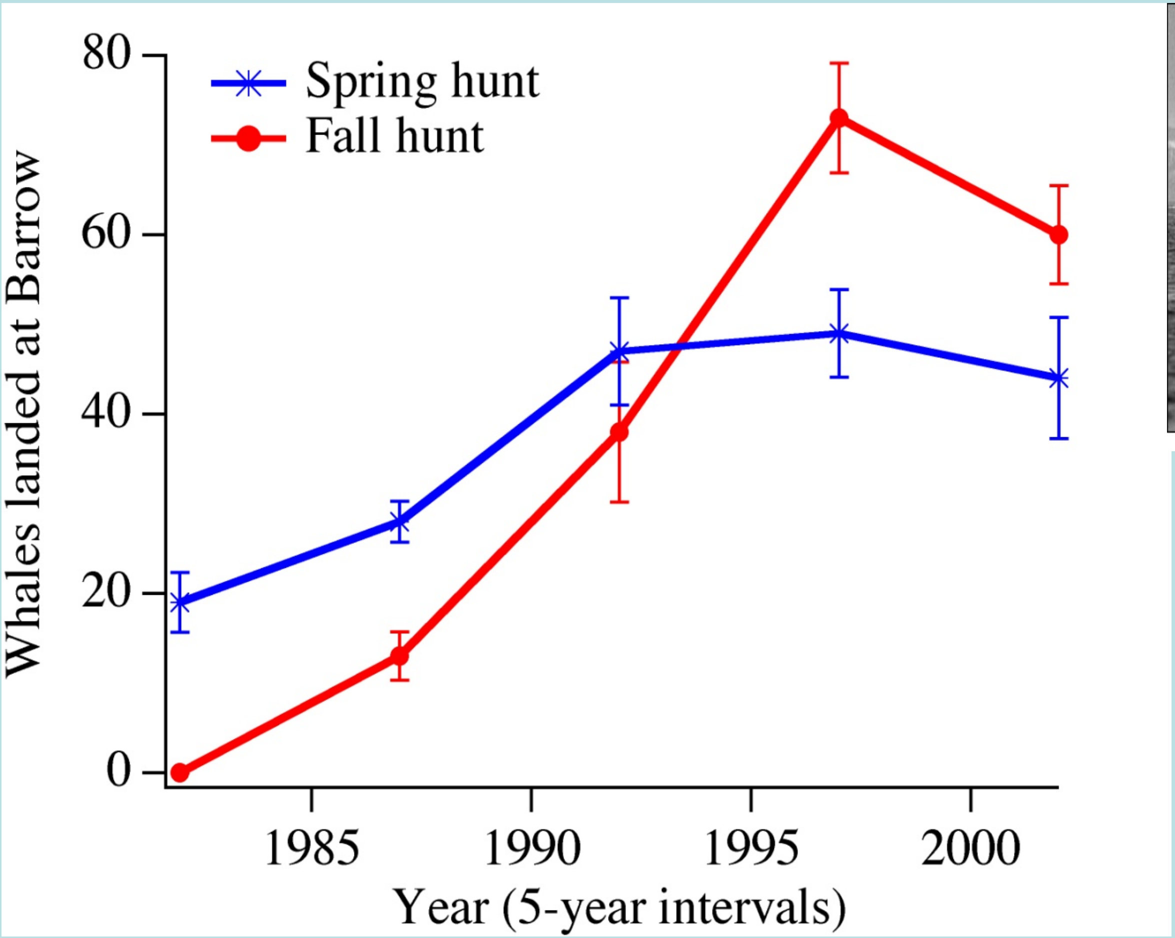
observed



IPCC models(actual GHG)



Alaska coastal communities' response to changing ice conditions: Resilience and adaptation - Barrow subsistence whaling

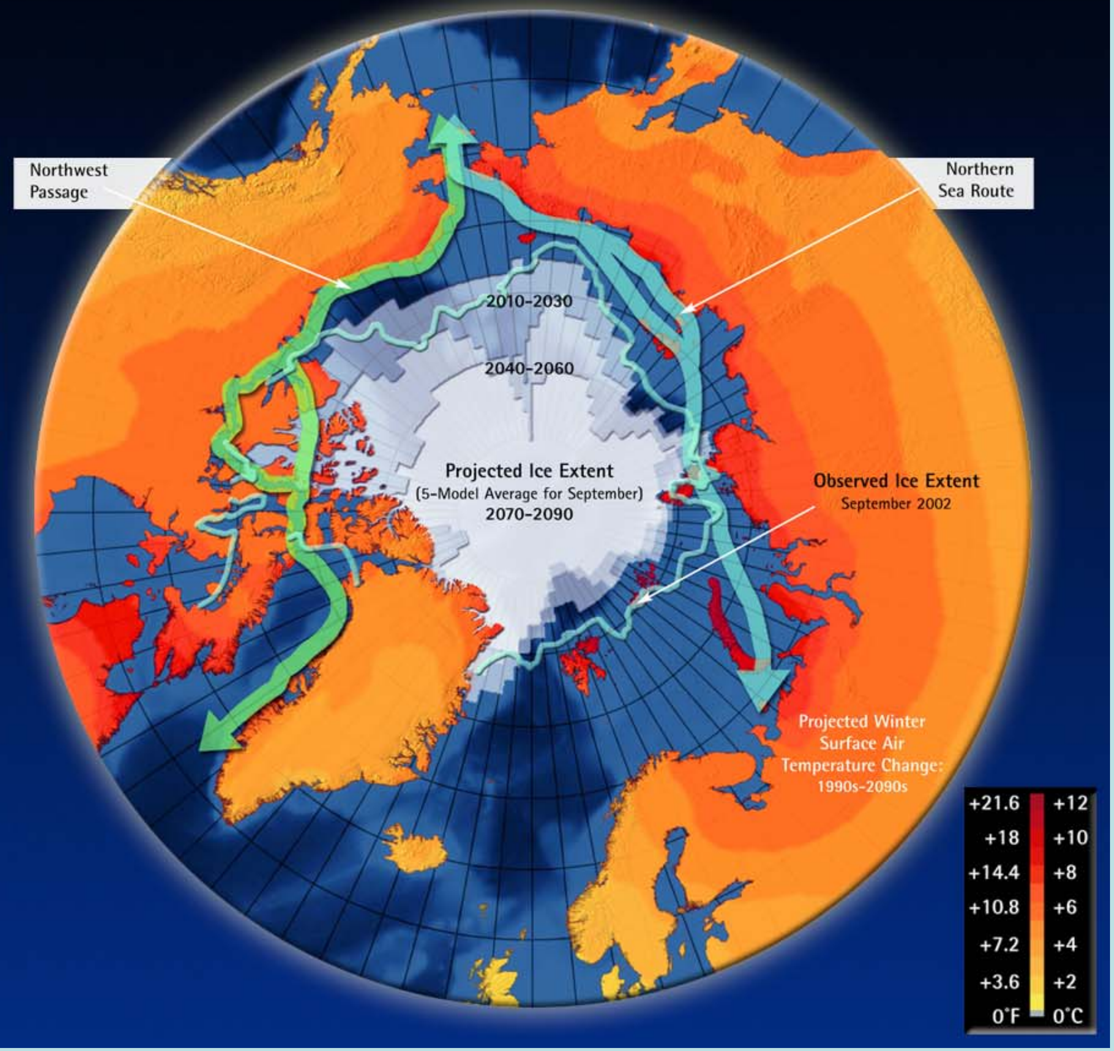


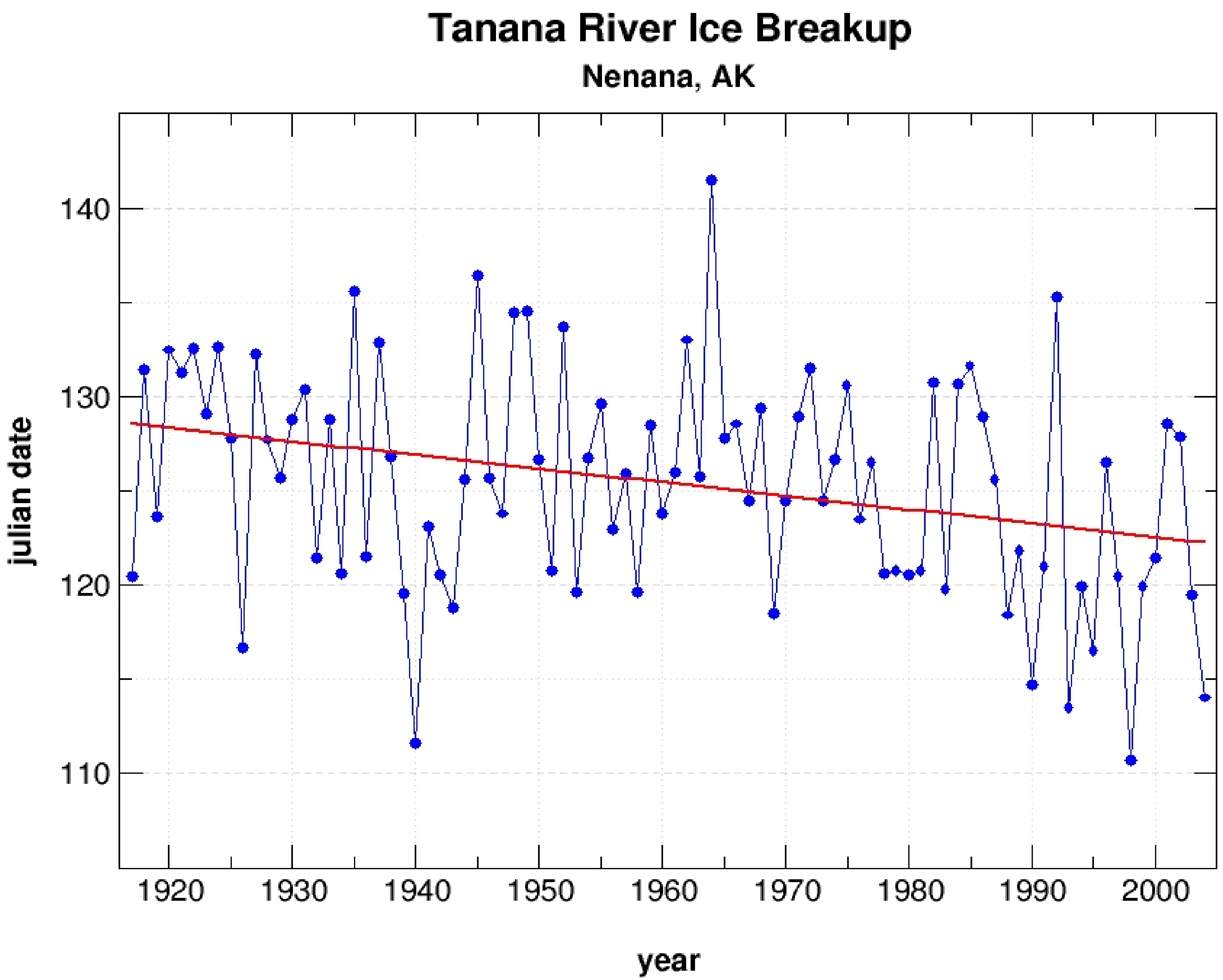
Data: Craig George, North Slope Borough Dept. of Wildlife Management

Photos: ©Bill Hess

ARCTIC CLIMATE IMPACT
ACIA
ASSESSMENT

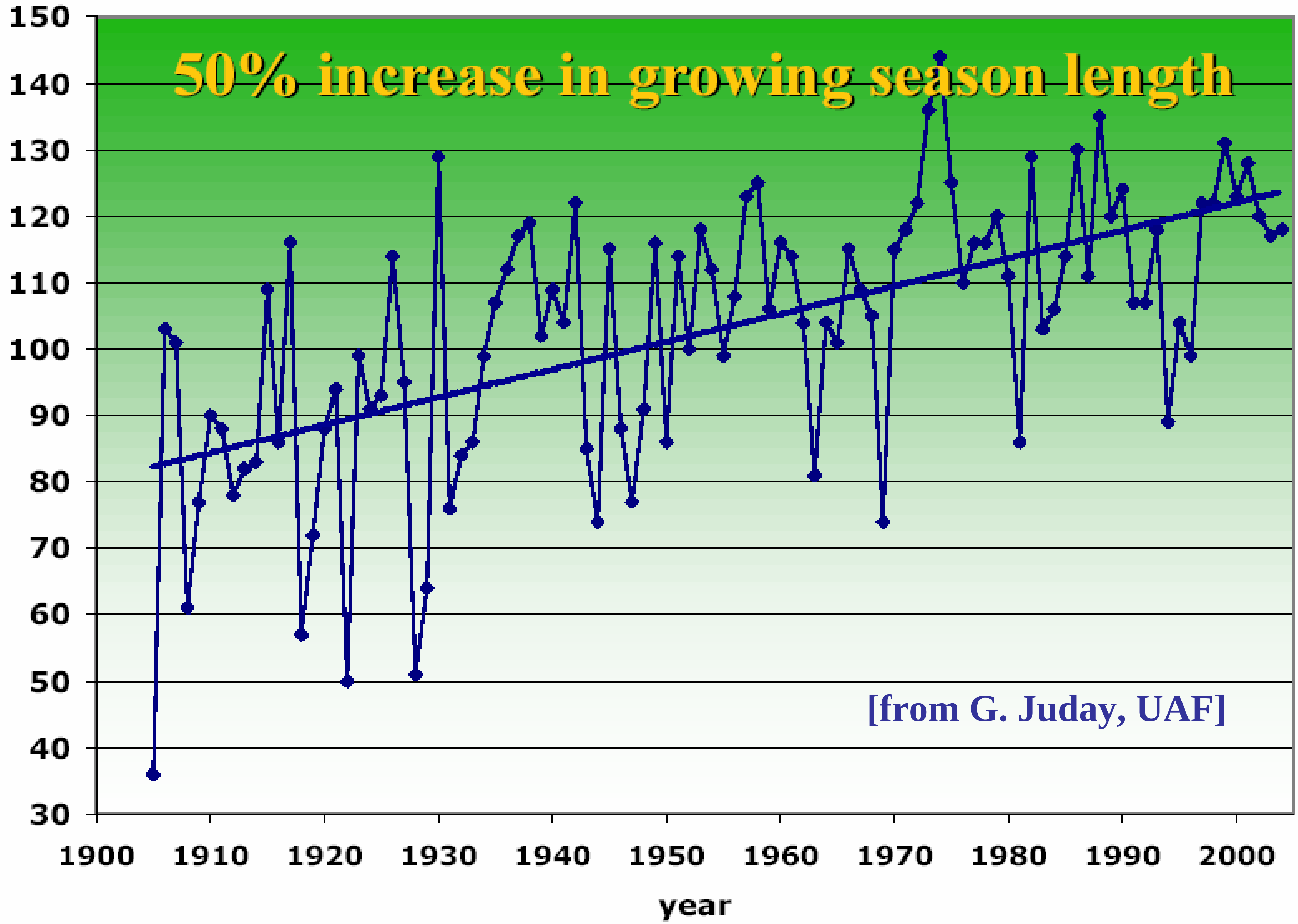
IMPACTS OF A WARMING ARCTIC



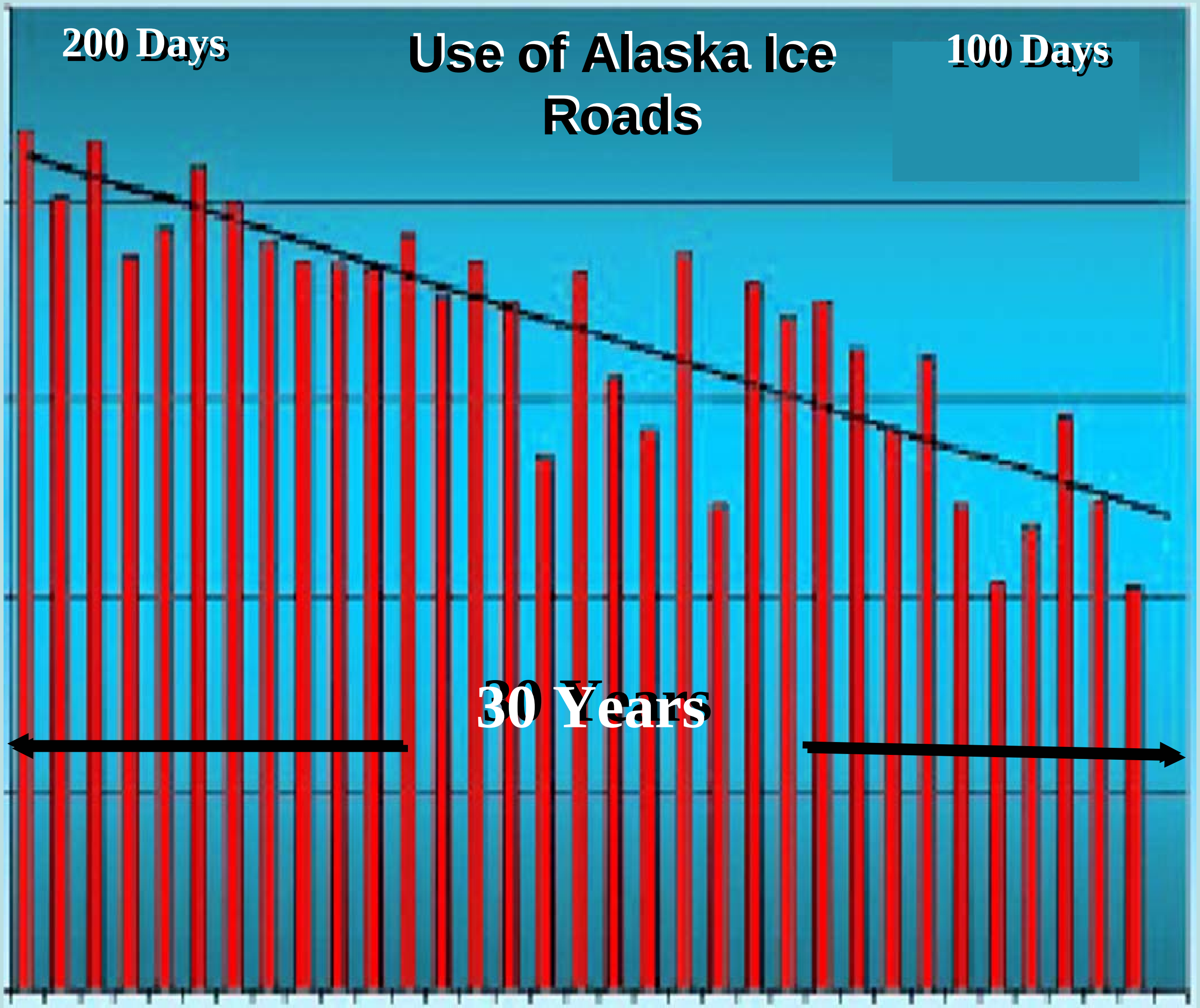


Tanana River Ice Breakup
Nenana, AK
julian date
140
130
120
110
1920
1930
1940
1950
1960
1970
1980
1990
2000
year

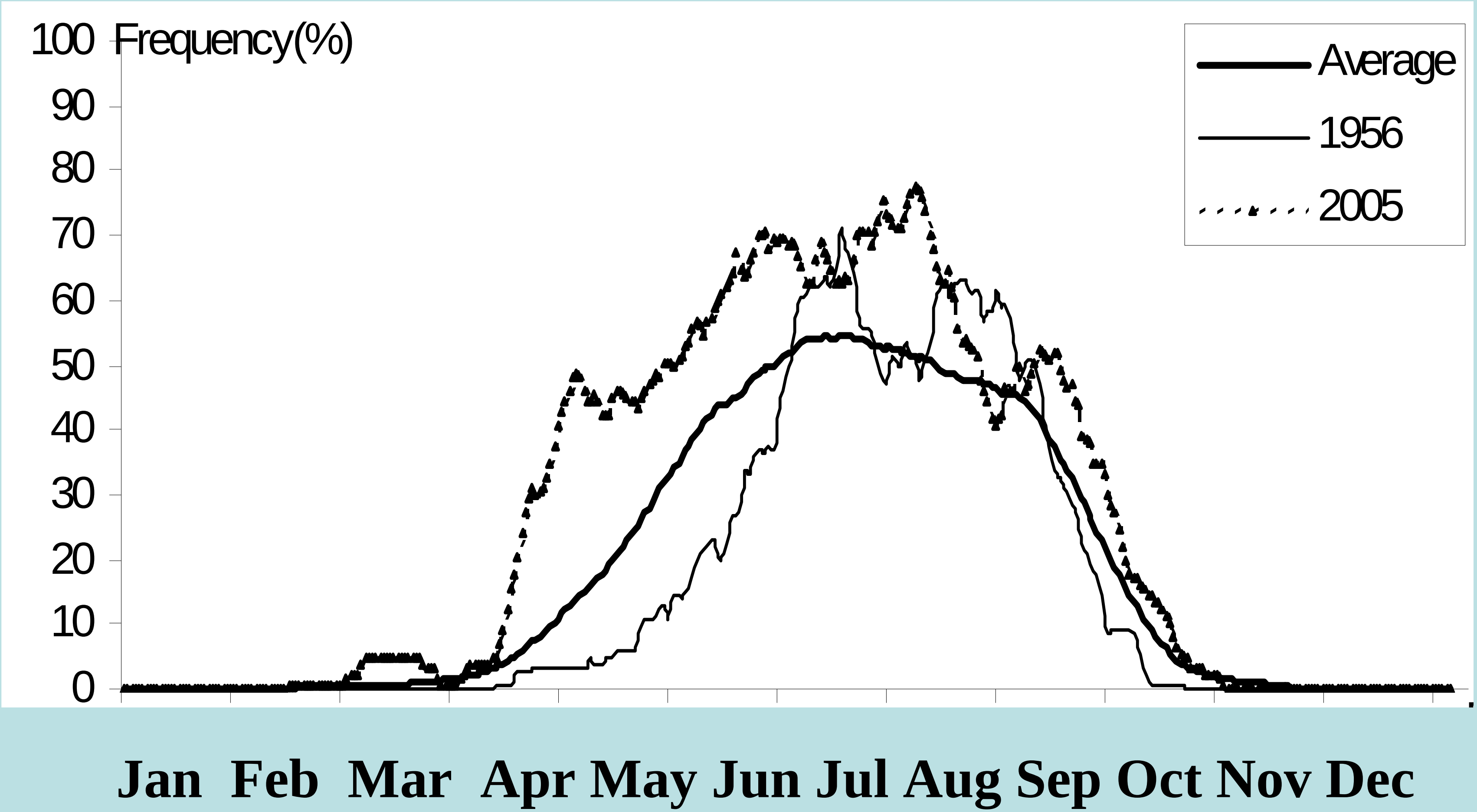
Fairbanks frost-free season

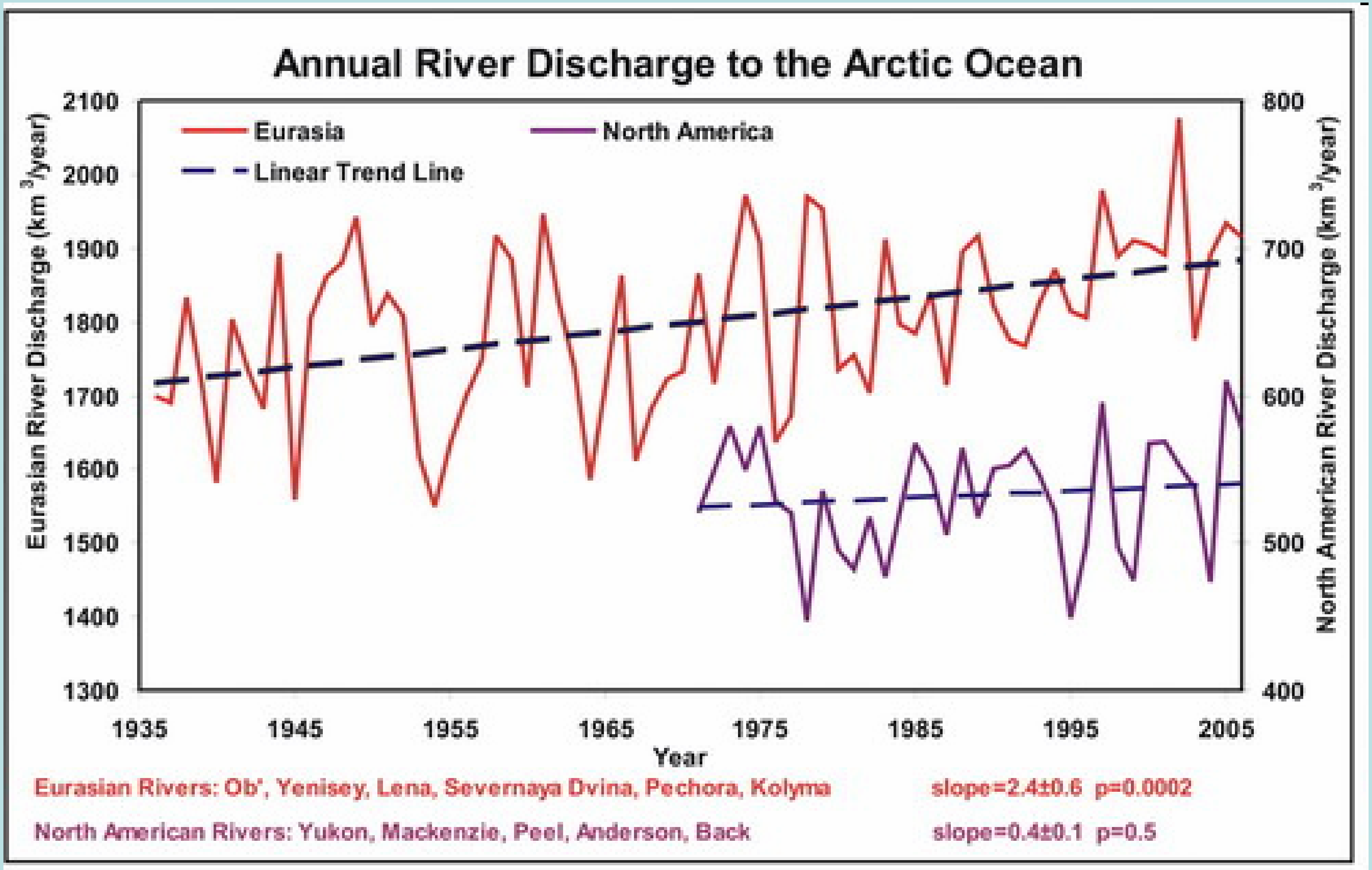


Trends of Alaska tundra travel season length: BLM permit days



Seasonal frequency of weather conducive to sightseeing (King Salmon, AK)



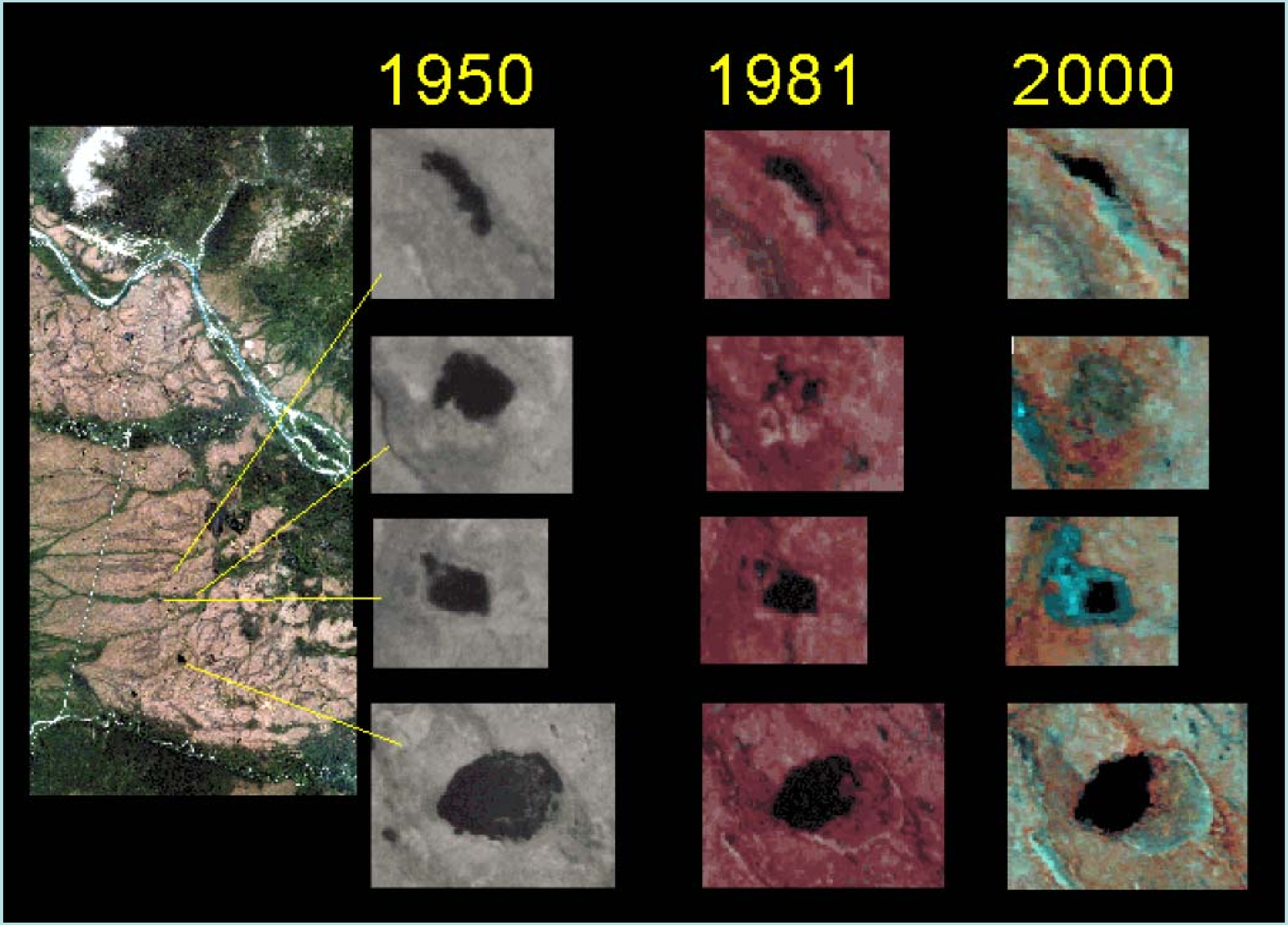


From NOAA Arctic Report Card 2008

[updated from Peterson et al., 2002, Science]

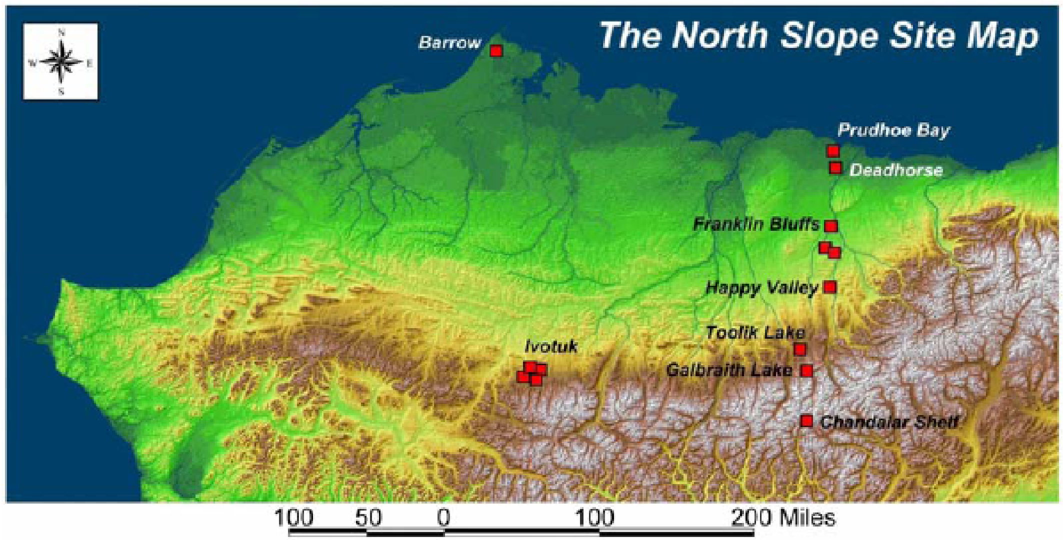
Drying of Arctic lakes

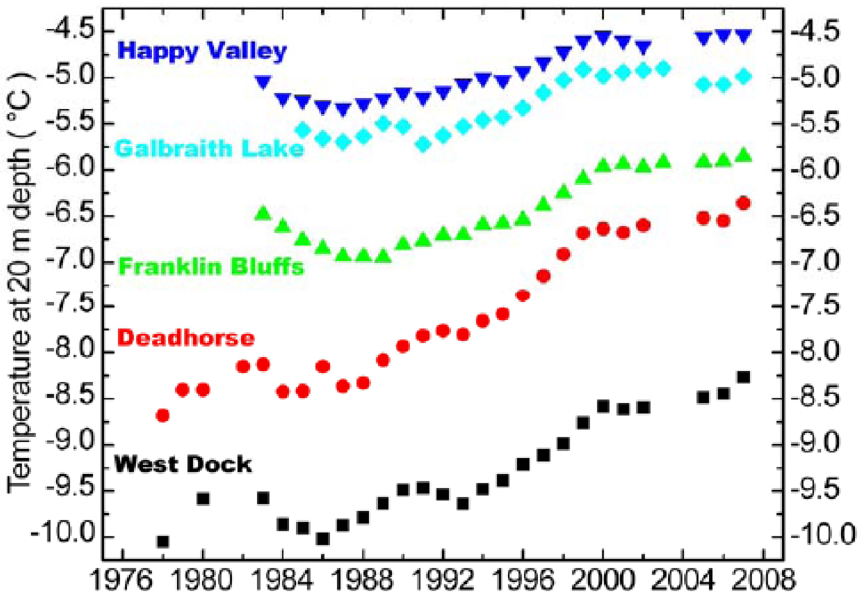
[from L. Hinzman et al.]

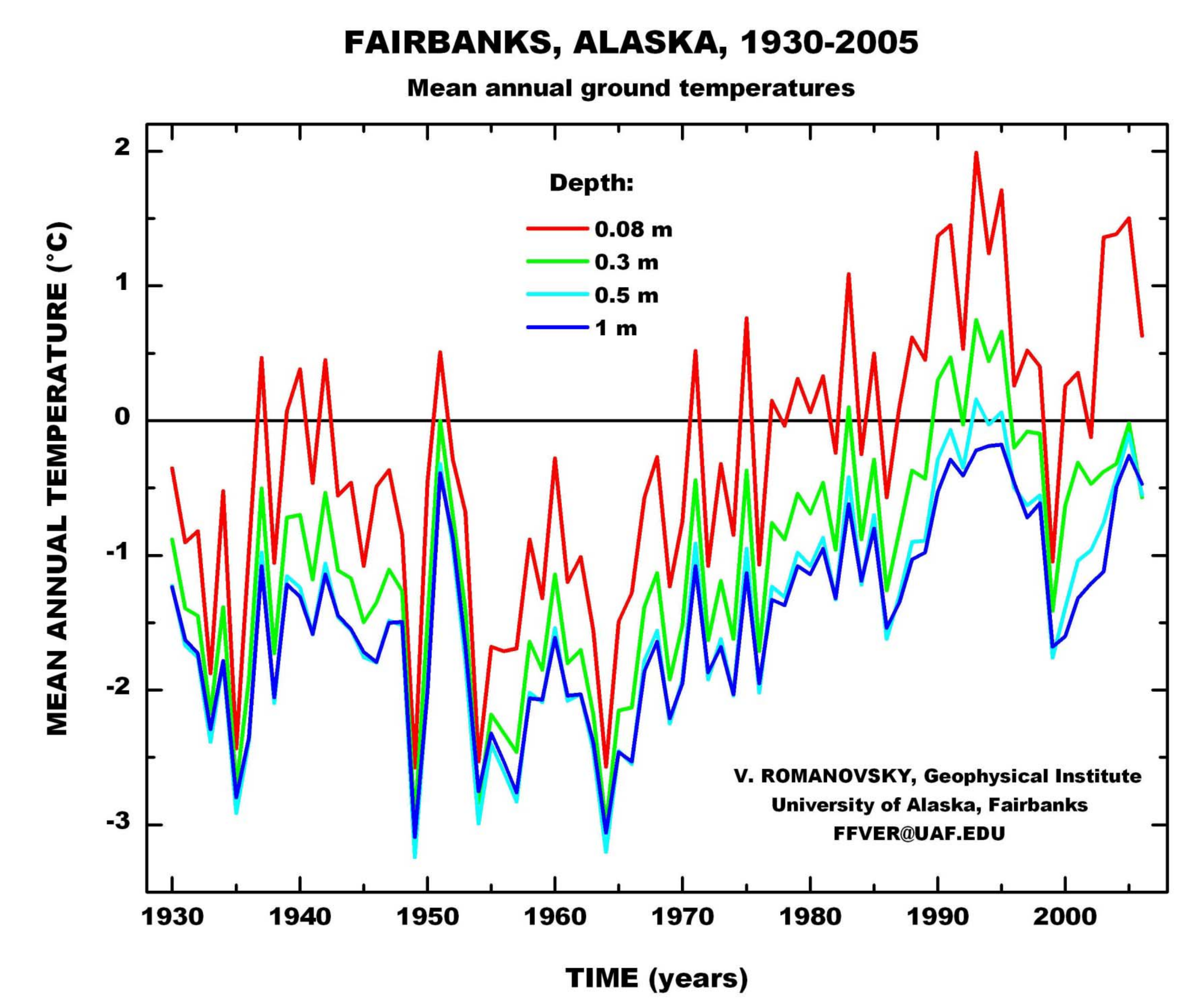


Permafrost in Alaska is warming

[from V. Romanovsky, 2008]

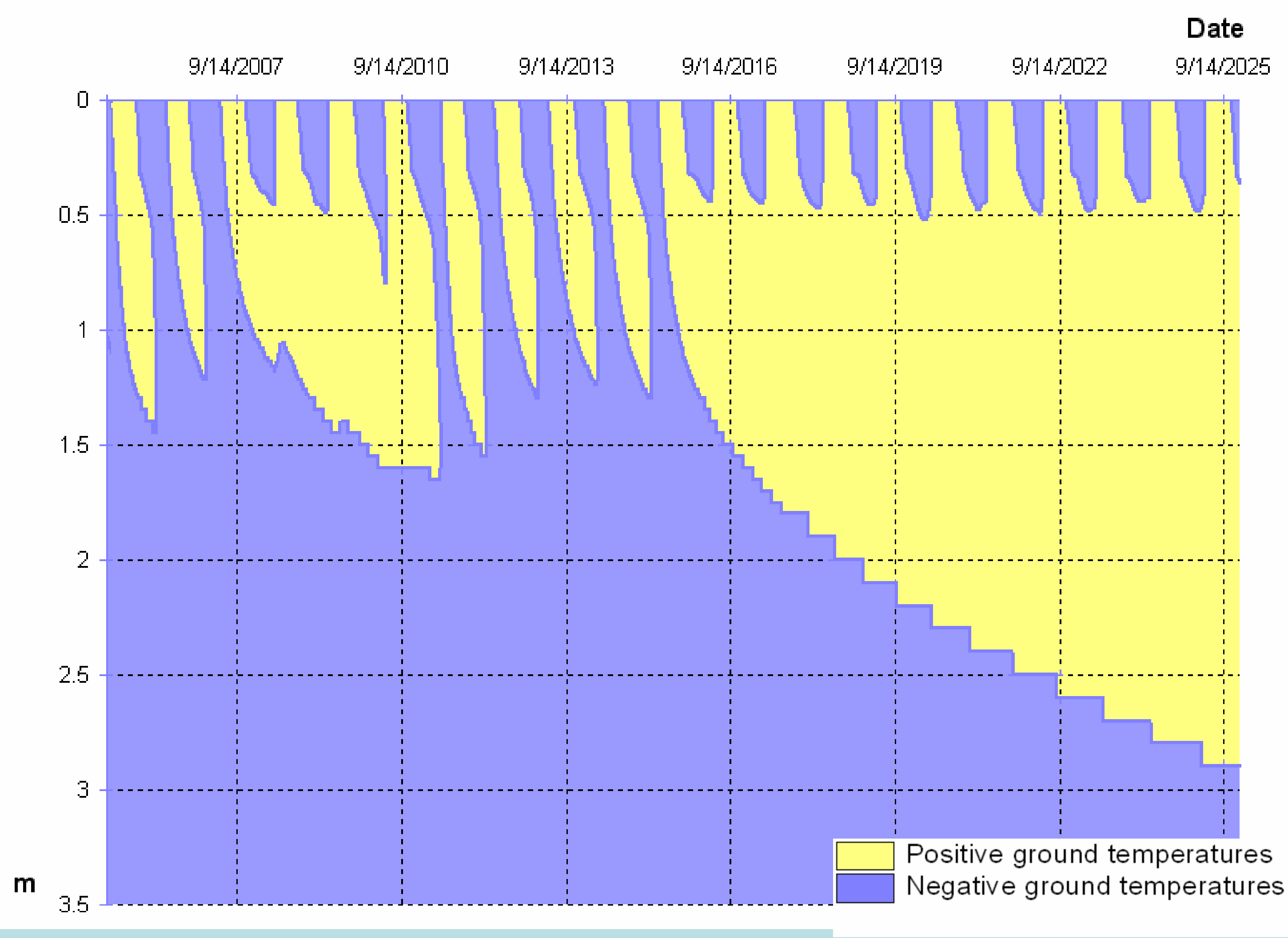





FAIRBANKS, ALASKA, 1930-2005
Mean annual ground temperatures
Depth:
0.08 m
0.3 m
0.5 m
1 m
MEAN ANNUAL TEMPERATURE (°C)
2
1
0
-1
-2
-3
1930
1940
1950
1960
1970
1980
1990
2000
TIME (years)
V. ROMANOVSKY, Geophysical Institute
University of Alaska, Fairbanks
FFVER@UAF.EDU

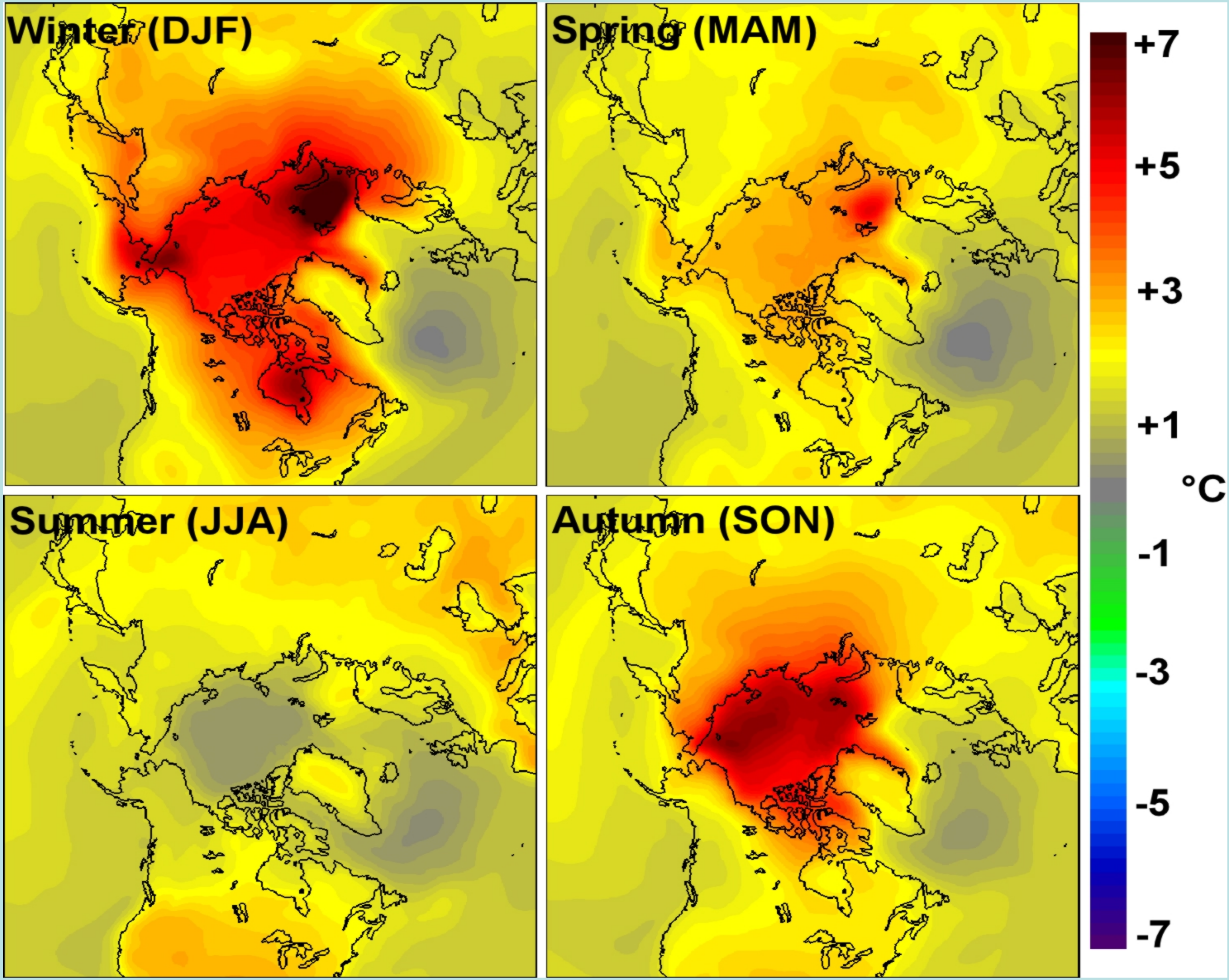
Permafrost degradation (Fairbanks) 2005-2025 Hadley model forcing

[from V. Romanovsky, UAF]



When surface temperatures increase, the active layer does not freeze up during the winter, and permafrost degradation starts.

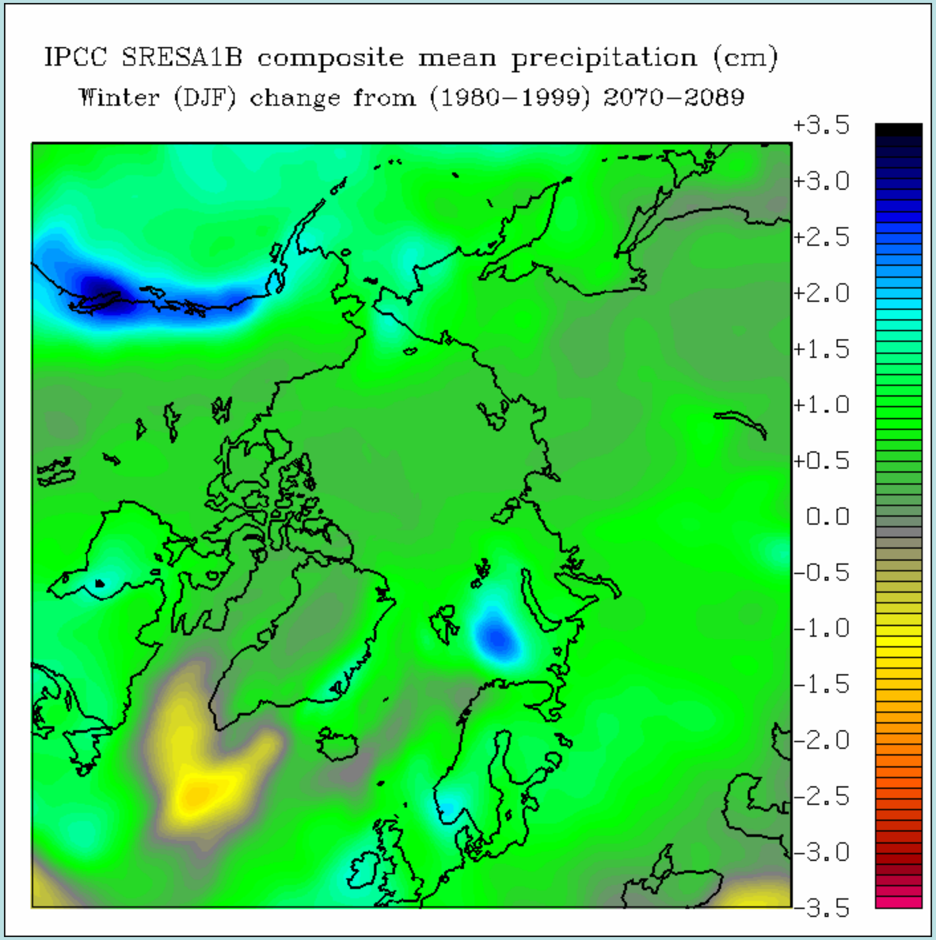
Projected changes of temperature: 2070-2090



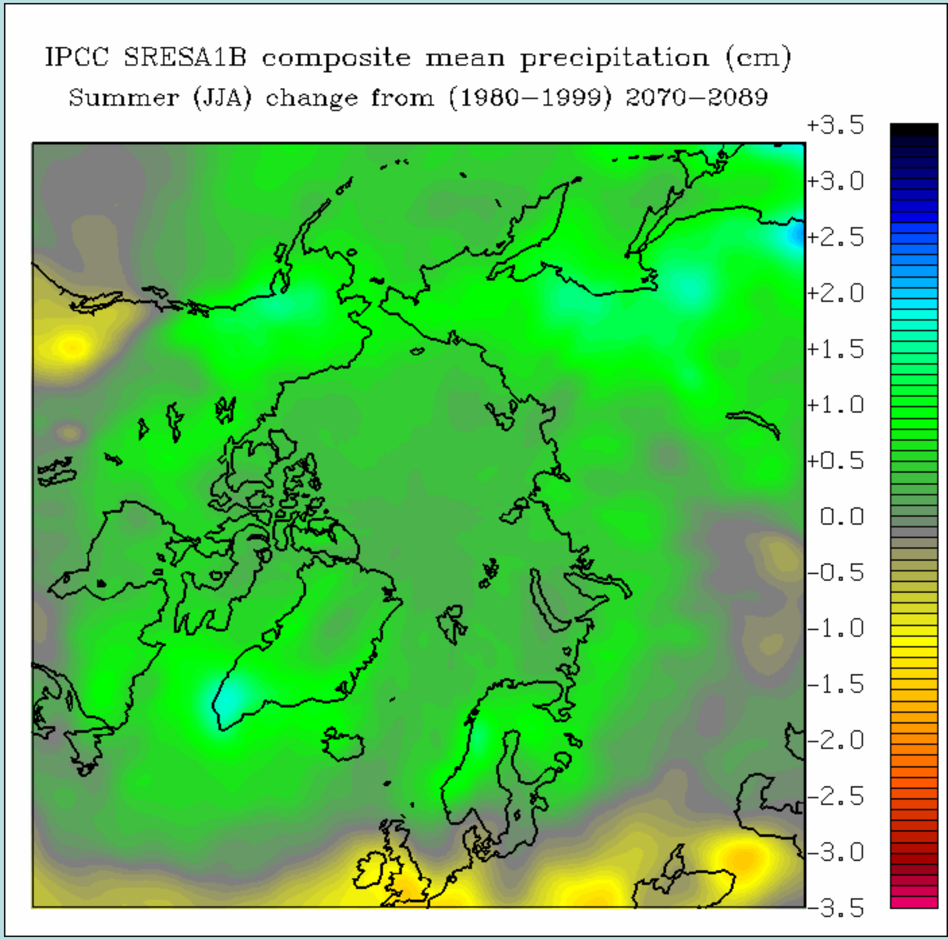
Projected changes of precipitation for 2070-2090

(models used by IPCC, 2007)

winter

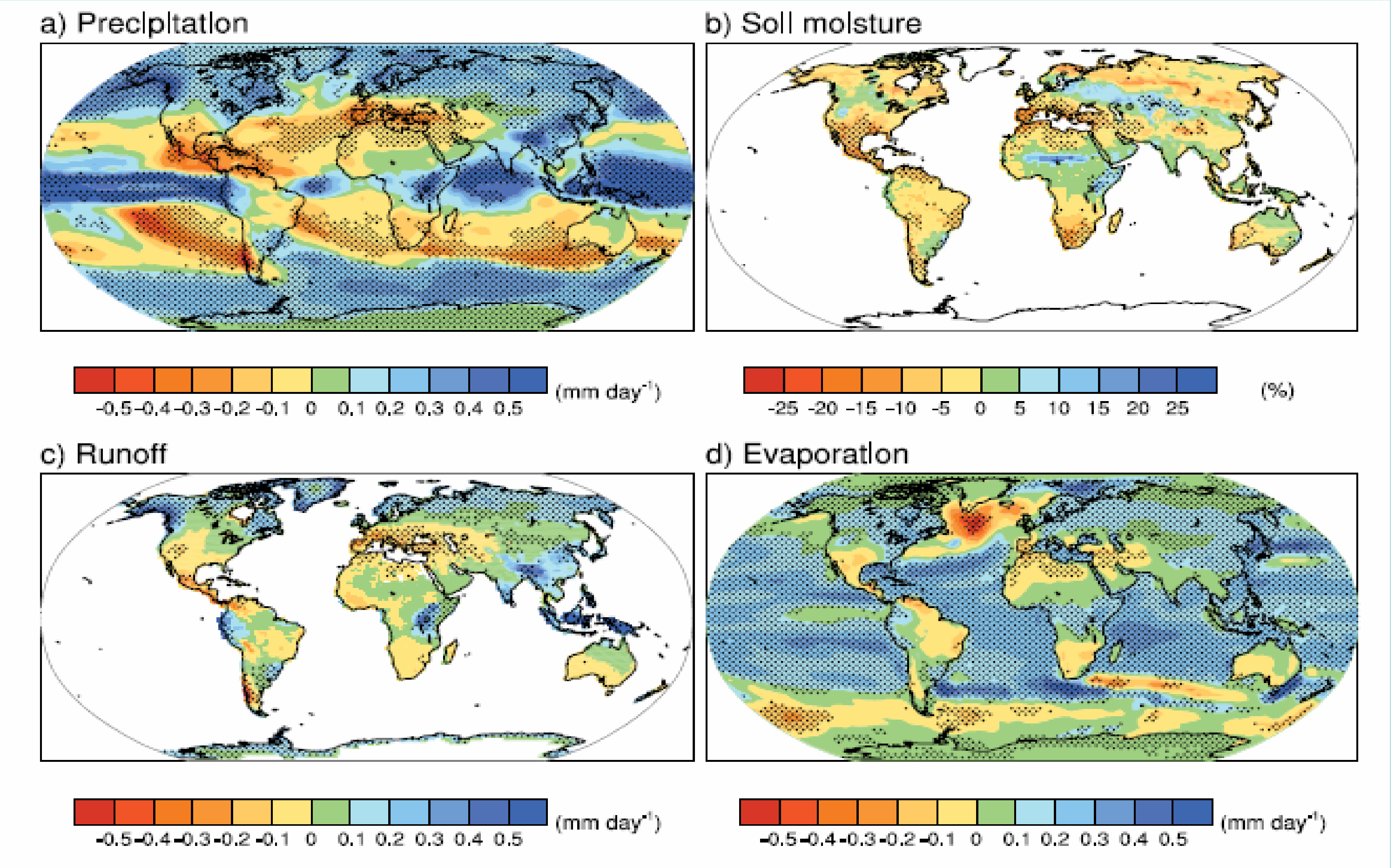


summer



IPCC, 2007: projected hydrologic changes, 2080-2099:

In Arctic: Precip. ↑, Runoff ↑(10-30%), Evap. ↑, Soil moisture ↓



Conclusions

- **Over the past 50-60 years, temperatures in the Arctic, particularly Alaska, have warmed; summer sea ice has diminished**

  -- Regional changes are shaped by variations of the atmospheric circulation (PDO, AO)

  -- Sea ice retreat appears to have been influenced by Atlantic (and Pacific) water inflows

- **Ecosystem impacts have been detected in the Bering, emerging in the Arctic seas?**
- **Trace gas fluxes (especially methane) are locally large; spatially integrated estimates are a priority**
- **Projections: warmer, more precipitation, drier land surfaces**