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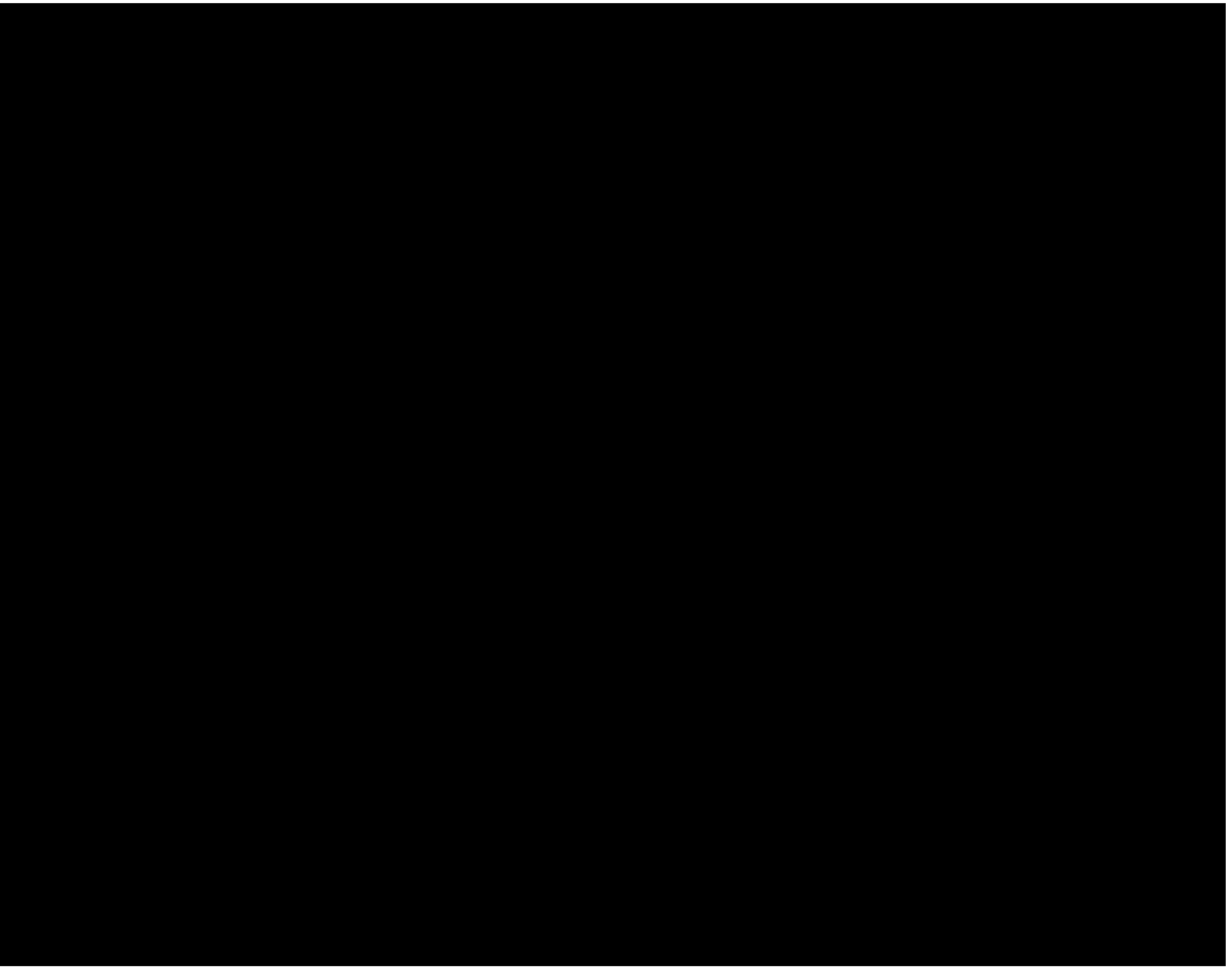
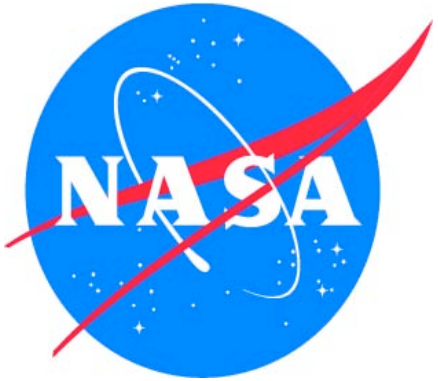
Current Research:
- Arctic hydro-climatology
- synoptic variability
- sea-ice variability





Background on Sea Ice and Arctic Climate

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Setting the Stage

Point #1:

The Arctic's sea ice cover is shrinking (about 3% per decade since 1979). These sea ice losses are part of a larger pattern of Arctic change including general warming and altered atmospheric circulation.

Point #2:

Most climate models predict continued sea ice losses through the 21st century as the climate warms in response to GHG loading.

Point #3:

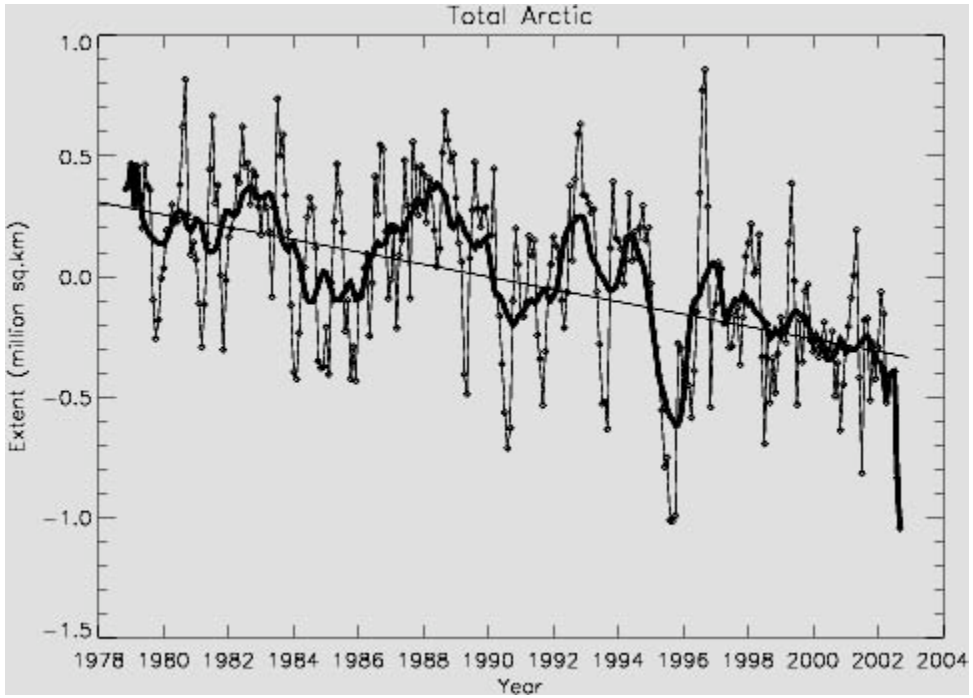
Over the past century, global average temperatures have risen by about 0.7 deg. C. Some of the most extreme warm years have occurred in the past decade. Recent warming has been especially pronounced in northern high latitudes.

Question:

Are the sea ice losses one of the emerging signs greenhouse warming? What are the ramifications?

The Sea Ice Record

Since regular monitoring began in 1979 from passive microwave sensors (SMMR, SSM/I), Arctic sea ice extent (the region with at least 15% ice cover) has declined by about 3% per decade. Similar changes are noted for ice area (extent adjusted by concentration). The changes have been largest in late summer and early autumn, with extreme minima in 1990, 1993, 1995, 1998, 2002 and 2003.

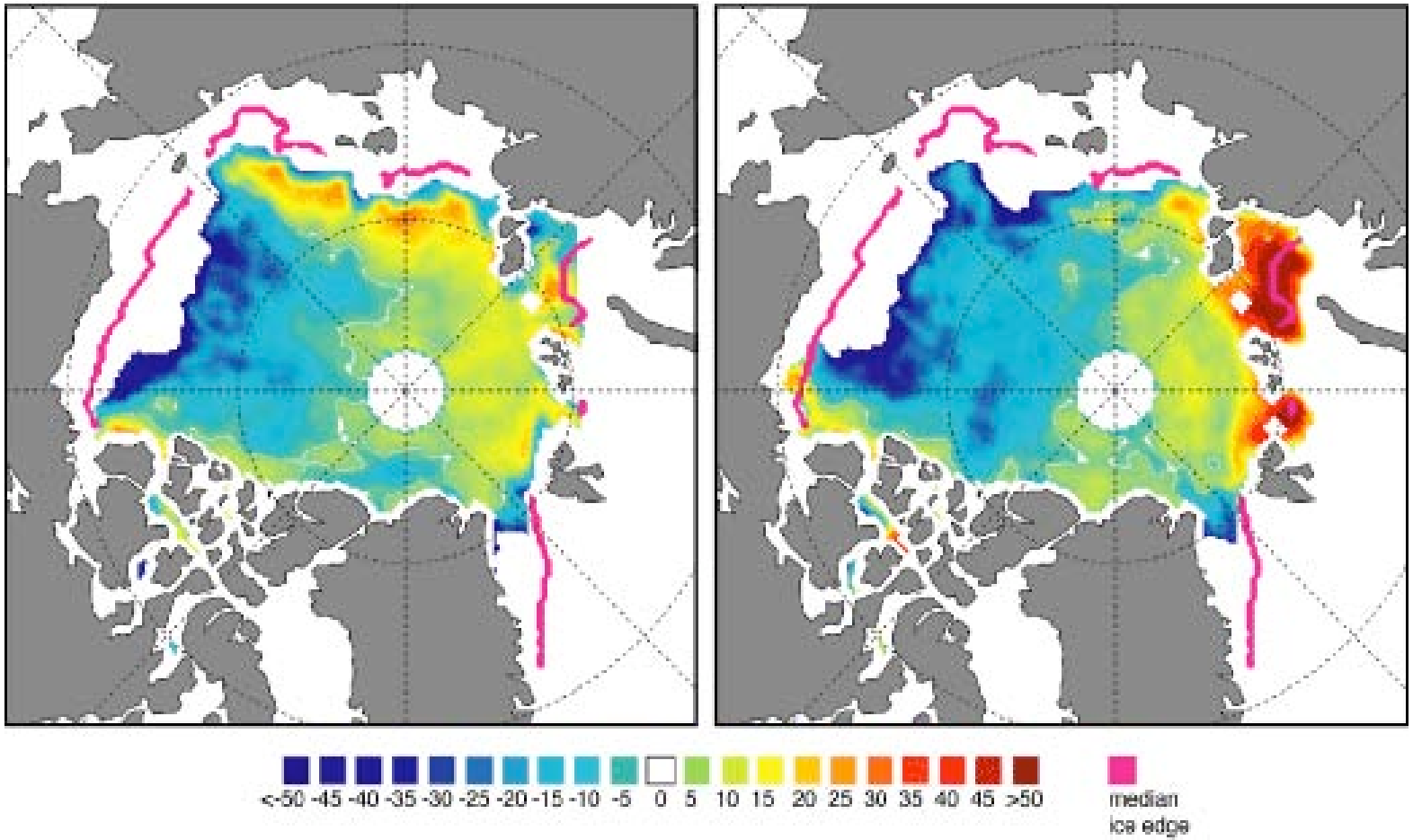


Extreme Sea Ice Minima

Sea ice extent in September 2002 set a new record low in the passive microwave era (1979-present) with September 2003 nearly as extreme.

September 2002

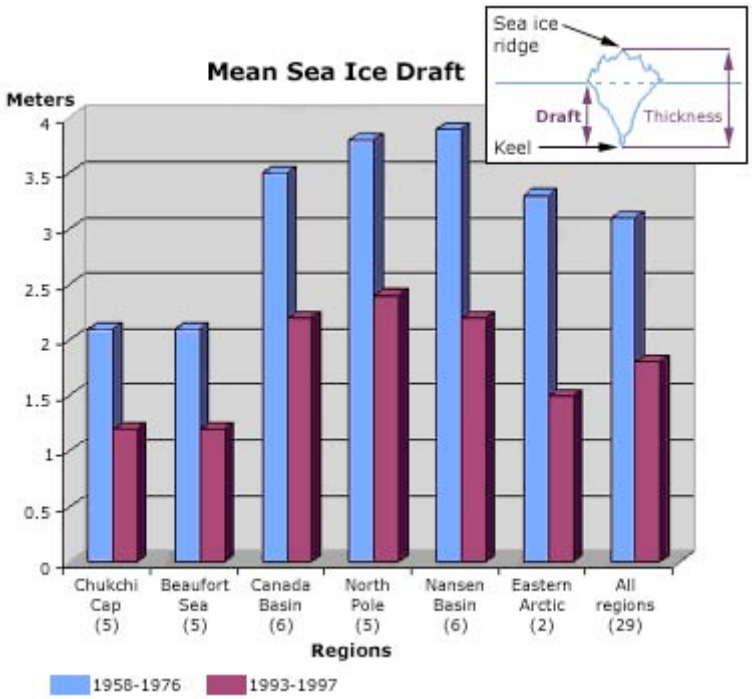
September 2003



Derived from Rothrock et al. (1999)

Sea Ice Thickness

Based on the differences in sea ice thickness measured by submarines (upward-looking sonar) from cruises over the period 1958-1976 and from later cruises over the period 1993-1997, there appeared to have been significant thinning of the ice pack – around 50% in some areas. But there is controversy over the magnitude and cause of these changes.

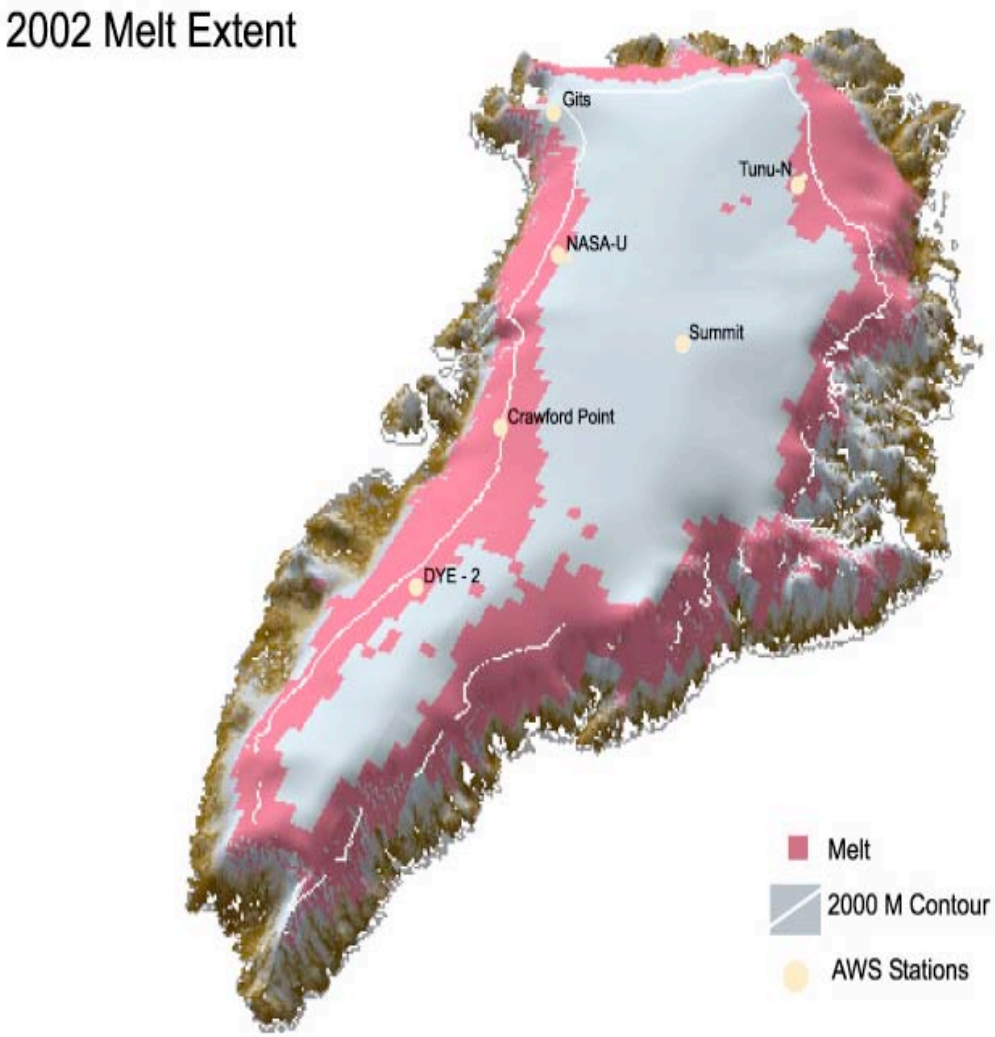


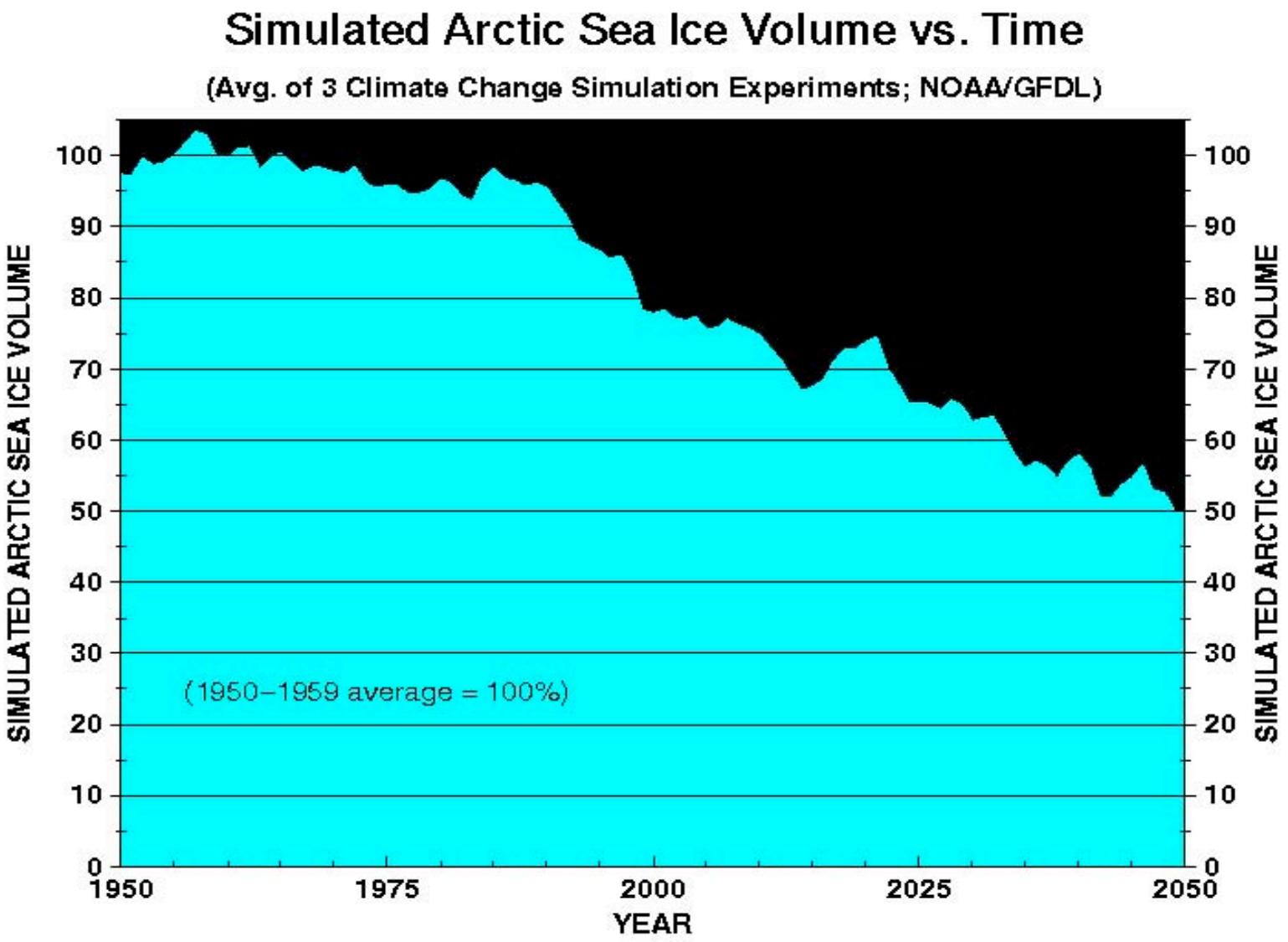
NSIDC DAAC

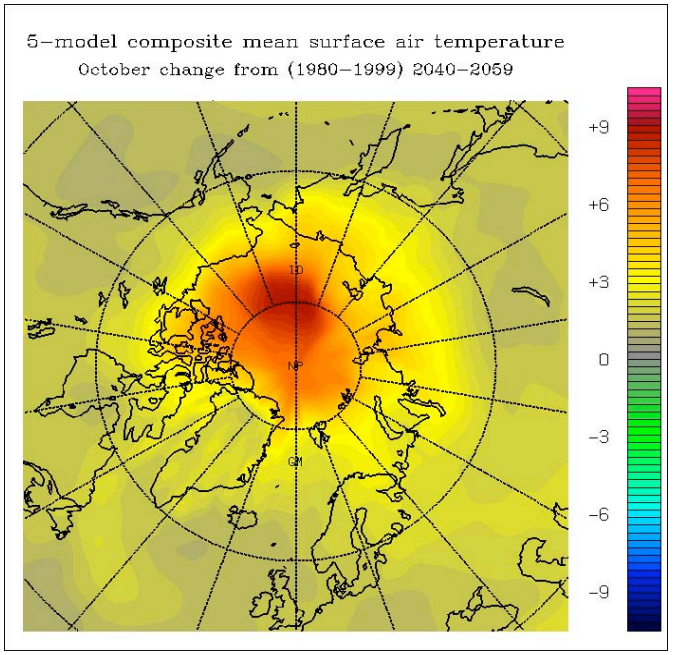
Courtesy K. Steffen, Univ. CO

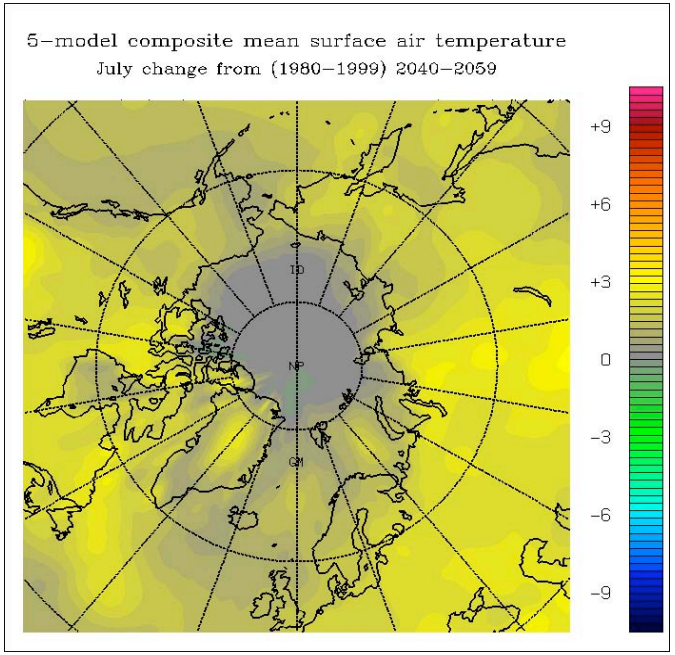
Greenland Melt Extent

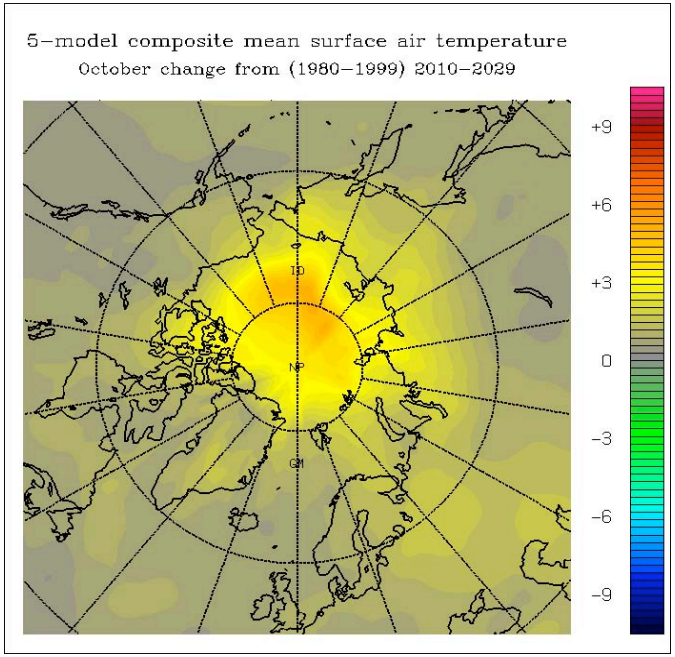
Other elements of the cryosphere are changing. Since 1979, the area of of the Greenland Ice Sheet undergoing summer melt has increased, with a new record set in 2002.

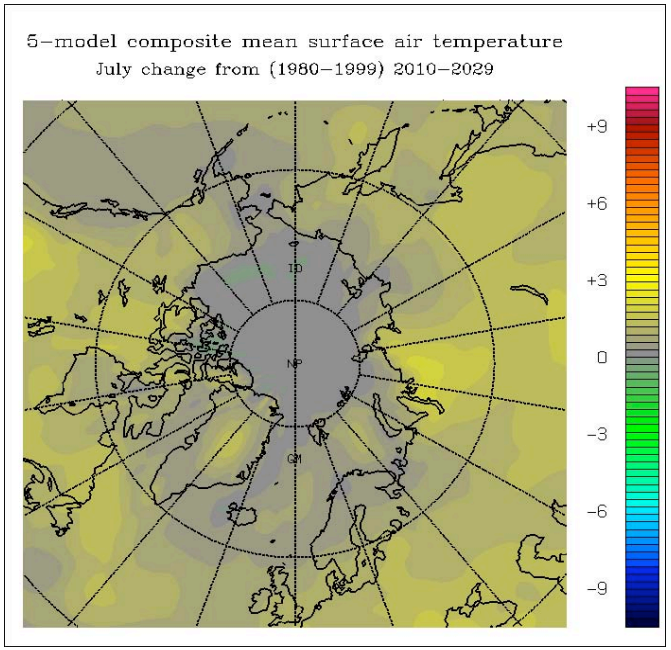



Simulated Arctic Sea Ice Volume vs. Time
(Avg. of 3 Climate Change Simulation Experiments; NOAA/GFDL)
SIMULATED ARCTIC SEA ICE VOLUME
SIMULATED ARCTIC SEA ICE VOLUME
100
90
80
70
60
50
40
30
20
10
0
(1950–1959 average = 100%)
1950
1975
2000
2025
2050
YEAR





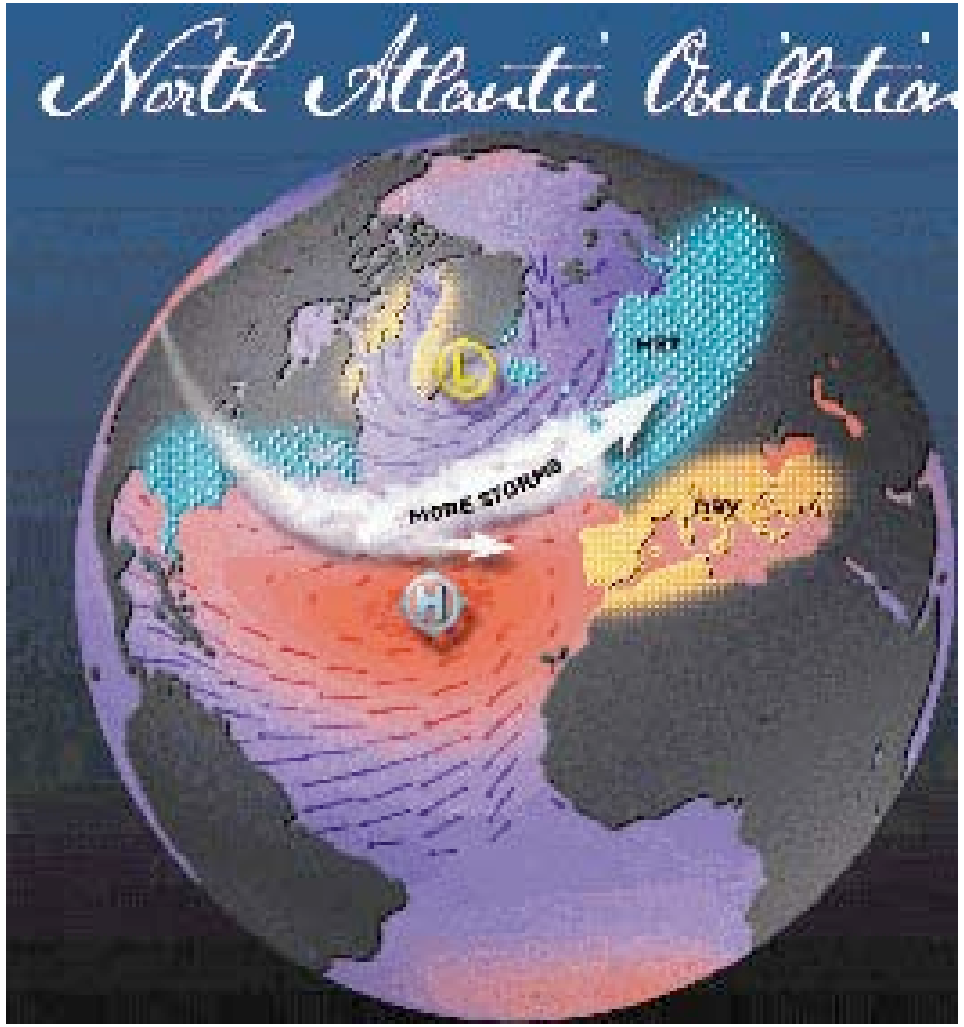




Courtesy J. Walsh, ACIA Simulations

The North Atlantic Oscillation

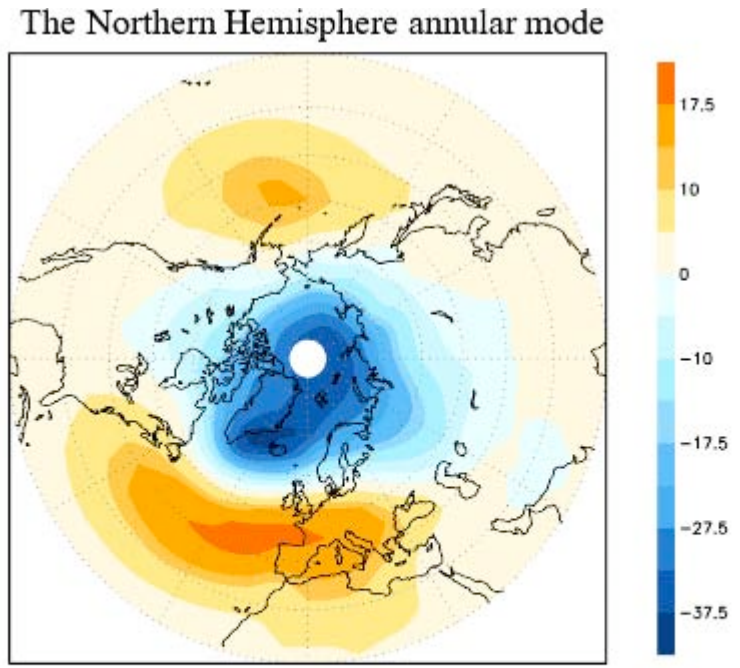
The North Atlantic Oscillation (NAO) is a key player in Arctic climate. The NAO is a large-scale mode of atmospheric variability that describes a correlation between the strength of the Icelandic Low and the Azores High. The positive mode is associated with a warmer Arctic (and wetter in places). The negative mode has roughly opposing signals



www.ldeo.columbia.edu/NAO, by Martin Visbeck

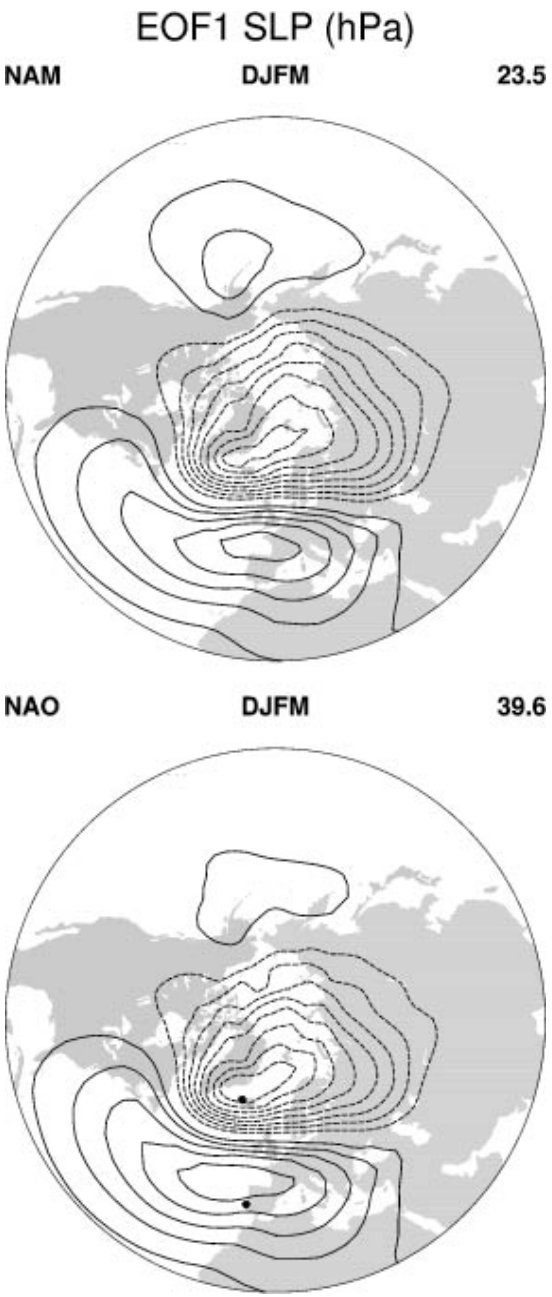
A few years later, Thompson and Wallace [1998] published a paper arguing for the NAO as a regional manifestation of a more primary mode of SLP variability which came to be known as the Arctic Oscillation (AO) or Northern Hemisphere Annular Mode (NAM).

Controversy – are the AO and NAO really separate modes? There are arguments for and against based on statistical and physical grounds [Thompson and Wallace, 1998, 2000; Deser, 2000; Ambaum et al., 2001; Hurrell, 2002].



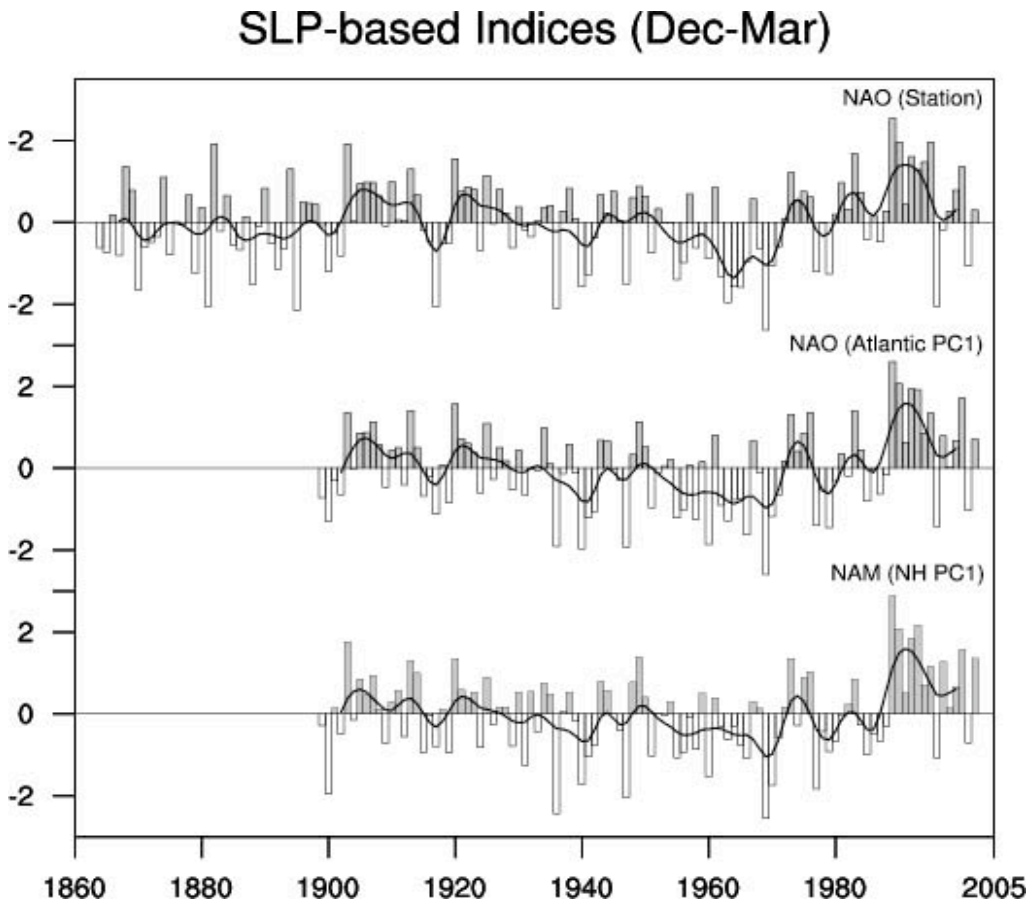
The surface signature of the Northern Hemisphere annular mode. The NAM is defined here as the leading EOF of NH monthly-mean 1000-hPa height anomalies. Units are m/std of the principal component time series.

From Thompson and Wallace [2000]



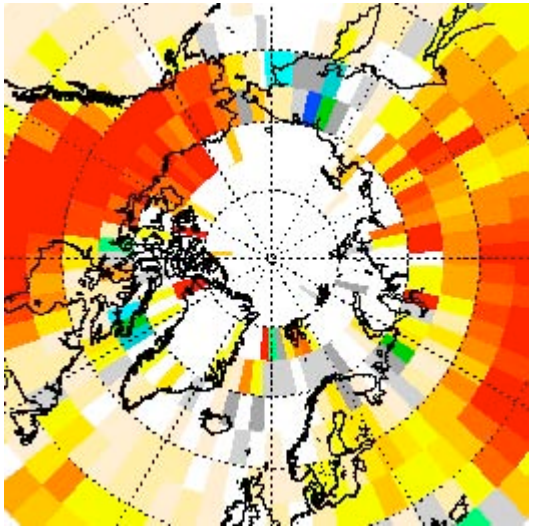
From Hurrell [2002]

In practice, one can generally use either paradigm. Key point: there has been a generally rising trend since about 1970, explaining part of the observed warming, especially for winter and spring

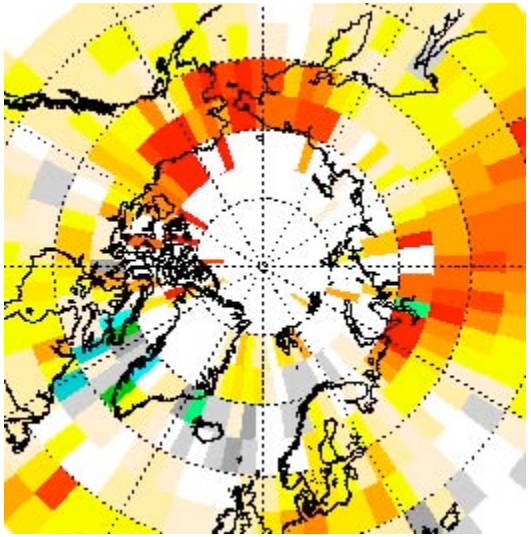


Temperature Trends: 1970-2003 (deg. C per decade)

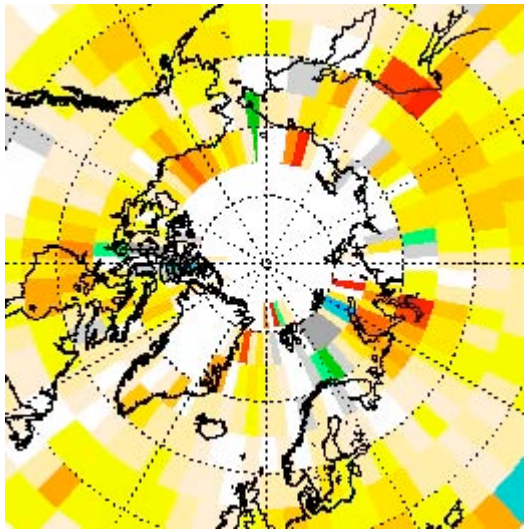
Winter



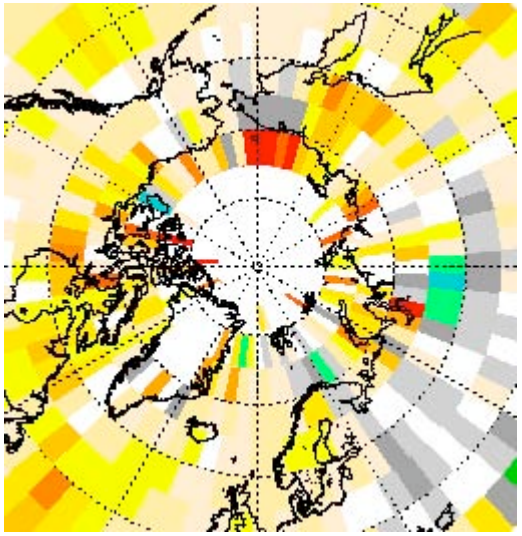
Spring

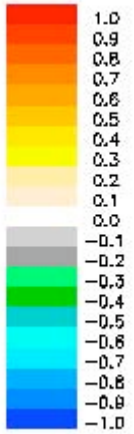


Summer



Autumn

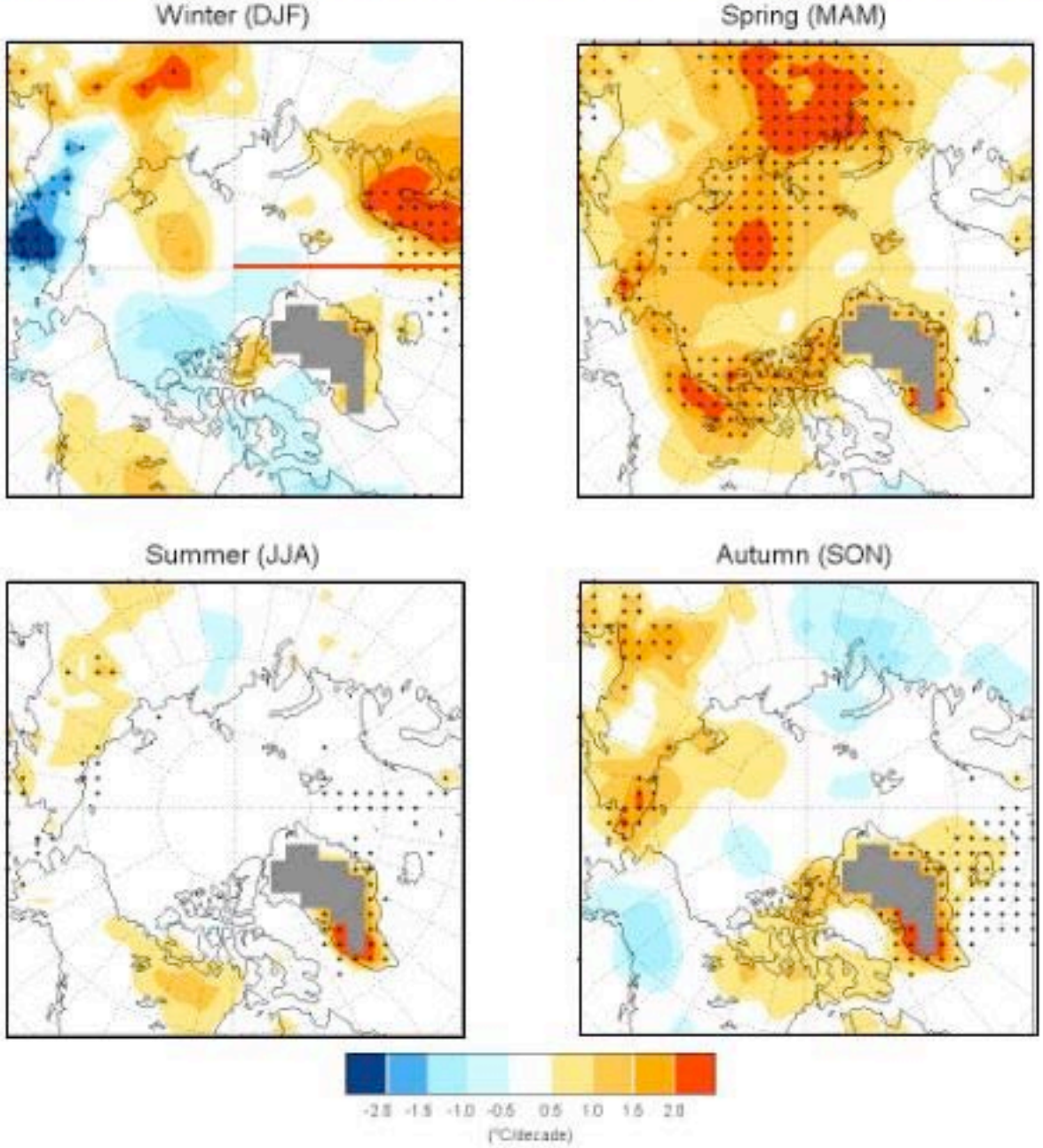




From Serreze and Francis [2004]

Based on data from Jones and Moberg [2003]

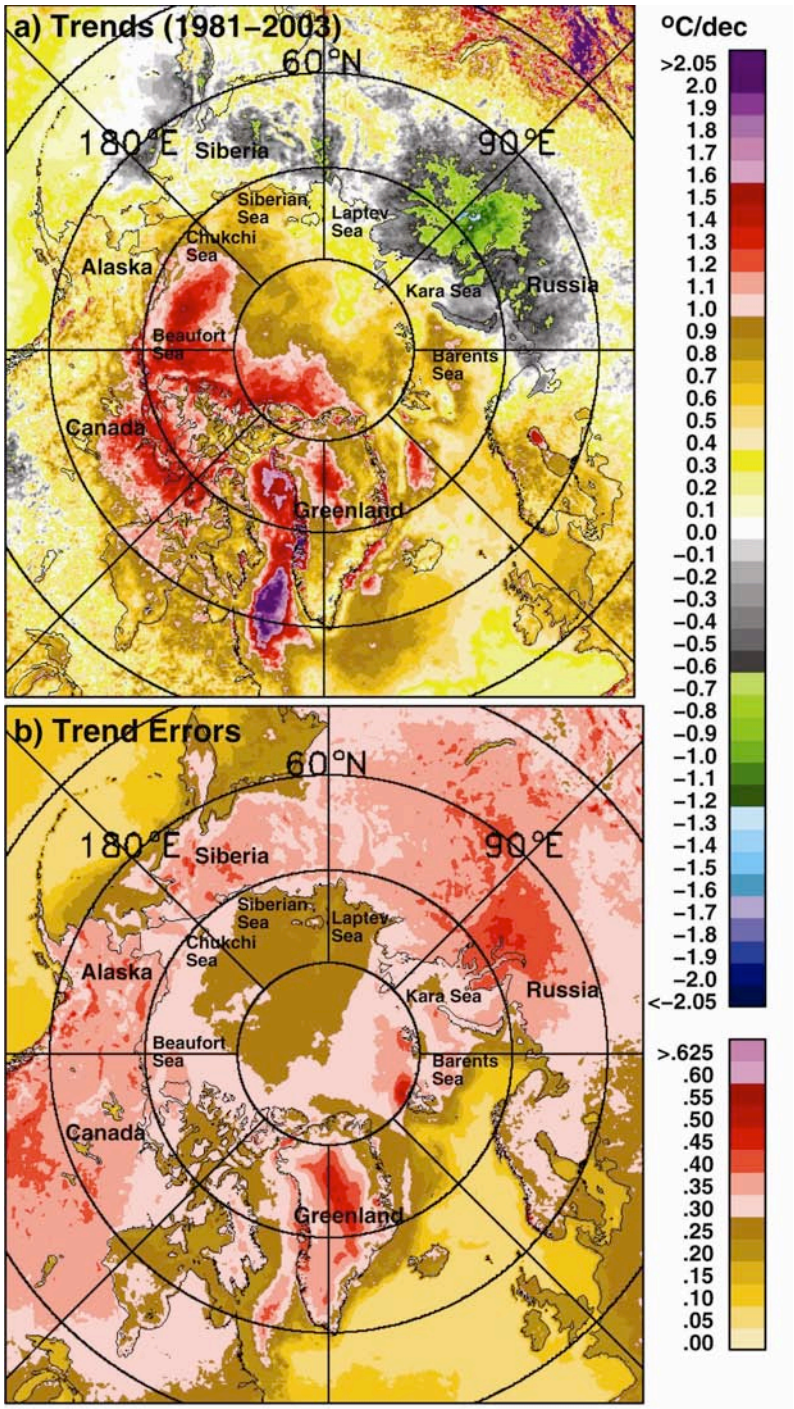
Surface Air Temperature Trends (1979 – 1997)



SAT has warmed during all seasons, especially during spring (Rigor et al., 2000).

Surface Temperatures from Satellite Data

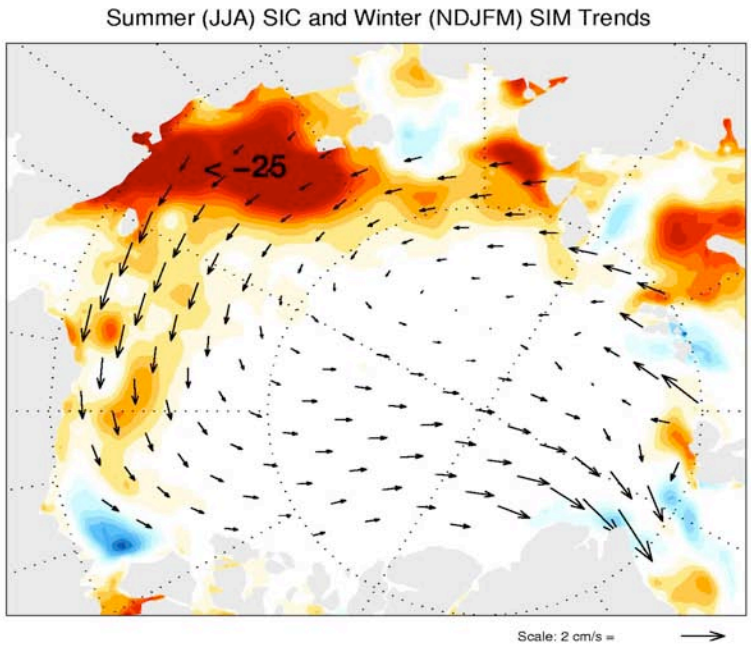
- Annual trends from AVHRR surface temperature data (1981-2003) show large spatial variability. There is an overall predominance of warming.
- Ocean: warming in spring, summer and autumn,largest in summer. Big warming in Beaufort Sea (autumn) and and Baffin Bay (winter/spring) relates in part to ice retreat. Summer warming relates to longer melt season.
- Land: warming in all seasons, but winter cooling over Eurasia. Biggest warmings in summer.
- Statistical errors are not correlated with the magnitude of the trends and are generally higher in land areas where surface infrared emissivity is less predictable than the other areas.
- Ref: Comiso, J. C., J. Climate, 16(21), 2003.

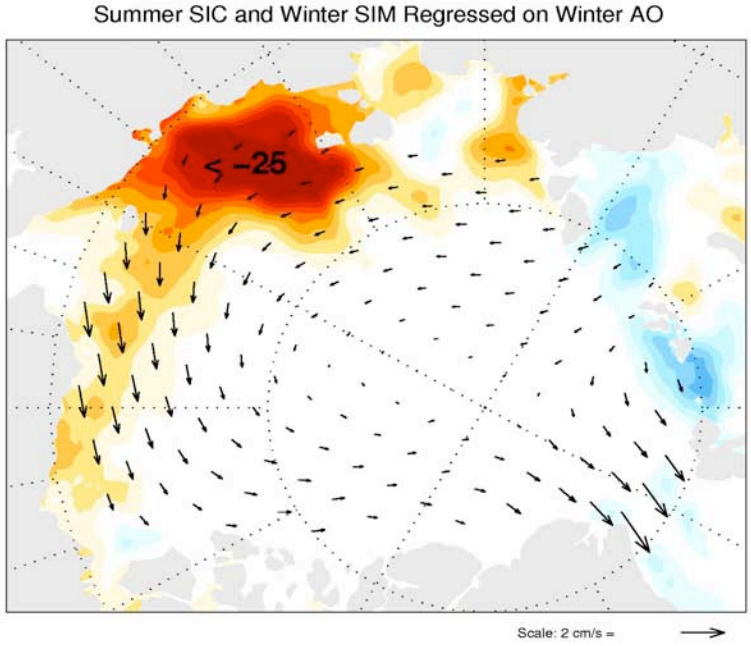


AO/Sea Ice Linkages

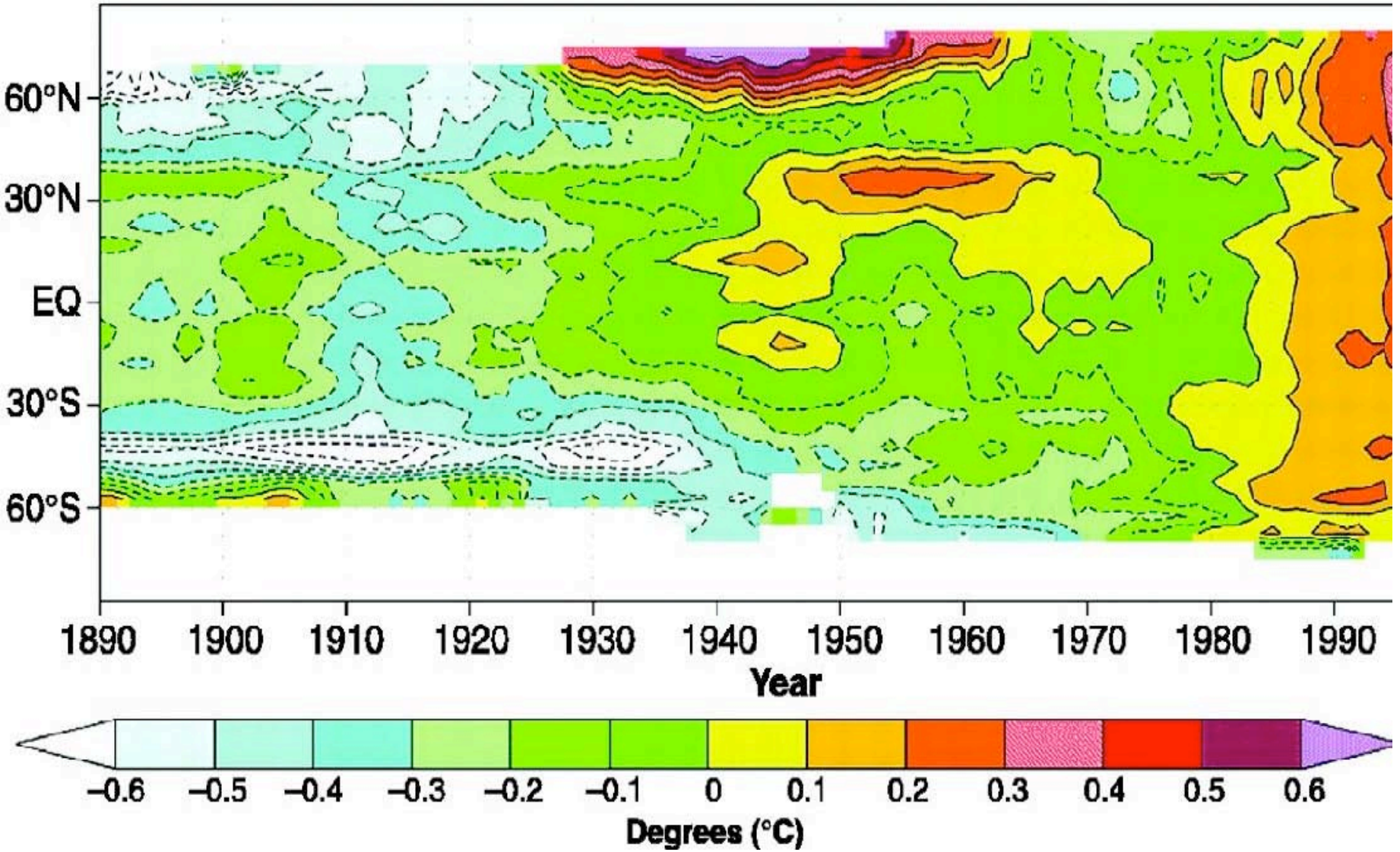
During winters with a positive AO, anomalous winds force a cyclonic anomaly in sea ice motion (SIM) along the Eurasian coast, helping to break up the ice cover and making it more prone to summer decay – a preconditioning mechanism [Rigor et al., 2002]. Further work [Rigor and Wallace, 2004] indicates that the "high" AO period of 1989-1995 strongly impacted on the age of sea ice, and that the extremely low ice years of 2002 and 2003 represent a delayed response to this preconditioning

From Rigor et al. [2002]

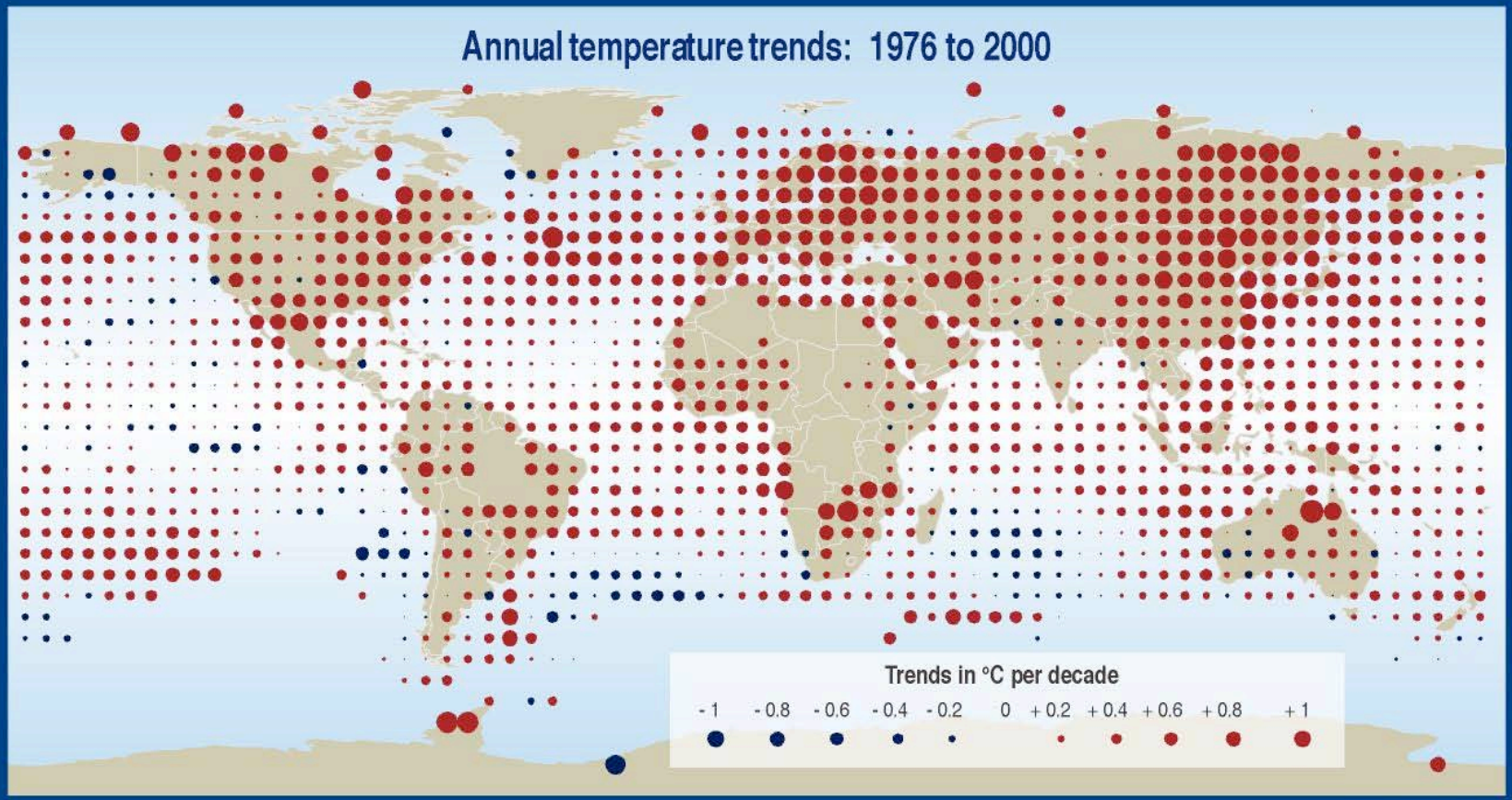




Temperature Anomalies Referenced to 1961-1990 Means

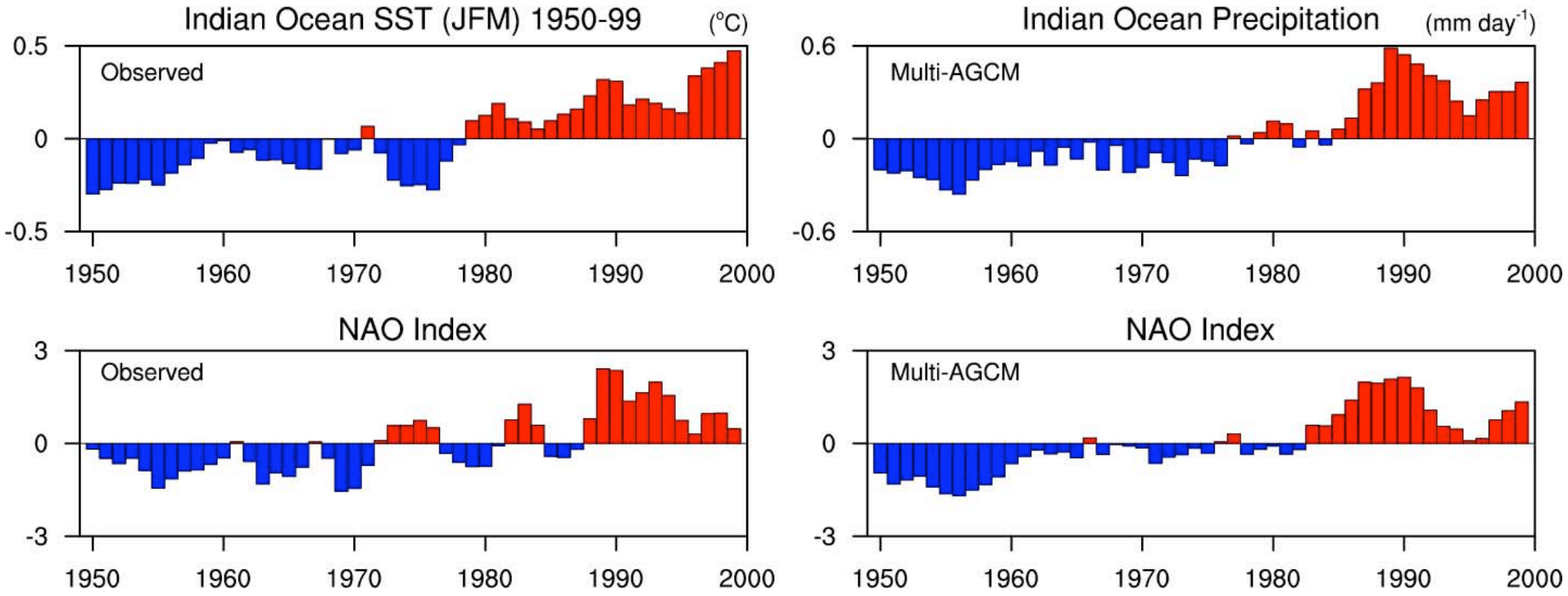


From Delworth and Knutson [2000]



SYR - FIGURE 2-6b

Tropical Forcing of the NAO



Recent work suggests that the NAO trend is at least partly driven by increasing sea surface temperatures (SSTs) in the tropical Indian Ocean and that the SST changes involve a non-linear response to GHG loading (Figure courtesy of J. Hurrell (NCAR) and M. Hoerling (CDC)). Other ideas: GHG and ozone influences on the stratosphere.

Putting it all Together:

Is the sea ice decline manifesting human impacts on Arctic climate? This is the million-dollar question.

An Argument Against:

The recent decline in the Arctic sea ice cover can be linked to both recent warming (a longer melt season) and changes in the sea ice circulation. Both processes can be associated with the general trend toward the positive mode of the NAO/AO. However, the AO/NAO are natural modes of atmospheric variability. Can have decadal-scale changes simply due to "internal" atmospheric dynamics. Oceanic coupling can give rise to longer-term variations.

Some Arguments For:

The recent warming is global, quite different from the earlier warming from about 1920-1940 that was focused on high latitudes. The high-latitude NAO/AO influence is superimposed on this global warming signal.

The basic physics behind climate model projections are sound

Recent studies suggest that tropical SST warming has "nudged" the AO/NAO to it's positive state and has an anthropogenic origin (the recent high latitude warming is a "remote" greenhouse signal). Seems that changes in the stratosphere associated with GHG loading and ozone loss can also influence the AO/NAO. But the jury is still out!

Proxy data indicates that the late 20th century Arctic is the warmest of the past 400 years - is best explained by GHG loading.

To Stick My Neck Out

As the 21st century unfolds, the model projected changes in Arctic sea ice and temperature will be realized.