Drivers and Causes in the SEARCH Context

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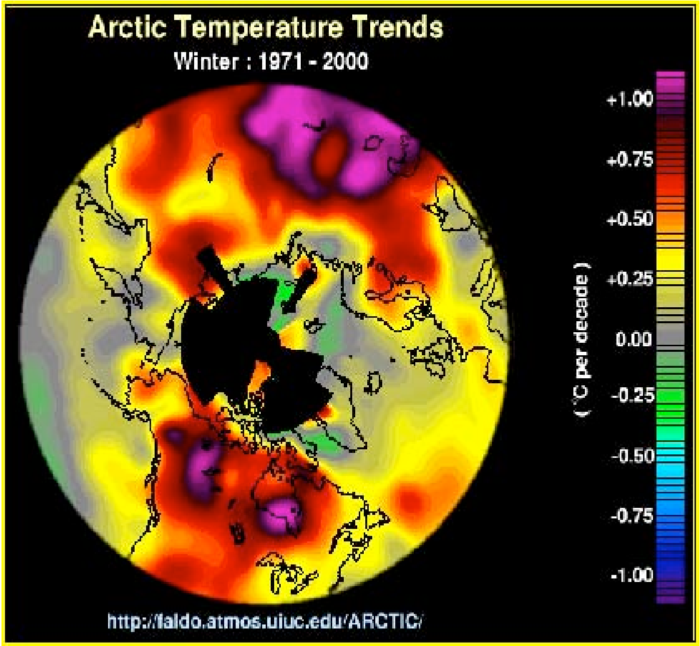
NSIDC DAAC


Arctic Temperature Trends
Winter : 1971 - 2000
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+0.75
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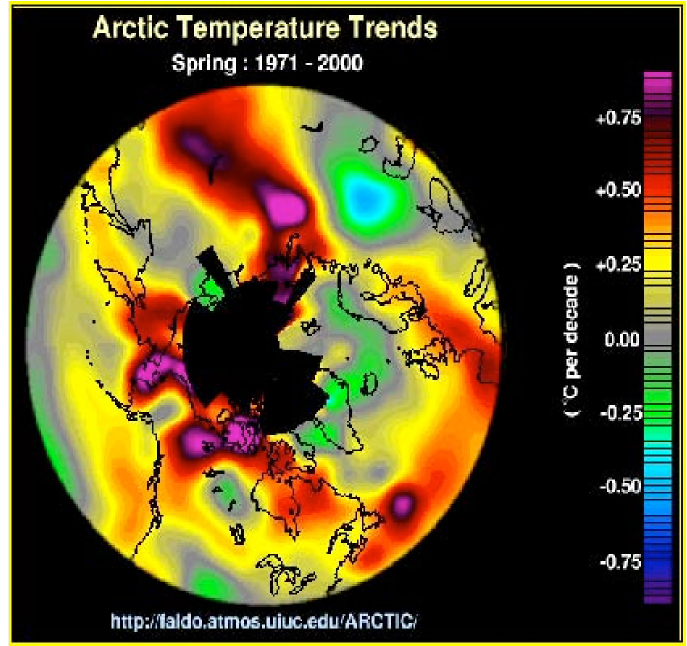
(°C per decade)
http://faldo.atmos.uiuc.edu/ARCTIC/


Arctic Temperature Trends
Spring : 1971 - 2000
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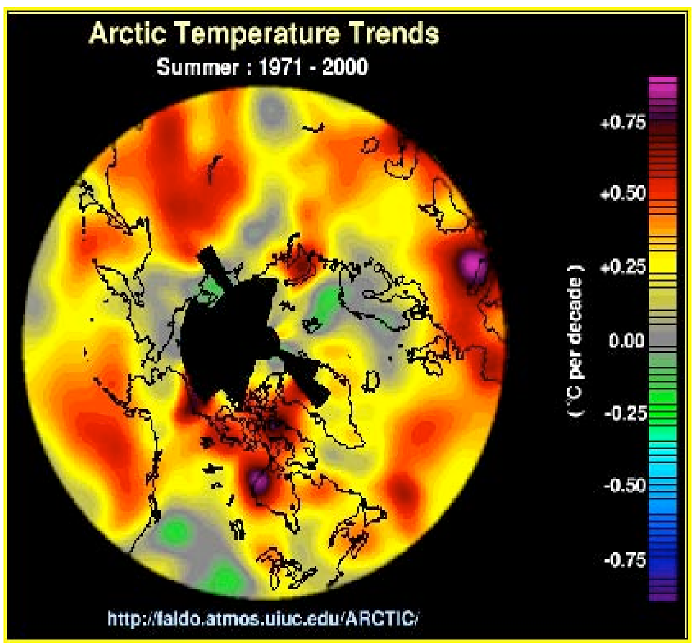
Arctic Temperature Trends
Summer : 1971 - 2000
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+0.50
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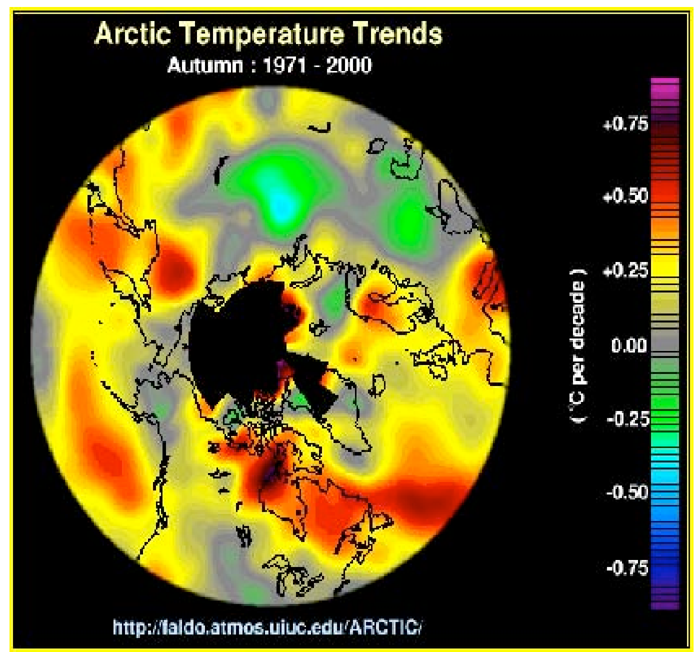
Arctic Temperature Trends
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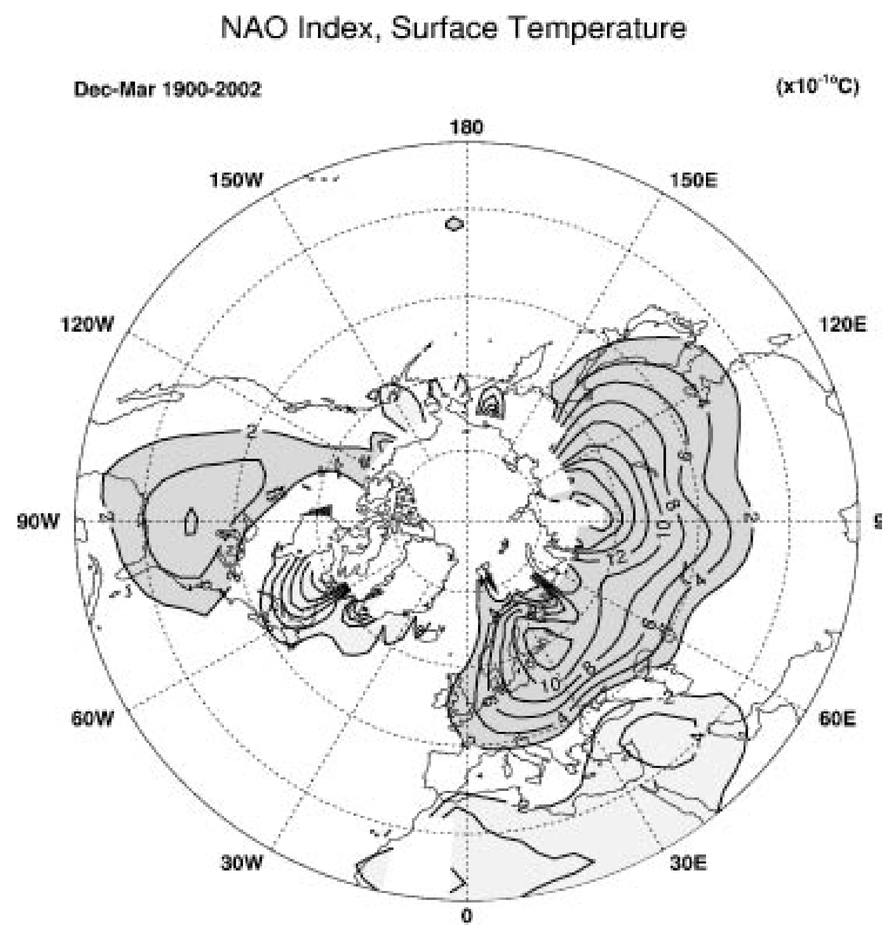
-0.50
-0.75
(°C per decade)
http://faldo.atmos.uiuc.edu/ARCTIC/

The NAO and Temperature

In the mid 1990s, Hurrell of NCAR published a pair of papers that were important in two respects (Hurrell, 1995,1996). He demonstrated that:

1) The NAO, which has been recognized for centuries, has much wider influences on winter surface air temperature (SAT) than was widely appreciated.

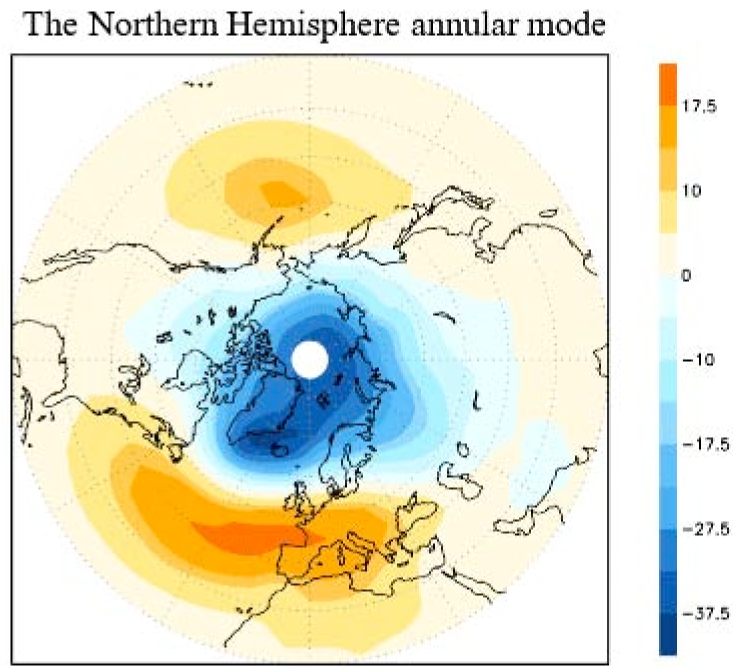
2) Since about 1970, the NAO had gone into a primarily positive mode (strong Icelandic Low), largely consistent with the pattern of recent SAT change in the Northern Hemisphere.



From Hurrell,2002

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).

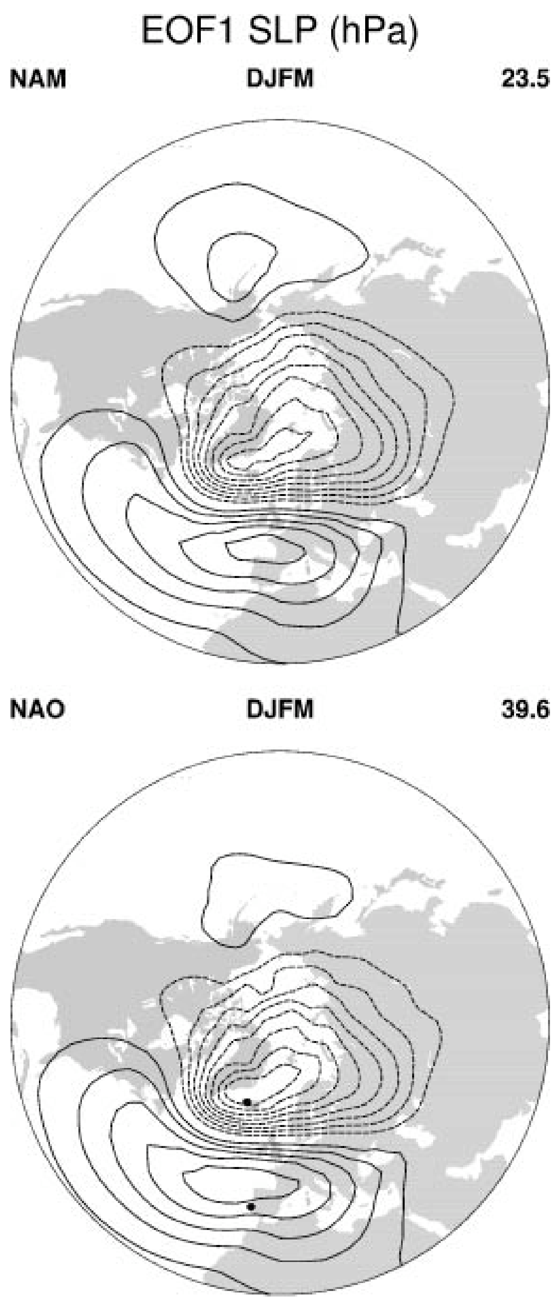
Are the AO and NAO really separate modes? There are arguments for and against based on statistical and physical grounds [Thompson and Wallace, 1998, 2000; Deser, 2000; Ambaum et al., 2001; Hurrell, 2002; Ambaum and Hoskins, 2002].

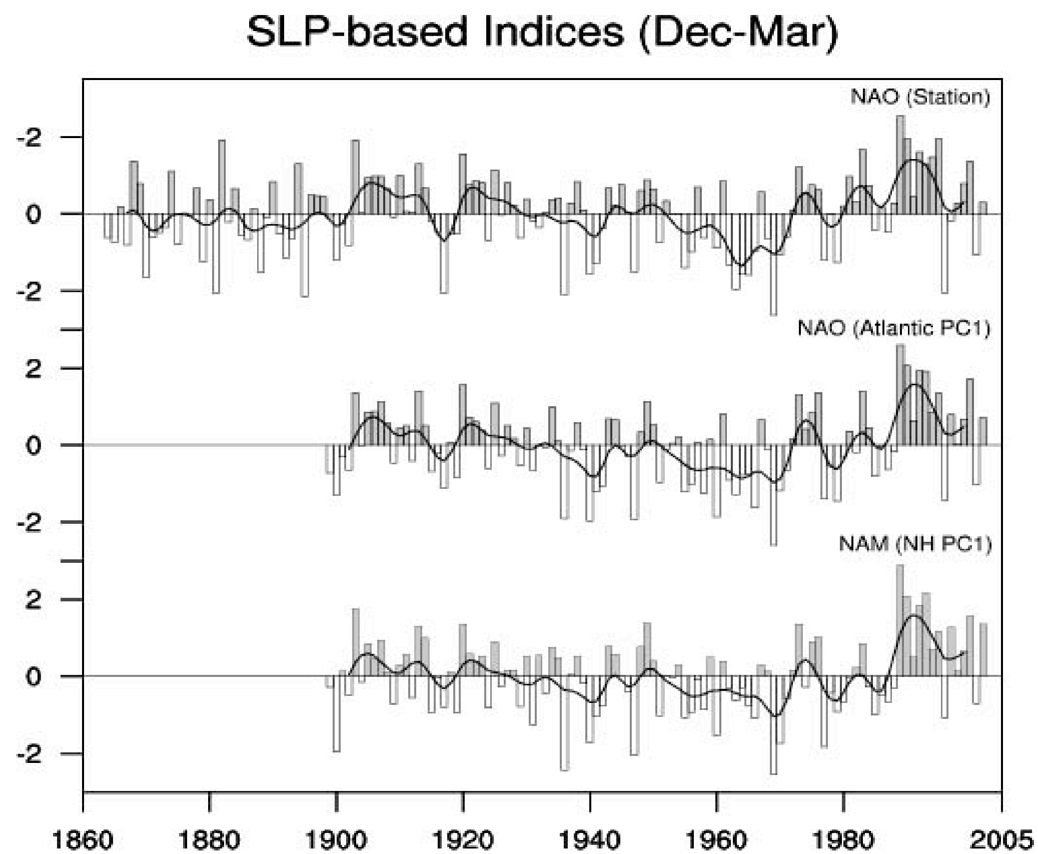


The surface signature of the Northern Hemisphere annular mode. The NAM is defined here as the leading EOF of NH monthly-mean 1000-hPa height anomalies. Units are m/std of the principal component time series.

From Thompson and Wallace [2000]

In practice, one can generally use either paradigm. If the recent change unusual? What is driving it? Lots of ideas: SSTs, greenhouse gases, ozone, solar variability. Some 1000 year simulations indicate recent change is within the "envelope" of natural variability.

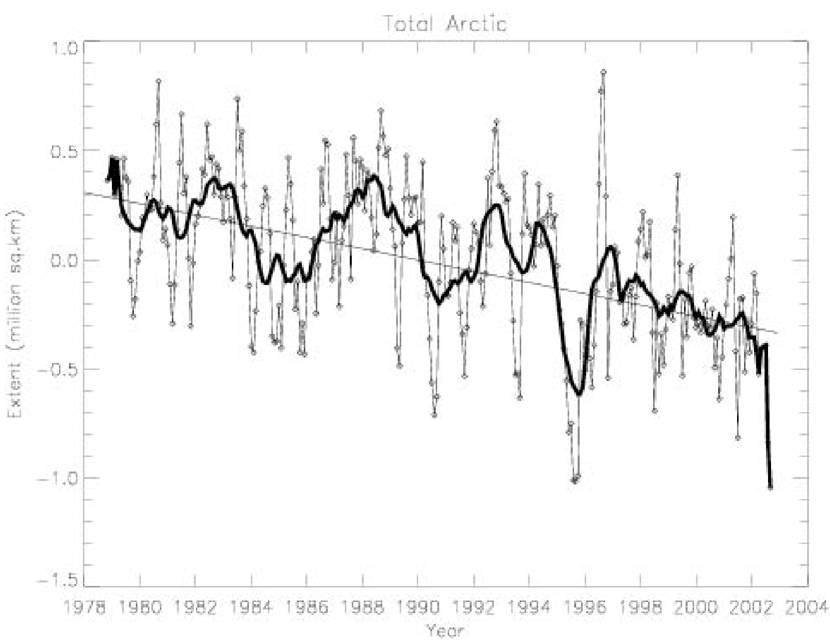




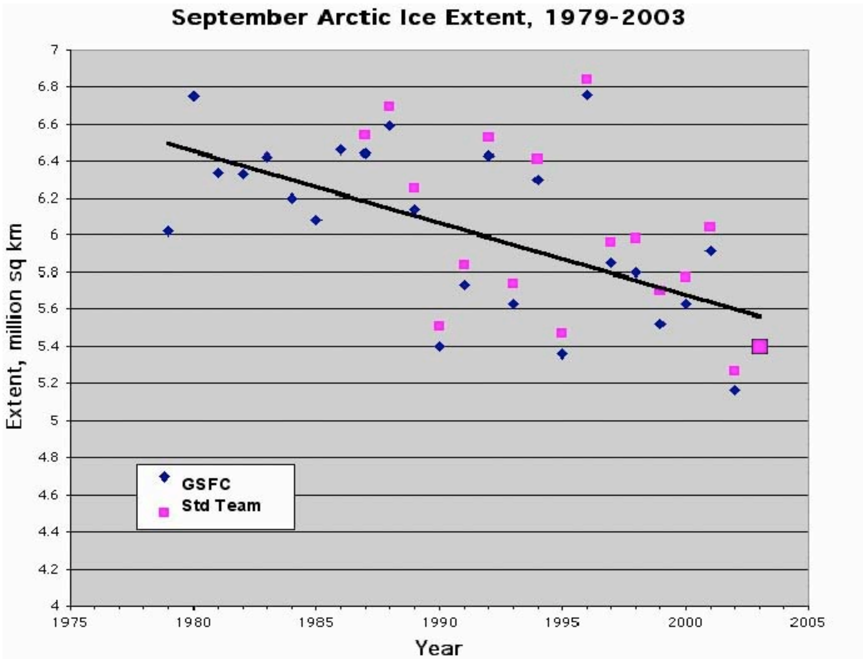
From Hurrell [2002]

The Sea Ice Record

Since regular monitoring began in 1978 from passive microwave (SMMR, SSM/I), Arctic sea ice extent has declined by about 3% per decade. The changes have been largest in late summer and early autumn, with extreme minima in 1990, 1993, 1995, 1998, 2002 and 2003. September of 2002 set a new record low, with 2003 close behind. What's the AO/NAO link?



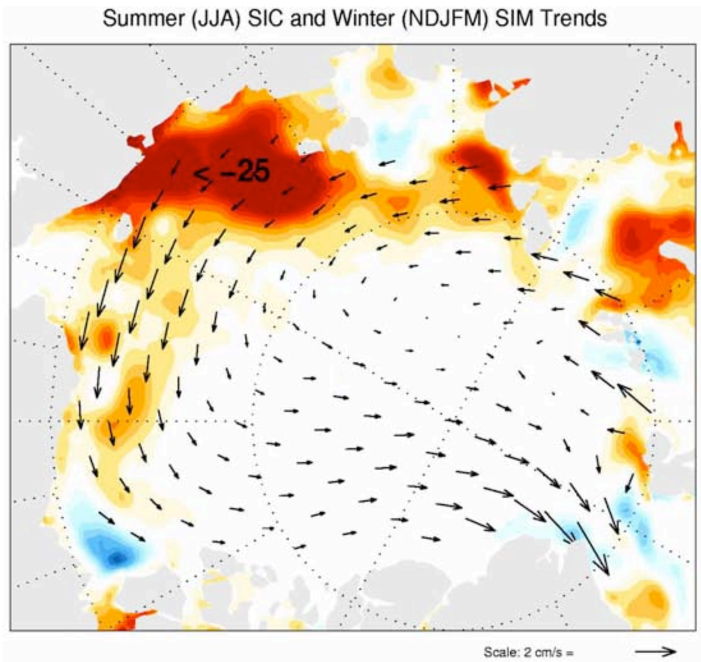
Monthly Ice Extent



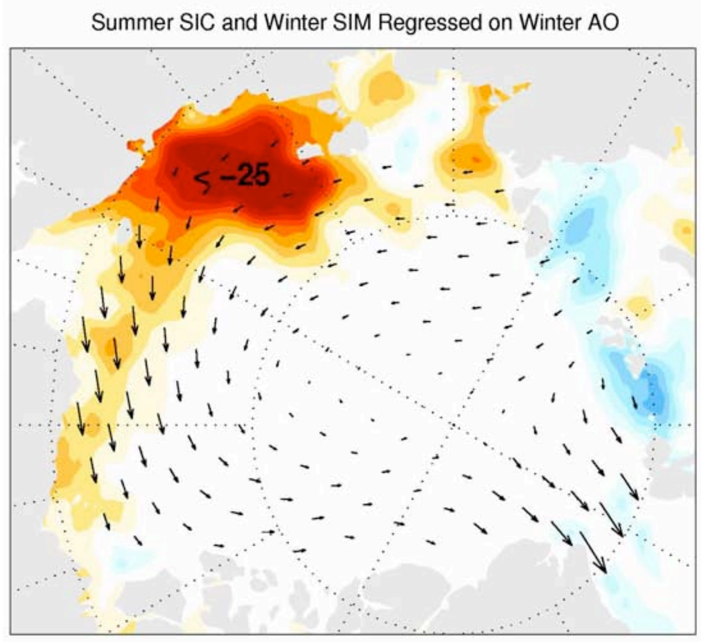
September Ice Extent

A Preconditioning Mechanism

Altered wind fields under the positive AO are associated with anomalous winter sea ice motion (SIM) that opens leads and polynyas along the Siberian and Alaskan coasts, hence more thin ice production. The thin ice will tend to melt first in spring and summer, leading to extensive late summer ice losses. Observed trends in winter SIM and summer sea ice concentration (SIC) (top) are very similar to winter SIM and summer SIC regressed on the winter AO index (bottom). Also explains spring and autumn SAT rises over the ice cover.

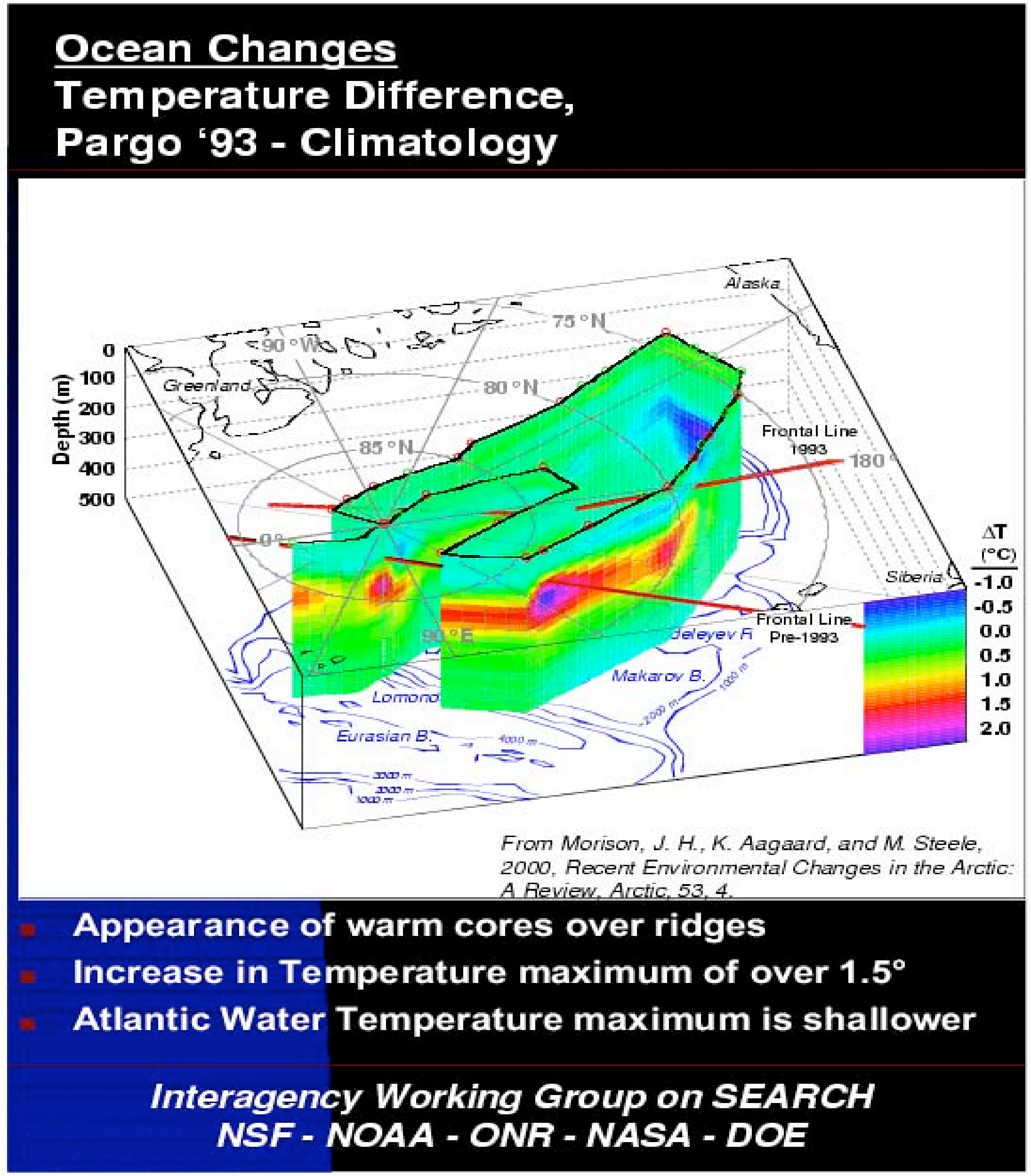


From Rigor et al. [2002]

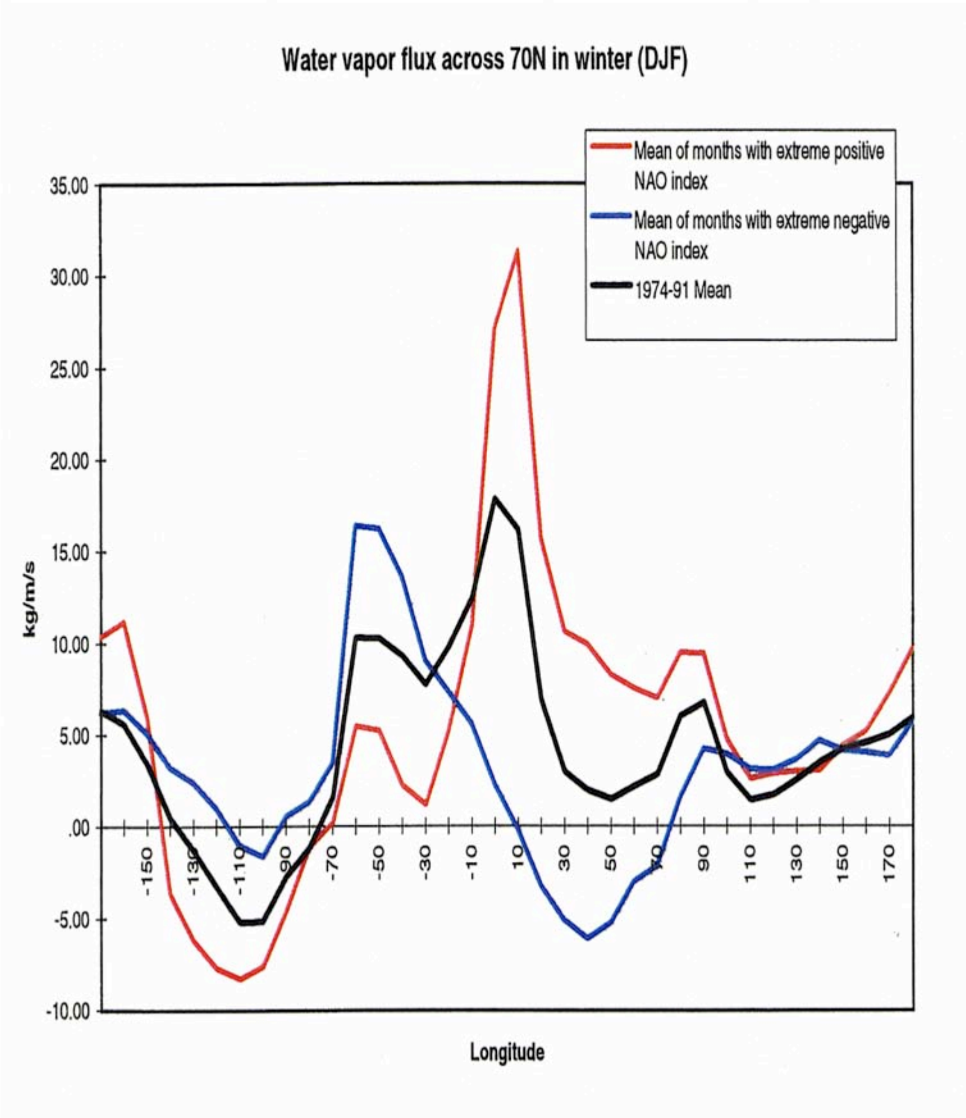


Ocean Circulation and Structure

Oceanographic data indicate warming and increased extent of Atlantic - derived waters in the Arctic Ocean (200-900 m depth). Seems consistent with greater inflow of Atlantic waters forced by change to the positive mode of the NAO/AO.

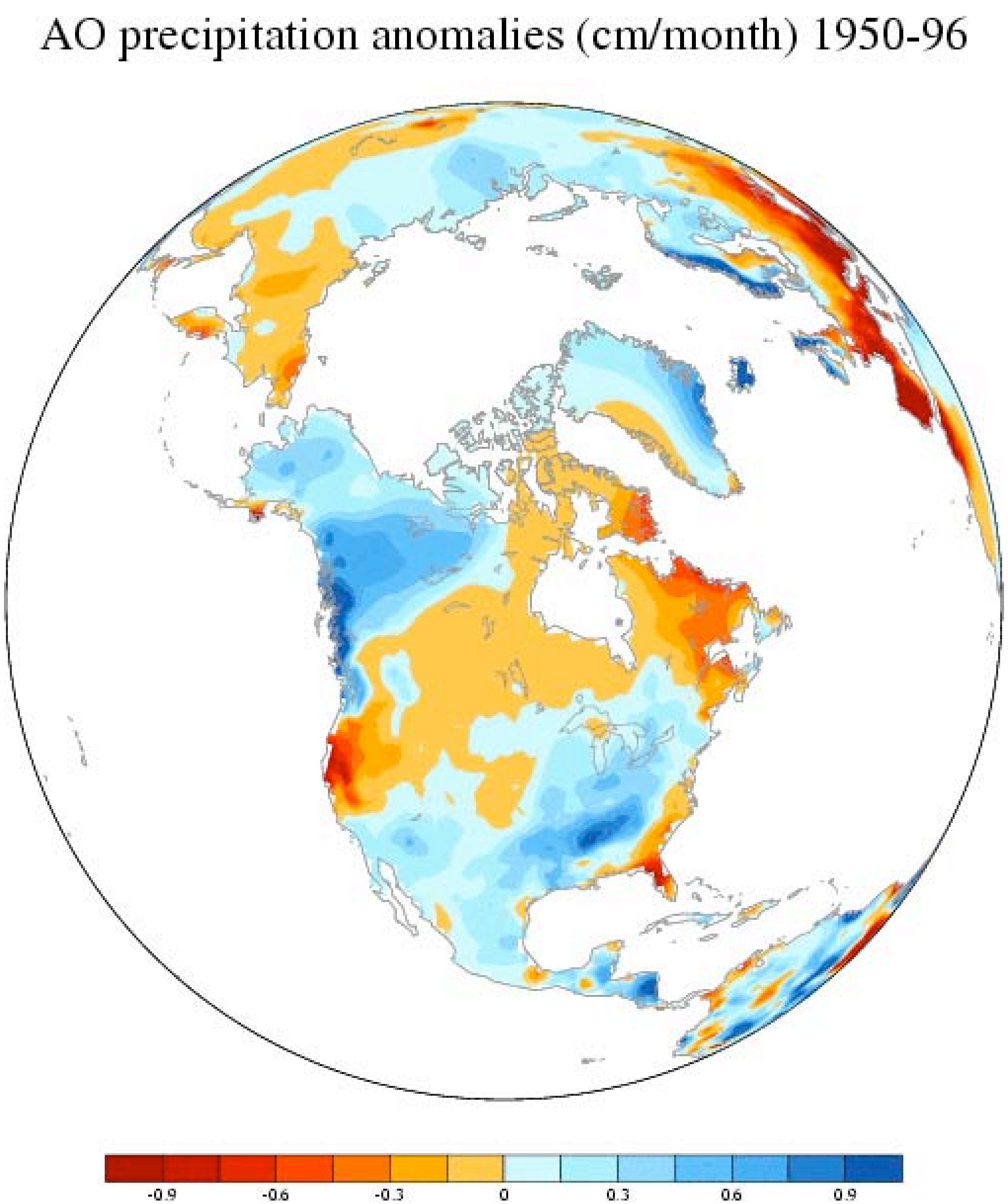


Hydrologic Budget



From Dickson et al. [2000]

Dickson et al. [2000] examined the vertically-integrated moisture flux across 70 deg. N under positive and negative extremes of the NAO. The characteristic feature is much stronger winter inflows along the "Atlantic corridor". The positive AO leads to higher winter P-ET for the region north of 70 deg. N. [Rogers et al., 2002]. The NAO/AO trend has been associated with positive changes in winter precipitation over the Atlantic corridor, parts of Eurasia, and Alaska/Yukon [Thompson et al., 2000].



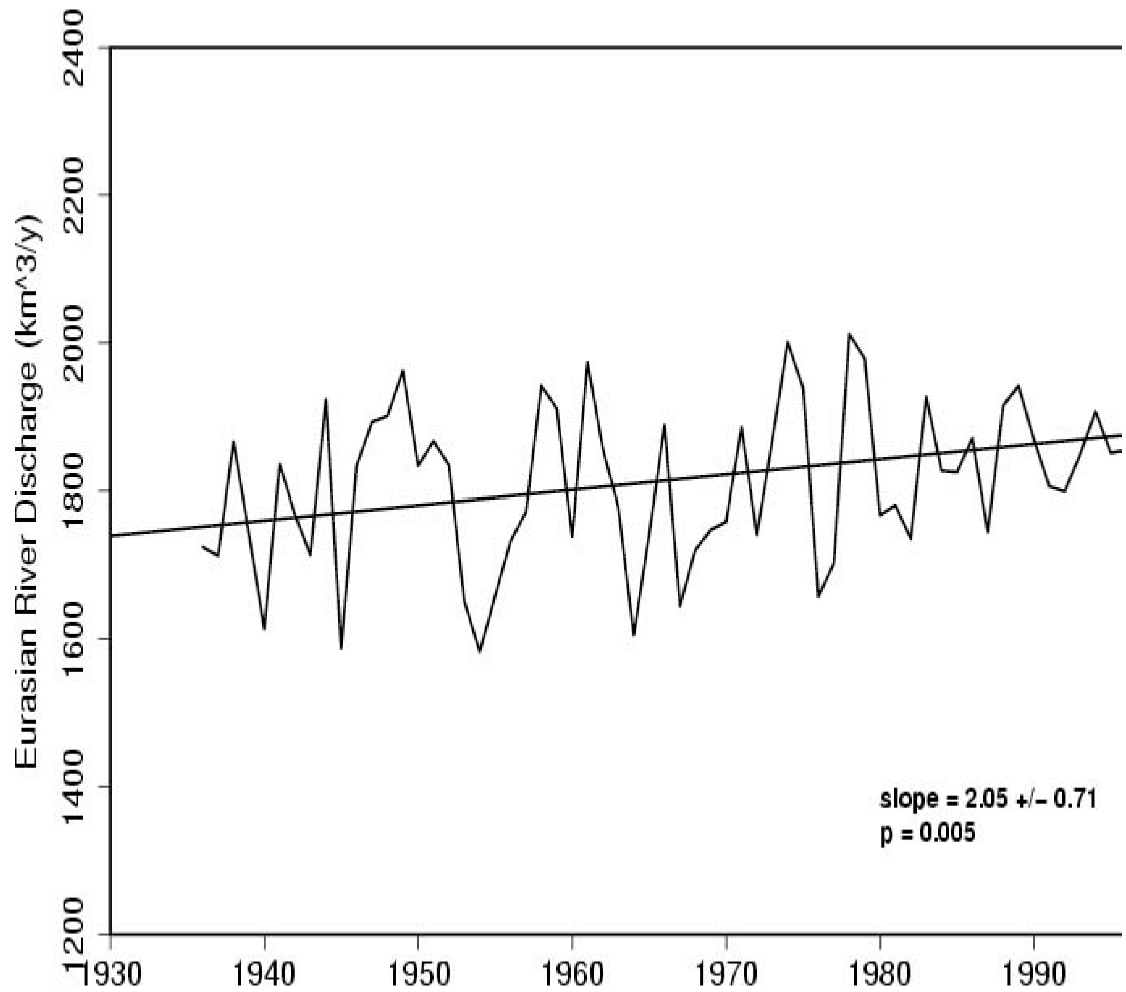
Hydrologic Budget

Following up on the previous slide, for winter, the positive phase of the AO is associated with positive terrestrial precipitation anomalies in the Atlantic corridor, parts of Eurasia, as well as the Alaska/Yukon region.

Courtesy of J.M Wallace

Increasing River Discharge

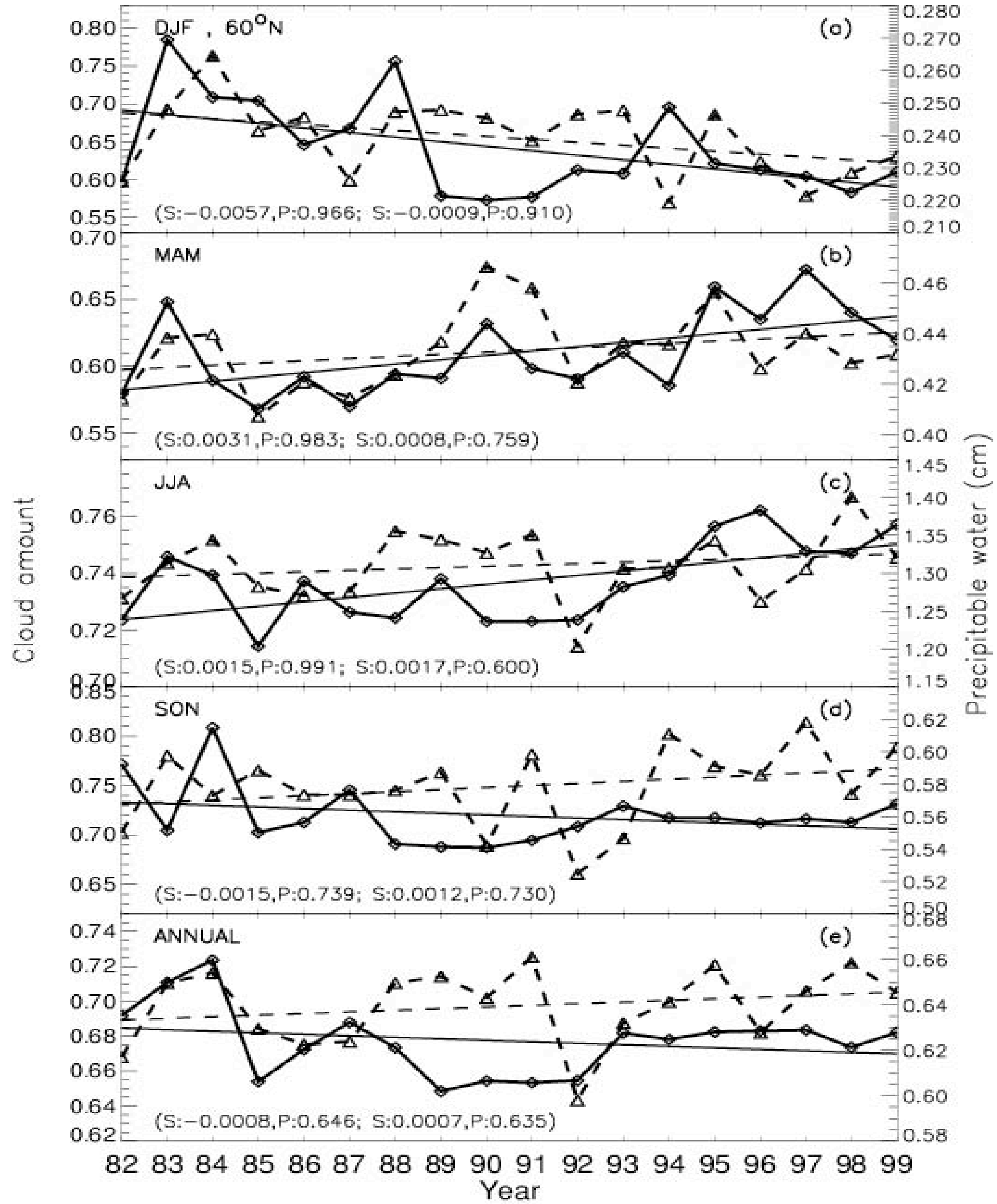
Since 1936, there has been an upward trend in annual average discharge from Siberian rivers which shows a broad relationship with the winter time series of the NAO/AO [Peterson et al., 2002]. May relate to both temperature and increased winter precipitation, but at present the link is not clear. There may be a role of changing active layer thickness and permafrost melting.



Courtesy of R. Lammers, UNH

Arctic Cloud Cover

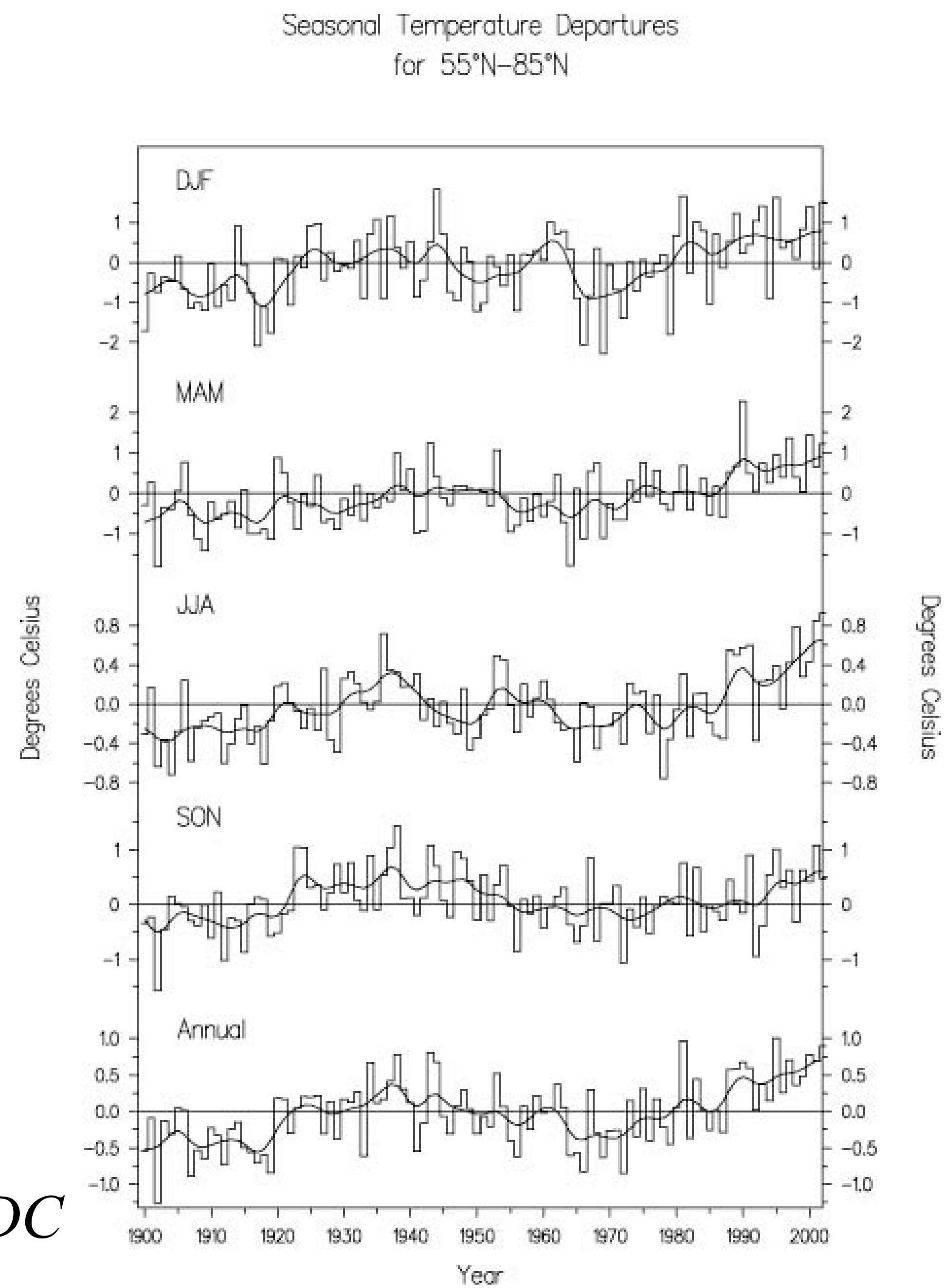
Some trends are puzling. Based on AVHRR pathfinder data from 1982 through 1999, Wang and Key [2003] document a decline in winter cloud amount north of 60 deg. N and a rise in summer cloud amount. Based on the seasonality of cloud radiative forcing, this should be working against the observed surface air temperature trends. If the positive NAO/AO results in a stronger moisture flux convergence in the Arctic, then why negative cloud trends?



From Wang and Key [2003]

Closer Look at Temperature

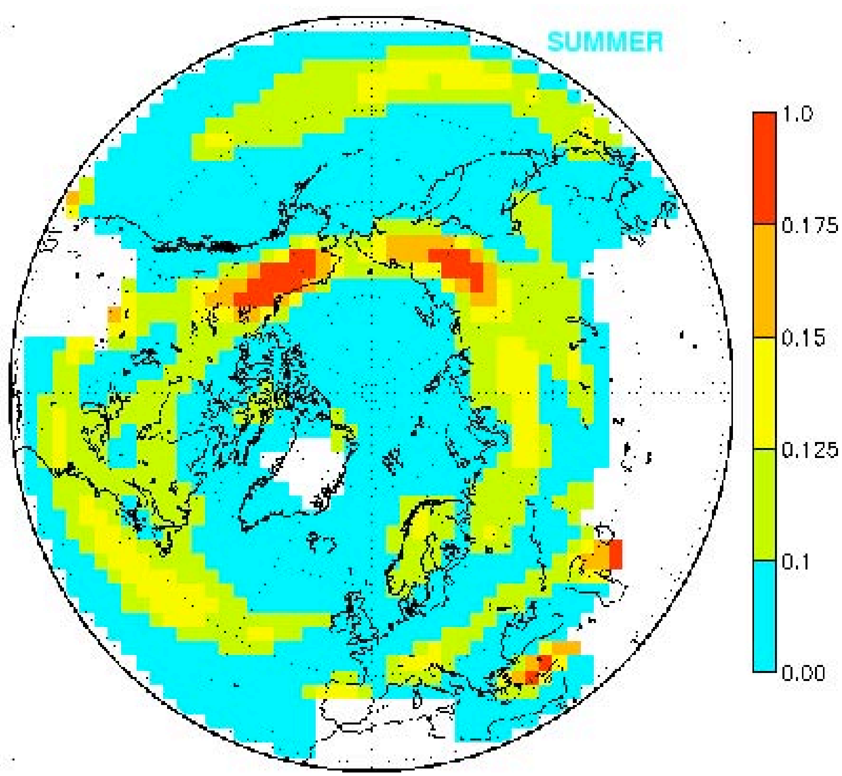
The recent warming since about 1970 (which was initially a recovery from below-normal conditions) is fairly well explained by the rise in the winter NAO/AO. But the record back to 1900 shows strong low-frequency variability for which an NAO/AO link is not so clear. Changes in Atlantic inflow? [e.g., Polyakov and Johnson, 2000; Semenov and Bengtsson, 2003]



Courtesy J. Eischeid, CDC

Summer is Important

The Arctic Front

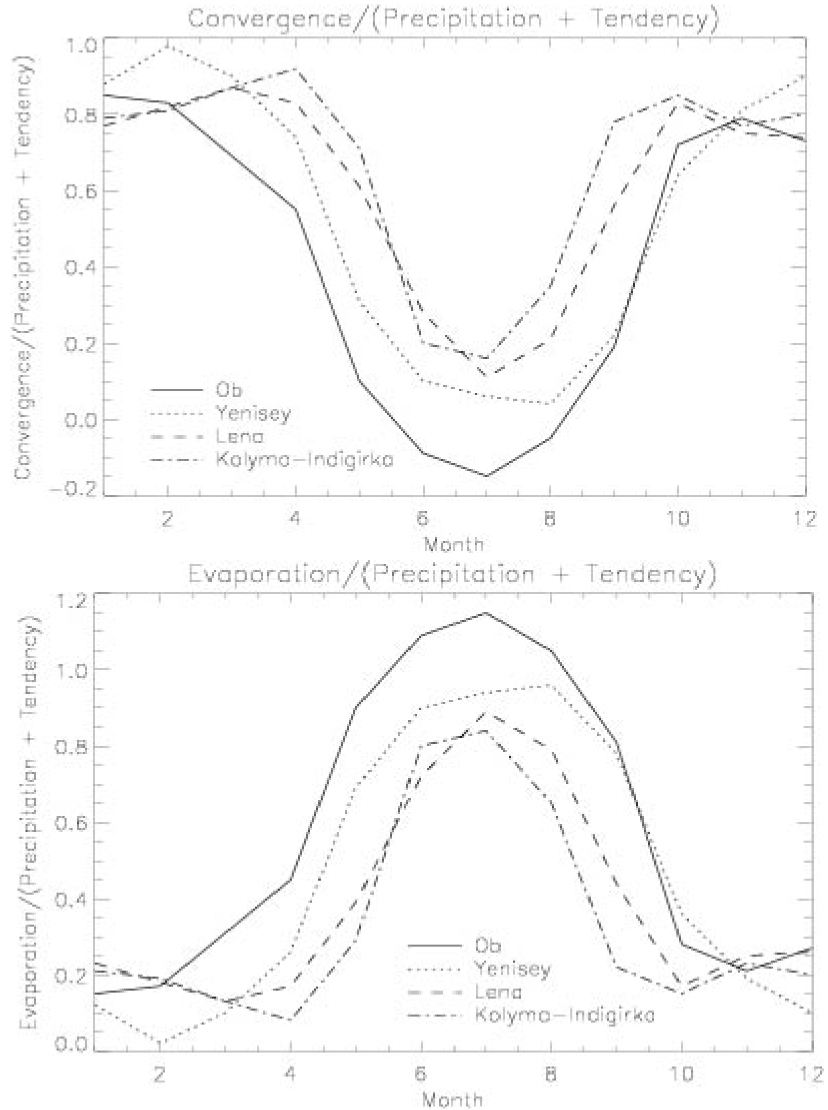


Based on Serreze et al. [2001]

Many important climatic processes occur during summer, when NAO/AO forcings are fairly weak. A good example is the summer Arctic frontal zone, which arises from strong differential heating between the snow-free land and cold Arctic Ocean and topographic “trapping” of cold Arctic Ocean air. It is best expressed over eastern Siberia and Alaska. Development of the frontal zone corresponds to removal of the seasonal snow cover.

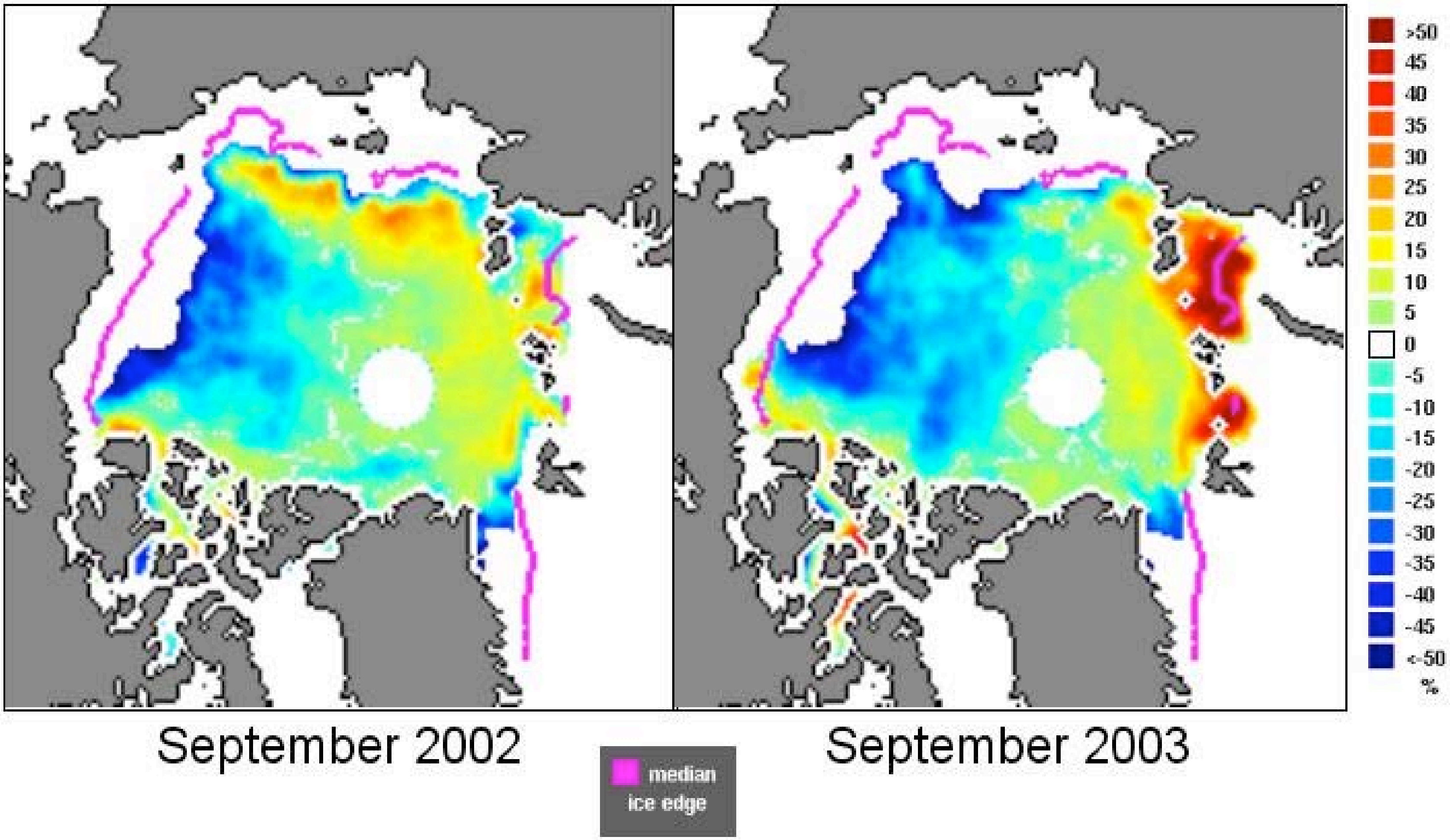
Summer Precipitation Processes

Most winter precipitation in the Arctic terrestrial watersheds is associated with the large-scale vapor flux convergence. But during summer, the contribution by the large-scale vapor flux convergence is rather small- precipitation is primarily associated with evaporation from the surface. How will the precipitation regime change in response to earlier snowmelt and vegetation changes?

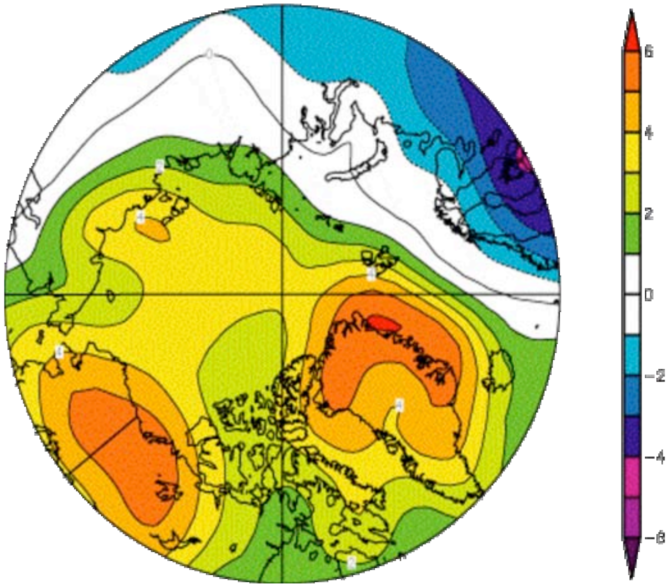


From Serreze et al. [2003c]

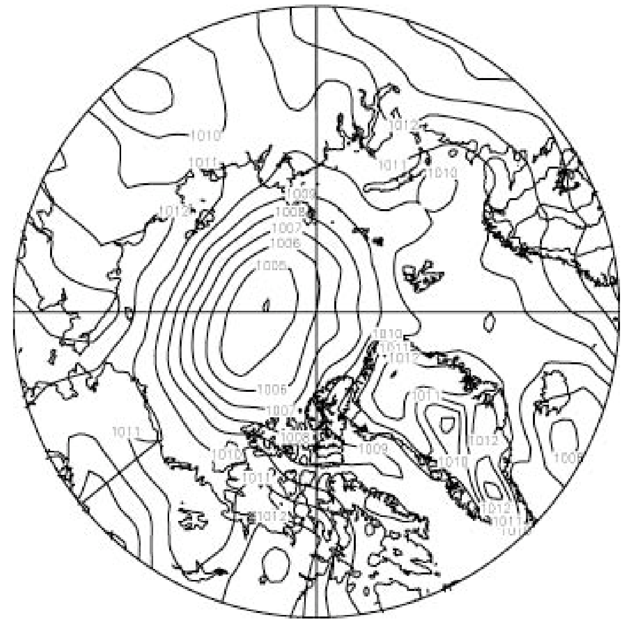
Sea Ice Extent and Concentration Anomalies Relative to 1988-2000



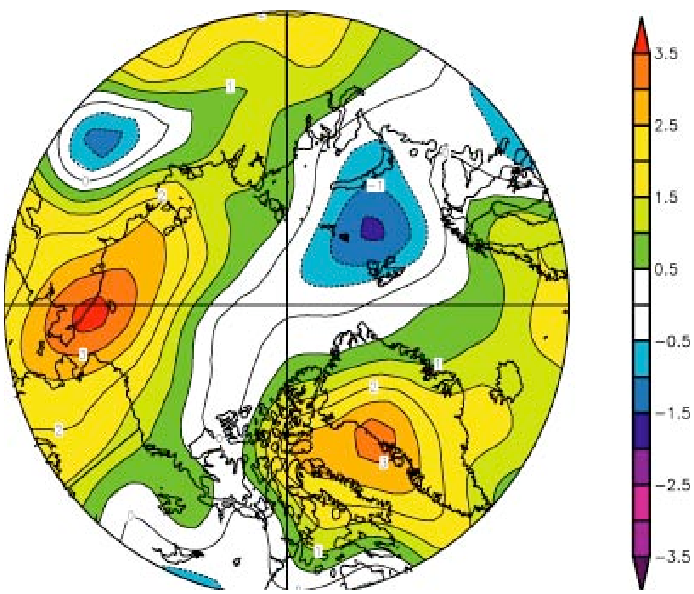
925 hPa Temp.,Oct-Dec 2002



SLP, Jun-Sep, 2003



925 hPa Temp., Jan-Jun, 2003



The 2002 anomaly was driven by warm southerly winds in spring, advecting ice poleward from the Siberian coast and persistent low pressures/high temperatures in summer, promoting divergence and melt. Broadly similar forcings explain the 2003 anomaly. The AO link is unclear – summer is important!

Summary

1) There have been significant changes in the Northern Hemisphere atmospheric circulation seen in winter time series of the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO). Whether the general upward trend contains an anthropogenic component is an active area of debate.

2) The NAO/AO provides a valuable integrating framework to understand high-latitude changes such as in winter surface air temperature, sea ice, ocean circulation and some aspects of the moisture budget.

3) The NAO/AO does not explain everything. For example, links with summer air temperature and summer precipitation processes over the major terrestrial Arctic watersheds are not strong. Circulation variability in summer, when NAO/AO links tend to be weaker, can be very important. A good example is provided by the extreme minima in sea ice extent/area for 2002 and 2003.

[redacted]