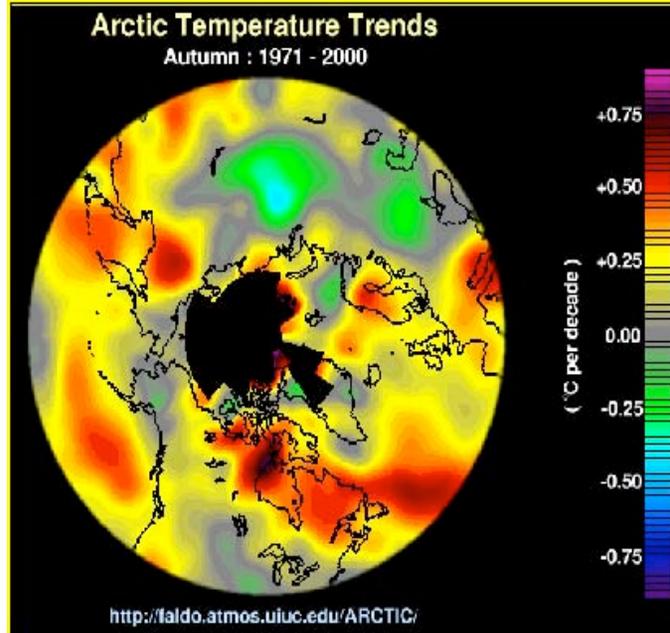
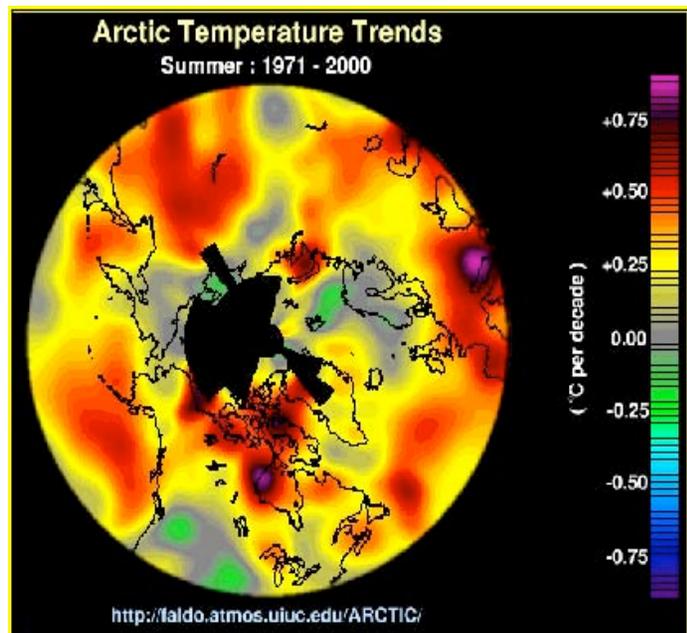
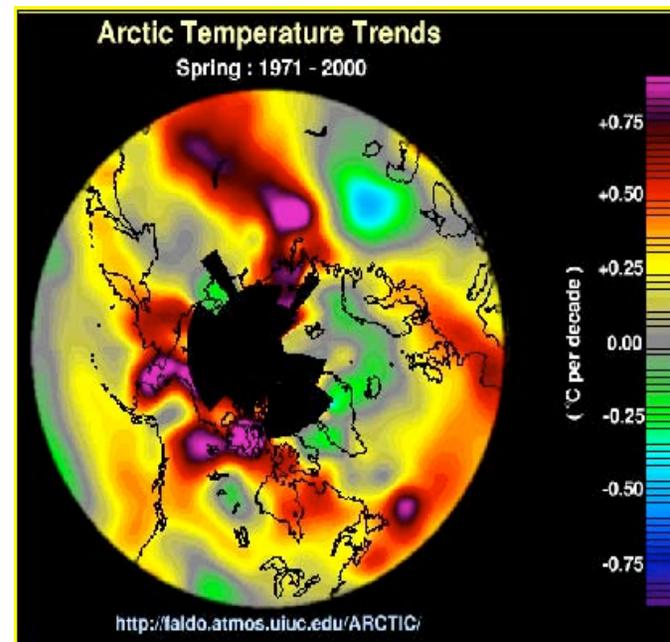
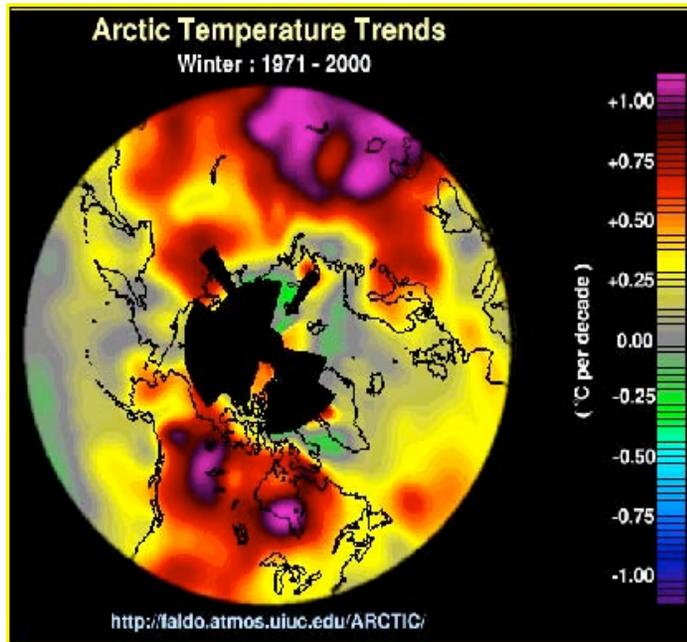


*Recent Environmental Changes in the
Arctic and Links
with the Atmospheric Circulation*

Mark C. Serreze

Cooperative Institute for Research in Environmental
Sciences, University of Colorado, Boulder, CO



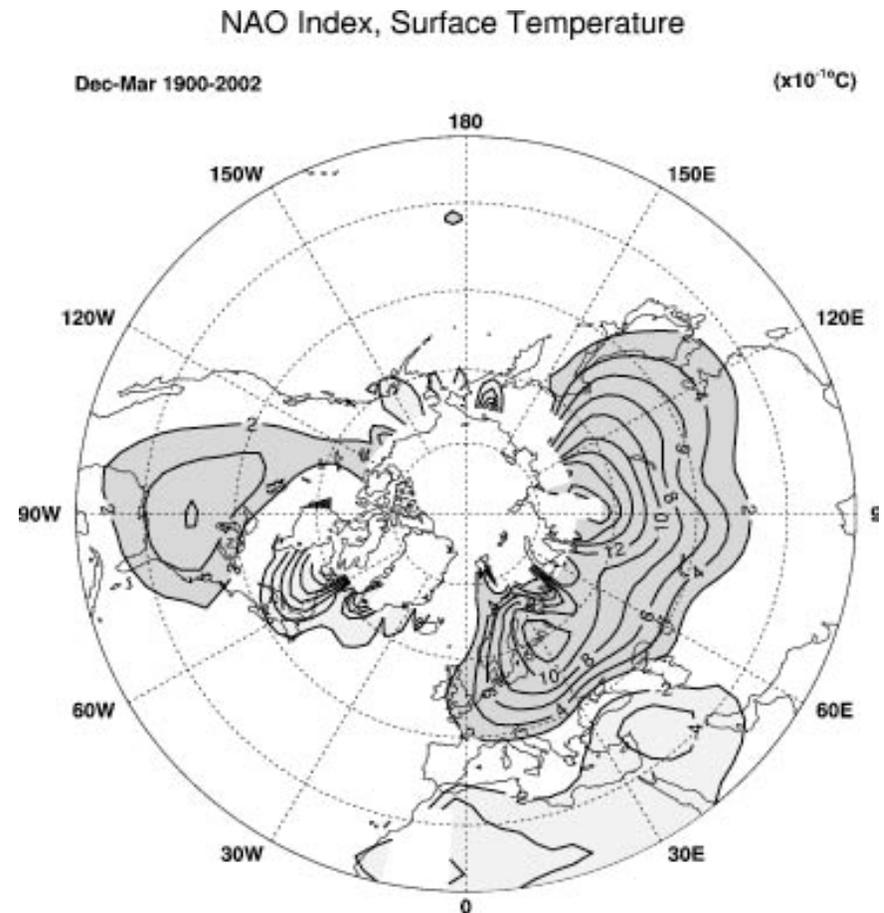


The NAO and Temperature

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.

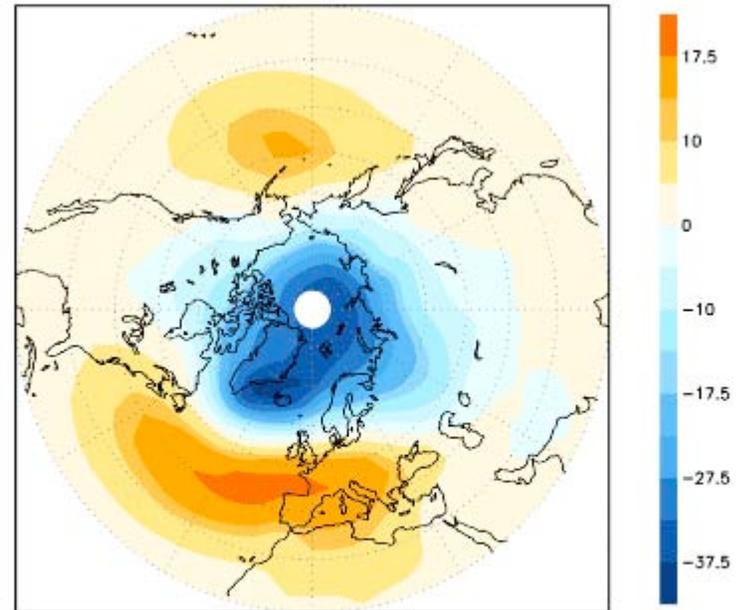


From Hurrell, 2002

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).

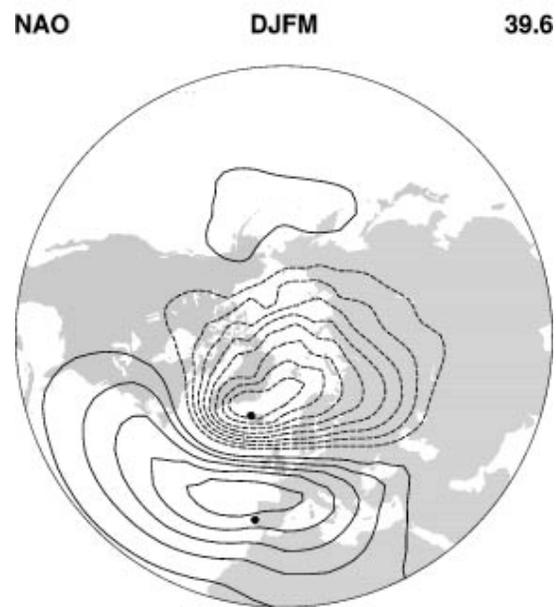
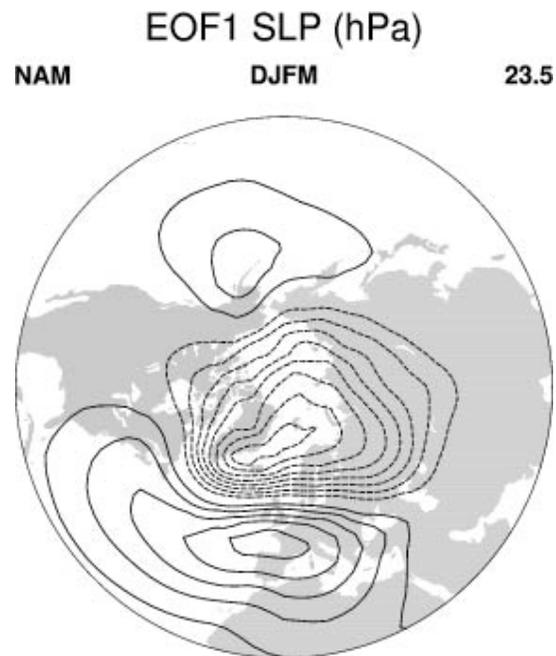
Controversy – are the AO and NAO really separate modes? There are arguments for and against based on statistical and physical grounds [Thompson and Wallace, 1998, 2000; Deser, 2000; Ambaum et al., 2001; Hurrell, 2002].

The Northern Hemisphere annular mode



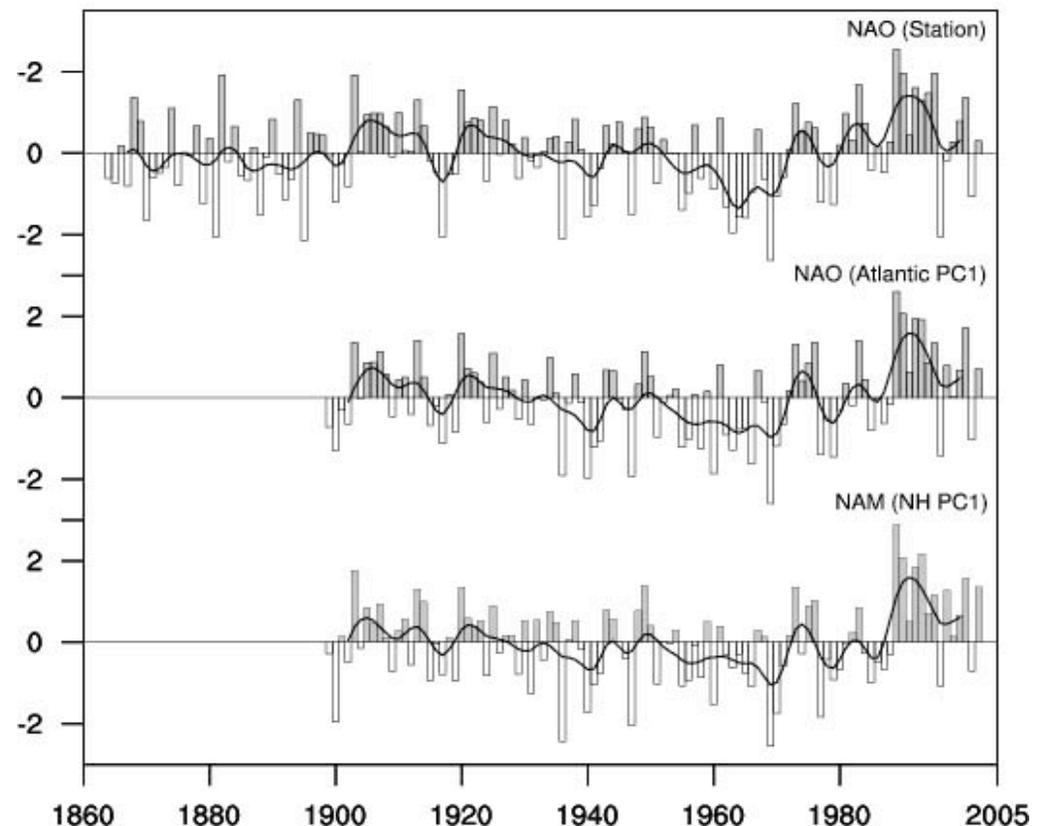
The surface signature of the Northern Hemisphere annular mode. The NAM is defined here as the leading EOF of NH monthly-mean 1000-hPa height anomalies. Units are m/std of the principal component time series.

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, ozone. Some recent 1000 year simulations indicate recent change is within the “envelope” of natural variability.

SLP-based Indices (Dec-Mar)



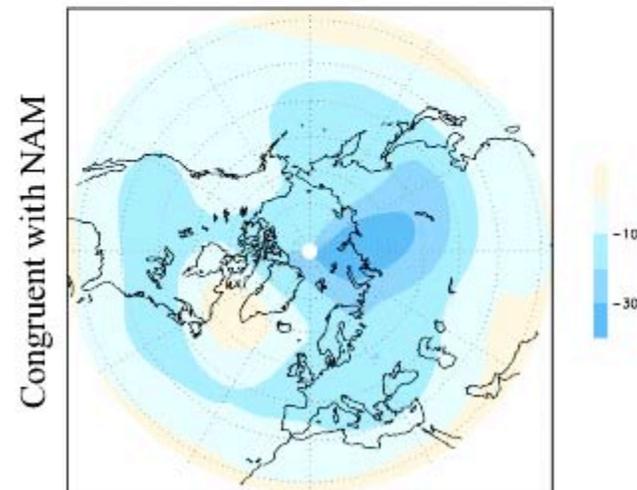
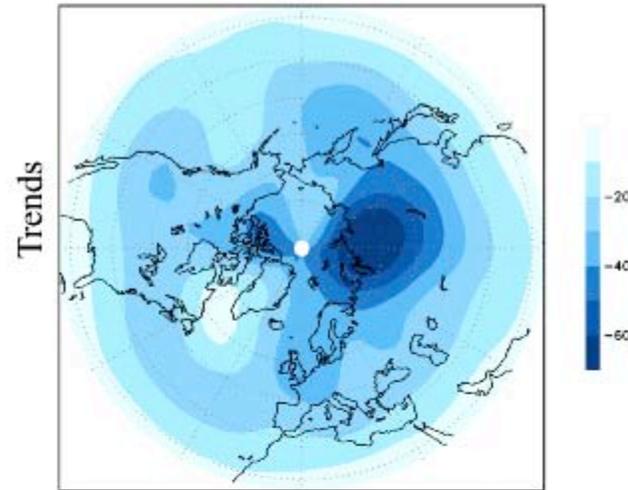
From Hurrell [2002]

Ozone Link

Part of the recent winter AO trend is linearly congruent with the observed downward trend in stratospheric ozone

From Thompson et al. [2000]

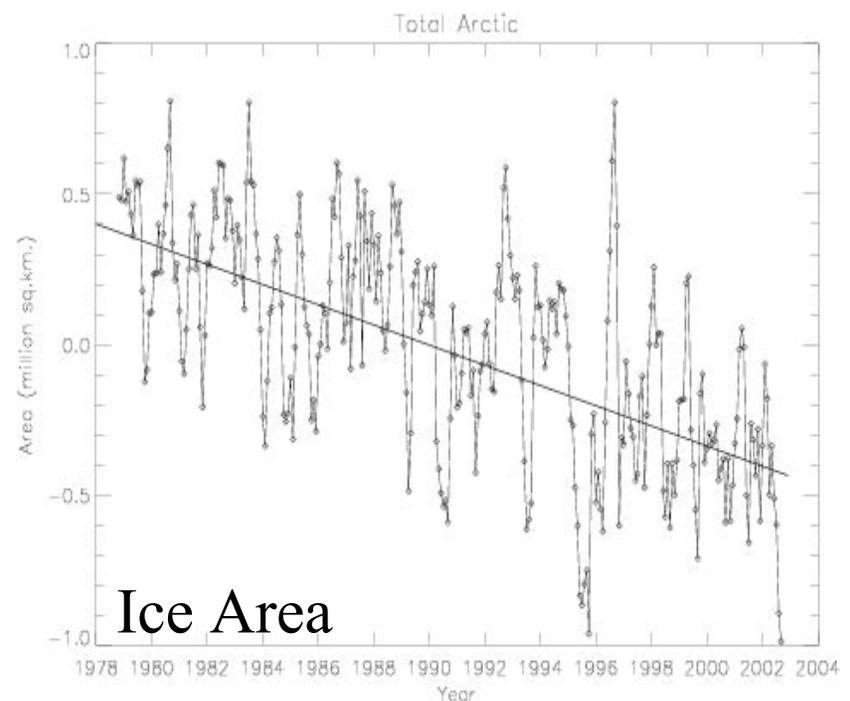
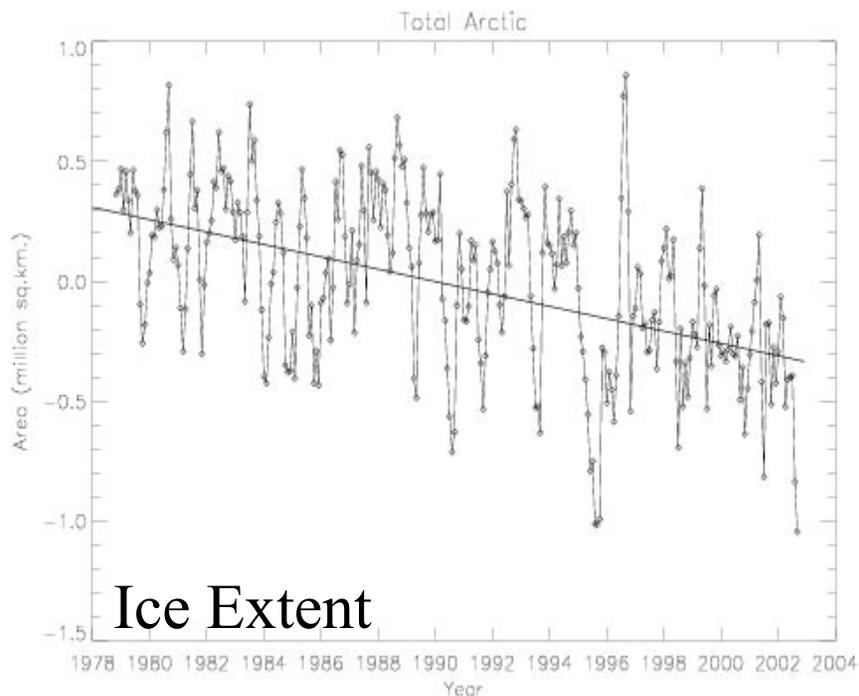
March total column ozone trends



Top: 1979-93 March trends in total column ozone (DU/14 yr).
Bottom: The fraction of the trends congruent with the NAM.

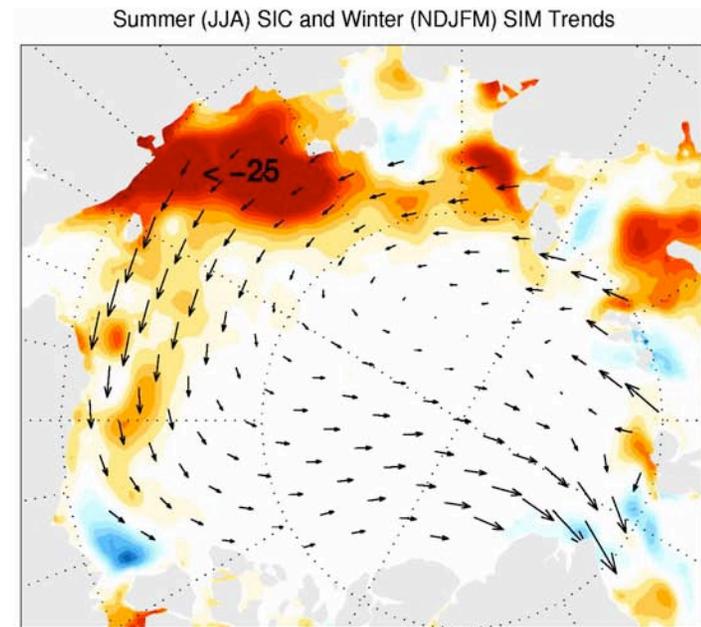
The Sea Ice Record

Since regular monitoring began in 1978 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 and 2002. September of 2002 set a new record low. What's the AO/NAO link?

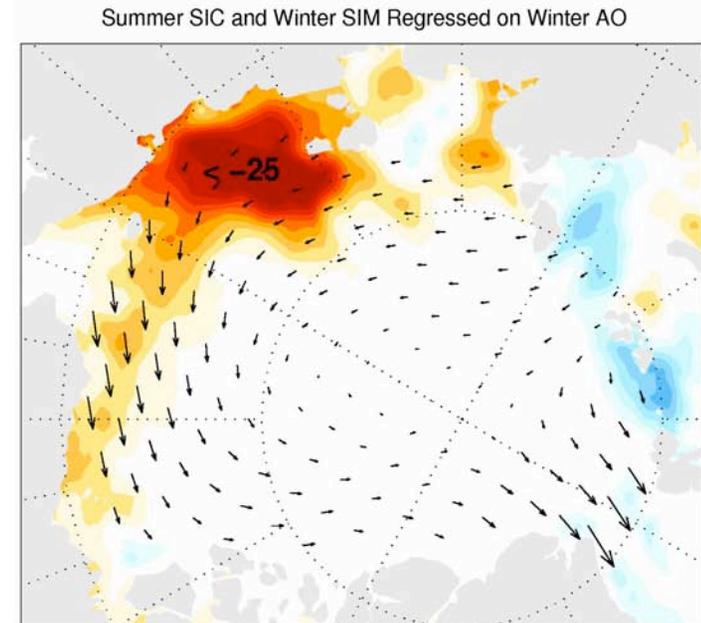


A Preconditioning Mechanism

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.



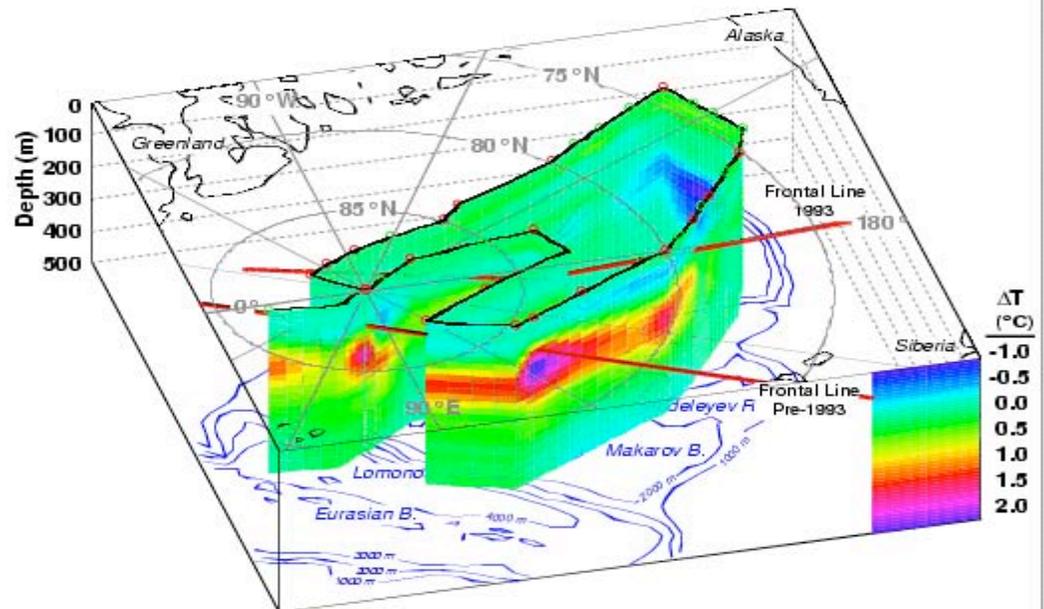
From Rigor et al. [2002]



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.

Ocean Changes Temperature Difference, Pargo '93 - Climatology

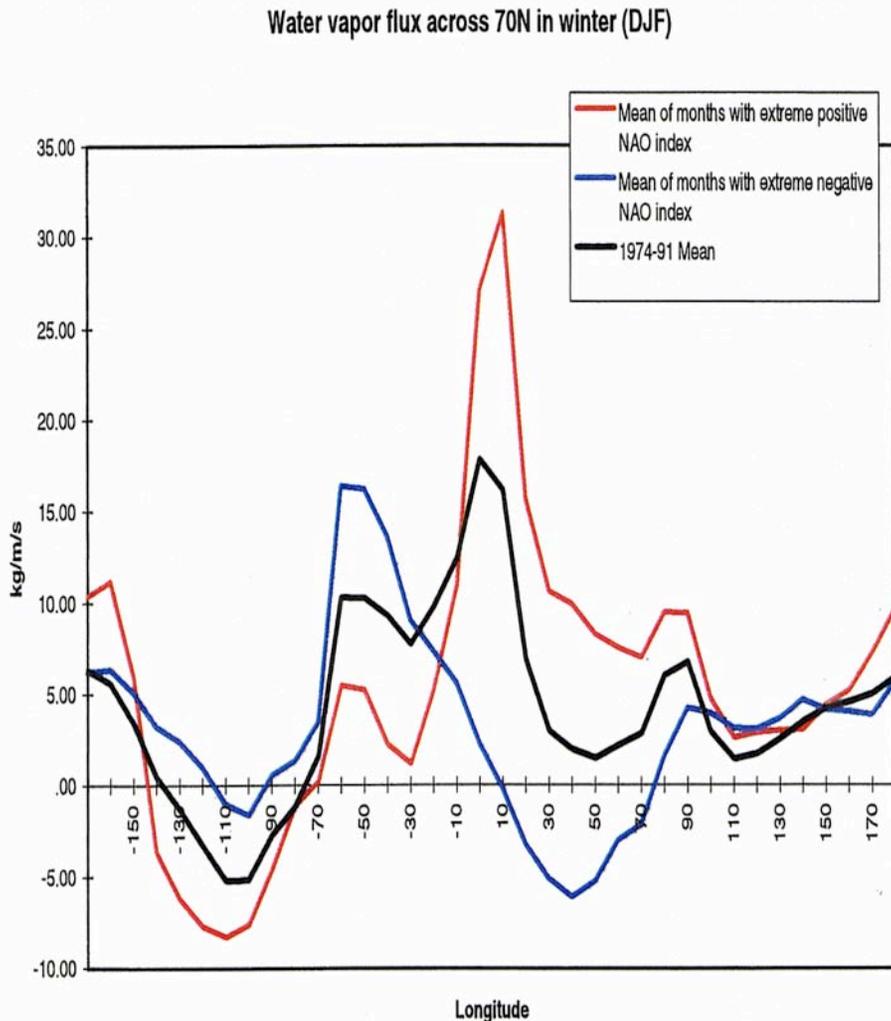


From Morison, J. H., K. Aagaard, and M. Steele, 2000, Recent Environmental Changes in the Arctic: A Review, *Arctic*, 53, 4.

- Appearance of warm cores over ridges
- Increase in Temperature maximum of over 1.5°
- Atlantic Water Temperature maximum is shallower

Interagency Working Group on SEARCH
NSF - NOAA - ONR - NASA - DOE

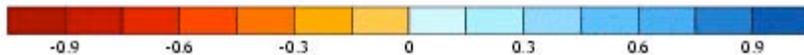
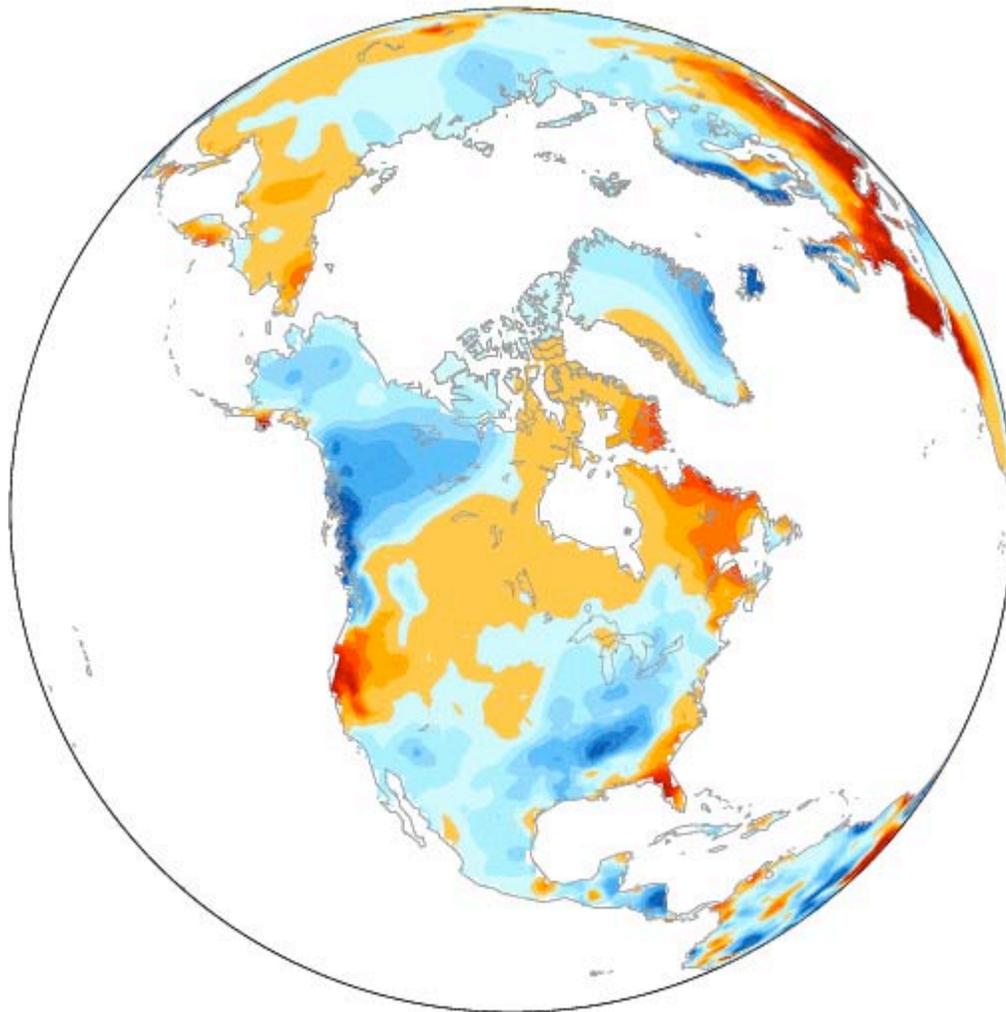
Hydrologic Budget



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].

AO precipitation anomalies (cm/month) 1950-96



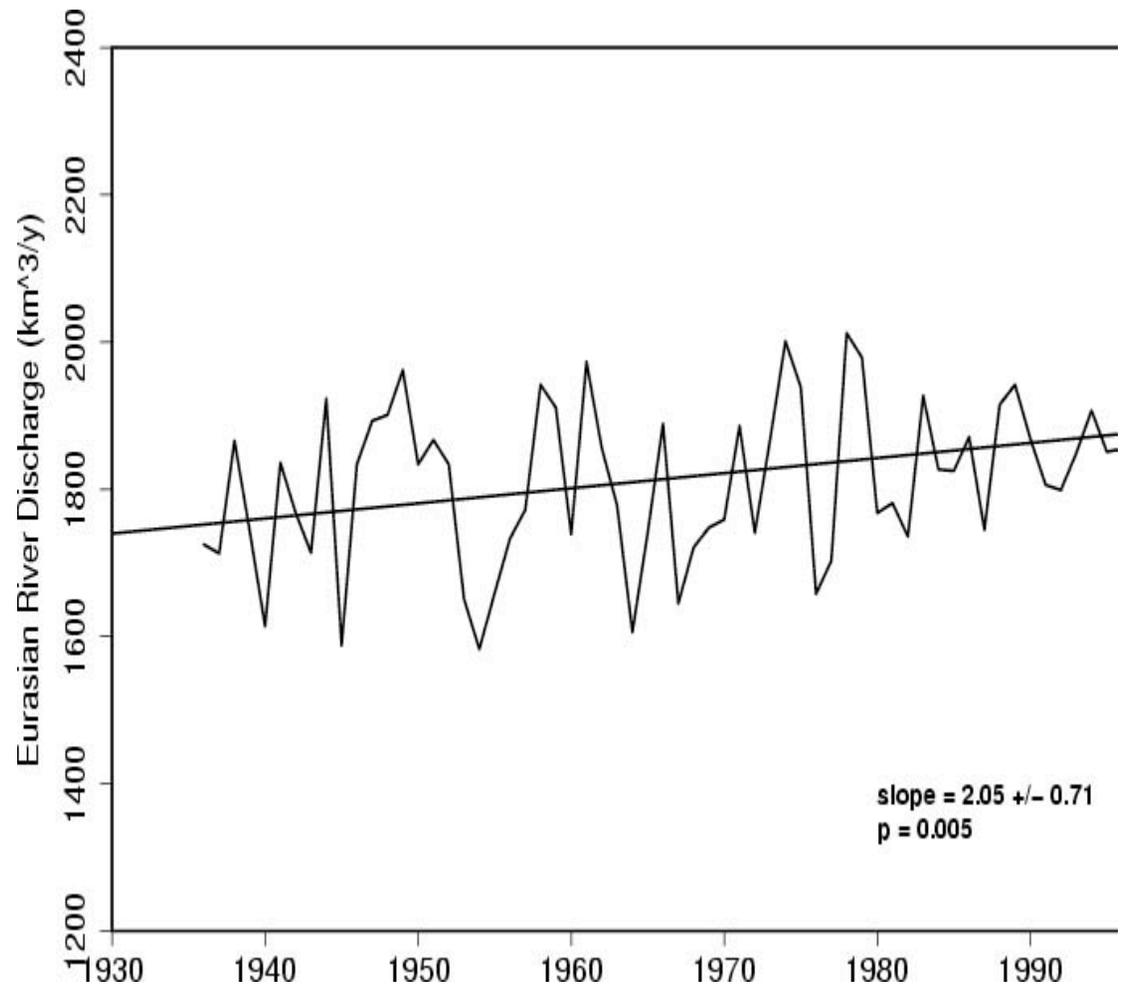
Hydrologic Budget

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

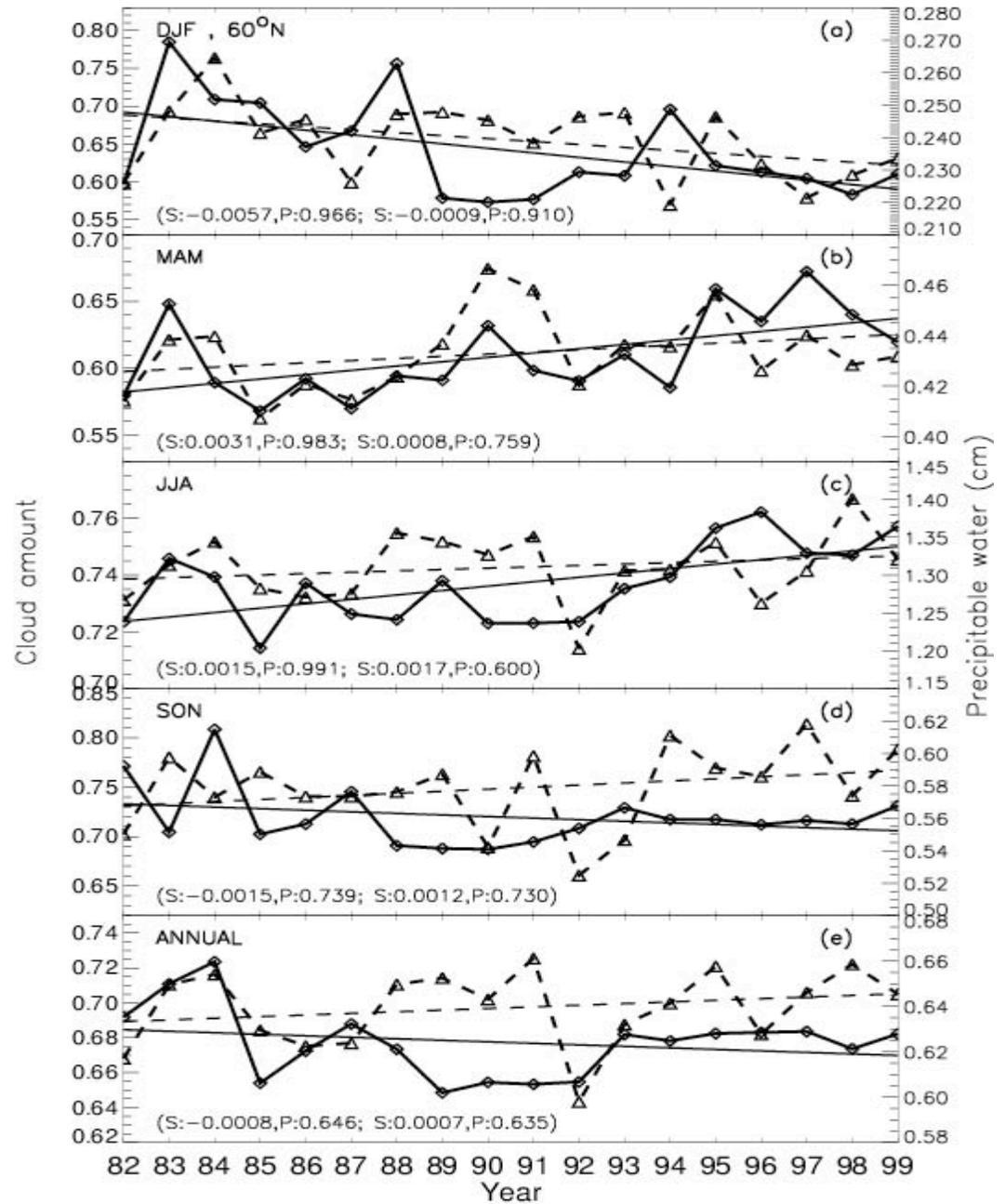
Since 1936, there has been an upward trend in annual average discharge from Siberian rivers which shows a broad relationship with the winter time series of the NAO/AO [Peterson et al., 2002]. May relate to both temperature and increased winter precipitation, but at present the link is not clear. There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



Courtesy of R. Lammers, UNH

Arctic Cloud Cover

Some trends are puzzling. 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?

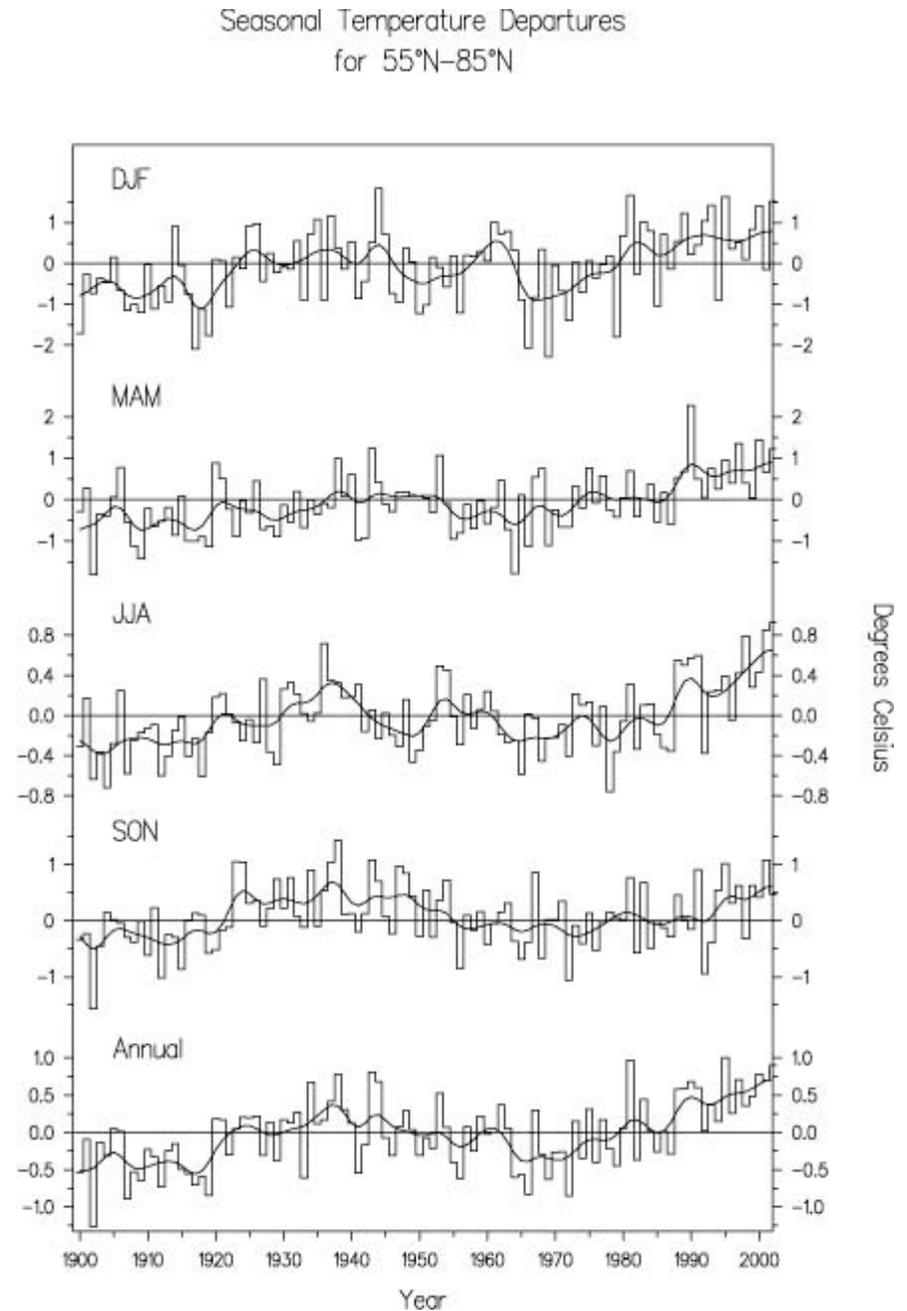


From Wang and Key [2003]

Closer Look at the Temperature Record

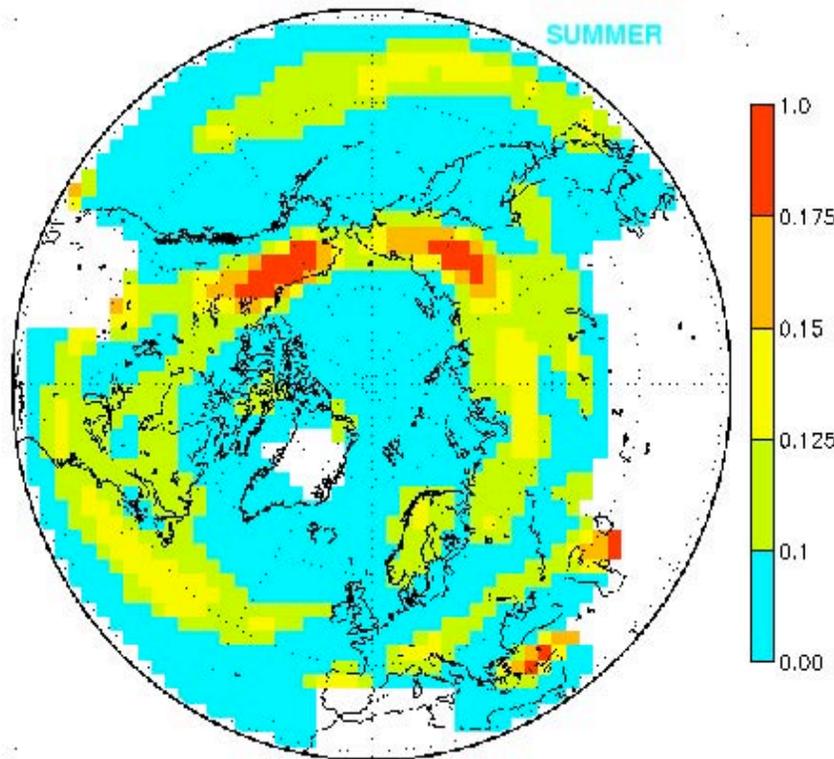
The recent warming since about 1970 (which was initially a recovery from below-normal conditions) is fairly well explained by the rise in the winter NAO/AO. But winter temperatures rose just as strongly from about 1920-1940, at which time the NAO/AO was showing a NEGATIVE trend. What was going on?

Courtesy J. Eischeid, CDC



Summer is Important

The Arctic Front

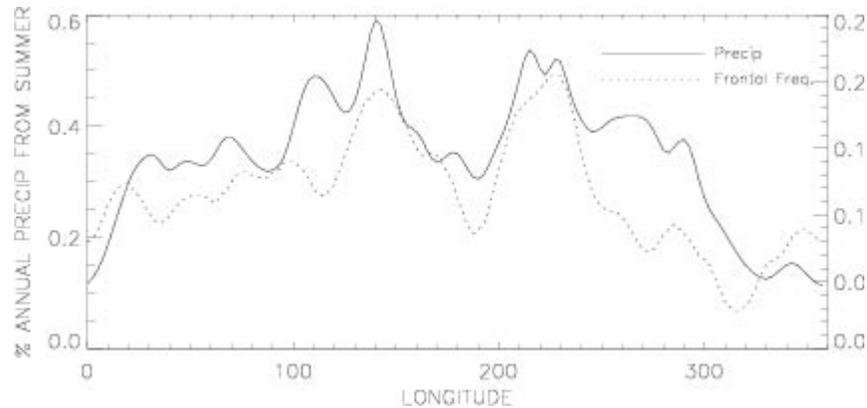


Many important climatic processes occur during summer, when NAO/AO forcings are fairly weak. A good example is the summer Arctic frontal zone, which arises from strong differential heating between the snow-free land and cold Arctic Ocean and topographic “trapping” of cold Arctic Ocean air. It is best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

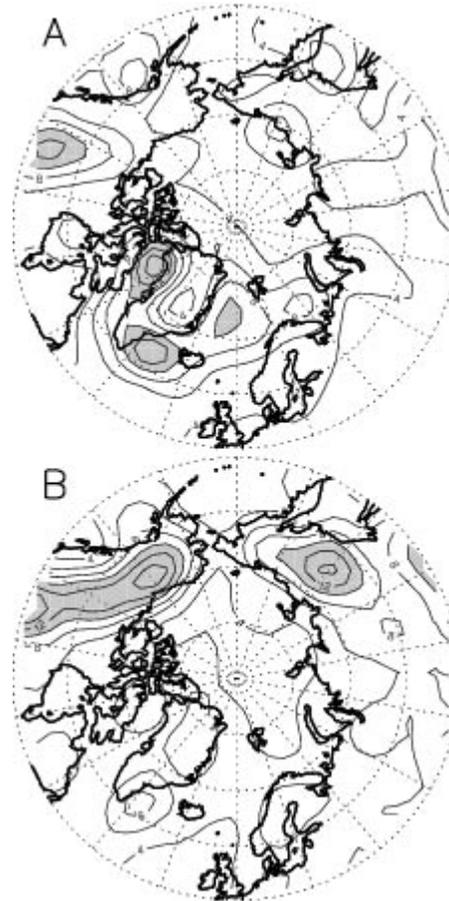
Development of the frontal zone corresponds to removal of the seasonal snow cover.

Based on Serreze et al. [2001]

Frontal Frequency (62.5 to 67.5 deg. N) and fraction of annual precipitation falling during the summer season



The summer Arctic frontal zone has strong impacts on the regional circulation and precipitation. Summer cyclogenesis peaks where frontal activity is strongest. In these areas, a particularly large fraction of annual precipitation falls during summer.



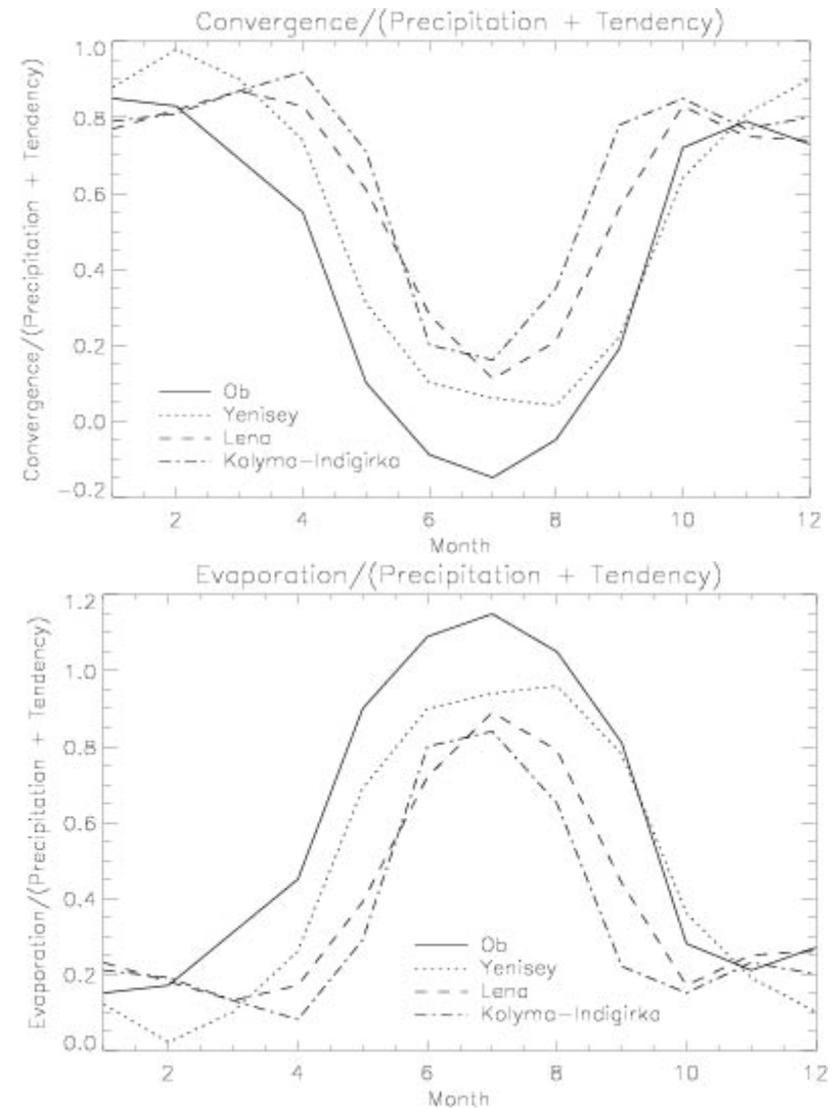
*Winter
Cyclogenesis
Counts*

*Summer
Cyclogenesis
Counts*

From Serreze et al. [2001]

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?

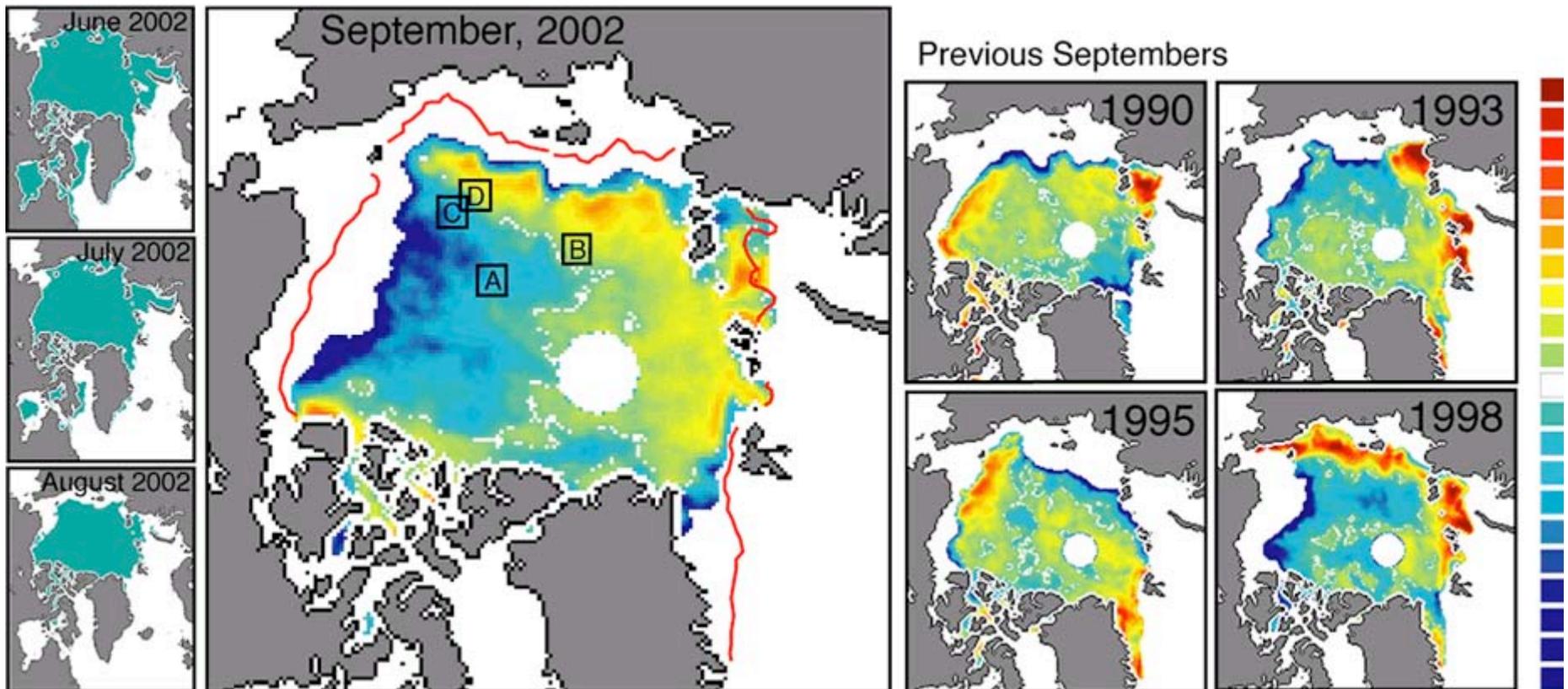


From Serreze et al. [2003c]

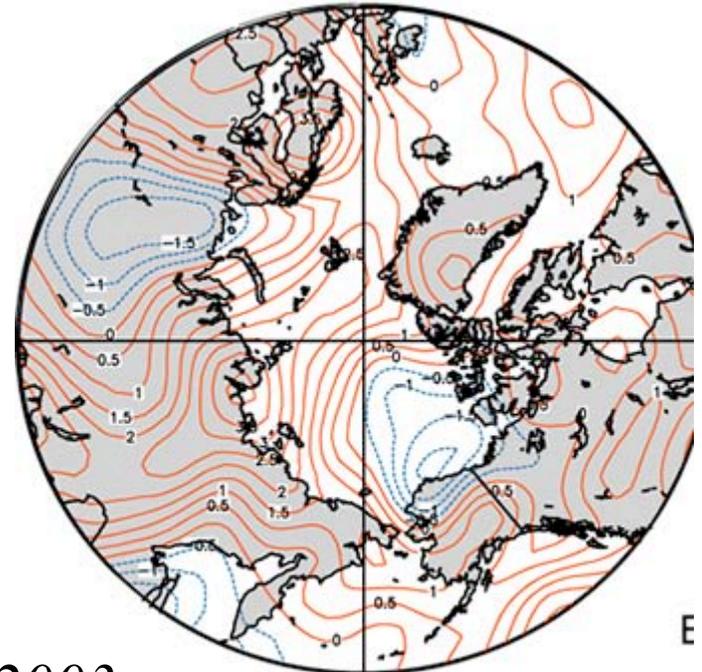
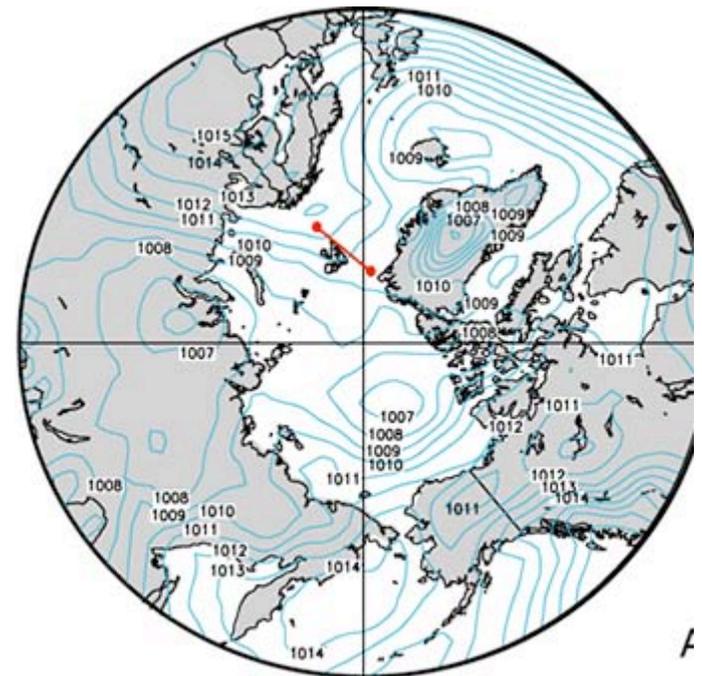
The 2002 Sea Ice Anomaly

Sea ice extent in September 2002 was the lowest recorded during the passive microwave era, and probably in at least the past 50 years. Ice concentrations were also very low and there was virtually no ice in the East Greenland Sea. Was there an NAO/AO link?

From Serreze et al. [2003a]



The Rigor et al. [2002] model doesn't seem to work as well in this particular year. The winter AO index was indeed high, and there is evidence of winter “preconditioning” of the pack ice by anomalous winds. But it seems that the more important factor was unusually warm temperatures from winter through summer (bottom, at 925 hPa) and an extremely cyclonic atmospheric circulation from June through August which promoted ice divergence, melt and breakup (top, MSLP). Each month from June through August showed a mean closed low over the central Arctic Ocean. NAO/AO was near neutral or negative during summer.



From Serreze et al., 2003a

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 winter surface air temperature, the sea ice trend, 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 record minimum sea ice extent/area seen in 2002.