The Arctic Oscillation (AO) or Northern Annular Mode (NAM)

Required reading for Thursday, Oct.14:

-Kerr, R.A., 1999: A new force in high-latitude climate. *Science*, 284, 5412, 241 - 242.

-Thompson DWJ, Wallace JM., 2001: Regional climate impacts of the Northern Hemisphere annular mode. *Science*, 293, 5527, 85-89.

- Thompson, DWJ, 2007: A Brief Introduction to the Annular Modes and Annular Mode Research.
  http://ao.atmos.colostate.edu/introduction.html
  (last updated March 17, 2007)

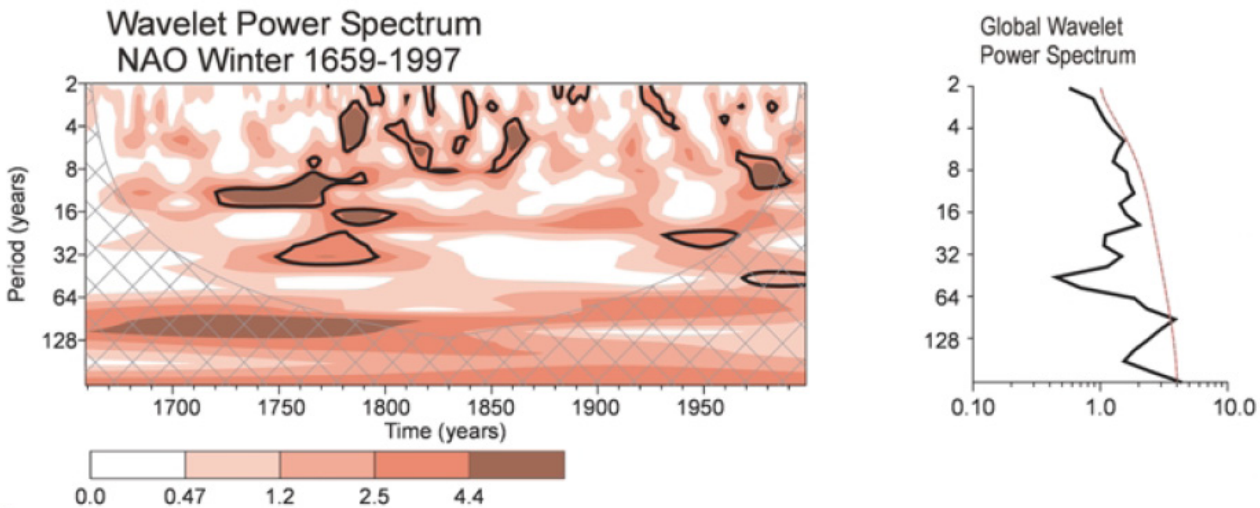
Exam moved to Nov 2., 2010

Make-up class on Monday Oct. 18. @ 2:45pm (B13)

KNMI climate explorer

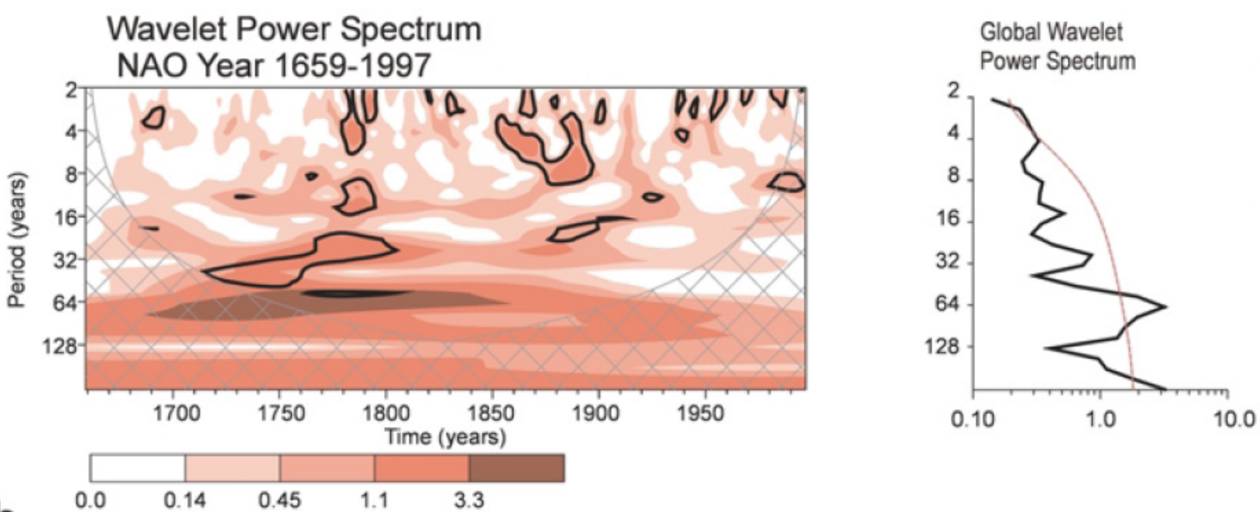
http://climexp.knmi.nl/

Spectral behavior of the NAO



a

winter



b

Annual mean

Luterbacher et al., 2001

Spectral behavior of the NAO

NAO shows a strongly intermittent behavior, with active phases and corresponding maximum amplitudes in different frequency bands

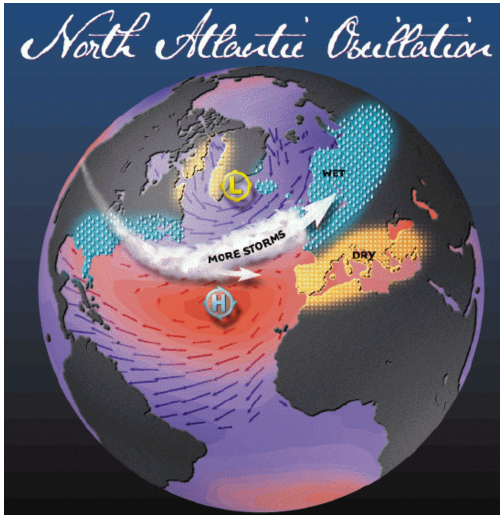
Frequencies with enhanced power are not stable through time

NAO is neither a purely random process, nor does it exhibit a clear and preferred mode of oscillation

The lack of evidence for the NAO to vary on any preferred time scale is consistent with the notion that much of the atmospheric circulation variability in the form of the NAO arises from processes internal to the atmosphere

Impacts of the NAO

NAO+ phase:

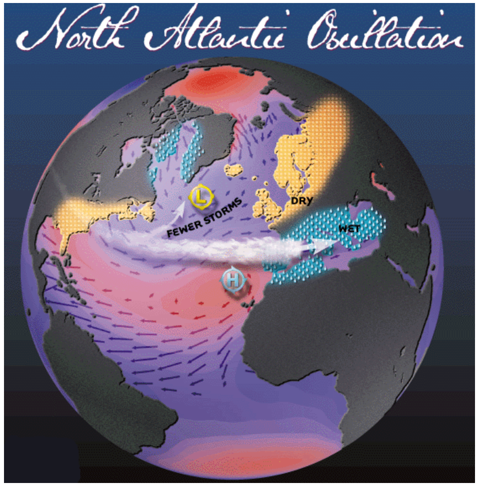


Icelandic Low, Azores High well developed, (anomalous low / high pressure cores)

enhanded meridonal pressure gradients, strengthened westerlies and trade winds

strom tracks oriented SW-NE, shift to the north

NAO- phase:



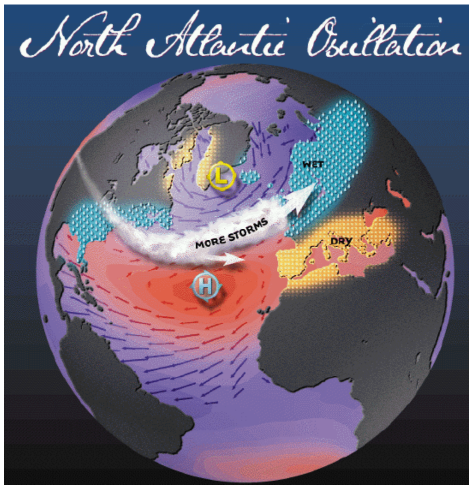
opposite effects observed

storm track axis zonally aligned, located further south

Impacts of the NAO

SLP and storm track changes influence transport of heat and moisture to the European continent

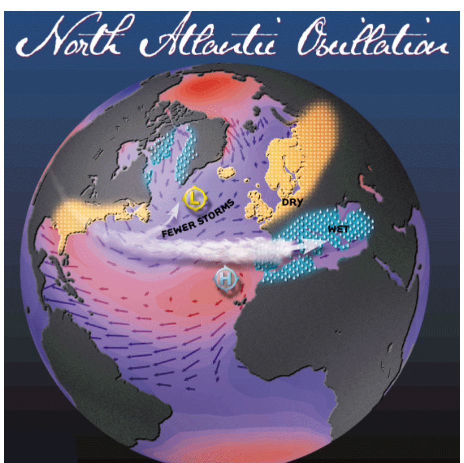
NAO+ phase:



wet / warm winter climate in Scandinavia
cool / dry conditions in S. Europe & N. Africa

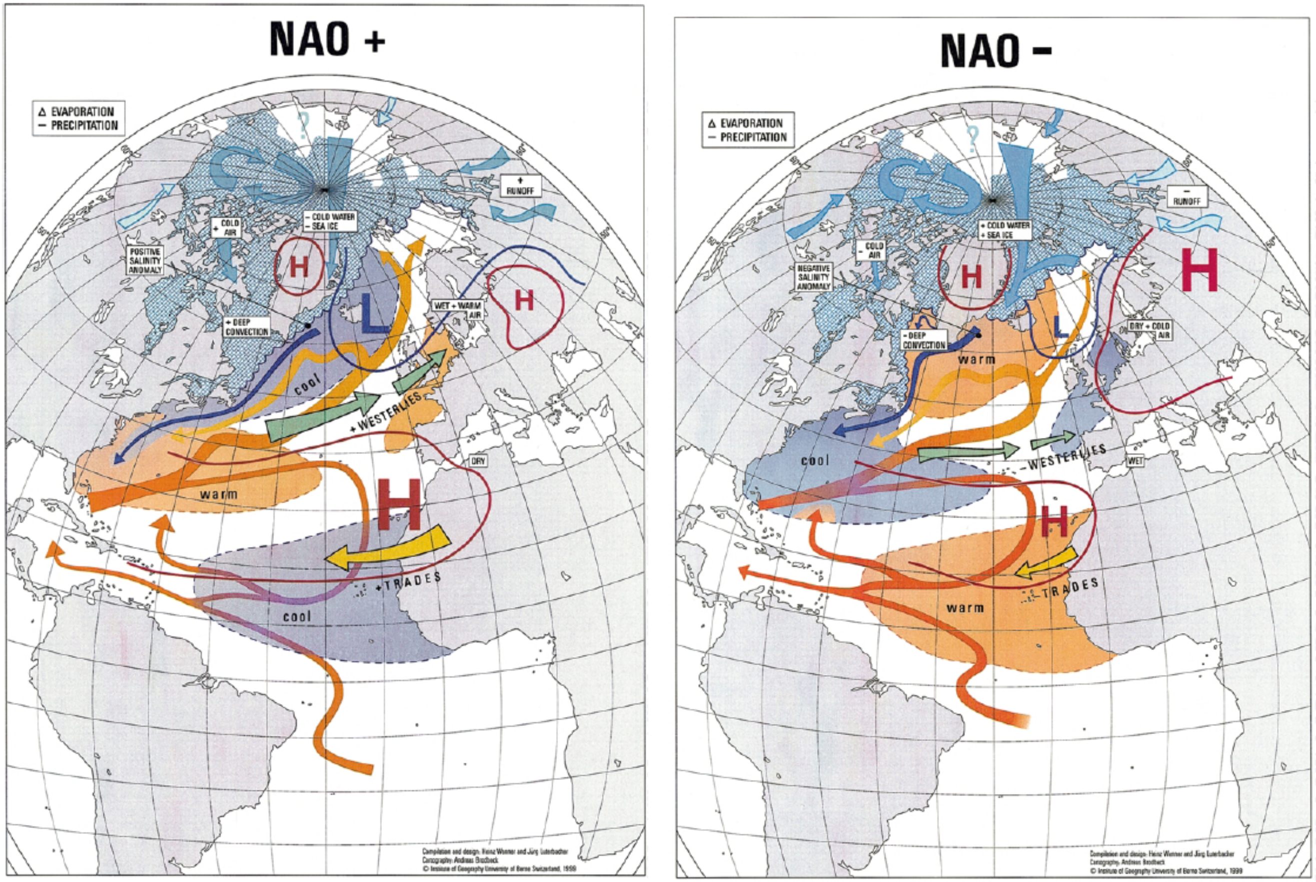
N. Siberia wet / N. Canada dry

NAO- phase:



almost opposite conditions

Impacts of the NAO



Wanner, 2001

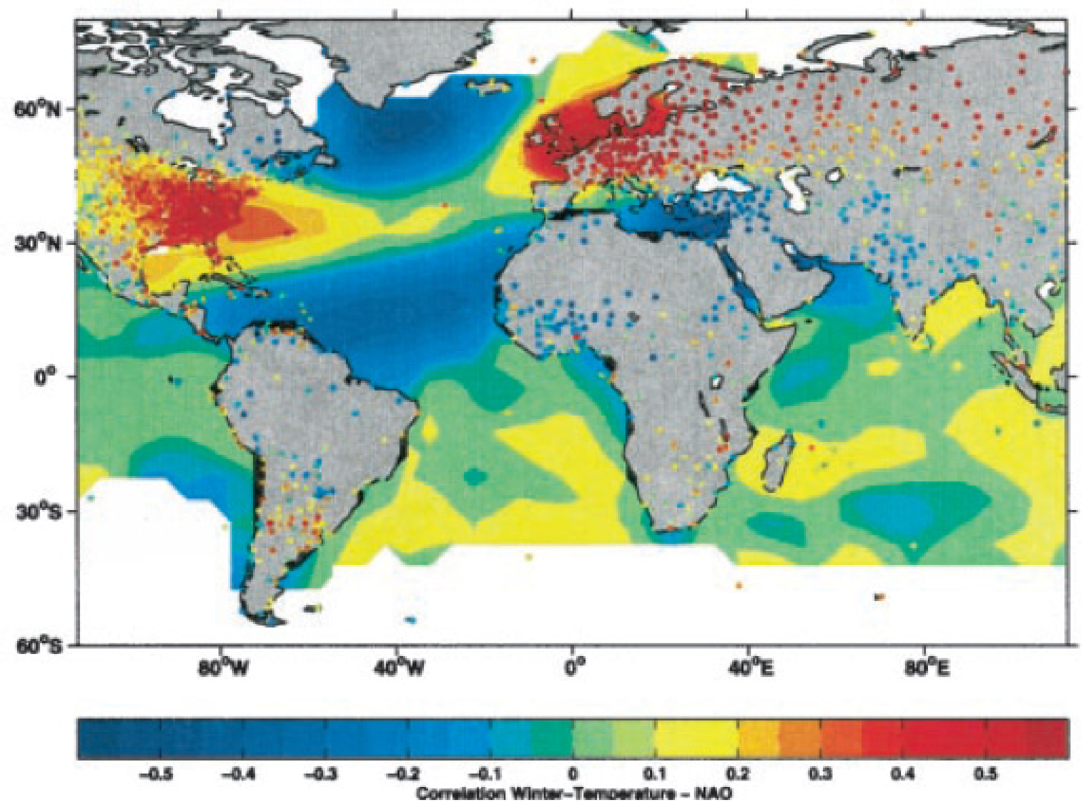
Anomalous SST east/southeast of Greenland and west of N. Africa (both with neg. SSTA during NAO+ phase, and positive SSTA in the NAO- phase).
Regions with oppositely phased SSTA exist over the N. American Basin and the English Channel.

Impacts of the NAO on SAT/SST and Gulf stream

<u>Pos. NAO:</u> warmer and wetter conditions in N. Europe, but also eastern US

NAO explains ~ 30% of the variance of mean wintertime extratropical N. Hemisphere temperatures

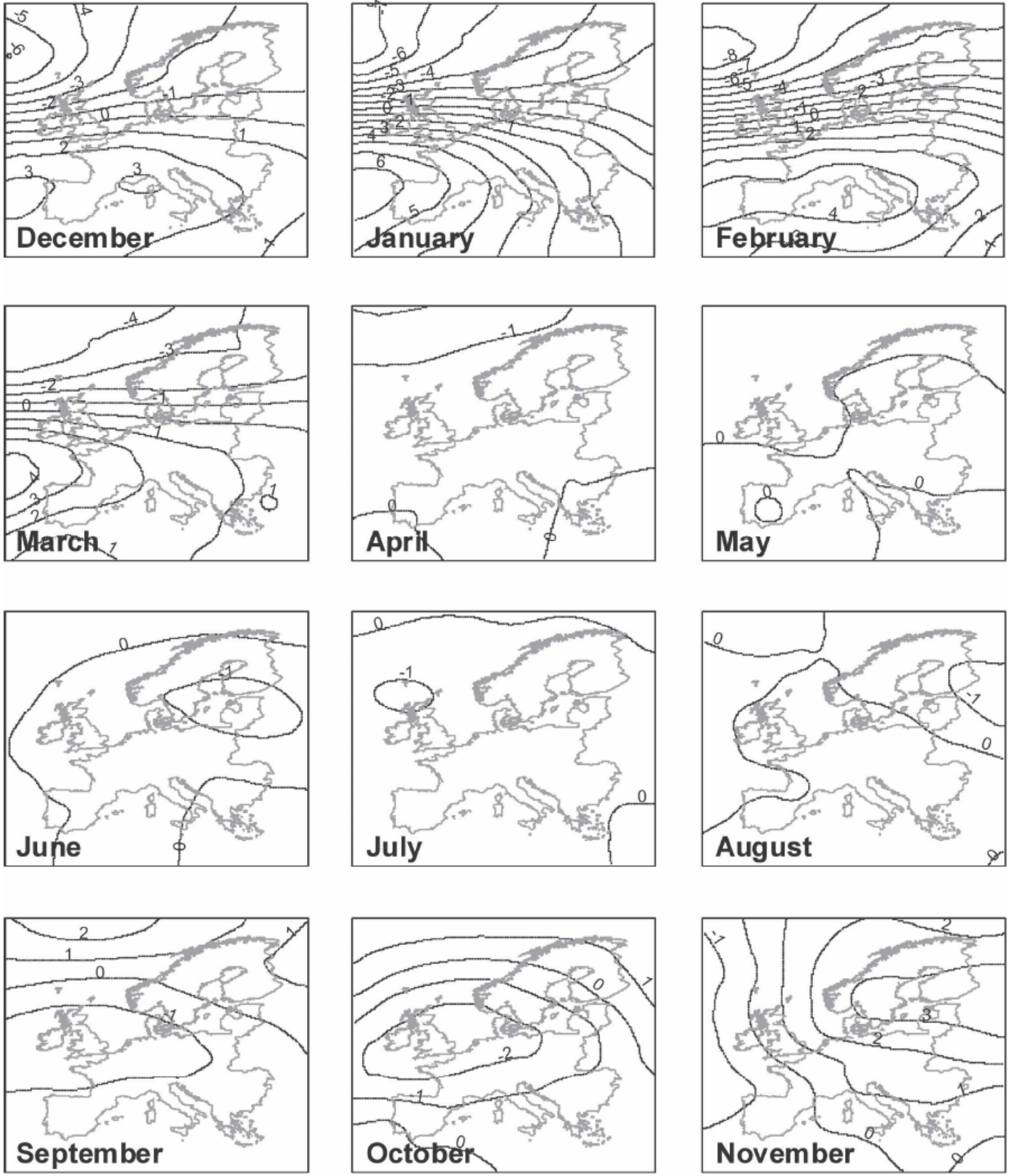
Winter (DJFM) SST and Land Temperature correlated with NAO index



Mean latitudinal position of Gulf Stream is also correlated with NAO. Positive NAO: more northern path of the Gulf Stream (time lag of ~ 2 yrs.) (In 1992–1998 high NAOI period excursion of Gulf Stream 50–100 km north of its climatological mean position occurred. More than half of interannual variability in the position of the Gulf stream can be explained by NAO.

Visbeck et al., 2001; Wanner et al., 2001

Impacts are most pronounced during winter months

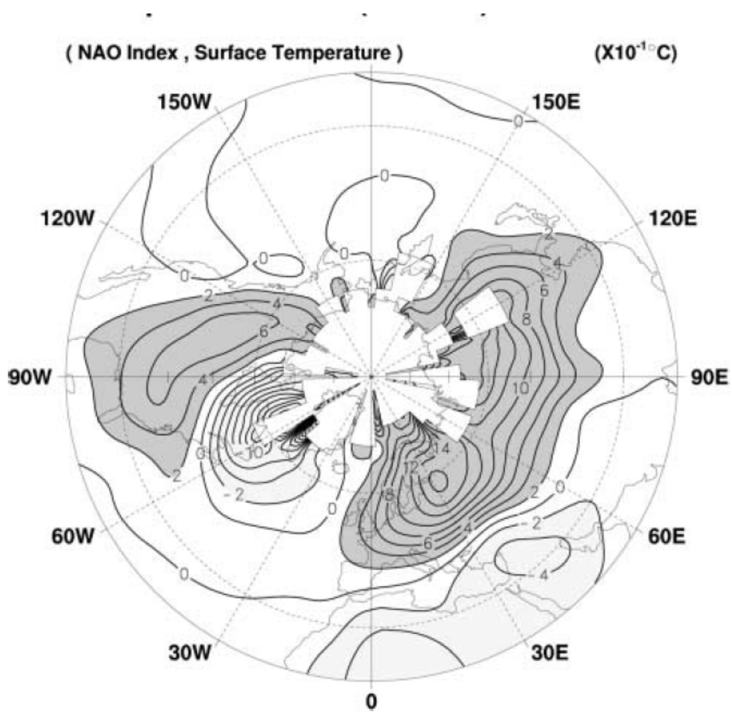


Average anomalies of SLP during the positive extreme phases of the NAO

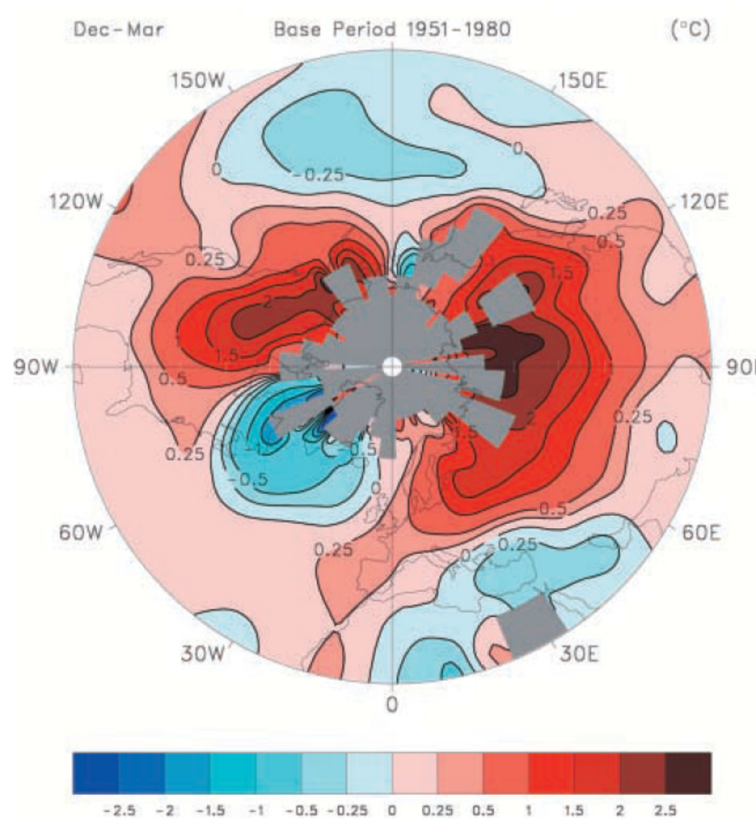
Lopez-Moreno et al., 2008

Impacts of the NAO on SAT

SAT change (0.1°C) associated with a 1 stdev change in the NAO index



SAT winter temperature difference for (1981-97) – (1951-80)



Striking similarity between NAO-related SAT anomalies and observed SAT trend → lead to speculation that NAO was responsible for observed warming over US and Europe

→ however warming has continued in the 21st century, despite neg. trend in NAO…

Greatbach, 2000

Impacts of the NAO on SAT

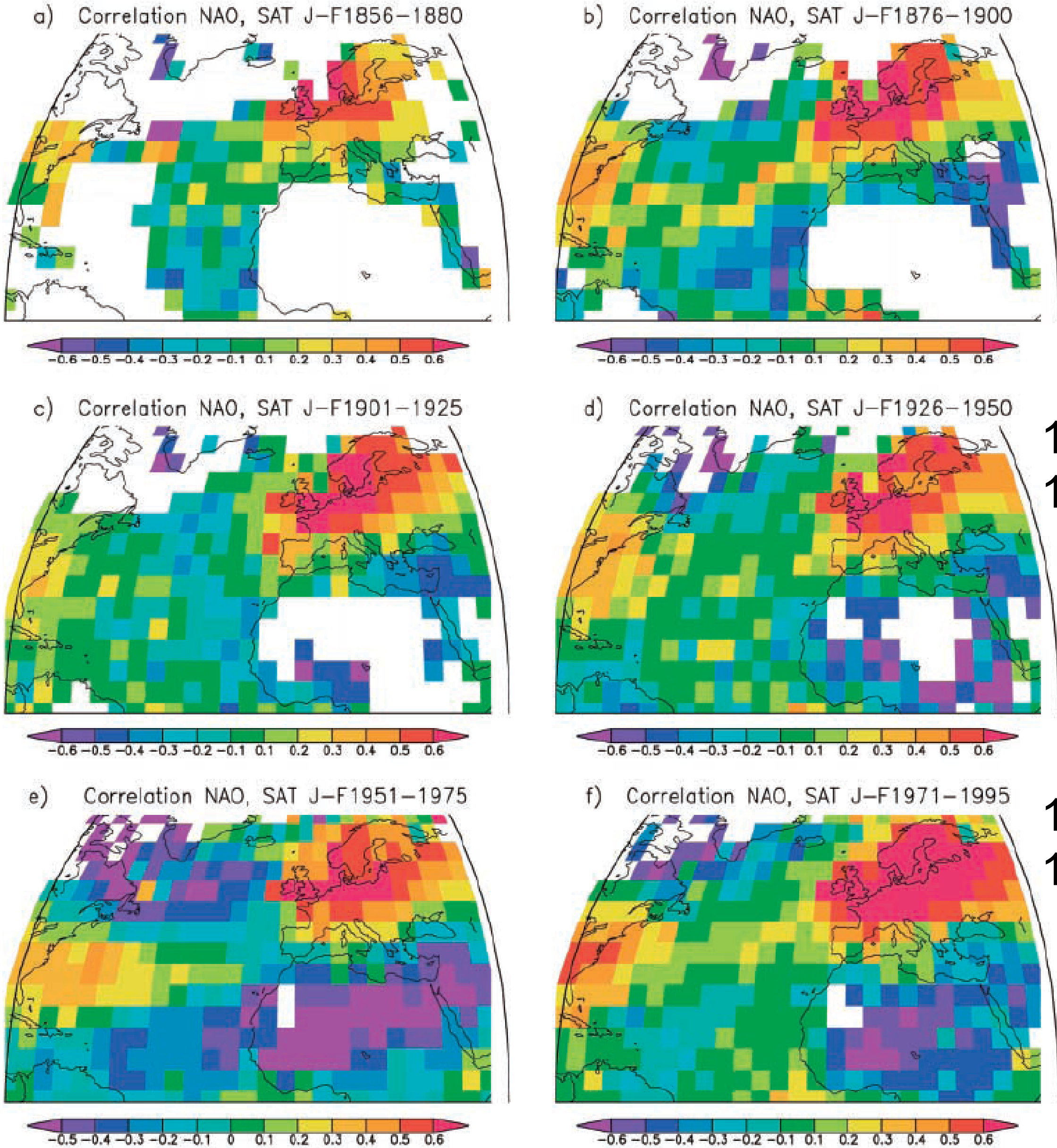


Fig. 7 Snapshot correlation maps between the NAO (Gibraltar–Reykjavik) and surface temperature for January and February for a 1856–1880, b 1876–1900, c 1901–1925, d 1926–1950, e 1951–1975, and f 1971–1995

1876-1900

1926-1950

1971-1995

Relationship remained fairly stable over time

Quadruple correlation pattern with NAO and SAT positively correlated over Europe and Sargasso Sea and negatively correlated over northwest Africa and Greenland/ Labrador Sea region

Slonosky and Yiou, 2002

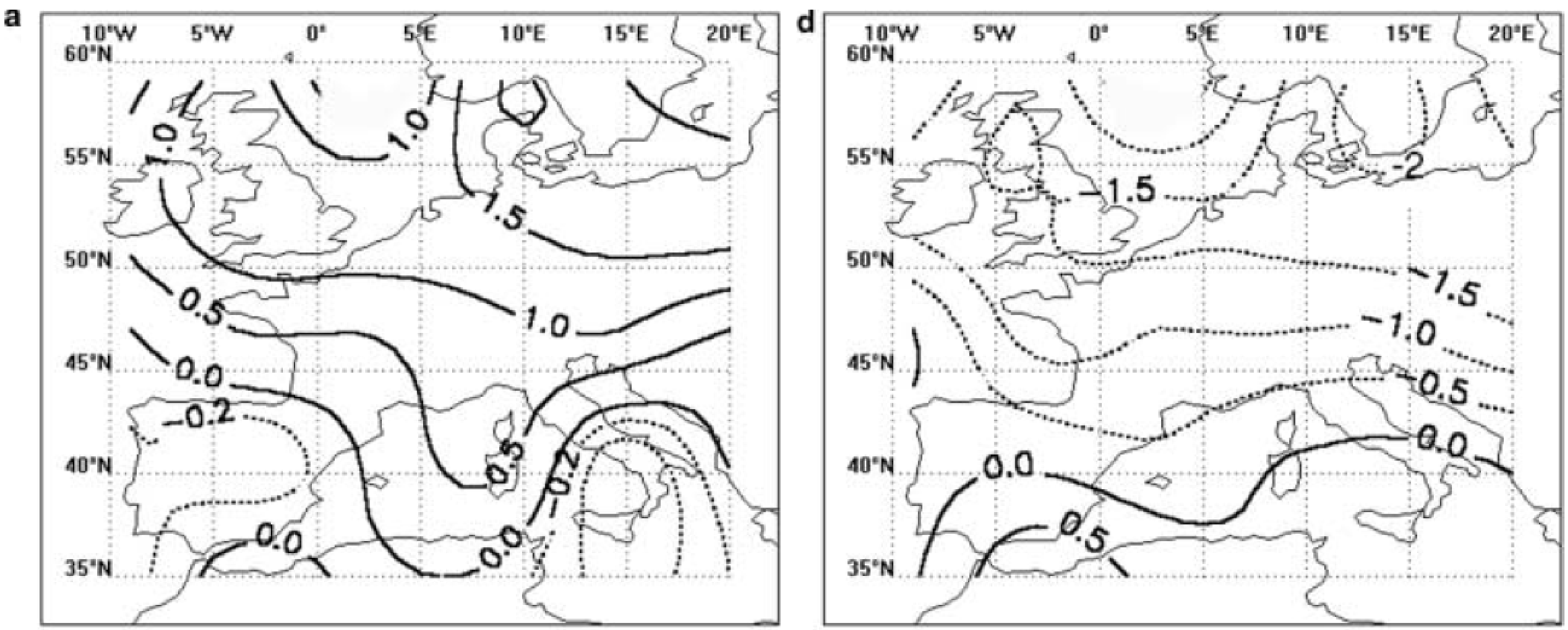
Impacts of the NAO on SAT in Europe

Composite temperature patterns over Europe for extreme phases of the NAO

Mostly linear response

NAO > 1.5

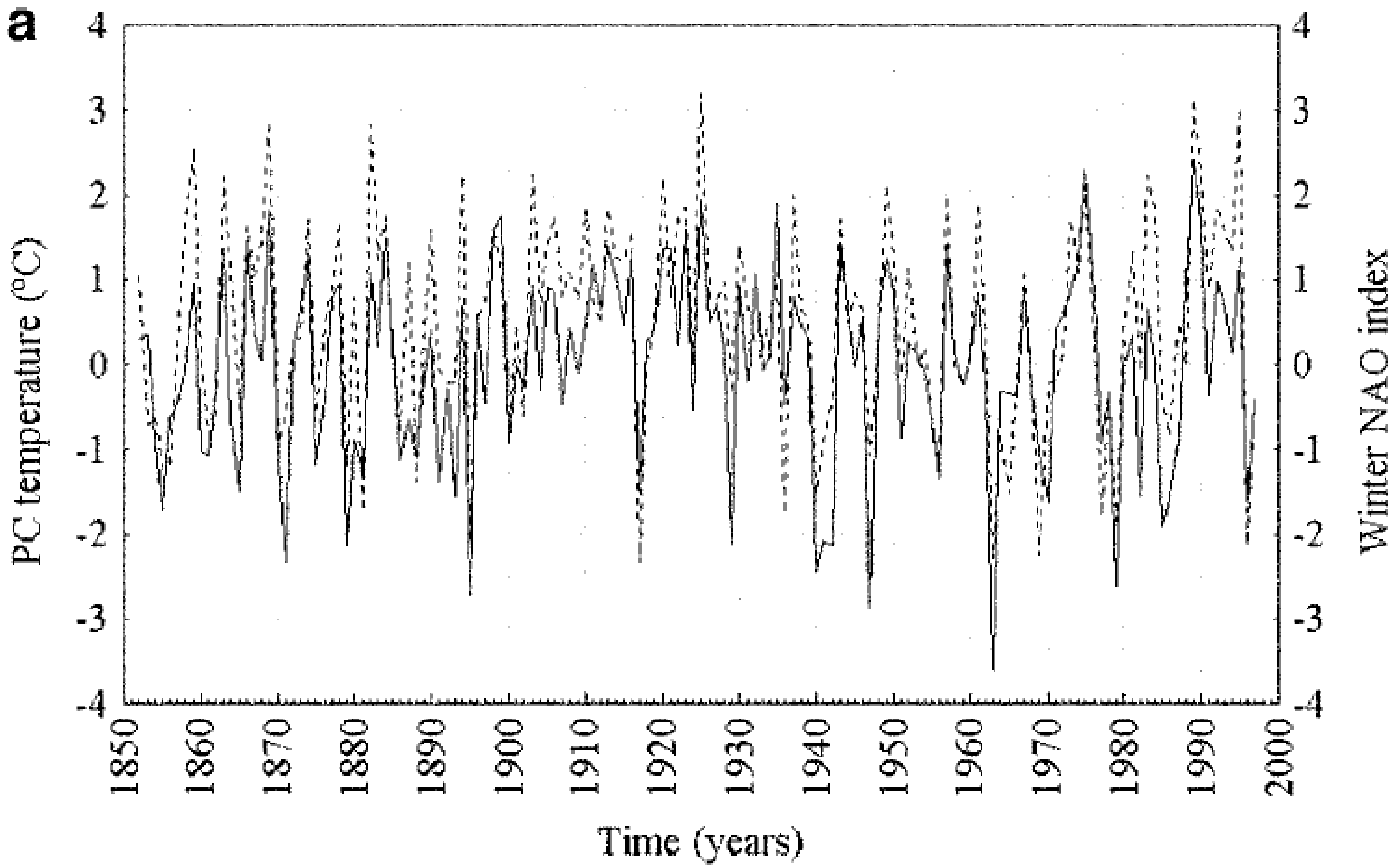
NAO < -1.5



Pozo-Vasquez et al., 2001

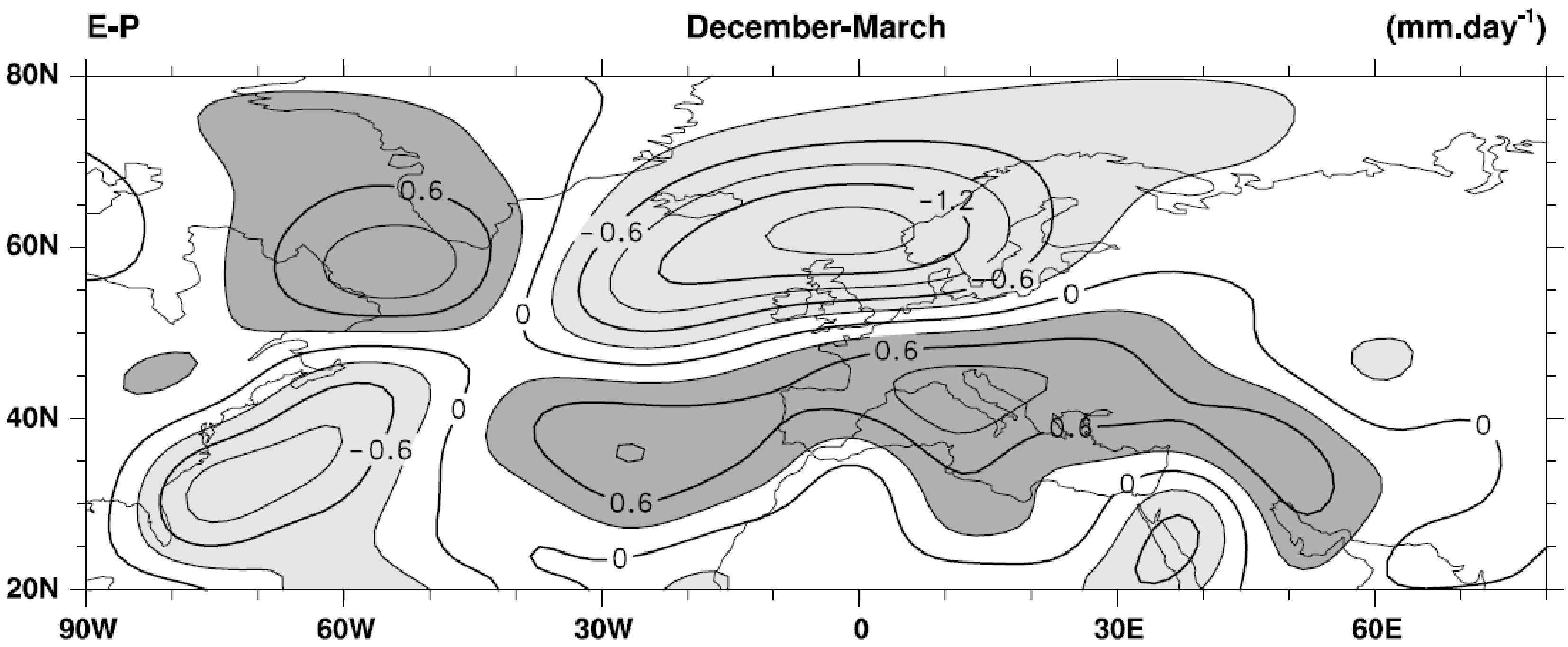
Impacts of the NAO on SAT in Europe

PC#1 of European winter temperature (solid line), 38.1% explained variance vs. NAO index (dashed line)



Pozo-Vasquez et al., 2001

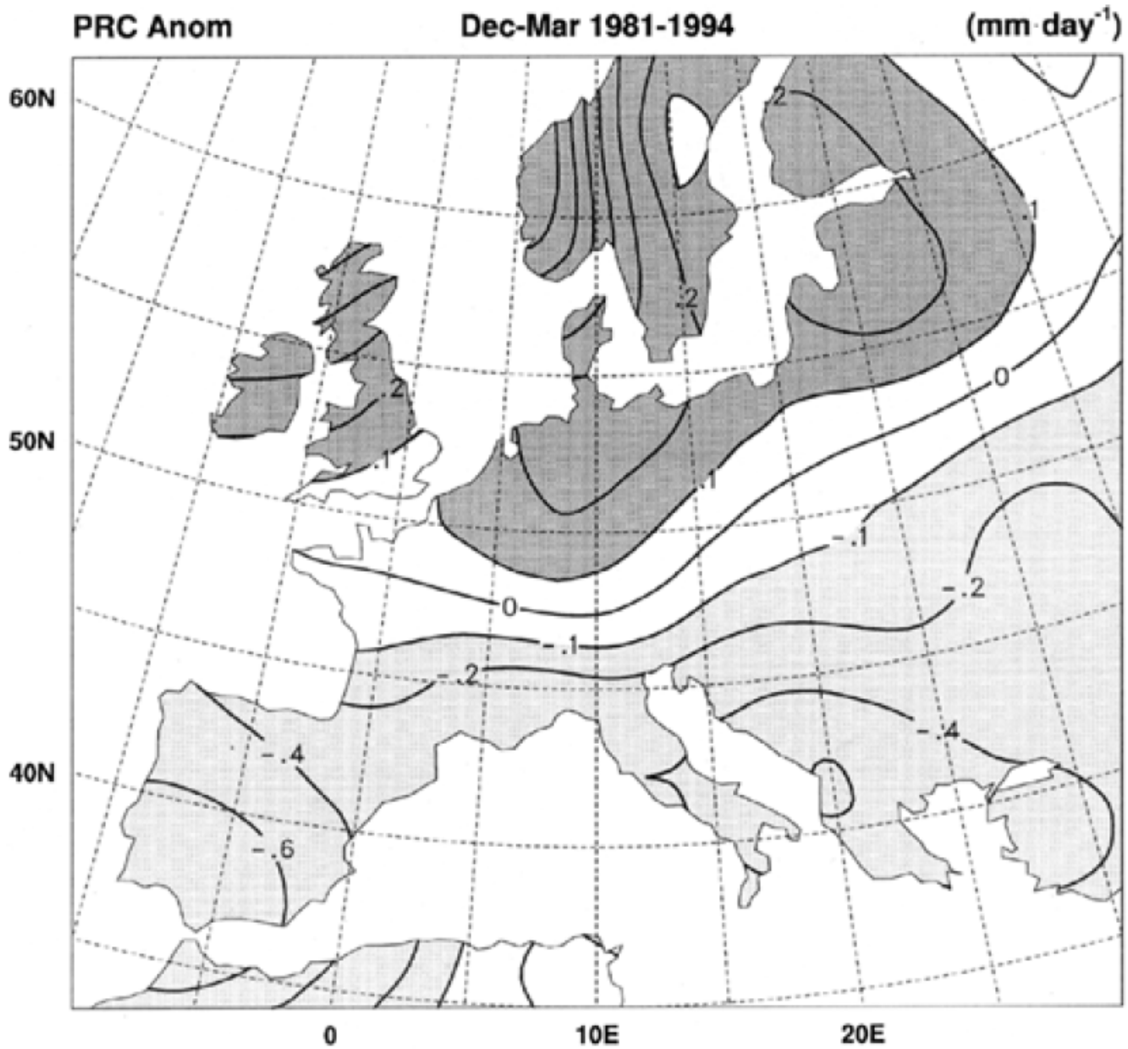
Impacts of the NAO on the moisture budget



E-P for high-low NAO index winters

Wanner et al., 2001

Impacts of the unusual 1980s and early 1990s on Precipitation in Europe

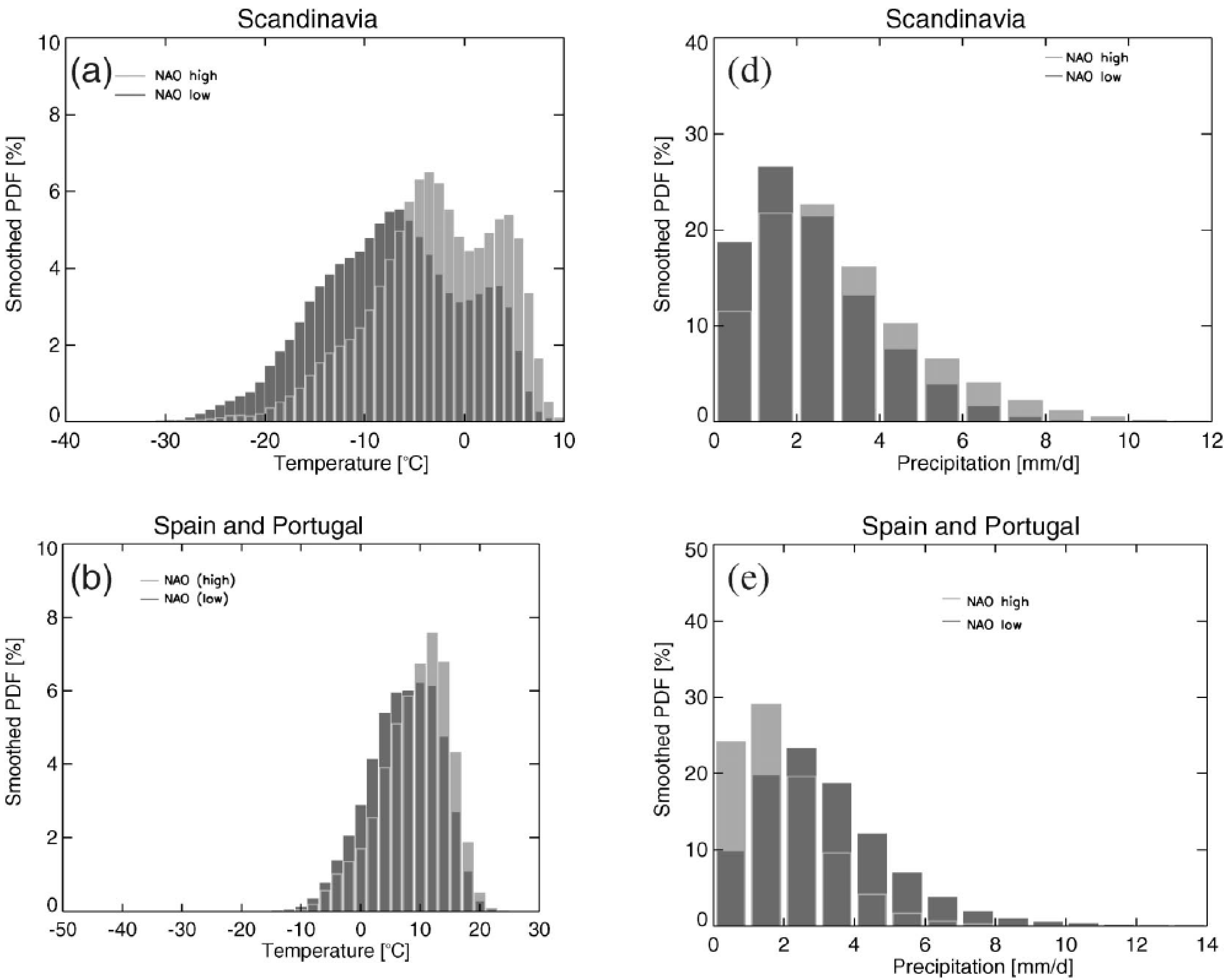


1981–1994 DJFM average precipitation anomalies (mm day^{-1}) expressed as departures from 1951–1980 mean

→ NAO signature in precipitation is visible due to continued positive polarity of index in this time period

Hurrell and van Loon, 1997

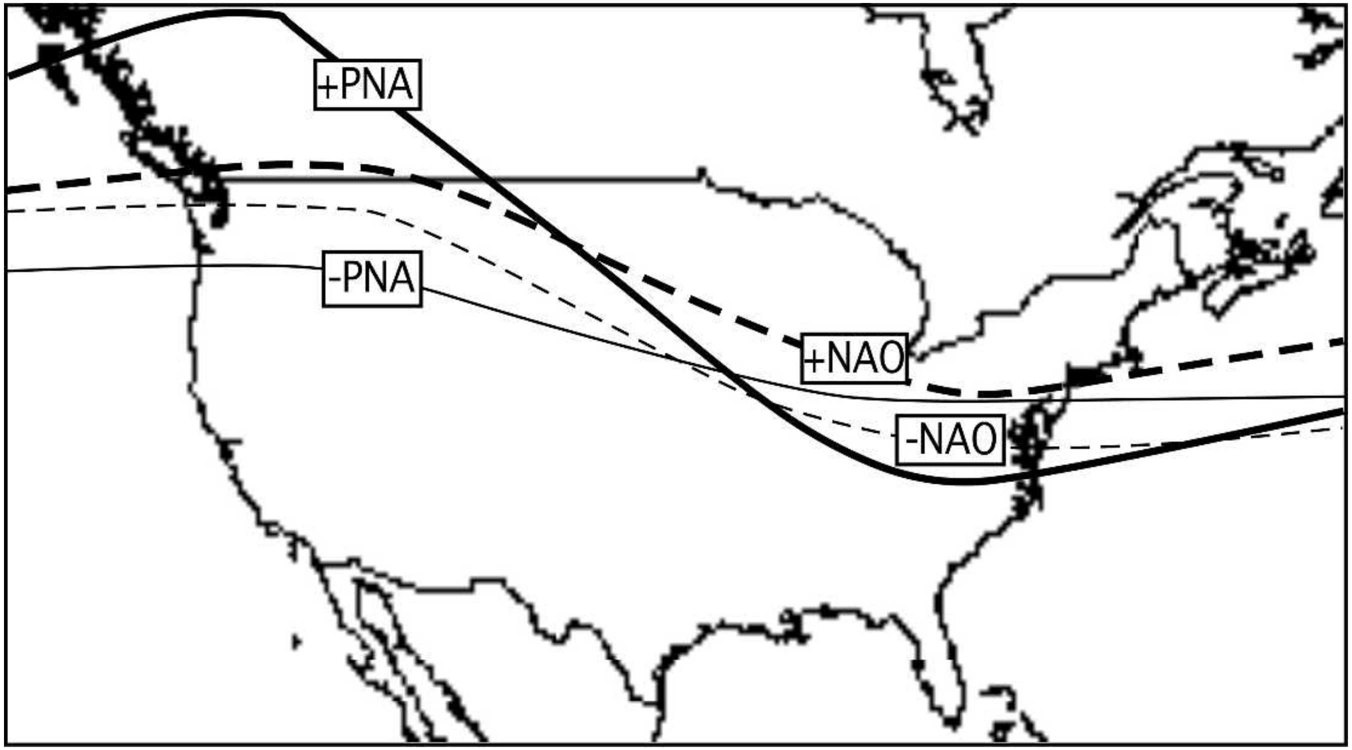
Impact of NAO on likelihood of high/low precipitation and SAT



Timm et al., 2004

Impact of NAO on US winter climate

Schematic of the typical December midtropospheric flow pattern during positive and negative phases of both the PNA and NAO patterns, based on 500-hPa winds



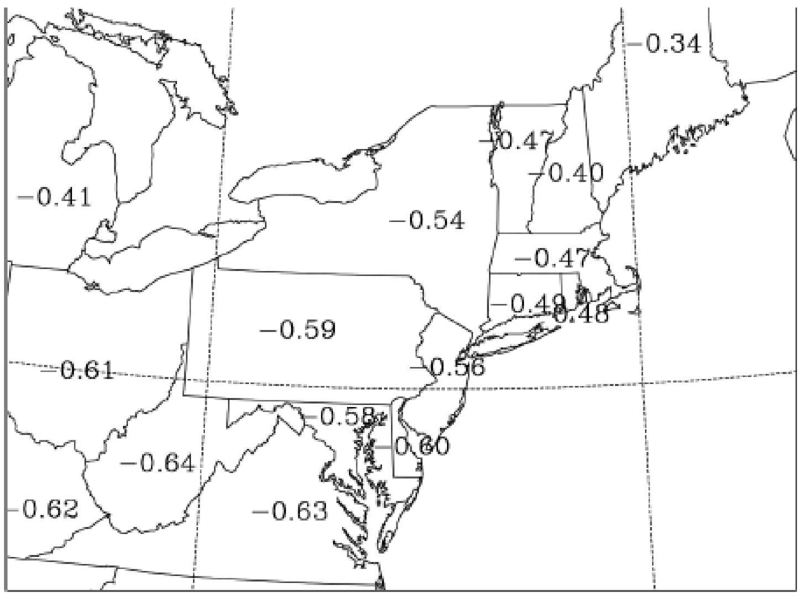
Compared to PNA pattern NAO influence is rather modest

Notaro et al., 2006

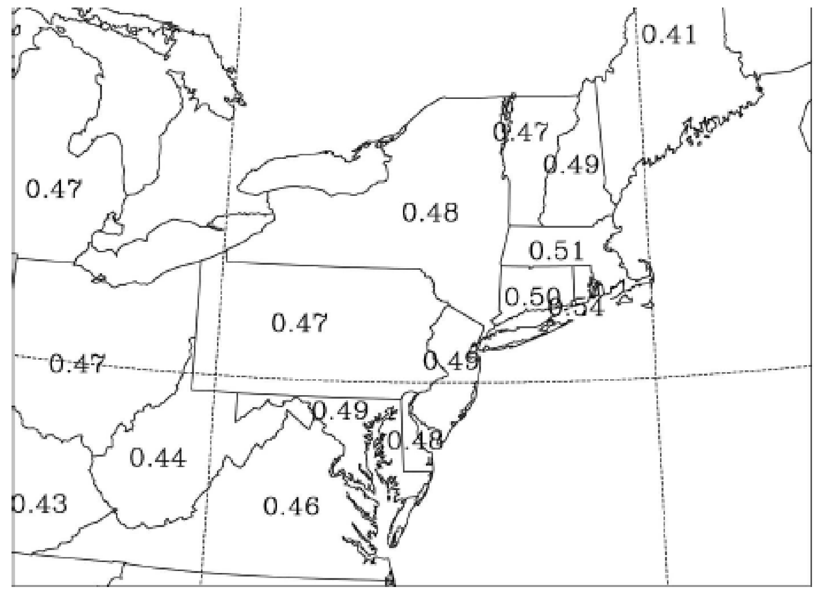
Impact of NAO on US winter climate

Correlation coefficients for (left) PNA index and (right) NAO index vs. NCDC observed state-mean SAT (Dec., 1958–2000)

PNA



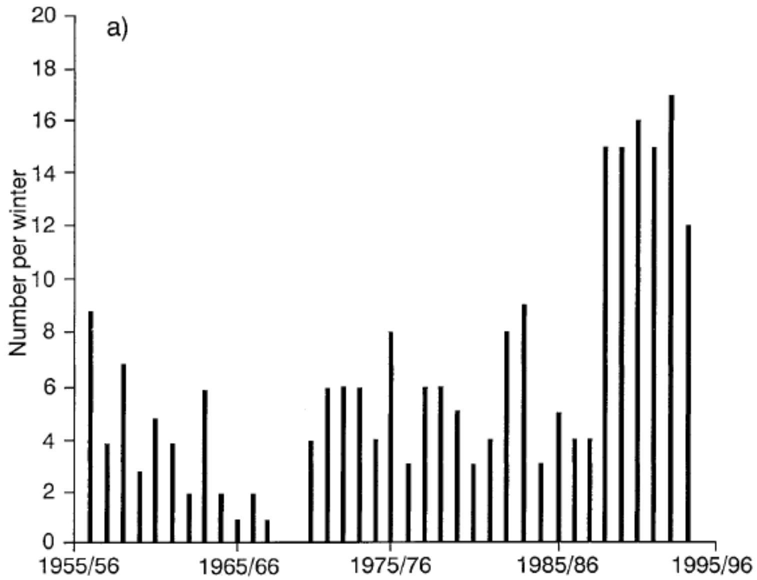
NAO



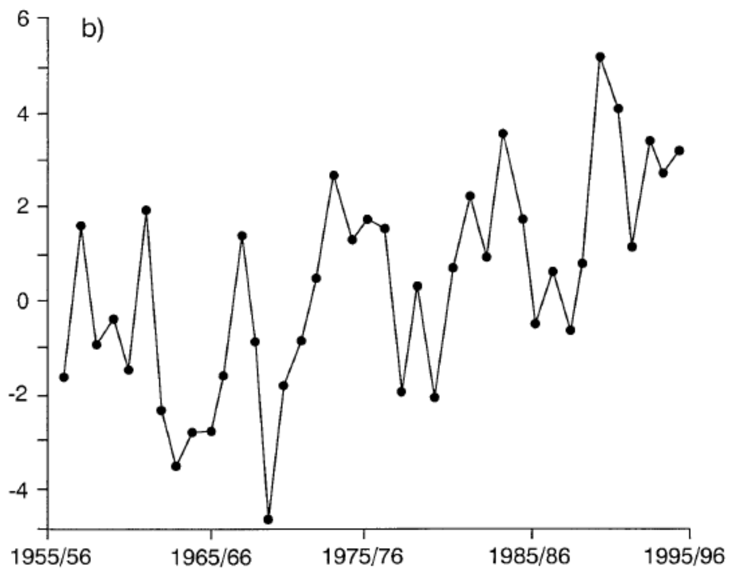
NAO influence stronger in New England, PNA dominates everywhere else

Notaro et al., 2006

Impact of NAO on Atlantic storms



# of Atlantic winter storms deeper than 950 hPa

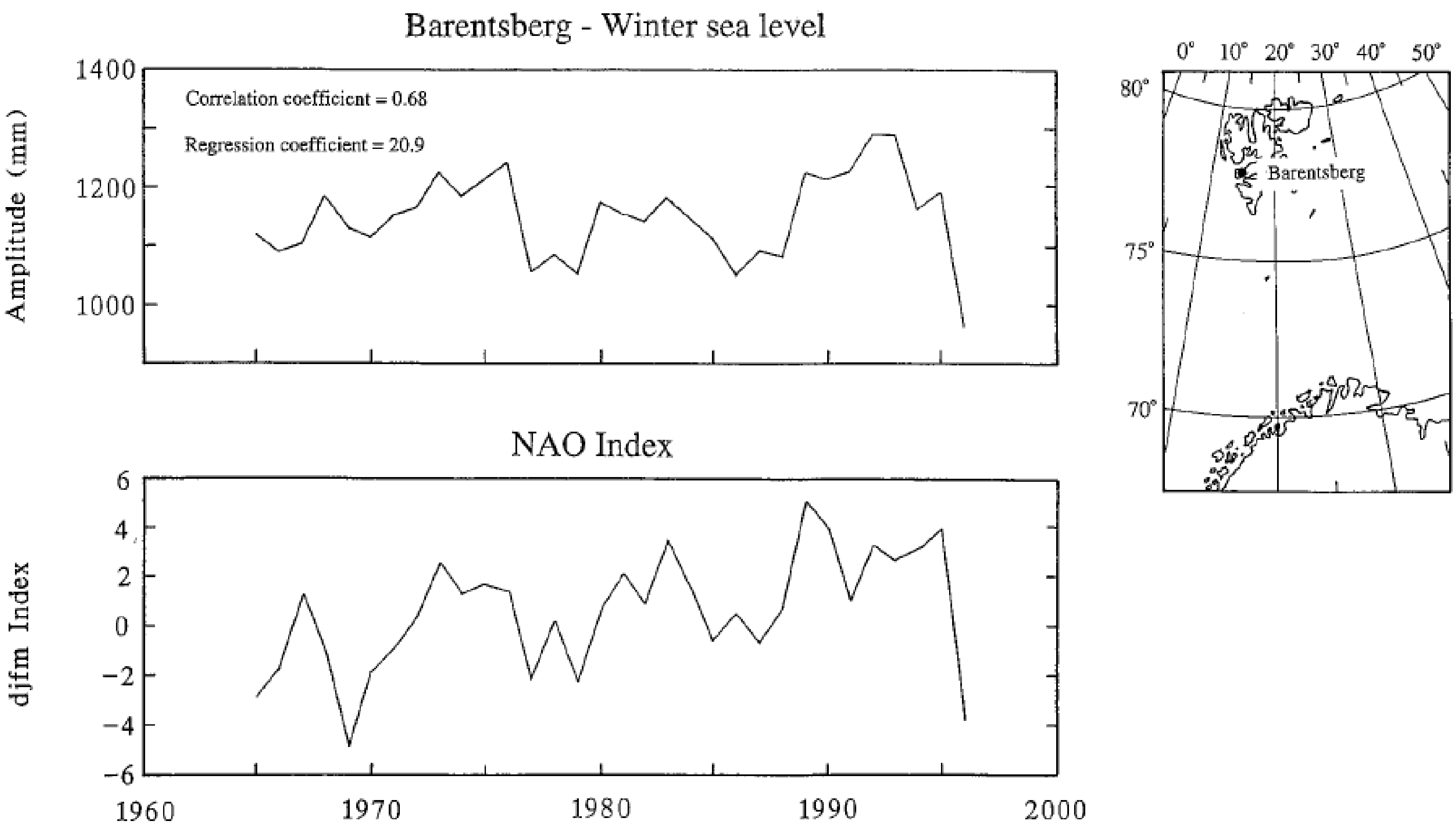


Winter NAO index

Deep Atlantic storms increase from near-zero during low index conditions to around 15 per winter during high-index phase.

Dickson et al., 2000

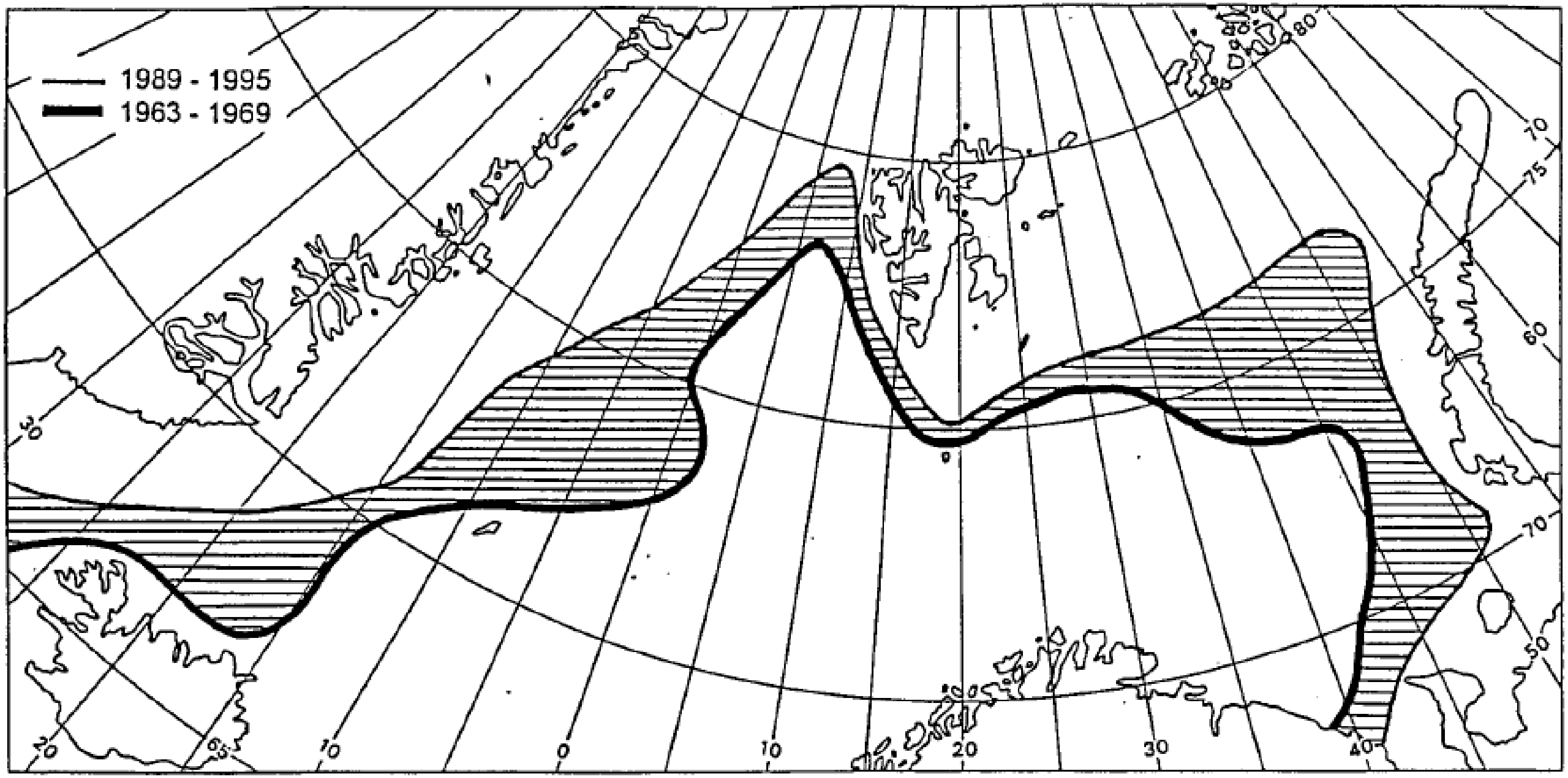
Impact of NAO on sea level variations



Variation of winter mean sea level (mm) at Barentsberg compared with winter NAO index, 1965–96

Dickson et al., 2000

Impact of NAO on Arctic sea-ice extent

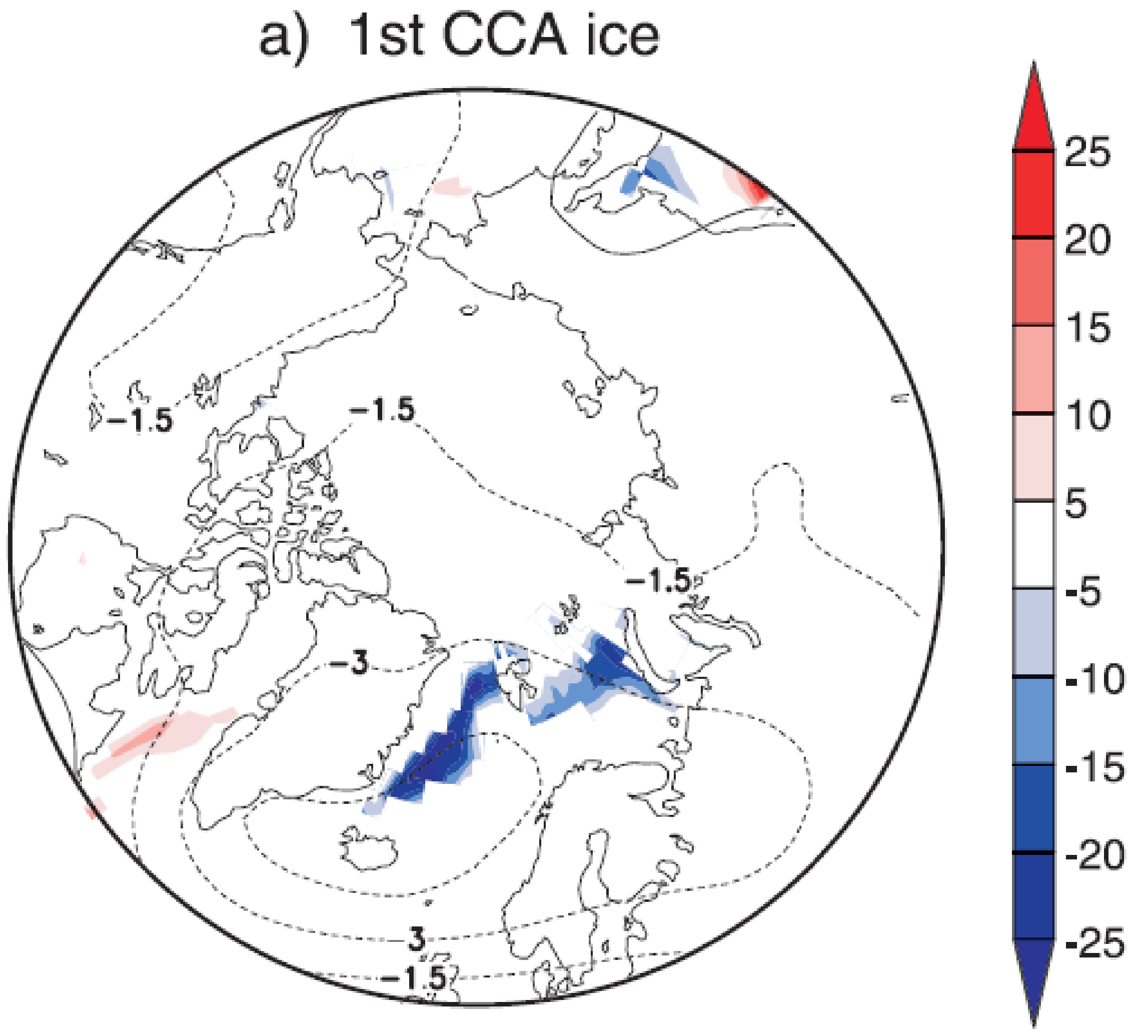


Median ice border at end of April for periods 1963–69 (neg. NAO) and 1989–95 (pos. NAO phase).

→ Reduction in ice extent of ~ 587,000 km^2 during two periods

Dickson et al., 2000

Impact of NAO on Arctic sea-ice extent



Canonical correlation analysis (CCA) reveals regions of strong co-variance between NAO and sea-ice

Bojariu and Gimeno, 2003

Ecological impacts of the NAO

Impact on fish populations (Cod) and marine food web due to NAO induced temperate changes or changes in ocean vertical mixing

Impact on terrestrial animals and plants through changes in SAT and precipitation

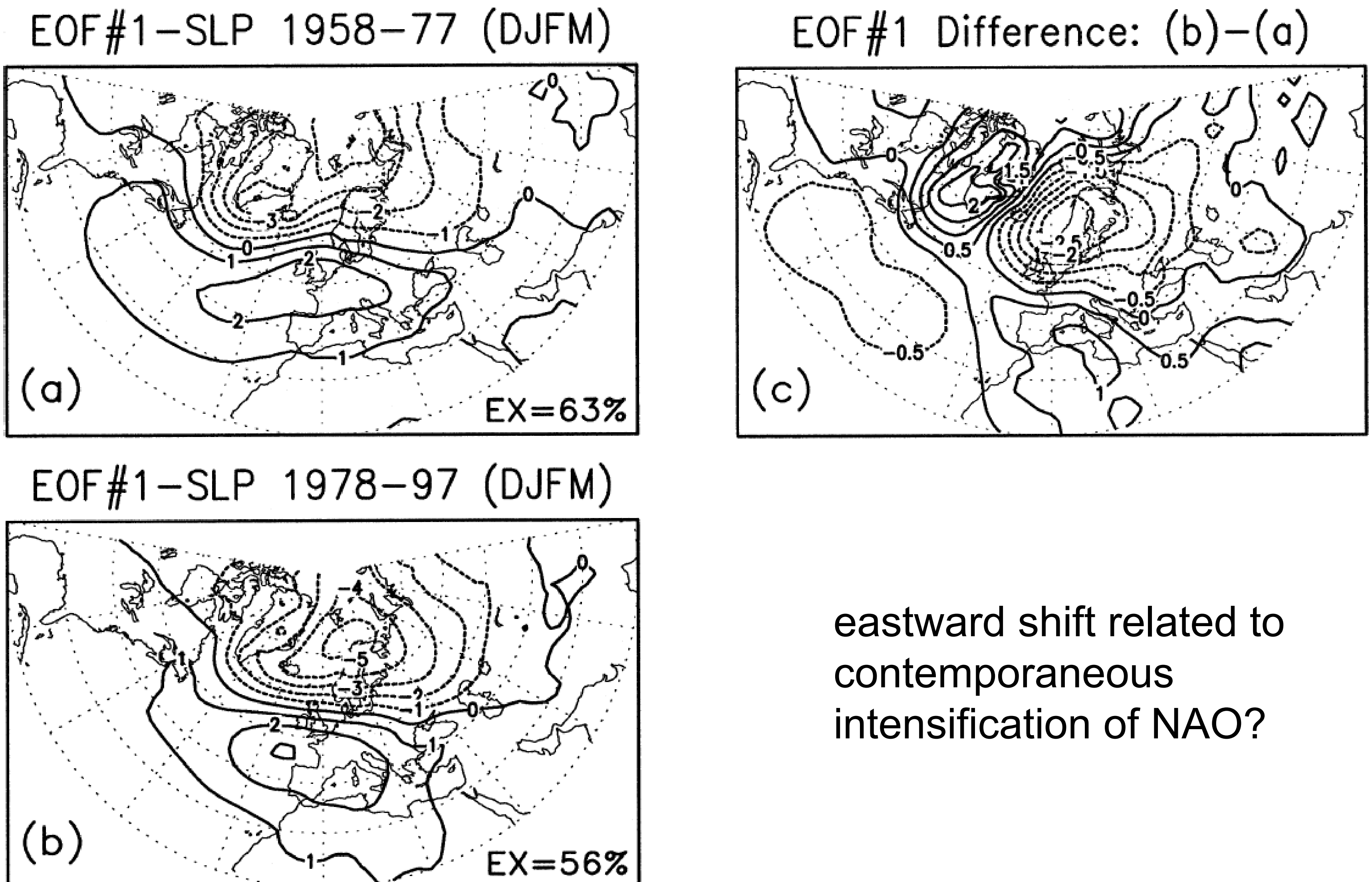
Economic impacts of the NAO

-off-shore oil drilling

-stream flow (water supply and hydropower production)

-Agriculture (crop yields)

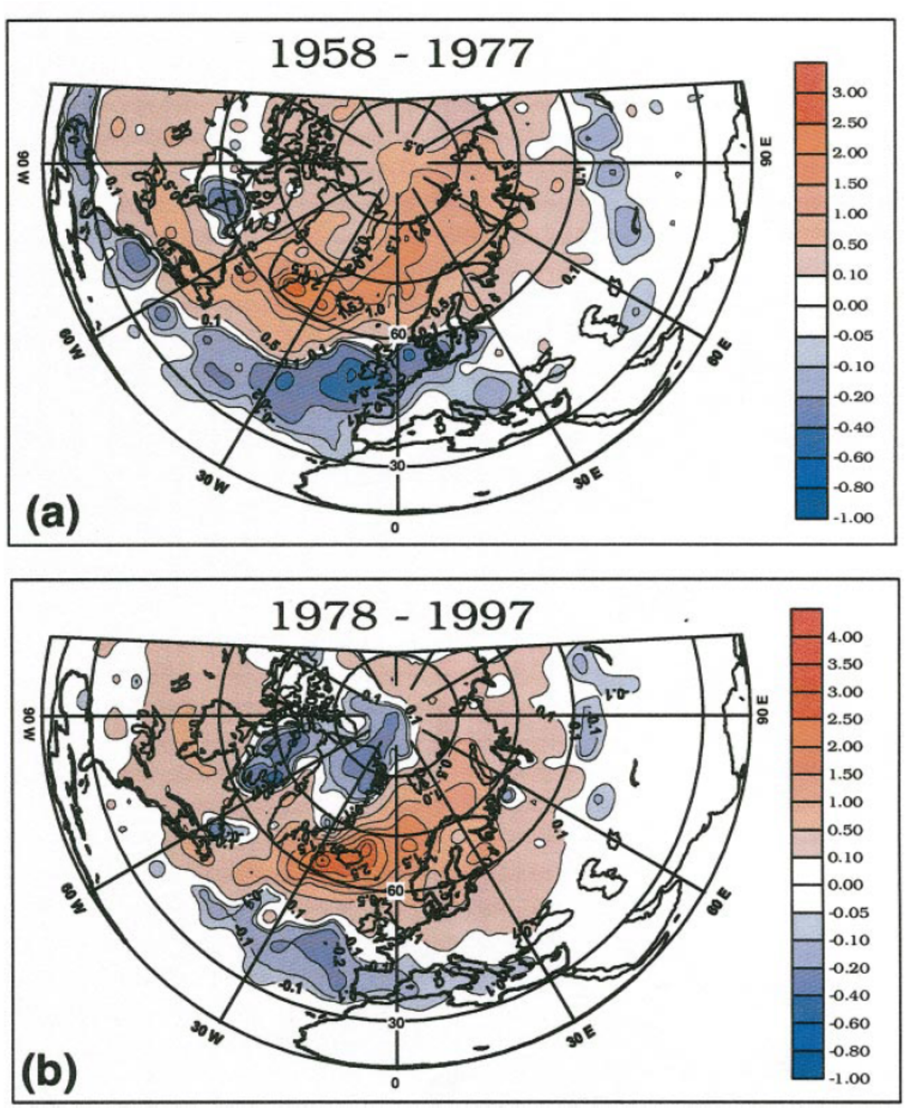
Recent Eastward Shift of Interannual NAO Variability



eastward shift related to contemporaneous intensification of NAO?

Jung et al., 2003

Recent Eastward Shift of Interannual NAO Variability



Southeastward shift and intensification of deep cyclone (<980 hPa) development

Cyclone anomalies regressed upon NAO-index

Jung et al., 2003