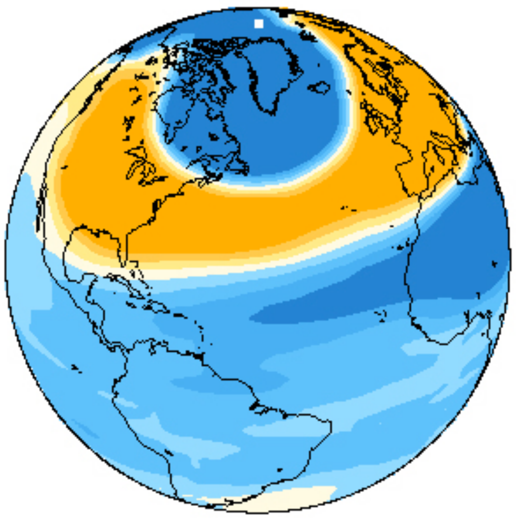
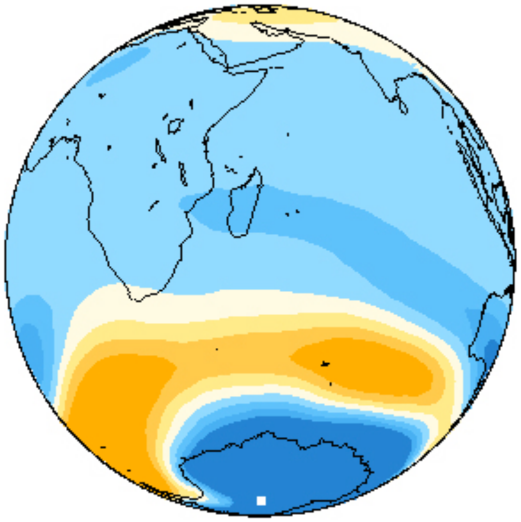
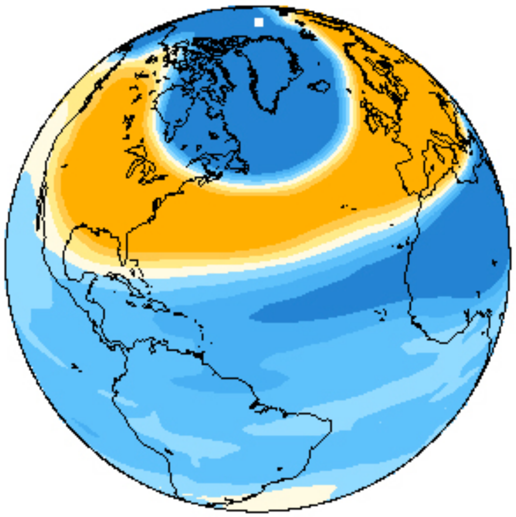
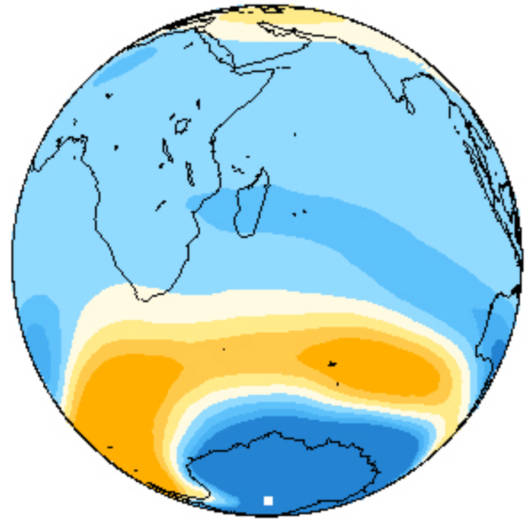
The Arctic and Antarctic Oscillations



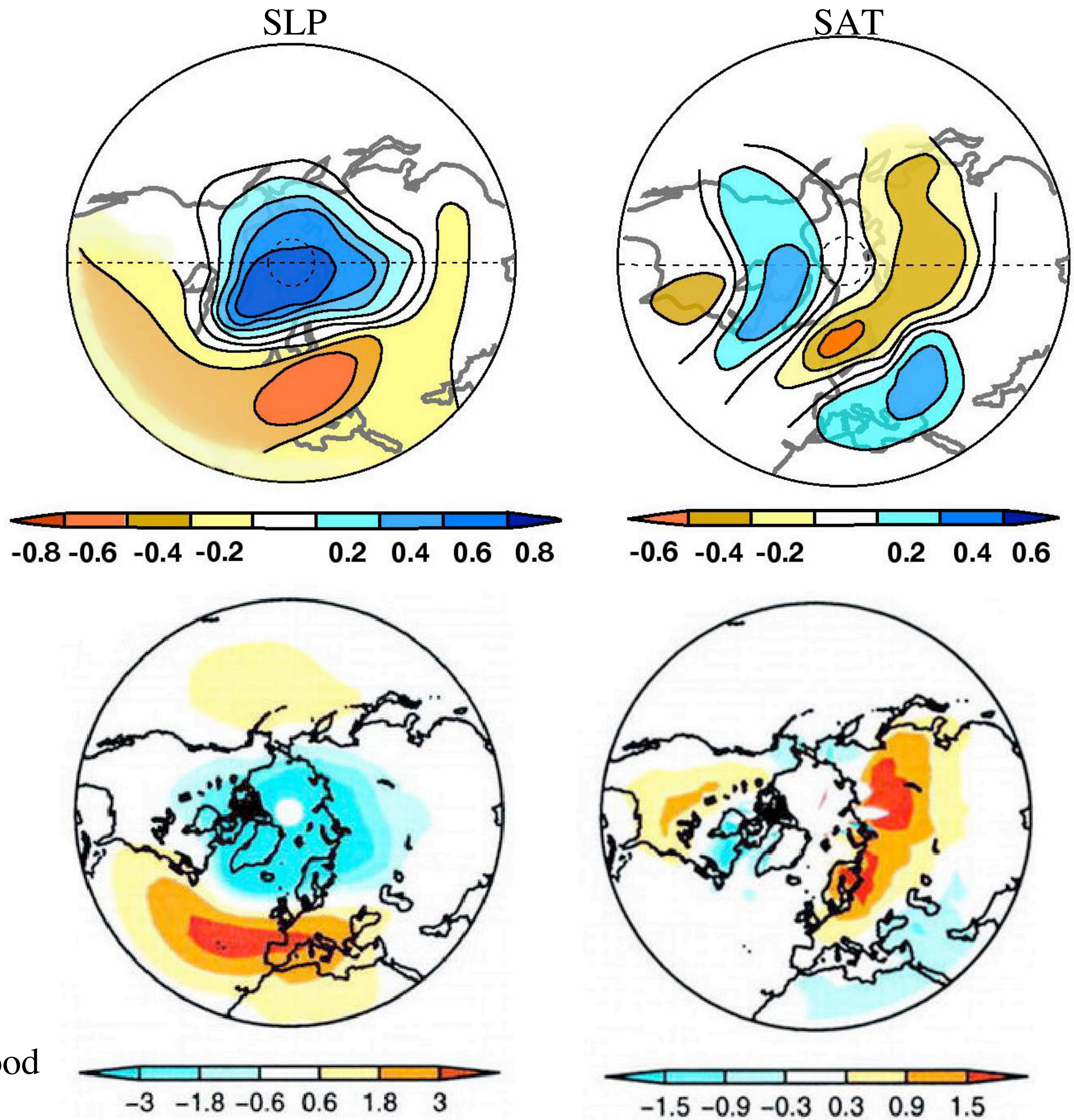


John M. Wallace
University of Washington

1. Historical perspective
2. Structure of AO/AAO
3. Are the AO/AAO really modes?
4. The AO/AAO in global climate
5. The AO/AAO in polar climate
6. Secular trends in the AO/AAO

Exner (1913)

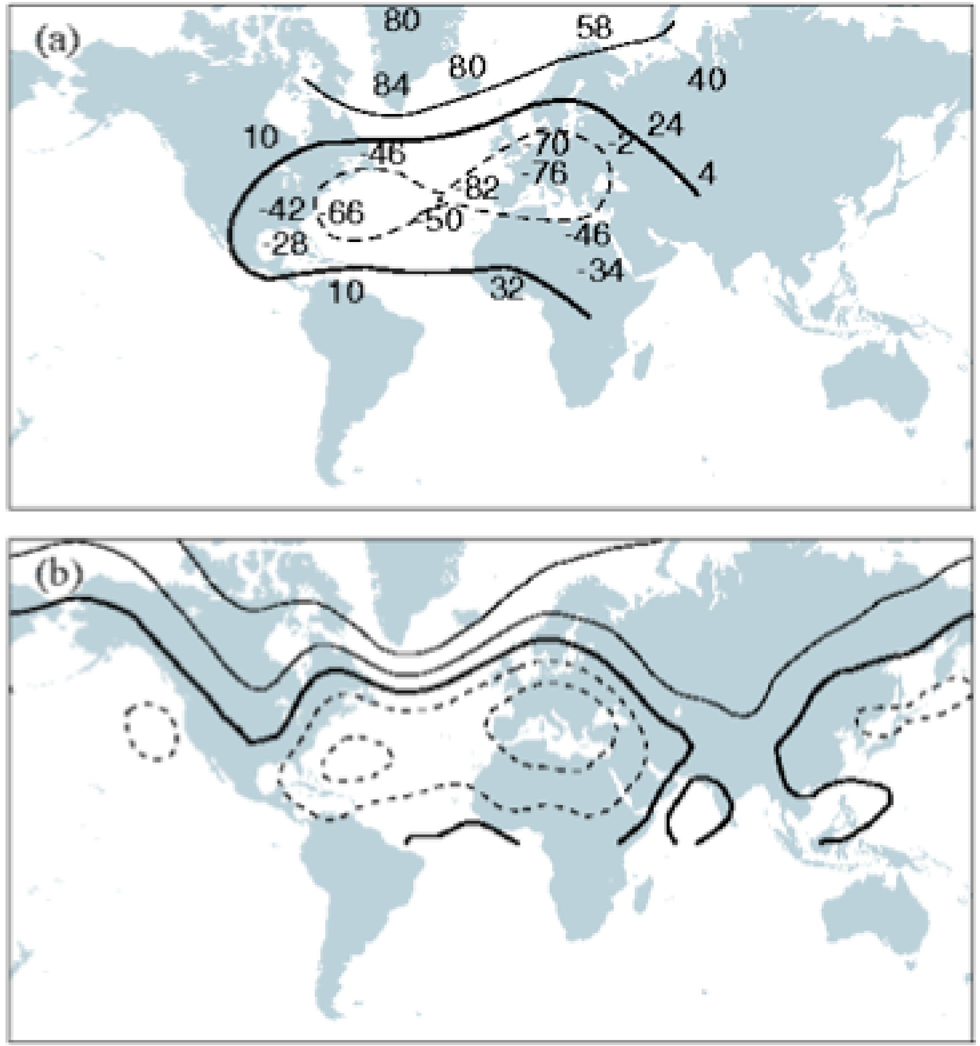


modern

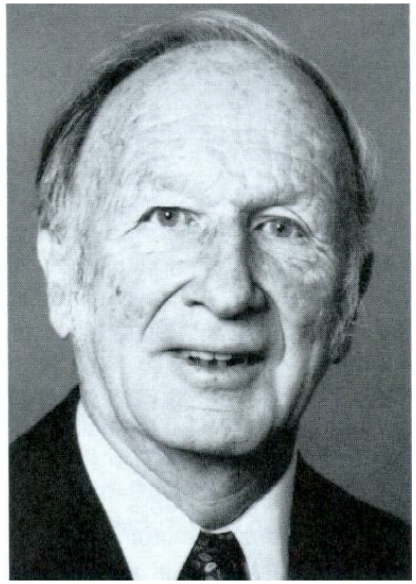
Courtesy of Kevin Wood

NAO

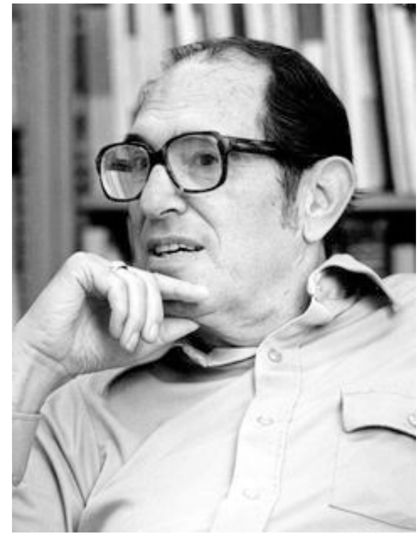
Walker and Bliss
(1932)



Lorenz 1951



Namias 1951



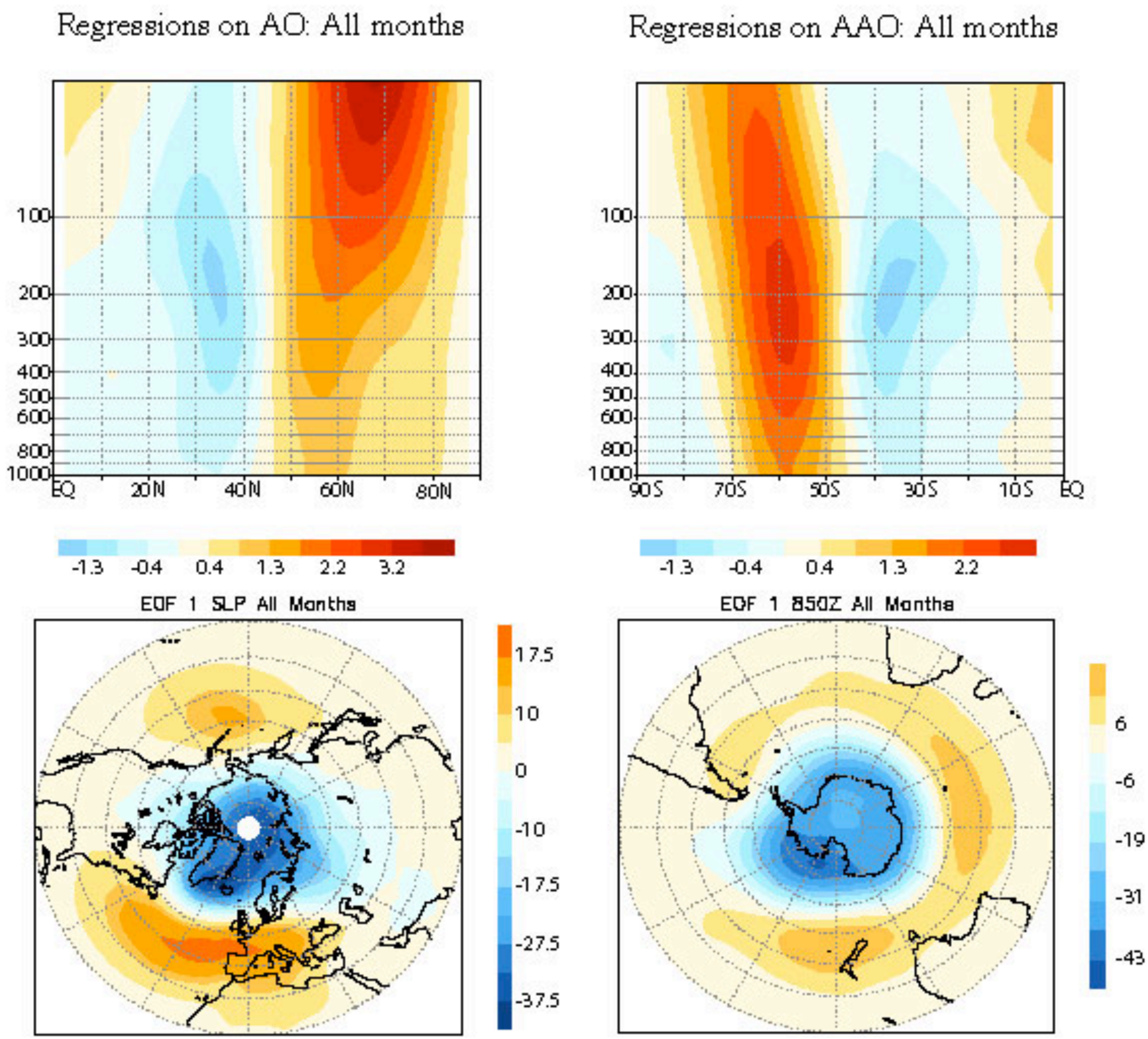
van Loon and Rogers 1978

Kidson 1988

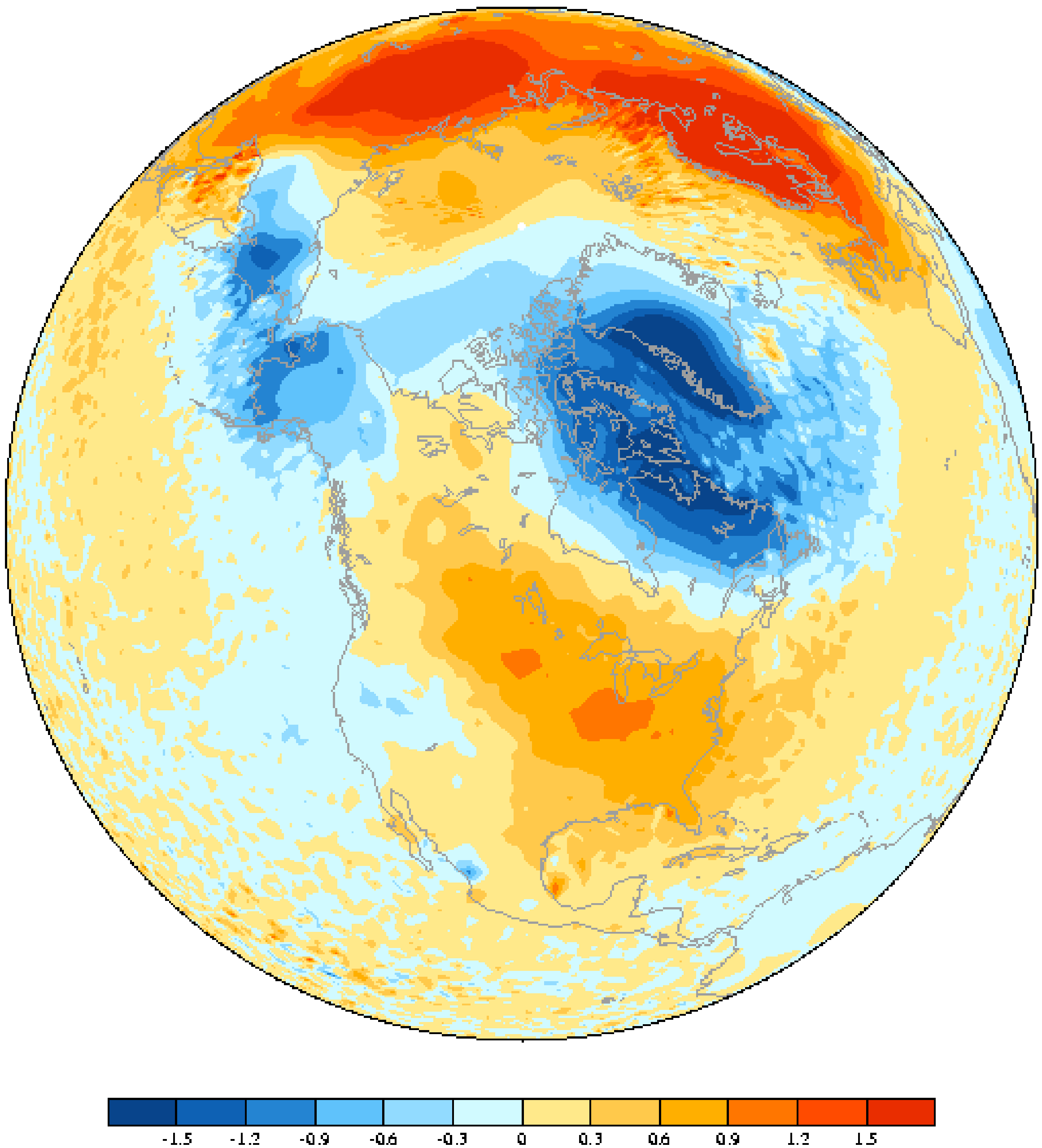
Hurrell 1995
Thompson 2000

AO / AAO

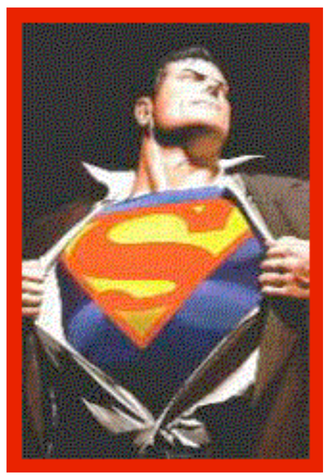
Structure of the AO/AAO

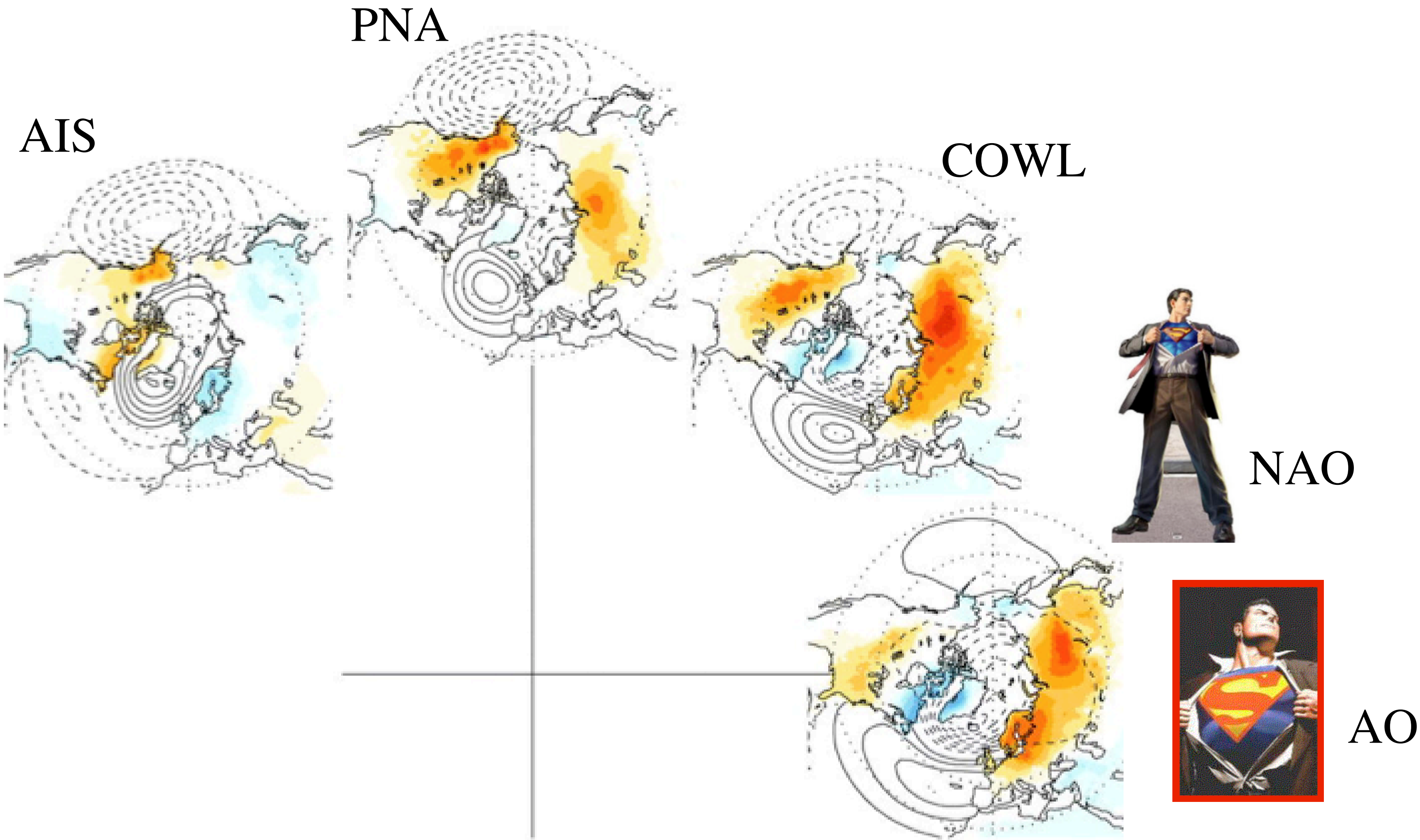


AO surface temperature anomalies (C) 1979-97



AO or NAO?

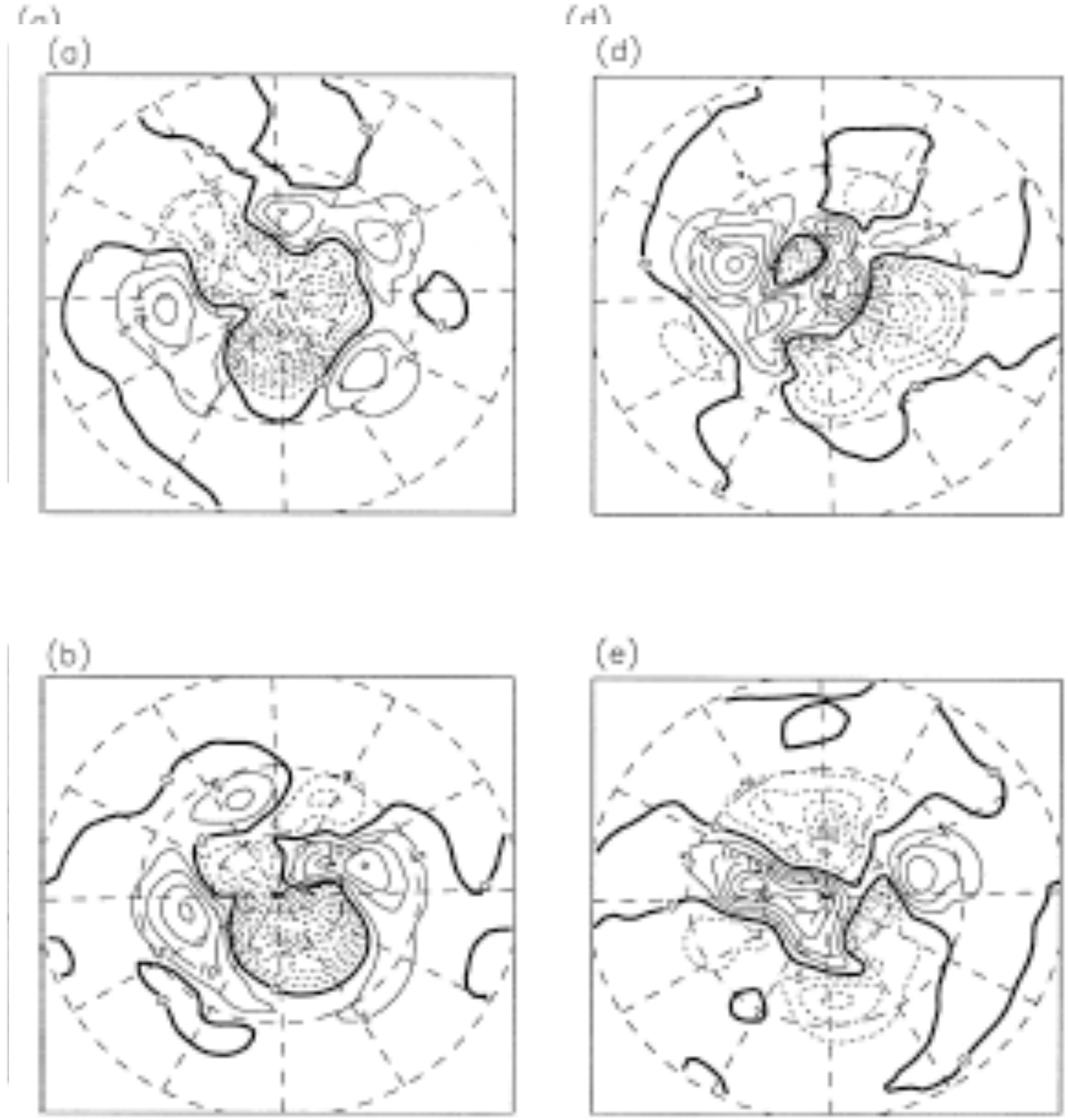




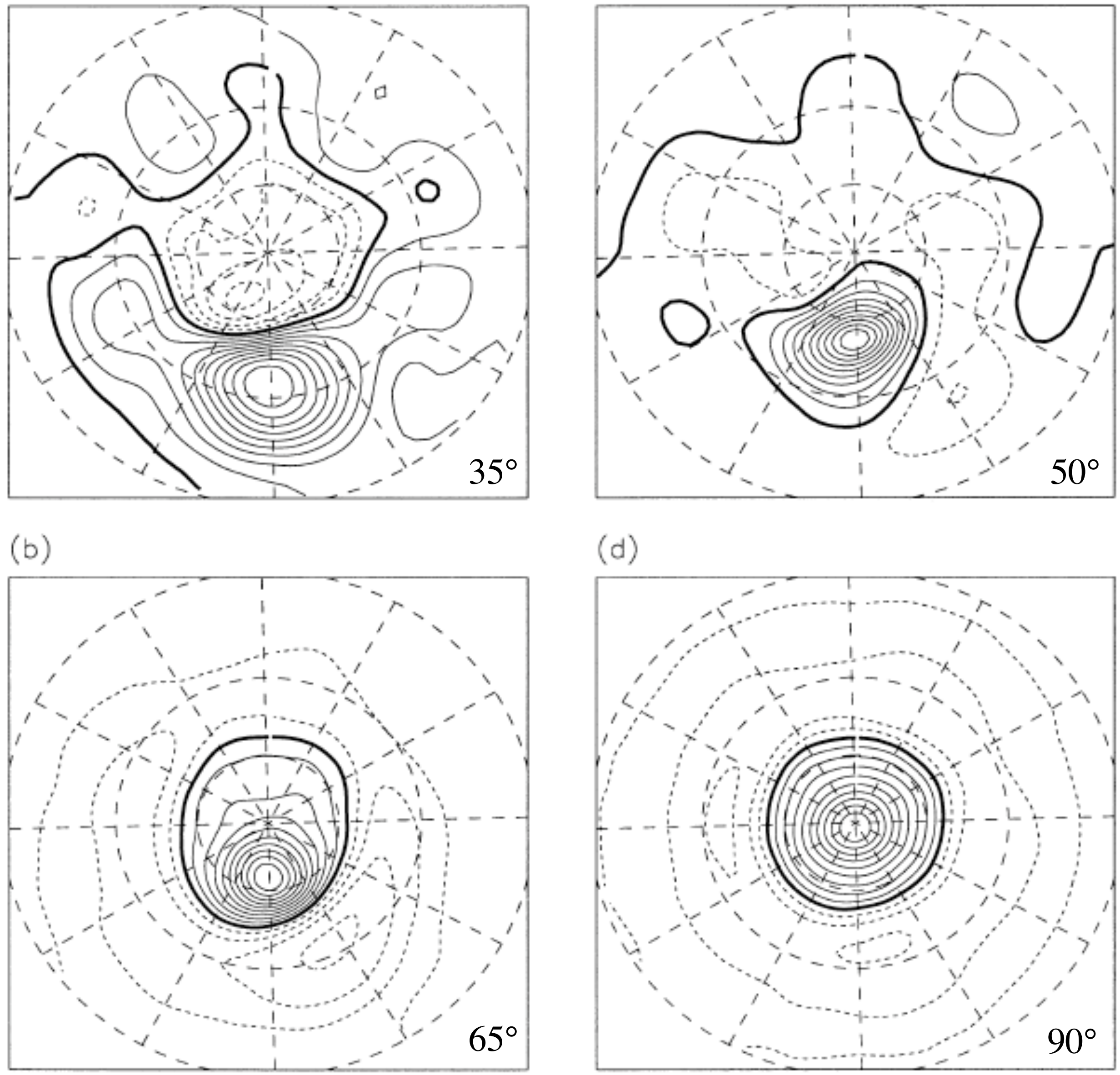
Quadrelli and Wallace, JCL 2004

Are annular modes really modes?

CKV (2002)



CKV (2002)



Are annular modes really modes?

- Not a well defined mode of variability in aqua-planet models

but

- More prominent at lower frequencies
- Prominent in one-point correlation maps for temperature

More prominent at lower frequencies

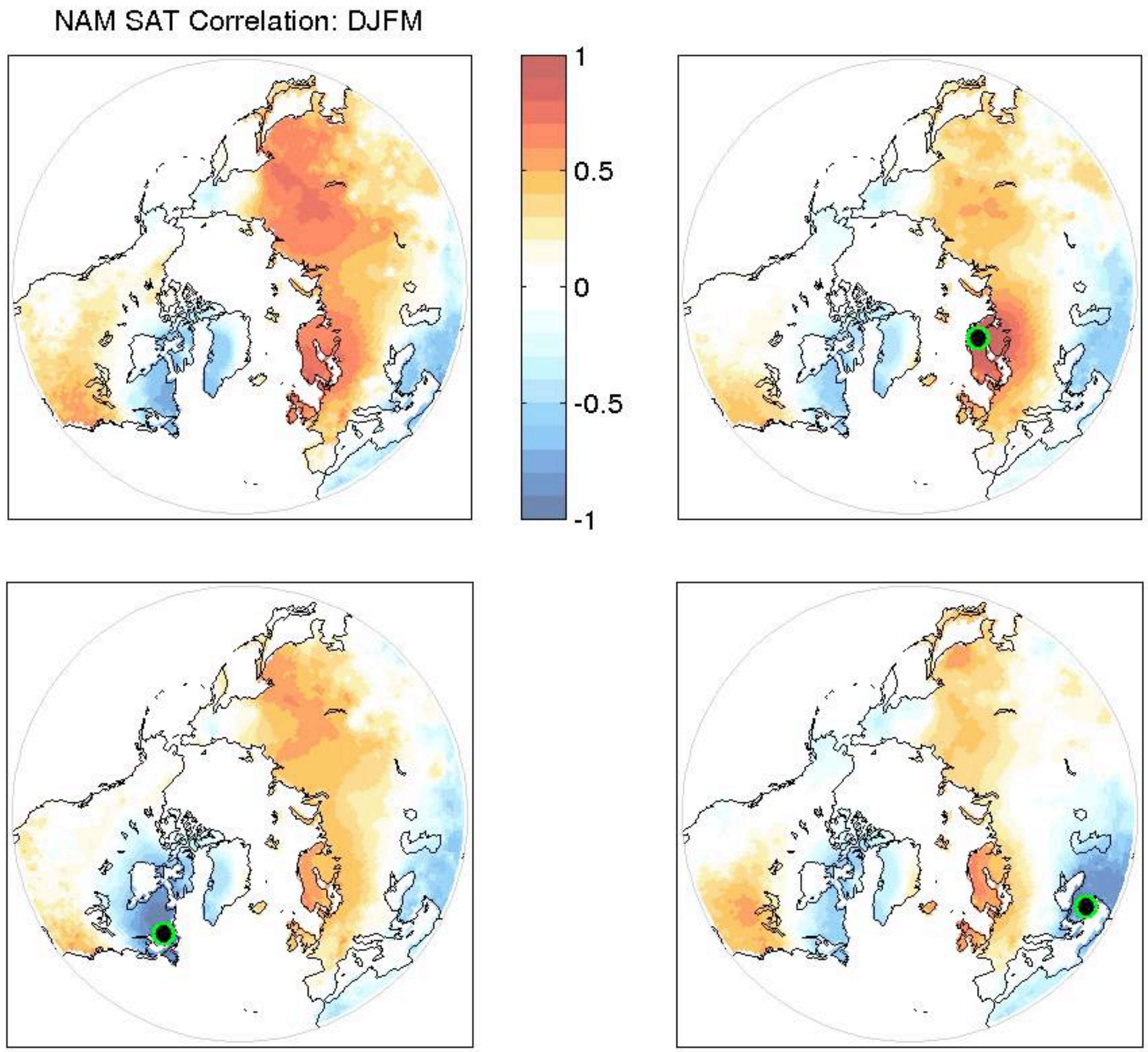
	v/v_m	$(PC1 + PC2)_m$	PC1 + PC2
Monthly	1	36	36
Seasonal	0.39	49	51
5-yr mean	0.15	72	74

5–99 SLP data.

	v/v_m	$(PC1 + PC2)_m$	PC1 + PC2
Monthly	1	34	34
Seasonal	0.38	43	44
5-yr mean	0.12	52	52

Quadrelli and Wallace, JCL 2004

Prominent in one-point correlation maps for temperature



Are annular modes really modes?

- Not a well defined mode of variability in aqua-planet models

but

- More prominent at lower frequencies
- Prominent in one-point correlation maps for temperature

Are annular modes really modes?

- Not a well defined mode of variability in aqua-planet models

but

- More prominent at lower frequencies
- Prominent in one-point correlation maps for temperature
- Meaningful in context of wintertime stratospheric circulation
- Useful for characterizing Arctic / Antarctic variability

AO/AAO in Global Climate

- Latitude of jet streams and storm tracks
- Wind forcing of ocean currents
- NH winter severity
- NH tropical cyclones (AAO)
- ENSO (AAO)

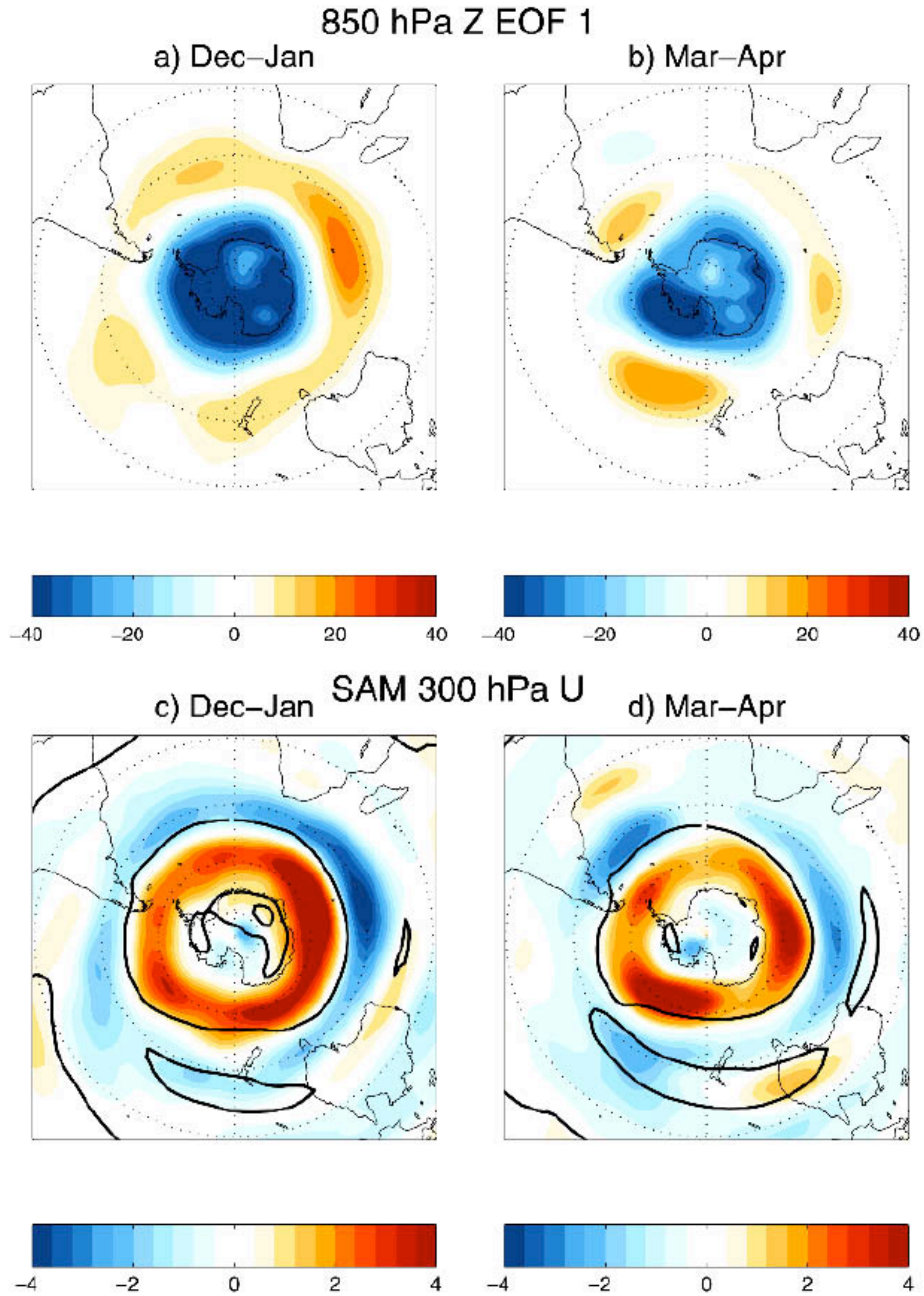
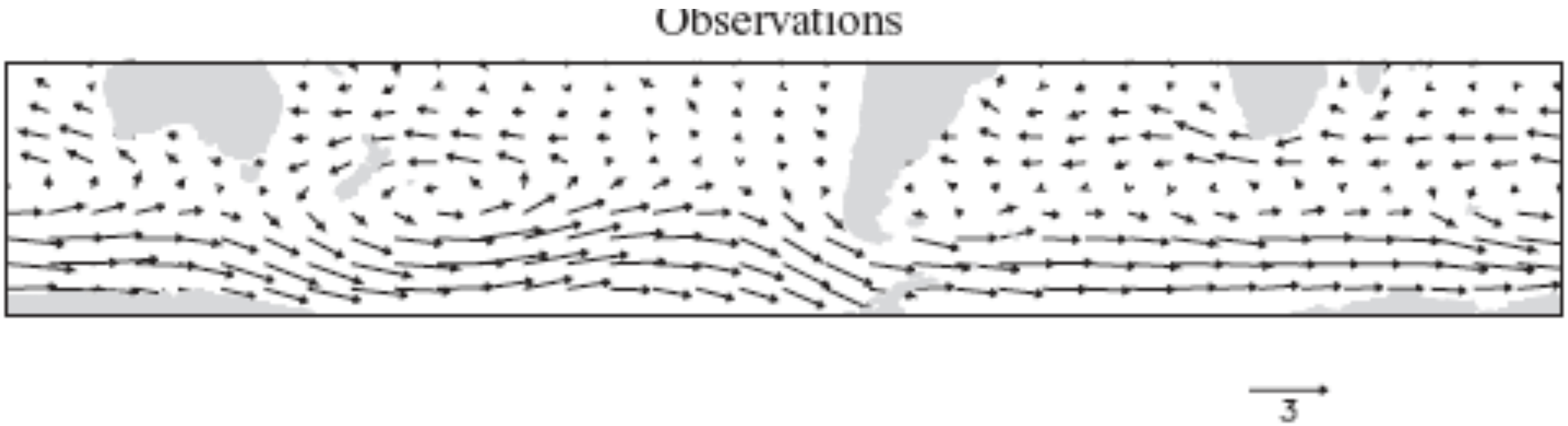


FIG. 1. NCEP–NCAR data regressed onto the standardized SAM time series. (a),(b) 850-hPa height (m); (c),(d) 300-hPa zonal wind (m s^{-1}). (a),(c) Dec–Jan; (b),(d) Mar–Apr. The black line indicates the extrema of the background mean zonal wind.

Codron JCL (2005)



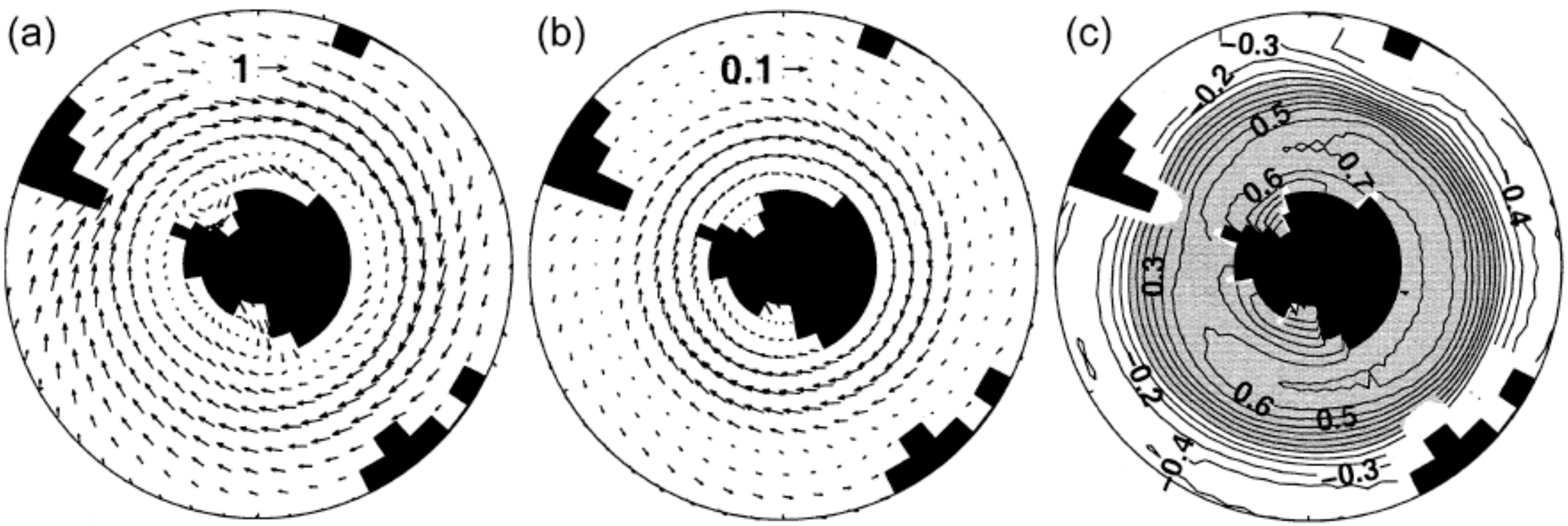


Fig. 4. (a) The annual-mean climatological wind stress imposed on the ocean by the model atmosphere in the circumpolar region. (b) The regression of annual-mean wind stress onto the annual-mean SAM index. Regressions for the zonal and meridional components of the wind stress were calculated separately. Units for (a) and (b) are dyn cm^{-2}. For clarity, every other arrow in each latitude row is suppressed in (a) and (b). Arrows illustrating the scaling of the vectors are shown in the top middle of the panels. (c) The correlation between the zonal component of the annual-mean wind stress and the annual-mean SAM index.

Cold events associated with high and low NAM-index days. *NAM+*, and *NAM-* are the number of events falling on high and low index days, respectively. Results are based on daily data, JFM 1958-97, except buoy data which are available 1981-1997.

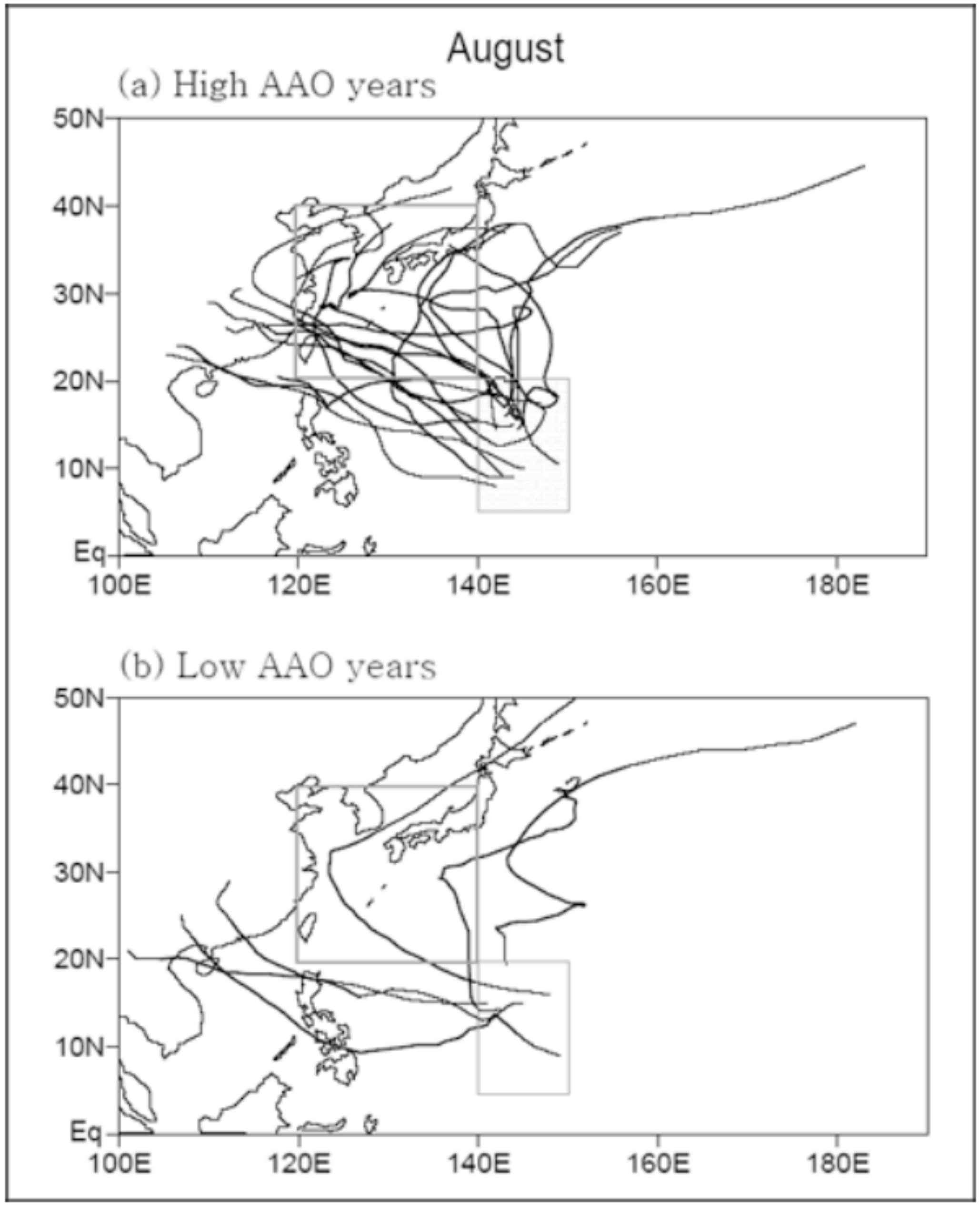
Event type and location	Total	NAM+	NAM-
< -15ΥC in Juneau, Ak.	352	32	84
< -18ΥC in Chicago, Il.	330	29	84
< 3ΥC in Orlando, Fl.	267	31	68
< -3ΥC in Paris, France	298	23	97
< -29ΥC in Novosibirsk, Ru.	268	21	85
< -19ΥC in Beijing, China	212	21	55
< -1ΥC in Tokyo, Japan	304	20	93
> trace snow in Dallas, Tx.	56	1	17
> trace snow in Memphis, Tn.	130	7	36
> trace snow in Atlanta, Ga.	67	4	19
> 5 cm snow in Baltimore, Md.	119	11	31
> 0.5 cm snow in Paris, France	182	11	63
> 0 cm snow in Tokyo, Japan	109	8	25

Thompson and Wallace, Science 2001

Positive Phase

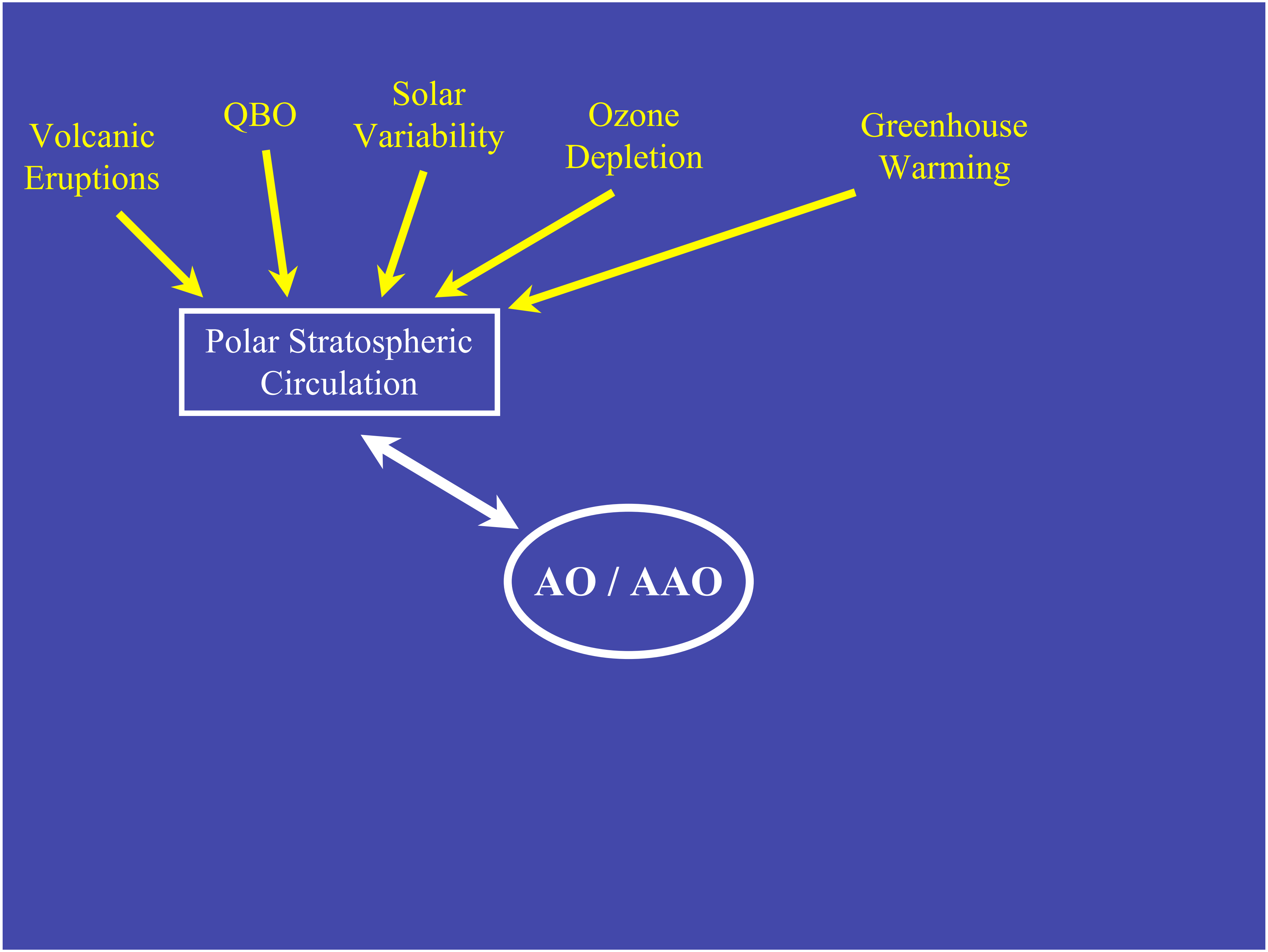
Negative Phase

Chang-Hoi Ho
Seoul National. University



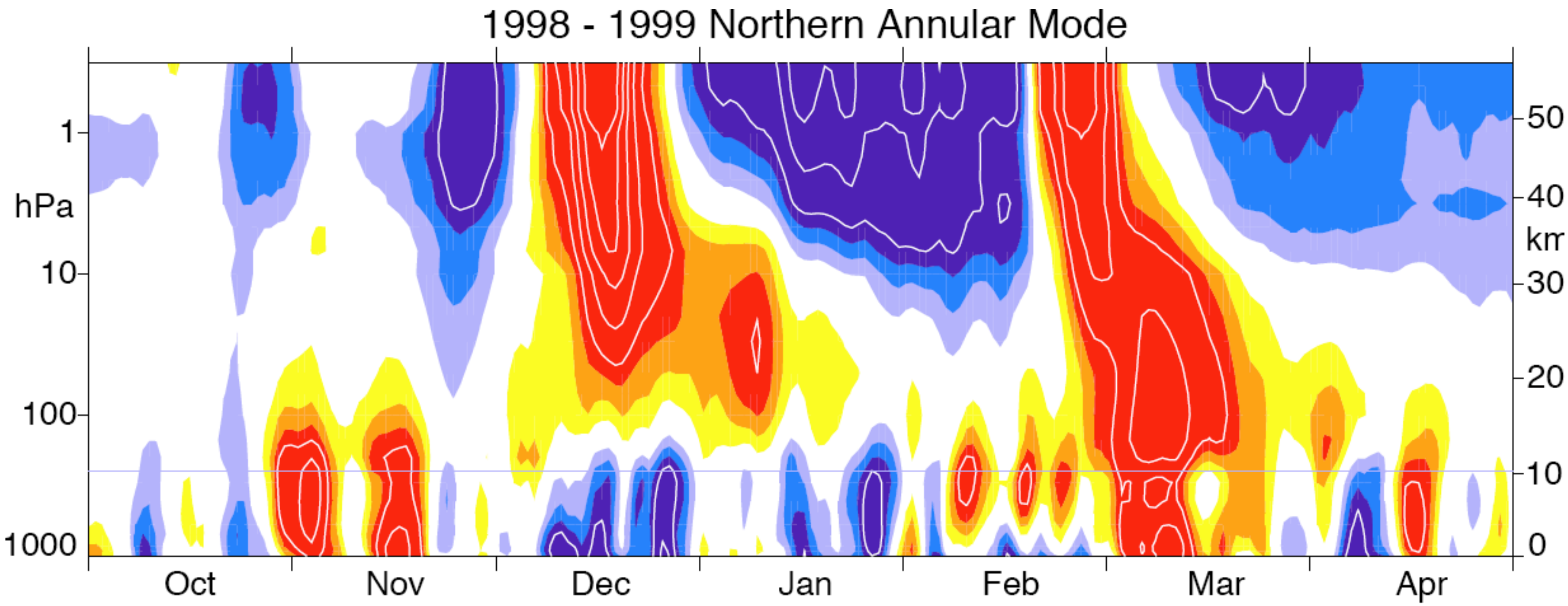
The Regional Specialized Meteorological Centers best tracks of all tropical cyclones originated from the eastern Philippine Sea (shaded box) in August for the eight high AAO years and the eight low AAO years.

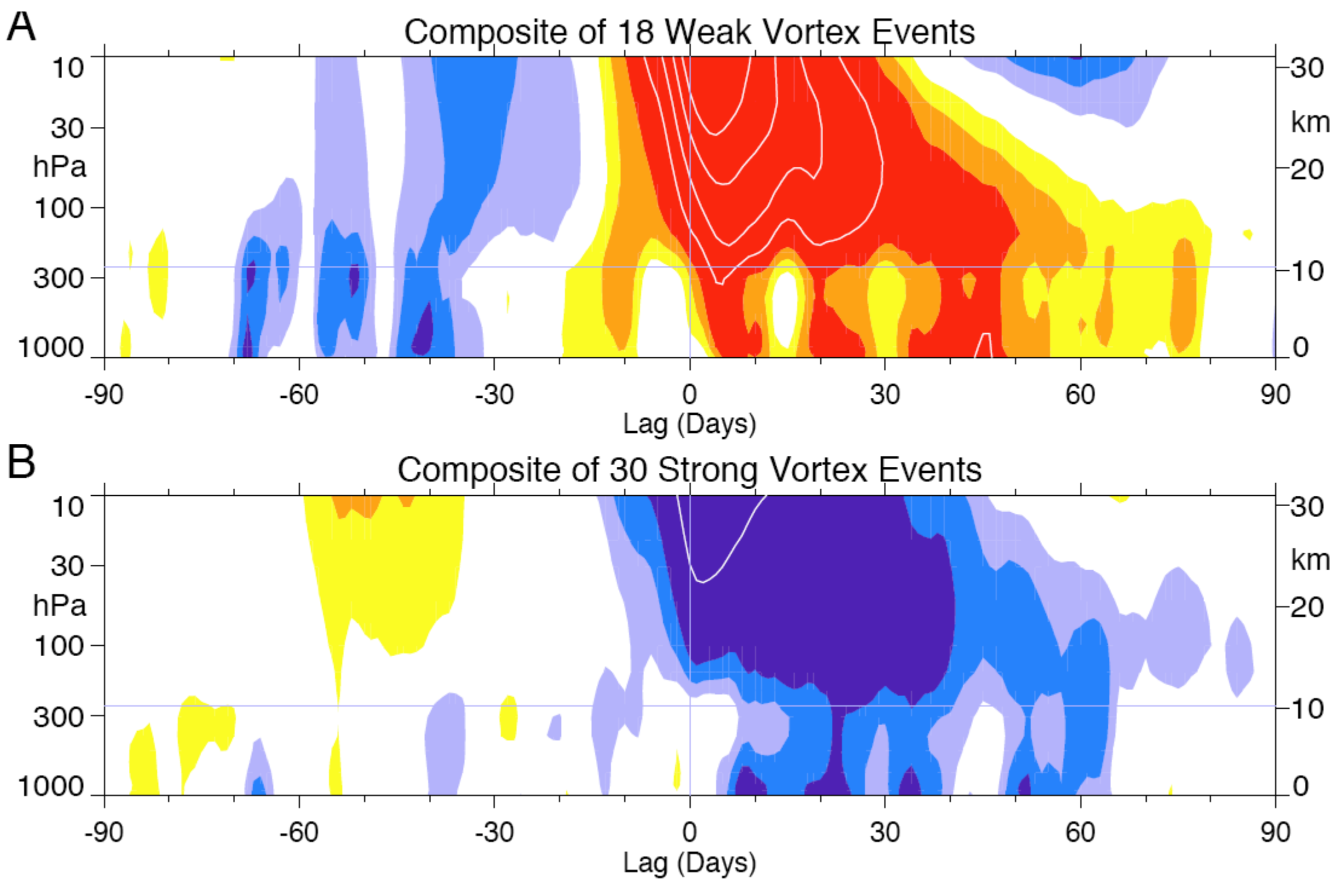
AO / AAO

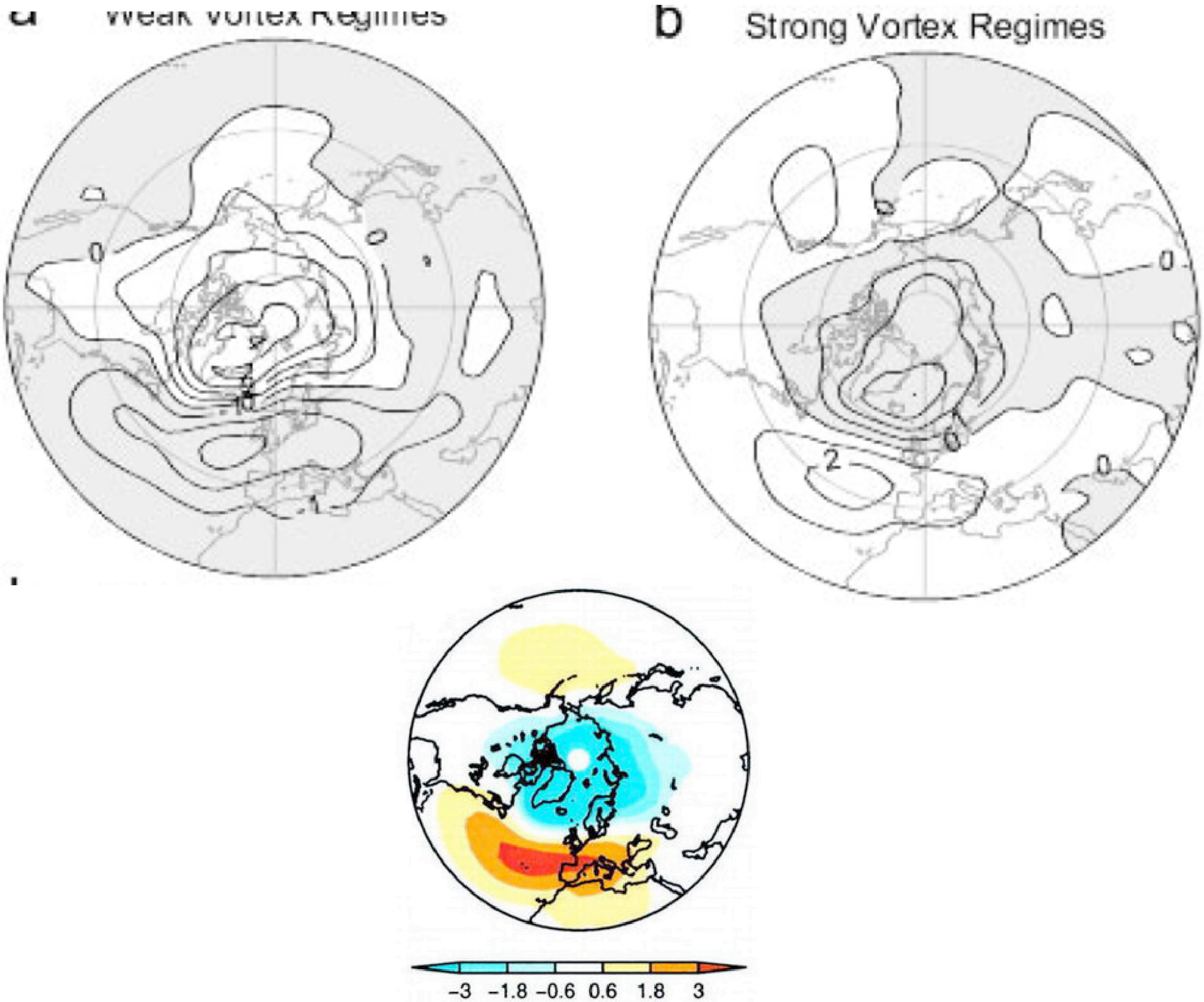


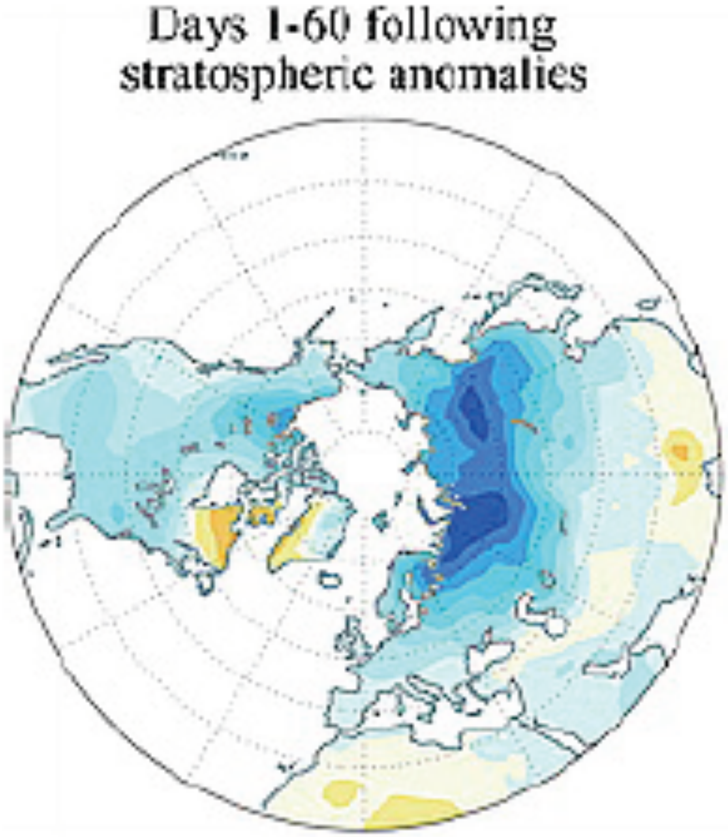
Volcanic Eruptions
QBO
Solar Variability
Ozone Depletion
Greenhouse Warming
Polar Stratospheric Circulation
AO / AAO

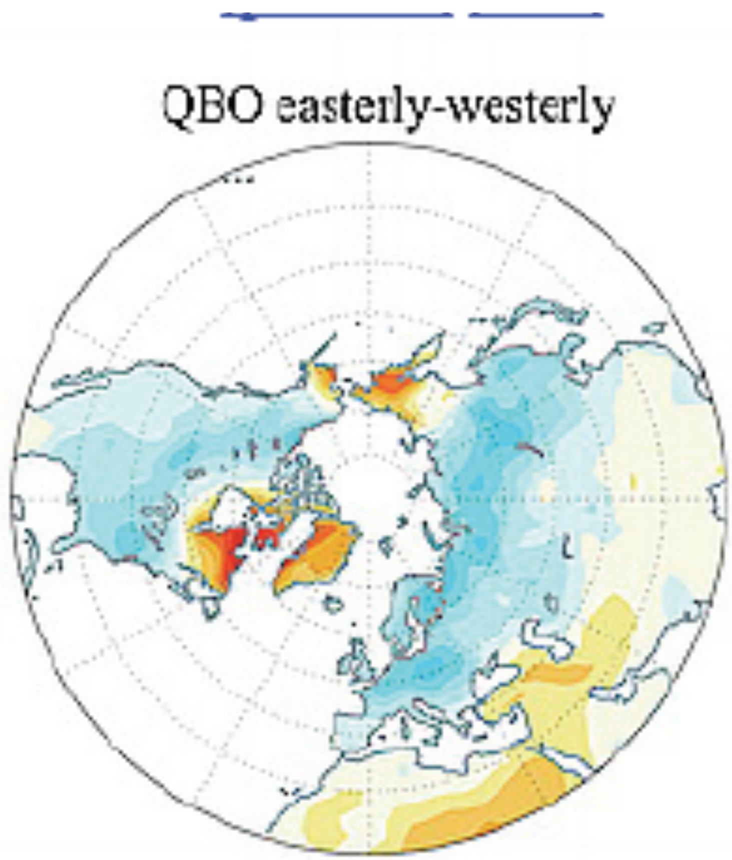
Baldwin and Dunkerton 2001

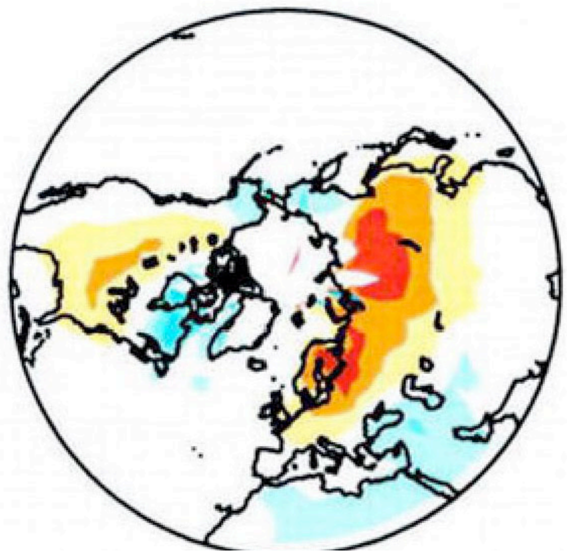


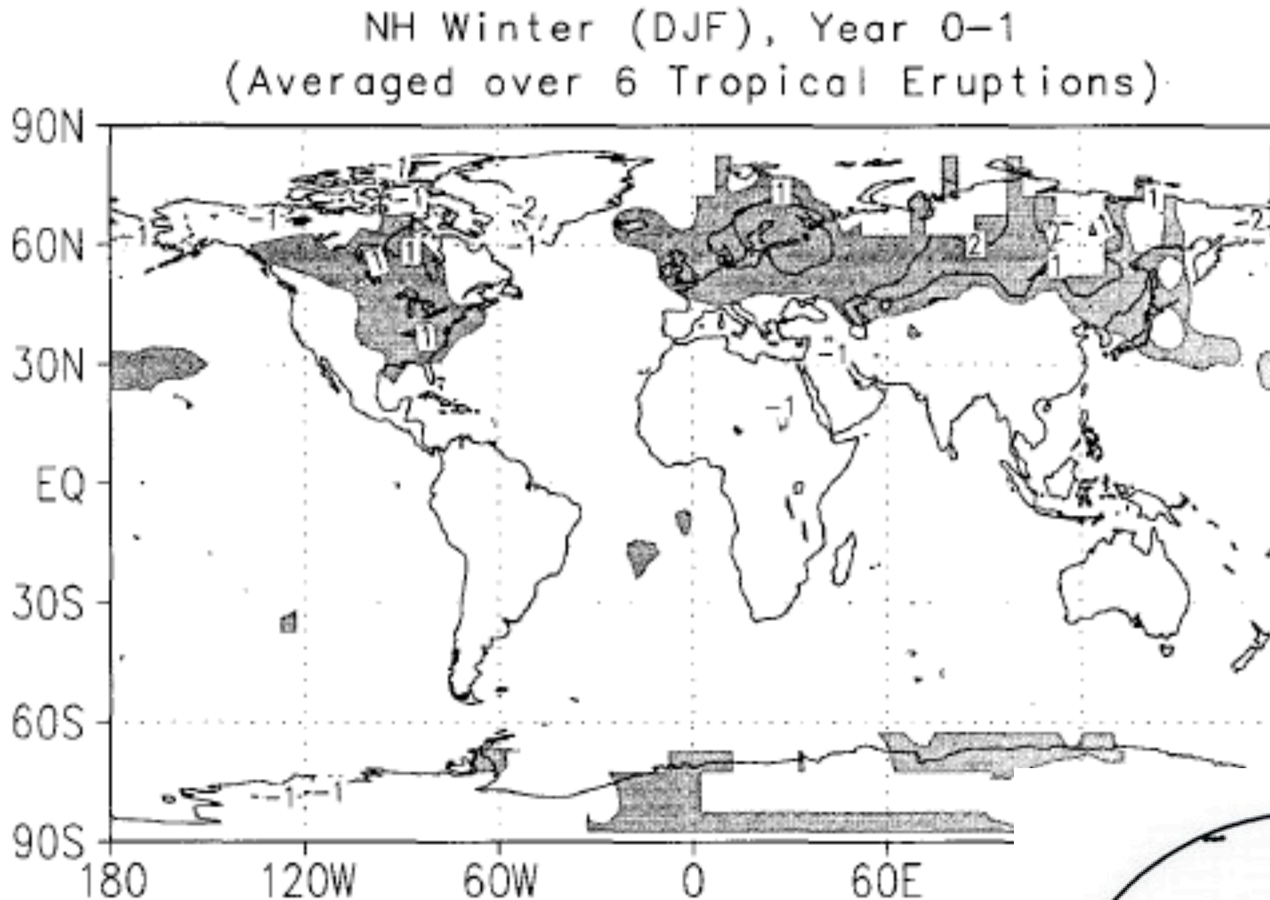

A
Composite of 18 Weak Vortex Events
10
30
hPa
100
300
1000
30
km
20
10
0
-90
-60
-30
0
30
60
90
Lag (Days)
B
Composite of 30 Strong Vortex Events
10
30
hPa
100
300
1000
30
km
20
10
0
-90
-60
-30
0
30
60
90
Lag (Days)

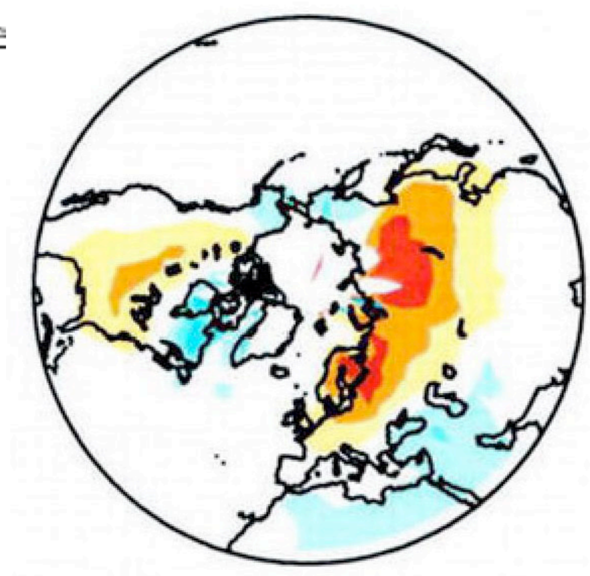

Weak Vortex Regimes
b
Strong Vortex Regimes
−3 −1.8 −0.6 0.6 1.8 3


Days 1-60 following
stratospheric anomalies


QBO easterly-westerly







Robock and Mao (1995)

Simulation of Recent Southern Hemisphere Climate Change

Nathan P. Gillett[1]* and David W. J. Thompson[2]

www.sciencemag.org SCIENCE VOL 302 10 OCTOBER 2003

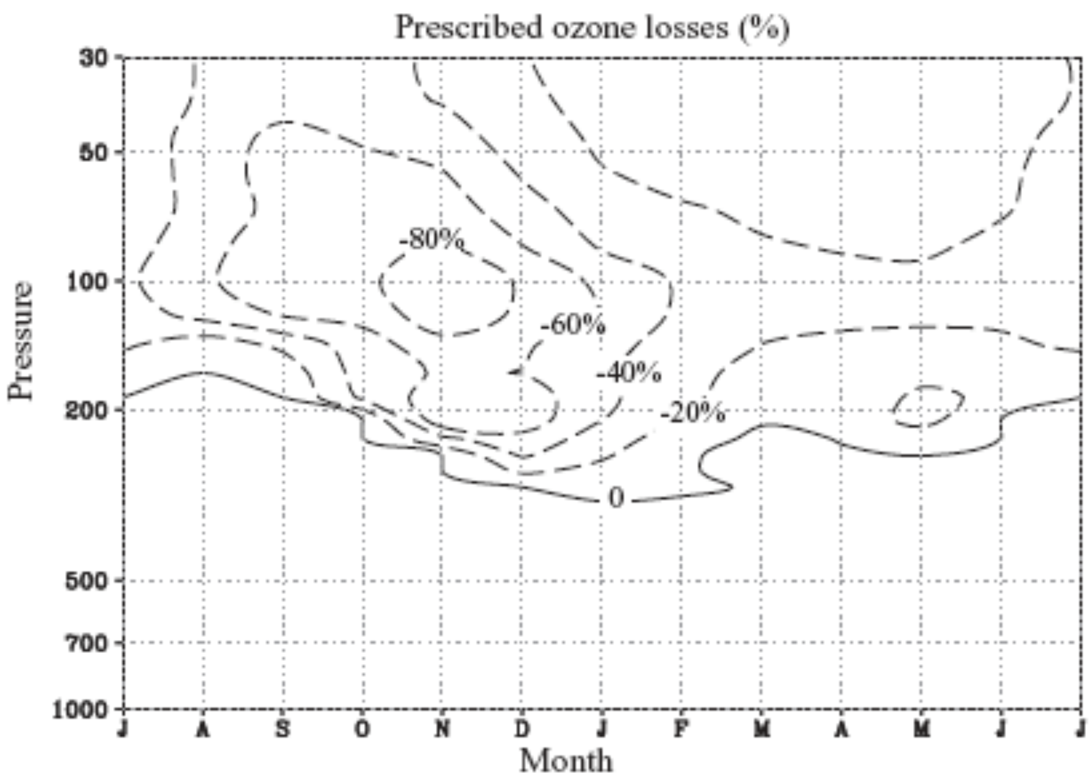
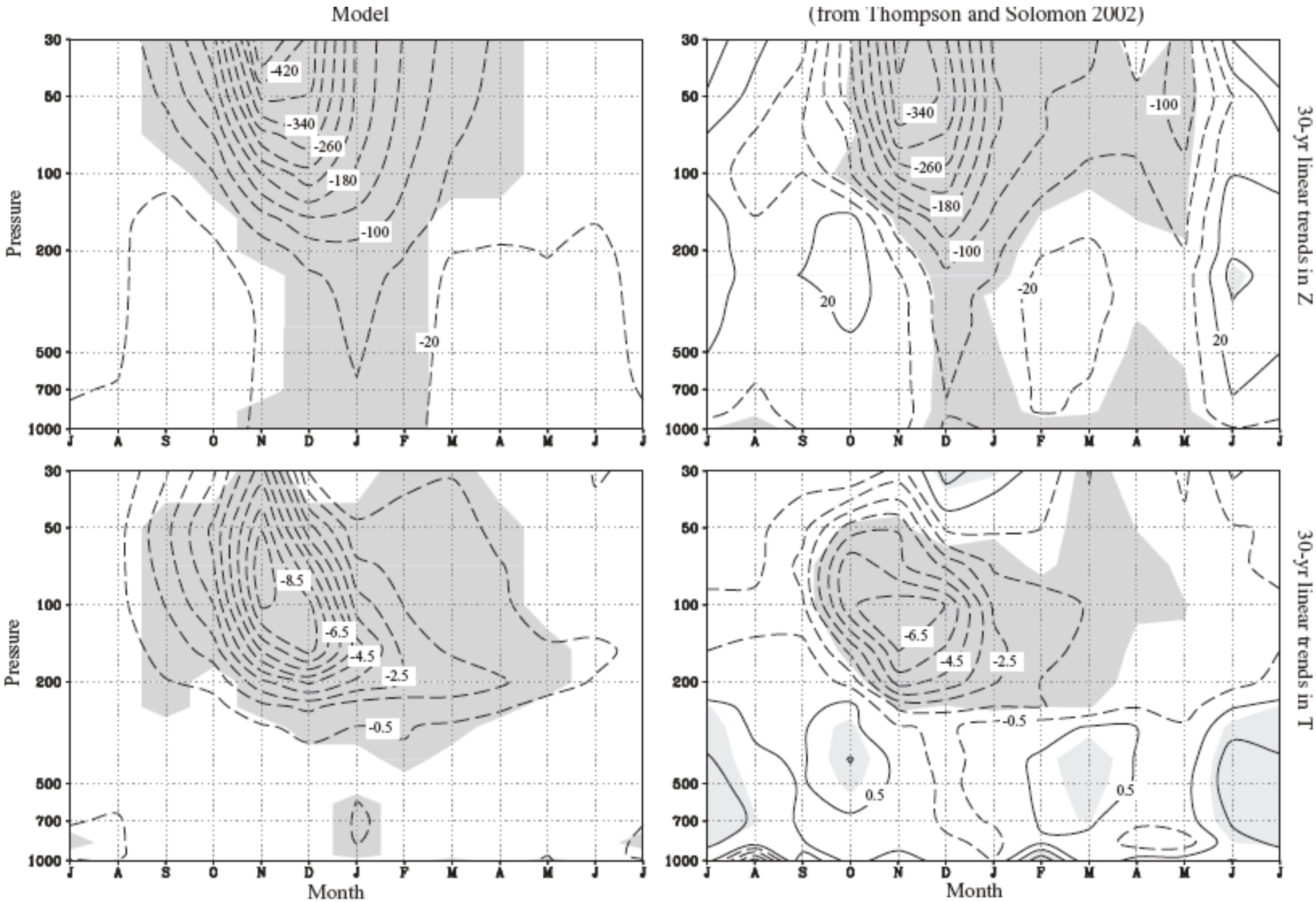
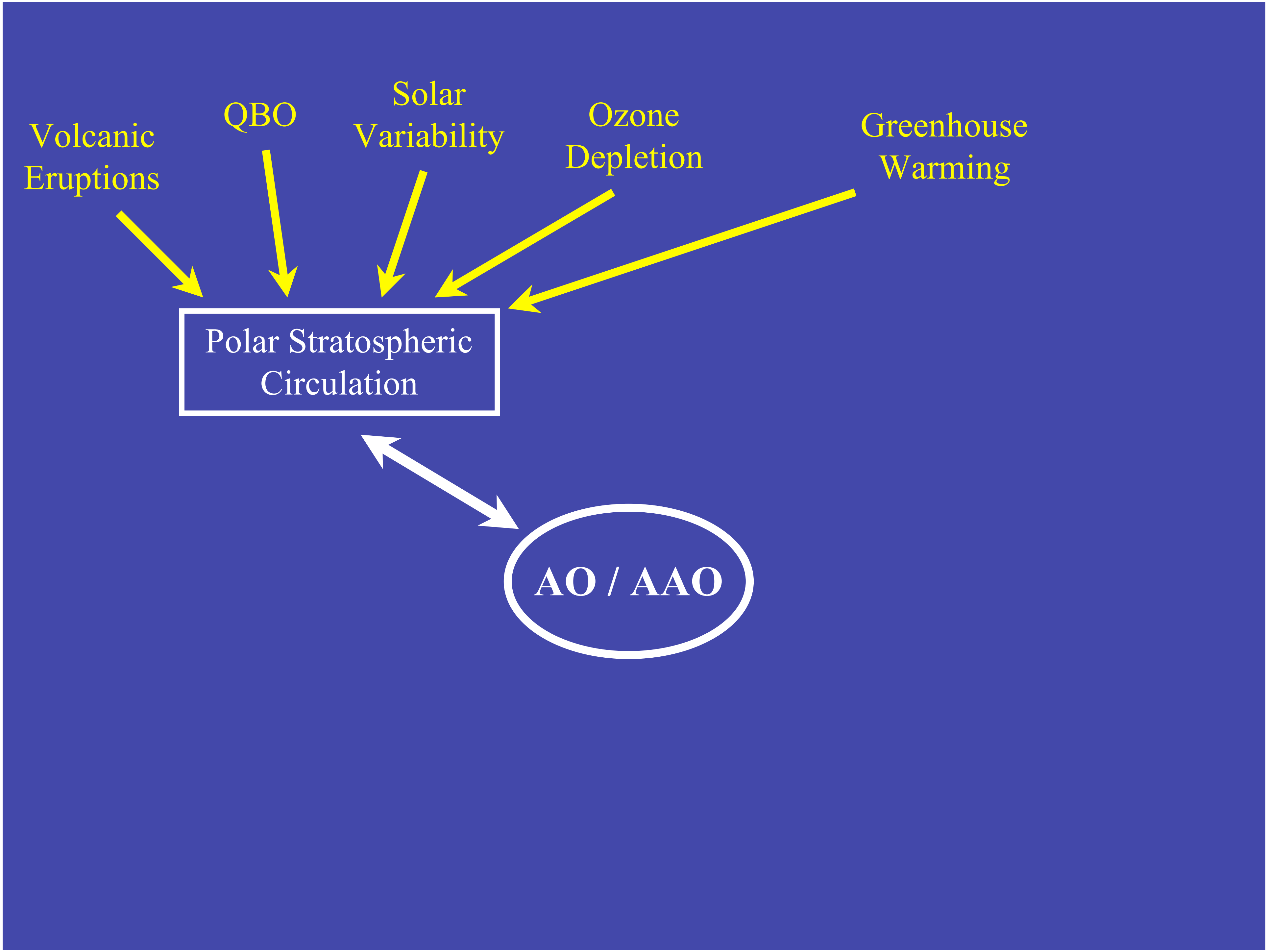
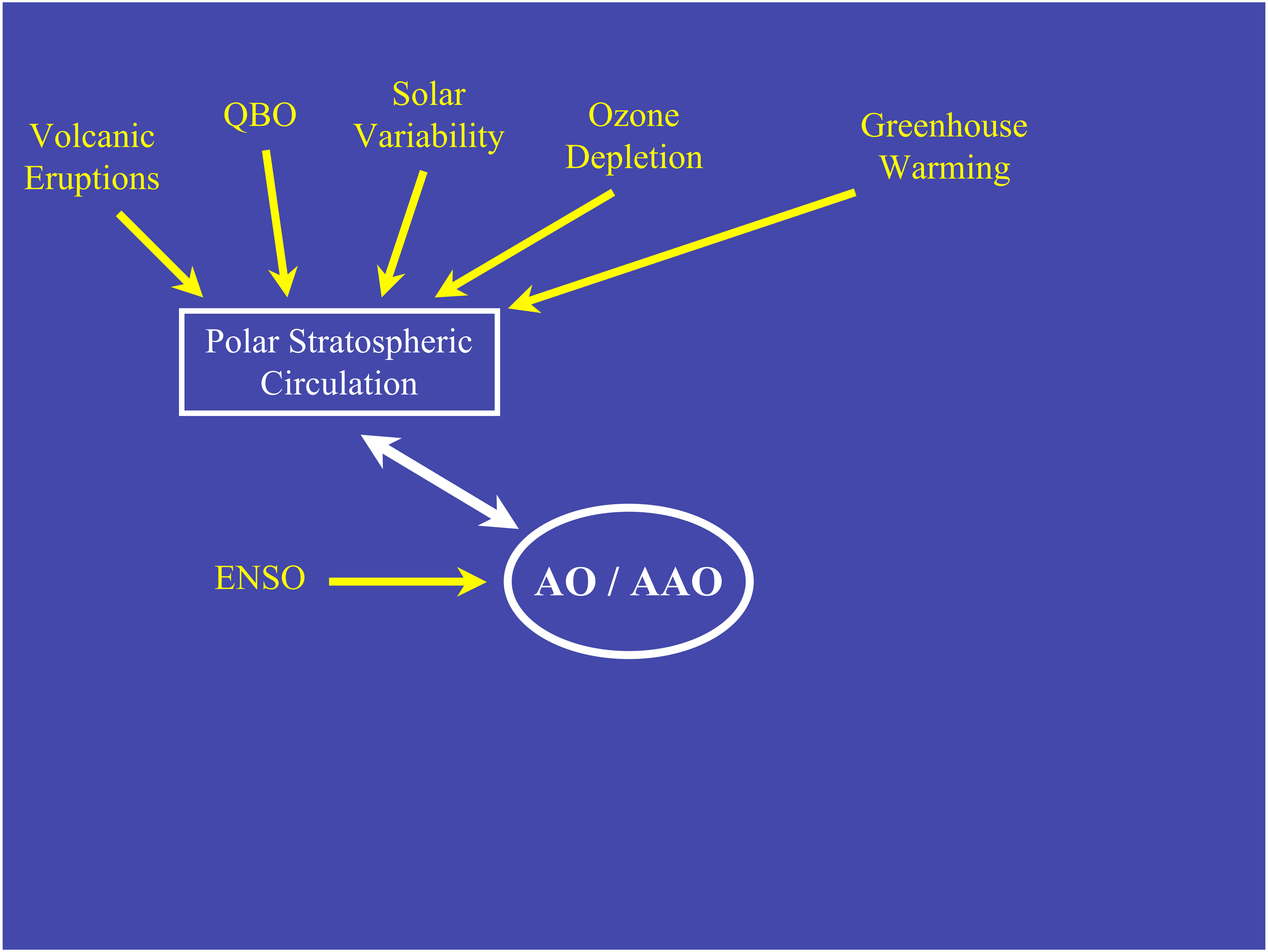


Fig. 1. Prescribed change in ozone plotted as a function of month and pressure at 70°S, based on observed ozone trends from 1979 to 1997 (*16*).

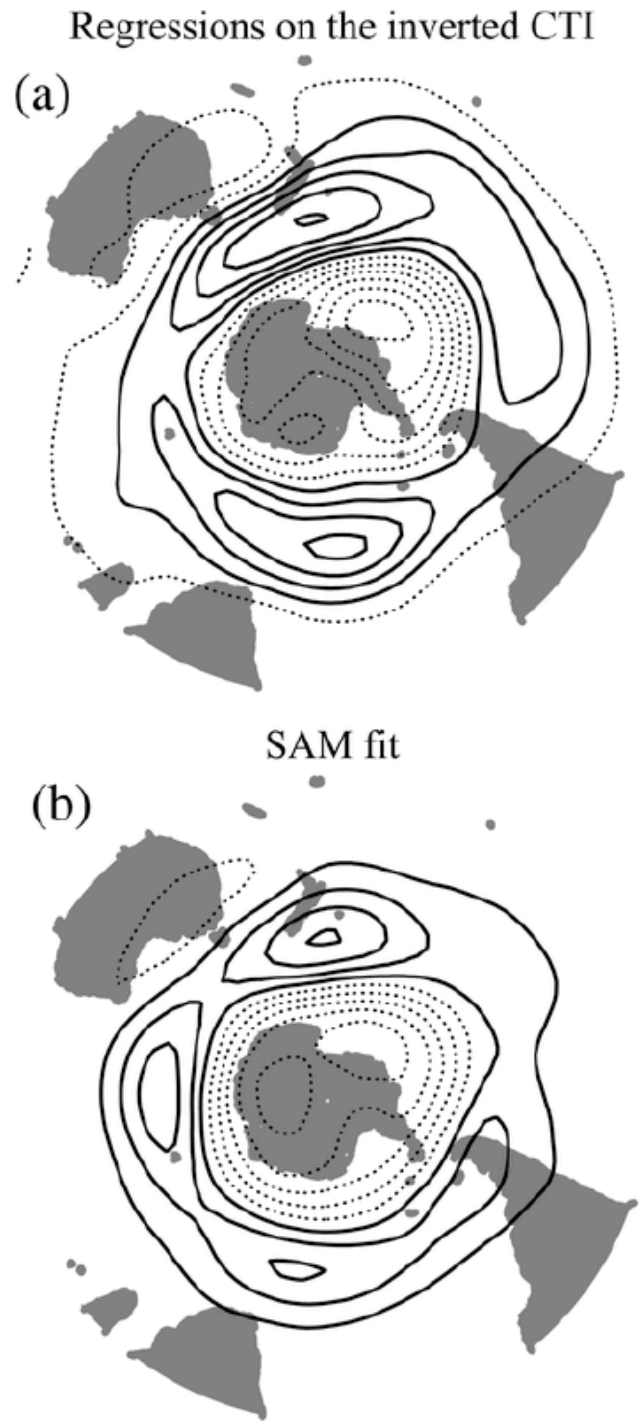


Model
(from Thompson and Solomon 2002)
30-yr linear trends in Z
30-yr linear trends in T
Pressure
Month
30
50
100
200
500
700
1000
J
A
S
O
N
D
J
F
M
A
M
J
J
-420
-340
-260
-180
-100
-20
20
-8.5
-6.5
-4.5
-2.5
-0.5
0.5

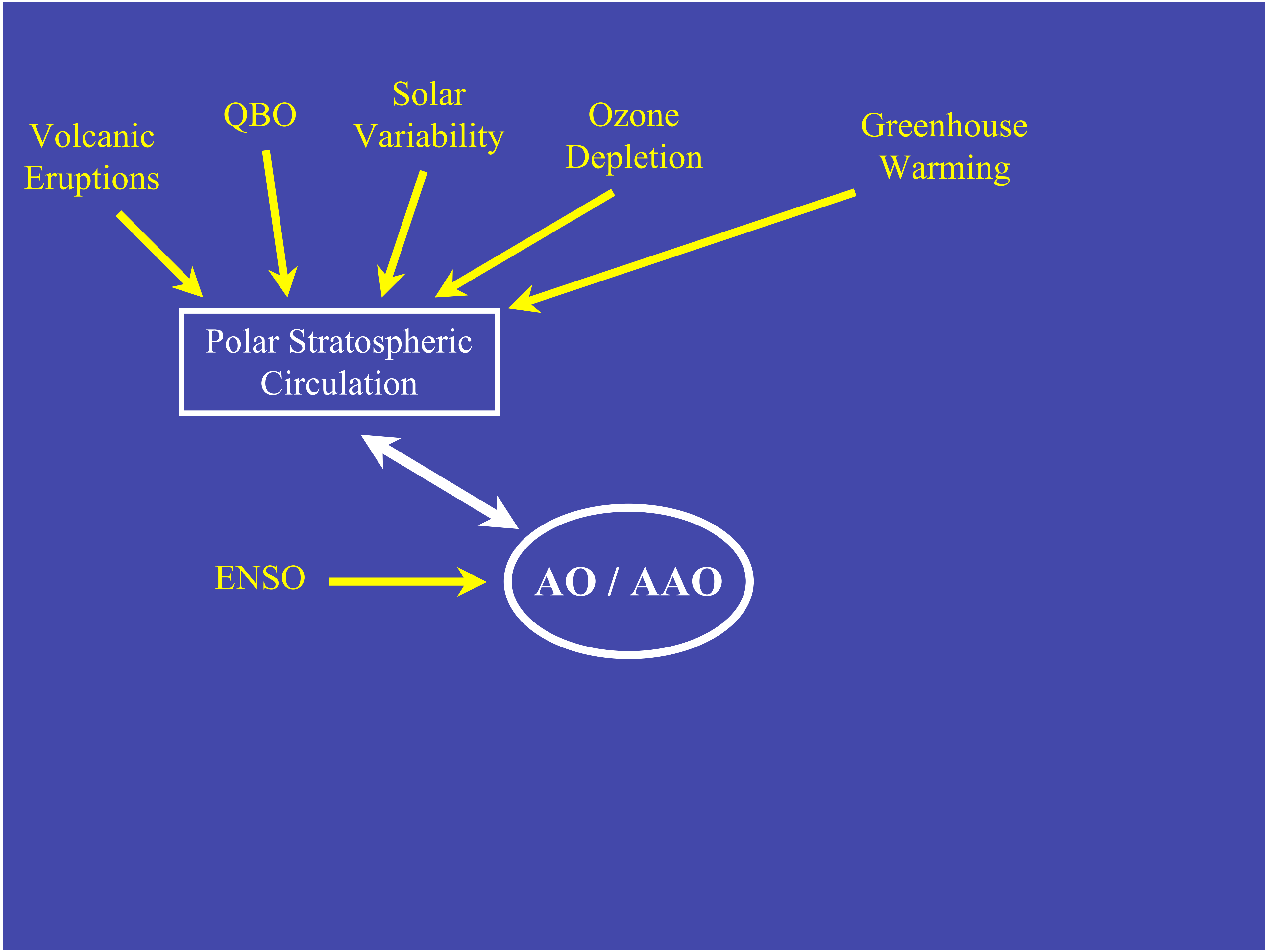

Volcanic Eruptions
QBO
Solar Variability
Ozone Depletion
Greenhouse Warming
Polar Stratospheric Circulation
AO / AAO



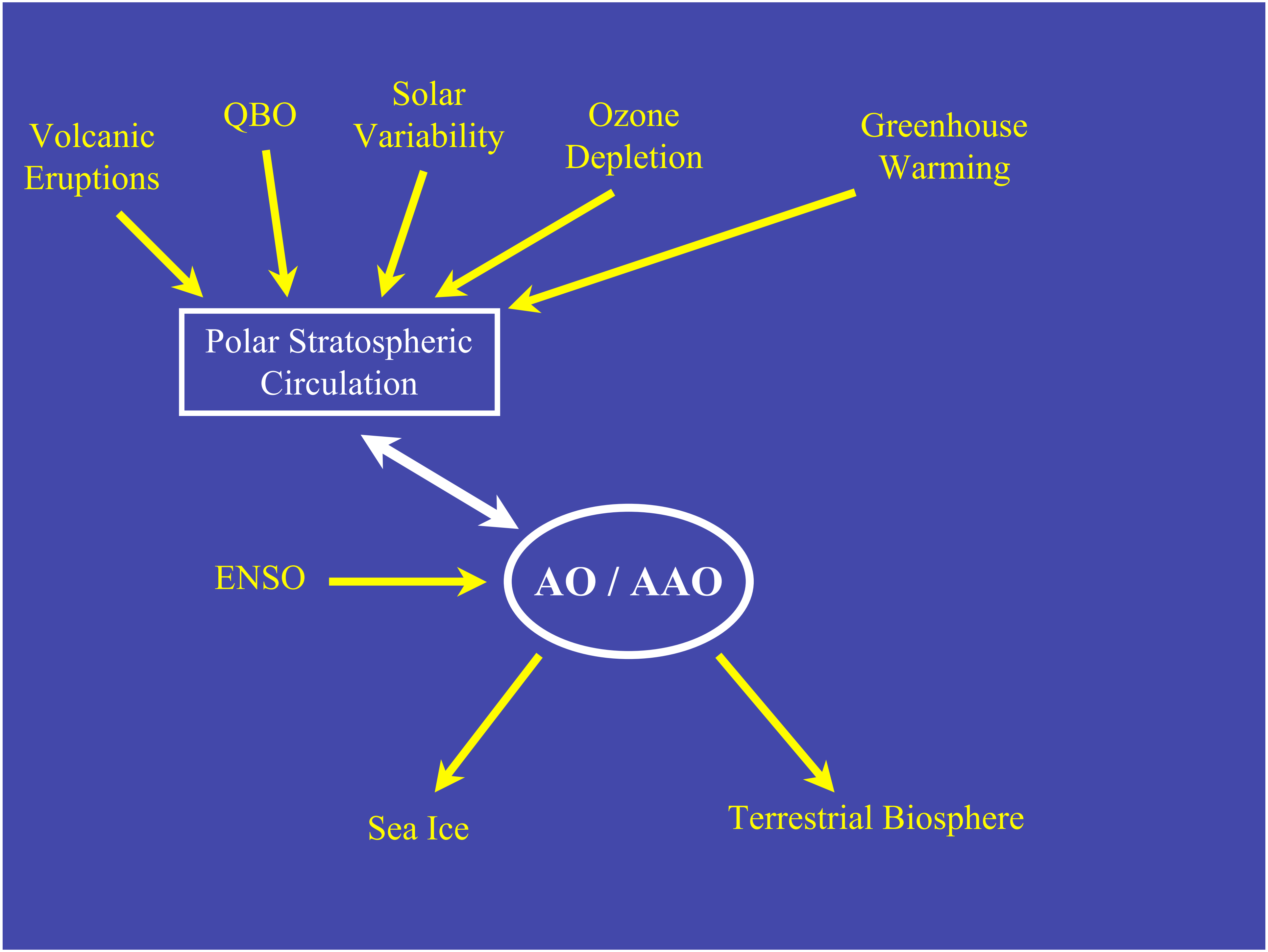
Volcanic Eruptions
QBO
Solar Variability
Ozone Depletion
Greenhouse Warming
Polar Stratospheric Circulation
ENSO
AO / AAO



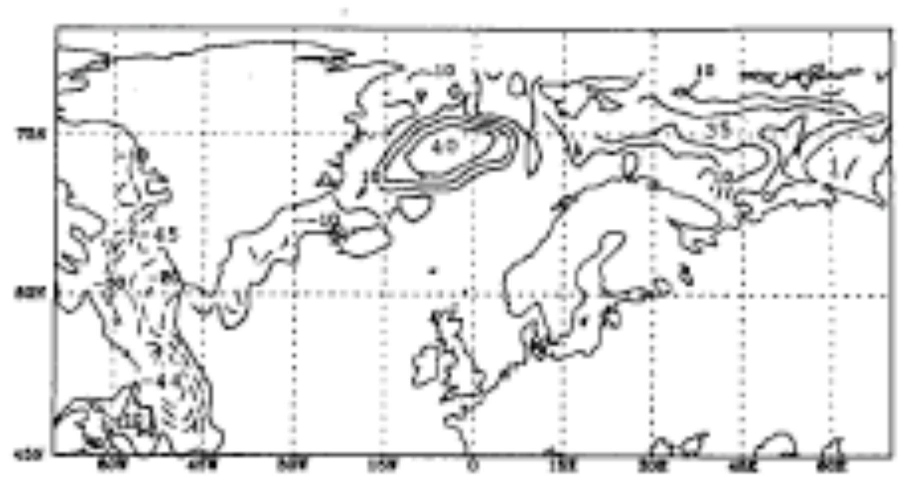
L’Heureux and Thompson
JCL (2005)



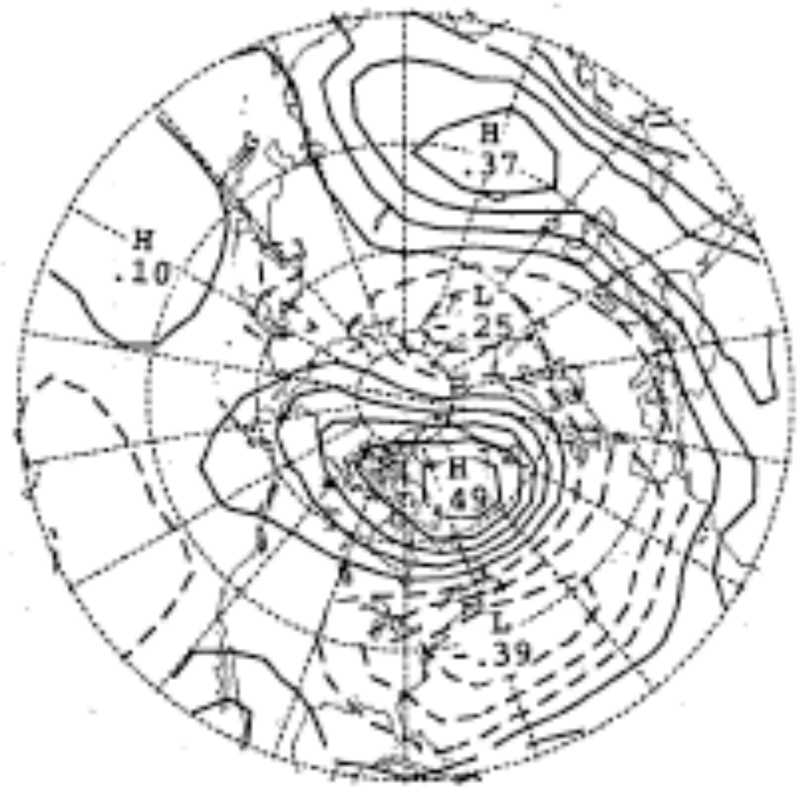
Volcanic Eruptions
QBO
Solar Variability
Ozone Depletion
Greenhouse Warming
Polar Stratospheric Circulation
ENSO
AO / AAO


Volcanic Eruptions
QBO
Solar Variability
Ozone Depletion
Greenhouse Warming
Polar Stratospheric Circulation
ENSO
AO / AAO
Sea Ice
Terrestrial Biosphere

Wintertime sea ice extent



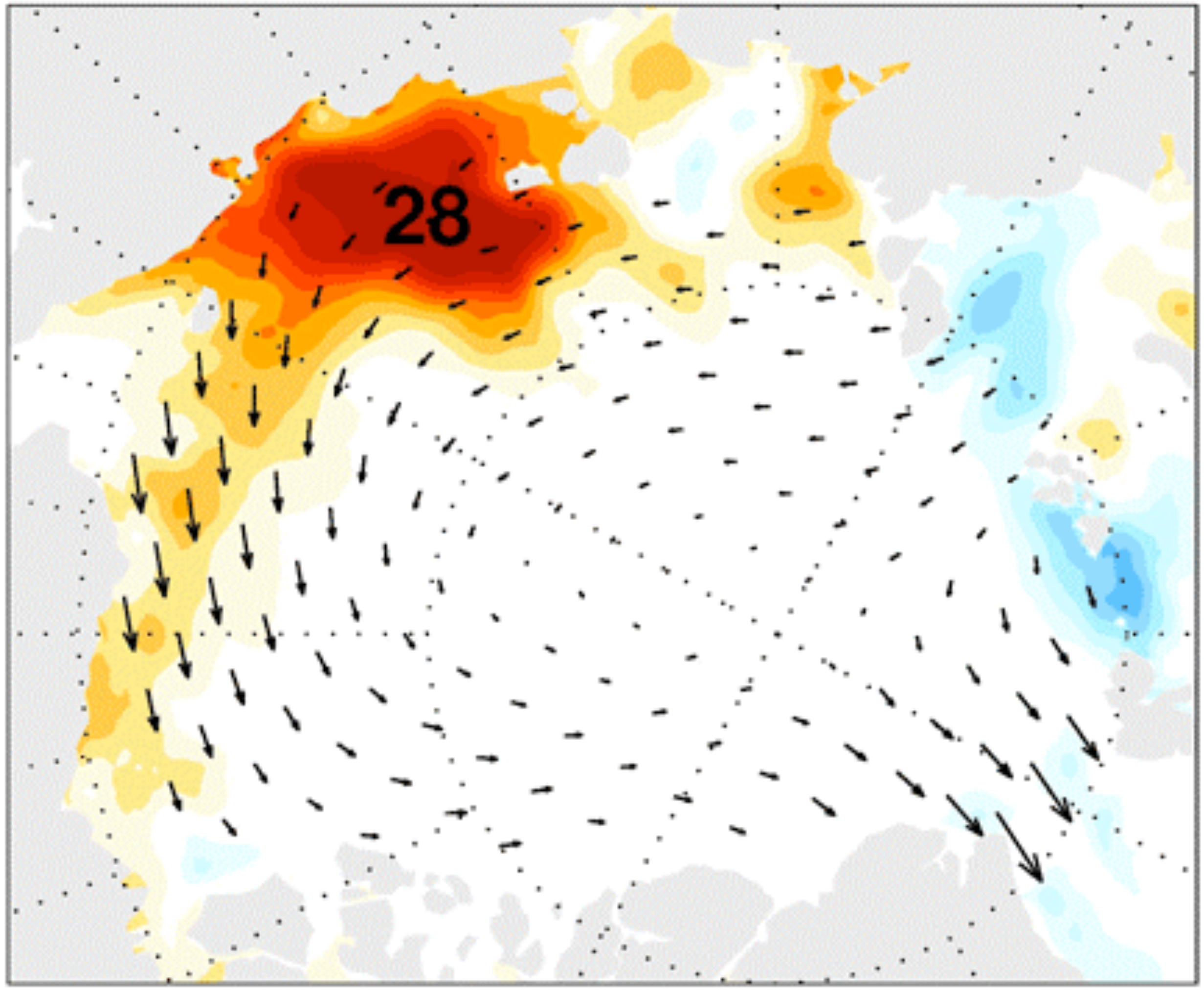
(a)



(b)

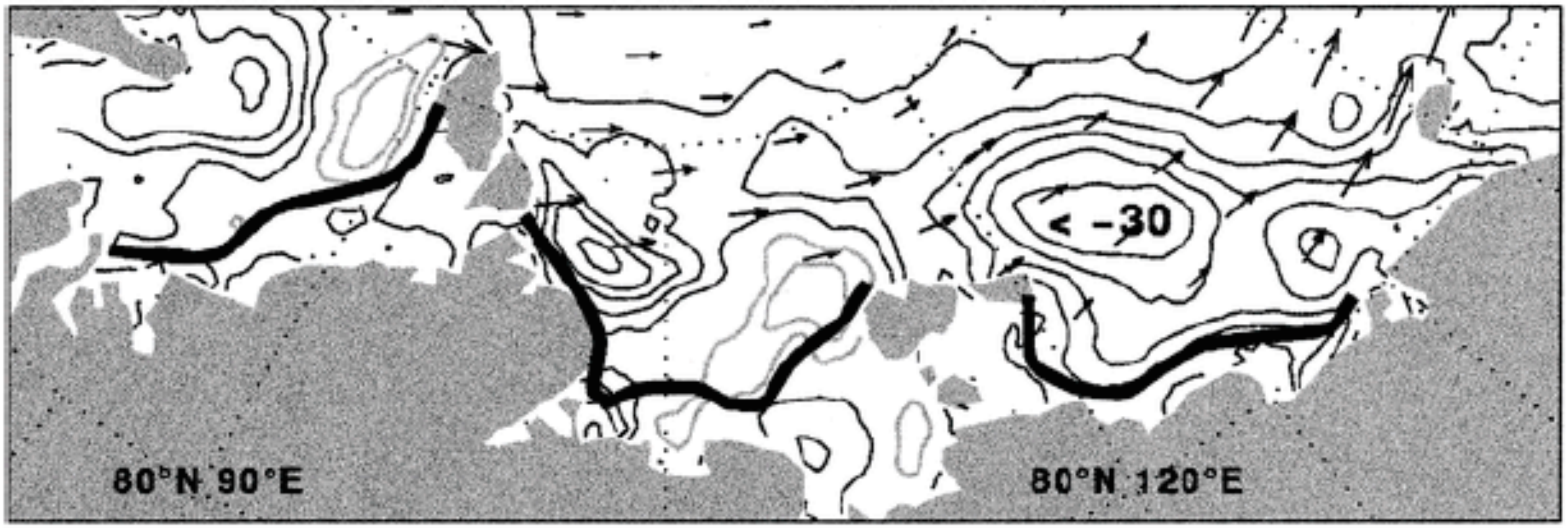
Fang and Wallace 1994

Summer SIC and Winter SIM Regressed on Winter AO

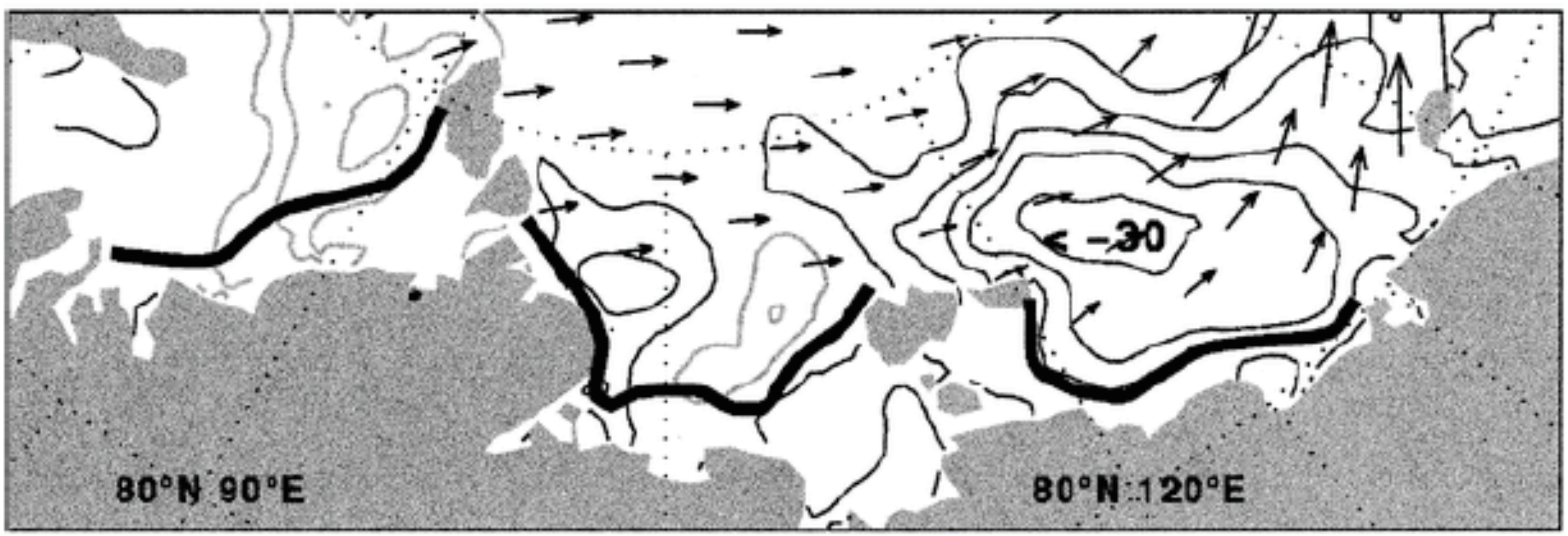


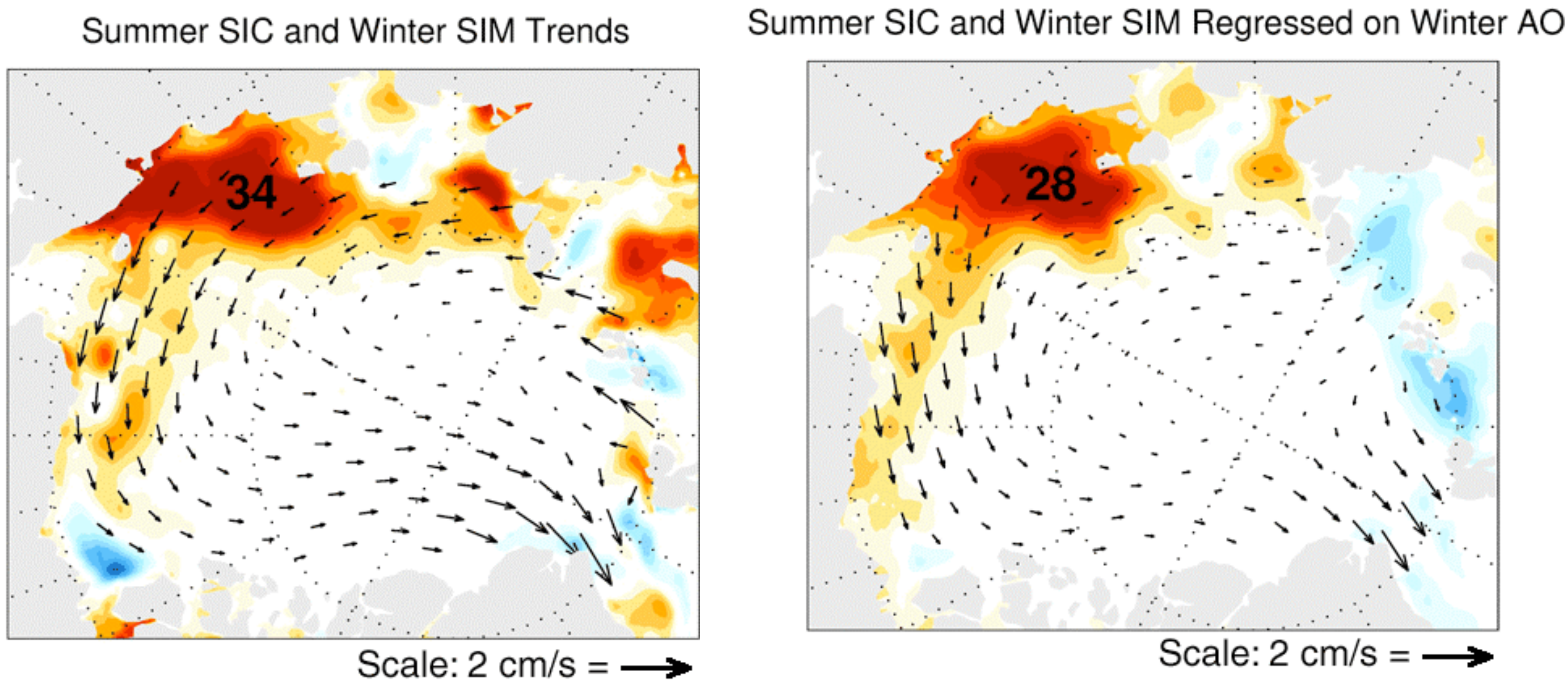
Rigor, Wallace, and Colony JCL (2002)

(a) Summer SIC and Winter SIM Trends

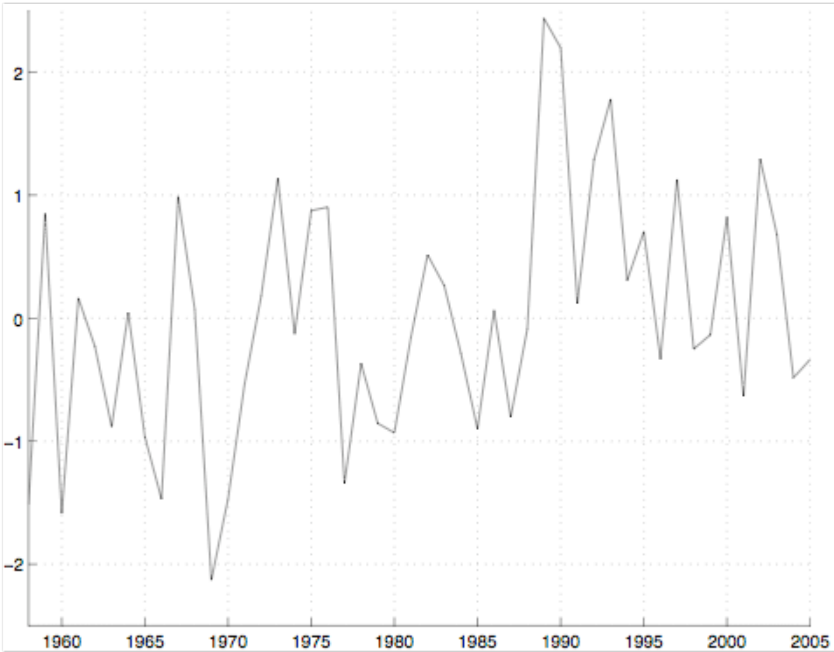


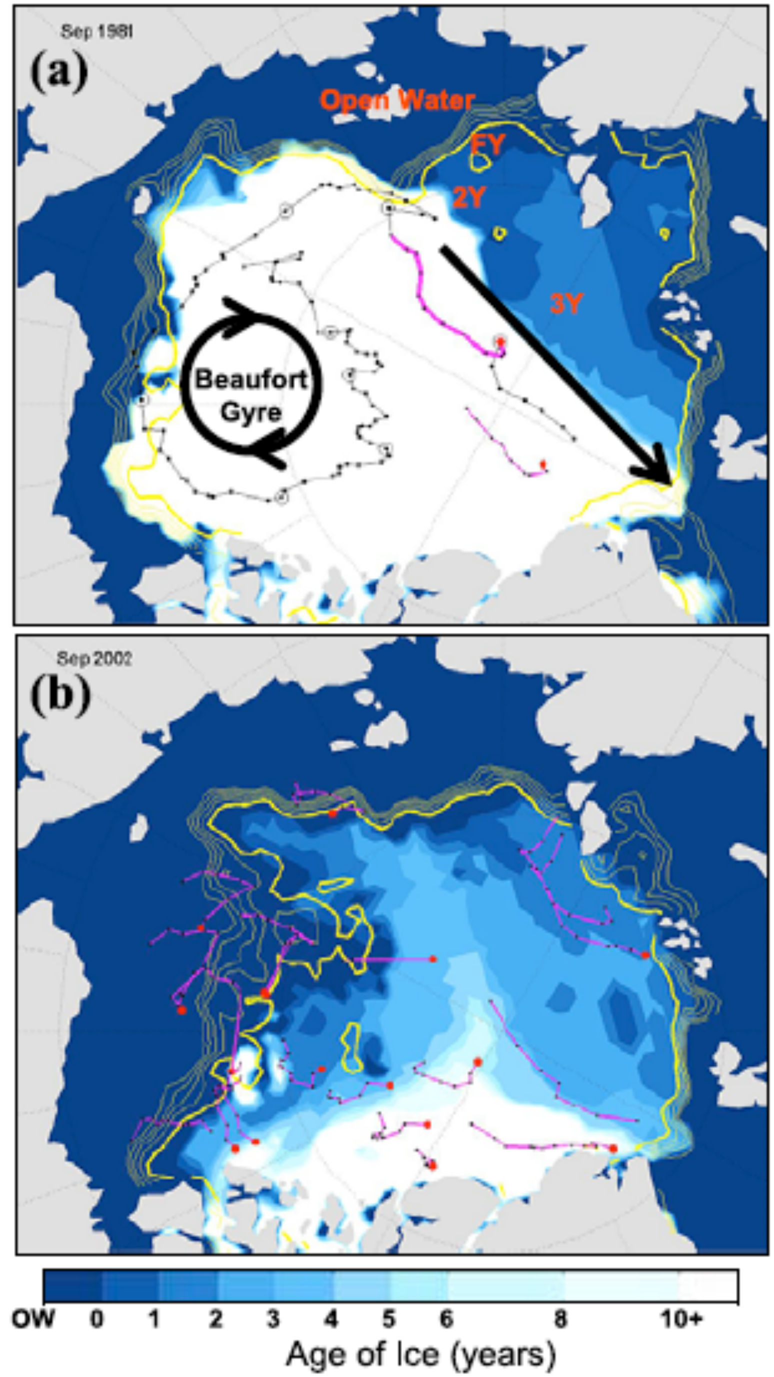
(b) Summer SIC and Winter SIM Regressions





Summer SIC and Winter SIM Trends
34
Scale: 2 cm/s =
Summer SIC and Winter SIM Regressed on Winter AO
28
Scale: 2 cm/s =





Rigor and Wallace, GRL (2002)

News Feature

Nature **441**, 802-805(15 June 2006) | doi:10.1038/441802a; Published online 14 June 2006

Climate change: The tipping point of the iceberg

Gabrielle Walker[1 (#a1)]

1. Gabrielle Walker is a writer who specializes in Earth science and cold places.

Abstract

Could climate change run away with itself? Gabrielle Walker looks at the balance of evidence.

Pointing tip: an iceberg off the coast of Greenland, shed from the edge of the island's icepack.

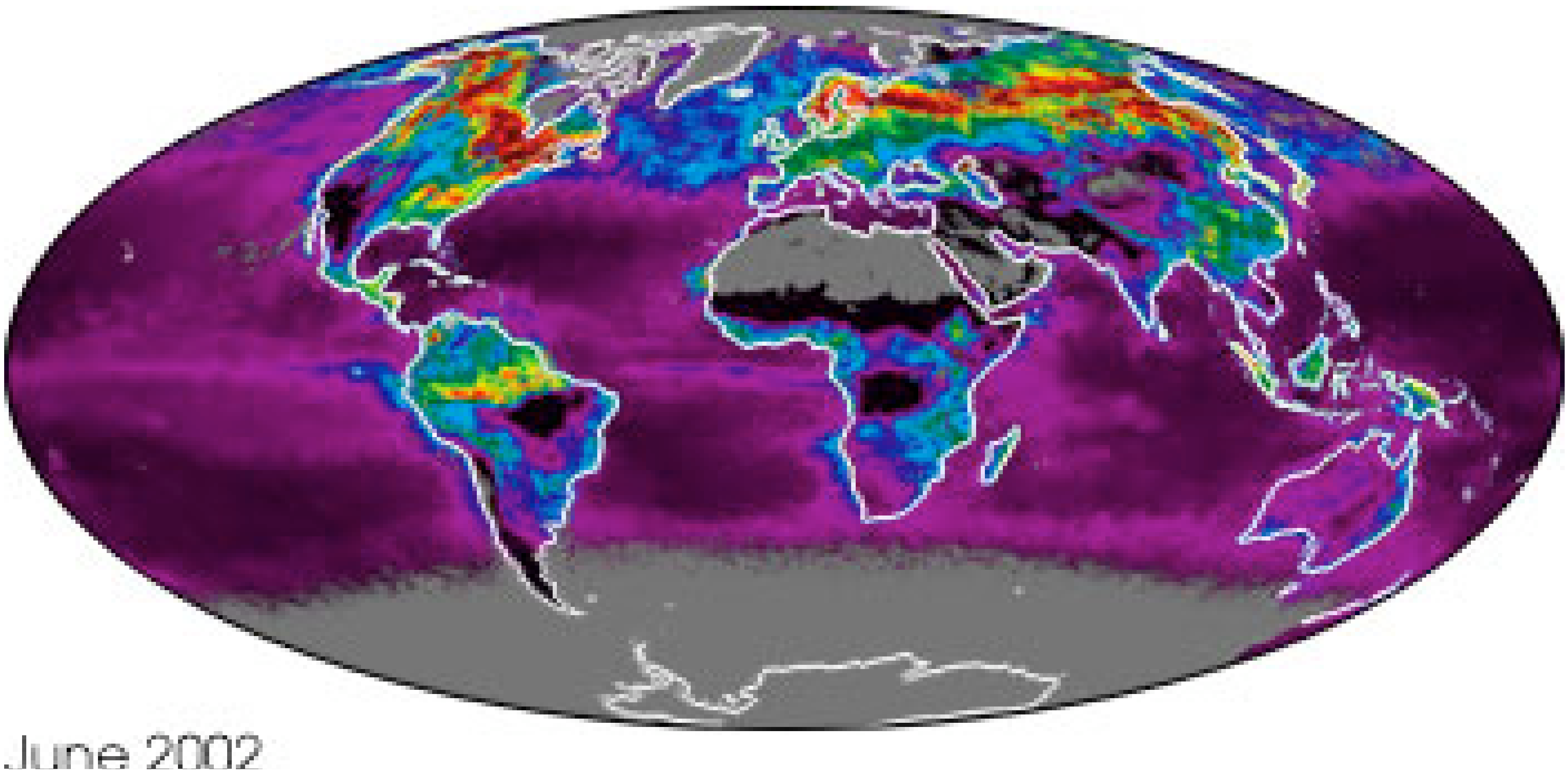
"Be worried. *Time* magazine advised those looking at its 3 April cover showing a forlorn polar bear surrounded by puddles of melted ice. "Be very worried." Immediately below came the occasion for such alarming counsel: "Earth at the tipping point."

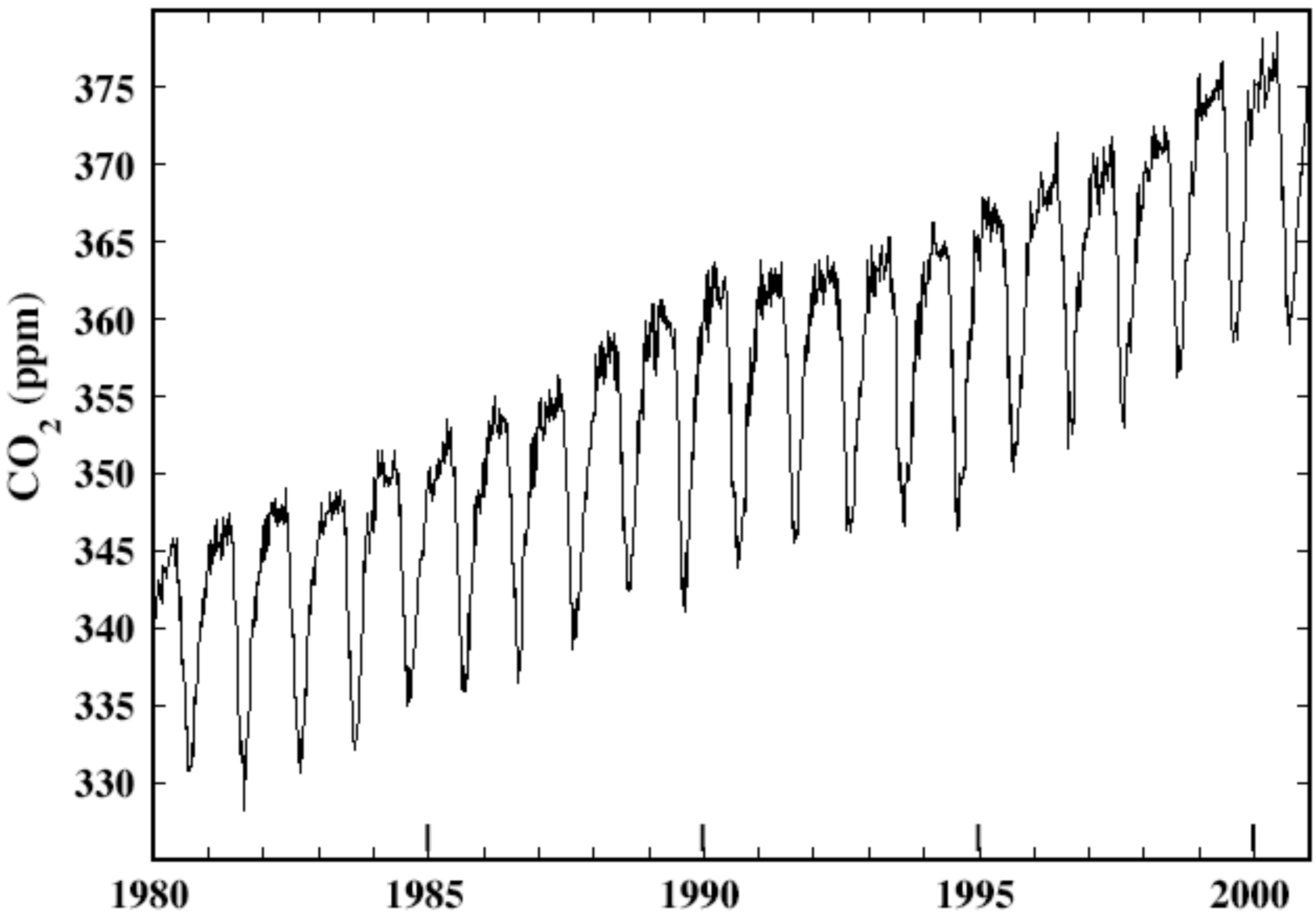
The idea that passing some hidden threshold will drastically worsen man-made climate change has been around for decades, normally couched in technical terms such as 'nonlinearity', 'positive feedback' and 'hysteresis'. Now it has gained new prominence under a new name. In 2004, 45 newspaper articles mentioned a 'tipping point' in connection with climate change; in the first five months of this year, 234 such articles were published. "Warming hits tipping point," one UK newspaper recently warned on its front page; "Climate nears point of no return," asserted another. The idea is spreading like a contagion.

The infectious analogy is appropriate. When the writer Malcolm Gladwell unleashed the idea of tipping points on the popular imagination in his book of the same name[1 (#B1)], he was comparing the way aspects of life suddenly shift from obscurity to ubiquity to effects normally studied in epidemiology. Gladwell's tipping points were manifestations of the catchiness of behaviours and ideas. The notion that climate change is getting out of control is catchy, and it has caught on in academic papers and political debates as well as headlines. But is the climate really on the point of tipping over into a radically different state? And if so, what are the implications?

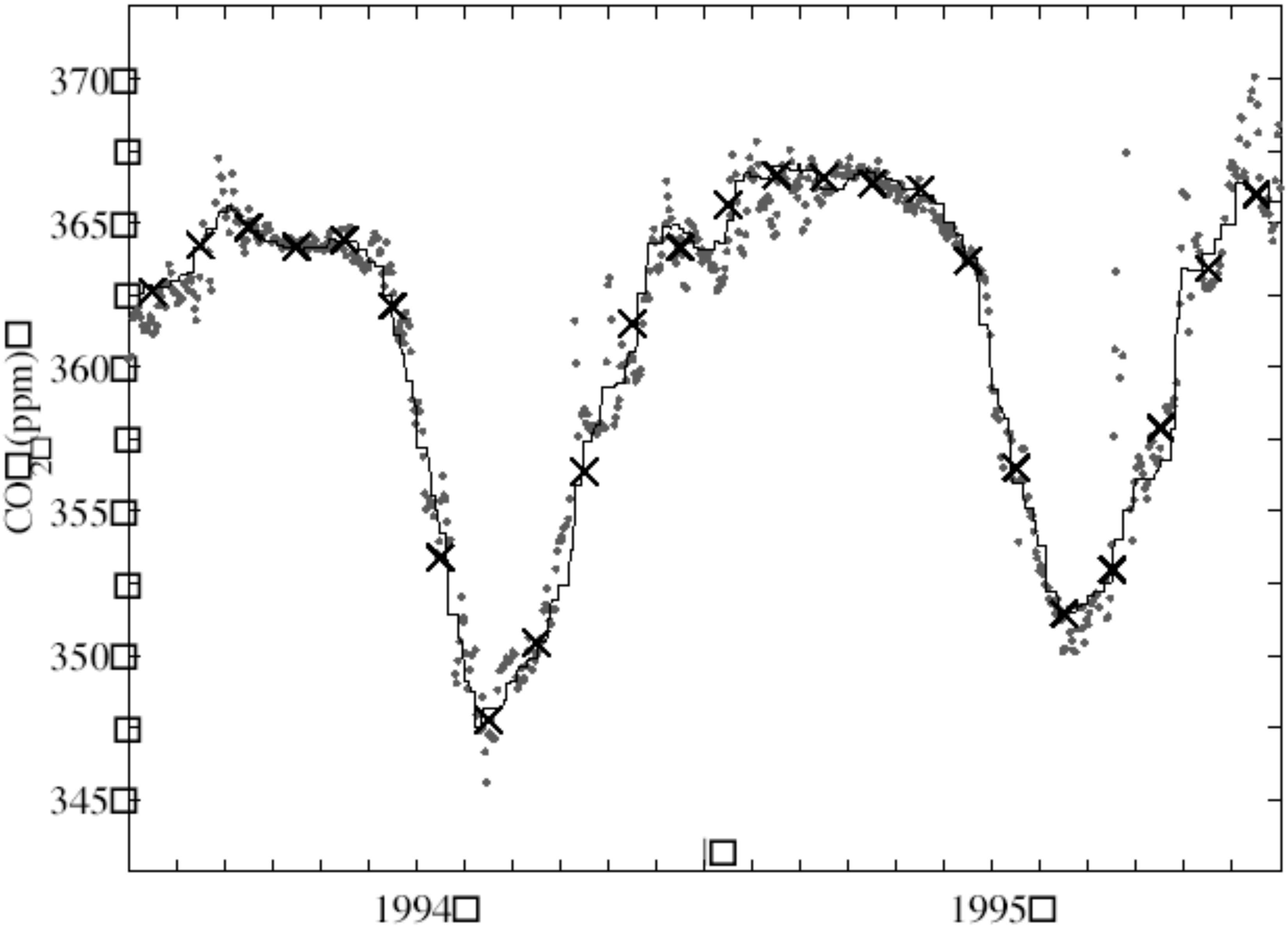
A tipping point usually means the moment at which internal dynamics start to propel a change previously driven by external forces. The idea raises two questions. First, when will that moment be reached? Second, after it has been passed, is the system now destined to run its course regardless of what goes on elsewhere — is a tipping point a point of no return?

Biospheric imprint of the AO

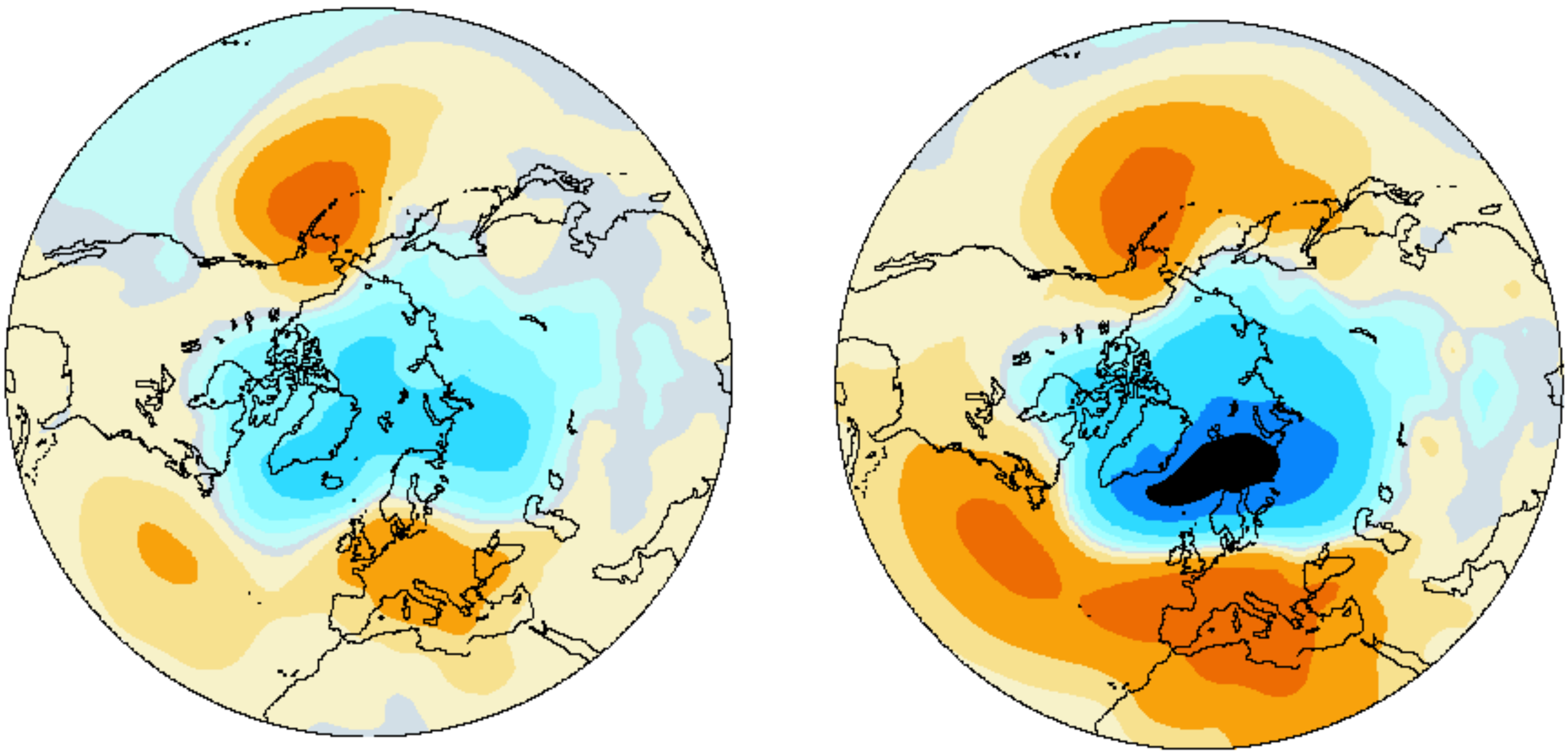




Russell and Wallace, GBC (2004)


370
365
360
355
350
345
CO2 (ppm)
1994
1995

1979-2002



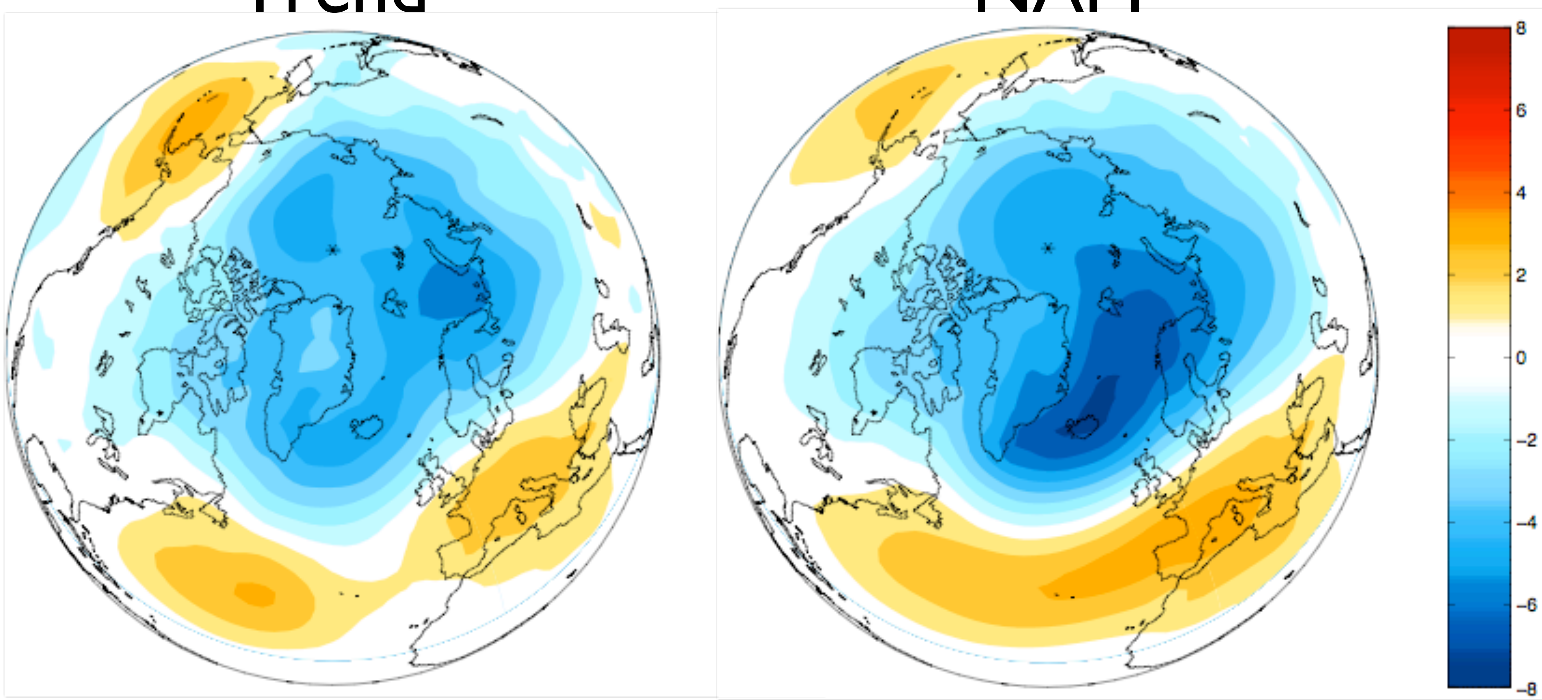
SLP regressed on MLO

Leading SLP EOF

Secular trends in the AO/AAO

NAM and 1979-97 SLP trends

Trend NAM

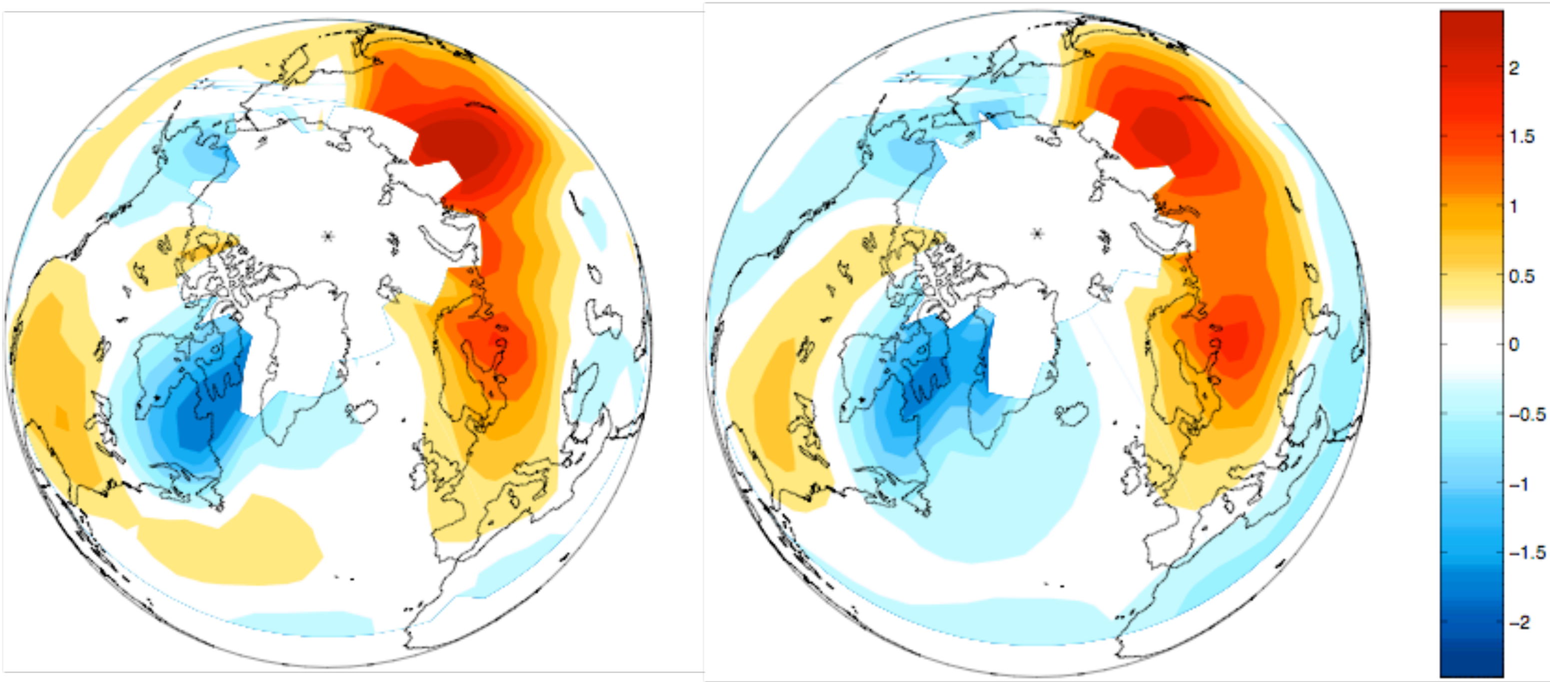


hPa/dec hPa/std

Thompson, Wallace, Hegerl 2000

NAM and 1979-97 temperature trends

Trend NAM

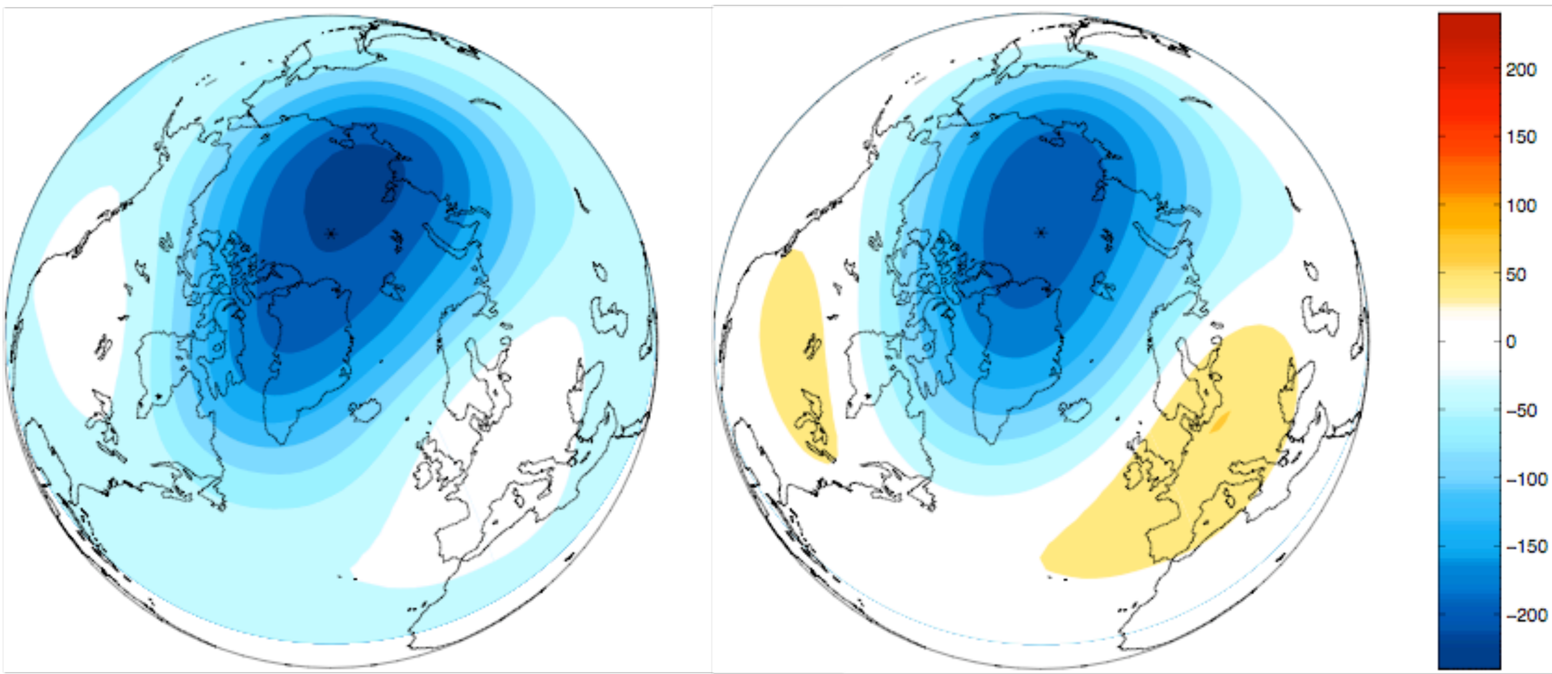


K/dec K/std

Thompson, Wallace, Hegerl 2000

NAM and 1979-97 stratospheric trends

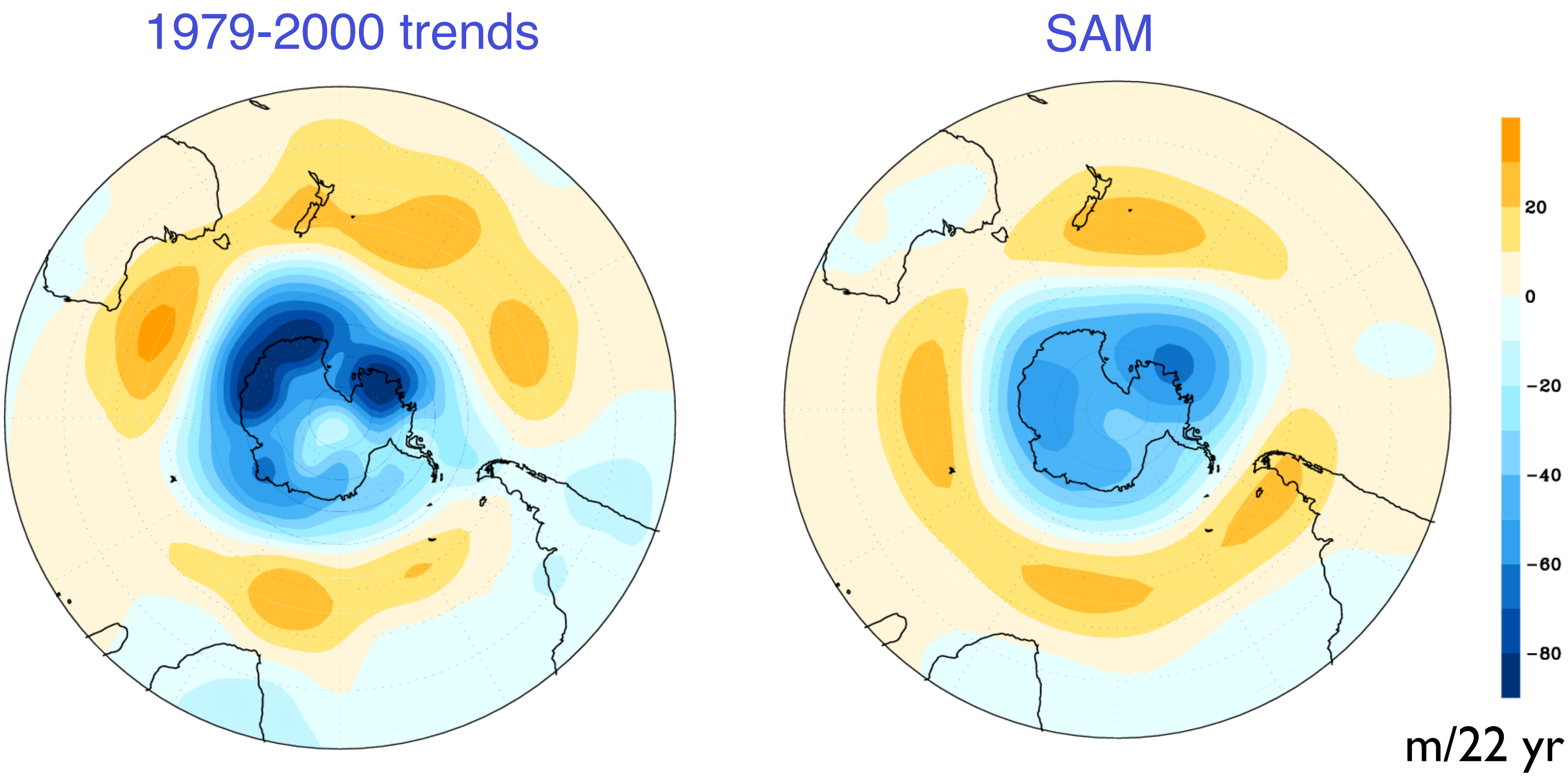
Trend NAM



m/dec m/std

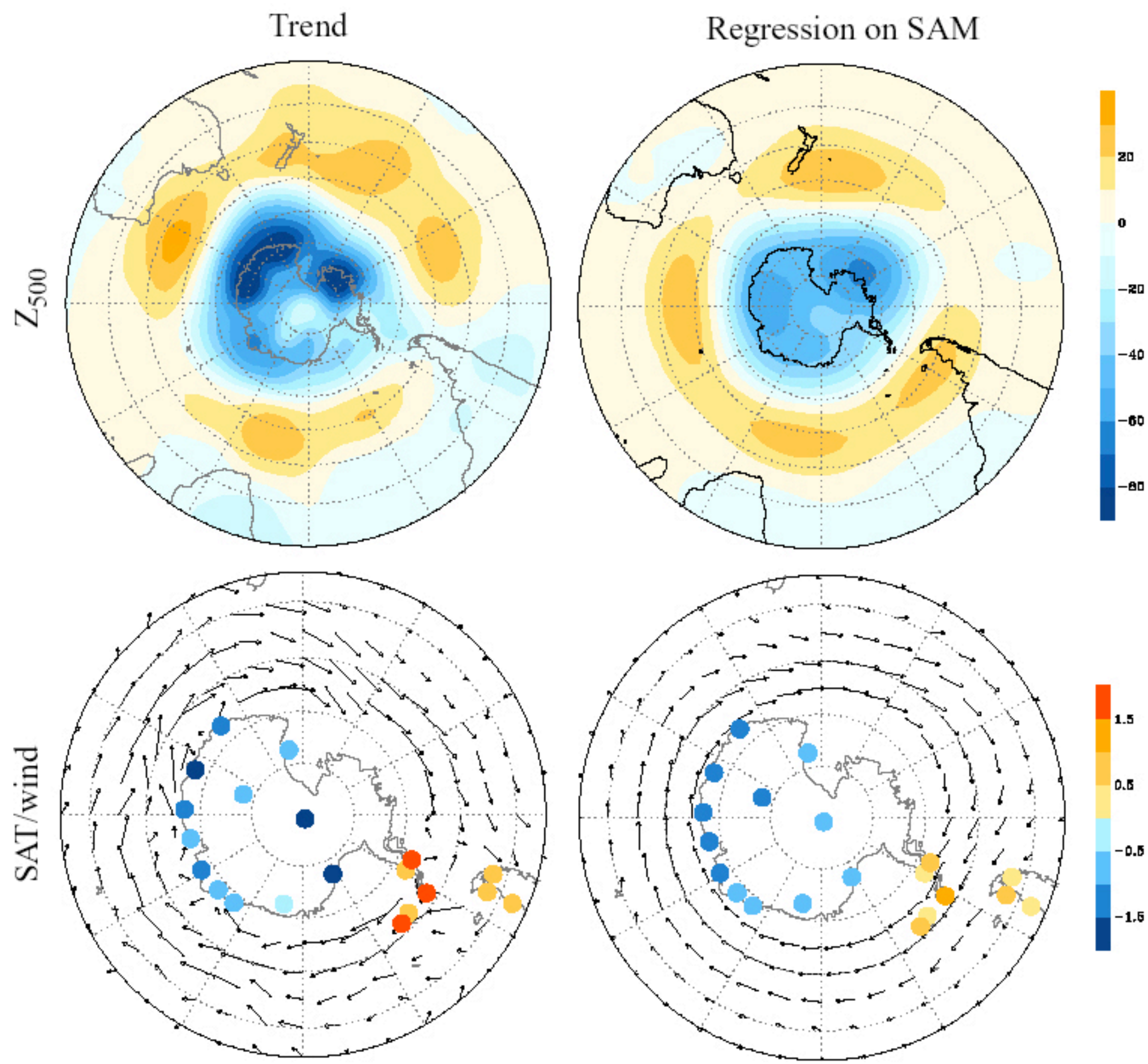
Thompson, Wallace, Hegerl 2000

SH polar geopotential height trends



Recent trends in SH Z500 (Dec.-May 1979-2000).

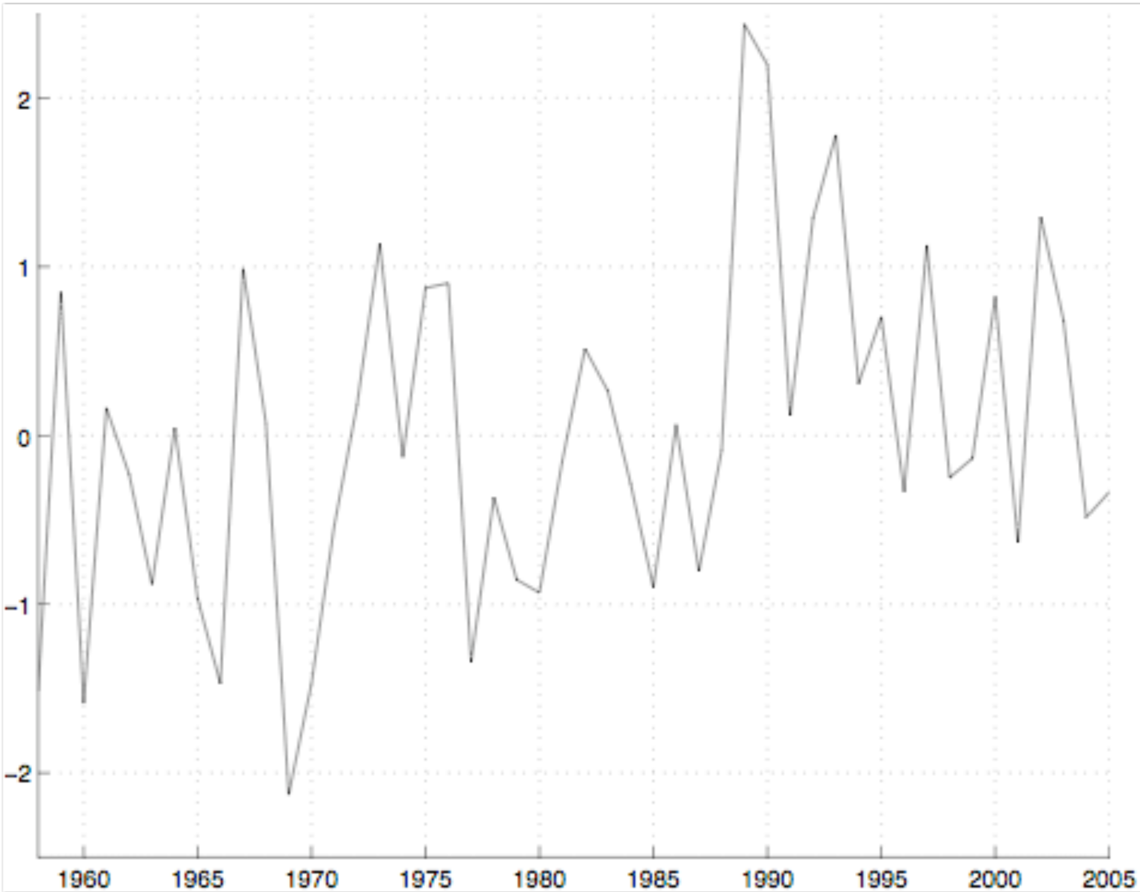
Thompson and Solomon 2002



December-May 1979-2000

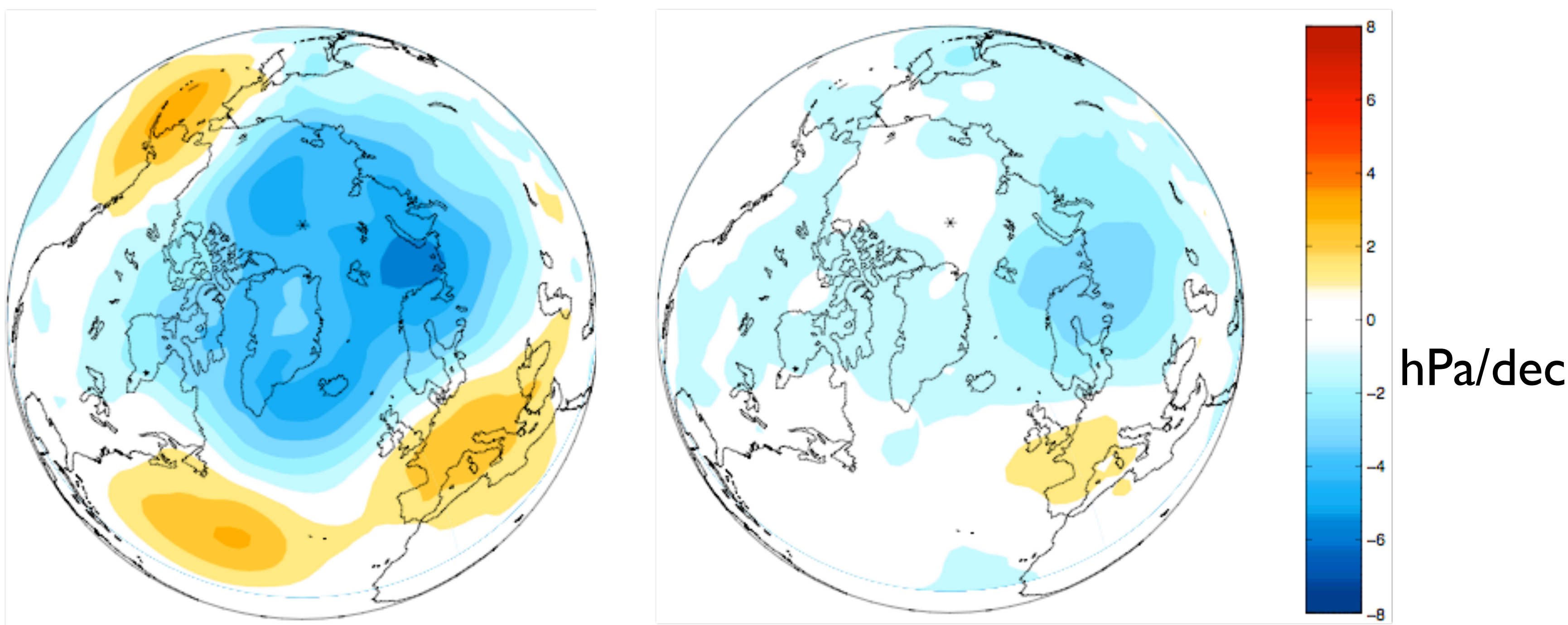
Thompson and Solomon
Science (2002)

Wintertime values of the NAM

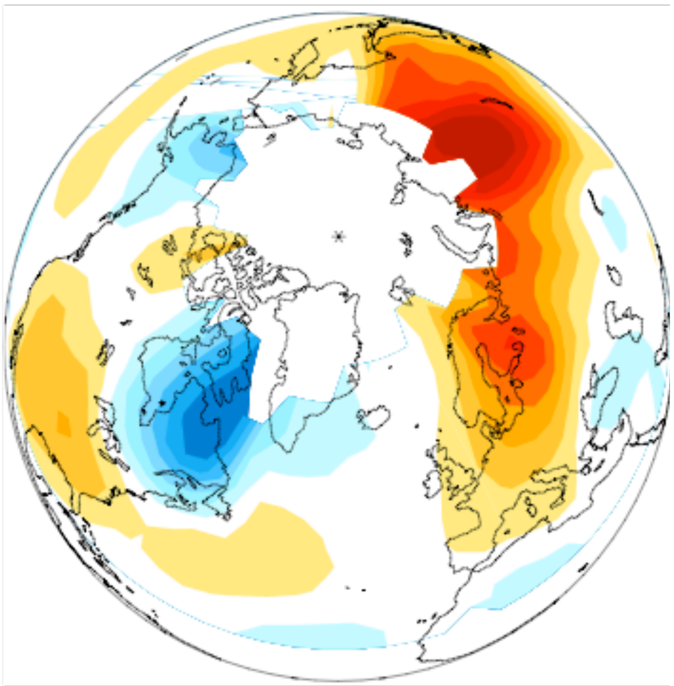


NAM index through 2005

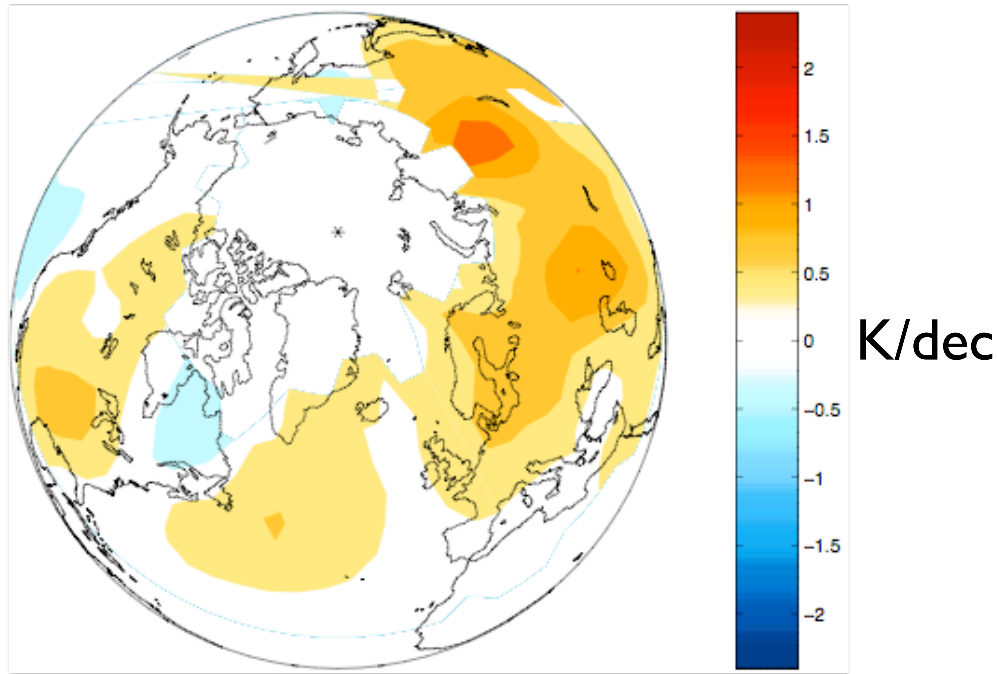
1979-1997 1979-2005

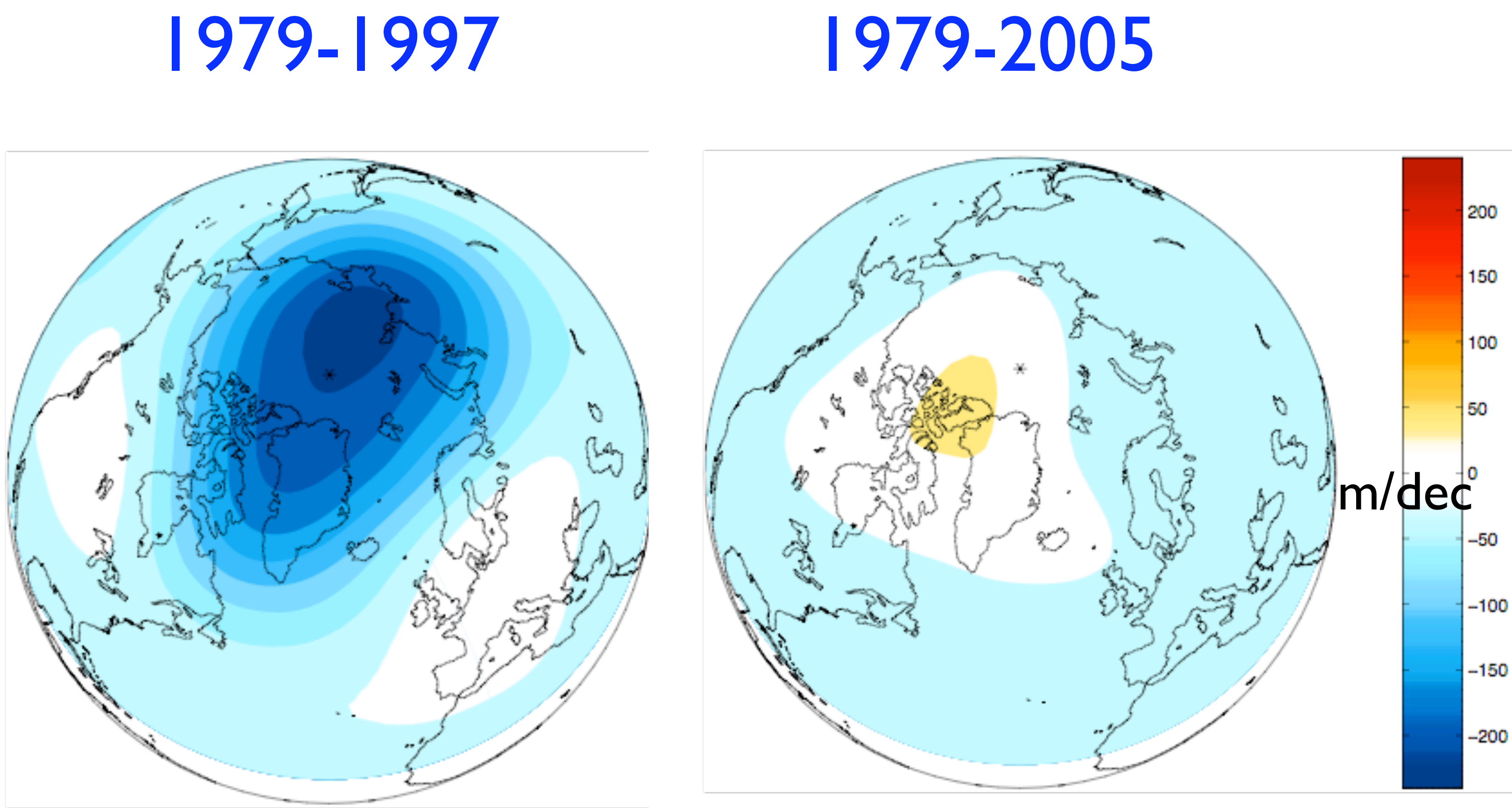


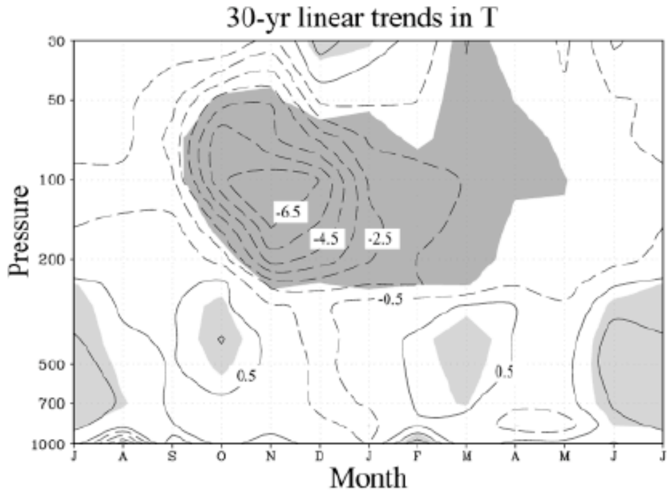
1979-1997

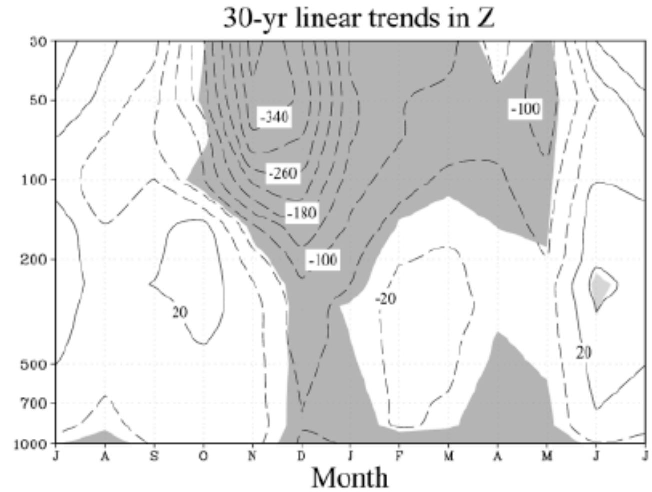


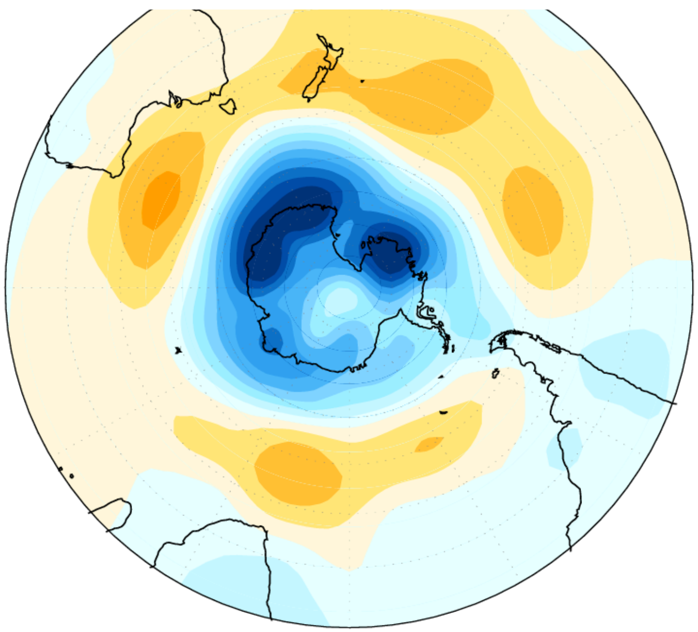
1979-2005



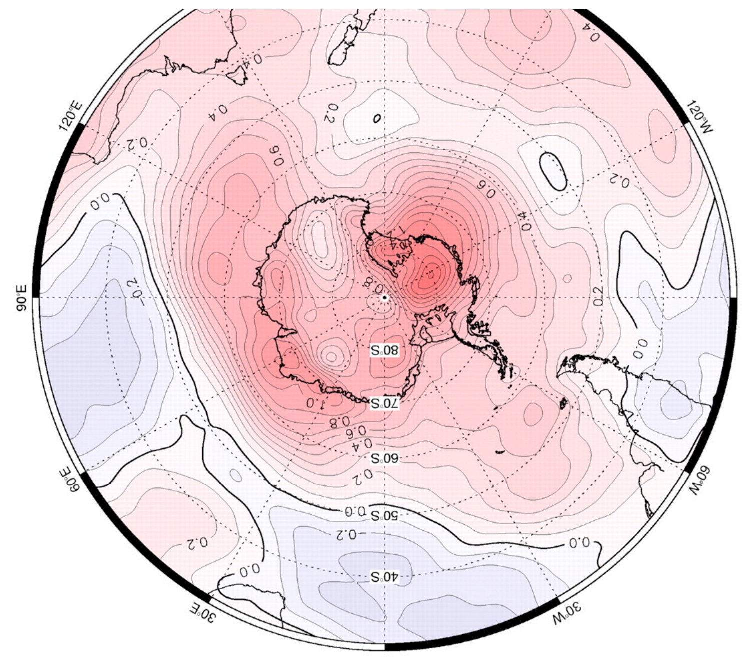

1979-1997
1979-2005
200
150
100
50
0
m/dec
−50
−100
−150
−200







Z_{500} December - May
1979-2000



T_{500} 1979-2001

Thompson and Solomon, Science (2006)

Turner et al., Science (2006)

Jones and Widmann
Nature (2004)

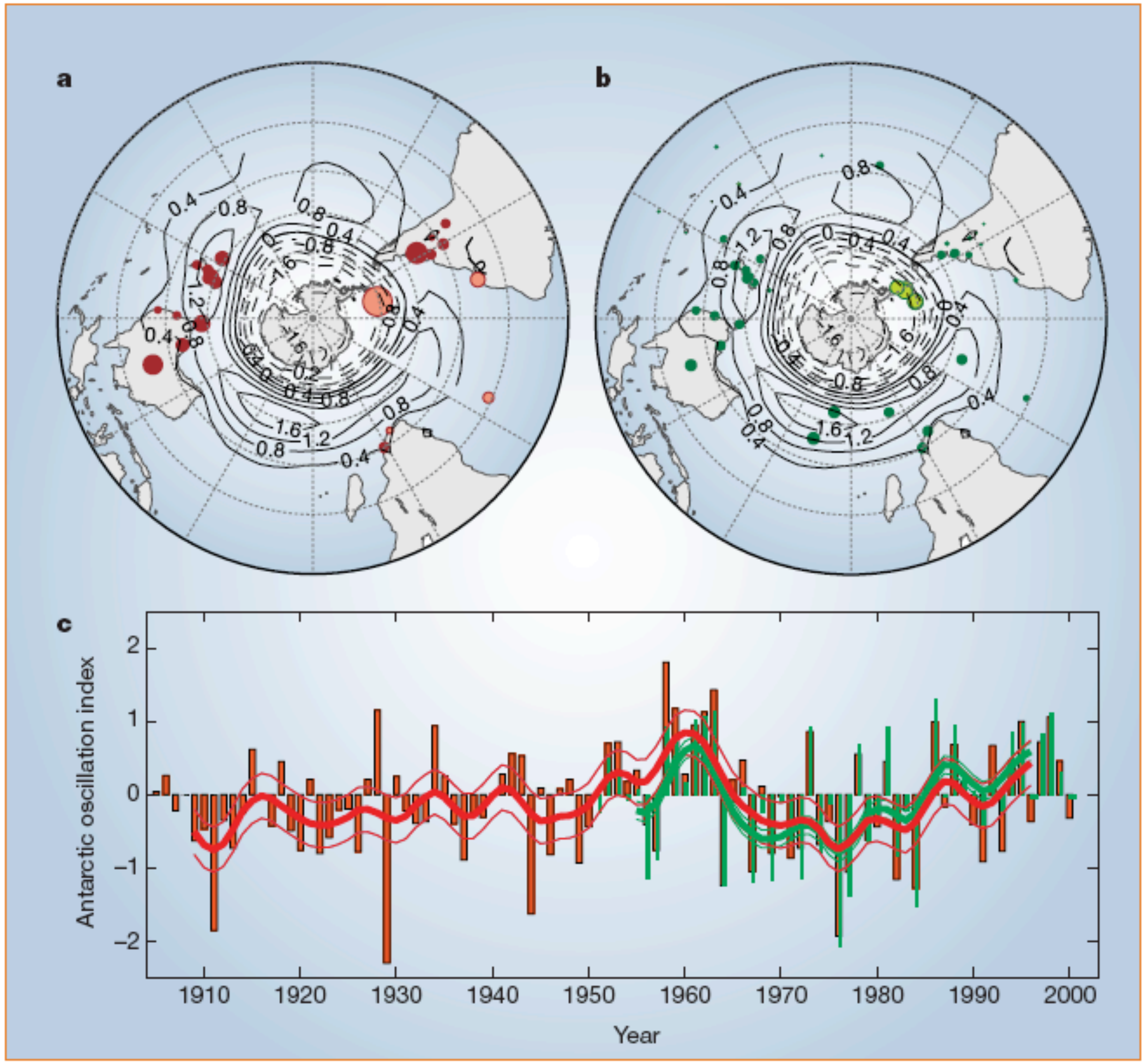
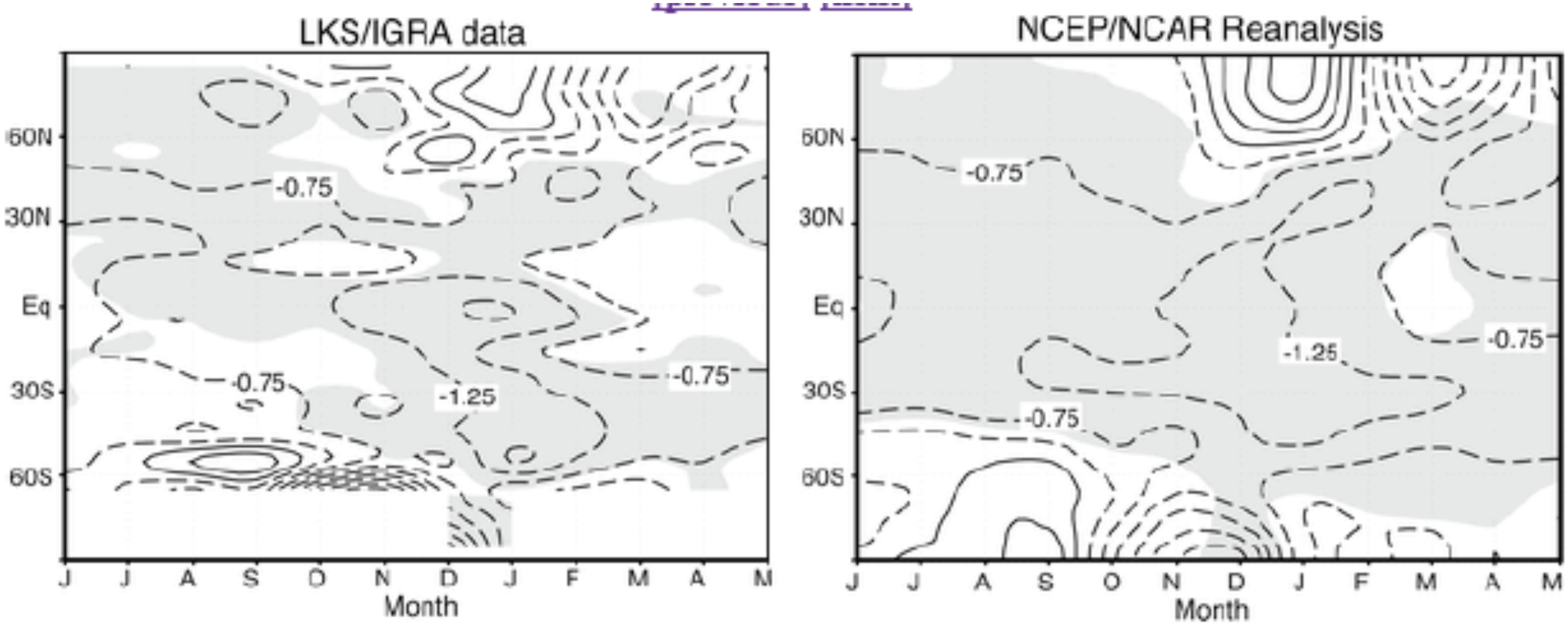


Figure 1 Reconstruction of the December–January Antarctic oscillation index (AAOI). **a,** The Antarctic oscillation pattern and regression weights for normalized station sea-level pressure used for the 1905 AAOI reconstruction. Isolines show the sea-level pressure anomaly (in hundreds of pascals) for the AAOI + 1. The red circles denote positive values and the pink circles denote negative ones; the area is proportional to the weight; **b,** as in **a**, but for the 1951 AAOI reconstruction, with dark green denoting positive values and light green denoting negative ones. **c,** Reconstructed December–January AAOI. Red bars show the 1905 reconstruction; green bars, the 1951 reconstruction. The thick red line is the nine-year low-pass-filtered 1905 reconstruction; the green, the 1951 reconstruction. The thin red and green lines show the 95% confidence intervals for the filtered data. Years are dated from December.



70 hPa temperature trends 1979-2003

Thompson and Solomon, JCL (2005)

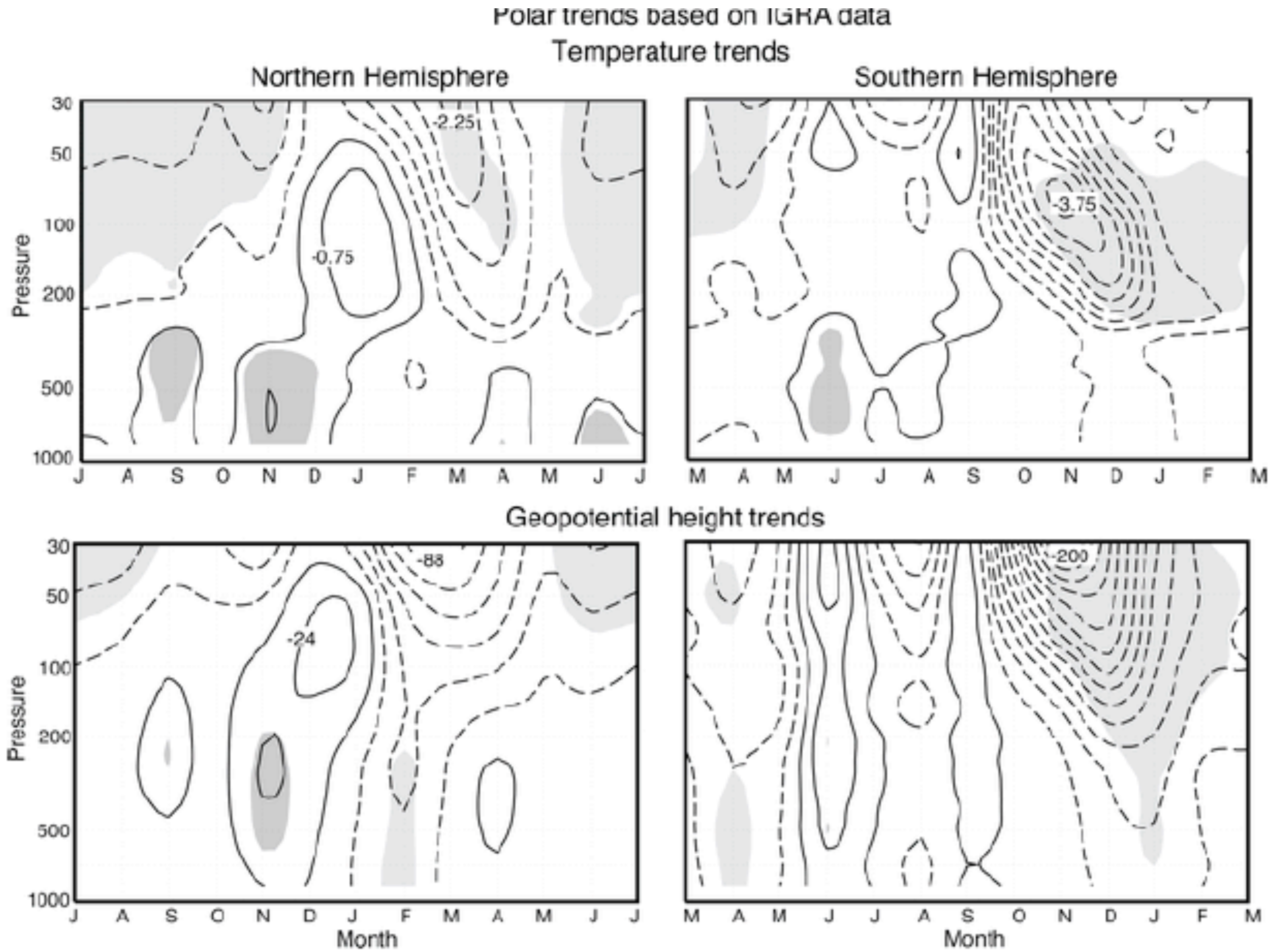
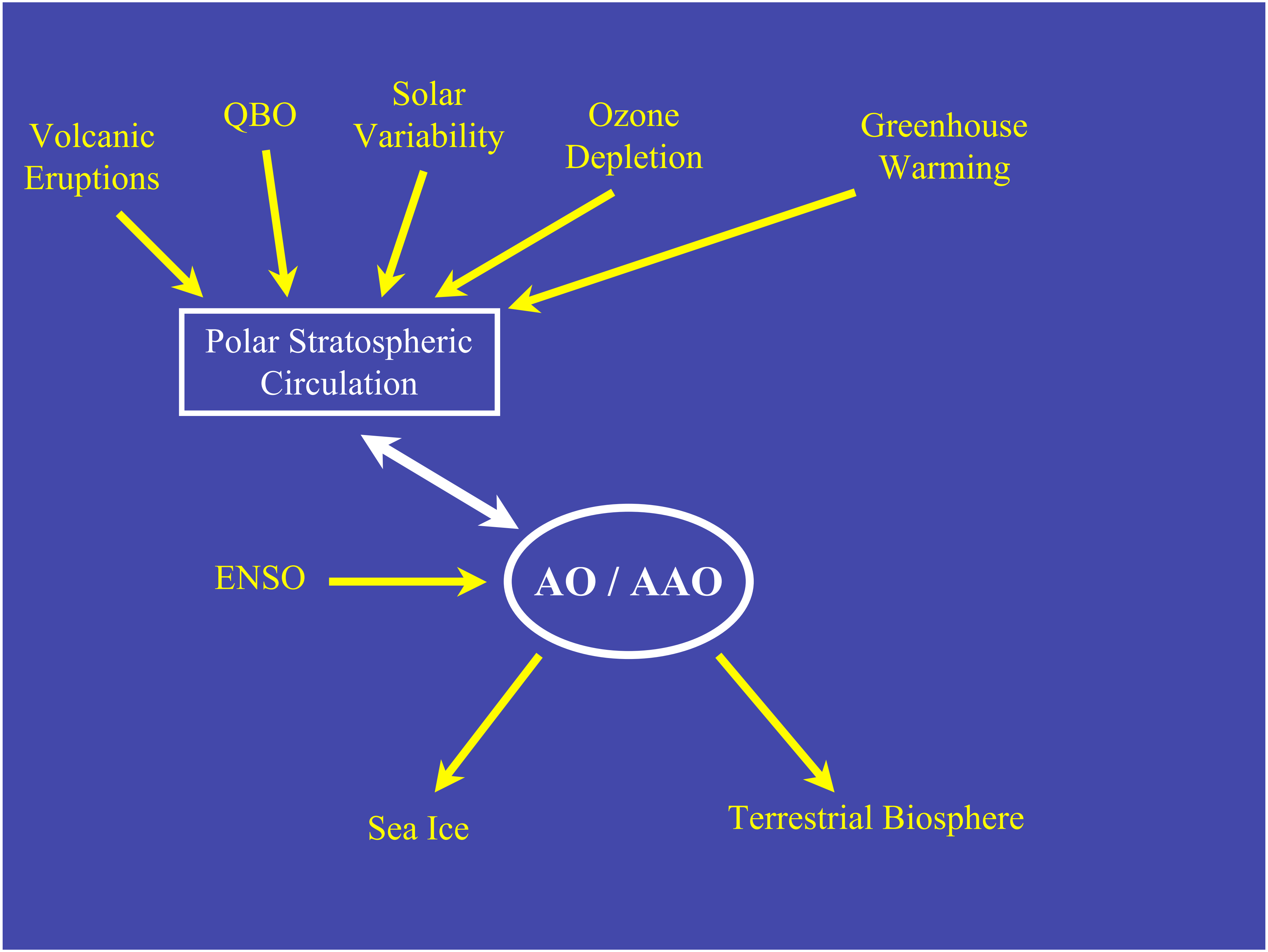
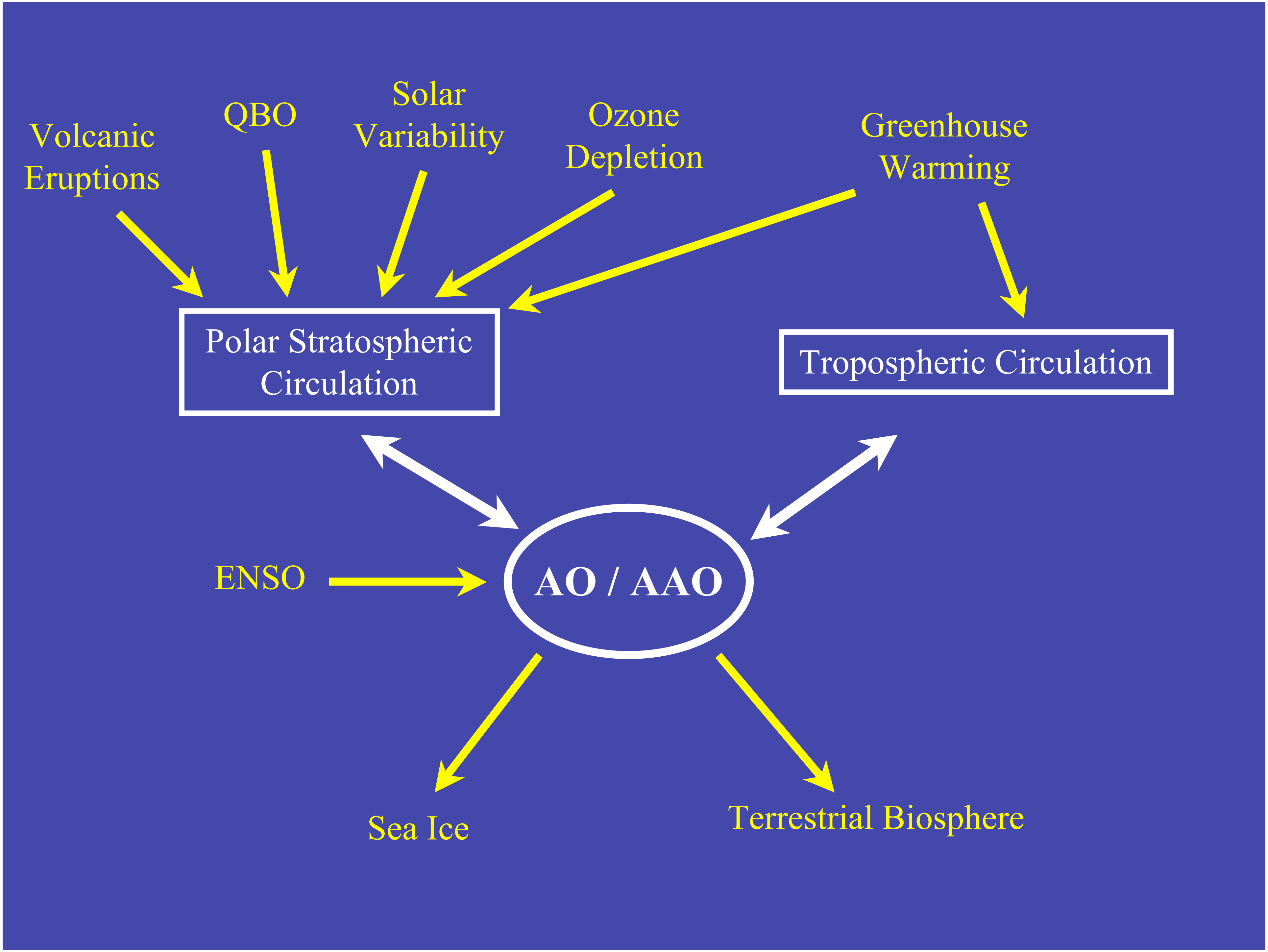


FIG. 7. Trends in (top) temperature and (bottom) geopotential height anomalies averaged over (left) 60°-90°N and (right) 60°–90°S for 1979–2003. Trends are shown as a function of month and pressure level. Shading denotes trends that exceed the 95% confidence level. Tick marks on the ordinate axis denote the center of the respective month. Note that the NH ordinate axis is shifted relative to the SH ordinate axis. Trends based on radiosonde data from the IGRA. Units: K decade^{-1} (–0.25, 0.25, 0.75 . . .) and m decade (–8, 8, 24 . . .).

Secular trends in the AO/AAO

- Secular trends may not be as robust as we thought
- AO/AAO prominent in decadal-scale variability
- Important to take seasonality into account


Volcanic Eruptions
QBO
Solar Variability
Ozone Depletion
Greenhouse Warming
Polar Stratospheric Circulation
ENSO
AO / AAO
Sea Ice
Terrestrial Biosphere


Volcanic Eruptions
QBO
Solar Variability
Ozone Depletion
Greenhouse Warming
Polar Stratospheric Circulation
Tropospheric Circulation
ENSO
AO / AAO
Sea Ice
Terrestrial Biosphere