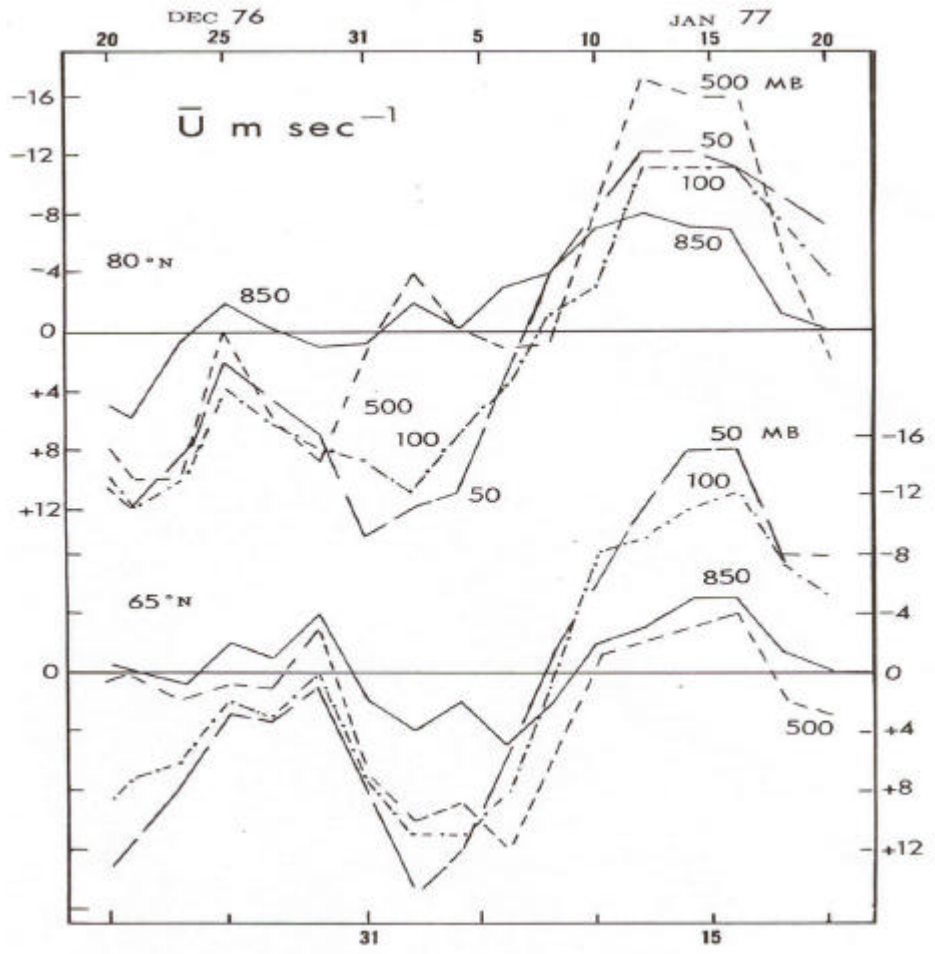
The role* of the stratosphere in tropospheric climate: Observational evidence

David Thompson
Colorado State University

The role of the stratosphere in tropospheric climate: Observational evidence

Anecdotal evidence
Statistical evidence
    Coupling with the NH polar vortex
Annular modes
Downward propagation
Signature of volcanic eruptions
Relationship with the QBO
Evidence in recent climate change

Anecdotal evidence

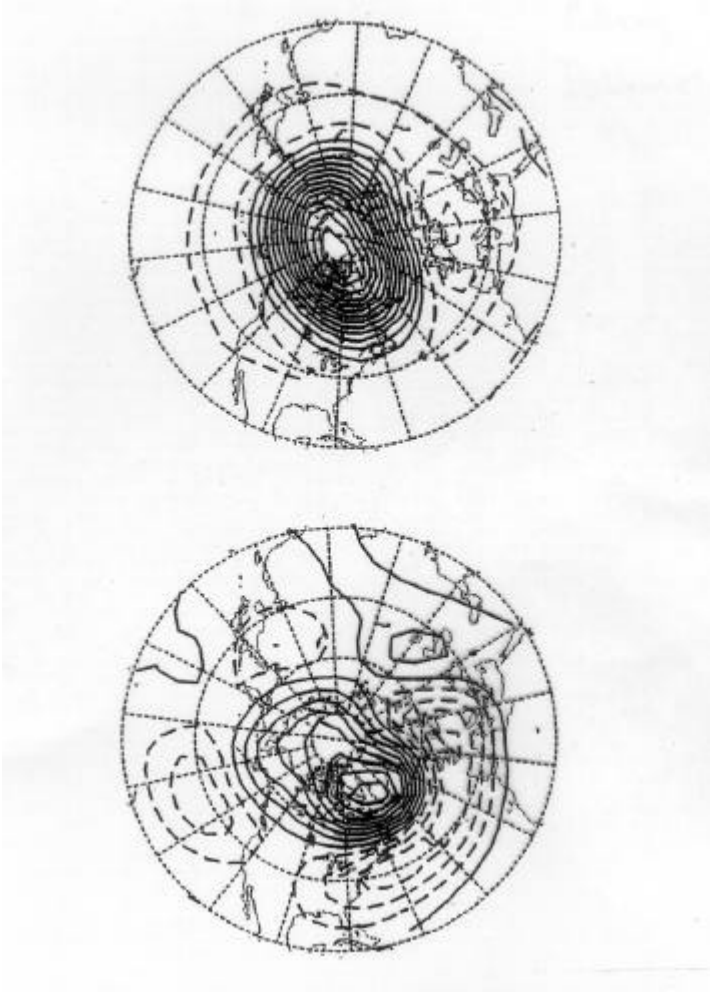


From Quiroz 1977

Dec 1976 Jan 1977

Changes in the tropospheric circulation during the SSW of January 1977

Statistical evidence

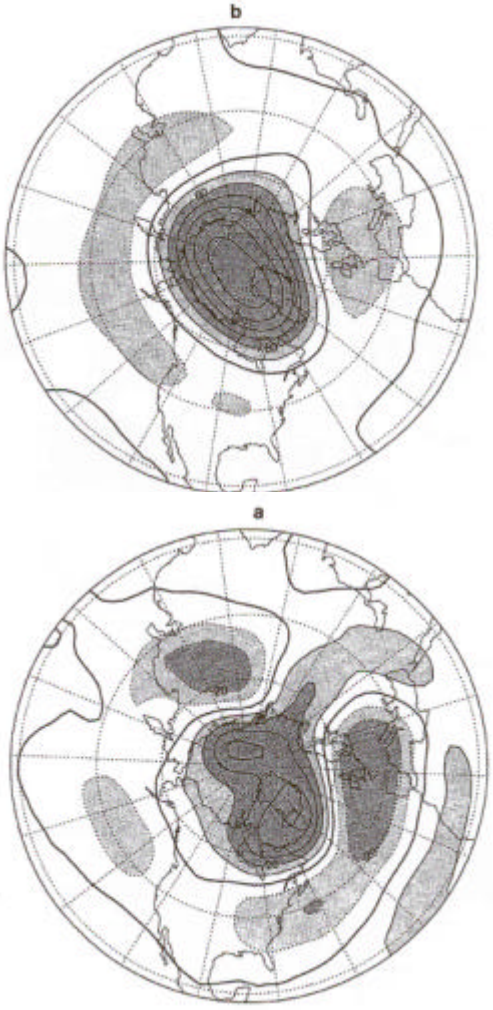


From Cheng
(UW PhD thesis 1993)

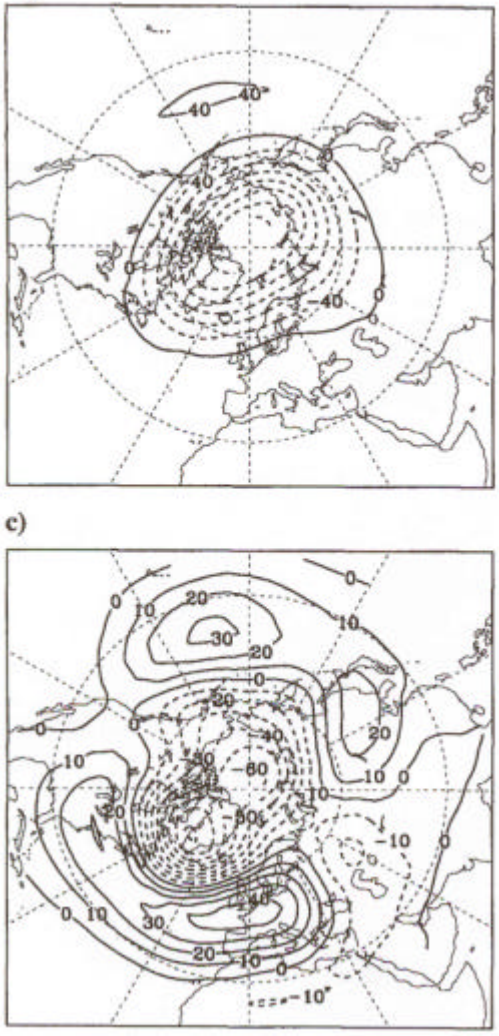
MCA between 50-hPa and 500-hPa height

Statistical evidence

Baldwin, Cheng, Dunkerton 1994



a) *Perlwitz and Graf 1995*



See also:
Kitoh et al. 1996

MCA (left) and CCA (right) between 50-hPa and 500-hPa height

(contours at: left, 10m, 30m; right:, 10m, 40m)

Statistical evidence

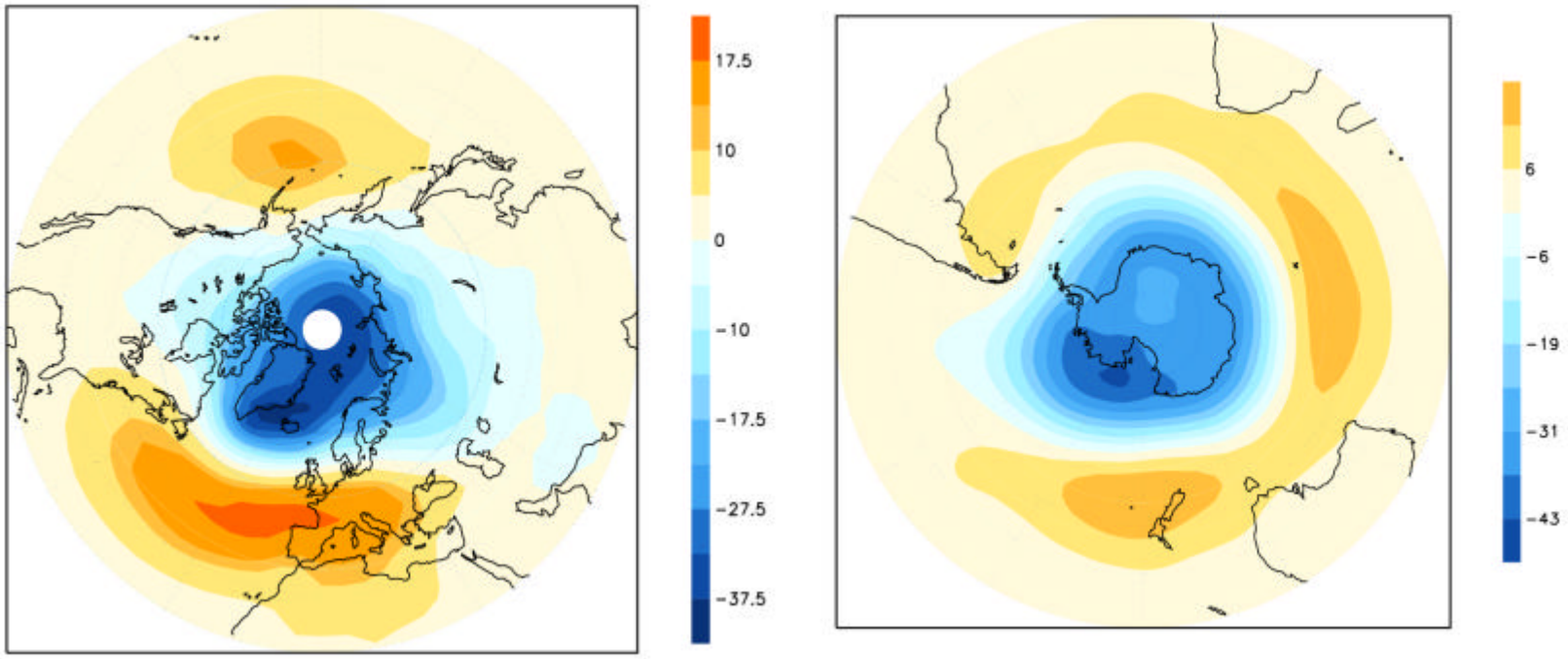
Variations in the stratospheric polar vortex are coupled to a wavelike pattern of variability in the troposphere centered “about Greenland”.

“The displacement off the pole seems important, as it may result in a wave-1 anomaly which could act to force the stratosphere from below”.

“Analysis of daily data … indicates the strongest lag correlations … occur when the troposphere leads the stratosphere…suggesting that the direction of cause and effect is for the most part upward”.

- Baldwin et al. 1994

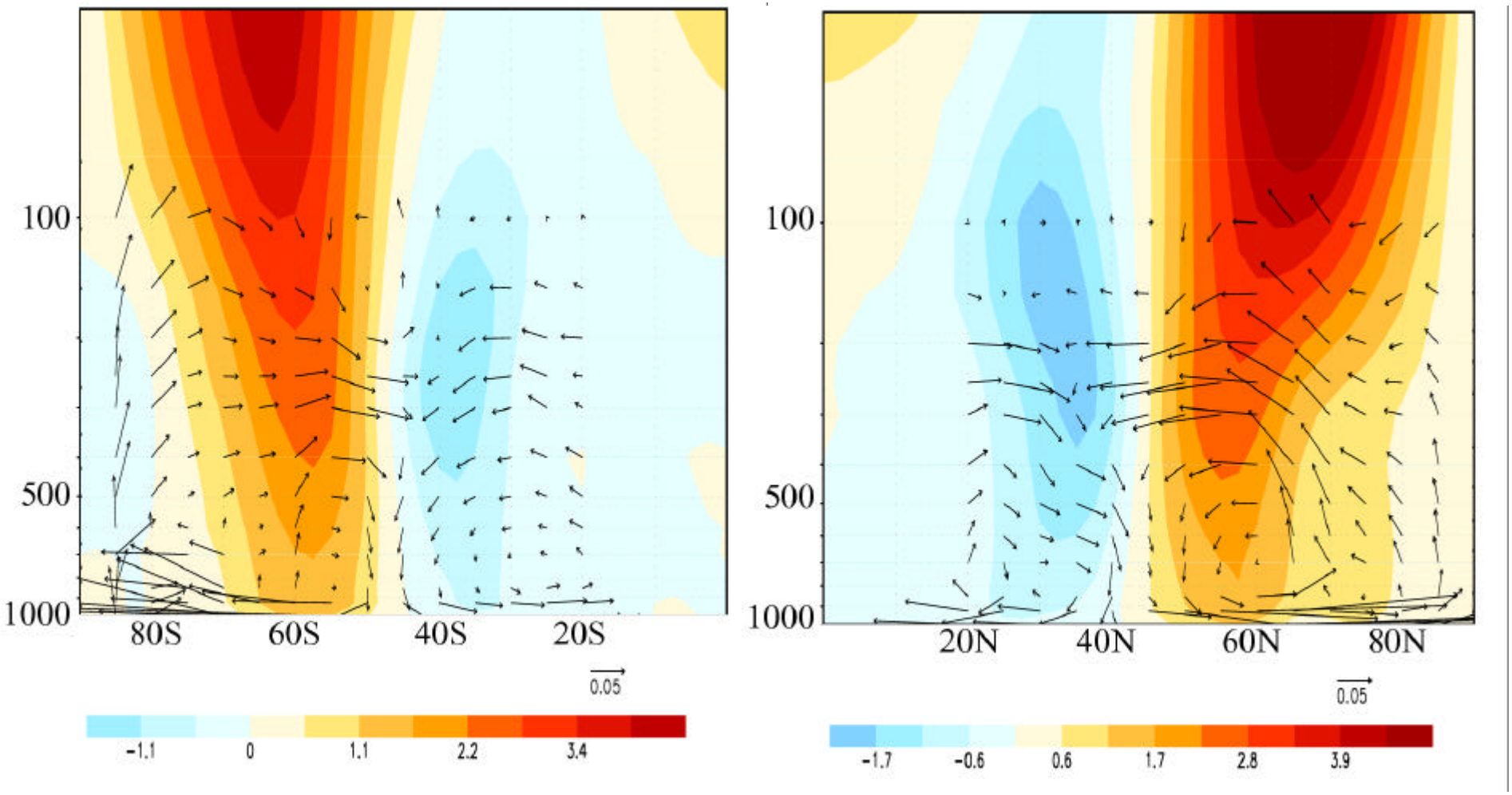
The annular modes



Geopotential height regressed on indices of the annular modes (m/std)

From Thompson and Wallace 2000

The annular modes



Zonal wind and mean-meridional circulation anomalies regressed on *active* season segments of the annular mode indices.

From Thompson and Wallace 2000

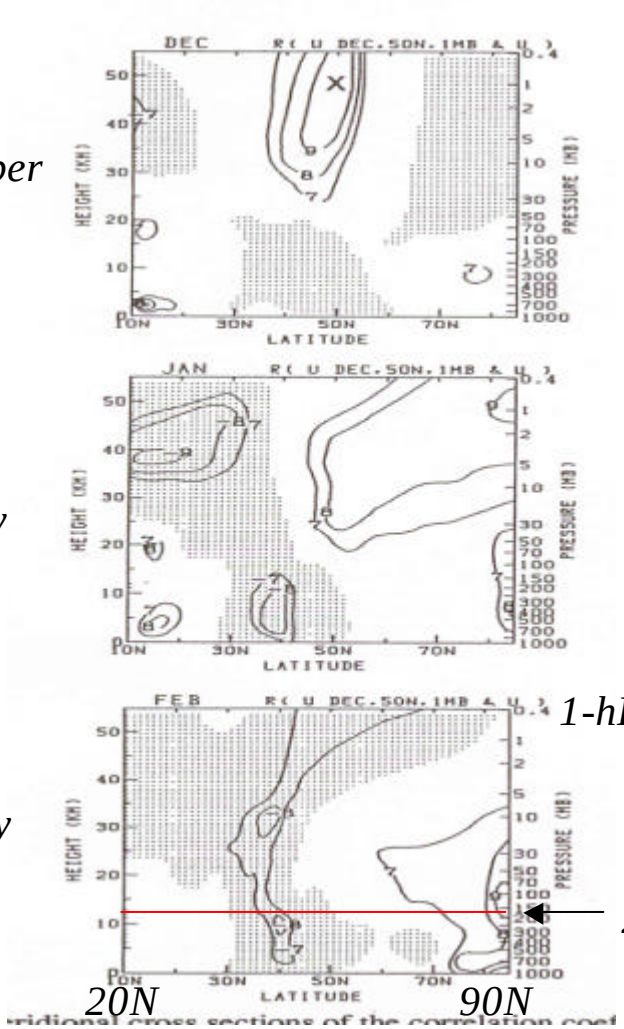
The annular modes

"Coupling between the troposphere and stratosphere is intrinsic to the dynamics of the zonally symmetric polar vortex: dynamical processes at stratospheric levels can affect the strength of the polar vortex all the way down to the Earth's surface through the combined effects of an induced … meridional circulation … and induced changes in the eddy fluxes of zonal momentum at intermediate levels."

From Thompson and Wallace 1998

Downward propagation

From Kodera et al. 1990



December

January

February

1-hPa

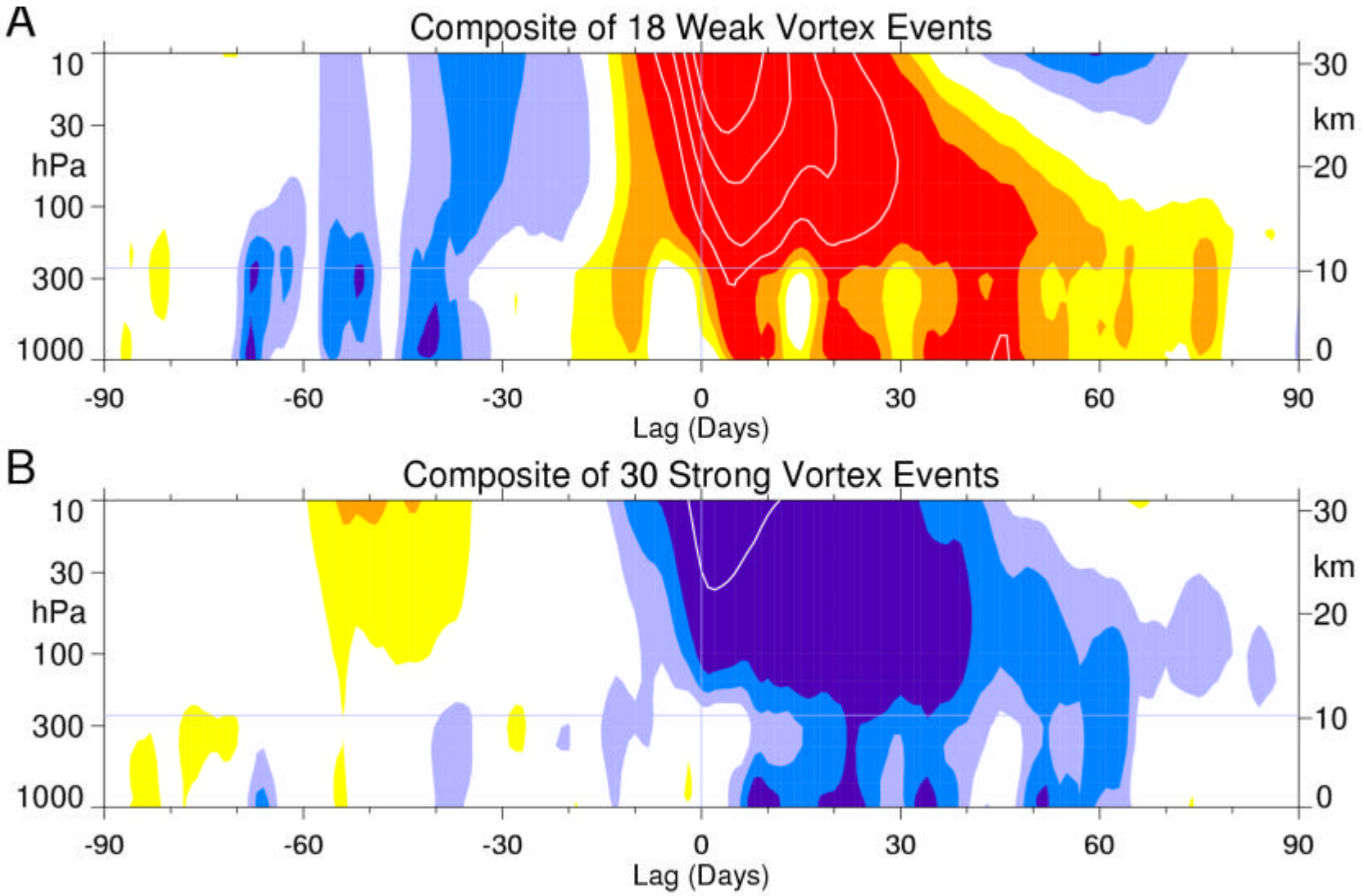
200-hPa

20N

90N

Zonal wind correlated with December mean wind at 1mb, 50 degrees N for months indicated (eight years of data).

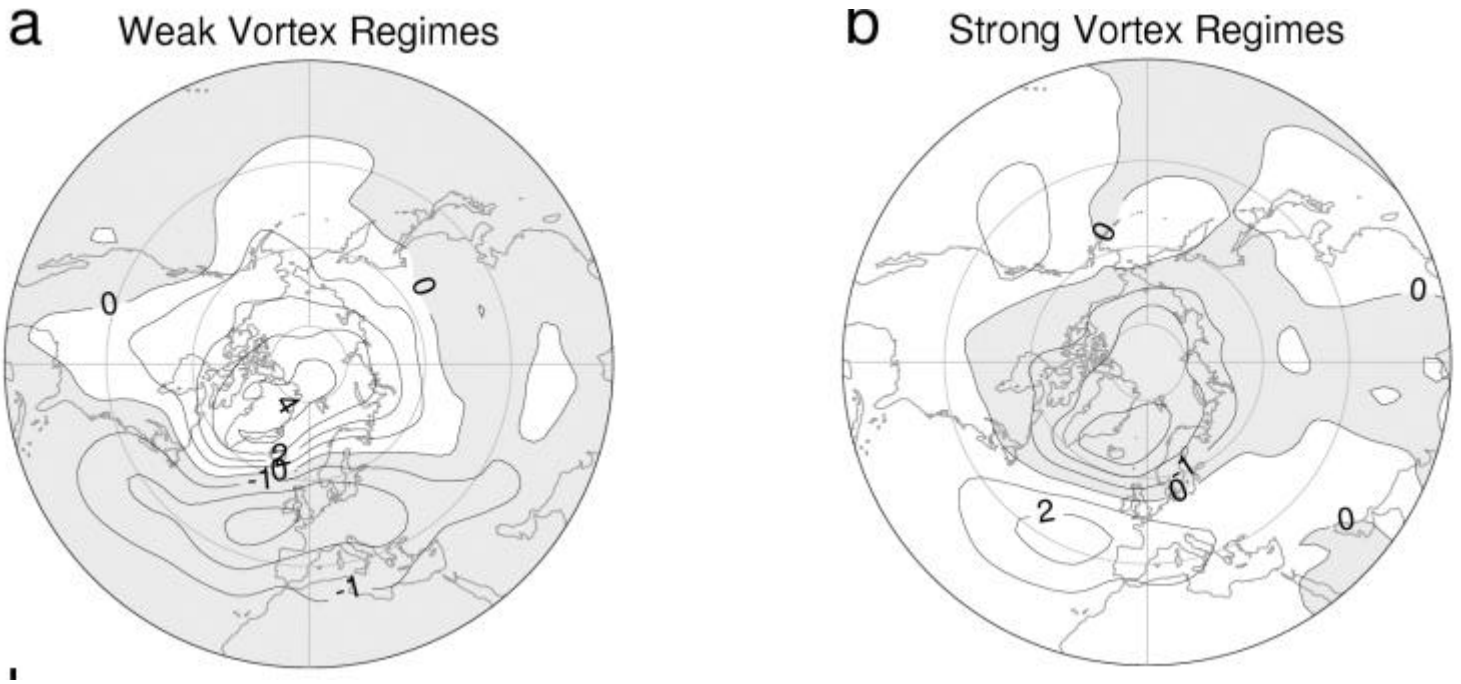
Downward propagation in the context of the NAM



Composites of the NAM index

From Baldwin and Dunkerton 2001

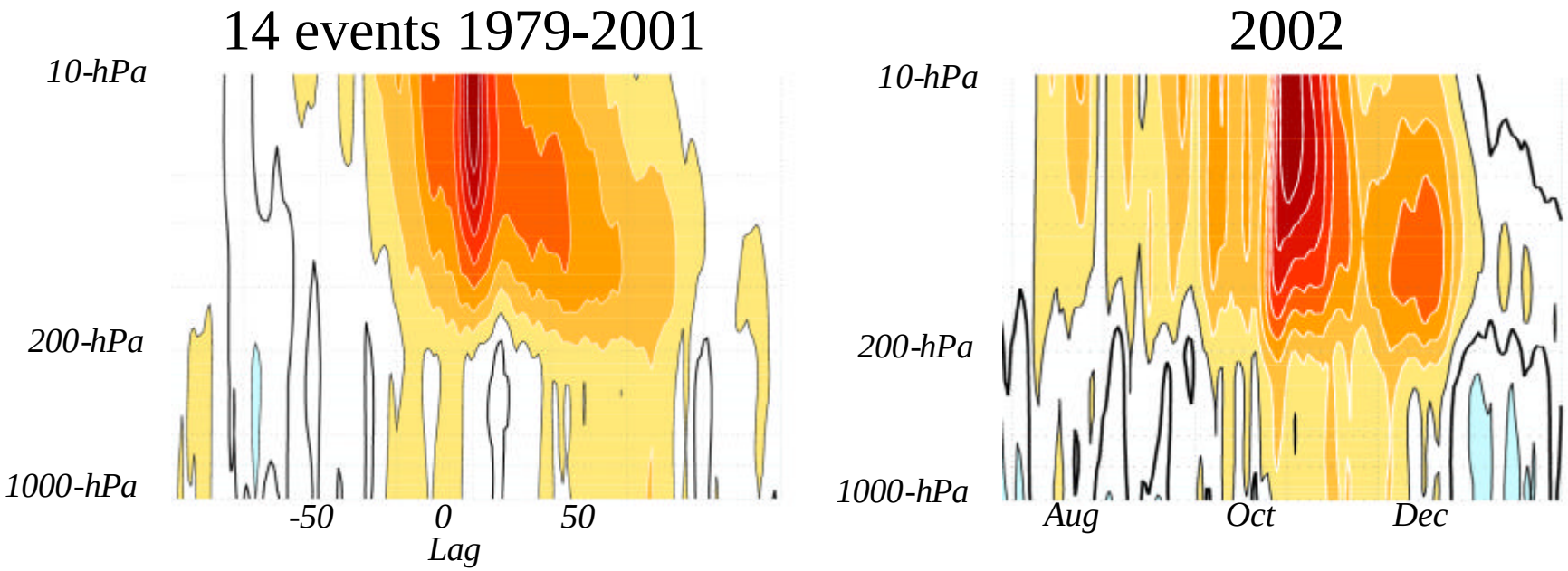
Downward propagation in the context of the NAM



SLP composites during days 1-60 following anomalies in the stratospheric vortex

From Baldwin and Dunkerton 2001

Downward propagation in the context of the SAM



Composites of the SAM index

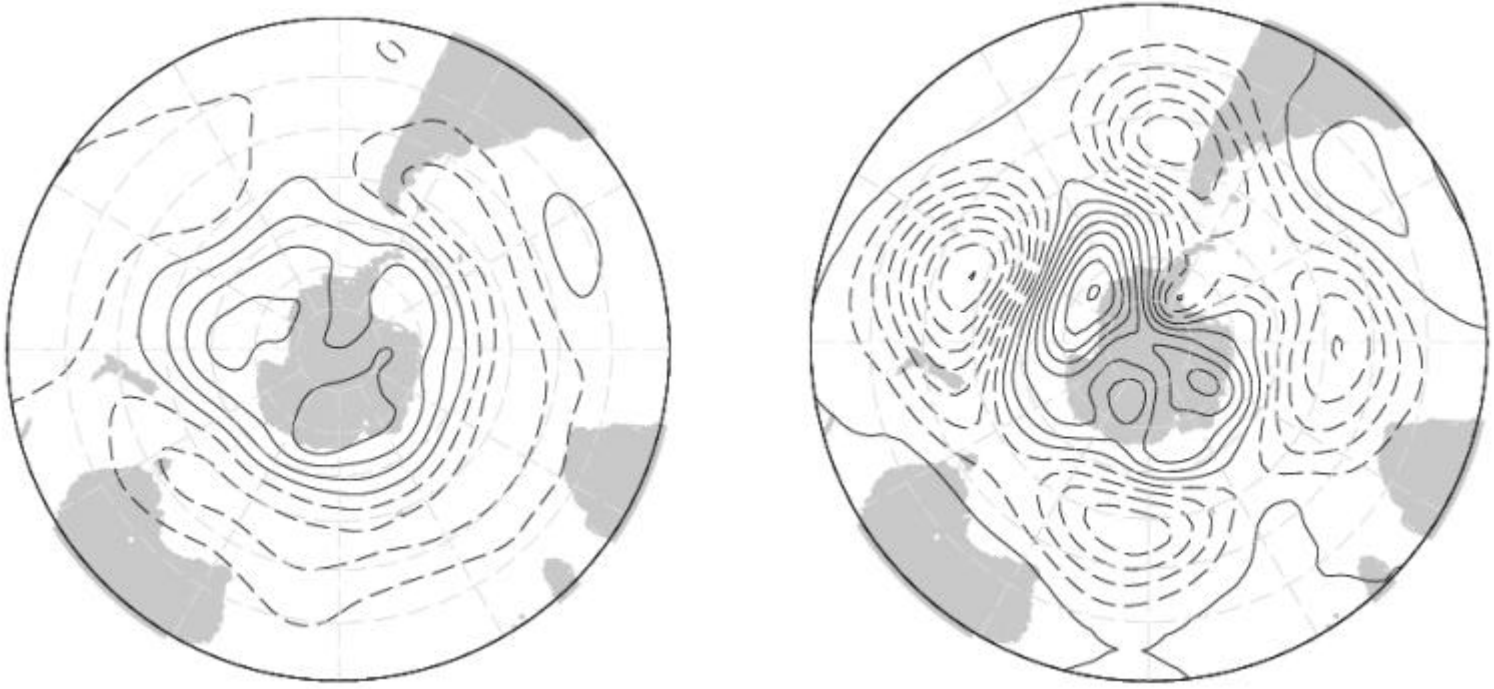
(contours at 0.5 and 1.0 std)

From Thompson, Baldwin, Solomon 2003

Downward propagation in the context of the SAM

14 events 1979-2001

2002



Z500 composites during days 11-60 following anomalies in the stratospheric vortex

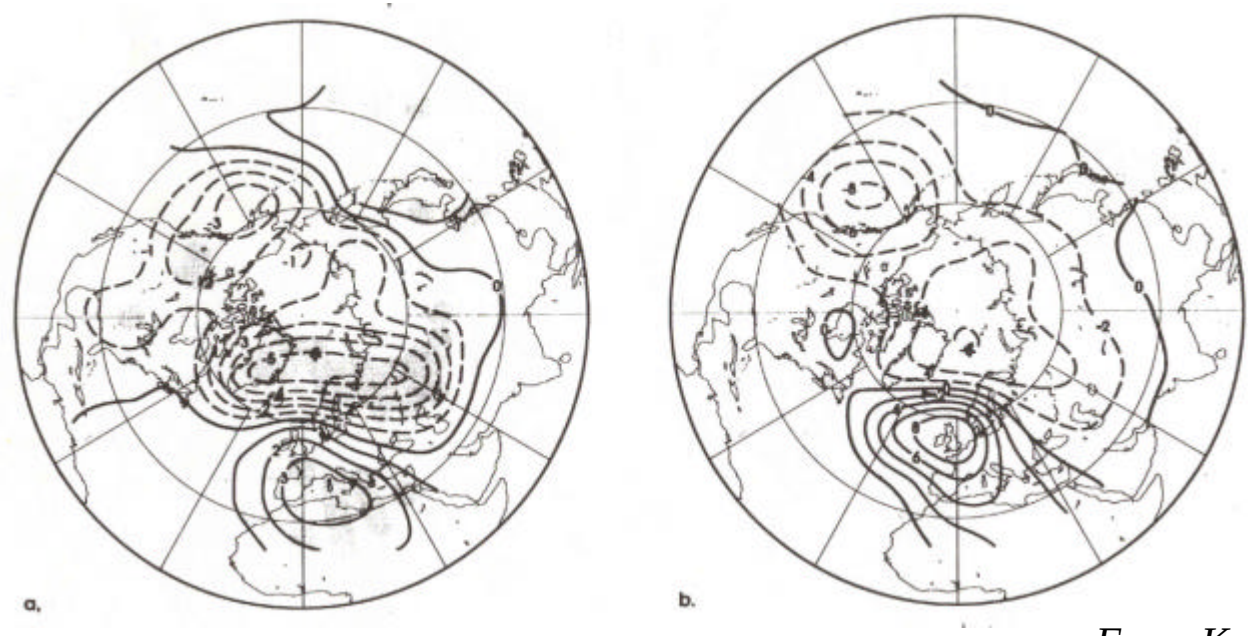
Contours at 20m.

From Thompson, Baldwin, Solomon 2003

A NAM-like structure is evident in SLP and SAT following volcanic eruptions…

4 previous events

Pinatubo



See:
Robock and Mao (1992),
Graf et al. (1994),
Kodera (1994),
Kodera and Yamazaki (1994)

From Kelly et al. 1996

Sea level pressure composited during winters following (left) 5 large eruptions prior to Pinatubo and (right) Pinatubo.

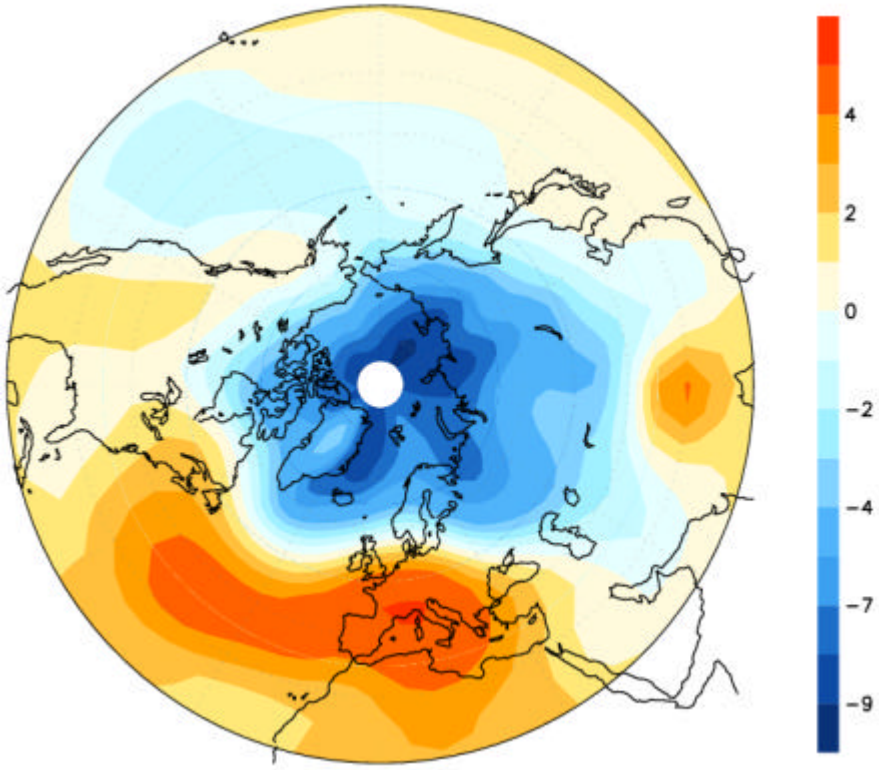
And during the contrasting phases of the QBO…

See:
Coughlin and Tung 2001
Thompson et al. 2002

From Holton and Tan 1980

Difference in sea level pressure between the contrasting phases of the QBO at 50-hPa (westerly-easterly).

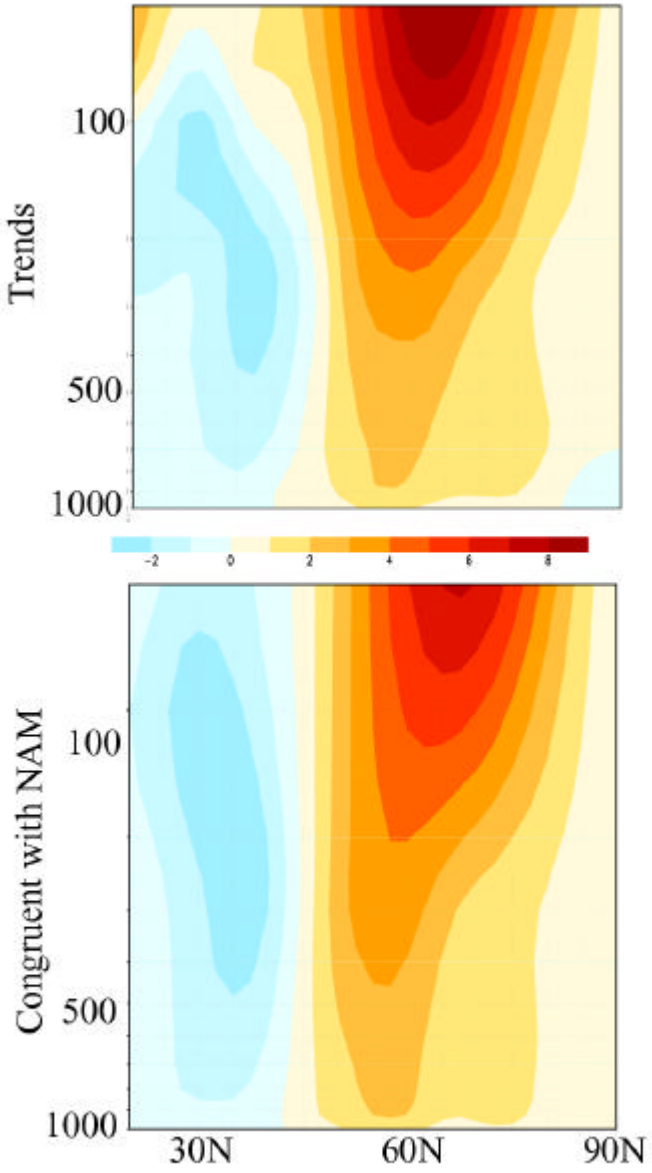
And in recent climate trends



Recent trends in NH SLP (Jan-March 1968-1997).

e.g., Walsh et al. 1995

Climate trends and the NAM



Top: 1968-97 January-March trends in zonal wind (m/s 30-yrs).
Bottom: The fraction of the trends congruent with the NAM.

e.g.,
Kodera and Yamazaki 1994;
Hurrell 1995;
Perlwitz and Graf 1995;
Walsh et al. 1995;
Thompson et al. 2000;
Thompson and Solomon 2002

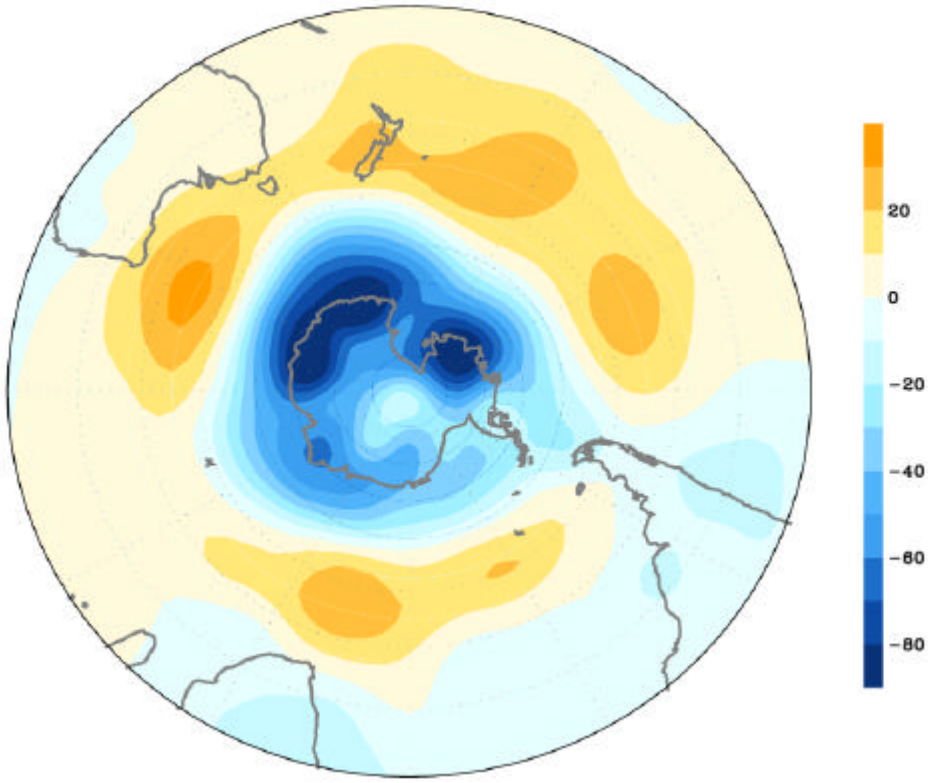
Possible causal mechanisms for the trend in the NAM

1 - Greenhouse gases (e.g., Shindell et al. 1999; Fyfe et al. 1999; Gillett et al. 2001).
2 - Ozone/greenhouse gases (e.g., Hartmann et al. 1999; Kindem and Christiansen 2001).
3 - Tropical SSTs (Hoerling et al. 2002).

Has the stratosphere played a role in the trends?

1 - Via greenhouse gases (Shindell et al. 1999).
2 - Ozone? (But ozone related trends are largest in March).

Climate trends and the SAM



Recent trends in SH 500-hPa Z (Dec-May 1979-1998)

e.g., Thompson and Solomon 2002

Possible causal mechanisms for the trend in the SAM

1 - Greenhouse gases (e.g., Fyfe et al. 1999; Kushner and Held 2001).

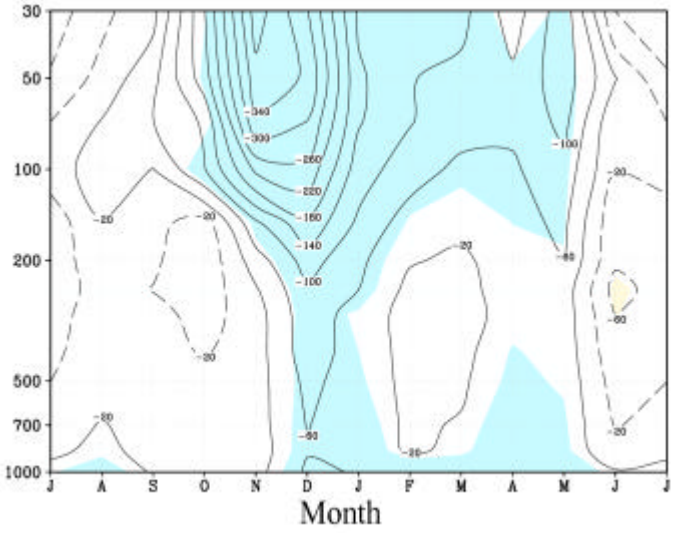
Has the stratosphere played a role in the trends?

2 - Ozone? (Thompson and Solomon 2002).

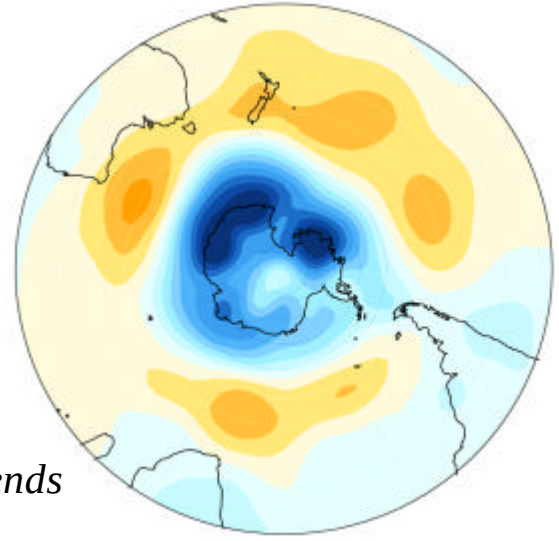
Recent climate trends and the SAM

Observations

$Z_{65S-90S}$



Z500



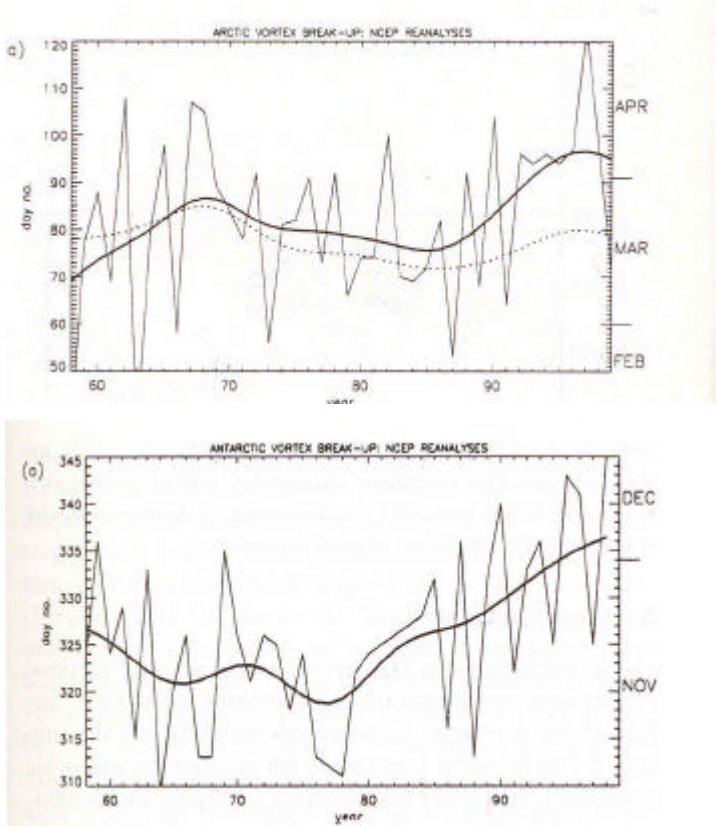
DJFMAM trends

•The NAM exhibits considerably variability that is independent of the stratosphere.
•But the NAM also repeatedly emerges in association with variations that appear to be stratospheric in origin, e.g.:
- the ~60 day timescale;
- the QBO;
- volcanic aerosols;
- trends (particularly in association with SH ozone losses).

Next…

Warrick Norton: modeling the impact of the stratosphere on the troposphere…
Peter Haynes: likely mechanisms…

Recent climate trends and the stratosphere



From Kodera and Yamazaki 1994