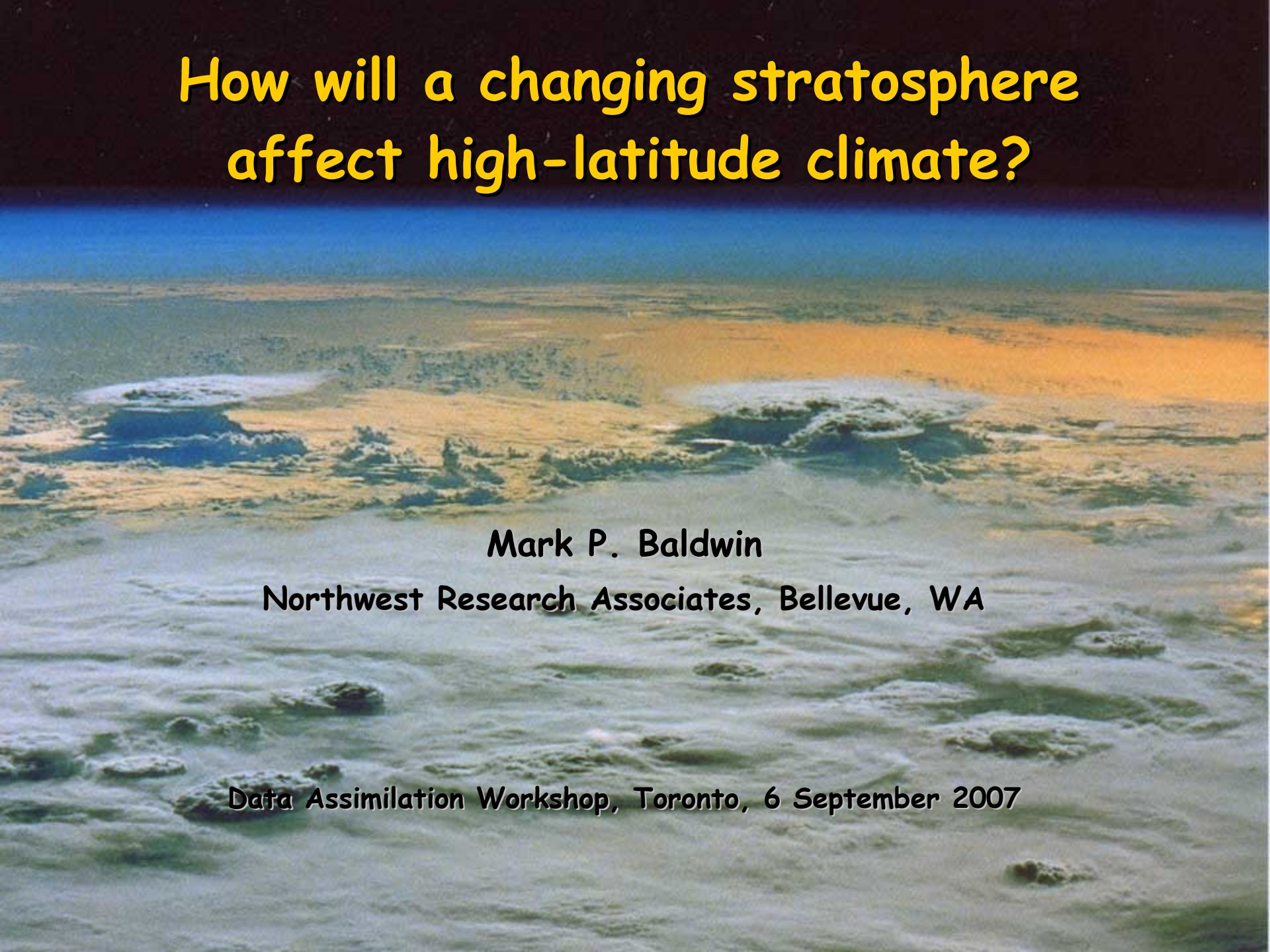
How will a changing stratosphere affect high-latitude climate?



Mark P. Baldwin

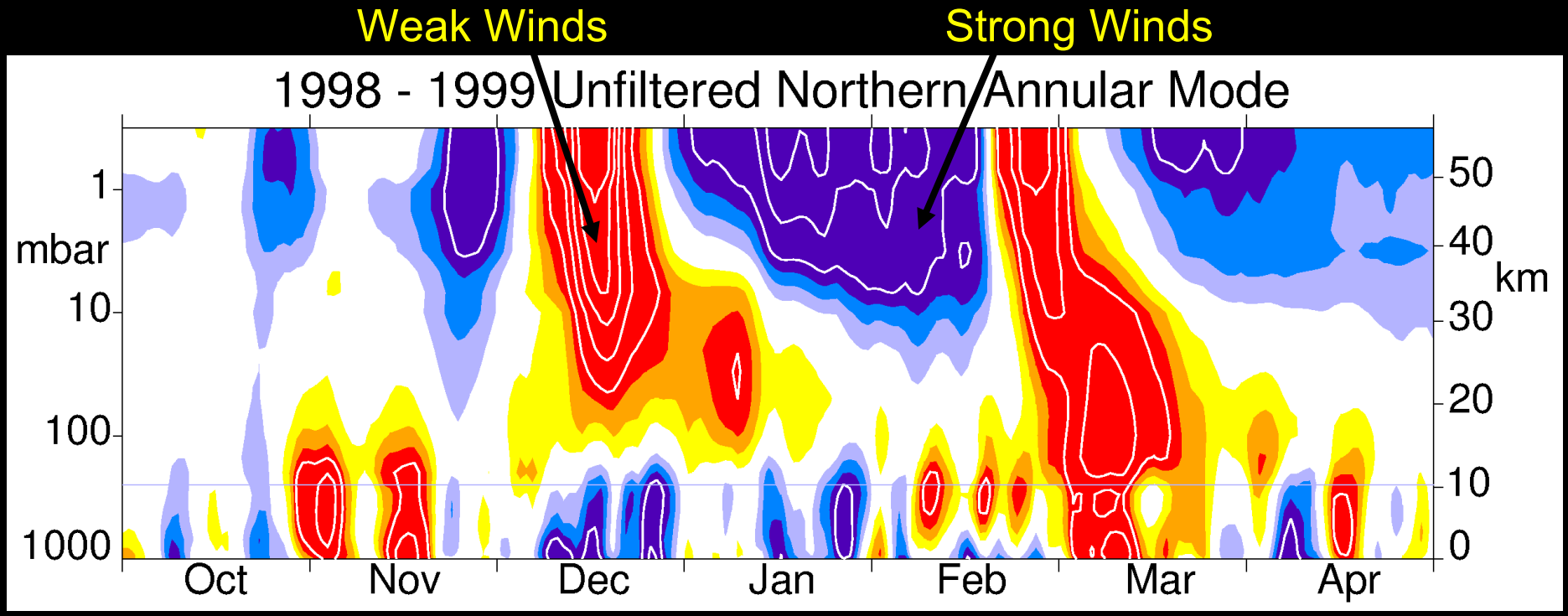
Northwest Research Associates, Bellevue, WA

Data Assimilation Workshop, Toronto, 6 September 2007

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Outline

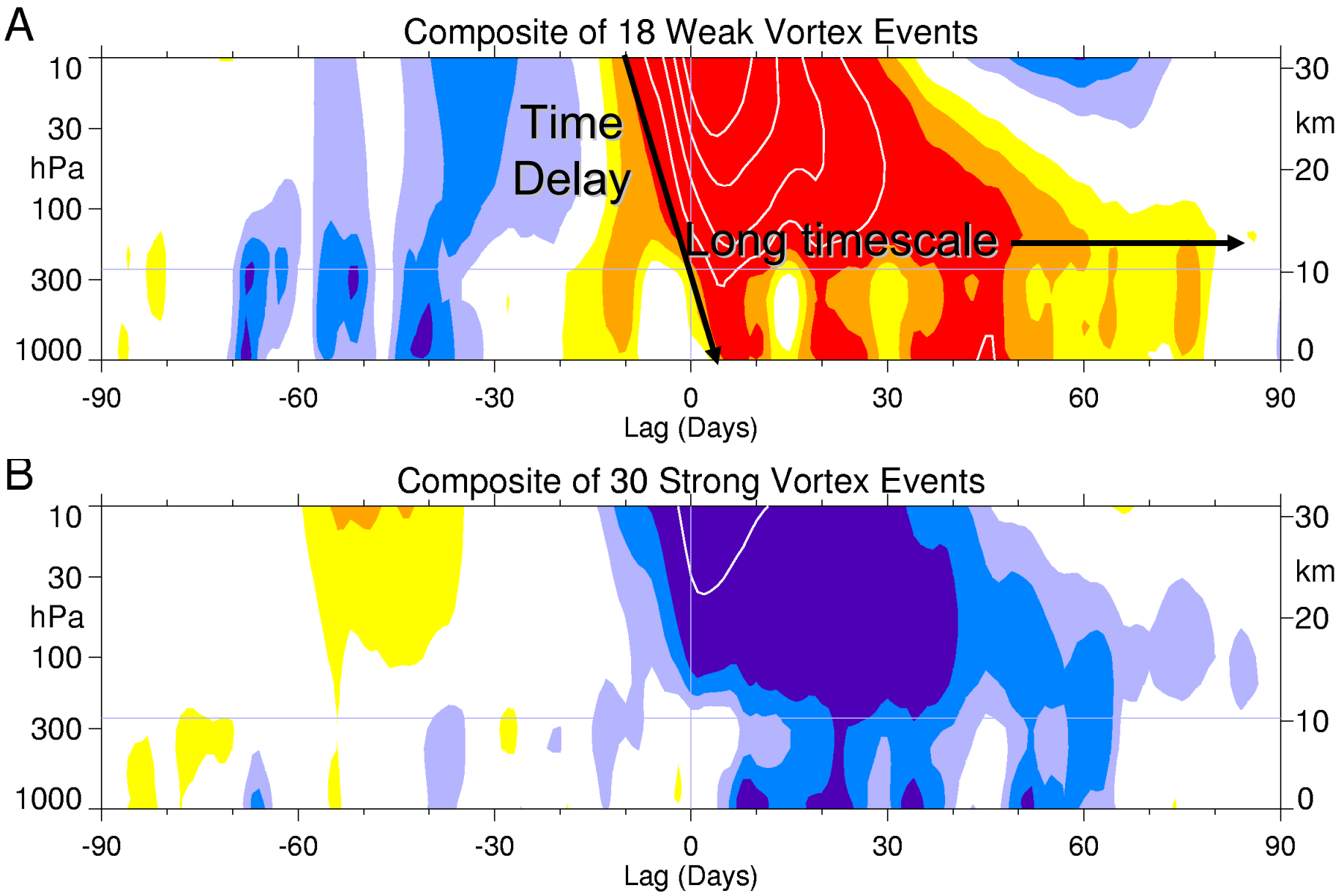
- Evidence that stratospheric changes affect high northern latitudes.
- Evidence that ozone loss has affected Antarctic climate.
- Projections of future climate.
- Some possible model diagnostics of stratosphere/troposphere coupling.
- How confident are we in predictions of the future?



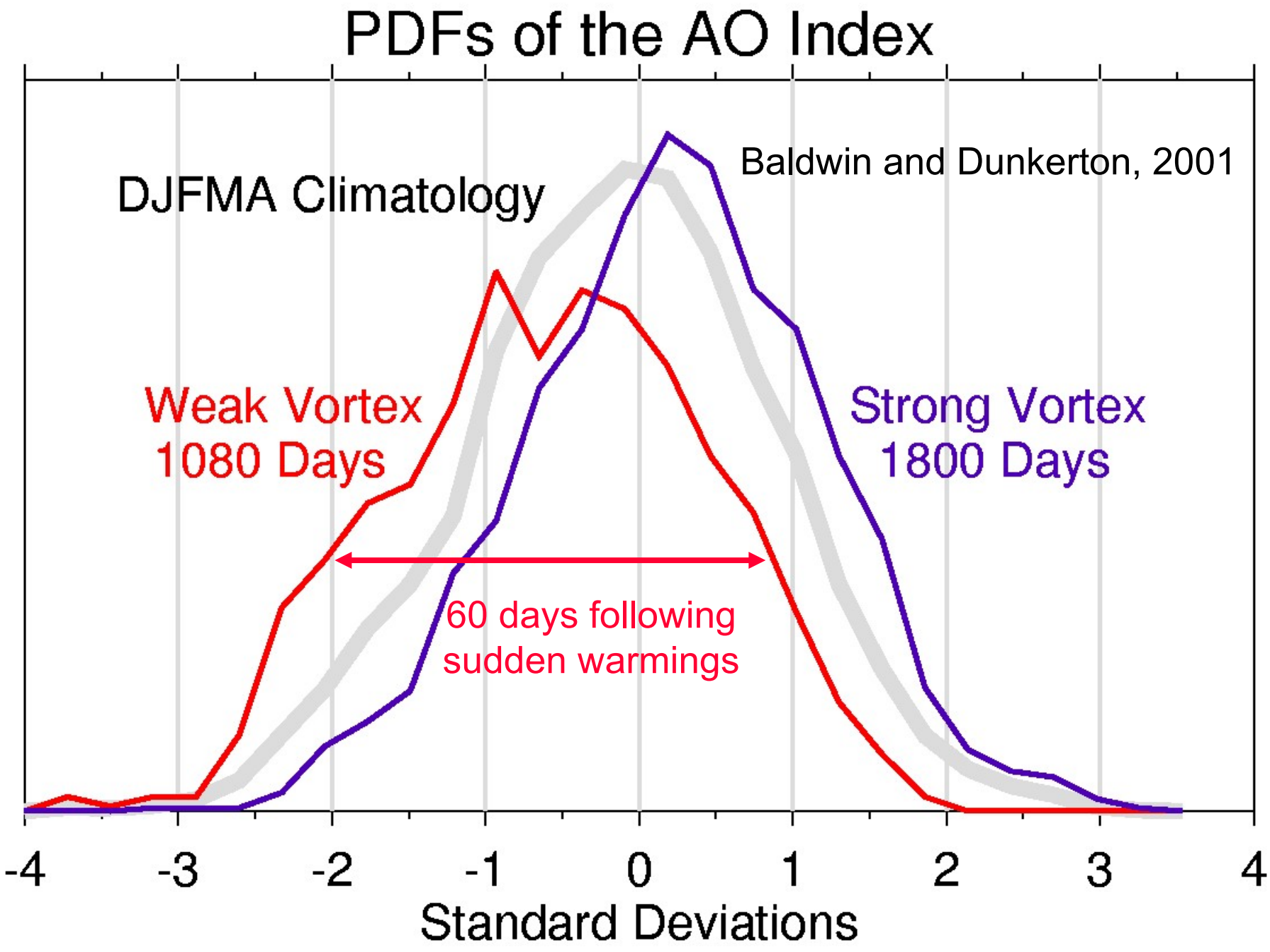
NAM index for 1998–1999.

The lowest level is the AO index.

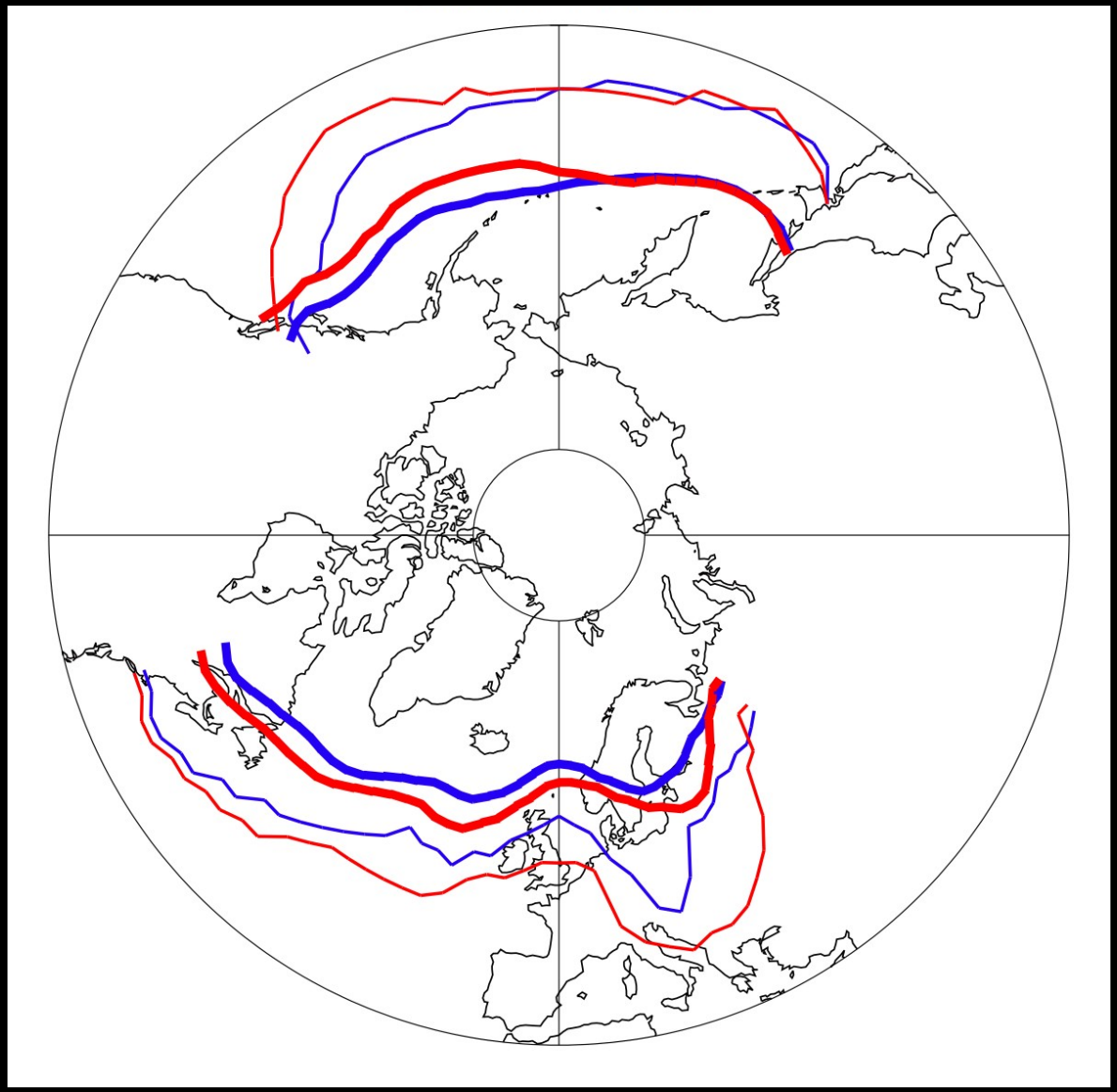
From Baldwin and Dunkerton, Science 2001

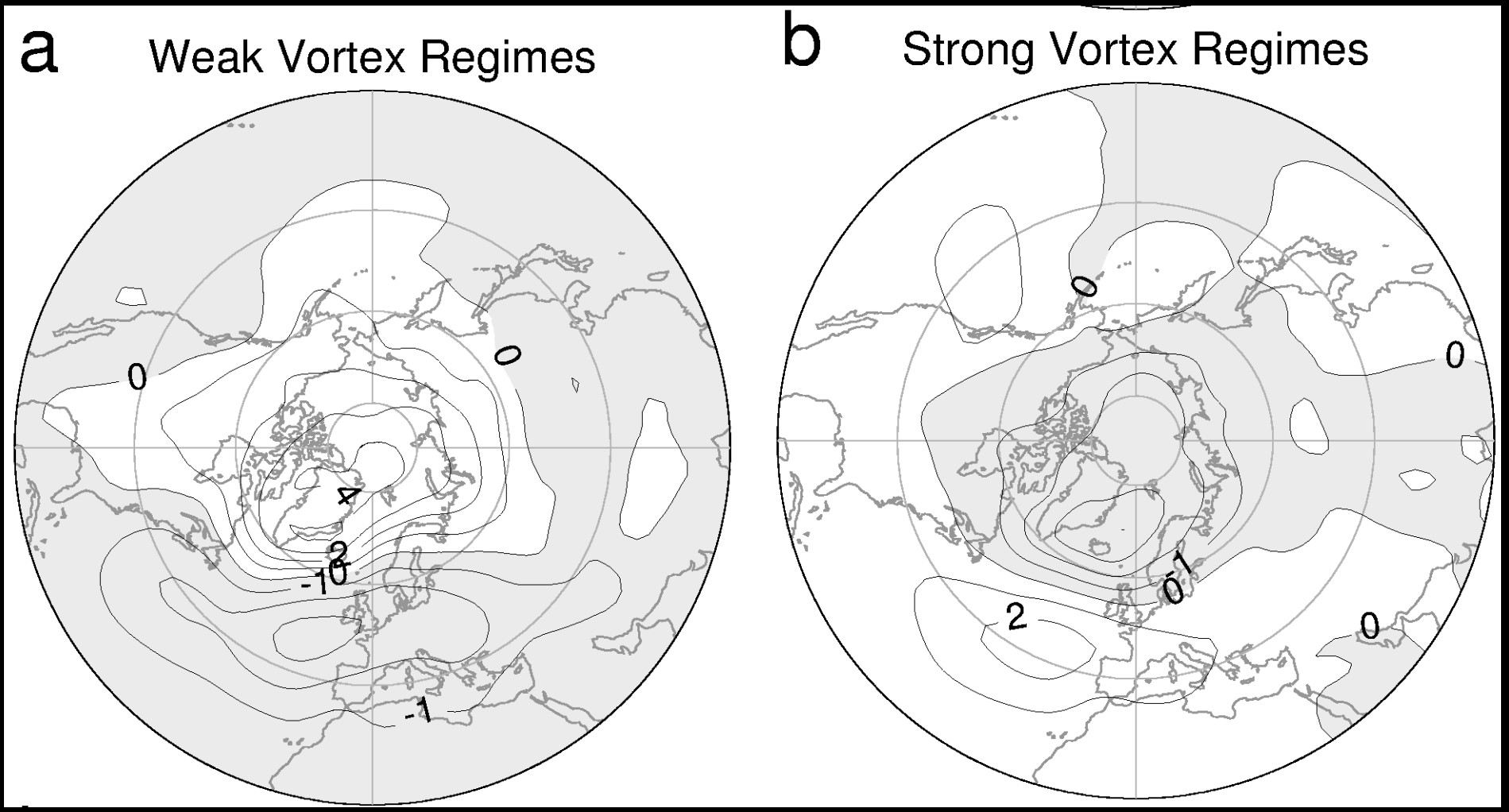


Baldwin and Dunkerton, 2001


PDFs of the AO Index
DJFMA Climatology
Baldwin and Dunkerton, 2001
Weak Vortex
1080 Days
Strong Vortex
1800 Days
60 days following
sudden warmings
-4
-3
-2
-1
0
1
2
3
4
Standard Deviations

Storm tracks during weak and strong regimes



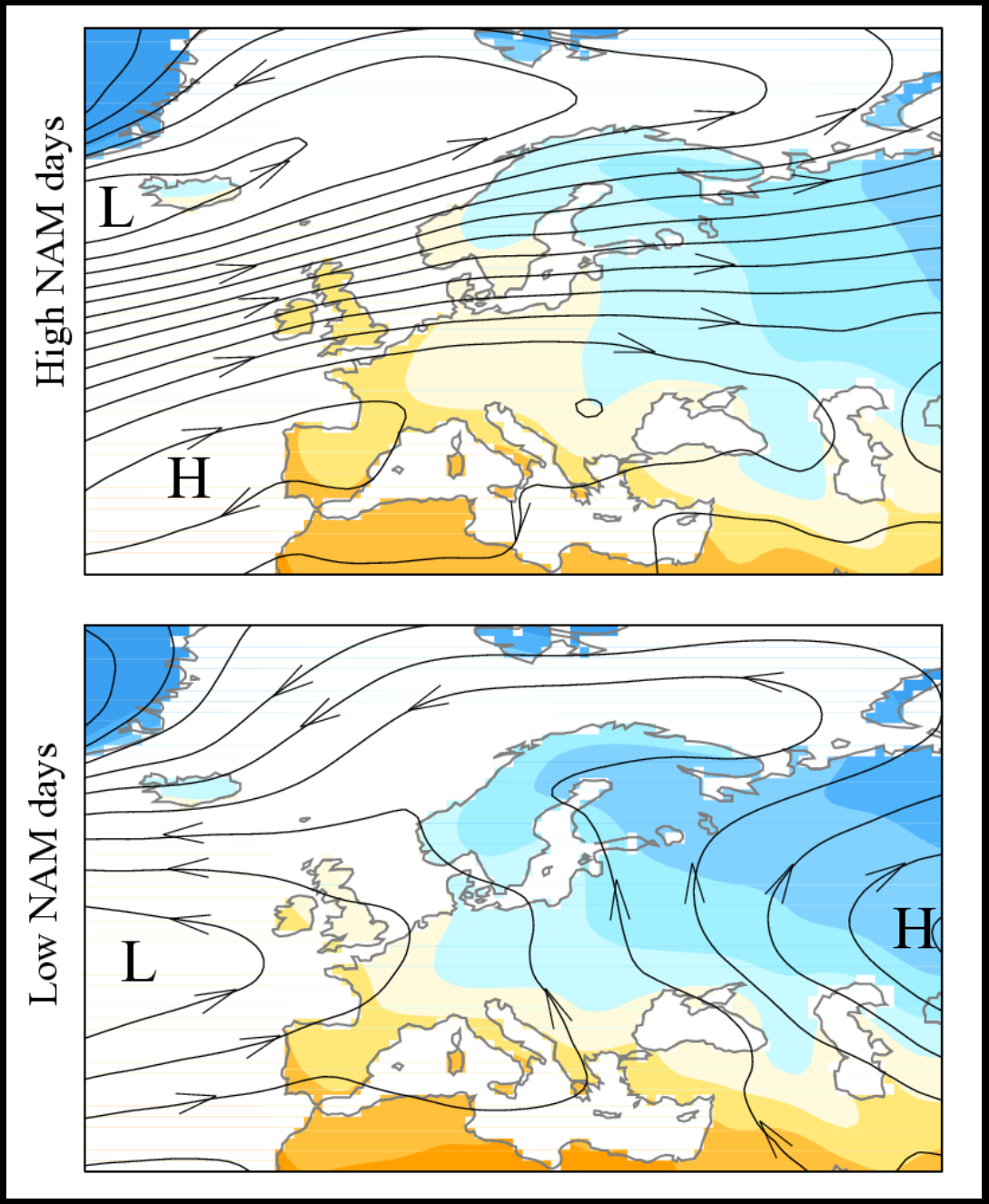


Surface pressure anomalies after stratospheric events look like the Arctic Oscillation.

Baldwin and Dunkerton, 2001

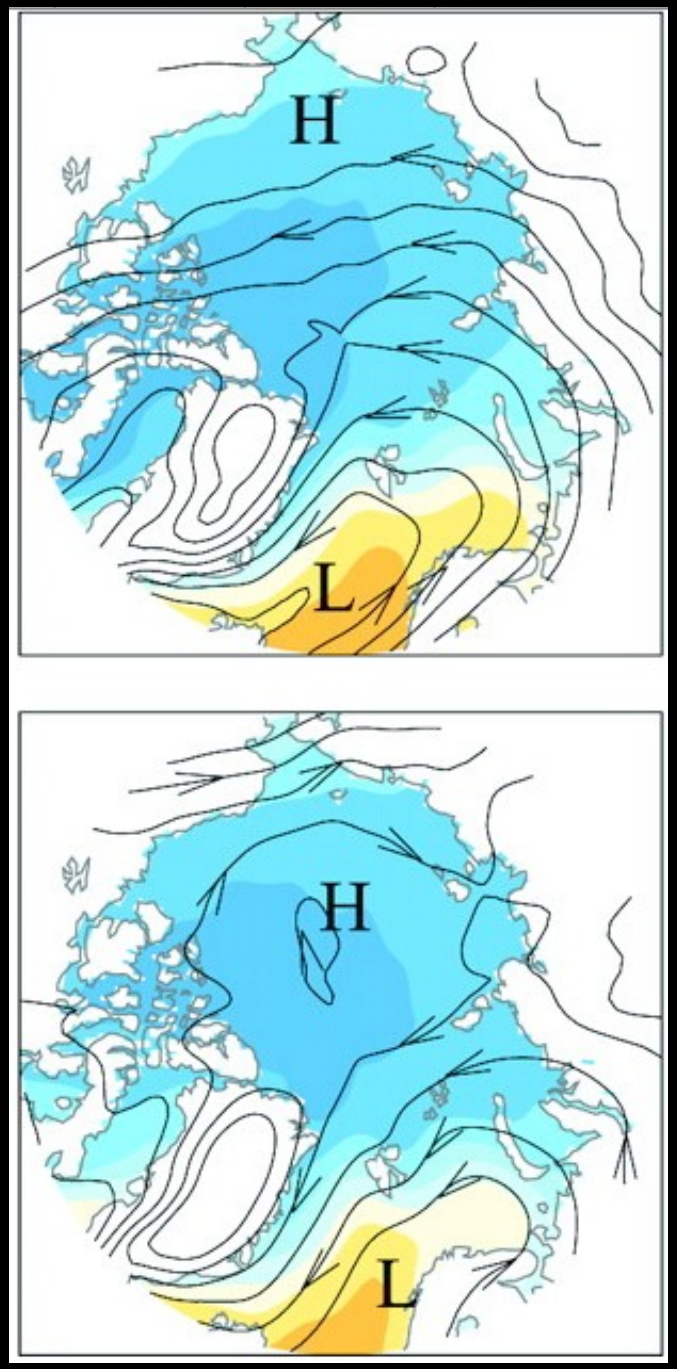
Possible Dynamical Mechanisms

- Direct effect of stratospheric wave driving and stratospheric temperature anomalies (Thompson et al., 2006)
- Indirect effects involving waves
- Effect on baroclinic waves/life cycles
- Effect on planetary-scale waves
- Wave reflection in the stratosphere



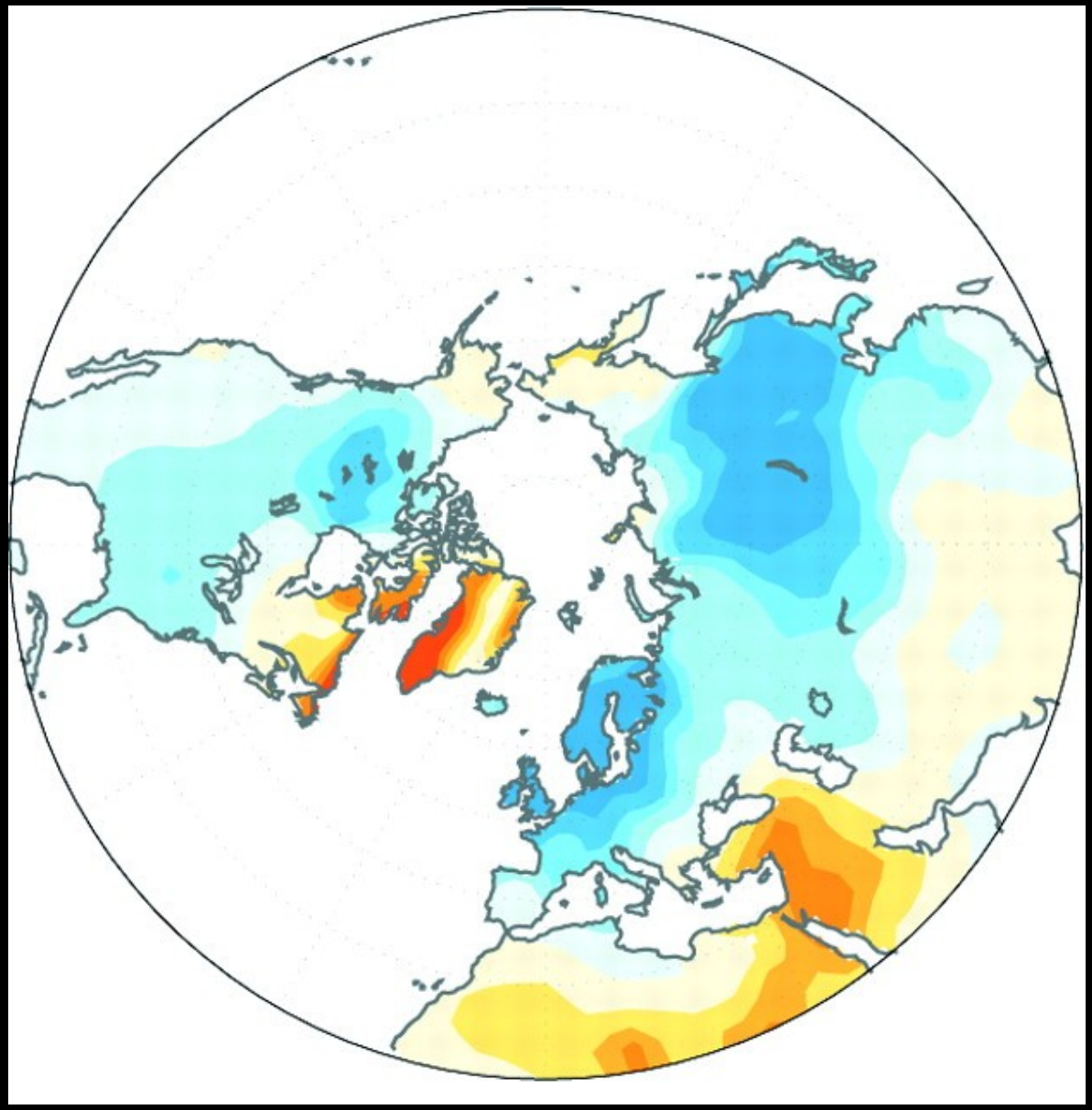
Composite surface maps for high and low AO index.

(From Thompson and Wallace, *Science* 2001)



Composite surface maps for high and low AO index.

(From Thompson and Wallace, *Science* 2001)



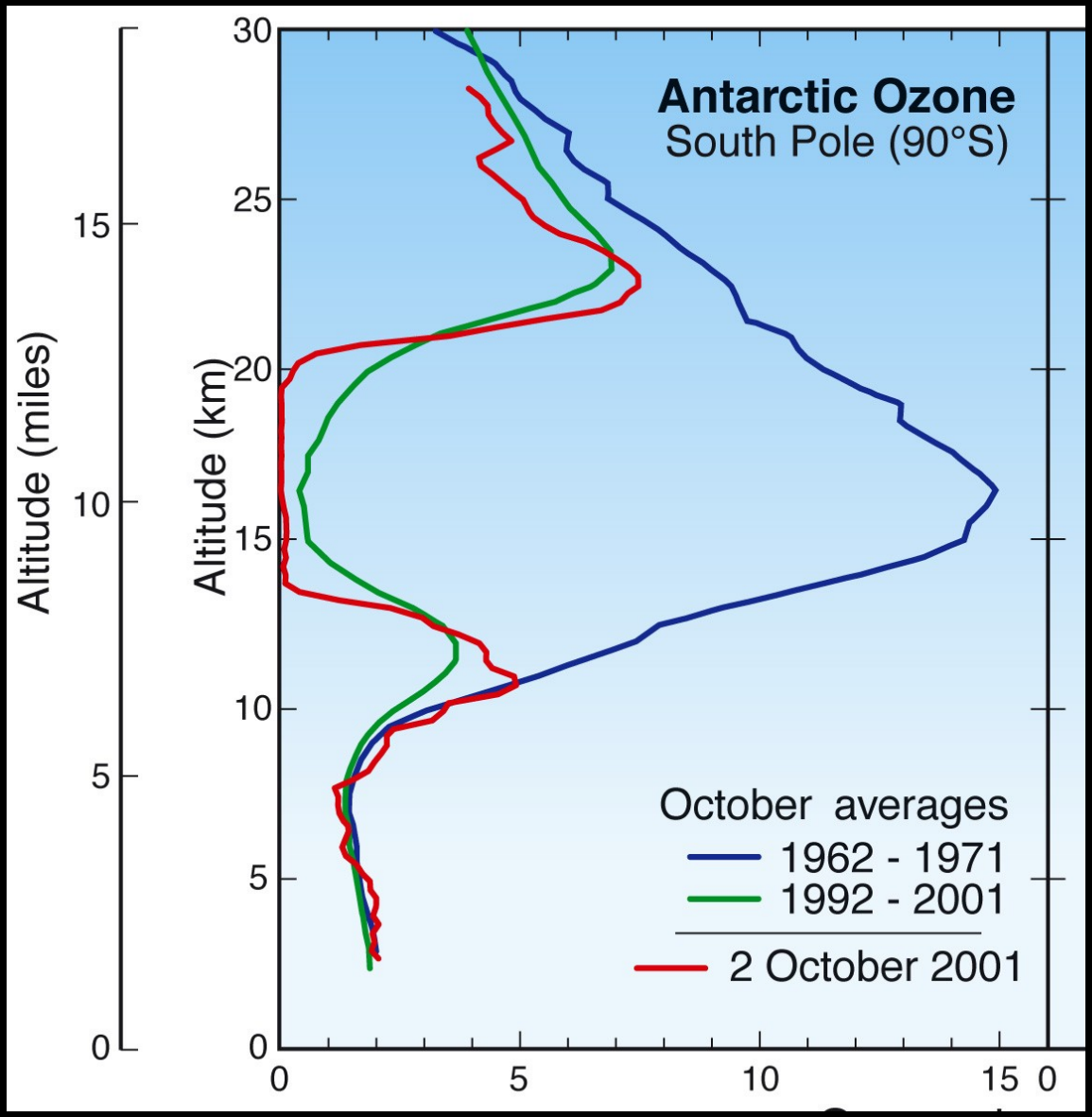
Ratio of the frequency of occurrence of cold events, between high NAM and low NAM index days.

(From Thompson and Wallace, *Science* 2001)

Southern Hemisphere surface climate response to ozone depletion

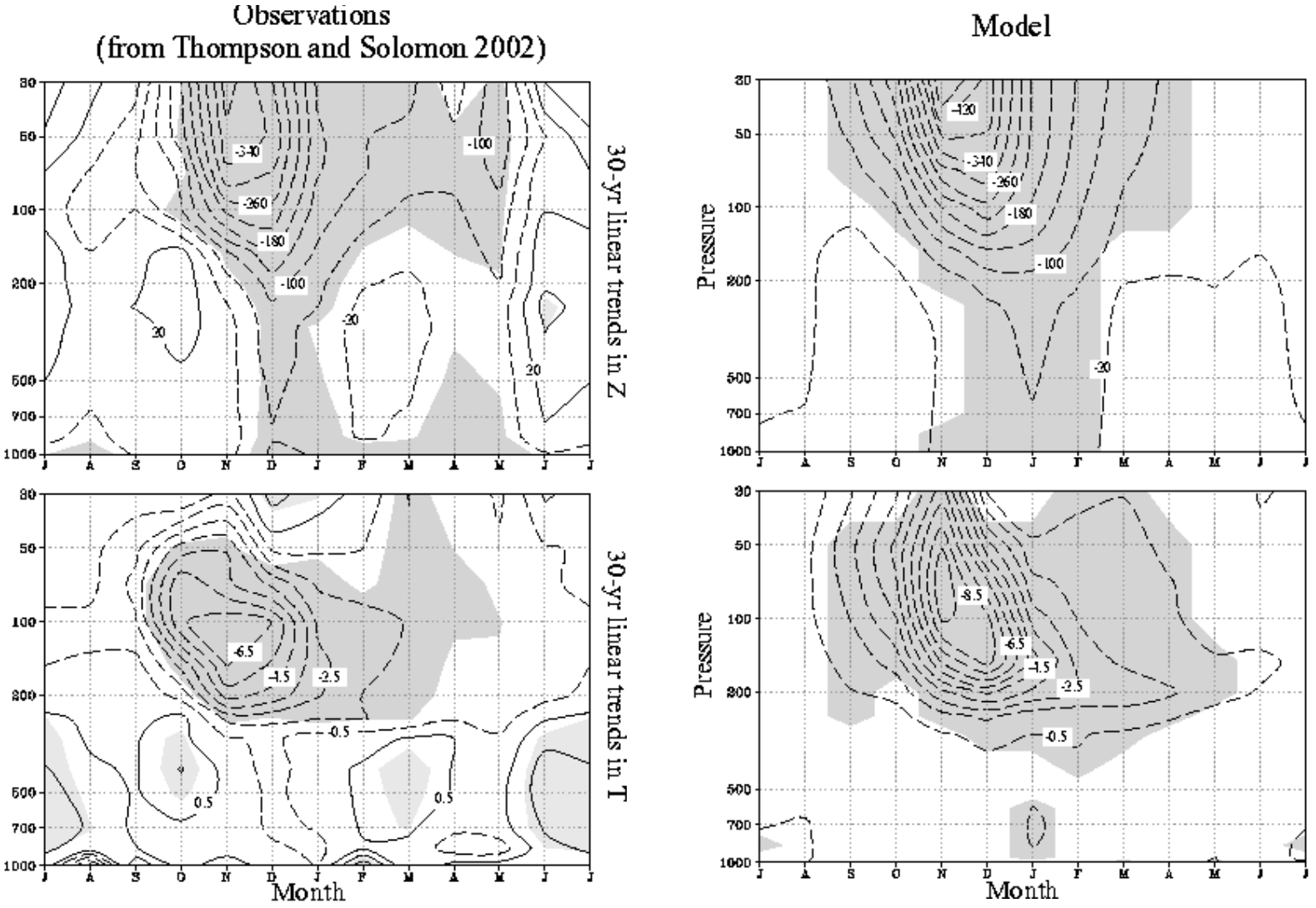
- Observations and model
- Springtime ozone loss appears to drive changes in surface climate from late spring to summer.

Ozone Depletion



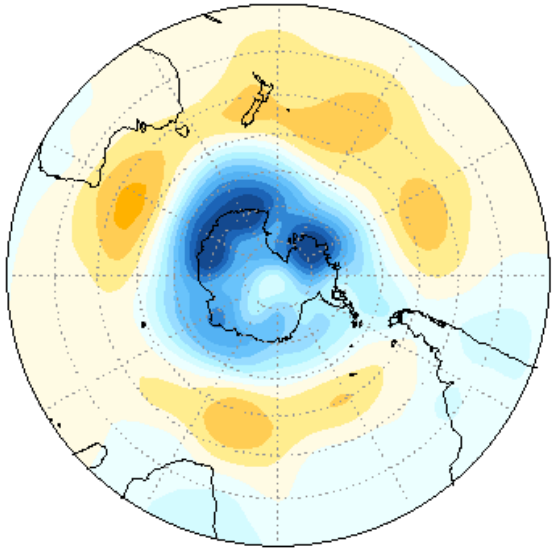
Simulated and observed geopotential height and temperature changes

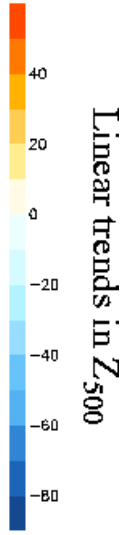
Model results from Gillett & Thompson, Science 2003



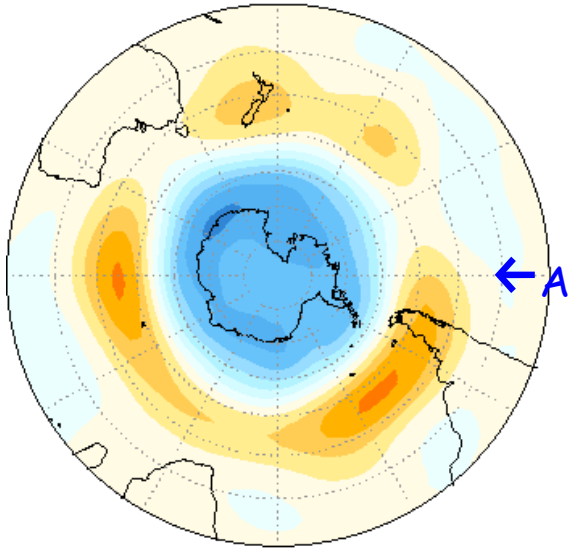
Tropospheric changes

Observations
(from Thompson and Solomon 2002)

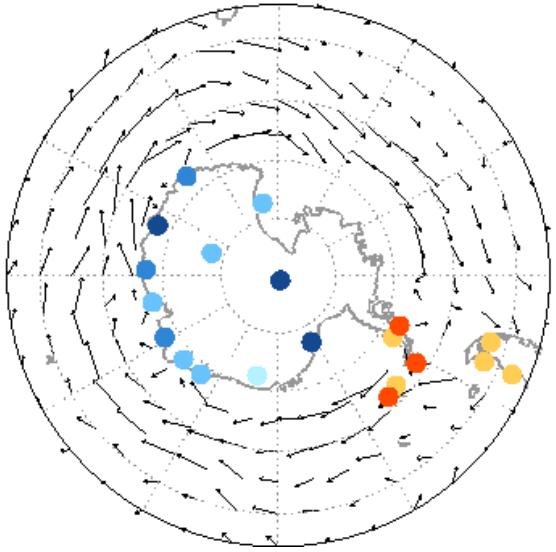


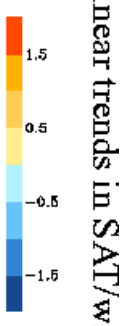


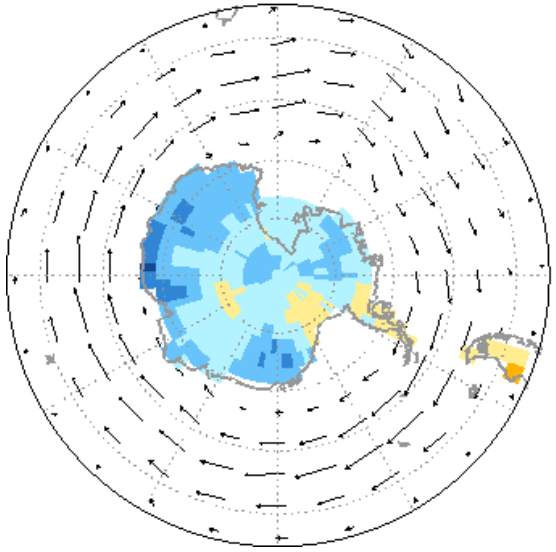
Model



← Annular Mode pattern



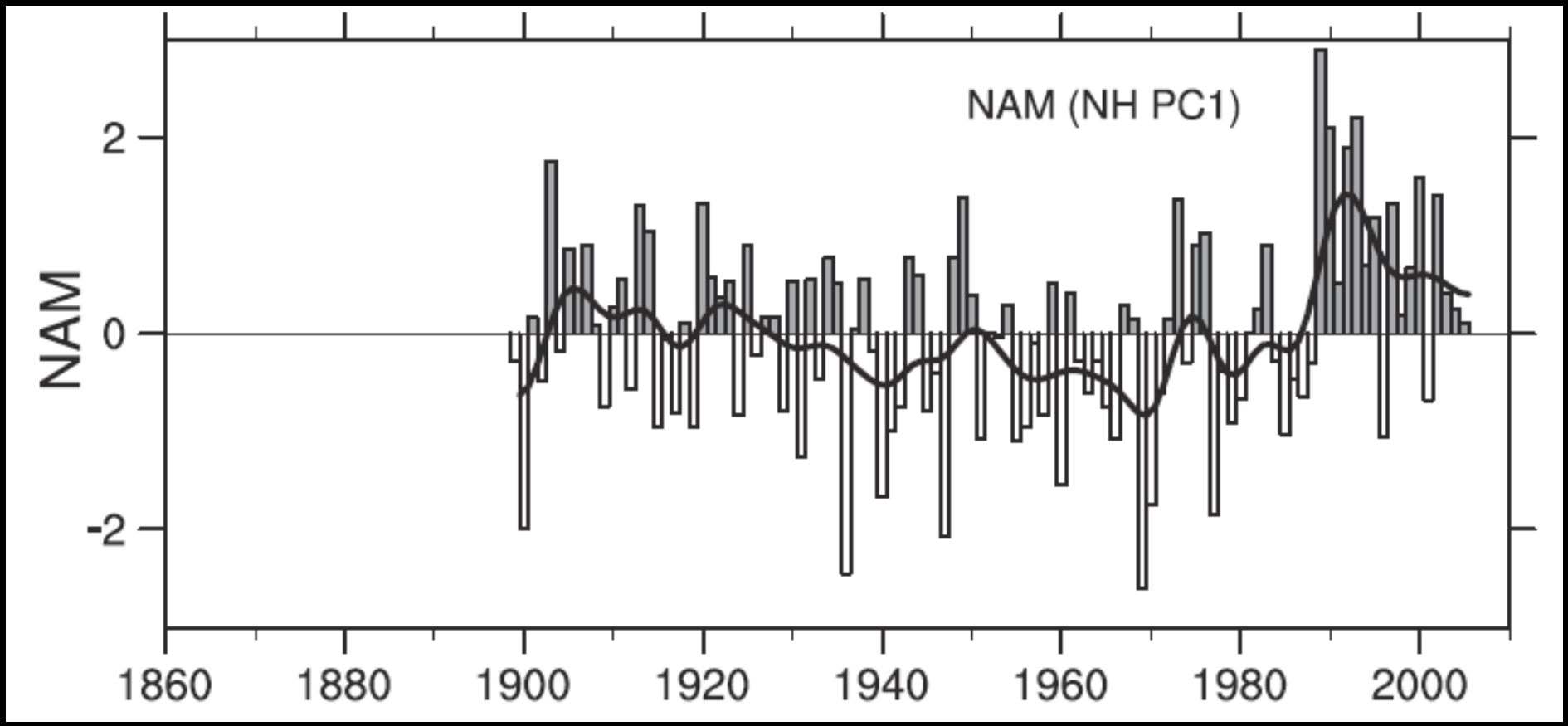


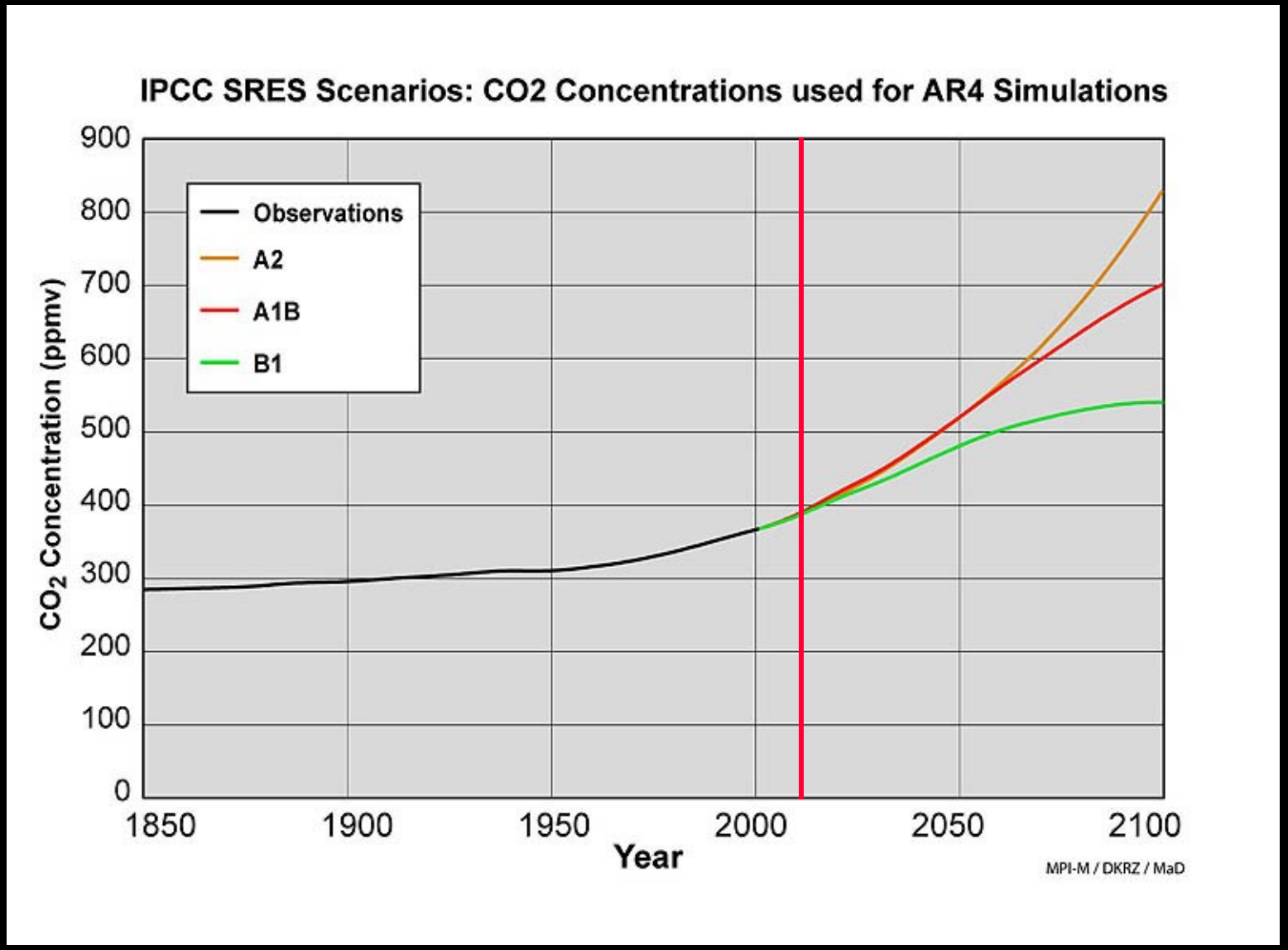


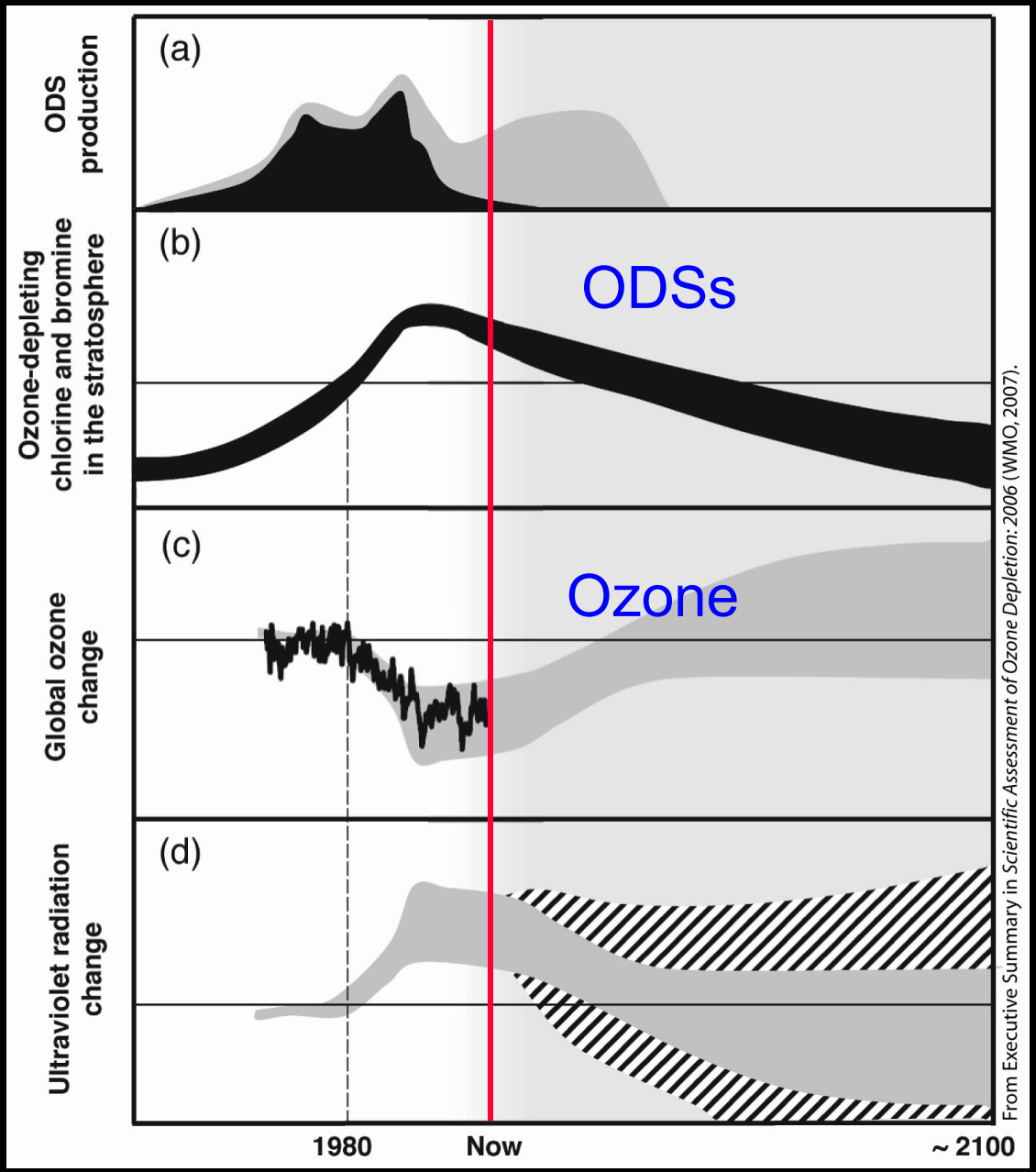
Model results from Gillett & Thompson, 2003

Projections of future climate

- Increasing Greenhouse gases
- Ozone recovery
- IPCC-type models
- Chemistry-climate models


NAM (NH PC1)
NAM
2
0
-2
1860
1880
1900
1920
1940
1960
1980
2000

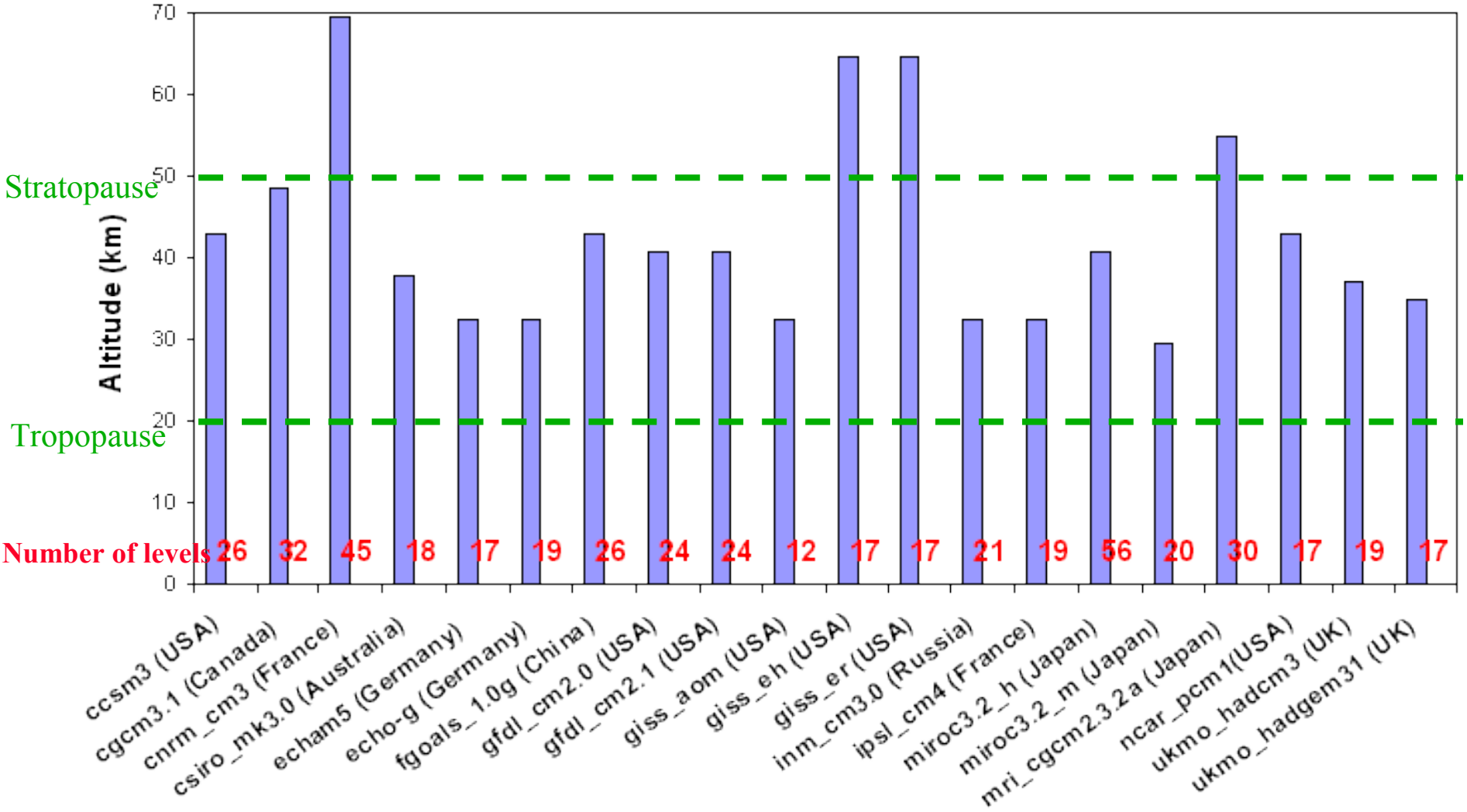

IPCC SRES Scenarios: CO2 Concentrations used for AR4 Simulations
Observations
A2
A1B
B1
CO2 Concentration (ppmv)
900
800
700
600
500
400
300
200
100
0
1850
1900
1950
2000
2050
2100
Year
MPI-M / DKRZ / MaD


(a)
ODS production
(b)
Ozone-depleting chlorine and bromine in the stratosphere
ODSs
(c)
Global ozone change
Ozone
(d)
Ultraviolet radiation change
1980
Now
~ 2100
From Executive Summary in Scientific Assessment of Ozone Depletion: 2006 (WMO, 2007).

Ozone recovery vs. increasing GHGs

- Ozone depleting substances are already decreasing.
- Ozone abundances will be increasing.
- GHGs will continue to increase.
- Ozone recovery will not be a simple reversal of ozone depletion.

IPCC: Altitude of the Model Top



(From Eugene Cordero)

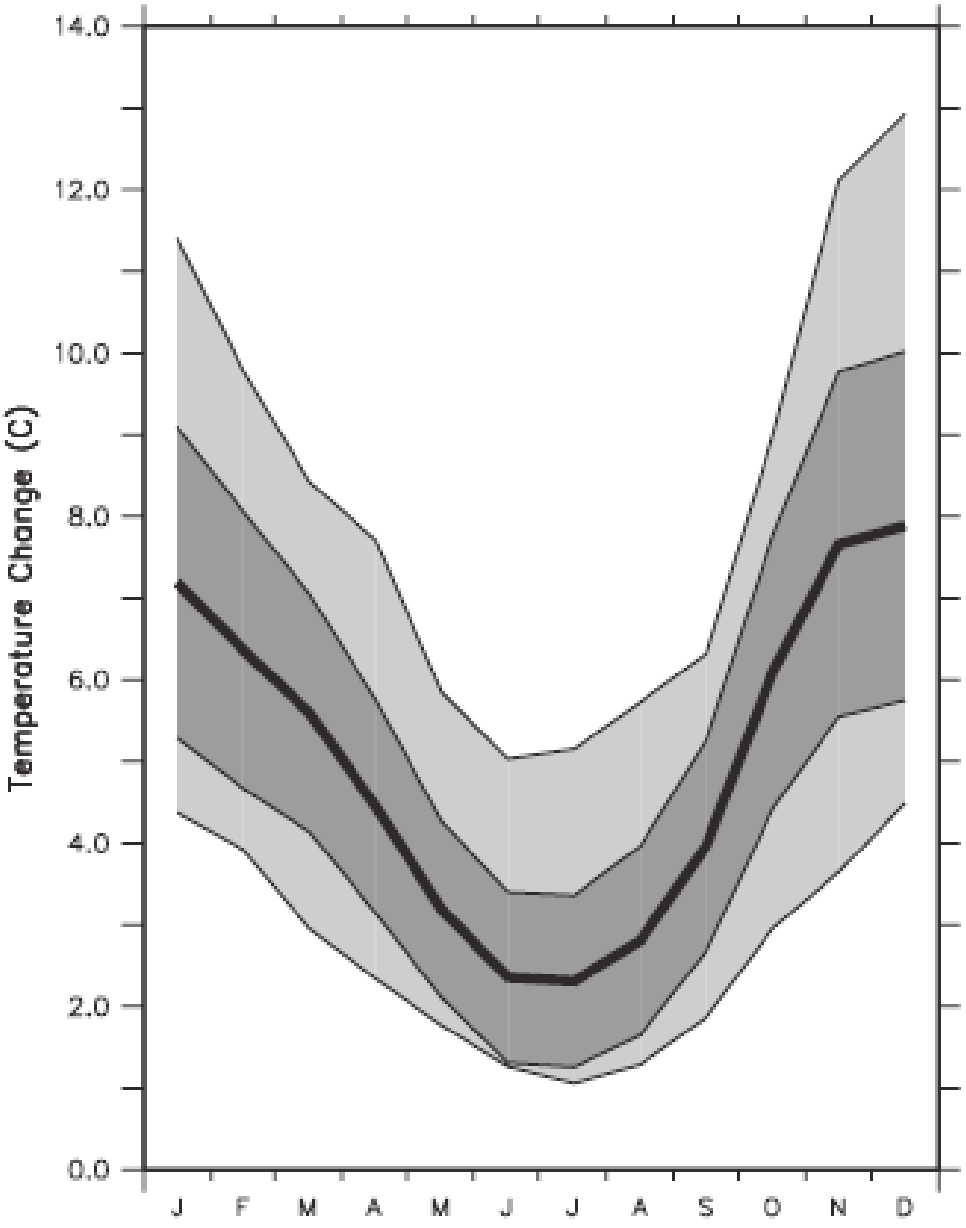
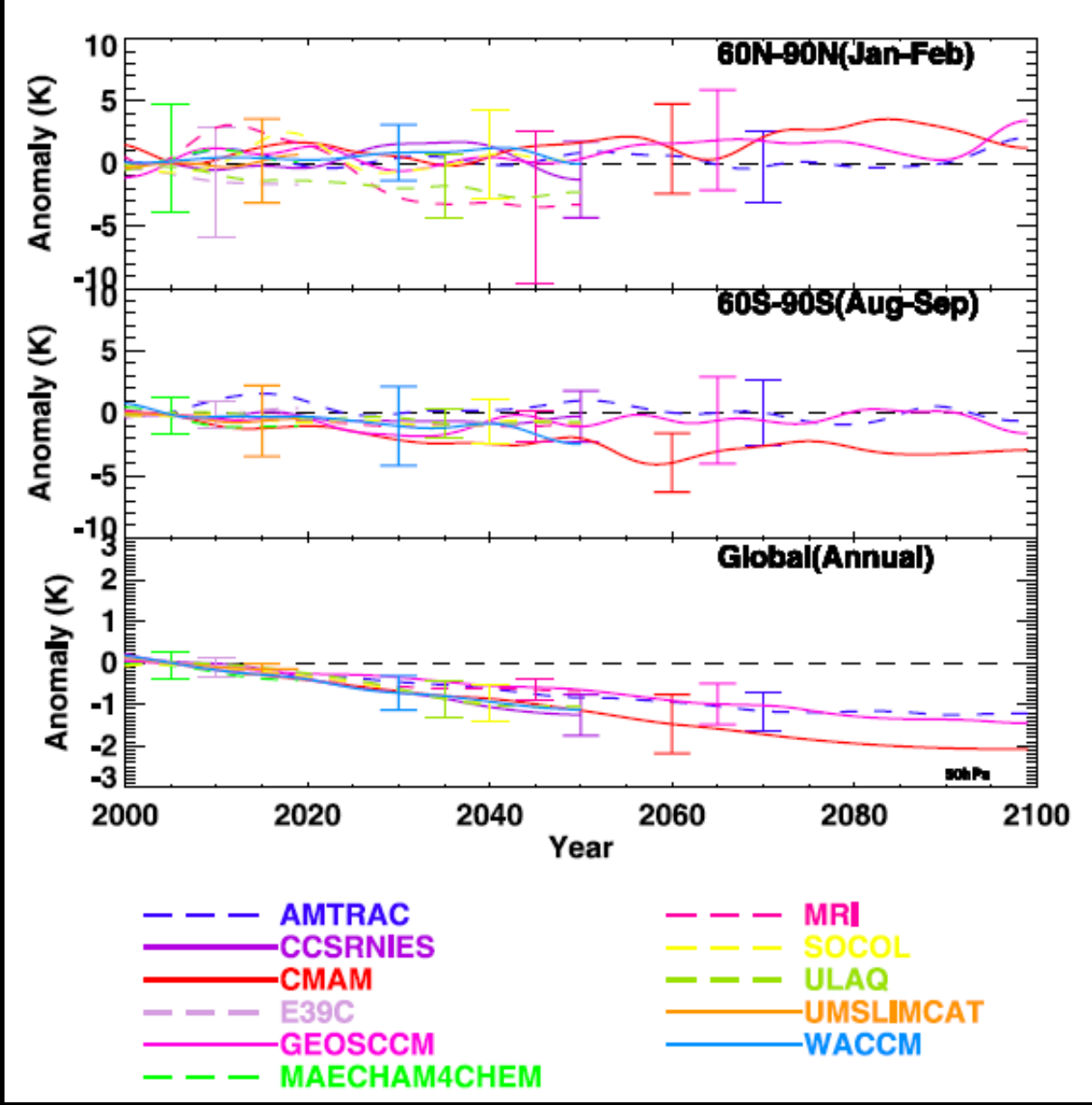


Figure 11.19. *Annual cycle of arctic area mean temperature and percentage precipitation changes (averaged over the area north of 60°N) for 2080 to 2099 minus 1980 to 1999, under the A1B scenario. Thick lines represent the ensemble median of the 21 MMD models. The dark grey area represents the 25 and 75% quartile values among the 21 models, while the light grey area shows the total range of the models.*

IPCC Arctic T change projections, 2080-2099 minus 1980-1999

How will the stratosphere change?



From Eyring et al., 2007

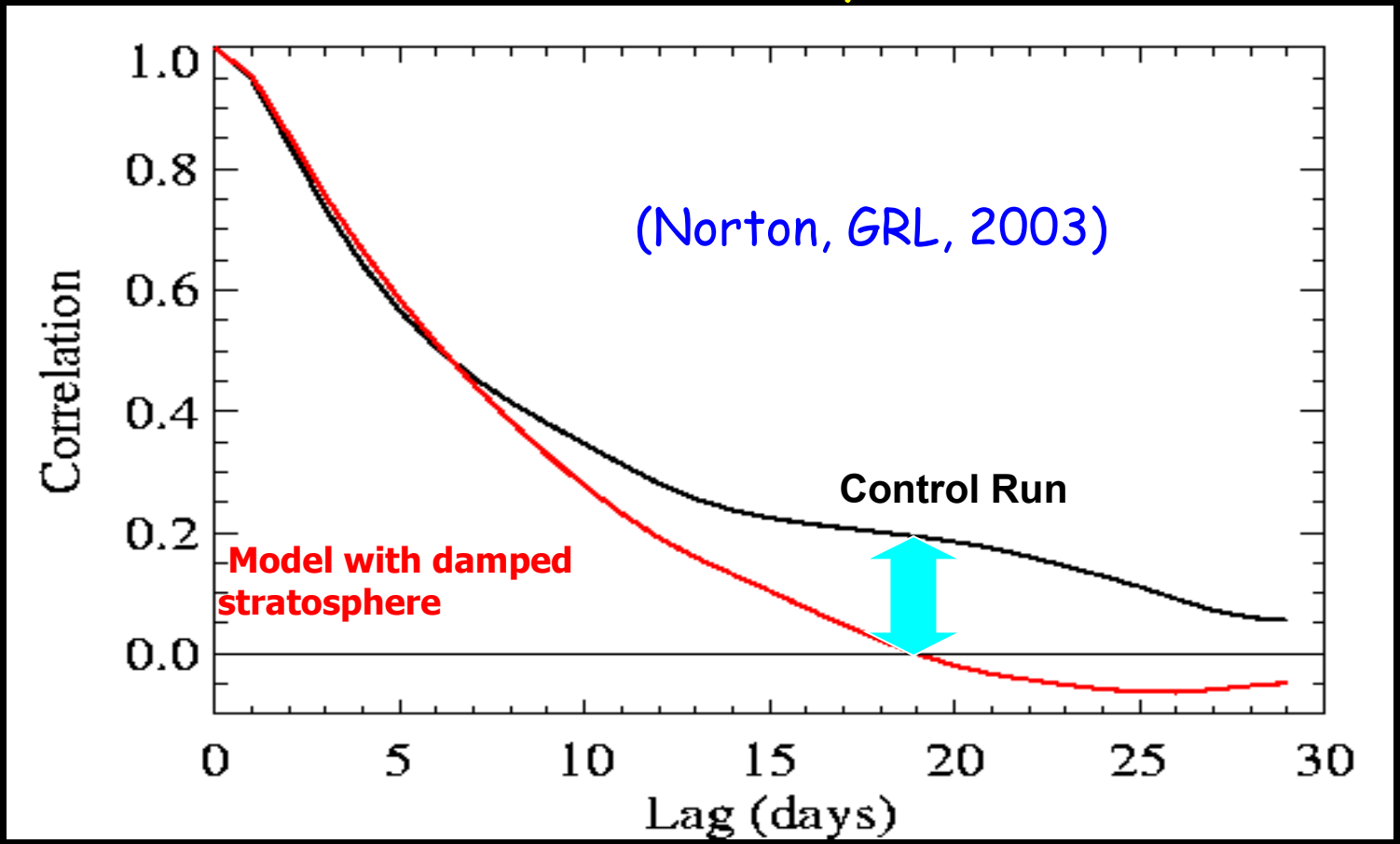
How stratospheric change will affect surface climate depends on:

1) trends in the strength of the polar vortex

2) variability of the polar vortex

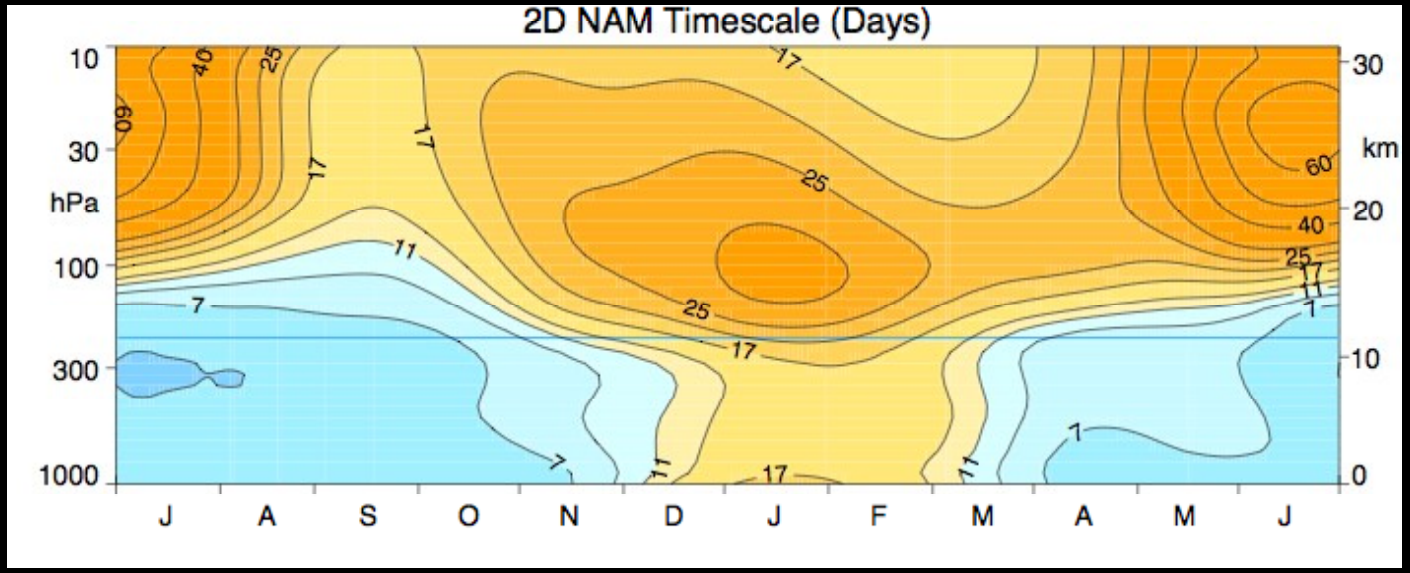
How will the troposphere be affected?

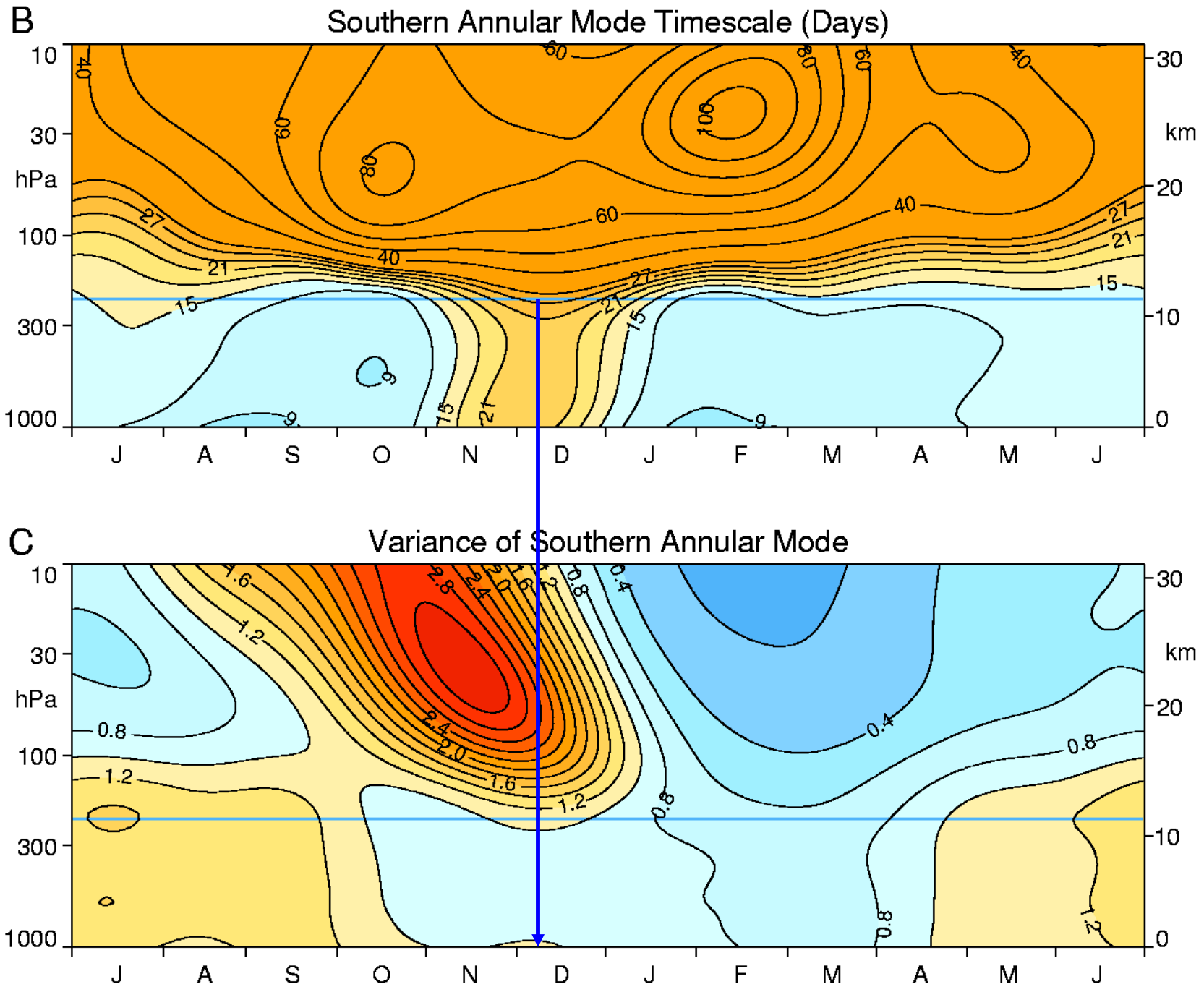
Autocorrelation of daily surface AO index

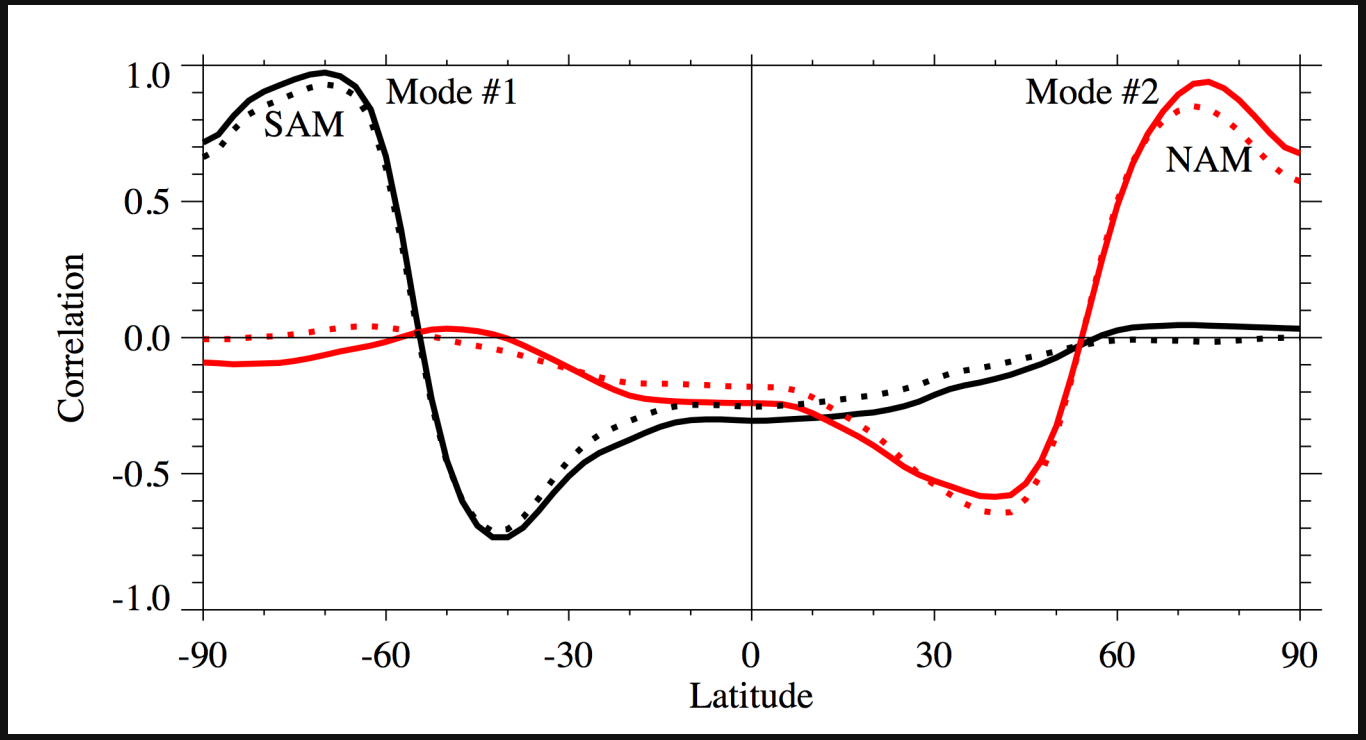


Without stratospheric variability, the timescale of the surface AO is shorter.

How can we assess stratosphere-troposphere coupling in models?

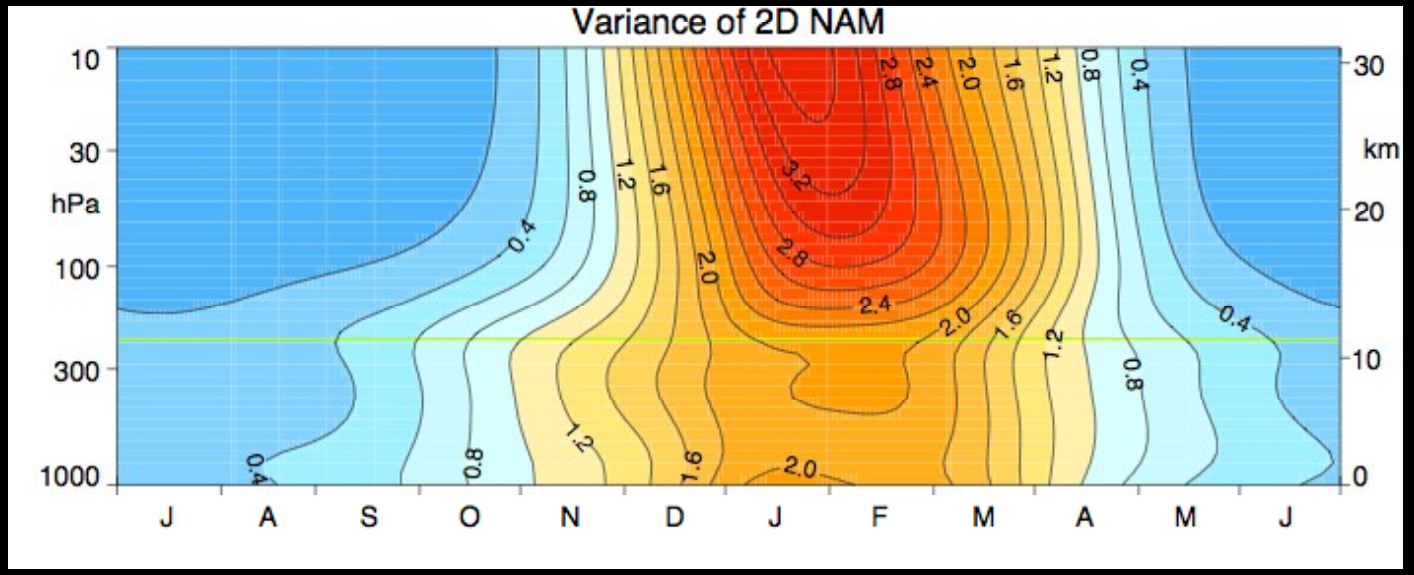

2D NAM Timescale (Days)
10
30
hPa
100
300
1000
30
km
20
10
0
J
A
S
O
N
D
J
F
M
A
M
J
60
40
25
17
11
7
1


B
Southern Annular Mode Timescale (Days)
10
30
hPa
100
300
1000
30
km
20
10
0
J A S O N D J F M A M J
C
Variance of Southern Annular Mode
10
30
hPa
100
300
1000
30
km
20
10
0
J A S O N D J F M A M J



Leading EOFs of daily, zonally-averaged surface pressure.
From Baldwin (2001).

NAM index from *zonally averaged* data (Gerber et al., 2007).


Variance of 2D NAM
10
30
hPa
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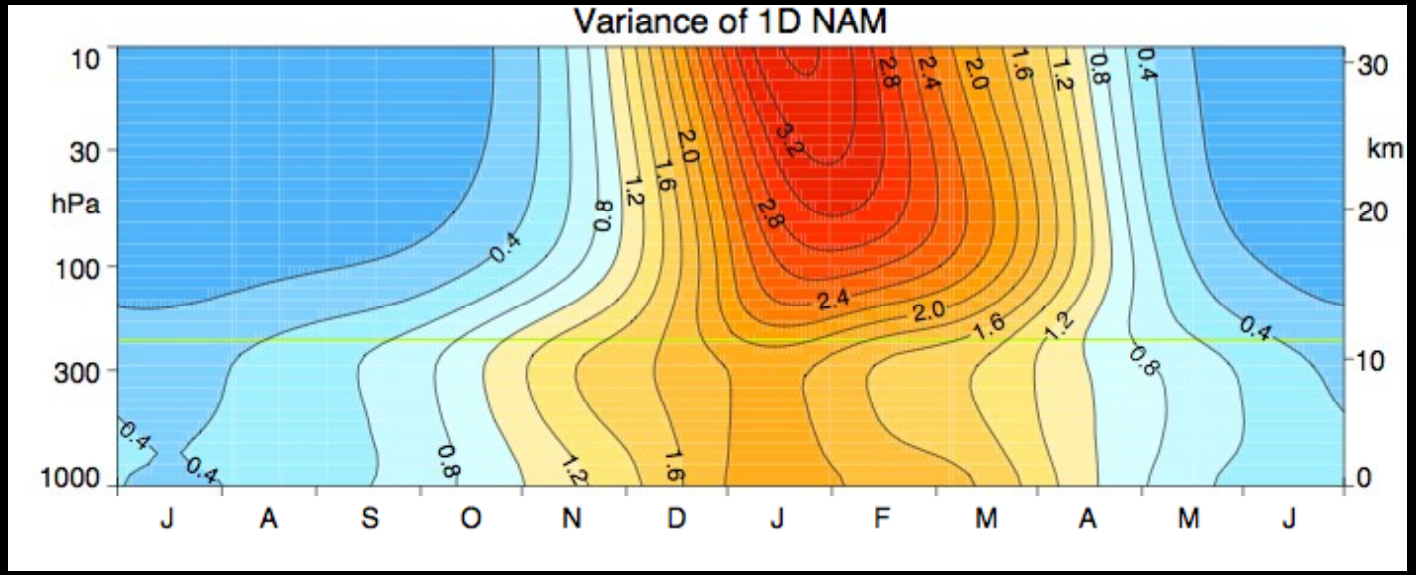
Variance of 1D NAM
10
30
hPa
100
300
1000
30
km
20
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0
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S
O
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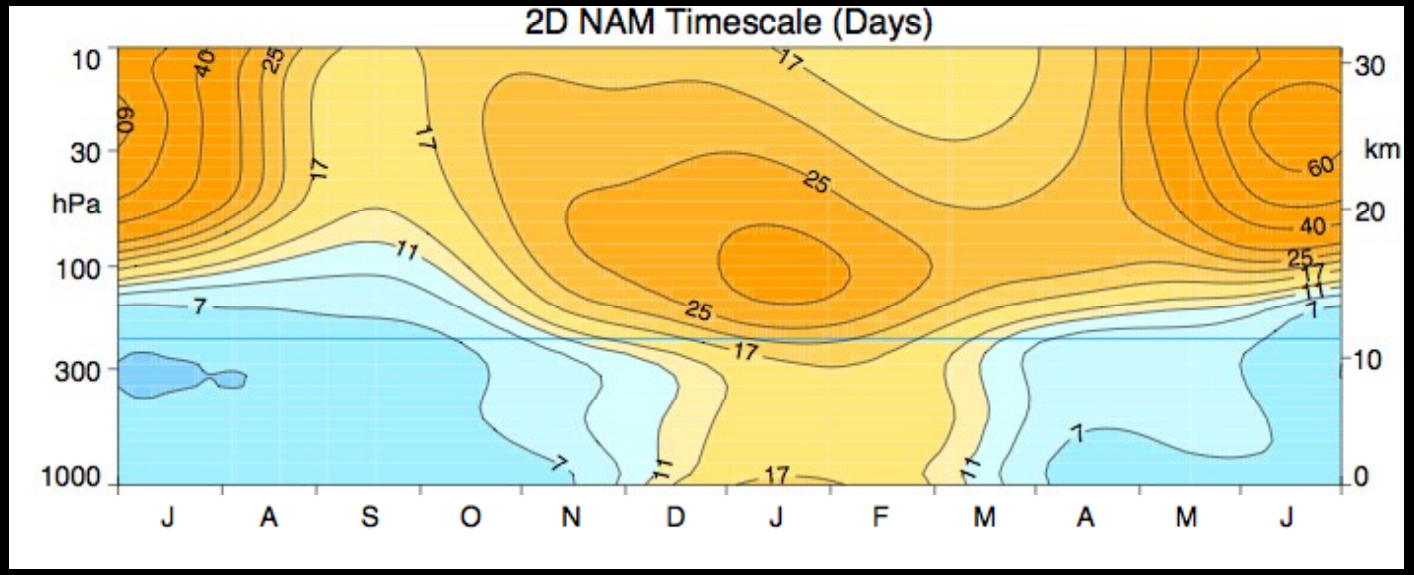
2D NAM Timescale (Days)
10
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hPa
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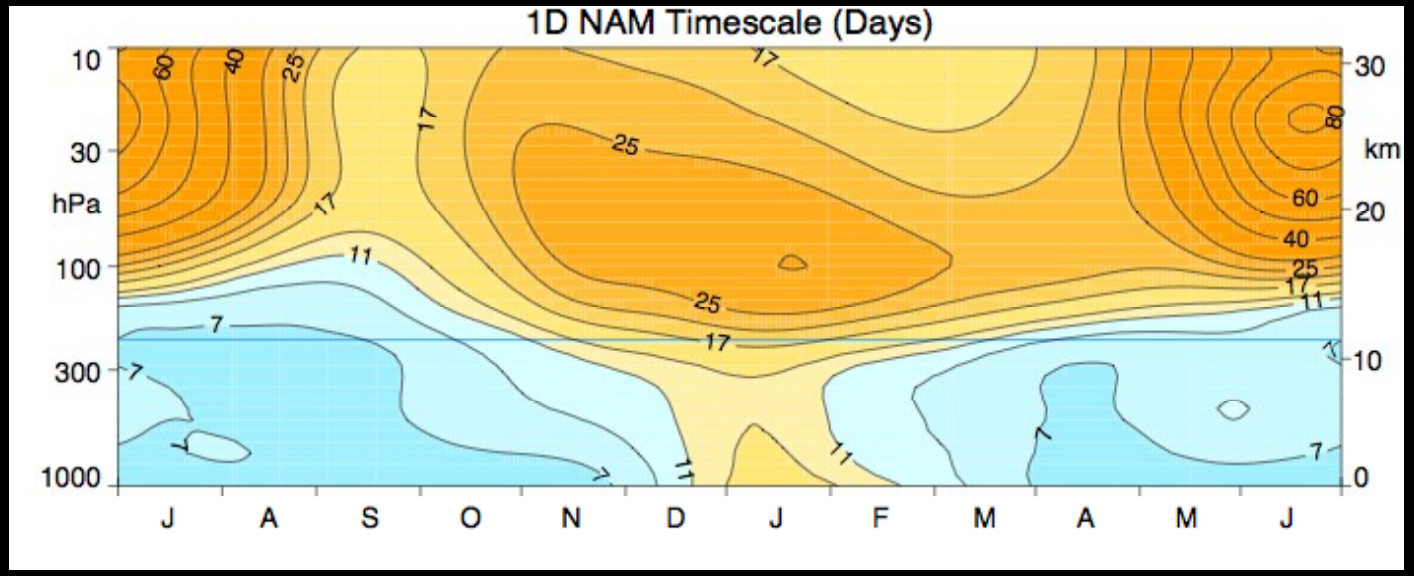
1D NAM Timescale (Days)
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hPa
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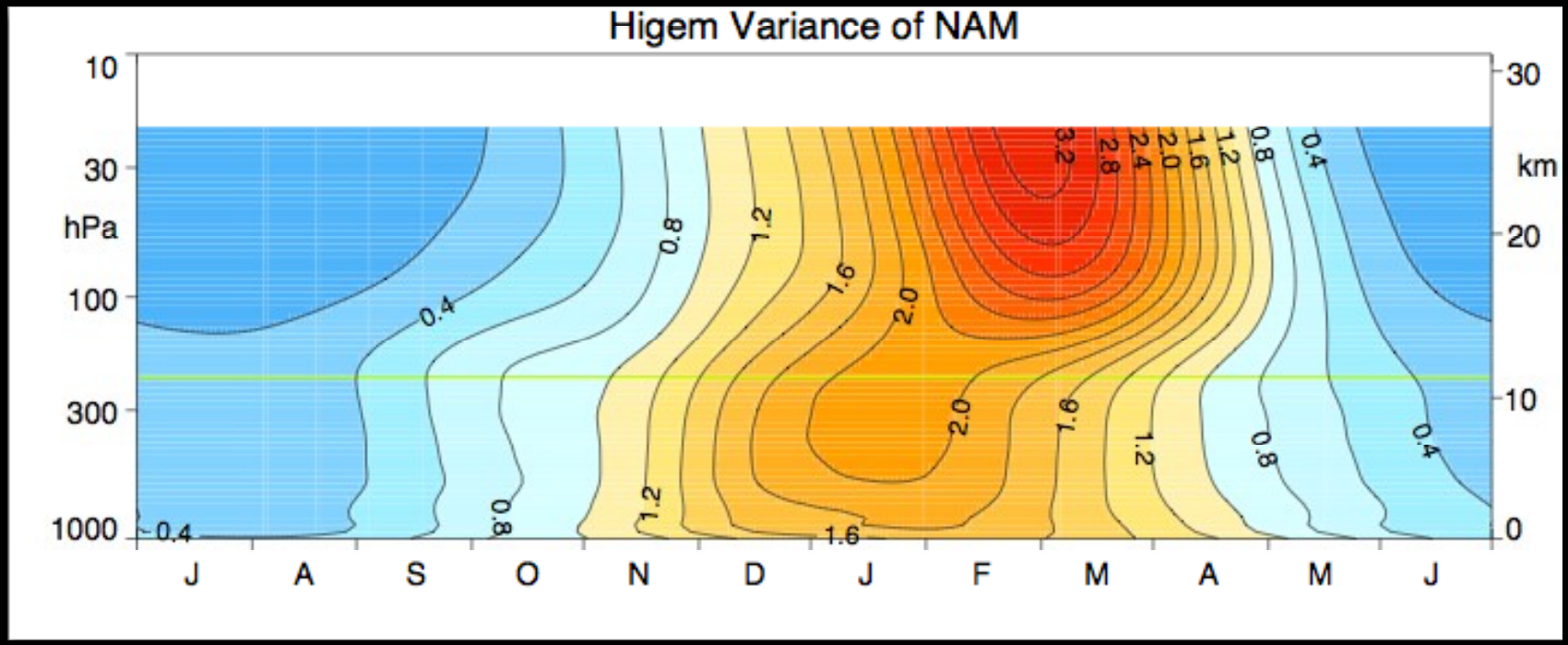
Higem Variance of NAM
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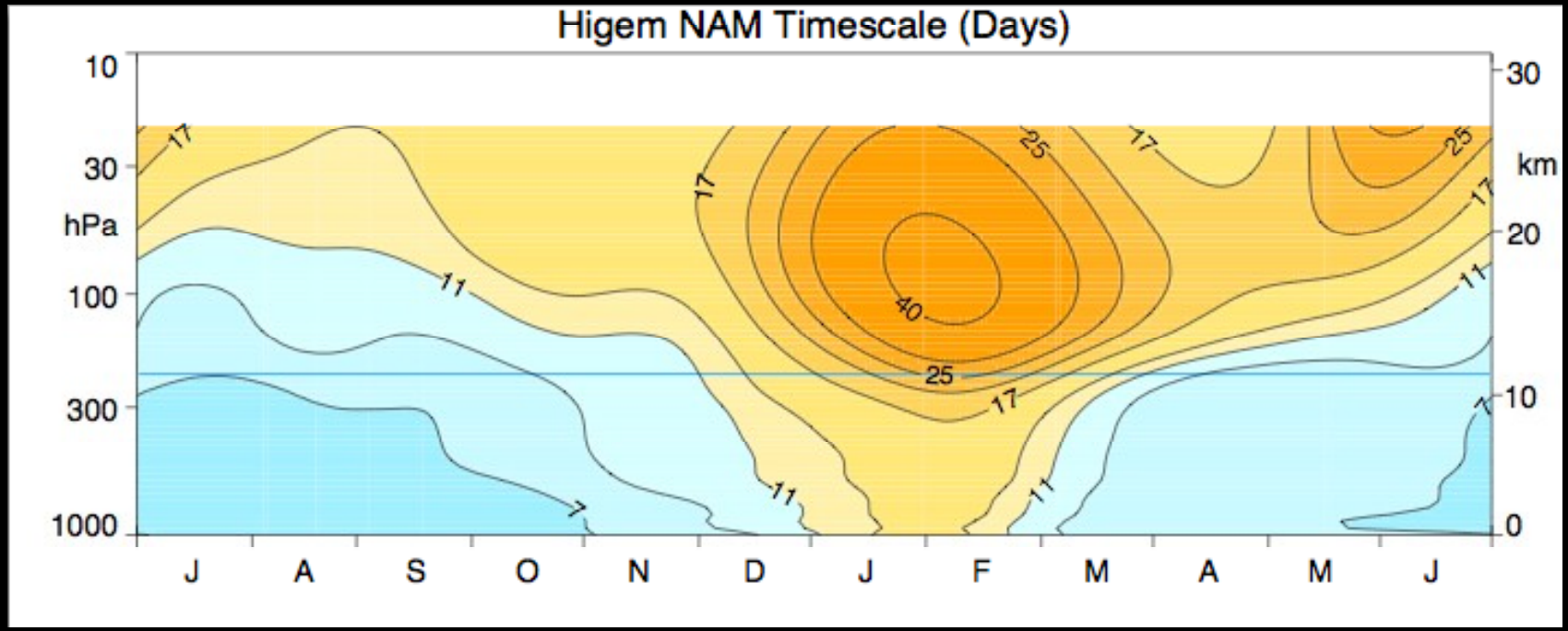
Higem NAM Timescale (Days)
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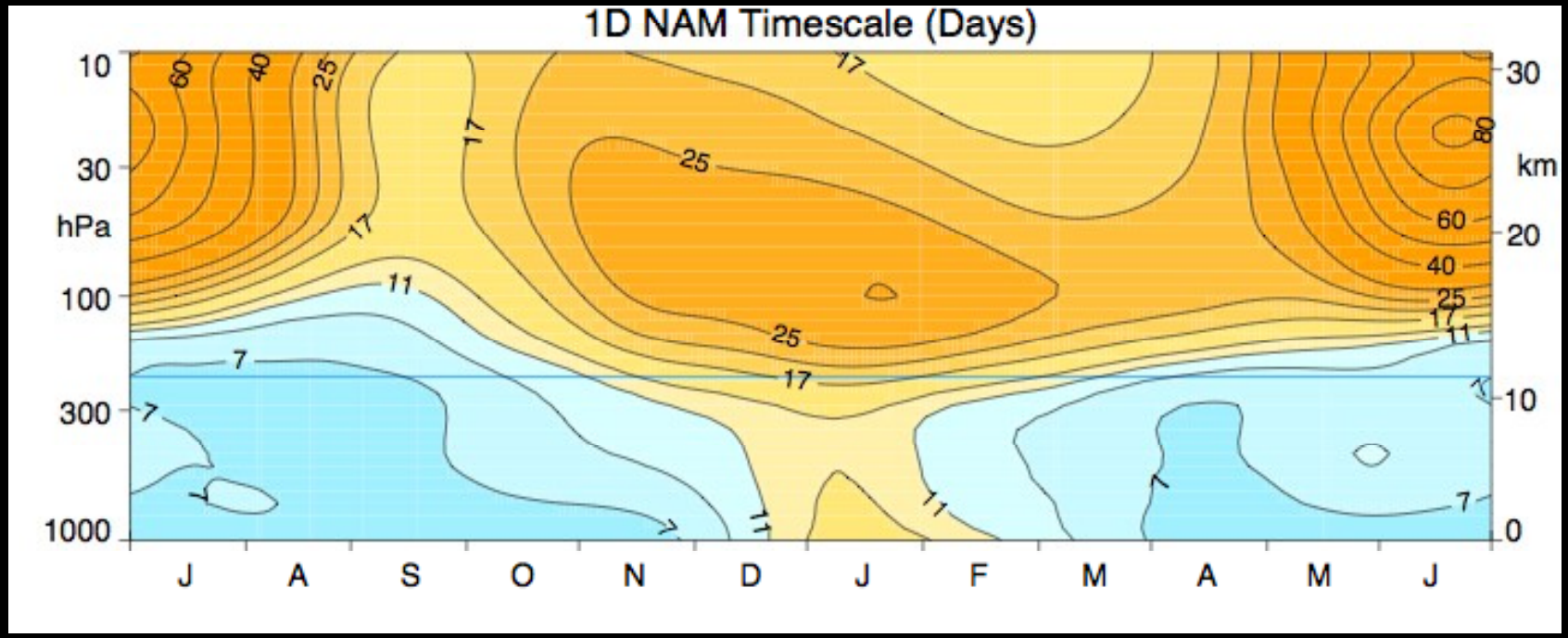
1D NAM Timescale (Days)
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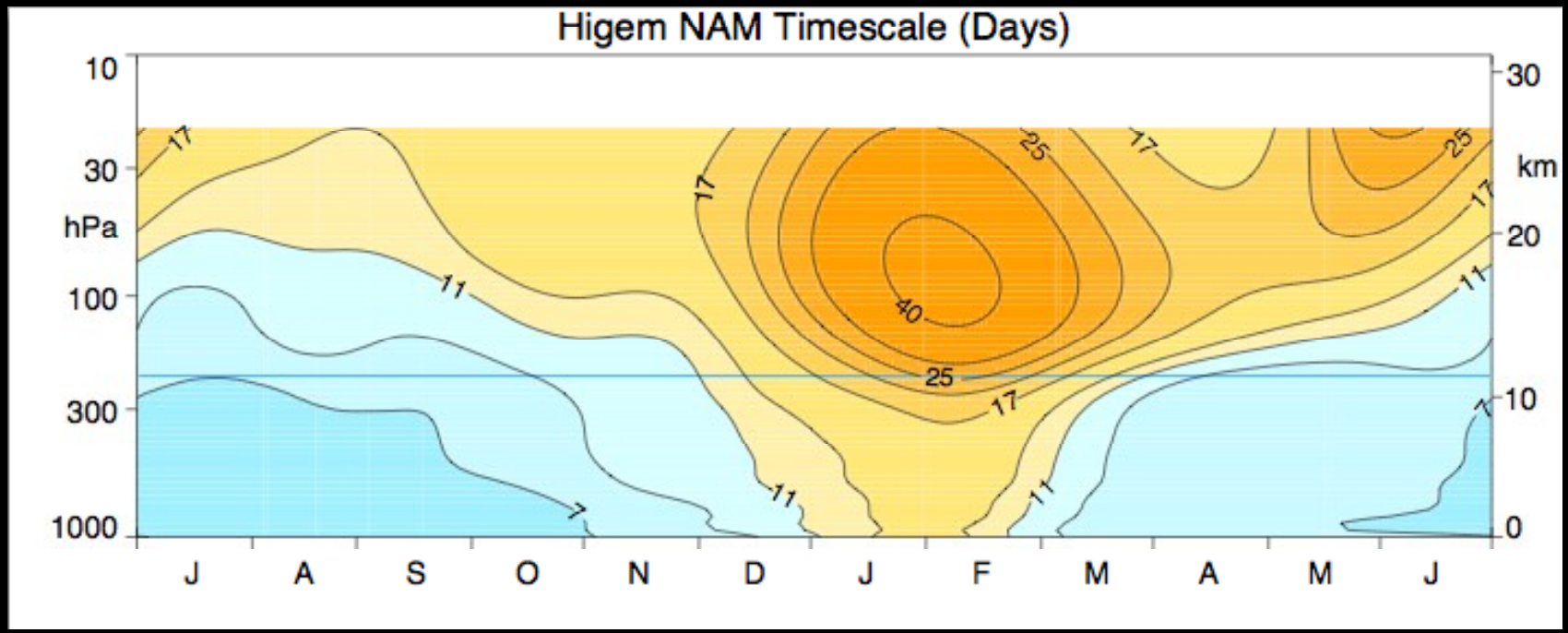
Higem NAM Timescale (Days)
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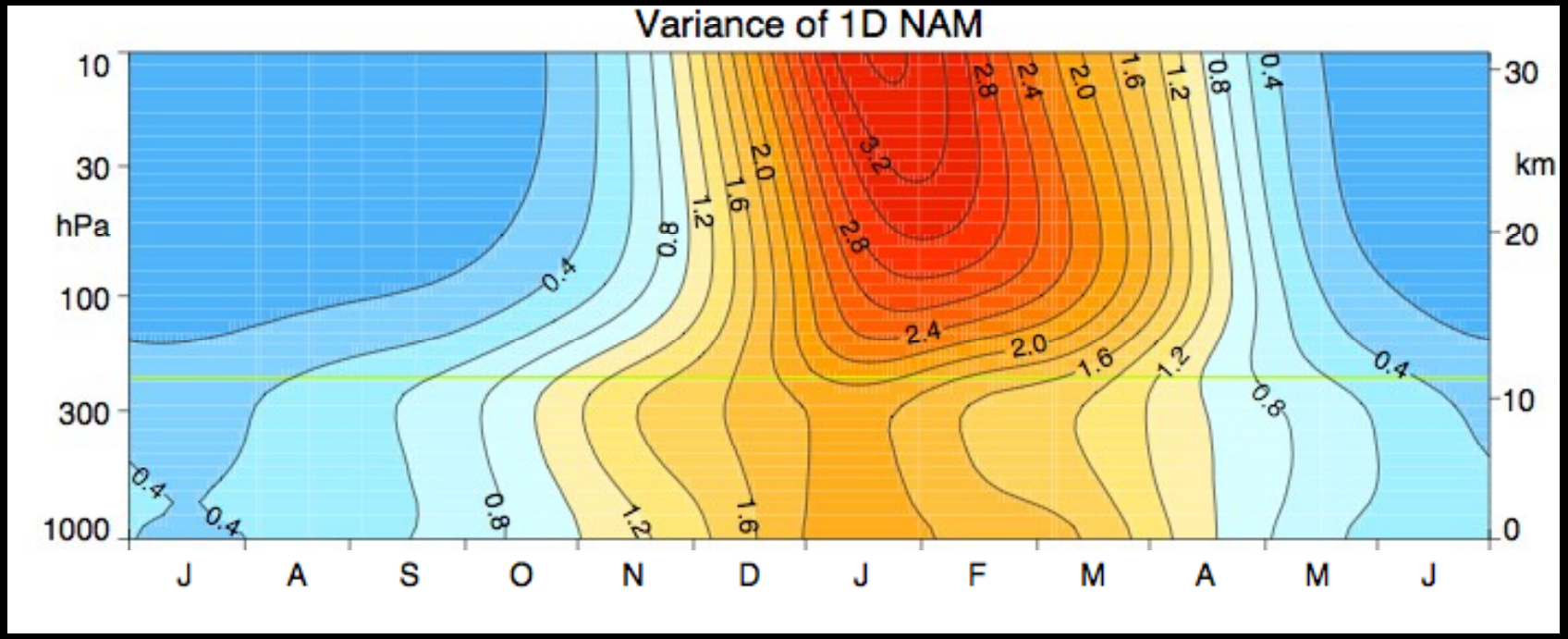
Variance of 1D NAM
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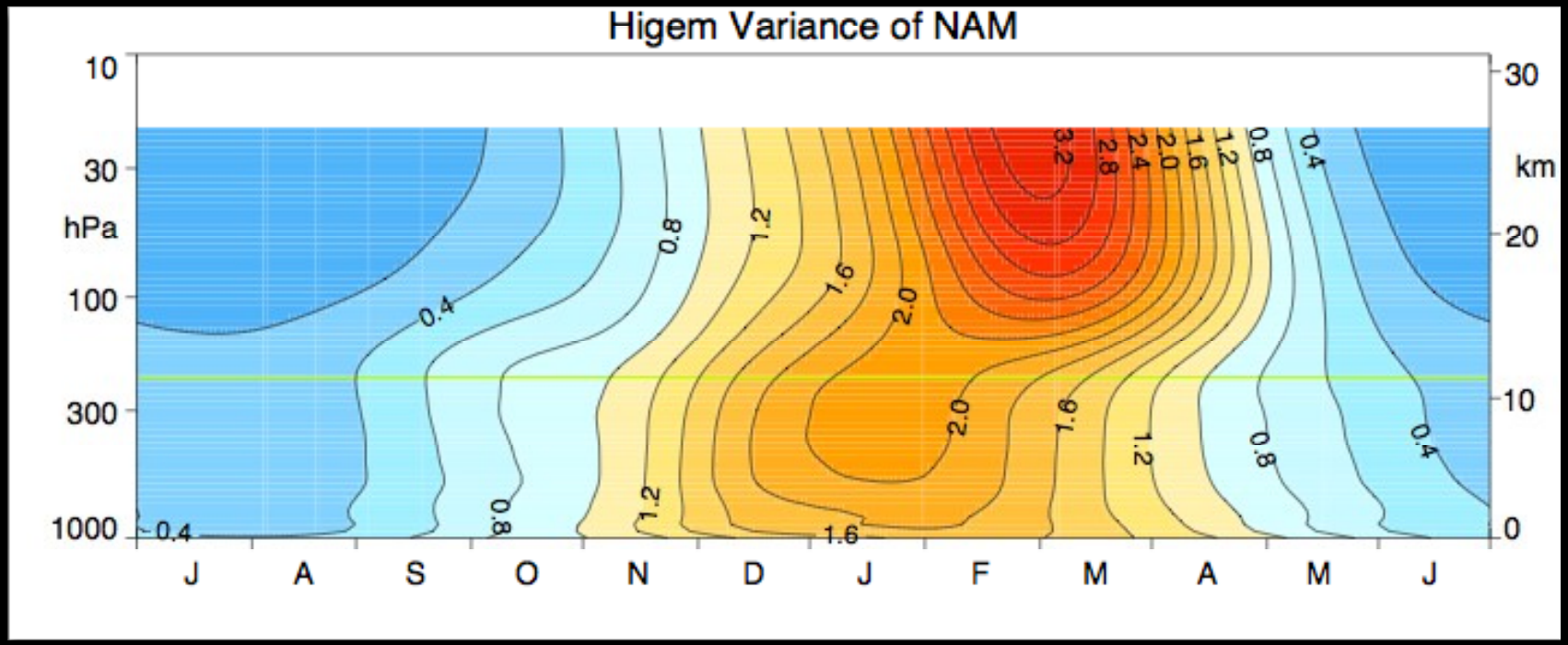
Higem Variance of NAM
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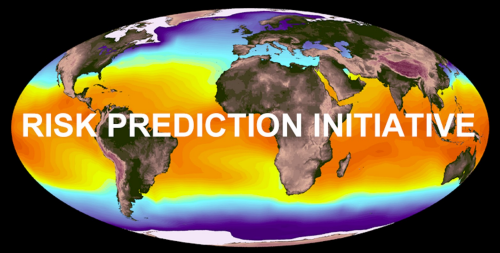
The Future of the Stratosphere?

- Increasing greenhouse gases cool the stratosphere.
- Ozone recovery reverses SH trends.
- Stratospheric NAM index trend would depend on relative cooling of the polar cap.
- Most models show a warmer, weaker NH vortex in winter and spring.

Summary

- Ozone and ODS forcing trends will be the opposite of what they were until ~2000, in contrast to GHG forcing.
- CCMs predict that a cooling stratosphere will accelerate ozone recovery.
- Feedbacks to high-latitude surface climate are uncertain, because we are unsure how the high-latitude stratosphere will change.
- Diagnostics of S-T coupling in climate models are needed.

mark@nwra.com www.nwra.com/baldwin




TAYLOR FLADGATE
LAPH