11-year solar cycle Mechanisms and Modelling in the Stratosphere and Troposphere

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University of Reading U.K.

1. Overview of Gray et al. 2010, Solar Influence on Climate, Rev. Geophys. (in press).

2. Mechanisms for solar influence in the stratosphere via UV variations.

3. Mechanisms for transmitting stratospheric signals to the troposphere and surface.

Solar Influences on Climate

L.J. Gray[1], J. Beer[2], M. Geller[3], J.D. Haigh[4], M. Lockwood[5,6], K. Matthes[7], U. Cubasch[7], D. Fleitmann[8], G. Harrison[9], L. Hood[10], J. Luterbacher[11], G. A. Meehl[12], D. Shindell[13], B. van Geel[14], W. White[15]

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[14] Universiteit van Amsterdam, The Netherlands
[15] Scripps Institute of Oceanography, La Jolla, CA, U.S.A.

1. Introduction

2. Solar Variability

- Causes of TSI variability
- Decadal-scale solar variability
- Century-scale variability
- TSI and Galactic cosmic rays

3. Climate Observations

- Decadal variations in the stratosphere
- Decadal variations in the troposphere
- Decadal variations at the Earth's surface
- Century-scale variations

4. Mechanisms

- TSI
- UV
- Centennial-scale irradiance variations
- Charged particle effects

5. Solar variability and global climate change

6. Summary / future directions

R: Sunspot number

F10.7 cm flux

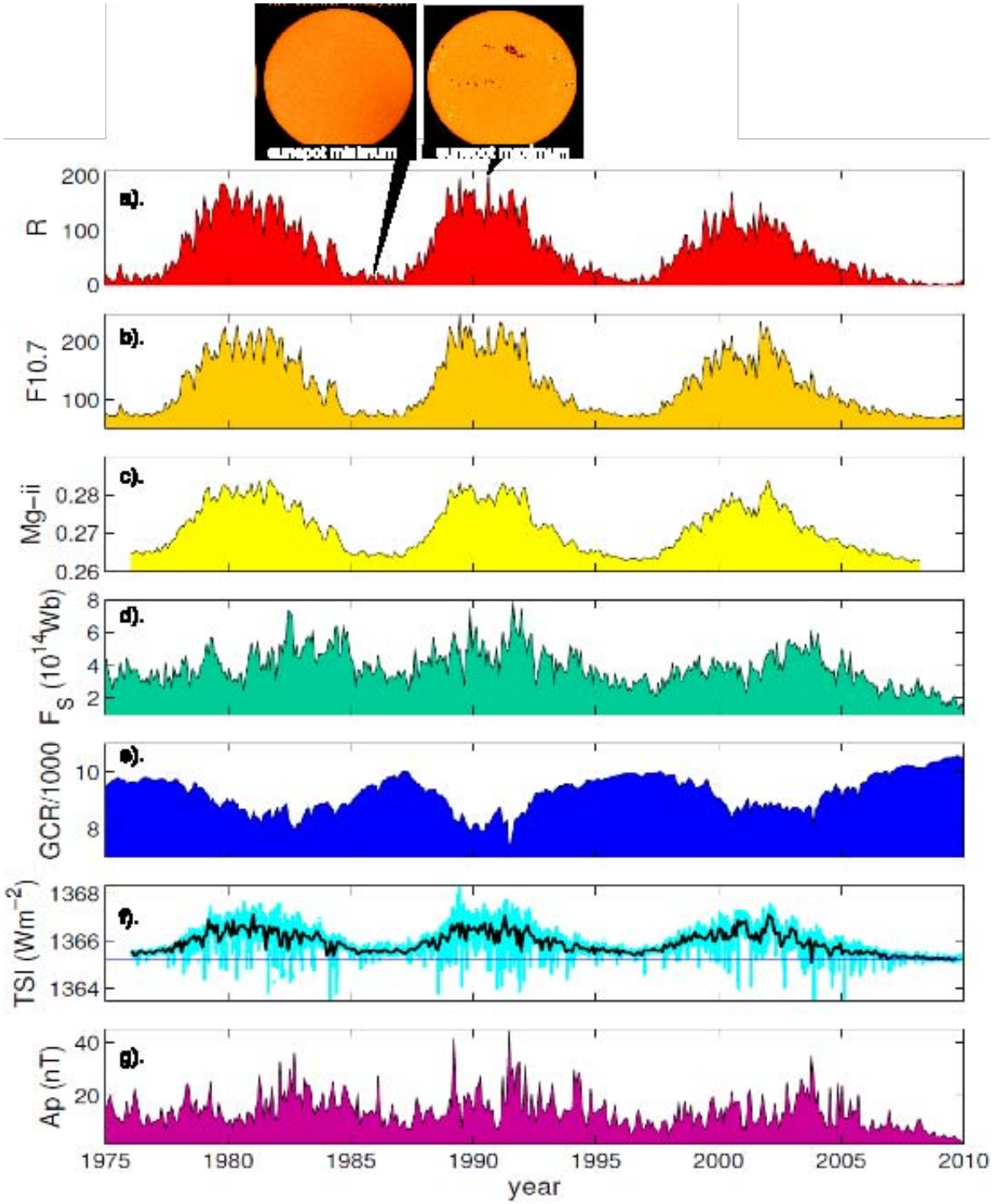
Magnesium ii

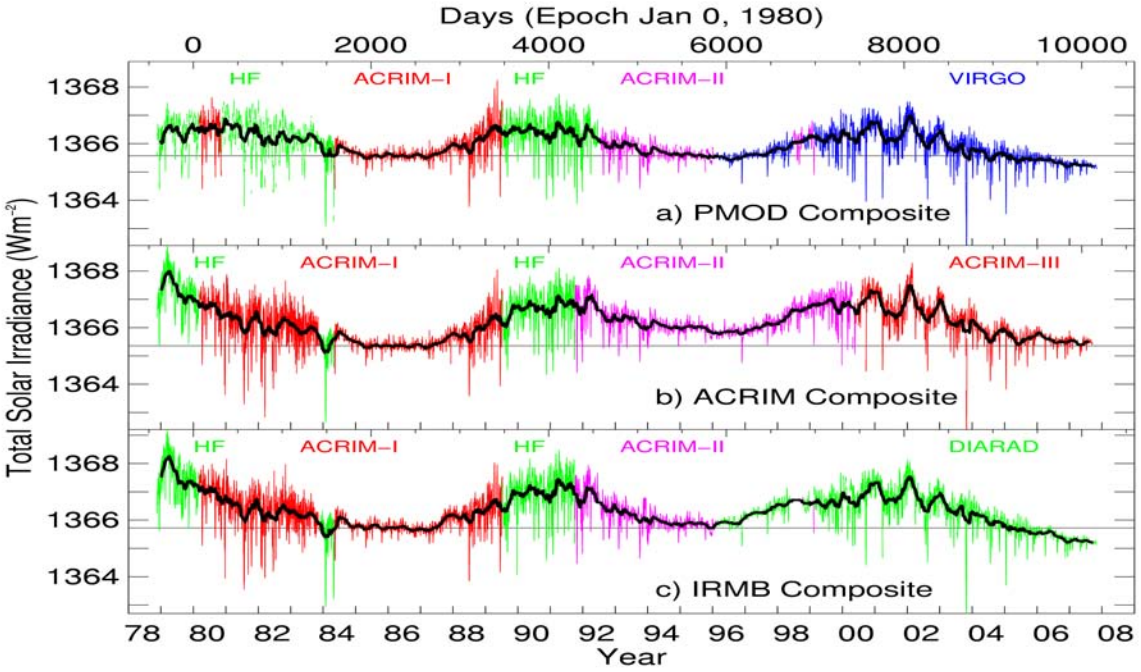
Open solar flux

Galactic cosmic ray counts

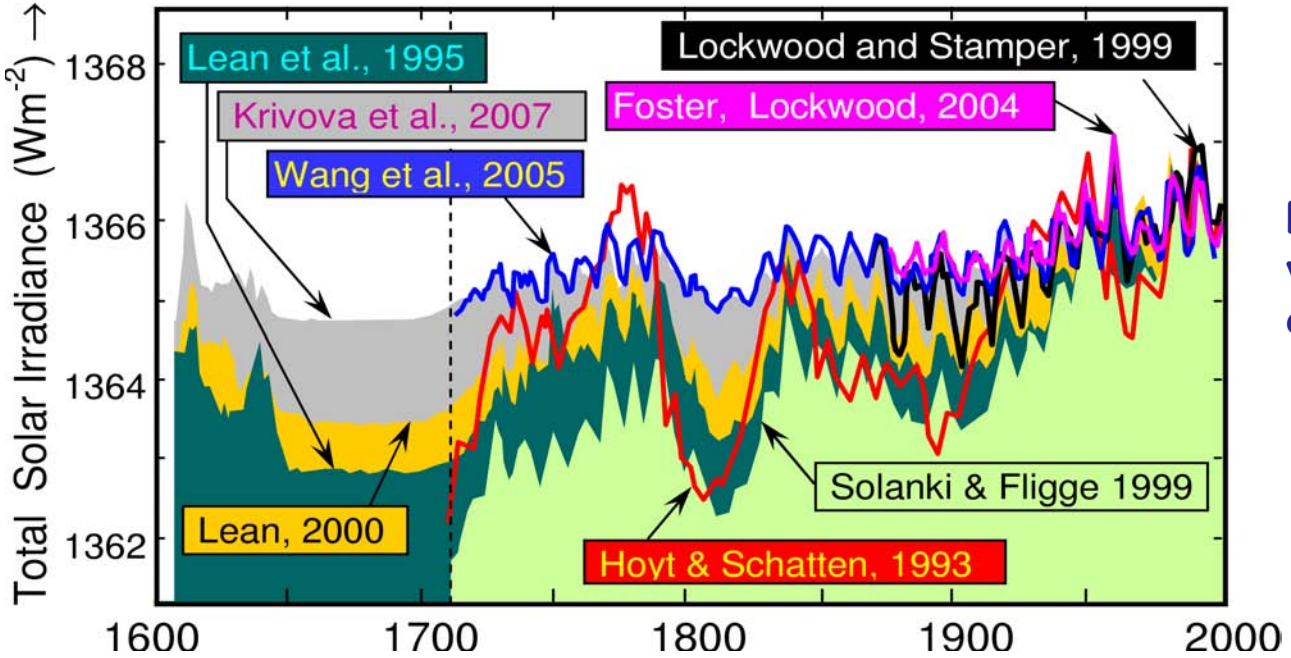
Total solar irradiance

Geomagnetic Ap index

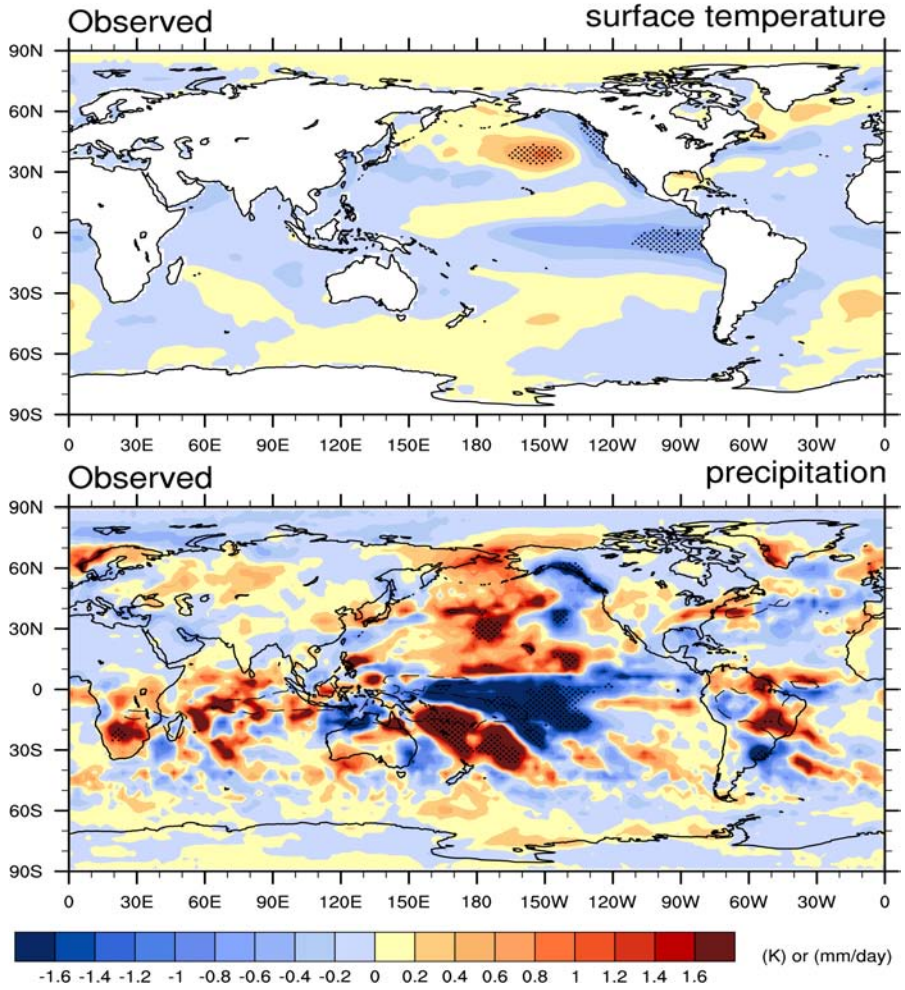




Composites of TSI 1978-2007

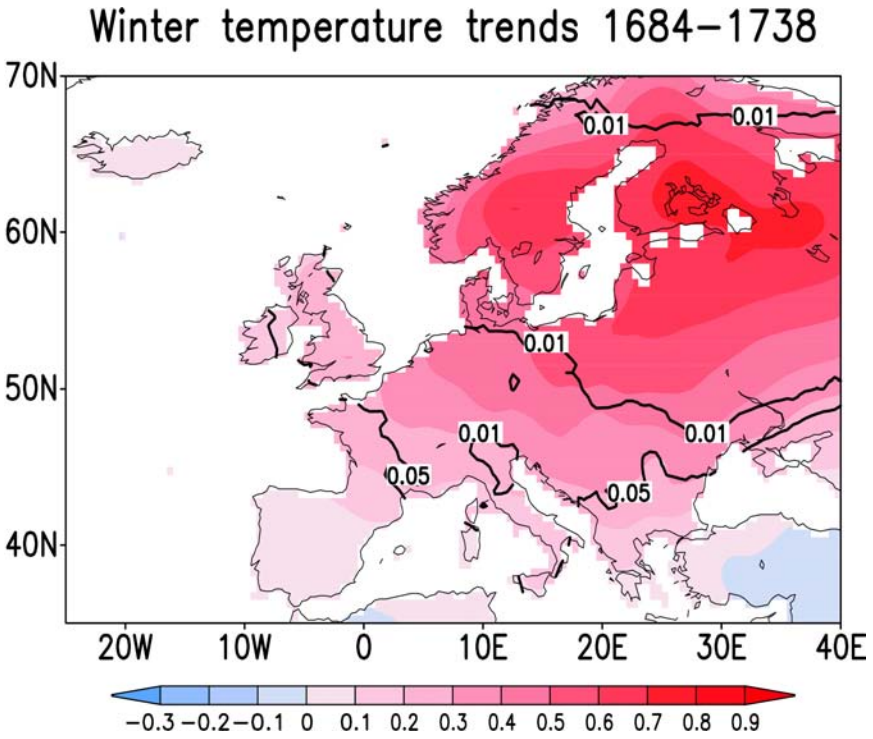


Reconstructions of past variations of TSI using different solar proxies

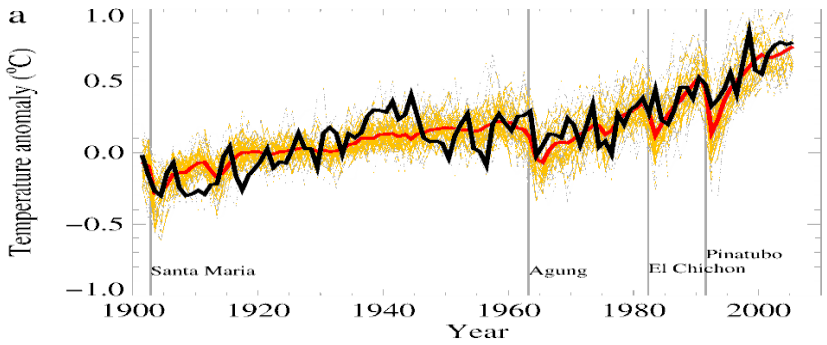


Observations:
composite SSTs / precipitation in DJF
Smax – Smin
(Meehl et al. 2009)

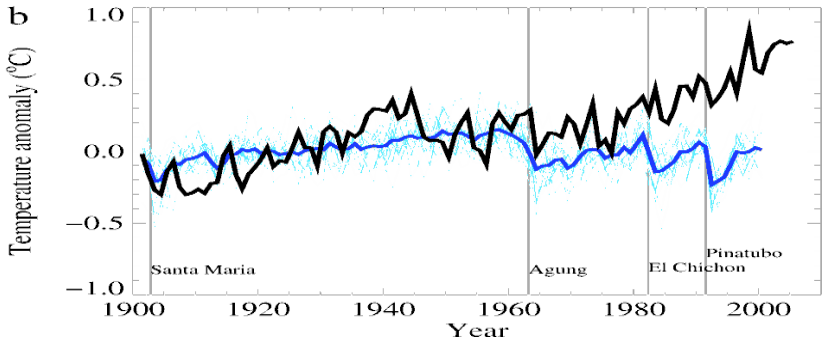
Winter temperature trends K/decade
1684 – 1738
(Luterbacher et al 2004)



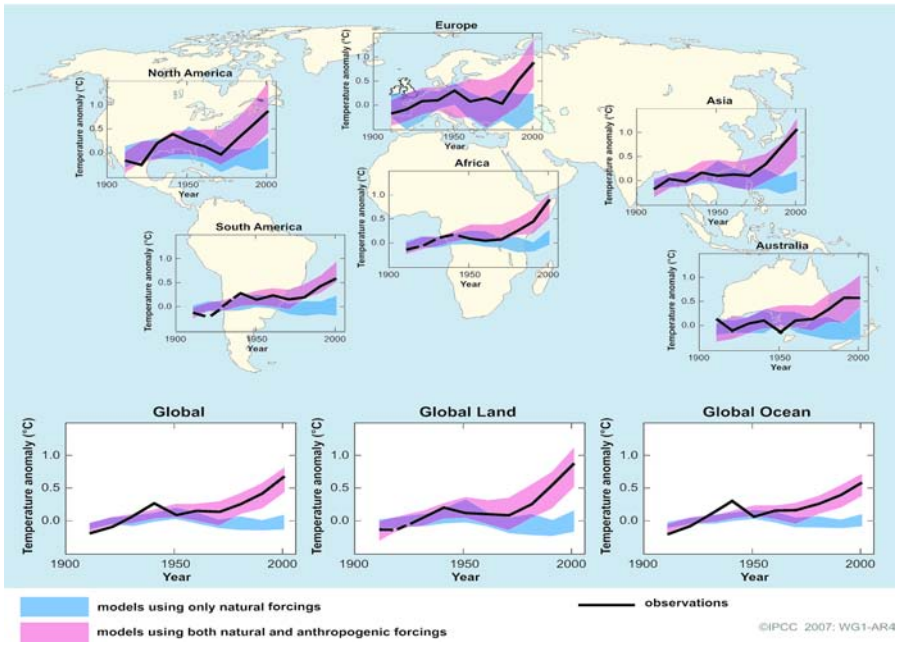
IPCC model simulations



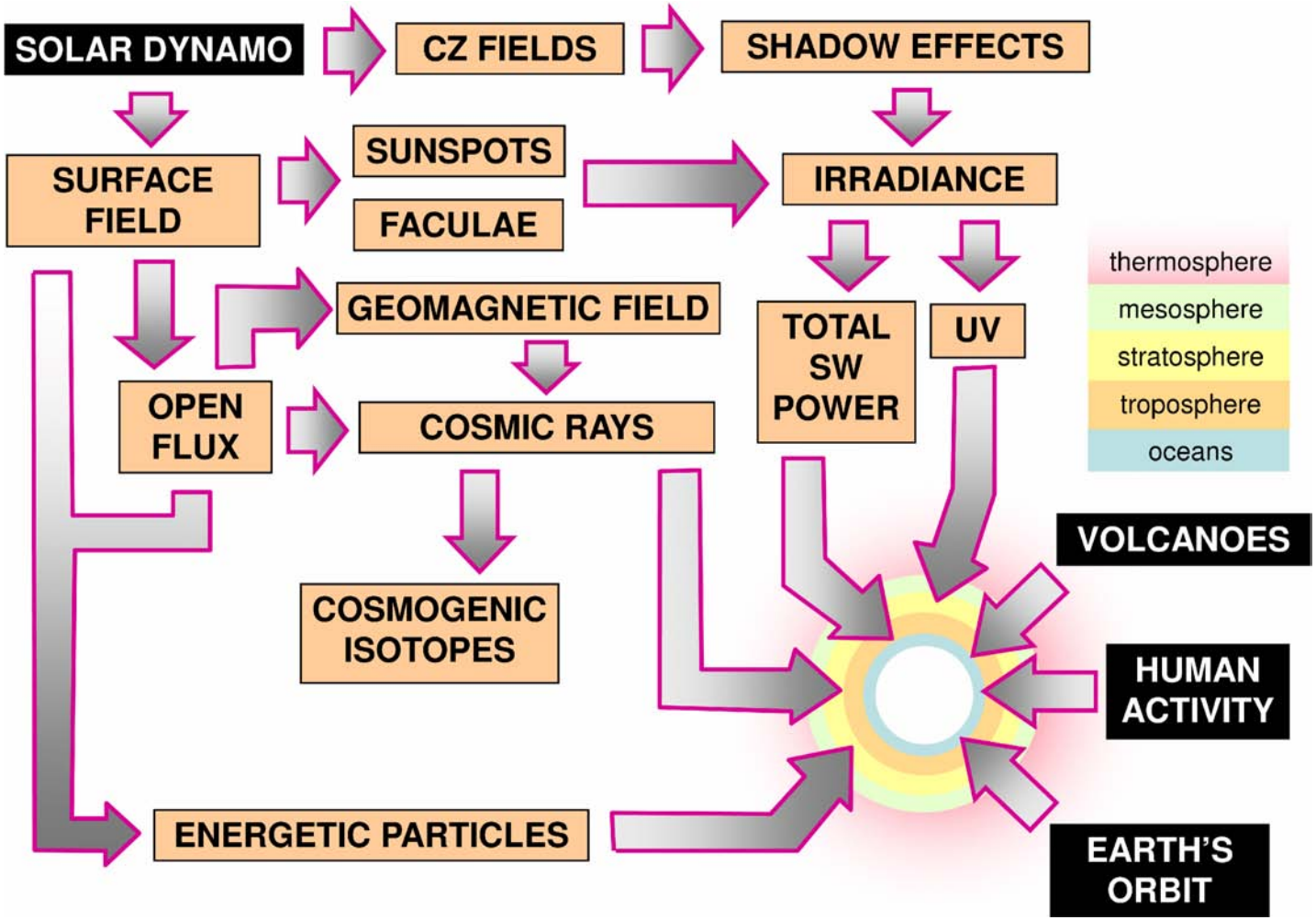
anthropogenic + natural forcings



natural forcings only

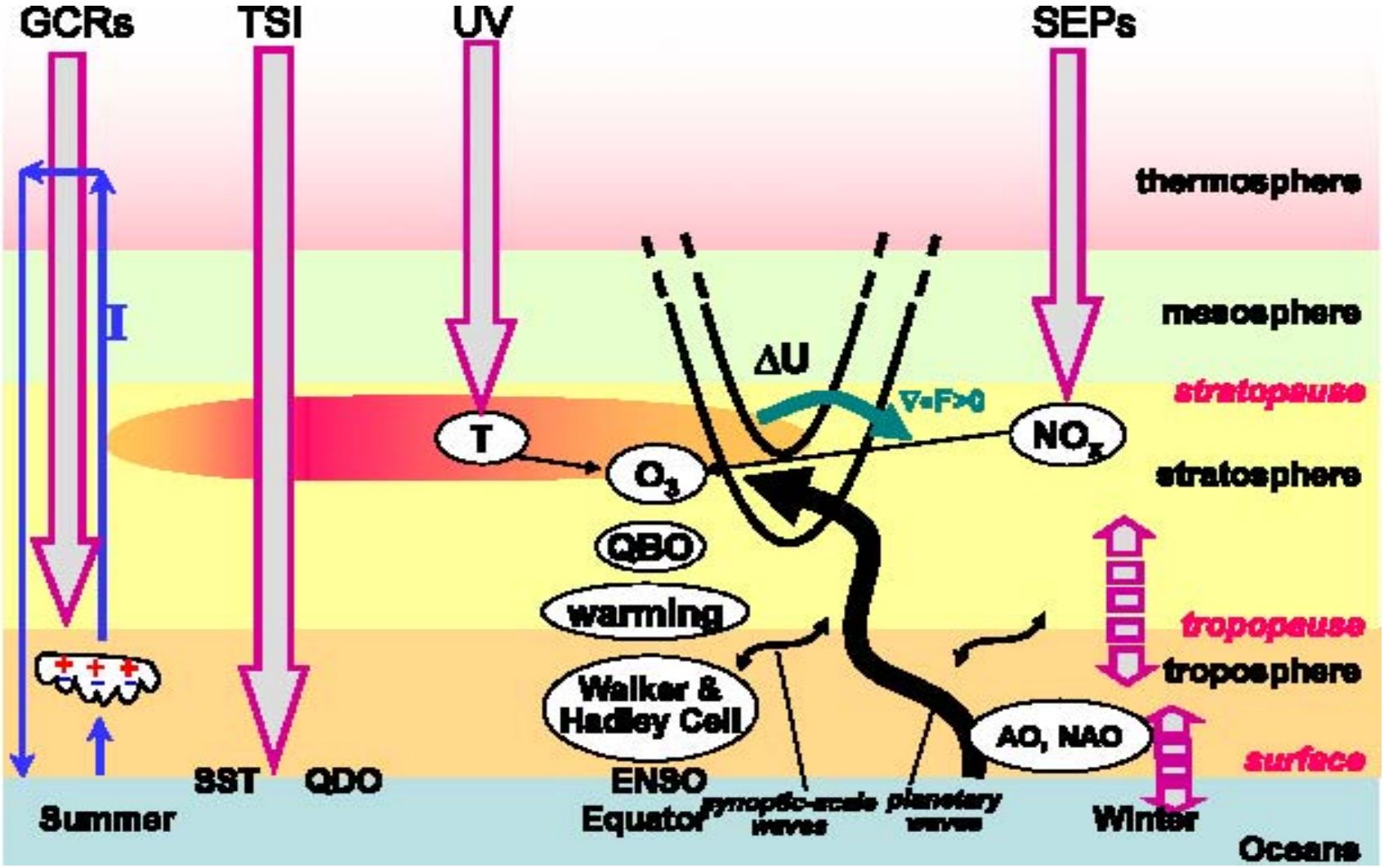


Schematic overview:
climate forcings associated with solar variability



Schematic overview
mechanisms for solar UV influence on climate

(based on Kodera and Kuroda 2002)

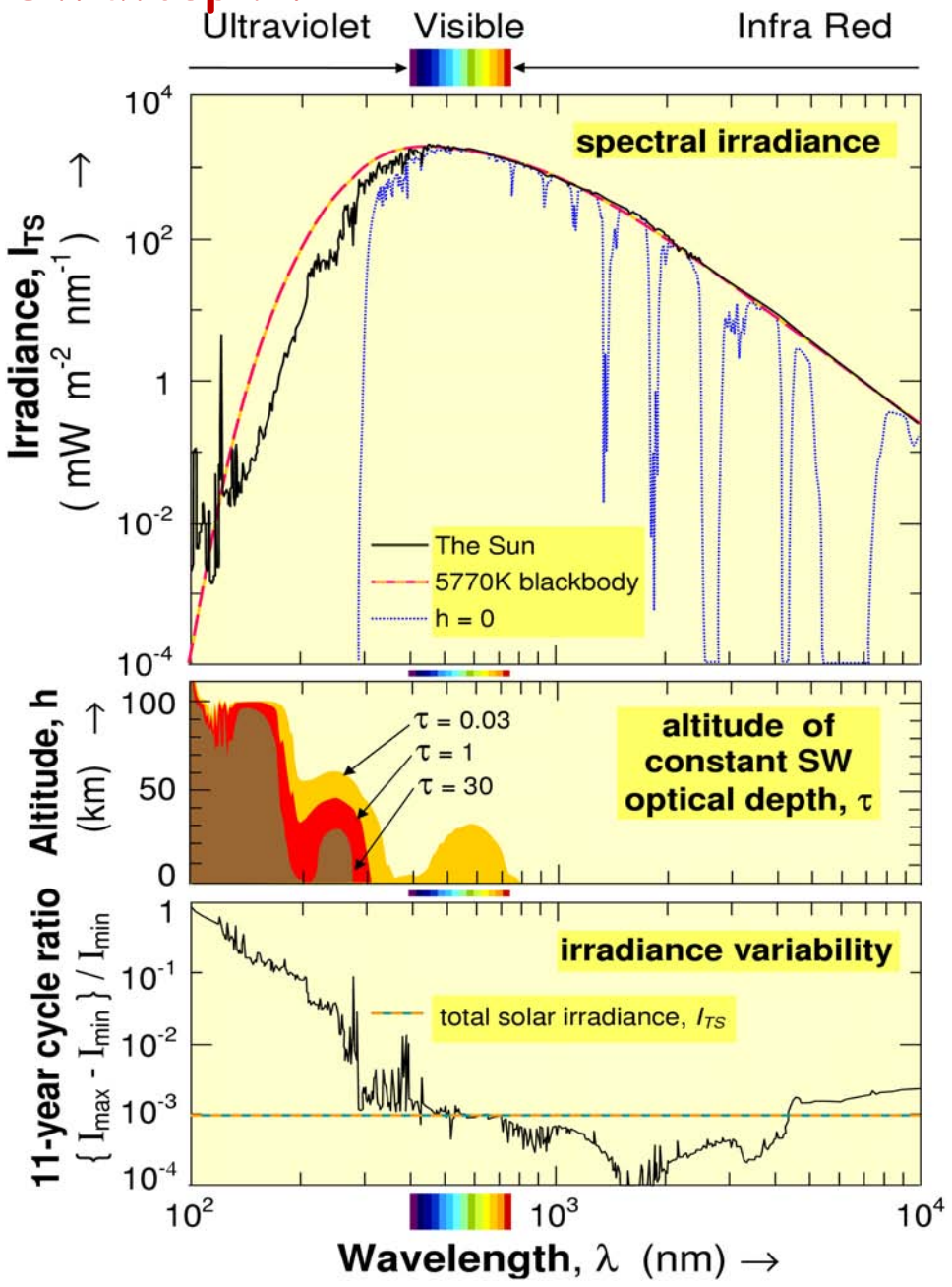


Mechanisms affecting the Stratosphere

Spectrum of solar irradiance (black) and spectrum of radiation reaching the Earth's surface (blue)

Indicator of altitude of penetration of shortwave radiation

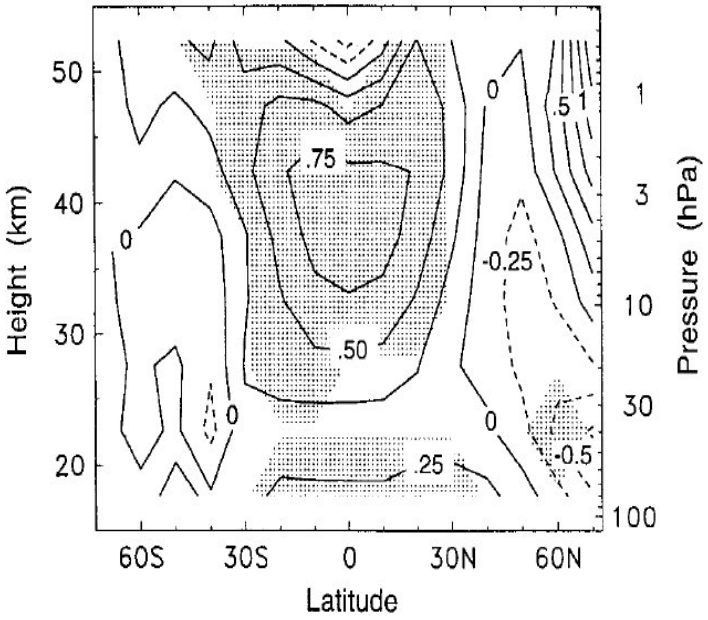
Percentage variability Smaxminus Smin
~6% near 200nm (ozone formation)
~4% 240-320nm (absorption by ozone)
~0.07% in TSI

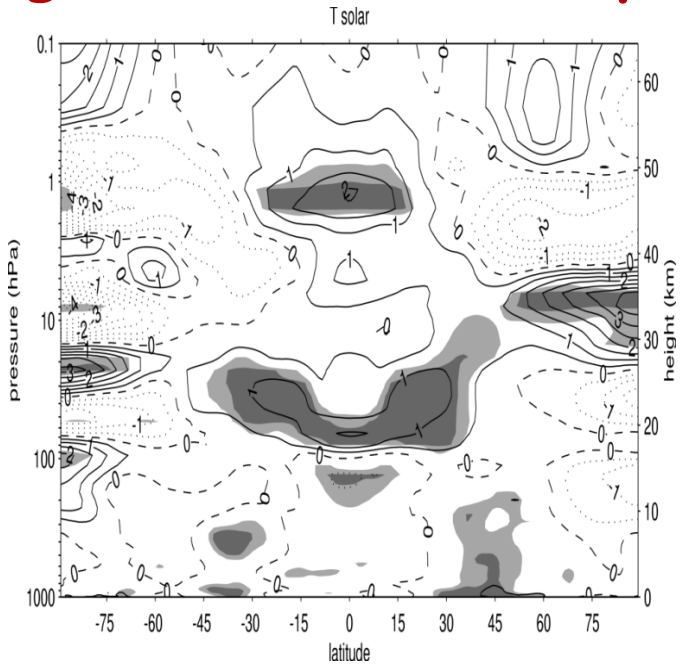


11-yr Temperature Signal in the Stratosphere (K)

Smax - Smin

SSU (Scaife et al. 2000)

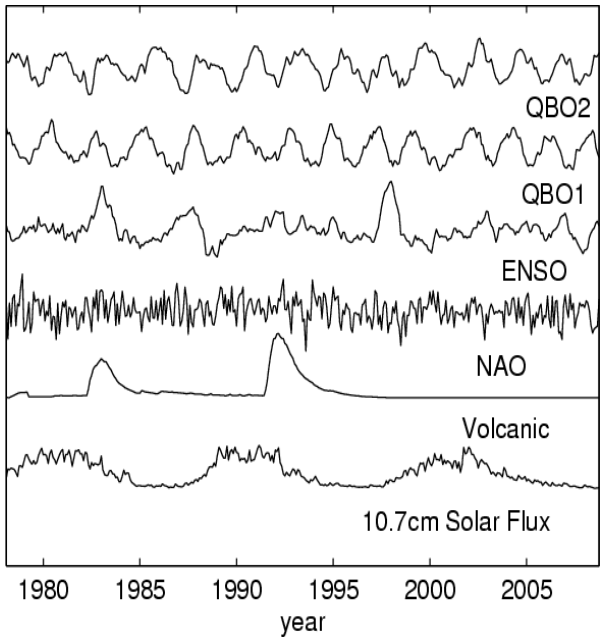




ERA-40 reanalysis

Crooks and Gray 2005 J. Clim

Frame and Gray 2010 J. Clim



Possible contamination by volcanic signal

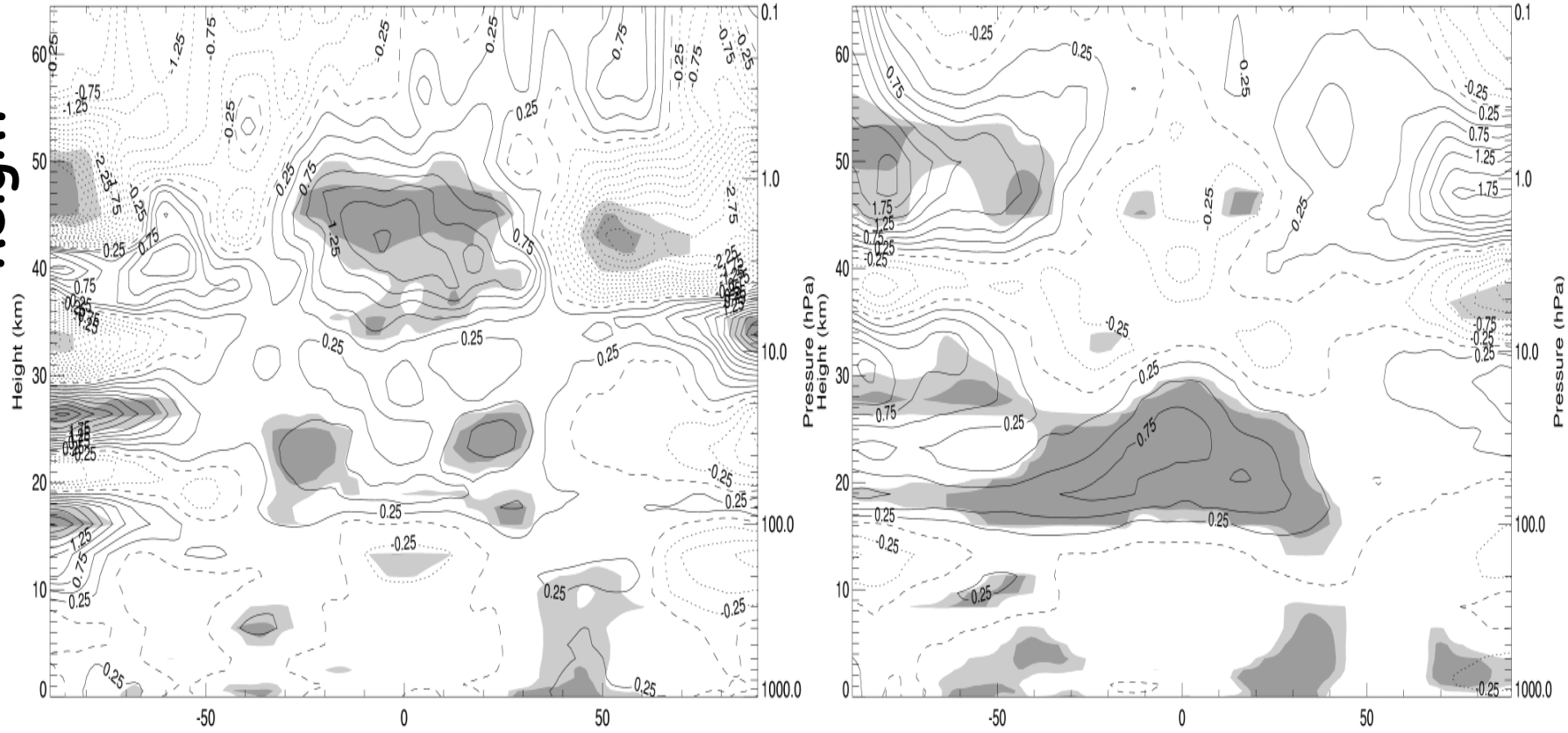
Solar and volcanic signal
ERA-40

Solar max - min

1979-2001

Volcanic

height

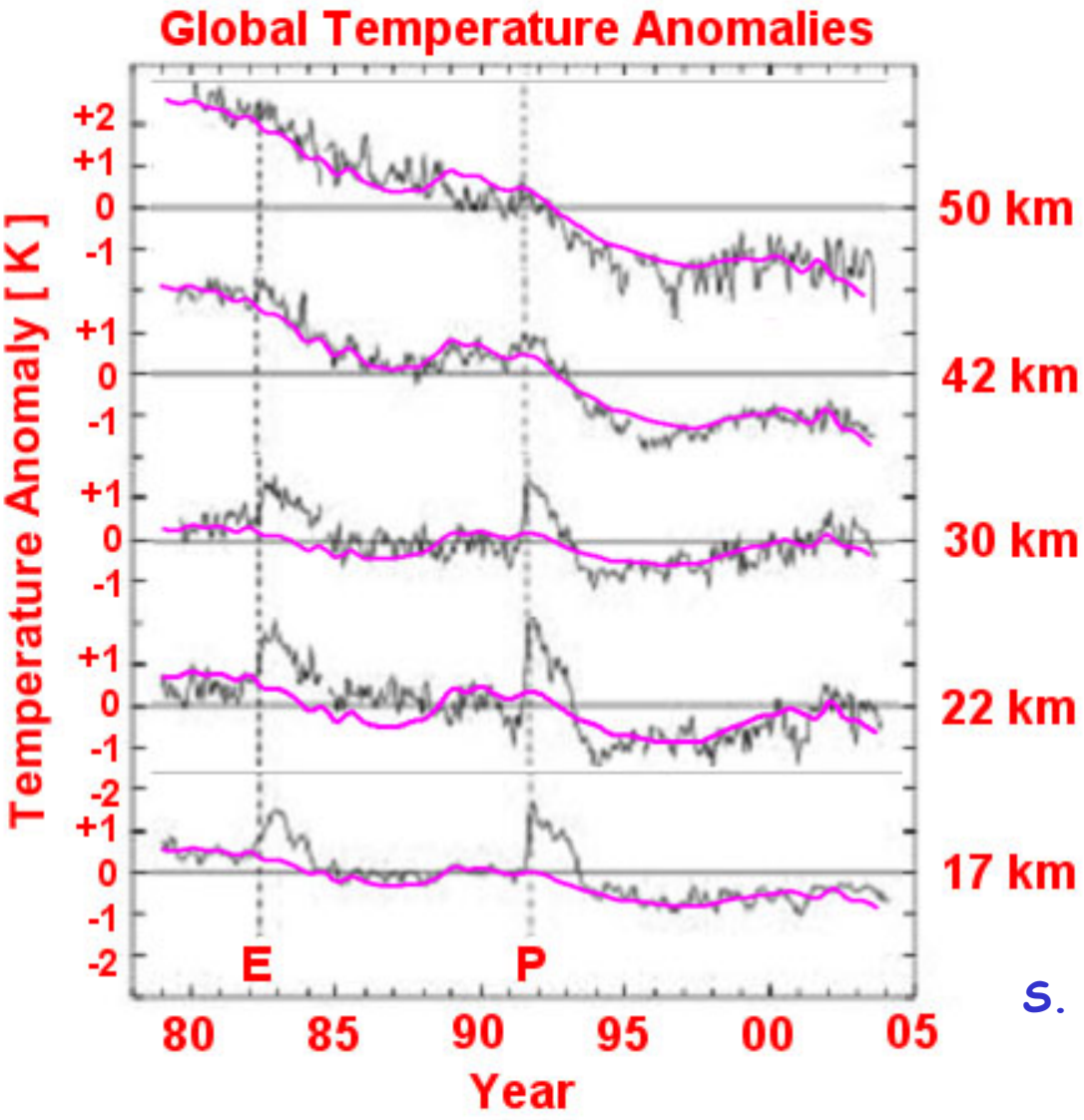


latitude

Crooks and Gray 2005

latitude

Temperature Trends: SSU observations



Black = SSU/MSU obs

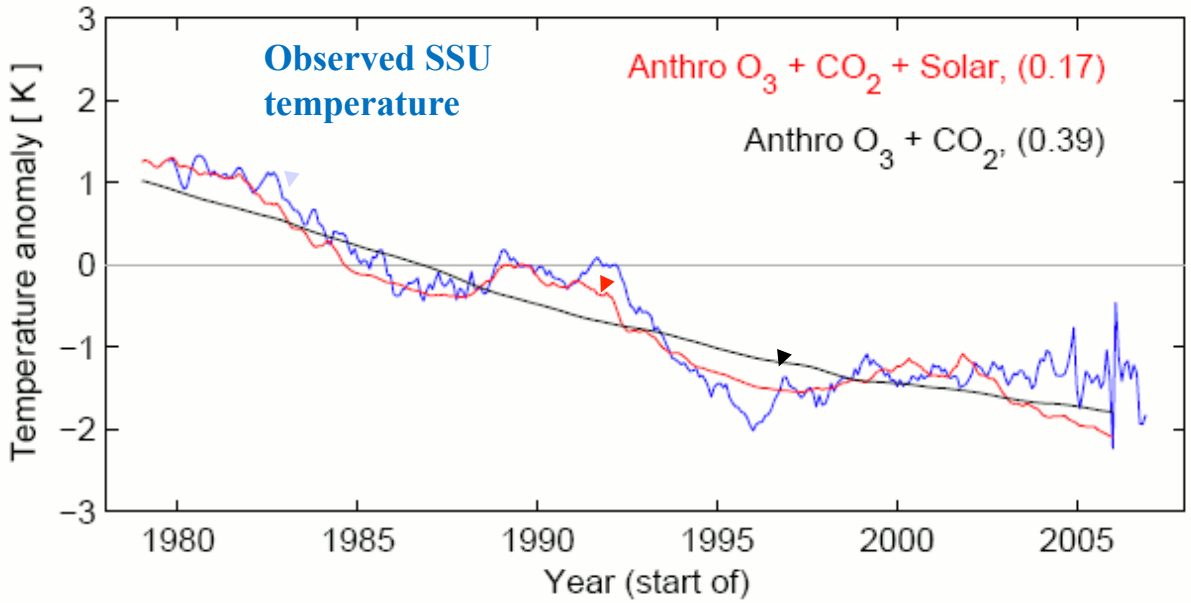
Purple = rad^n model with CO2, O3 trends plus solar cycle

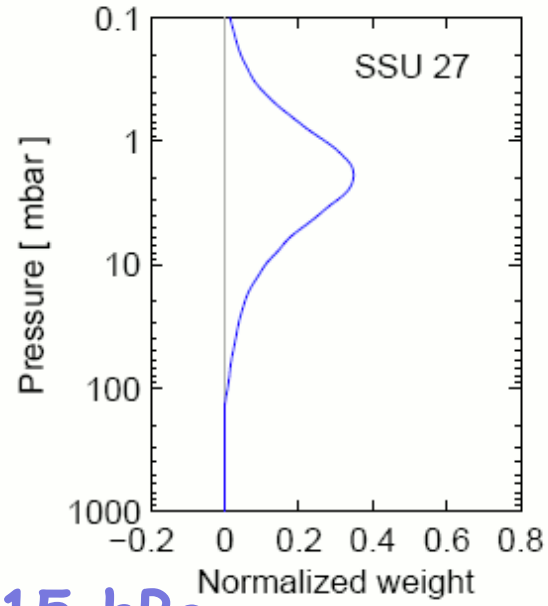
S. Rumbold, 2009 PhD thesis

Relative contributions of CO2, ozone, solar influence

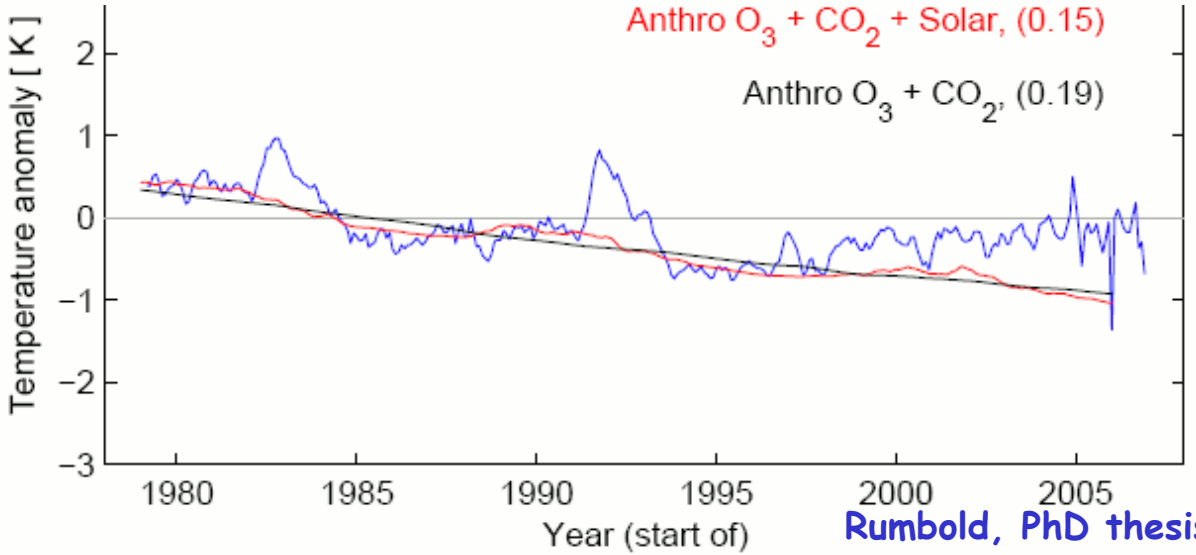
(high-res radiative heating calculations)

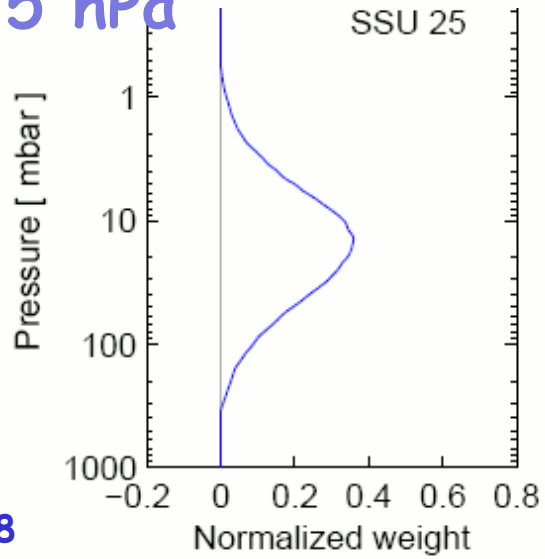
~3 hPa





~15 hPa

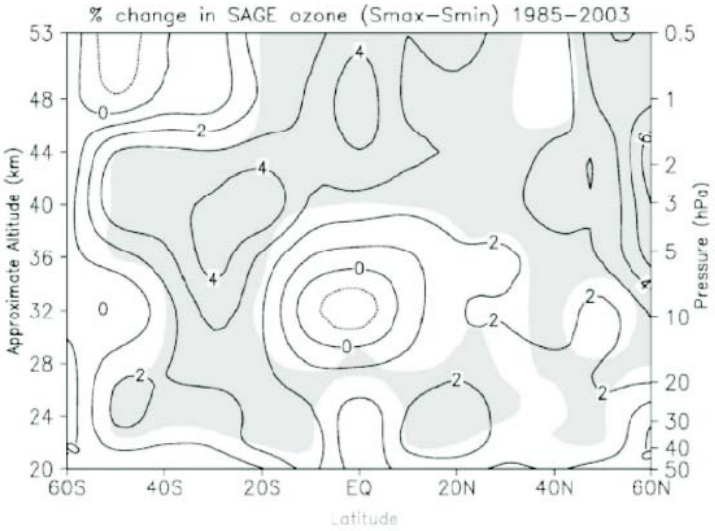




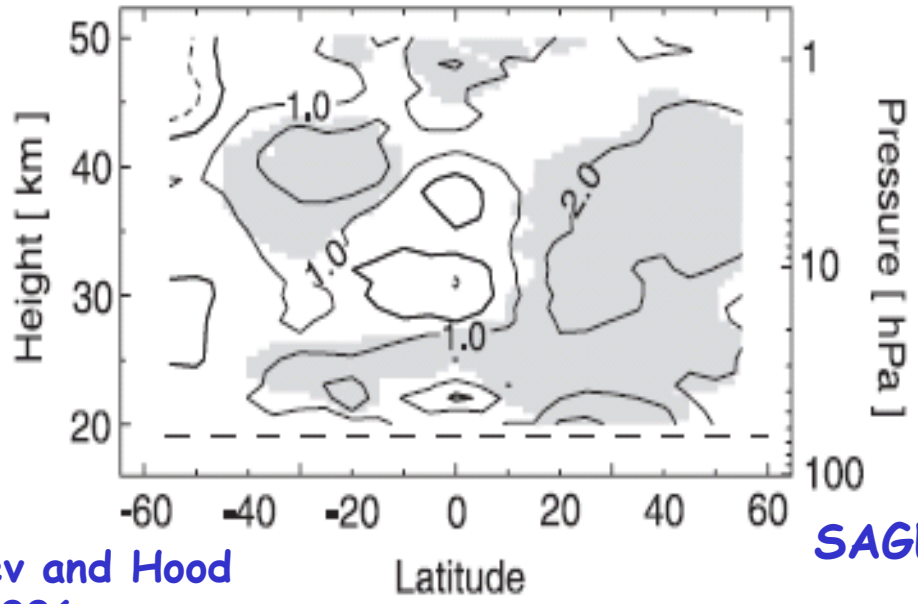
Rumbold, PhD thesis,2008

Ozone observations (% Smax-Smin)

Randel and Wu 2007

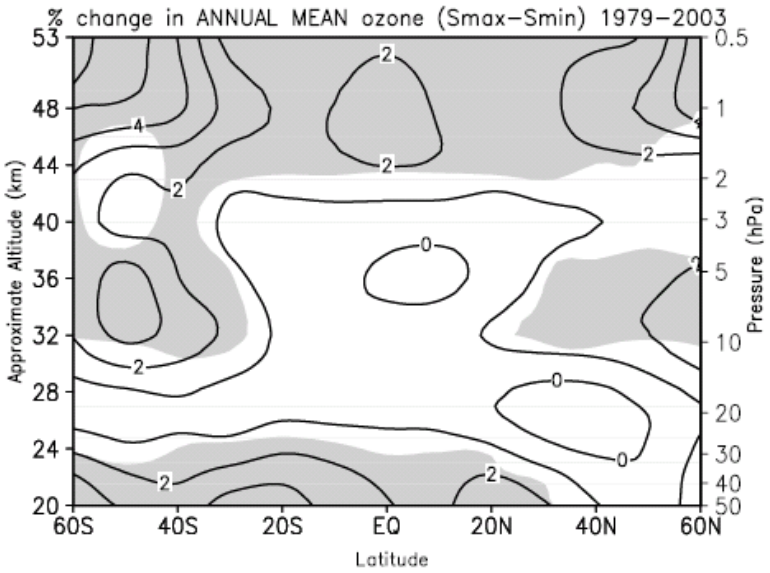


SAGE

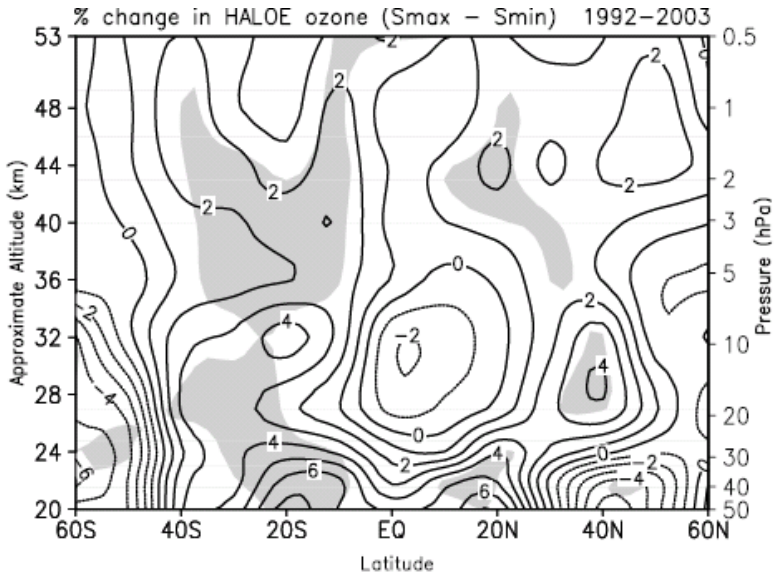


SAGE

Soukharev and Hood 2006



SBUV



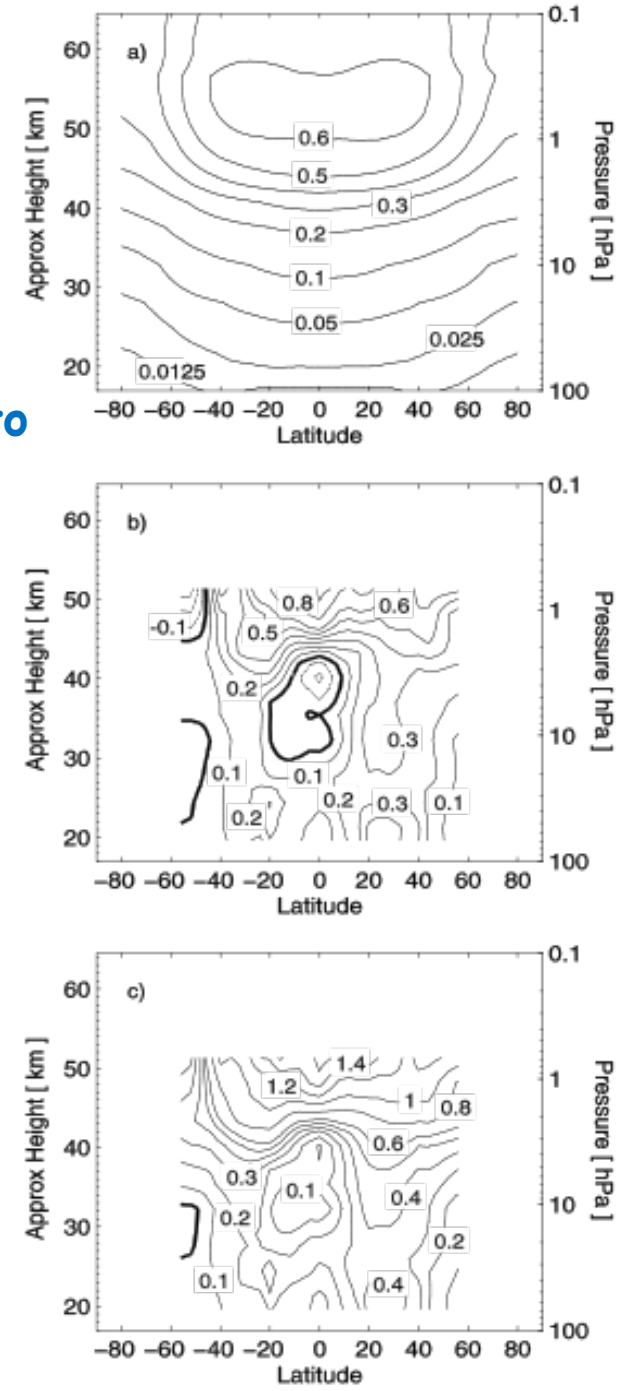
HALOE

Modelled radiative response to irradiance and ozone changes

Use a very high-res radiation model to assess temp response to

(a) irradiance changes
(b) ozone changes

(Gray, Rumbold and Shine JAS, 2009, see also Shibata and Kodera 2005)



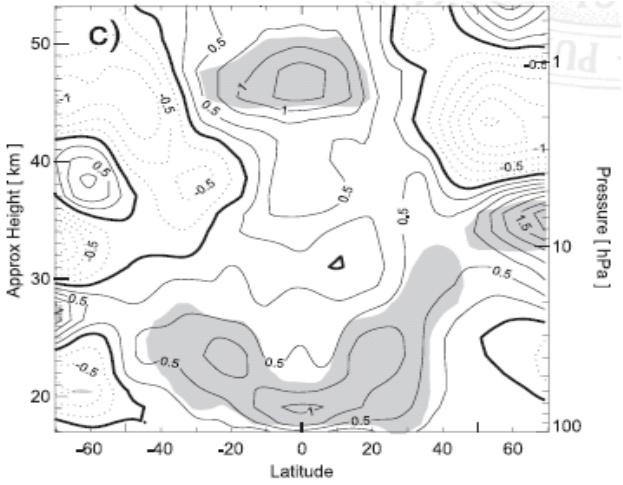
Smax – Smin T (K)

(a) temp response to irradiance changes (from Lean et al).

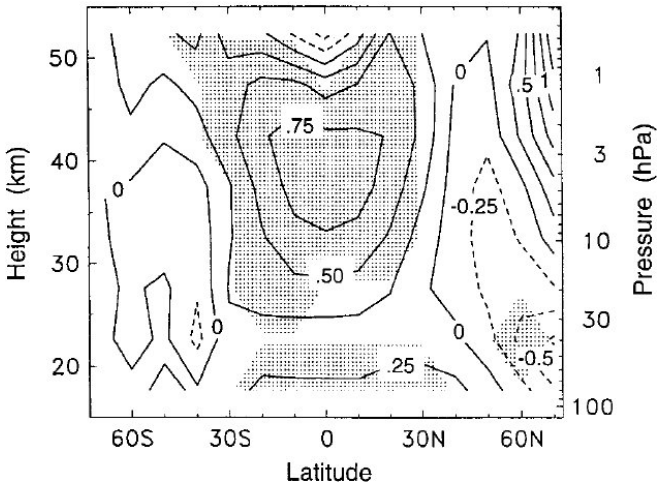
(b) temp response to ozone changes (SAGE)

(a) + (b)

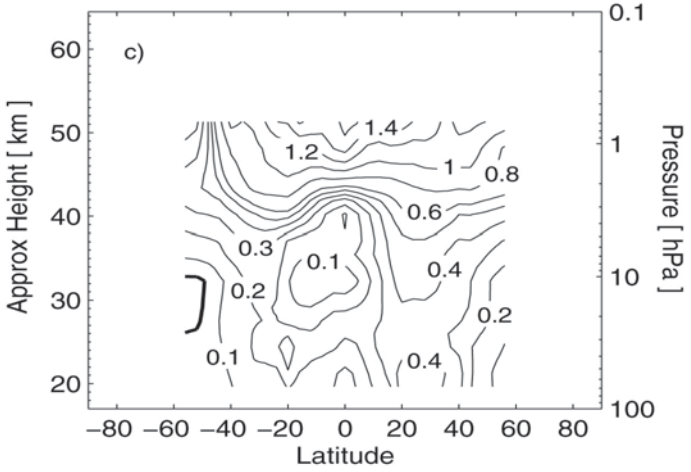
Model / Obs comparison
Temperature response Smax minus Smin (K)



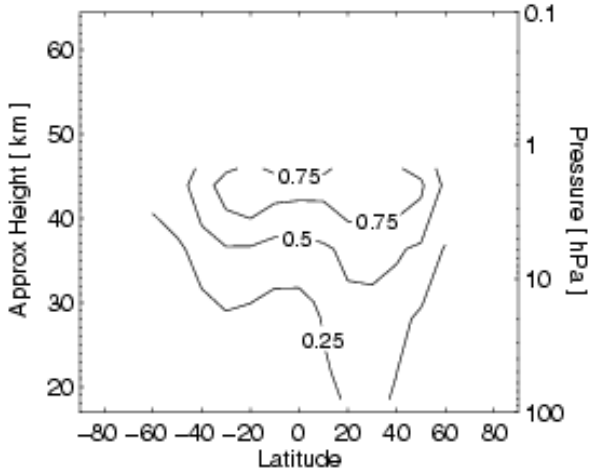
ERA



SSU

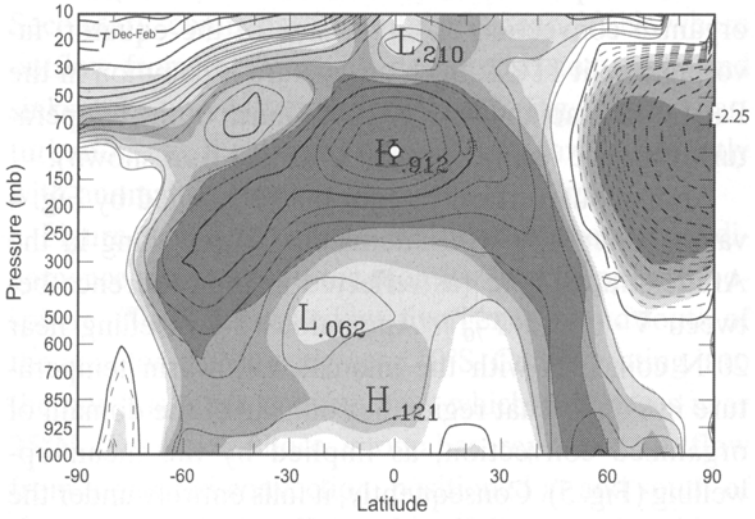


Radiative model response to irrad + ozone (a) + (b)

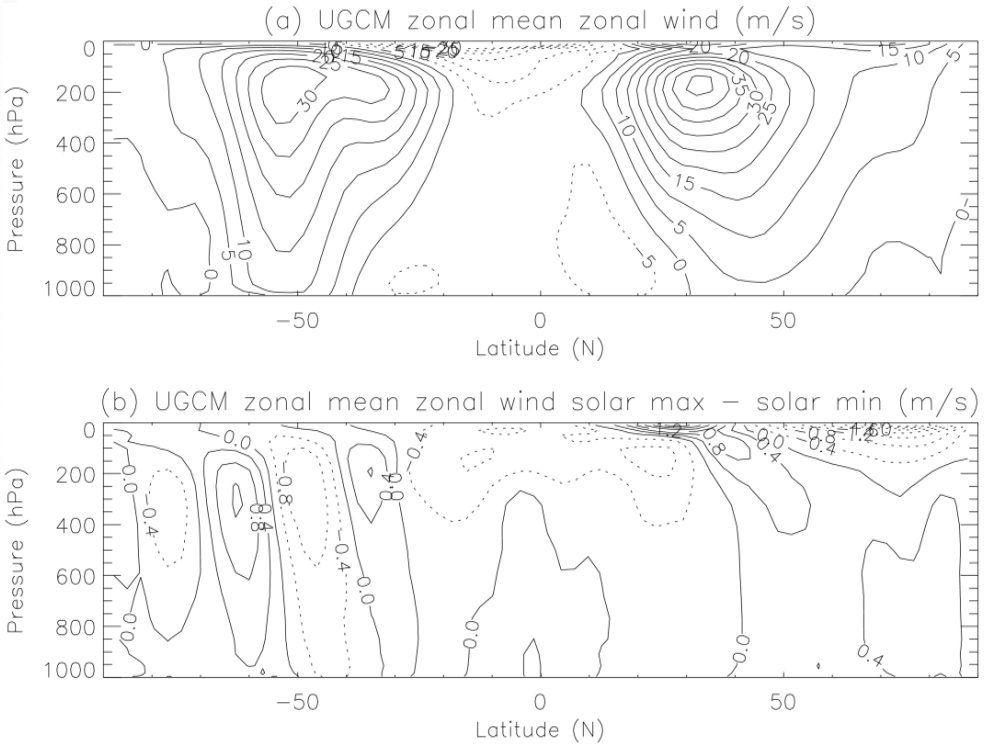


Radiative model response (a) + (b) sampled using the SSU weighting functions

Why does the lower stratospheric signal matter?

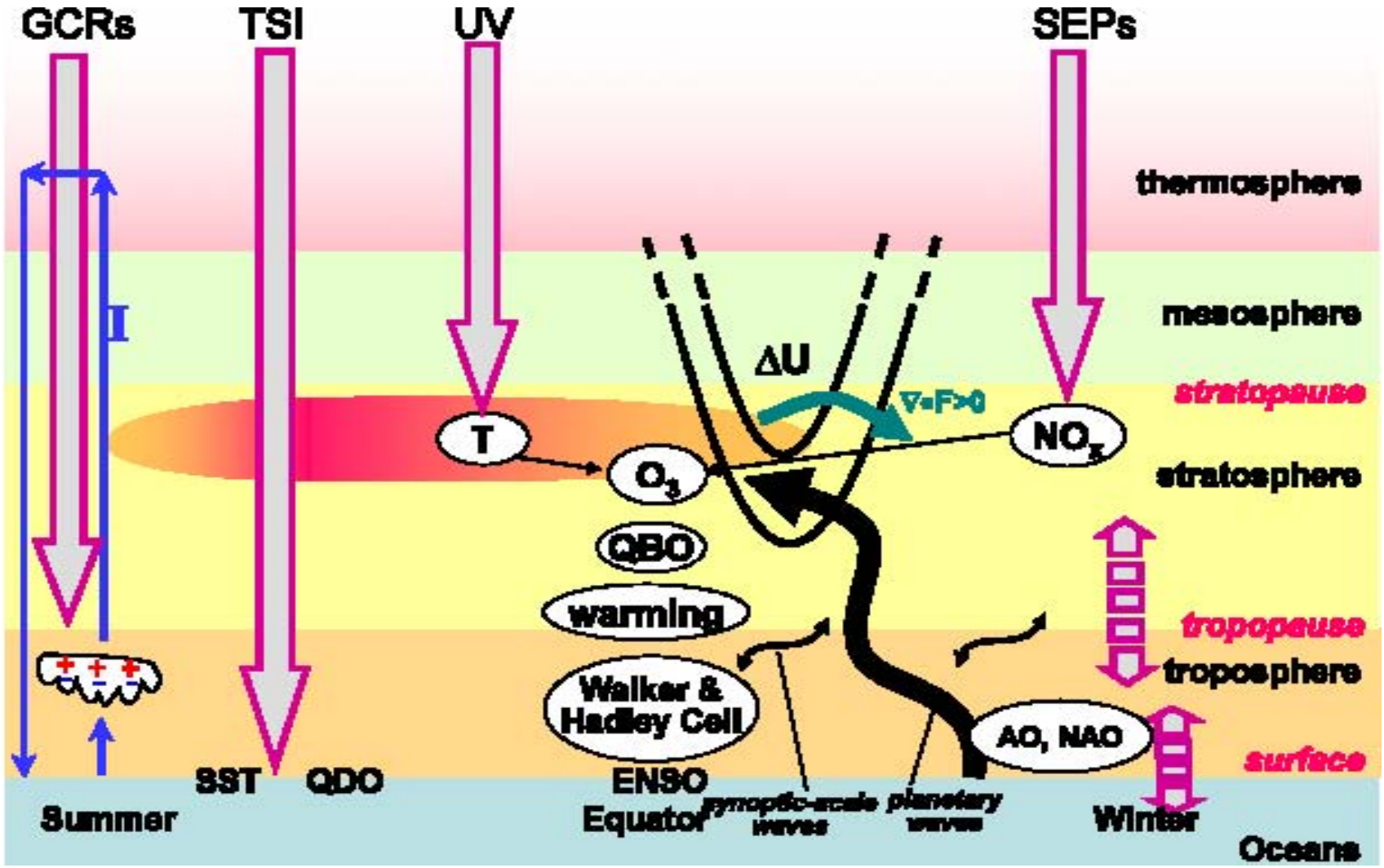


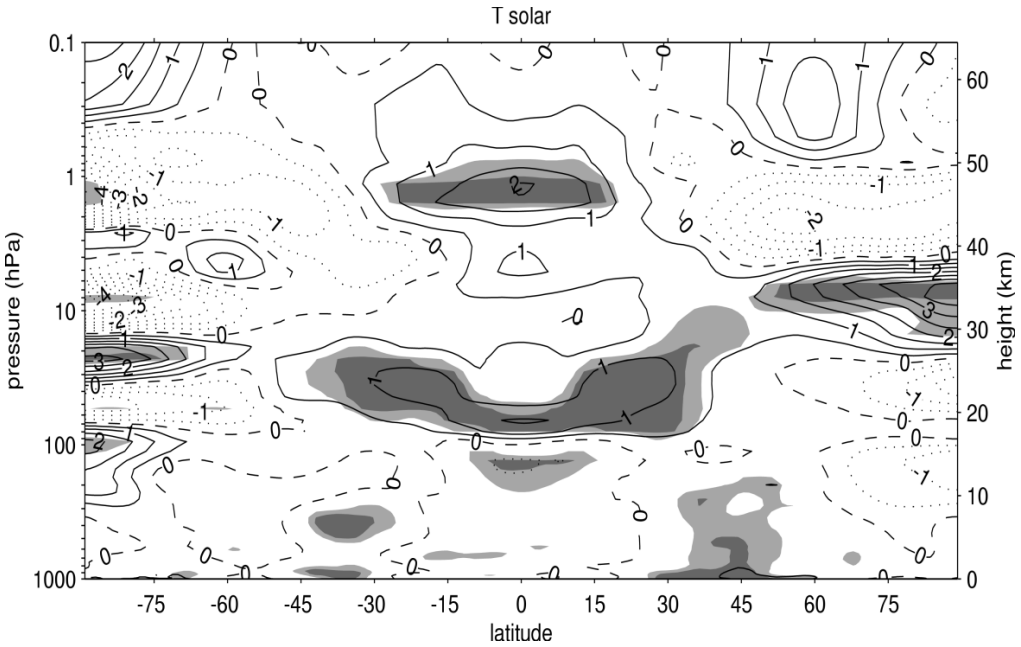
Correlation:
Observed DJF 100 hPa equatorial T with T elsewhere
Salby and Callaghan 2005



Model: zonal wind response to an imposed temp anomaly in equatorial lower strat.
Haigh and Blackburn 2006

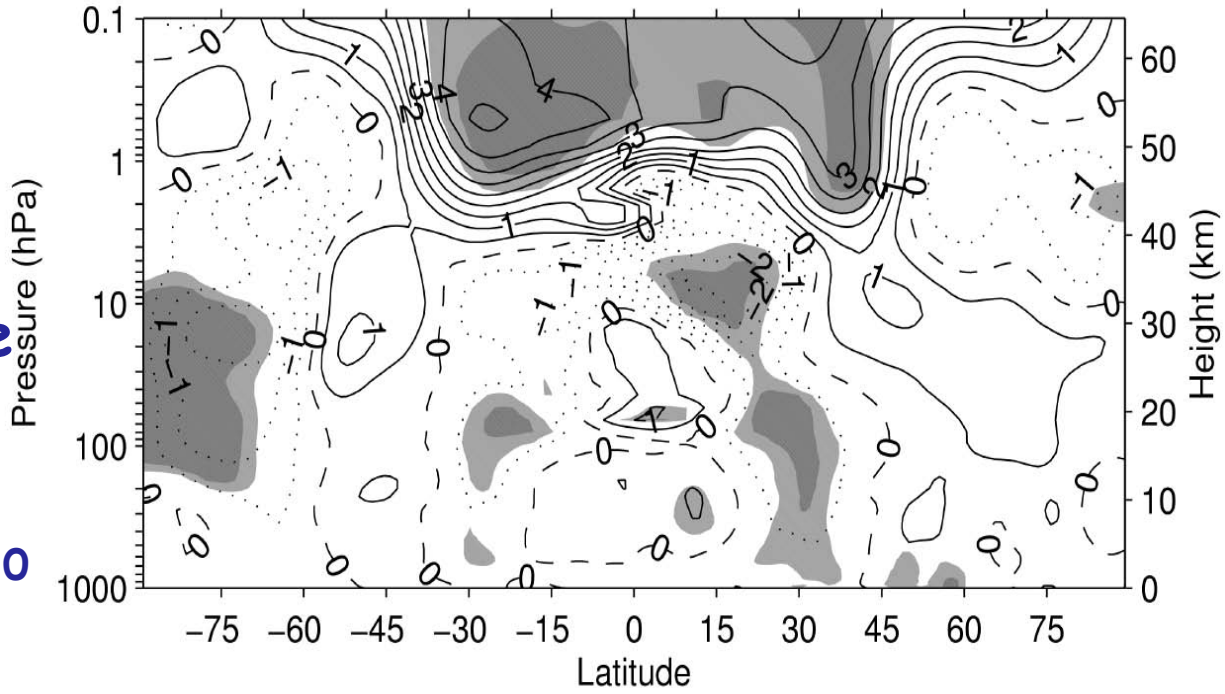
1. Where does the lower stratospheric temp / ozone signal come from?
(polar route vs equatorial route)





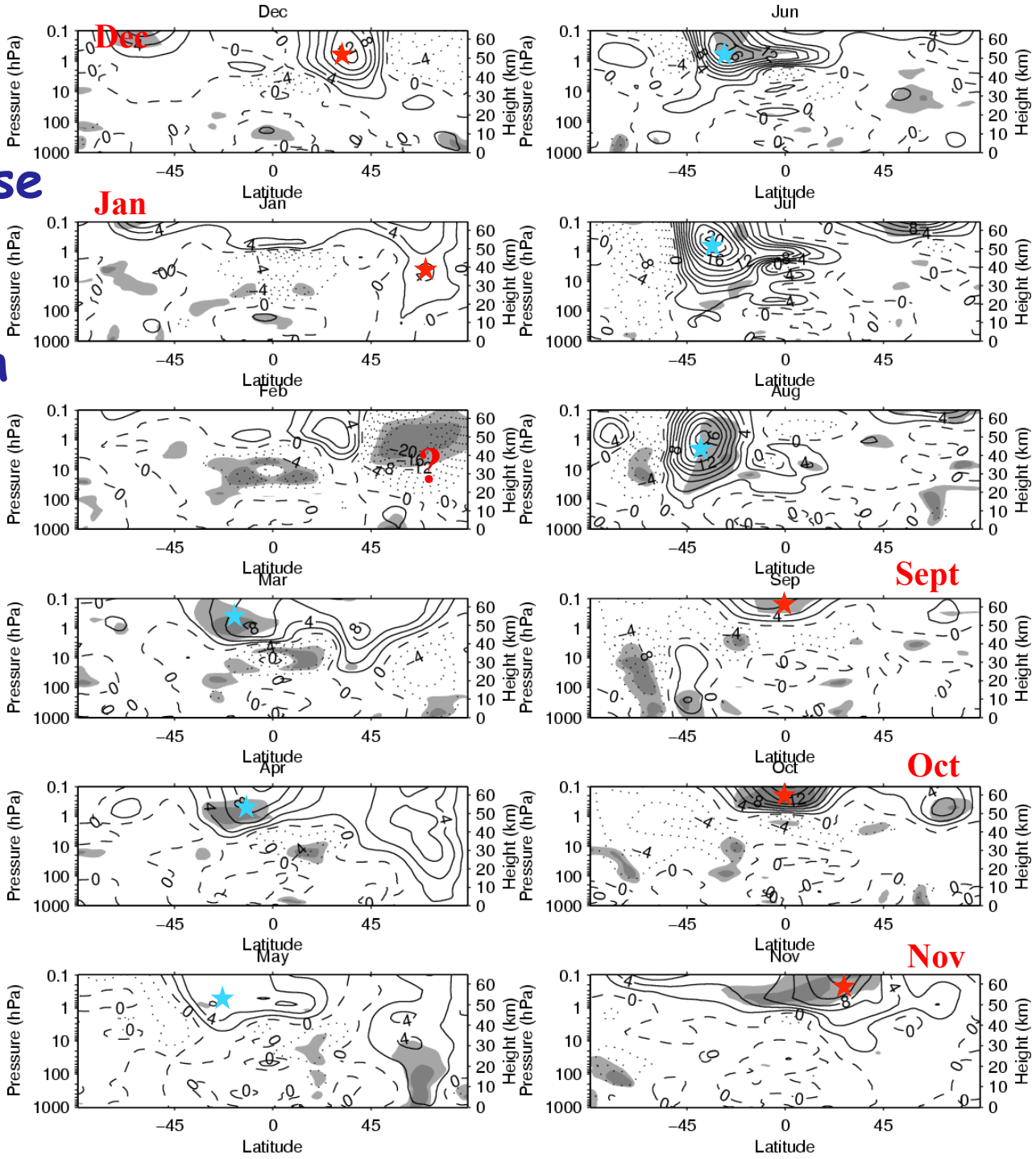
ERA-40
temperature response
Smax minus Smin (K)
annual average 1979-2008

ERA-40
zonal wind response
Smax minus Smin (m/s)
annual average
1979-2008
Frame and Gray, J. Clim 2010

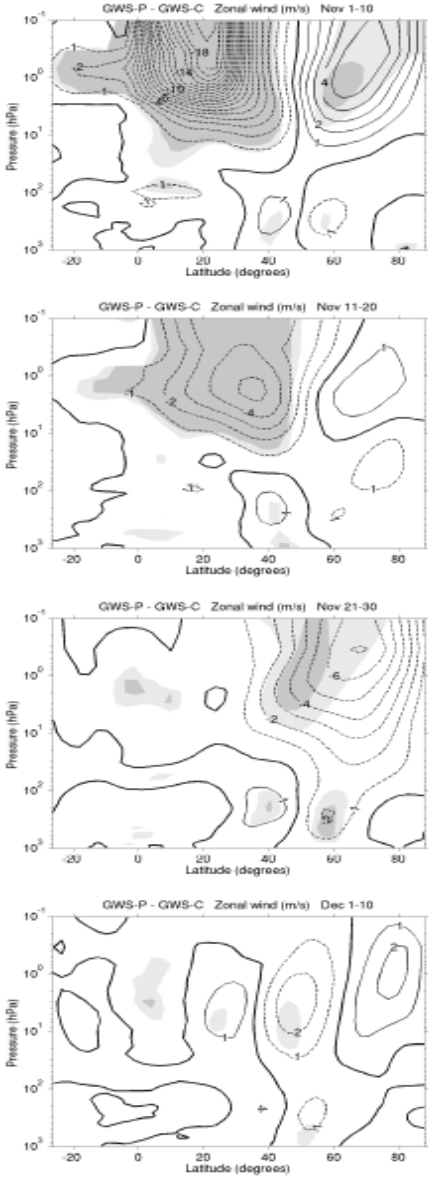


ERA-40 zonal wind response (m/s) Smax-Smin month-by-month

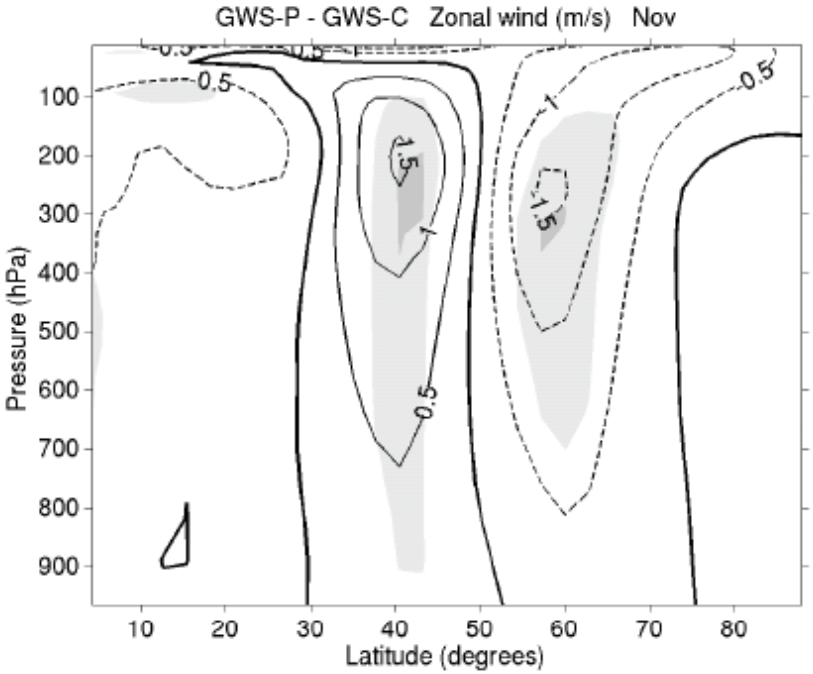
Frame and Gray, 2010
see also Kodera et al. papers



Polar route

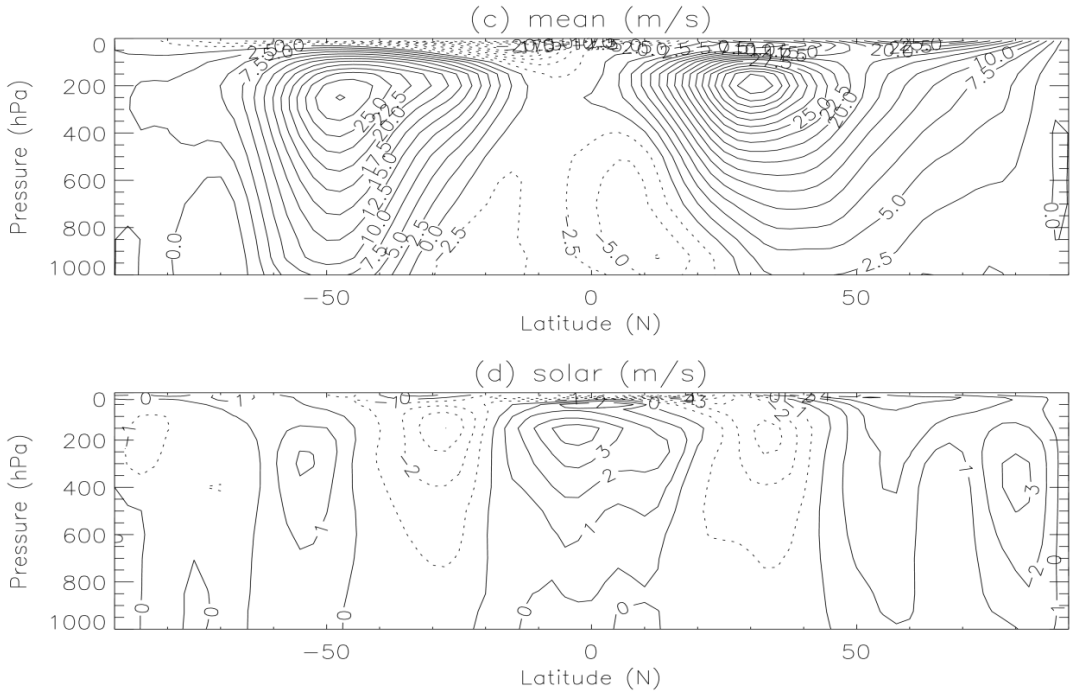


Gnossen et al. 2010
See also Matthes et al. 2006

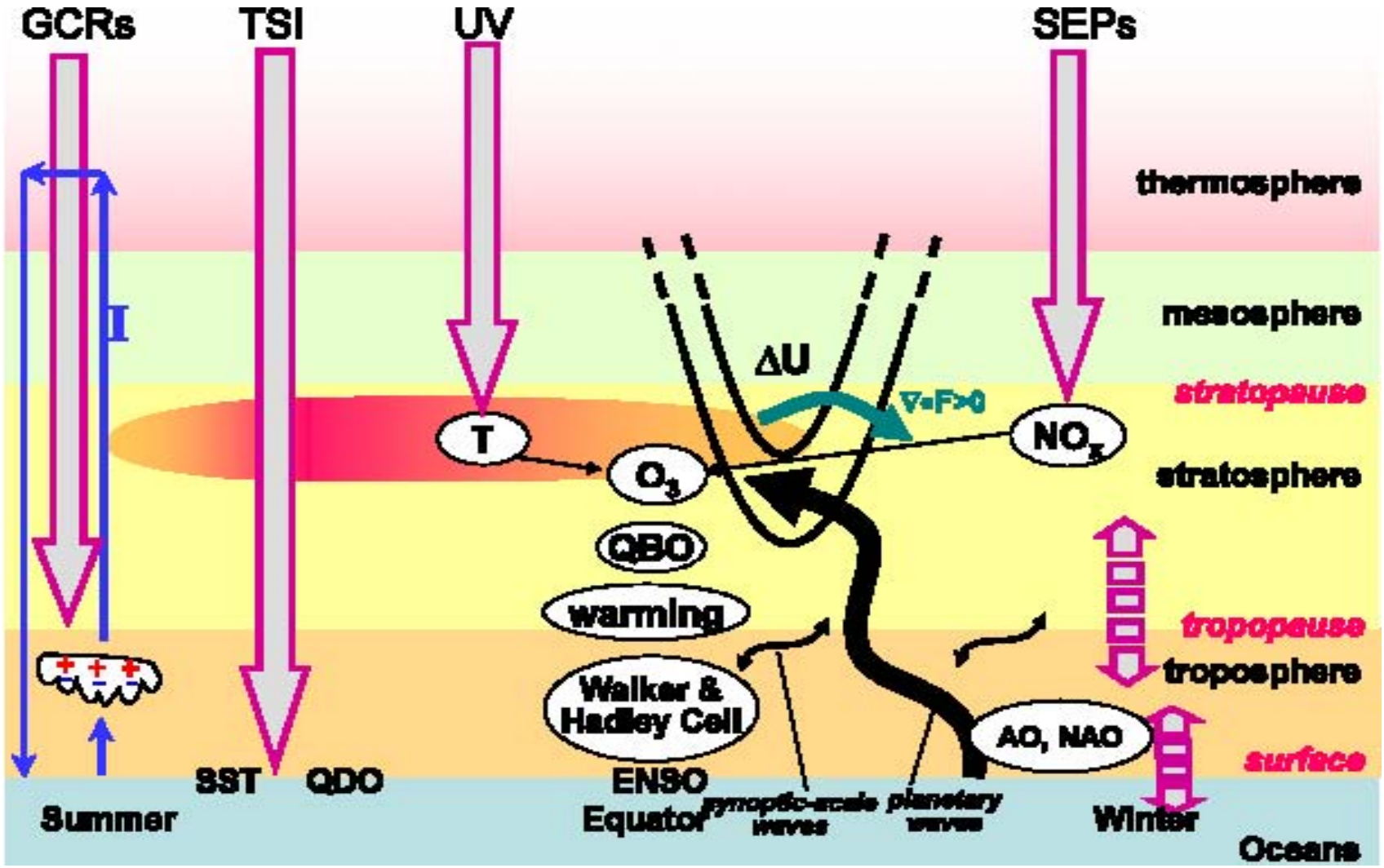


Modelled solar response in zonal winds
Gnossen et al. 2010

Observed solar response NCEP zonal winds
Haigh and Blackburn 2006

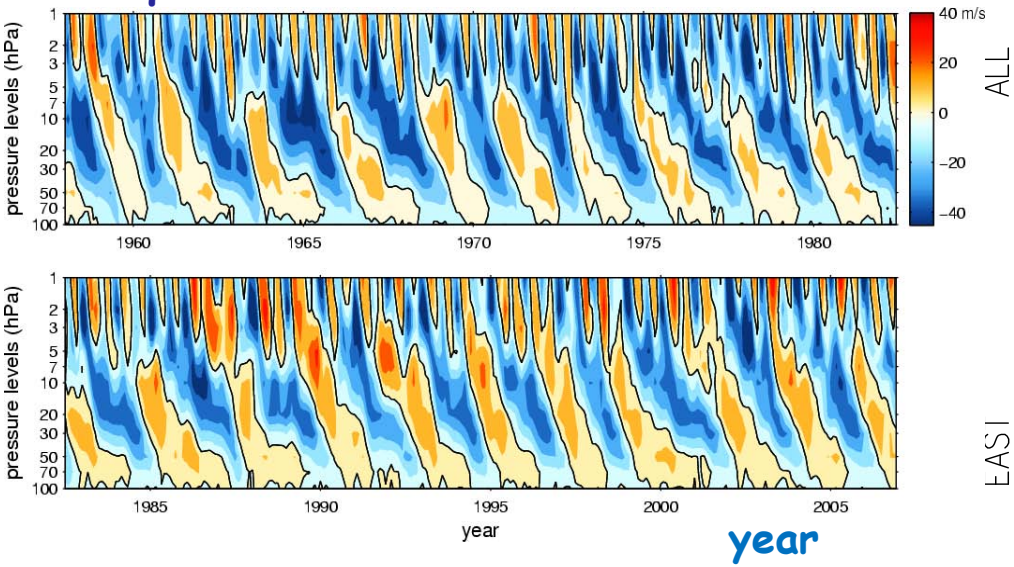


The quasi biennial oscillation (QBO)
Complicating influence on the polar response
Plus possible equatorial route

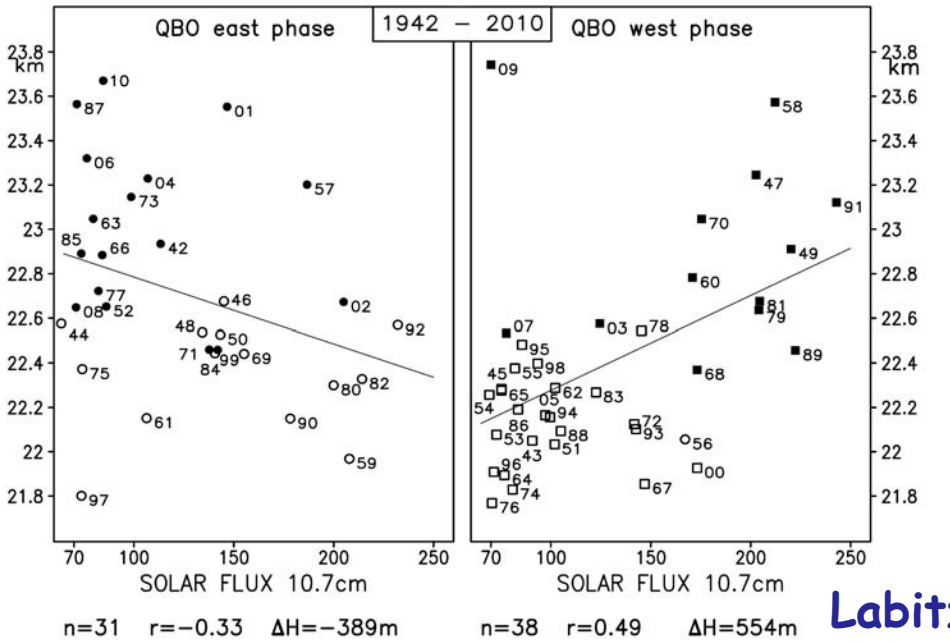


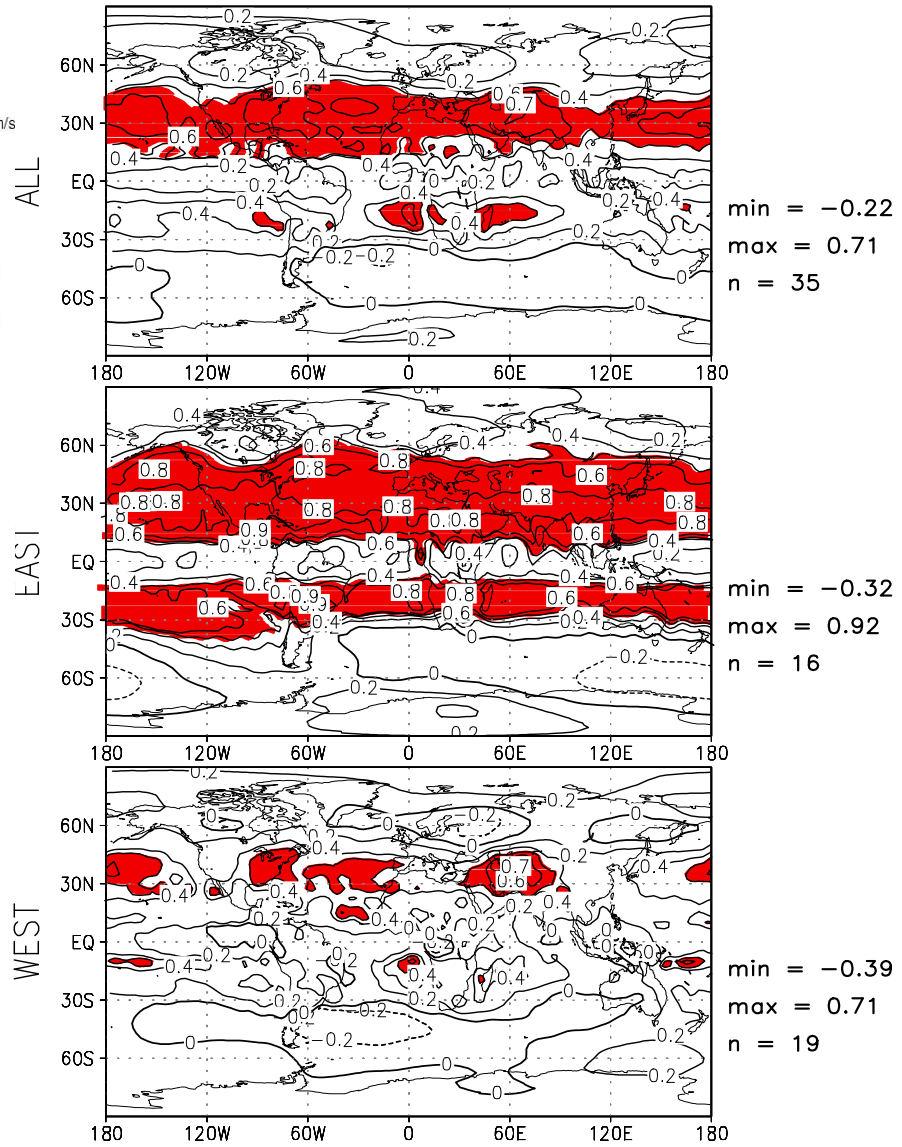
The Quasi Biennial Oscillation (QBO)

Equatorial wind time-series



year





min = −0.22
max = 0.71
n = 35

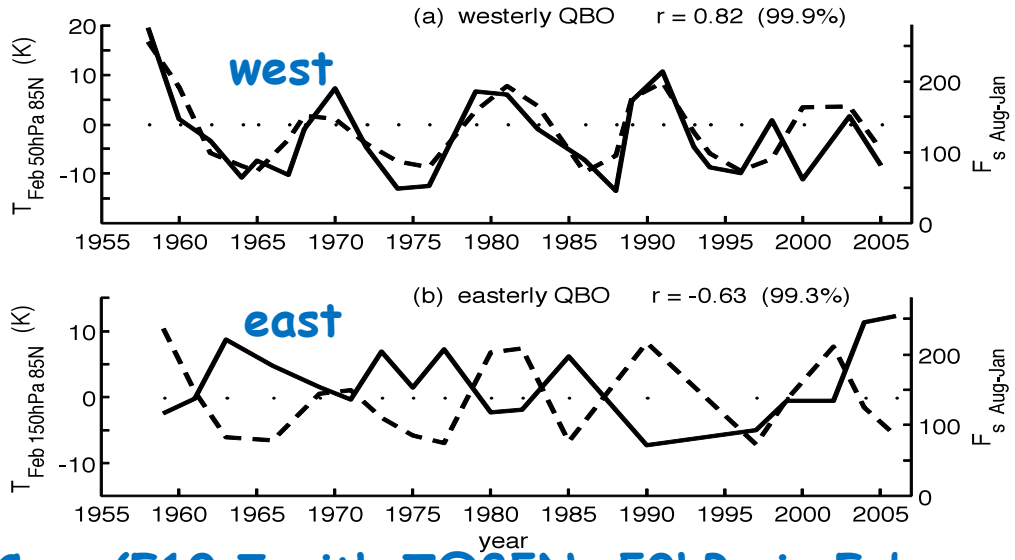
min = −0.32
max = 0.92
n = 16

min = −0.39
max = 0.71
n = 19

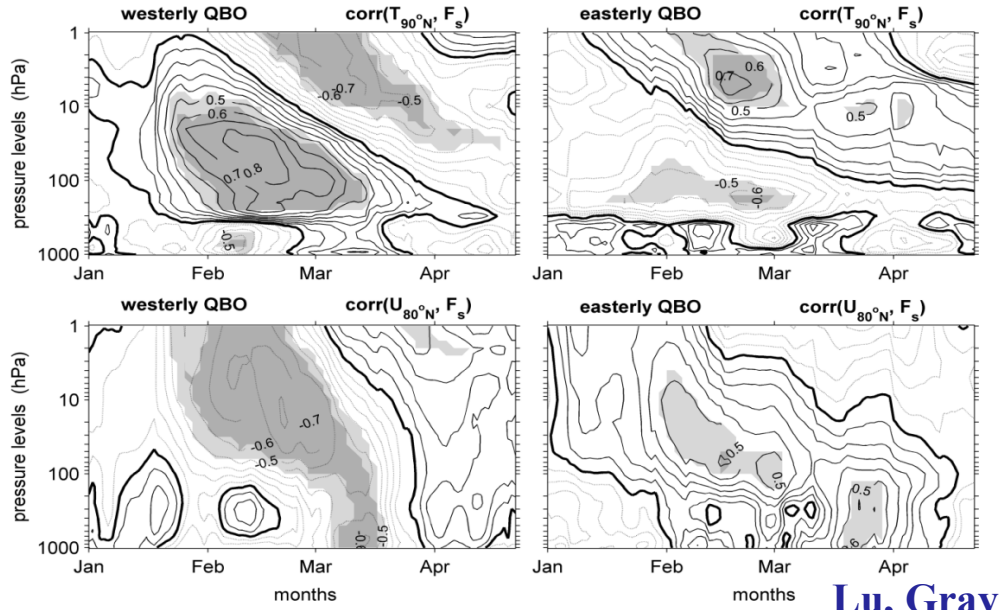
Corr: F10.7 with February 30 hPa T

Labitzke, van Loon 1987+

The Quasi Biennial Oscillation (QBO)



Corr (F10.7 with T@85N, 50hPa in February)



Corr (F10.7 with zonal wind @80N)

Lu, Gray et al. 2009

Zonal wind composites W-E

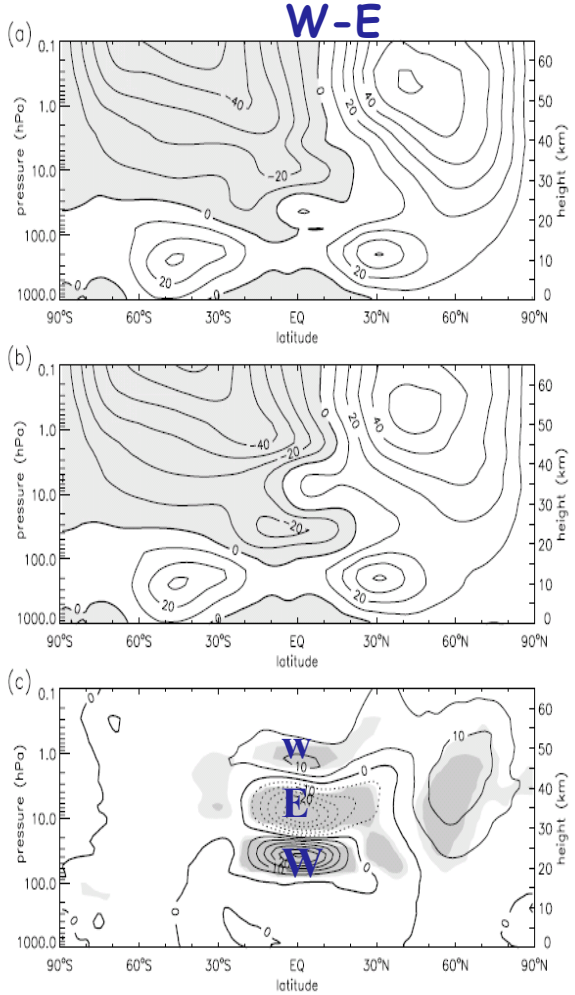
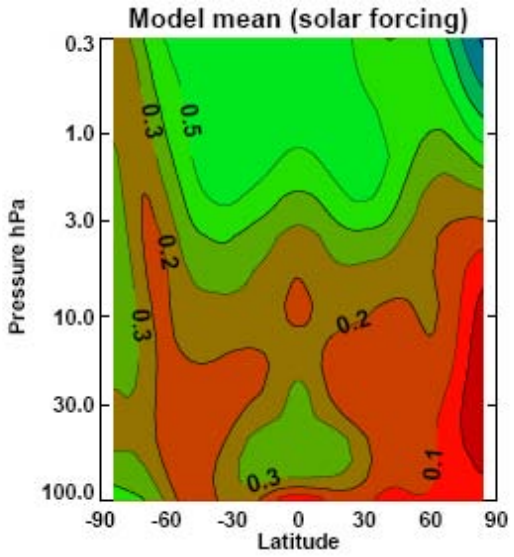


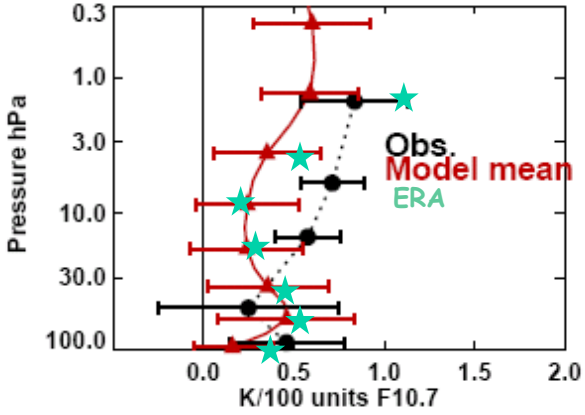
Figure 5. December–January zonal mean zonal wind for (a) QBO west and (b) QBO east years. Easterly zonal mean wind is shown shaded, and contours are at 10 m s^{-1} intervals. (c) West minus east zonal wind difference with *t* test confidence shading shown at 95% and 99%; contours are at 5 m s^{-1} intervals.

Pascoe, Gray et al. 2005

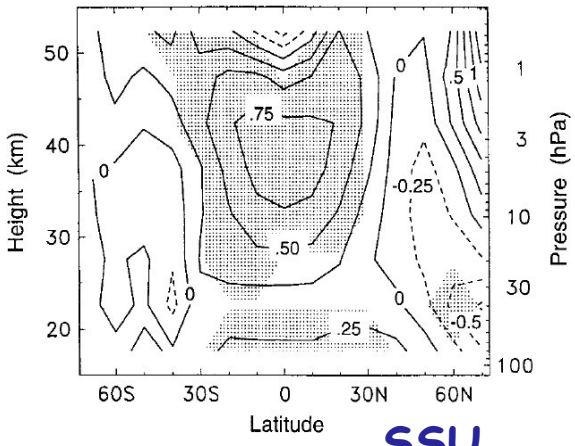
How well do models reproduce the temperature signal?



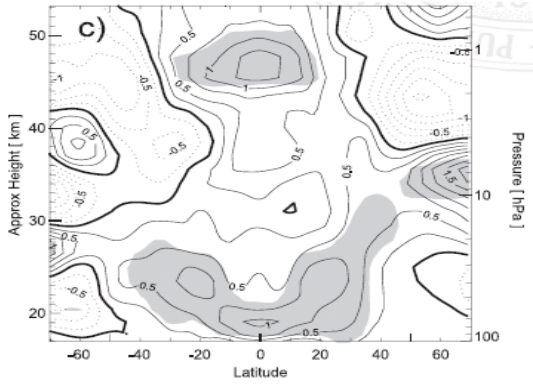
Average temperature response from coupled chemistry models (Austin et al. JGR 2008)



25N-25S



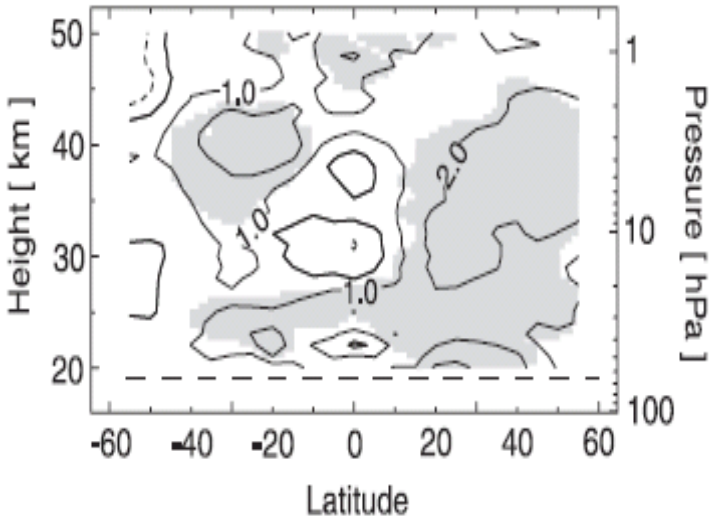
SSU



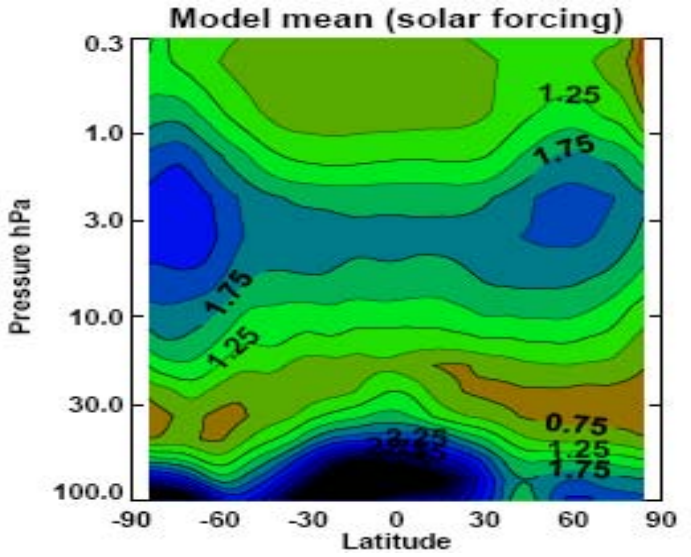
ERA-40

- Double peak structure in vertical – good match to ERA
- Lower strat peak wrong shape (role of QBO?)
- Upper strat temperature maximum too small and too wide

Why is upper strat temperature maximum too small and too wide?



SAGE ozone response (%)



Modelled ozone response (%)

Mid-lat signals OK – possibly too far poleward?

Upper strat peak ~50km is missing

Lower strat peak has wrong structure (QBO?)

Summary / Discussion UV Influence

Mechanism

- Solar UV influences stratospheric temps directly and via ozone

- resulting temp gradient influences zonal winds

- winds then influences wave propagation, enabling signal to extend deeper into the lower stratosphere and thence into the troposphere

Stratospheric response

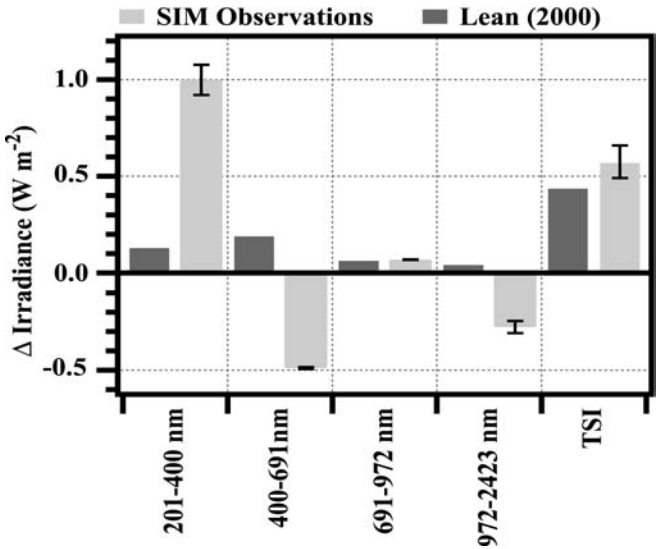
Inclusion in coupled chemistry models reproduces some of the observed 11-yr solar signals in the stratosphere, but still many details unresolved e.g. lower stratospheric temperature signal; solar / QBO interaction, surface response. BUT – are models using the correct UV variations (c.f. Recent SIM results, Harder et al. 2009)

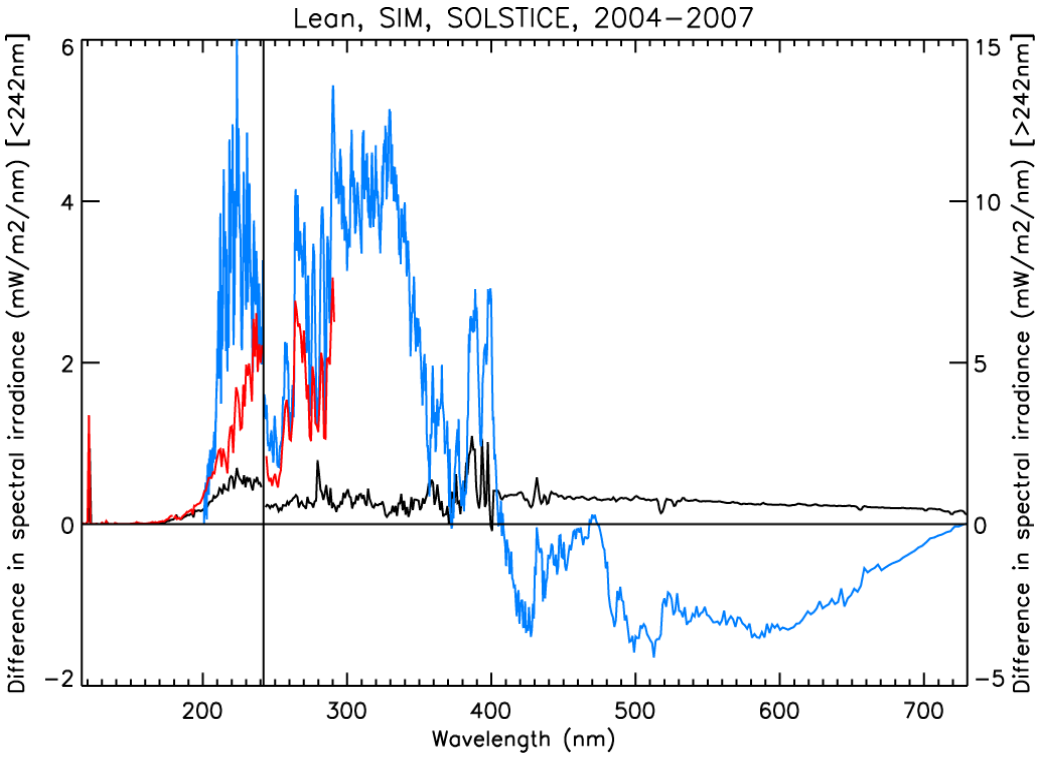
Tropospheric response

Inclusion of UV mechanism leads to a response in the troposphere (the 'top-down' response); coupled ocean models with TSI forcing produce a tropospheric response (the 'bottom-up' response);
The 2 effects appear to be additive; we need more fully coupled chemistry – stratosphere - troposphere – ocean models simulations to investigate this.

Major question: are we using the correct estimates of UV variations in our models?

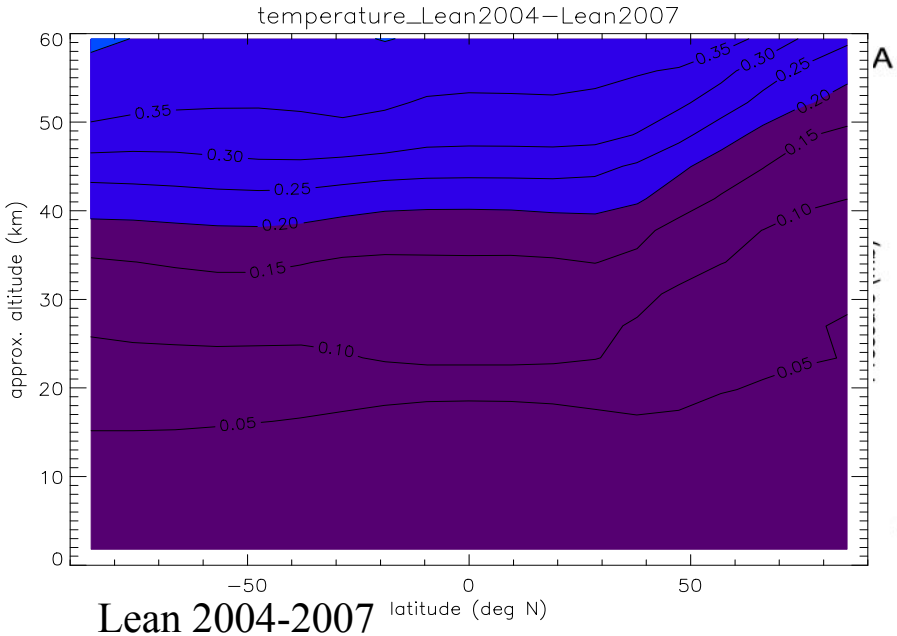
SIM Spectra differences 2004 - 2007



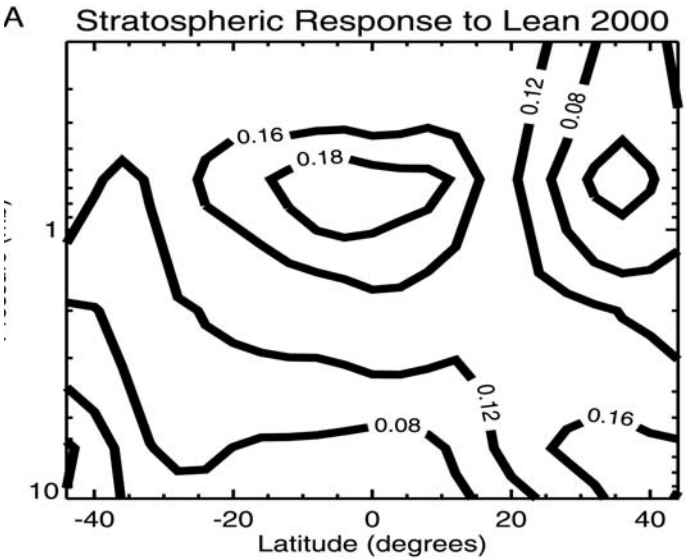


Harder et al. 2009

Spares

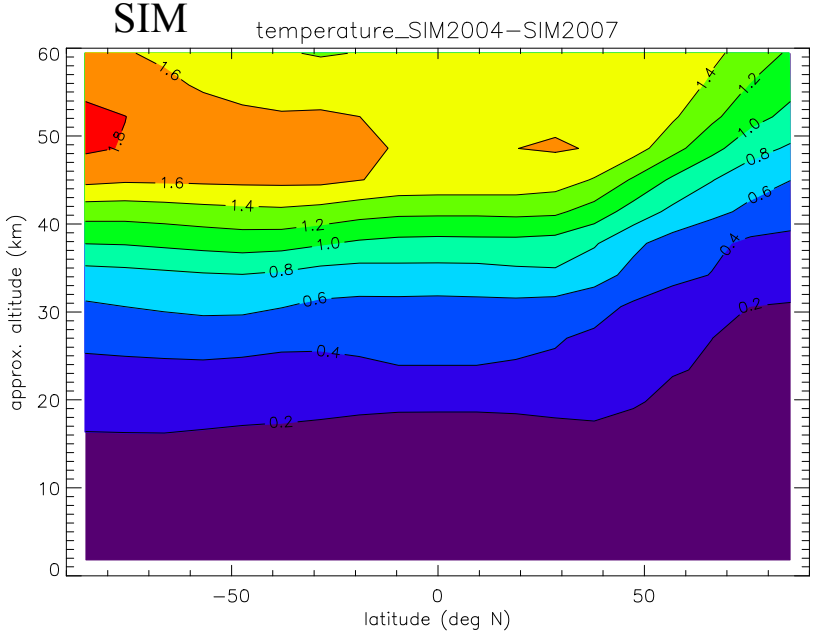


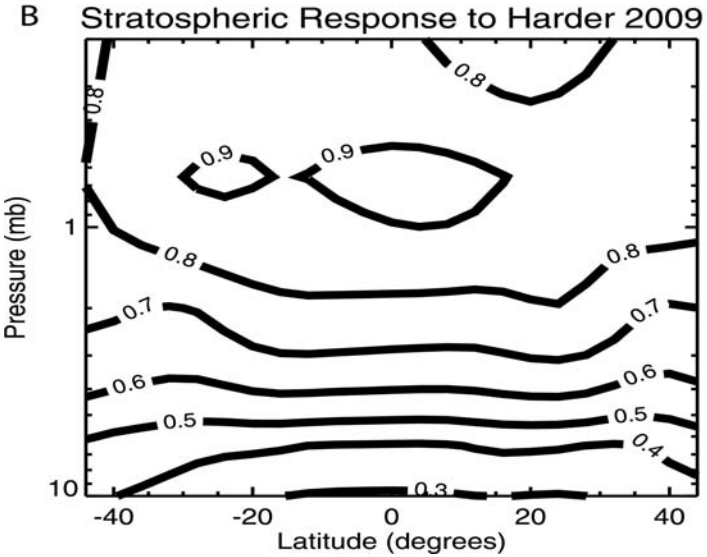
Lean 2004-2007



Haigh 2010 2-d model

SIM

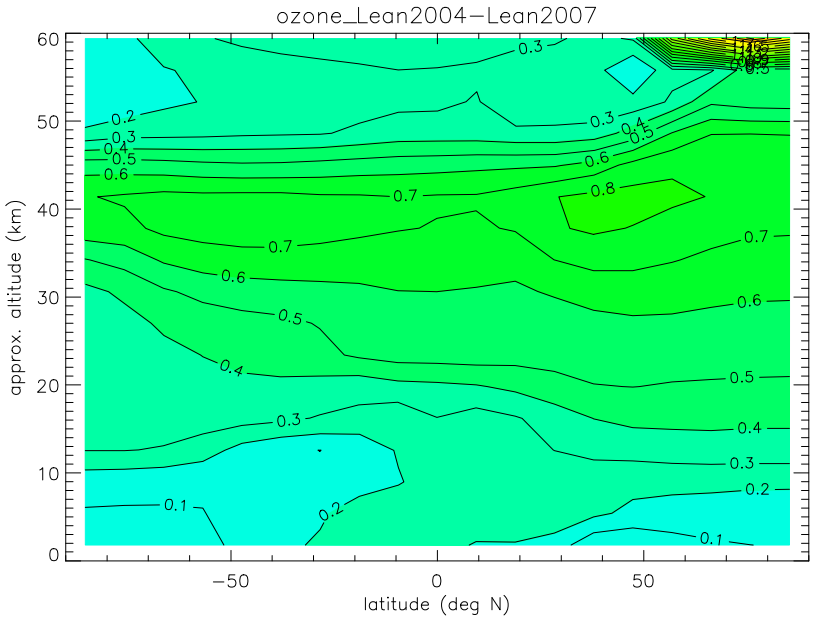




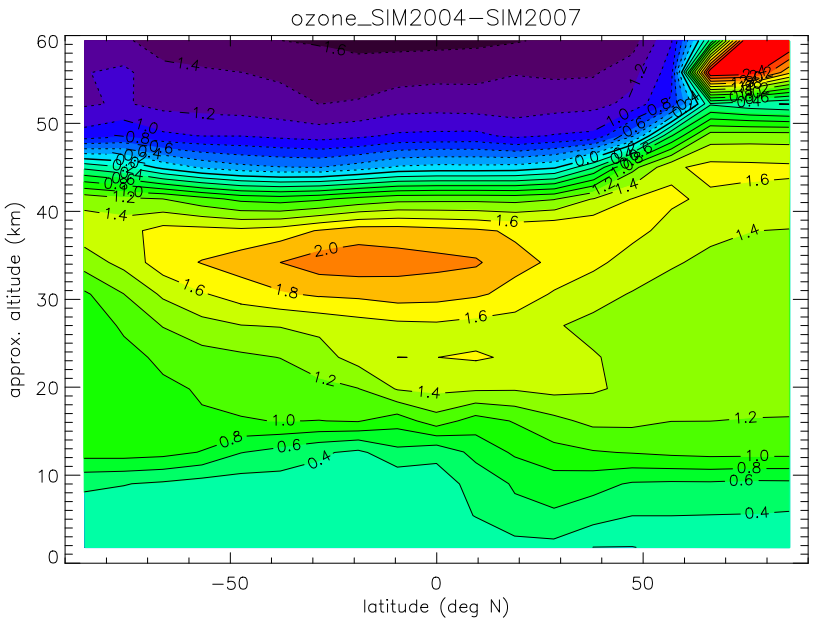
Cahalan et al 2010

2D model O_3 differences (%) 2004-2007

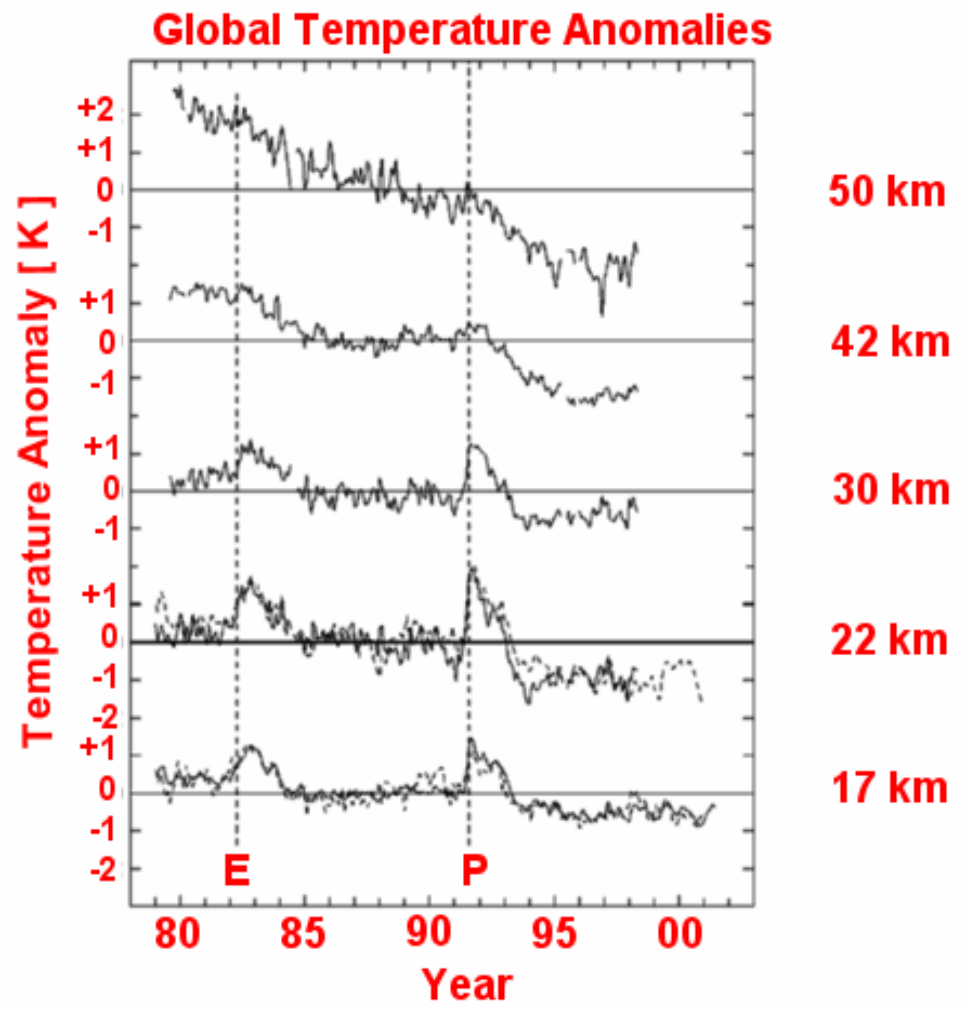
Lean



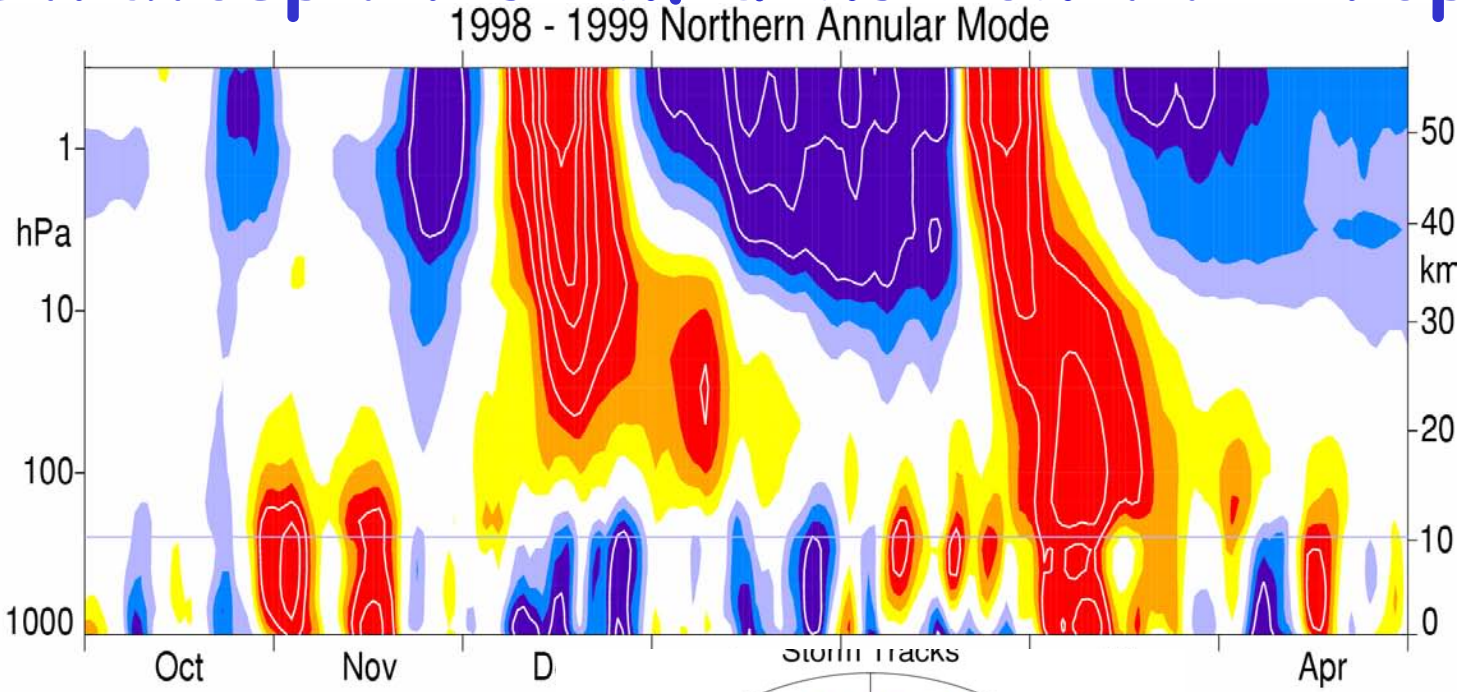
SIM



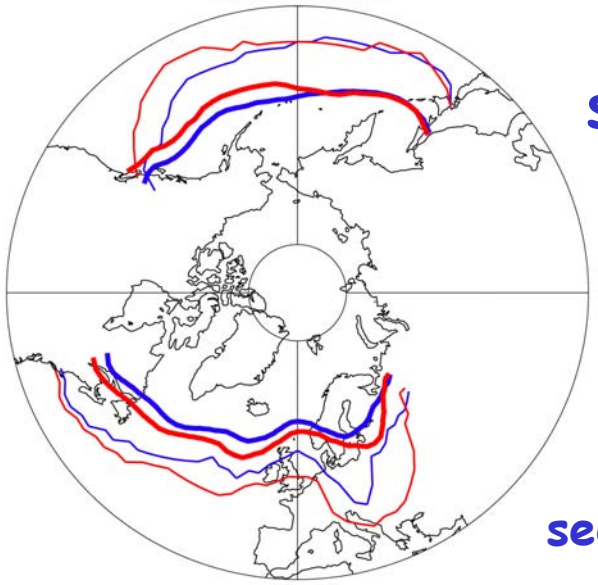
Climate change simulations with an improved stratosphere
Observed SSU temperature anomalies



Stratospheric Influence on the Troposphere



Baldwin and Dunkerton 2001

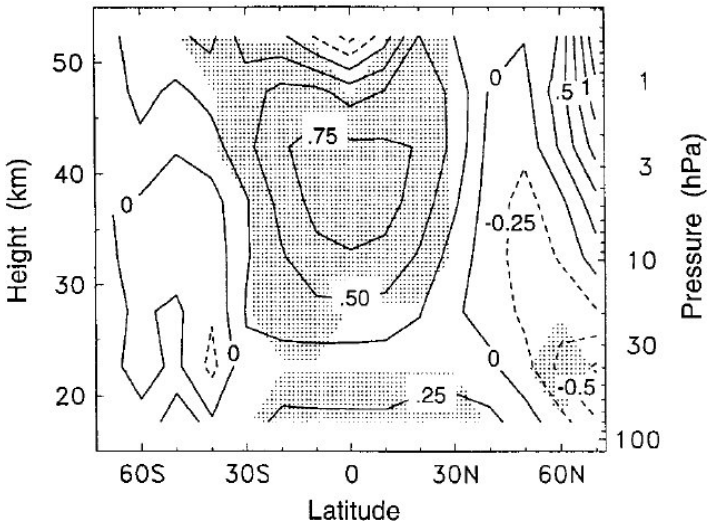


strong vortex regime

weak vortex regime

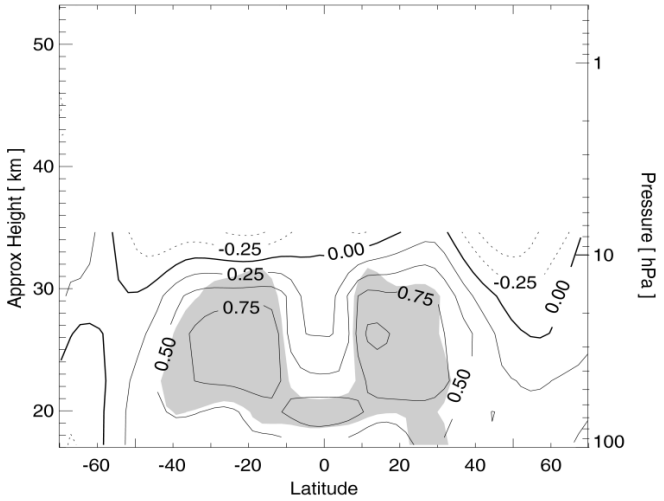
see also Woollings et al 2009

Solar min-to-max temp difference



SSU

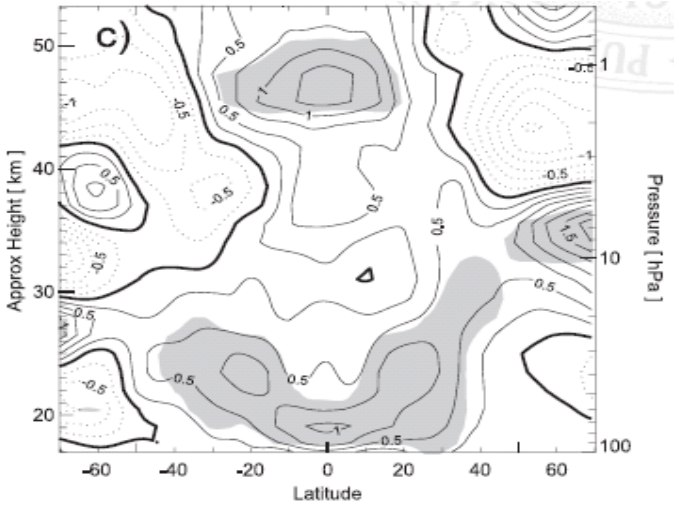
Ramaswamy et al. 2001
see also: Scaife et al 2000, Keckhut et al 2005



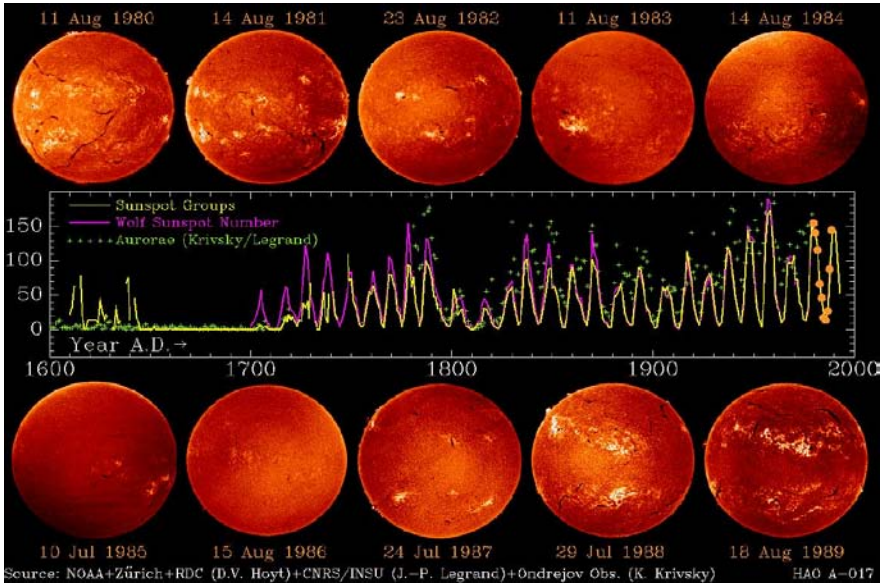
NCEP

Haigh 2003

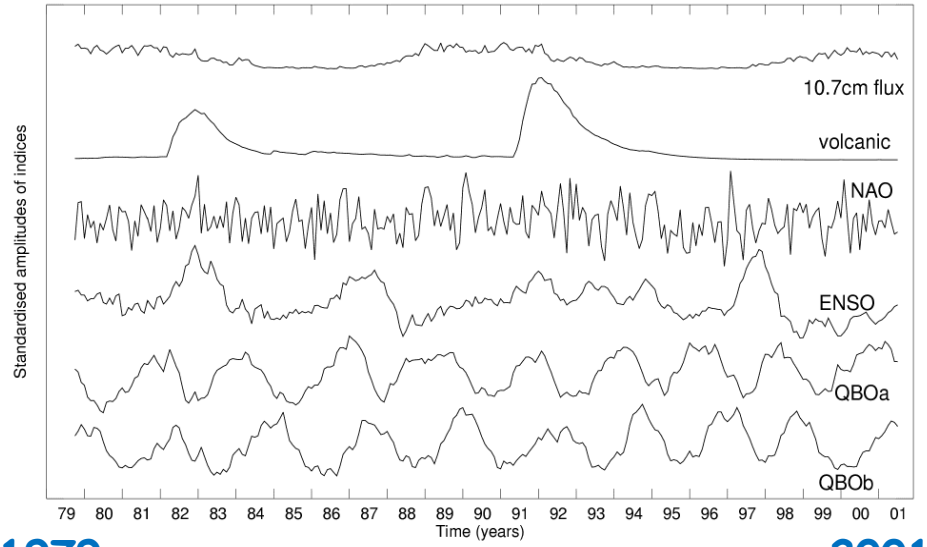
ERA-40



Corrected Crooks and Gray plot
in Frame and Gray 2009, submitted



11-year solar Cycle



1979 2001

Multiple Linear Regression using ERA-40 dataset:

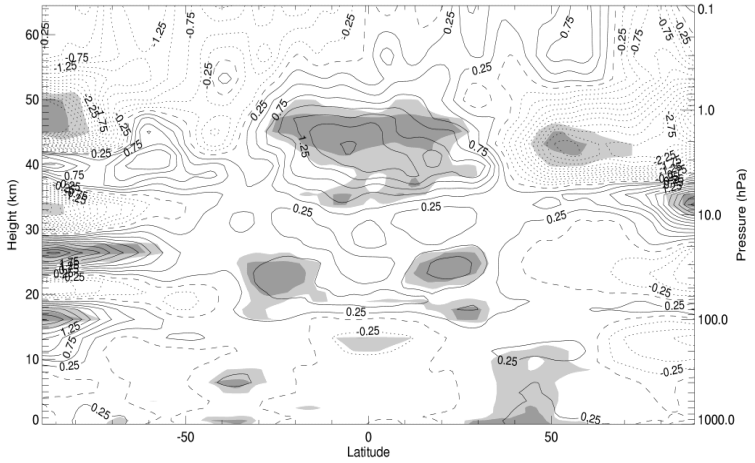
Question / objections to using re-analyses:

- Jumps in data due to changing instruments and data streams
- Possible contamination by volcanic signal

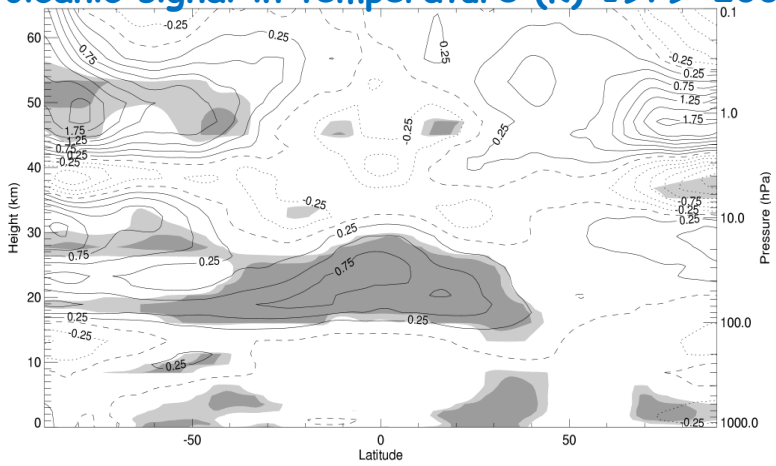
The 11-solar cycle signal

Solar min-to-max differences

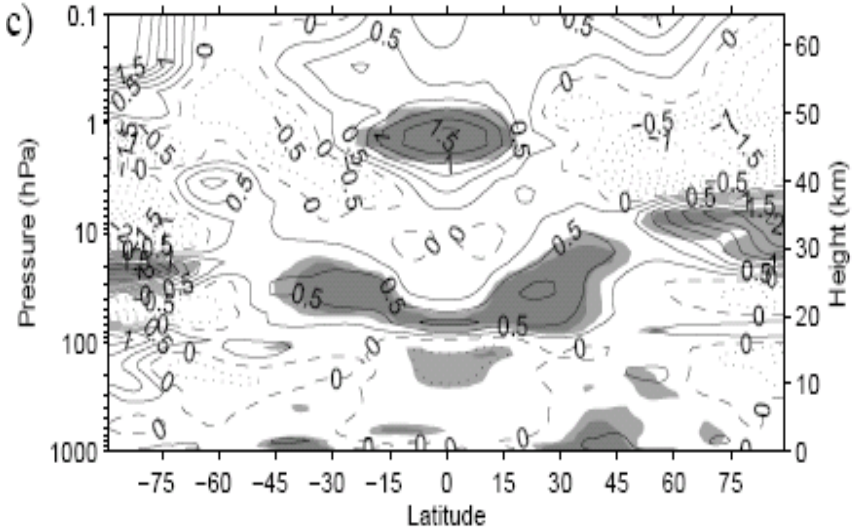
Solar signal in temperature (K) 1979-2001



Volcanic signal in temperature (K) 1979-2001



Solar signal in temperature (K) 1979-2008



Crooks and Gray 2005
Gray, Rumbold and Shine JAS 2009
Frame and Gray J. Clim 2009

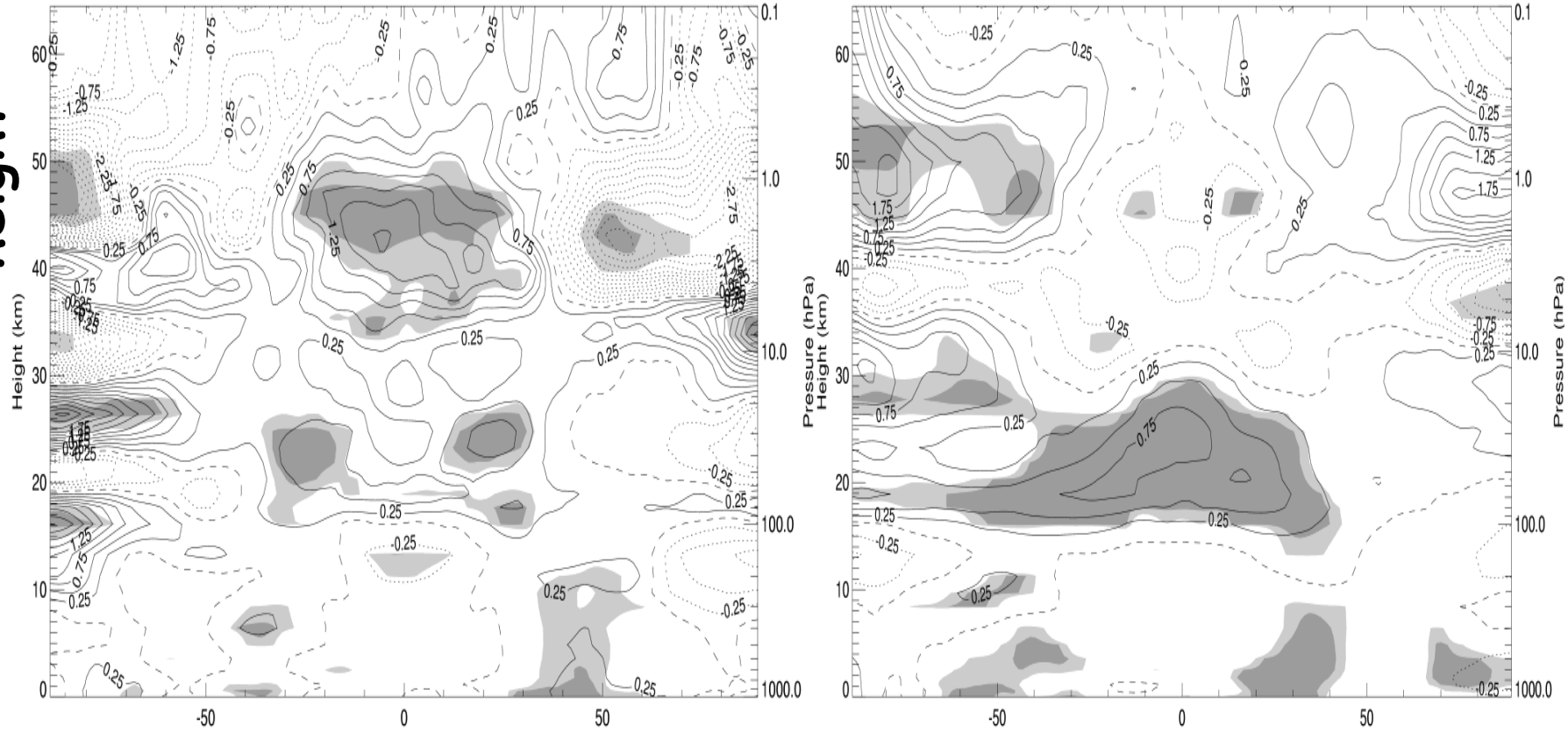
Comparison of solar and volcanic signal

Solar max - min

1979-2001

Volcanic

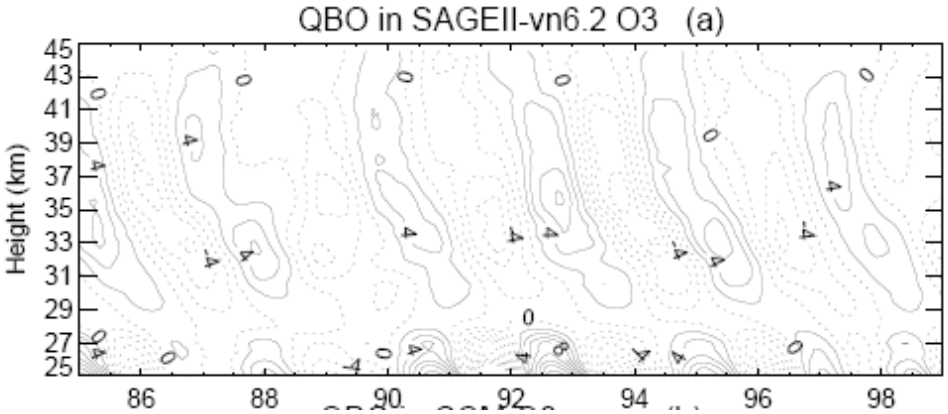
height



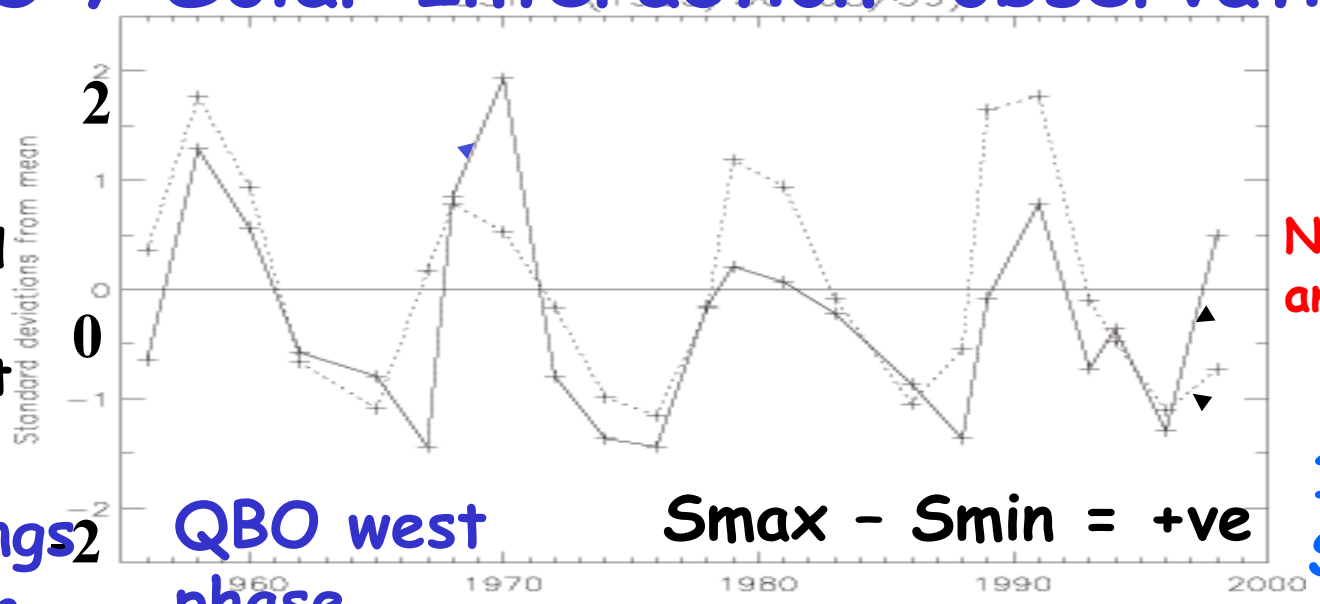
latitude

Crooks and Gray 2005

latitude


QBO in SAGEII-vn6.2 O3 (a)
Height (km)
45
43
41
39
37
35
33
31
29
27
25
86
88
90
92
94
96
98

QBO / Solar Interaction: observations



Standard deviations from mean

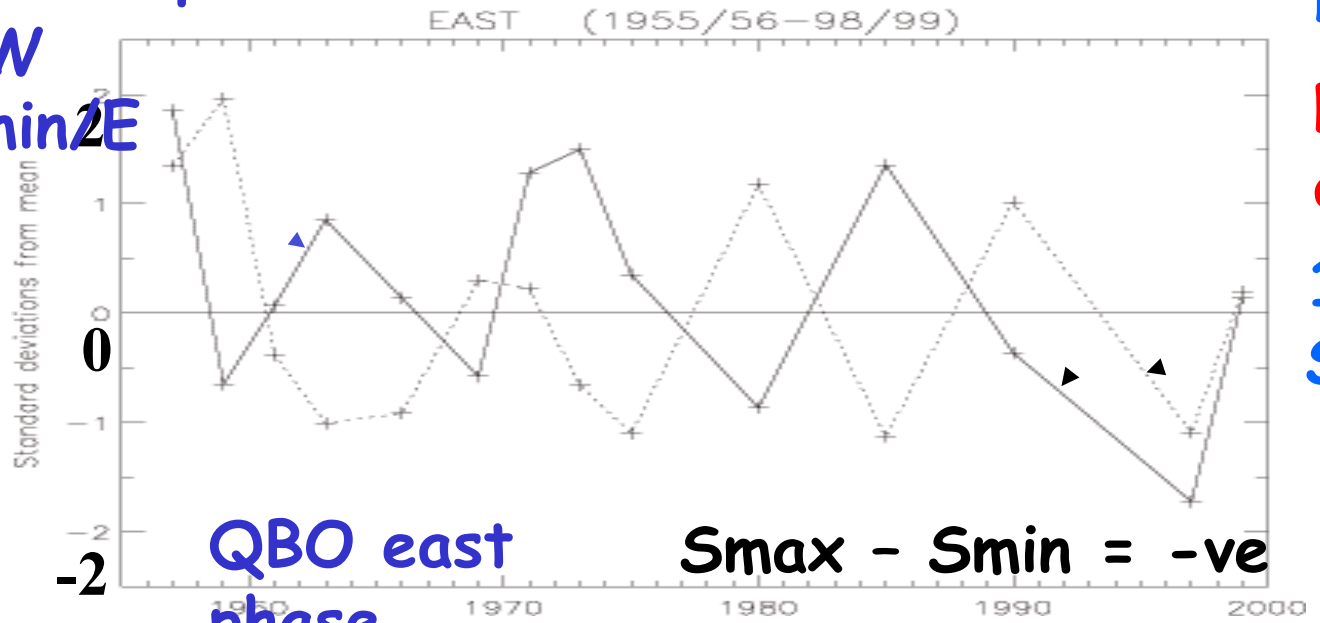
NH polar temp anomaly 24 km

10.7 cm Solar flux

QBO west phase

Smax – Smin = +ve

Warmings occur in Smax/W And Smin/E



NH polar temp anomaly 24 km

10.7 cm Solar flux

QBO east phase

Smax – Smin = -ve

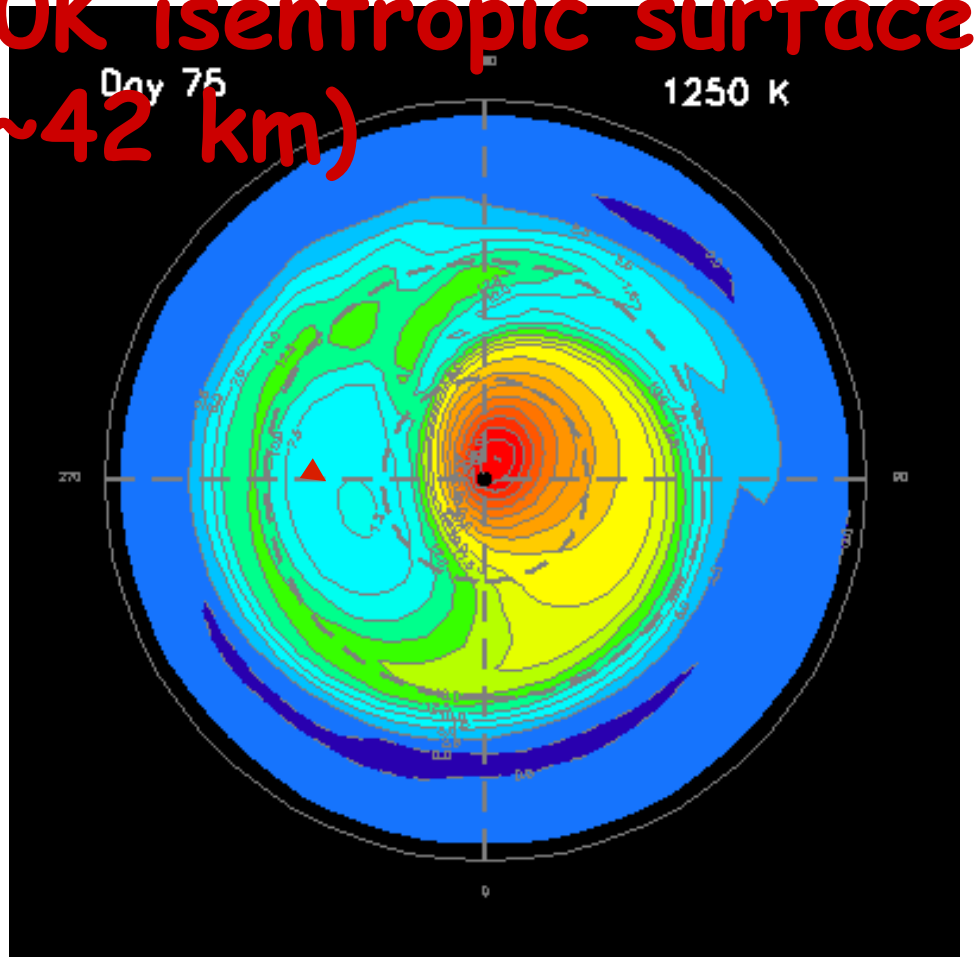
19 60 19 70 19 80 19 90 20 00

Labitzke and van Loon

Example of a Stratospheric Sudden Warming

PV on the 1250K isentropic surface

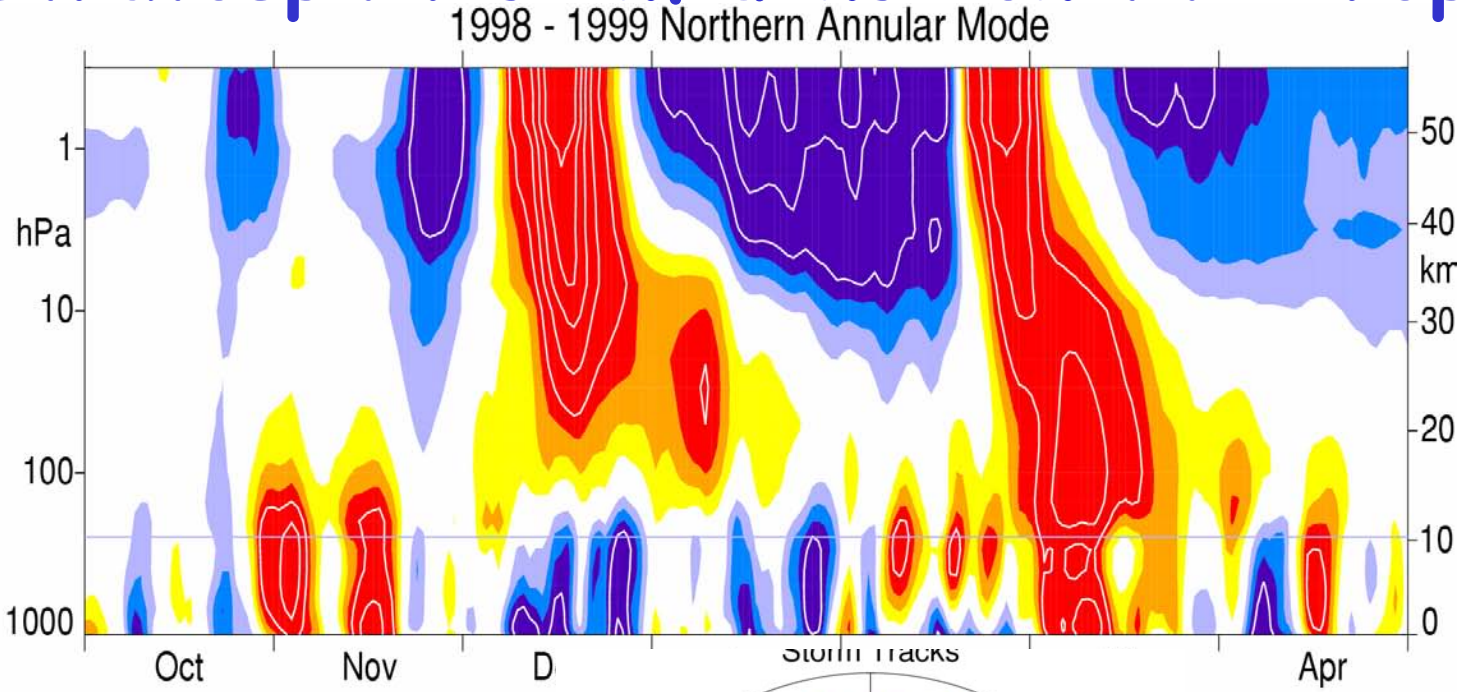
Aleutian High (~42 km)



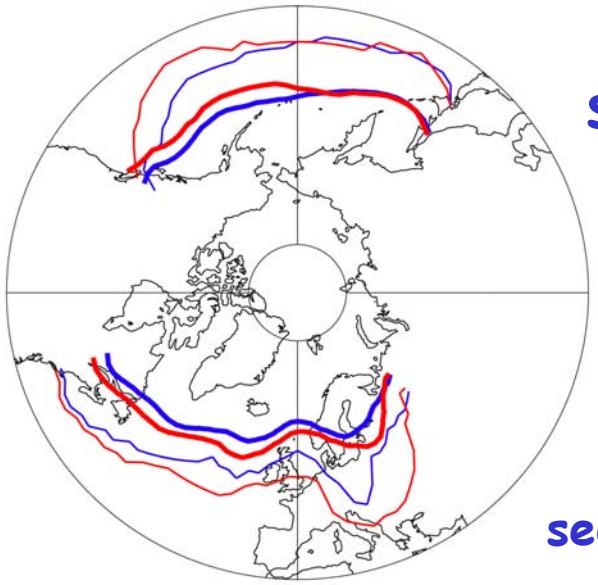
- Gray, Drysdale, Dunkerton and Lawrence, QJRMS, 2001

- Gray, Sparrow, Juckes, O'Neill and Andrews, QJRMS, 2003

Stratospheric Influence on the Troposphere



Baldwin and Dunkerton 2001



strong vortex regime

weak vortex regime

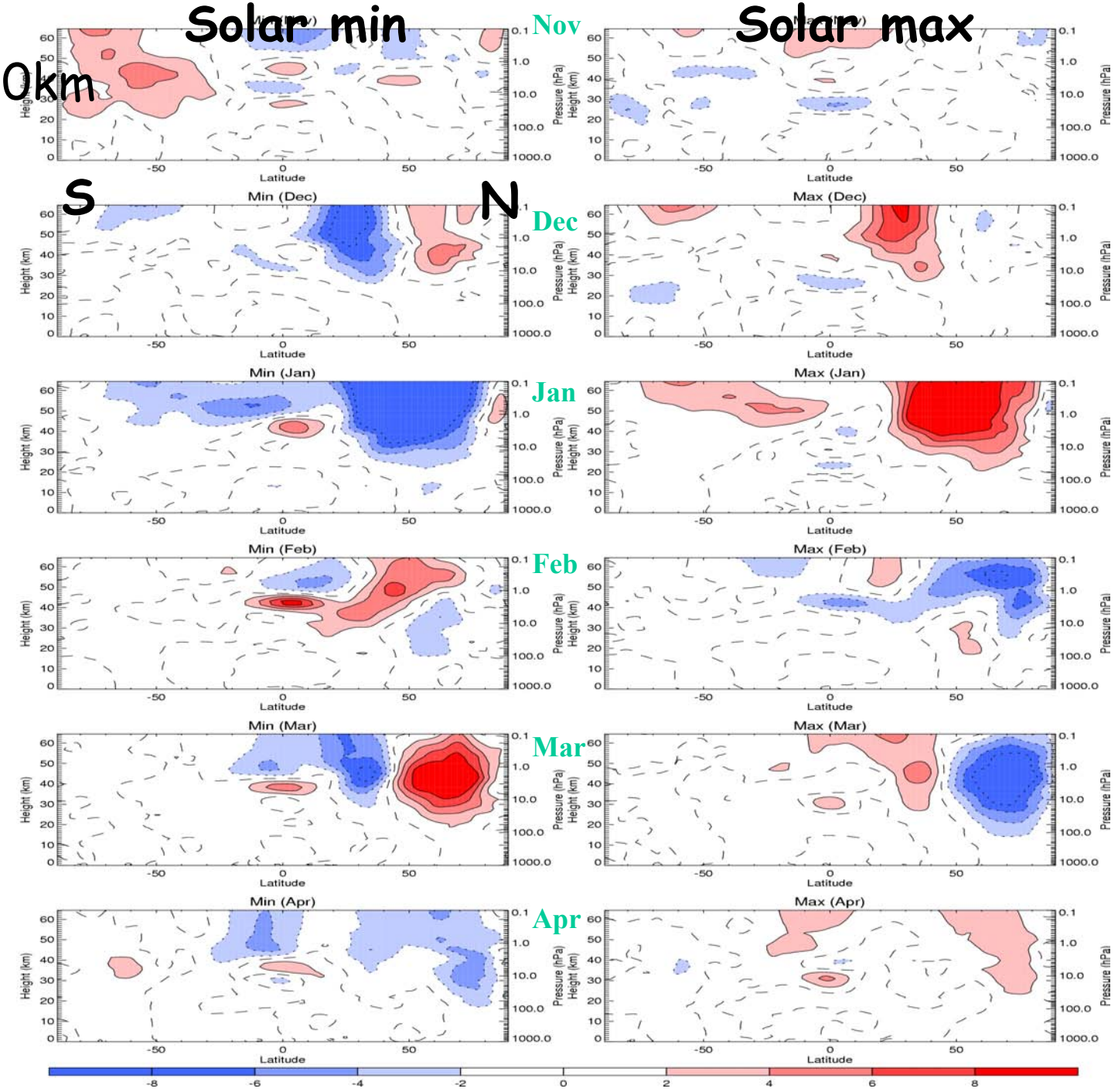
see also Woollings et al 2009

ERA-40

Composites of zonal mean wind anomalies

Blue=easterly
Red=westerly

Gray et al. 2005, JAS

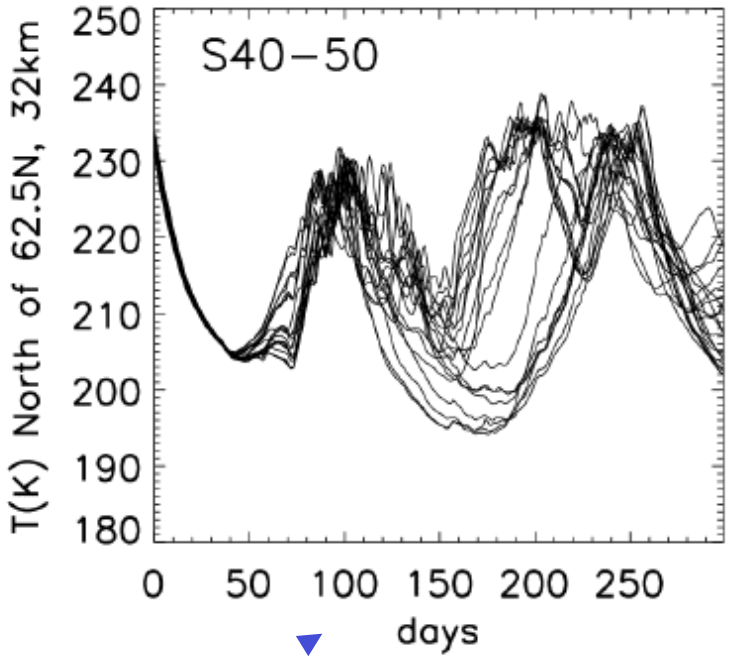


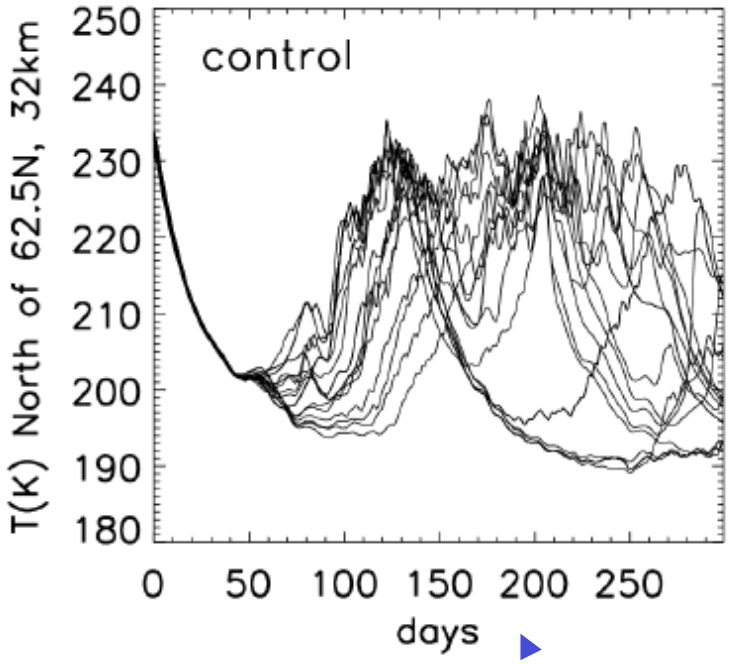
'Polar route' for solar influence

Stratosphere Mesosphere Model expt

Time-series of polar temperature

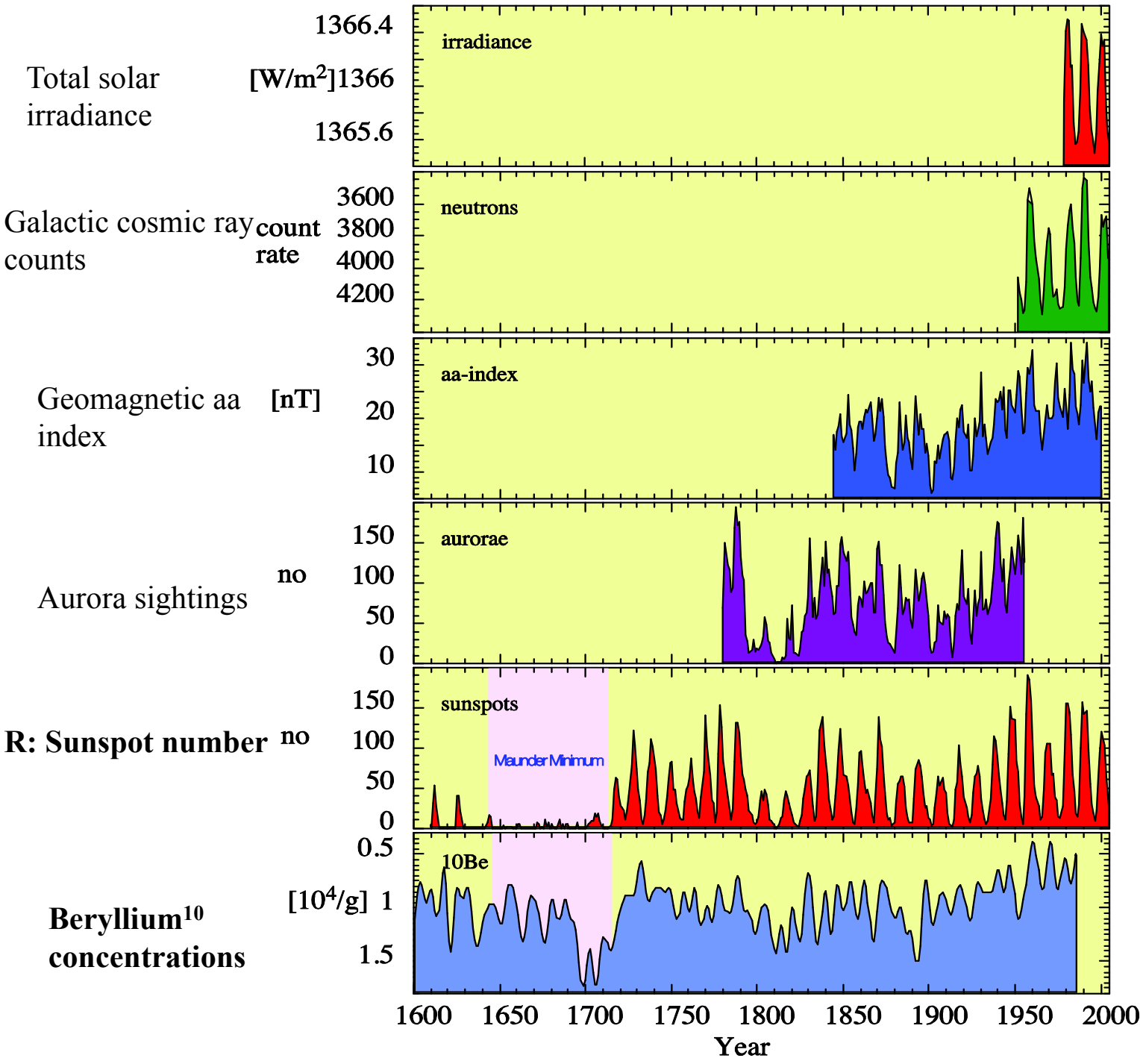
20-member ensemble



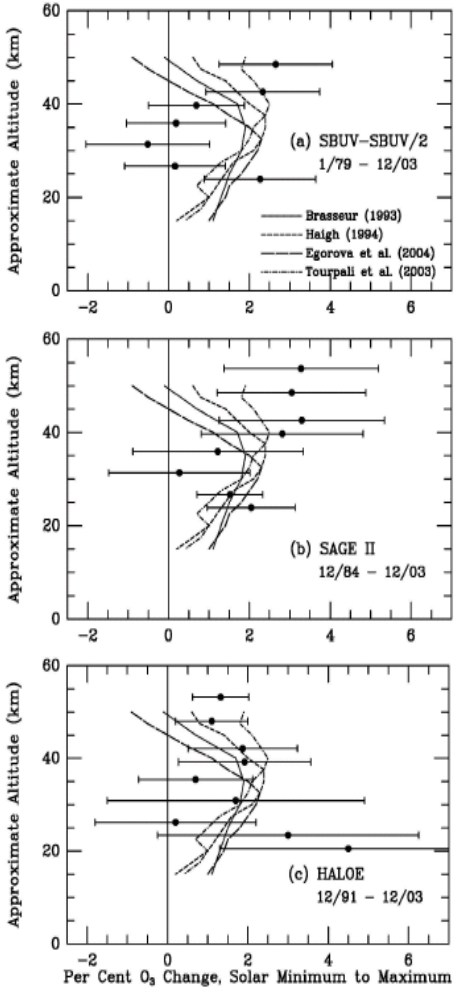


Easterly anomaly imposed in subtropics at 40-50km to mimic a solar minimum anomaly

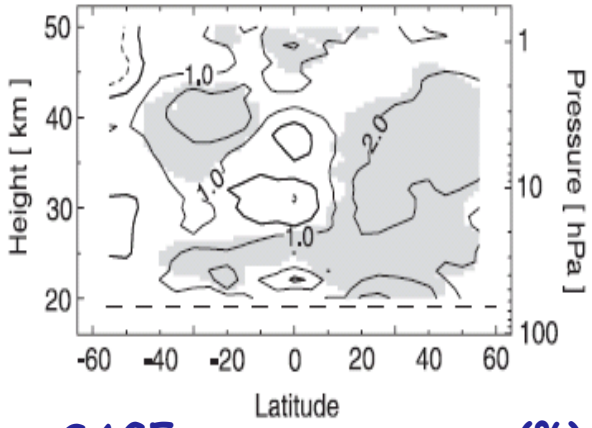
Timing of sudden warmings is very variable in control run


Total solar irradiance
[W/m2]
1366.4
1366
1365.6
irradiance
Galactic cosmic ray counts
count rate
3600
3800
4000
4200
neutrons
Geomagnetic aa index
[nT]
30
20
10
aa-index
Aurora sightings
no
150
100
50
0
aurorae
R: Sunspot number
no
150
100
50
0
sunspots
Maunder Minimum
Beryllium10 concentrations
[10^4/g]
0.5
1
1.5
10Be
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year

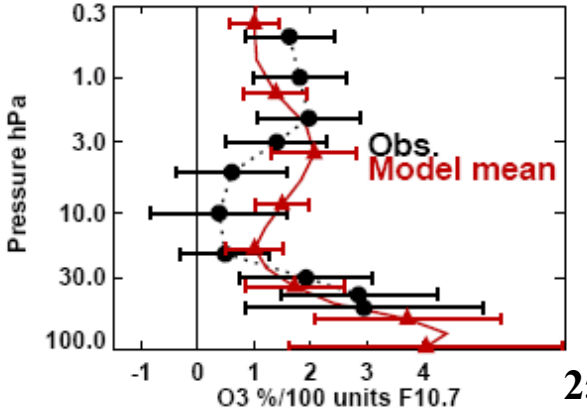
Why is upper strat temperature maximum too small and too wide?



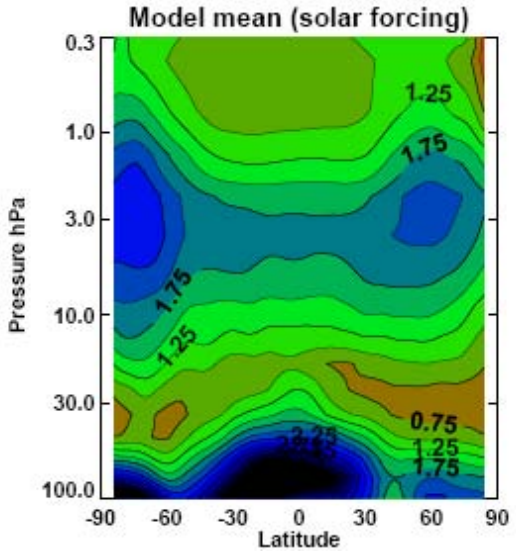
Ozone 25S-25N



SAGE ozone response (%)



25S-25N



Modelled ozone response (%)

Mid-lat signals OK – possibly too far poleward?
Upper strat peak ~50km is missing (see also Soukharev and Hood 2006)
Comparison with obs in Austin et al. is skewed by HALOE
Lower strat peak has wrong structure (QBO?)