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The Influence of Solar Spectral Variations on Climate

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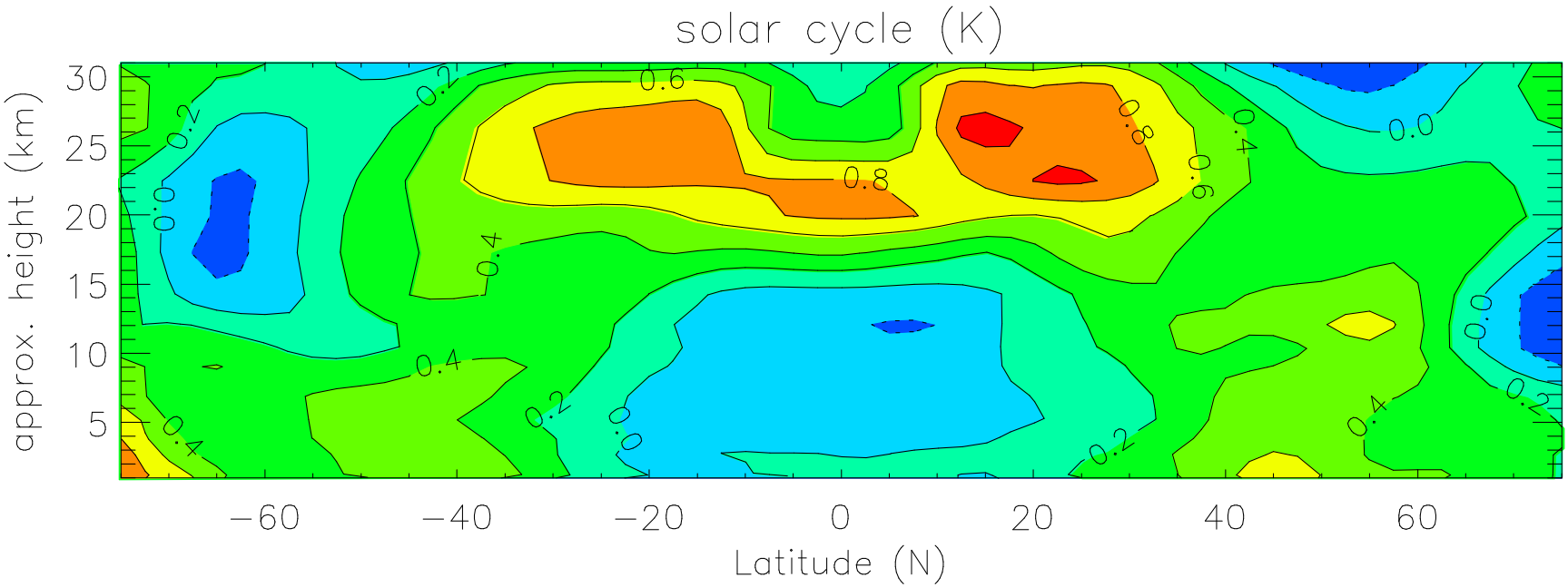
Outline

- Observed impact of solar variability on temperature and zonal wind in lower atmosphere.
- Mechanisms?
- GCM study of impact of UV variation.
- Simplified model to study stratosphere-troposphere coupling mechanisms.
- Implications for stratospheric composition (and solar forcing of climate) of recent SSI measurements.
- Attempt to combine solar and stratospheric observations, with atmospheric model, to advance understanding of both.

Solar cycle signal in zonal mean temperature

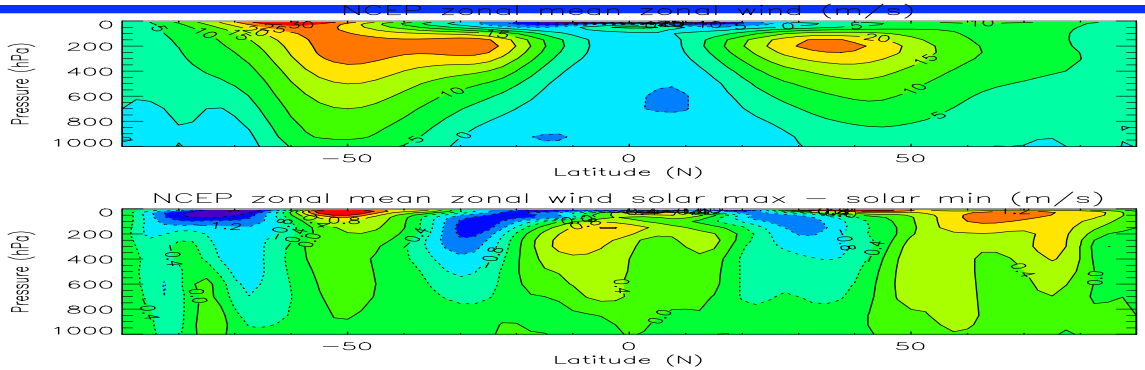
NCEP reanalysis data 1979-2004



Heating in tropical lower stratosphere and throughout troposphere in mid-latitudes

after Haigh (Phil Trans Roy Soc, 2003)

Solar cycle signal in westerly wind (observed)



mean

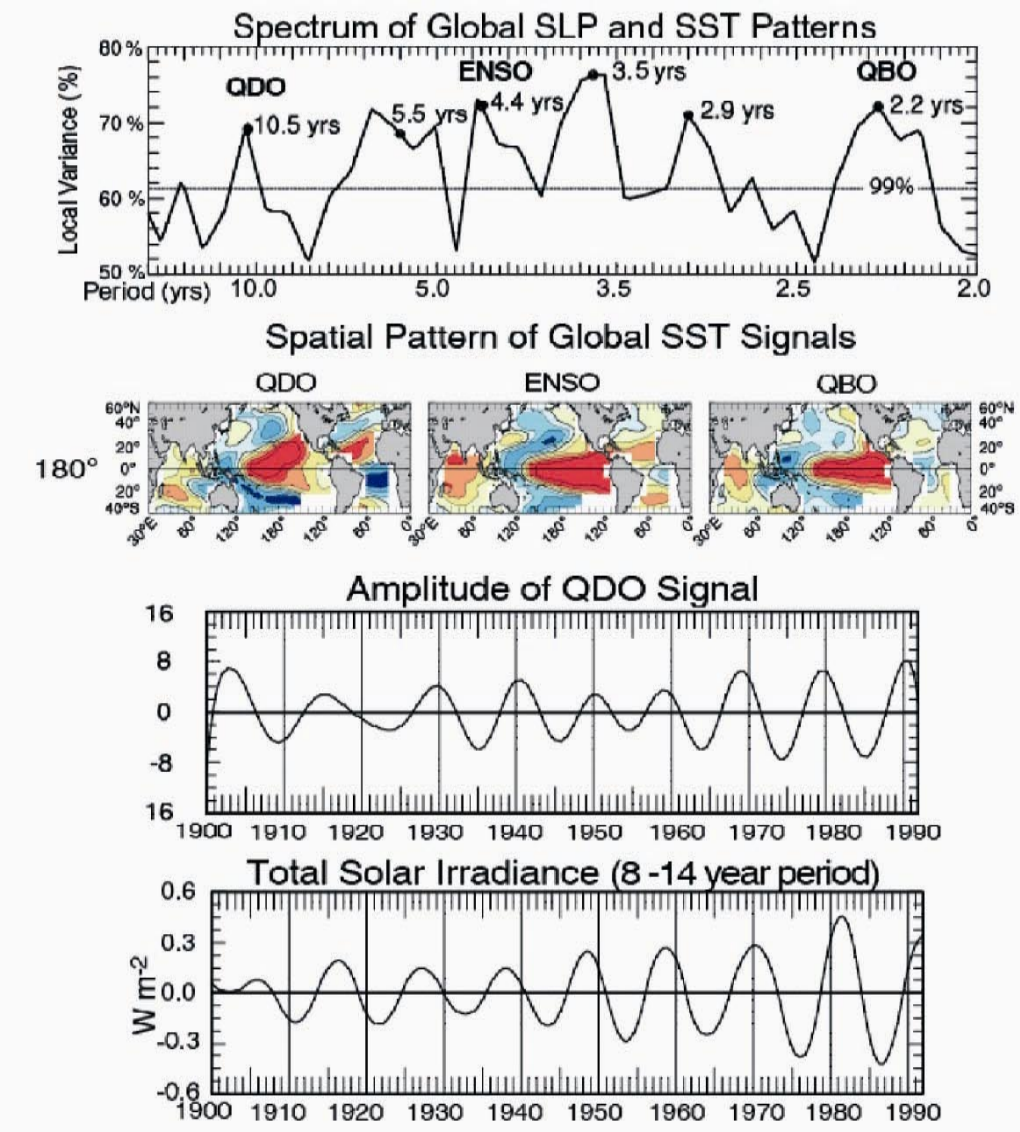
max-min

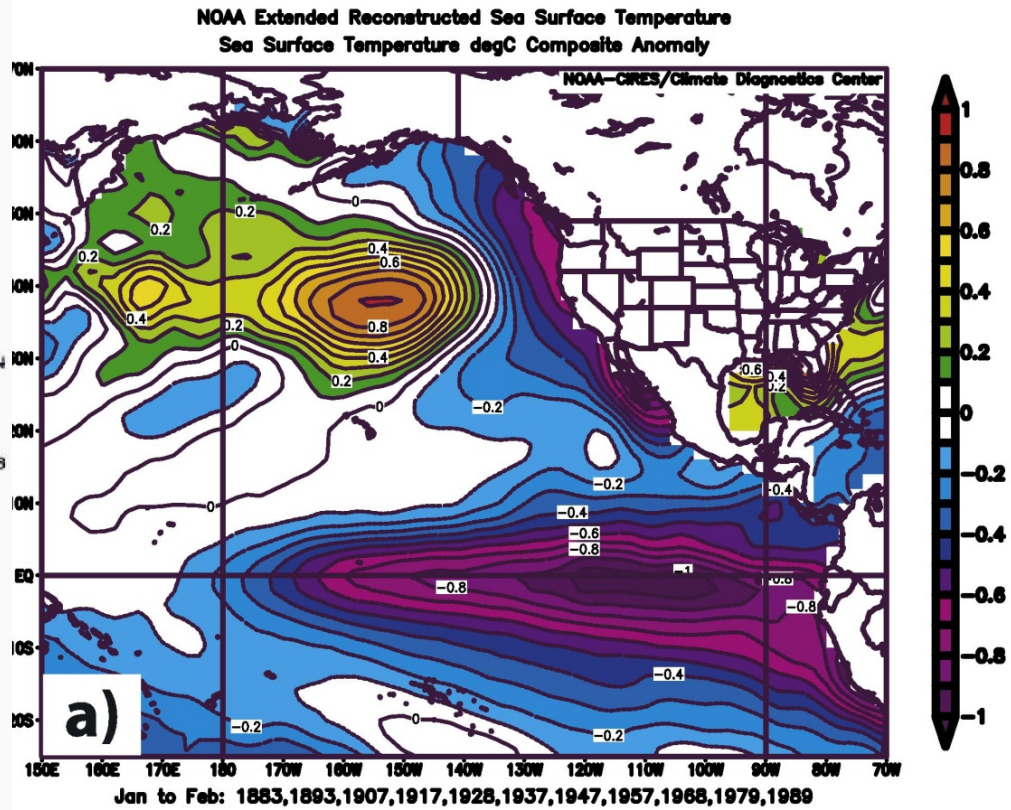
Weakening and poleward shift of the mid-latitude jets

Haigh et al (J.Clim., 2005)

Im
Lo

Pacific Sea Surface Temperatures





solar max anomaly
(van Loon et al 2007)

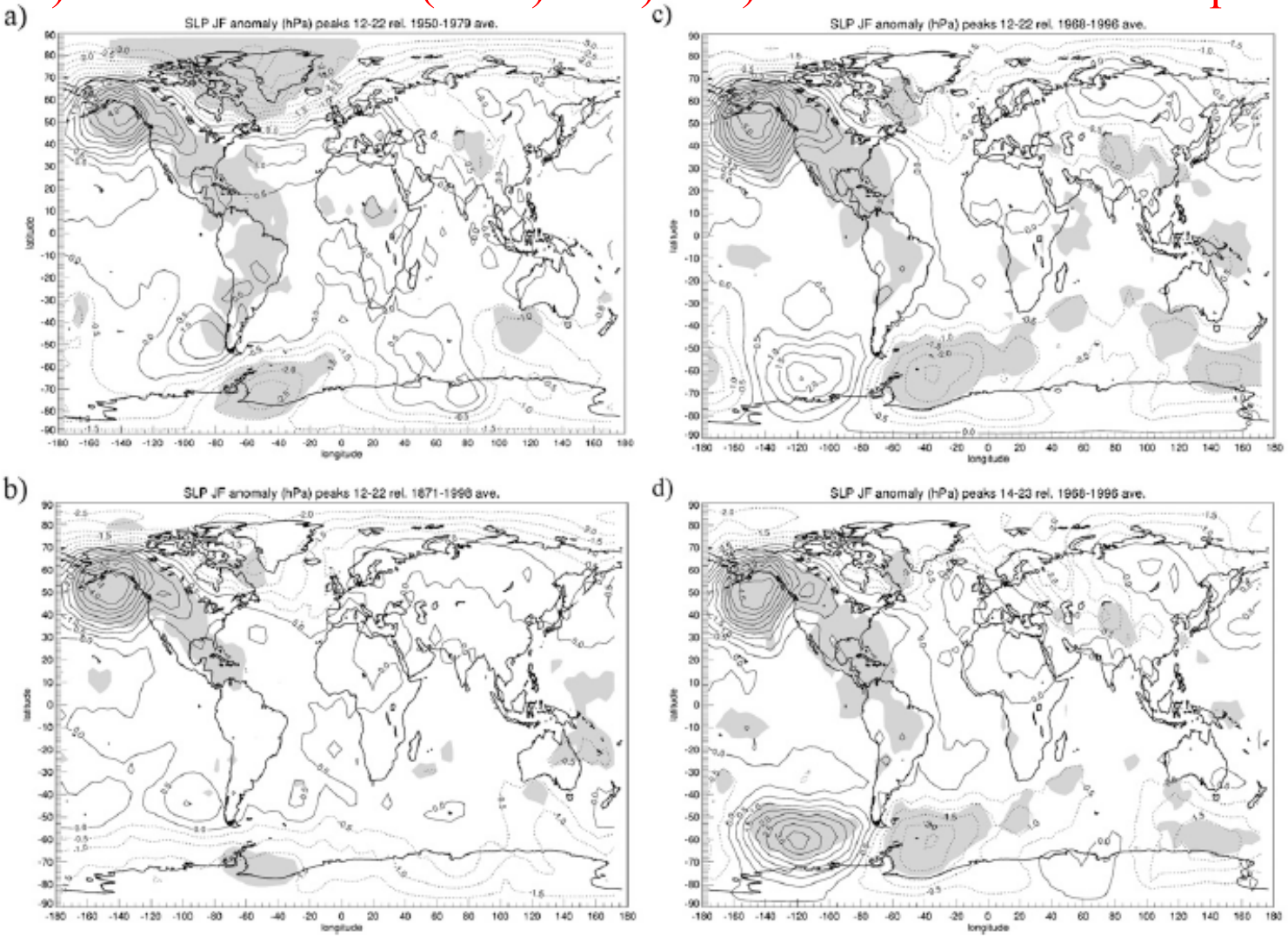
?

White and Touree (2003)

Composites : choice of time periods for sunspot max years and for reference climate period

a) as van Loon et al (2007)

c) as a) but different reference period



b) as Meehl et al (2008)

d) as van Loon and Meehl (2011)

Roy and Haigh (2012)

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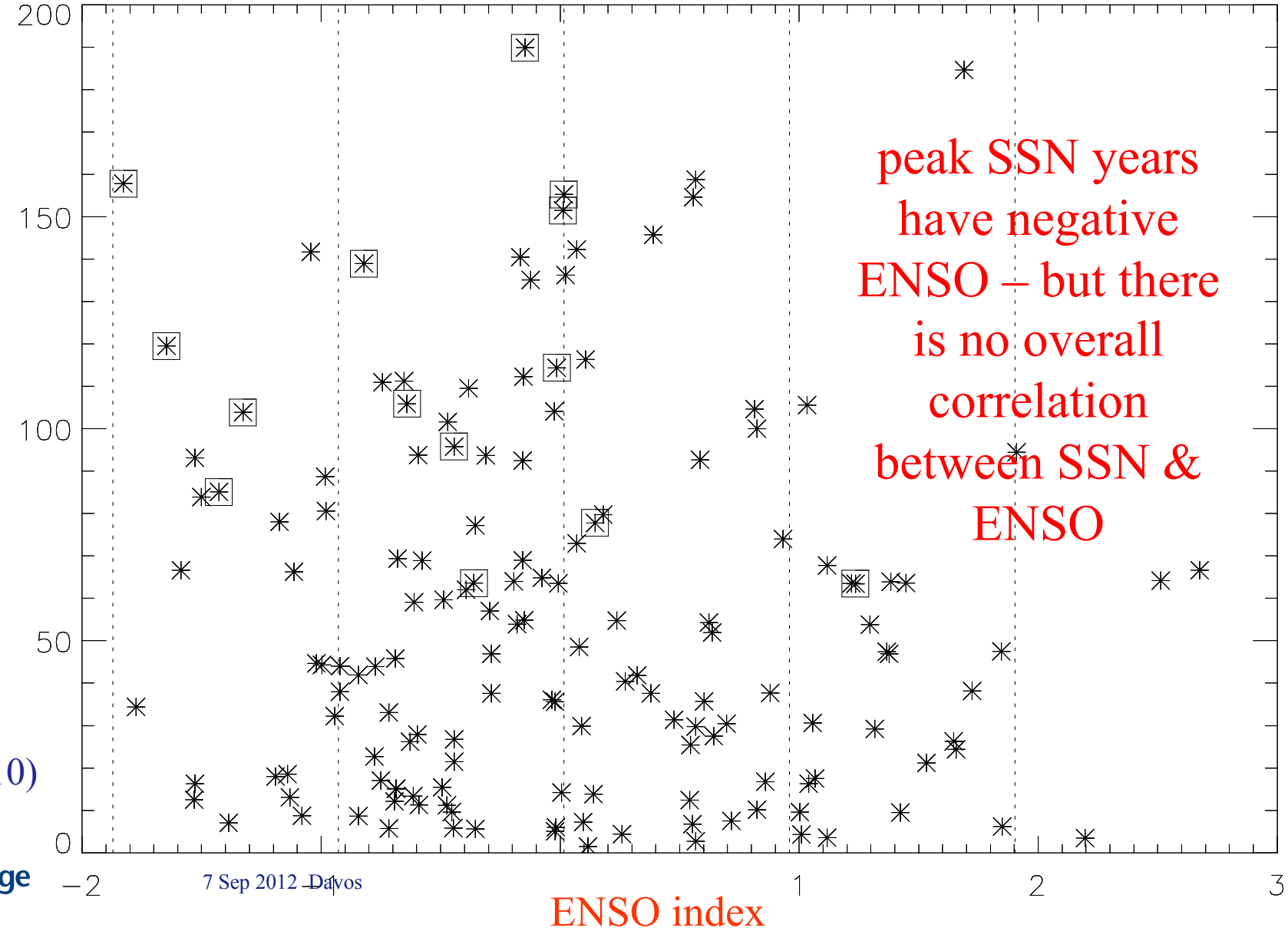
Solar variability & ENSO



□ solar cycle peak years

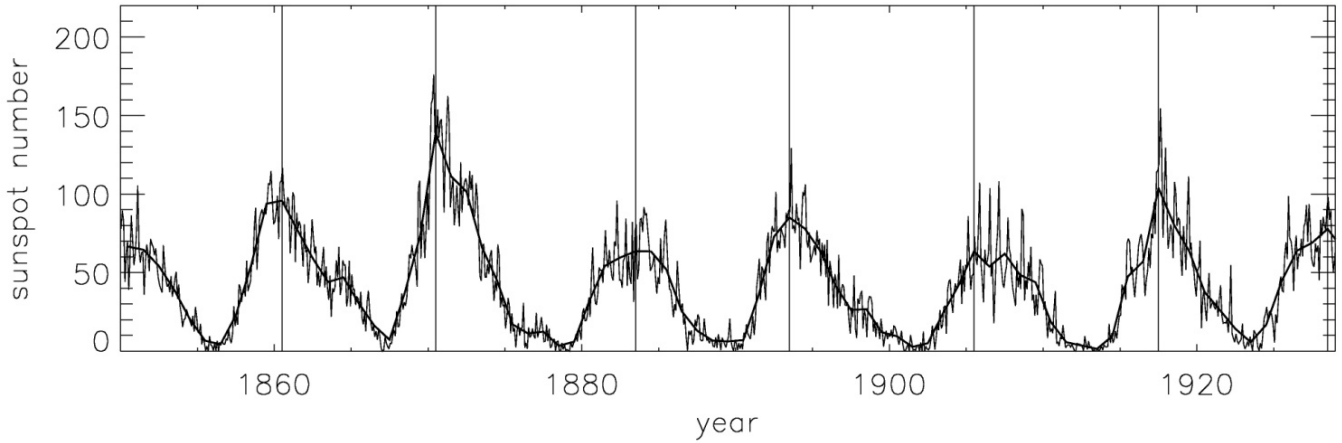
peak SSN years have negative ENSO – but there is no overall correlation between SSN & ENSO

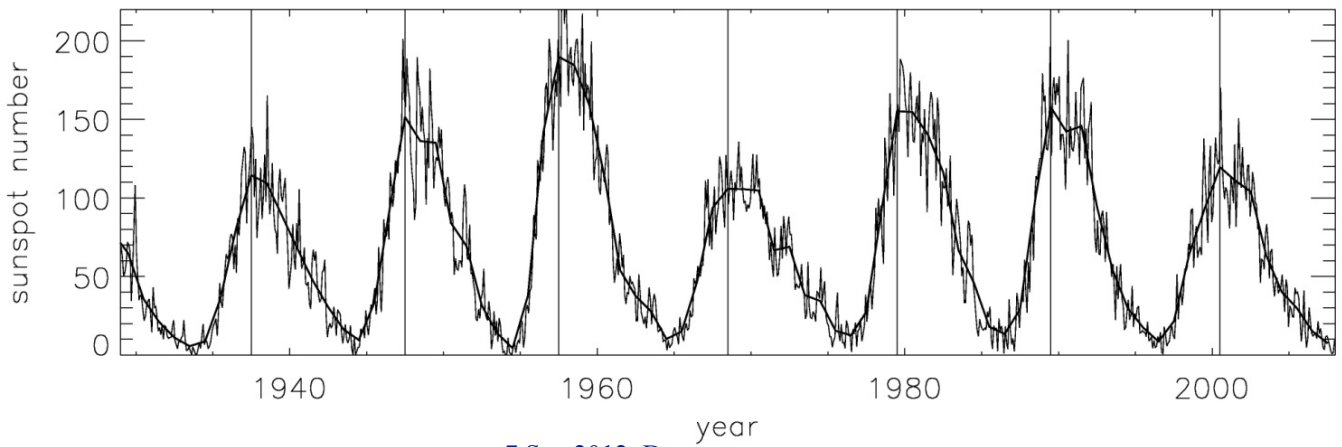
Roy and Haigh (2010)

Solar variability & ENSO

years of peak annual sunspot number

peak SSN years usually occur before broad solar max



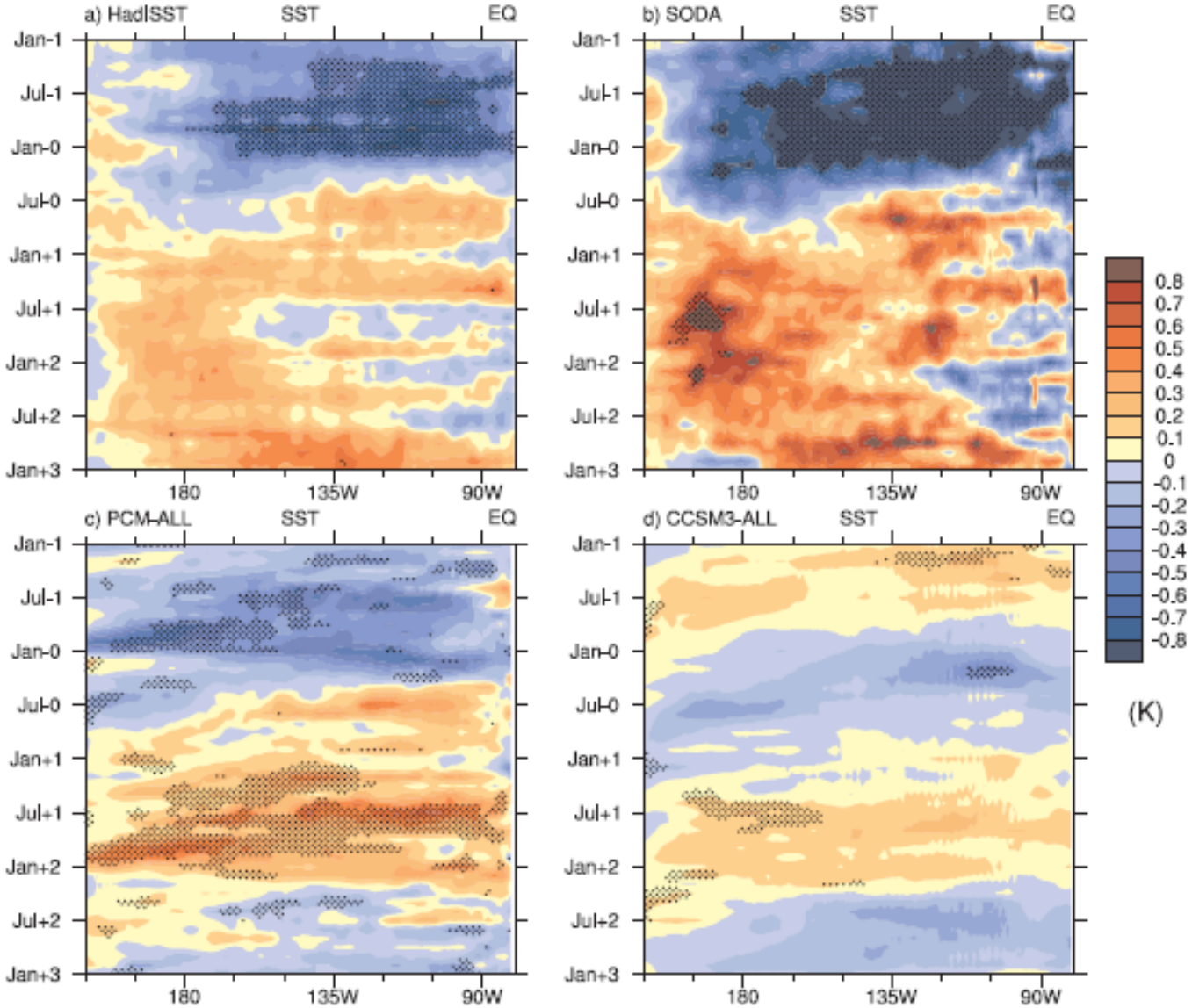


Roy and Haigh (2010)

Tropical Pacific SST: evolution relative to sunspot peak year

observations

GCMs



Meehl and Arblaster (2009)

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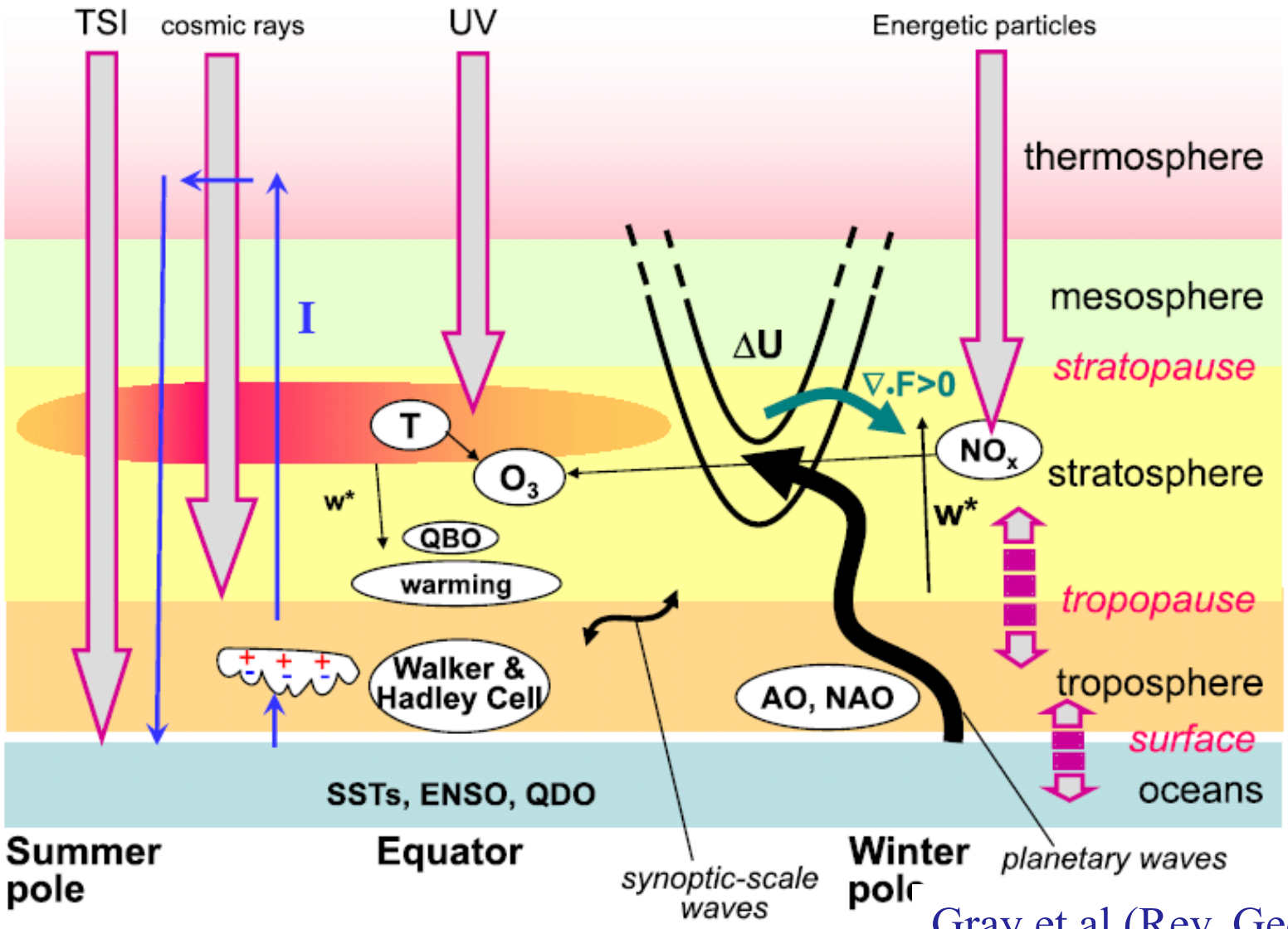
Little evidence of cold to warm evolution (?)

Solar cycle number	Years	Peak year	State of ENSO (DJF) Peak year	1 year after peak year	2 years after peak year
10	1856–67	1860	C	C	C
11	1867–78	1870	C	C	C
12	1878–90	1883	C	–	W
13	1890–1901	1893	C	C	C
14	1901–13	1905	W	W	C
15	1913–23	1917	C	C	W
16	1923–33	1928	W	C	W
17	1934–44	1937	–	C	C
18	1944–54	1947	–	W	C
19	1955–64	1957	C	W	W
20	1964–76	1968	C	W	W
21	1976–86	1979	–	W	C
22	1986–96	1989	C	W	W
23	1996–2007	2000	C	C	C
Total		C	9	7	8
		–	3	1	0
		W	2	6	6

Roy and Haigh (2012)

Mechanisms for a solar influence on climate



Gray et al (Rev. Geophys., 2010)

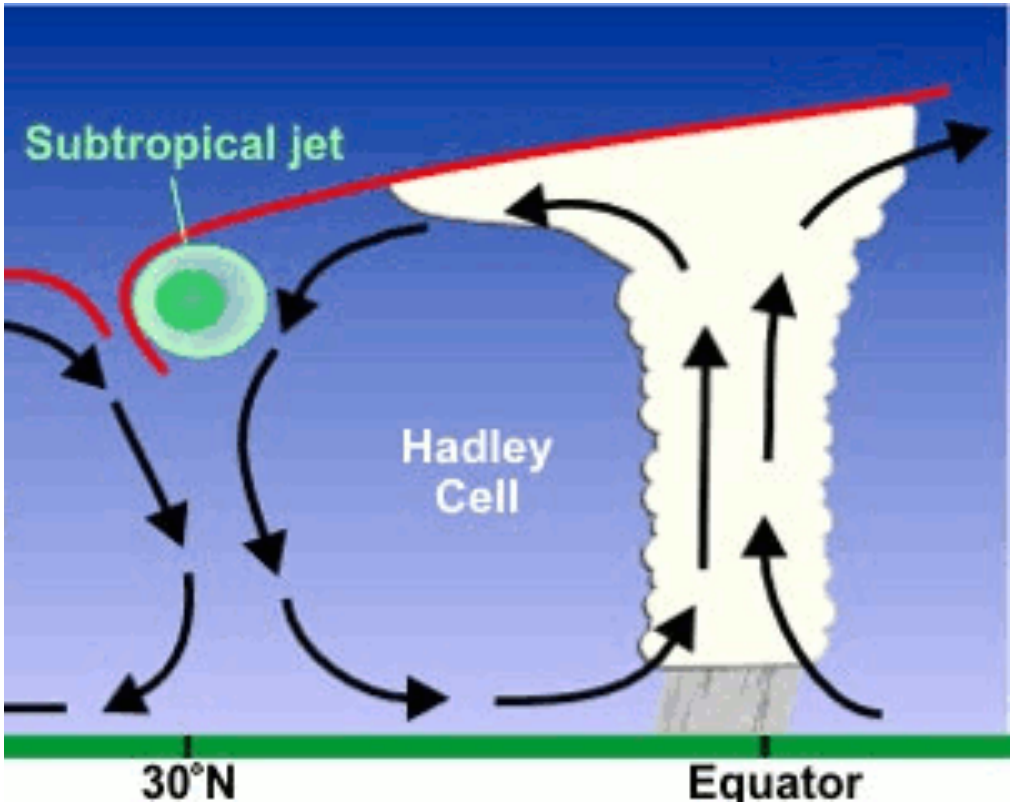
Solar forcing of climate: radiative mechanisms

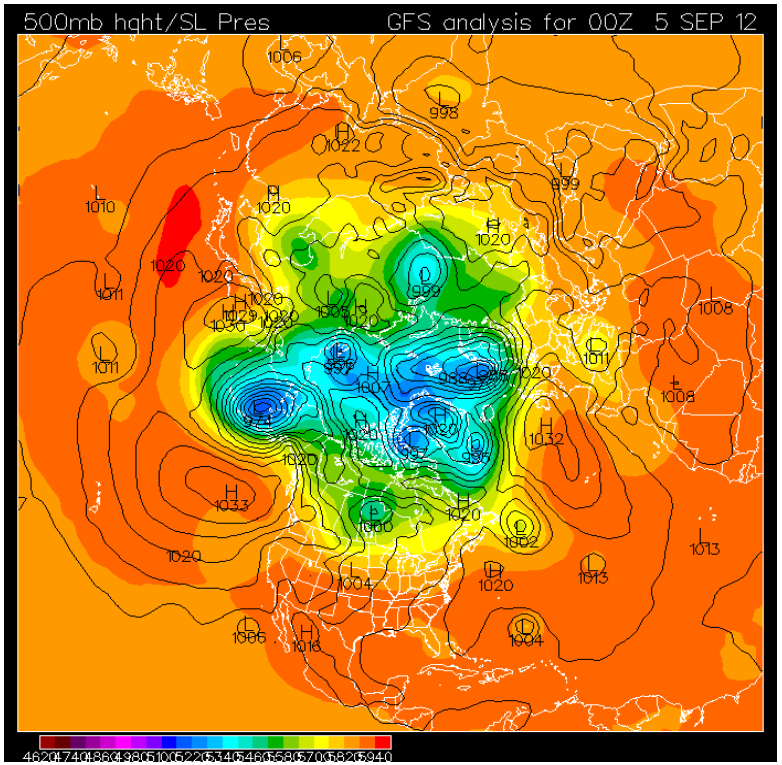
"Top-down" via UV heating the stratosphere

and/or

"Bottom-up" via visible radiation warming surface ?

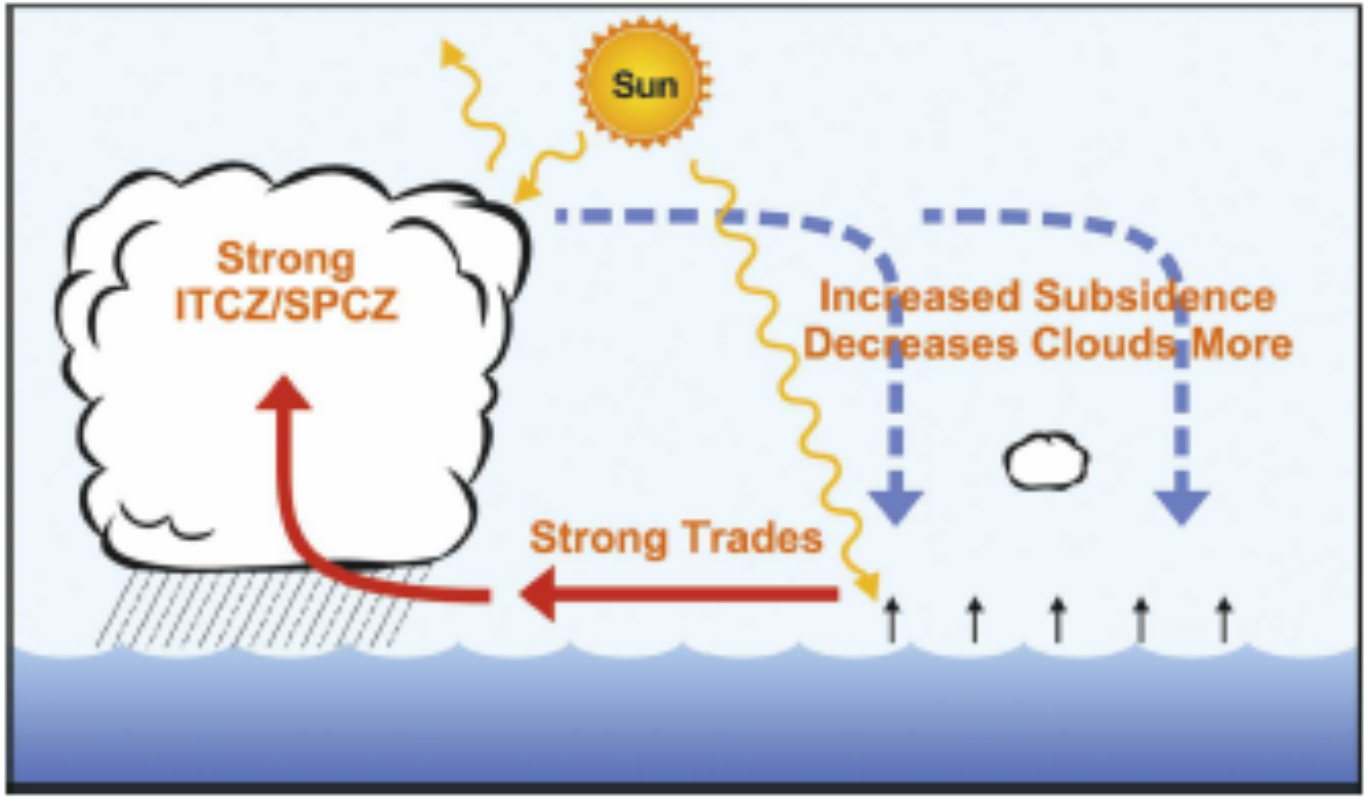
Mean circulation and waves





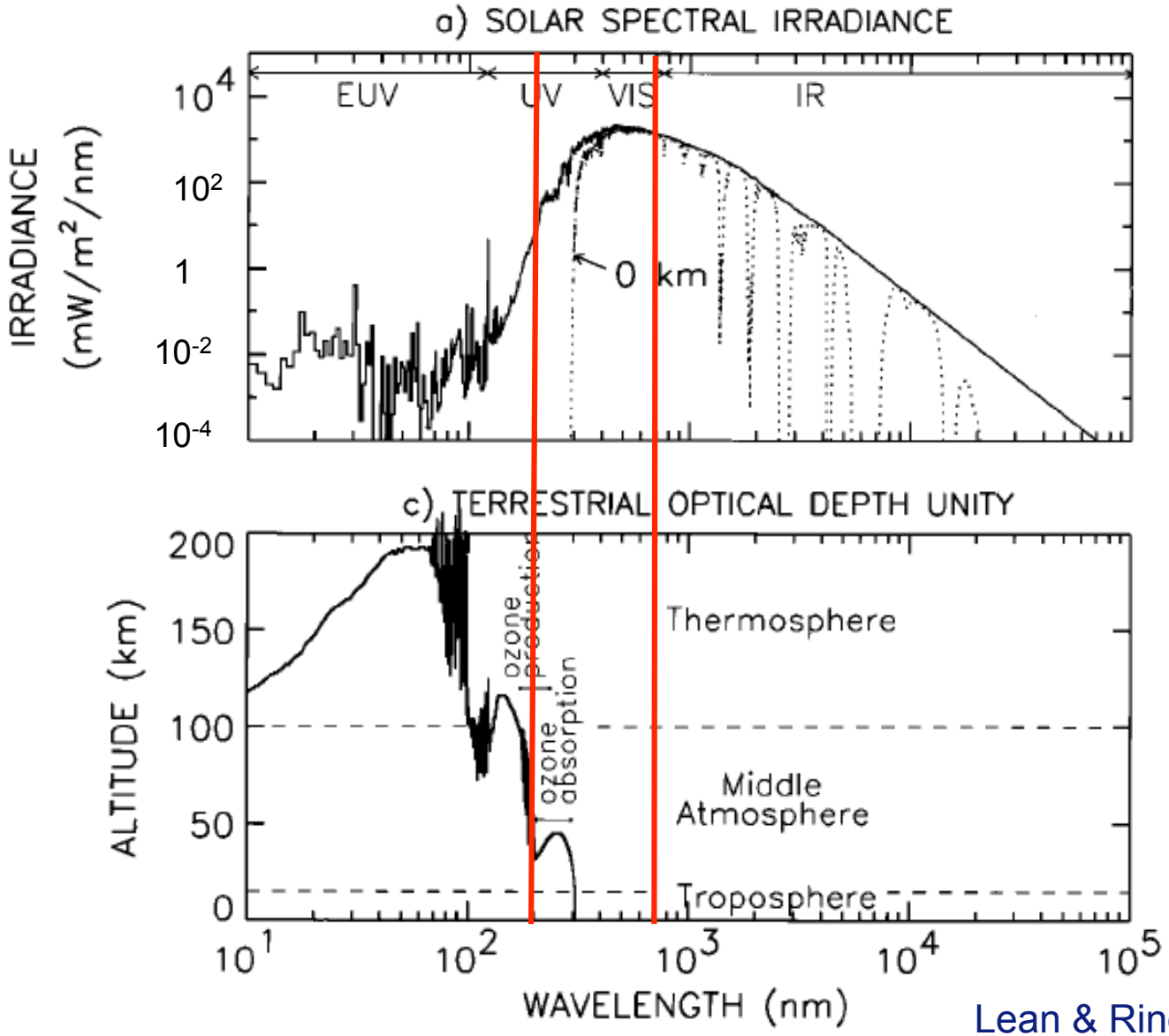
Transfer heat and momentum within atmosphere.

Tropical TSI/ evaporation/ convection mechanism



Meehl et al (2008)

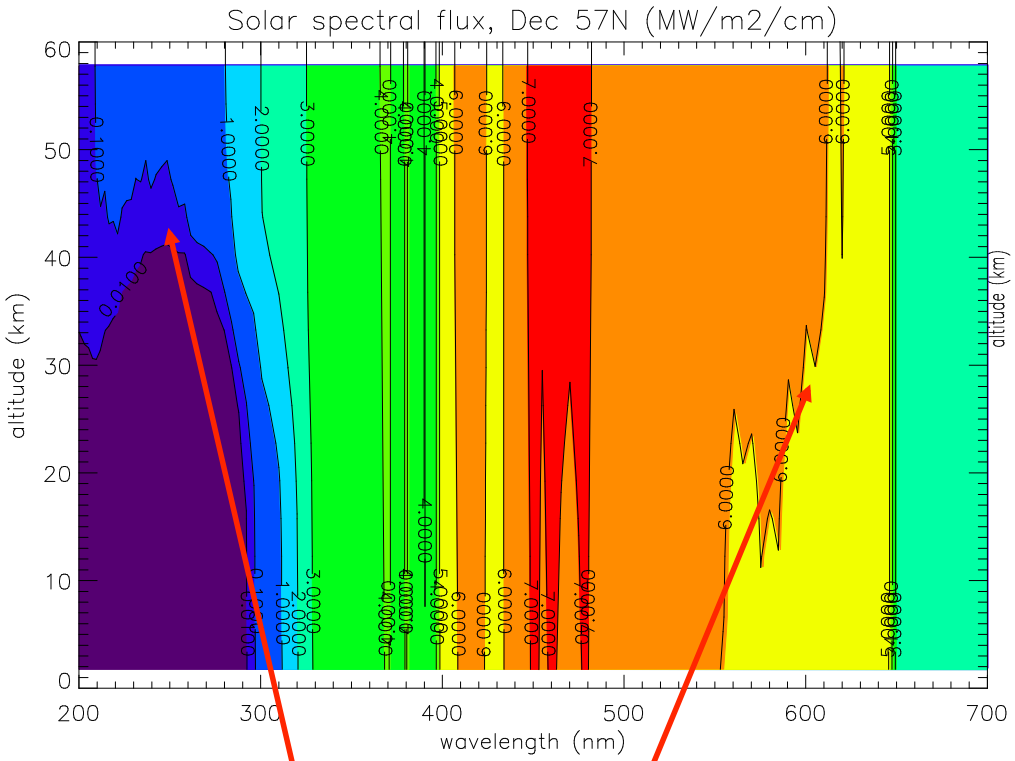
Absorption of solar radiation within atmosphere

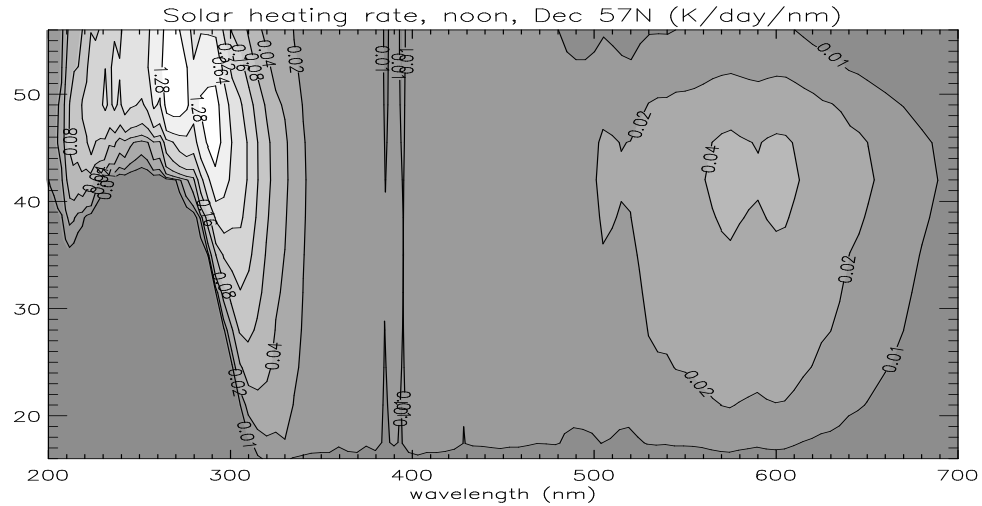


Lean & Rind (J. Clim.,1998)

Solar spectral irradiance & heating rate

irradiance (Dec, 57N) heating rate

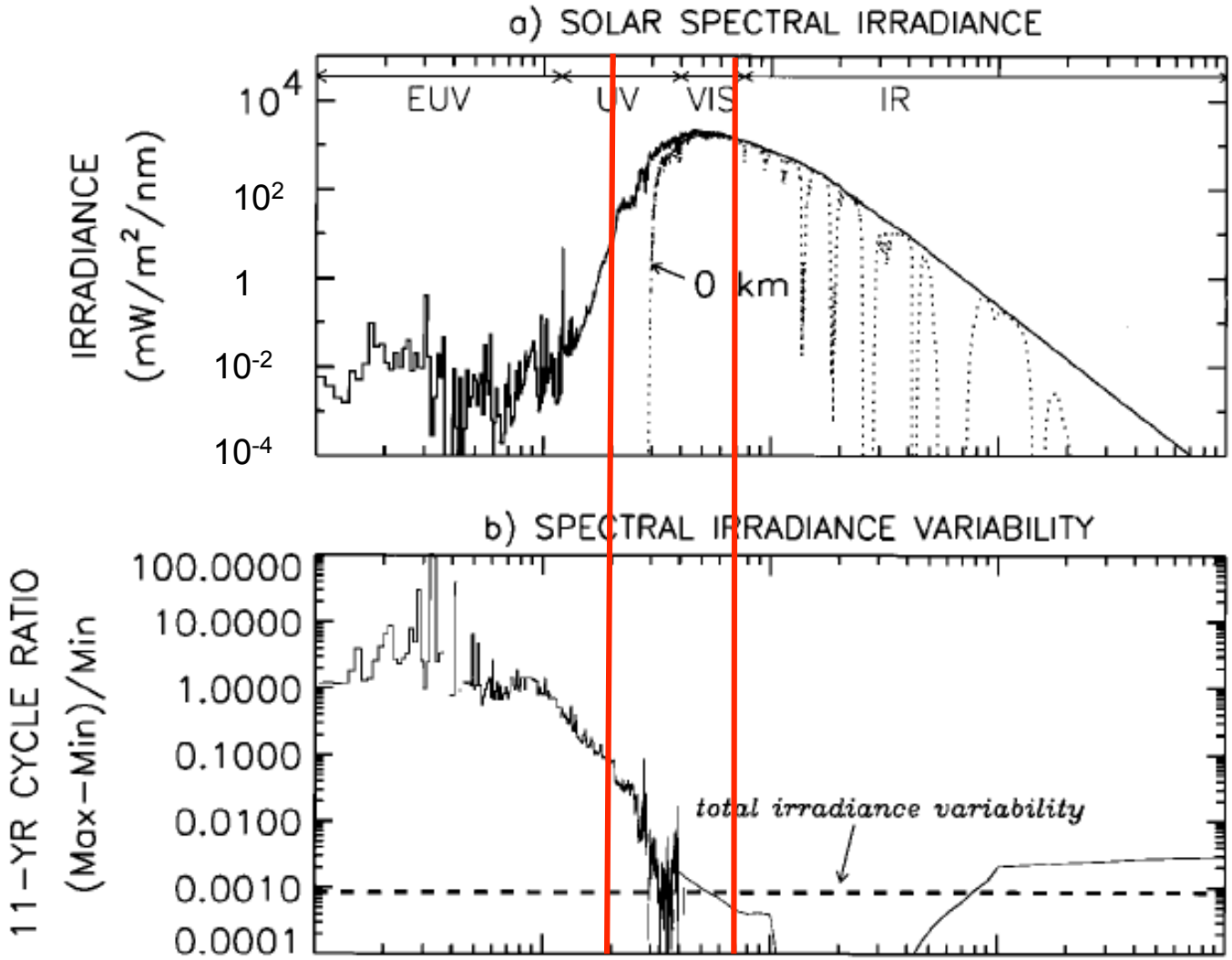




Ozone absorption

Haigh (Nature, 1994)

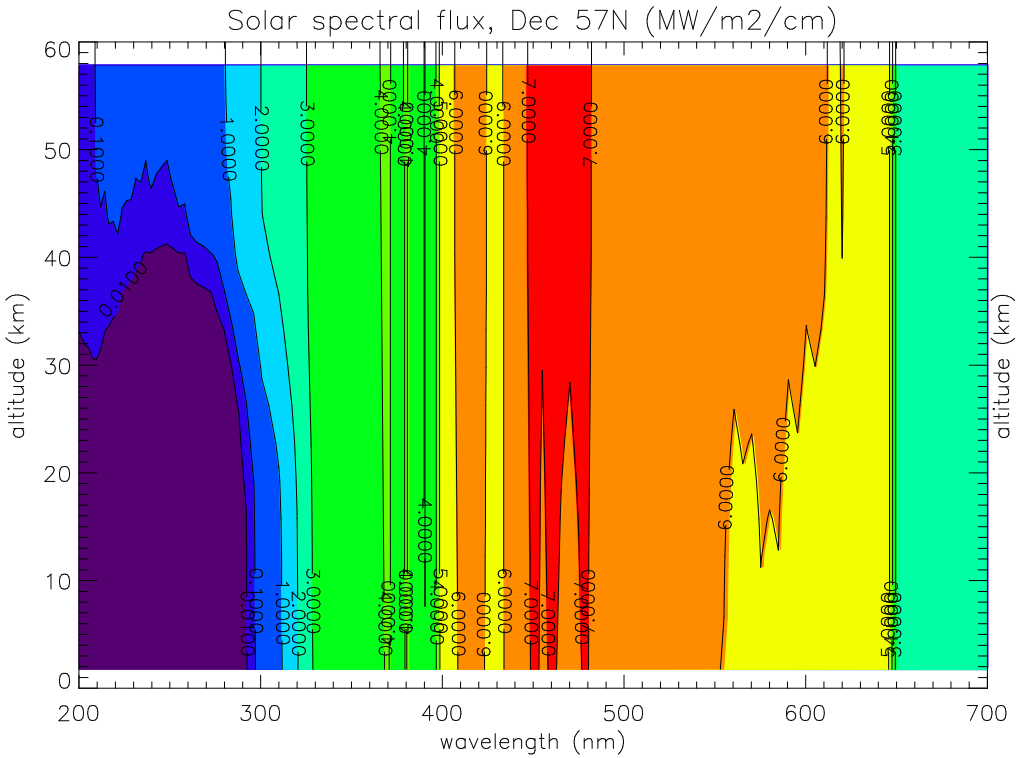
Solar cycle variability

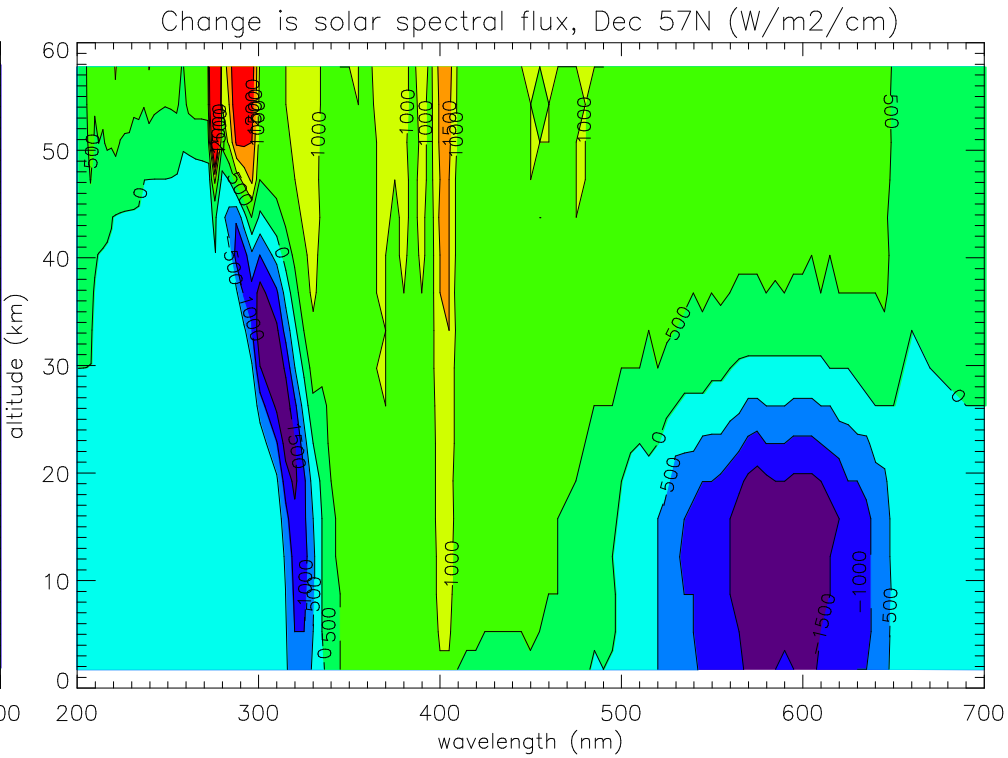


Lean & Rind (J. Clim.,1998)

Background:
Solar cycle variation in spectral irradiance

solar min (Dec, 57N) max-min

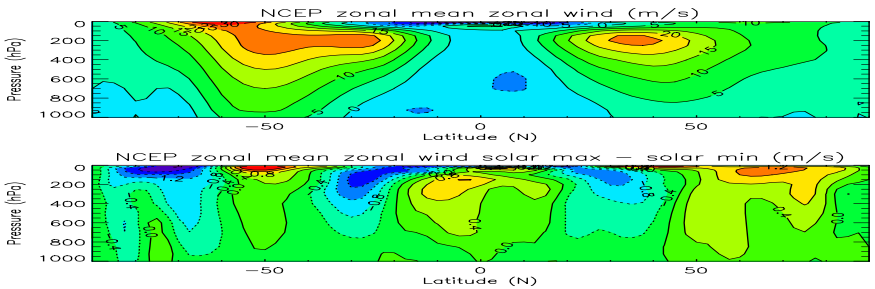




Solar irradiance reaching lower atmosphere depends on response in stratospheric ozone.

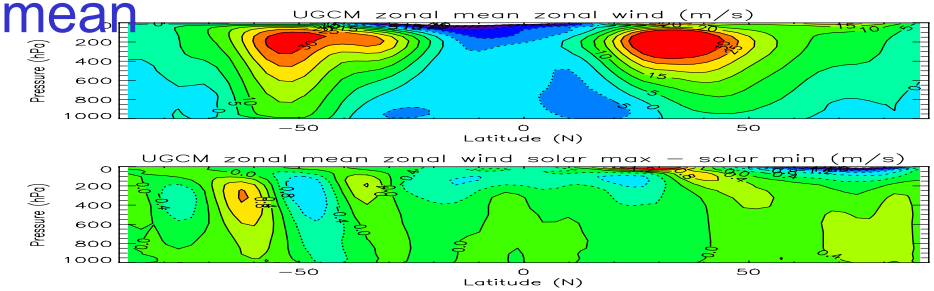
Solar signal in zonal wind: obs *cf* climate model

Observations



GCM response to changes in solar UV radiation & O_3

mean

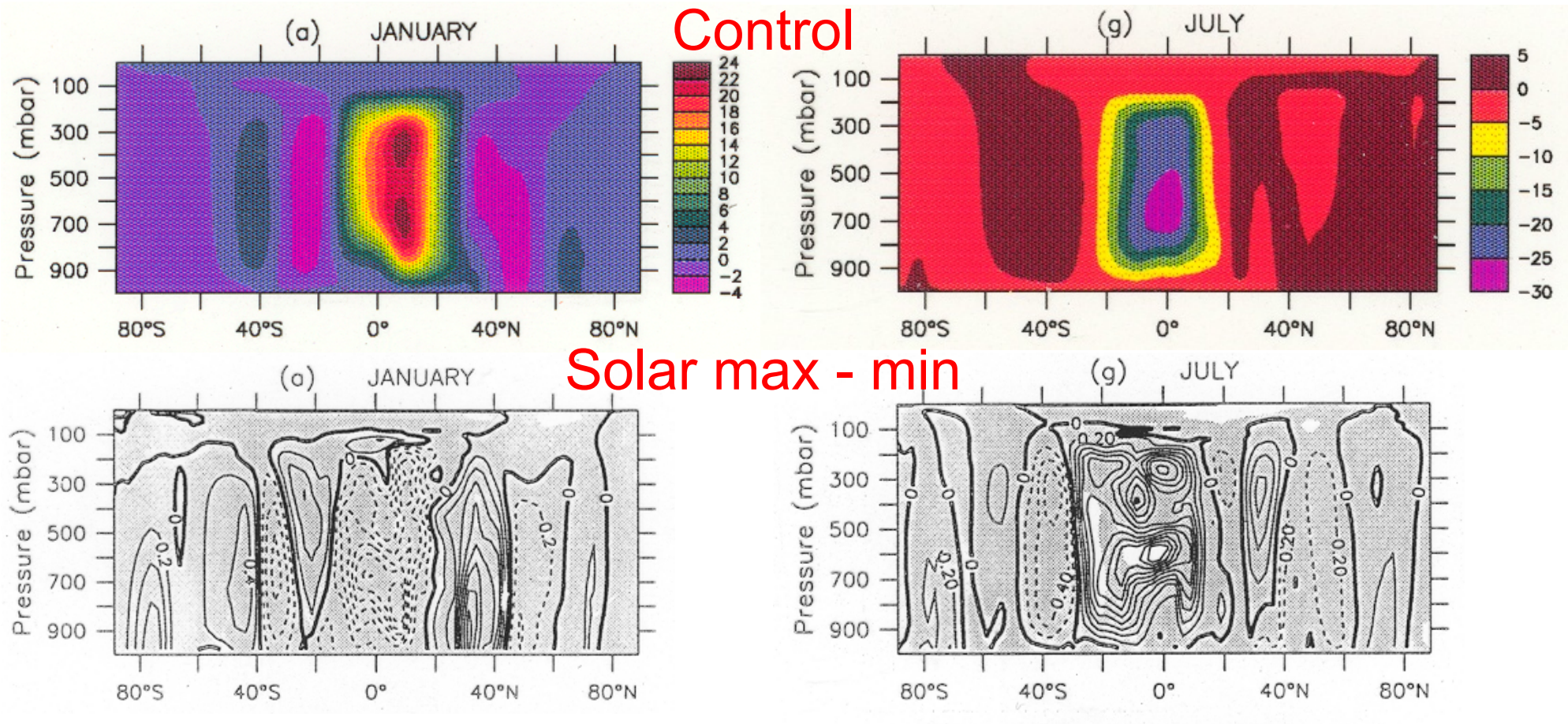


max-min

Haigh et al (J. Clim., 2005)

N.B. Similar pattern in response but much smaller amplitude without O_3 changes

GCM UV experiment: mean overturning circulation

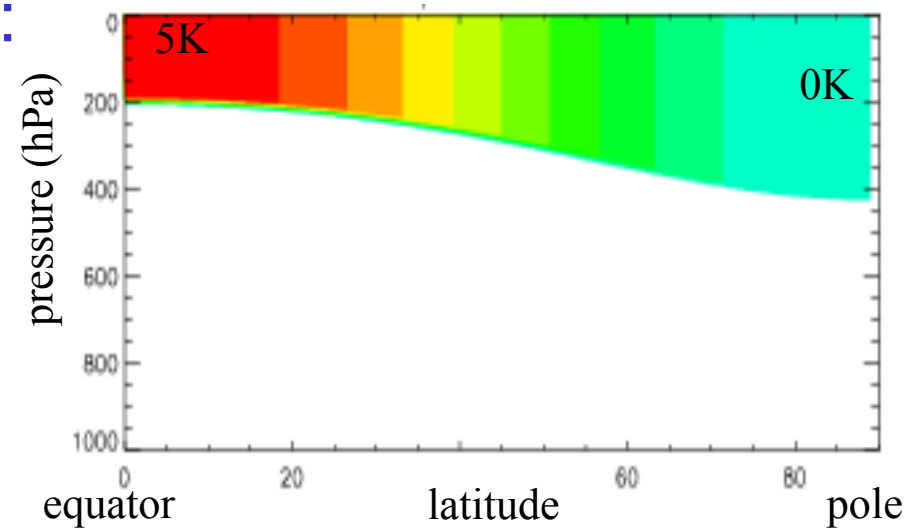


Hadley cells weaker and broader when Sun more active

Larkin (2000)

Study using a simple climate model

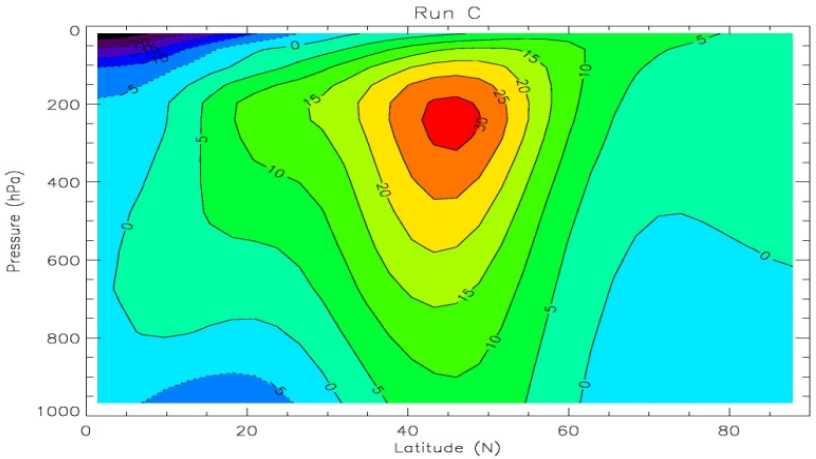
- Uses U. Reading "Intermediate GCM"
  - full dynamics but highly simplified physics
    (so can try out ideas and do many runs cheaply)
  - no orography
    (so no planetary scale waves but retaining synoptic scale waves)
- Apply simplistic heating perturbation to the stratosphere:



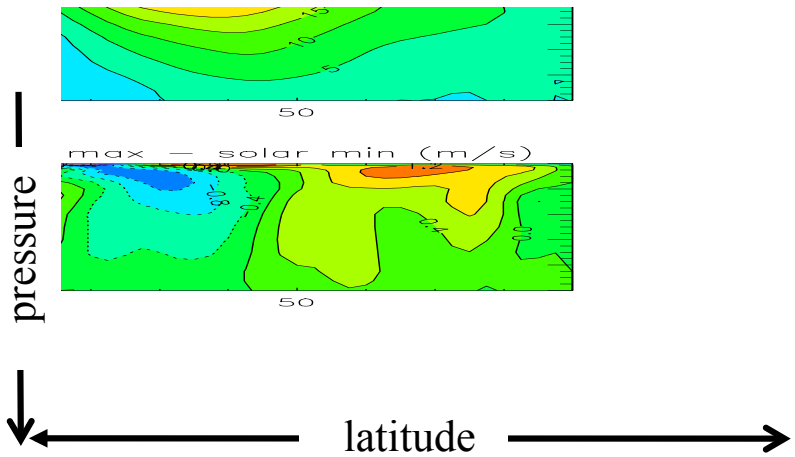
Haigh, Blackburn & Day (J.Clim., 2005)

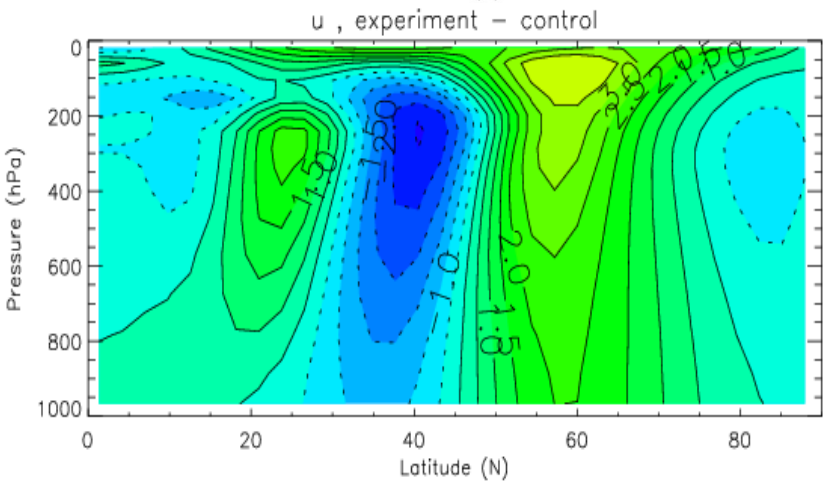
Heating applied ONLY in the stratosphere:

Simple model zonal wind Observations of solar impact



mean





solar
max - min

the jet weakens and moves polewards

Haigh, Blackburn & Day
(J.Clim., 2005)

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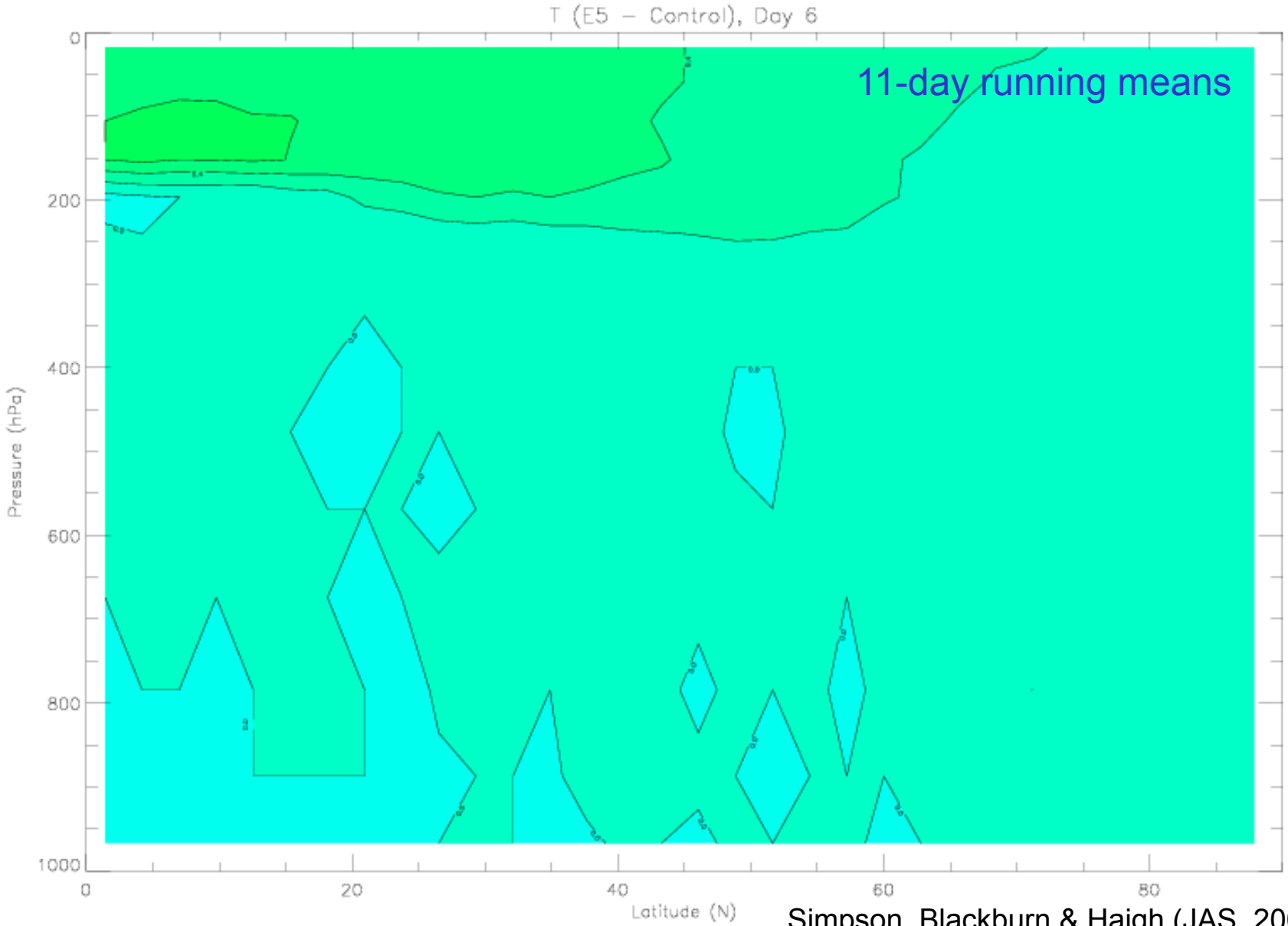
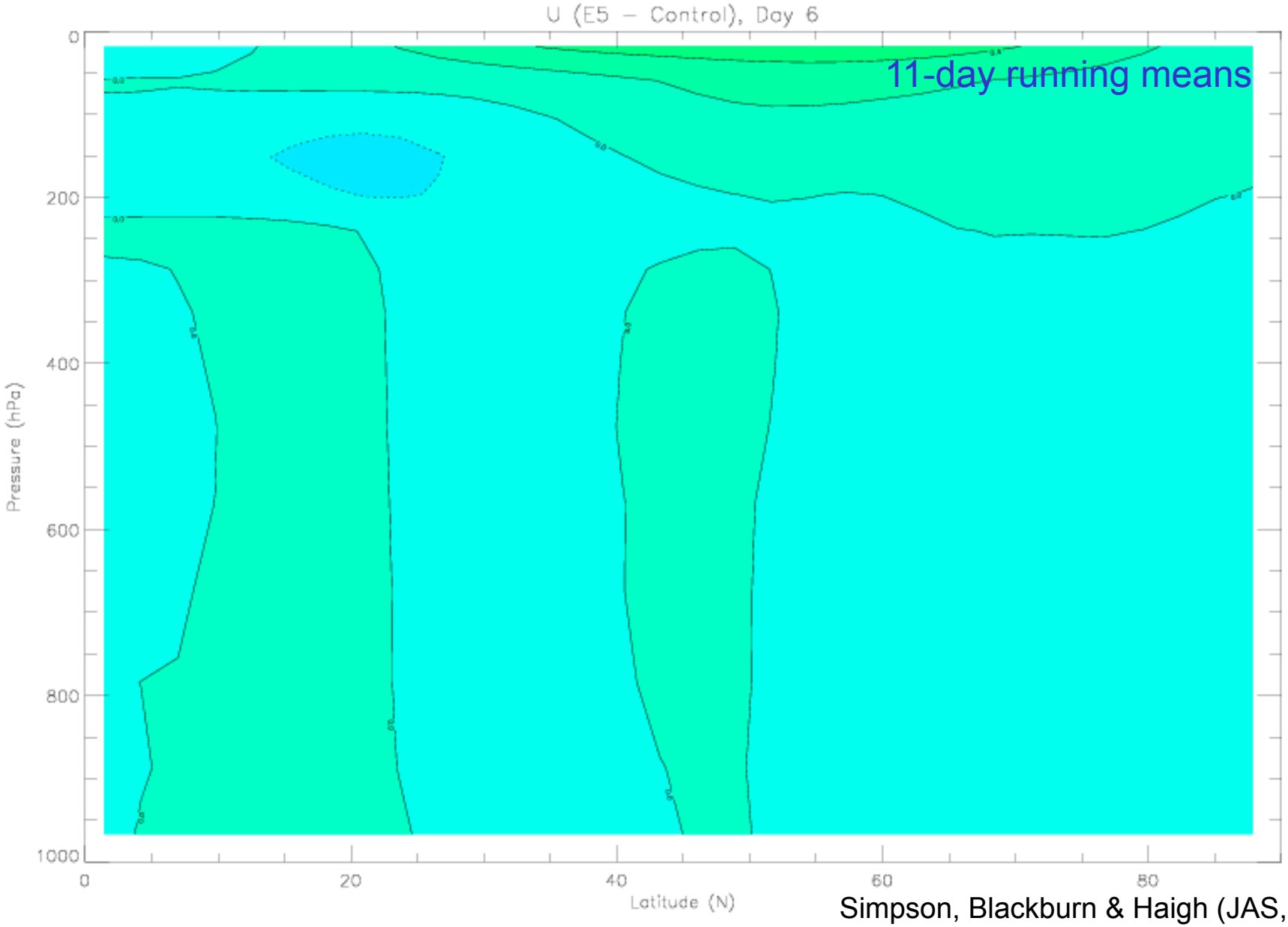
Spin-up of temperature anomalies



Simpson, Blackburn & Haigh (JAS, 2009)

Spin-up of wind anomalies



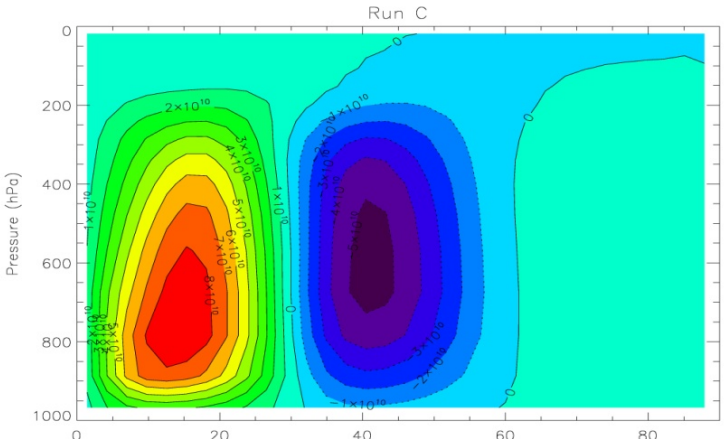
Simpson, Blackburn & Haigh (JAS, 2009)

Imp
Lon

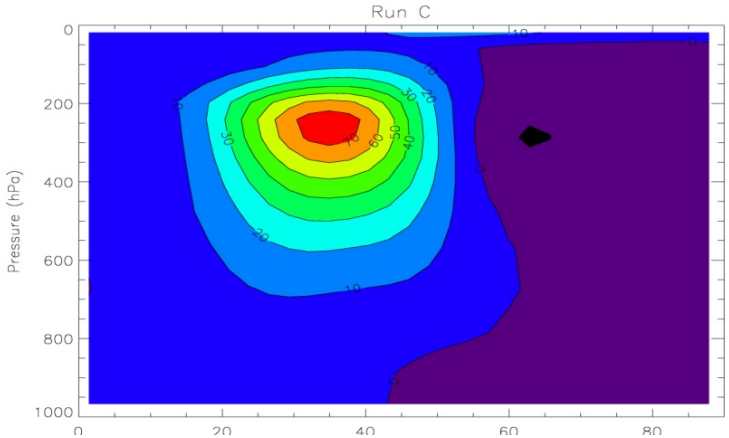
Simple model results:

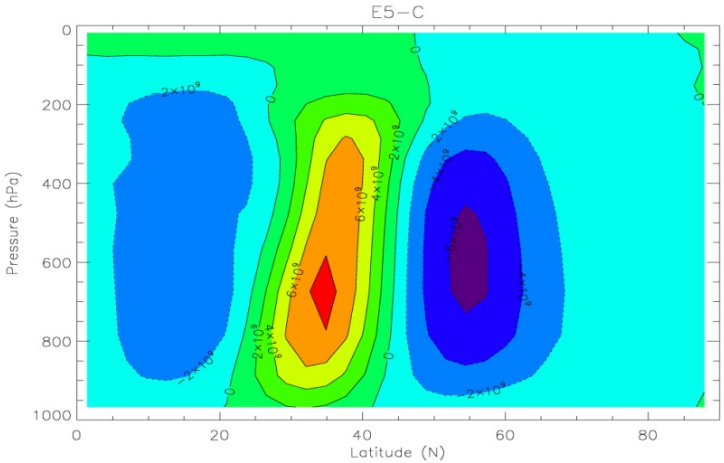
Mean meridional circulation

Horizontal wave momentum flux

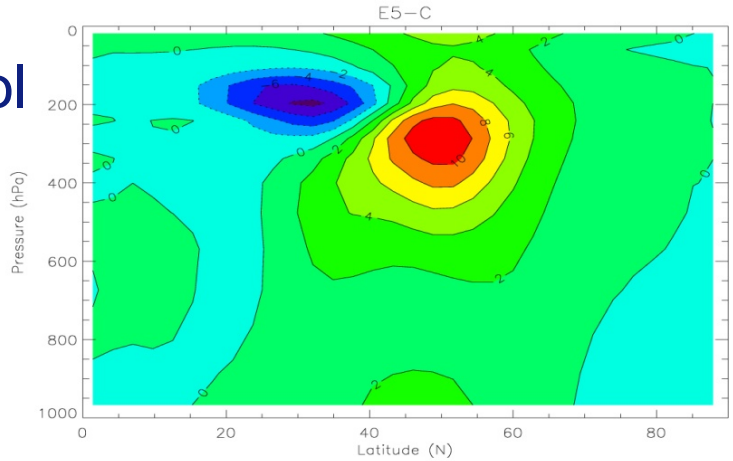


control





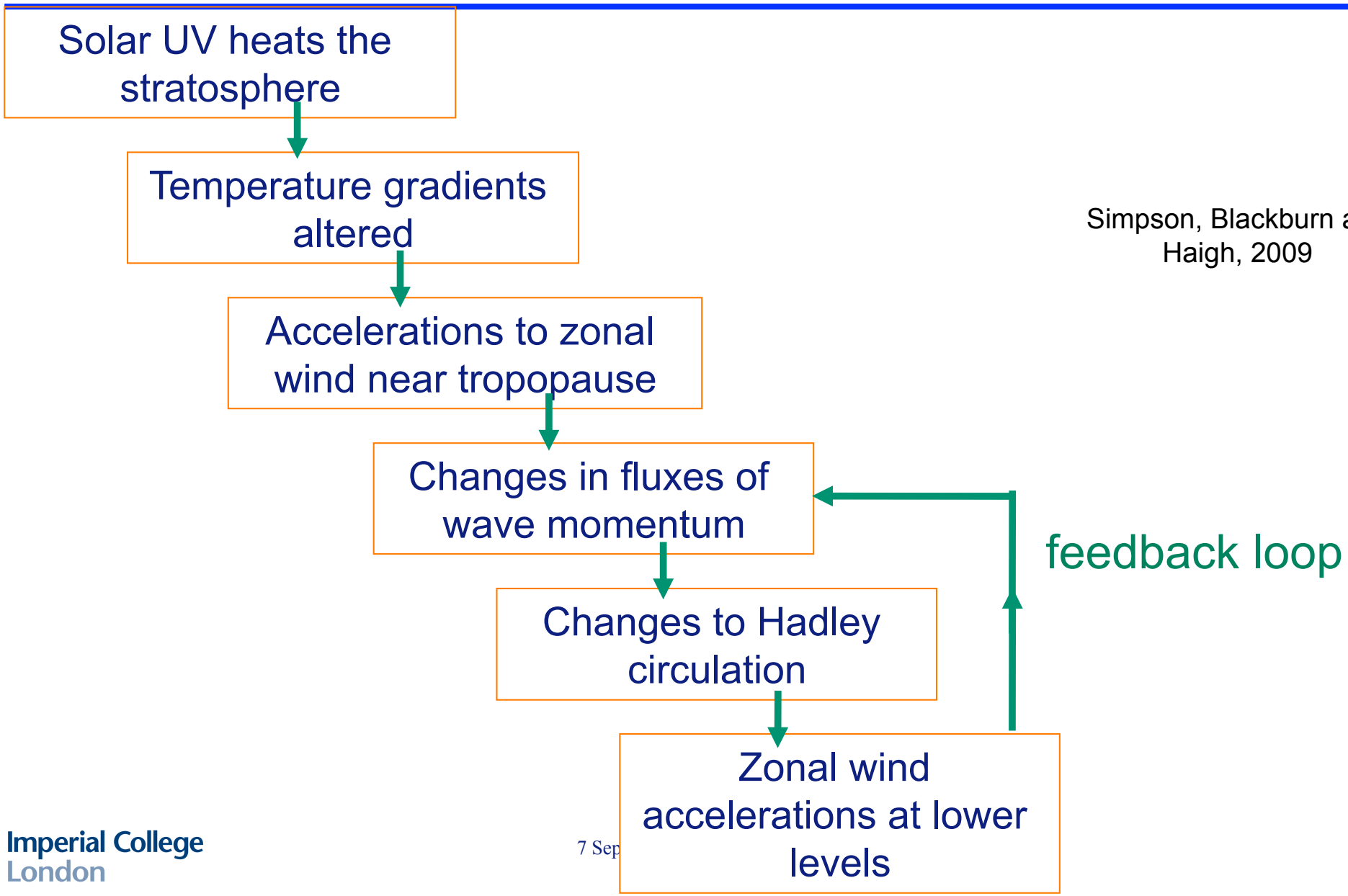
experiment - control



The Hadley cell weakens and expands; wave fluxes moves polewards

Simpson, Blackburn & Haigh (JAS, 2009)

Potential mechanism:



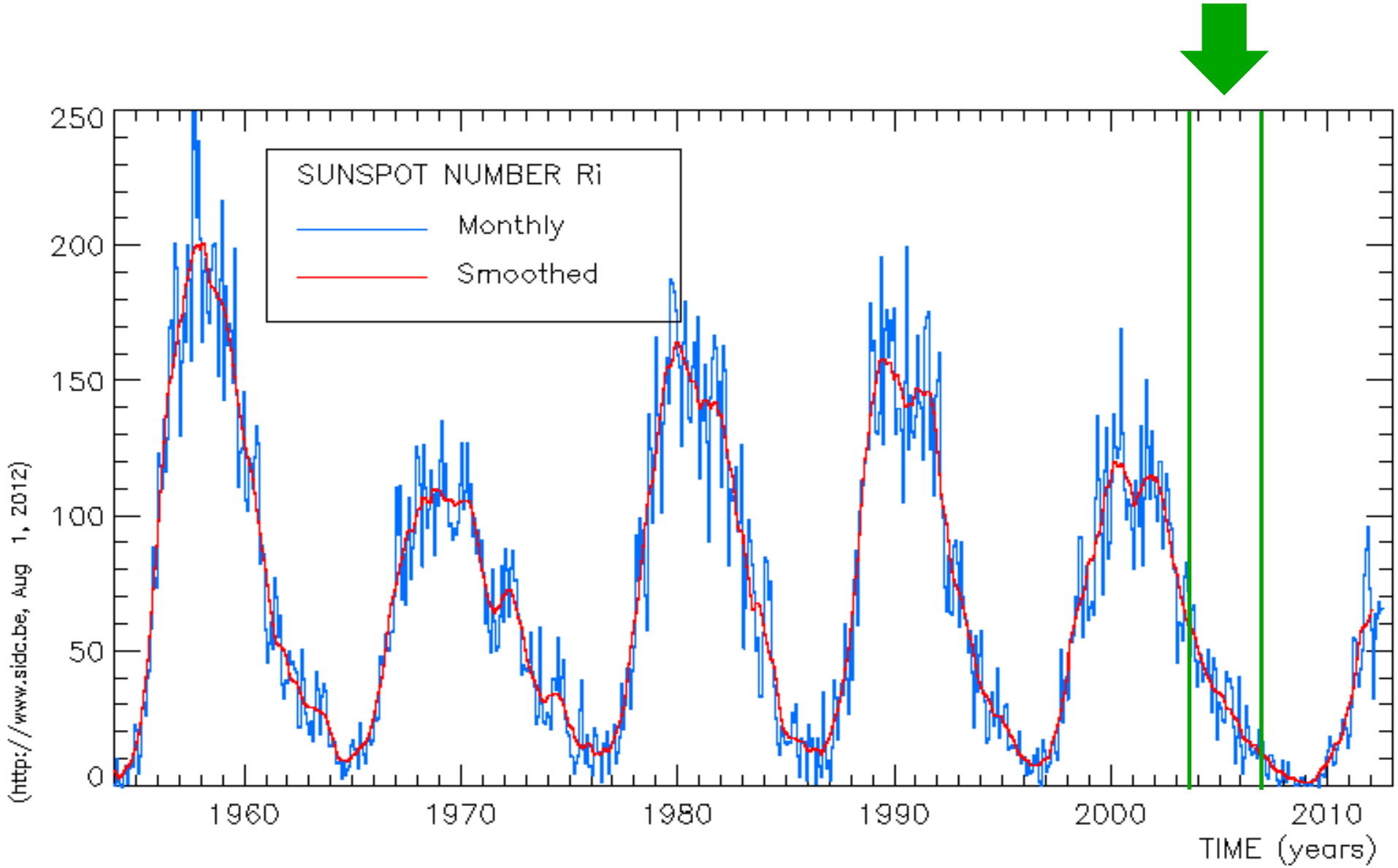
Simpson, Blackburn and Haigh, 2009

Simpson et al mechanism…

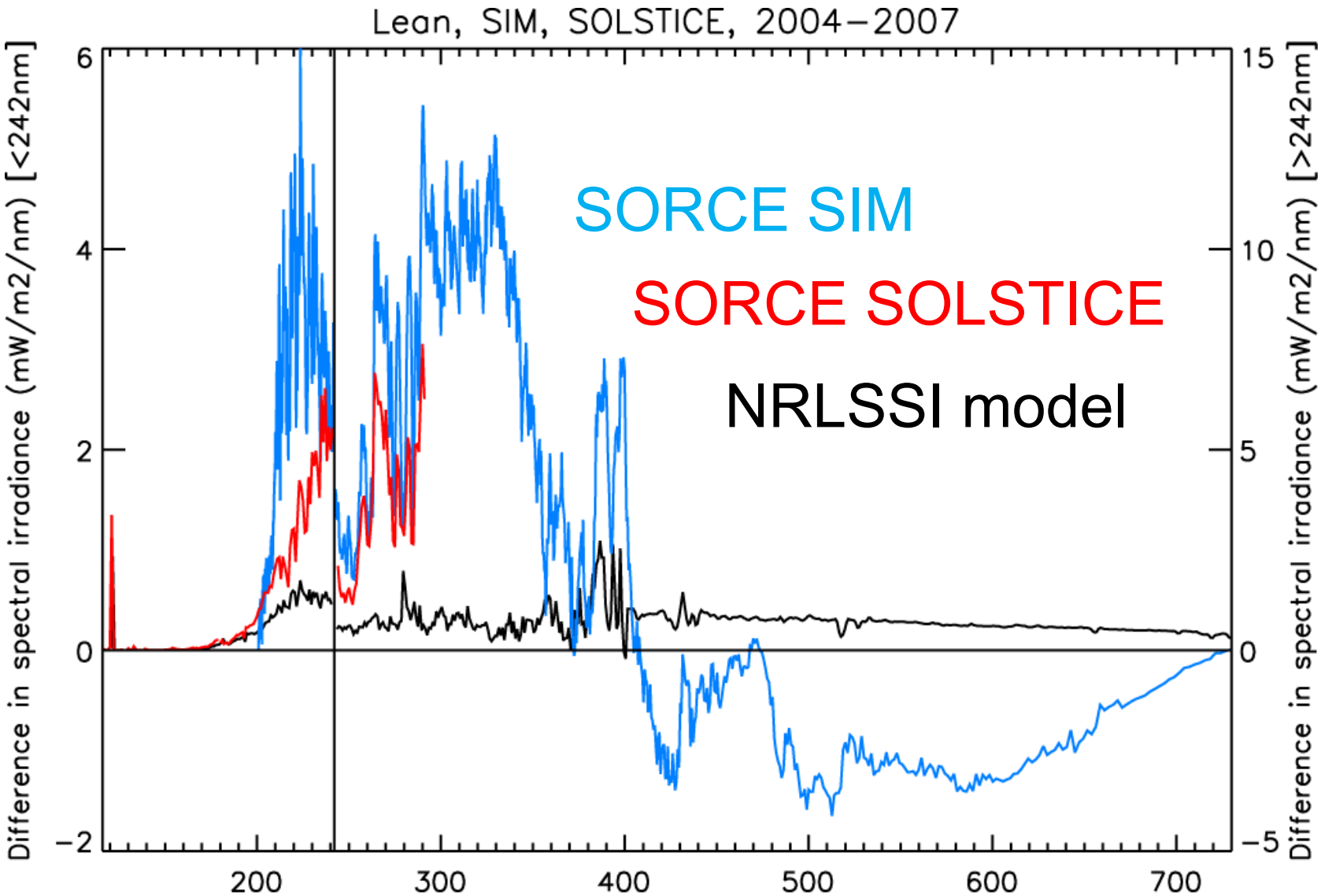
…depends on UV impact in stratosphere.

How large is that?

SORCE data availability (as of 2009)



Solar spectra: differences 2004-2007, as of 2009



Harder et al (GRL, 2009)

Haigh et al (Nature, 2010)

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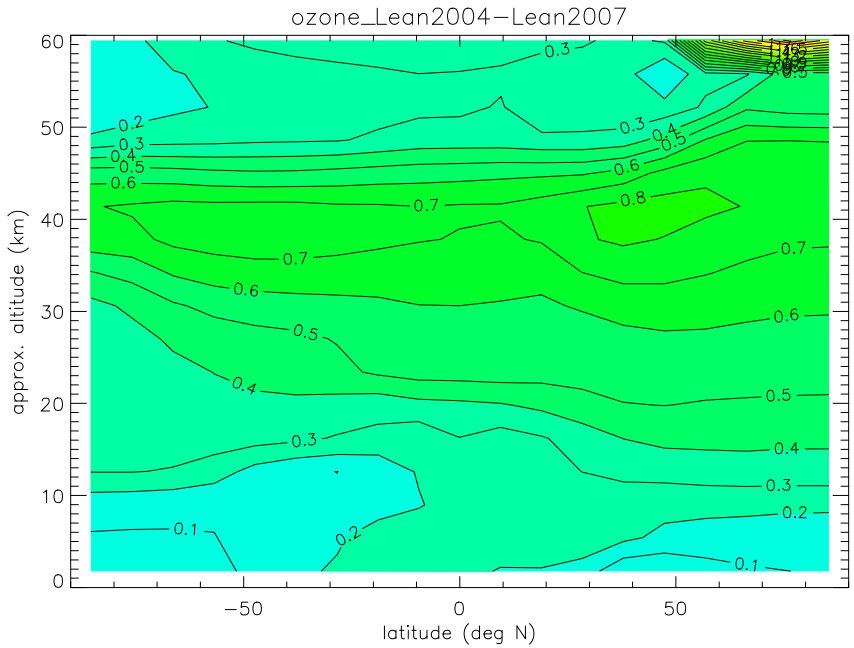
Questions

- What do these spectra imply for changes in the atmosphere?

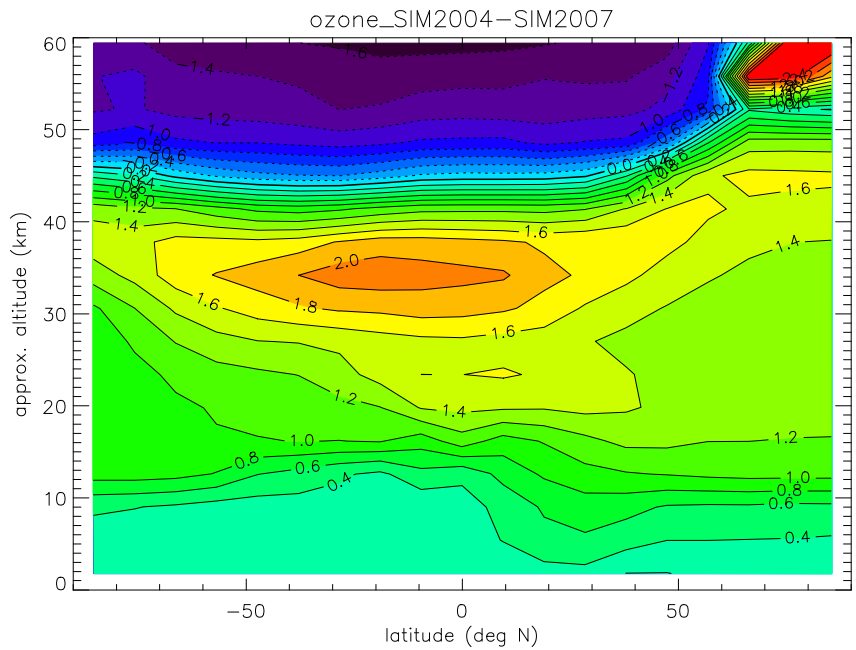
- Are the implied changes detectable in observations?

2D model O_3 differences (%) 2004-2007

NRLSSI



SIM



O_3 destruction due to increase in J_3/J_2 → inc $O(^1D)$ → inc OH

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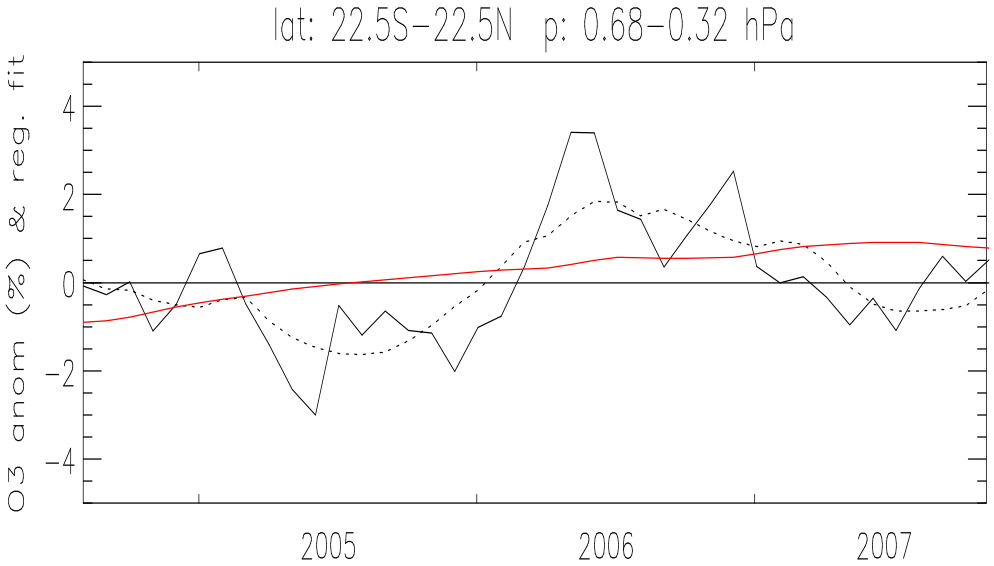
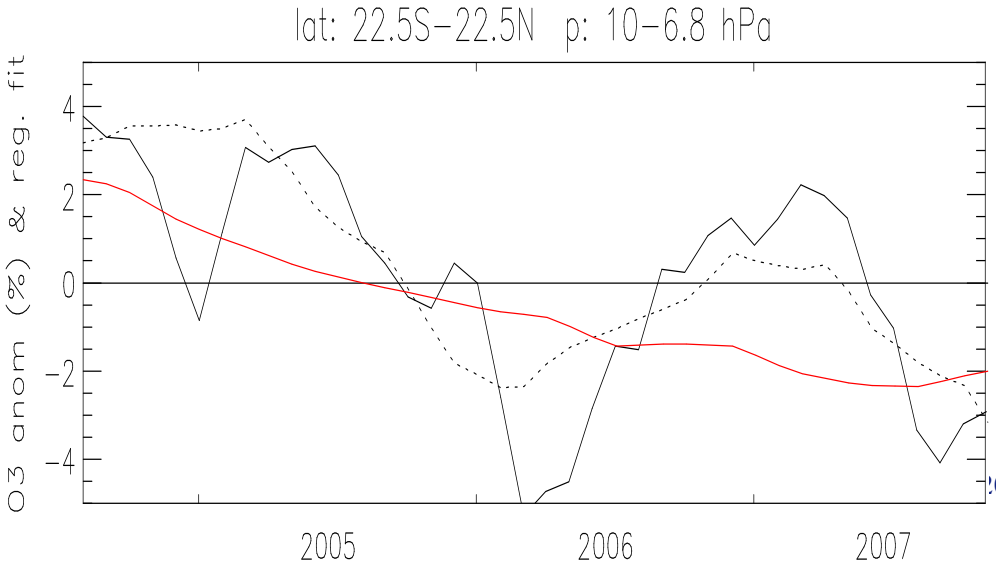
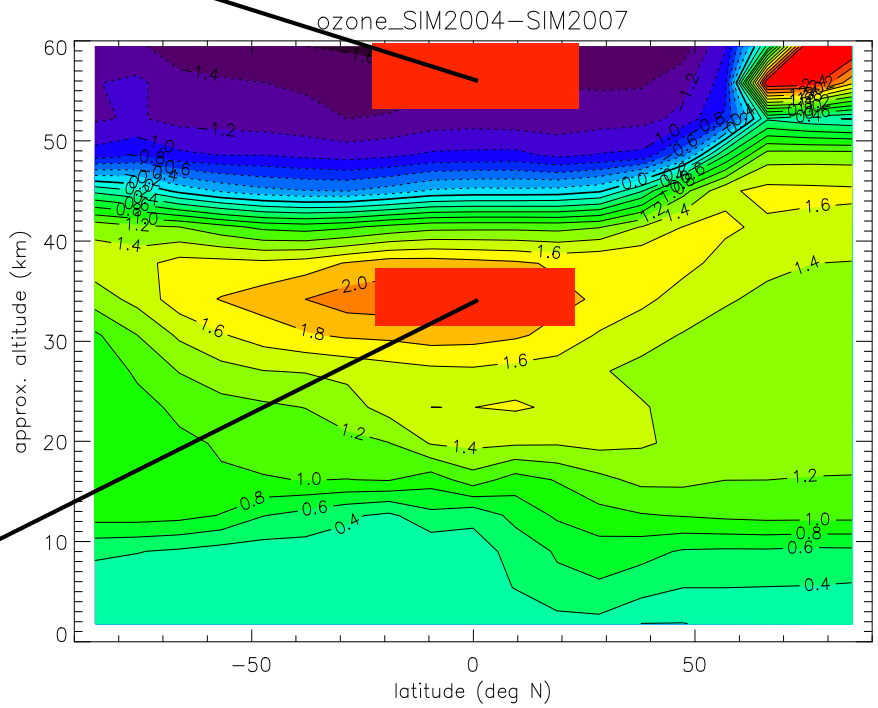
Multiple regression analysis of AURA MLS O_3 data 2004-2007



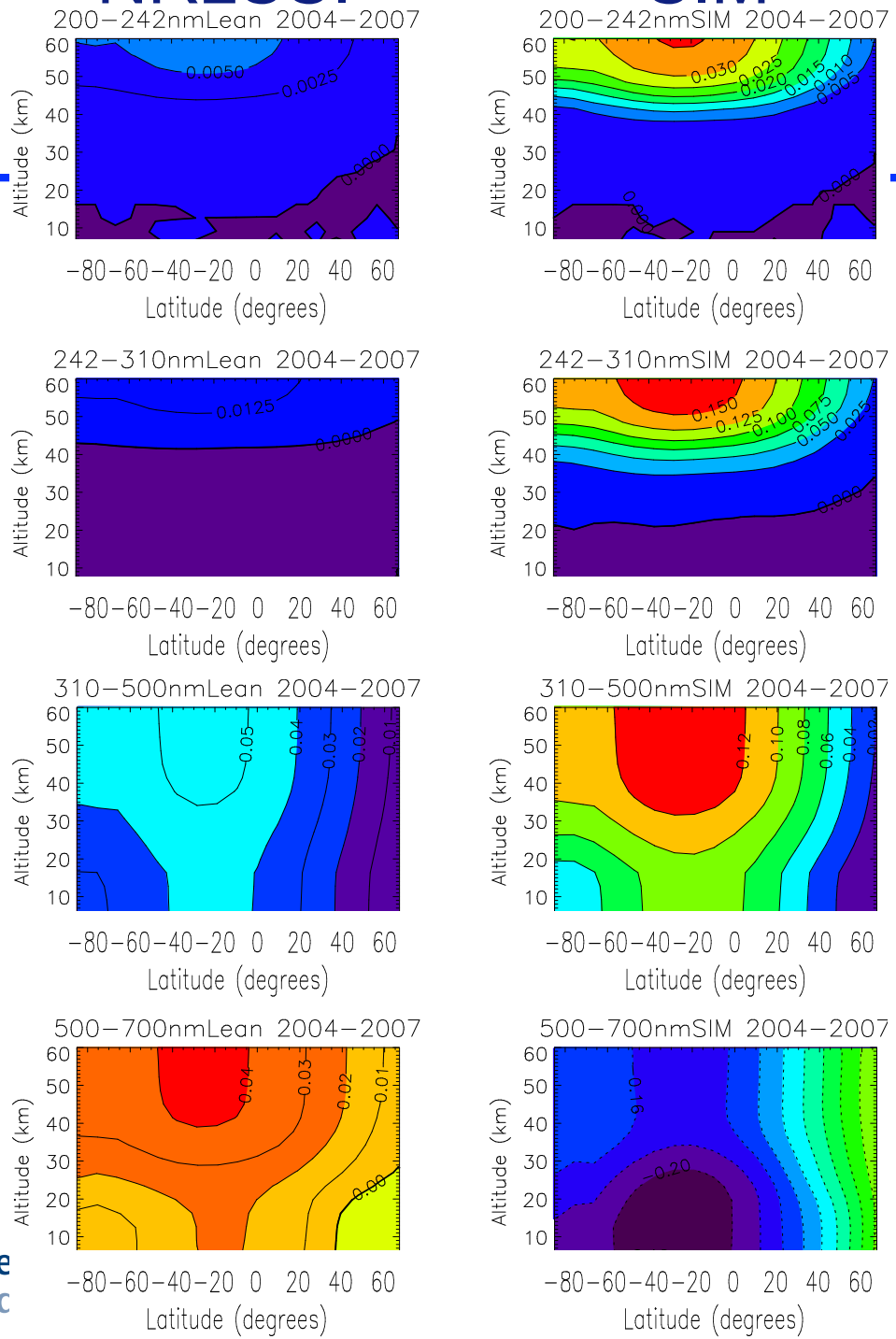


Opposite trends also seen in independent ozone data



Integrated solar flux 2004-2007 (Wm^{-2})

NRLSSI | SIM



200-242 nm

242-310 nm

310-500 nm

500-700 nm

Impe
Lonc

Solar Radiative Forcing of Climate*
2004-2007 (mW m^{-2})

NRLSSI

	200-310 nm	310-500 nm	500-700 nm	700-1600 nm	Total solar 200-1600 nm	Thermal (LW)	Net
TOA	20	40	30	20	110	0	110
105hPa	0	30	10	20	60	20	80

SIM

	200-310 nm	310-500 nm	500-700 nm	700-1600 nm	Total solar 200-1600 nm	Thermal (LW)	Net
TOA	160	110	-130	-50	90	0	90
105hPa	0	60	-170	-50	-160	60	-100

*IPCC: global average net downward radiative flux at the tropopause

Solar forcing of climate: radiative mechanisms

"Top-down" via UV heating the stratosphere

SIM (2009) data would make much larger

and/or

"Bottom-up" via visible radiation warming surface ?

SIM (2009) data would invert

Climate model UV experiment

Ineson et al (*Nature Geoscience*, 2011)

Model:

- UK Met Office HadGEM3 coupled atmosphere-ocean GCM, extends from surface to 85km, 42 levels in ocean.

Experiment:

- UV in 200-320nm band decreased by 4% representing solar cycle variation based on SIM data (Harder et al, 2009)
- No changes in other spectral bands.
- 80-year control run (solar min)
- 20x5-year experiment runs (max)

Reanalysis data:

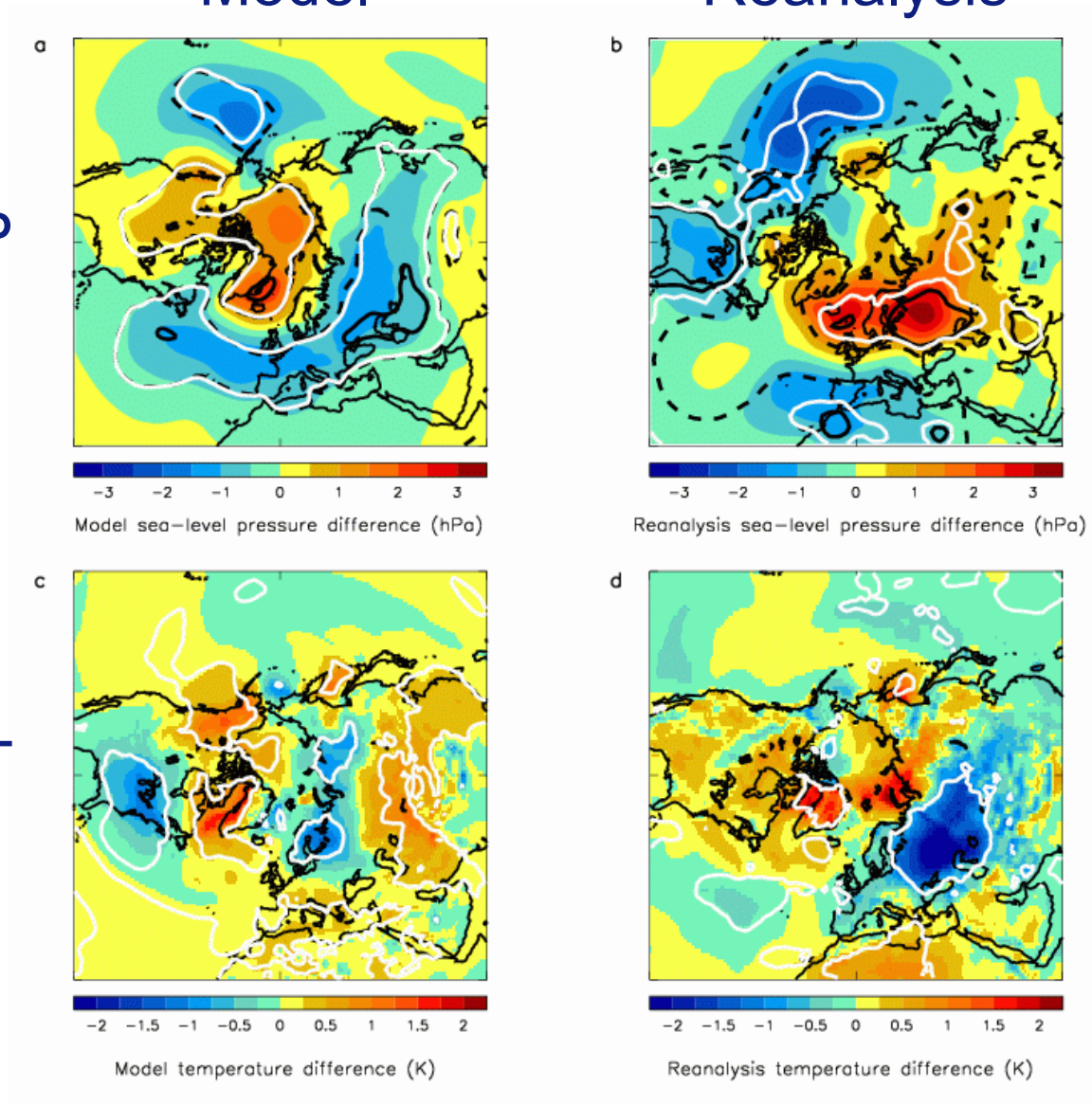
- ERA-40/Interim 1957-2010
- Winter data composited into thirds (min, n/a, max) according to solar open flux.

Surface climate response (solar min – max)

Model | Reanalysis

SLP

surface T

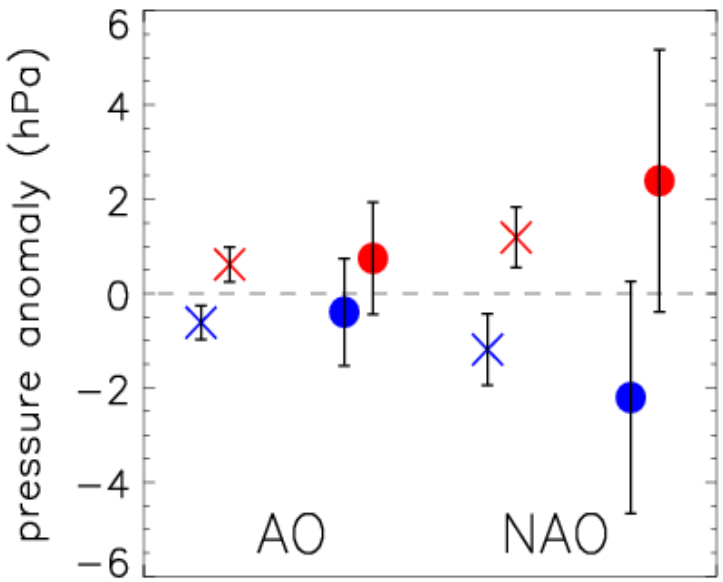


Ineson et al (2011)

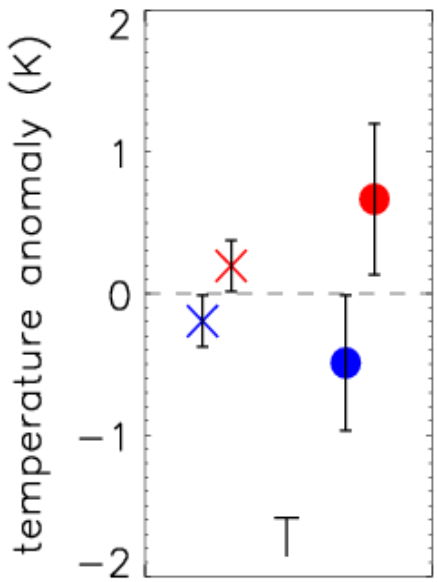
Climate model SIM-like UV experiment

Ineson et al (*Nature Geoscience*, 2011)

Surface pressure gradients



N. Europe surface air temperature



DJF composite anomalies

model (x) reanalysis (•)

solar minimum solar maximum

error bars indicate +/- 1 s.e.

Consider…

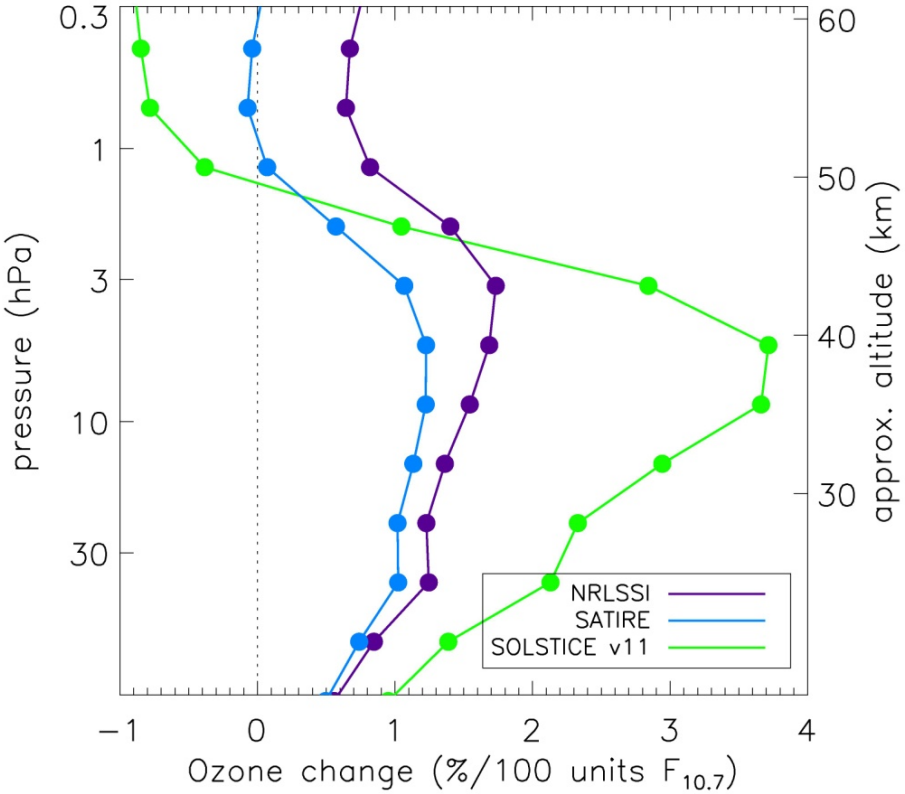
These results depend fundamentally on the changes in solar spectrum.

SIM data being recalibrated.
Other SSI data include SOLSTICE
Modelled spectra include SATIRE

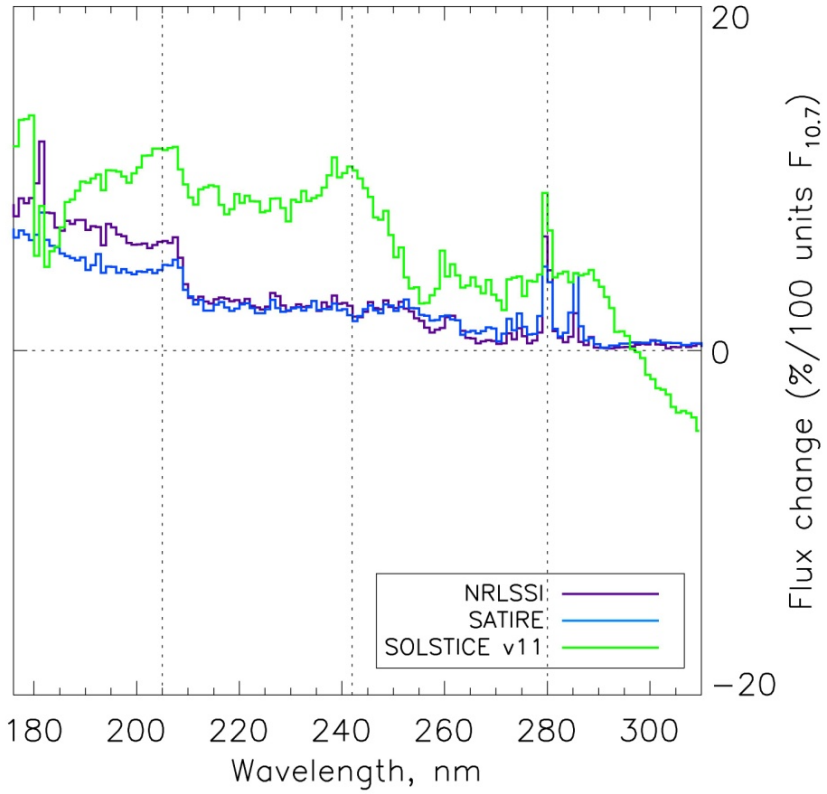
Can we better combine information available on solar spectrum with that on ozone to constrain variations in either?

Modelled O_3 response to different spectra

Ozone change (%/100units $F_{10.7}$)



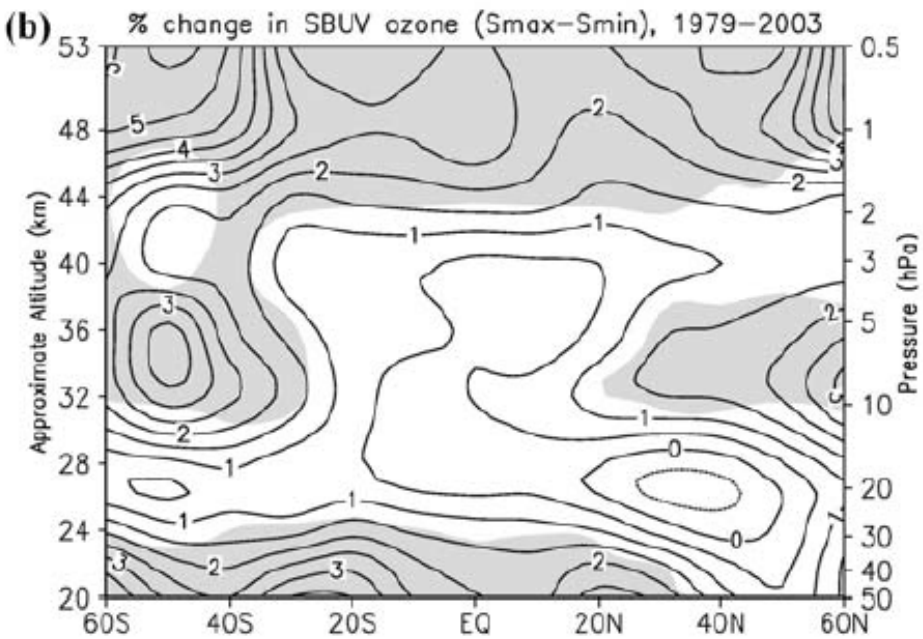
Spectra



Will Ball (Imperial College)

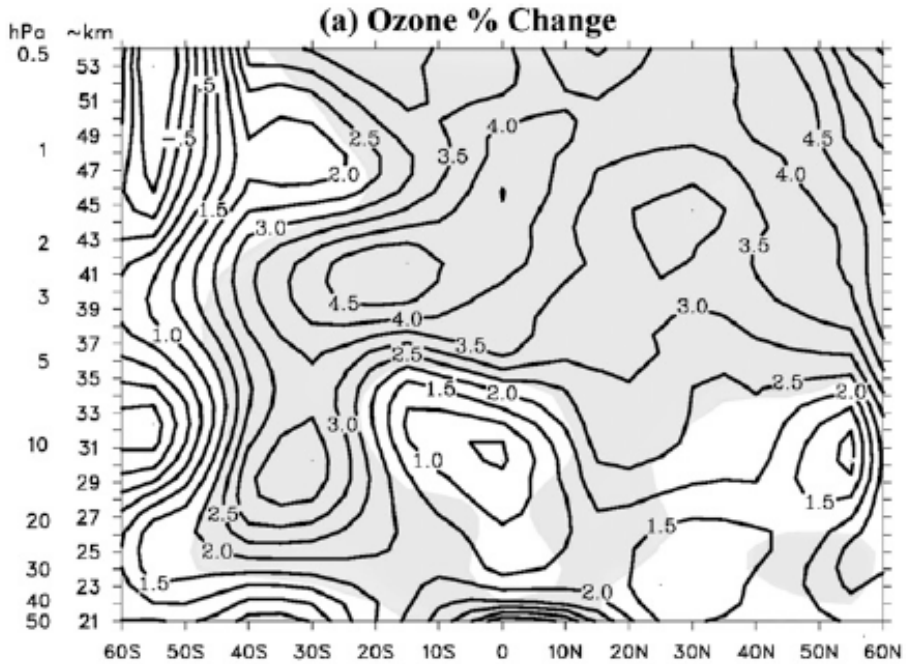
Solar cycle signal in ozone

SBUV



Hood et al (2010)

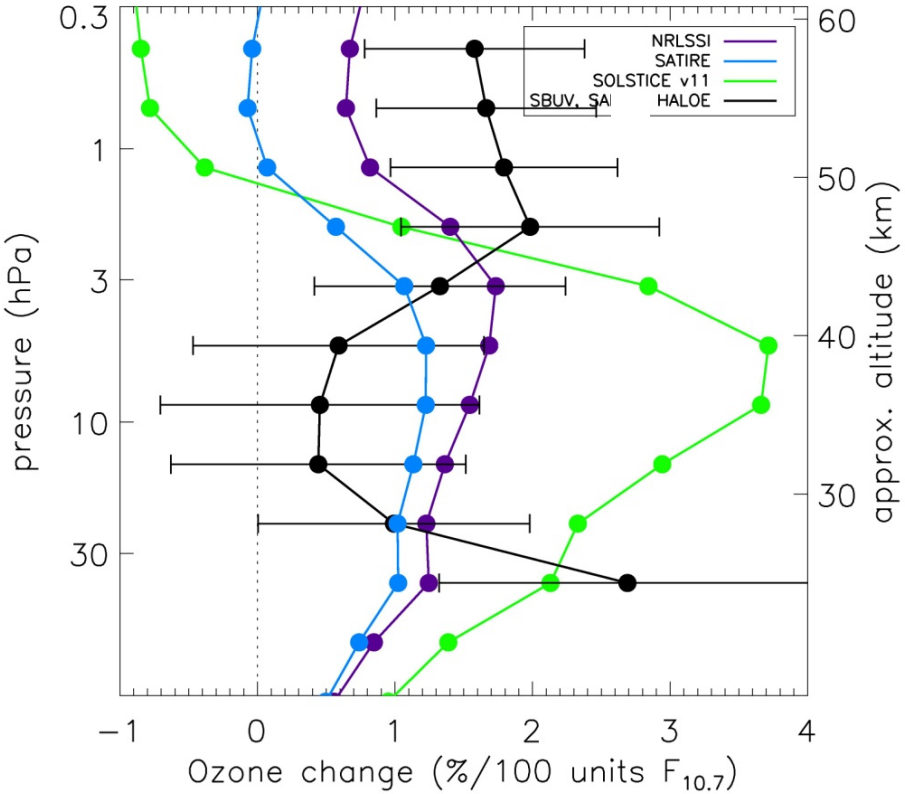
SAGE



Hood & Soukharev (2012)

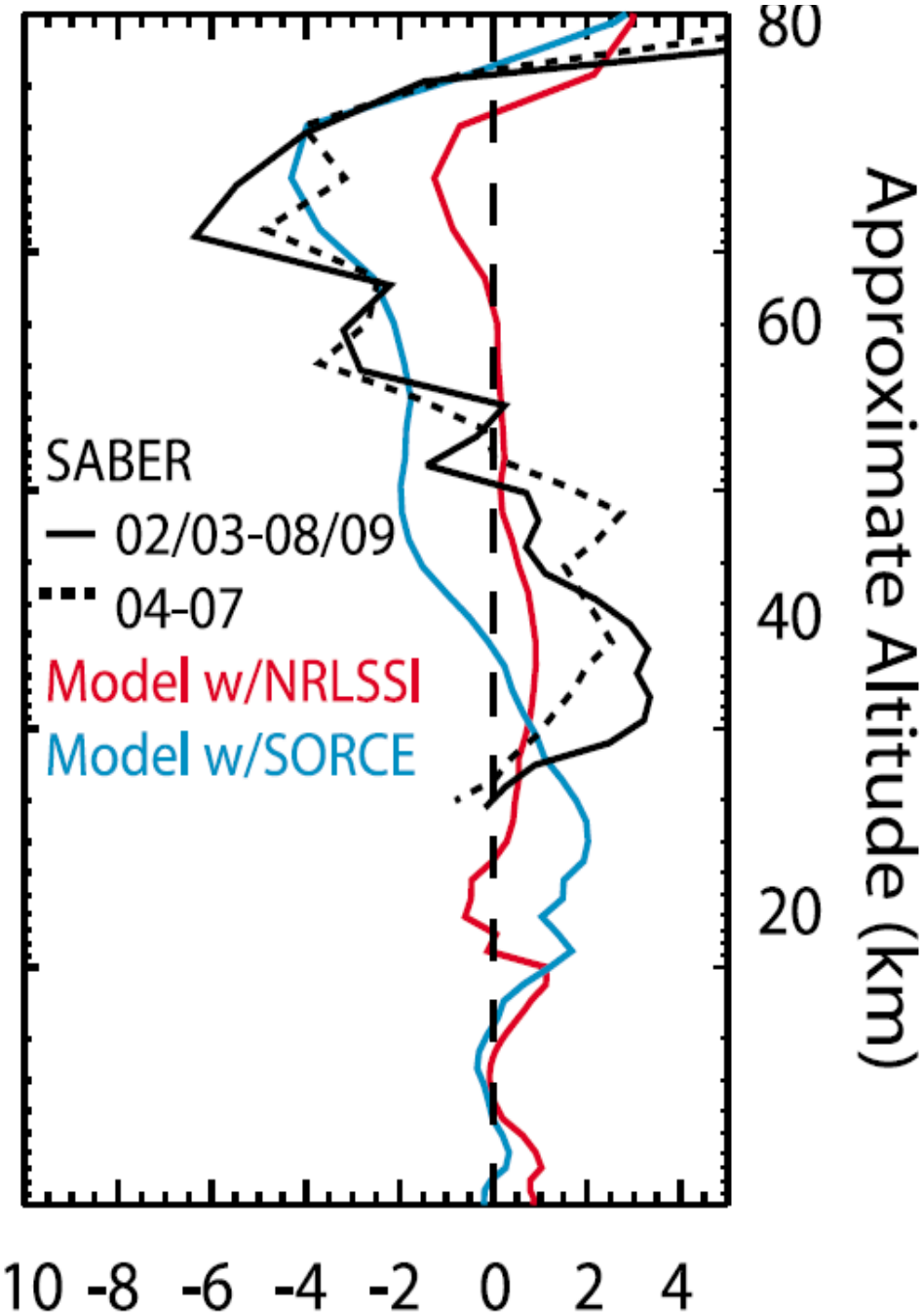
Comparison of model O_3 spectra with c

Ozone change (%/100units $F_{10.7}$)

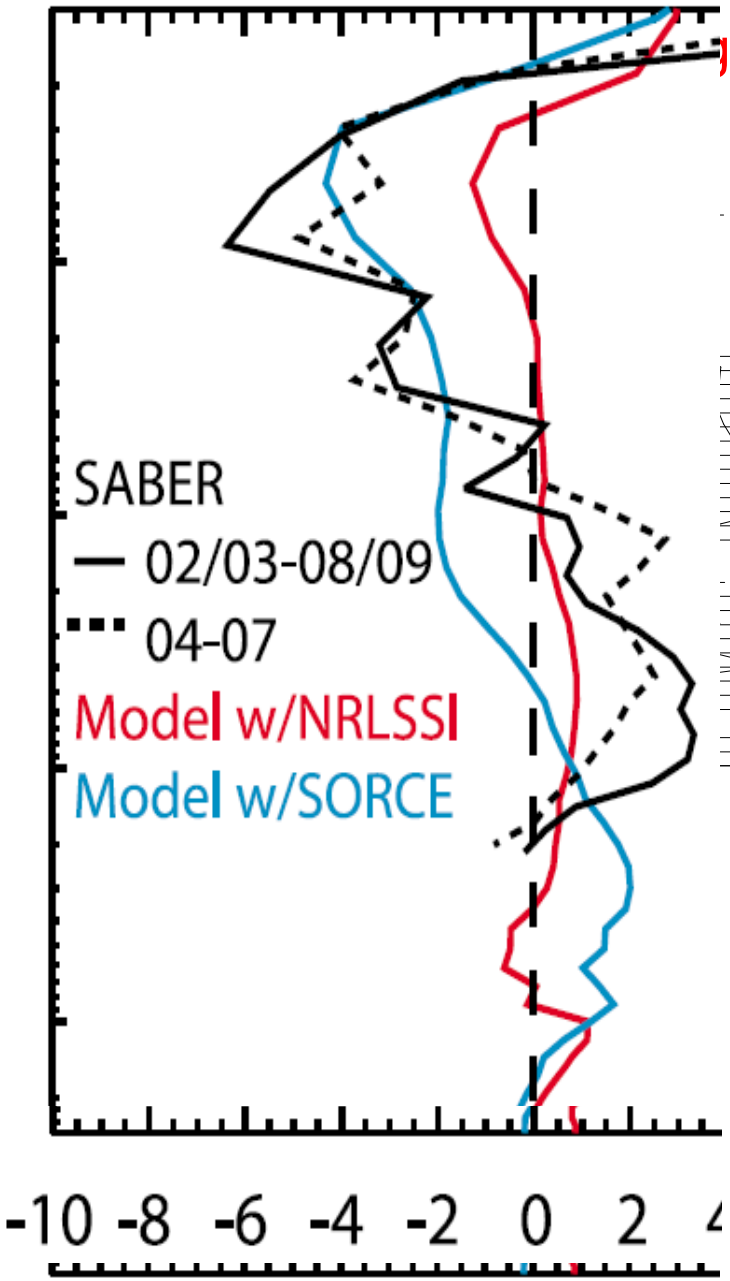


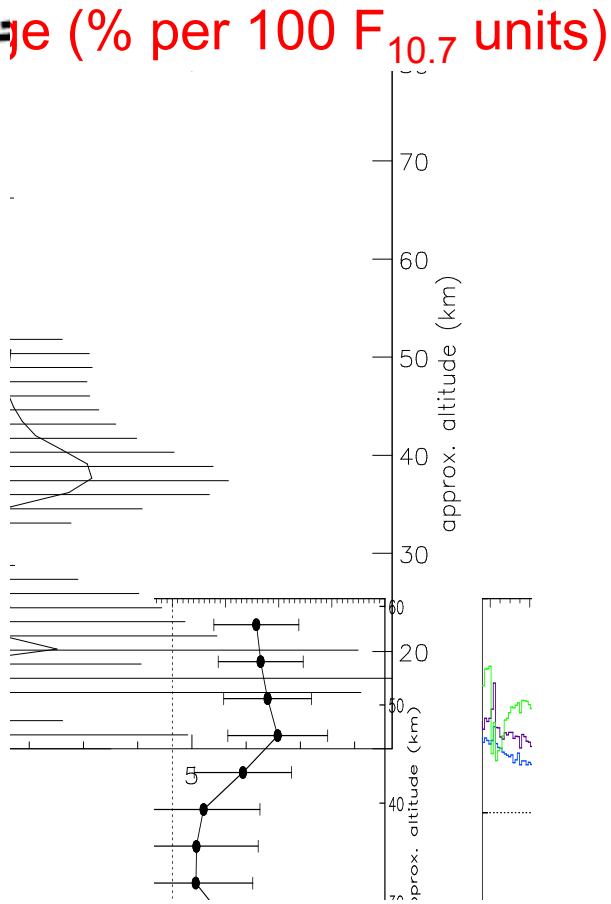
data profile: Austin et al (2008) after Soukharev & Hood (2006)

Merkel et al (2011) 2004-2007
WACCM model & SABER obs (daytime)



Multiple regression of Aura MLS tropical O_3 data 2003-2012

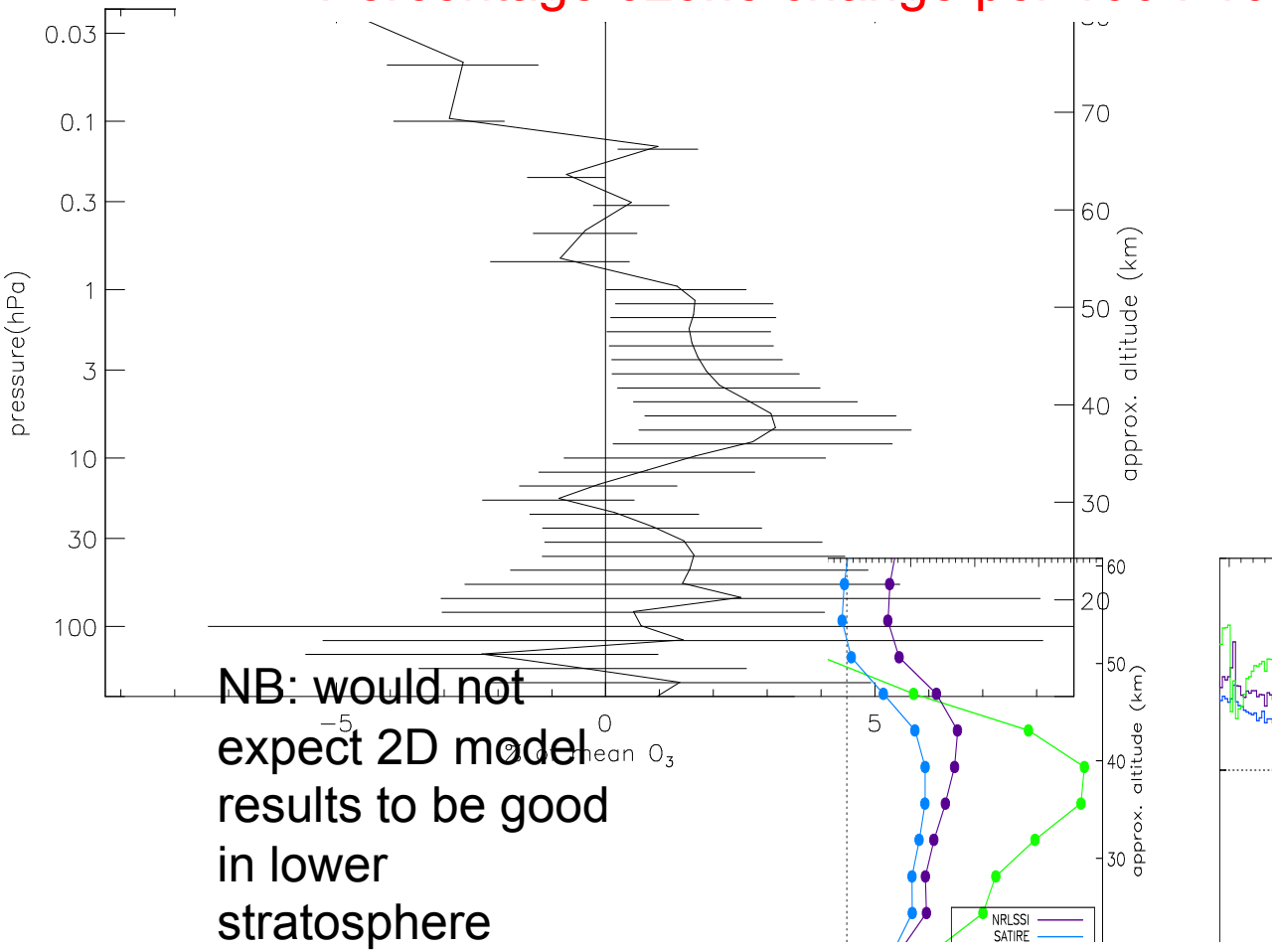




Jack Egerton (Imperial College)

Multiple regression of Aura MLS tropical O_3 data 2003-2012

Percentage ozone change per 100 F10.7 units



NB: would not expect 2D model results to be good in lower stratosphere

Statistical analysis of sensitivities

Tropical O_3 change profile from 512 model runs with variations in imposed UV spectrum applied in 4 broad bands

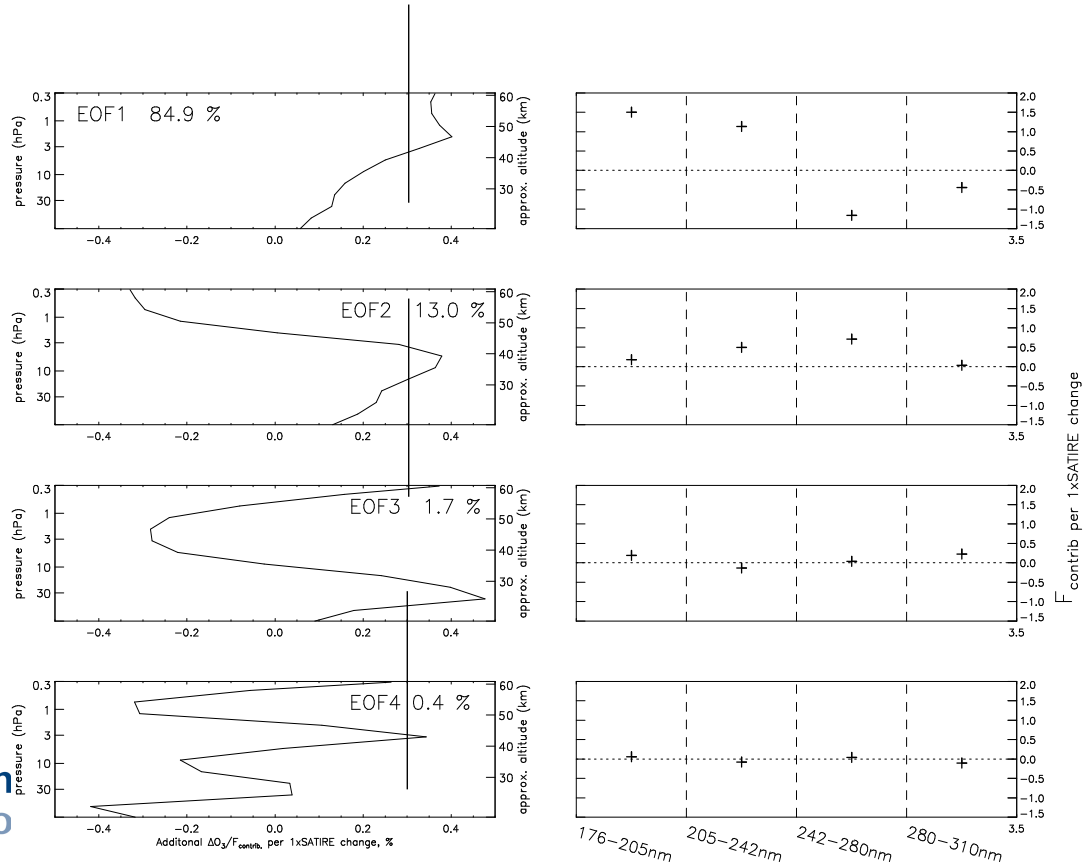
[Very preliminary analysis …]

Will Ball (Imperial College)

O_3 (difference from solar minimum)

EOFs weightings

spectral



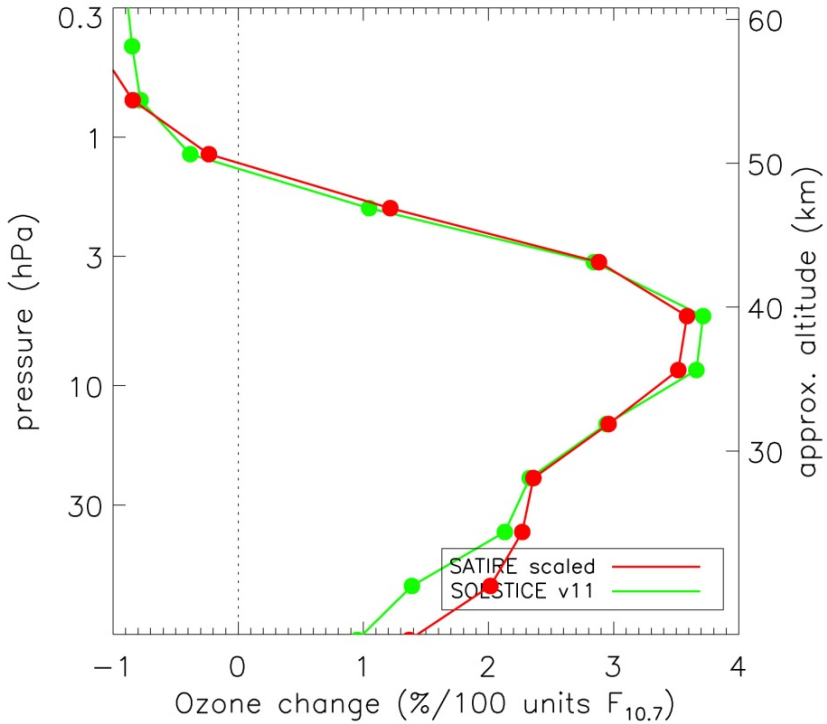
Statistical analysis of sensitivities

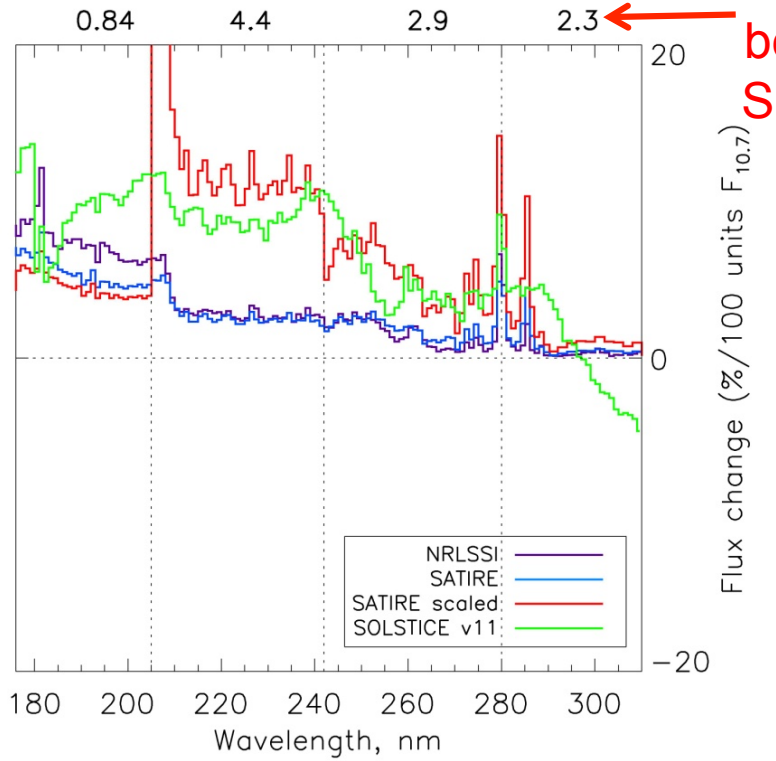
Can make linear combinations of EOFs to match any given O_3 change and deduce required spectrum.

Some examples…

Spectrum constructed to produce best match to SOLSTICE - derived O_3 profile

weightings applied to SATIRE needed to best match SOLSTICE O_3





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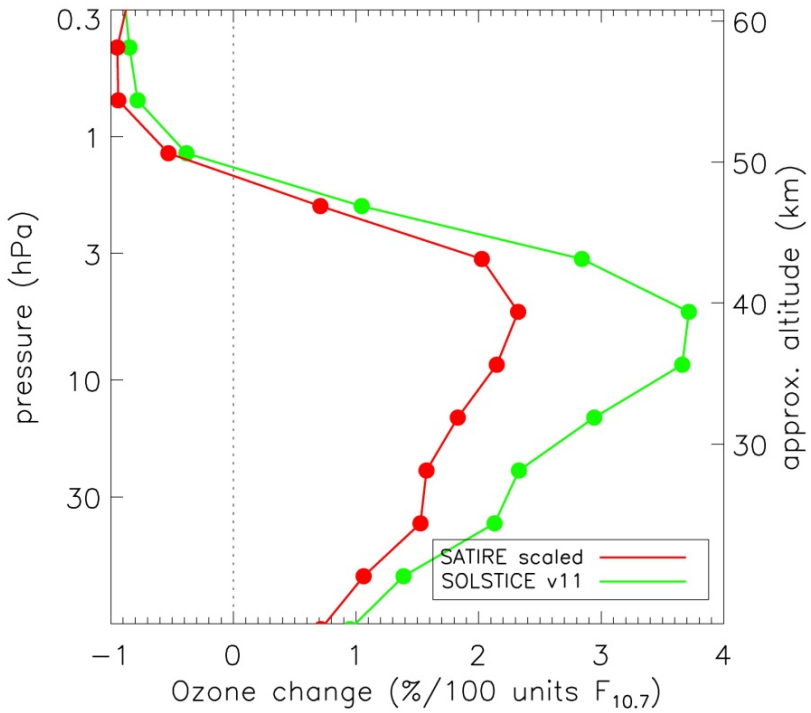
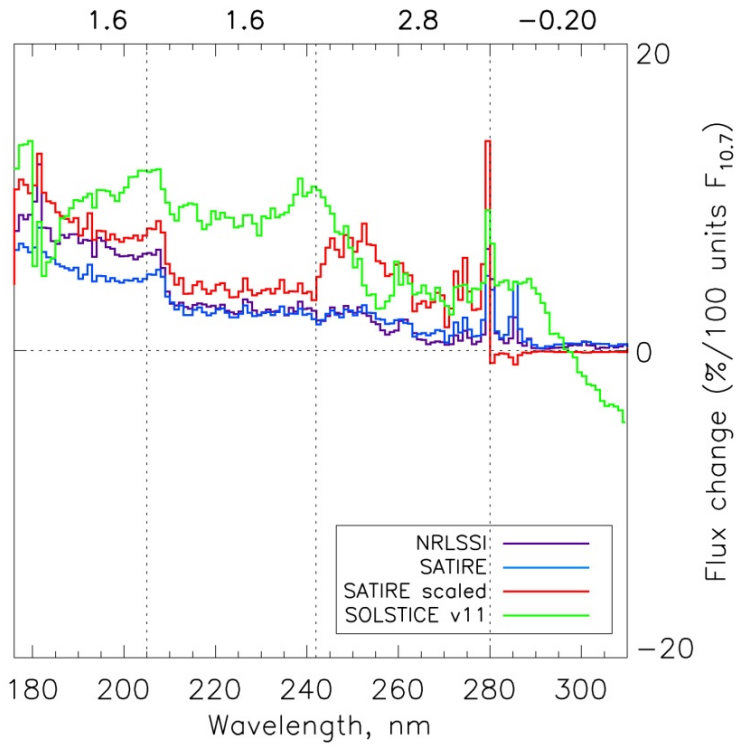
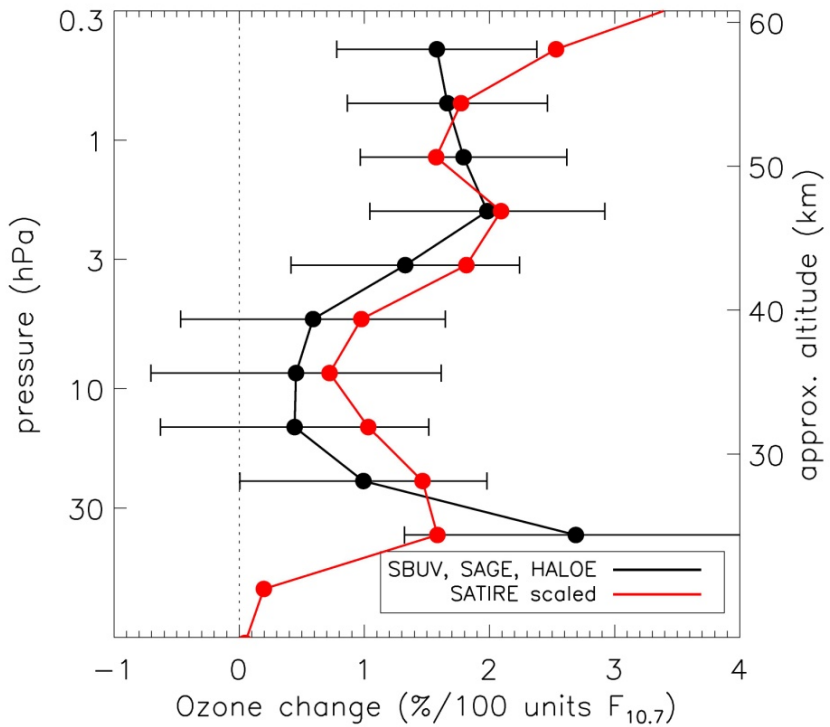
Spectrum constructed to produce best match to SOLSTICE - derived O_3 in upper stratosphere/lower mesosphere

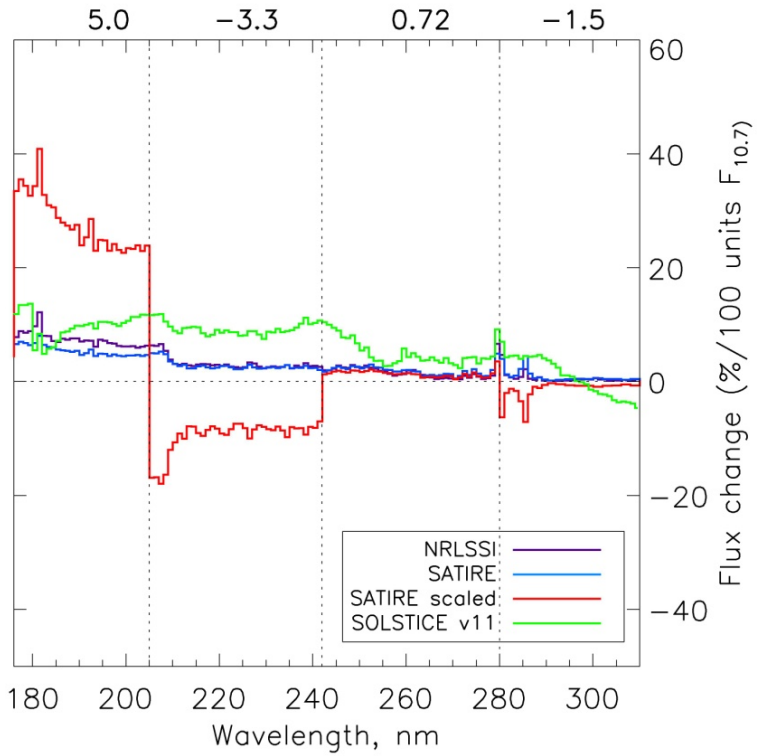




Will Ball (Imperial College)

Spectrum constructed to produce best match to SAGE/ SBUV/HALOE





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Can we better combine information available on solar spectrum with that on ozone to constrain variations in either?

Answer probably yes –

but a work in progress.

Summary 1/3

- Solar cycle variability in Pacific SST – uncertain.
- Troposphere: shifts in jets & storm tracks (greater solar activity → jets poleward).
- UV heating of stratosphere produces similar patterns in low-top GCM.
- Mechanistic model: thermal perturbation near tropopause influences deposition of eddy momentum, with feedback on wave propagation and impact on jets and overturning circulation.
- Magnitude of effect is **crucially dependent** on magnitude of lower stratospheric heating & thus **on changes in UV spectrum** (& stratospheric response).

Summary 2/3

- SORCE spectra very different to semi-empirical models of SSI implying at higher solar activity:
  - a *reduction* in O_3 in lower mesosphere
  - a *large* increase in O_3 in mid- to upper stratosphere.
  - an out-of-phase solar radiative forcing of climate
- These are not inconsistent with contemporaneous measurements of O_3 from AURA-MLS and TIMED-SABER, but appears at odds with values from earlier instruments over previous solar cycles.

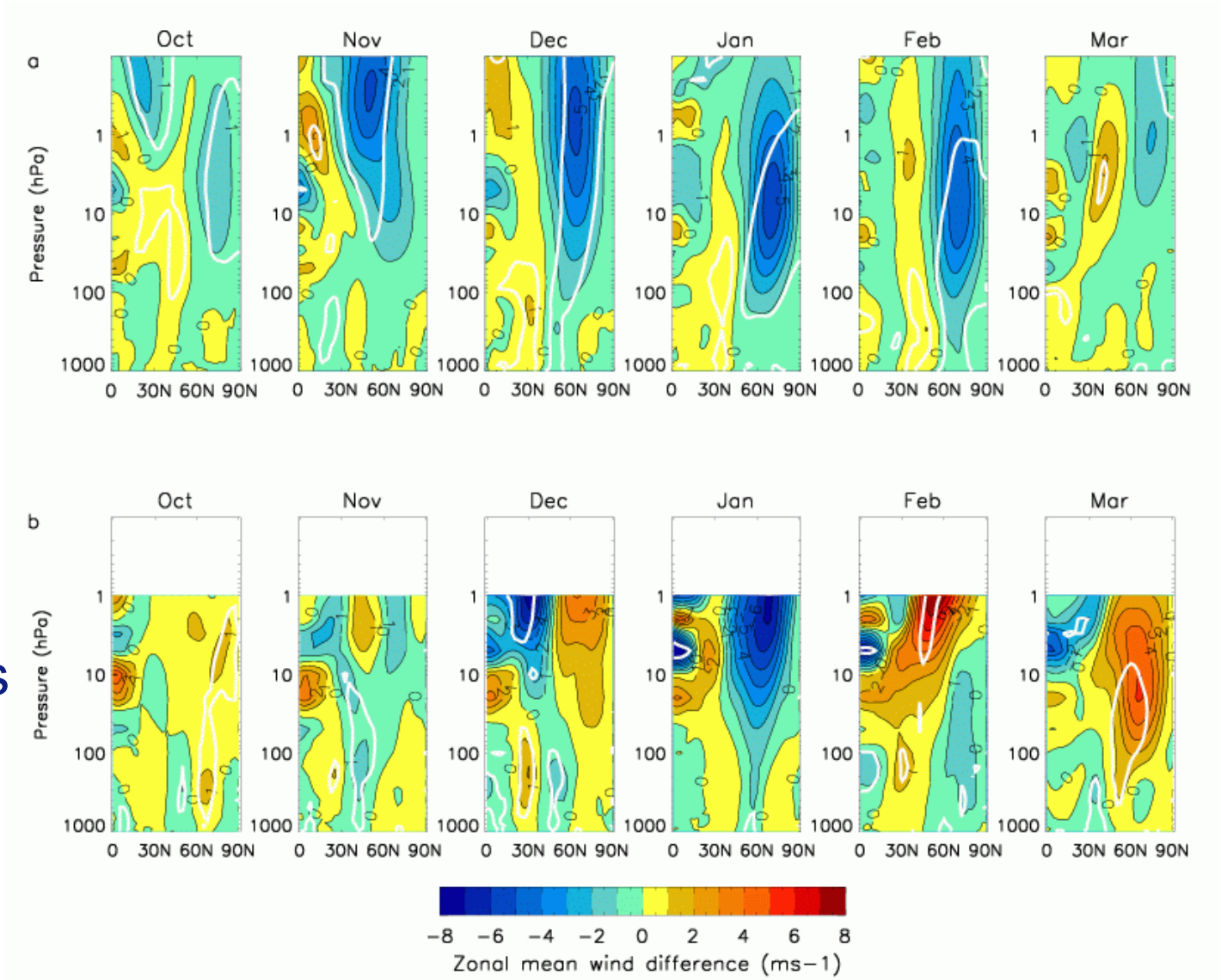
Summary 3/3

- SIM spectra also imply
  - an out-of-phase solar radiative forcing of climate
- This is difficult to align with regression results from surface temperature data
- Intelligent use of available solar spectra and stratospheric observations, with atmospheric models, should be able to better constrain values.
- Need ongoing, well-calibrated measurements of SSI and atmospheric variables.

Evolution of wind anomaly through winter

Model

Reanalysis



Winter polar stratosphere

Solar min – solar max in JF

Zonal wind (contours)

EP flux divergence (colours)