Solar irradiance variability and climate

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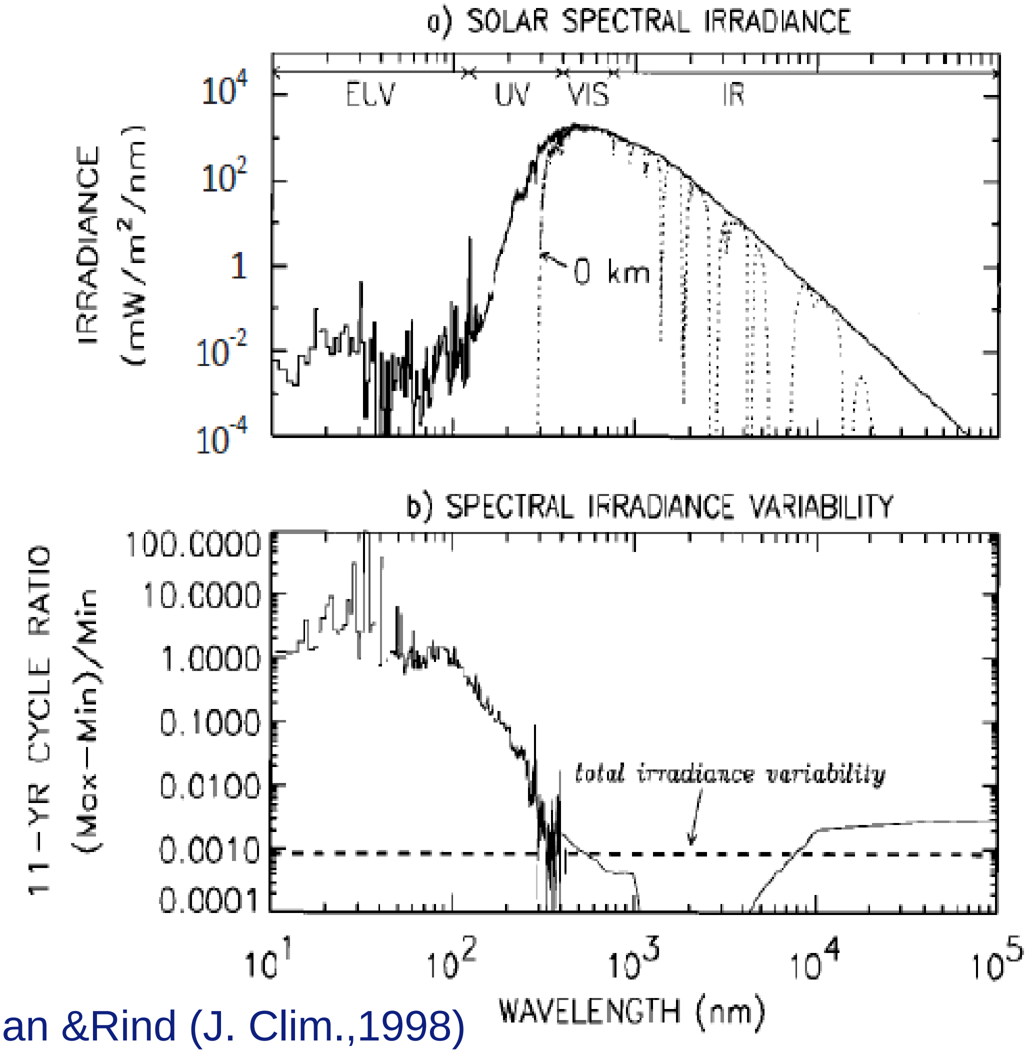
Background

- Evidence for solar influence on climate difficult to explain by small variations in total solar radiative output.

- UV variations (fractionally) much larger.



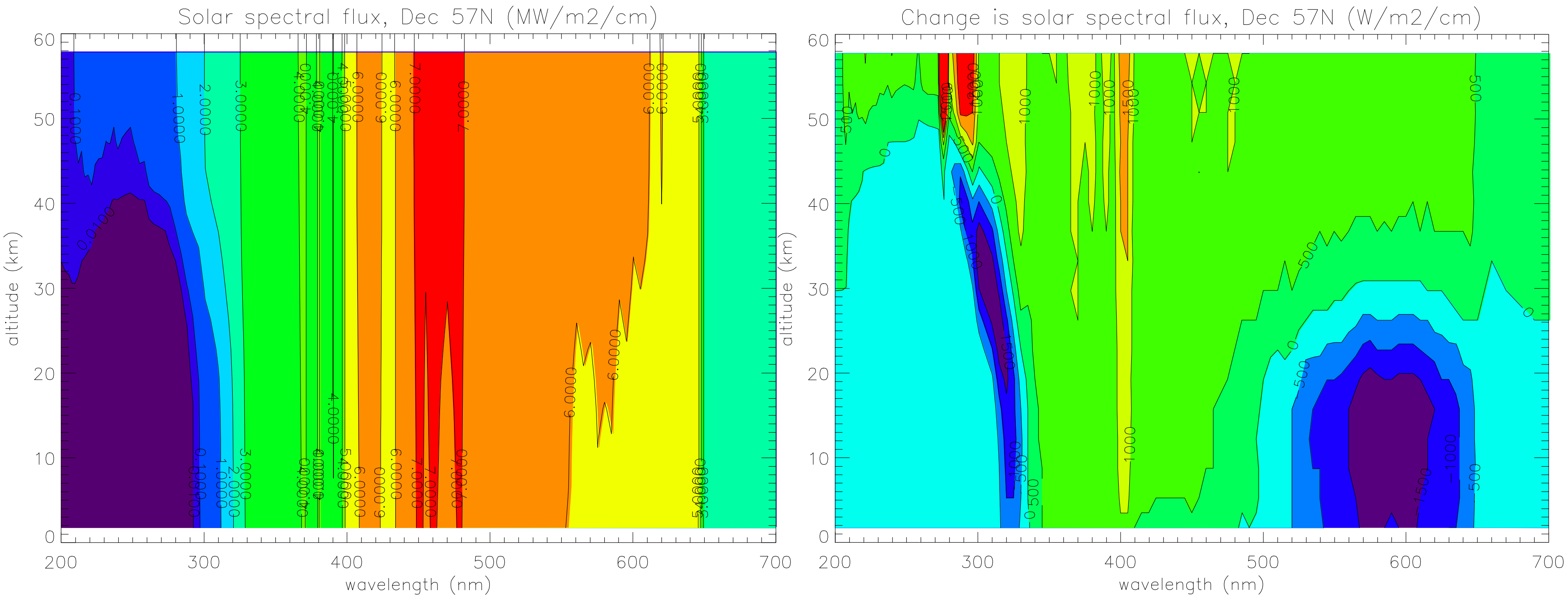
Lean &Rind (J. Clim.,1998)

- Visible wavelength radiation mainly reaches Earth's surface.

- UV radiation mainly absorbed in stratosphere.

Background:
Solar cycle variation in spectral irradiance

solar min (Dec, 57N) max-min



Haigh (Nature, 1994)

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

Solar forcing of climate: radiative mechanisms

“Top-down” via UV heating the stratosphere

and/or

“Bottom-up” via (visible) radiation warming surface ?

Outline

- Impact of solar variability on wind and circulation of troposphere: observations and models.

- Mechanism proposed via UV heating of stratosphere and dynamical coupling.

- Unusual behaviour of solar spectrum over declining phase of solar cycle 23.

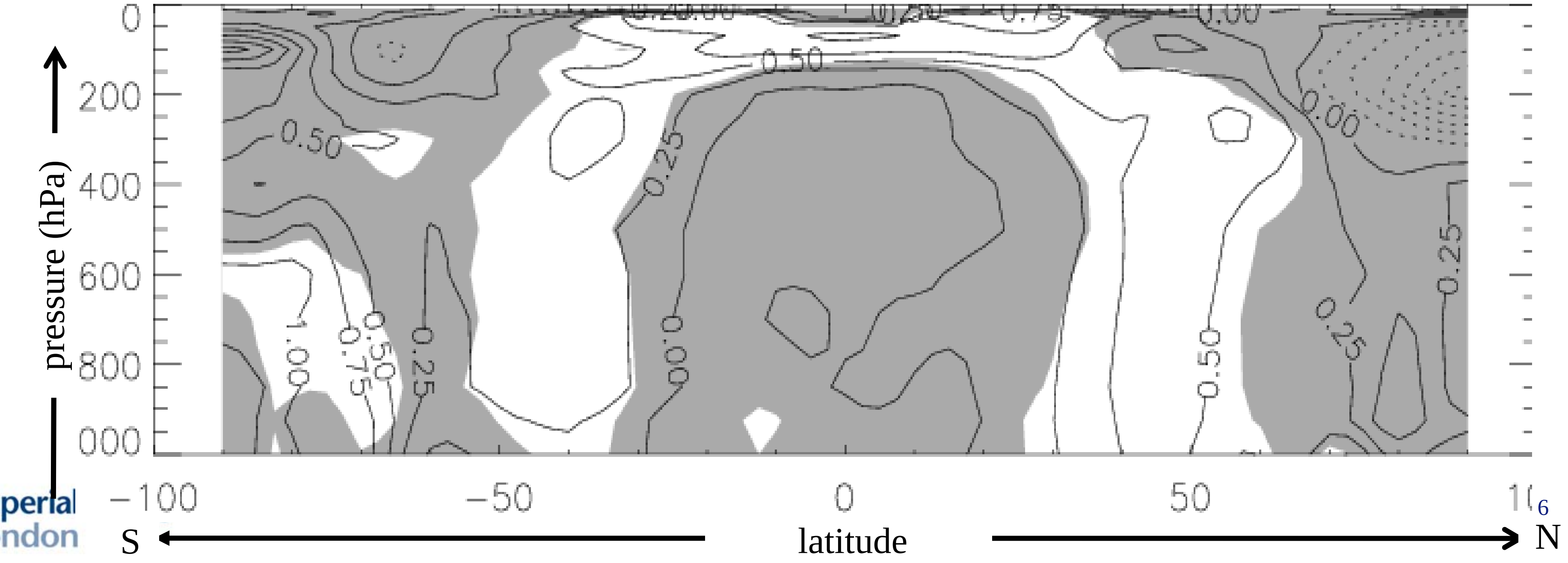
- Implications for stratospheric composition and solar forcing of climate.

Temperature changes over the 11-year solar cycle

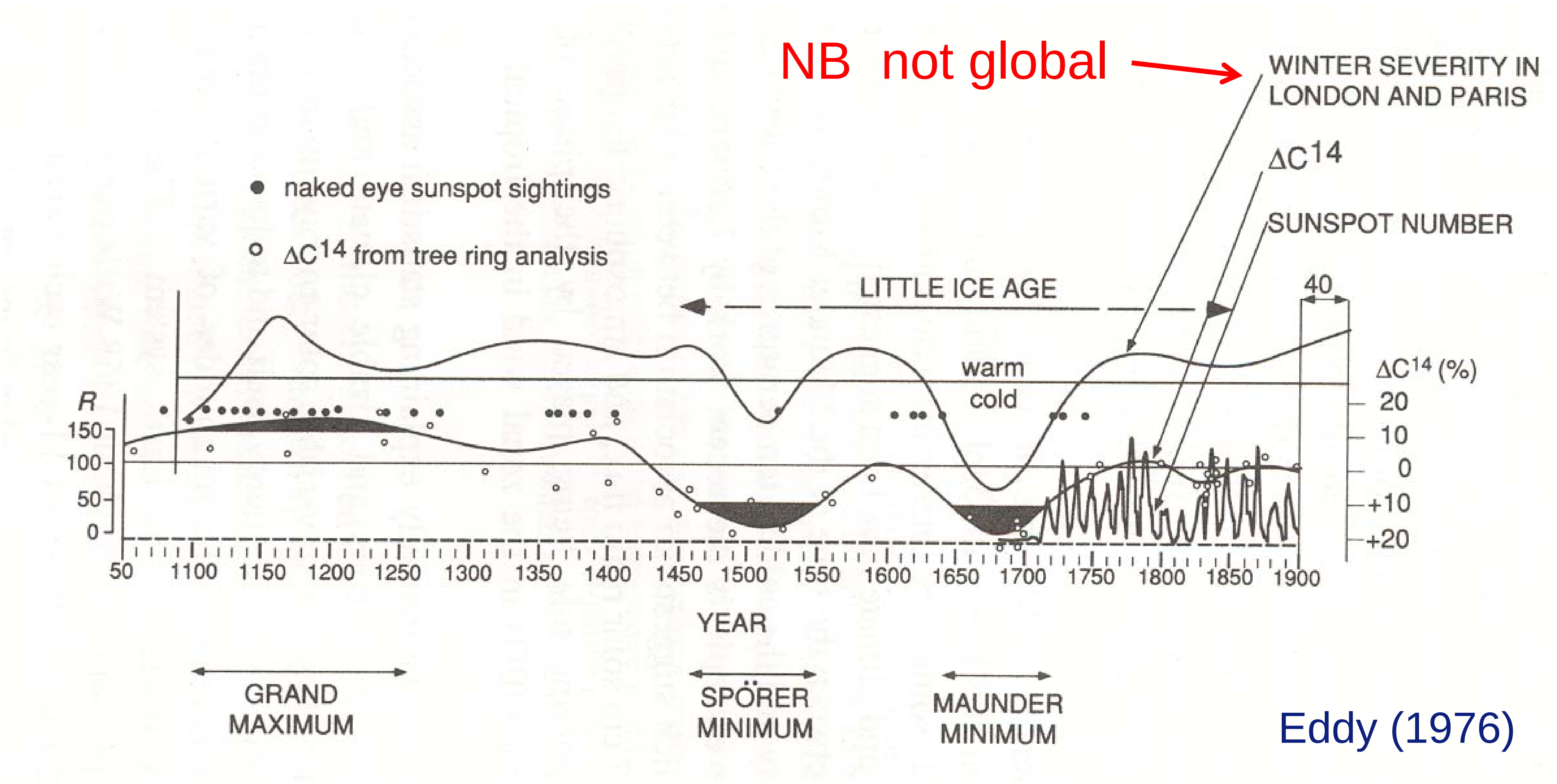
- Non-uniform.
- Warming in equatorial stratosphere, less towards the poles.
- Bands of warming in mid-latitudes.

Multiple regression analysis of zonal mean temperature1979-2000

Haigh (Phil Trans, 2003)



Temperature in NW Europe

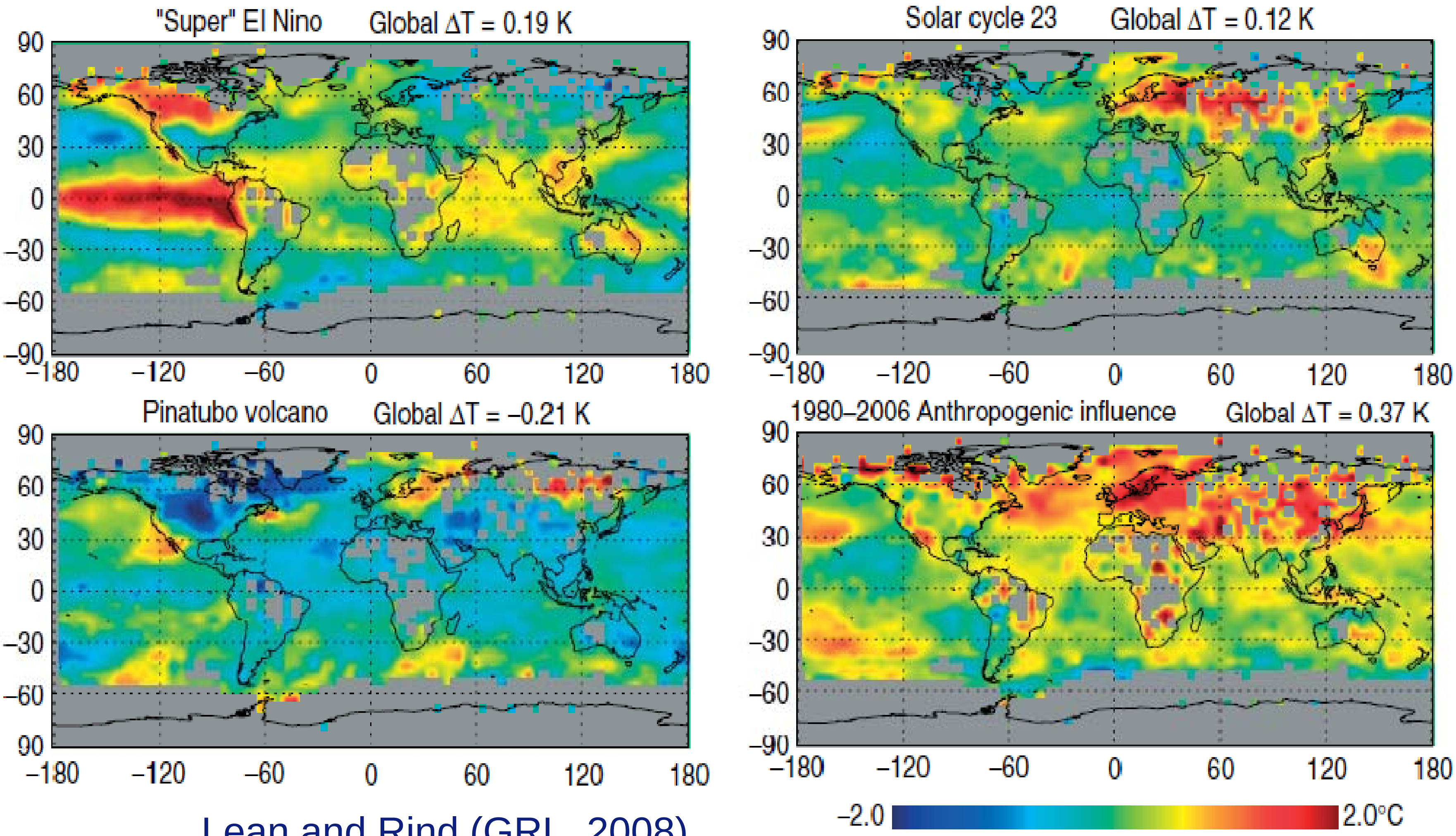


NB not global

Eddy (1976)

NB C^{14} produced by cosmic rays: more when Sun less active

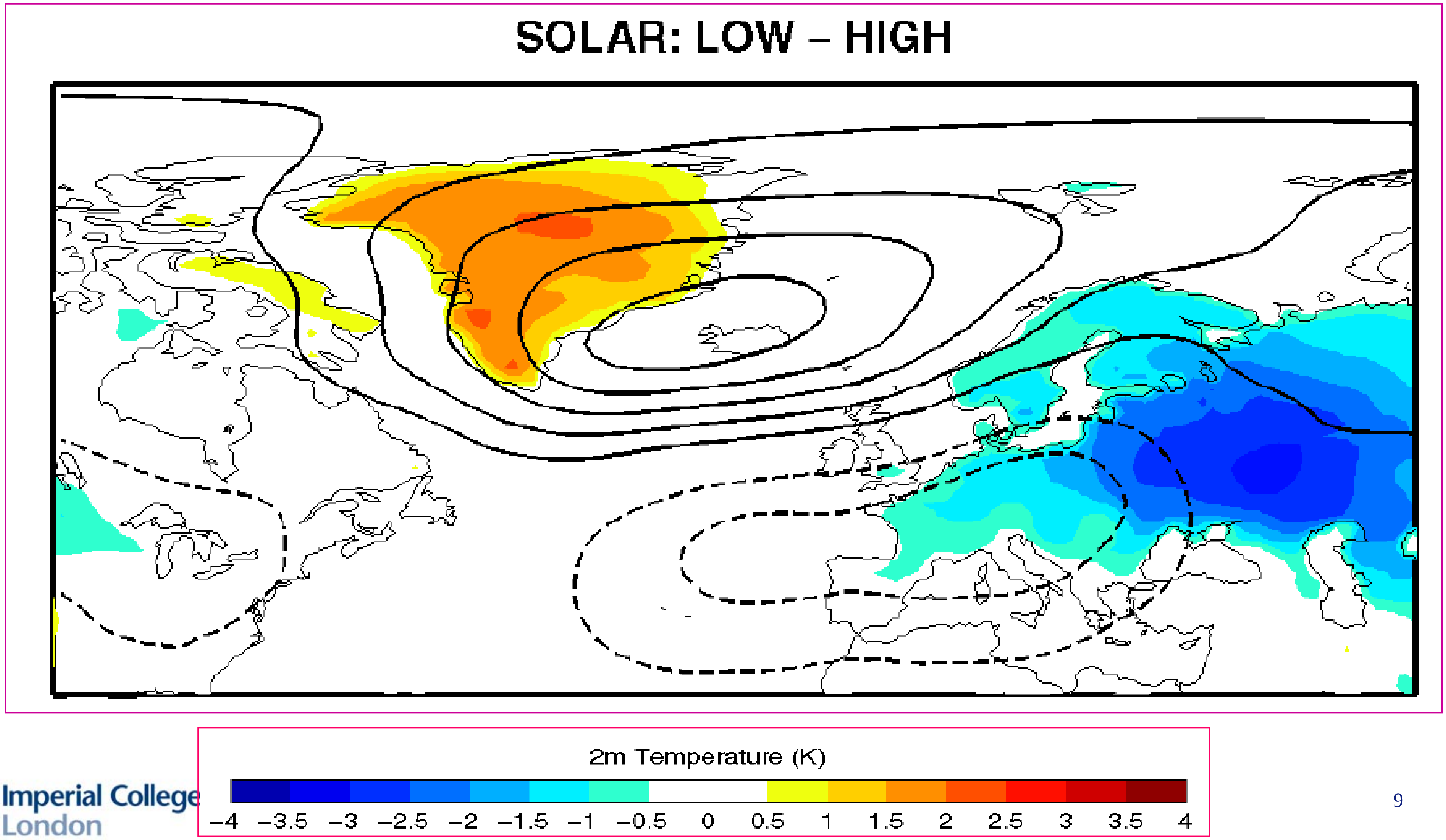
Signals in surface air temperature



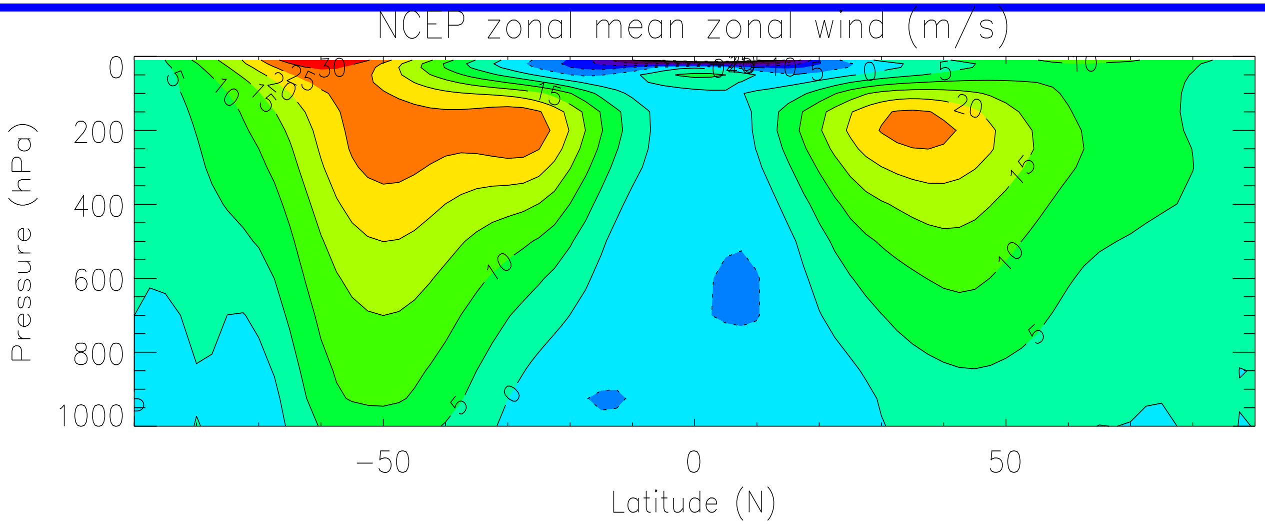
Lean and Rind (GRL, 2008)

Winter land surface air temperature and pressure

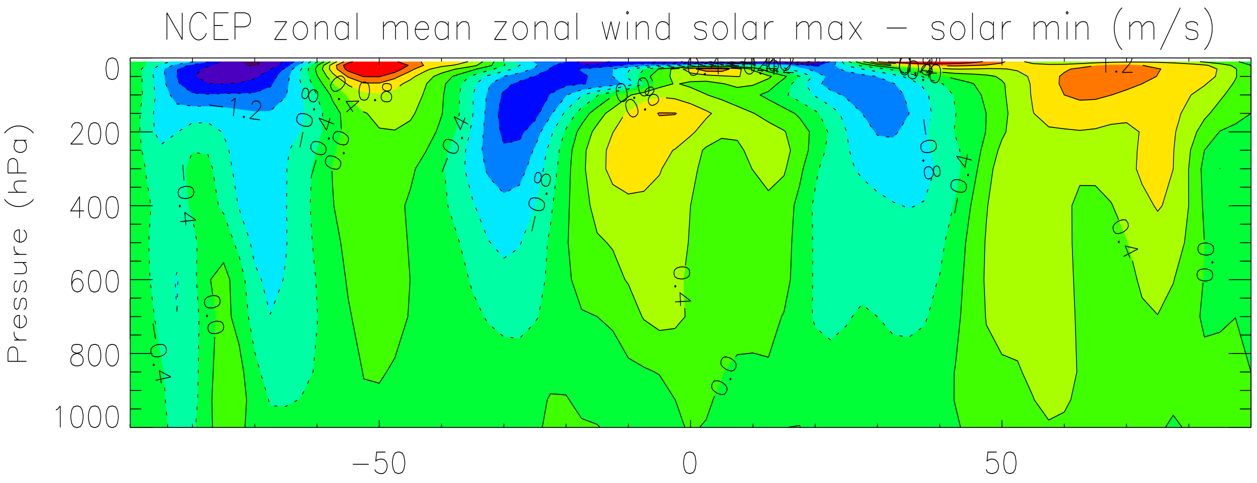
Lockwood et al. (ERL, 2010)



Solar cycle signal in westerly wind (observed)



mean



max-min

Weakening and poleward shift of the mid-latitude jets

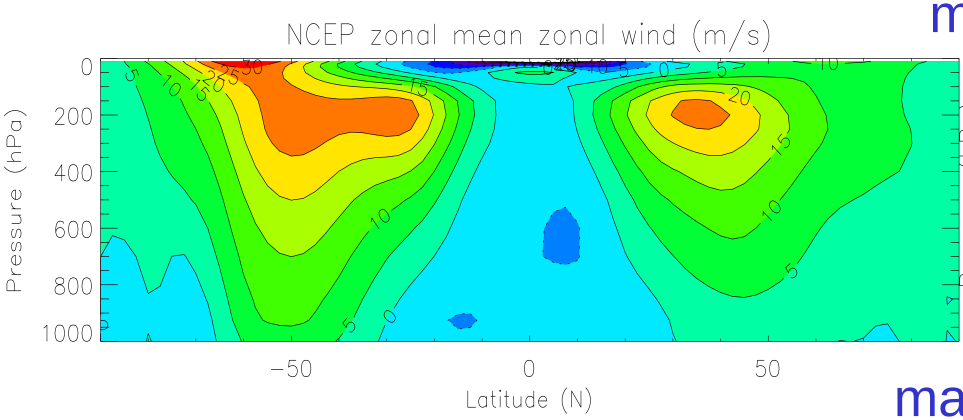
Haigh et al (J.Clim., 2005)

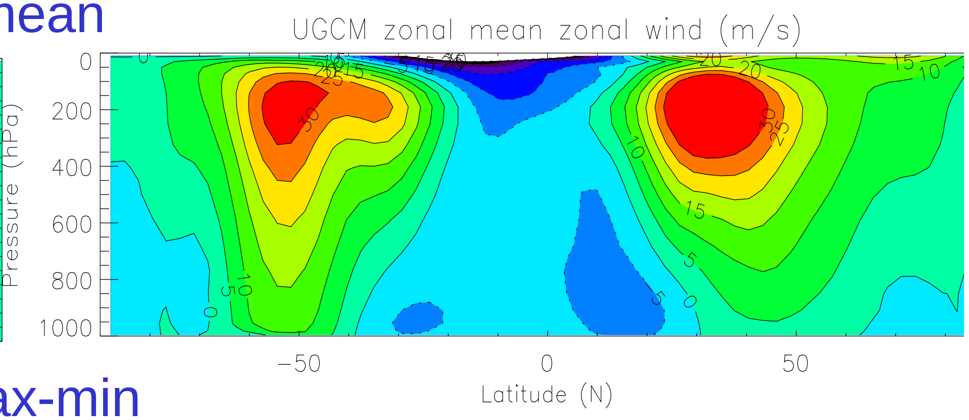
Solar signal in zonal wind: obs *cf* climate model

Observations

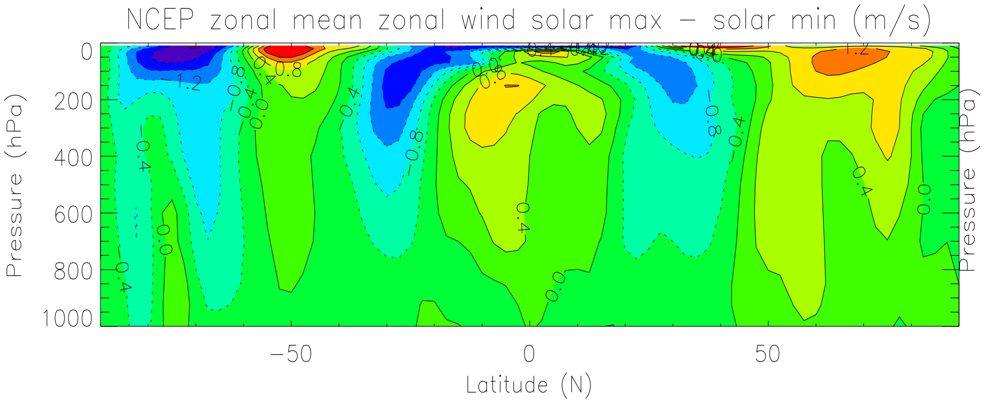
GCM response to changes in solar radiation & O_3

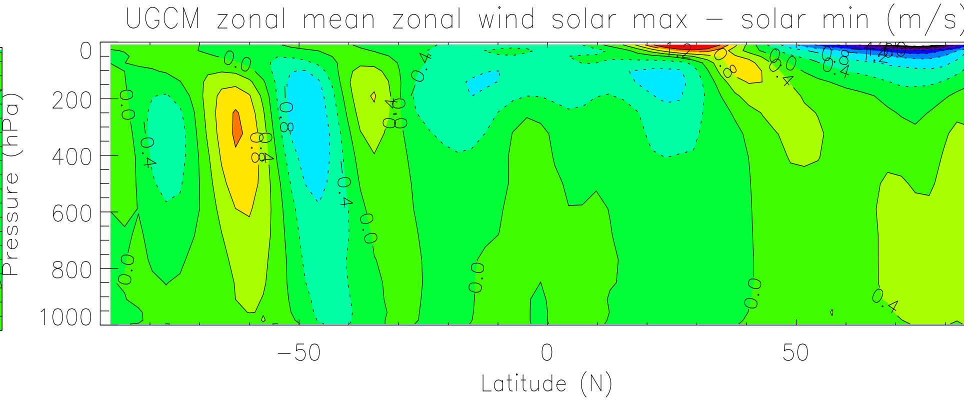
mean





max-min



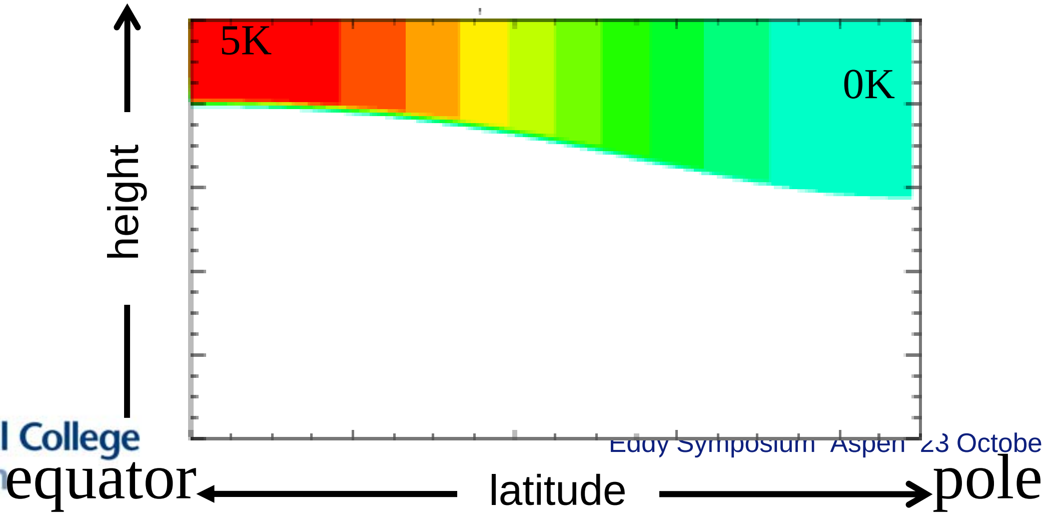


Haigh et al (J. Clim., 2005)

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

Study using a simplified climate model

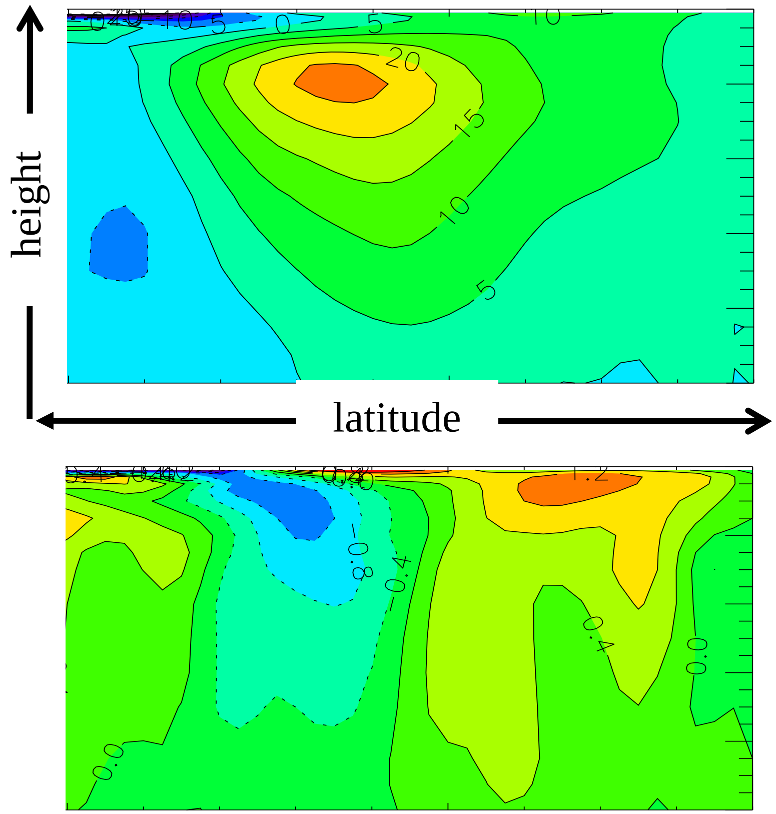
- Uses “Intermediate GCM”
  - full dynamics but highly simplified physics
    (so can try out ideas and do many runs cheaply)
  - no orography
    (so no planetary scale waves but still synoptic scale waves)
- Apply simplistic heating perturbation to the stratosphere:



Haigh, Blackburn & Day (2005)

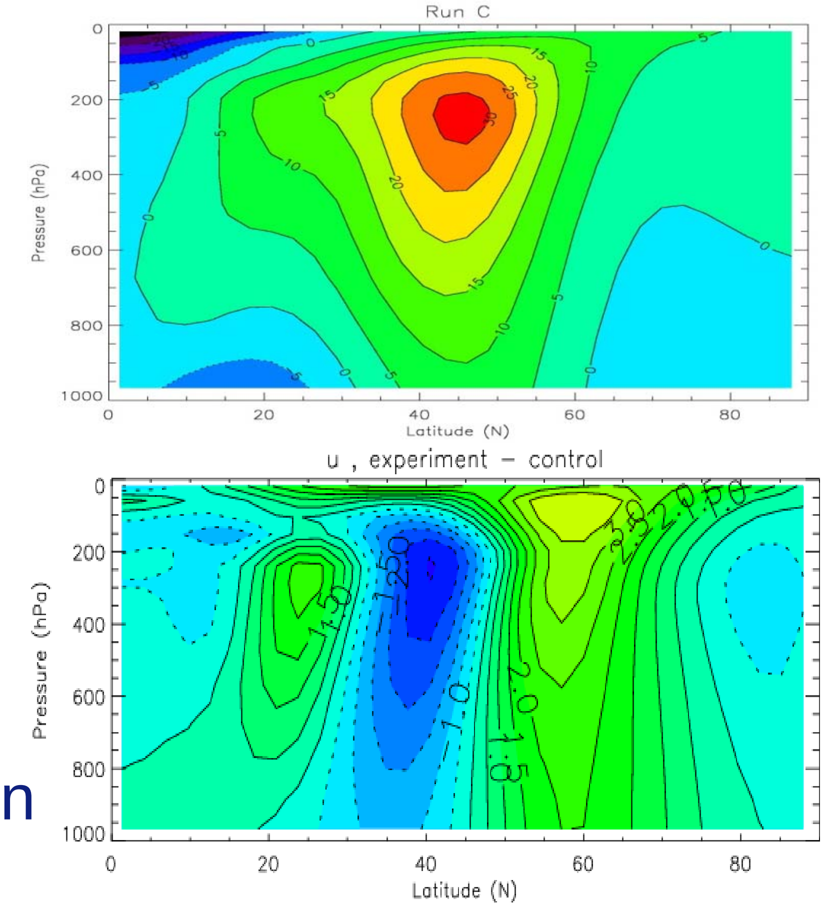
Heating applied ONLY in the stratosphere:

Observations of solar impact zonal wind Simple model



mean

solar
max - min



the jet weakens and moves polewards

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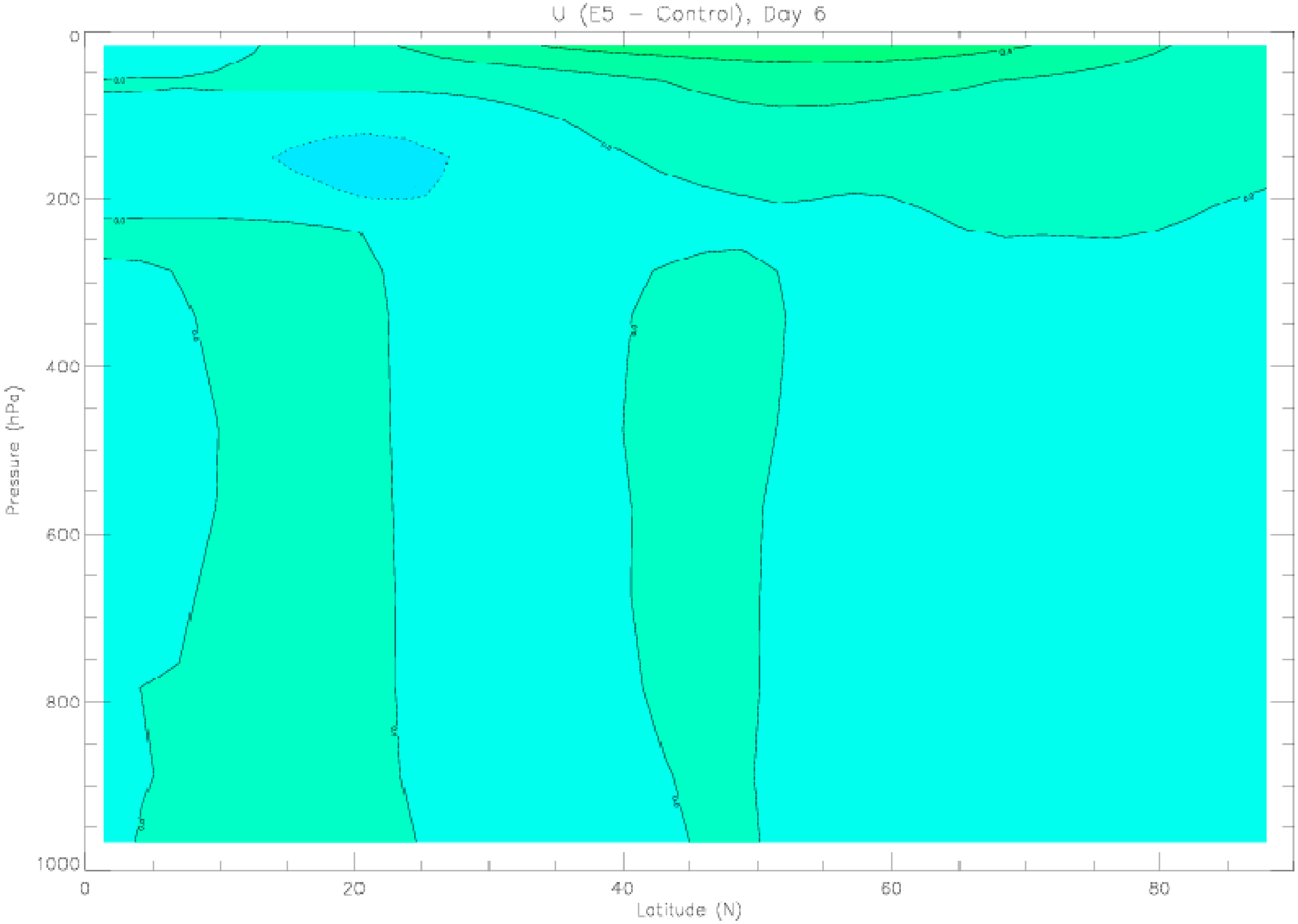
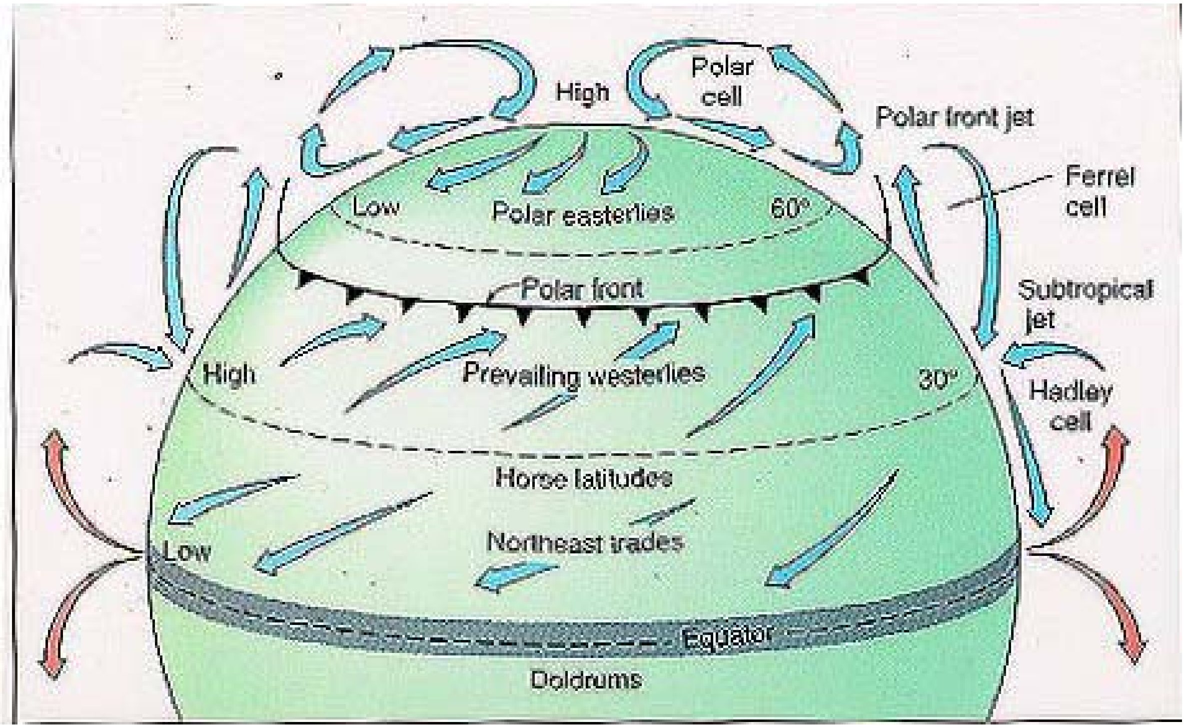
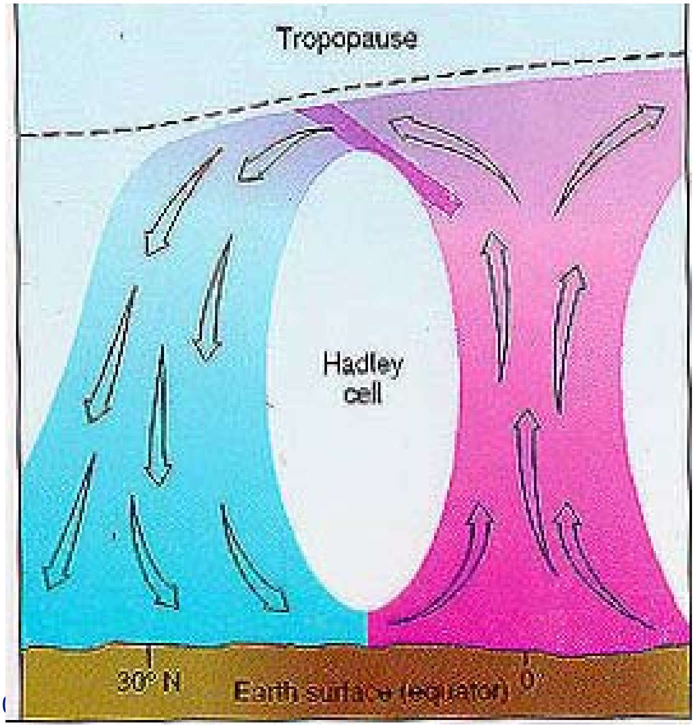
Evolution of zonal wind response 11-day running means



Mean circulation of the tropical atmosphere: the Hadley cell

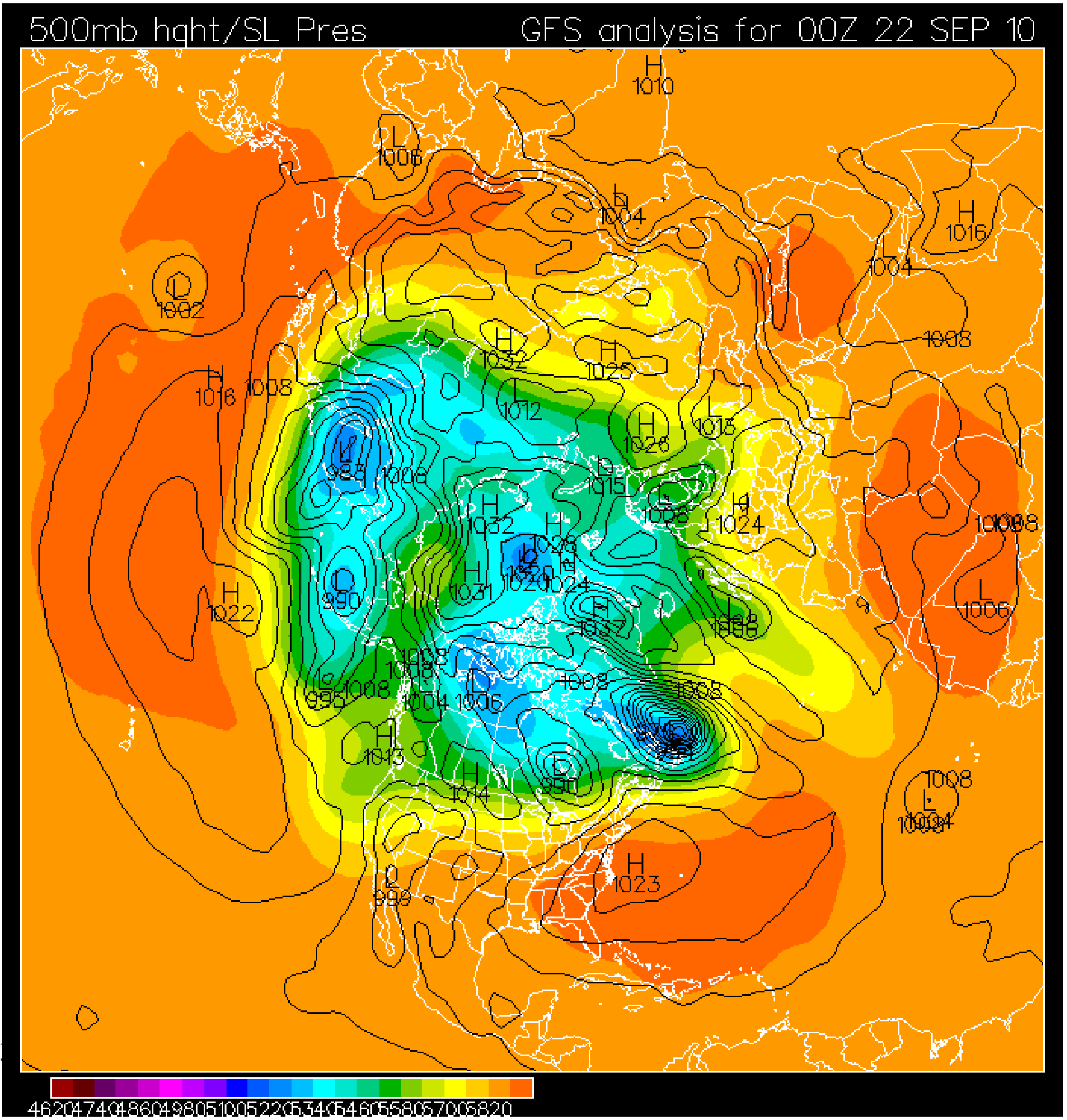




Waves in the atmosphere

Contours: surface pressure (mb)

Colours: temperature of lowest 5.5km (approx)

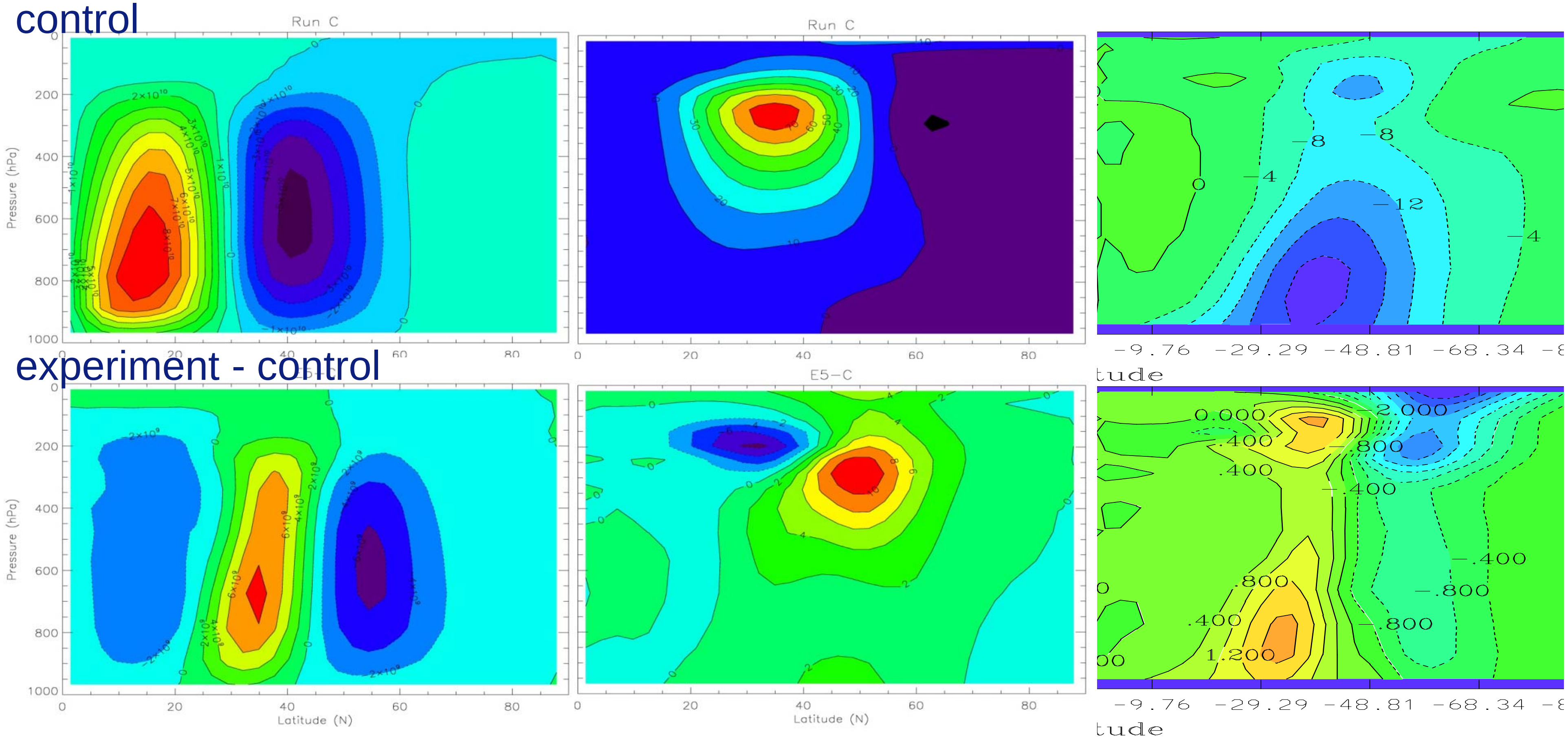


Simple model equatorial heating (E5) results:

Mean meridional circulation   Horiz. wave momentum flux   Horiz. wave heat flux

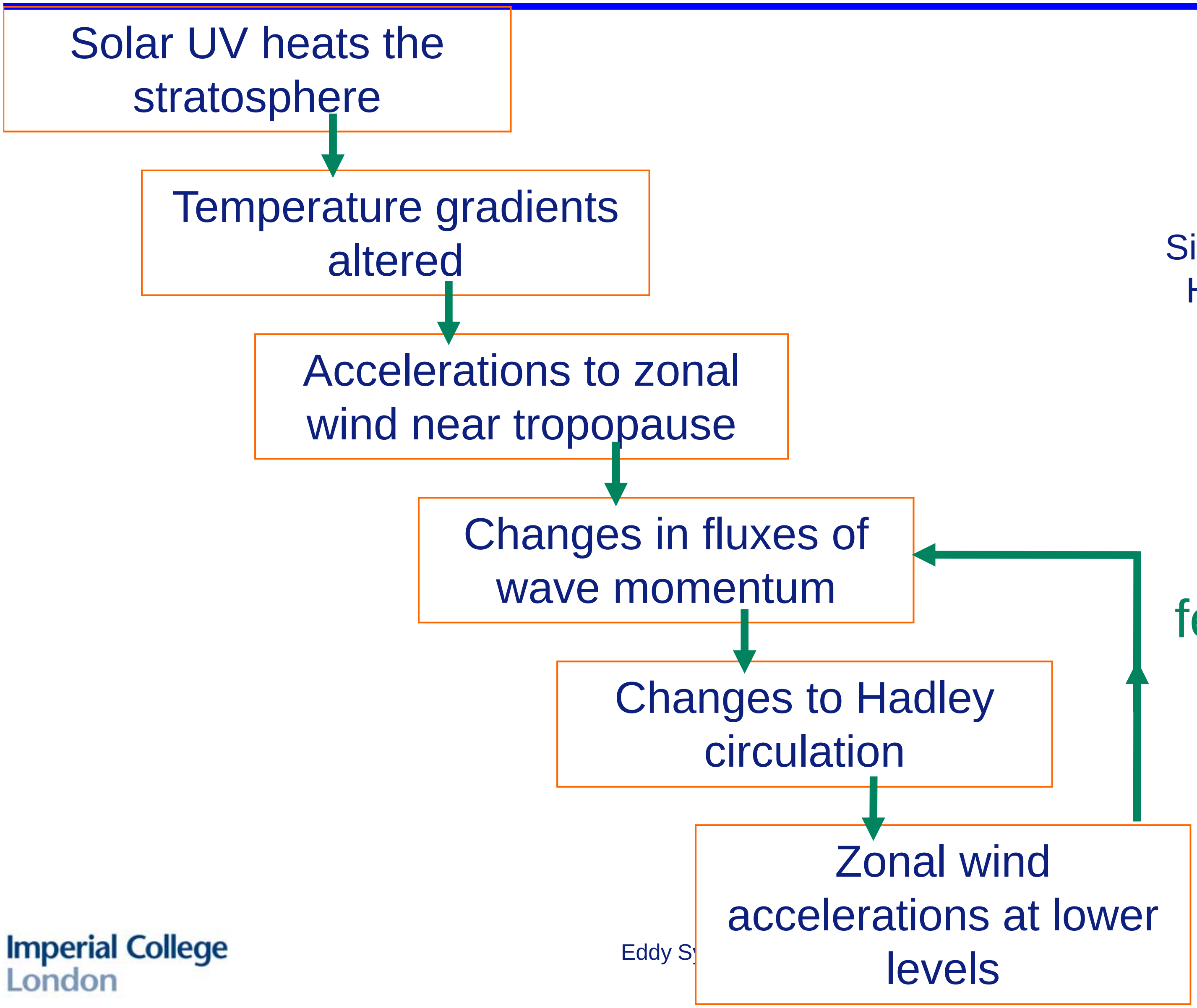
control

experiment - control



The Hadley cell weakens and expands; wave fluxes moves polewards

Outline of mechanism:



Solar UV heats the stratosphere

Temperature gradients altered

Accelerations to zonal wind near tropopause

Changes in fluxes of wave momentum

Changes to Hadley circulation

Zonal wind accelerations at lower levels

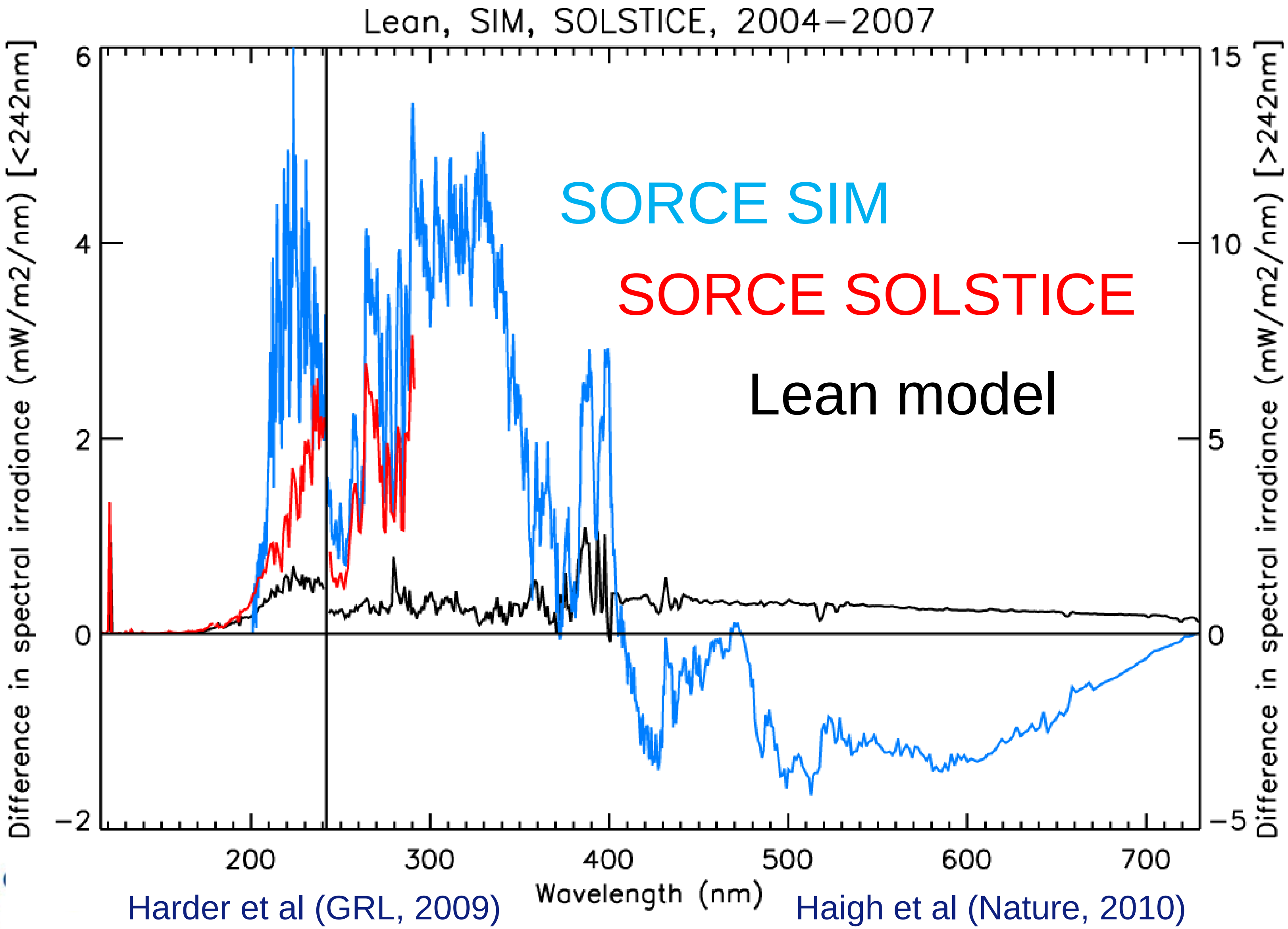
feedback loop

Simpson, Blackburn and Haigh (J. Clim., 2009)

Summary: Part I

- (Solar) heating of the lower stratosphere produces changes in tropospheric circulation.
- Tropical heating produces a weakening and poleward shifts of the jets and a weakening and expansion of the Hadley cells.
- This results from the impact on the momentum budget of a feedback between vertically propagating, synoptic-scale waves and the mean flow.
- Crucially dependent on magnitude and location of stratospheric heating.

Solar spectra: differences 2004-2007



Harder et al (GRL, 2009)   Haigh et al (Nature, 2010)

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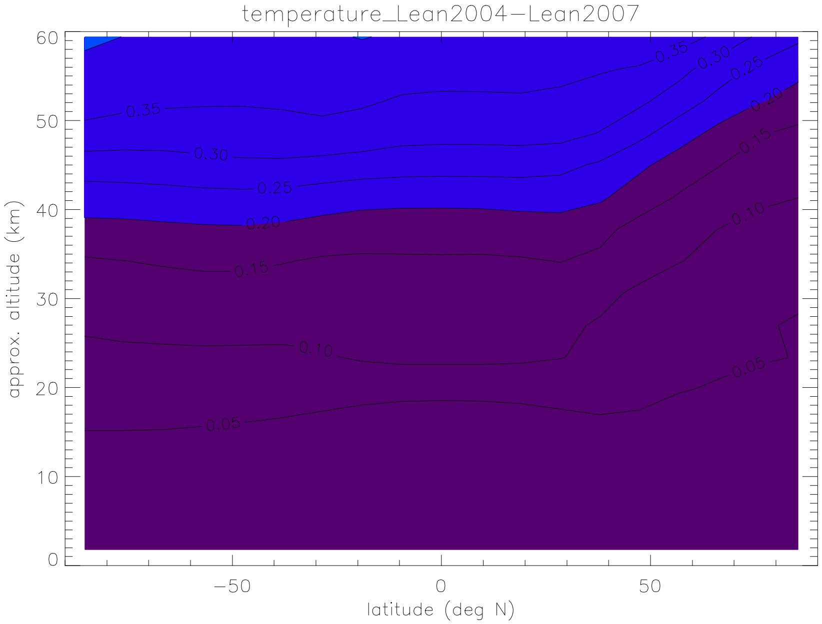
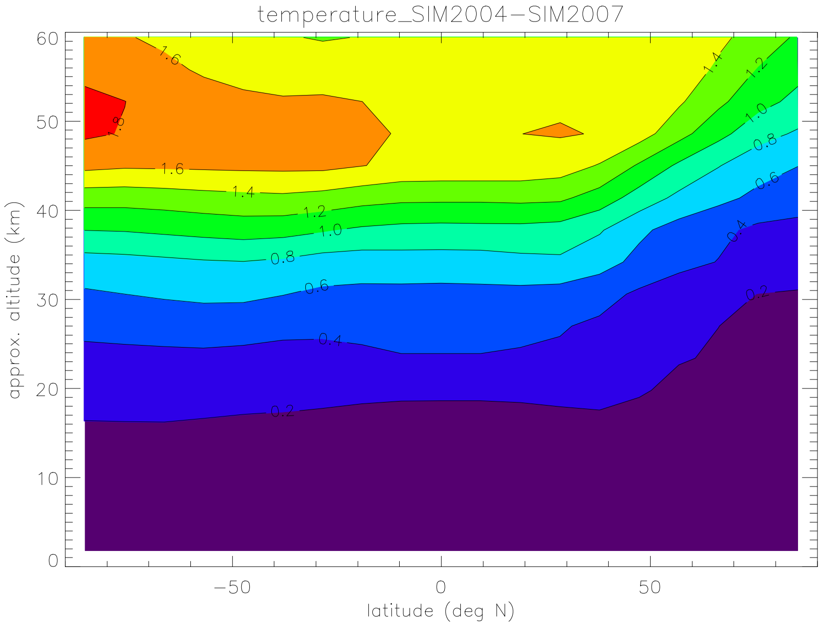
2D model temperature differences (K) 2004-2007

Lean



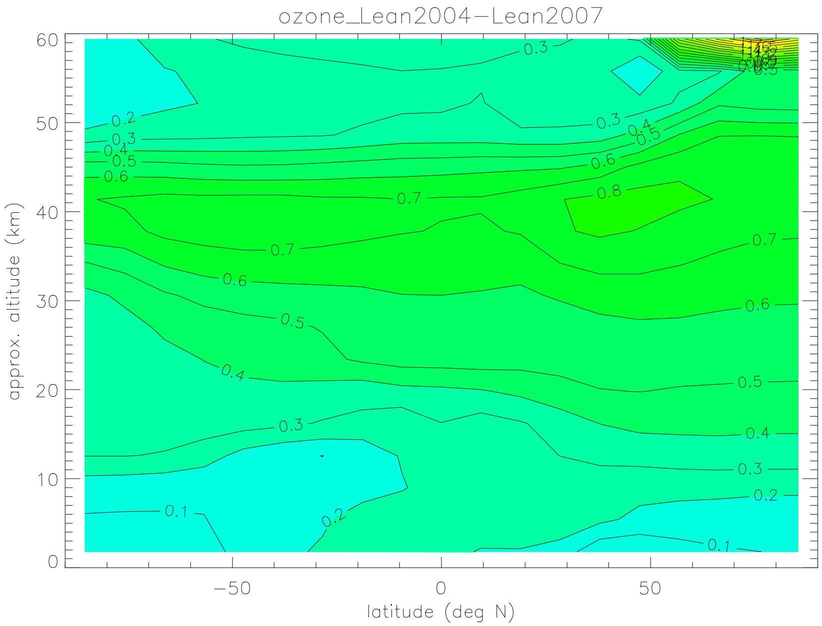
SIM



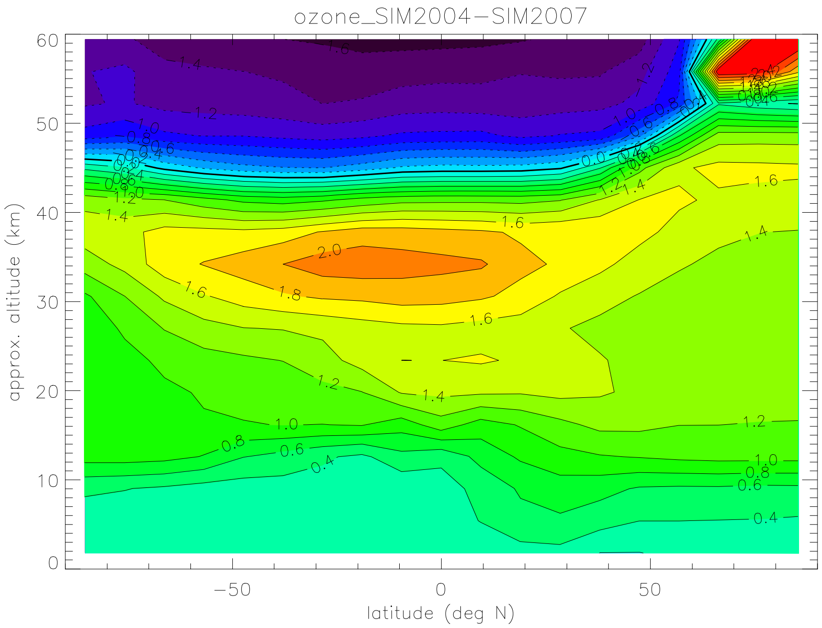
Haigh et al (Nature, 2010)

2D model O_3 differences (%) 2004-2007

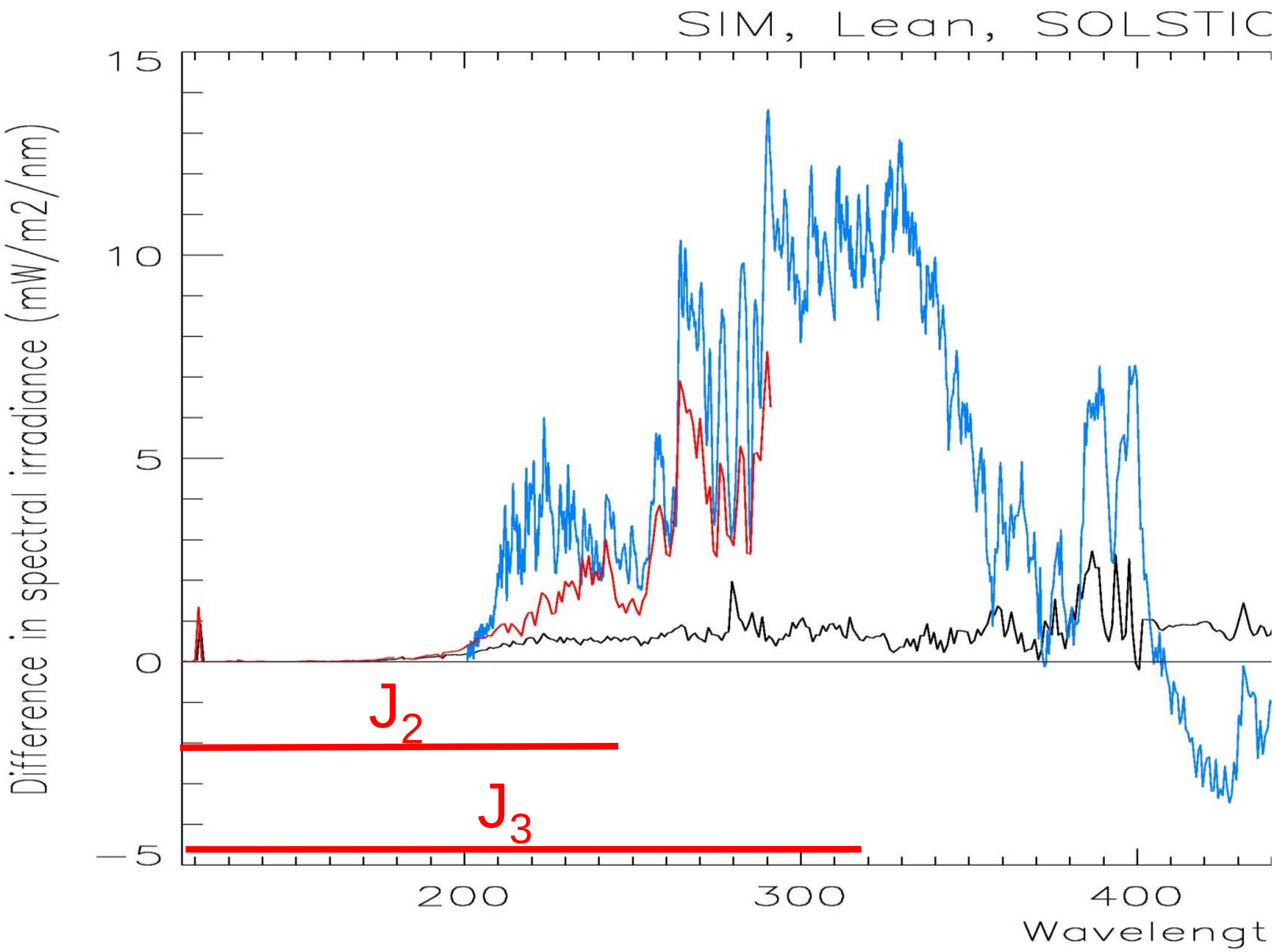
Lean



SIM



Photodissociation



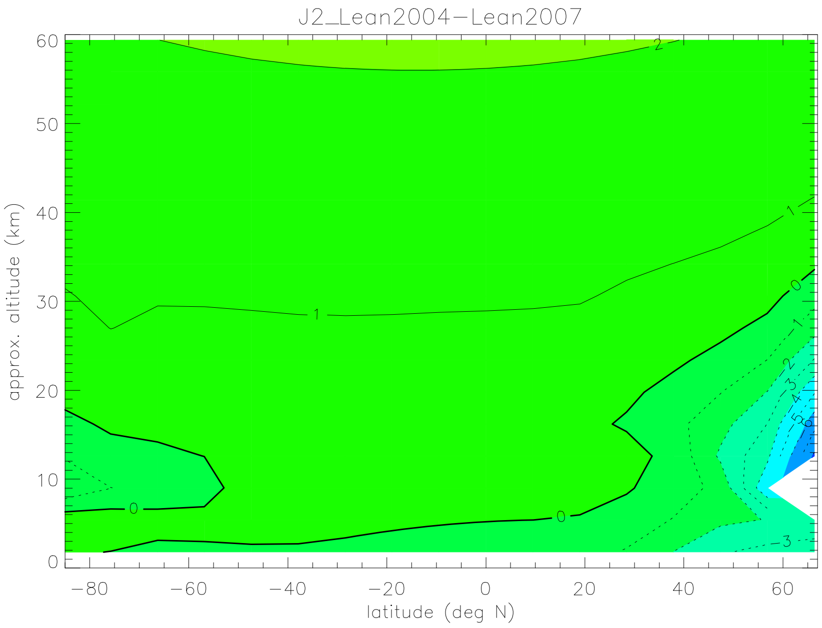
J_2 produces O and O_3

J_3 produces $O(^1D)$ and determines O/O_3 ratio

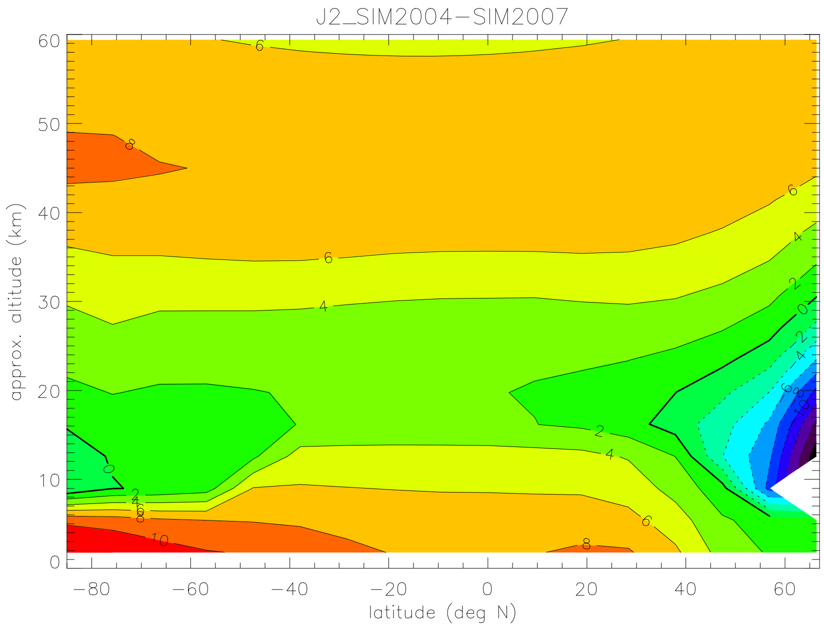
J_2 : O_2 Photodissociation rate

2004 – 2007 (%)

Lean



SIM

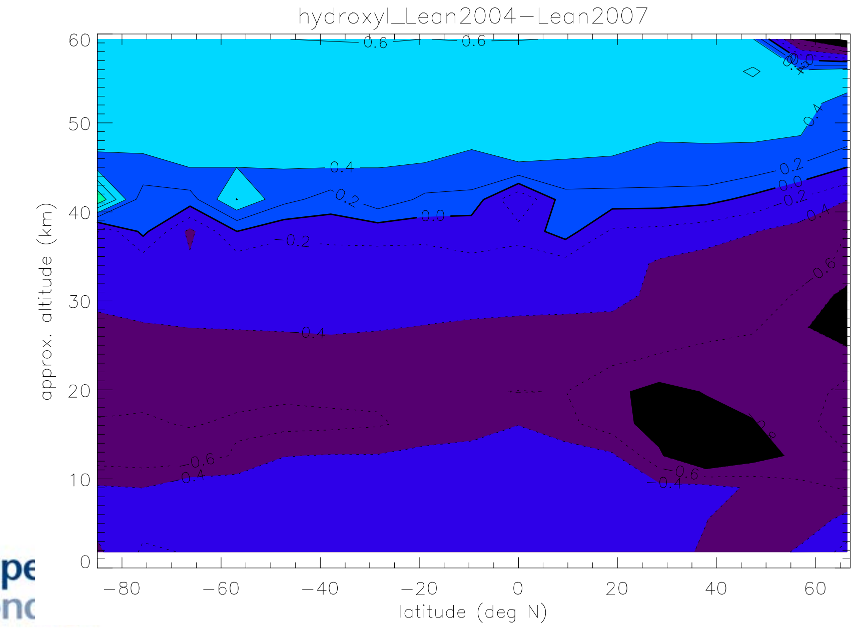


OH

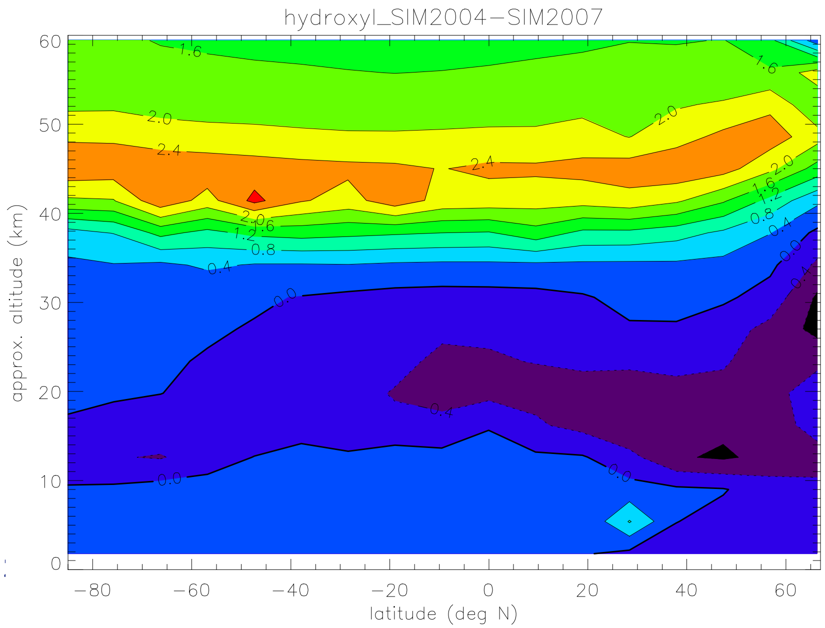
Produced by reaction of H_2O with $O(^1D)$

2004 – 2007 (%)

Lean



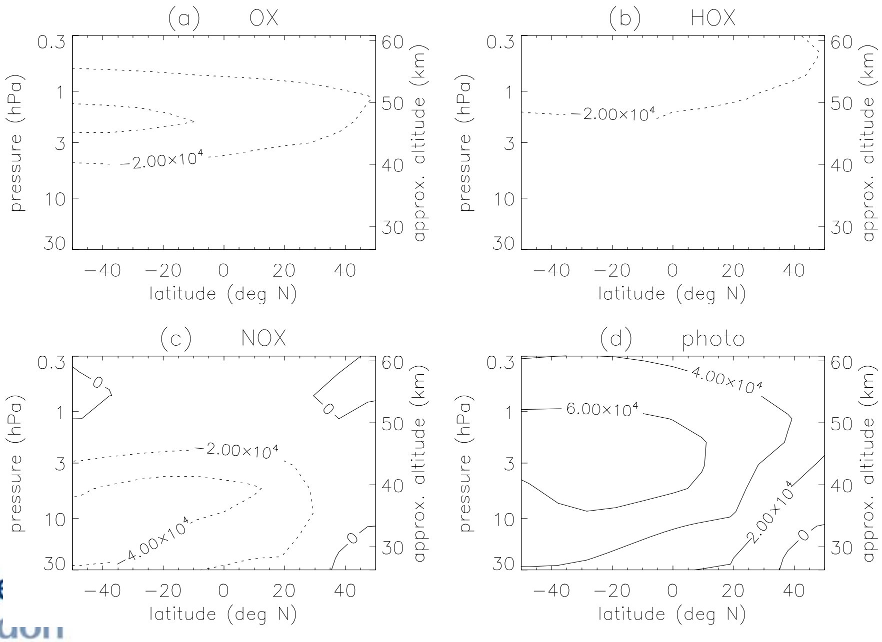
SIM



O_3 production and destruction rates

a) combination $O+O_3$
b) catalytic destruction by HO_x
c) catalytic destruction by NO_x
d) production by photodissociation of O_2

Lean



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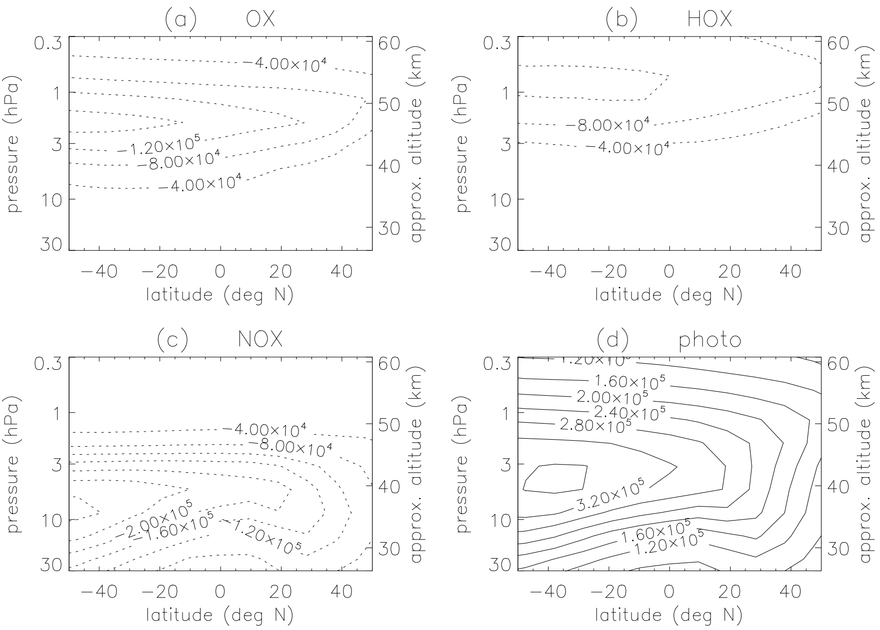
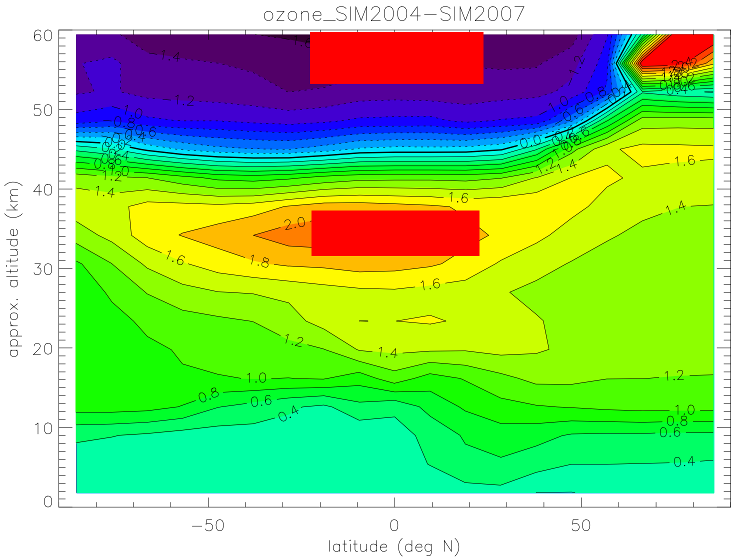


Multiple regression of AURA MLS O_3 data



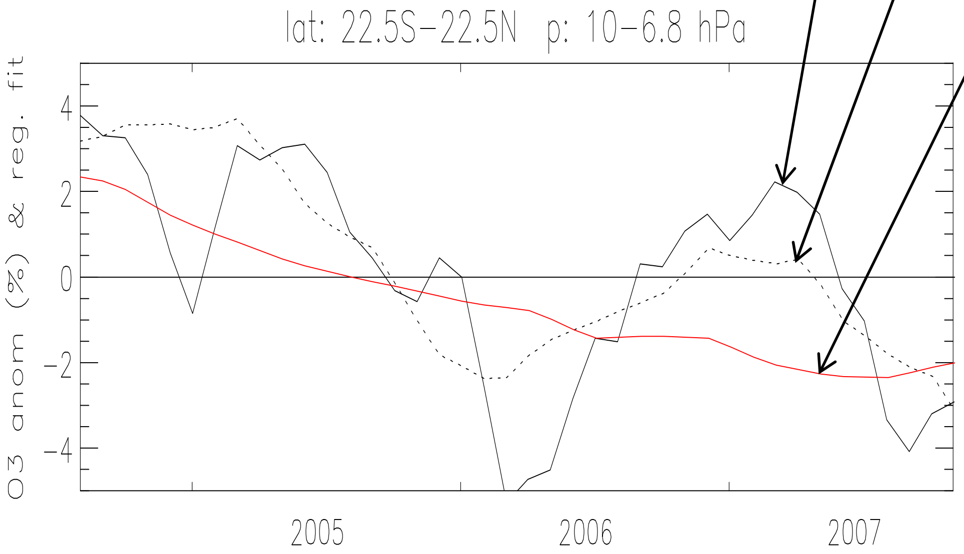
Regions chosen based on model results

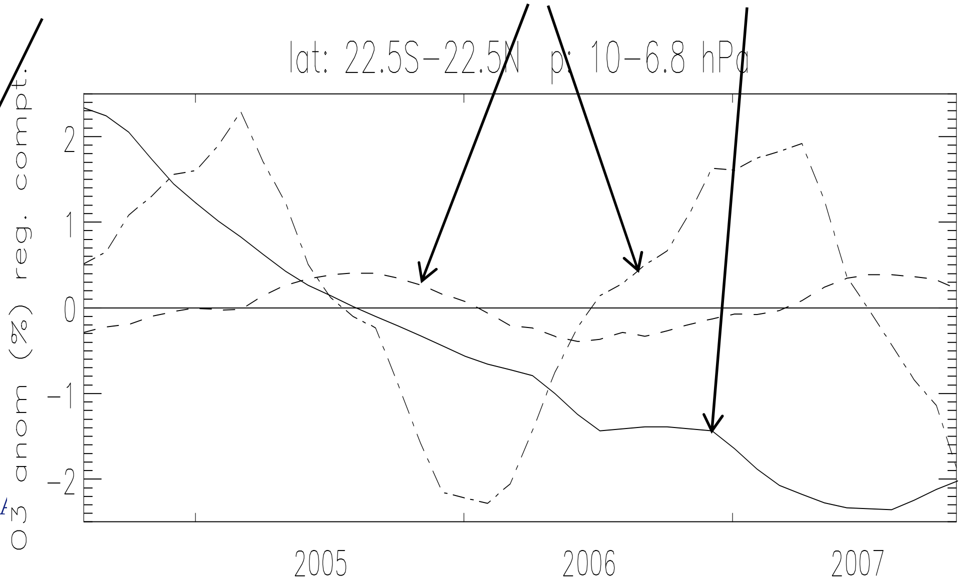
Raw data (deseasonalised monthly means) for lower layer

Regression fit

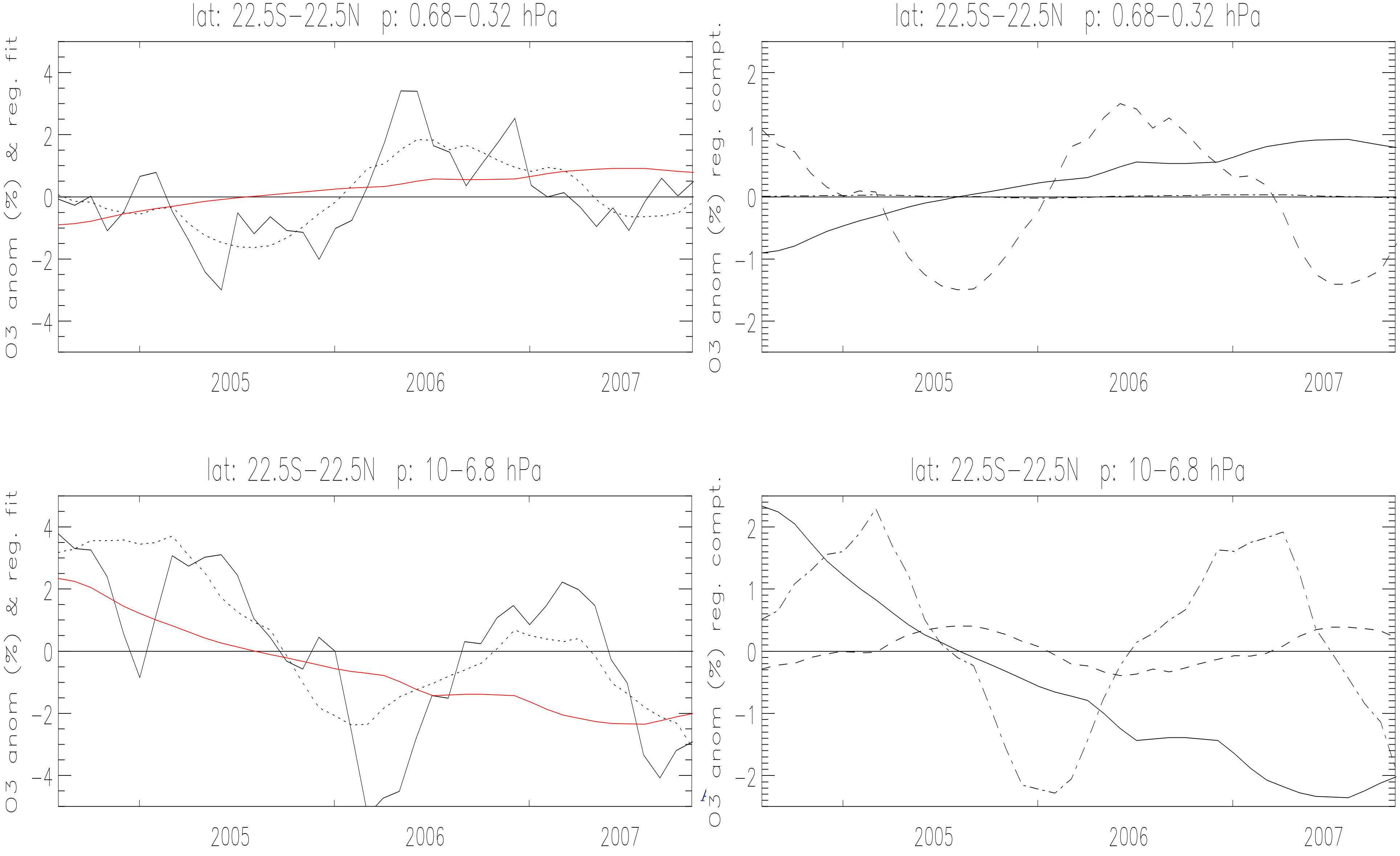
Solar?

Regression indices: constant, 2 QBO, SIM UV

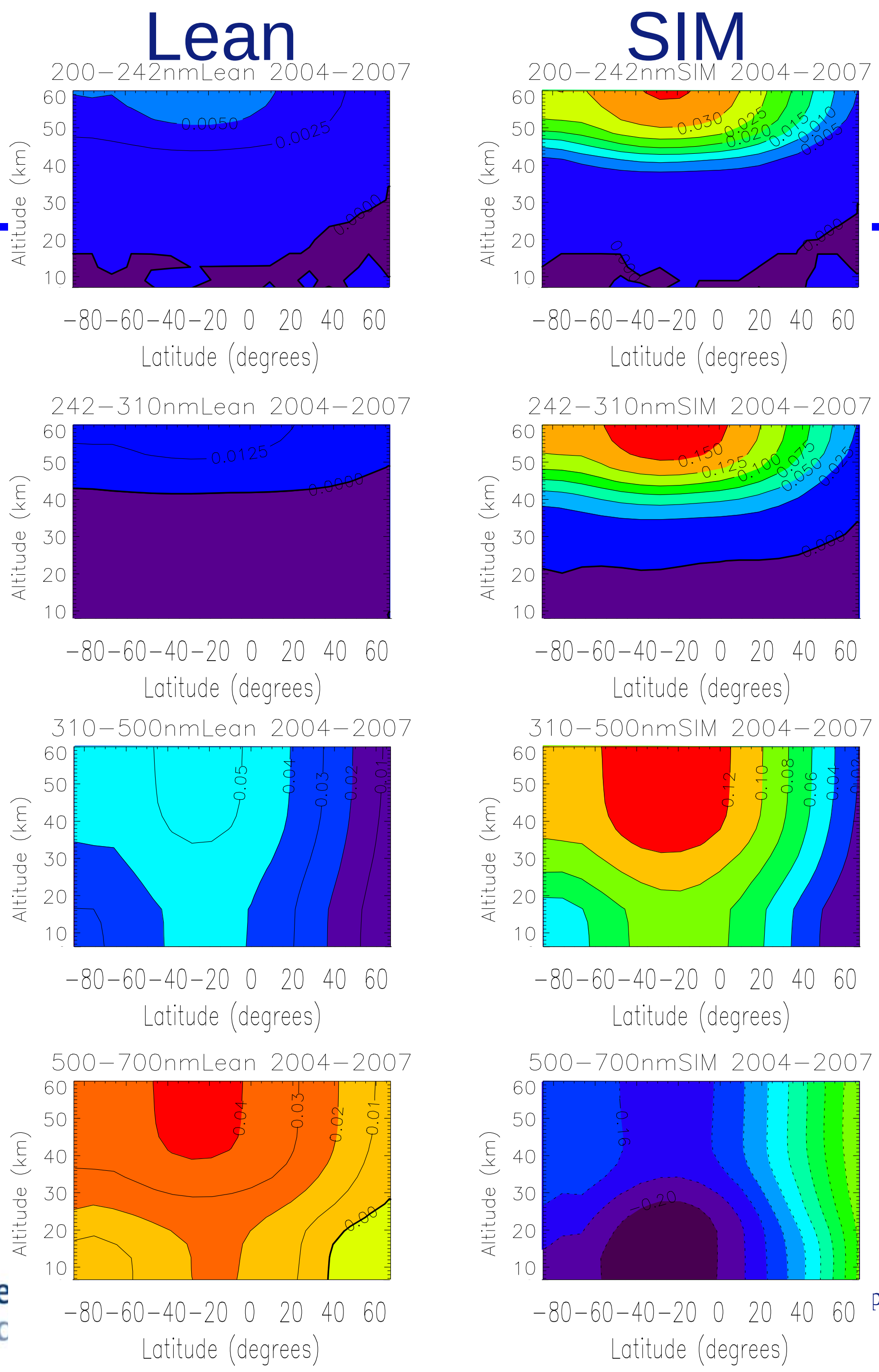




Multiple regression of AURA MLS O_3 data



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



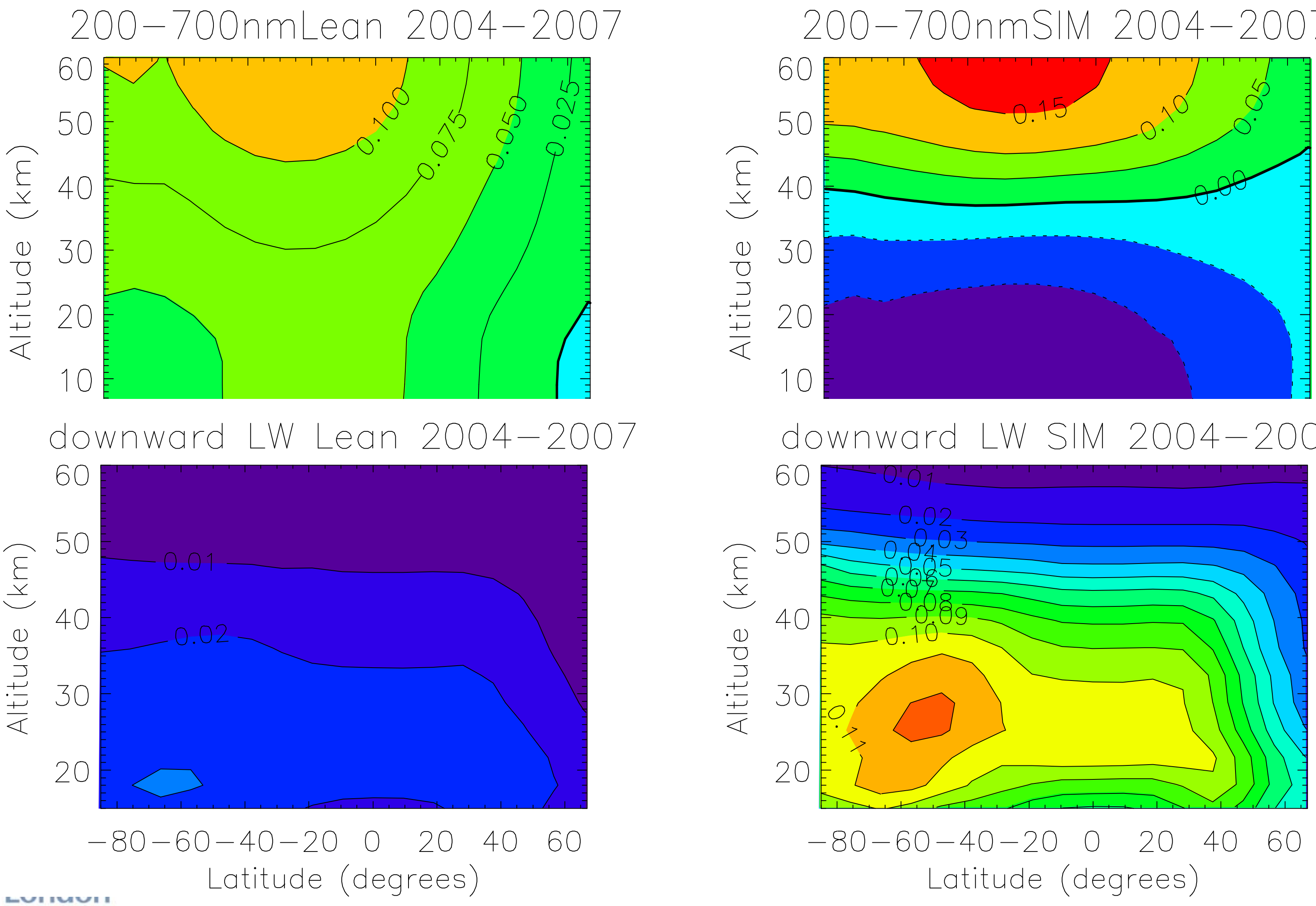
200-242 nm

242-310 nm

310-500 nm

500-700 nm

Integrated radiative fluxes 2004-2007



SW

(200-700nm)

LW

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

Lean

	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

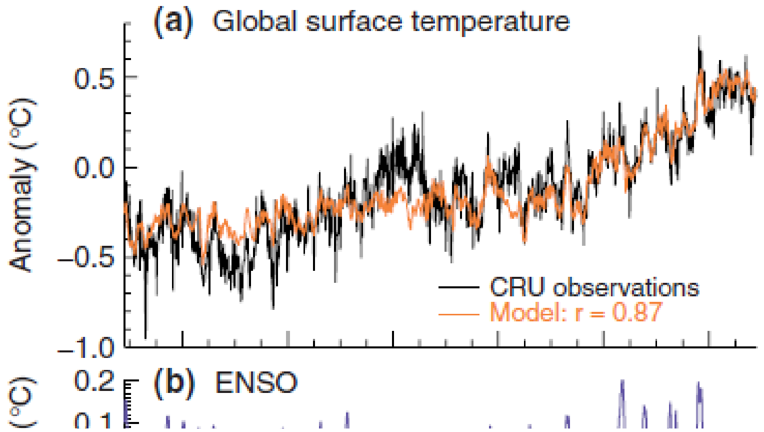
SIM

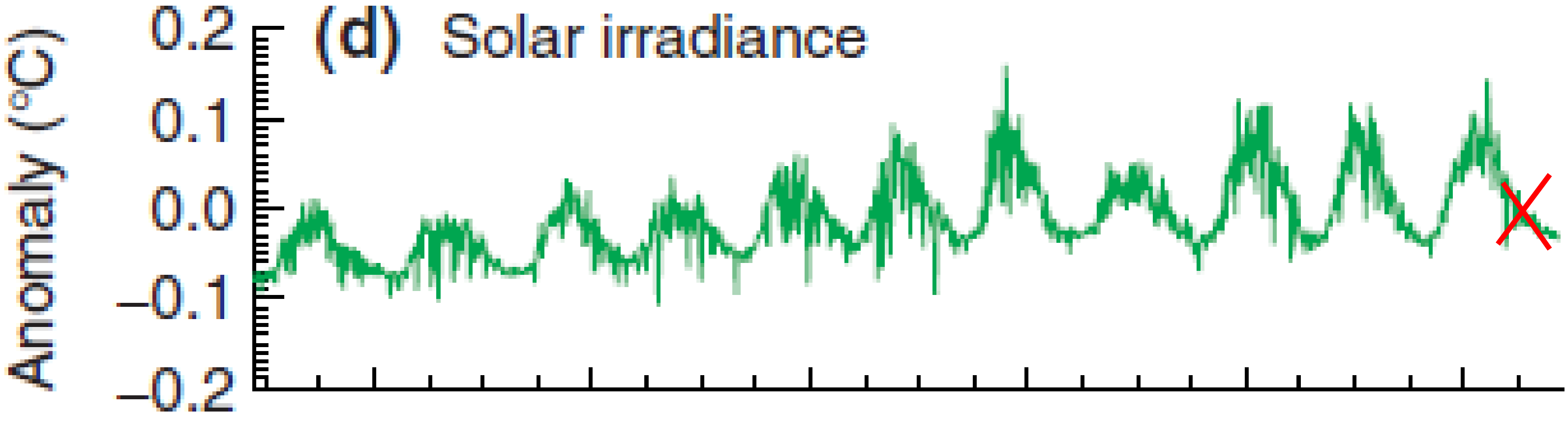
	200-310 nm	310-500 nm	500-700 nm	700-1600 nm	Total solar 200-1600 nm	Thermal (LW)	Net
TOA	160	110	-130	-50	90	0	90
105hPa	0	60	-170	-50	-160	60	-100

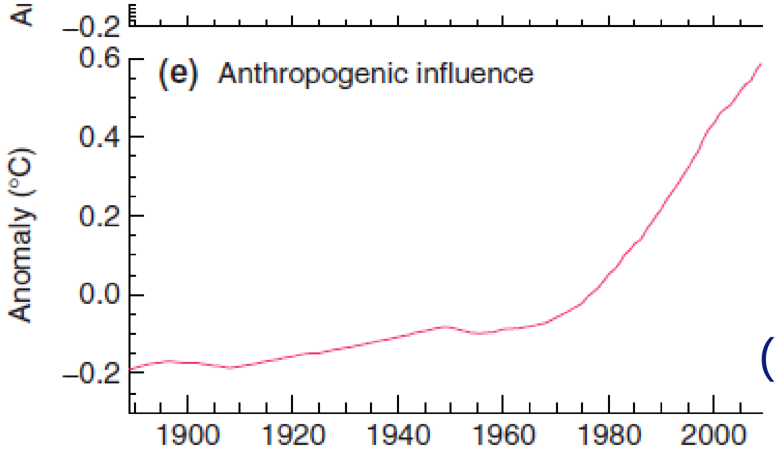
*IPCC: global average net downward radiative flux at the tropopause

Global surface temperature

Influences of various







Lean (2010)

Solar forcing of climate: current understanding

"Top-down" via UV heating the stratosphere

New solar data would make much larger

and/or

"Bottom-up" via visible radiation warming surface ?

New solar data would invert

Summary: Part 2

- Input to 2D model SIM (& SOLSTICE) spectra produce a very different response in O_3 from semi-empirical models of SSI: a *reduction* in lower mesosphere at higher solar activity and a large increase in mid- to upper stratosphere.

- This structure can be explained by enhanced production of HO_x, and by a shift of O_x from O_3 to O.

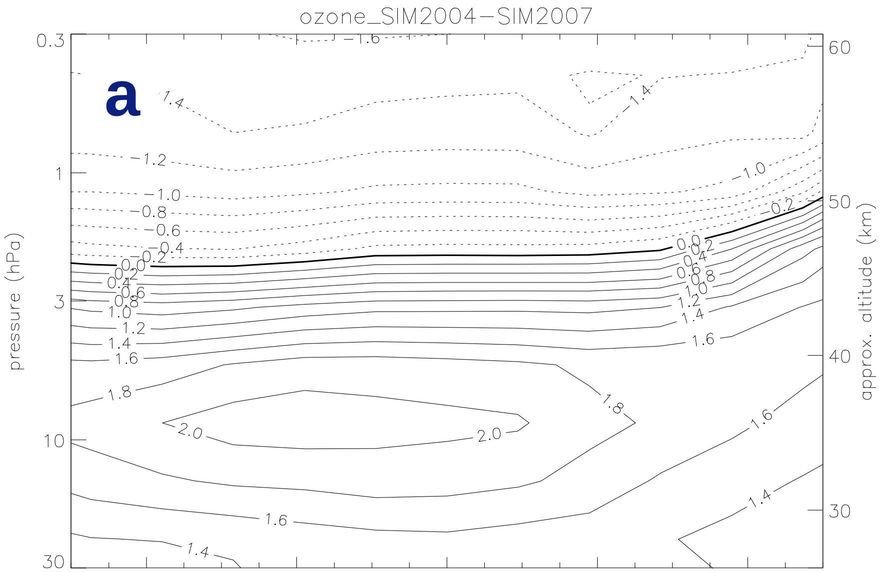
- This structure is not inconsistent with contemporaneous measurements of O_3 from AURA-MLS.

- SIM data would suggest that solar radiative forcing of climate produced a warming from 2004 to 2007, despite declining TSI.

- Is the Sun behaving oddly at present? Has this happened before? What will the Sun do over the next few years...?

SPARES

Choice of spectra λ < 240 nm



	λ < 200	**200 < λ < 240**	**λ > 240**
a Lean	SIM	SIM	
b SOLSTICE	SIM	SIM	
c SOLSTICE	SOLSTICE	SIM	

Ozone difference (%) 2004-2007