The response of tropospheric circulation to perturbations in lower stratospheric heating

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Outline

• GGM studies of response to solar UV.
• Sensitivity experiments.
• Comparison of model results with observational data.
• Understanding the response using a “dynamical core” model.
UGCM
zonal
wind

solarmax-solarmin

(2D model ΔO₃)

Haigh
(Science1996; QJRMS1999)
Further UGCM solarmax-solarmin zonal wind results

Haigh (1999)
UM zonal wind

solarmax-solarmin

Hou (2000) GCM response to “artificial” delta O$_3$
\[ \frac{dT}{dt} = 0.02 \text{ K day}^{-1} \text{ in daylight hours (power} = c_p \rho \frac{dT}{dt}) \]

UM zonal wind response to heating of tropical lower stratosphere

Westerly component of wind \( U_w \) (m s\(^{-1}\))

Without heating

With heating
UGCM O$_3$ downward shift experiment

$\Delta u$ (m s$^{-1}$)

$\Delta T$ (K)

Thuburn & Craig (2000)
UGCM mean meridional circulation

change in MMC at 682hPa

Haigh (1999)
UM mean meridional circulation

Larkin (2000)
UM mean meridional circulation (tropical heating experiment)
UGCM mmc

\( \Delta \text{mmc due O}_3 \text{ shift} \)
Multiple regression of observational data

\[ y(x, t) = \sum \beta_i(x) f_i(t) + \text{noise} \]

- \( y(x, t) \) are data
- \( f_i(t) \) is time-dependent climate factor \( i \)

10 factors are taken into account:
  - trend
  - solar irradiance
  - volcanic aerosol
  - ENSO
  - NAO
  - QBO
  - amplitude & phase of annual cycle
  - amplitude & phase of semi-annual cycle
Regression results: NCEP Tbar

mean
trend

ENSO
NAO

solar
volcanic

solar (+95% sig)
volcanic (+95% sig)

Haigh (Phil.Trans. 2003)
Regression results: NCEP ubar

Mean

Solar

Trend

Volcanic

ENSO

Components (35°N, 200hPa)

NAO

Components (30°S, 200hPa)
NCEP u-bar regression results
Dynamical core model experiments

As Held and Suarez (1994):
  Full dynamics T42 L20. No orography.
  Newtonian cooling (equinoctial radiative equilibrium temperatures). Rayleigh friction.

All experiments involved heating the lower stratosphere:
  • 1K at all latitudes
  • 1K at equator, cos²(lat) variation
  • 5K at all latitudes
  • 5K at equator, cos²(lat) variation

All runs 1200 days.
Temperatures
rad. eq.
control run

Whistler 02/05/03 18
Uniform heating expt
\( \nabla F \)

Uniform heating expt
$\cos^2(\text{lat})$ heating expt.
\( \nabla' \cdot \mathbf{T}' \)

\( u'v' \)

\( \nabla \cdot \mathbf{EPF} \)

\( \cos^2(\text{lat}) \)

heating expt.
uniform heating  \( \cos^2(\text{lat}) \) heating

ubar

5K heating

1K heating
uniform heating  \hspace{1cm} \text{cos}^2(\text{lat}) \text{ heating}

5K heating

shaded areas not statistically significant at 95\% level

1K heating
ubar

control

uniform heating

$\cos^2(\text{lat})$ heating
mean meridional circulation

control

uniform heating

$\cos^2(\text{lat})$ heating
TEM residual circulation

control

uniform heating

\(\cos^2(\text{lat})\) heating
Conclusions - I

• Model simulations show a characteristic pattern of response to enhanced solar UV: the sub-tropical jets weaken & move poleward, the Hadley cells weaken.

• The same patterns, with similar magnitudes, are found in multiple regression studies of observational data.
Conclusions - II

- Results from a simplified model suggest that:

(a) Heating of the lower stratosphere tends to weaken the sub-tropical jets as a result of reduced eddy activity.

(b) The distribution of the heating in the stratosphere determines any shift in position of the jets.