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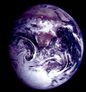
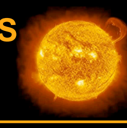


THE ROLE OF EDDIES IN DRIVING THE TROPOSPHERIC RESPONSE TO STRATOSPHERIC HEATING PERTURBATIONS



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INTRODUCTION

- Previous experiments using a simplified general circulation model (sGCM) have demonstrated that stratospheric heating perturbations can result in altered tropospheric circulation (Haigh et al. 2005).
- Equatorial heating results in a poleward shift of the jet whereas polar or uniform heating results in an equatorward shift of the jet.
- We now present spin-up ensemble experiments to investigate the chain of causality whereby changes in tropospheric circulation and temperature are produced in response to stratospheric heating perturbations. This is presented in the context of an equatorial heating case, as it is relevant for understanding the observed tropospheric response to changing solar activity (Haigh et al. 2005).

THE MODEL AND EXPERIMENTS

- Reading IGCM2.2
- Dry, spectral dynamical core
- Newtonian relaxation of the temperature field towards a zonally symmetric reference state (Held and Suarez 1994)
- Equinox mode.
- No orography
- 200 × 50 day runs.
- Each run starting from a different day of a control run simulation.
- Heating perturbation applied to the stratosphere by changing T_{ref} as in Fig. 1.

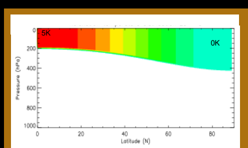


Fig 1. Change in T_{ref} applied to the model during the spin-up.

SPIN-UP EVOLUTION

The spin-up evolution for 4 fields is shown in Fig. 2. This shows:

- A weakening and poleward shift of the mid-latitude jets.
- A weakening and expansion of the Hadley cell and a poleward shift of the Ferrell cell.
- A dipole change in poleward eddy momentum flux ( ) with a reduction around the tropopause on the equatorward side of the jet and an increase on the poleward side stretching down into the troposphere.
- A change in Eliassen-Palm flux. The horizontal component ( ) can be seen to be consistent with the change in

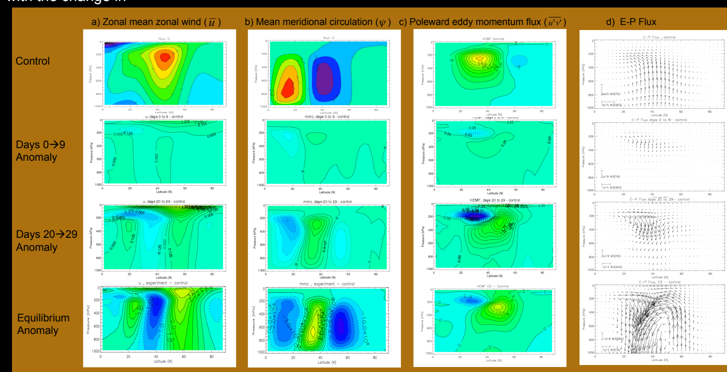


Fig 2: Evolution of zonal mean zonal wind (a), stream function of the mean meridional circulation (b), horizontal eddy momentum flux (c) and Eliassen-Palm flux (d) in response to the heating perturbation shown in Fig. 1. Top row = Control run (10 000 day average), 2nd (3rd) rows = difference between the average of days 0 to 9 (20-29) of the spin-up and the equivalent days of the control run, bottom row = Equilibrium – Control (5000 day average).

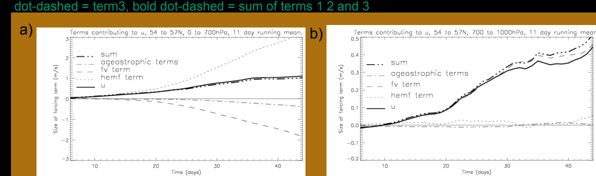
WHAT DRIVES THE TROPOSPHERIC ZONAL WIND CHANGES?

Solving momentum balance for gives 3 different contributions to the anomaly at time *t* as follows (See Simpson et al. for details):

TERM (1) TERM (2) AGEOSTROPHIC TERMS (3)

- 0→700hPa vertically averaged: Dominant balance between term 1 and 2 with 2 being larger to give a net acceleration (See Fig.3 a).
- 700hPa→Surface: Term 1 dominates and gives the increased zonal wind. (See Fig. 3b)

Fig 3. a) Terms contributing to the change in averaged between 54° and 57° lat and from 0 to 700hPa. b) as (a) but for 700hPa to the surface. Solid = change in u, dashed = term 1, dotted = term 2, dot-dashed = term3, bold dot-dashed = sum of terms 1 2 and 3



➡ **Changes in poleward eddy momentum flux at upper levels accelerate the zonal wind and drive changes in meridional circulation which impact the zonal wind at lower levels. Similar results are found for the region of deceleration on the equatorward side of the jet.**

WHAT CAUSES THE CHANGE IN POLEWARD EDDY MOMENTUM FLUX?

A refractive index can be defined for eddies in the atmosphere (Matsuno 1970). It is given by:

The meridional gradient of potential vorticity ( ) , the zonal wind ( ) and the eddy phase speed (*c*) are the dominant terms. The E-P flux gives an indication of the direction of eddy propagation. Eddies are refracted up the gradient of .

Altered eddy propagation changes eddy momentum flux through the dependence of the horizontal component of E-P flux on .

Figs. 4 and 5 b and c show the importance of the change in and on respectively.

- Days 0 to 9 - dominant term is
- Days 40 to 49 – the change in is responsible for the increased equatorward gradient of and thus equatorward E-P flux and anomalous poleward in the troposphere.

➡ **Initially the altered PV gradient around the tropopause affects eddy propagation. As the zonal wind starts to change in the troposphere it further affects the eddies → feedback.**

Fig. 4 Days 0 to 9

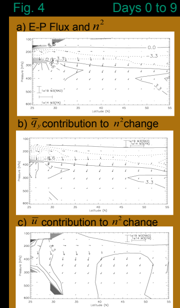


Fig. 5 Days 40 to 49

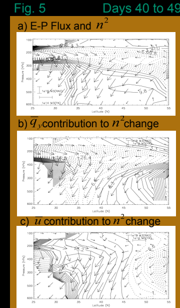


Fig. 4:a) change in and E-P flux, b) contribution to change in from , c) contribution to change in from for days 0 to 9. Fig. 5: as Fig. 4 but for days 40 to 49.

WHAT CAUSES THE CHANGE IN PV GRADIENT?

- PV gradient can be thought of as consisting of 3 terms:

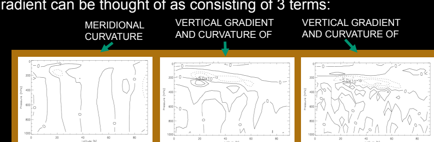


Fig. 6: Contributions to the change in PV gradient for days 0 to 9 of the spin-up

- Both the vertical shear and curvature of and change the PV gradient with the contribution being slightly larger.
- Analysis of the uniform and polar heating cases (not shown) demonstrates that it is the change in vertical temperature gradient and how it is localised in latitude that determines the initial eddy changes and consequent direction of jet shift.

CONCLUSION

- A summary of the proposed mechanism whereby the stratospheric heating perturbation alters tropospheric circulation is given in Fig. 7.
- Altered vertical temperature gradients and vertical wind shear around the tropopause affects eddy propagation initially.
- There is a feedback with the zonal wind changes in the troposphere affecting eddy propagation there.
- The change in vertical temperature gradient and its localisation in latitude is important in determining the direction of jet shift.

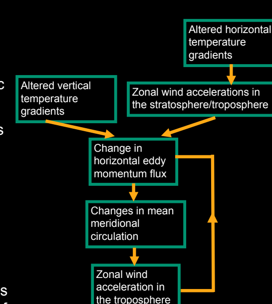


Fig. 7: Summary of mechanism

REFERENCES

Haigh, J. D., M., Blackburn and R. Day (2005) The response of tropospheric circulation to perturbations in lower stratospheric temperature. *Journal of Climate,* **18(17)**, 3672-3685

Held, I. M. and M. J. Suarez (1994) A proposal for the intercomparison of the dynamical cores of atmospheric general circulation models. *Bulletin of the American Meteorological Society,* **75(10)**, 1825-1830

Matsuno, T (1970) Vertical propagation of stationary planetary waves in winter northern hemisphere. *Journal of the Atmospheric Sciences,* **27(6)**, 871-883

Simpson I. R., M. Blackburn and J. D. Haigh, The role of eddies in driving the tropospheric response to stratospheric heating perturbations. *Journal of the Atmospheric Sciences,* Submitted.