How does the stratosphere influence the troposphere in mechanistic GCMs?

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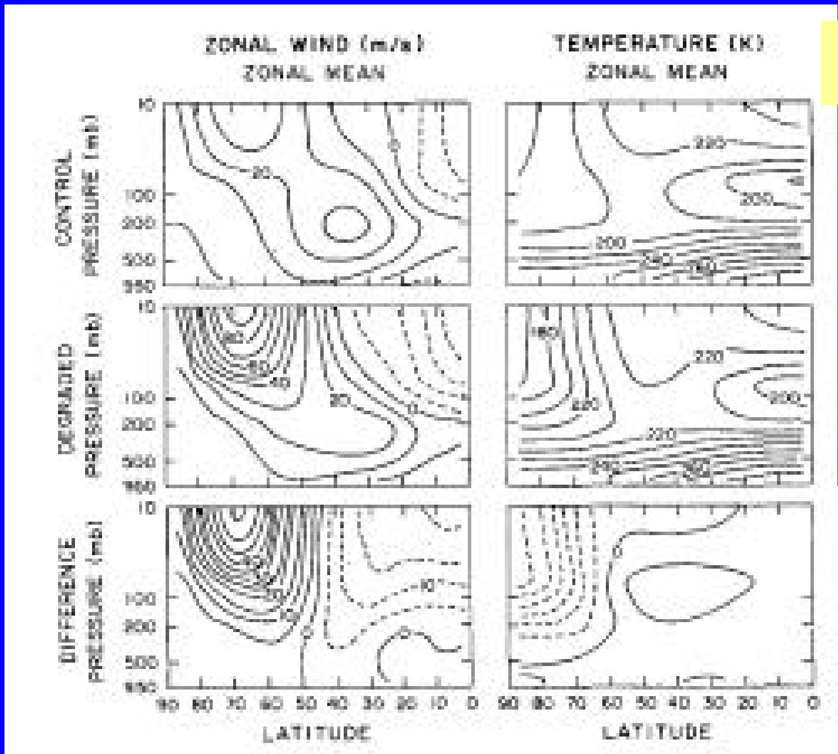
outline

- **introduction**
  - **Boville’s experiment**
  - **a possible mechanism**
  - **idealized models**
- the 3 experiments
- comparing results
- tests of mechanisms
- summary and remaining questions

Bovilles experiment



[u] and [T]

- R15 L9 CCM
- Runs differ by spectral coverage of diffusion in stratosphere

Boville, 1984 *JAS*

[u*v*]

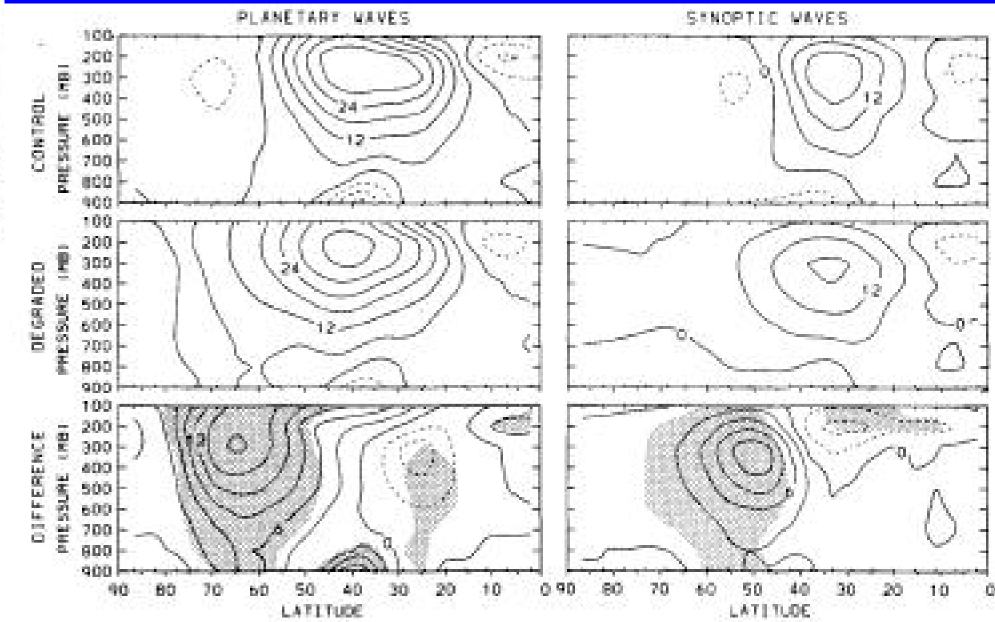


FIG. 8. As in Fig. 6, except that the zonally averaged total momentum flux by the planetary waves (left) and synoptic waves (right) is shown. Contour interval is 6 $m^2 s^{-2}$ for CS and DS and 3 $m^2 s^{-2}$ for the difference.

possible mechanism

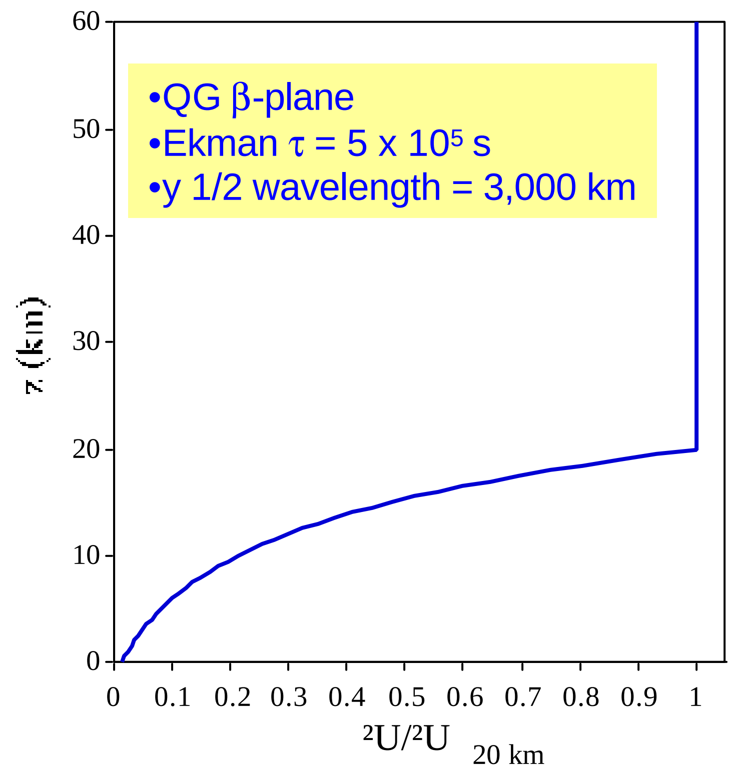
given a change in the wave driving of the polar vortex:

- downward control* provides weak vortex-scale forcing in the troposphere
- tropospheric eddies reinforce response at tropospheric annular-mode scale

the “downward control with eddy feedback” (DCWEF) hypothesis

*Haynes *et al*., 1991

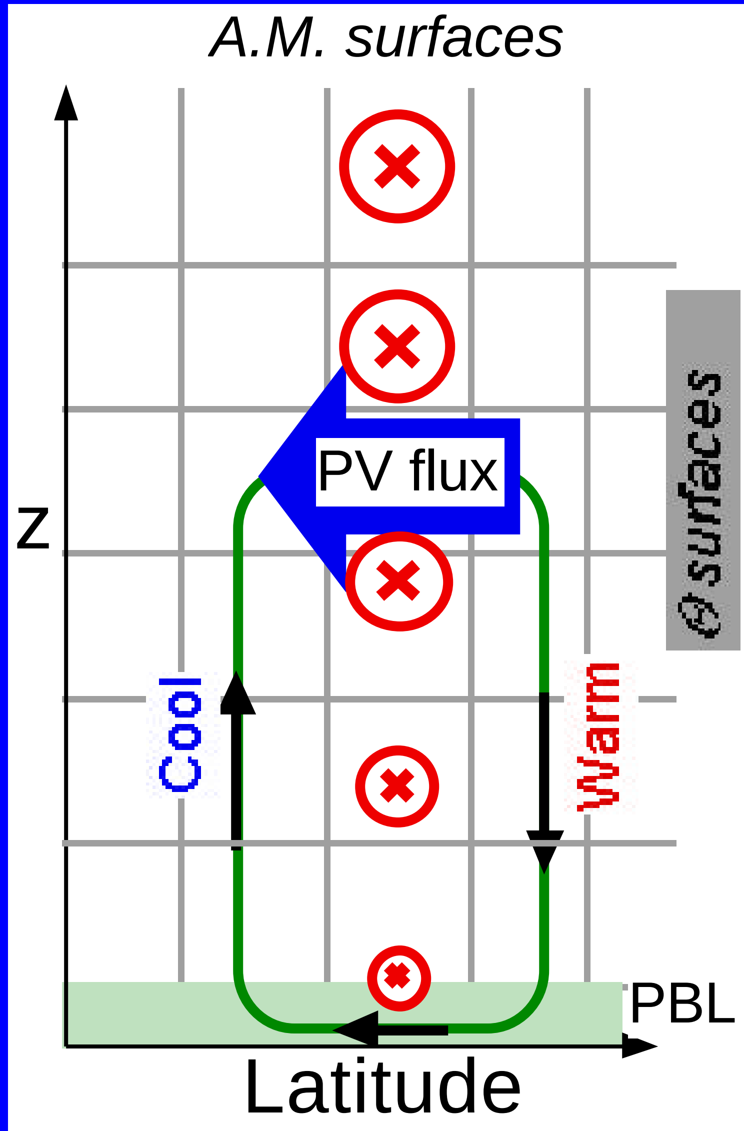
“downward control”



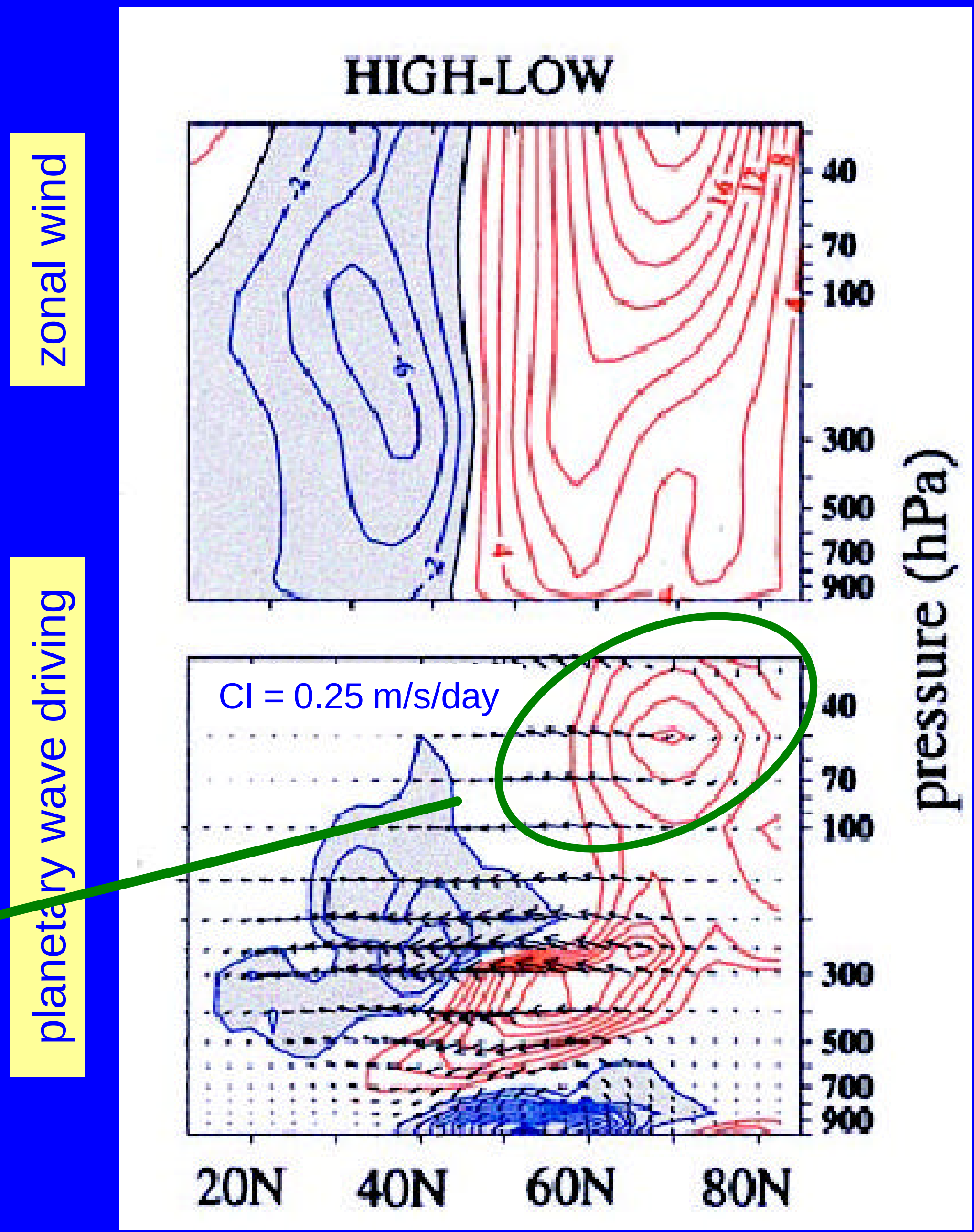
$$fv = -\frac{1}{\rho_0}\nabla\cdot\mathbf{F}$$

$$u_{z=0} = \tau_{Ekman}\int_0^\infty \frac{\nabla\cdot\mathbf{F}}{\rho_{00}}\frac{dz}{H}$$

$$Q(z) = \tau_{Newtonian}\frac{dQ_0}{dz}\frac{1}{\rho_0}\int_z^\infty \frac{\partial}{\partial y}[\nabla\cdot\mathbf{F}]dz'$$



Observed AO in [u] and planetary wave driving

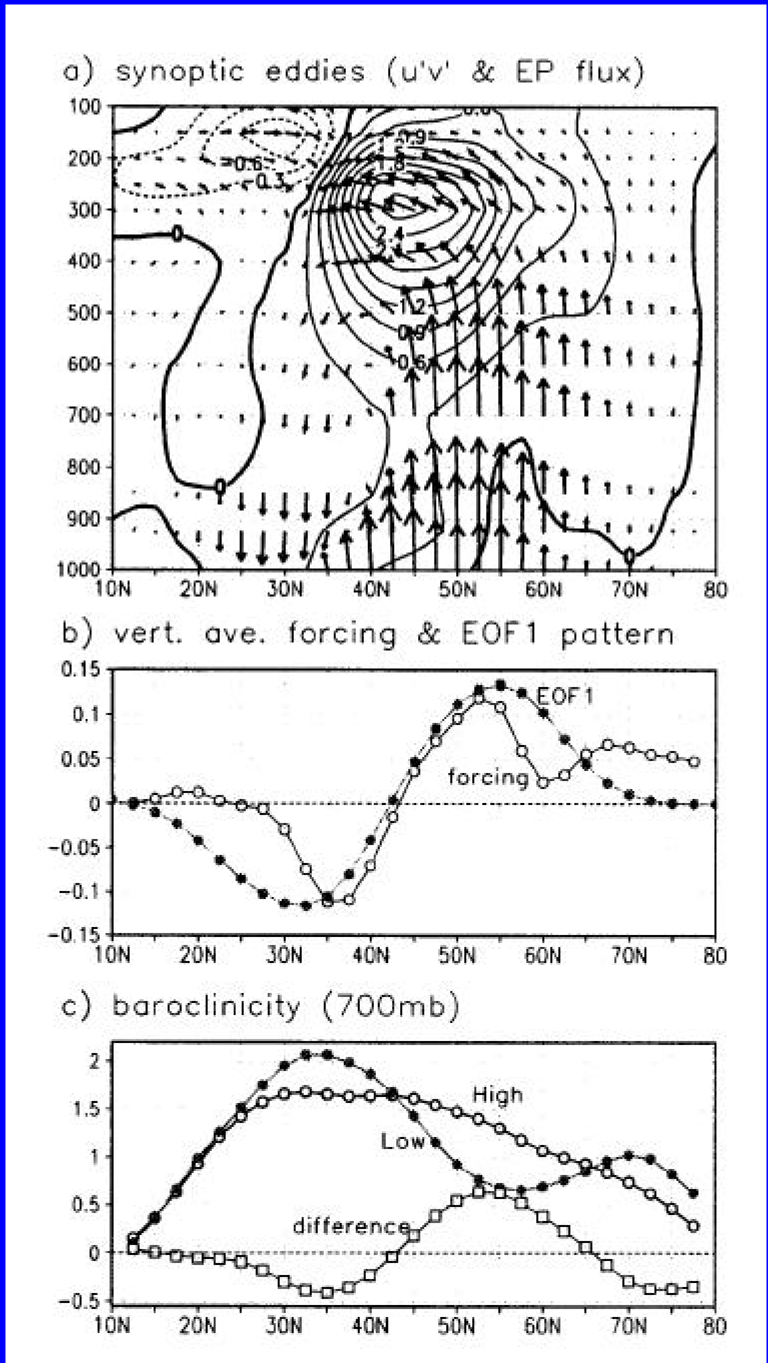


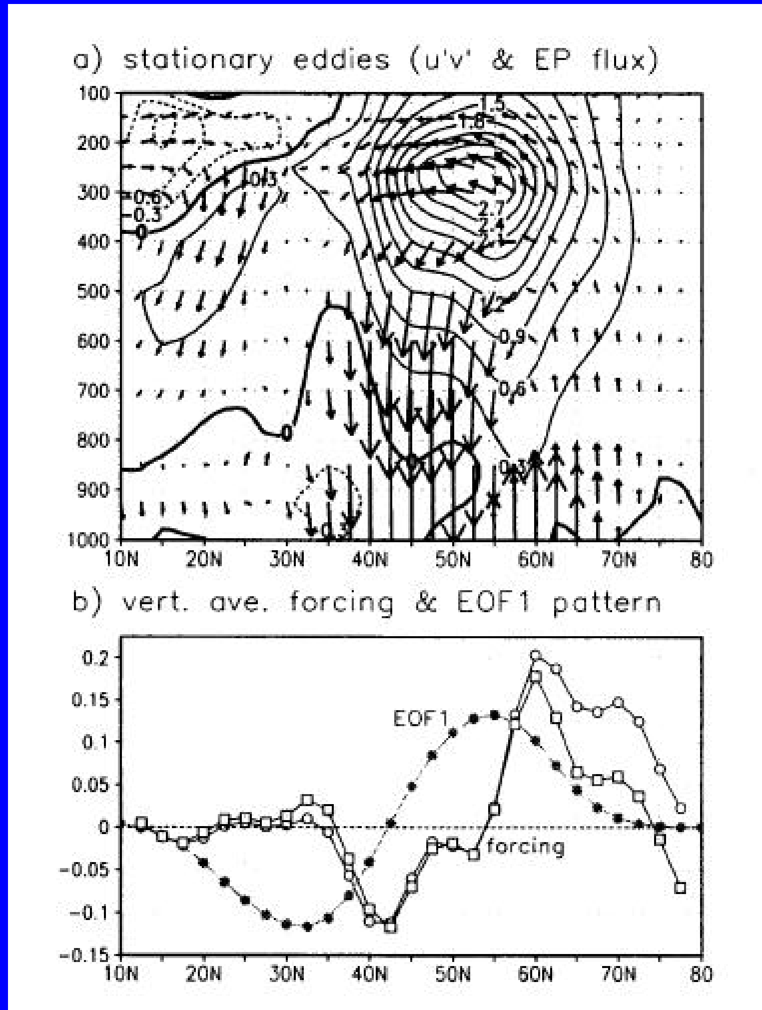
By itself, would produce surface [u] anomaly ~ 1 m s^{-1}

Hartmann *et al*., 2000, *PNAS*

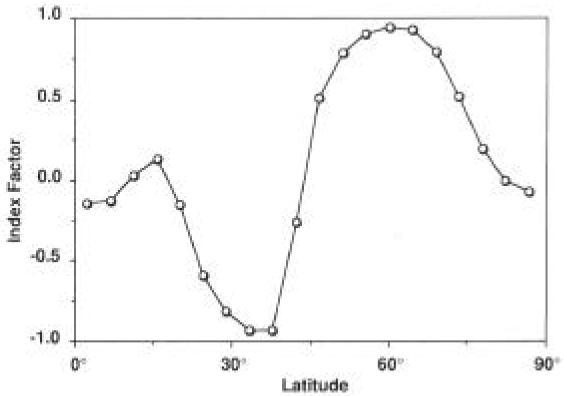
synoptic-eddy feedback reinforces AO in obs

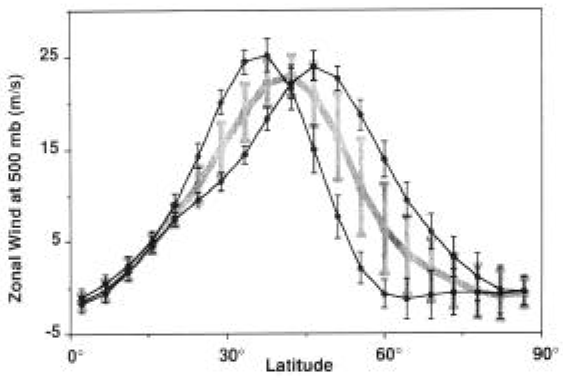
NH data, DJFM : 8-30 day lag of annular mode (PC1 of [u])





Lorenz & Hartmann, 2003, JAS



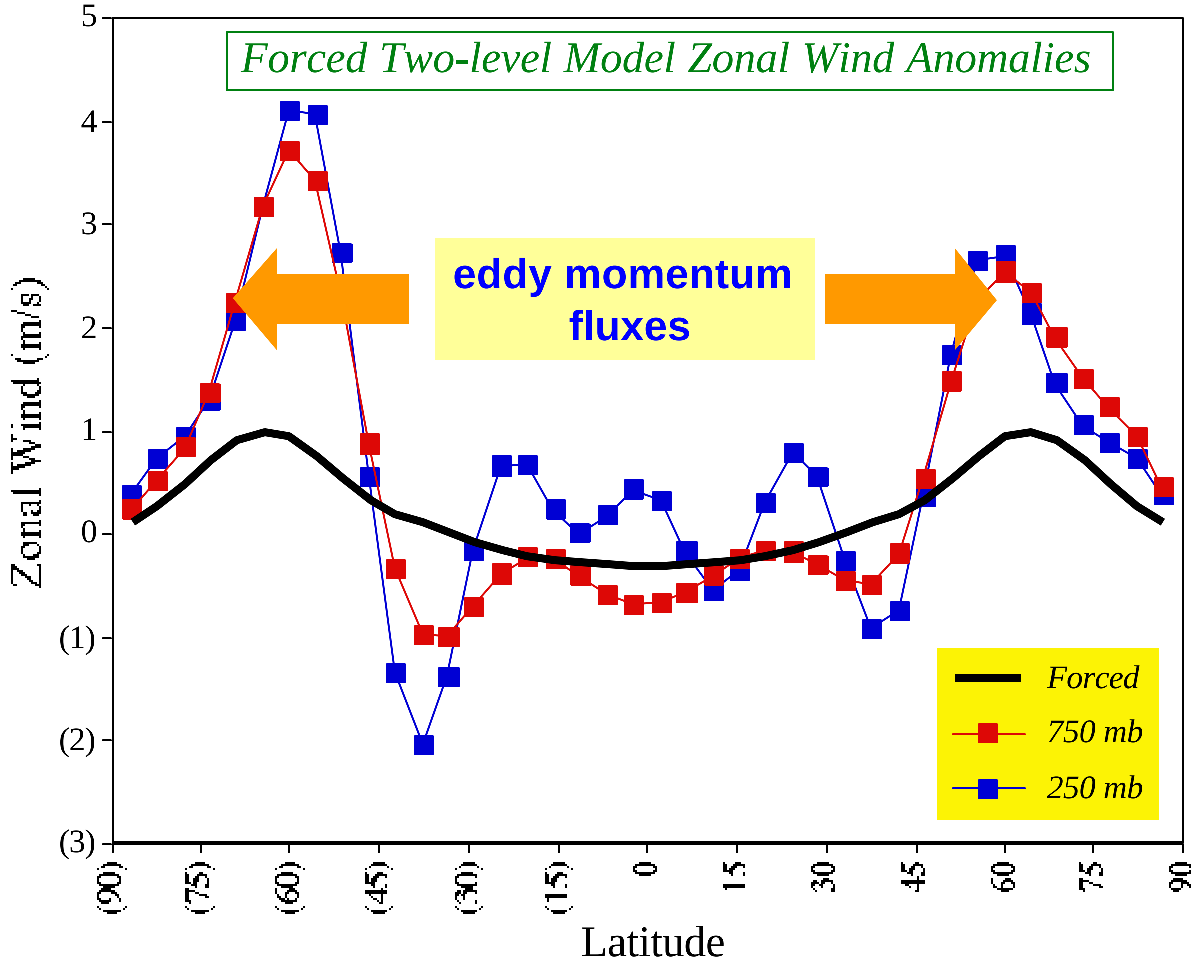


stimulating the AO from "above" in a simple model

Robinson, 1991, *Tellus*

response of two-level model to "polar-vortex-like" forcing.

- forced - Control
- 1500 day runs
- 2-level R15 truncation
- zonally homogeneous



nice simple story, but is it right?

- DCWEF implies:
  - stratosphere communicates with troposphere primarily through MMC (m=0)
  - tropospheric response should scale with net change in stratospheric wave driving
  - tropospheric response strongest when it projects on tropospheric internal modes of variability
    - which are sustained by eddy feedback

idealized GCM studies

- Controlled forcing
  - compared with global warming/O_3 depletion experiments
- Simplified "radiation"

$$\frac{dT}{dt} = \frac{1}{t}\left(T_{eq} - T\right)$$

- Controlled dynamical context
  - forced planetary waves present/absent
- Sufficient dynamical complexity

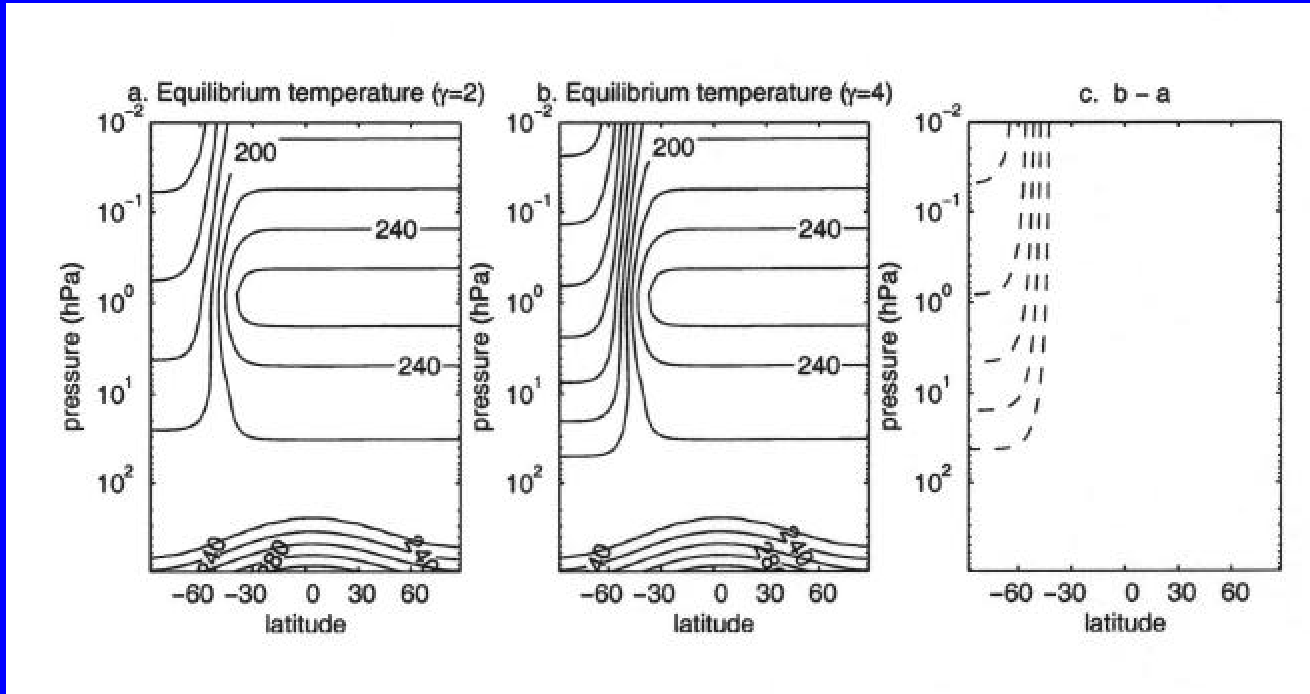
- introduction
- **the 3 experiments**
  - **Polvani & Kushner**
  - **Taguchi**
  - **Song & Robinson**
- comparing results
- tests of mechanisms
- summary and remaining questions

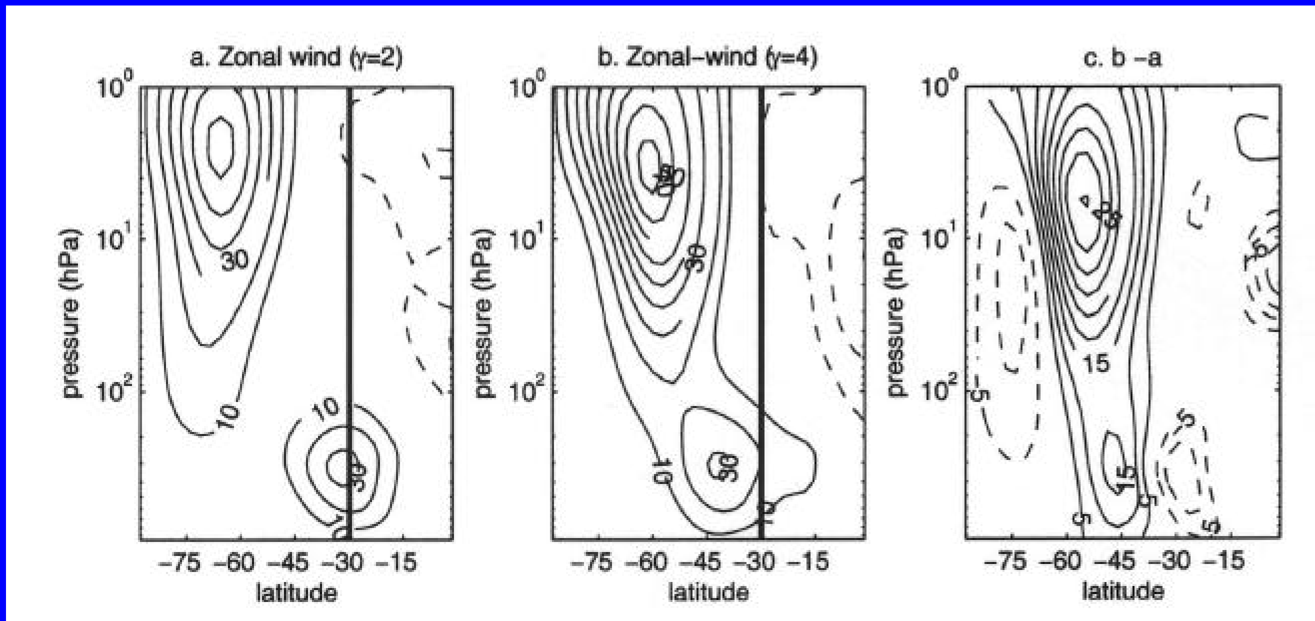
3 sets of experiments

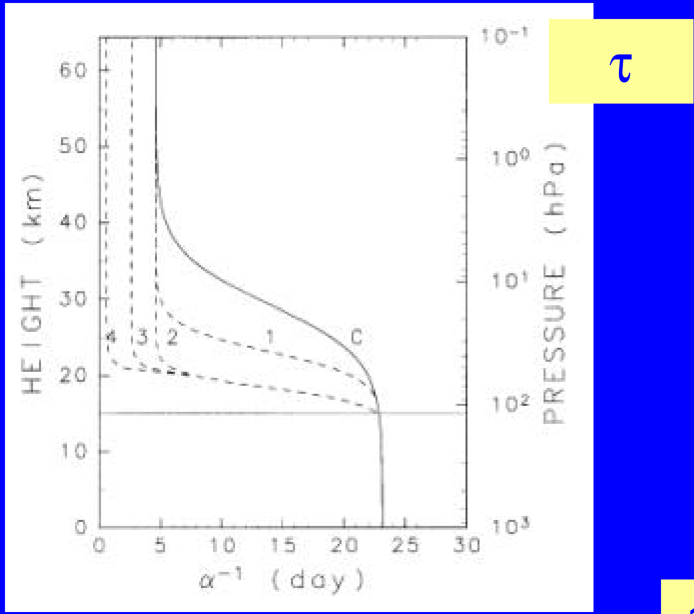
- Polvani & Kushner (2002, *GRL*; 2003, *J Clim*)
  - change T_{eq}
- Taguchi (2003, *JAS*)
  - change t
  - with and without topography
- Song & Robinson (2003, *JAS* - in preparation)
  - direct forcing of stratospheric zonal momentum

Polvani & Kushner

T 42 L40

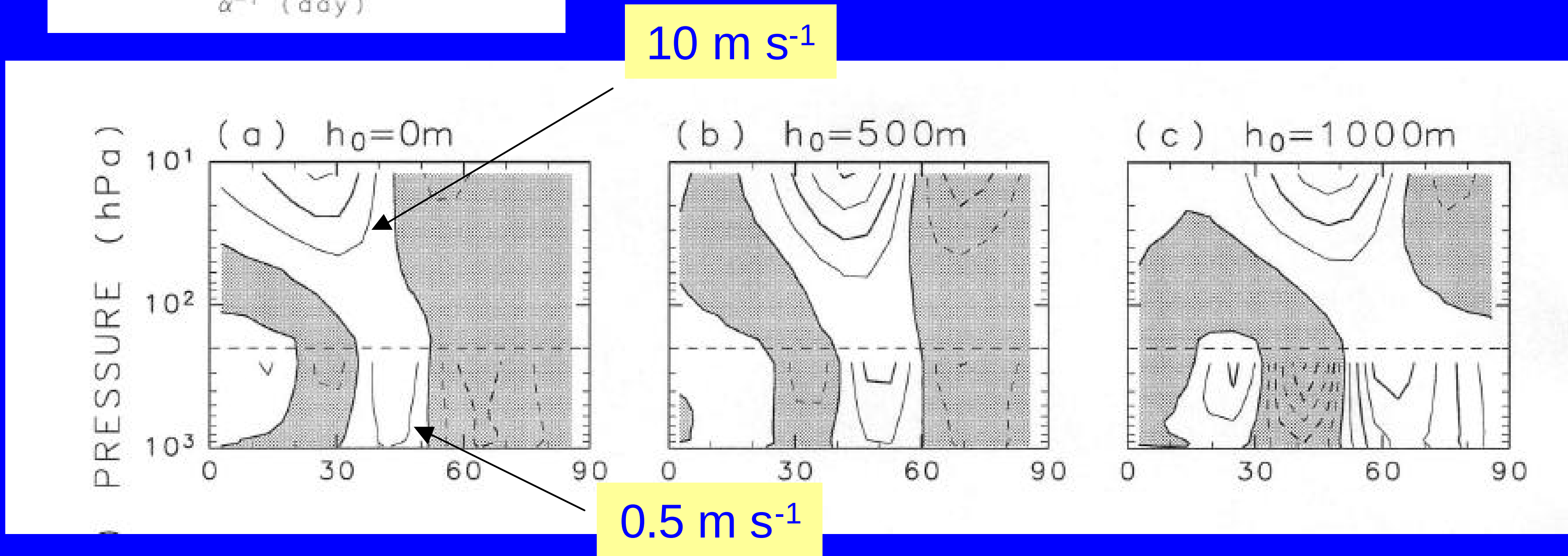






Taguchi

T 21 L42
(checked at T42 L42)

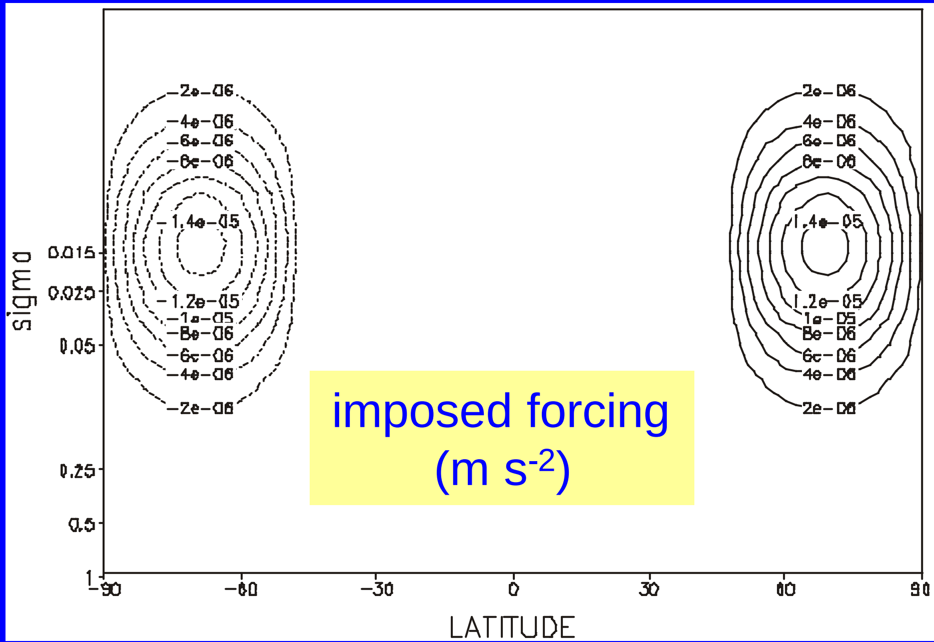


? [u] case 3 - control

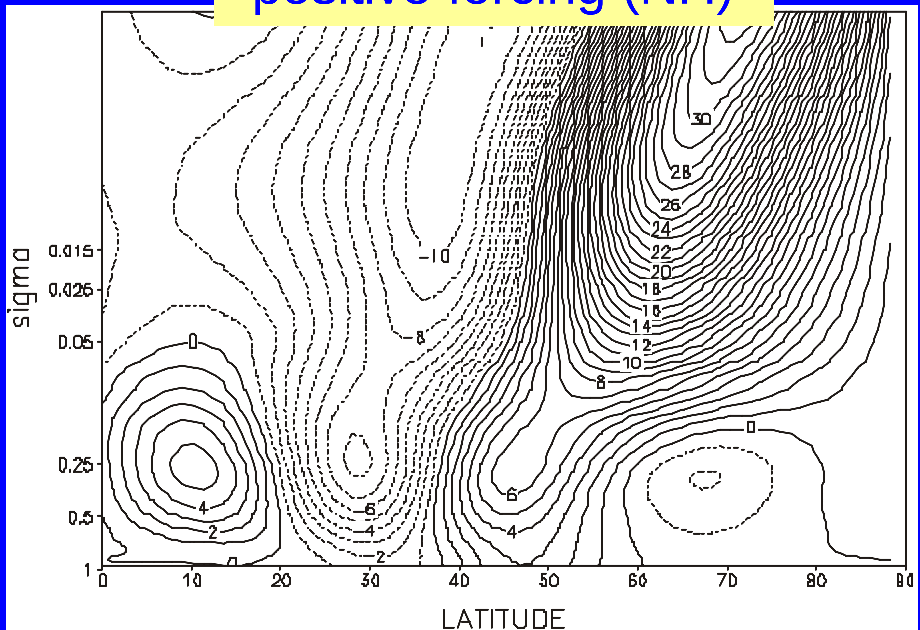
different amplitudes of wave-1 topography

Song & Robinson

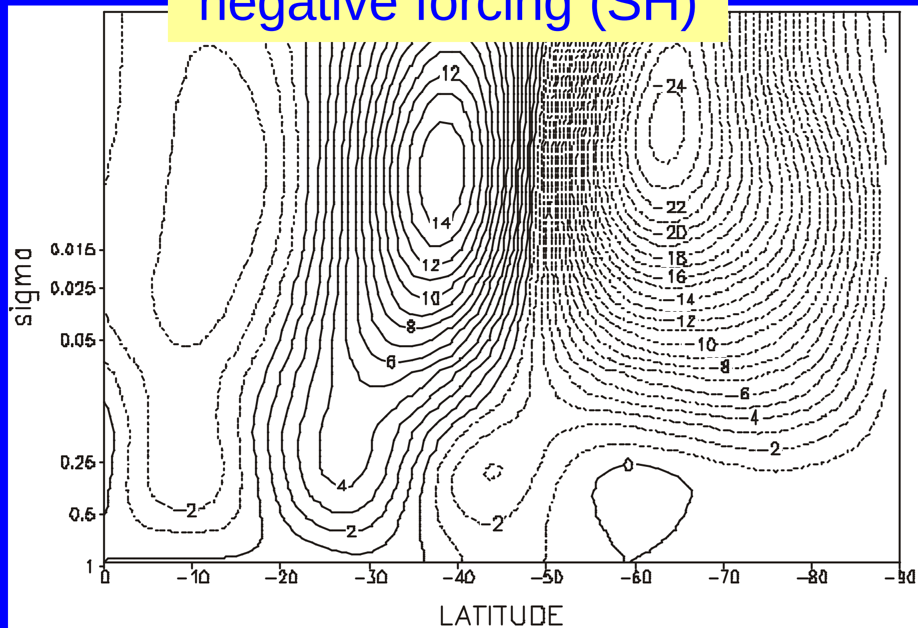
R30 L30



positive forcing (NH)



negative forcing (SH)

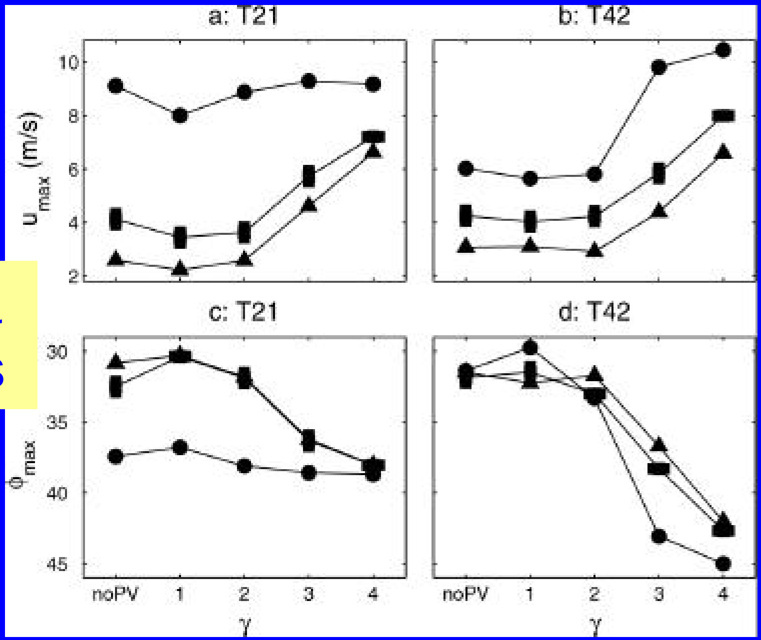


- introduction
- the 3 experiments
- **comparing results**
- tests of mechanisms
- summary and remaining questions

comparison

- Tropospheric response present in all 3 cases
- Strongest in PK - weakest in T
  - measured by ? u_{trop}/? u_{strat}
- Banded response in troposphere
  - projects on leading mode of tropospheric variability
- Similar nonlinearity in PK & SR

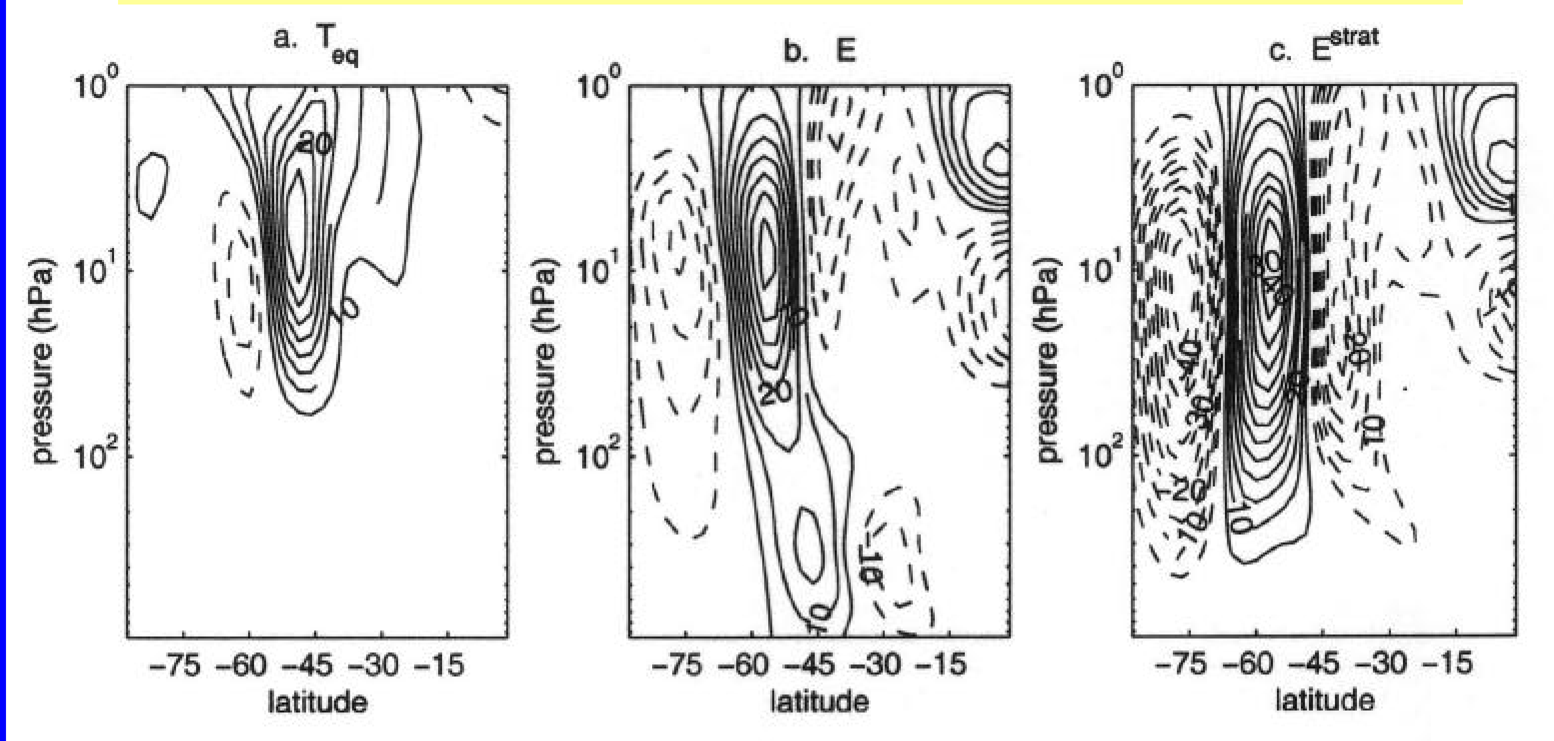
PK parameter & resolution scans



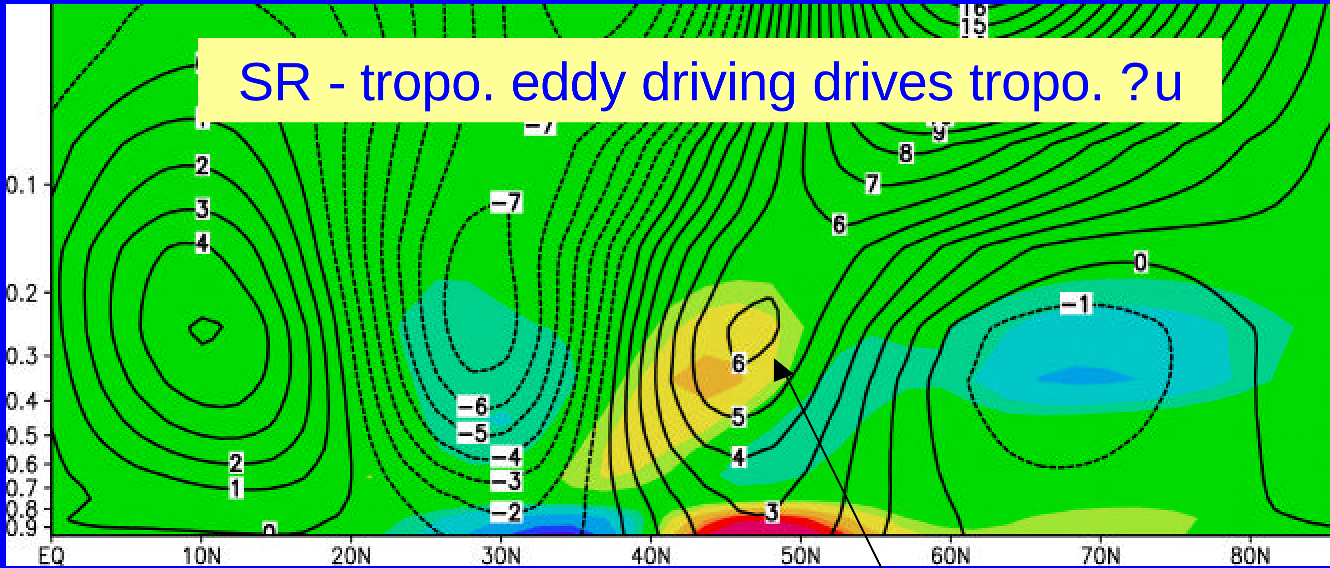
dynamics

- Tropospheric eddy forcing is proximate source of tropospheric response
  - as for internal variability

PK diagnosed responses to ?T_{eq}; ? eddy forcing; ?strat. eddy forcing



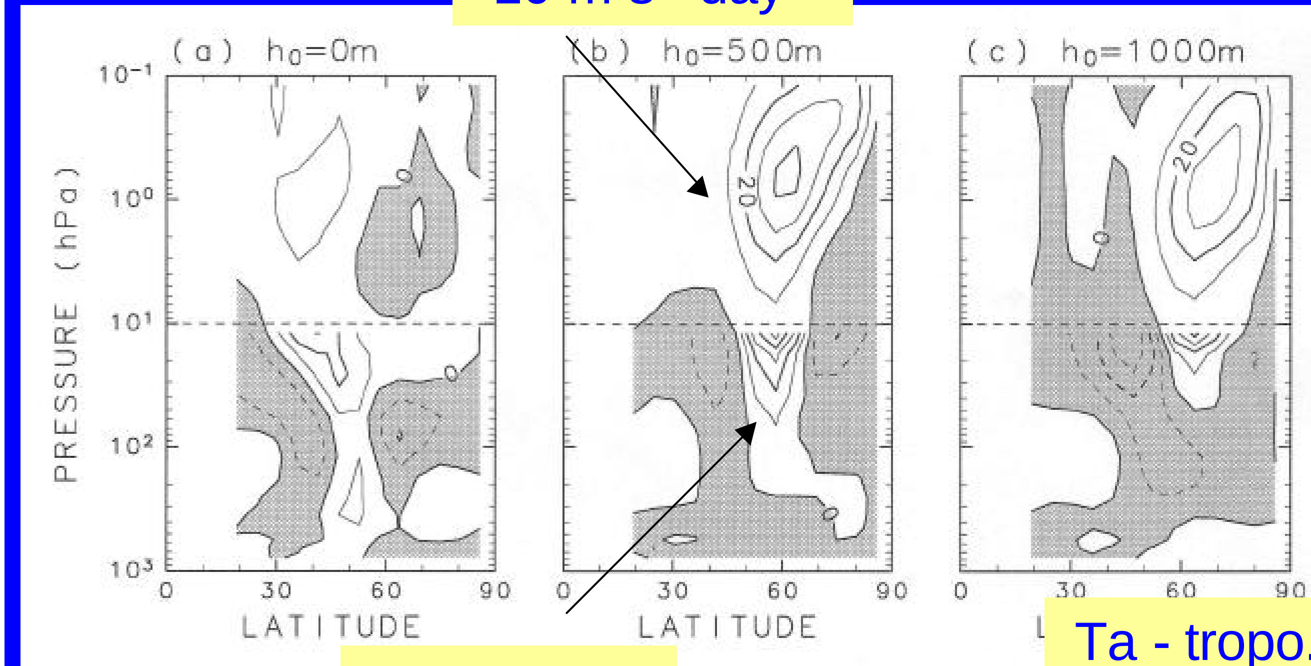
dynamics (cont'd)



SR - tropo. eddy driving drives tropo. ?u

10 m s^{-1} day^{-1}

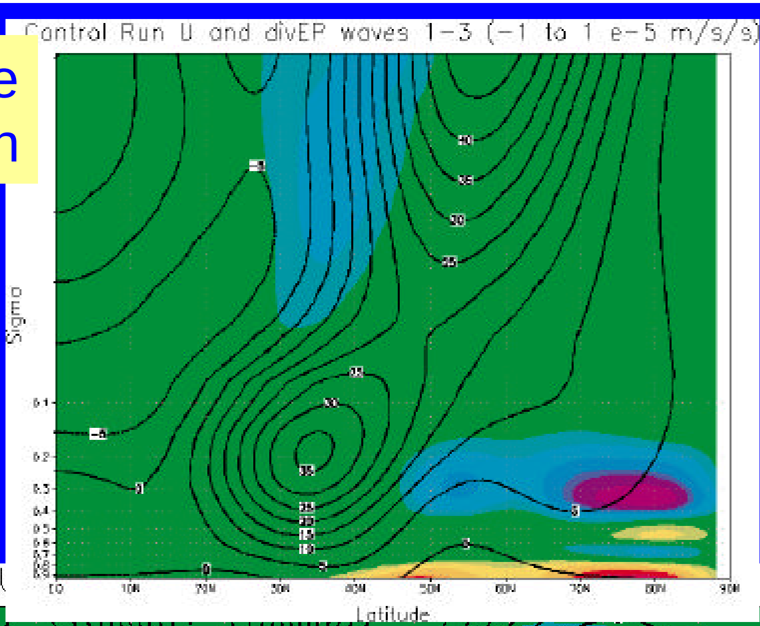
0.5 m s^{-1} day^{-1}



Ta - tropo. eddy driving is weak

1 m s^{-1} day^{-1}

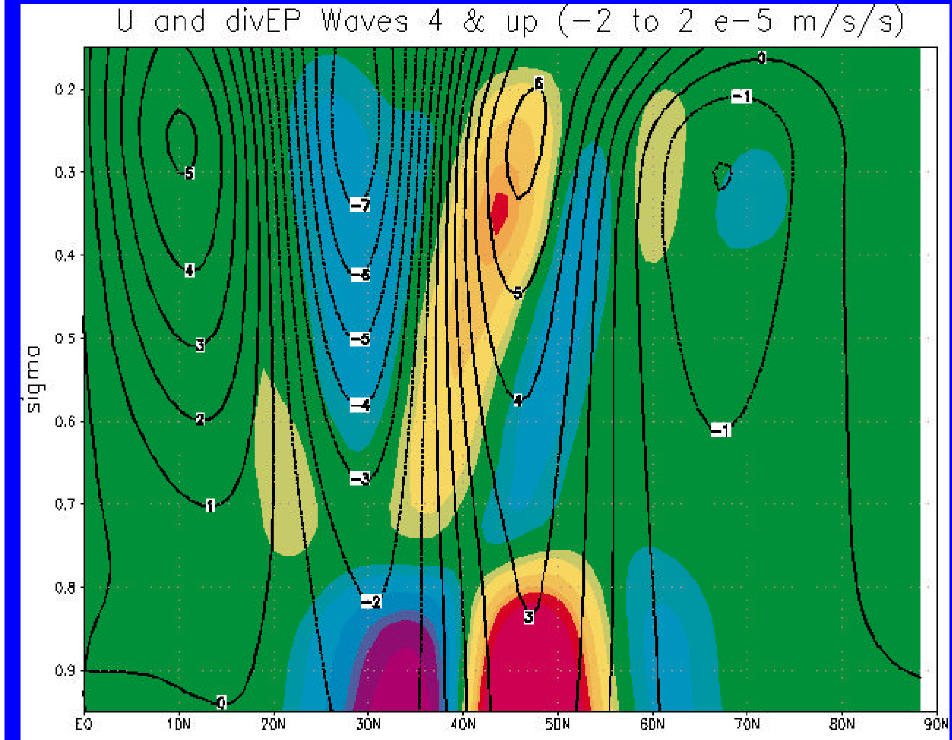
- introduction
- the 3 experiments
- comparing results
- **tests of mechanisms (test DCWEF in SR model)**
  - **which waves where?**
  - **how does the signal get into the troposphere?**
- summary and remaining questions



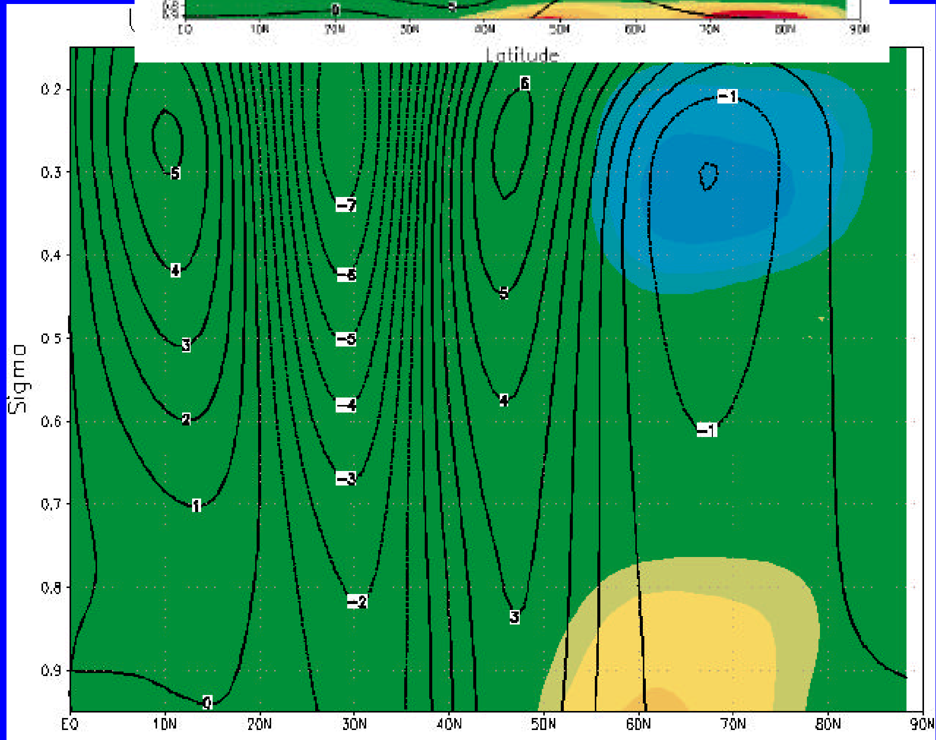
planetary wave driving in control run

which waves?

wave forcing of *tropospheric* response (forced – control)



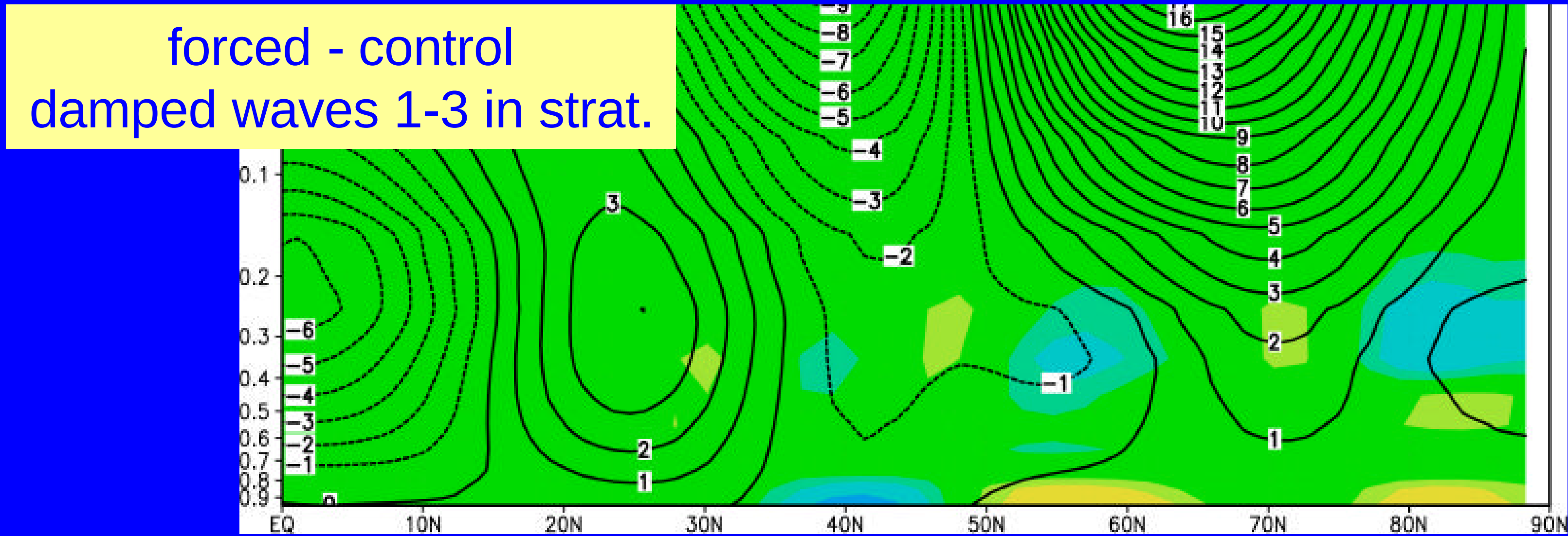
short waves (4 & up)

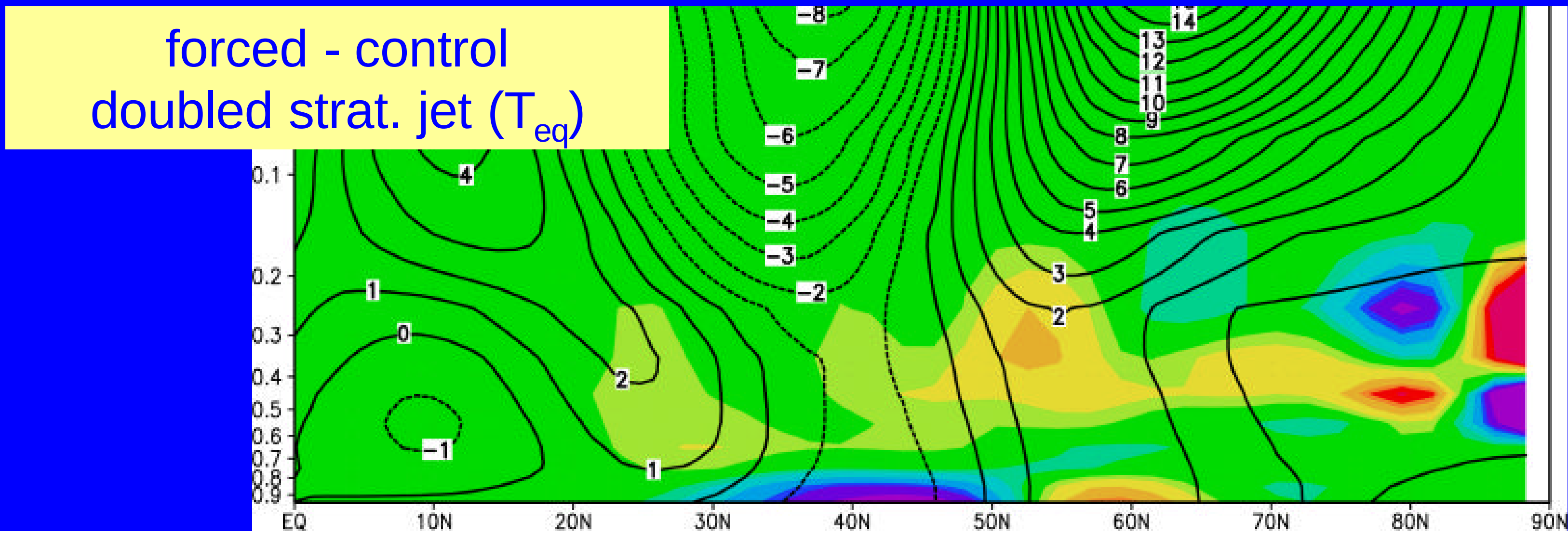


planetary waves (1-3)

mechanism

- Tropospheric response is weakened when long-wave response is weakened or suppressed….

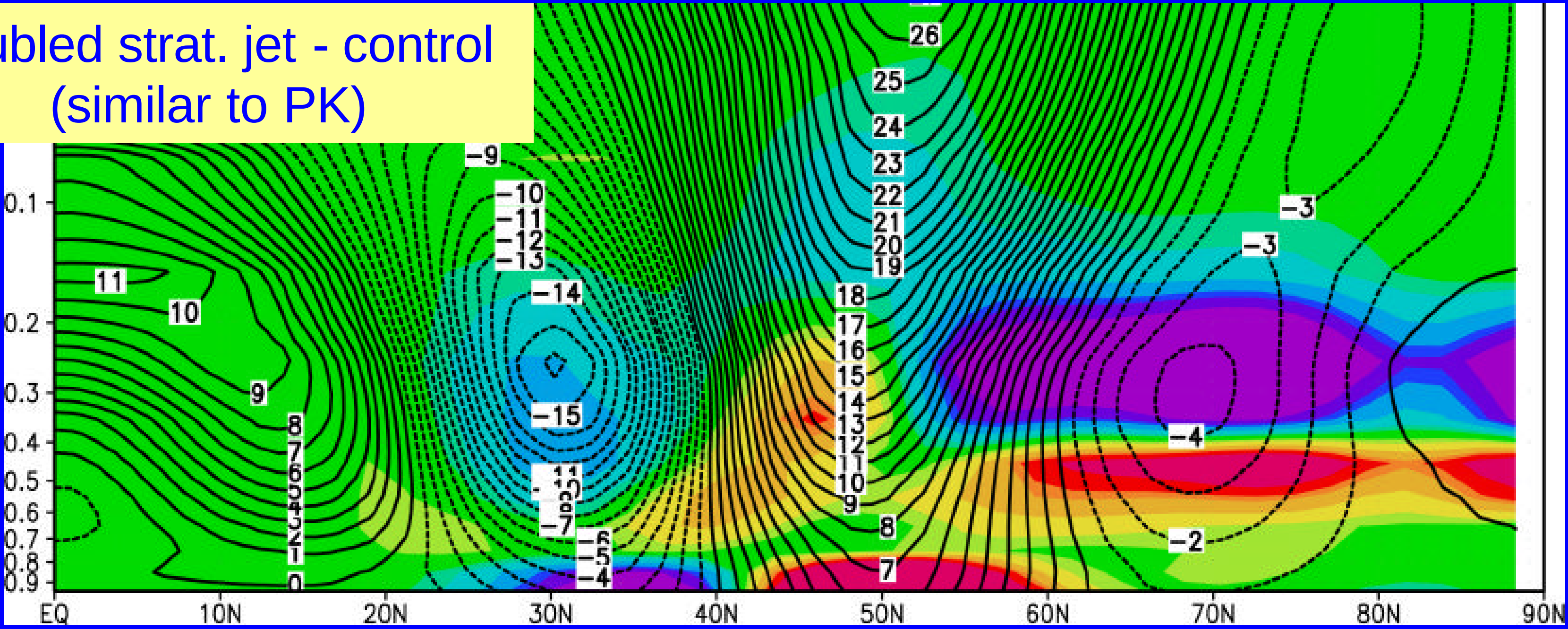




mechanism (cont’d)

….but strengthened when long-wave response is strong

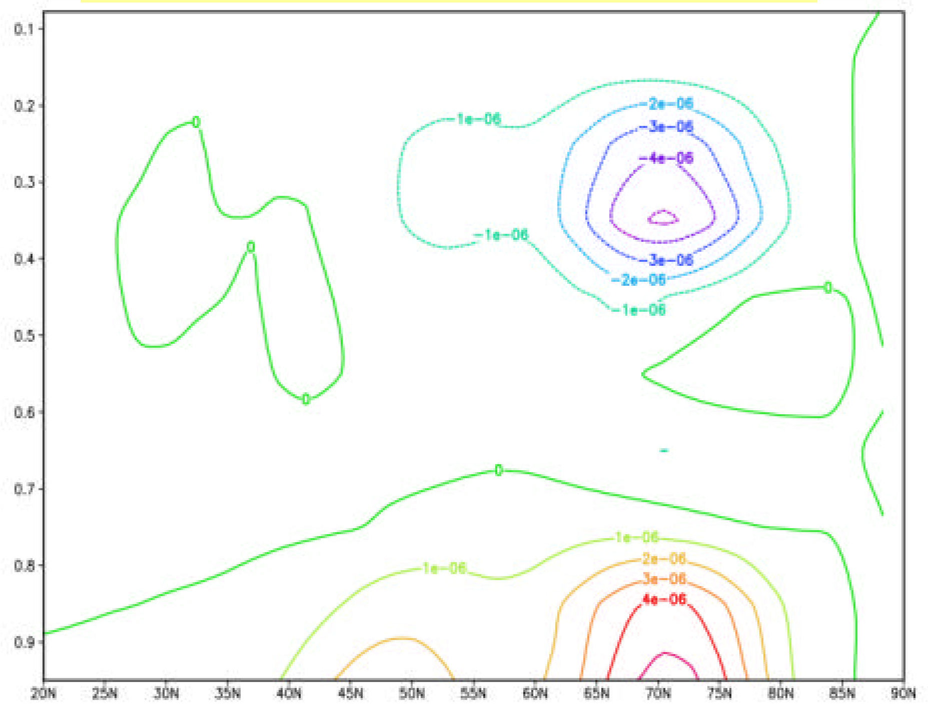
doubled strat. jet - control
(similar to PK)



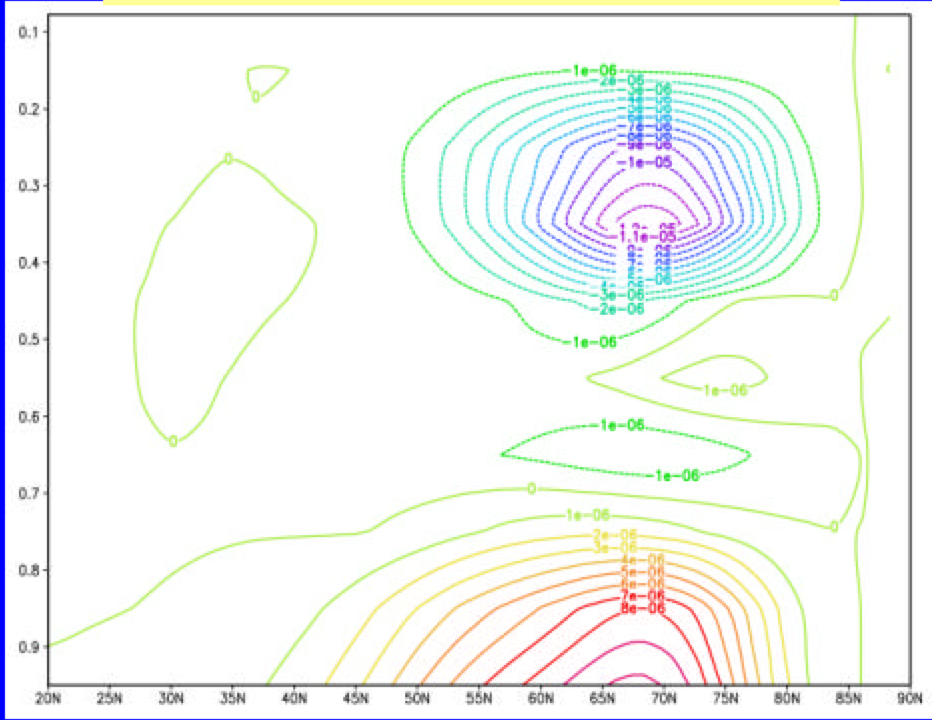
wave 3

- wave 3 dominates long-wave forcing in high latitude upper troposphere

wave 3 wave driving - control



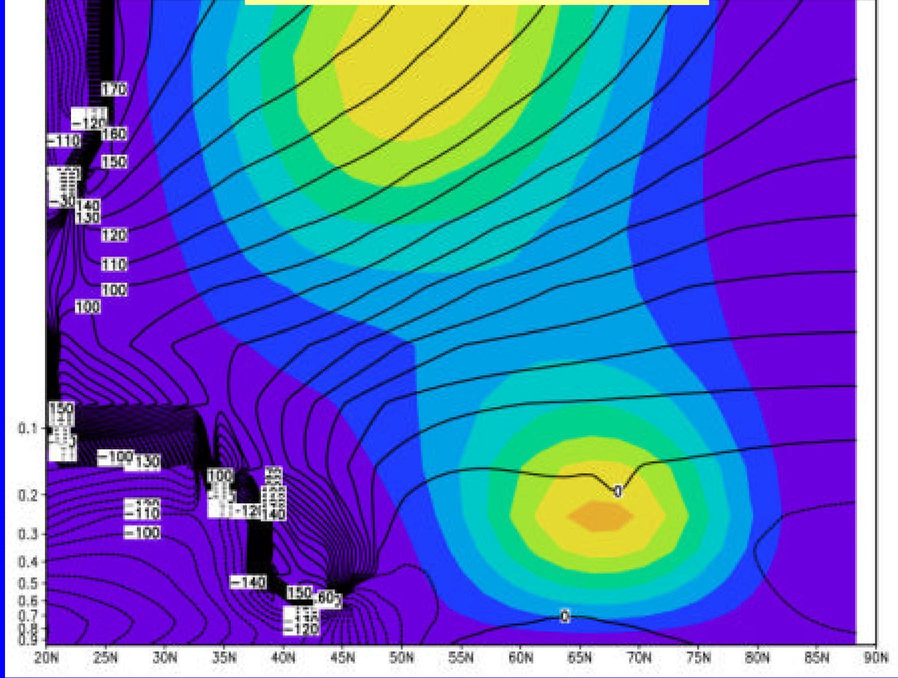
wave 3 wave driving - forced



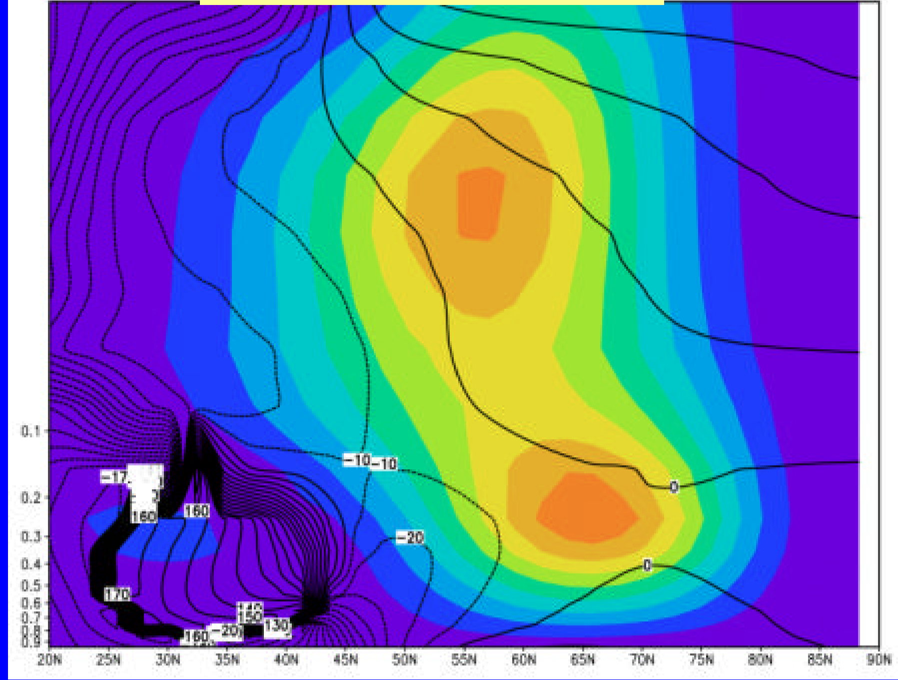
wave 3 (cont'd)

- Change in wave 3 structure
  - composited with ridge rotated to 0° long. at 68 N, σ=.15

wave 3 - control



wave 3 - forced

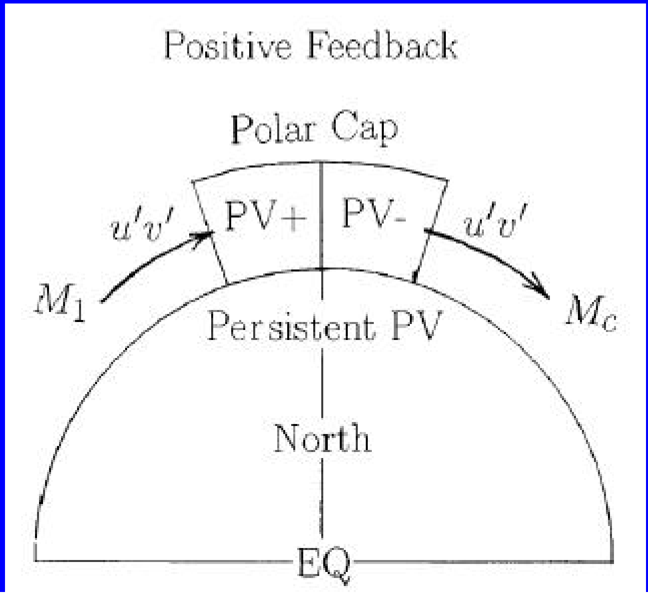


how does DCWEF fare?

- Supported by:
  - robust tropospheric response (PK & SR)
  - projection on tropospheric mode (PK, Ta, SR)
- *Not* supported by:
  - sensitivity of tropospheric response to stratospheric manipulations (SR)
    - which do not degrade tropospheric internal modes
- Ambiguous:
  - nonlinearity of response in PK & SR

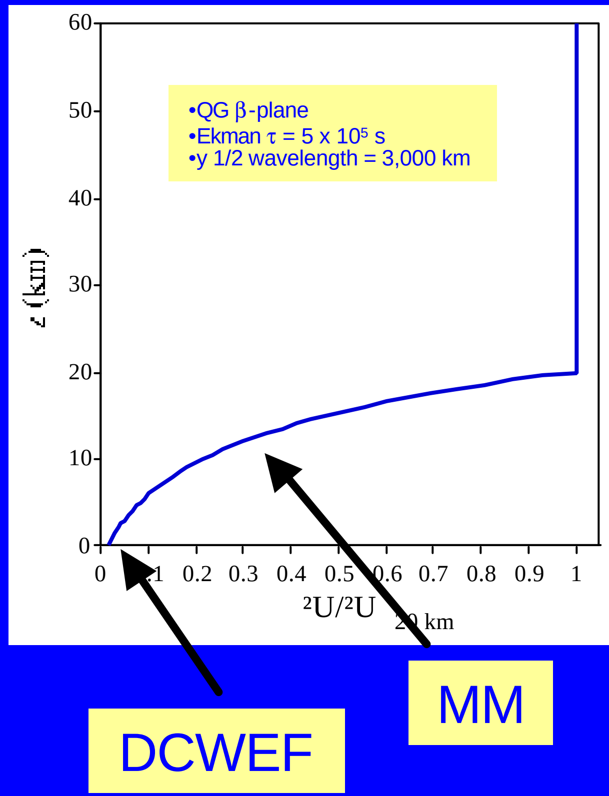
a messier mechanism

- Increased strat. [u] confines long baroclinic waves to troposphere in high latitudes
  - stronger long-wave baroclinic instability
  - stronger response to nonlinear forcing
- Increased wave driving from long waves slows upper tropo. [u] in high latitudes
- Tropospheric response reinforced in lower latitudes by synoptic-eddy feedback (as in DCWEF)
- Tanaka & Tokinaga (2002, *JAS*)
  - but T&T expect *increased* high-latitude [u] from stronger baroclinic instability



MM hypothesis

- Does not rule out direct influence on troposphere by downward control
- But influence on lower stratospheric shear is more important
- Changes in stratospheric wave driving in PK-type experiments may *not* be essential for the tropospheric response
  - since radiative equilibrium profile has increased vertical shear in the lower stratosphere



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summary

- Stratospheric changes induce robust tropospheric responses by stimulating changes in tropospheric eddy driving
  - Projects on internal mode of tropospheric variability
    - Taguchi's weak tropospheric response – forcing nearly orthogonal to leading mode (?)
- How does signal get into troposphere?
  - "Downward control" -
    - cannot explain nonlinearity or sensitivity to stratospheric mean flow/long-wave damping
      - changes that do not affect structure of tropospheric leading mode
  - Through influence on high-latitude long (baroclinic?) waves
    - more complicated, but consistent with SR results

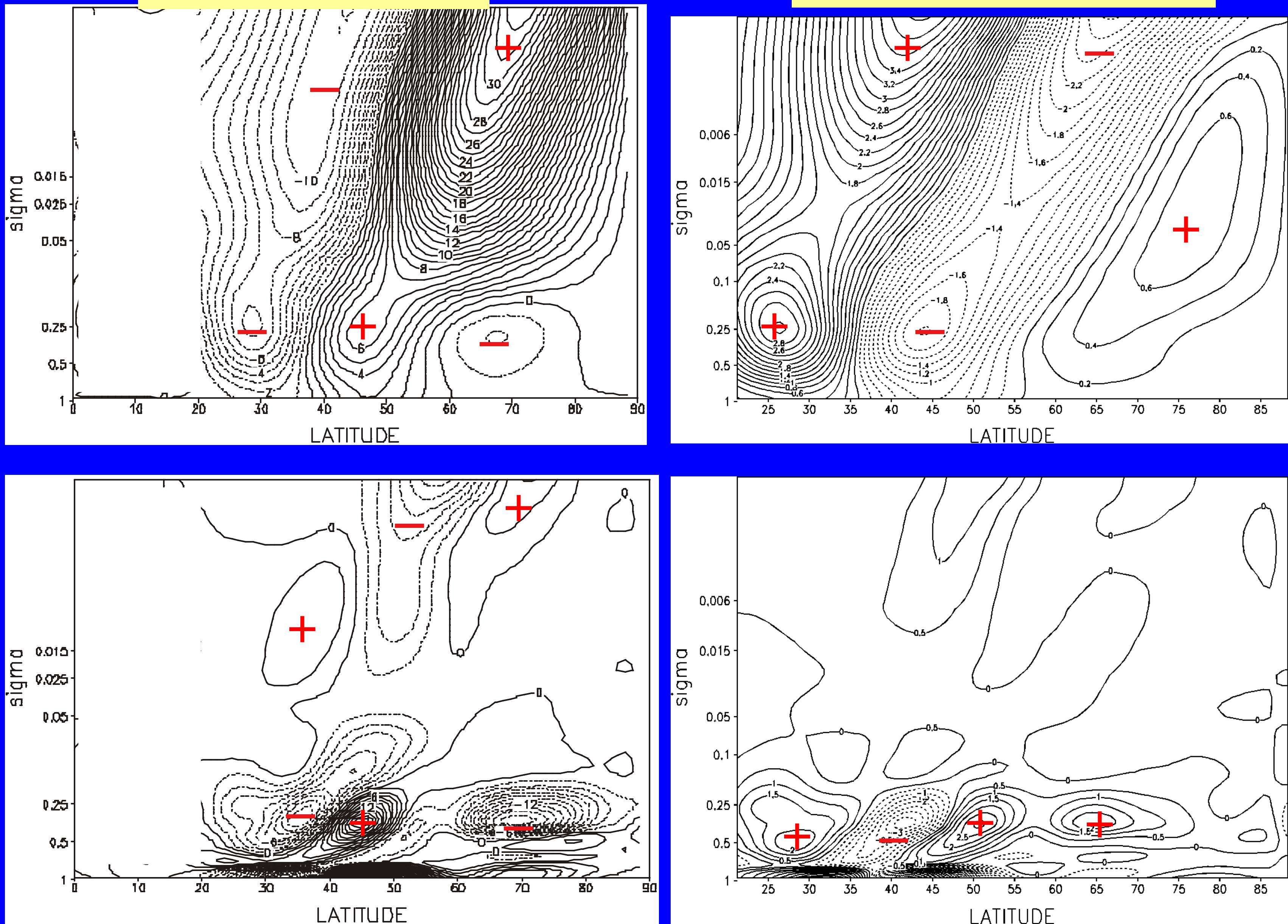
questions

- Long waves respond to zonal wind changes at what levels?
  - importance of wave 3 points to lower stratosphere
  - Perlwitz & Harnik (2003, *J Clim*) point higher
- How do mechanisms change in presence of strong planetary waves?
- How general are these results?
  - unpleasantly similar to extra-tropical SST problem

forced response and internal variability

forced - control

EOF (control run)



zonal wind

wave driving (10^{-6} m/s^2)