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
Boville’s experiment

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

Boville, 1984 JAS
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
\[ f v = -\frac{1}{\rho_0} \nabla \cdot F \]
\[ u_{z=0} = \tau_{\text{Ekman}} \int_0^\infty \frac{\nabla \cdot F}{\rho_0} \frac{d z}{H} \]
\[ \Theta(z) = \tau_{\text{Newtonian}} \frac{d \Theta}{dz} \frac{1}{\rho_0} \int_0^\infty \frac{\partial}{\partial y} [\nabla \cdot F] d z' \]

“downward control”

A.M. surfaces

Cool

Warm

PV flux

Latitude

PBL

- QG β-plane
- Ekman \( \tau = 5 \times 10^5 \) s
- y 1/2 wavelength = 3,000 km
Observed AO in [u] and planetary wave driving

By itself, would produce surface [u] anomaly \( \sim 1 \text{ m s}^{-1} \)

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\textsubscript{3} depletion experiments

• Simplified “radiation”

\[ \frac{dT}{dt} = \frac{1}{\tau} (T\textsubscript{eq} - T) \]

• 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

  – change $T_{eq}$
• Taguchi (2003, *JAS*)
  – change $\tau$
  – with and without topography
• Song & Robinson (2003, *JAS* - in preparation)
  – direct forcing of stratospheric zonal momentum
Taguchi

T 21 L42
(checked at T42 L42)

\[ \tau \]

? [u] case 3 - control
different amplitudes of wave-1 topography
imposed forcing (m s^{-2})

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 $\frac{u_{\text{trop}}}{u_{\text{strat}}}$
- 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\(^{-1}\)

1 m s\(^{-1}\) day\(^{-1}\)

Ta - tropo. eddy driving is weak
• 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
which waves?

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

- short waves (4 & up)
- planetary waves (1-3)

planetary wave driving in control run
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 (cont’d)

- Change in wave 3 structure
  - composited with ridge rotated to 0° long. at 68 N, $\sigma=.15$
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
• introduction
• the 3 experiments
• comparing results
• tests of mechanisms
• summary and remaining questions
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 \((10^{-6} \text{m/s}^2)\)