"Do plausible perturbations to the stratosphere influence the troposphere? The null hypothesis is that they do not."
Long-term and Short-term Strat-Trop Coupling: Lessons from a Simple AGCM

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Outline

• Introduction
• Response to stratospheric cooling:
  ➢ Equilibrated response
  ➢ Adjustment to equilibrium
  ➢ Response in presence of seasonal cycle
• Strat-to-Trop (Baldwin-Dunkerton) Signals
• Conclusion

➢ Further details
  • Polvani & Kushner, GRL, 2002;
  • Kushner & Polvani, J. Clim. submitted
Introduction

• We need simplified settings to understand stratospheric influences on tropospheric climate and weather

• Our idea:
  ➢ Set up a simple stratosphere-troposphere model
  ➢ Give the stratosphere a thermal kick ... see what happens in the troposphere
  ➢ The stratospheric influence here is unambiguous

• Aim for clean results:
  ➢ Robust
  ➢ Reproducible
  ➢ (Hopefully) Explicable
Polvani-Kushner Model

• Dry primitive-equation model

• Very simple “physics:”
  - Newtonian cooling to reference $T_{eq}$ profile
  - Rayleigh drag in PBL and in sponge

• Zonally symmetric forcing and boundary conditions (à la Scinocca and Haynes)
  - No stationary wave forcing of the stratosphere
  - A representation of the Southern Hemisphere

• Details in P & K 2002 GRL, results reproduced independently by R. Scott
Controlling Field: $T_{eq}$

- **Stratosphere:**
  - Transition from winter polar vortex to summer stratosphere
  - Single parameter, $\gamma$, controls stratospheric winter polar temp

- **Troposphere:**
  - Held & Suarez
Equilibrated Response

- First, we look at long-term mean response to a change in $T_{eq}$
Imposed cooling in winter stratosphere
Equilibrated Response

- Since $\gamma$ controls the polar winter temperature, it also controls the strength of the stratospheric polar vortex ...
• Polar vortex strengthens
• Trop jet shifts polewards dramatically
The Trop Change: a Classical AM Response

• Trop response projects entirely onto internal variability
• A positive & stratospherically forced annular mode response, *a la* Thompson & Solomon 2002
Robustness of Response to Resolution

Latitude of Surface Wind Max vs $\gamma$

20 levels
40 levels
80 levels
Recap

• “Do plausible perturbations ... ?”
  ➢ Yes!

• We have a robust, easily reproducible example of stratospheric influence.
  ➢ Gets the sense of the observed SH annular mode trends, presumably forced by photochemical ozone loss (T&S2002)

• But how to explain it?

• We examine the change to the eddy forcing...
EP Flux Budget for Two Boxes

“High-Lat” box: budget for the polar vortex

“Low-Lat” box: detect changes in synoptic waves
EP Flux Budget

“High-Lat” box

“Low-Lat” box
EP Flux Budget

EP flux through bdry

Net EP flux convergence
EP Flux Budget

EP flux through bdry

Net EP flux convergence

"High-Lat" box

"Low-Lat" box

Red: $\gamma = 2$

Blue: $\gamma = 4$
• As stratosphere cooled:
  1. Eddy drag in both boxes reduced.
  2. High-lat box: enhanced equatorward deflection
  3. Low-Lat box: reduced upward flux
Response of Upward EP Flux into Strat

\[ F(p)(100\text{mb}) \]

\( \gamma = 2 \) \hspace{1cm} \( \gamma = 4 \)

Biggest reduction at synoptic scales
All very well, but ...

- What do these changes in the EP flux actually explain about the changes to the mean state?
- Which is cause, which is effect?
  - Is the vortex stronger because it absorbs less upward propagating wave activity?
  - Or, is there less upward propagating wave activity because the vortex is less absorbing?
- The EP flux diagnostics do not provide independent insight into the workings of the tropospheric response.
- So, we pursue an even simpler model ...
Zonally Symmetric Model Experiments

- We perform a “downward control” (TEM circulation) calculation
- To do so, we use a zonally symmetric version of the model.
  - We use this to see how changes to the eddy driving impact the circulation in the absence of eddy feedbacks
Zonally Symmetric Model Experiments

- First, we put in the changes to the EP fluxes from $\gamma=2$ to $\gamma=4$ for $p < 100$ mb ...

- The response penetrates into upper trop, but trop jet does not shift.
• Next, we put in the changes to the EP fluxes from $\gamma=2$ to $\gamma=4$ for $p > 100$ mb ...

• The response extends into the troposphere, as expected from Haynes et al. 1991, and partially cancels response from strat.

$\Delta(\text{EPFD})$
Response of the Eddy Driving

- Zonally symmetric model:
  - The change to the stratospheric eddy forcing does penetrate into the troposphere.
- But tropospheric eddy feedbacks are involved in bringing the response to the surface.
- There is strong coupling through the lower stratosphere
  - Large change to synoptic-scale eddy driving
  - Eddy forcing changes can change winds both up and down (as Alan said yesterday)
Timescales of Adjustment

• We now use our model to look at the tropospheric adjustment to stratospheric perturbations
• This is the kind of experiment that Peter Haynes was proposing yesterday
Timescales of Adjustment

- Ensemble of 10 $\gamma = 4$ integrations
- Each realization branches from $\gamma = 2$ control run every 1,000 days
- Thus, each realization is a switch-on cooling experiment
Timescales of Adjustment

Difference of $U$ from $\gamma=2$ Case

One realization …
Timescales of the Transient Adjustment

- stratosphere adjusts very rapidly $O(50 \text{ days})$
- troposphere adjusts more slowly $O(200 \text{ days})$
Timescales of the Transient Adjustment

- $\Delta$: measure of ensemble-mean extratropical wind difference from $U(\gamma=2)$
- $\Delta \to 1$ as $U \to U(\gamma=4)$
Timescales of the Transient Adjustment

- Initially, signal propagates from 1 to 100 mb in roughly 150 days $\rightarrow 0.23 \text{ km/day}$
- Dickinson (1968), Haynes et al. (1991) predicts $c \sim k_T H \sim 0.2 \text{ km/day}$
- Then, a longer adjustment timescale of 300-700 days
Transient Adjustment: Conclusions

• To describe the tropospheric response, we propose a 2-step adjustment:

1. An initial stratosphere-driven & linear adjustment \( (t<200d) \)
   - Linear means that the response is state independent and can be modeled by the Haynes et al. 1991 methods.

2. A coupled strat-trop nonlinear adjustment with synoptic eddy feedbacks \( (200d<t<800d) \).
Transient Adjustment: Conclusions

• Thus, the stratosphere “tickles” the troposphere, and the tropospheric baroclinic eddy circulation responds, unpredictably and strongly, over a longer time scale
Response in Presence of Seasonal Cycle

• If adjustment to equilibrium is too slow, will the seasonal cycle wipe out the tropospheric response?
• We will answer this question in stages.
• First, we impose a seasonal cycle in the stratosphere only.
Seasonal Cycle of $T_{eq}(\gamma=2)$, 10mb
Seasonal Cycle of $U(\gamma=2)$, 10mb

Westerlies weaker than steady-forced case

(20-year climatology)
Seasonal Cycle of $U(\gamma=2)$, 500mb

(20-year climatology)

Very weak seasonal cycle in trop
Steady Forcing Case...

Extratropical $\delta U_{\text{trop}}/\delta U_{\text{strat}} \sim 0.25$
Representative Seasonal Cycle Case

(Combined NH + SH 20-year annual mean)

- Strat + trop response weaker, even for $\gamma=6$
- Extratropical $\delta U_{\text{trop}}/\delta U_{\text{strat}} \sim 0.25$
Seasonal Cycle: Conclusions

• The tropospheric response is also robust to the seasonal cycle.
• This occurs despite the slow adjustment timescale from the transient experiments.
Strat-to-Trop Signals

• T&S2002 discuss the connection between the strat/trop short-term (10-100 day) variability and its long-term response to ozone depletion.

• General idea: stronger polar vortex linked to
  - Less wave drag in strat
  - Less strat variability (fewer sudden warmings)
  - Weaker strat-trop coupling
  - Fewer or weaker Baldwin-Dunkerton events
Strat-to-Trop Signals

• How about our model?
• We have already seen that there is less wave drag in strat for the strong vortex case
• We examine impact of strat cooling on variability within model
Baldwin & Dunkerton construction

- Events propagate relatively slowly (as in externally forced response)
- Relatively few penetrate into trop

\[ \gamma = 2 \]
Strat-to-Trop Signals: Conclusions

- Downward propagating strat-to-trop AM signals do not change for strong vortex case
- Nevertheless, our model’s troposphere responds strongly to stratospheric thermal perturbations
- We thus have an example for which these signals may not be relevant to long-term response to externally imposed perturbations
Conclusion

• We have a clean (robust & reproducible) example of stratospheric influence.
• But the dynamics of the change are tricky
  ➢ Because they involve a long timescale adjustment with the tropospheric circulation
  ➢ Because synoptic-eddy details may be important
  ➢ Because the eddy driving influences extend up and down
• “Downward-control” linear models may help.
• Downward-propagating AM signals may not.