Thompson (2003)

"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

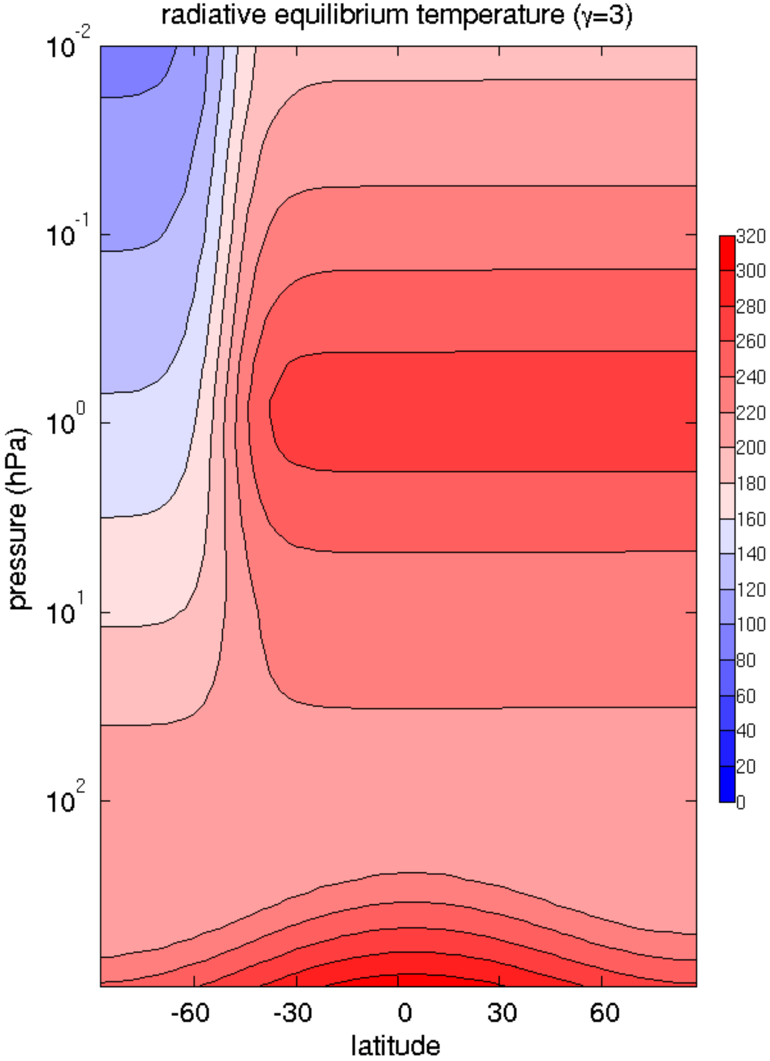
Introduction

- 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 (a 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}

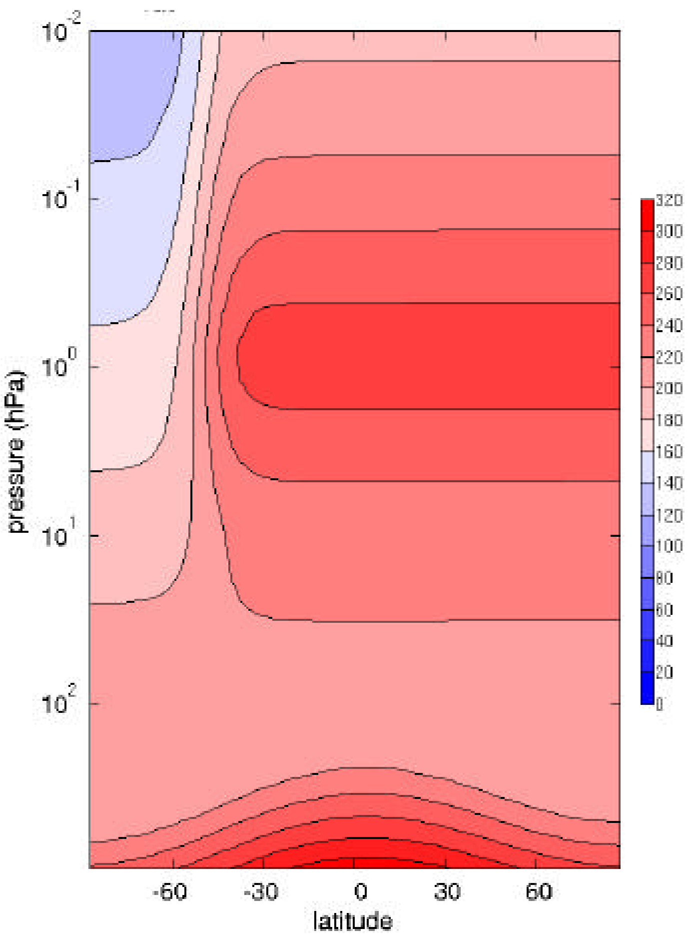


- Stratosphere:
  - Transition from winter polar vortex to summer stratosphere
  - Single parameter, *g*, controls stratospheric winter polar temp
- Troposphere:
  - Held & Suarez

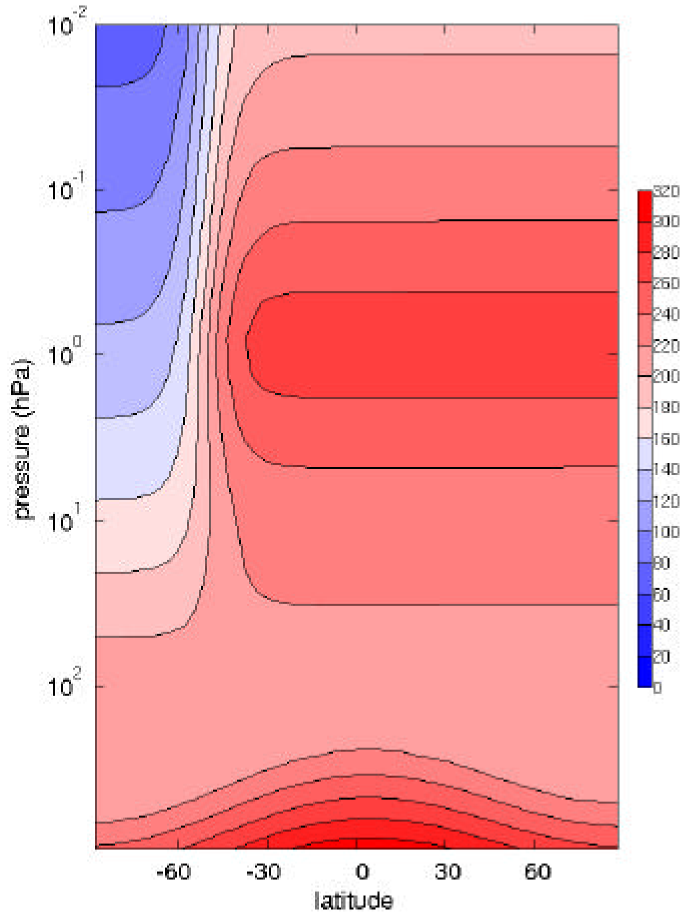
Equilibrated Response

- First, we look at long-term mean response to a change in T_{eq}

T_{eq}



$\gamma = 2$



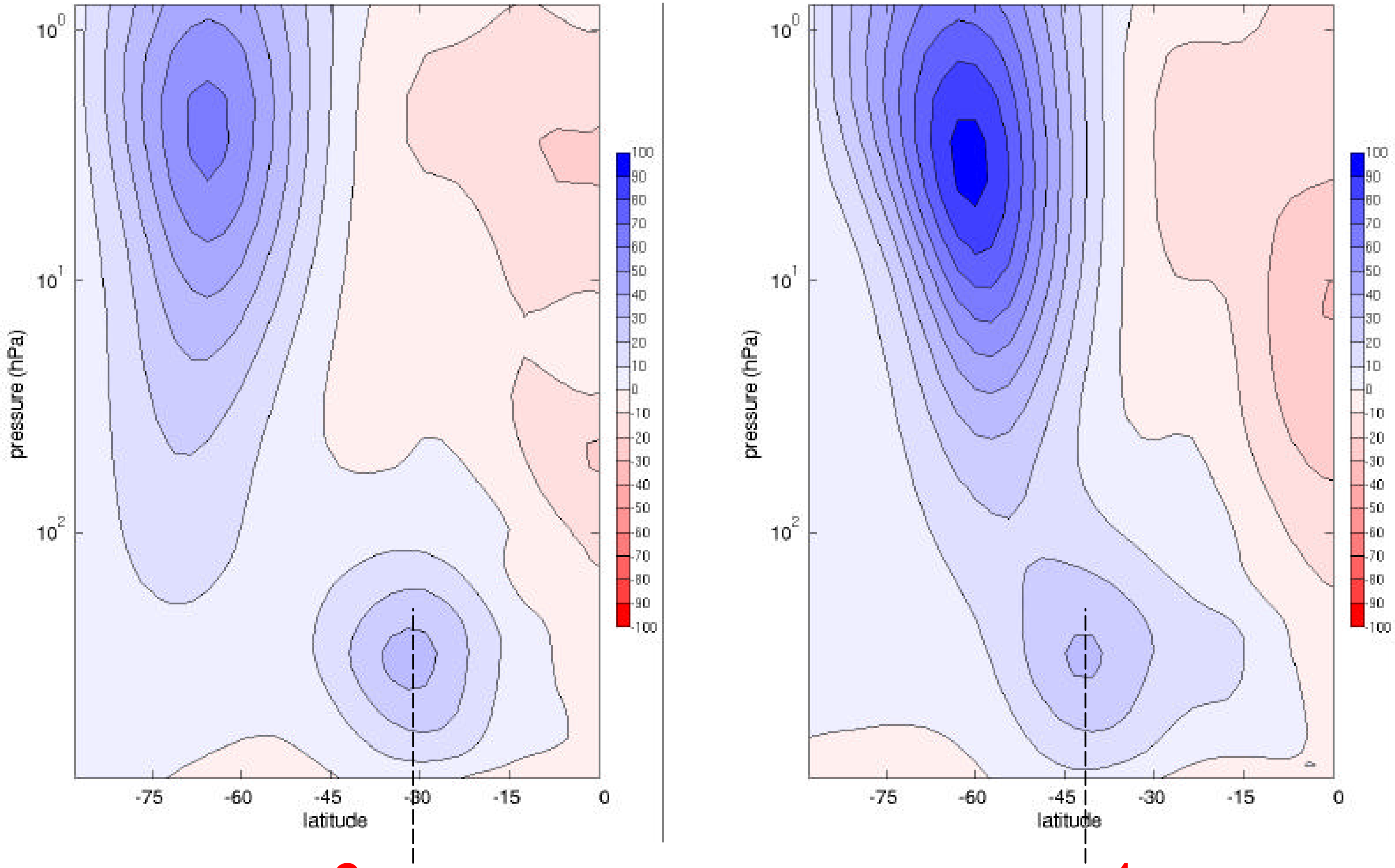
$\gamma = 4$

Imposed cooling in winter stratosphere

Equilibrated Response

- Since γ controls the polar winter temperature, it also controls the strength of the stratospheric polar vortex ...

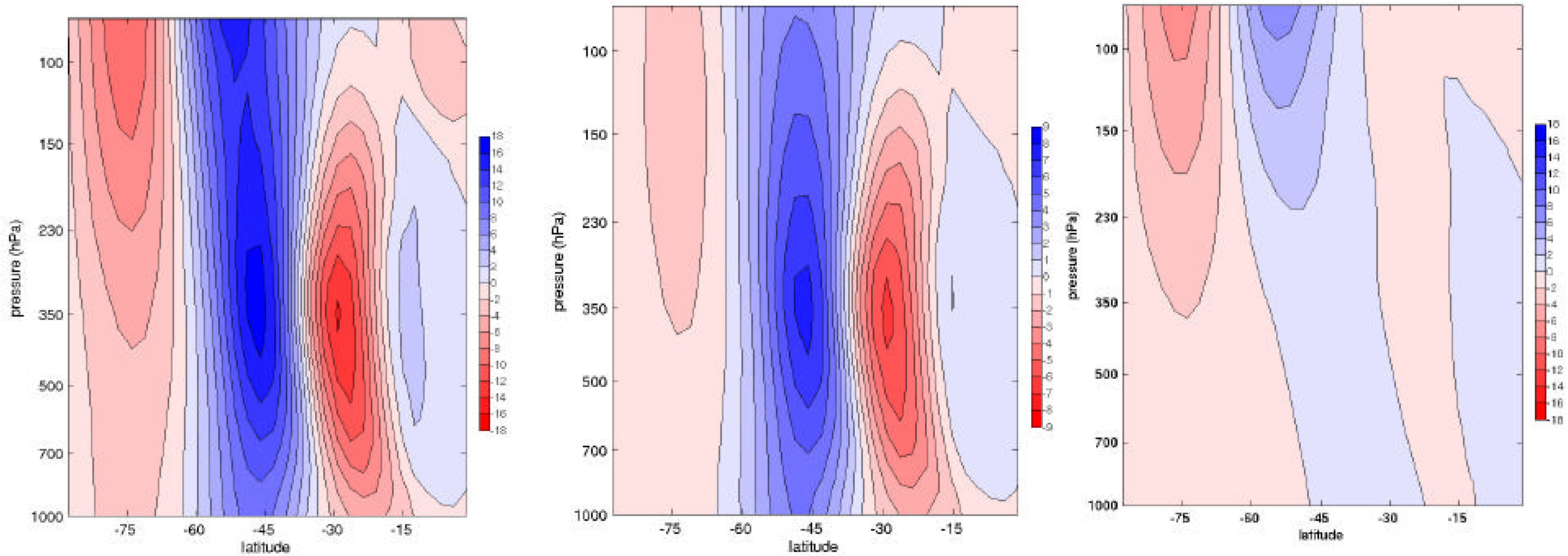
U



$\gamma = 2$ $\gamma = 4$

- Polar vortex strengthens
- Trop jet shifts polewards dramatically

The Trop Change: a Classical AM Response



U Response

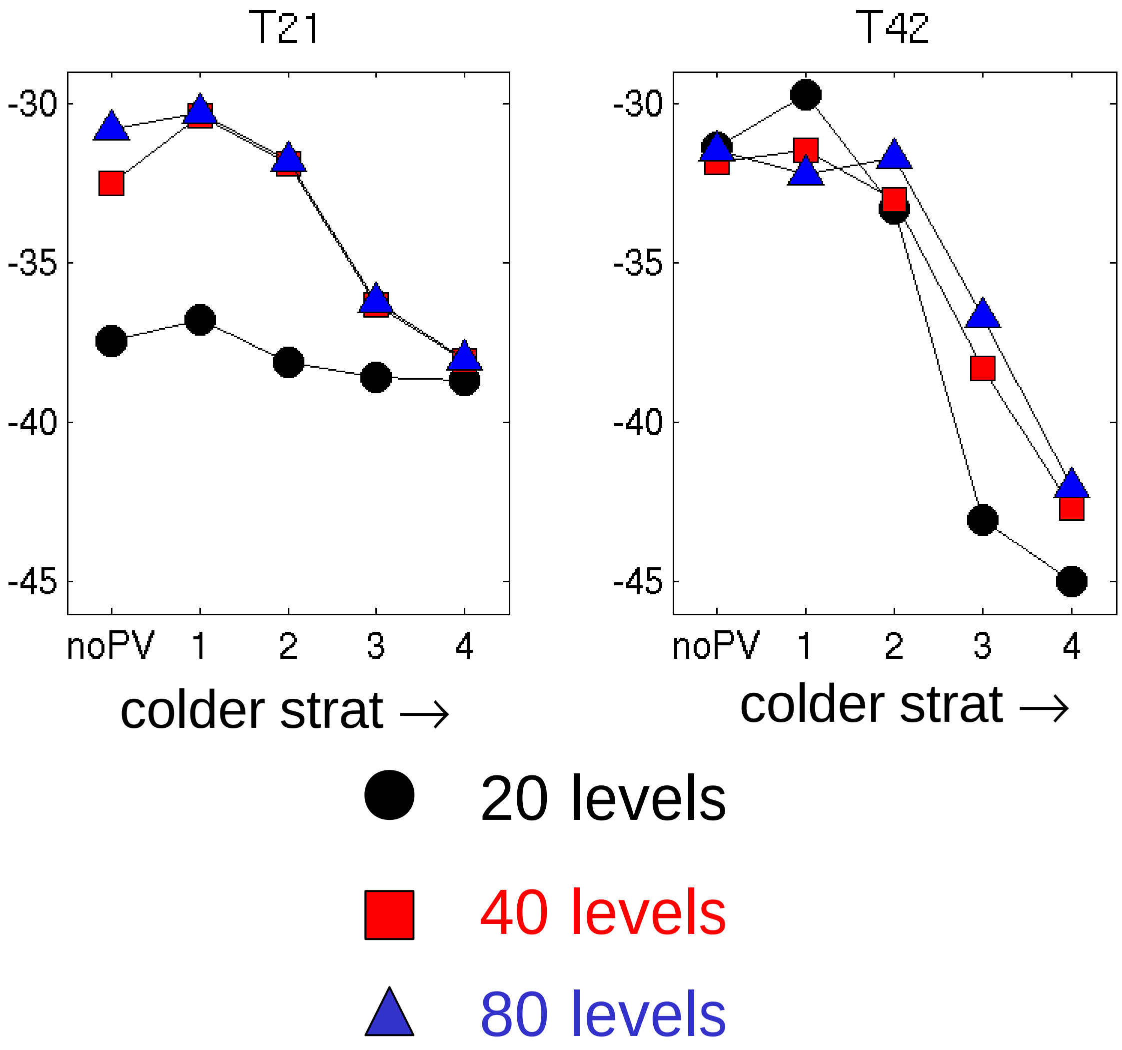
AM

Residual

•Trop response projects entirely onto internal variability
•A positive & stratospherically forced annular mode response, a la Thompson & Solomon 2002

Robustness of Response to Resolution

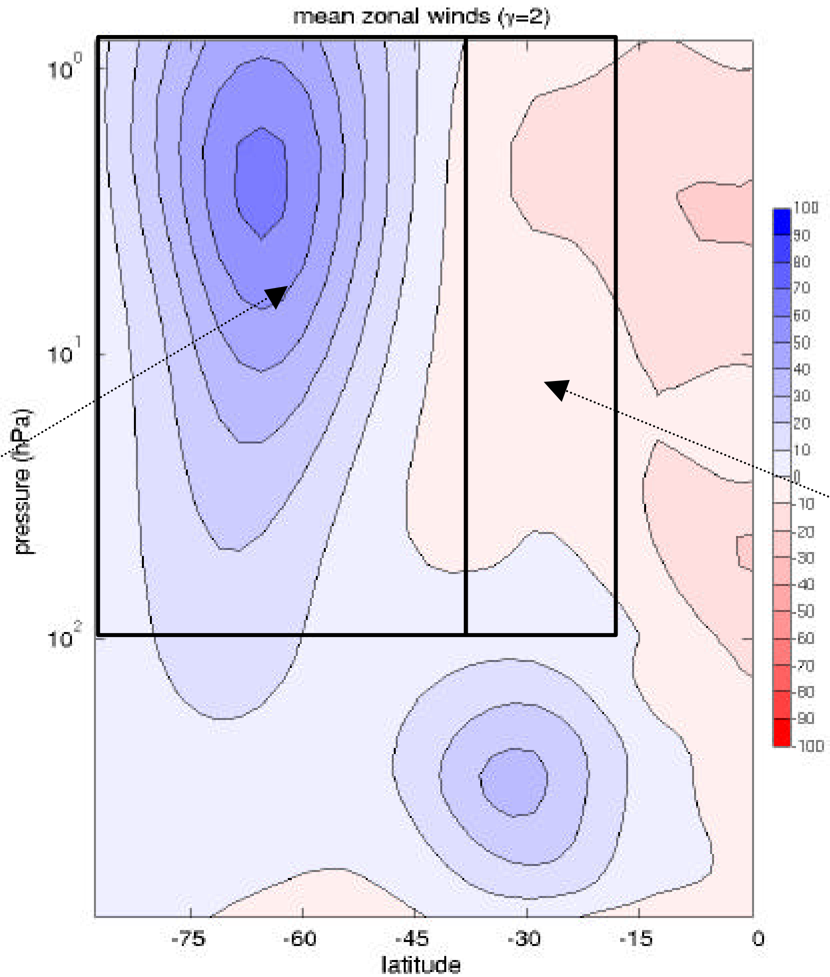
Latitude of Surface Wind Max vs γ



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...

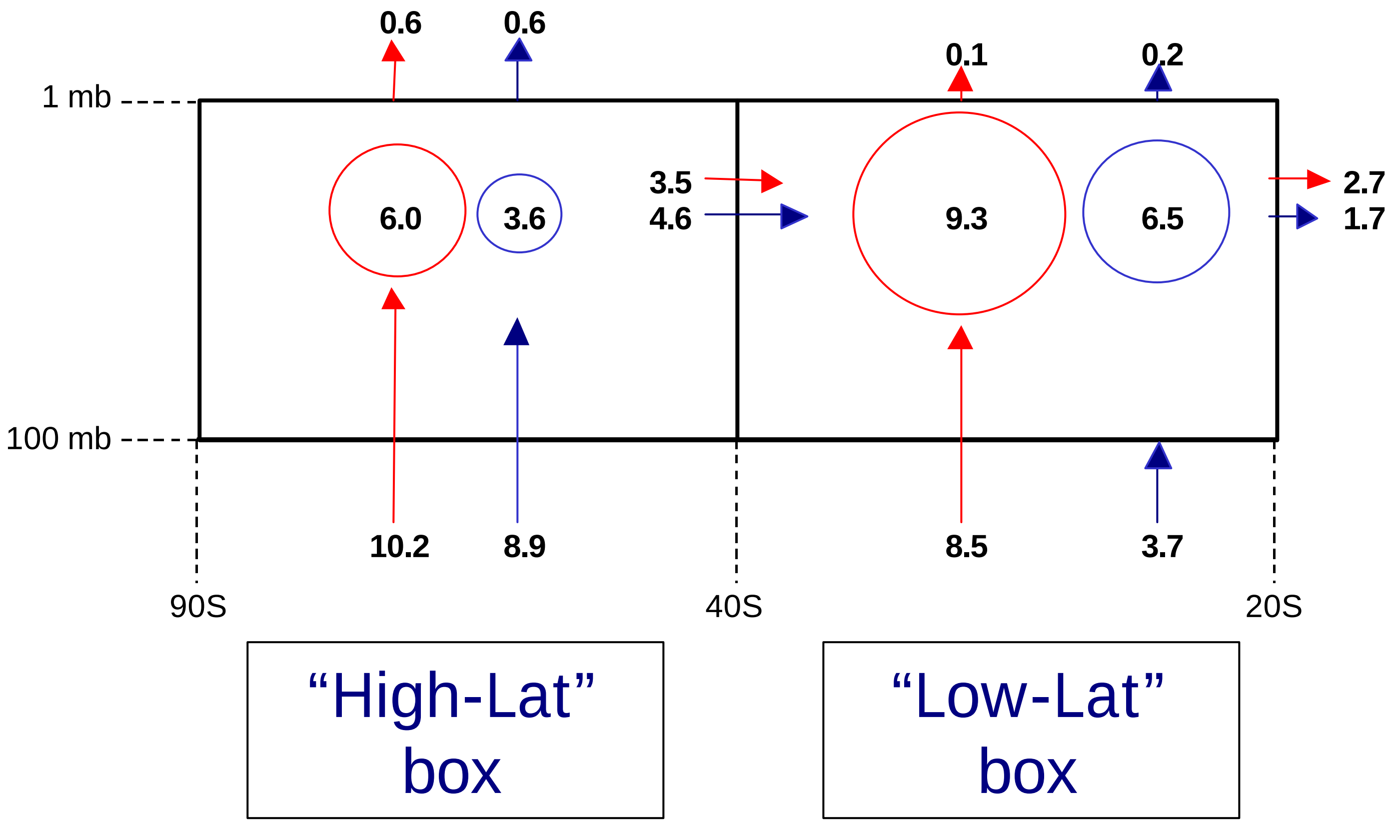
EP Flux Budget for Two Boxes



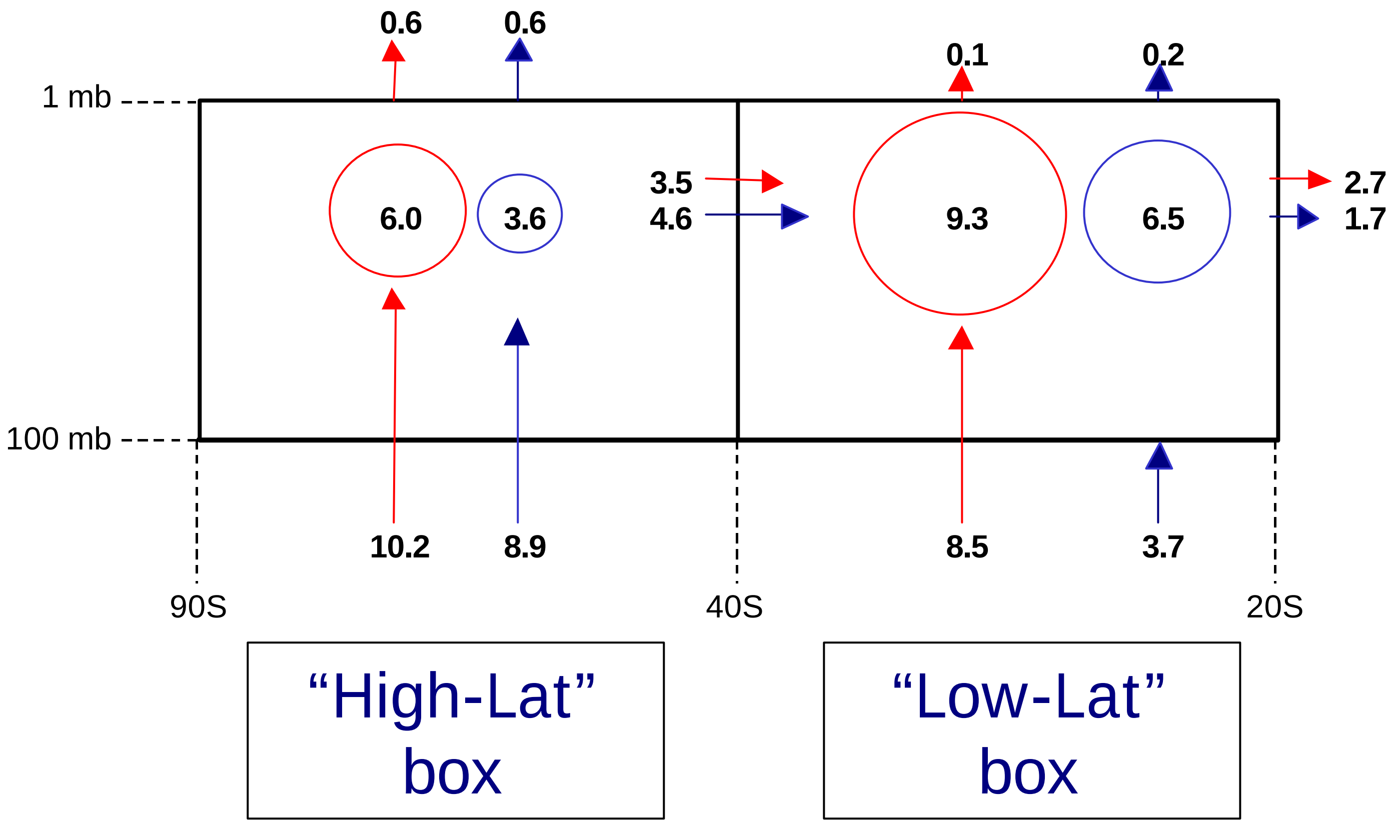
“High-Lat” box: budget for the polar vortex

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

EP Flux Budget



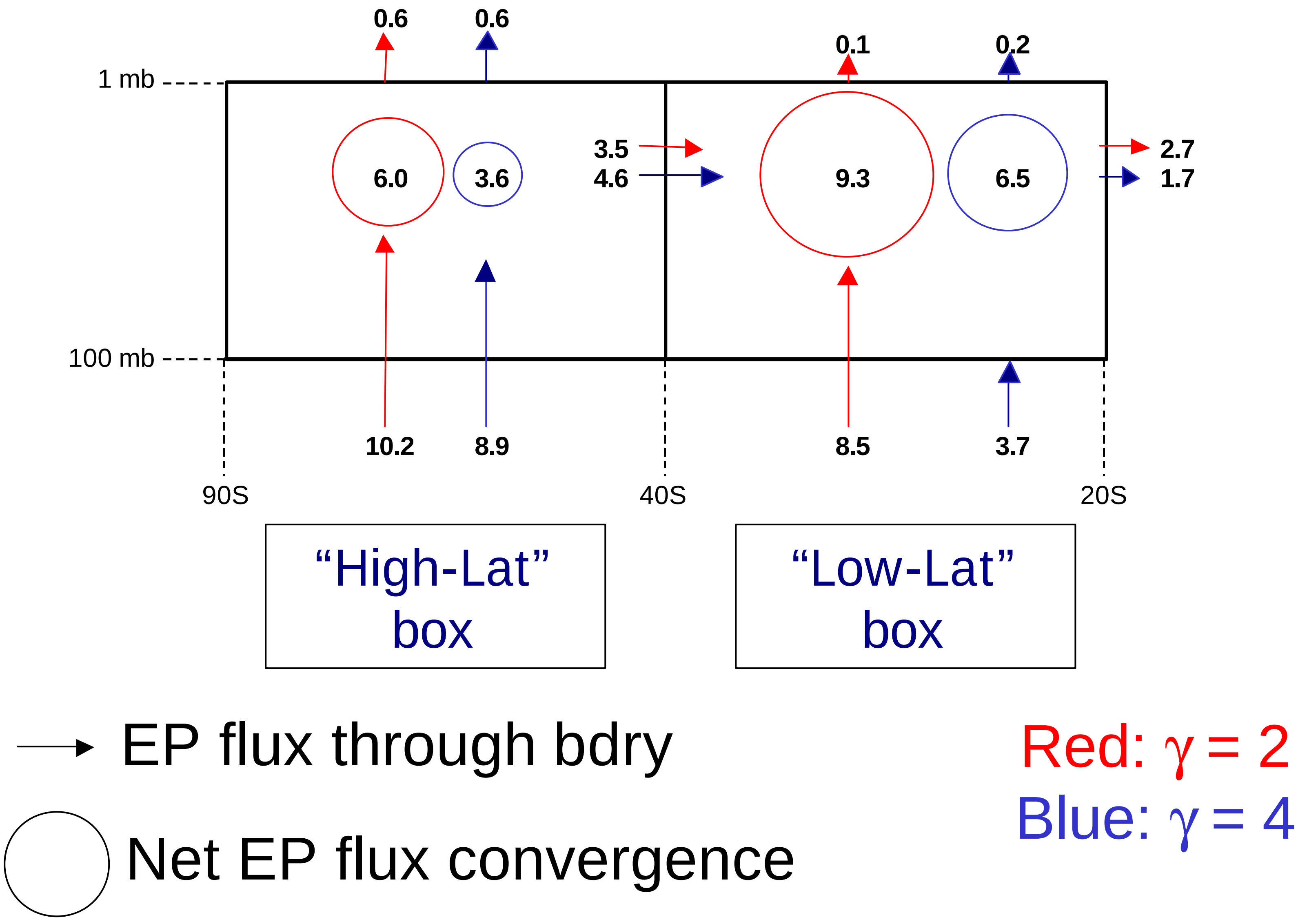
EP Flux Budget



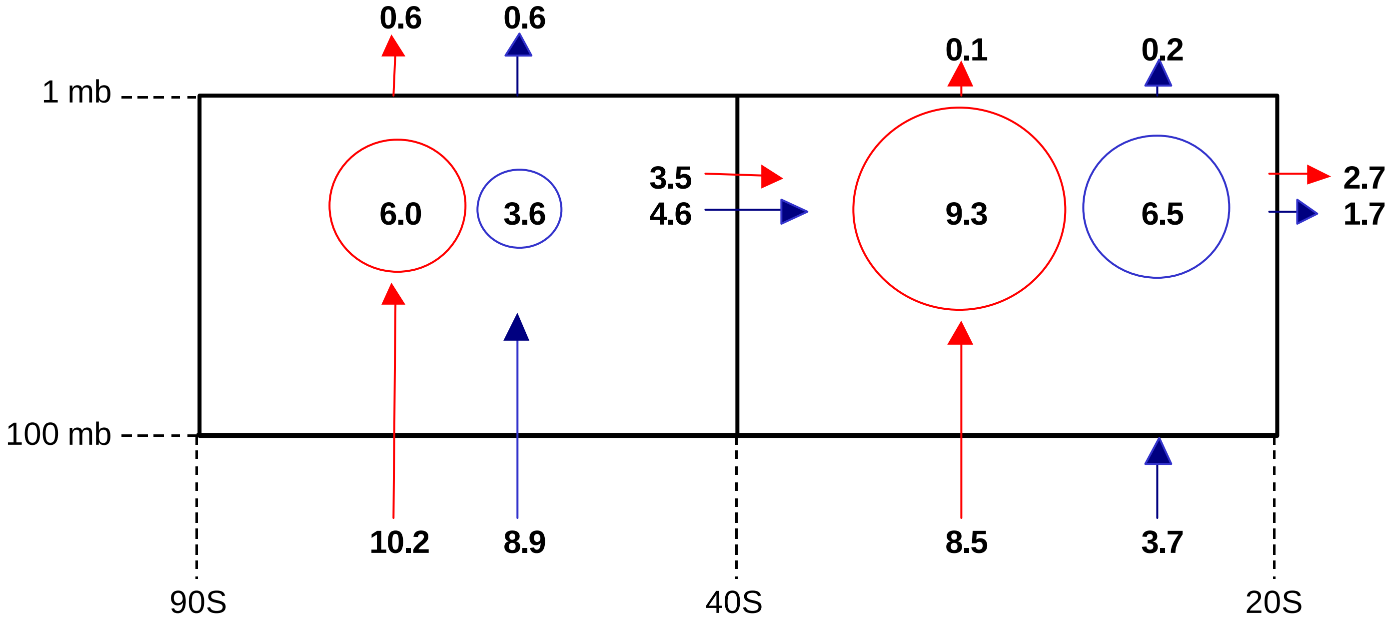
EP flux through bdry

Net EP flux convergence

EP Flux Budget



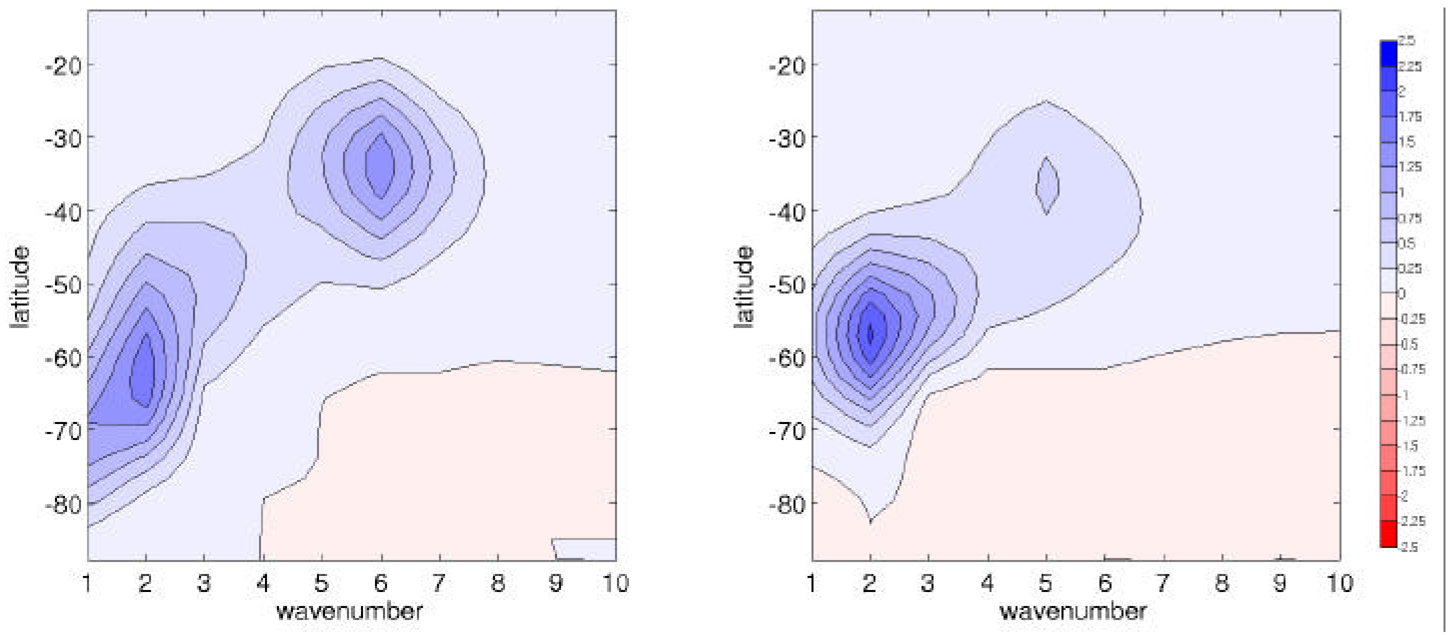
EP Flux Budget



- 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

$F_{(p)}$(100mb)



$\gamma = 2$ $\gamma = 4$

Biggest reduction at synoptic scales

All very well, but ...

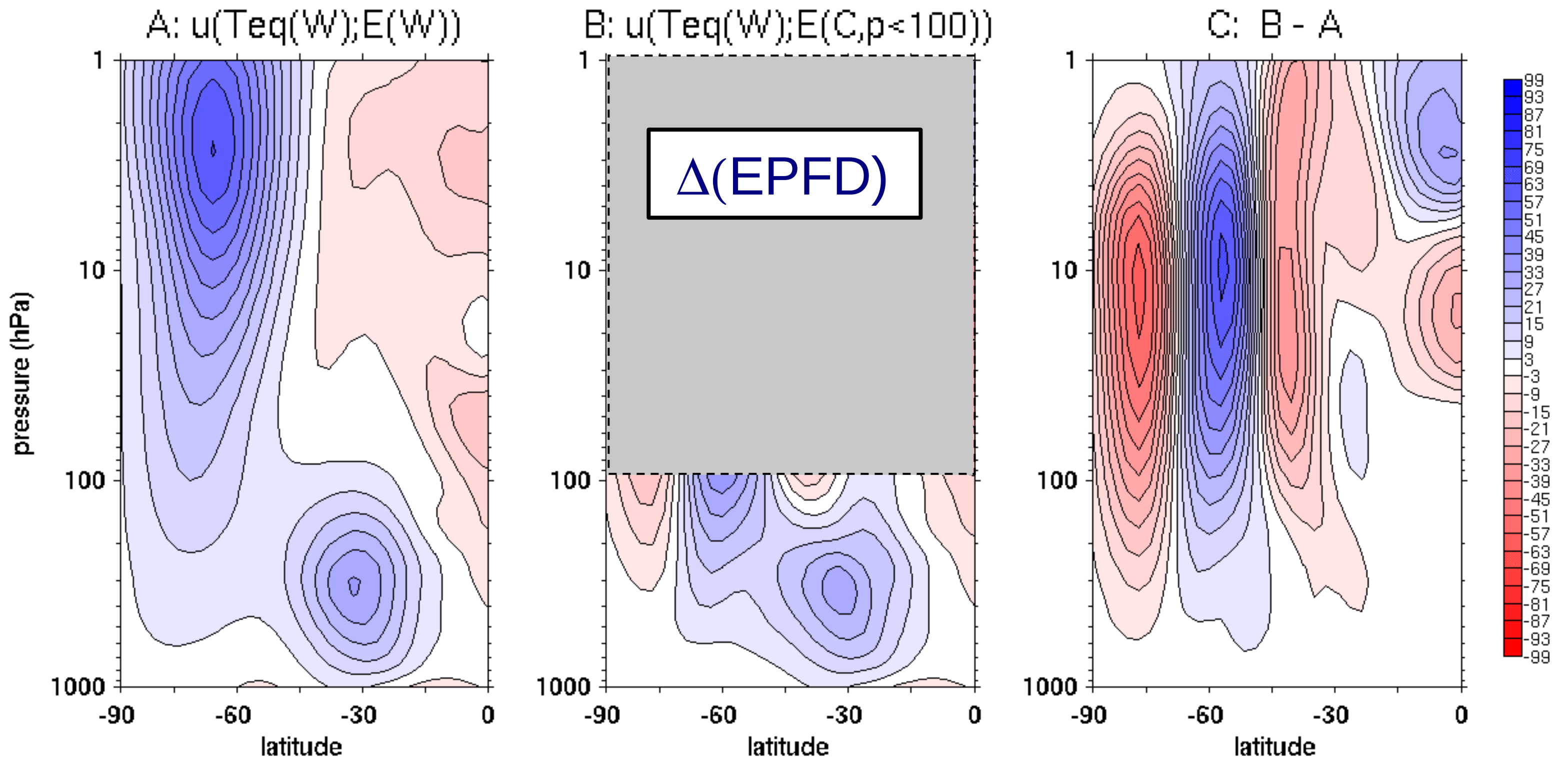
- What do these changes in the EP flux actually explain about the changes to the mean state?
- Which is cause, which is effect?
  - Is the vortex stronger because it absorbs less upward propagating wave activity?
  - Or, is there less upward propagating wave activity because the vortex is less absorbing?
- 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

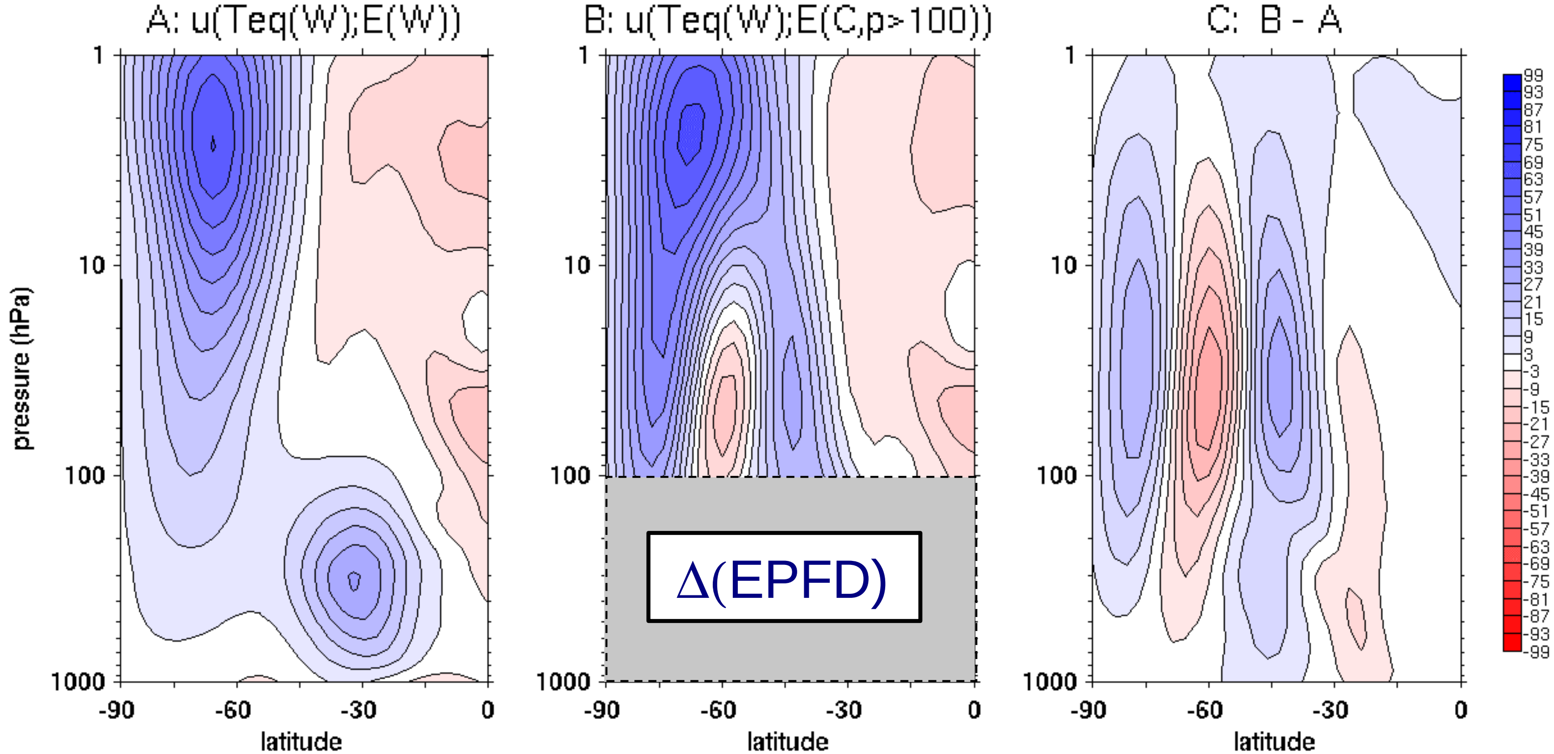
- First, we put in the changes to the EP fluxes from γ=2 to γ=4 for p < 100 mb ...



- The response penetrates into upper trop, but trop jet does not shift.

Zonally Symmetric Model Experiments

- Next, we put in the changes to the EP fluxes from γ=2 to γ=4 for p > 100 mb ...



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

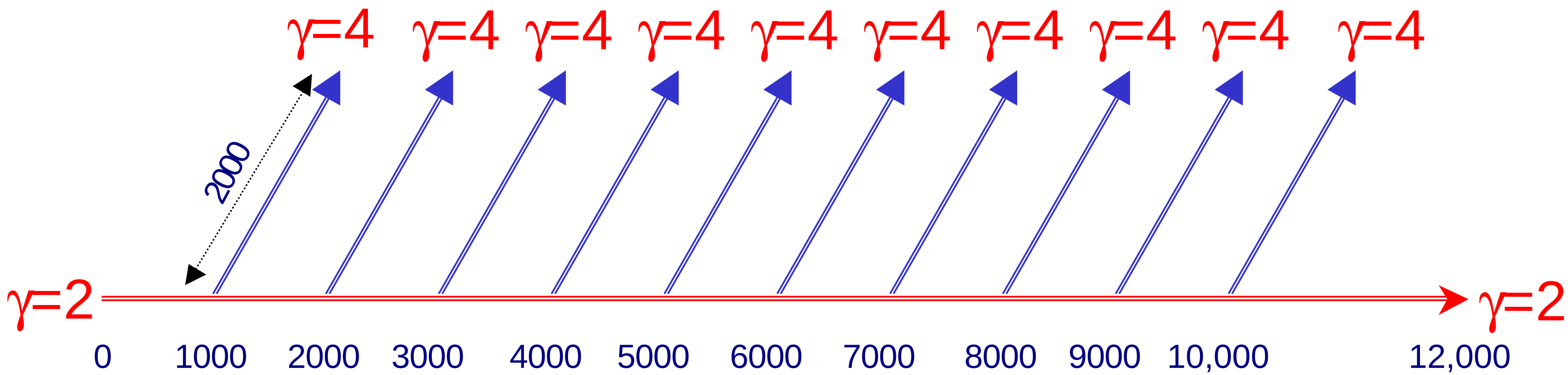
Response of the Eddy Driving

- 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

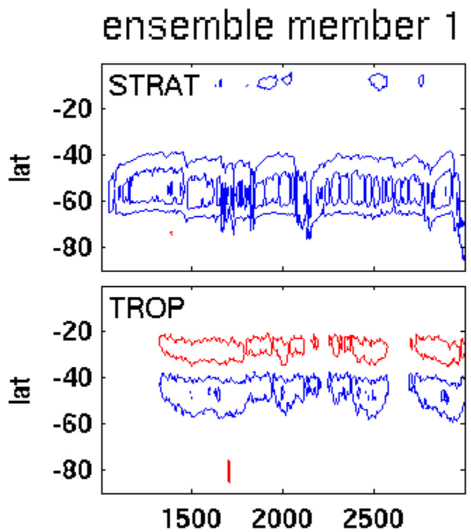
Timescales of Adjustment



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

Timescales of Adjustment

Difference of U from γ=2 Case

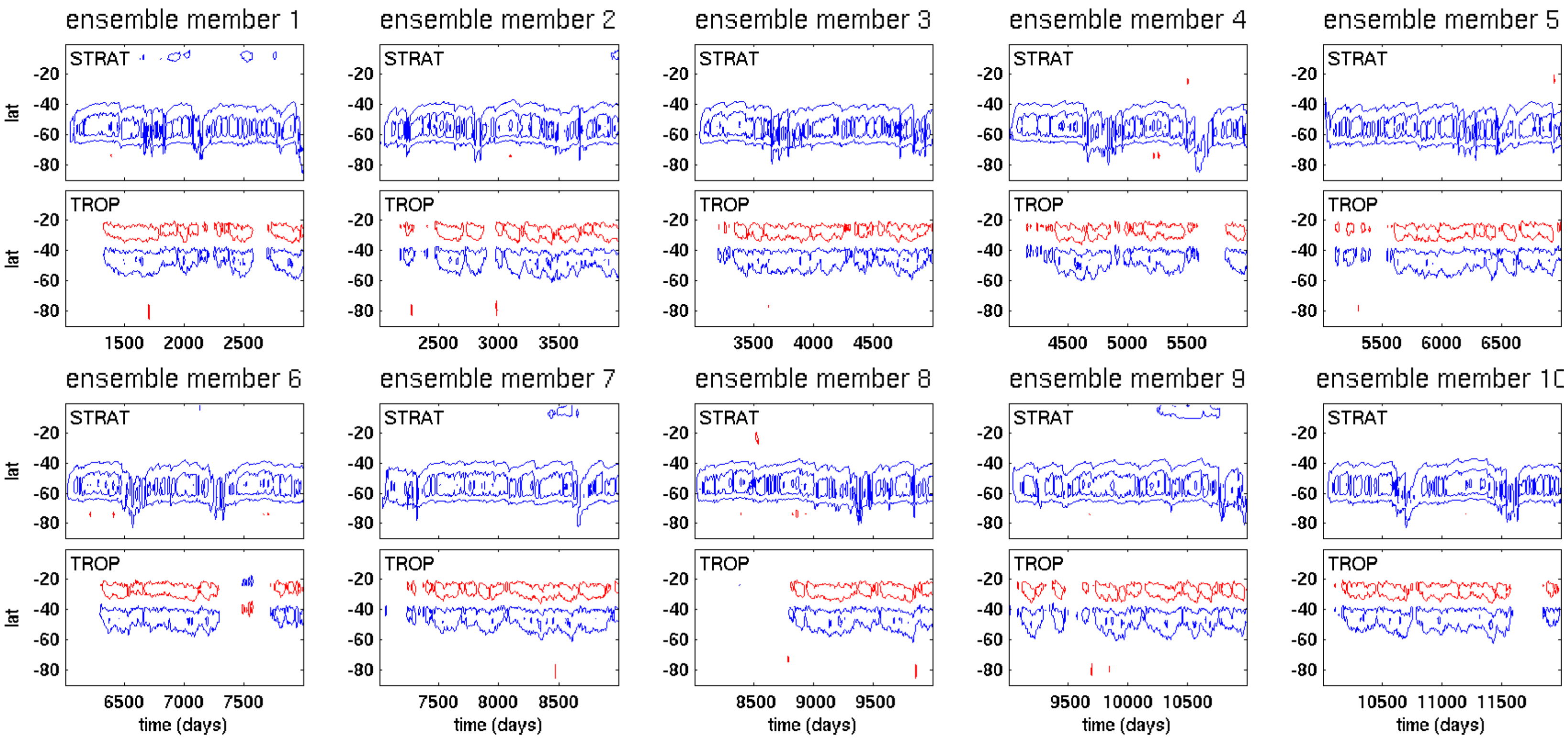


5 mb

500 mb

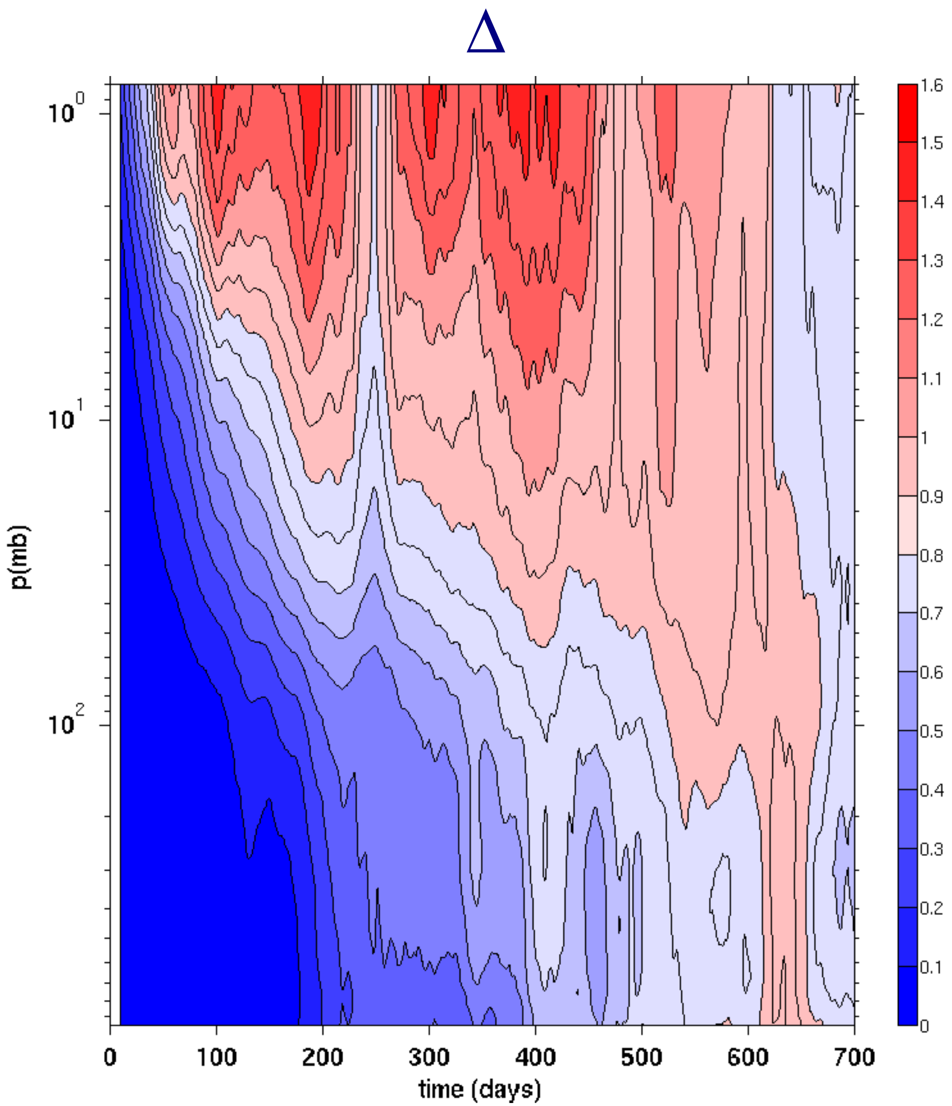
One realization …

Timescales of the Transient Adjustment



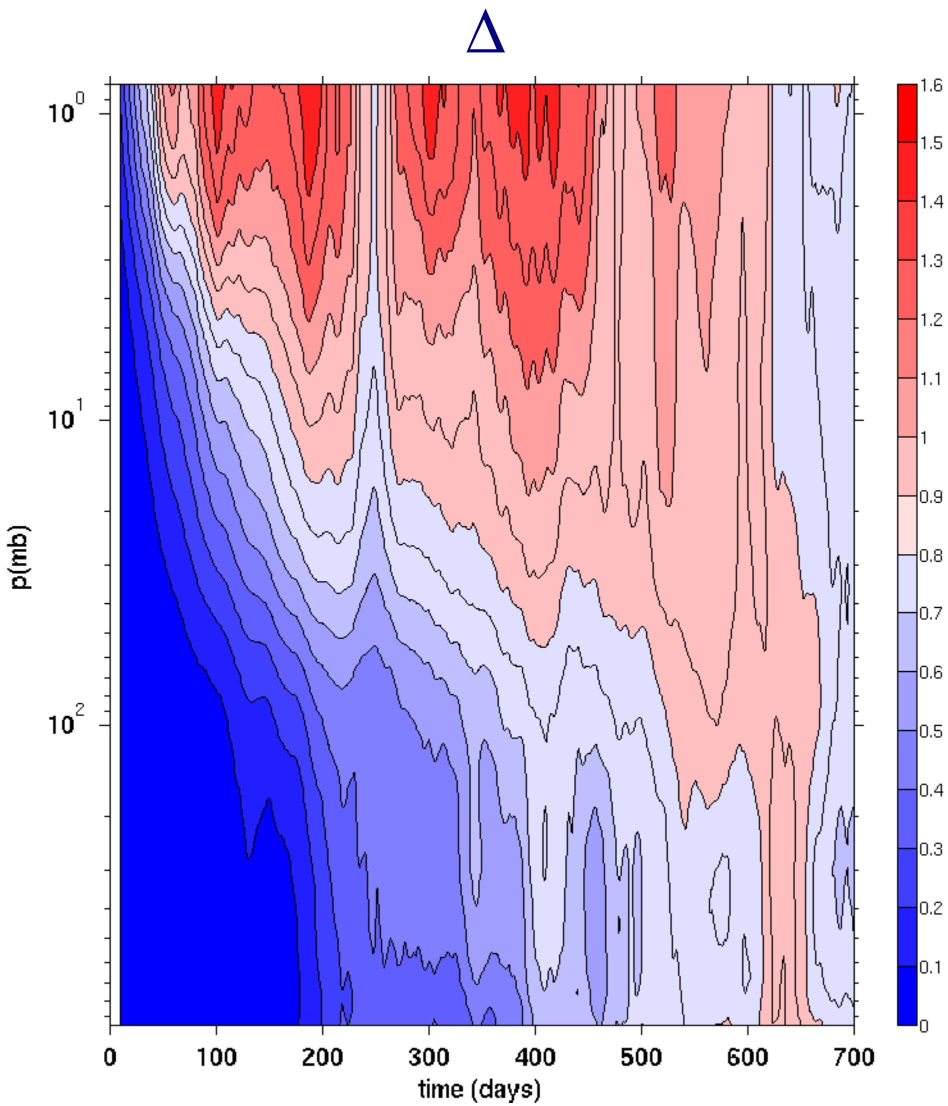
- stratosphere adjusts very rapidly O(50 days)
- troposphere adjusts more slowly O(200 days)

Timescales of the Transient Adjustment



- Δ: measure of ensemble- mean extratropical wind difference from U(γ=2)
- Δ→1 as U→U(γ=4)

Timescales of the Transient Adjustment



- Initially, signal propagates from 1 to 100 mb
  in roughly 150 days
  $\rightarrow$ 0.23 km/day
- Dickinson (1968), Haynes et al. (1991) predicts
  $\rightarrow c \sim k_T H$
  ~ 0.2 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).

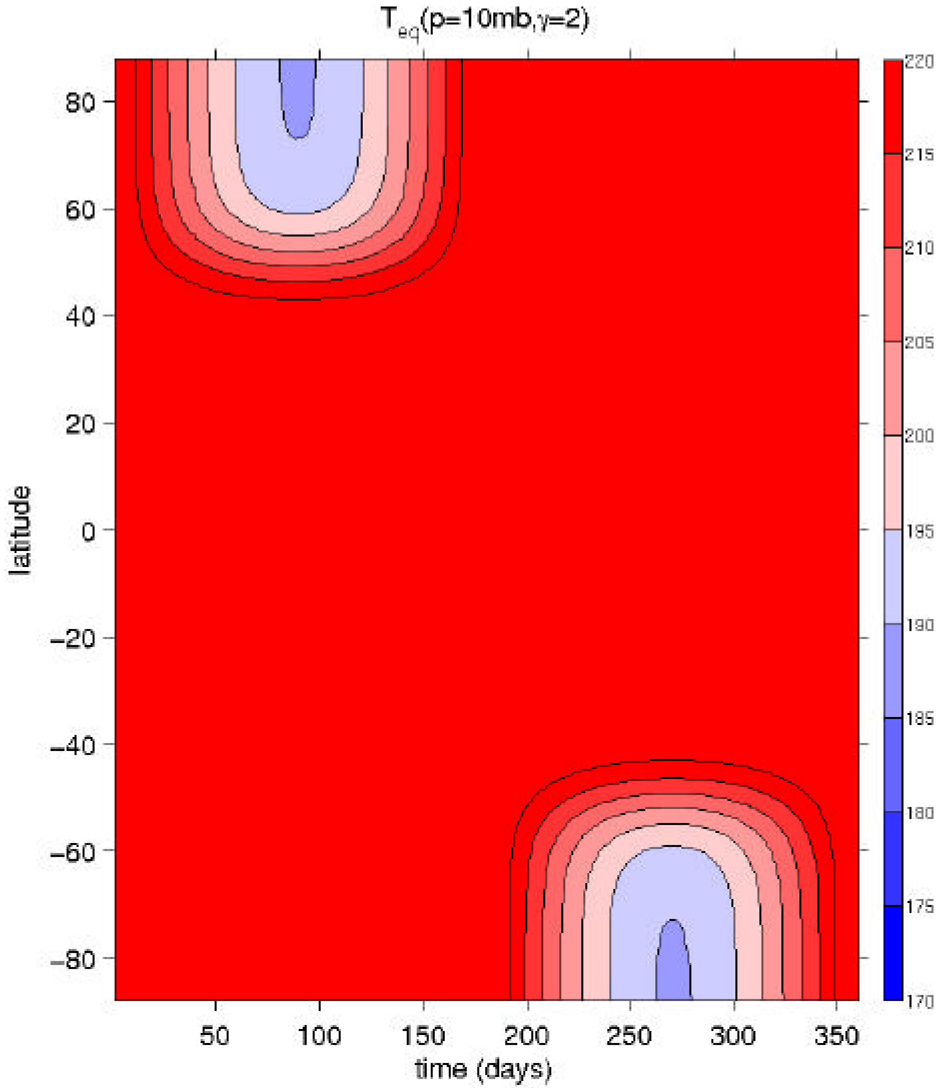
Transient Adjustment: Conclusions

- Thus, the stratosphere “tickles” the troposphere, and the tropospheric baroclinic eddy circulation responds, unpredictably and strongly, over a longer time scale

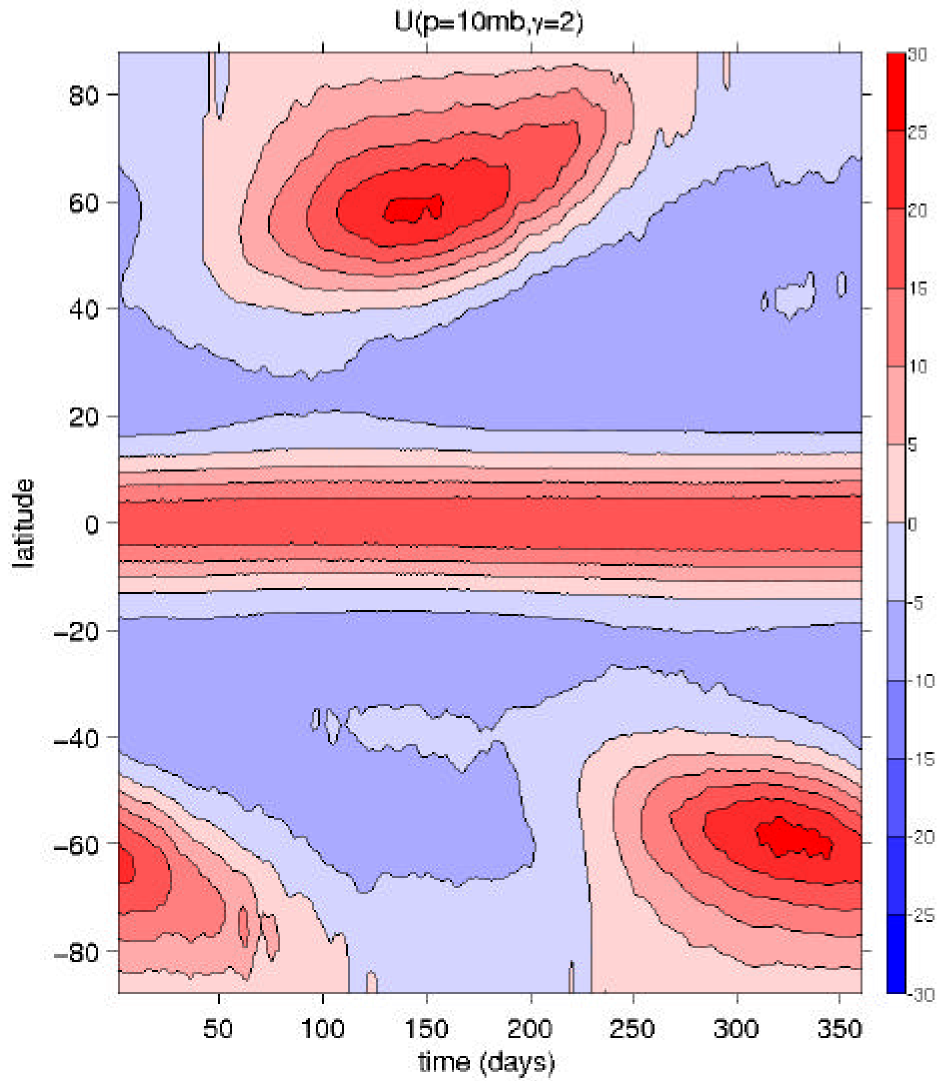
Response in Presence of Seasonal Cycle

- 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



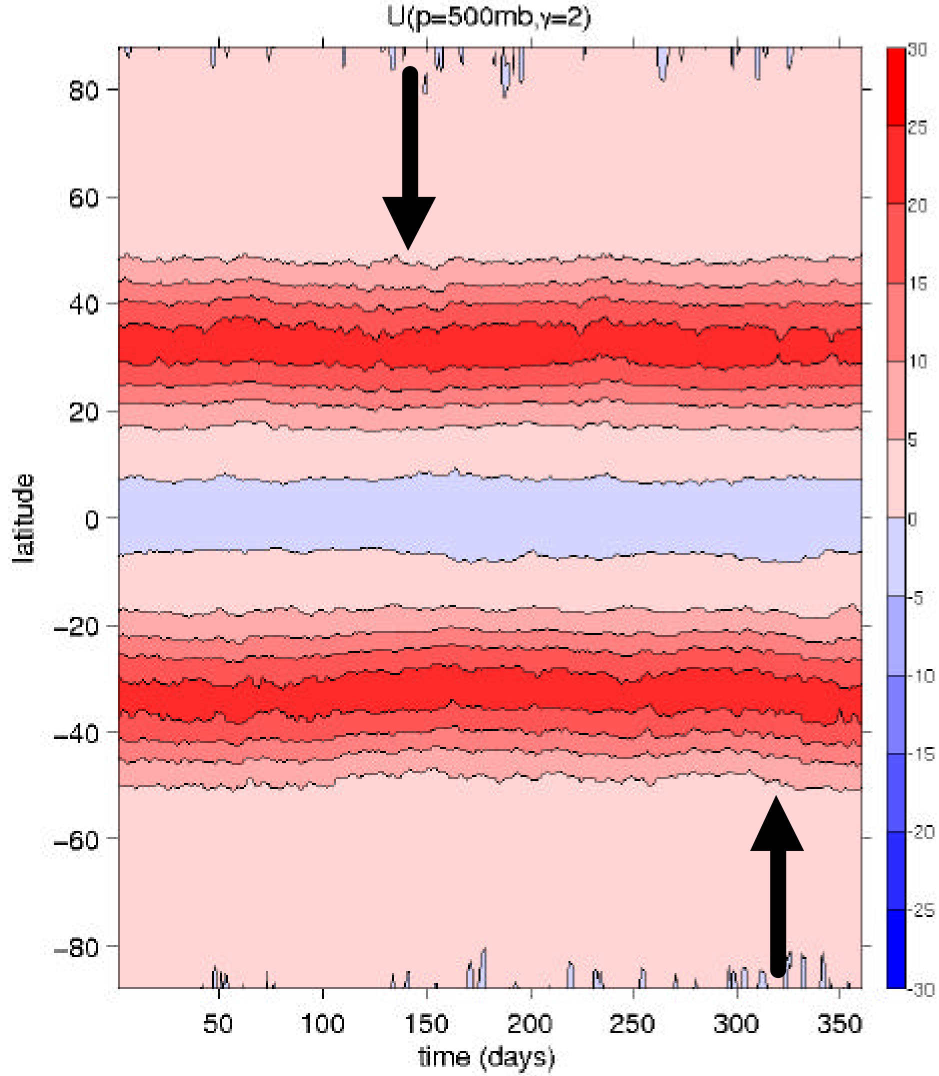
Seasonal Cycle of U(γ=2), 10mb



Westerlies weaker than steady-forced case

(20-year climatology)

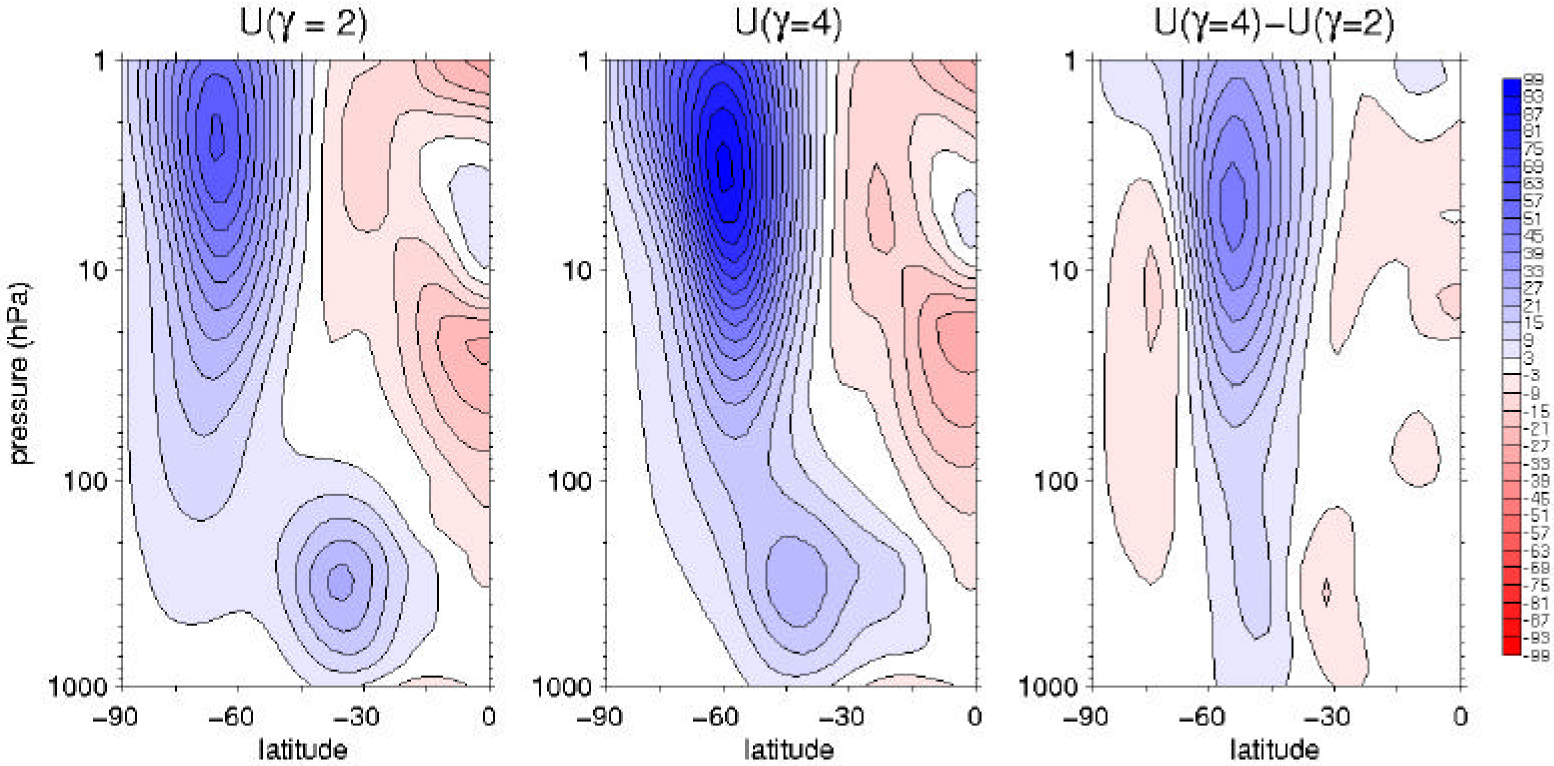
Seasonal Cycle of U(γ=2), 500mb



Very weak seasonal cycle in trop

(20-year climatology)

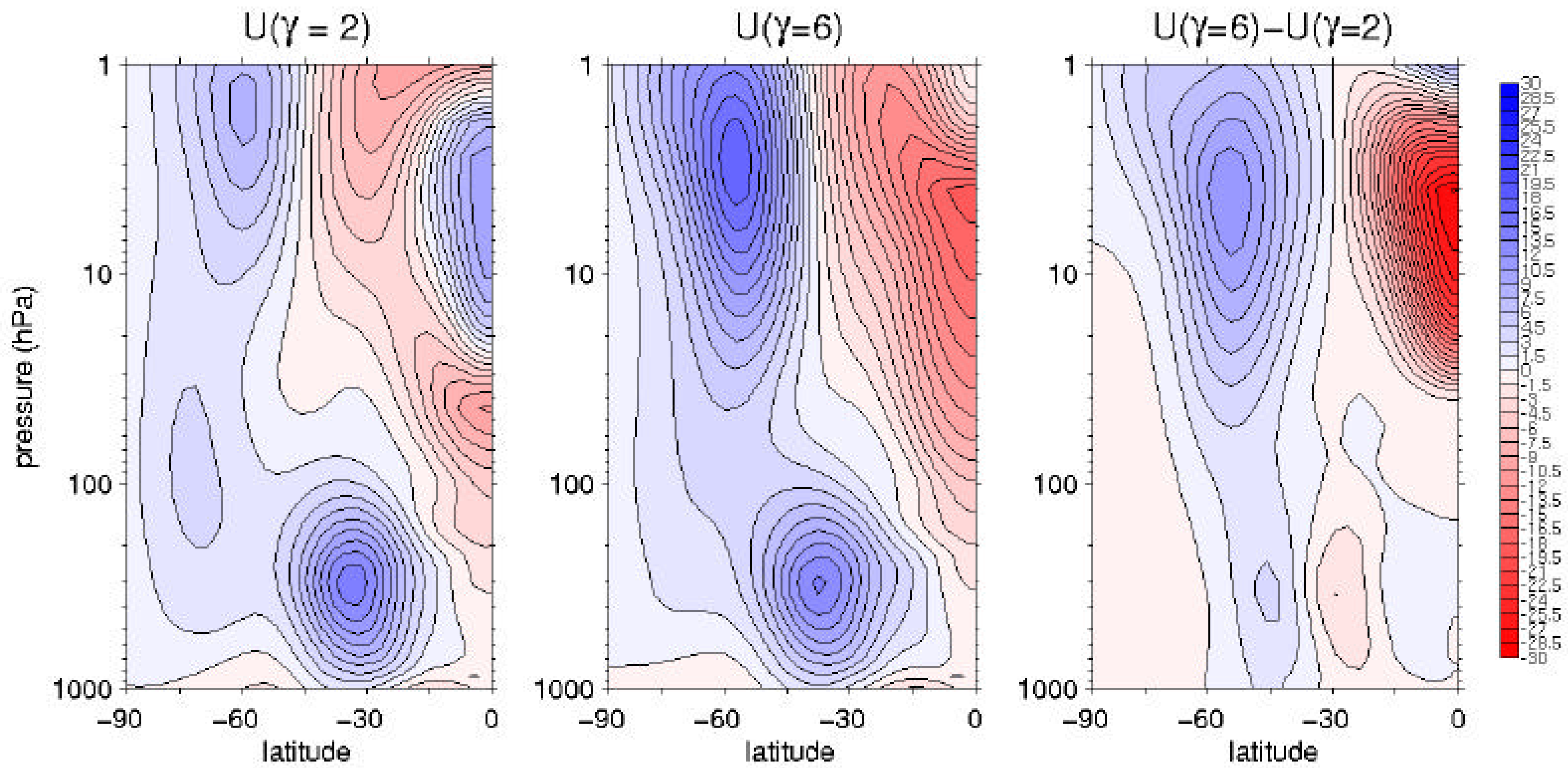
Steady Forcing Case...



Extratropical $\delta U_{trop}/\delta U_{strat} \sim 0.25$

Representative Seasonal Cycle Case

(Combined NH + SH 20-year annual mean)



- Strat + trop response weaker, even for γ=6
- Extratropical $\delta U_{trop}/\delta U_{strat}$~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.

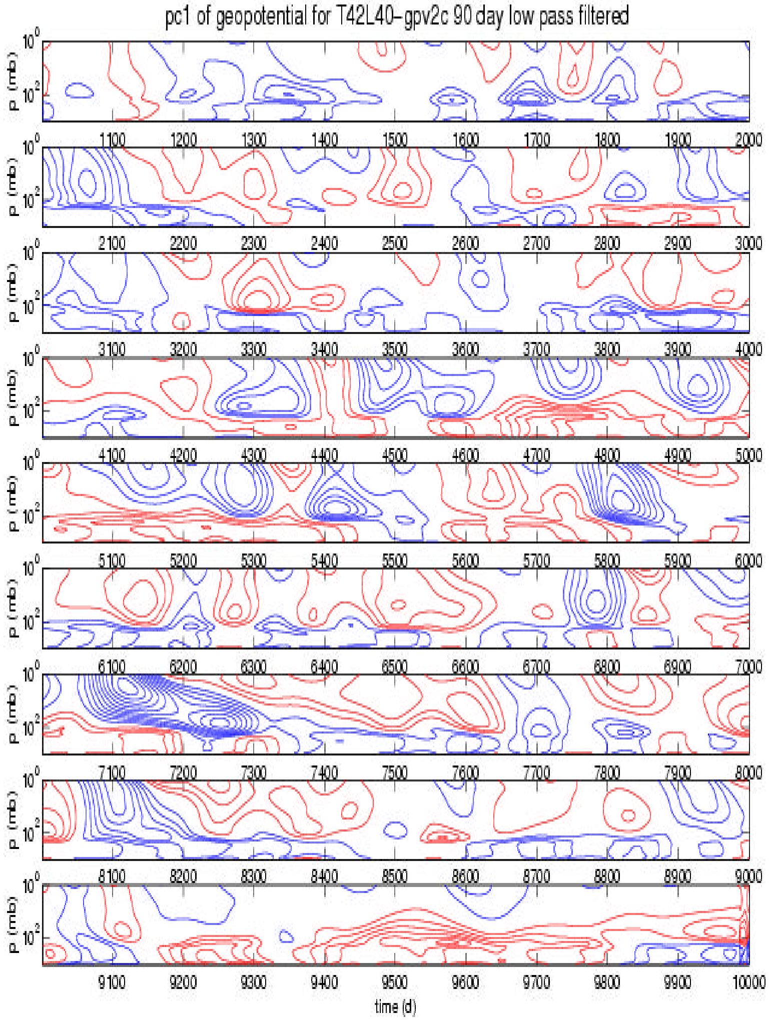
Strat-to-Trop Signals

- 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

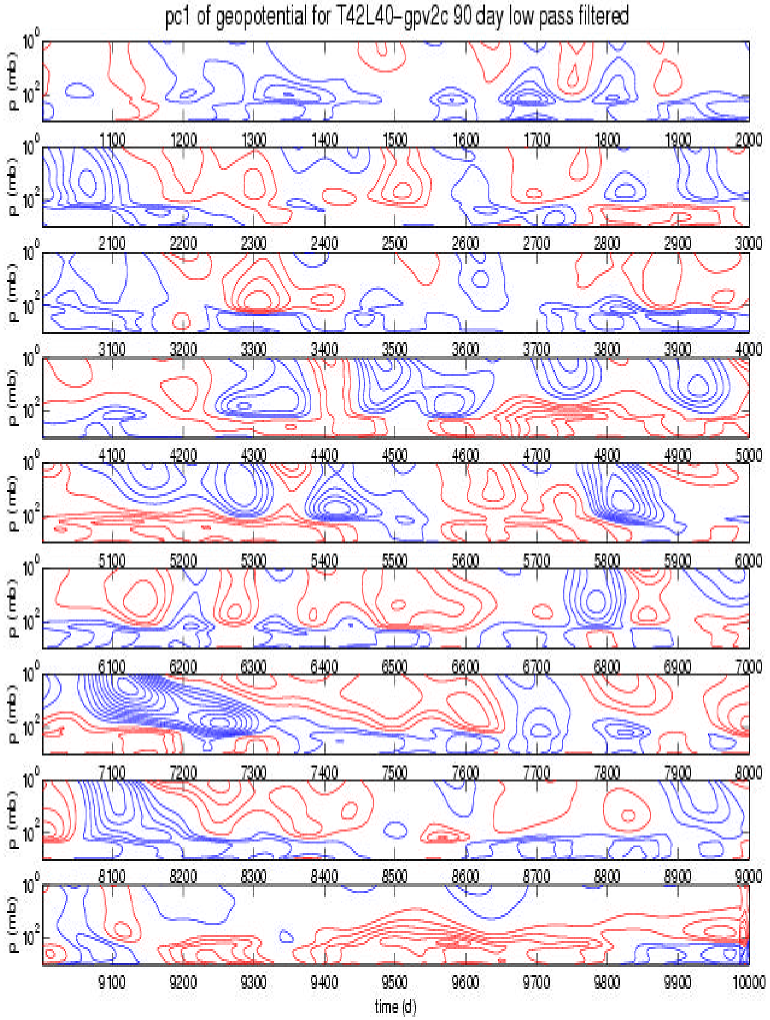
Baldwin & Dunkerton construction



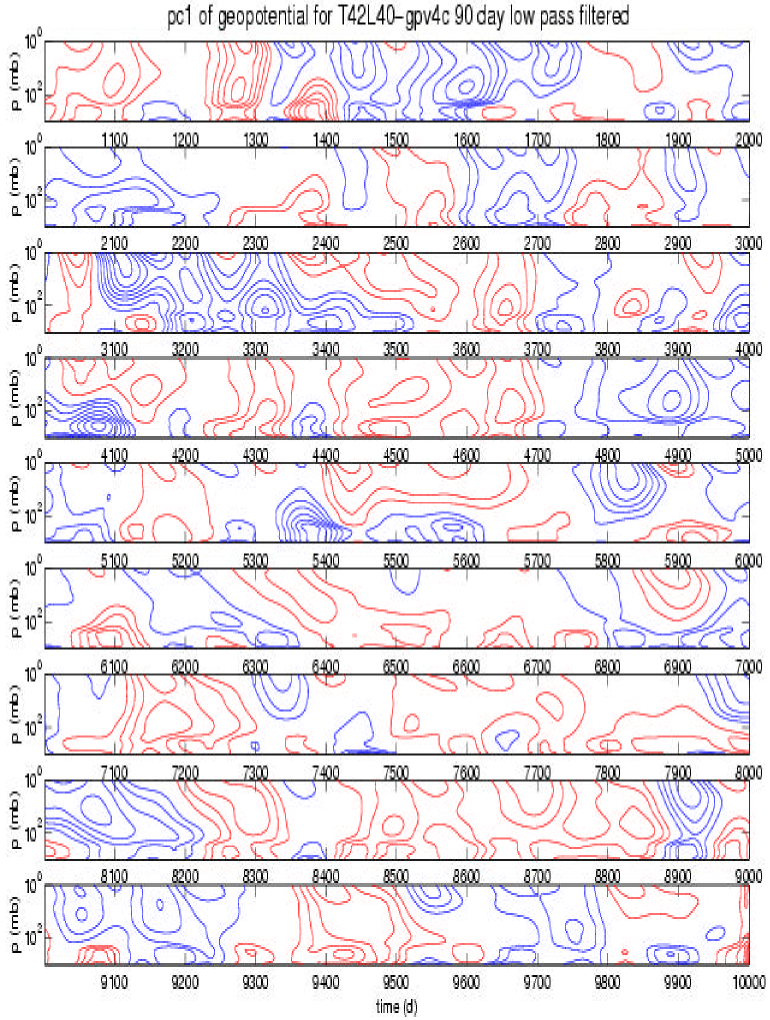
$$g = 2$$

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

Baldwin & Dunkerton construction



$g = 2$



$g = 4$

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.