Mechanisms for influence of the stratosphere on the troposphere

- Radiative
- Mass transfer/chemical
- Dynamical

Alan Plumb
M. I. T.
Apr 2003
What dynamical effect does the stratosphere have on the troposphere?
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- What does the question mean?
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- **What does the question mean?**
  - How does the troposphere react to a reasonable change in the stratospheric state?
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- **What does the question mean?**
  - How does the troposphere react to a reasonable change in the stratospheric state?
    - *What are the mechanisms?*
  - The stratosphere responds to the upwelling EP flux
Stratospheric response to tropospheric wave “bursts” [1]

Zonal mean winds, 60 °S, Sept 2002

- 10hPa
- 30hPa
- 50hPa
- 70hPa
- 100hPa
- 150hPa

u (ms⁻¹) [offset]

date

2002-09-01 2002-09-06 2002-09-11 2002-09-16 2002-09-21 2002-09-26

150hPa EP flux
What dynamical effect does the stratosphere have on the troposphere?

- **What does the question mean?**

  - How does the troposphere react to a reasonable change in the stratospheric state?
    - What are the mechanisms?

  - The stratosphere responds to the upwelling EP flux
    - What determines the EP flux into the stratosphere?
What dynamical effect does the stratosphere have on the troposphere?

- *Is there any unambiguous observational evidence for such an effect and how could it be identified?*
Possible mechanisms for feedback

- Planetary scale Rossby waves penetrate the winter stratosphere; drive circulation
- Synoptic scale eddies sensitive to near-tropopause conditions
- Reflection?
Lorenz & Hartmann
Possible mechanisms for feedback

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Planetary wave reflection

Fig. 7. Daily longitude-height cross sections at 60°S of wave 1 geopotential height for 10–15 Aug 1996. Contour intervals are at 0, ±100, ±200, ±400, ±800, and ±1000–2500, in jumps of 250 mb. Negative values are dashed. The vertical grid is the observational grid in millibars (100–0.4 mb).

The Effect of Reflecting Surfaces on the Vertical Structure and Variability of Stratospheric Planetary Waves

Nili Harnik and Richard S. Lindzen
Response of tropospheric Rossby waves to a stratospheric wind shift

(Courtesy of Michael Ring, MIT)
Possible mechanisms for feedback

- Planetary scale Rossby waves penetrate the winter stratosphere; drive circulation
- Synoptic scale eddies sensitive to near-tropopause conditions
- Reflection?
- Change in upwelling EP flux
Possible mechanisms for feedback

- Planetary scale Rossby waves penetrate the winter stratosphere; drive circulation
- Synoptic scale eddies sensitive to near-tropopause conditions
- Tropopause
- Reflection?
- Meridional circulation
Remote balanced interaction

FIG. 5. As in Fig. 4b but for PV inversions (a) using static stability values representing an average over latitudes from 5° to 90°N, (b) that include the contribution of surface theta anomalies, and (c) that include the contribution of PV anomalies located at high latitudes in the upper troposphere.
EQ POLE

z

form drag at surface
drag applied where wave is dissipated
drag applied where wave is dissipated

westerly force applied where wave is generated

non-orographic forcing
Short-term response
Short-term response

\[
\frac{\partial U}{\partial t} < 0
\]
\( v'q' < 0 \)
\( \delta \tilde{q} > 0 \)
\( \delta \tilde{q} < 0 \)
EQ POLE

\[ \delta U < 0 \]

\[ \delta \tilde{q} > 0 \]

\[ \delta \tilde{q} < 0 \]

EQ POLE
Long-term steady response

$\delta U < 0$
“Downward control” does not always mean downward control!
Drag applied where wave is dissipated.

Form drag at surface.
Surface mean wind—long term balance

**Long-term QG steady state**

\[- f \bar{v}^* = \frac{1}{\cos \phi} \nabla_p \cdot \mathbf{F} + g \frac{\partial \tau}{\partial p} \]

\[\tilde{\omega}^* \frac{\partial \theta}{\partial p} = \left( \frac{p_0}{p} \right)^\kappa \frac{J}{\rho c_p} \]

**Integrated angular momentum balance**

\[\tau_S = -\frac{1}{g} F_p^S - \frac{1}{a \cos^2 \phi} \frac{\partial}{\partial \phi} \left( \cos^2 \phi \int u'v' \, dp \right) \]

- **Surface stress**
- **Form drag**
- **Lateral radiation of angular momentum**
Steady zonal wind response to EP flux convergence

control  
vertical shift  
latitude shift

Δu (vert shift - control)

Δu (lat shift - control)
Surface mean wind—long term balance

**Long-term QG steady state**

\[-f
\vec{v}^* = \frac{1}{\cos \phi} \nabla_p \cdot \mathbf{F} + g \frac{\partial \tau}{\partial p}\]

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- surface stress
- form drag
- lateral radiation of angular momentum
Short-term behavior
Downward propagation?

Stratospheric response to tropospheric wave “bursts” [1]

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- 50hPa
- 70hPa
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- 150hPa

EP flux
Downward propagation?

Baldwin, M.P., and T.J. Dunkerton, 2001: 
*Stratospheric harbingers of anomalous weather regimes.*

Response of a truncated $\beta$-channel model to periodic wave driving

Left: Wave amplitude (m; top) and mean zonal wind in response to periodically modulated tropospheric wave forcing. Right: Composites over one wave period. [Plumb & Semeniuk, 2003]
3D model results

[Plumb & Semeniuk, 2003]
Migration is not (necessarily) information transfer

Wave amplitude (m; top) and mean zonal wind in response to periodically modulated tropospheric wave forcing. Left: full response.

[Plumb & Semeniuk, 2003]
Migration is not (necessarily) information transfer

Wave amplitude (m; top) and mean zonal wind in response to periodically modulated tropospheric wave forcing. Left: full response. Right: response suppressed above 25km.

[Plumb & Semeniuk, 2003]
Downward propagation?

Relation with upwelling EP flux

Time of maximum imposed flux
Detecting an effect

- *Is there any unambiguous observational evidence for such an effect and how could it be identified?*
Detecting an effect

- *Is there any unambiguous observational evidence for such an effect and how could it be identified?*
  - Most stratospheric behavior has precursors in the troposphere
  - Need independent stratospheric signals
Signals of Stratospheric Origin: QBO

[Diagram showing Singapore zonal wind over years 79 to 01 with altitude in km and pressure in mb]
Difference in SAT between days 1-60 following weak and strong vortex conditions at 10-hPa; Januaries when the QBO is easterly and westerly; winters corresponding to the opposing phases of ENSO.

Thompson, Baldwin, and Wallace, J. Climate 2001
Fig. 6. Meridional sections of the monthly mean composite difference of the EP flux vectors $F^*$ in the Southern Hemisphere for August, September, October and November. Two arrows in the right of the panel display the lengths of $8 \times 10^{14}$ m$^4$ s$^{-2}$ equatorward and $2 \times 10^{12}$ m$^4$ s$^{-2}$ upward, respectively.
Conclusions

• *Short-term (intraseasonal)*
  – Not clear what effect there is
  – Annular modes appear to be controlled by synoptic scale eddies; any effect on annular modes (unless coincidental) requires an impact on tropospheric eddy, mean flow interaction
  – Even if the stratosphere has little or no causal effect, stratospheric behavior may be useful in forecasting for the troposphere by virtue of the rapid stratospheric response
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• **Long-term (climate)**
  – Tropospheric response to tropospheric wave forcing sensitive to location (in latitude but **not** altitude) of stratospheric wave dissipation (effect $\sim 1 \text{ms}^{-1}$)
  – Tropospheric planetary-scale waves (and EP flux into the stratosphere) have some sensitivity to latitudinal shifts of stratospheric winds
  – What controls the EP flux into the stratosphere? – The capacity of the stratosphere to absorb wave activity is finite