Mechanisms for influence of the stratosphere on the troposphere

- Radiative
- Mass transfer/chemical
- **Dynamical**

Alan Plumb
M. I. T.
Apr 2003

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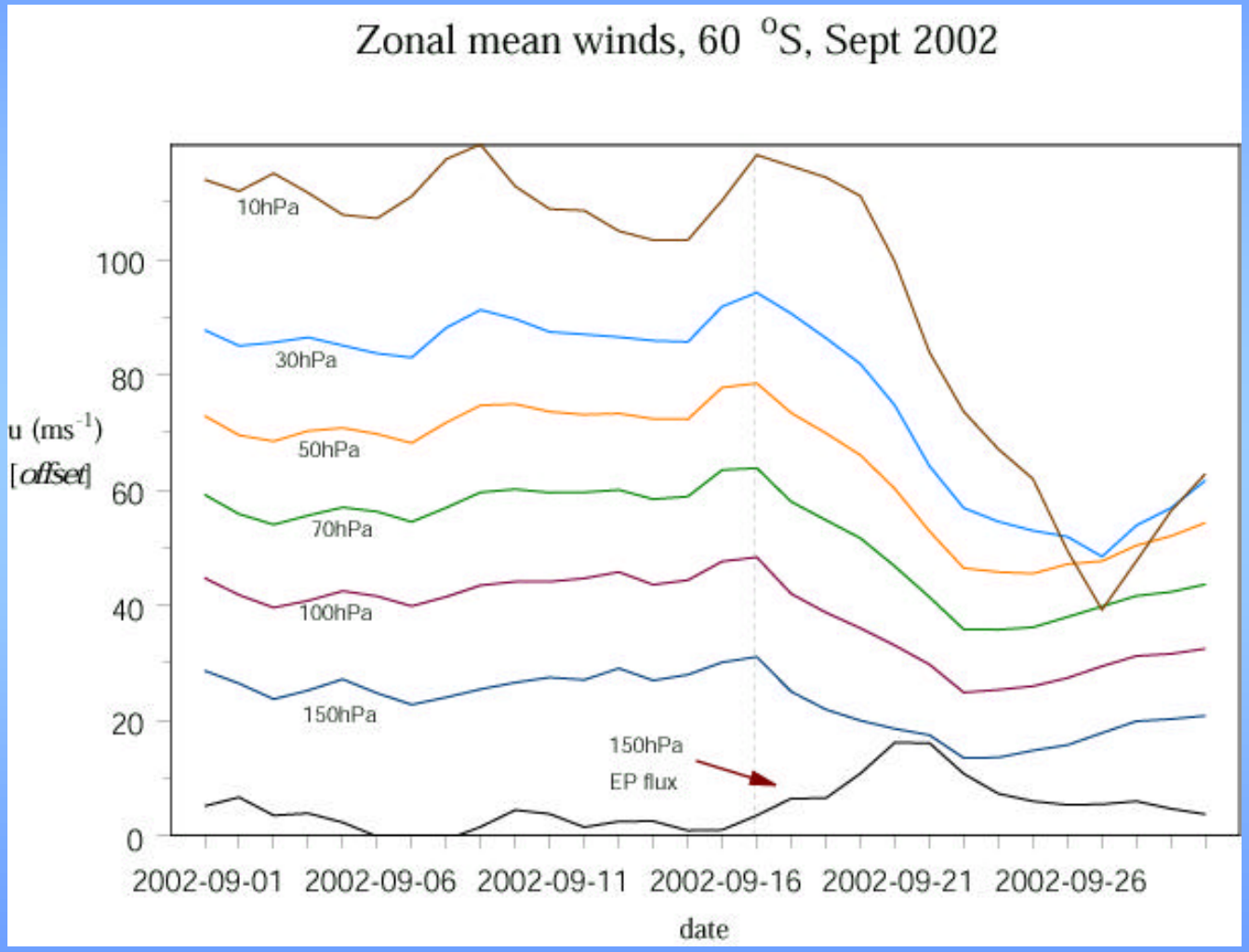
Stratospheric response to tropospheric wave “bursts” [1]



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- ***What does the question mean?***
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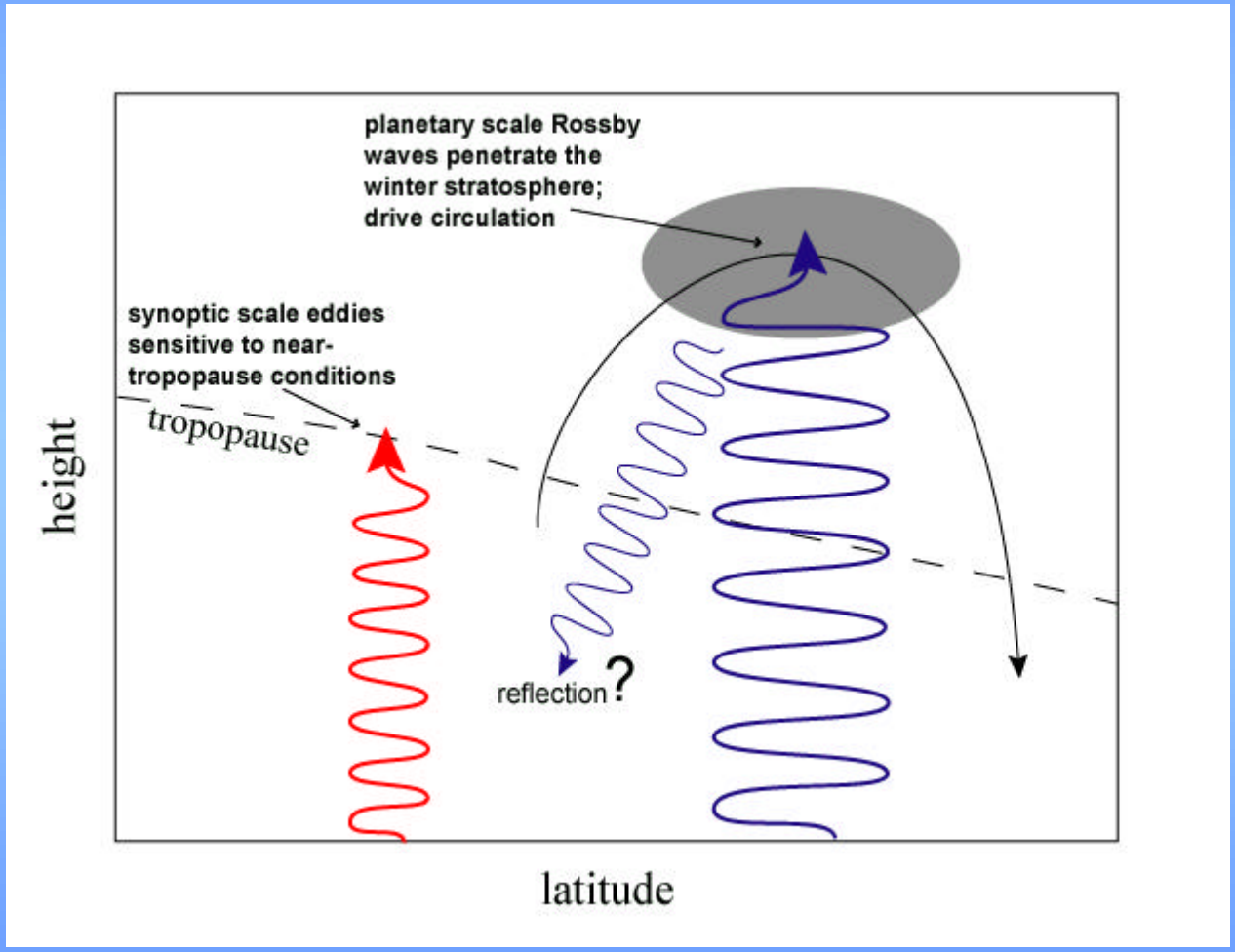
  - The stratosphere responds to the upwelling EP flux
    - ***What determines the EP flux into the stratosphere?***

What dynamical effect does the stratosphere have on the troposphere?

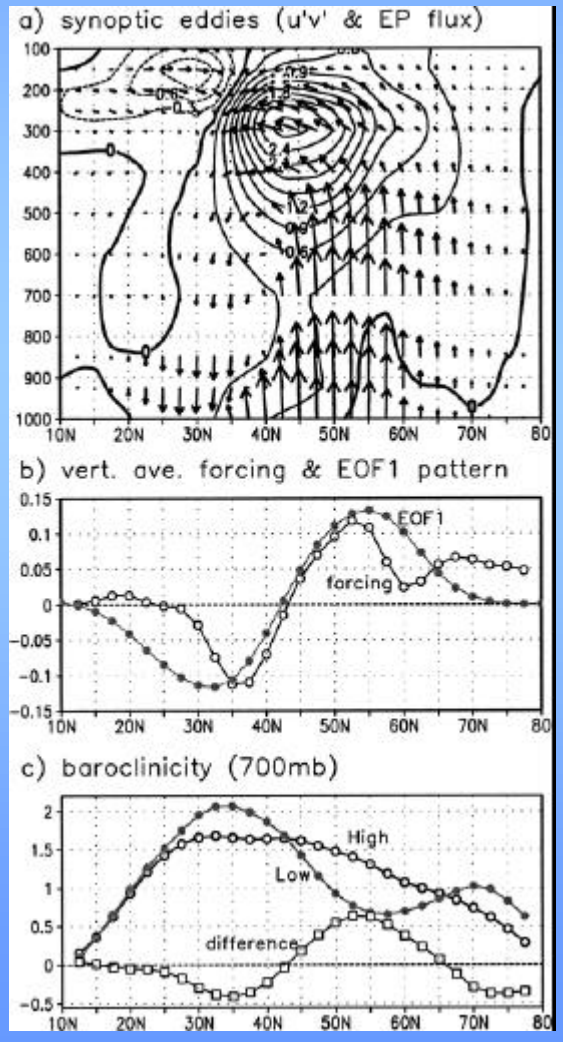
- ***Is there any unambiguous* observational *evidence for such an effect and how could it be identified?***

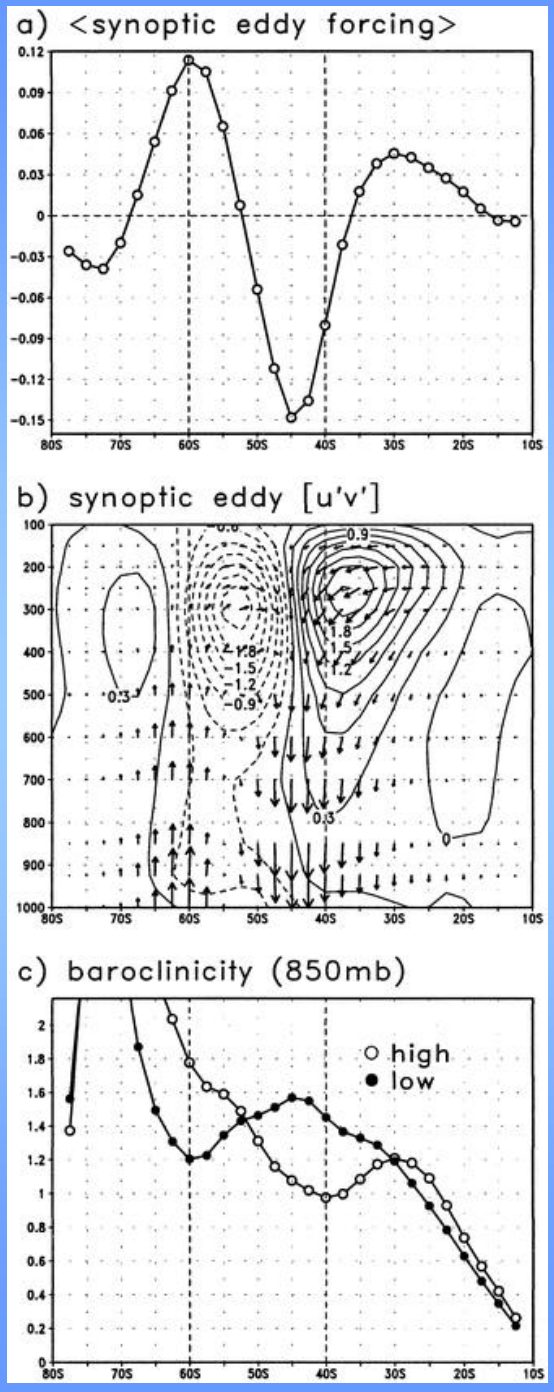
Possible mechanisms for feedback



Lorenz & Hartmann

J. Atmos. Sci (2001); J. Clim (2003)





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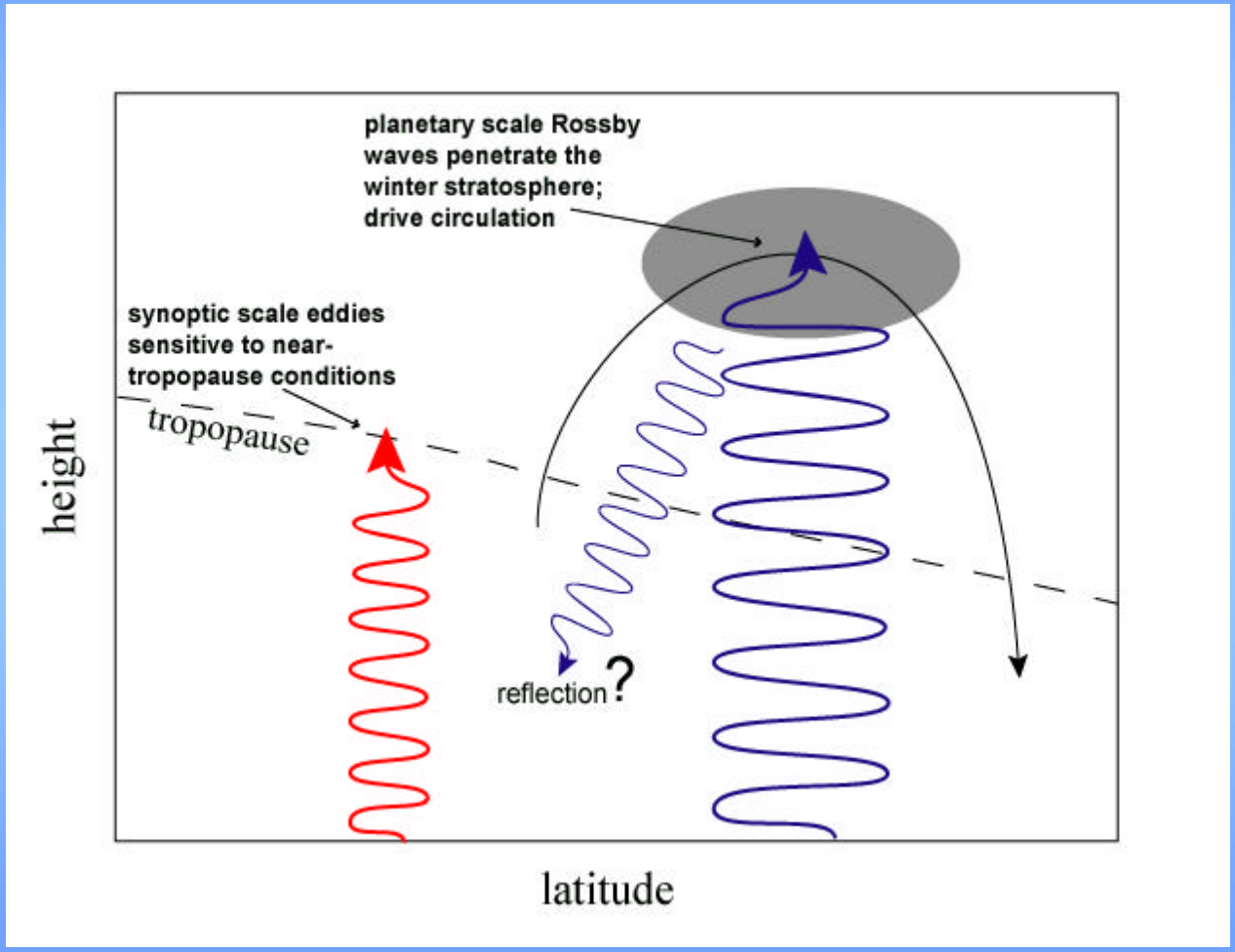


Planetary wave reflection

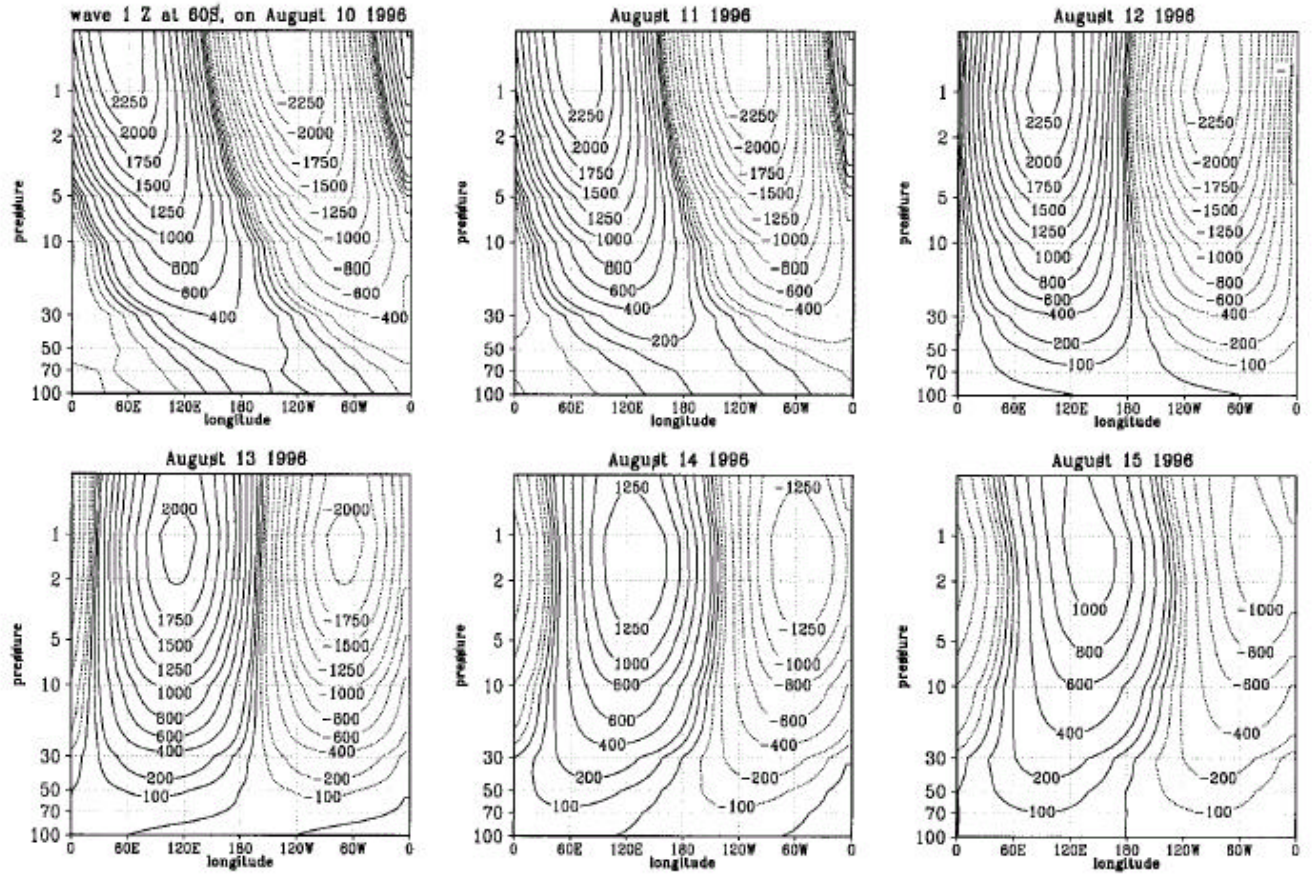
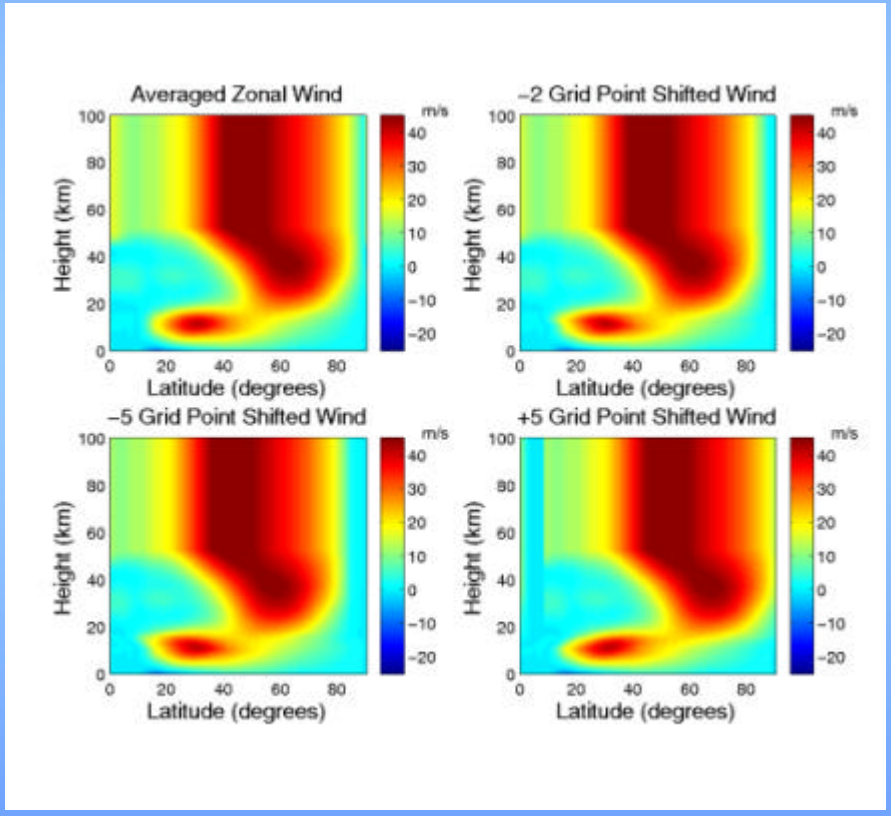


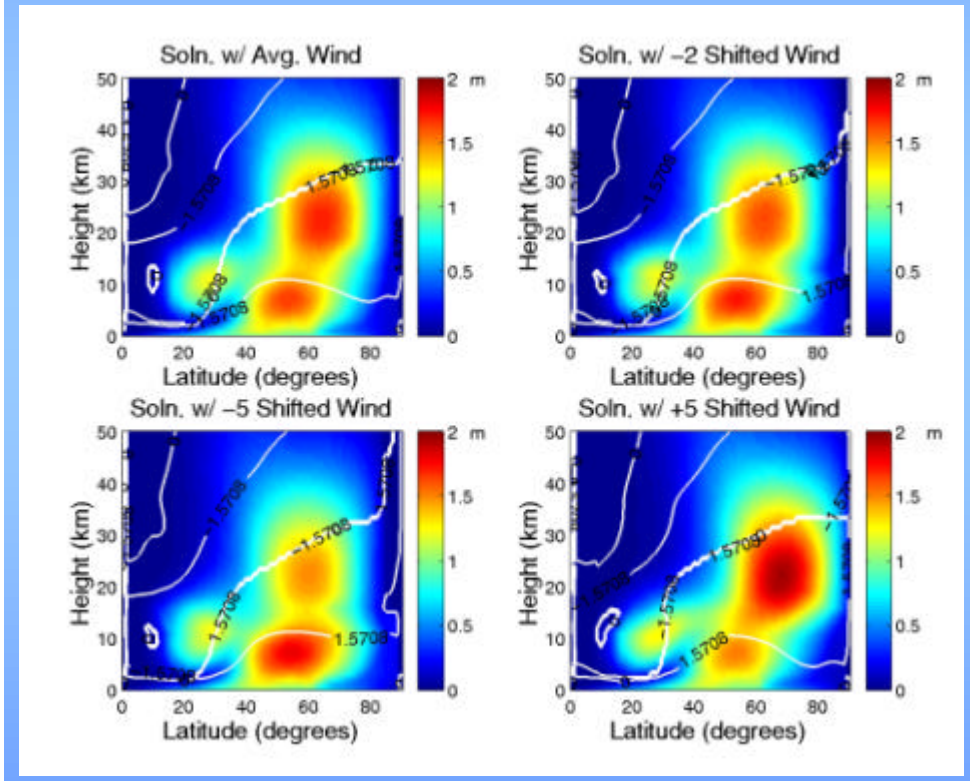
FIG. 7. Daily longitude–height cross sections at 60°S of wave 1 geopotential height for 10–15 Aug 1996. Contour intervals are at 0, ±100, ±200, ±400, ±600, ±800, and ±1000–2500, in jumps of 250 mb. Negative values are dashed. The vertical grid is the observational grid in millibars (100–0.4 mb).

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

NILI HARNIK AND RICHARD S. LINDZEN

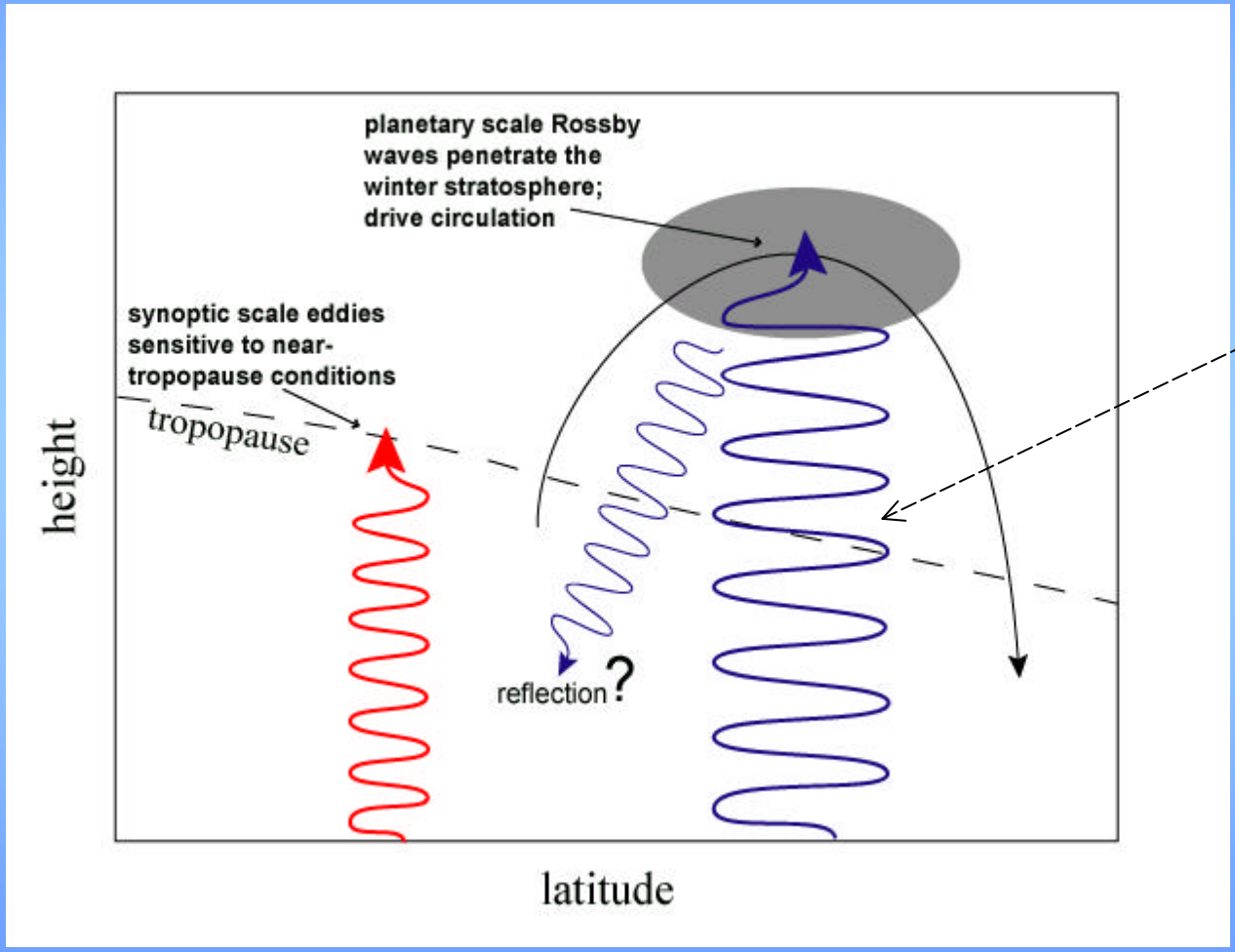
Response of tropospheric Rossby waves to a stratospheric wind shift





(Courtesy of Michael Ring, MIT)

Possible mechanisms for feedback



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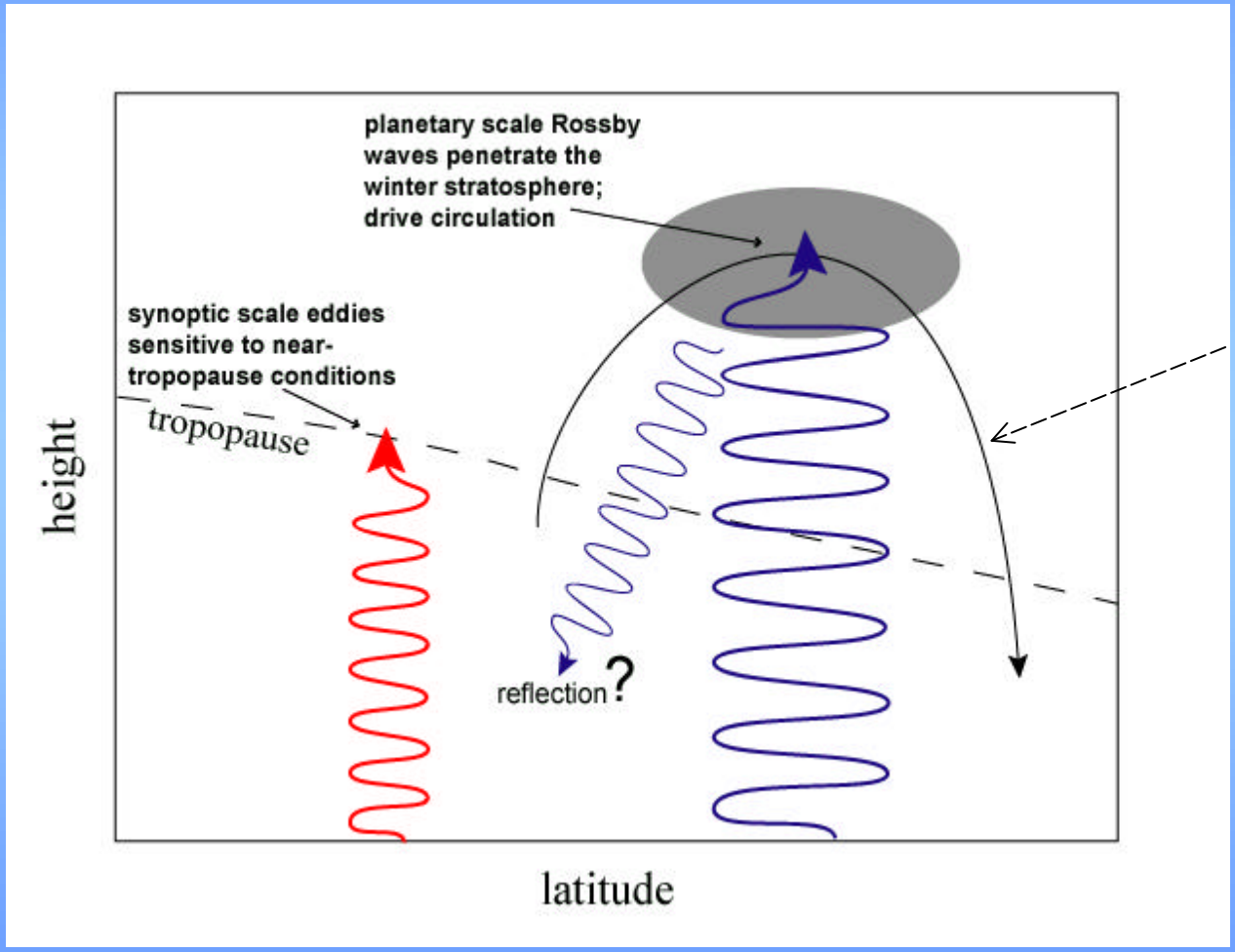


Remote balanced interaction

Stratospheric Forcing of Surface Climate in the Arctic Oscillation

ROBERT X. BLACK

School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, Georgia

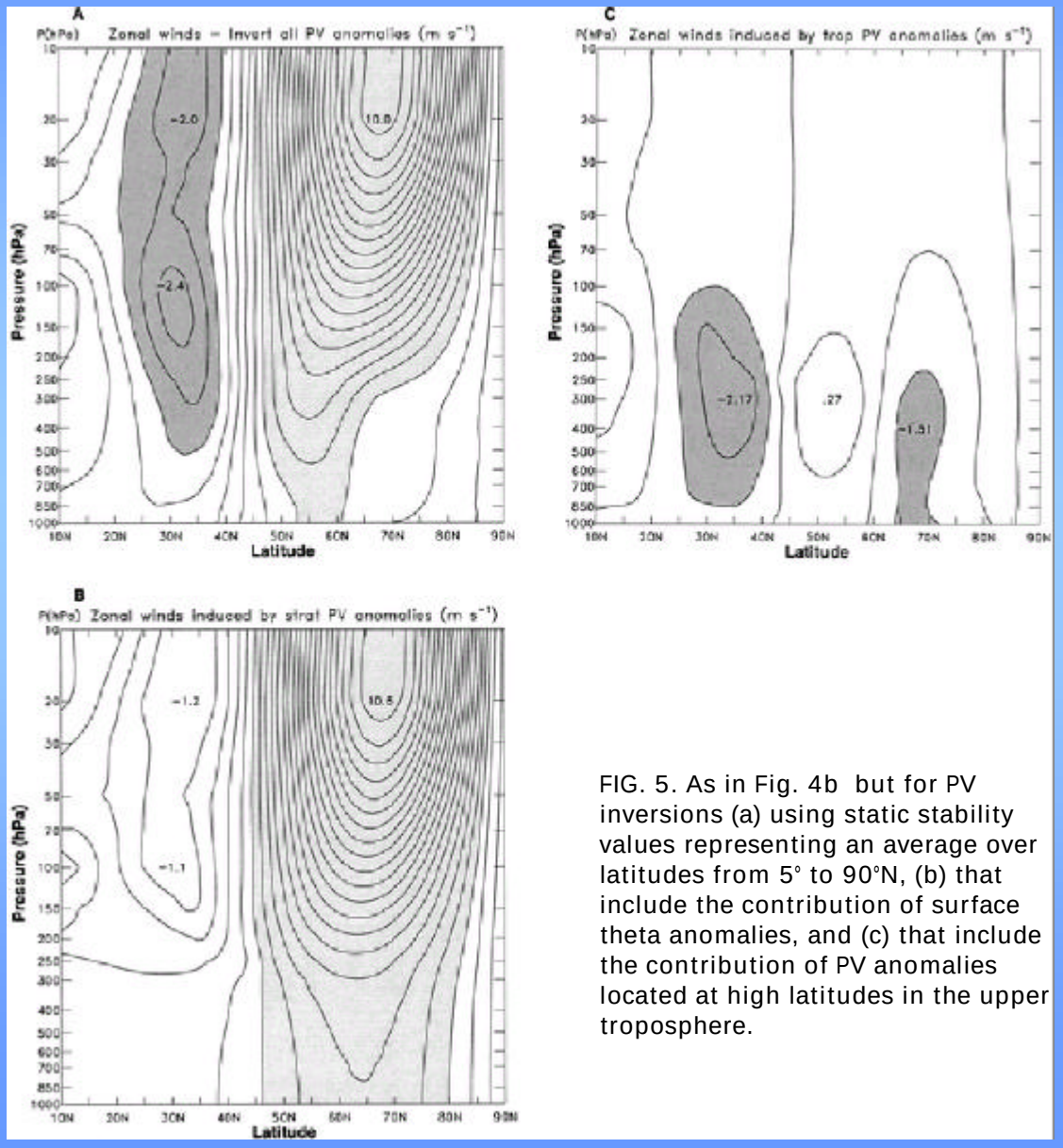
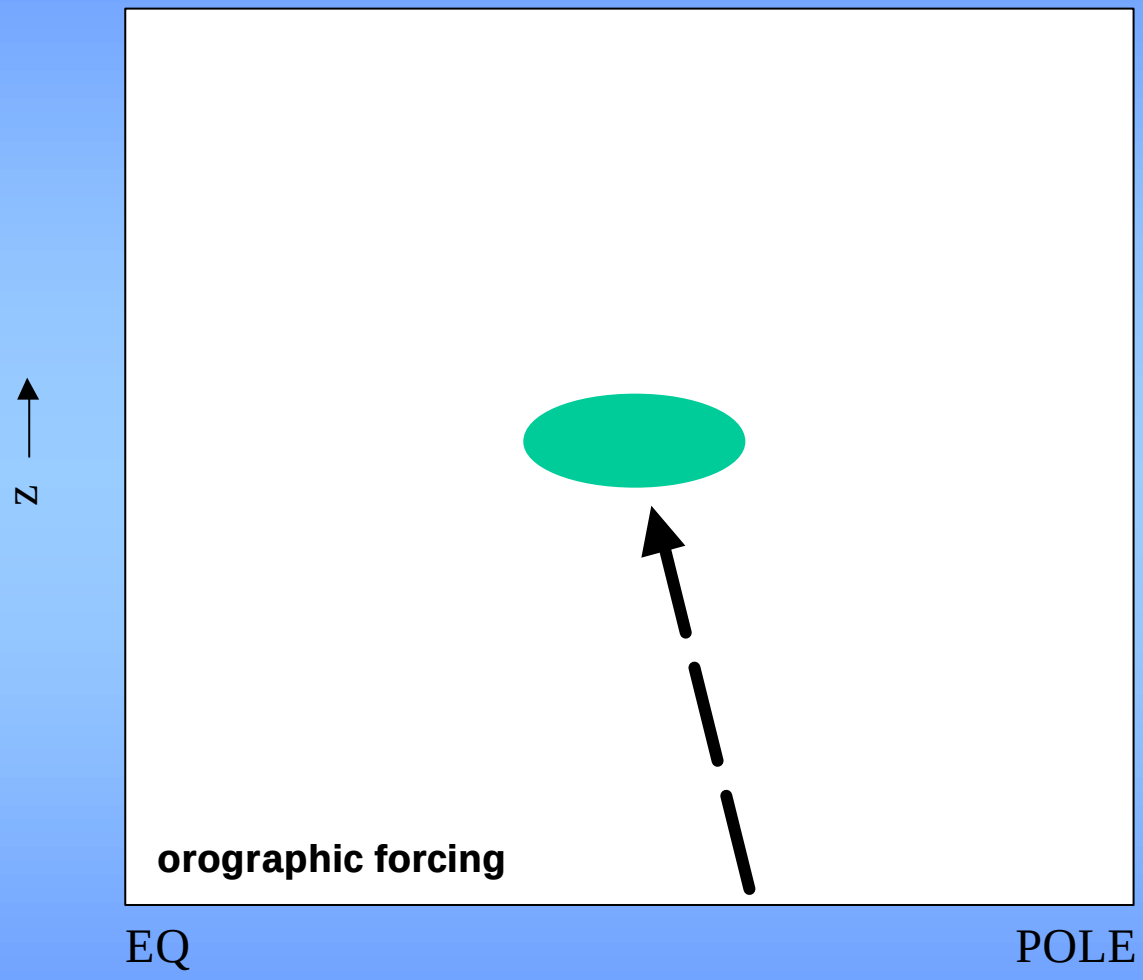


FIG. 5. As in Fig. 4b but for PV inversions (a) using static stability values representing an average over latitudes from 5° to 90°N, (b) that include the contribution of surface theta anomalies, and (c) that include the contribution of PV anomalies located at high latitudes in the upper troposphere.


z
orographic forcing
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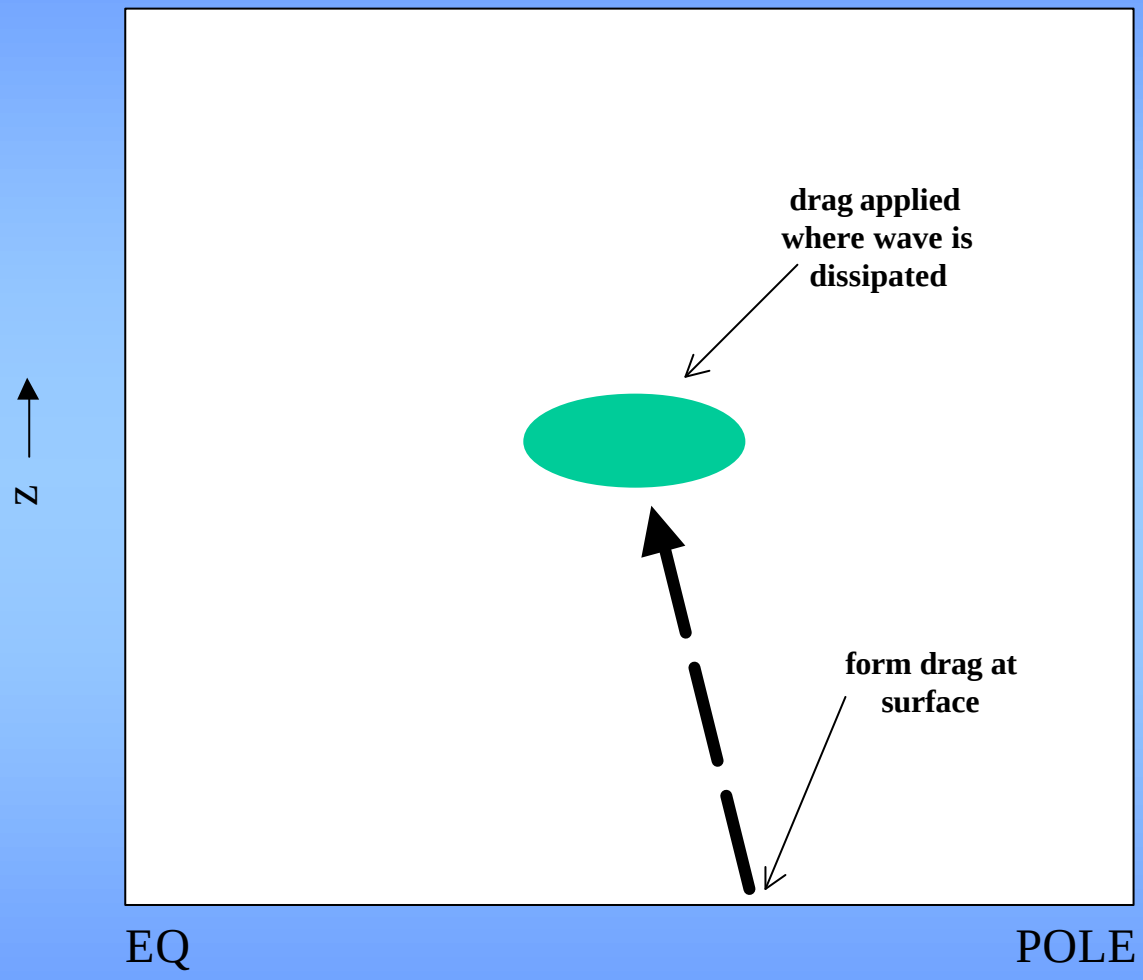
drag applied
where wave is
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form drag at
surface
EQ
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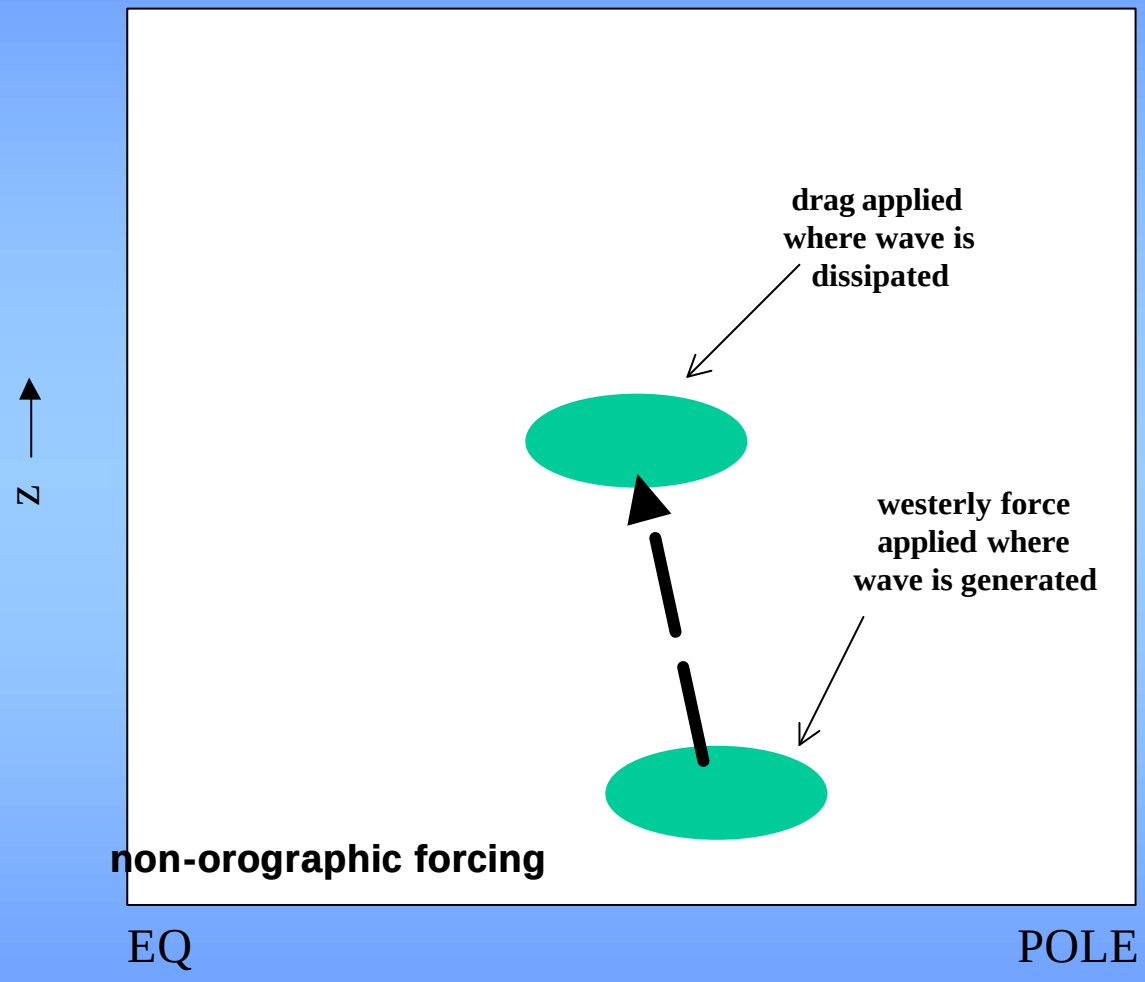
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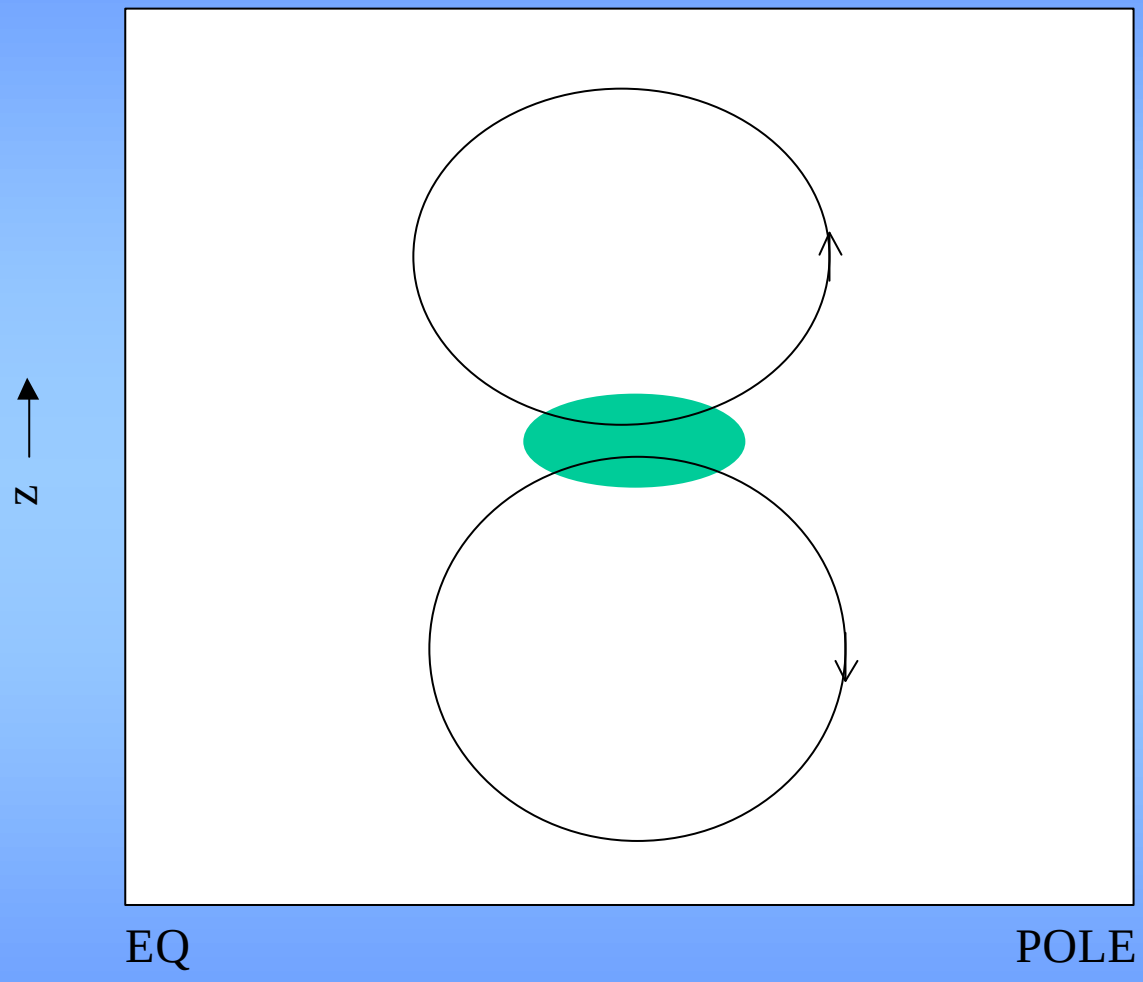
Short-term response



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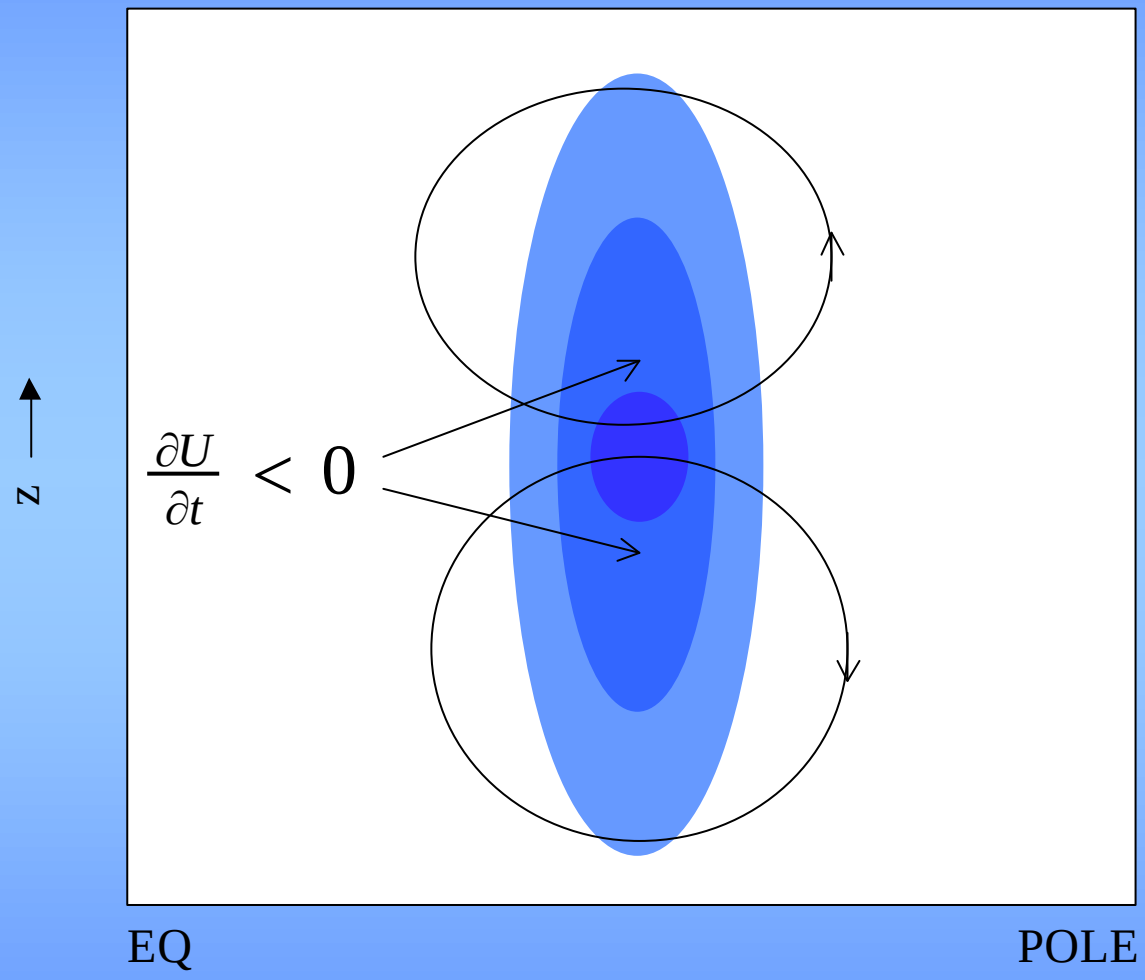

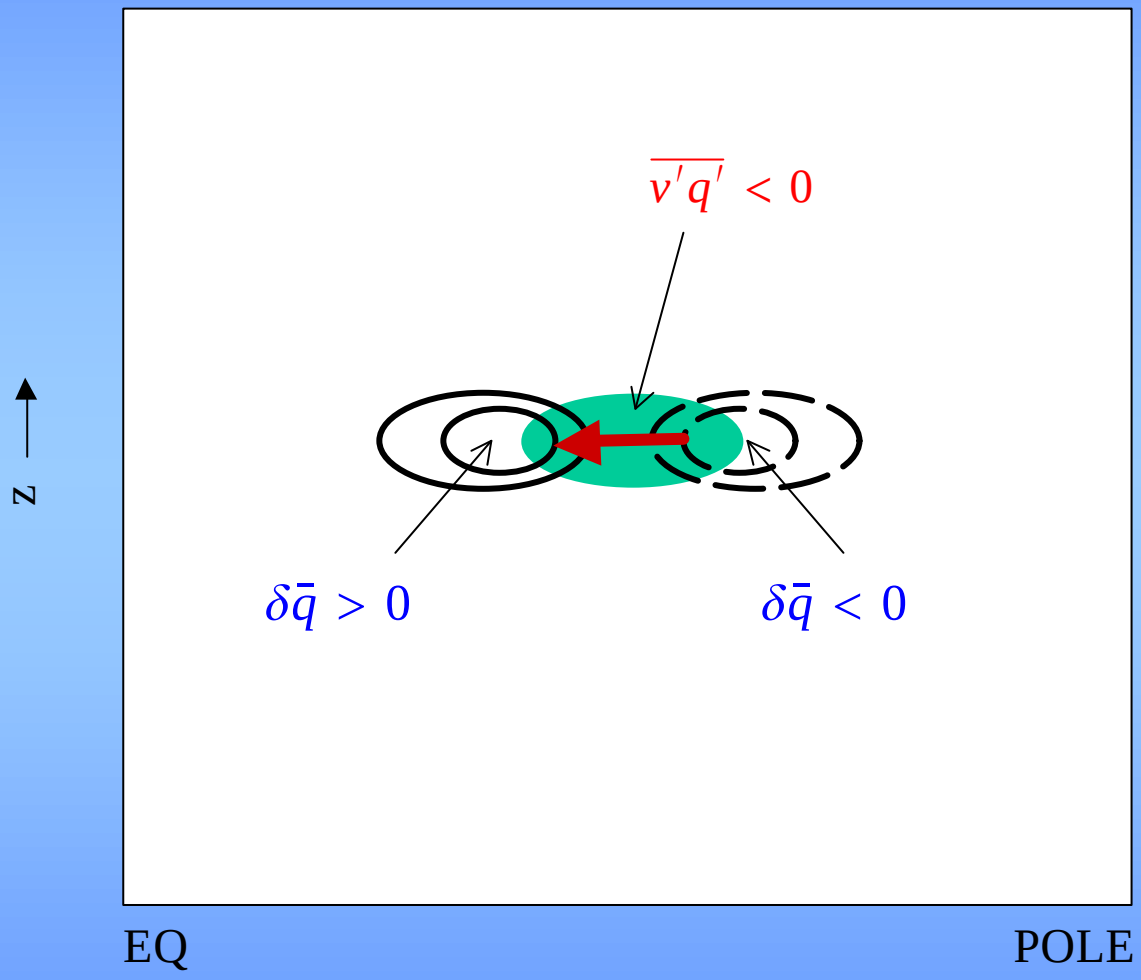
$\overline{v'q'} < 0$
z
$\delta\bar{q} > 0$
$\delta\bar{q} < 0$
EQ
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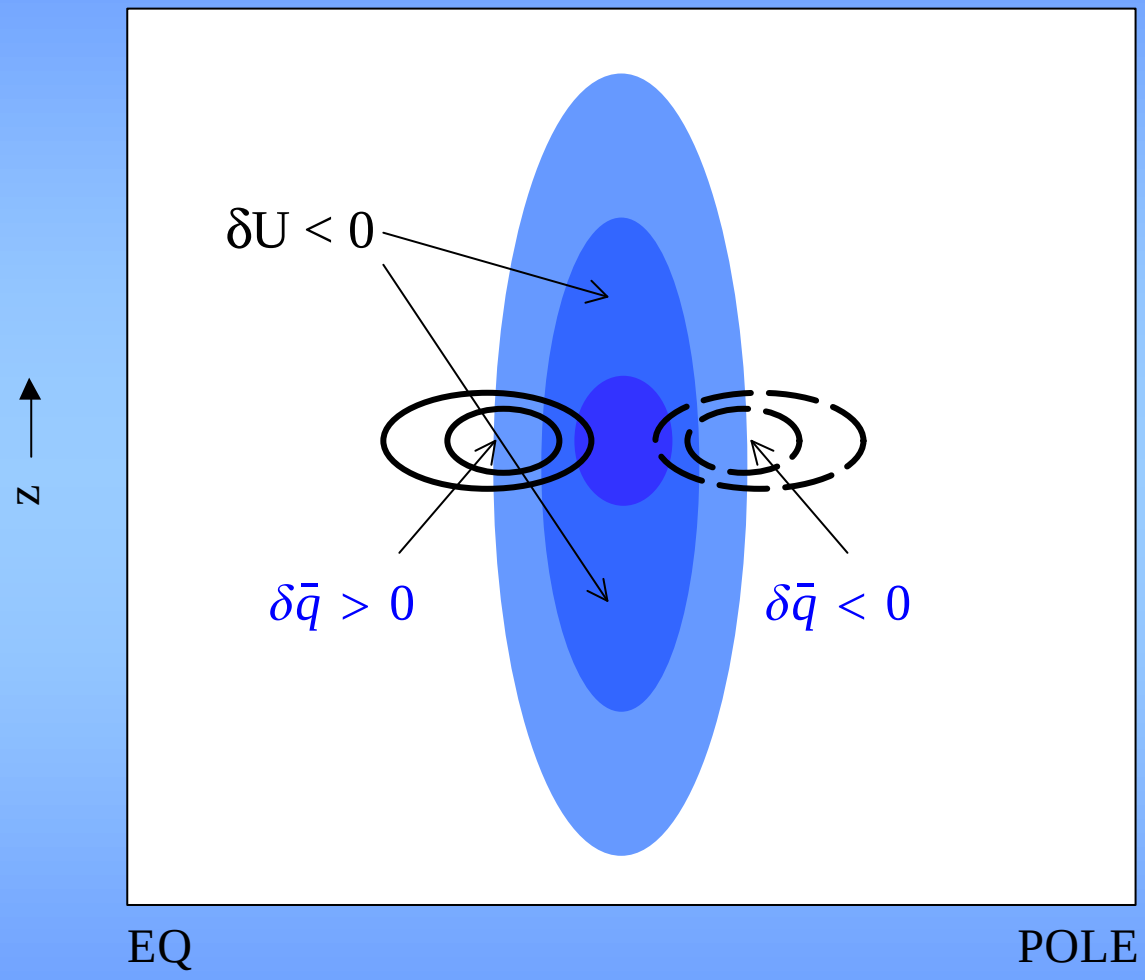
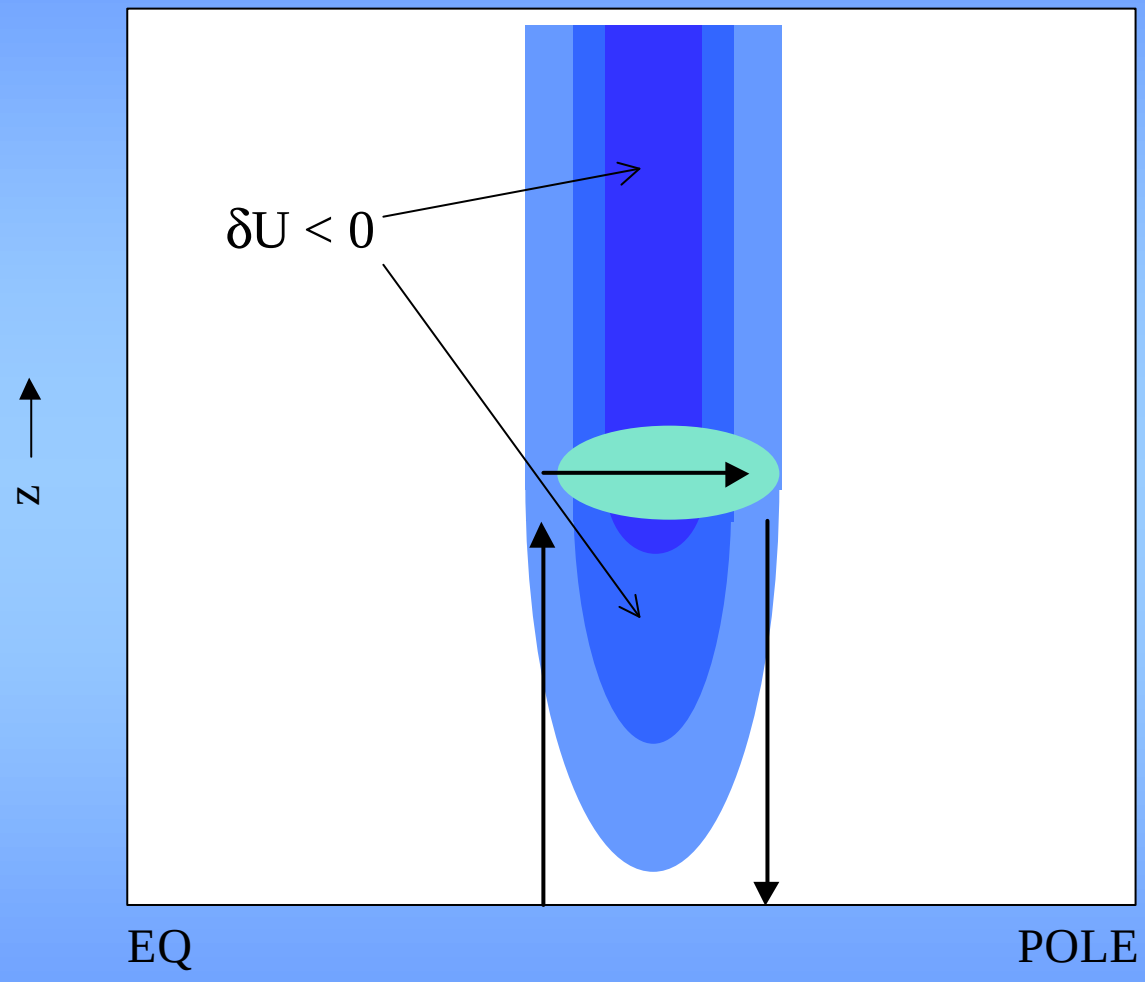
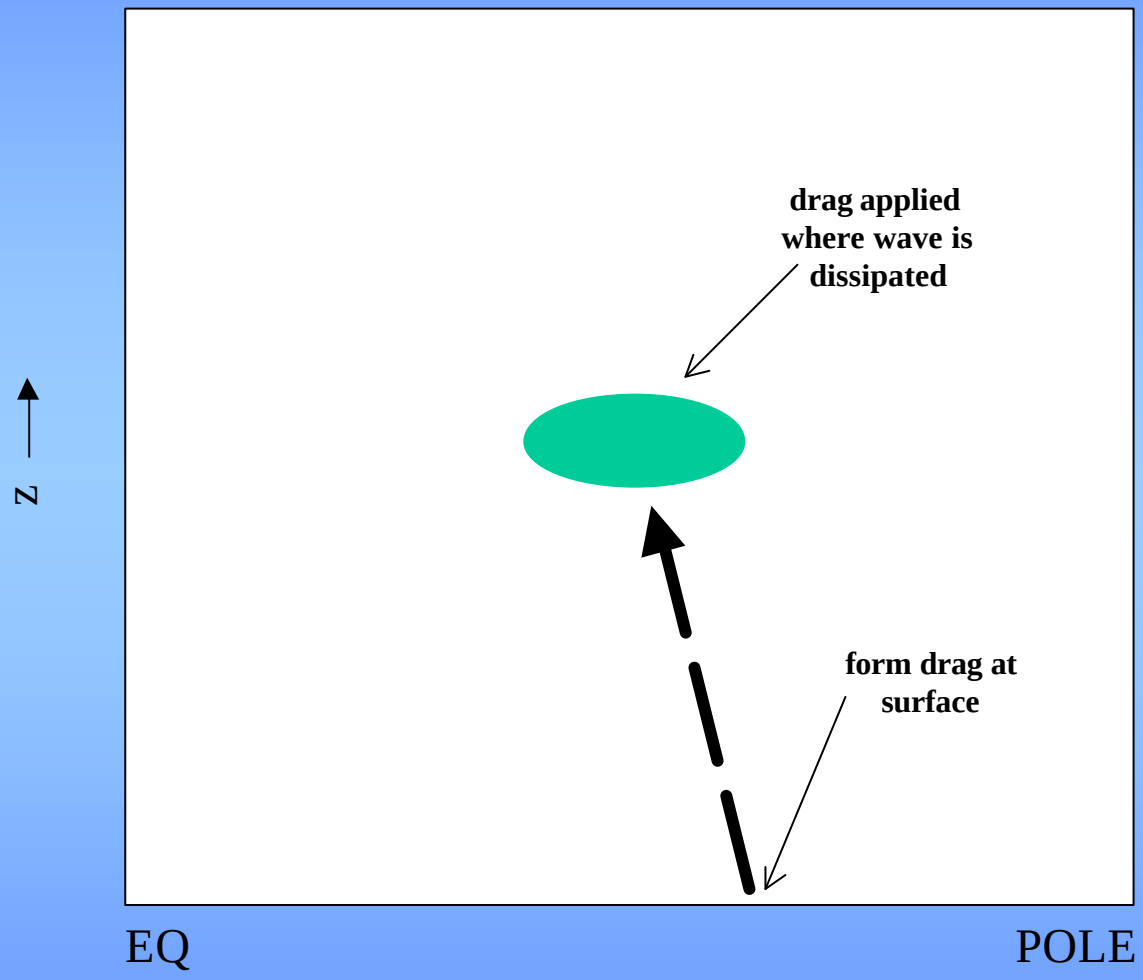

δU < 0
z
$\delta\bar{q} > 0$
$\delta\bar{q} < 0$
EQ
POLE

Long-term steady response



“Downward control” does not always mean downward control!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Surface mean wind—long term balance

Long-term QG steady state

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

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

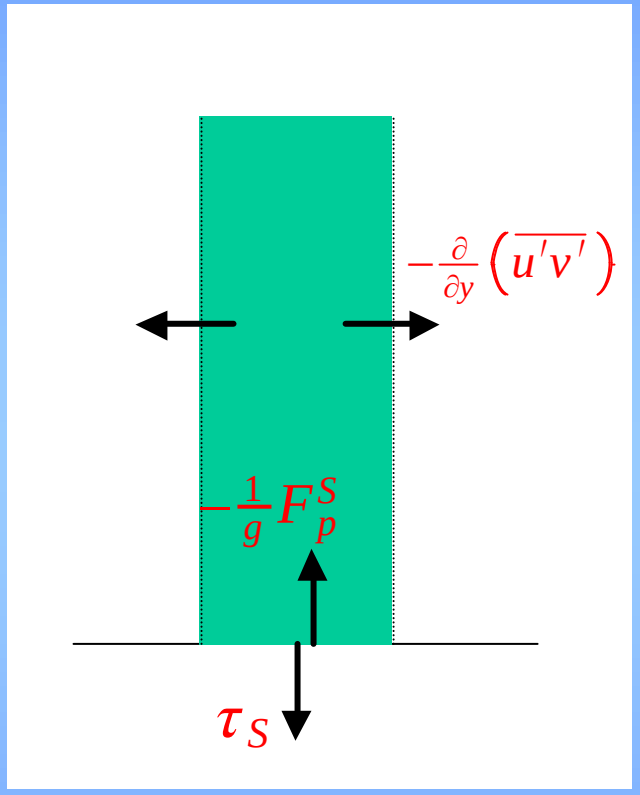
Integrated angular momentum balance

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

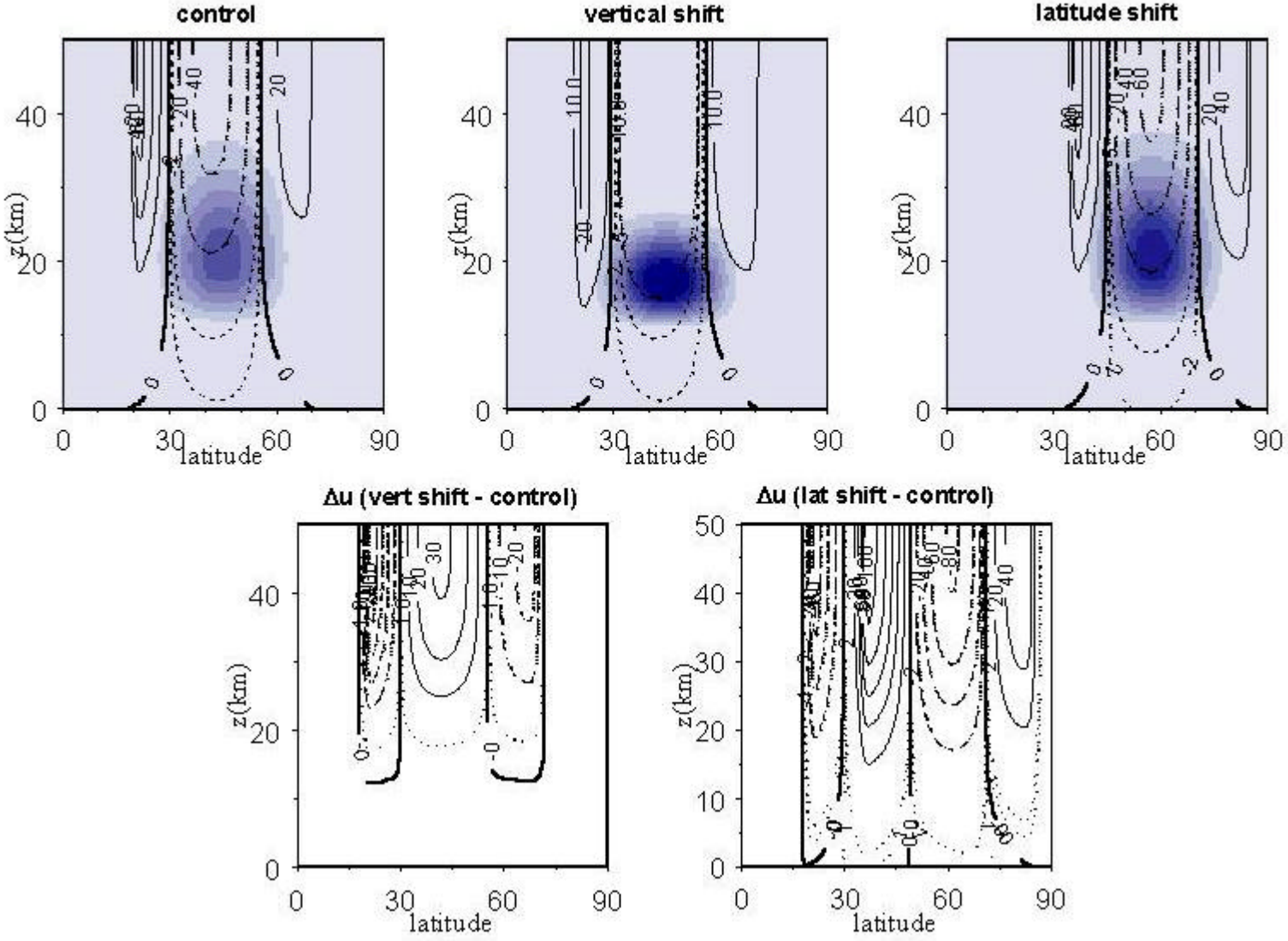
surface stress

form drag

lateral radiation of angular momentum



Steady zonal wind response to EP flux convergence



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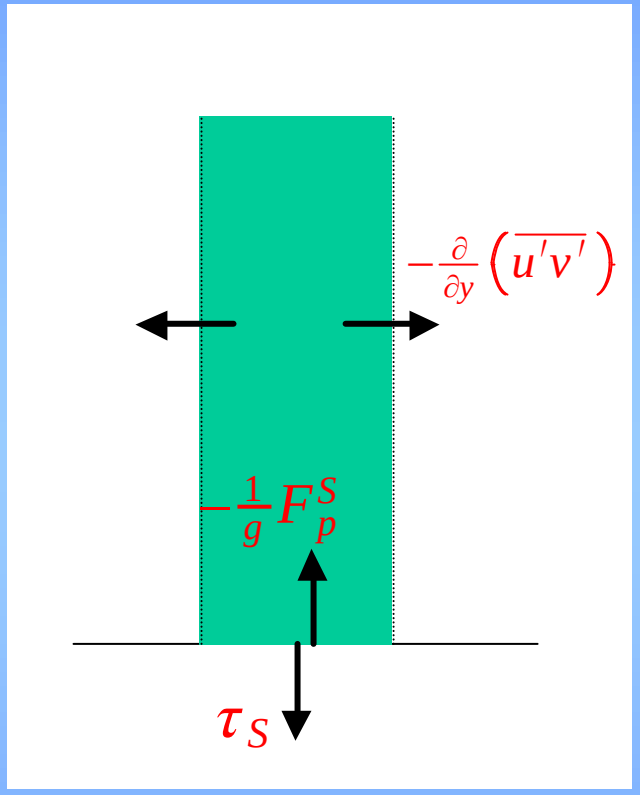
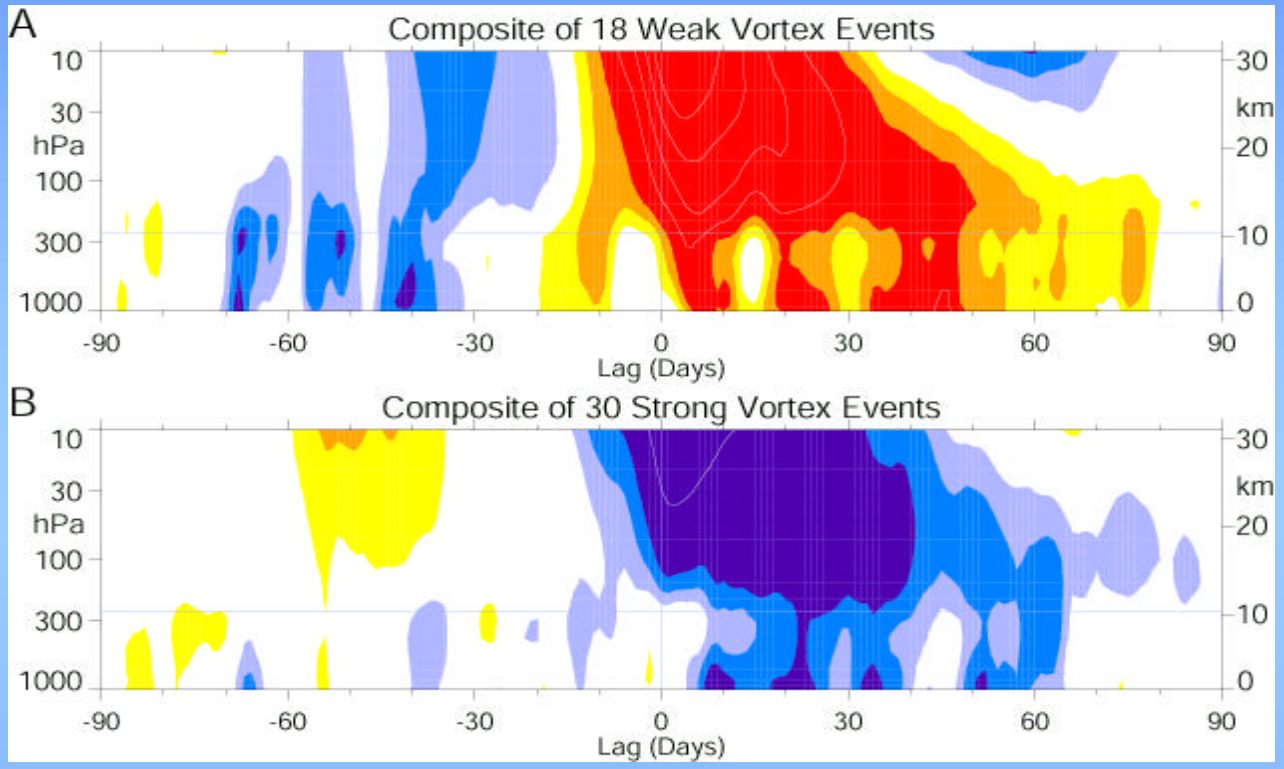


Short-term behavior

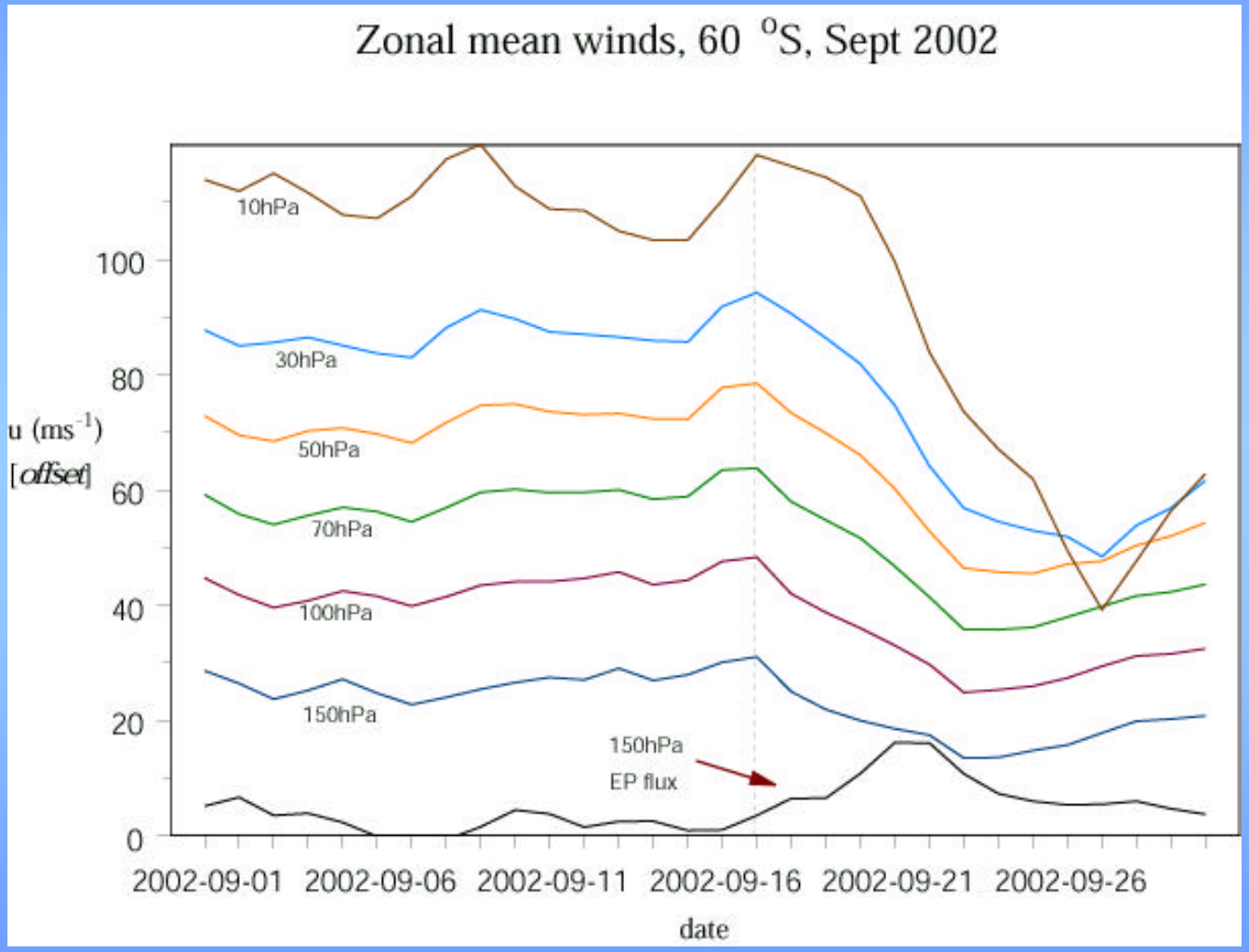
Downward propagation?



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

Science, 294 581-584.

Stratospheric response to tropospheric wave “bursts” [1]



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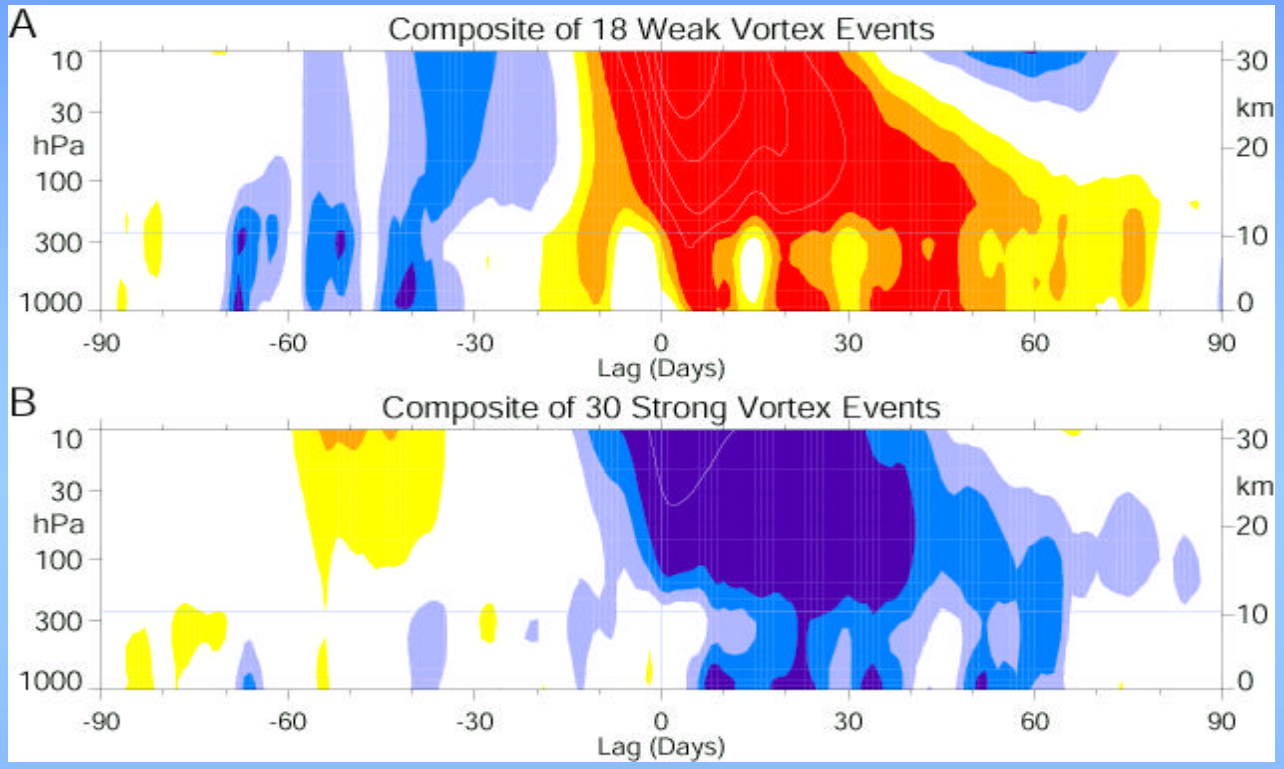

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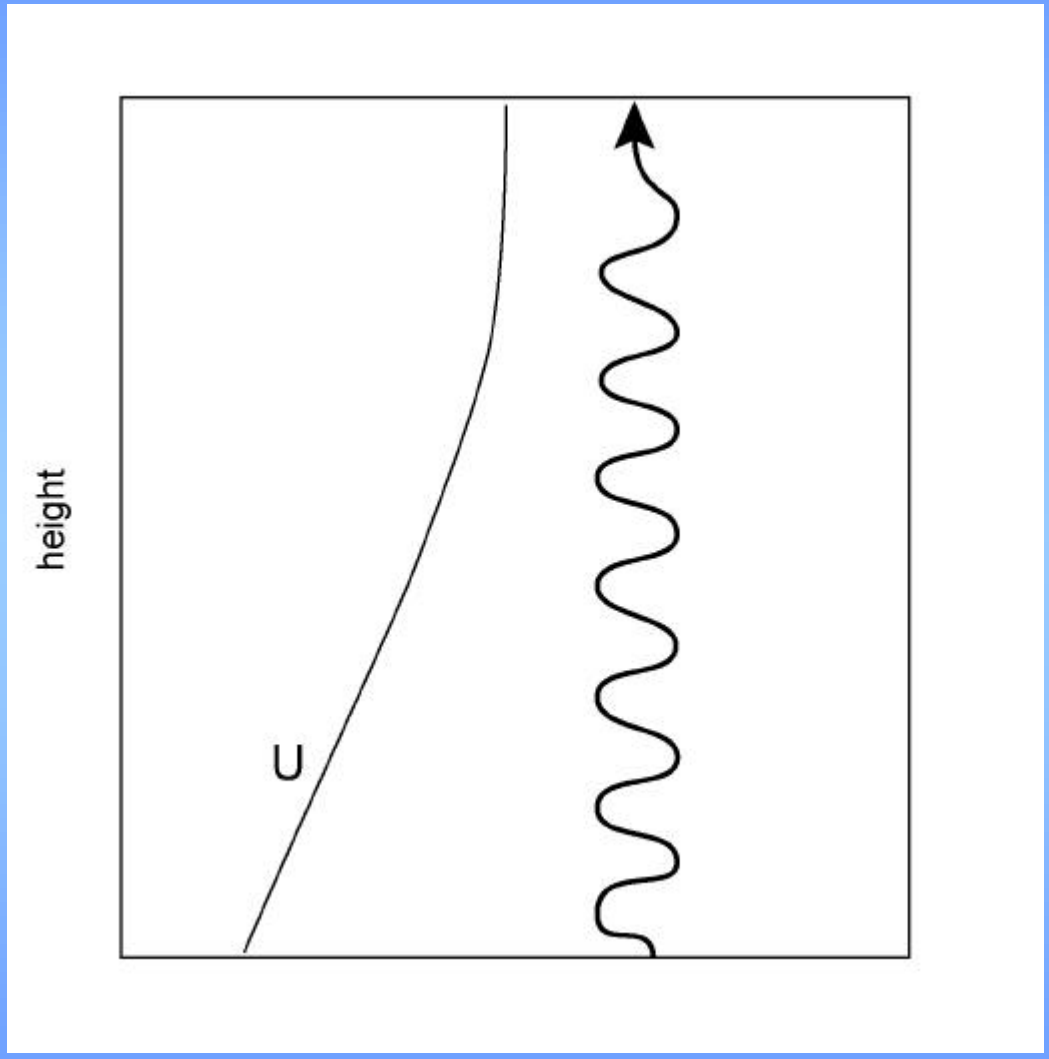
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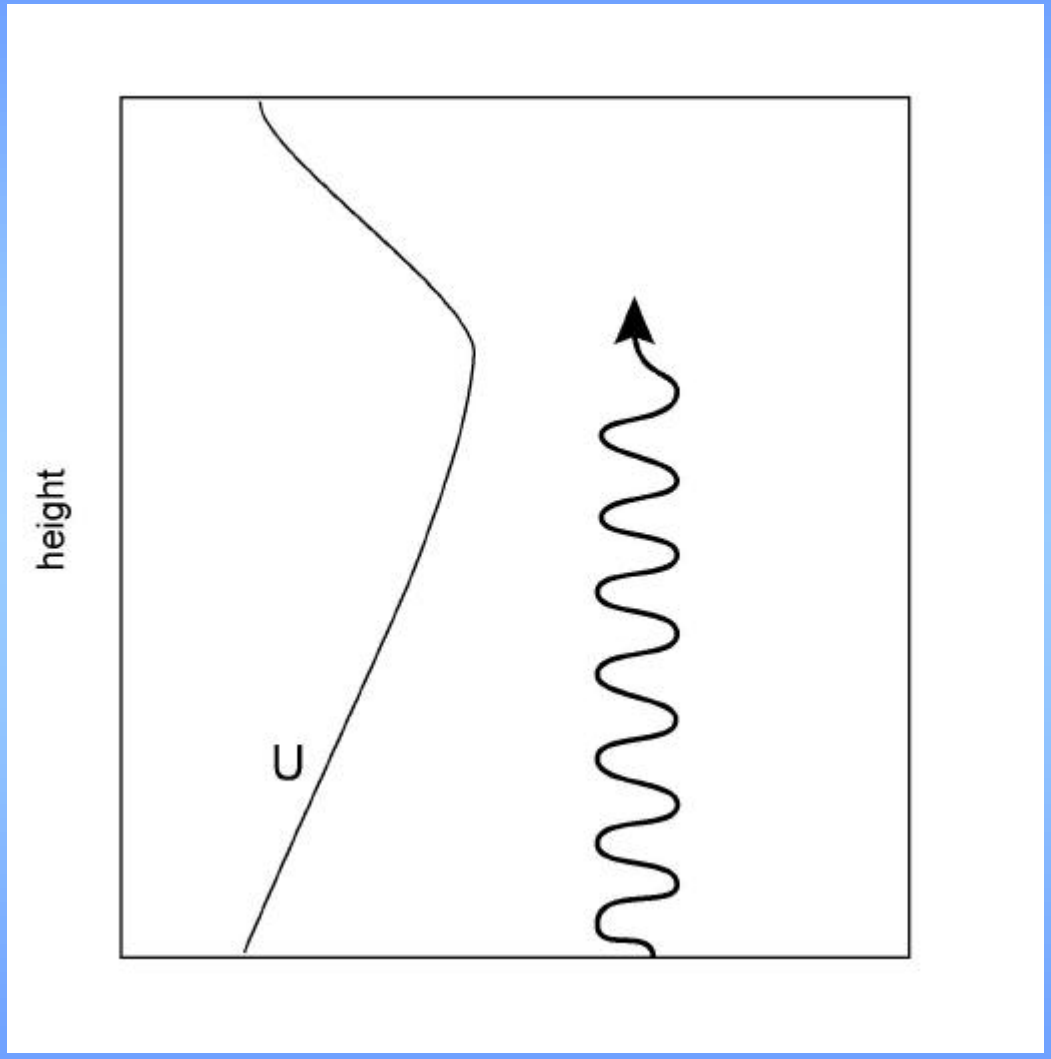
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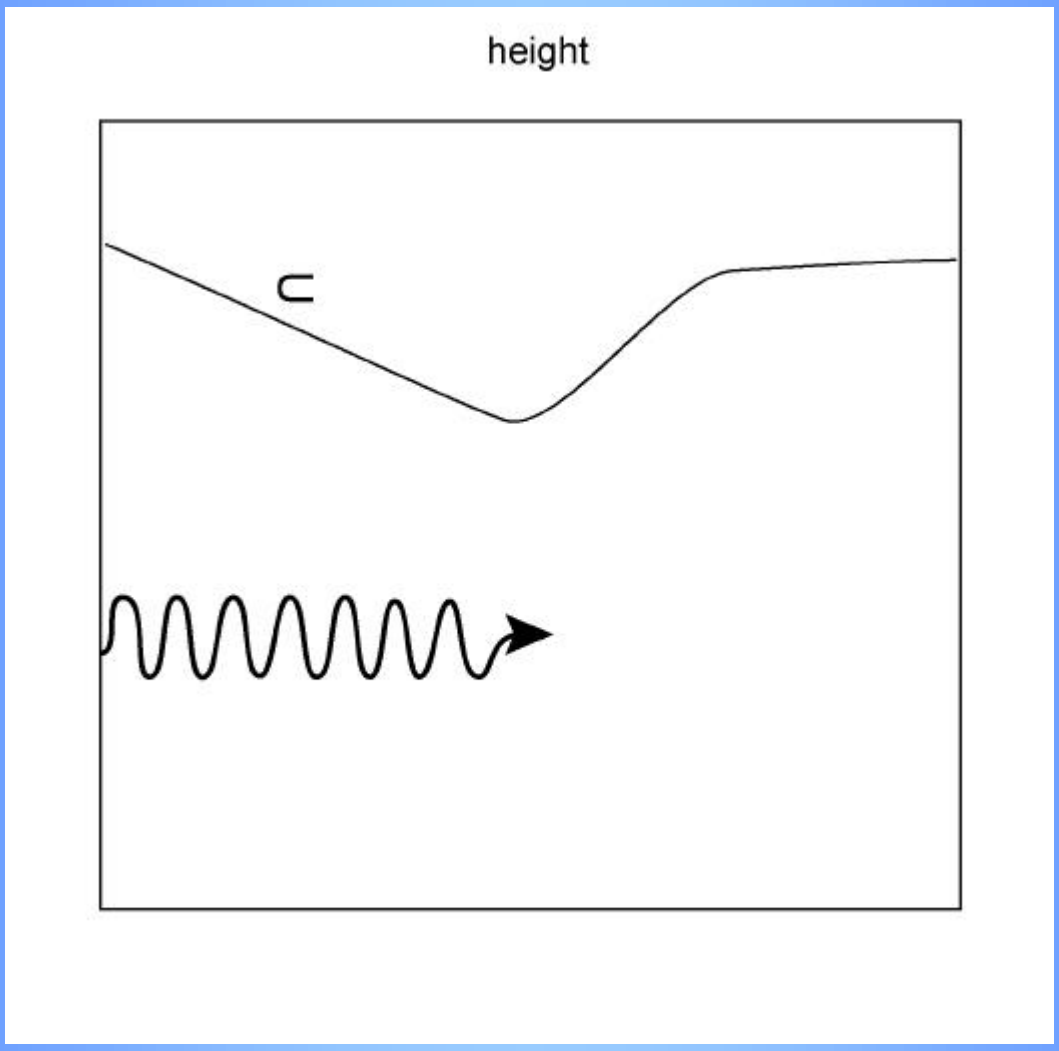
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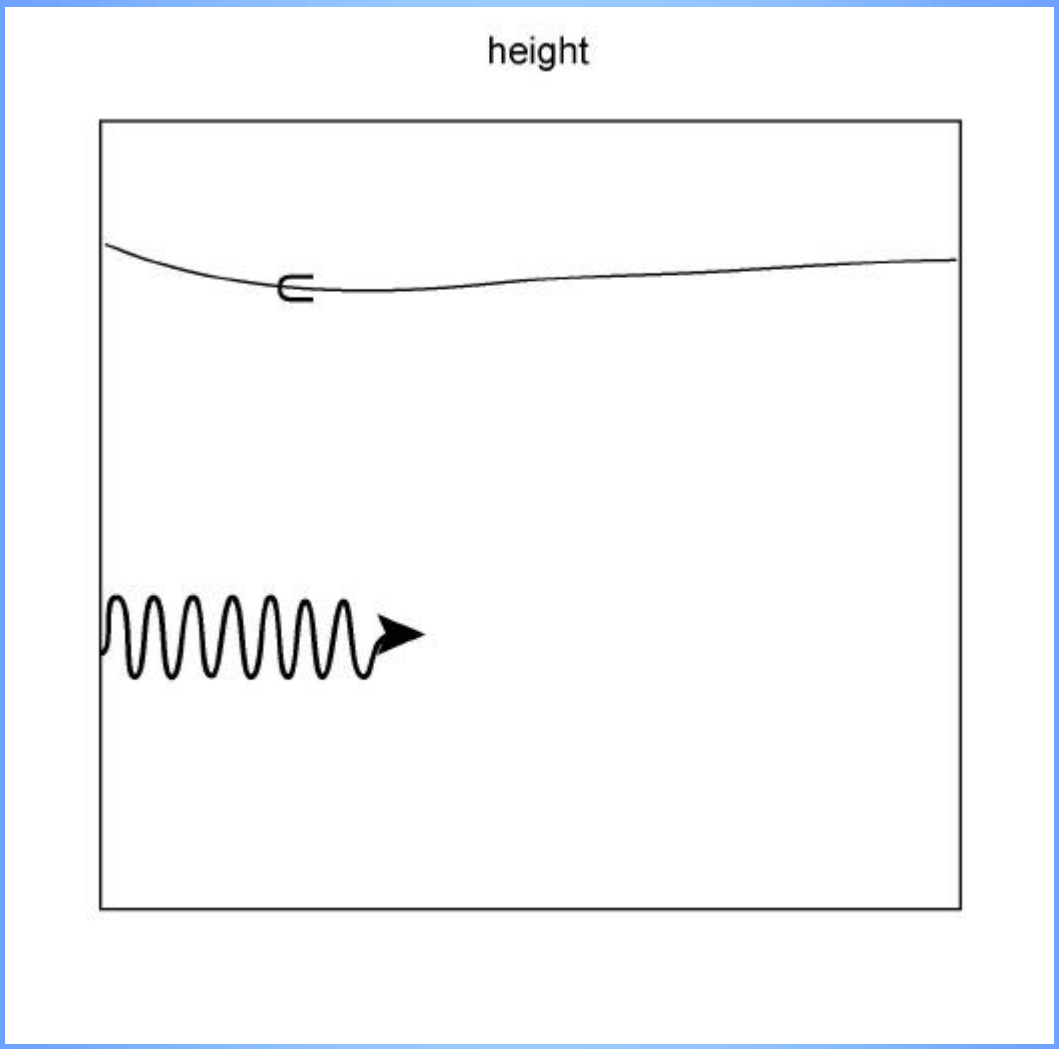
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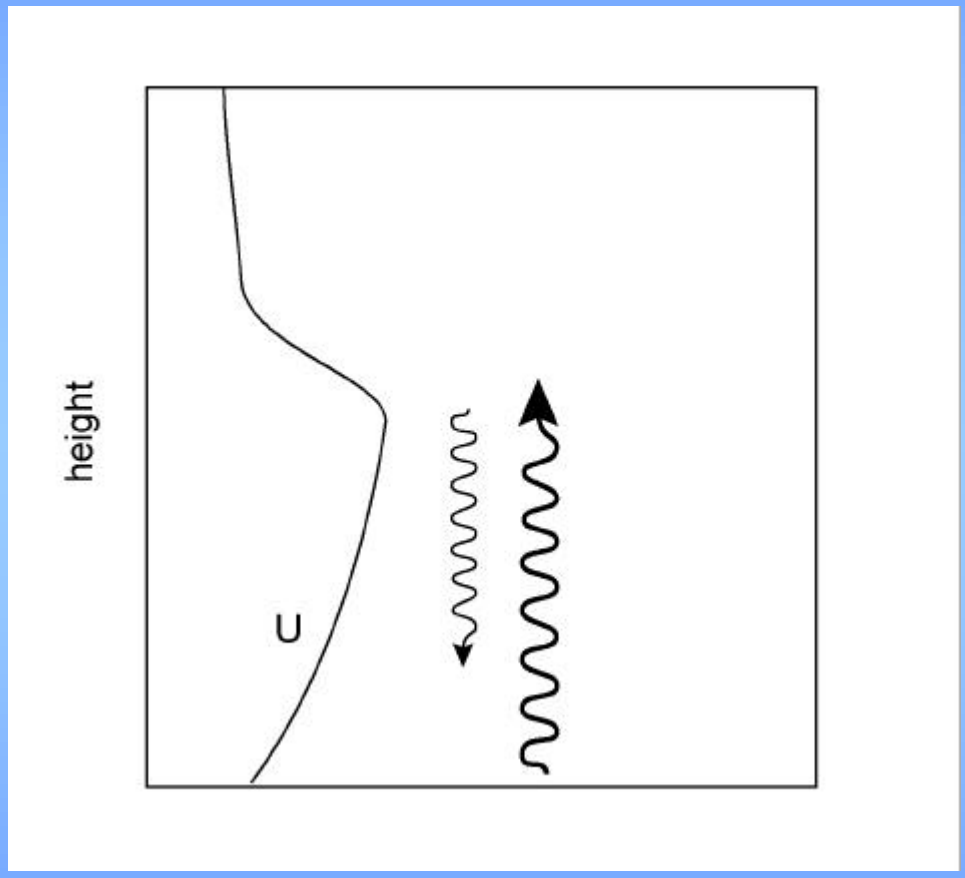
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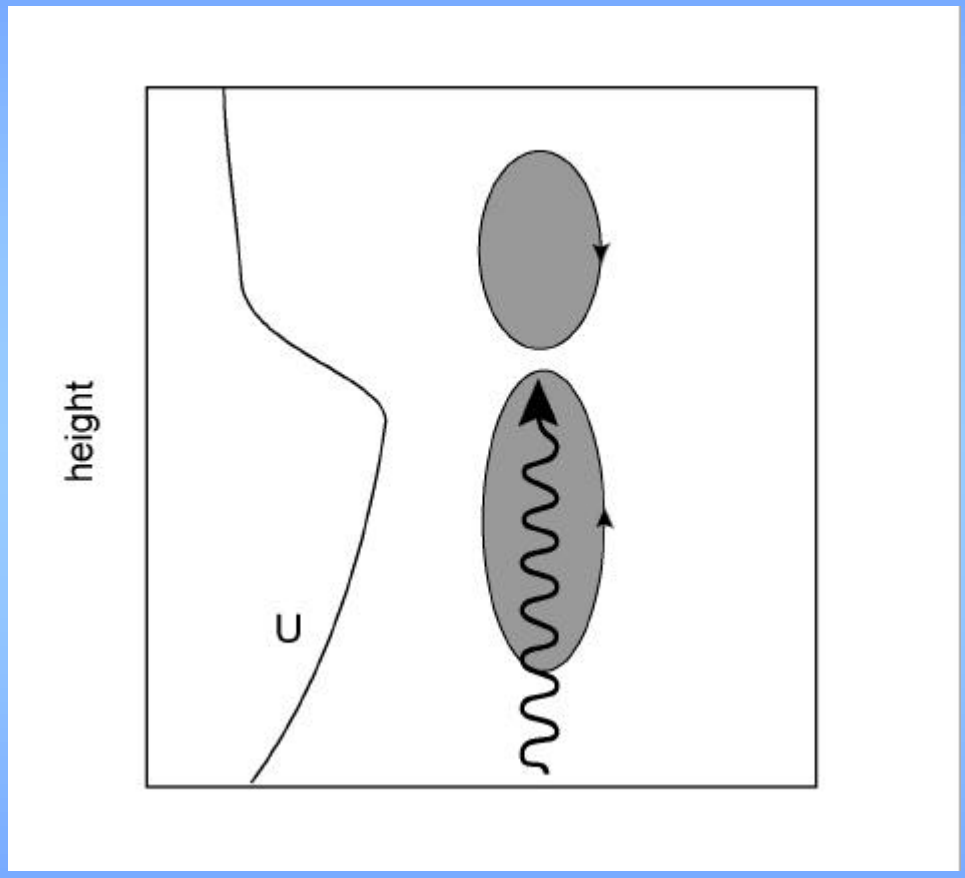
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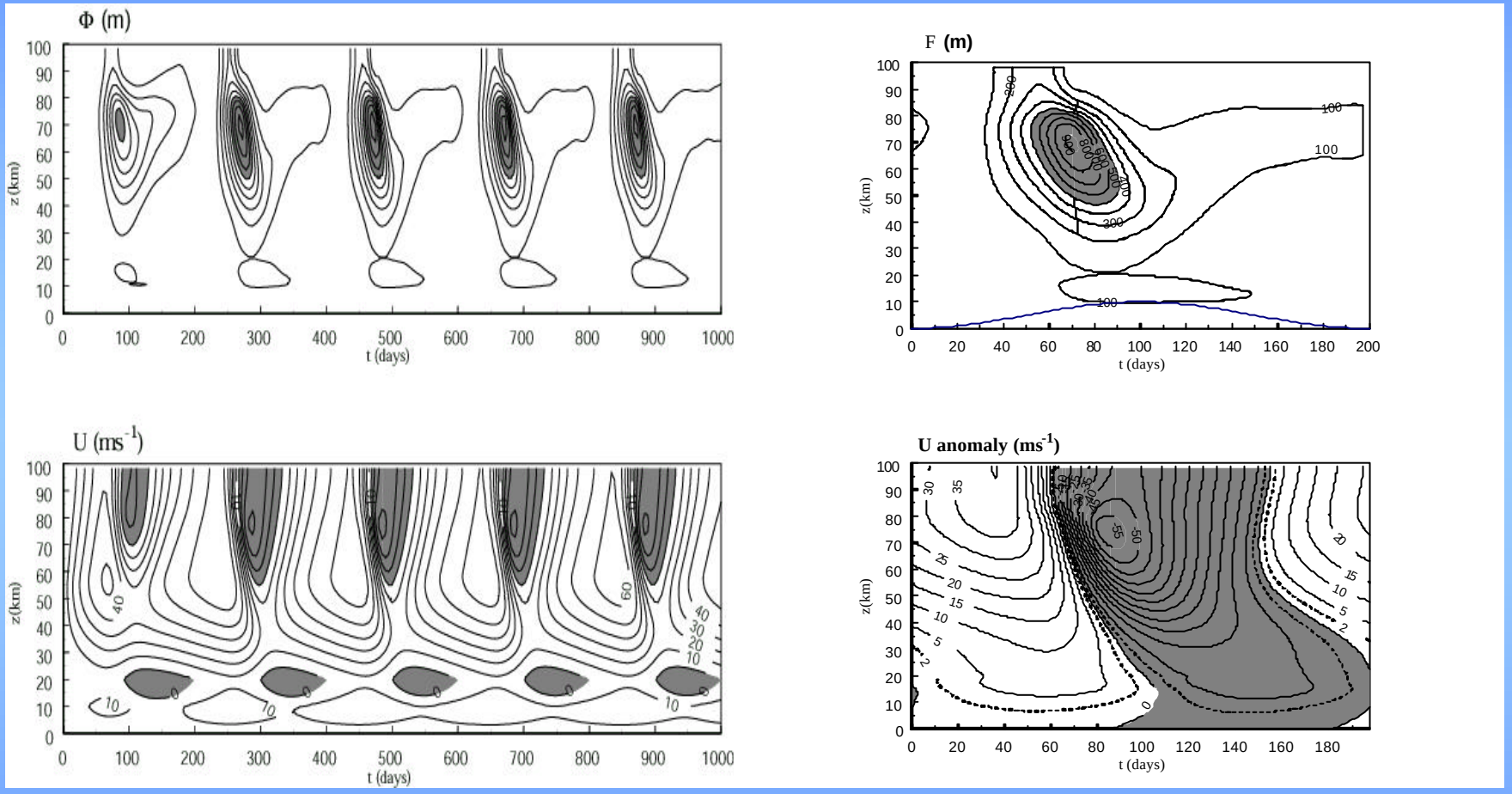
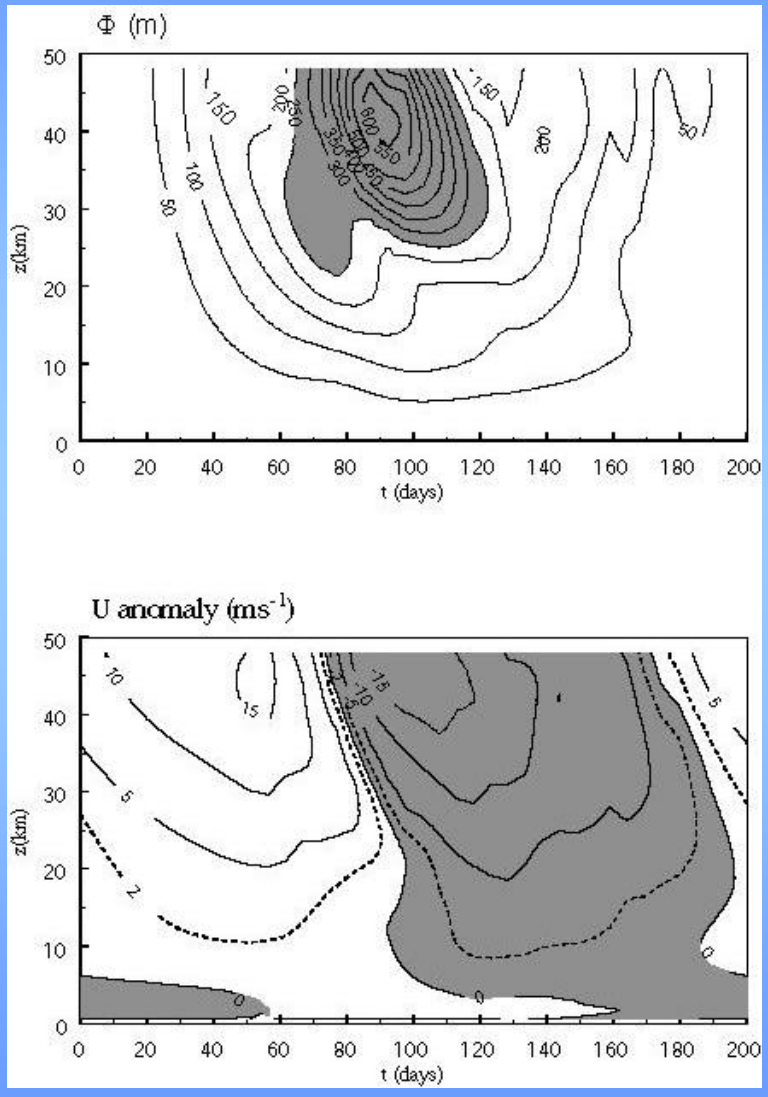
Response of a truncated b-channel model to periodic wave driving

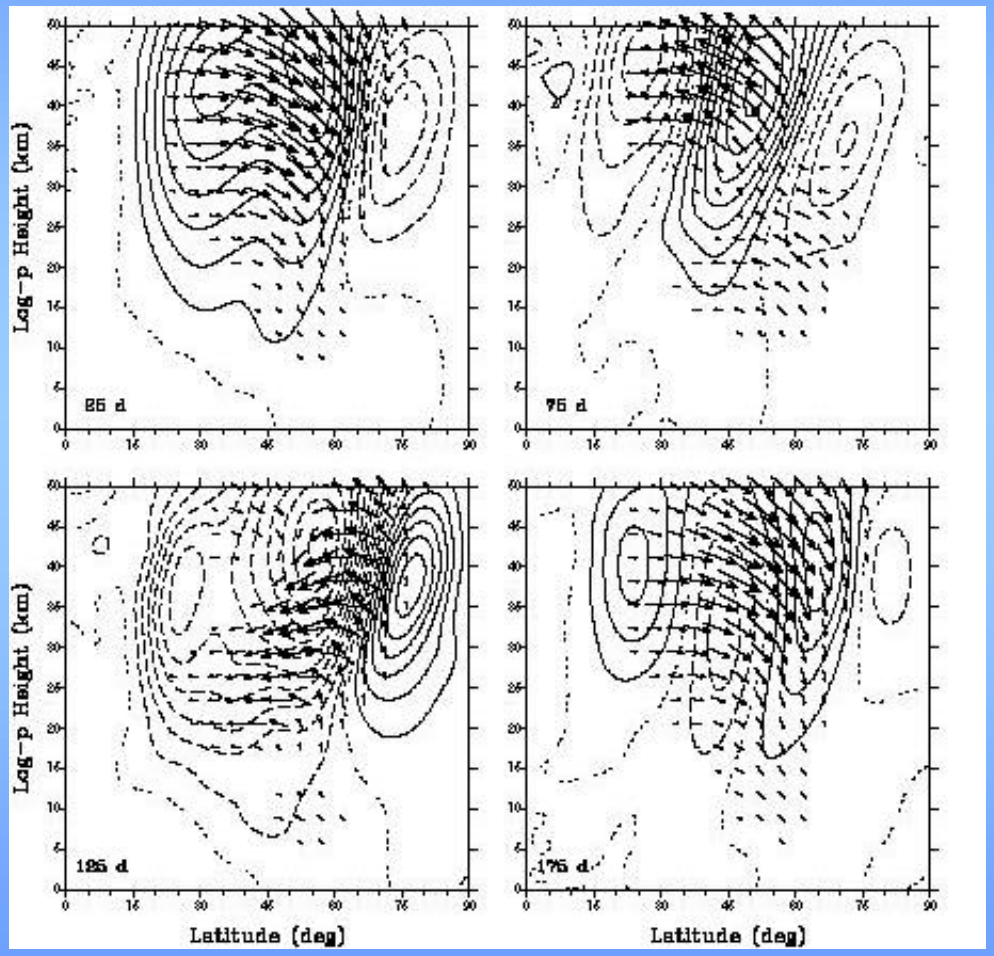


Left: Wave amplitude (m; top) and mean zonal wind in response to periodically modulated tropospheric wave forcing. Right: Composites over one wave period. *[Plumb & Semeniuk, 2003]*

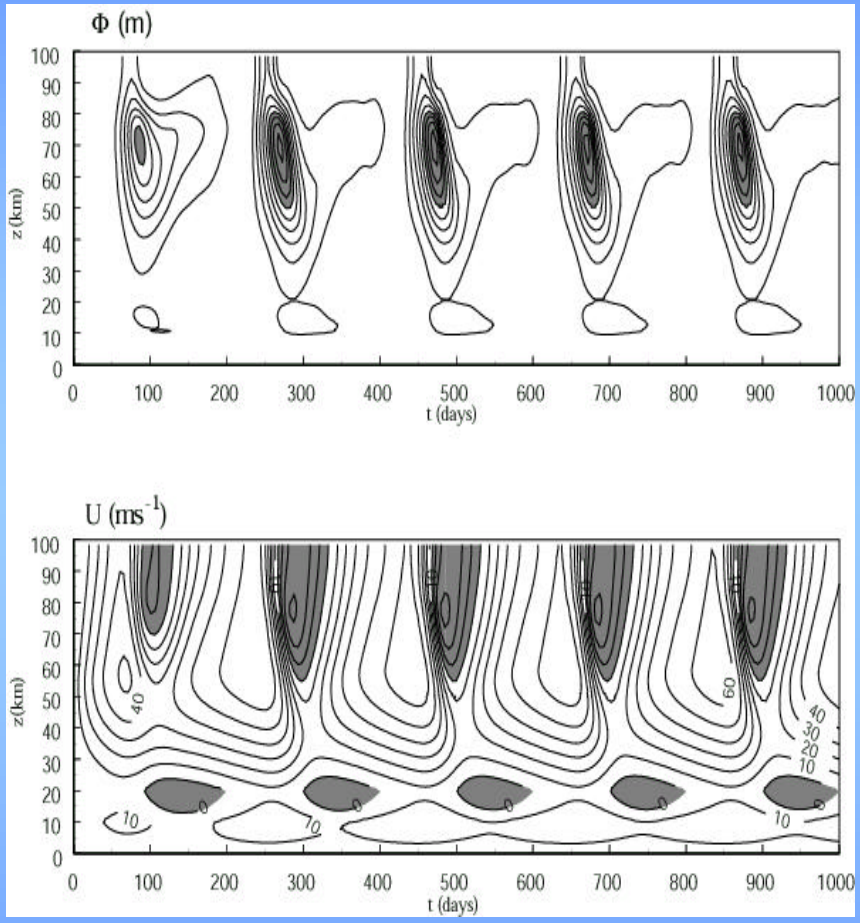
3D model results

[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]

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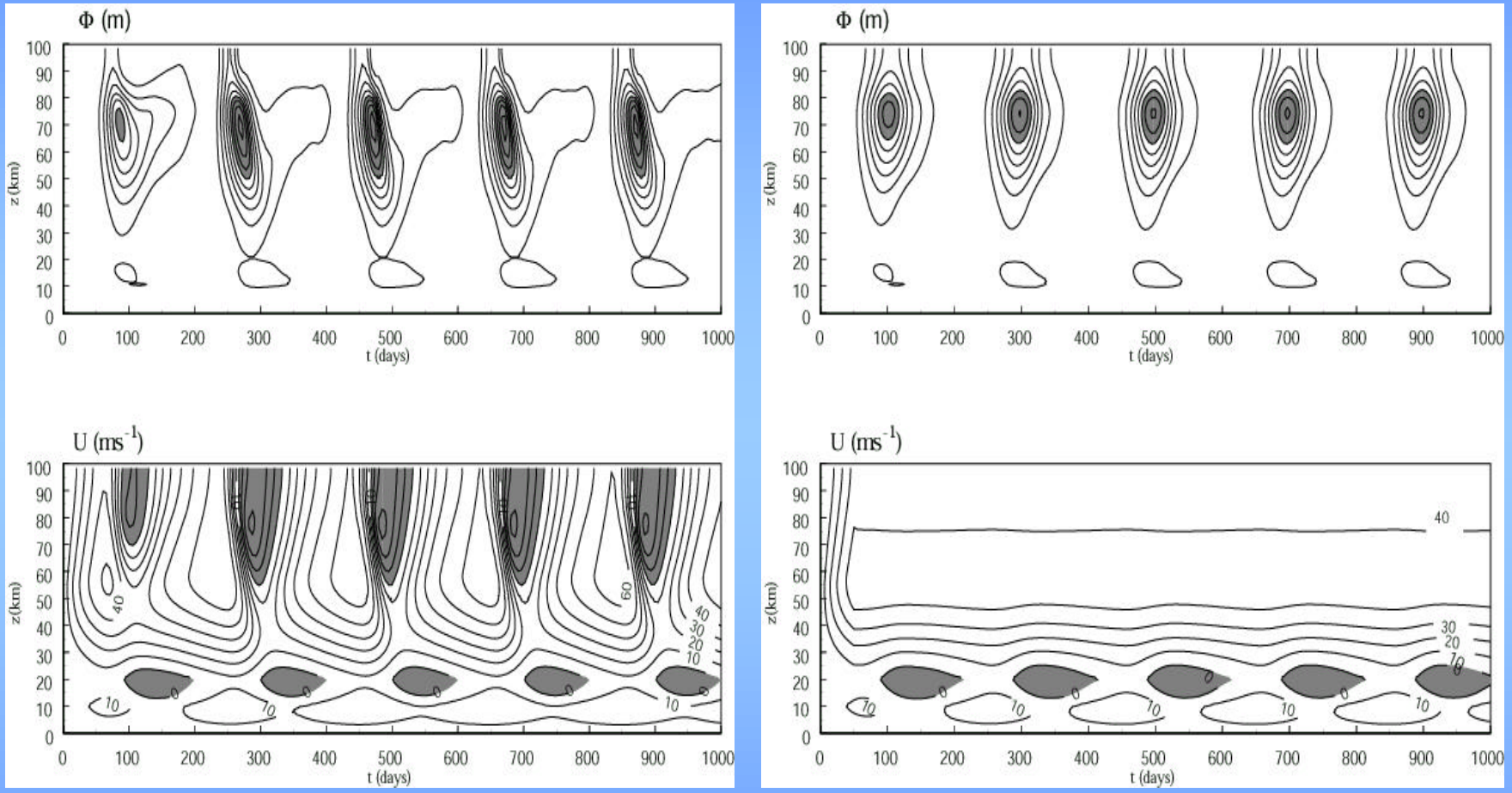
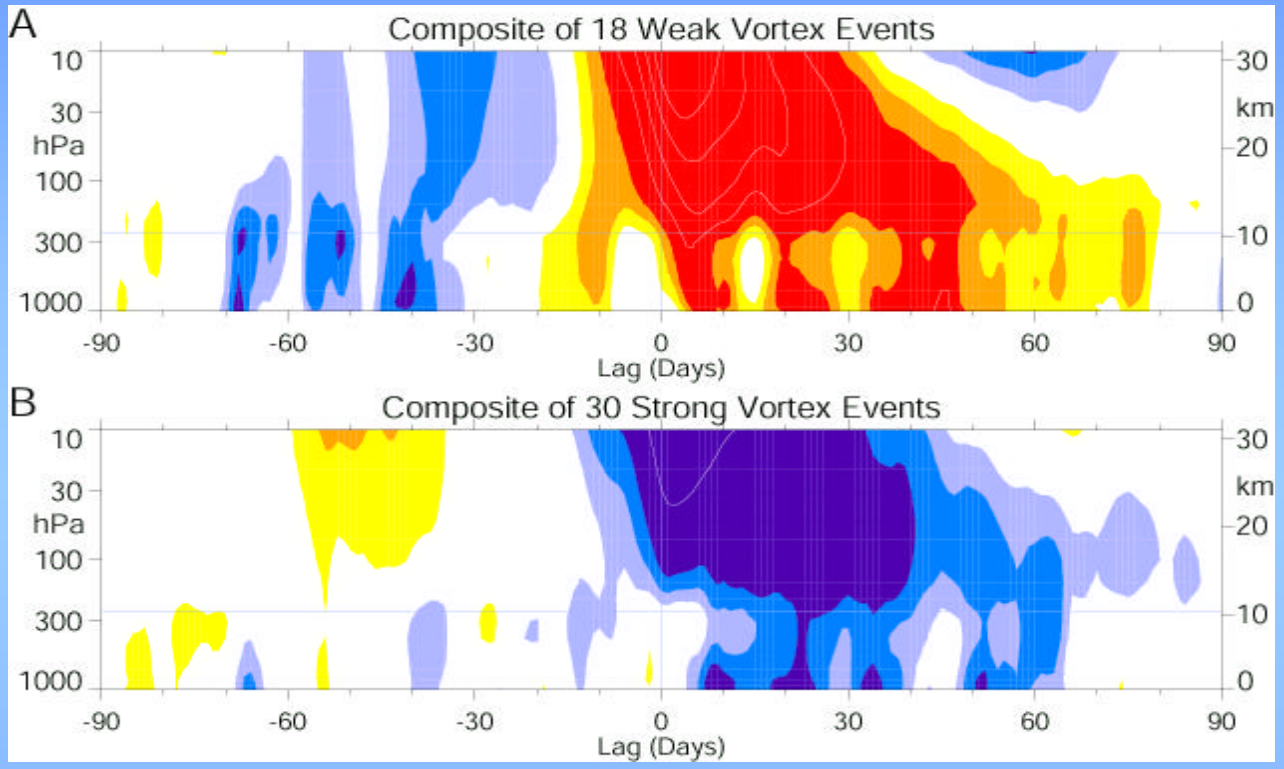


Wave amplitude (m; top) and mean zonal wind in response to periodically modulated tropospheric wave forcing. Left: full response. Right: response suppressed above 25km.

[Plumb & Semeniuk, 2003]

Downward propagation?



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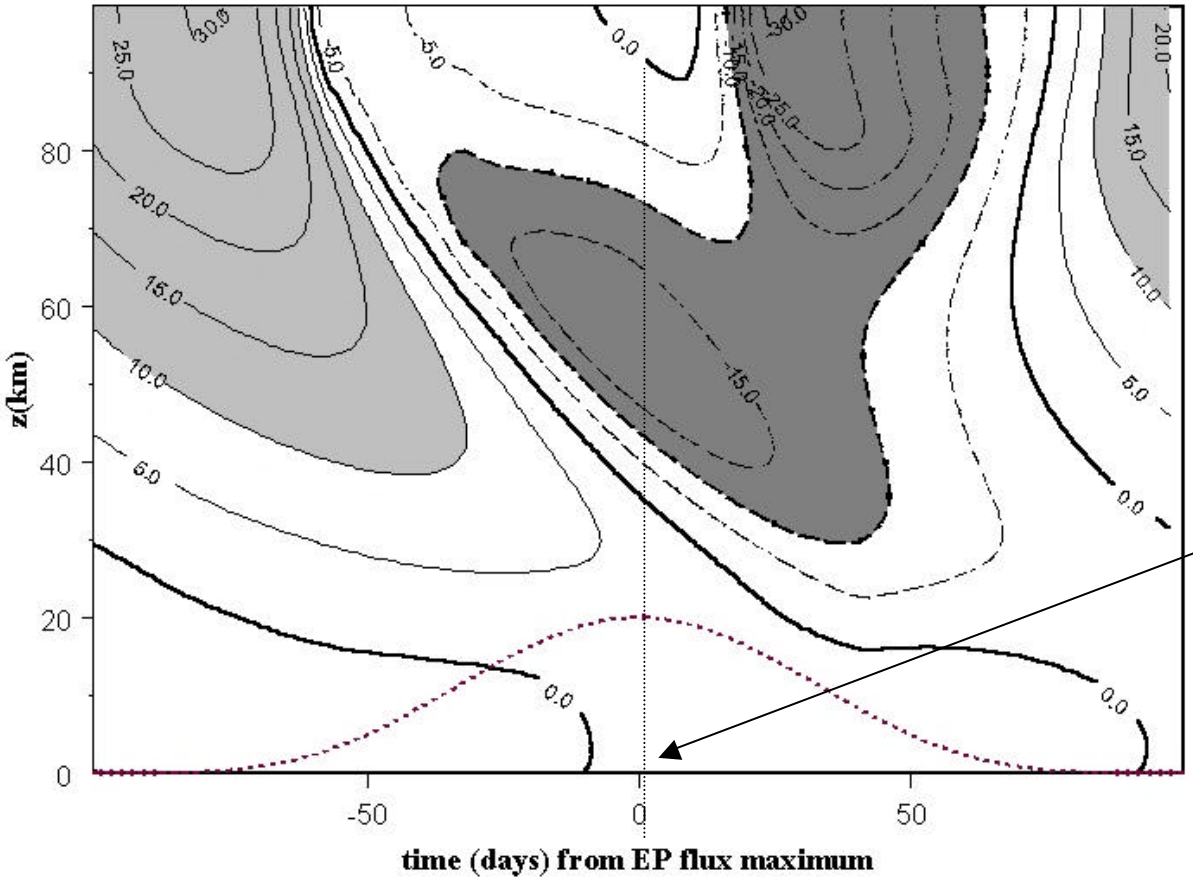
Relation with upwelling EP flux



Time of maximum imposed flux

Detecting an effect

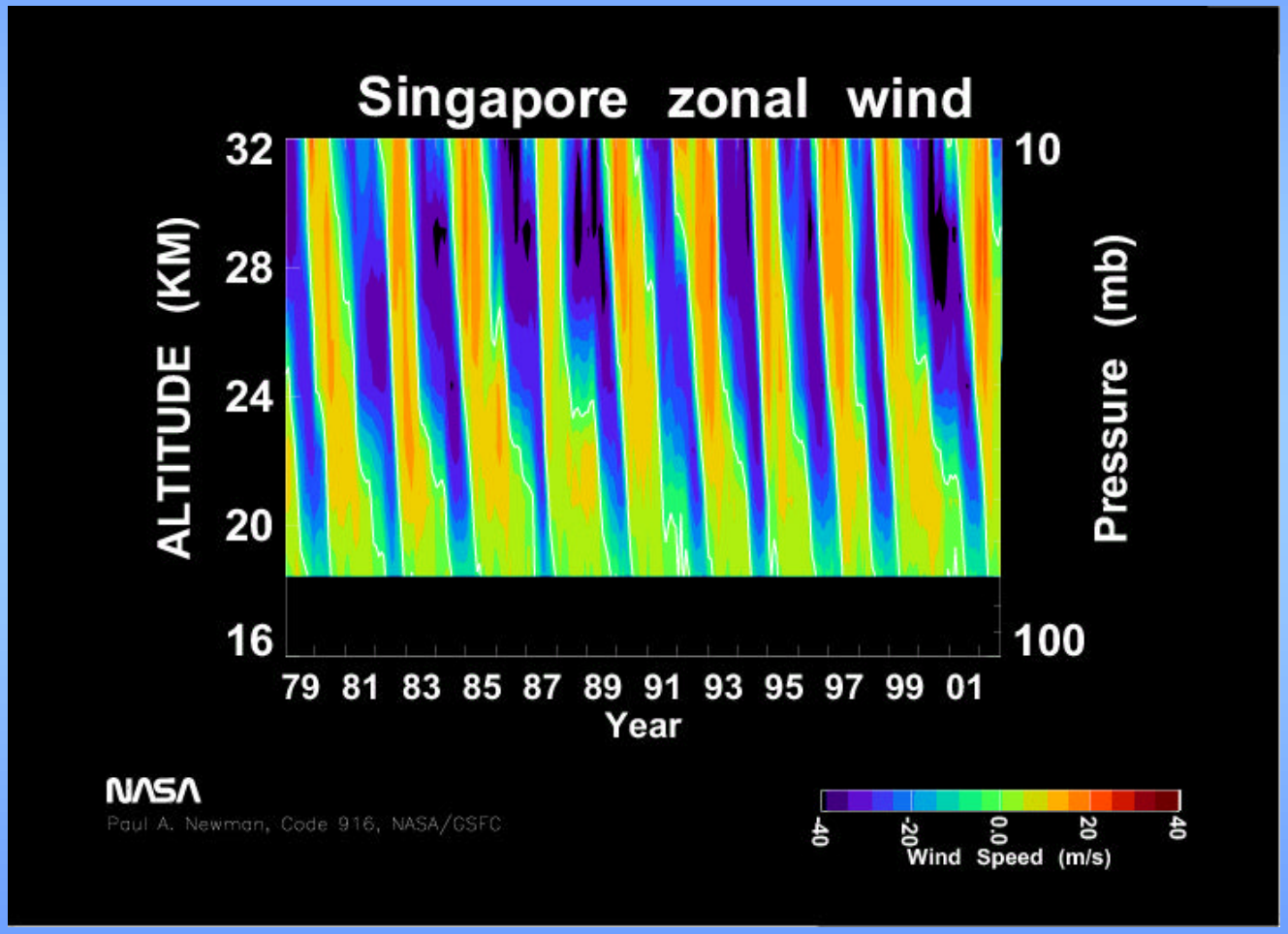
- ***Is there any unambiguous* observational *evidence for such an effect and how could it be identified?***

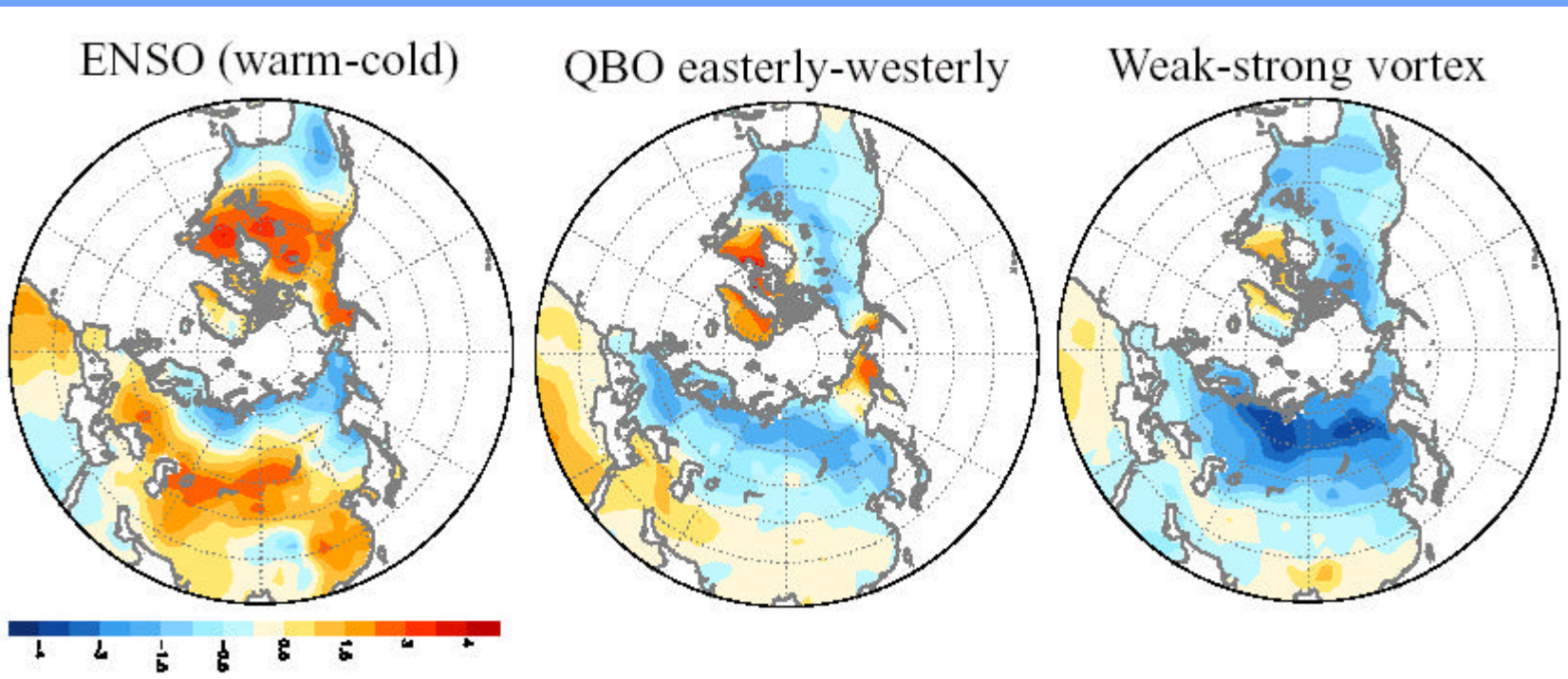
Detecting an effect

- ***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





Difference in SAT between days 1-60 following weak and strong vortex conditions at 10-hPa; Januarys when the QBO is easterly and westerly; winters corresponding to the opposing phases of ENSO.

Thompson, Baldwin, and Wallace, J. Climate 2001

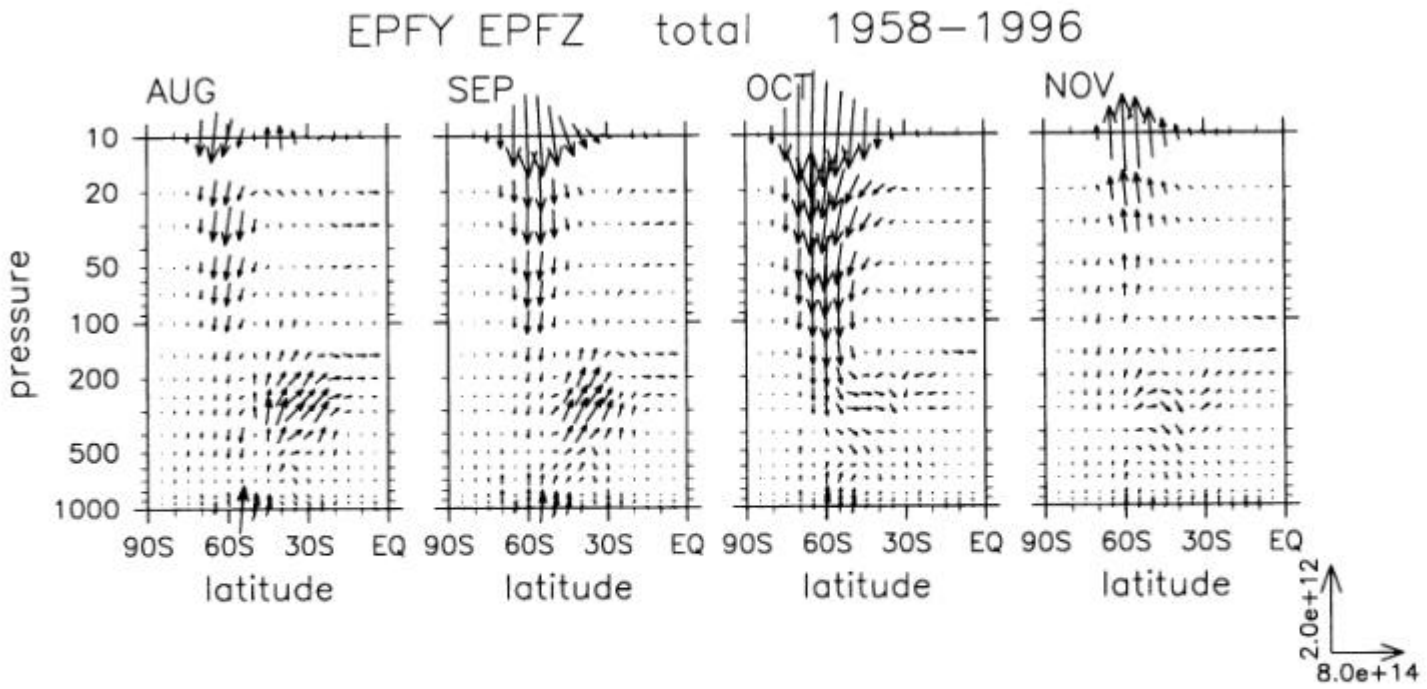


Fig. 6. Meridional sections of the monthly mean composite difference of the EP flux vectors $\boldsymbol{F}^*$ in the Southern Hemisphere for August, September, October and November. Two arrows in the right of the panel display the lengths of 8×10^{14} m^4 s^{-2} equatorward and 2×10^{12} m^4 s^{-2}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

Naito

J. Met. Soc. Japan (2002)

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 ~1ms^{-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