Intraseasonal Case Studies of the Annular Mode

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Comments Appreciated!!

We are also interested in pursuing parallel diagnoses of model simulations of annular mode behavior (mechanistic or otherwise).

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Outline

- Preliminaries
  - Mechanisms & diagnostic formalism
  - PV analyses of the Northern Annular Mode
  - Initial tangent: Recent climate variability
- Case Studies (NCEP/NCAR reanalyses)
  - Motivation and case selection
  - Downward protruding event
  - Stratosphere restricted event
- Summary

Downward Stratospheric Influences?

- Indirect influence via stratospheric modulation of tropospheric wave propagation (Shindell et al. 1999, Hartmann et al. 2000)
- Direct downward influence associated with adjustment to balance (Haynes et al. 1991, Ambaum and Hoskins 2002, Black 2002)
- Vertical Rossby wave reflection (Perlwitz and Harnik 2003)

Direct Downward Forcing?

- There is a well-recognized dynamical interplay between large-scale waves in the upper and lower troposphere
- The impact of upper tropospheric waves upon surface waves has been diagnosed using potential vorticity inversion methods (e.g., Hoskins et al. 1985, Black and Dole 1993)
- We use potential vorticity inversion methods to study direct downward forcing associated with stratospheric PV anomalies

PV Balance Condition:

- Large-scale atmospheric disturbances (waves) are governed by the *linear* balance condition:

$$q' = \frac{g}{f}\left\{ \frac{1}{(a\cos\phi)^2}\frac{\partial^2}{\partial\lambda^2} + \frac{f}{a^2\cos\phi}\frac{\partial}{\partial\phi}\left(\frac{\cos\phi}{f}\frac{\partial}{\partial\phi}\right) + f^2\frac{\partial}{\partial p}\left(\frac{1}{\sigma}\frac{\partial}{\partial p}\right)\right\} Z'$$

$$= \mathcal{L}(Z')$$

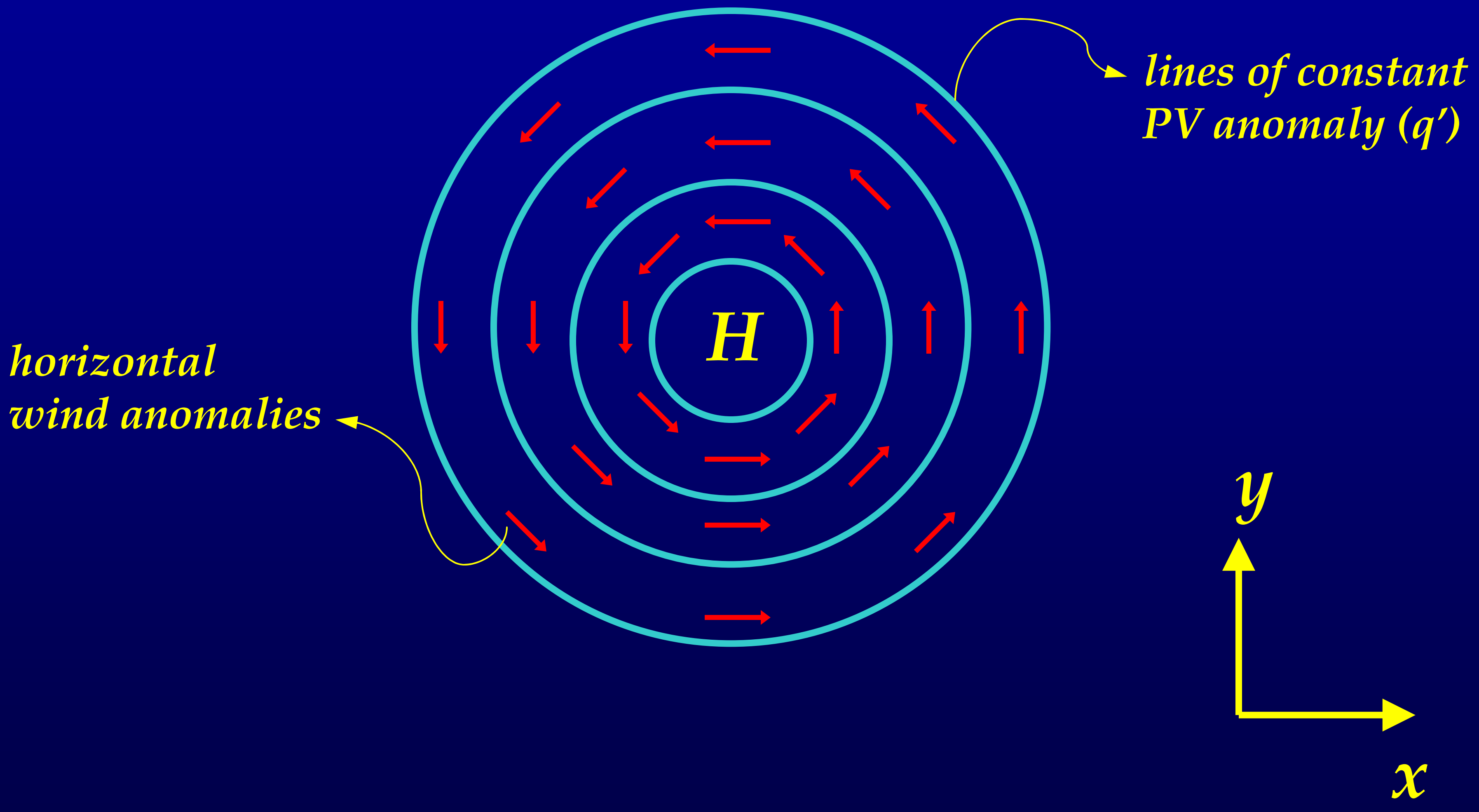
$$\Rightarrow \quad Z' = \mathcal{L}^{-1}(q')$$

- Poisson-like => nonlocal response in *Z'*

[variation of Black 2002]

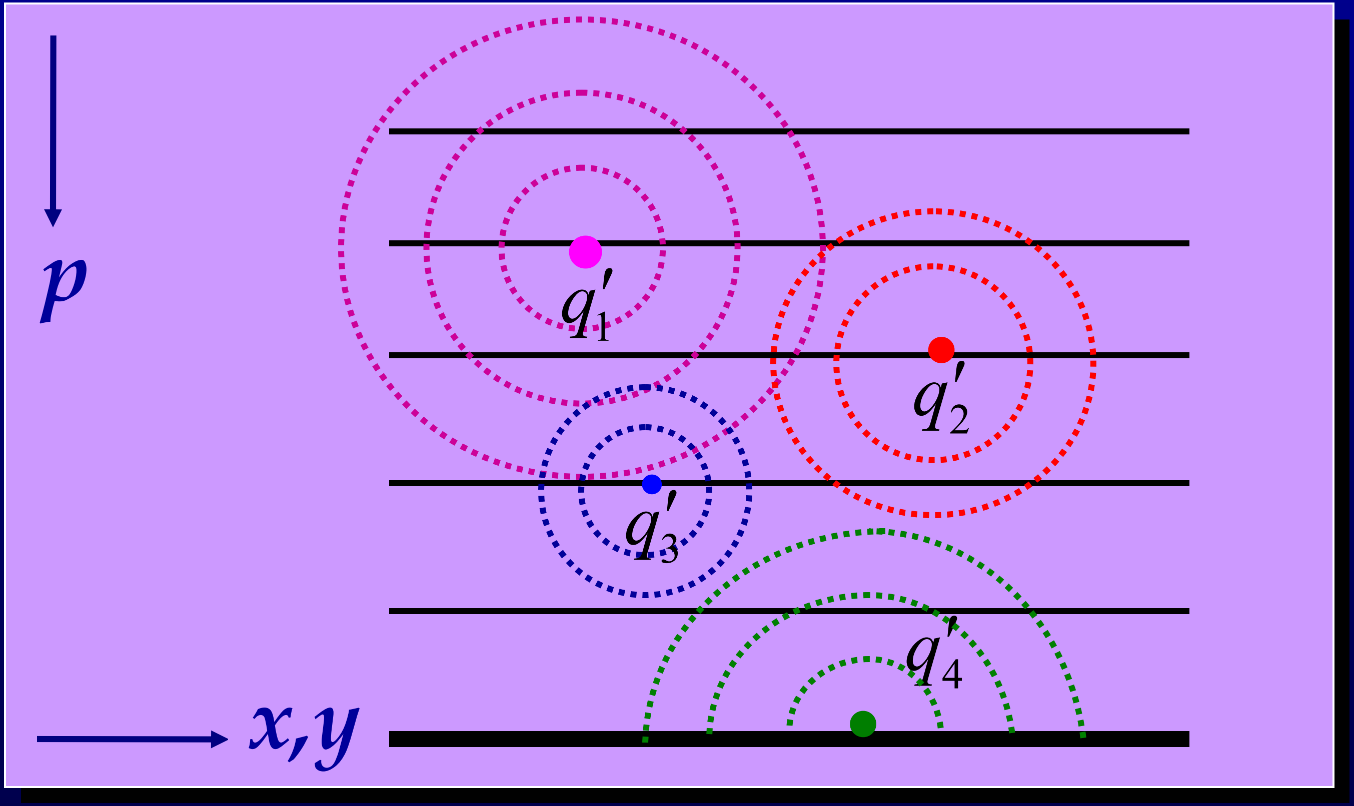
Horizontal PV Balance: Wind anomalies

(at constant pressure):



PV 'Charge' Distribution

- Poisson-like PV balance condition indicates nonlocal effects analogous to induction of electric field by localized charges

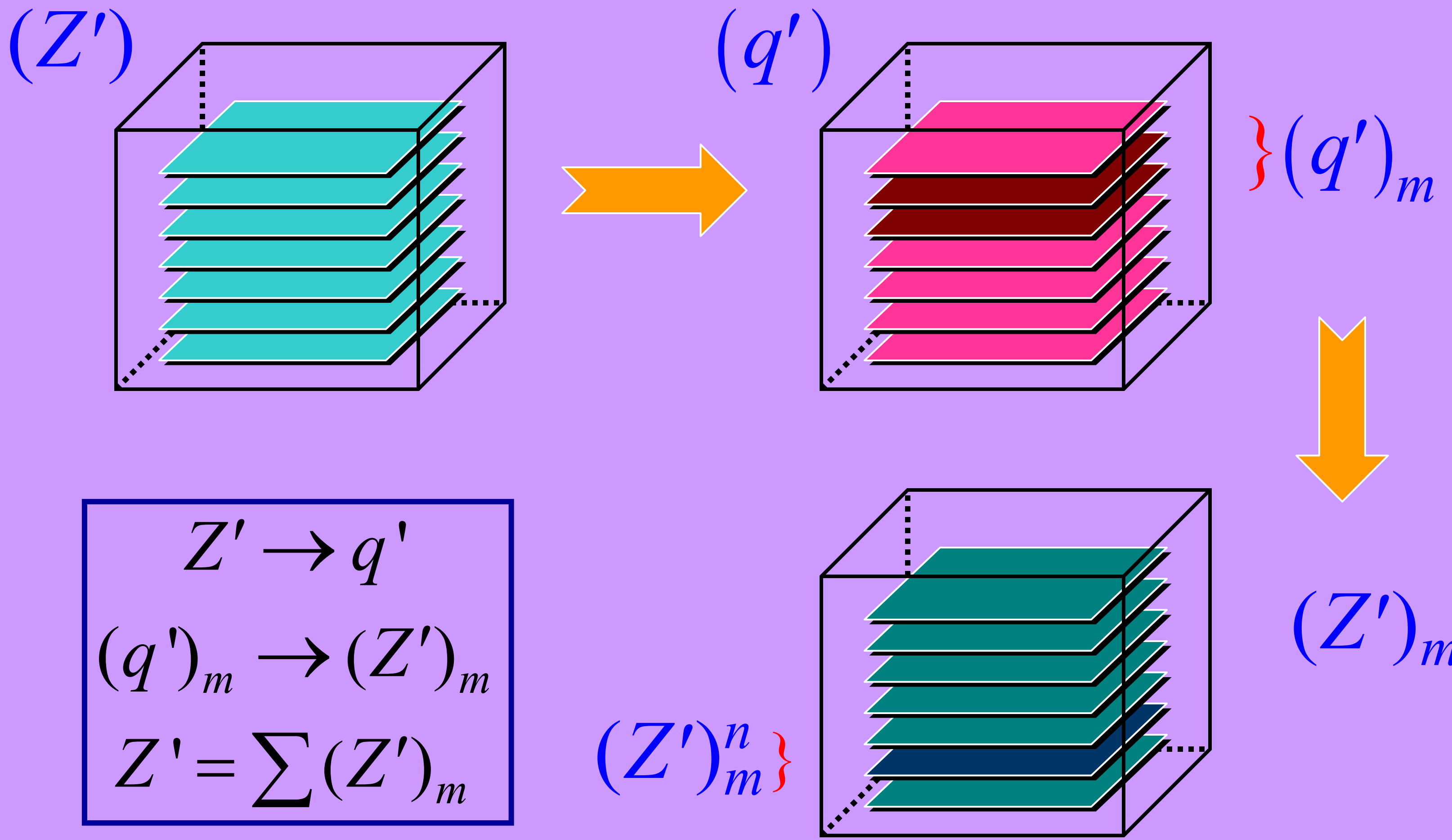


Spheroids of constant Z′ associated with isolated q anomalies

Vertical extent related to L/N; Large scales & weak N favor a downward influence

[e.g., Hoskins et al. 1985]

Piecewise PV Inversion: Mechanics



$$Z' \rightarrow q'$$

$$(q')_m \rightarrow (Z')_m$$

$$Z' = \sum (Z')_m$$

Boundary Conditions

- Polar Continuity
- Longitudinally cyclic
- $Z'=0$ at low latitude boundary (5^0N)
- Upper and lower boundaries:

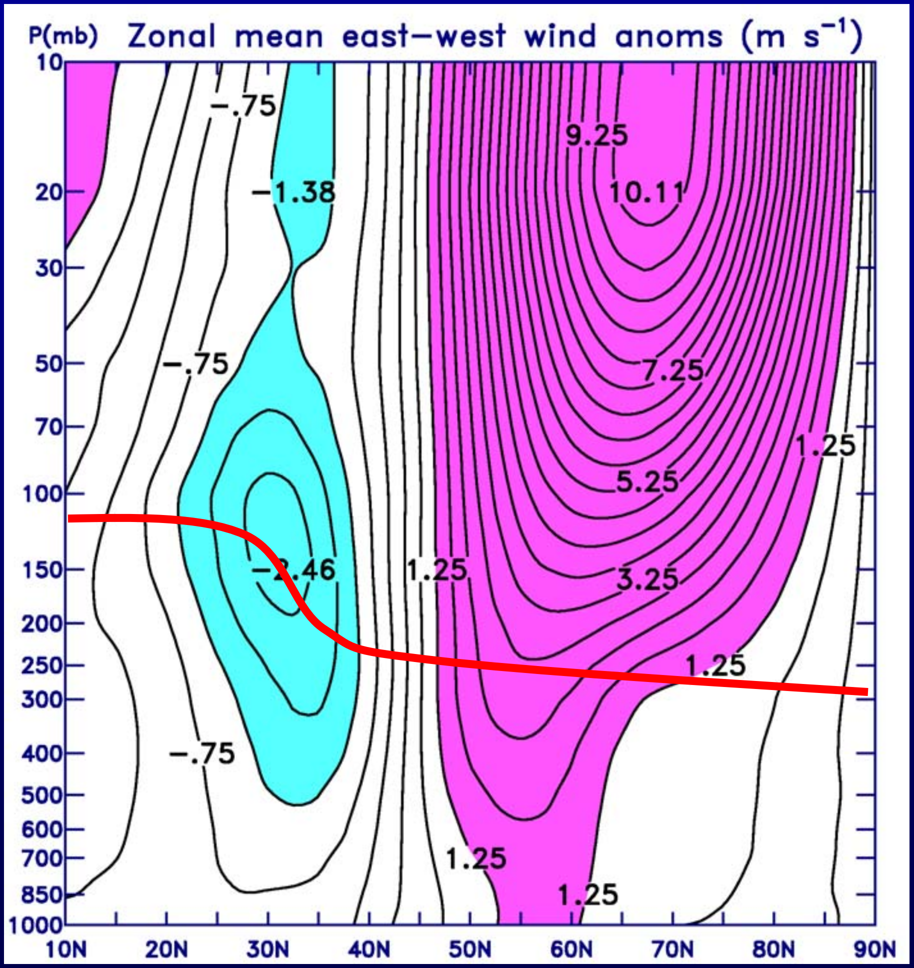
a) Boundary q' not included: $\dfrac{\partial Z'}{\partial p}=0$

b) If boundary q' is included: $\dfrac{\partial Z'}{\partial p}=-\dfrac{R\theta'}{gp}\left(\dfrac{p}{p_o}\right)^{R/C_p}$

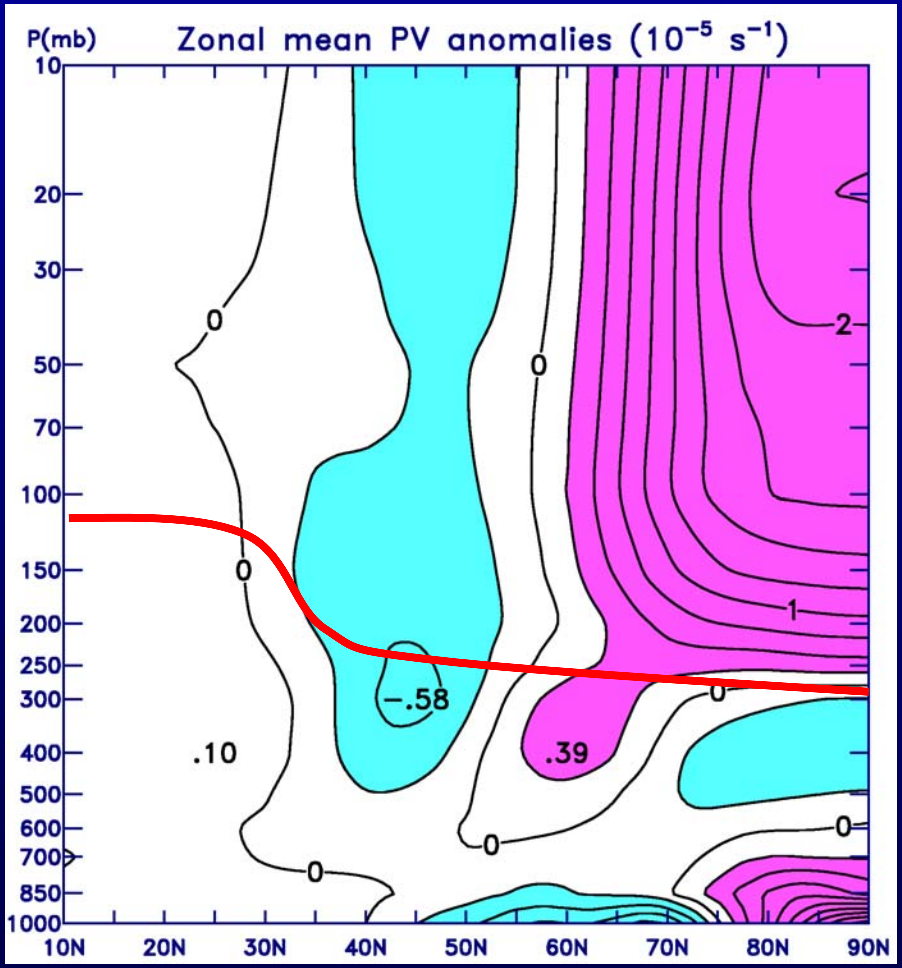
[Black 2002]

Time Averaged NAM Structure (winter)

East-West Wind Anomalies (*u'*)



PV Anomalies (*q'*)

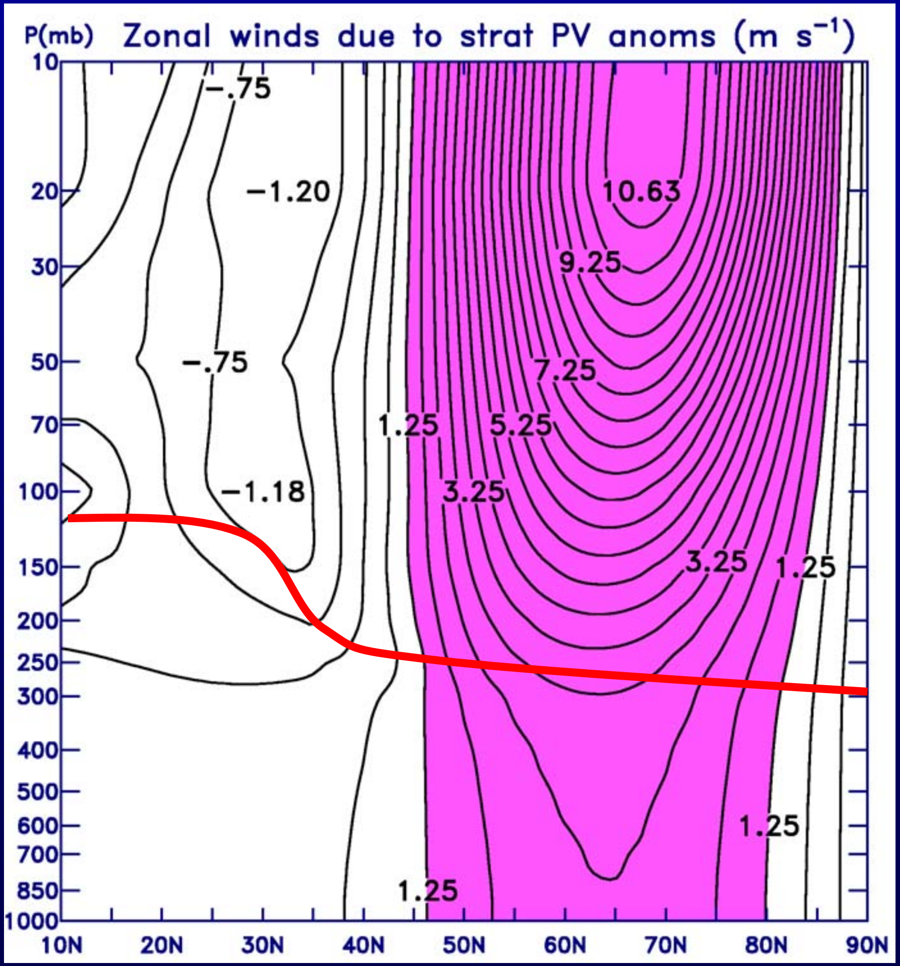


Time Averaged NAM Structure

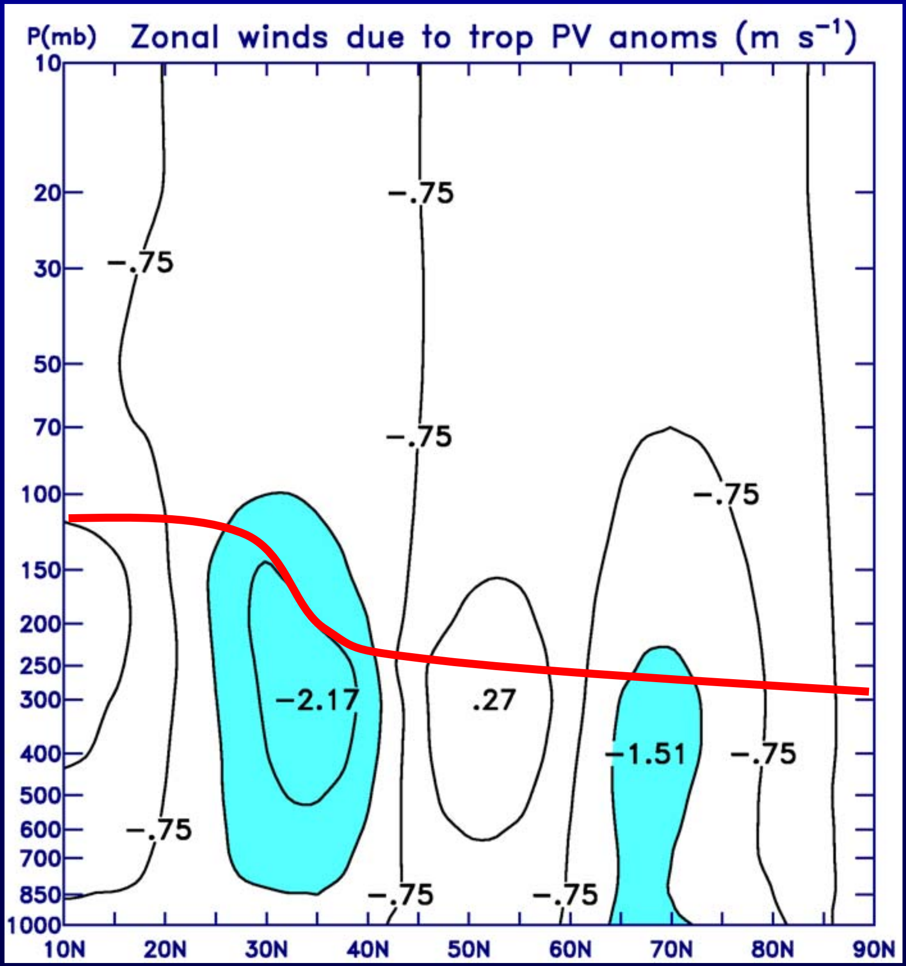
[Black 2002]

PV Inversion Results: East-West Winds (*u'*)

Invert Stratospheric PV Anoms



Invert Tropospheric PV Anoms

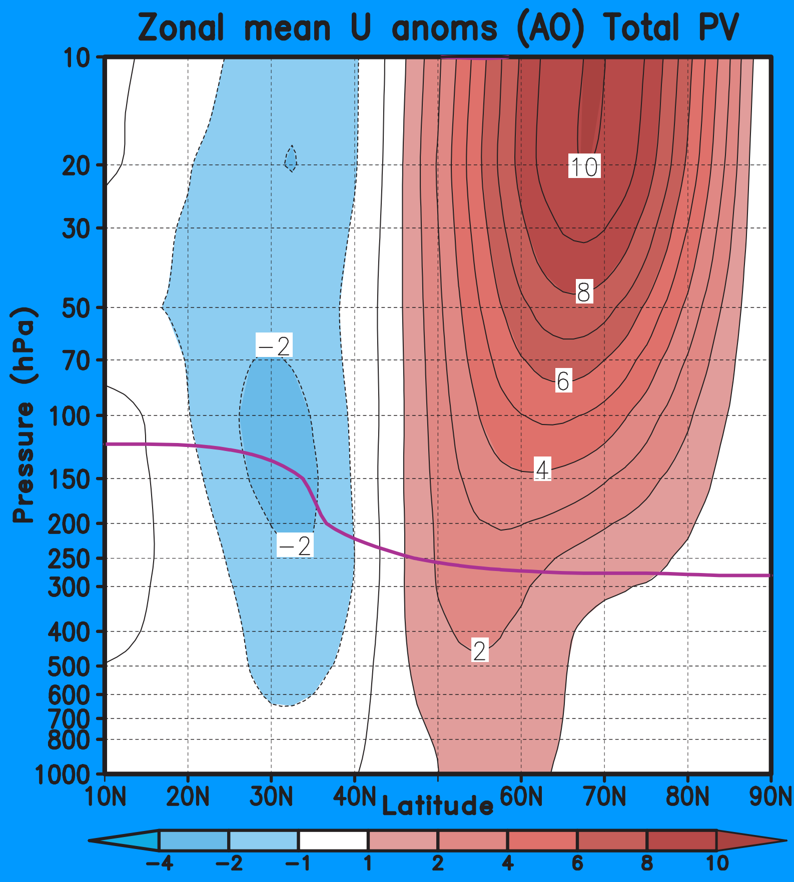


Time Averaged NAM Structure

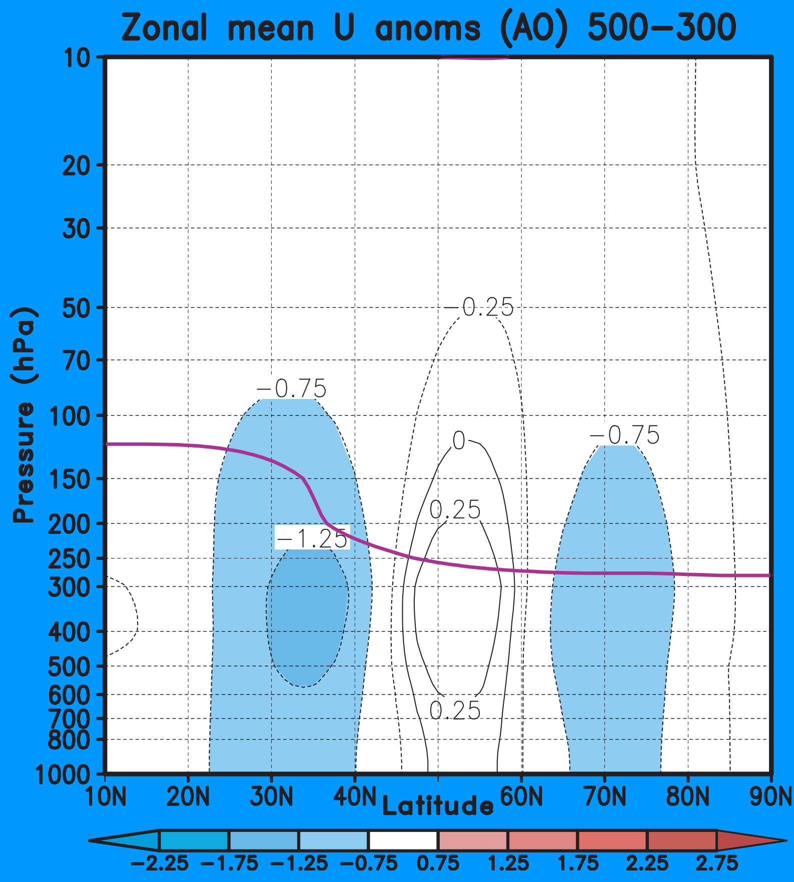
[Black 2002]

Nonlocalness of Upper Troposphere U

Invert All PV Anoms



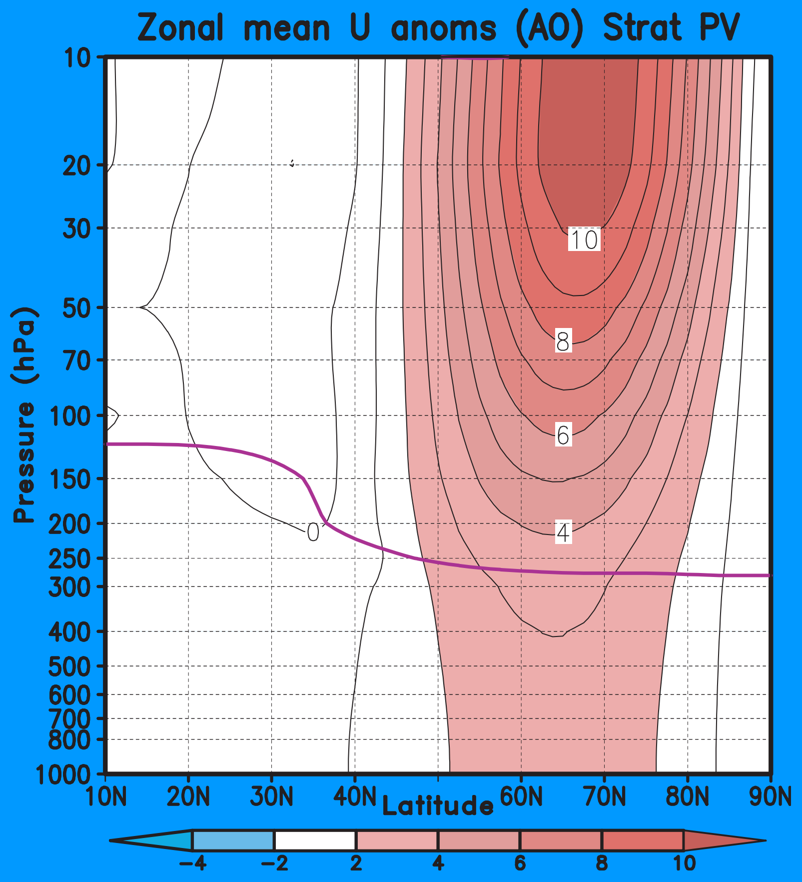
Invert 500-300 hPa PV



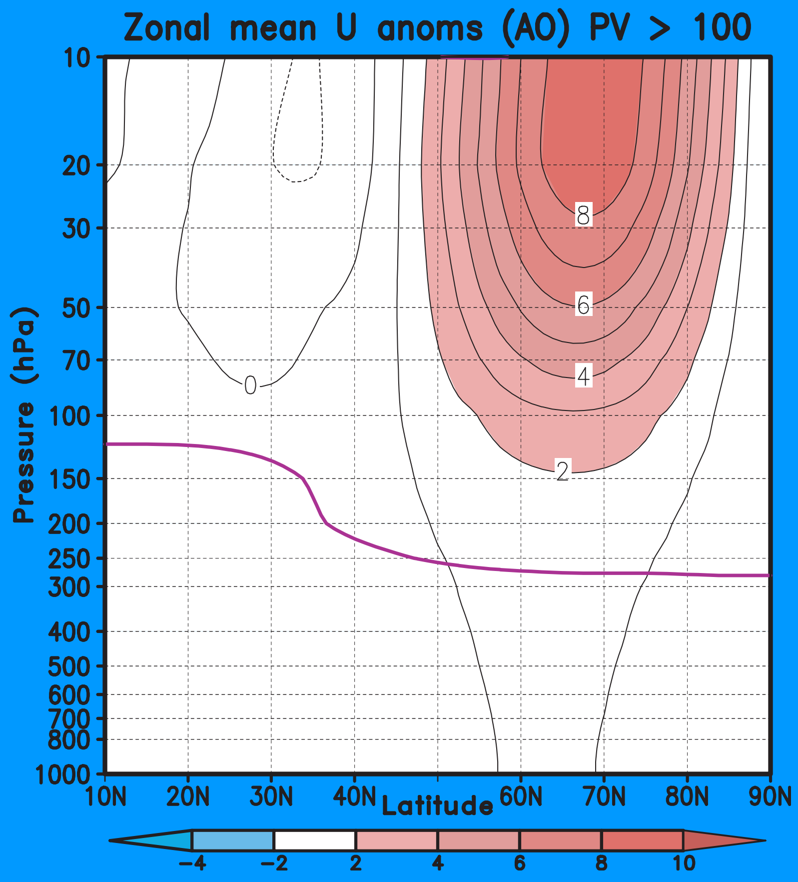
Time Averaged NAM Structure

Importance of Lowermost Stratosphere

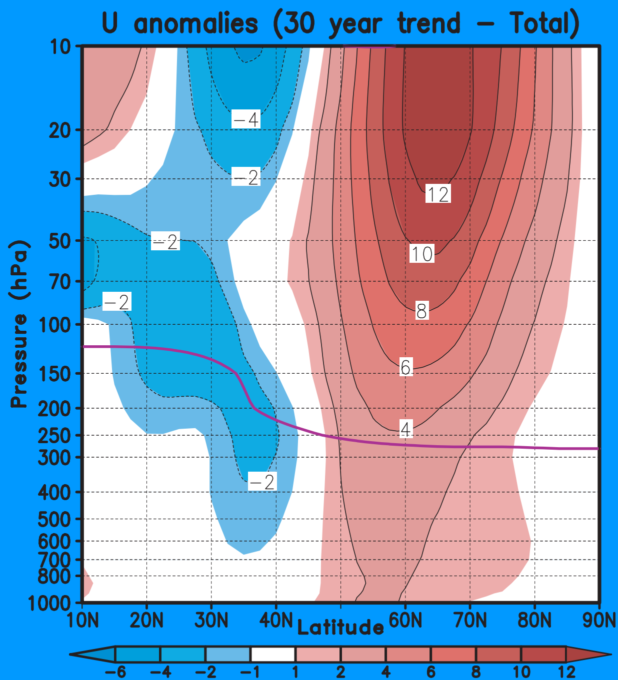
Invert Stratospheric PV Anoms



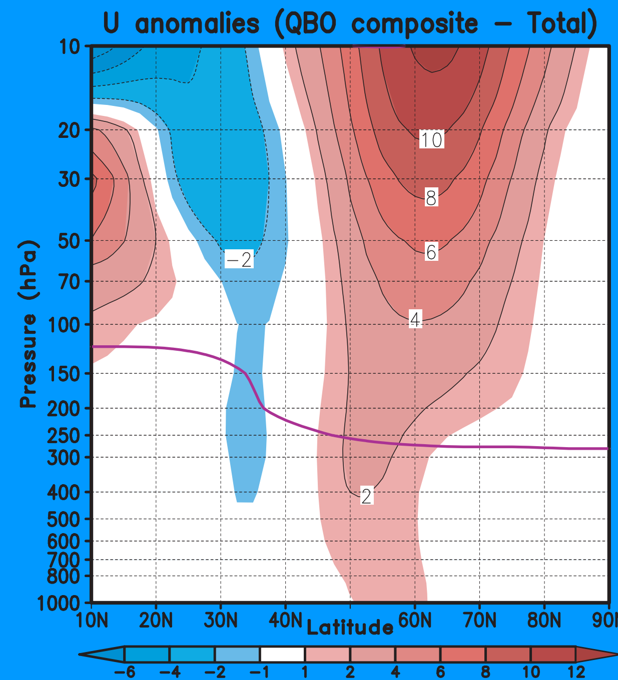
Invert PV Anoms > 100 mb



Time Averaged NAM Structure



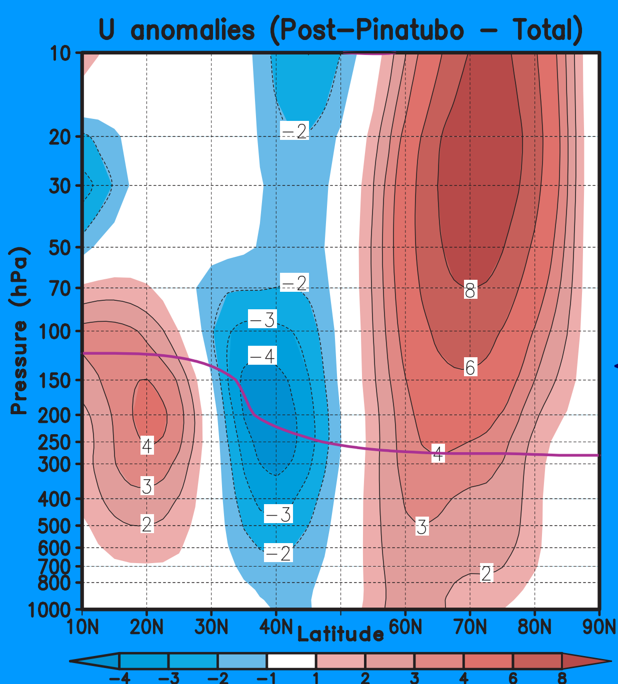
<= JFM trend (1968-97)
(Thompson et al. 2000)



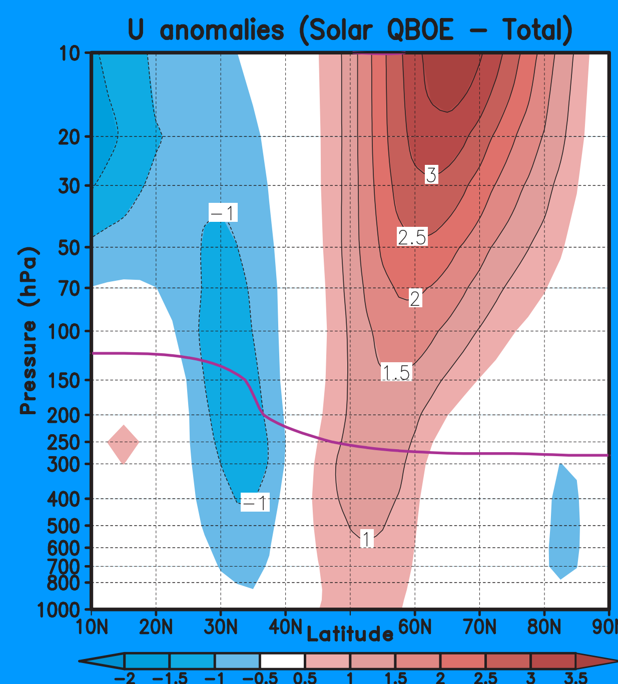
QBO composite (Jan) =>
(Thompson et al. 2002)

Recent NH Winter Climate Variability:

Zonal mean zonal wind anomalies



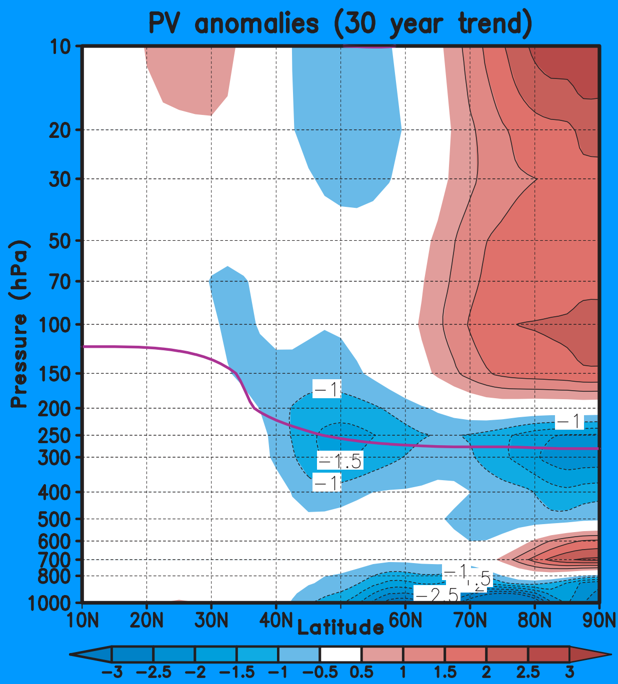
<= Post-Pinatubo composite
(Stenchikov et al. 2000)



Solar cycle regression =>
(QBO East - January)

Recent NH Winter Climate Variability:

Zonal mean PV anomalies



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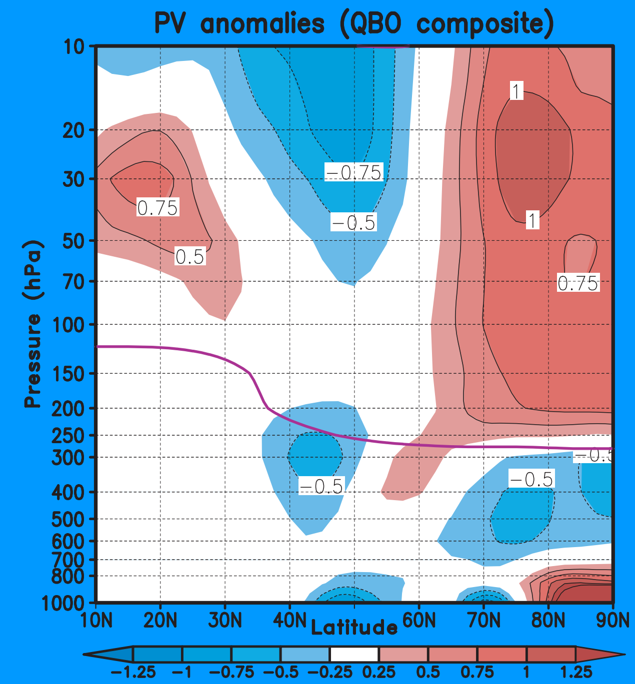

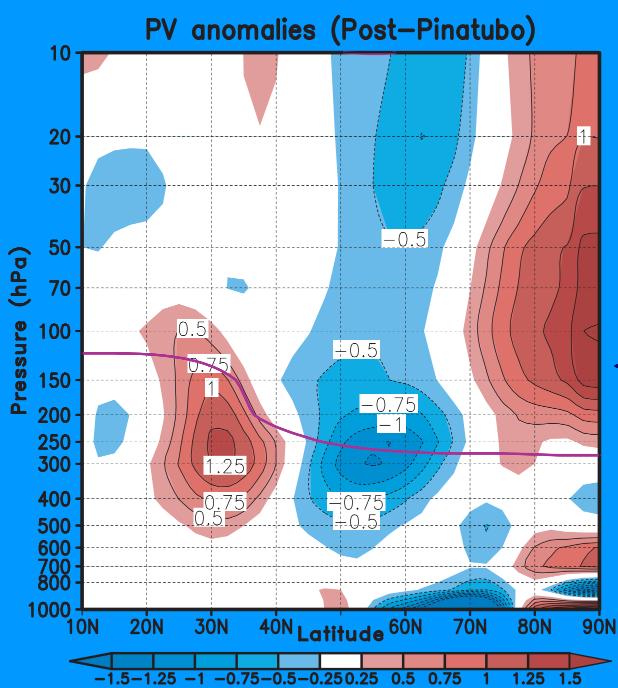

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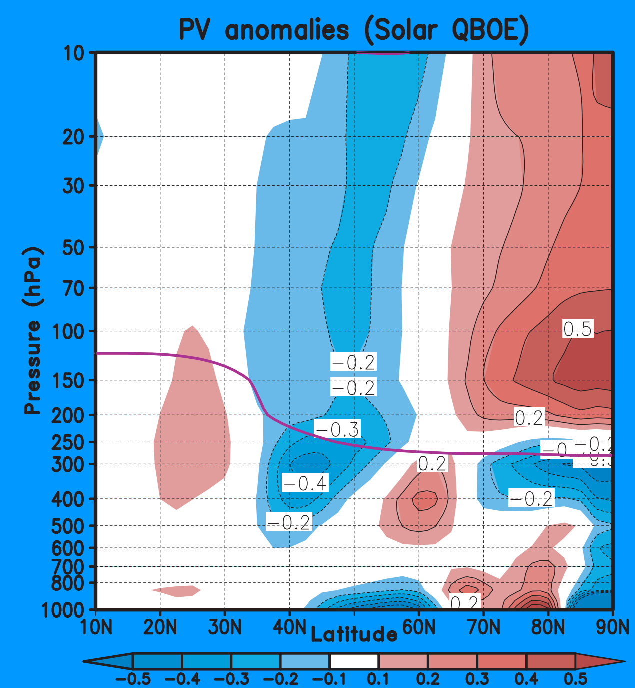

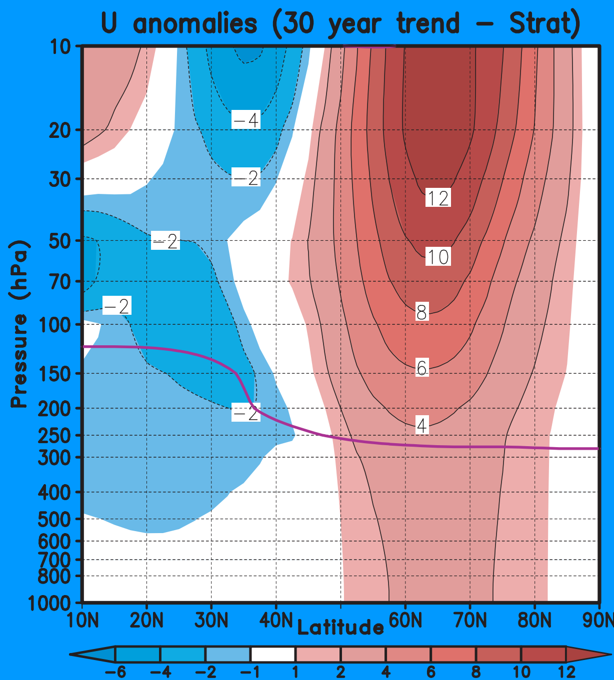

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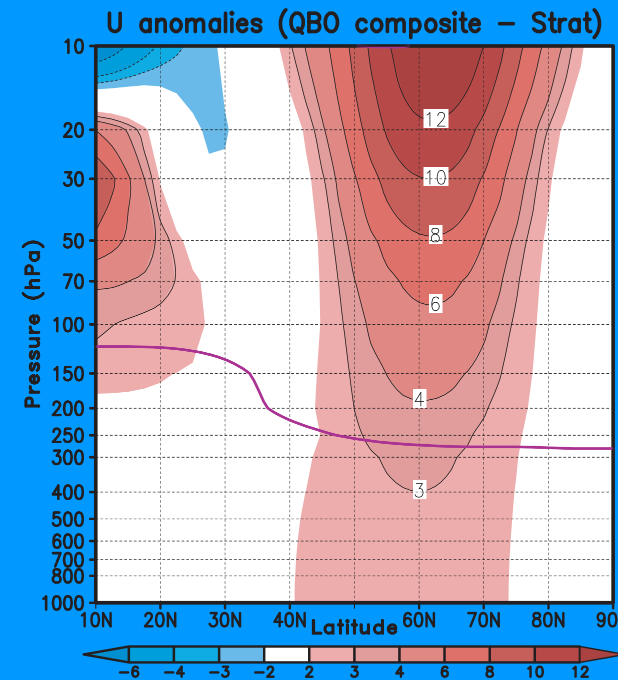
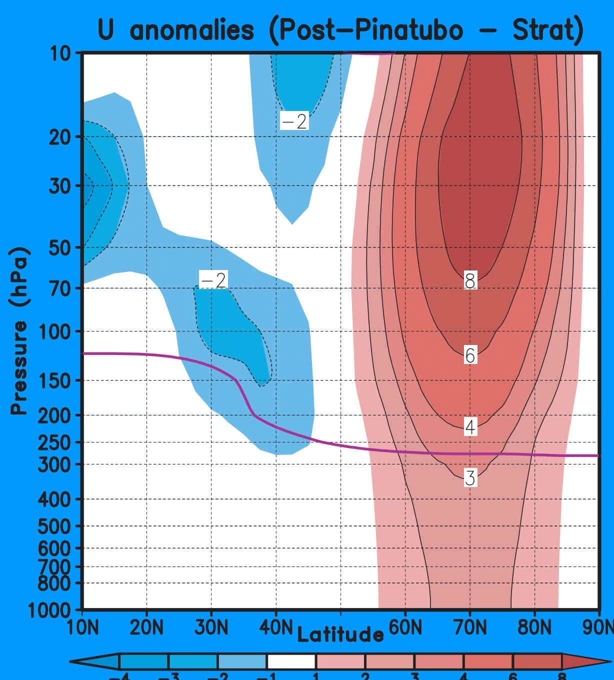


QBO composite (Jan) =>
(Thompson et al. 2002)

Recent NH Winter Climate Variability:

Zonal winds induced by stratospheric PV anoms



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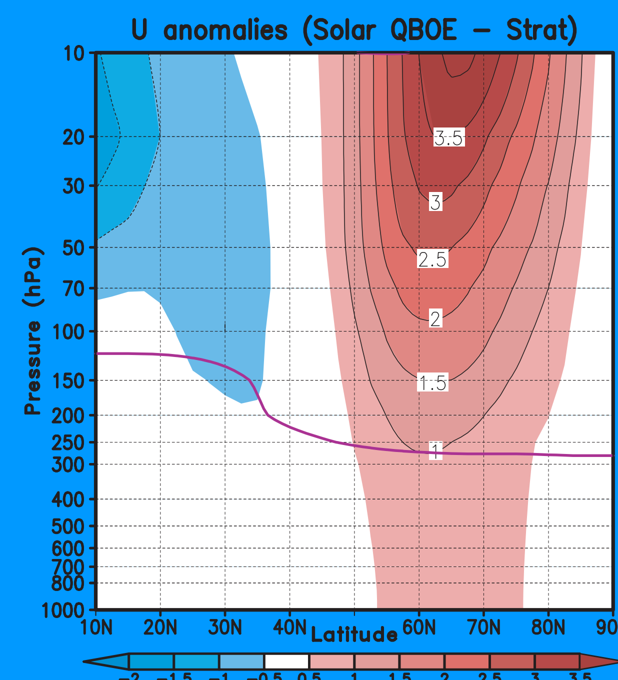

Solar cycle regression =>
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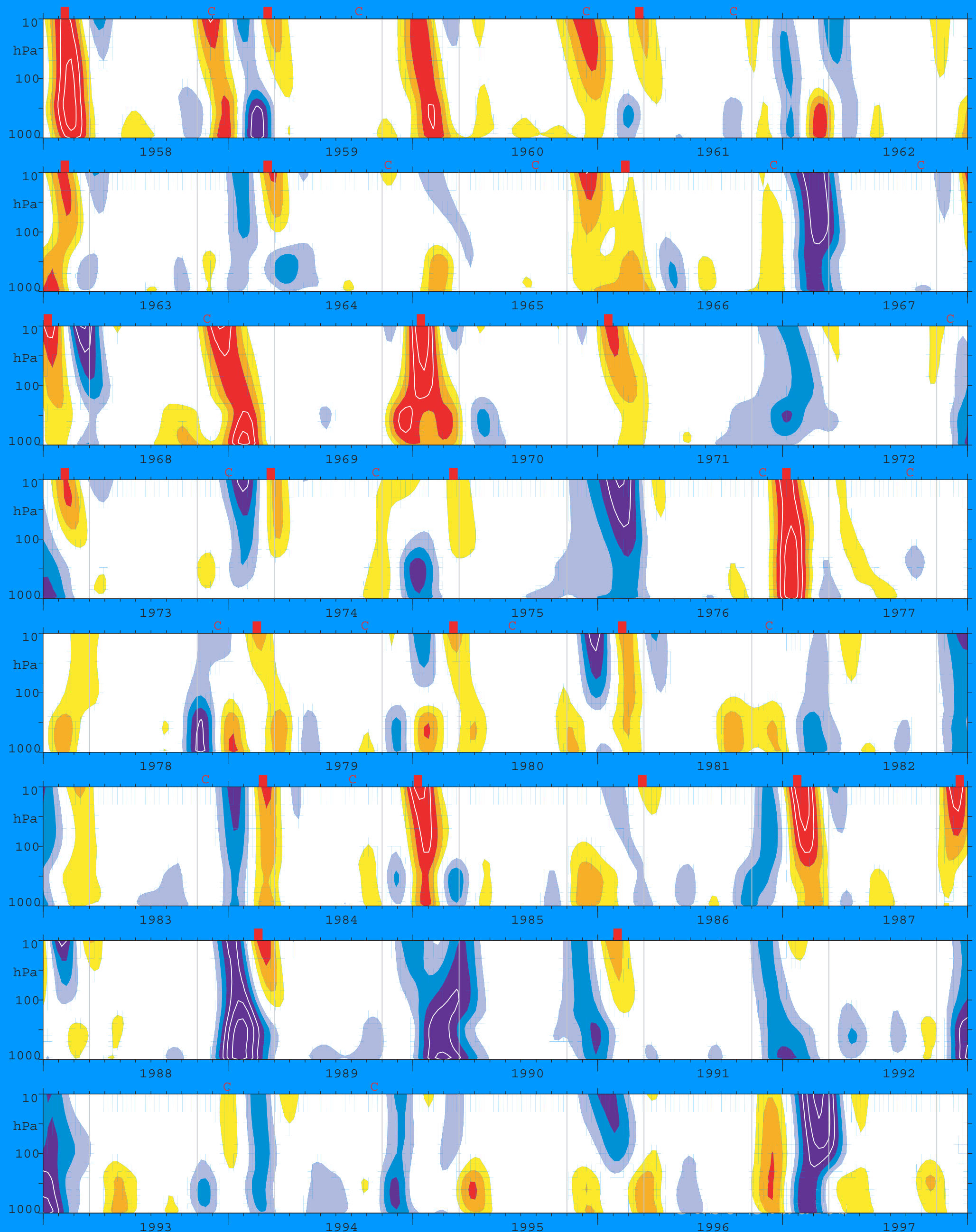
Case Studies of the NAM



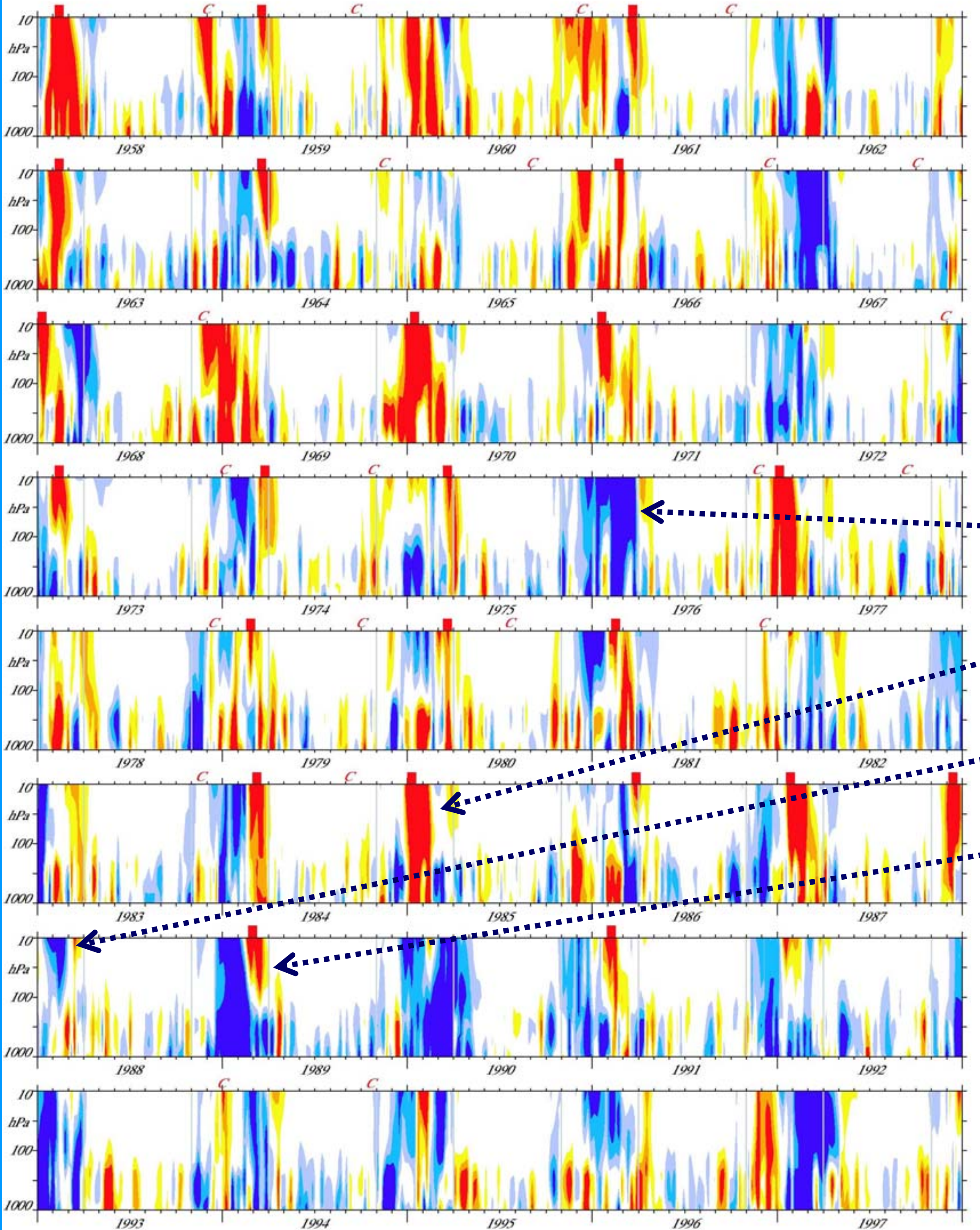
Some stratospheric events penetrate into the troposphere and some don't. Why?

- NCEP/NCAR daily data
- Deviations from seasonal trend
- Running 5-day average

90 Day LP Filter

[Baldwin and Dunkerton 1999]

Case Studies of the NAM



Case 1: Feb 1976

Case 2: Jan 1985

Case 3: Feb 1988

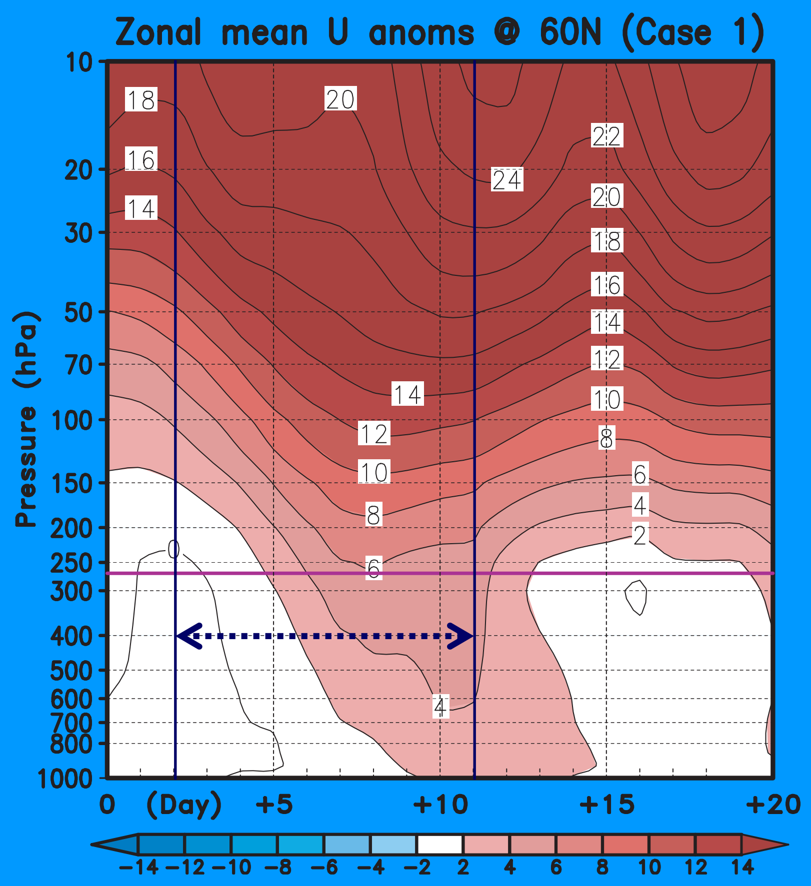
Case 4: Mar 1989

10 day LP Filter

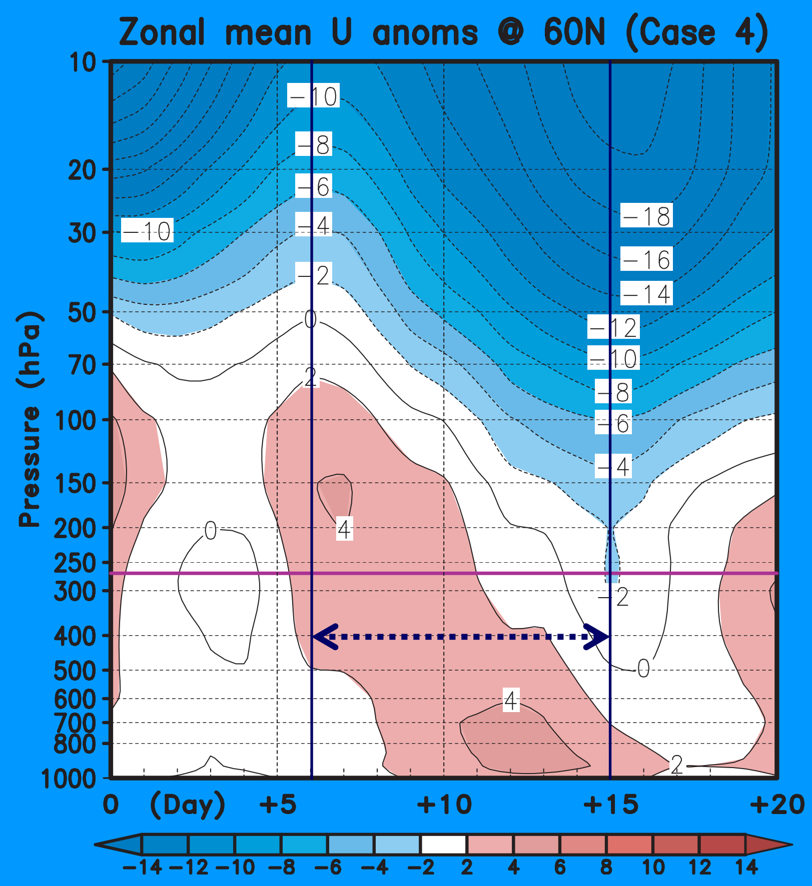
[Baldwin and Dunkerton 1999]

Case studies of NAM onset

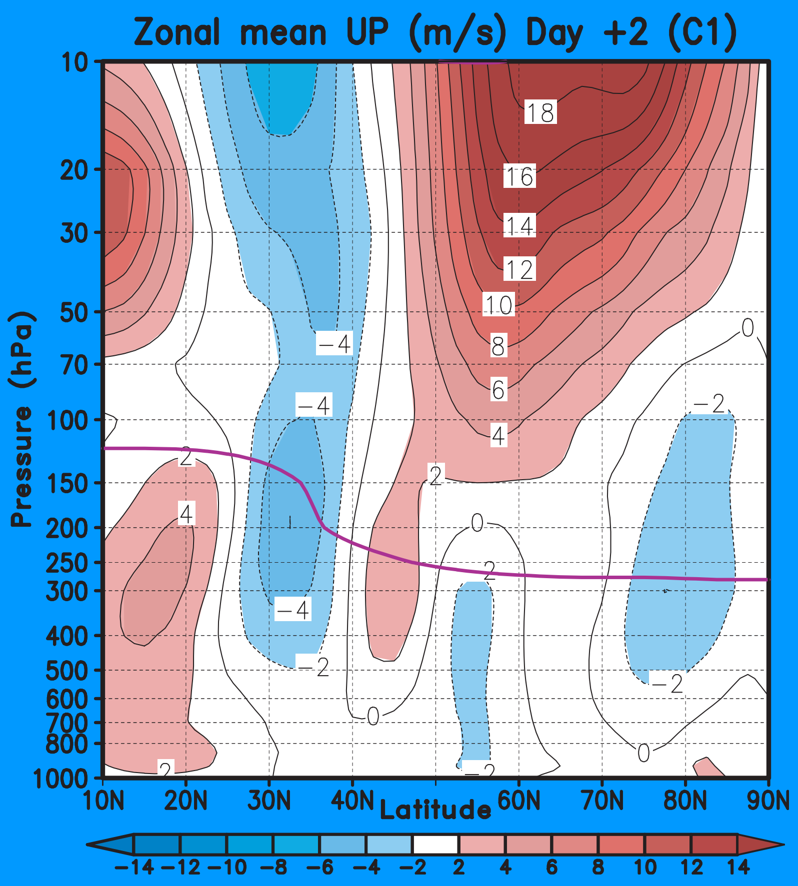
Case 1: 2/2/76 – 2/22/76

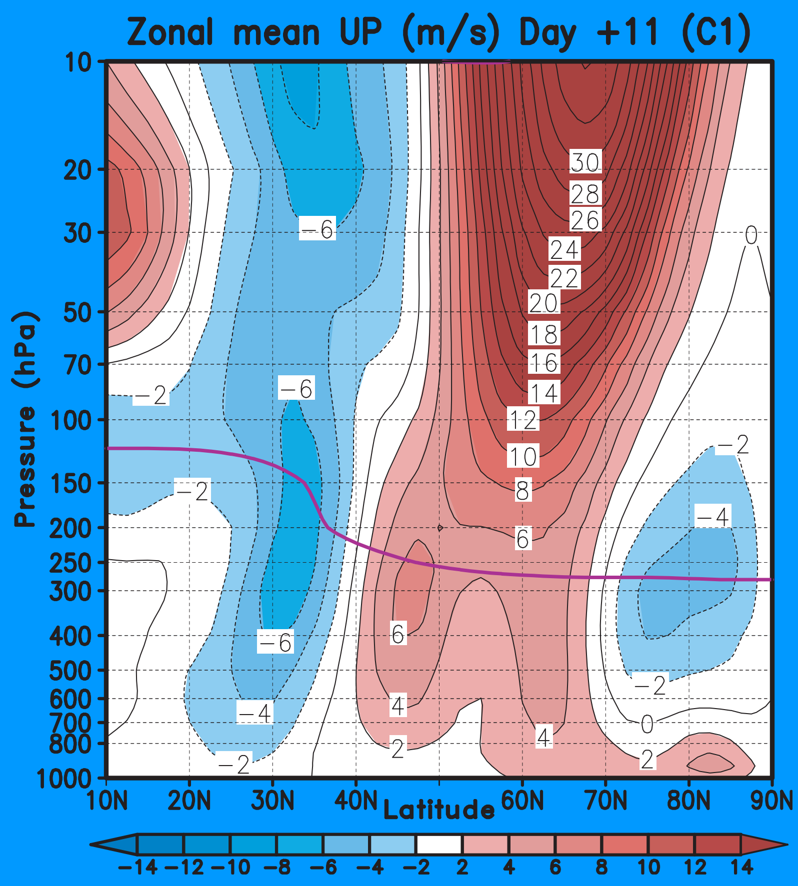


Case 4: 2/26/89 – 3/18/89



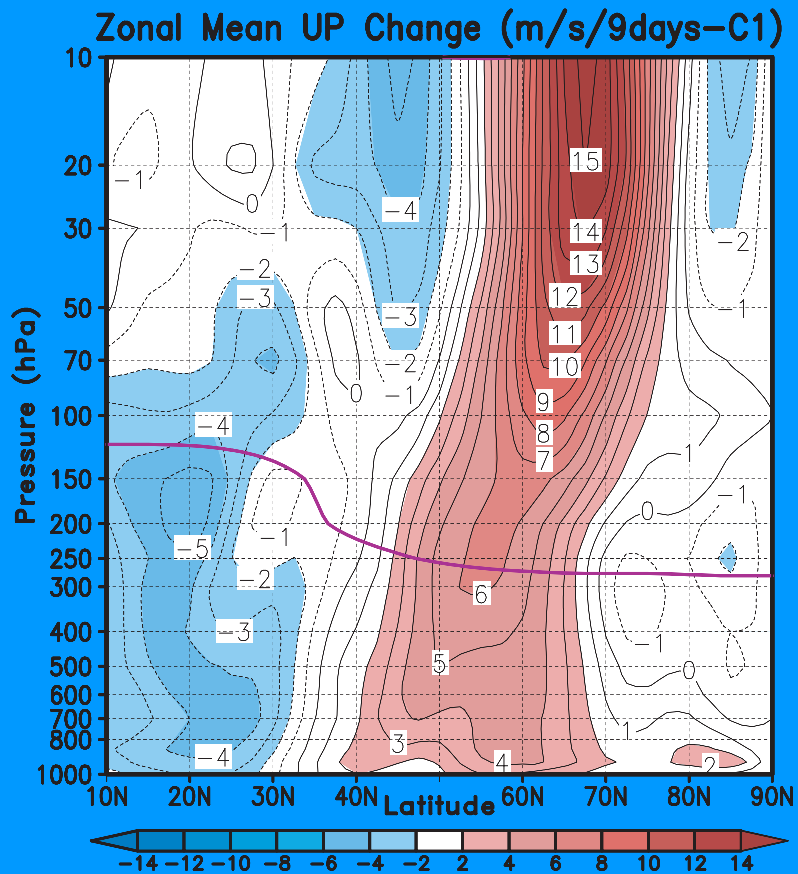
Case 1: Zonal wind evolution



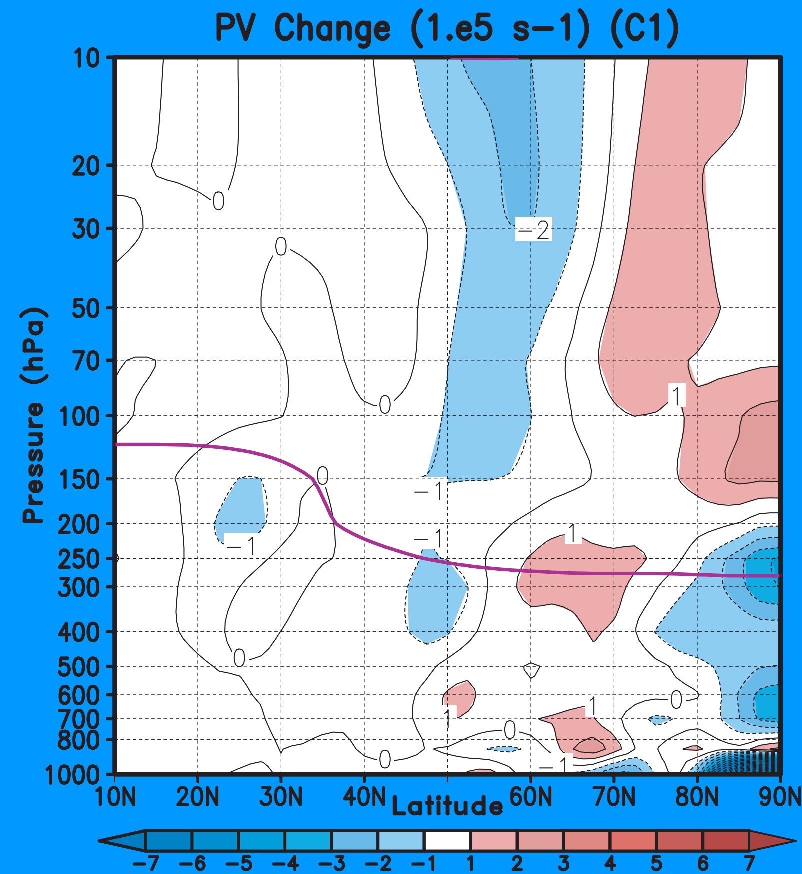


Case 1: Developmental Changes

Zonal Wind

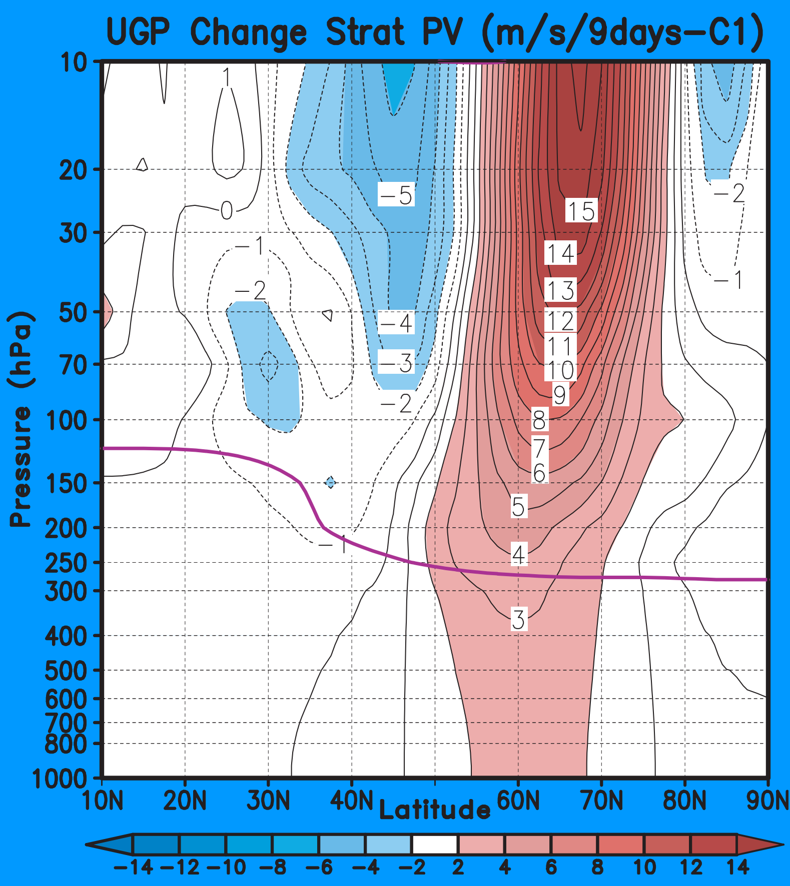


Potential Vorticity

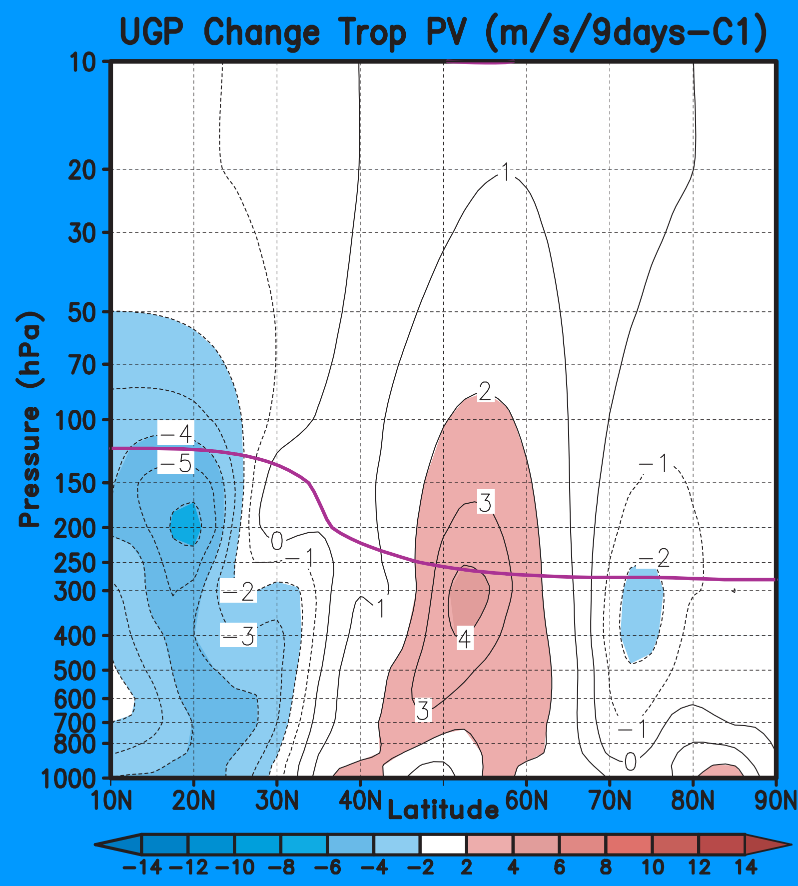


Case 1: Induced zonal wind changes

Stratospheric PV Anoms

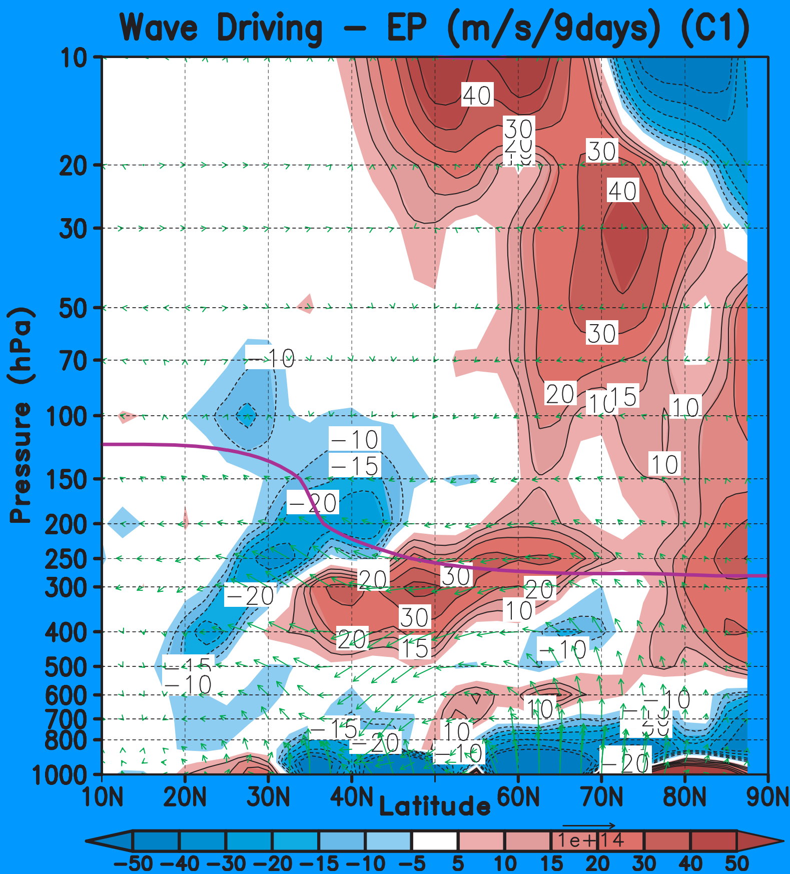


Tropospheric PV Anoms

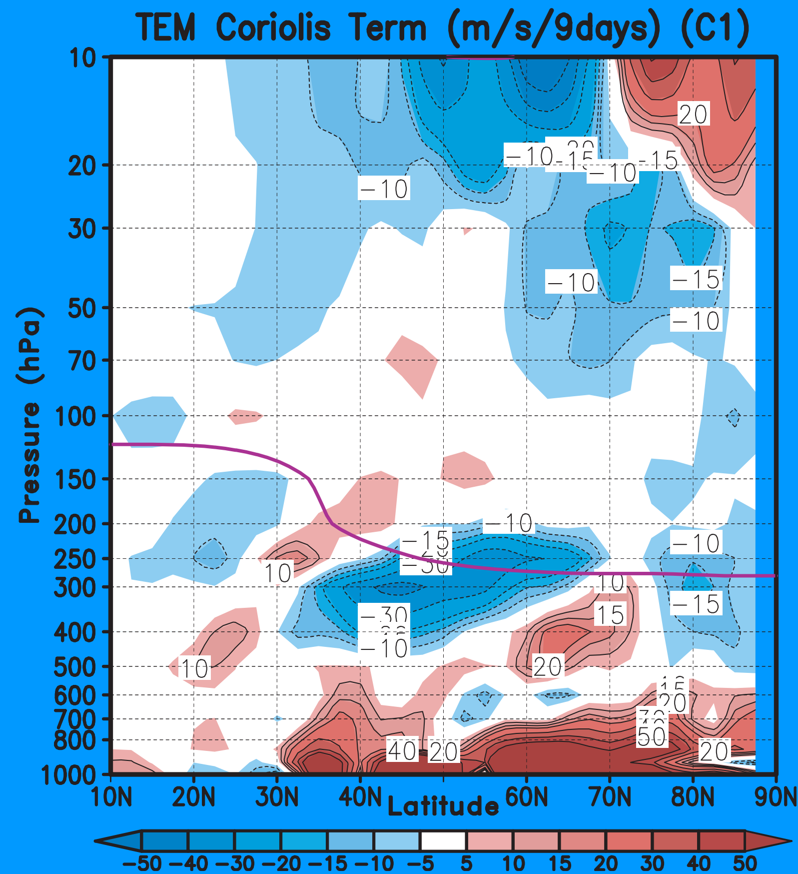


Case 1: Anomalous TEM Forcing

Wave Driving & EP Flux

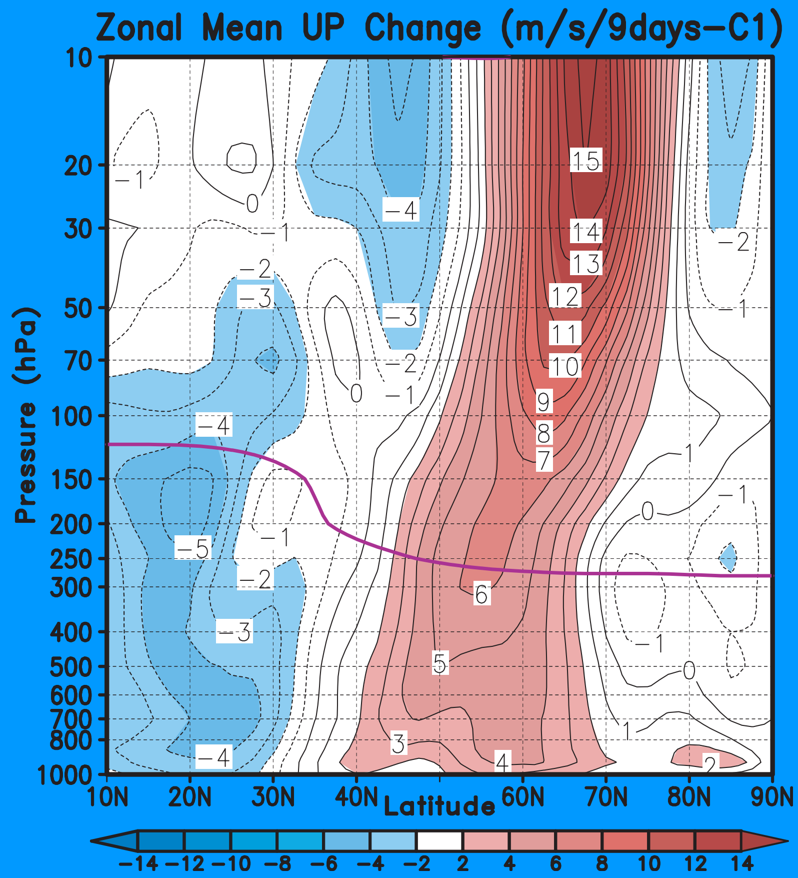


TEM Coriolis Acceleration

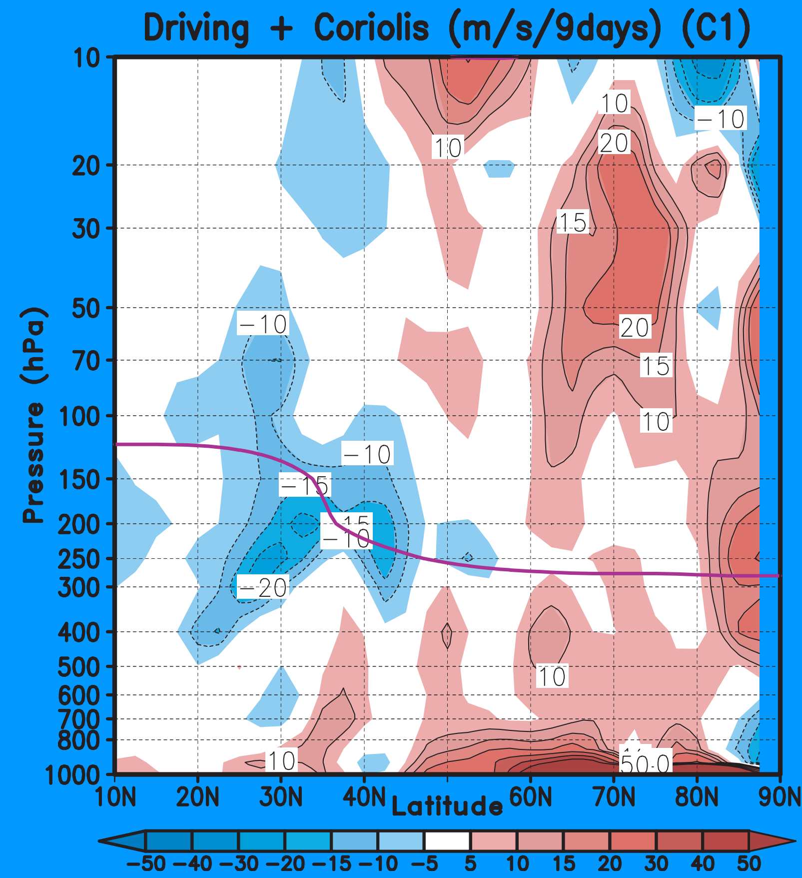


Case 1: Zonal wind changes

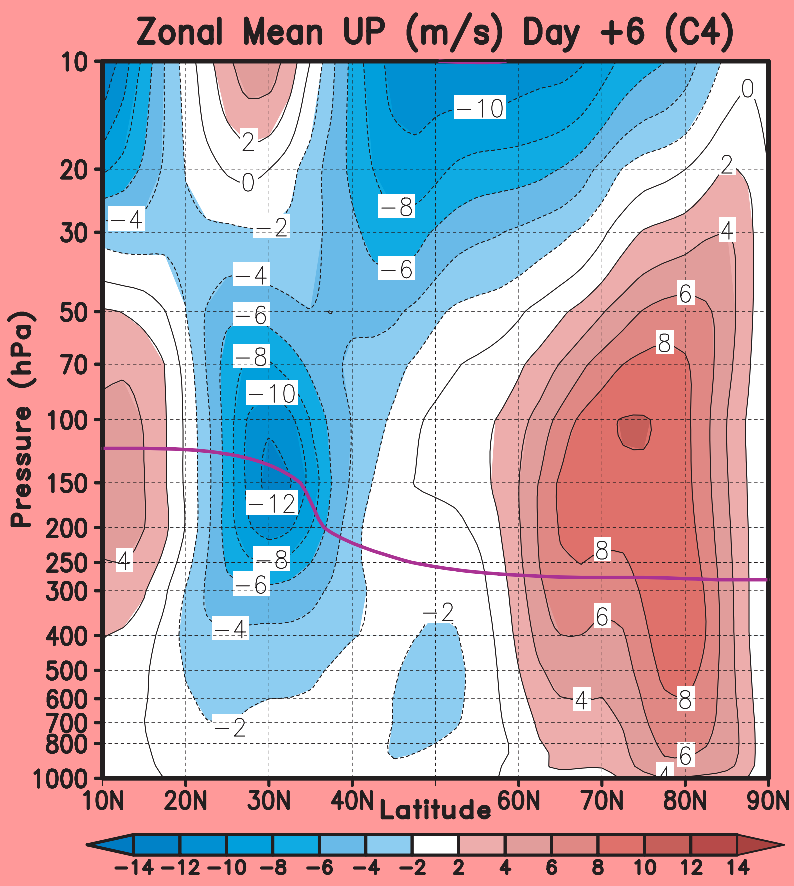
Observed

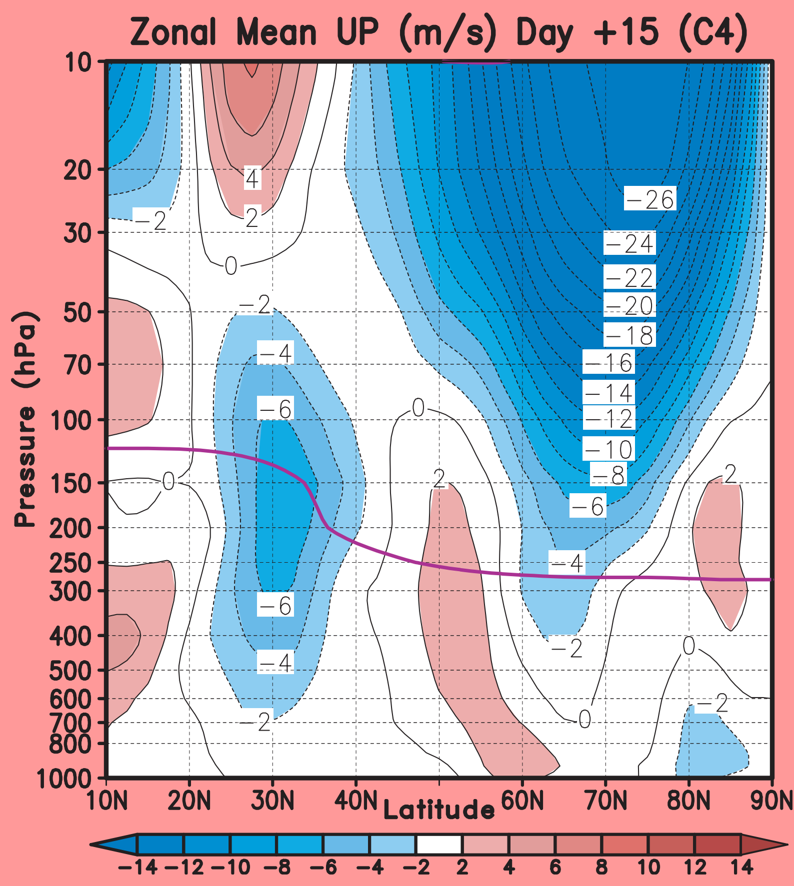


Net TEM forcing



Case 4: Zonal wind evolution

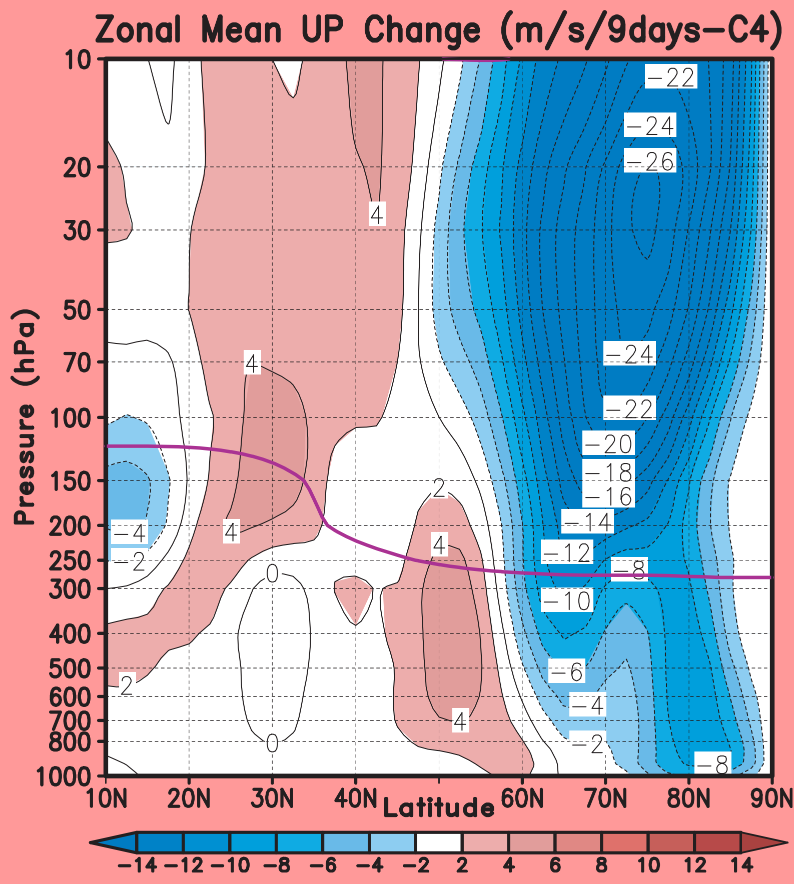


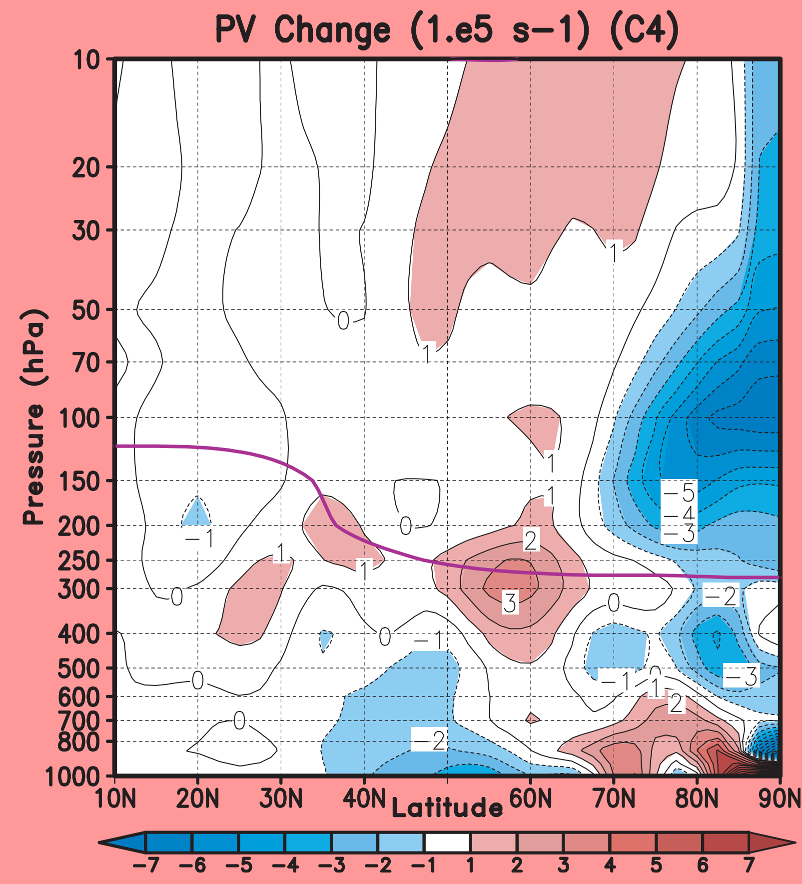


Case 4: Developmental Changes

Zonal Wind

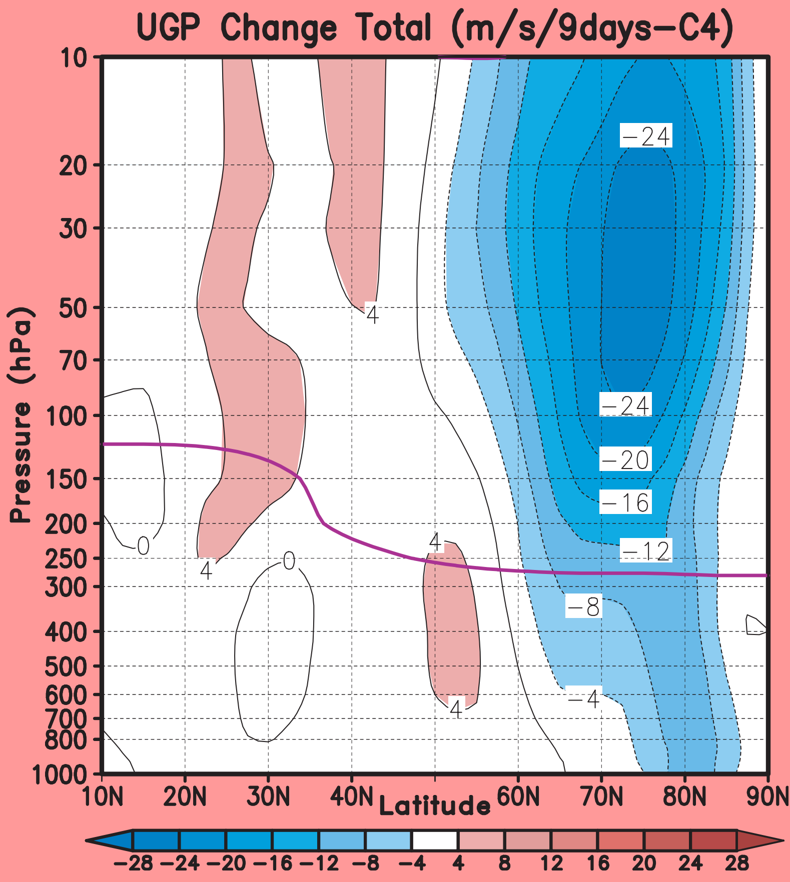
Potential Vorticity



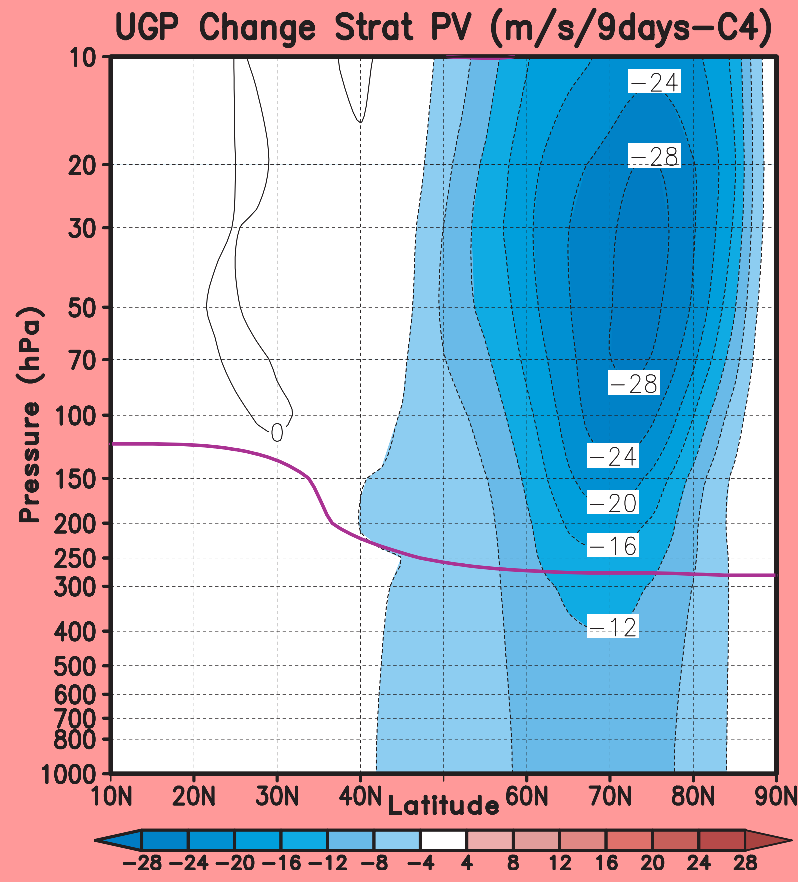


Case 4: Induced zonal wind changes

Total

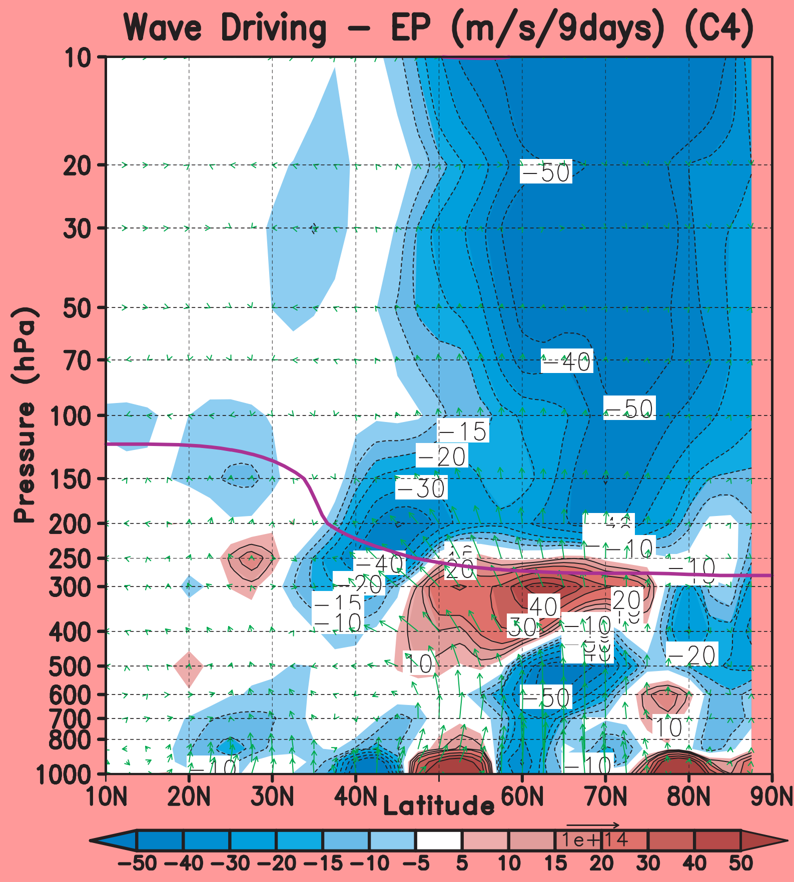


Stratospheric PV Anoms

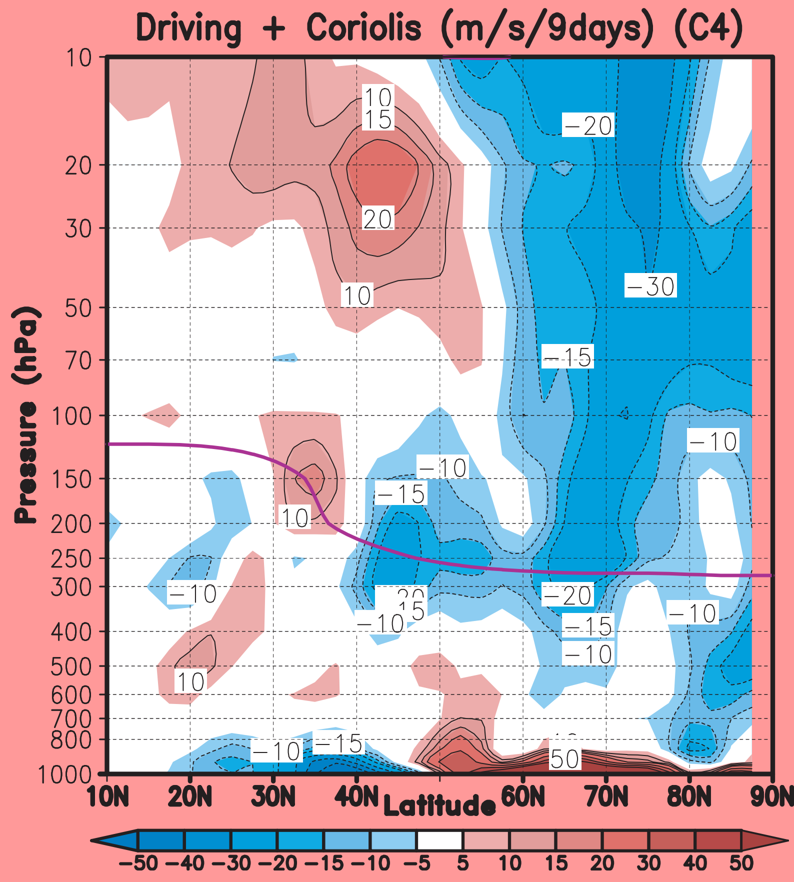


Case 4: Anomalous TEM Forcing

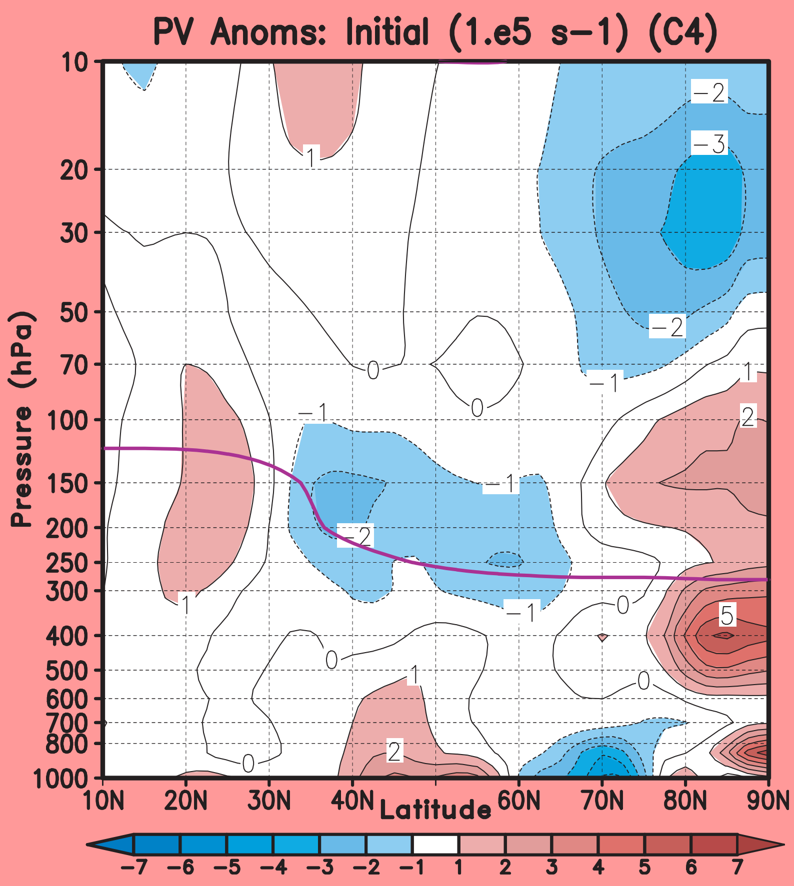
Wave Driving & EP Flux

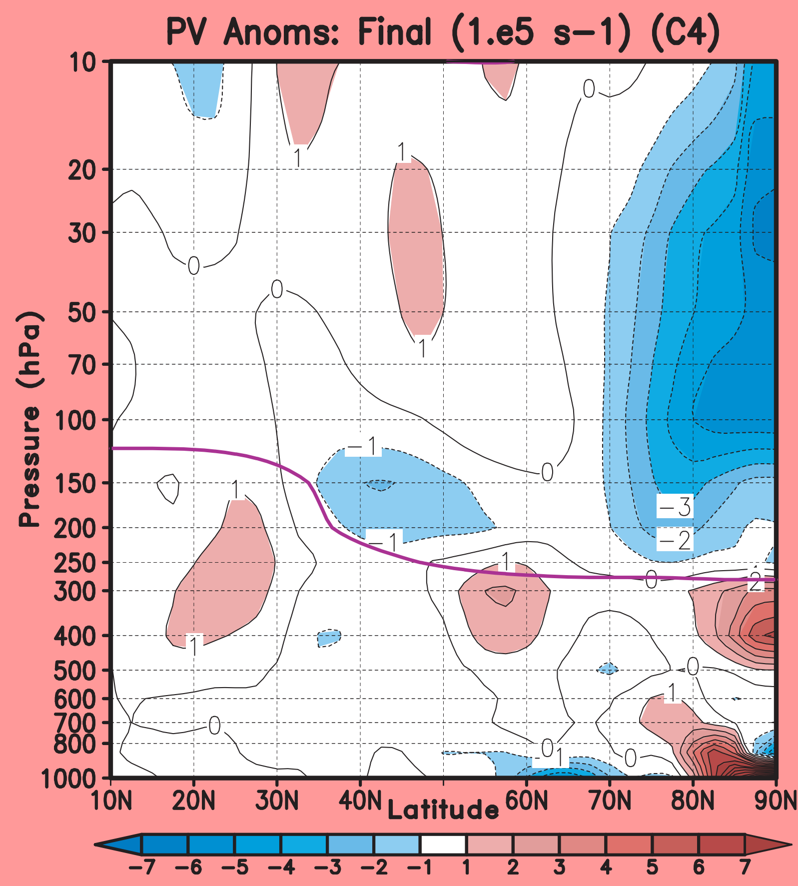


Net TEM Forcing



Case 4: PV evolution





Summary

- PV Anomalies in lowermost stratosphere (250-100 hPa) exert a downward influence
- This effect appears to be acting in recent climate variability
- Wave driving acts to initiate stratospheric changes implying a return feedback
- Pre-existing tropospheric PV anomaly features can mask the stratospheric influence in individual cases