The linkage of tropical/extratropical coupling with the stratosphere-troposphere coupling: A global mass circulation view in the isentropic coordinate

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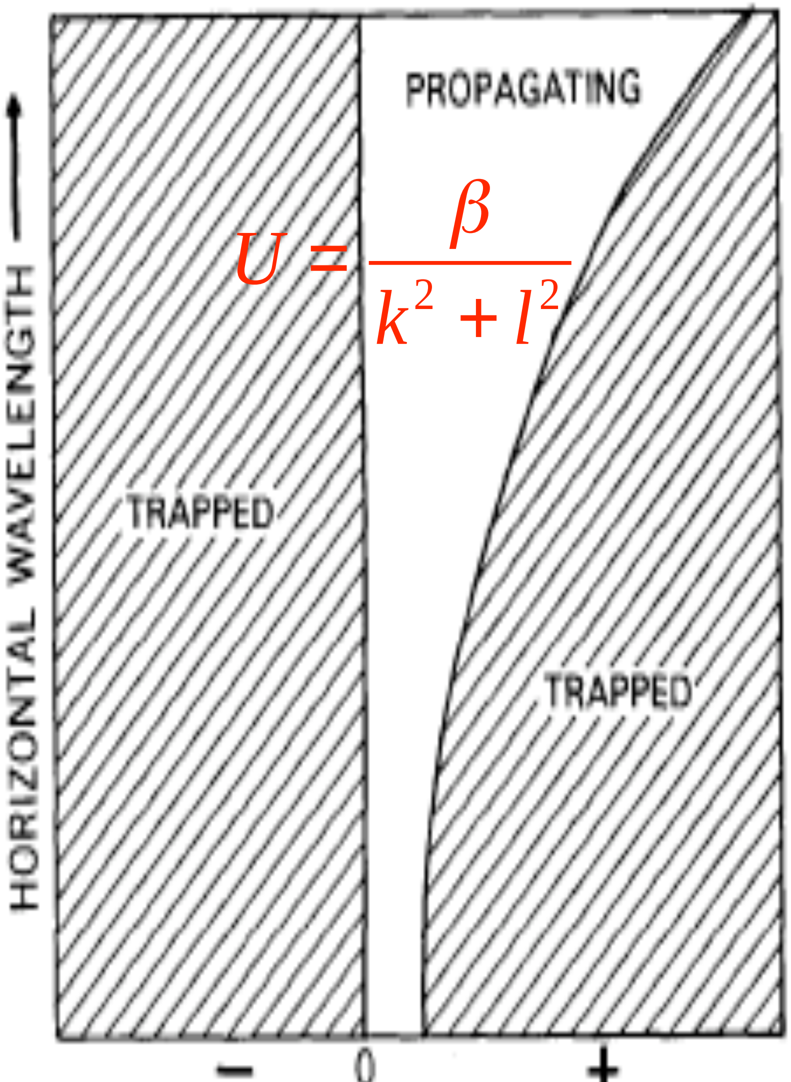
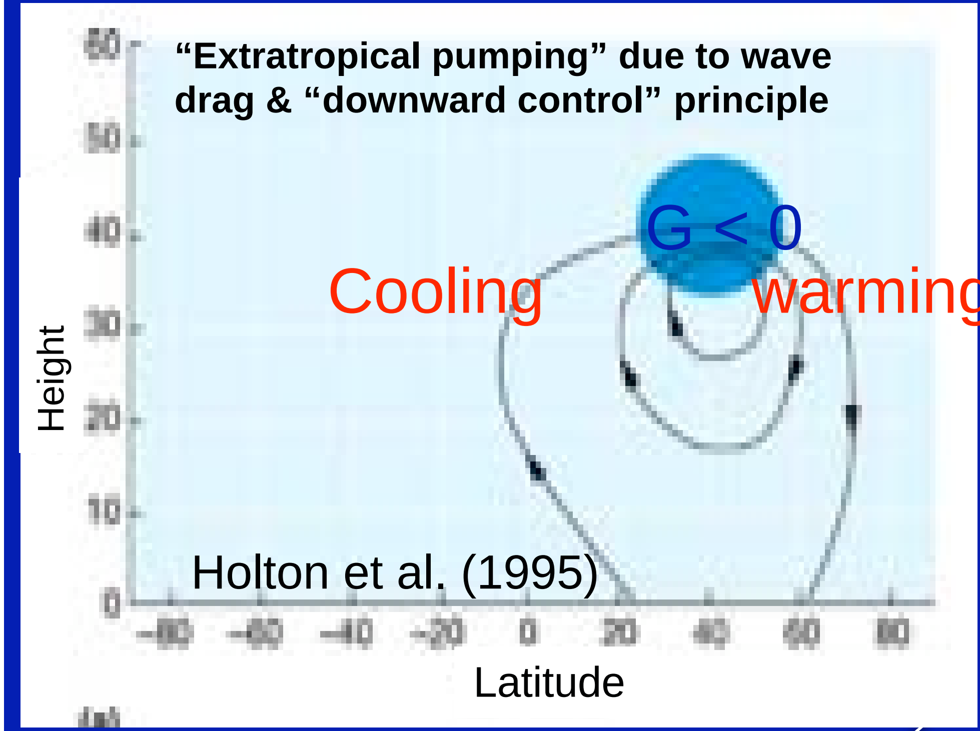
NH: Cai (2003, GRL); Cai and Ren (2006, GRL);
Ren and Cai (2006, AAS); Cai and Ren (2007, JAS);
Ren and Cai (2007, GRL); Cai and Shin (in preparation)
SH: Ren and Cai (2008, JAS)

Tropospheric forcing mechanism

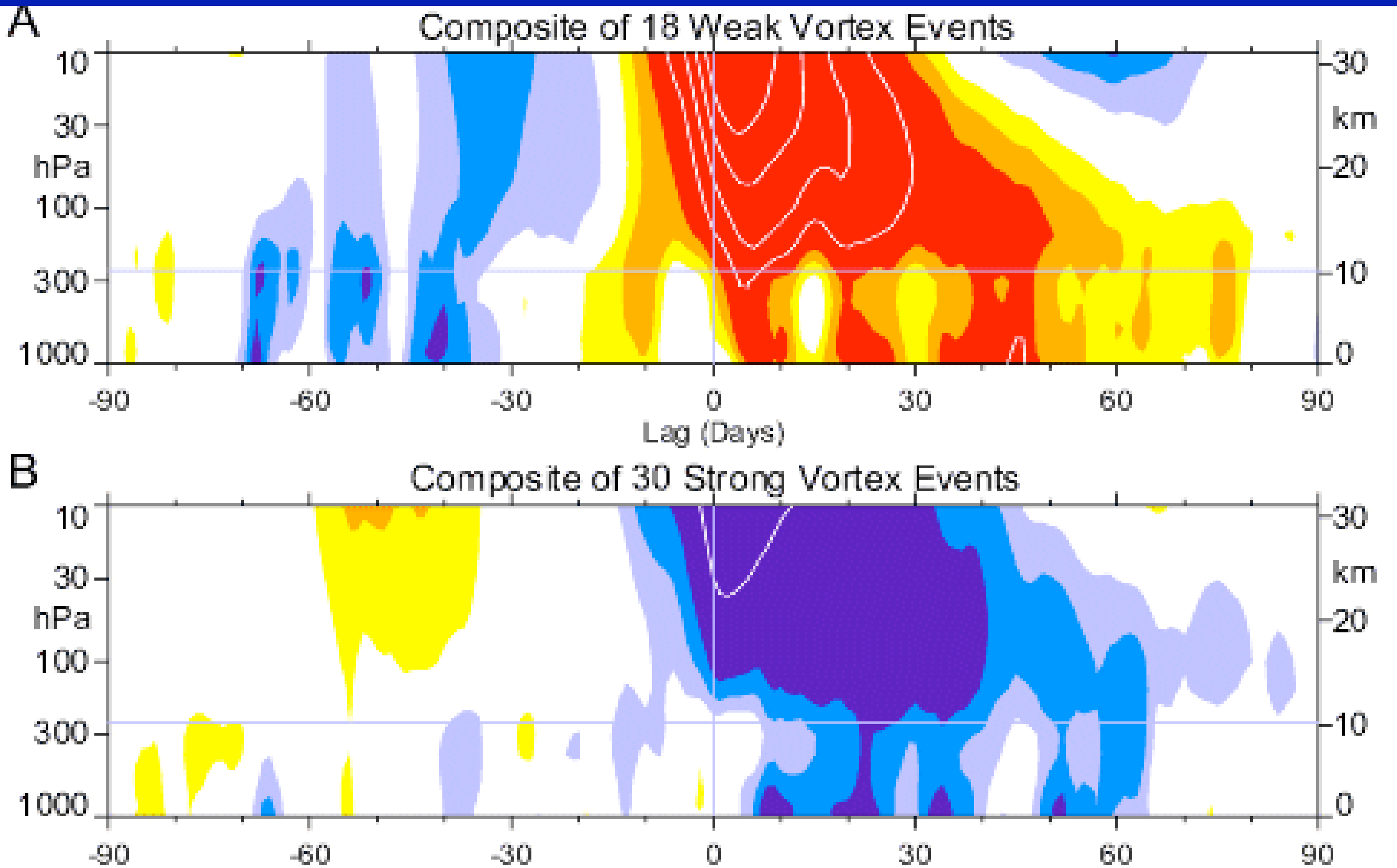
Charney & Drazin's Theory



Held(1993)

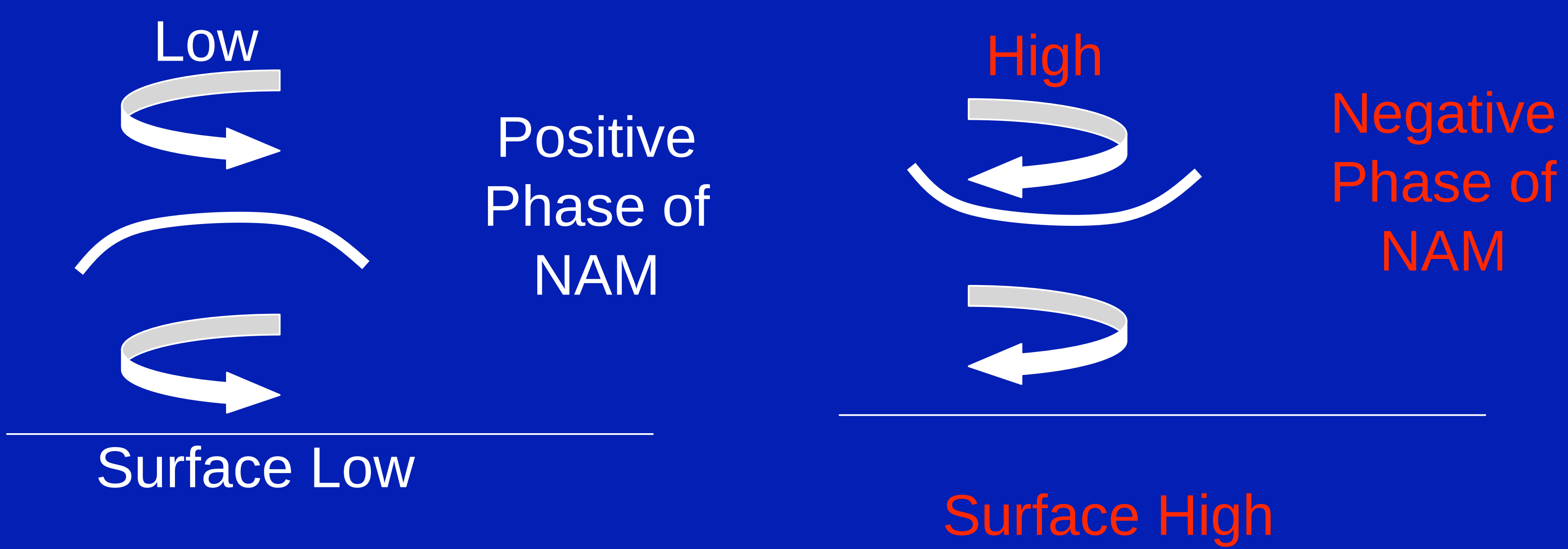


Downward Propagation



Baldwin and Dunkerton, 2001

The In-phase relation between NAM and AO (or SAM and AAO)



Some overlooked factors in the existing theory (QG)

- Meridional versus vertical coupling: Local coupling (vertically within the extratropics) cannot explain the subtropical-tropical coupling, which is intimately related to the vertical coupling between the stratosphere and troposphere.
- Coupling of diabatic heating and wave drag G: “G” is not determined by propagation of Rossby waves alone. The coupling of heating (or diabatic mass circulation) and “G” is the ultimate source for climate variability.
- The vertical thermal structure in QG is prescribed or fixed: the vertical thermal structure itself is determined by heating and motion and is one of the important factors for explaining/predicting climate variability.

The objectives

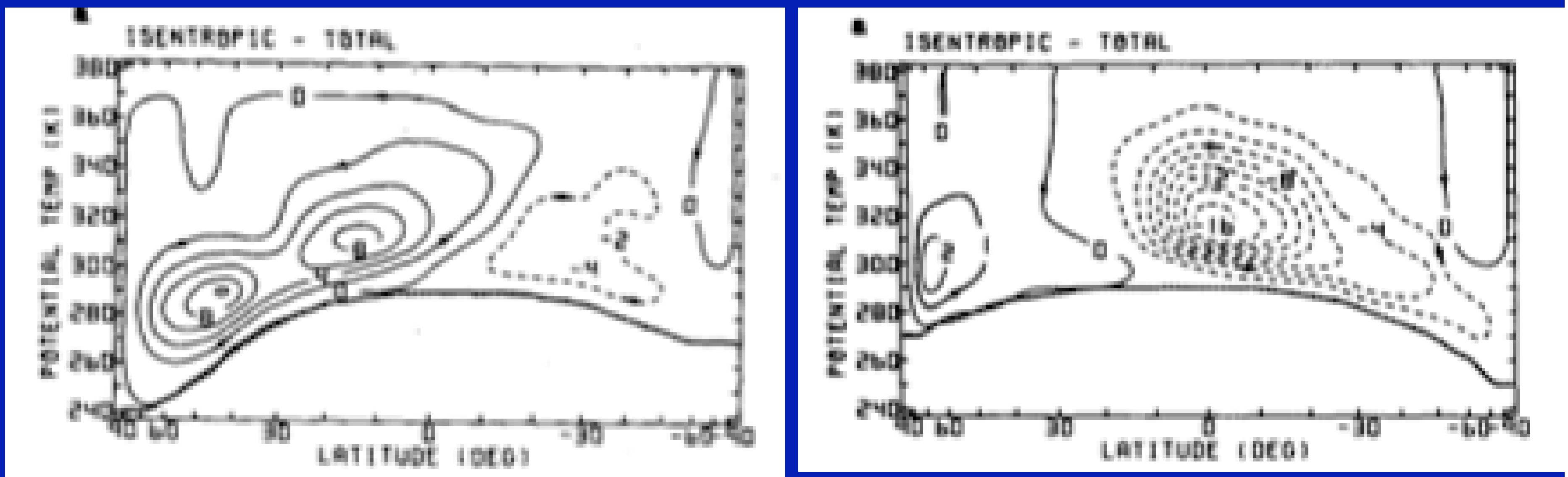
- To provide a physical explanation on the dynamical nature of the annular mode (global mass circulation paradigm).

- To link the stratosphere- troposphere coupling to the meridional ring-like seesaw pattern.

- To link the change in motion to the change in the thermal structure resulting from diabatic heating anomalies associated with the mass circulation variability.

Global zonal mean (mass) circulation viewed from isentropic coordinate

NH winter NH summer



Townsend and Johnson (1985)

Warm air branch flows from heating source to heating sink regions (poleward) at the upper layer and cold air branch flows from heating sink to heating source (equatorward) near the surface.

Data

- NCEP/NCAR isentropic reanalysis II (1979-2003)

- Daily 2.5ºx2.5º gridded data on 11 isentropic surfaces.

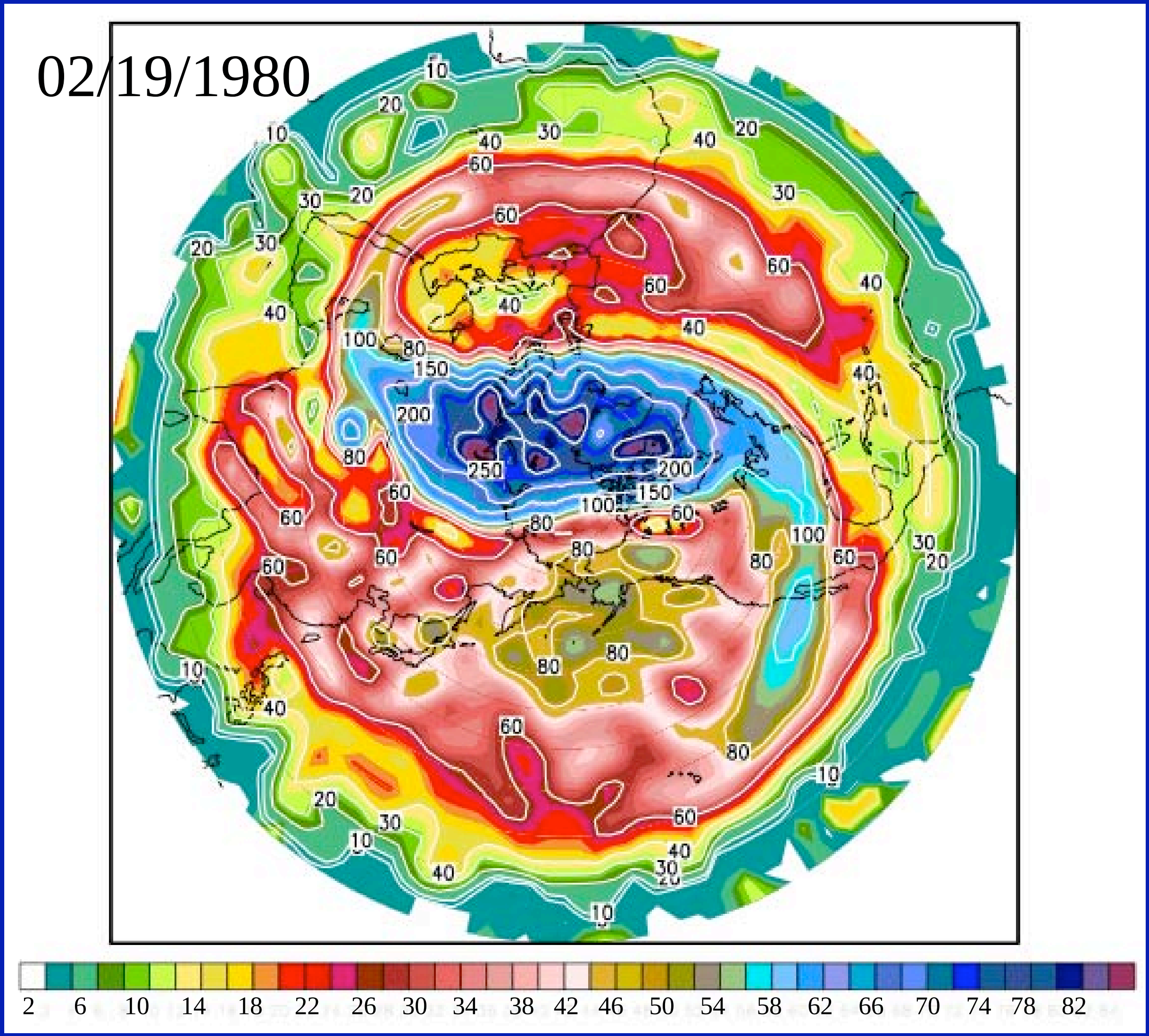
- PV, U, V, Temp./pressure, RH, N^2.

- NH and SH.

Mapping from PV contours to PV latitudes

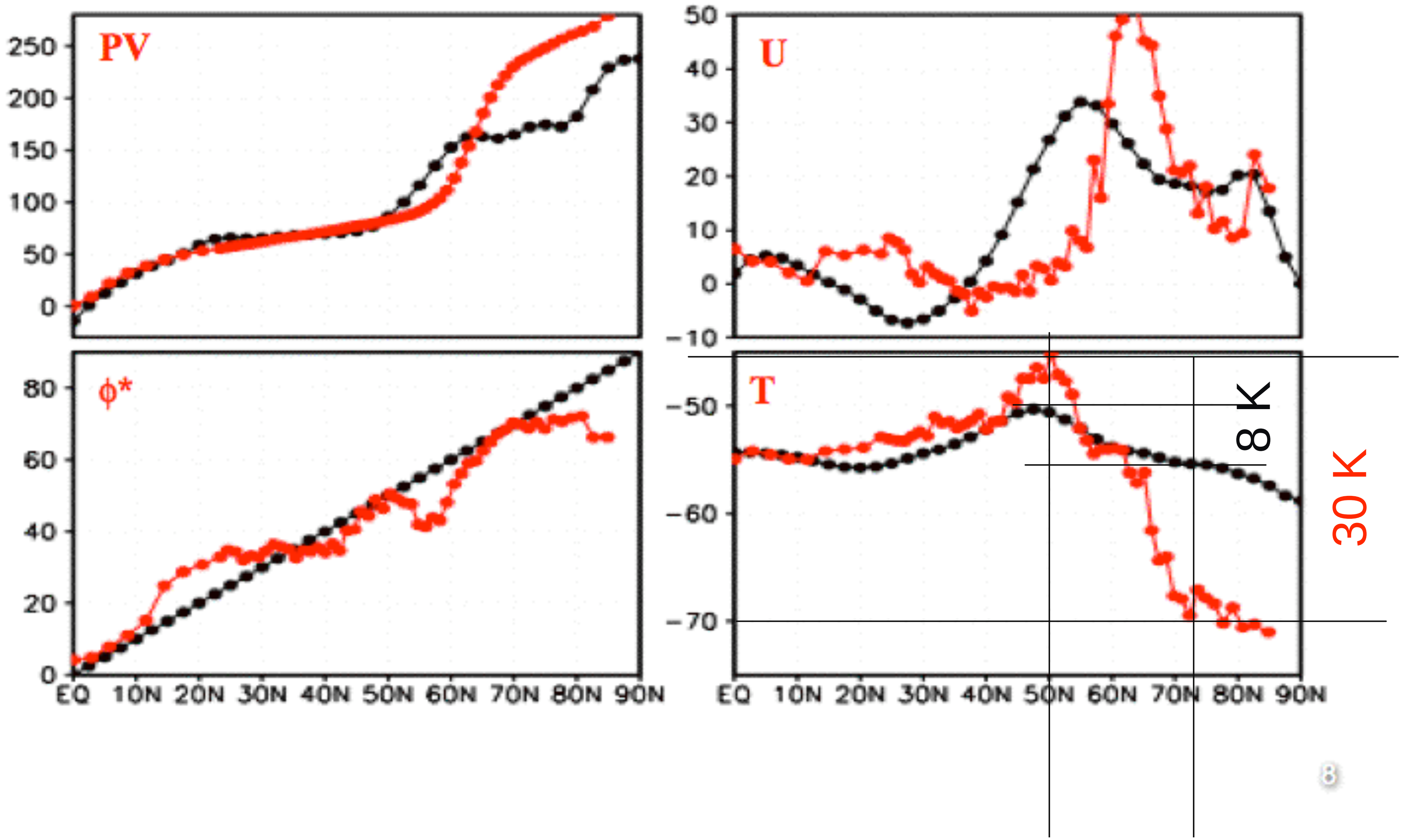
PV latitudes = Equivalent Latitudes (Butchart and Remsberg 1986; Norton 1994)

$\theta = 650K$

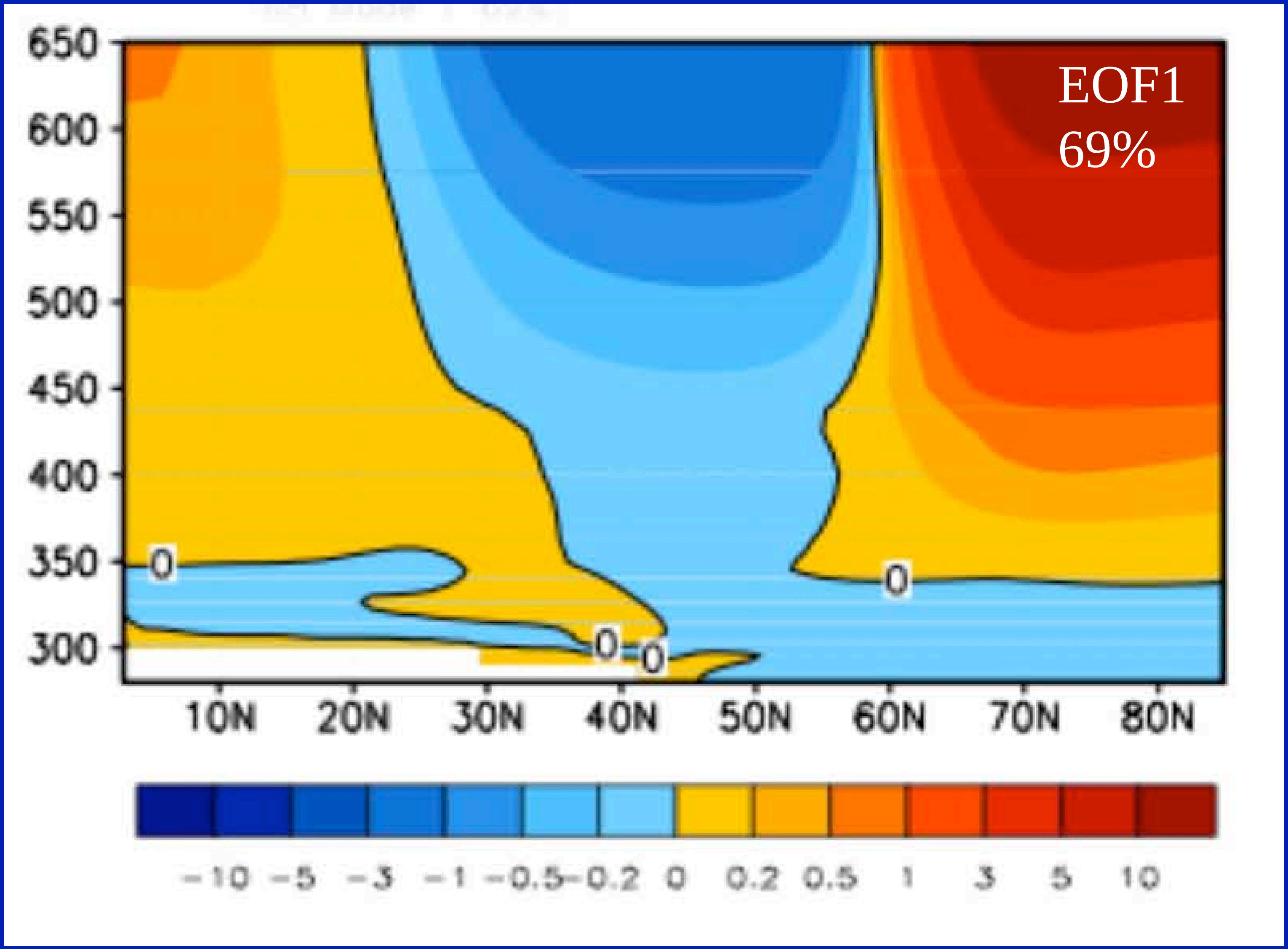


Zonal mean along PV latitudes VS latitudes

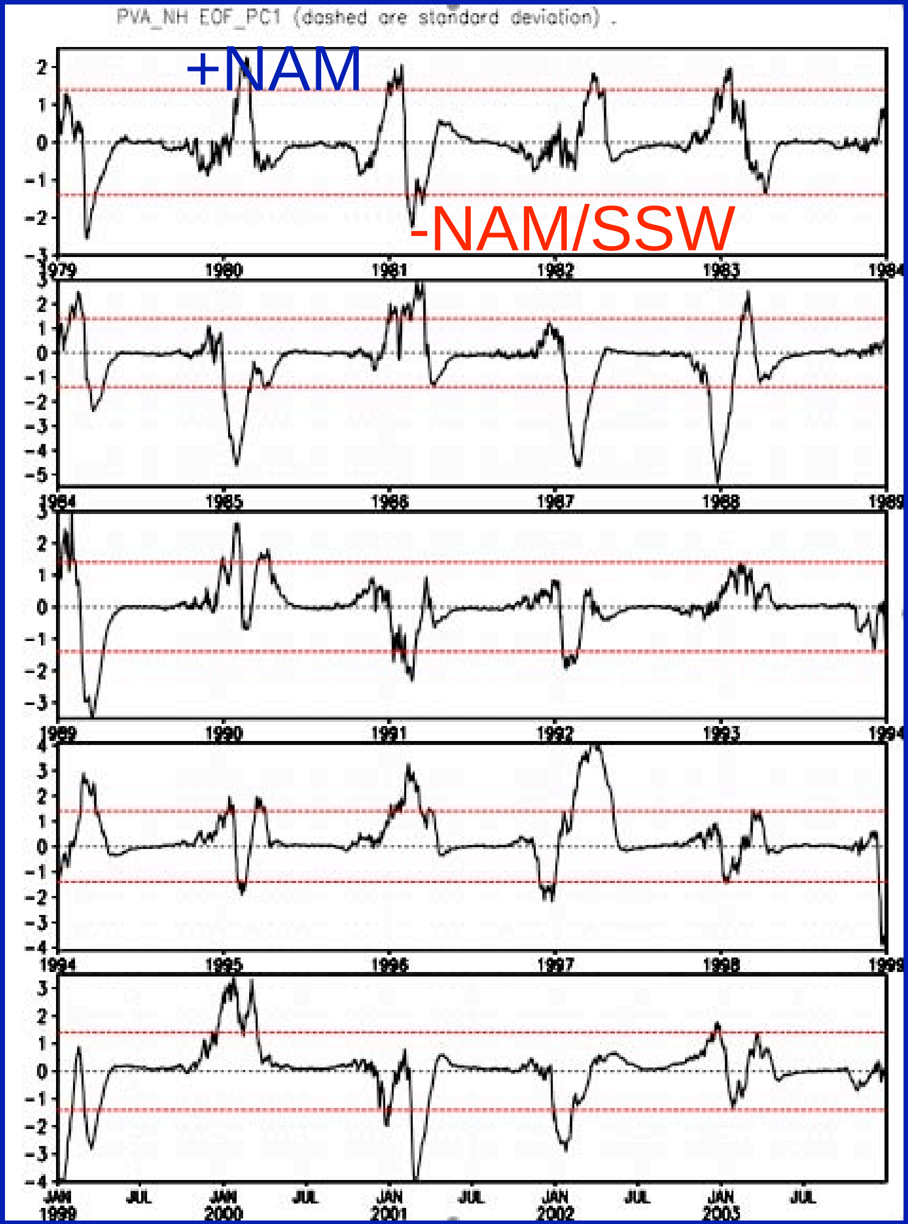
02/19/1980 and $\theta = 650K$



1st EOF mode of the NH DAILY PV anomalies



Daily time series of the NH PV EOF1

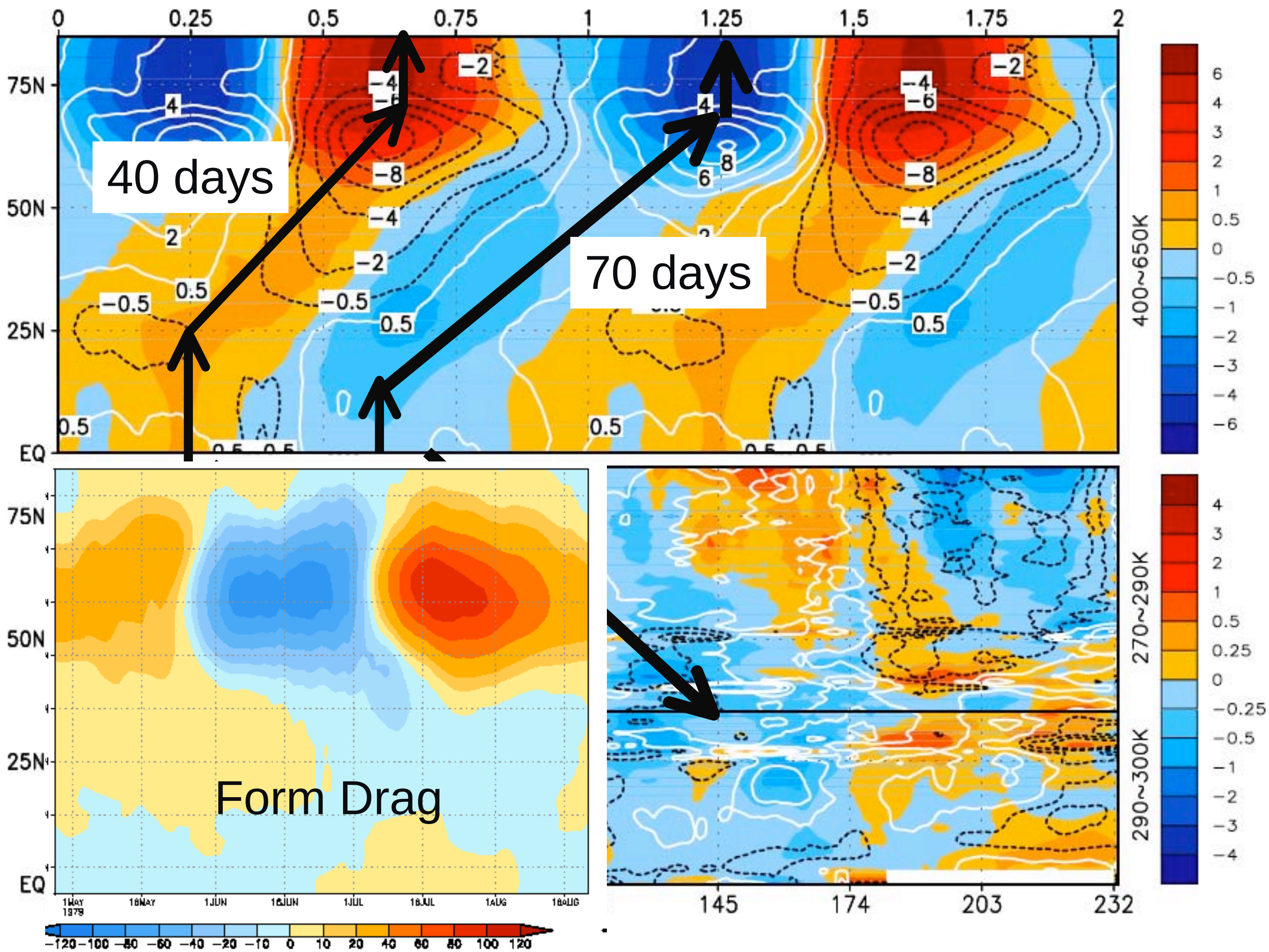


Meridional propagation

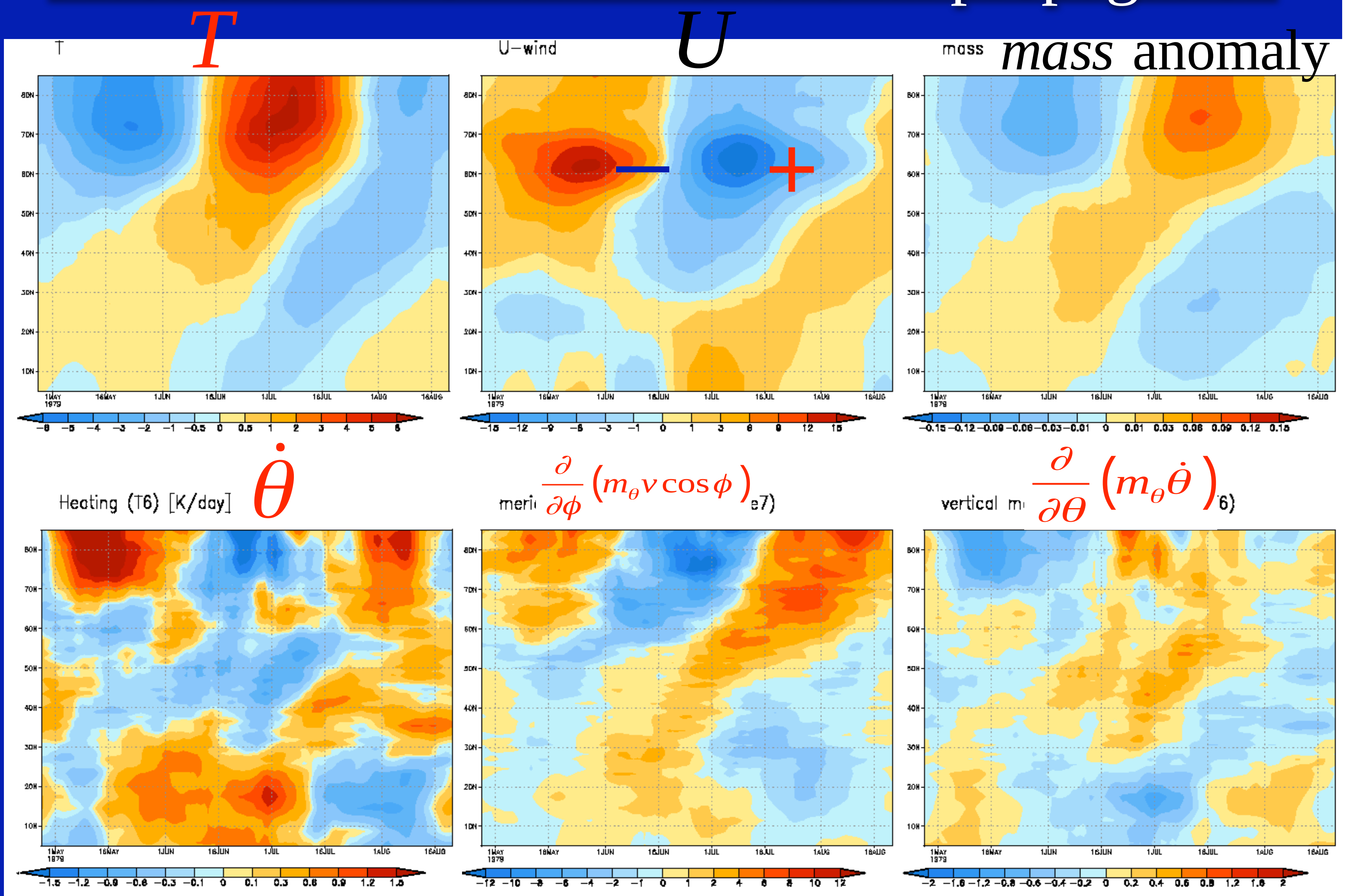
2 Periods

Poleward propagation in the stratosphere

Equatorward propagation in troposphere

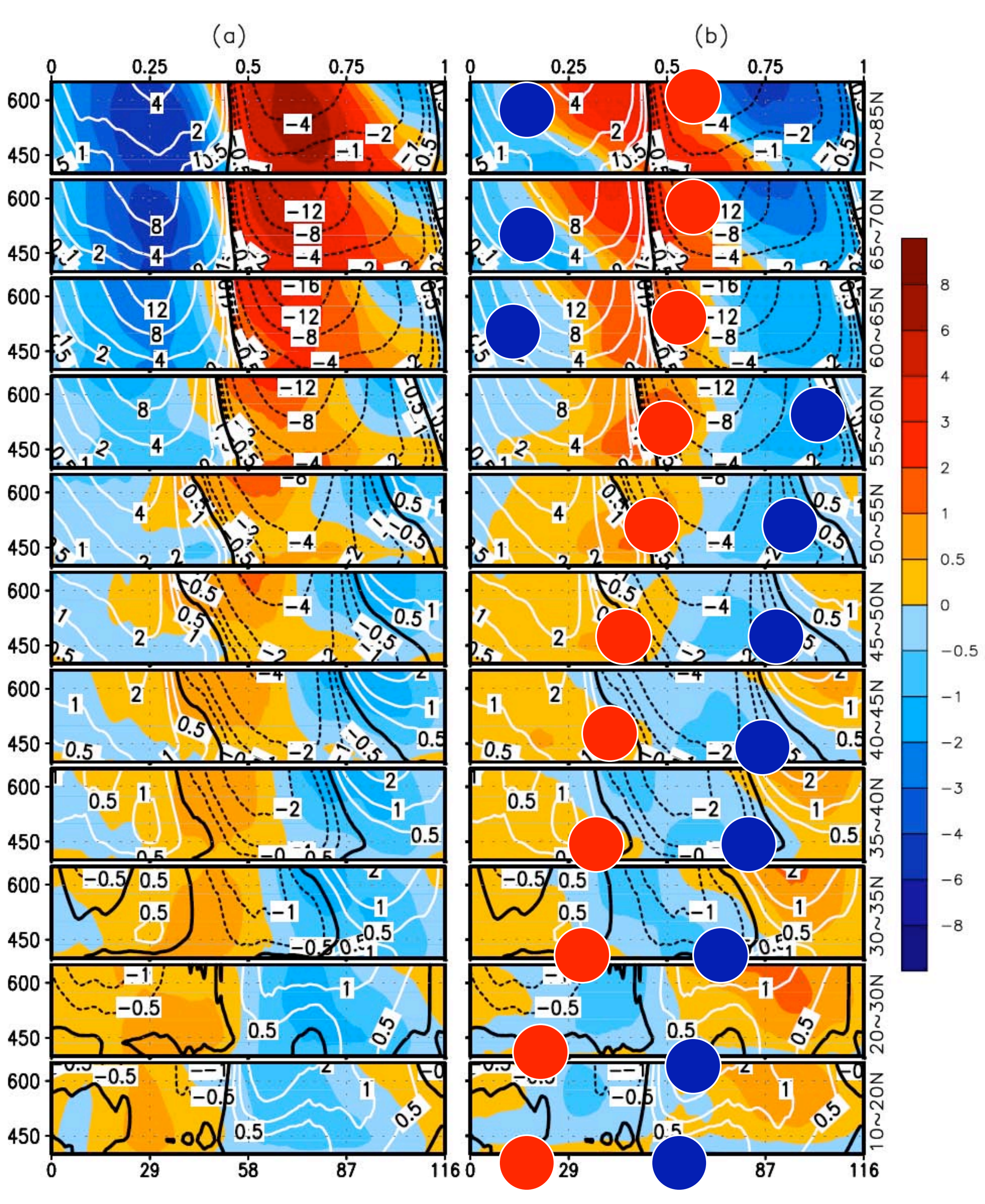


Mass circulation and Meridional propagation



Shading: temperature anomalies

Contour: zonal mean zonal wind anomalies



Shading: static stability anomalies

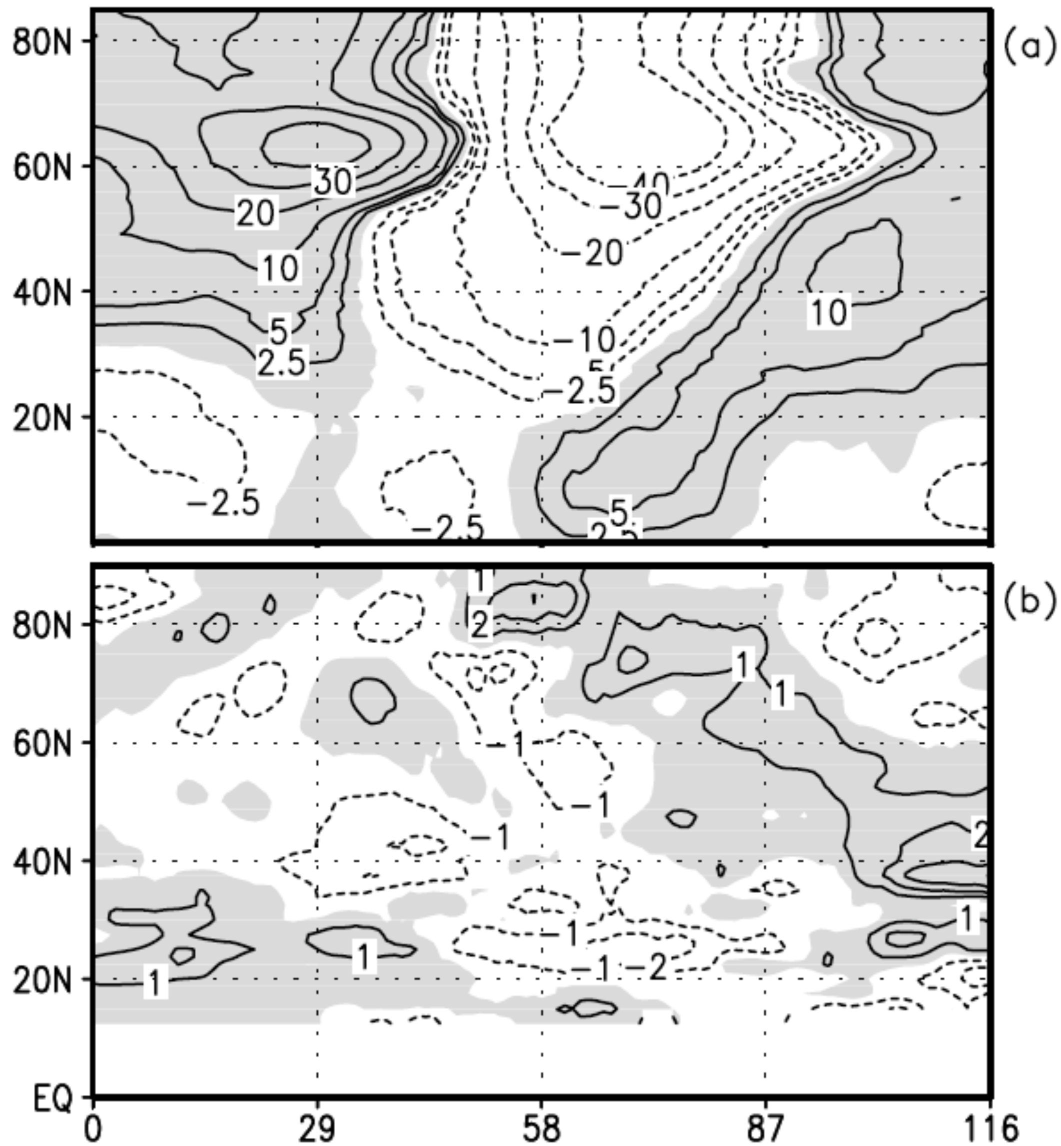
Contour: zonal mean zonal wind anomalies

The coupling of warm and cold branches

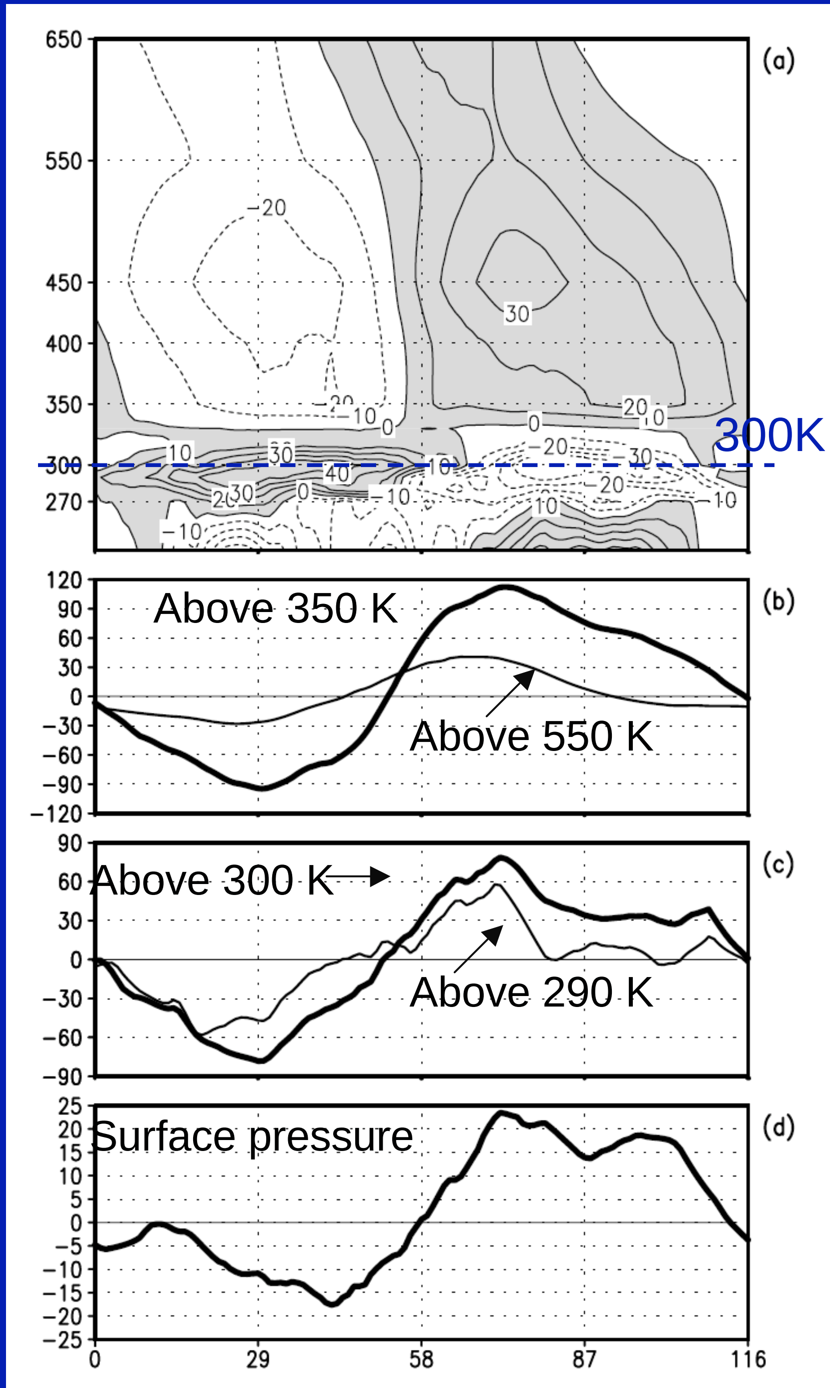
Stratospheric isentropic slope anomalies

$$\theta\_slope = -\frac{\partial\theta / \partial y}{\partial\theta / \partial z}$$

Lower tropospheric isentropic slope anomalies



Mass anomalies over polar region



$$\frac{\partial M_\theta}{\partial t} + \nabla_\theta \bullet (\vec{V} M_\theta) + \frac{\partial \dot{\theta} M_\theta}{\partial \theta} = 0$$

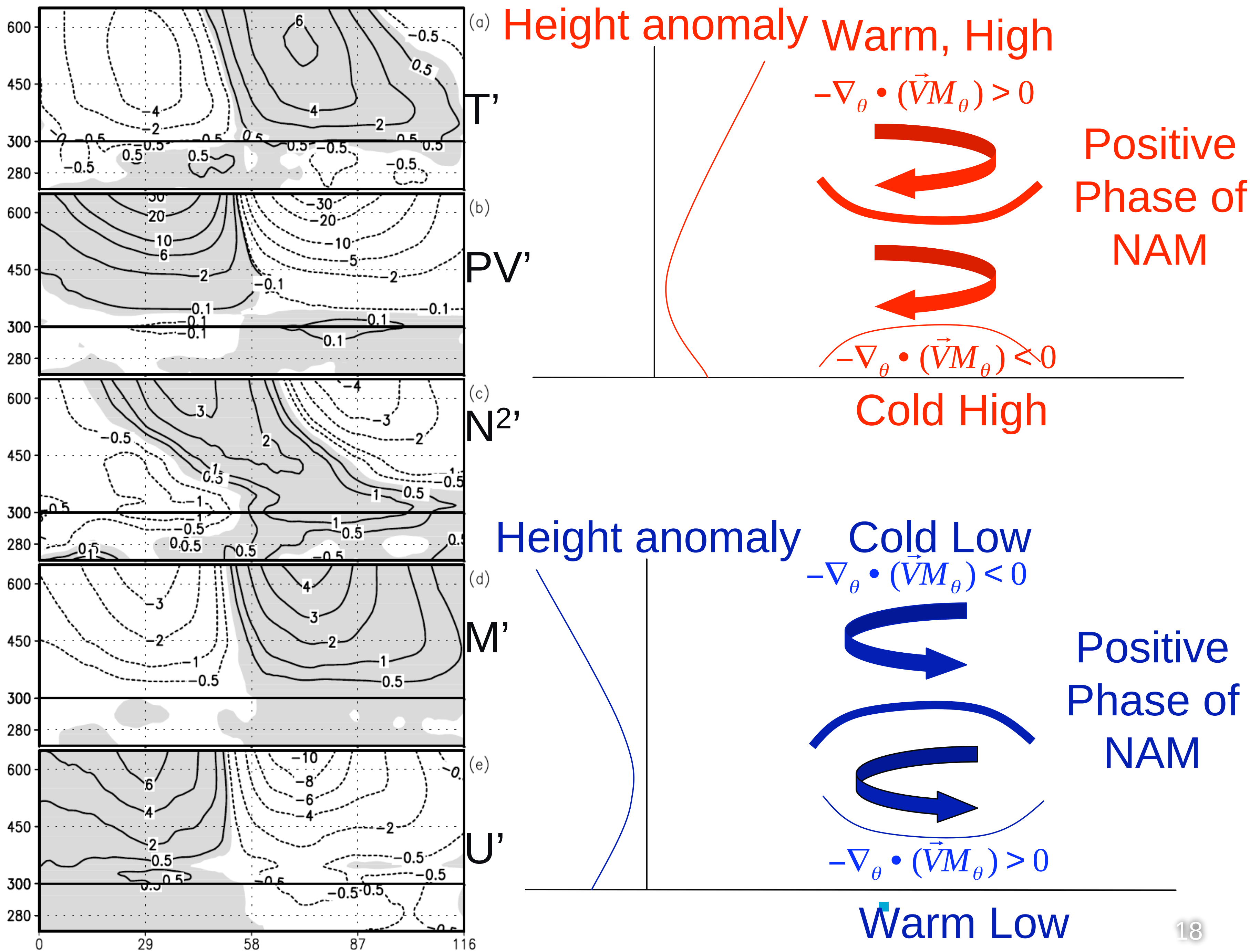
during warming event:

$$-\nabla_\theta \bullet (\vec{V} M_\theta)_{stratosphere} > 0$$

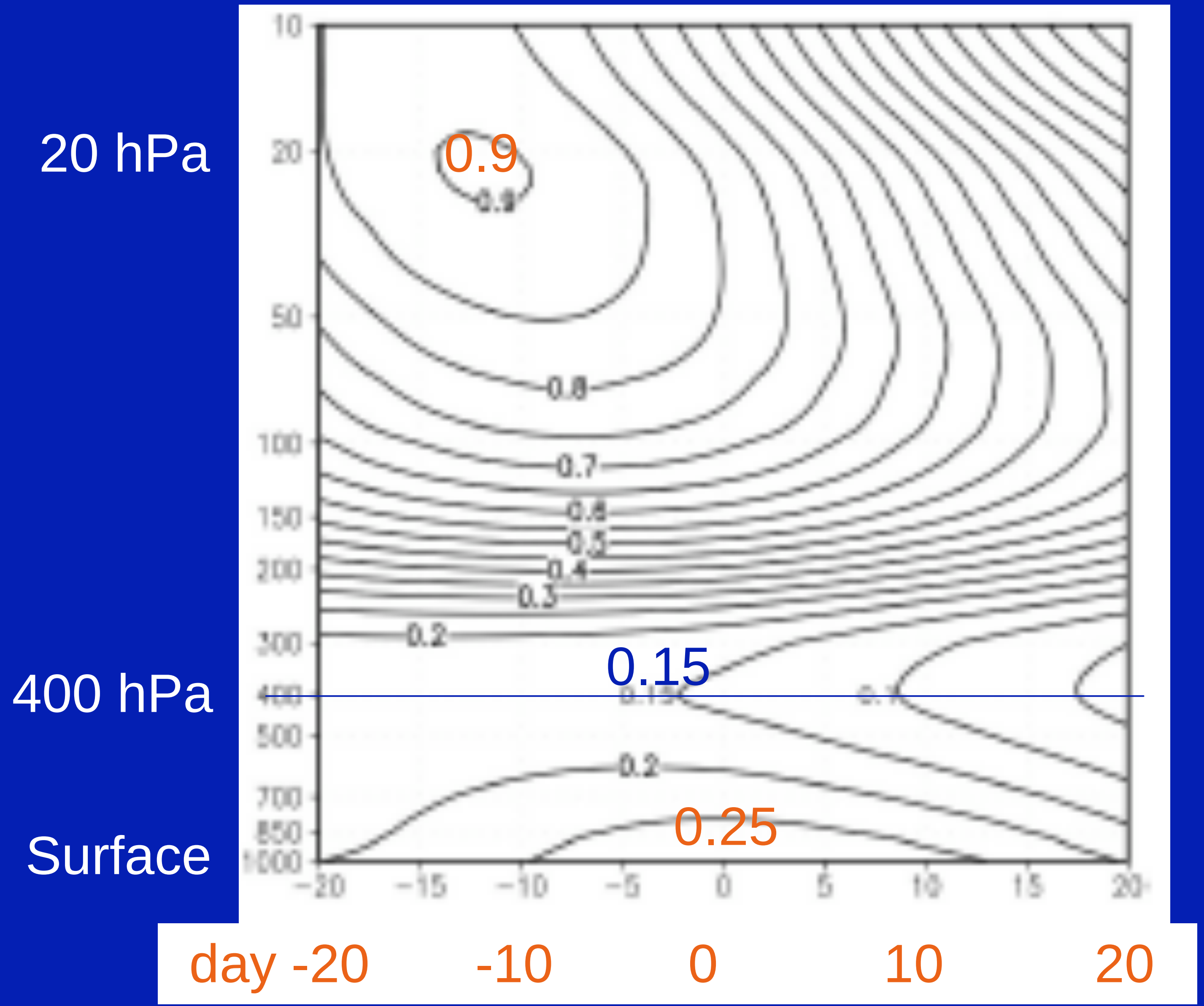
$$-\nabla_\theta \bullet (\vec{V} M_\theta)_{lower-troposphere} < 0$$

Rising of surface pressure due to arrival of the warm air in the stratosphere.

The coupling of stratosphere and troposphere



Lag/lead correlation between PVO and AO indices



Cai and Ren (2007, JAS)

Tropopause folding and frontogenesis

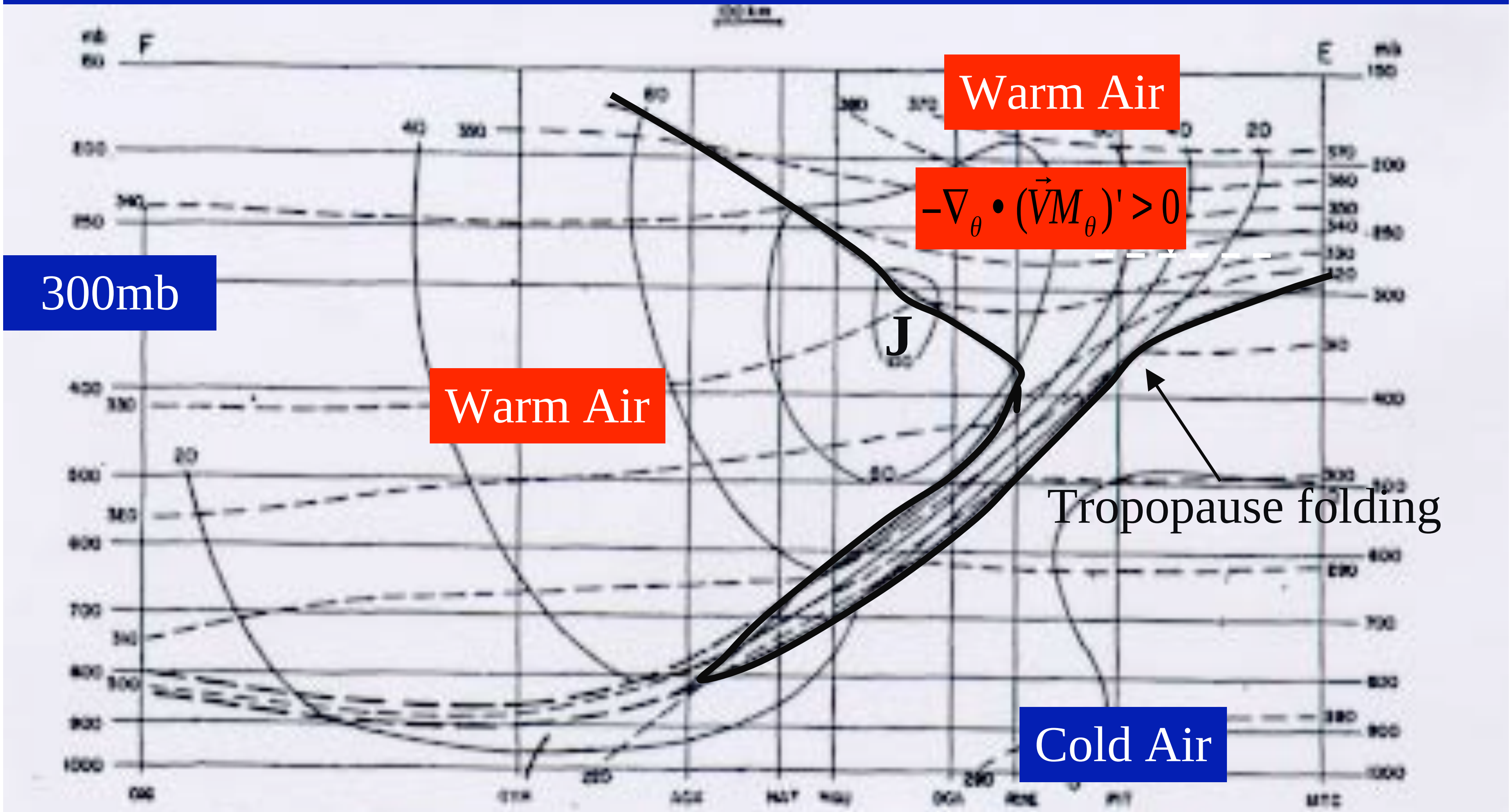


FIG. 13. Cross section along E–F in fig. 7. Notation as in figs. 11 and 12.

Reed, 1955; Sanders, 1955

Vertical Thermal Structure of a Cut-Off Low

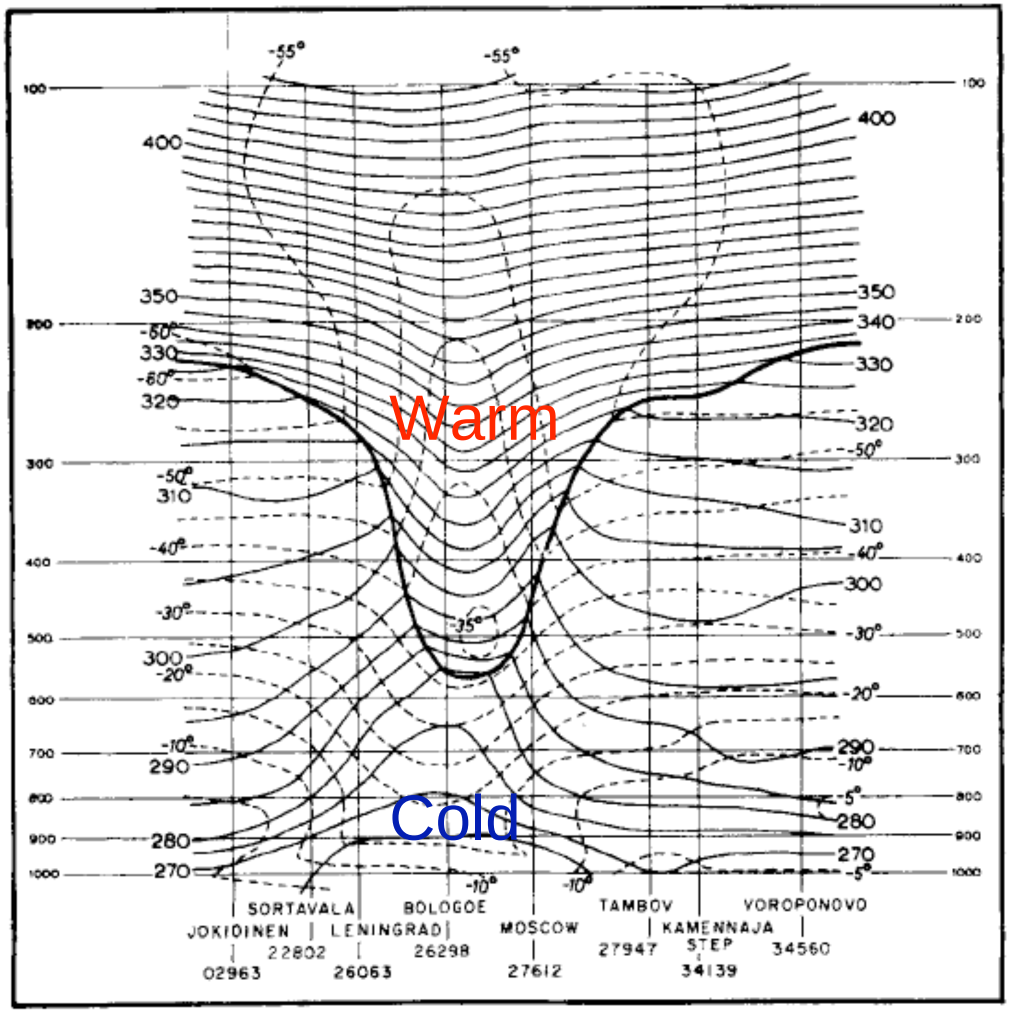


Figure 8. A vertical section through a cutoff cyclone at 12 GCT November 16 1959 produced by Peltonen (1963). The heavy line represents the tropopause; dashed lines are isotherms at 5°C intervals and solid lines isentropes every 5 K. The centre of the cyclone was at about 35°E, 58°N.

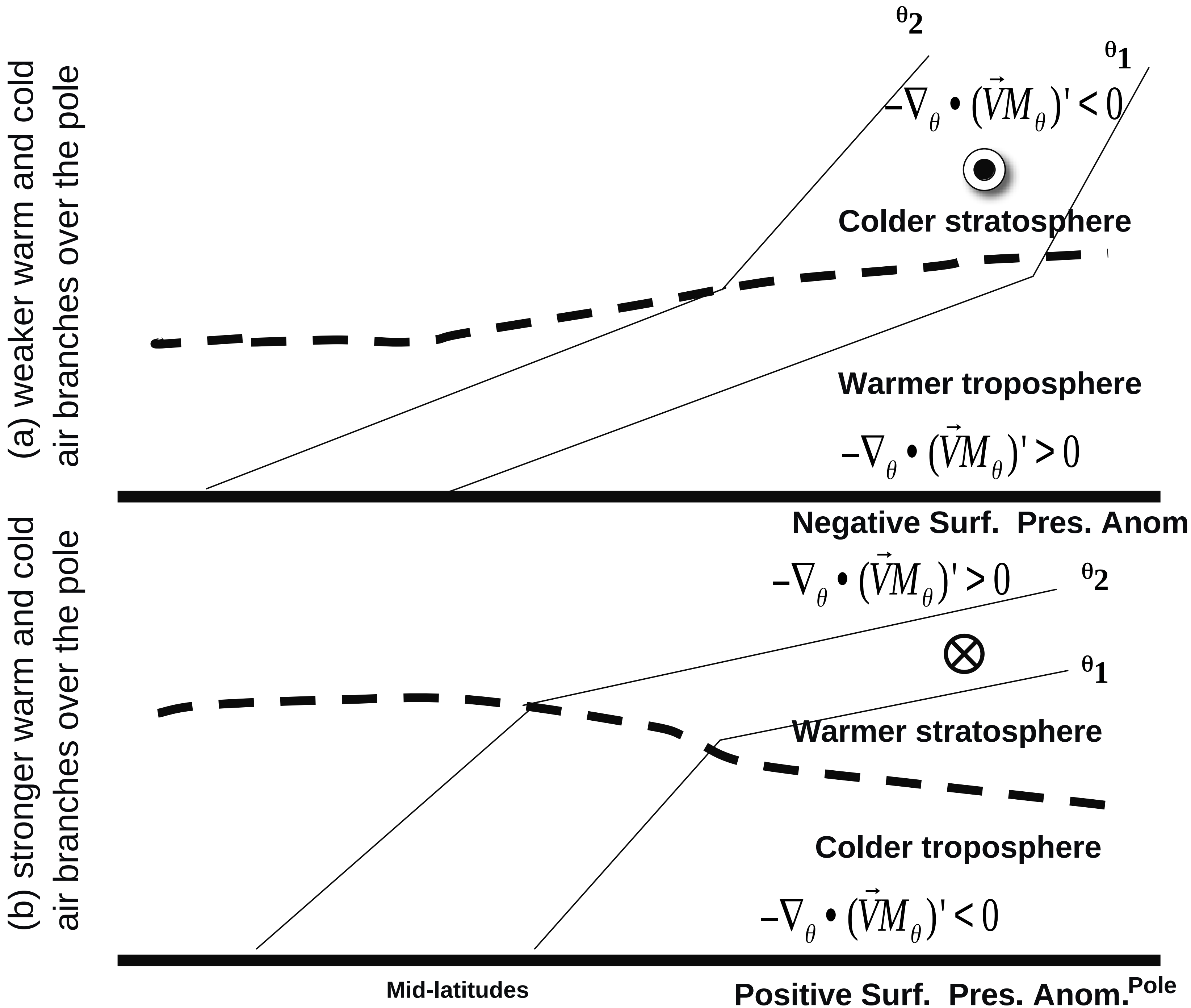
Peltonen (1963) cited in Hoskins et al. (1985)

Summary (1)

- **Stratospheric thermal anomalies propagate poleward whereas tropospheric thermal anomalies propagate equatorward.**
- **The temporal lead of the poleward propagation of thermal anomalies in upper stratosphere with respect to that in lower stratosphere results in an apparent downward propagation in the stratosphere.**
- **The poleward propagation of termal anomalies is responsible for the polar vortex oscillation or annular mode variability => arrival of the warm (cold) anomalies over the stratospheric polar region corresponds to a weaker (stronger) polar vortex or negative (positive) phase of the annular mode.**
- **The arrival of warm anomalies over the stratospheric polar region is bought by a stronger warm air branch of the global mass circulation whereas the arrival of the cold anomalies is due to a reduction of the warm air supply associated with a weaker warm air branch.**

Summary (2)

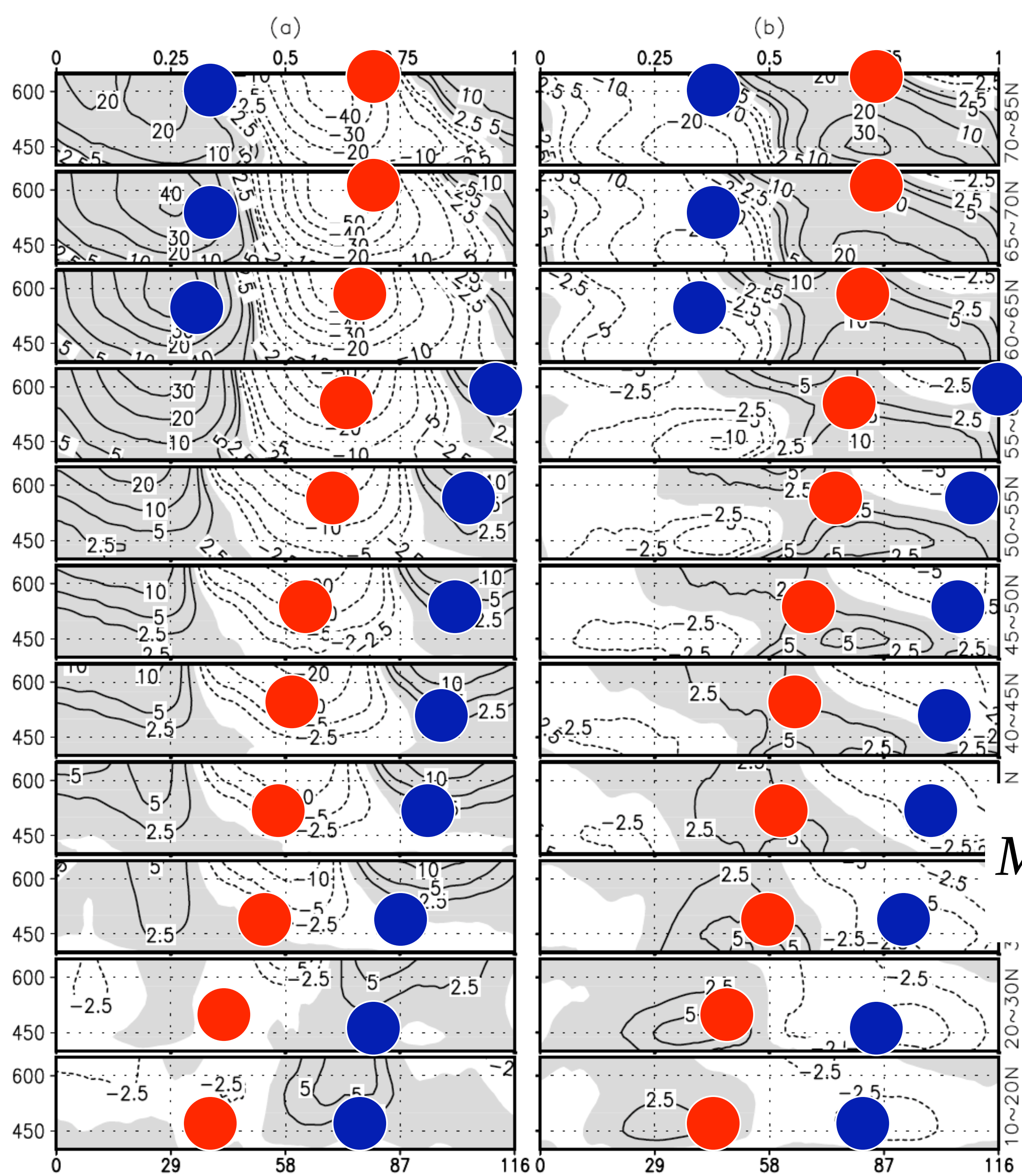
- The poleward propagation of stratospheric thermal anomalies is synchronized with the equatorward propagation of tropospheric thermal anomalies of the opposite sign ==> a stronger (weaker) warm air branch is associated with a stronger (weaker) cold air branch => vertically out-of-phase relationship of temperature anomalies over polar region. ==> The vertical out-of-phase relation is coupled with the meridional out-of phase relation.
- The amplitude of the stratospheric mass anomalies is larger than that of the tropospheric mass anomalies => NAM and AO (SAM and AAO) are positively correlated.
- Over the polar region, a warm high (cold low) anomaly with a lowered (raised) tropopause overlying a cold surface high (warm low) gives rise to the "equivalent barotropic" structure of the annular mode.
- Meridional and downward propagation takes place in both NH and SH winter seasons with an averaging time scale of 55 days in NH and 110 days in SH between the equator and the pole.



(a) weaker warm and cold air branches over the pole
θ_2
θ_1
$-\nabla_\theta \bullet (\vec{V}M_\theta)' < 0$
Colder stratosphere
Warmer troposphere
$-\nabla_\theta \bullet (\vec{V}M_\theta)' > 0$
Negative Surf. Pres. Anom.
(b) stronger warm and cold air branches over the pole
$-\nabla_\theta \bullet (\vec{V}M_\theta)' > 0$
θ_2
θ_1
Warmer stratosphere
Colder troposphere
$-\nabla_\theta \bullet (\vec{V}M_\theta)' < 0$
Mid-latitudes
Positive Surf. Pres. Anom.
Pole

Outline

- Brief literature review on TSE and Annular Modes
- Objectives
- Data
- Spatial and temporal evolution of the composite atmospheric anomalies in θ-PVLAT coordinate.
- Explanation: Mass circulation variability and the Annular Mode
- Summary



$$\theta\_slope = -\frac{\partial\theta / \partial y}{\partial\theta / \partial z}$$

$$M_{\theta} = -\frac{1}{g}\frac{\partial p}{\partial\theta}$$