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# **Interaction between the winter stratosphere and the tropospheric Arctic Oscillation in the Whole Atmosphere Community Climate Model (WACCM)**

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# Outline



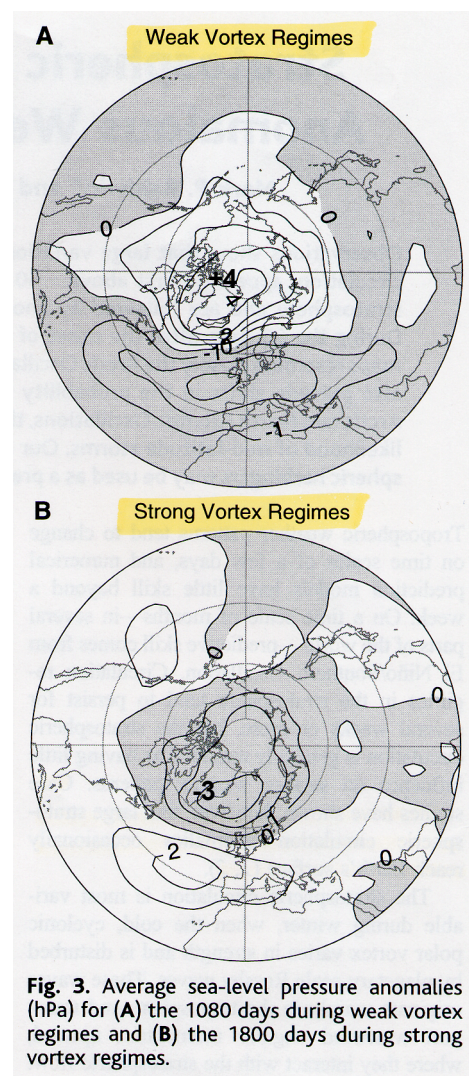
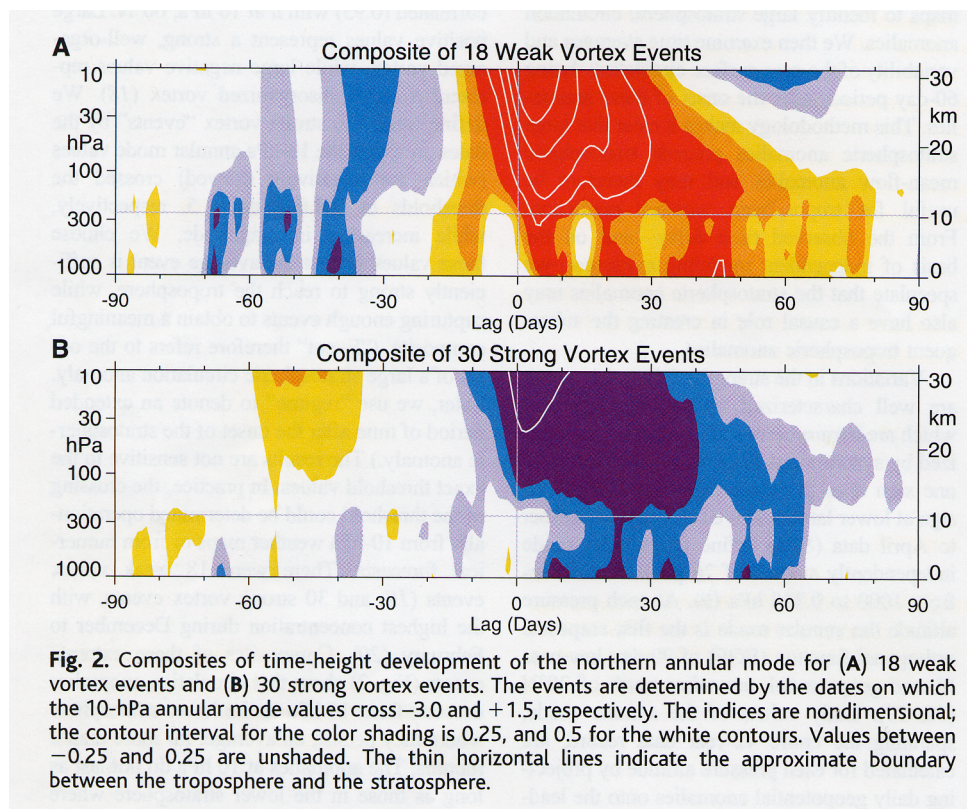
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- Introduction
- The Whole Atmosphere Community Climate Model
- EOF analysis
- “Strong” and “Weak” vortex events defined in the stratosphere
- Strong and Weak events defined in the troposphere
- Conclusions

# Annular Modes in the Stratosphere and Troposphere



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# WACCM Dynamics/Physics

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- WACCM is based on the NCAR Community Atmosphere Model (CAM), extended upward to the lower thermosphere, with physics upgrades (NLTE IR transfer, shortwave heating to Lyman-alpha, molecular diffusion effects, etc.)
- For the present study: 48 year integration (1950-1998)
  - Specified SST from observations
  - T63 horizontal resolution, semi-Lagrangian dynamics
  - Vertical resolution ~1.2 km in the troposphere/lower stratosphere; ~3.5 km in the lower lower thermosphere
- => A reasonably well resolved stratosphere <=



# EOF Analysis

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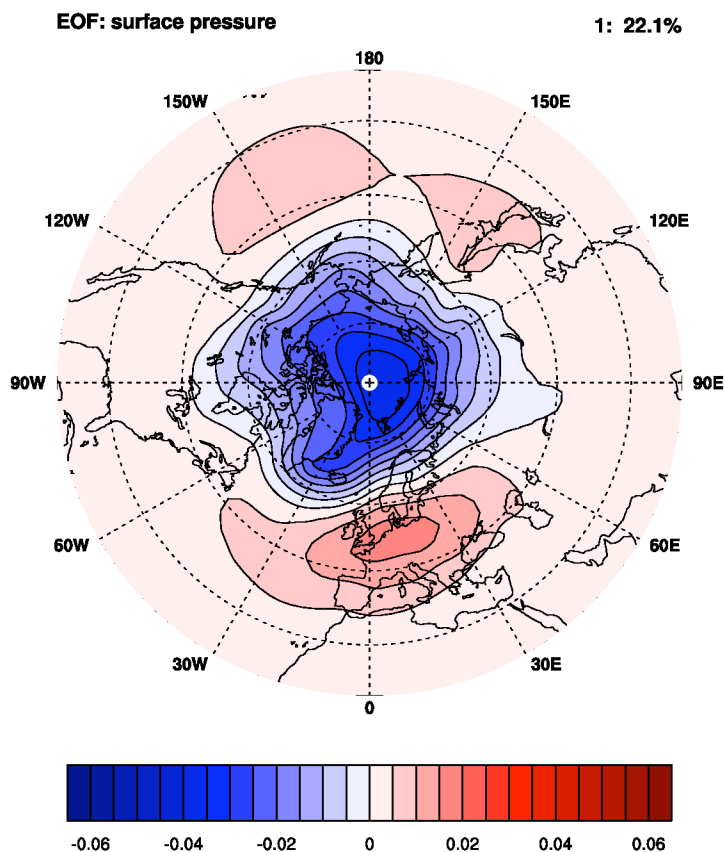
- Daily output from 48-year run (U, T, Z, TEM diagnostics)
- Consider results for November – April (“extended winter”)
- Composite seasonal cycle and smooth with 31-day running mean
- Compute daily unsmoothed Z deviations from seasonal cycle
- Obtain EOFs of unsmoothed Z deviations
- Project unsmoothed daily output onto EOF  $\Rightarrow$  PC(t)

# First EOF of PS and 10 mb Geopotential



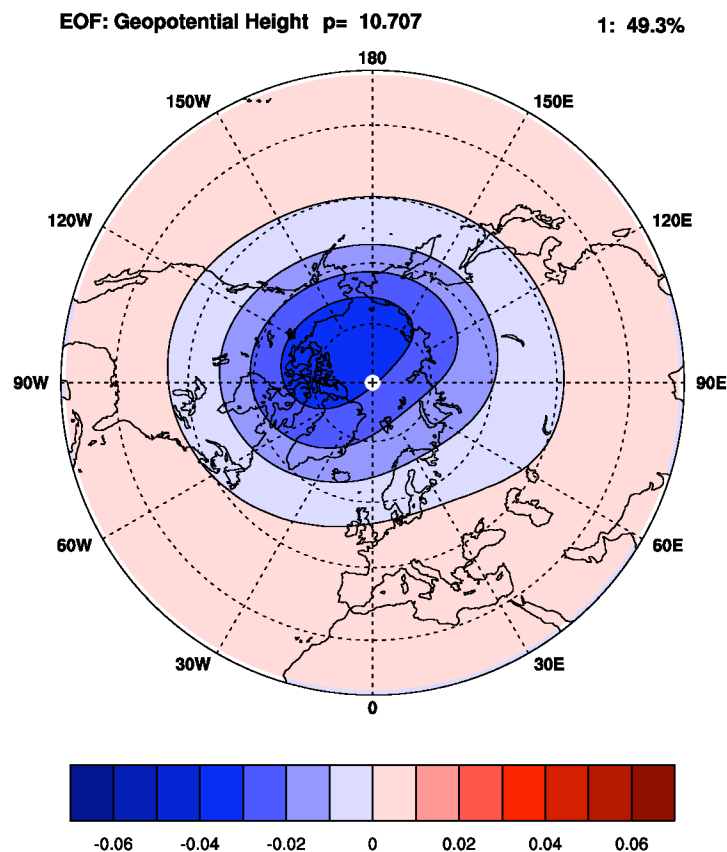
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PS: Nov-April: 1950-98 **22%**



EOF1 of PS

Z: Nov-April: 1950-98 **49%**

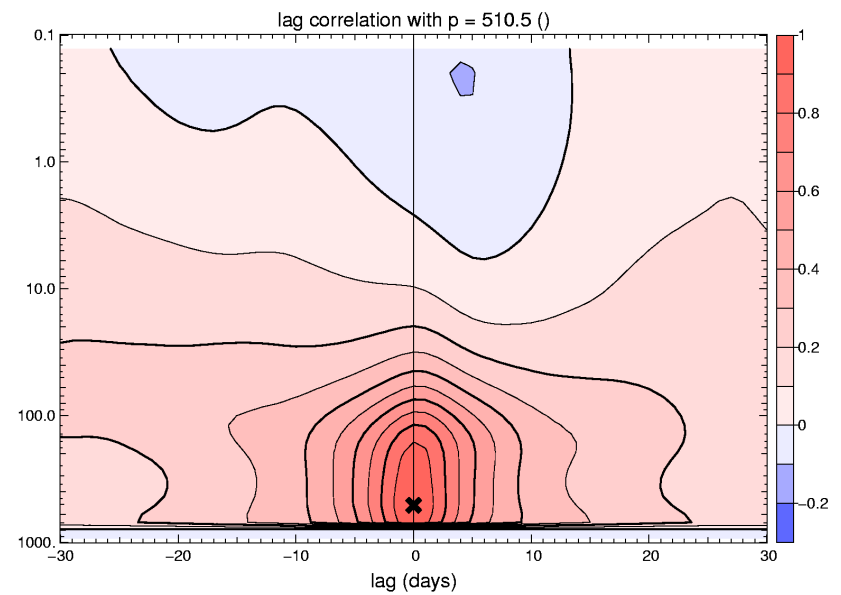
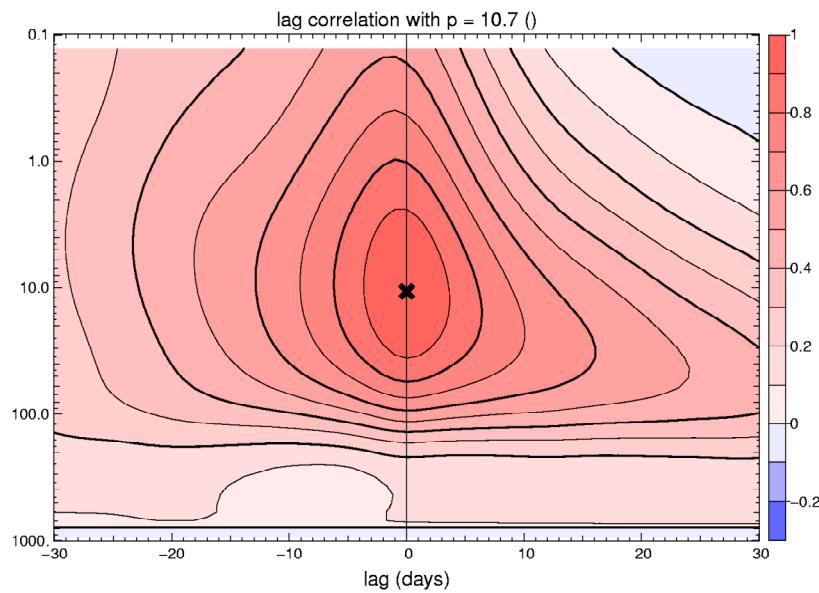


EOF1 of Z(10 mb)

# Lag Correlations: Geopotential PC1



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# Selecting “Weak” and “Strong” Vortex Events

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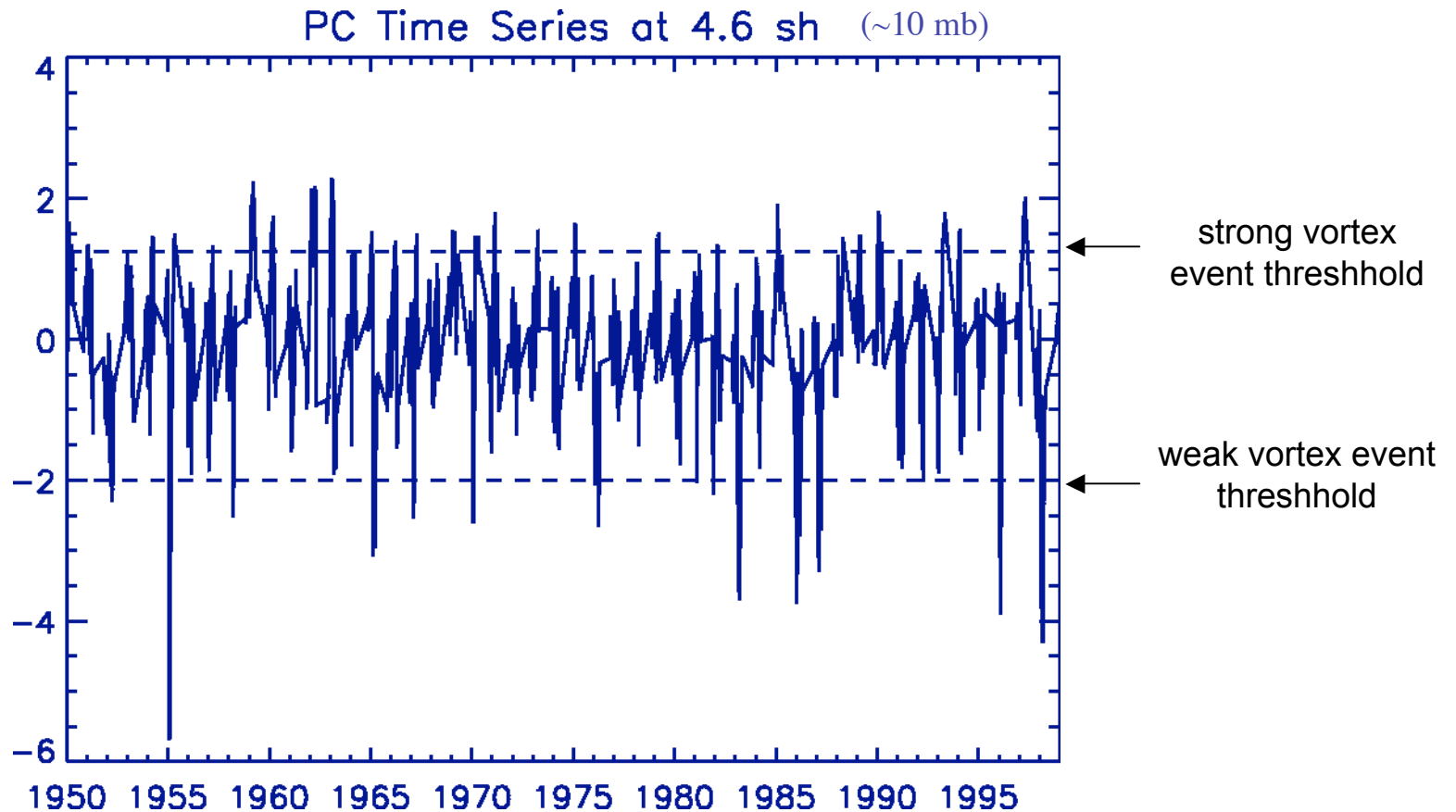
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- Standardize PC series of Geopotential EOF 1 at levels in the troposphere and stratosphere
- At reference level
  - Weak vortex events:  $PC(t) < -2.0$  for  $\geq 7$  consecutive days
  - Strong vortex events:  $PC(t) > 1.25$  for  $\geq 7$  consecutive days
- Reference levels
  - 10 mb
  - 434 mb

# Evolution of Geopotential PC1 at 10 mb 1950-1998



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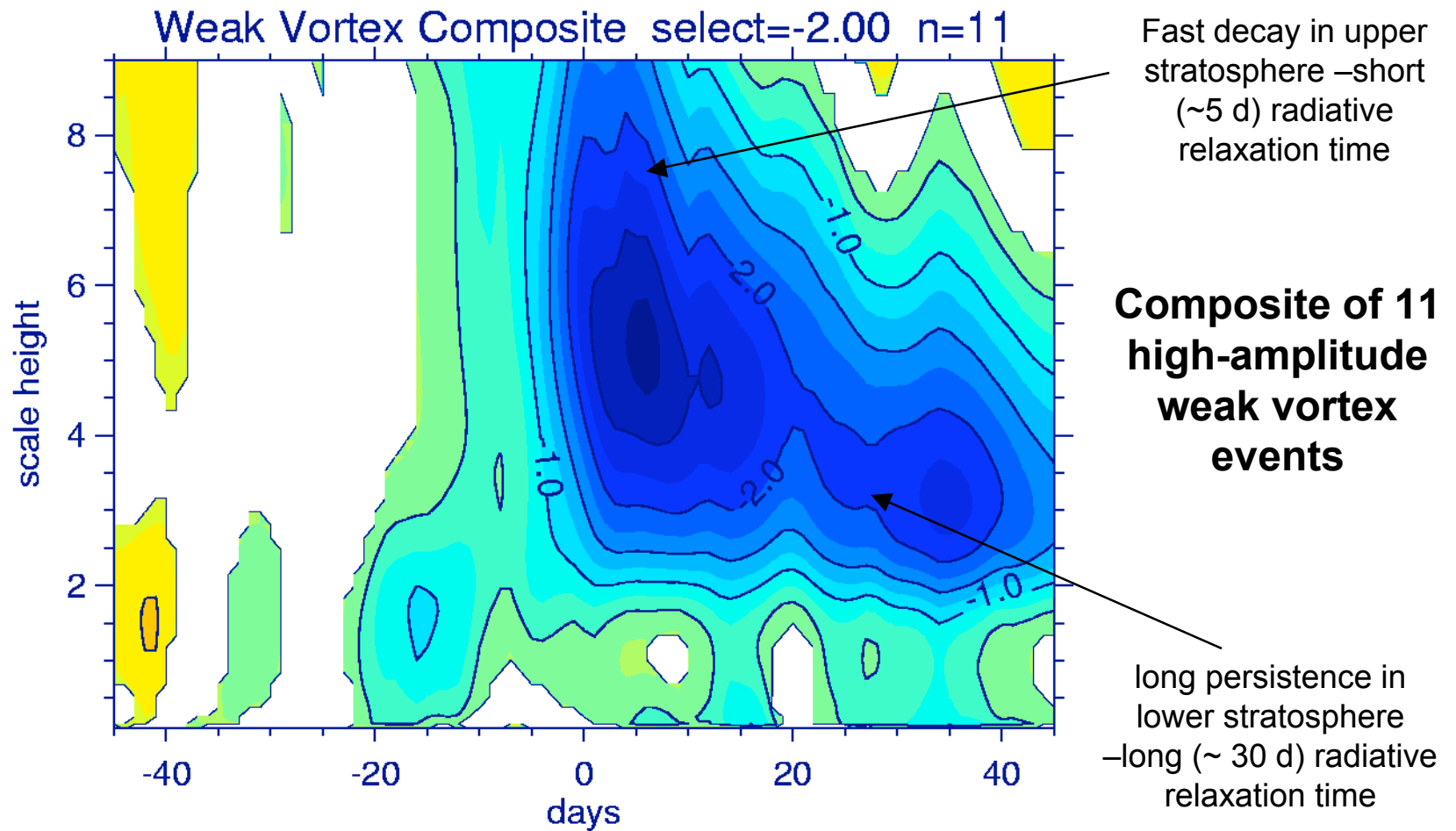


# Evolution of Geopotential PC1

## Weak events defined at 10 mb



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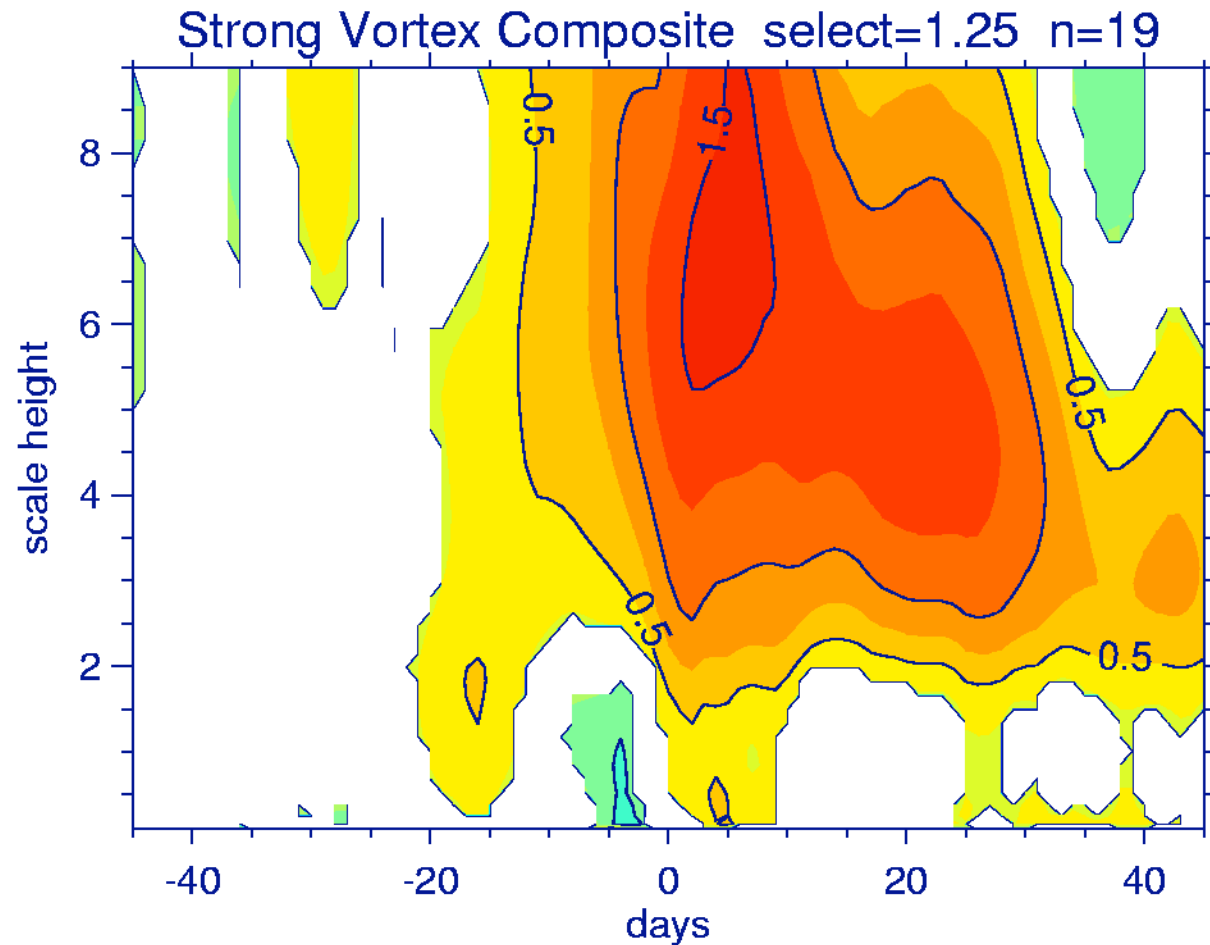


# Evolution of Geopotential PC1

## Strong events defined at 10 mb



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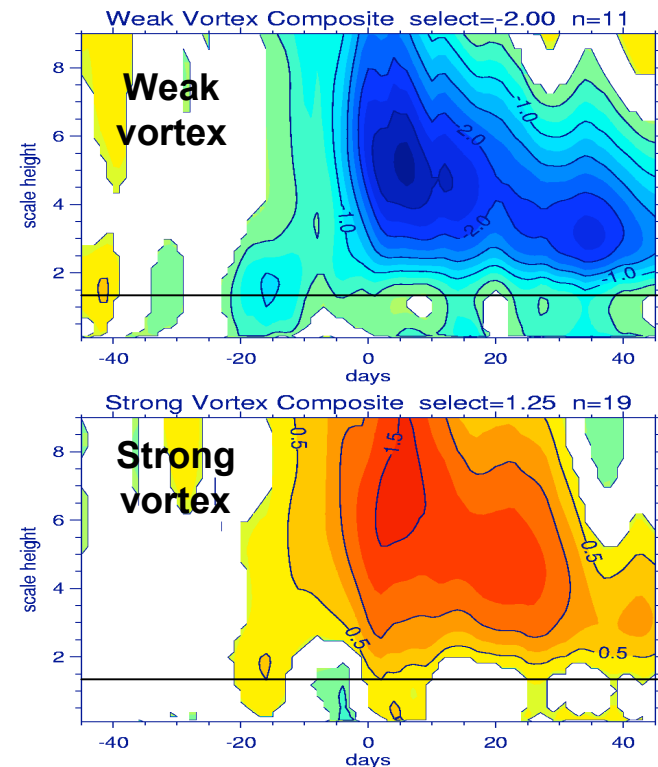
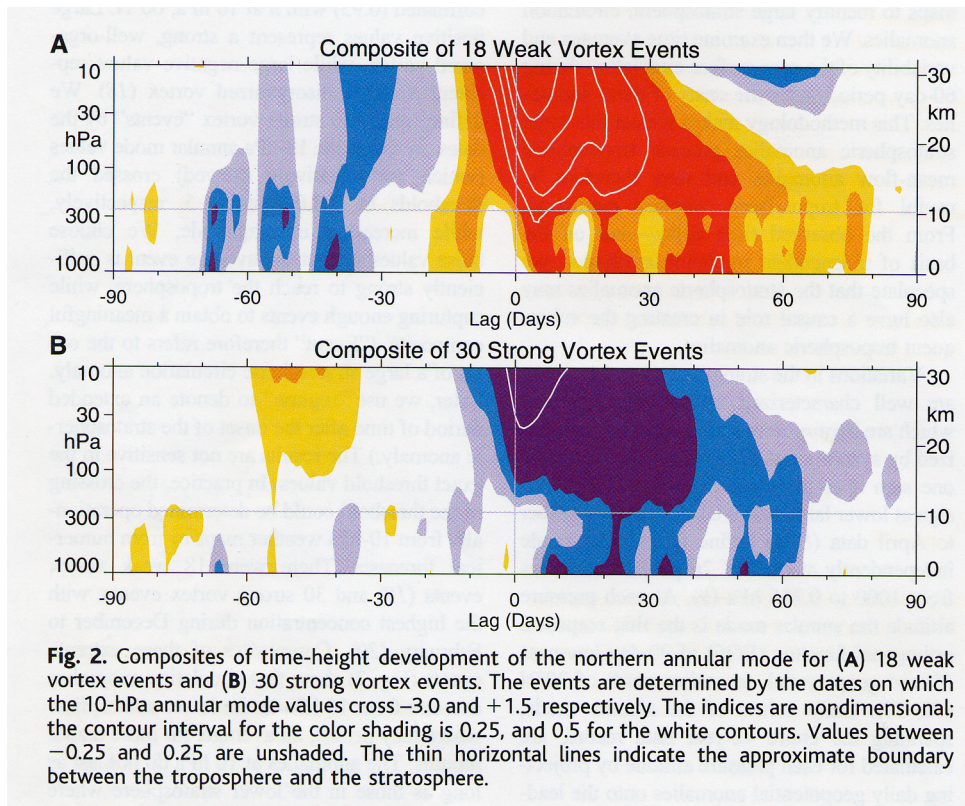
**Composite of 19  
high-amplitude  
strong vortex  
events**

# Weak and Strong Vortex Events

## Model vs Obs



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Note similarity to observations. Recall that model weak-vortex composites are strongly influenced by several large-amplitude events that coincide with ENSO-warm years (not shown).

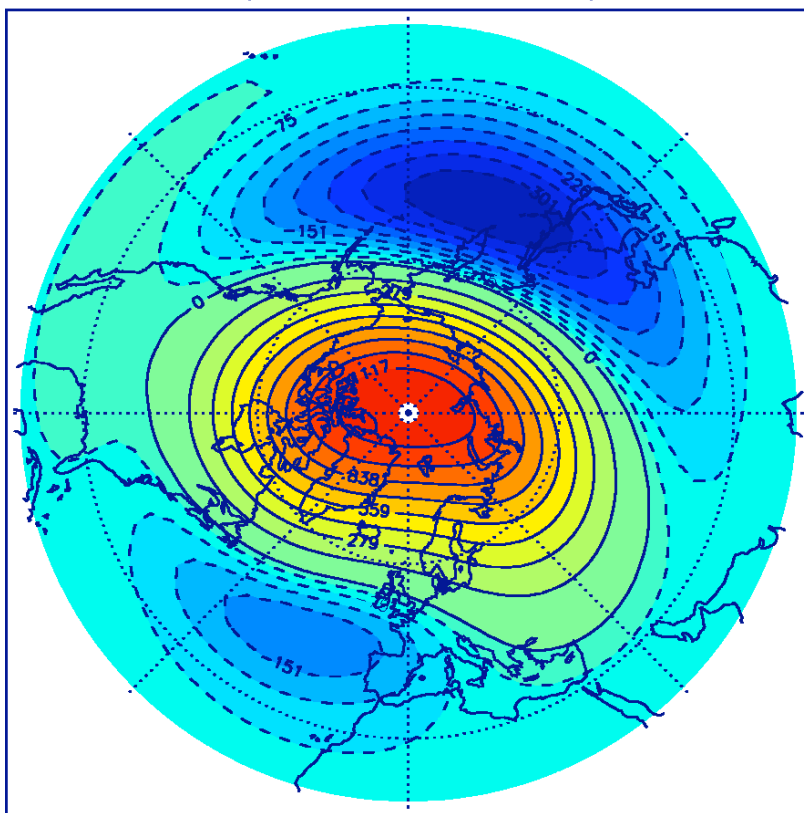
**Is this also true of observations?**

# Weak and Strong Composites: Z(1mb) defined at 10 mb

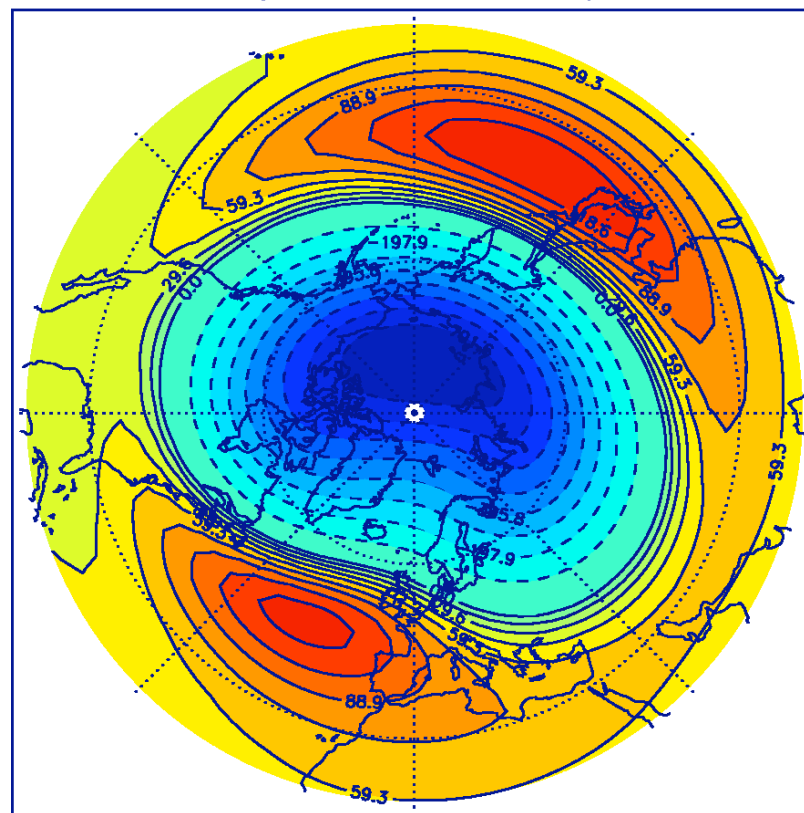


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Average of 11 Weak Vortex Events at  $9.559 \times 10^{-1}$  mb  
(max=1257.1, min=-339.0)



Average of 19 Strong Vortex Events at  $9.559 \times 10^{-1}$  mb  
(max=133.4, min=-890.5)



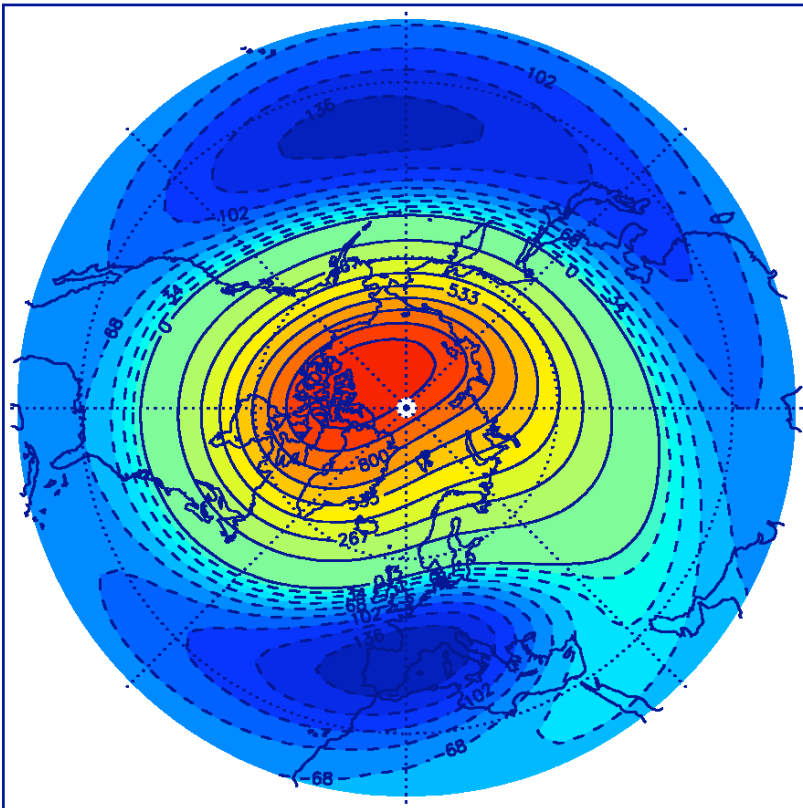
# Weak and Strong Composites: Z(10 mb)

defined at 10 mb

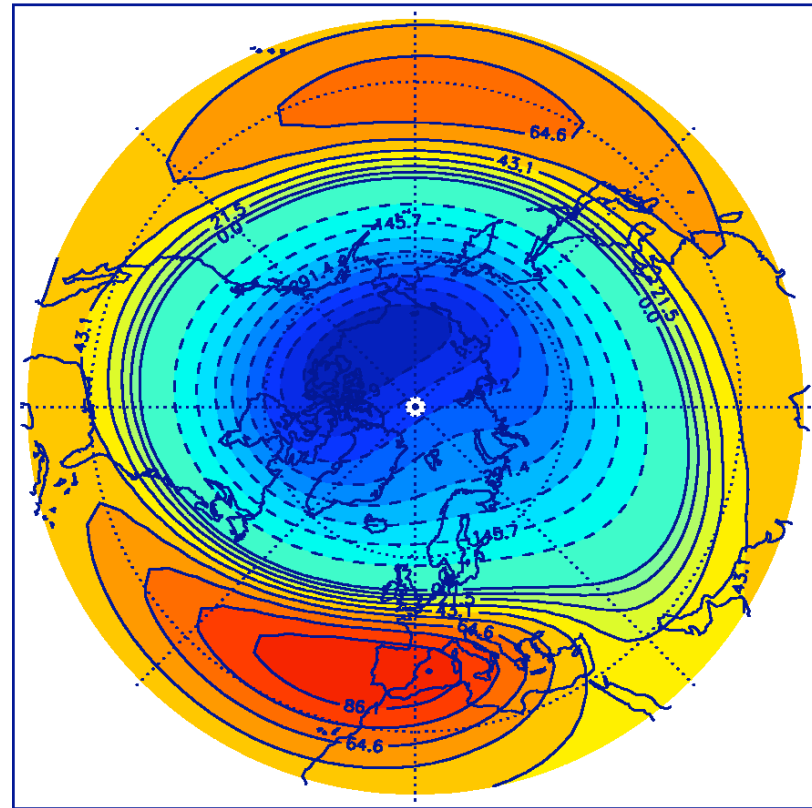


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Average of 11 Weak Vortex Events at  $1.071 \times 10^1$  mb  
(max=1199.5, min=-152.8)



Average of 19 Strong Vortex Events at  $1.071 \times 10^1$  mb  
(max=96.9, min=-655.7)





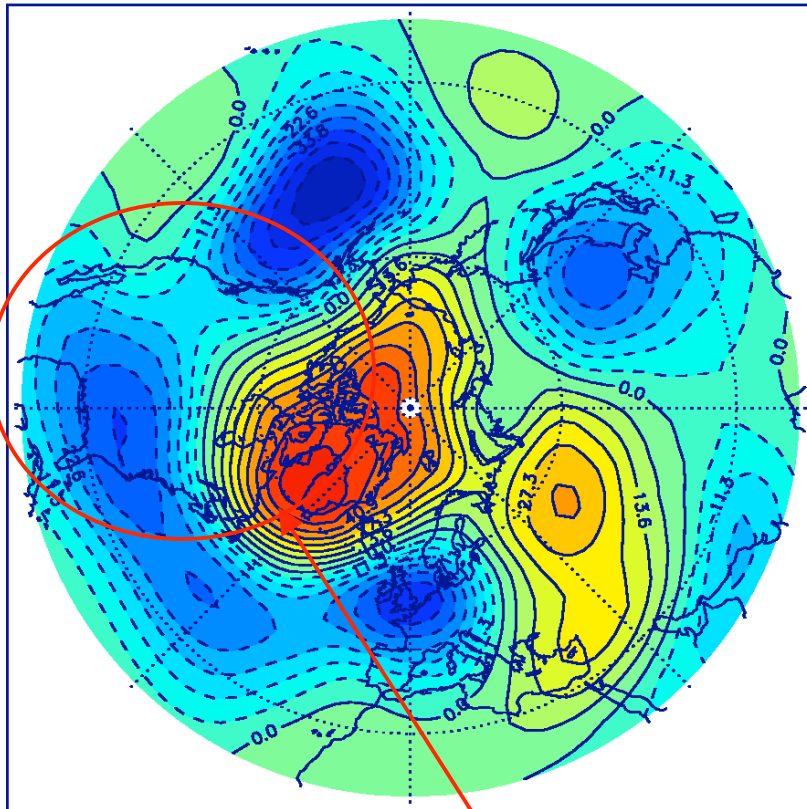
# Weak and Strong Composites: Z (434 mb)

defined at 10 mb

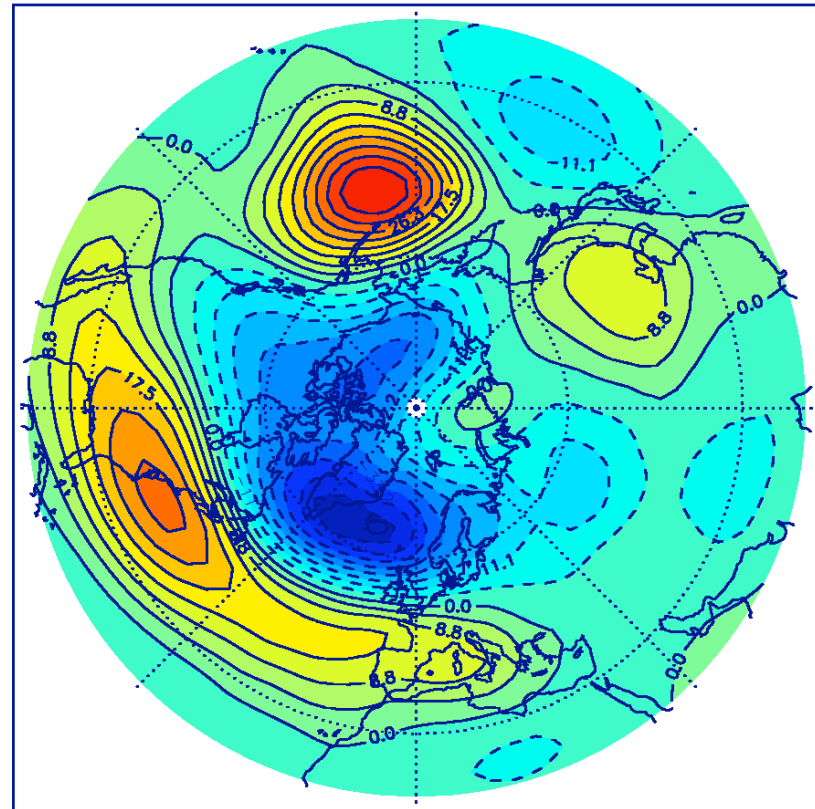


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Average of 11 Weak Vortex Events at  $4.339 \times 10^2$  mb  
(max=61.4, min=-50.8)



Average of 19 Strong Vortex Events at  $4.339 \times 10^2$  mb  
(max=39.4, min=-49.9)



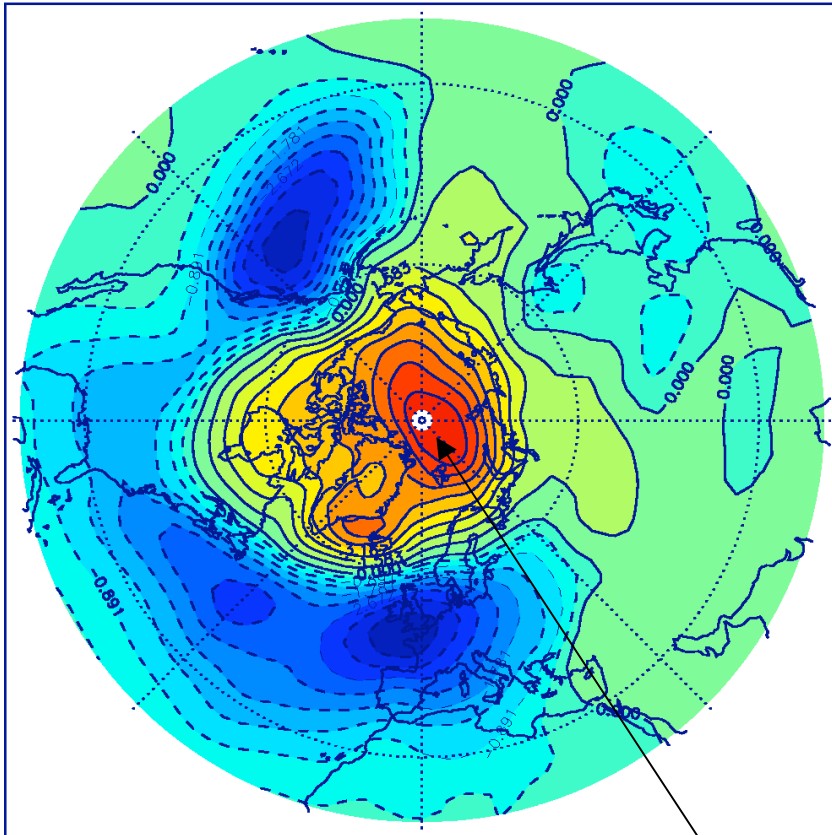
Note PNA-like pattern:  
Several large-amplitude weak  
events occur in ENSO years

# Weak and Strong Composites: PS defined at 10 mb

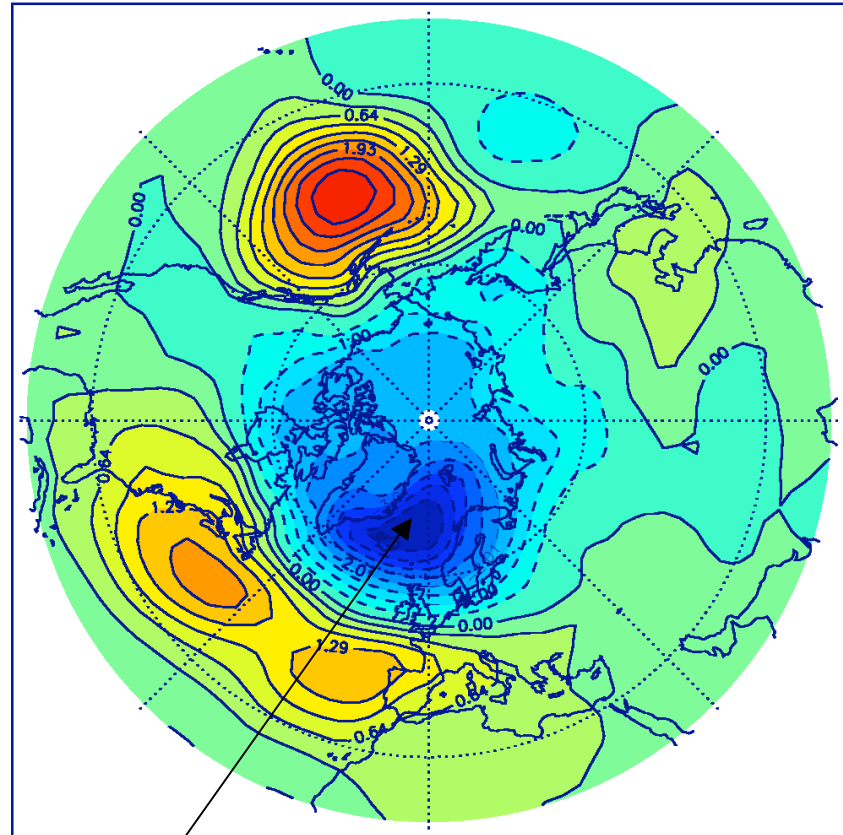


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Average of 11 Weak Vortex Events (mb) (max=7.1, min=-4.0)



Average of 19 Strong Vortex Events (mb) (max=2.9, min=-4.5)

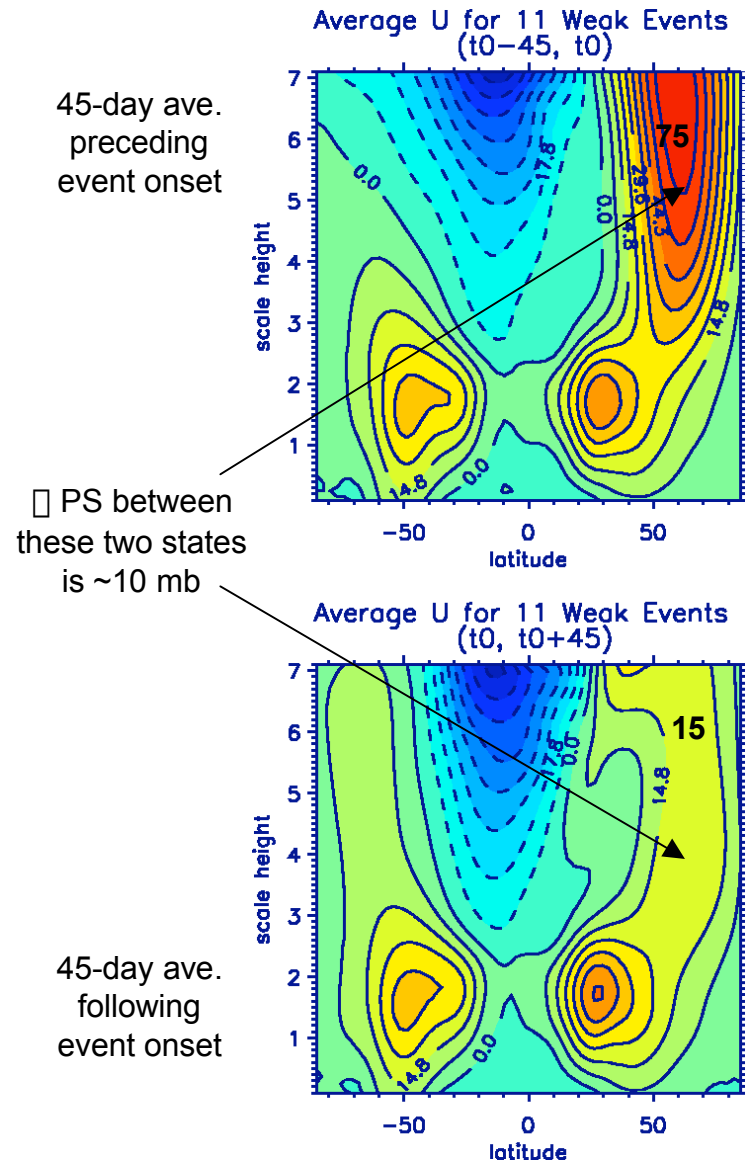


□ PS ~ 10 mb

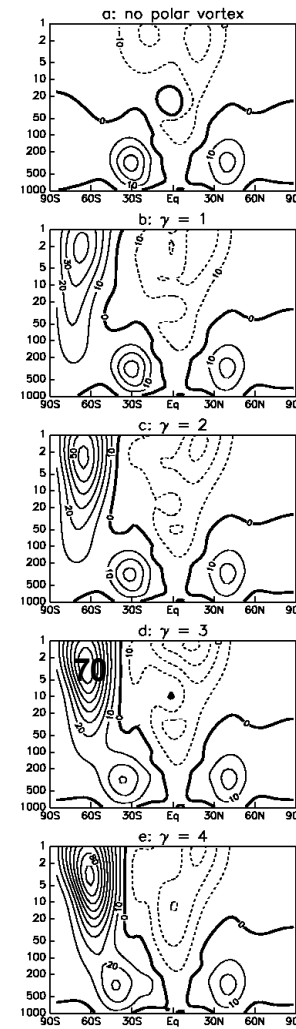
# Weak Event Composite Change in U and T



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Polvani and Kushner (GRL, 2002)



Polar cap pressure  
change as function of  
increasing jet strength

↓  
-3.1 mb

-4.4mb

-9.5 mb

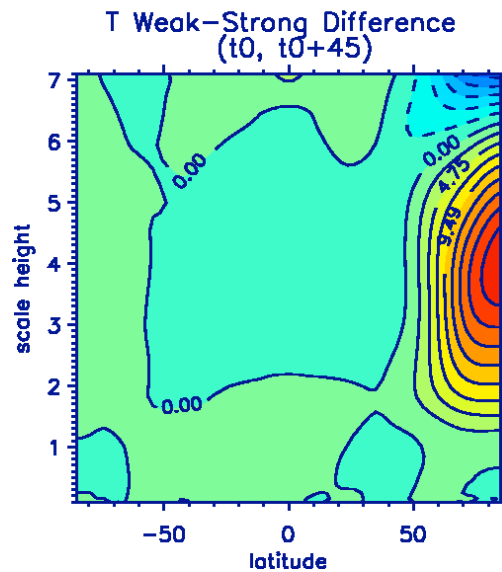
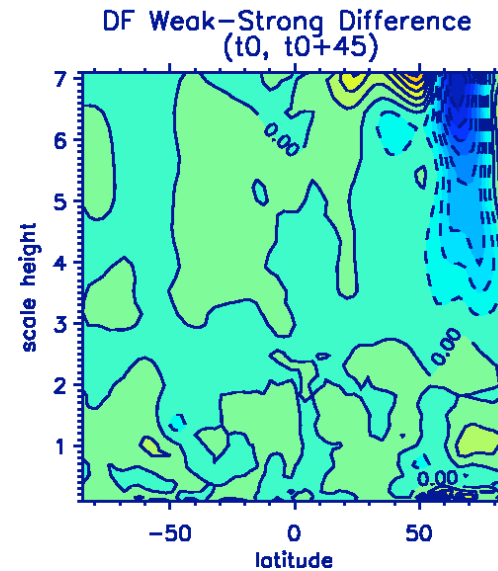
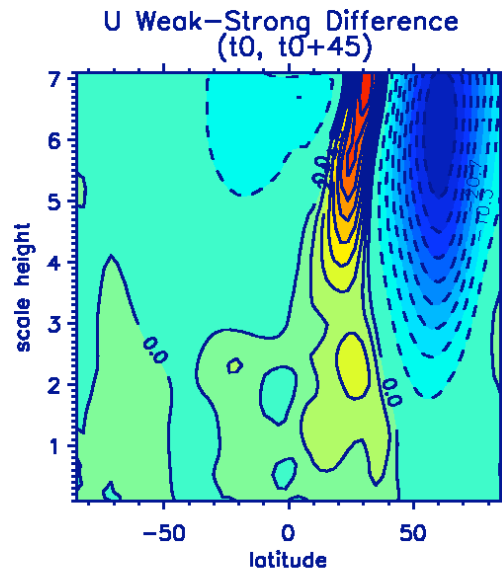
-16.6 mb

Figure 1. The time and zonally averaged zonal wind, as a function of latitude and pressure, for the experiment with a) no polar vortex in the stratosphere, b)  $\gamma = 1$ , c)  $\gamma = 2$ , d)  $\gamma = 3$ , e)  $\gamma = 4$ . The contour level is  $10 \text{ m s}^{-1}$ . Negative contours are dashed.

# Weak – Strong Composites: U, T, EP FLux defined at 10 mb



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## Some remarks about Weak Events defined at 10 mb

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- About 1/3 fewer events than identified by B&D over a data record approximately the same length as WACCM run. => Fewer sources of pw variability in model? e.g., absence of QBO?
- Annular modes are latitudinally “broad” in the stratosphere, with high degree of zonal symmetry; narrower in the troposphere with strong wave components;
- Large-amplitude weak vortex events extend into upper troposphere
- Weak event composites at Z(434 mb) display PNA-like pattern  
<=> several of the largest weak events occur in ENSO-warm years



# Stratospheric vs tropospheric influence on Annular Modes

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To what extent is the behavior in the troposphere influenced by the stratosphere?

Is it possible to identify distinct “tropospheric” vs “stratospheric” influences on tropospheric annular modes

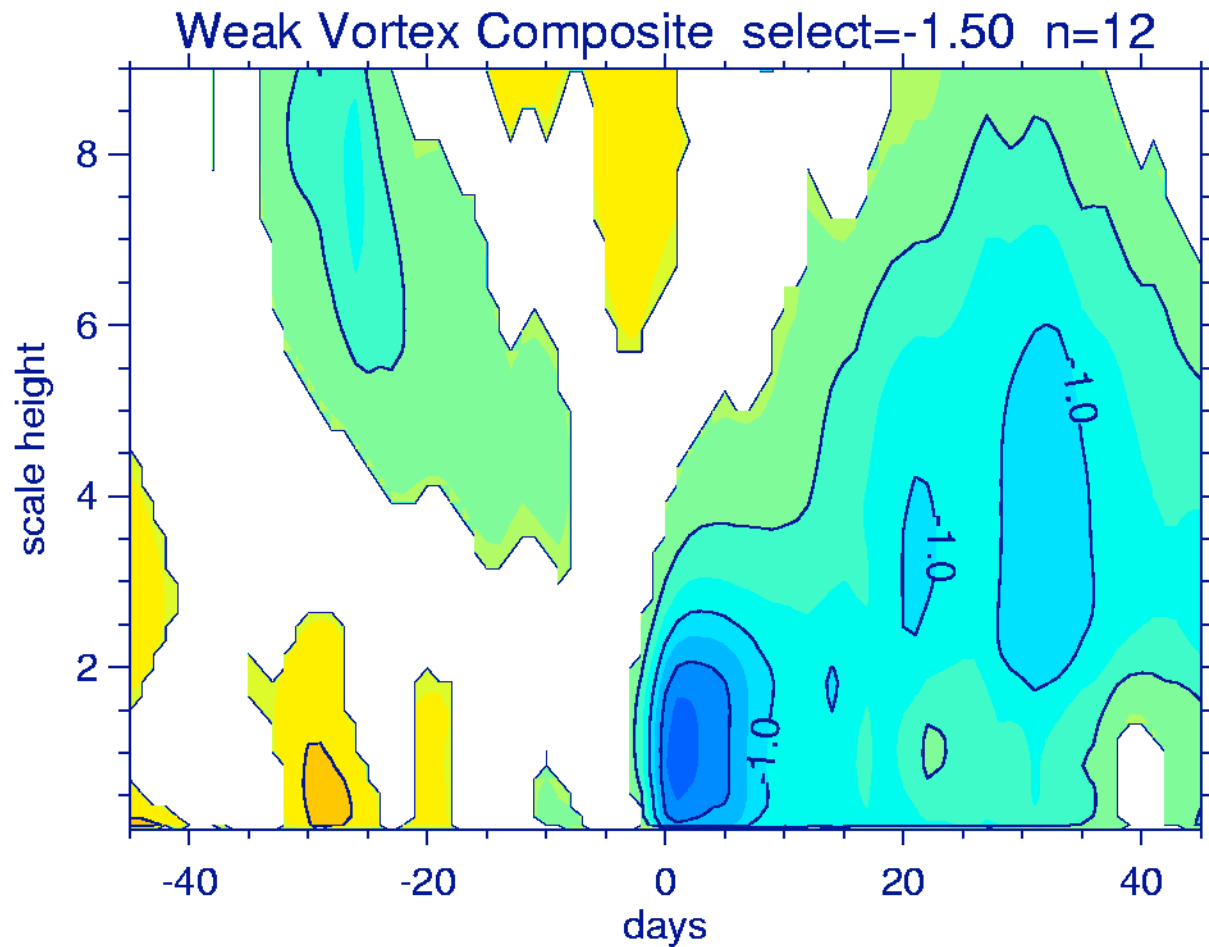
=> Look at strong and weak events defined in terms of behavior in mid-troposphere (~434 mb); same selection criteria as for the events defined at 10 mb

# Evolution of Geopotential PC1

## Weak events defined at 434 mb



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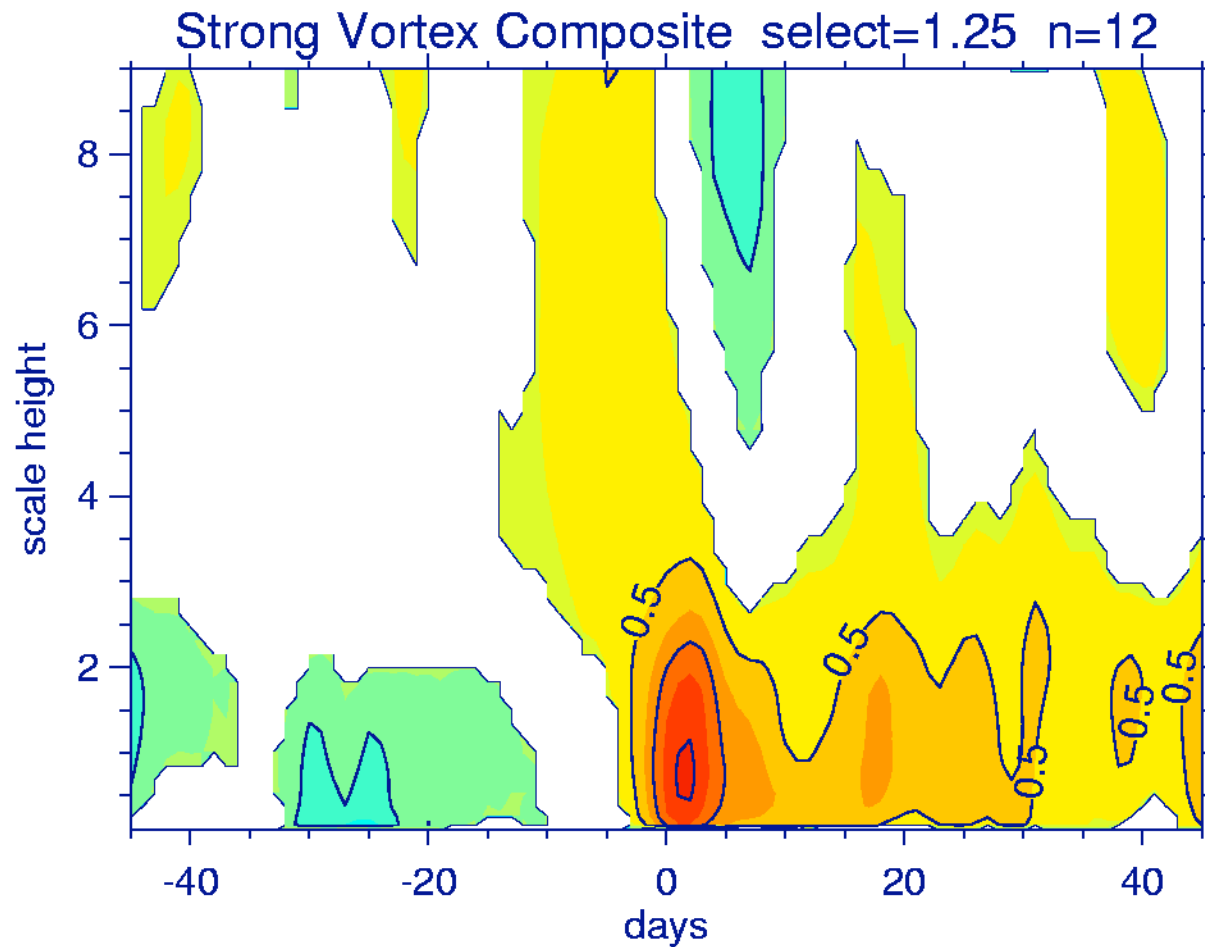
**Composite of 12  
high-amplitude  
weak vortex  
events**

# Evolution of Geopotential PC1

## Strong events defined at 434 mb



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**Composite of 12  
high-amplitude  
strong vortex  
events**

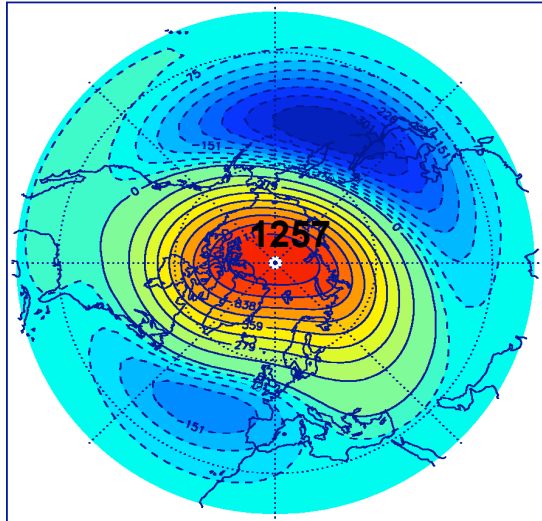
# Weak and Strong Composites: Z (1 mb) def 10 mb vs. def 434 mb



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## Weak vortex

Average of 11 Weak Vortex Events at 9.559e-01 mb  
(max=1257.1, min=-339.0)



# Weak and Strong Composites: Z (10 mb)

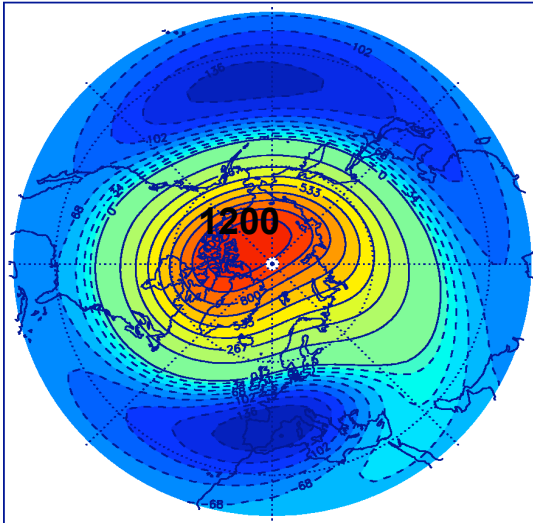
## def 10 mb vs. def 434 mb



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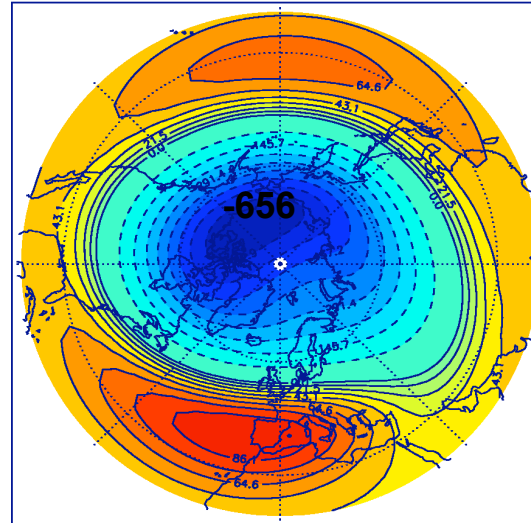
### Weak vortex

Average of 11 Weak Vortex Events at  $1.071 \times 10^1$  mb  
(max=1199.5, min=-152.8)



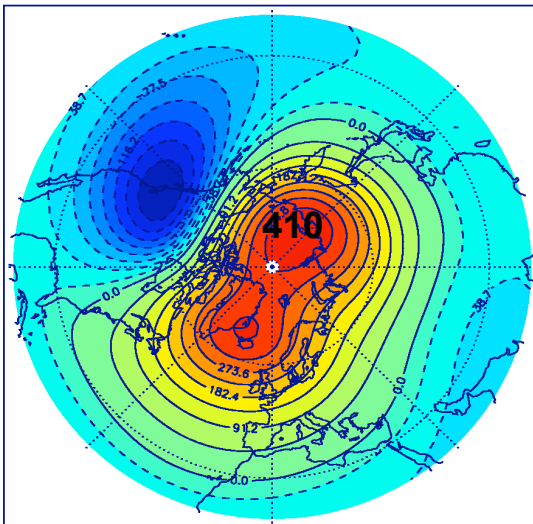
### Strong vortex

Average of 19 Strong Vortex Events at  $1.071 \times 10^1$  mb  
(max=96.9, min=-655.7)

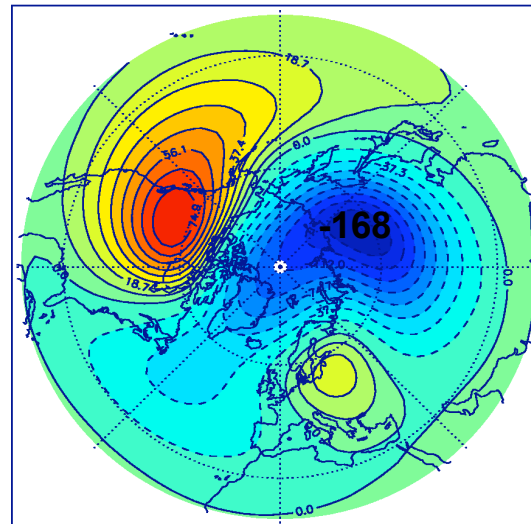


Events defined at 10 mb

Average of 12 Weak Vortex Events at  $1.071 \times 10^1$  mb  
(max=410.4, min=-174.4)



Average of 12 Strong Vortex Events at  $1.071 \times 10^1$  mb  
(max=84.2, min=-168.0)



Events defined at 434 mb



# Weak and Strong Composites: Z (434 mb)

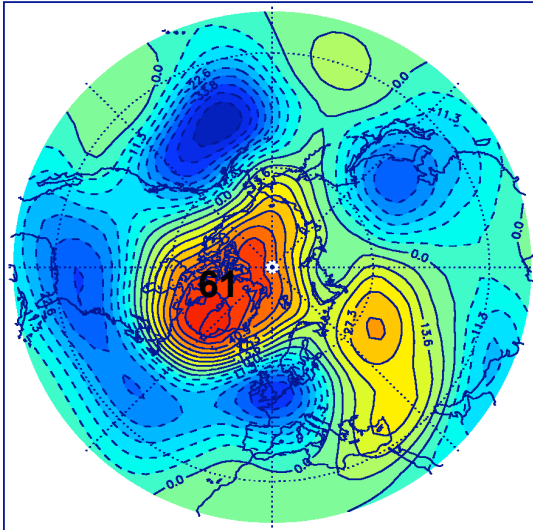
## def 10 mb vs. def 434 mb



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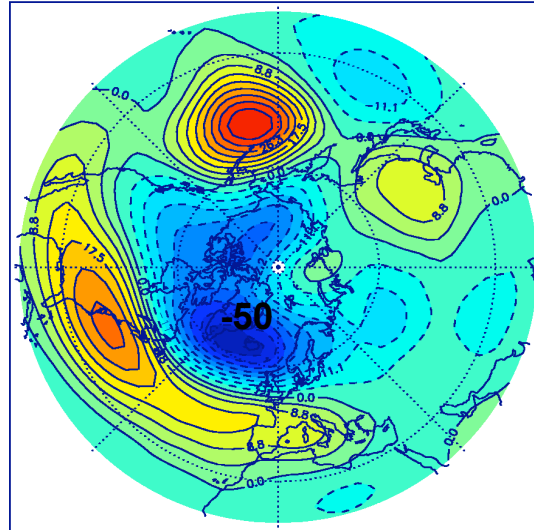
### Weak vortex

Average of 11 Weak Vortex Events at 4.339e+02 mb  
(max=61.4, min=-50.8)



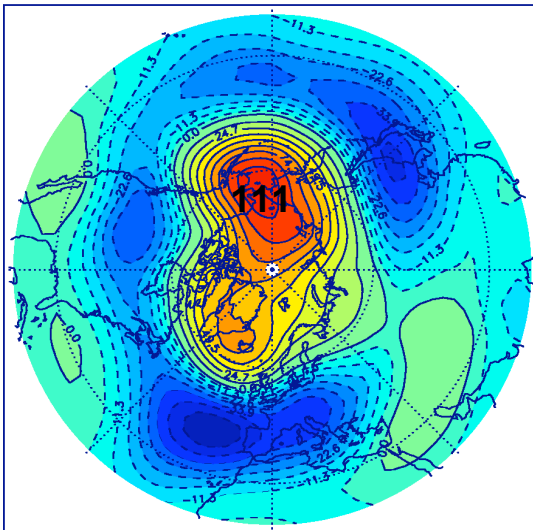
### Strong vortex

Average of 19 Strong Vortex Events at 4.339e+02 mb  
(max=39.4, min=-49.9)

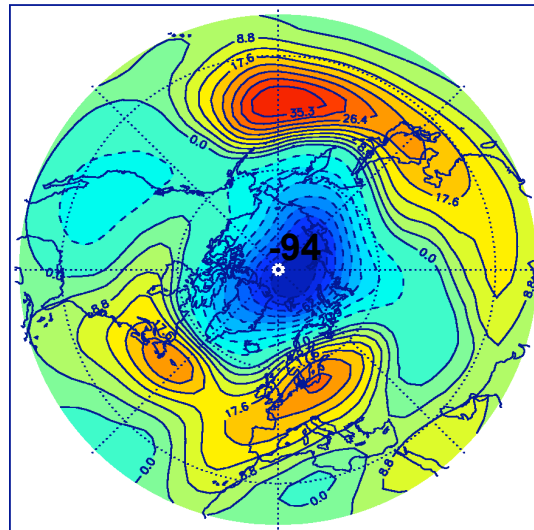


Events defined at 10 mb

Average of 12 Weak Vortex Events at 4.339e+02 mb  
(max=111.3, min=-50.8)



Average of 12 Strong Vortex Events at 4.339e+02 mb  
(max=39.7, min=-93.9)



Events defined at 434 mb

# Weak and Strong Composites: PS

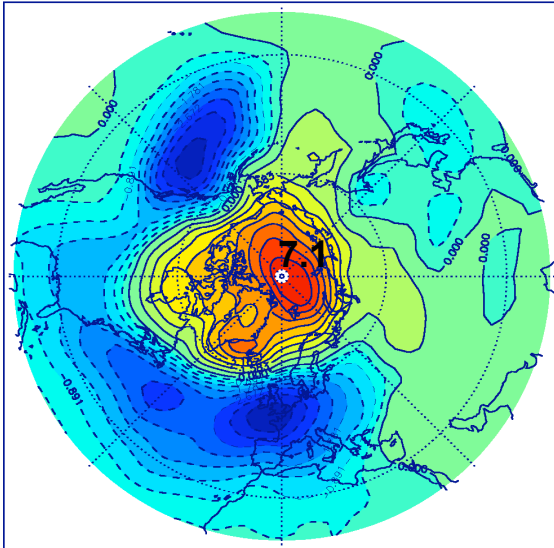
## def 10 mb vs. def 434 mb



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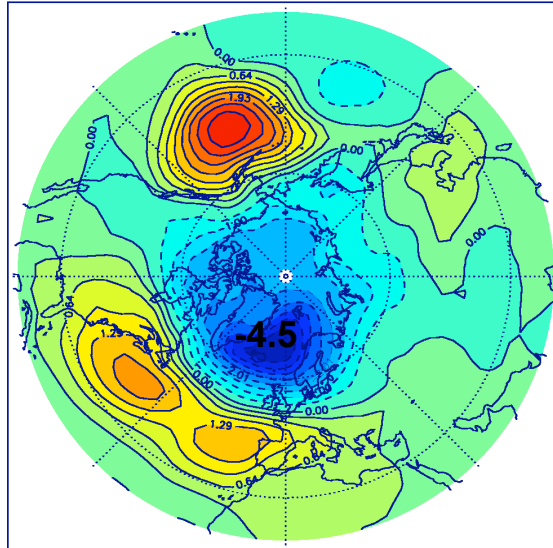
### Weak vortex

Average of 11 Weak Vortex Events (mb) (max=7.1, min=-4.0)



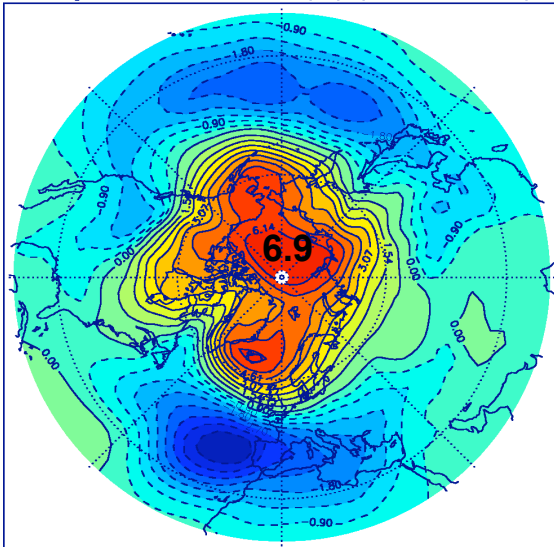
### Strong vortex

Average of 19 Strong Vortex Events (mb) (max=2.9, min=-4.5)

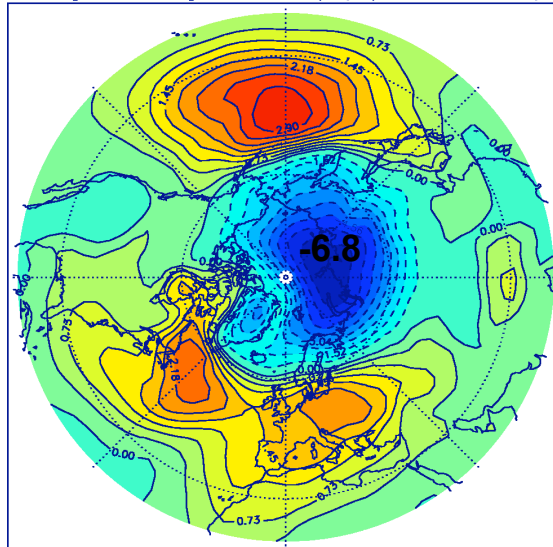


Events defined at 10 mb

Average of 12 Weak Vortex Events (mb) (max=6.9, min=-4.0)



Average of 12 Strong Vortex Events (mb) (max=3.3, min=-6.8)



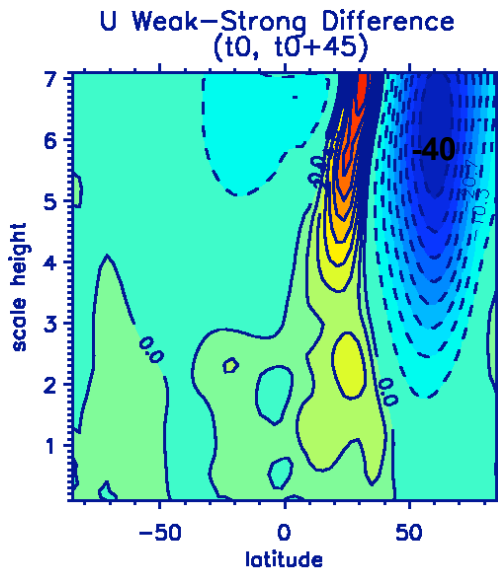
Events defined at 434 mb

# Weak-Strong Event Differences: U and T

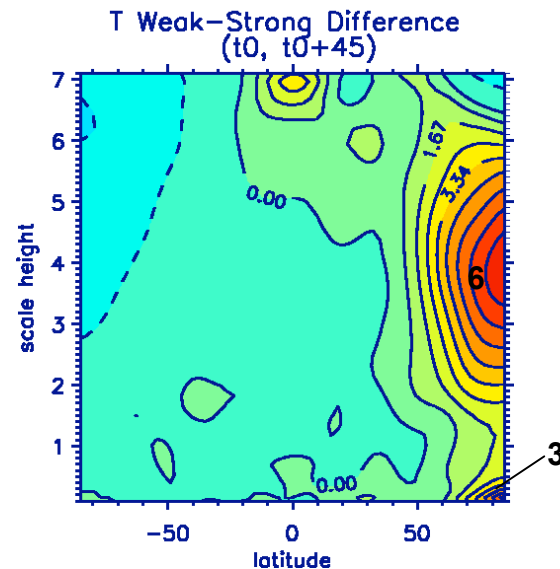
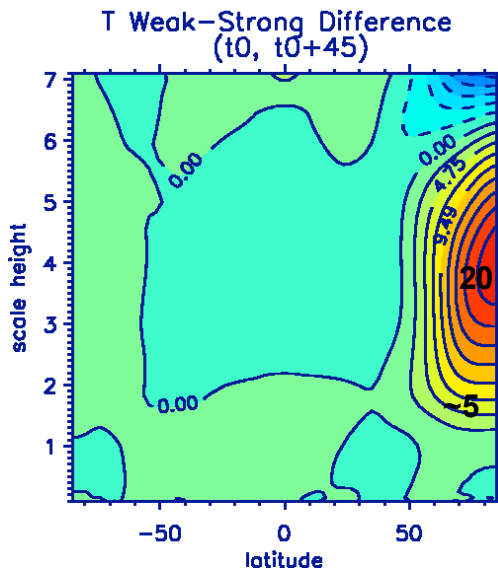
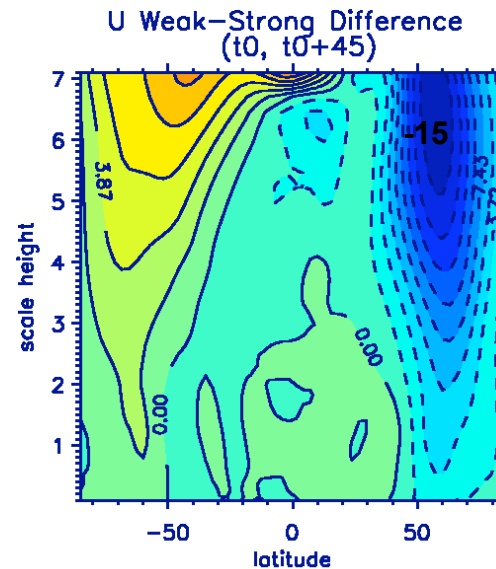


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Events  
defined at  
10 mb



Events  
defined at  
434 mb

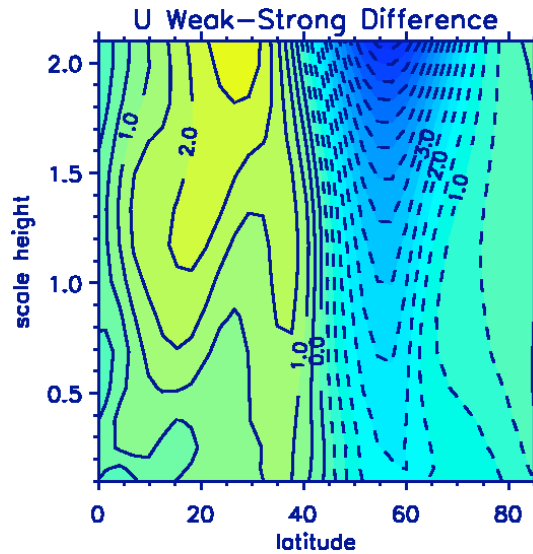


# Weak–Strong Event Differences: U and T (trop/lower strat)

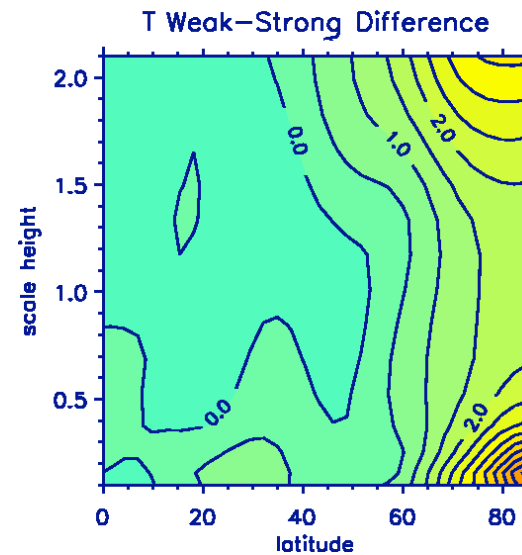
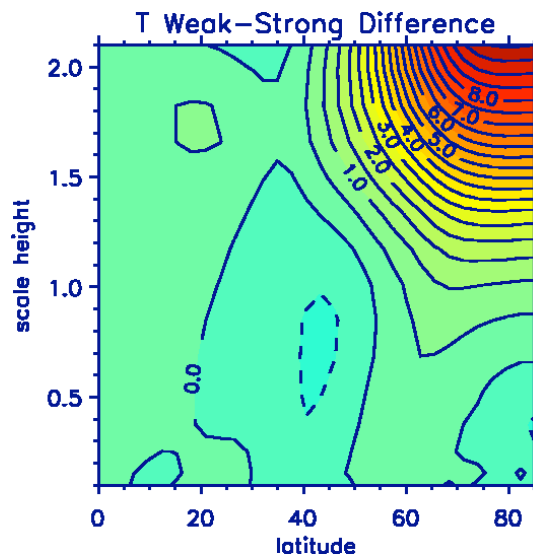
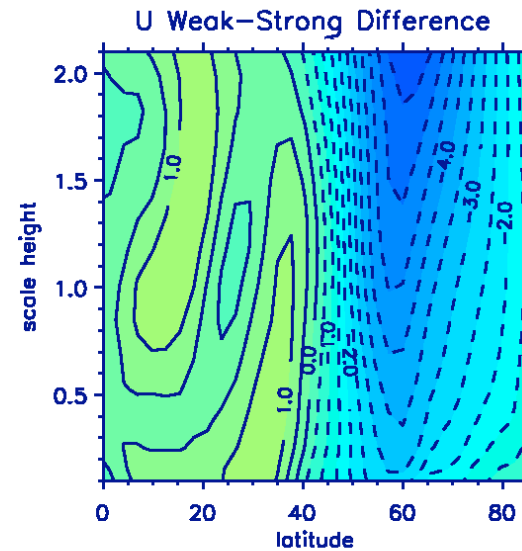


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Events  
defined at  
10 mb



Events  
defined at  
434 mb



# Conclusions

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- WACCM reproduces the main features of observed behavior of annular modes in the stratosphere and troposphere
- Model appears to have smaller number of extreme events than observations. Fewer sources of variability? e.g., no QBO
- Several of the largest amplitude weak events in the model occur in warm ENSO years
- Large-amplitude weak vortex events influence the troposphere if their effects extend down to ~ 200-300 mb
- Events defined in terms of behavior in the stratosphere (10 mb) have distinct structure from those defined in the troposphere (434 mb)  
=> separate role for the stratosphere in tropospheric AM variability