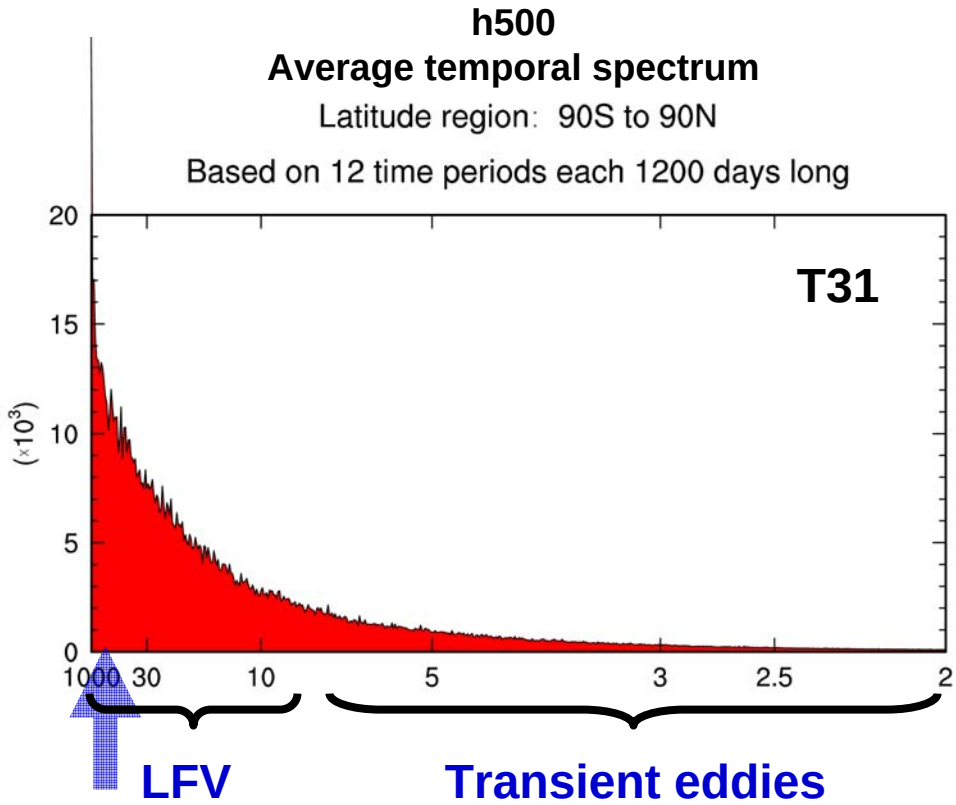
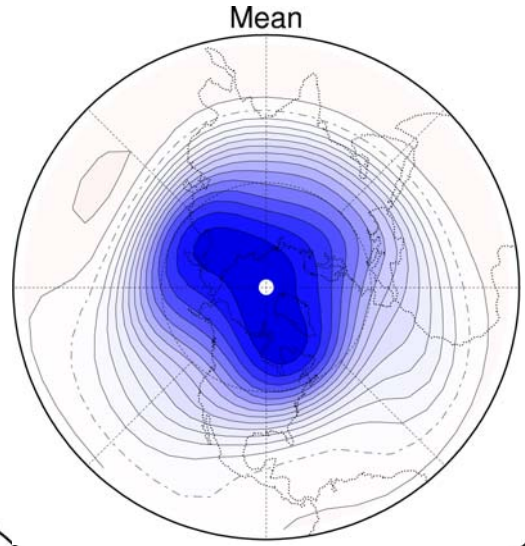
Planetary Wave Interactions across Time Scales

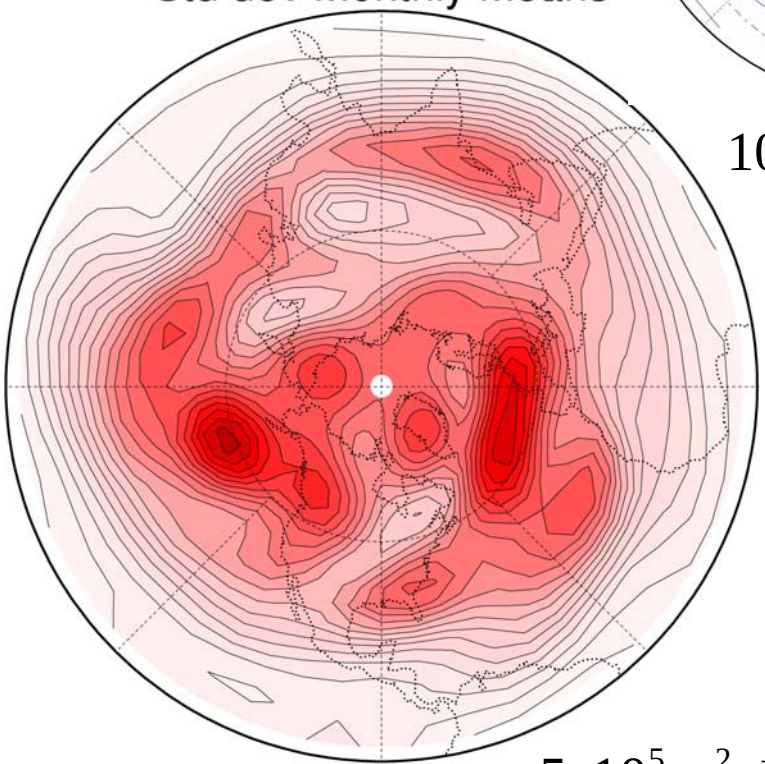
Grant Branstator, NCAR



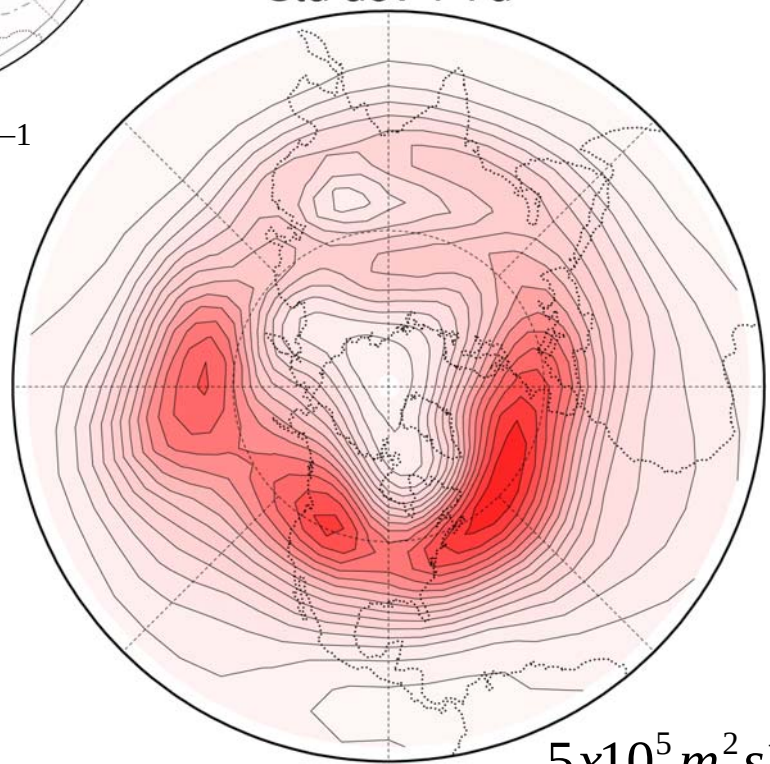
Jan Psi300



$100x10^5 m^2 s^{-1}$

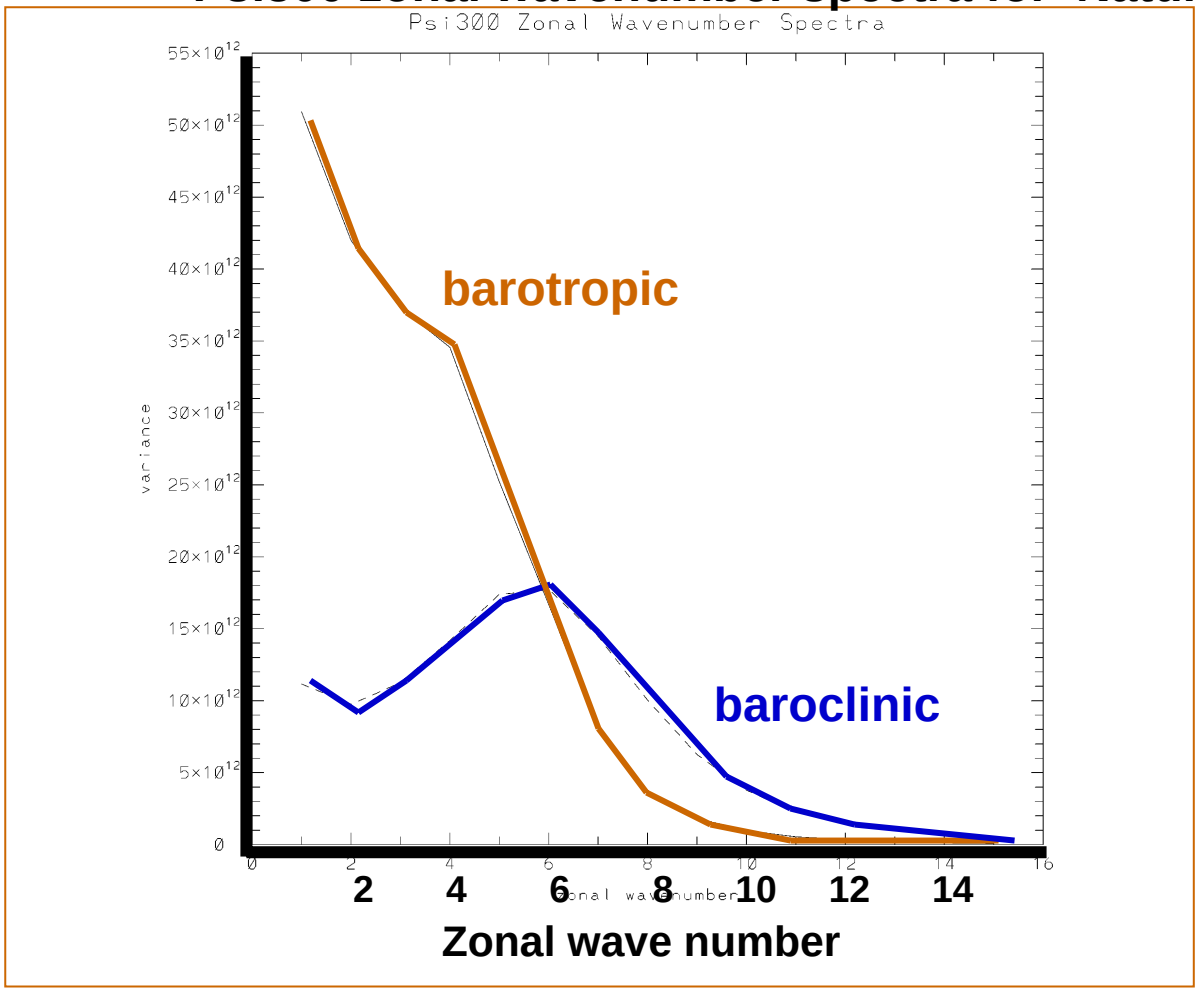


$5x10^5 m^2 s^{-1}$



$5x10^5 m^2 s^{-1}$

Psi300 zonal wavenumber spectra for Nature



Interaction between seasonal cycle and LFV

Do LF disturbances affect the seasonal mean?

$$\frac{\partial \varsigma}{\partial t} = -\vec{v}_{\psi} \cdot \nabla(\varsigma + f) - \ldots$$

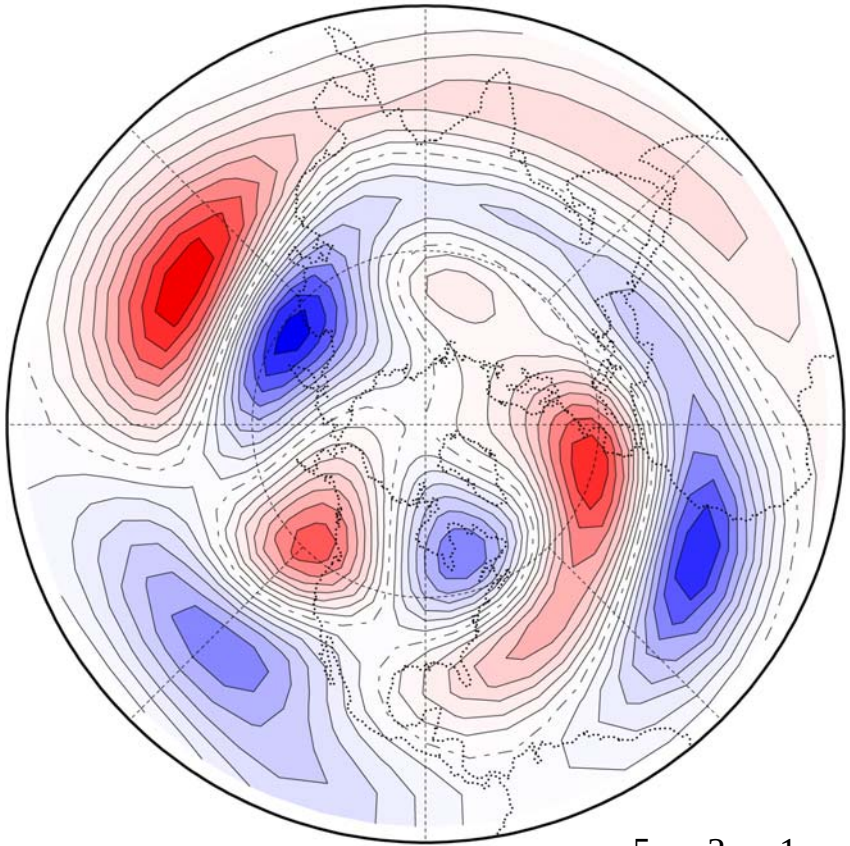
$$() = \frac{1}{T}\int_{0}^{T} () dt + ()'$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_{\psi} \cdot \nabla(\bar{\varsigma} + f) - \bar{\vec{v}}_{\psi} \cdot \nabla \varsigma' - \vec{v}'_{\psi} \cdot \nabla \bar{\varsigma} - \vec{v}'_{\psi} \cdot \nabla \varsigma' \ldots$$

$$\bar{\vec{v}}_{\psi} \cdot \nabla(\bar{\varsigma} + f) = -\overline{\vec{v}'_{\psi} \cdot \nabla \varsigma' + \ldots}$$

Jan Psi300

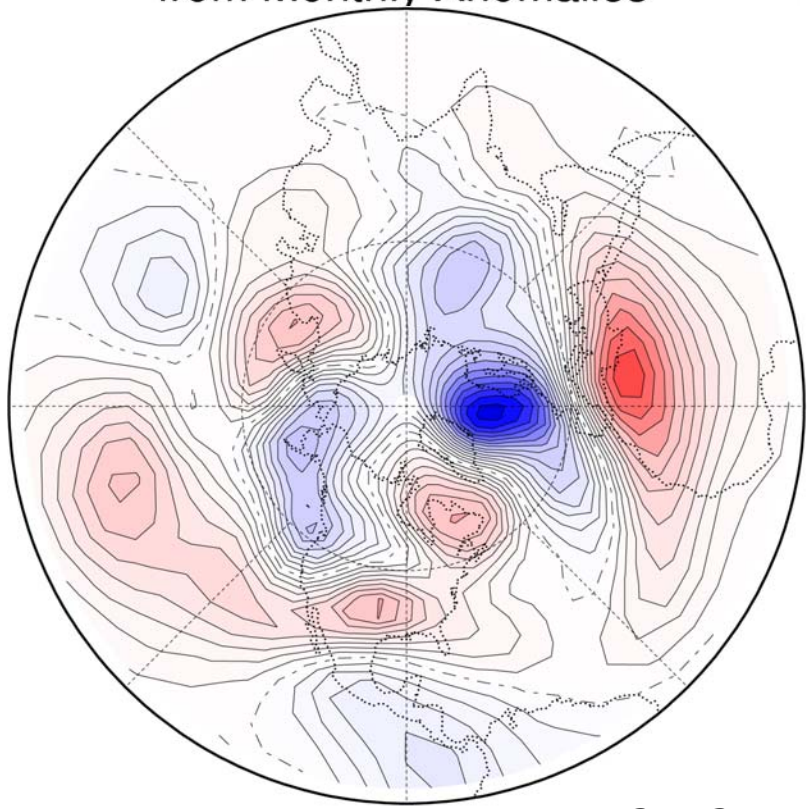
Mean Eddies



$25x10^5 m^2 s^{-1}$

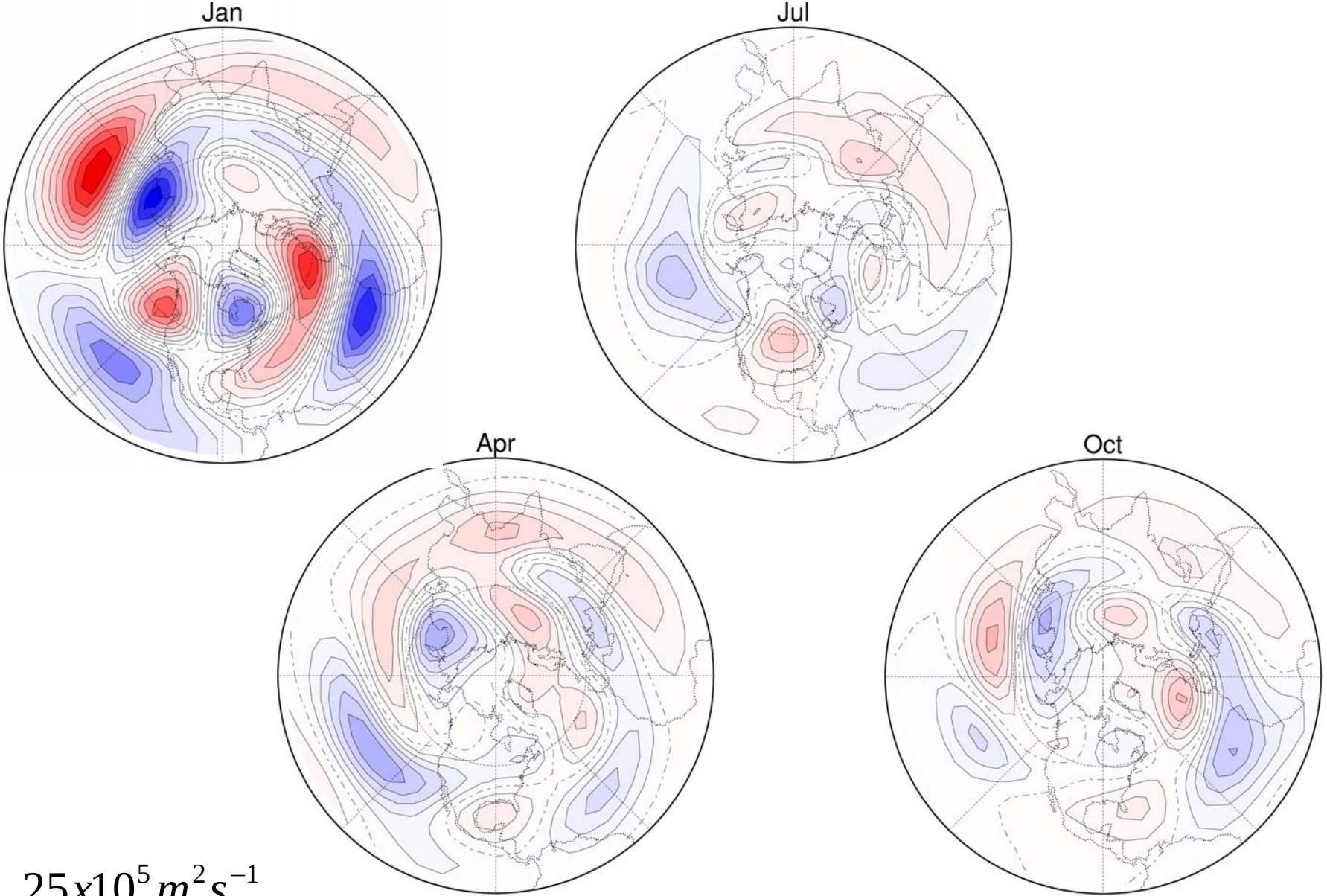
$-\nabla^{-2}\ \overline{\mathbf{v}_\psi' \cdot \nabla \zeta'}$

Mean Tendencies
from Monthly Anomalies

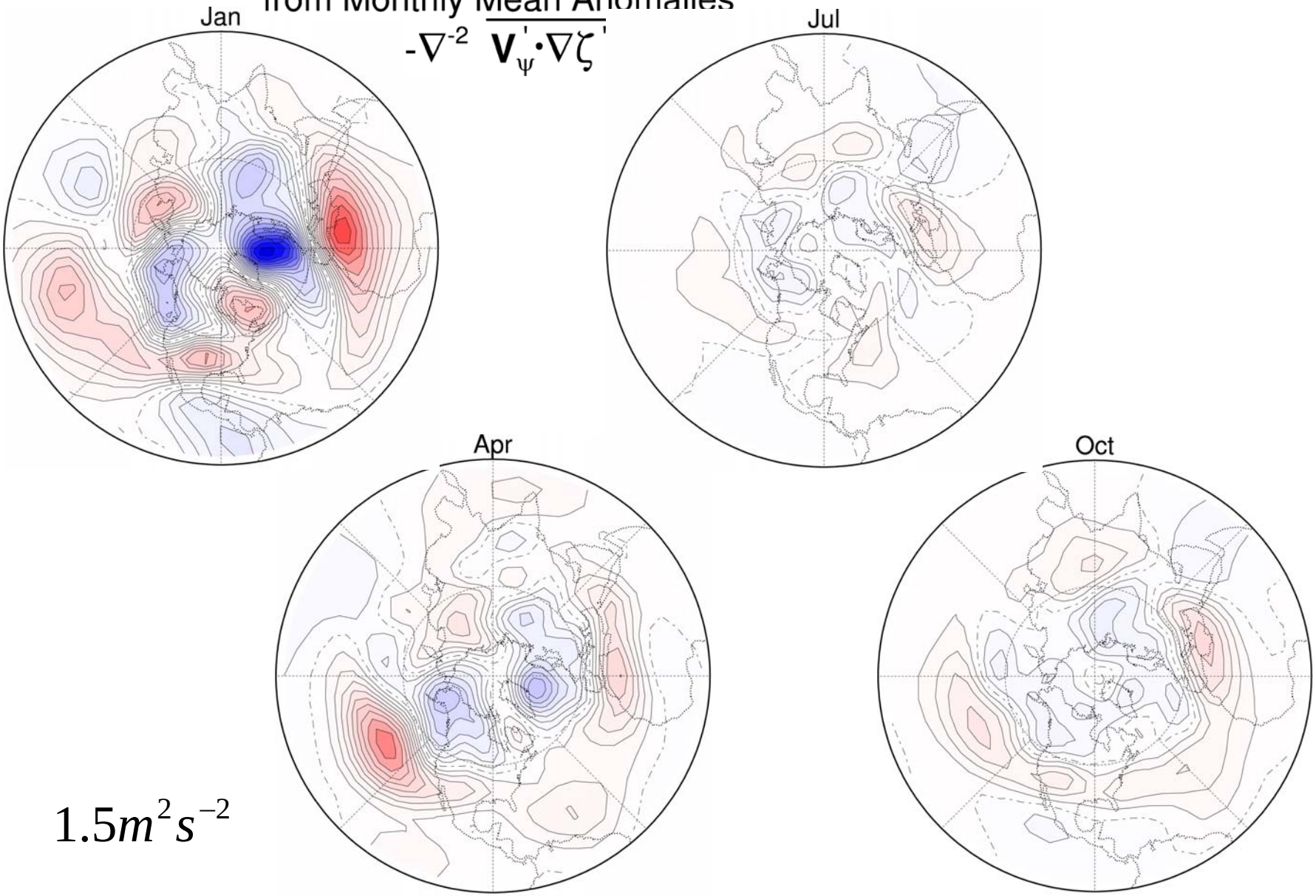


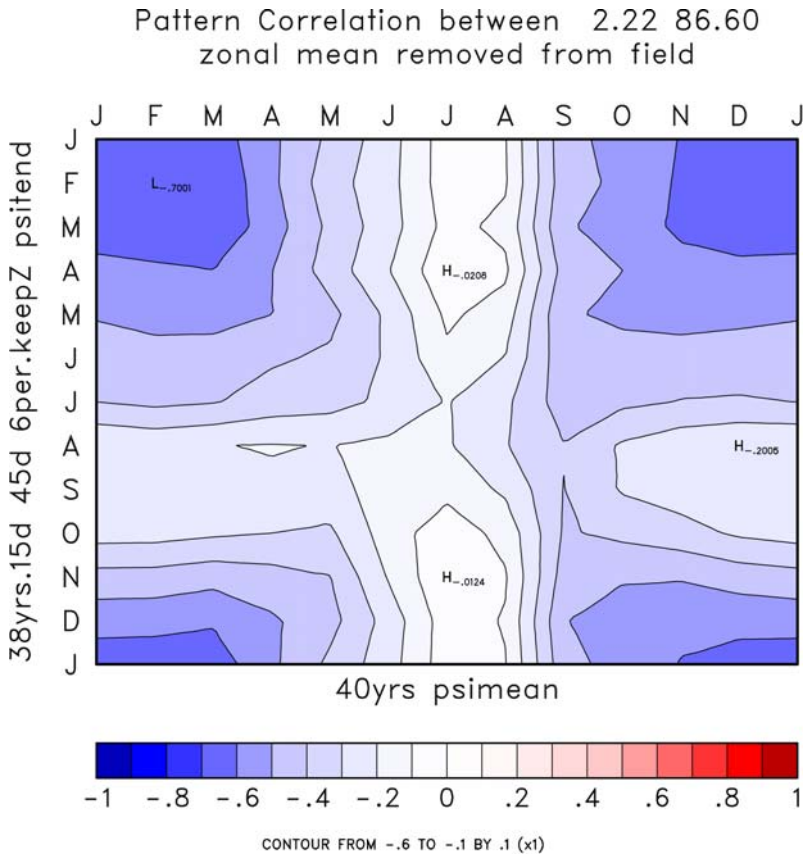
$1.5 m^2 s^{-2}$

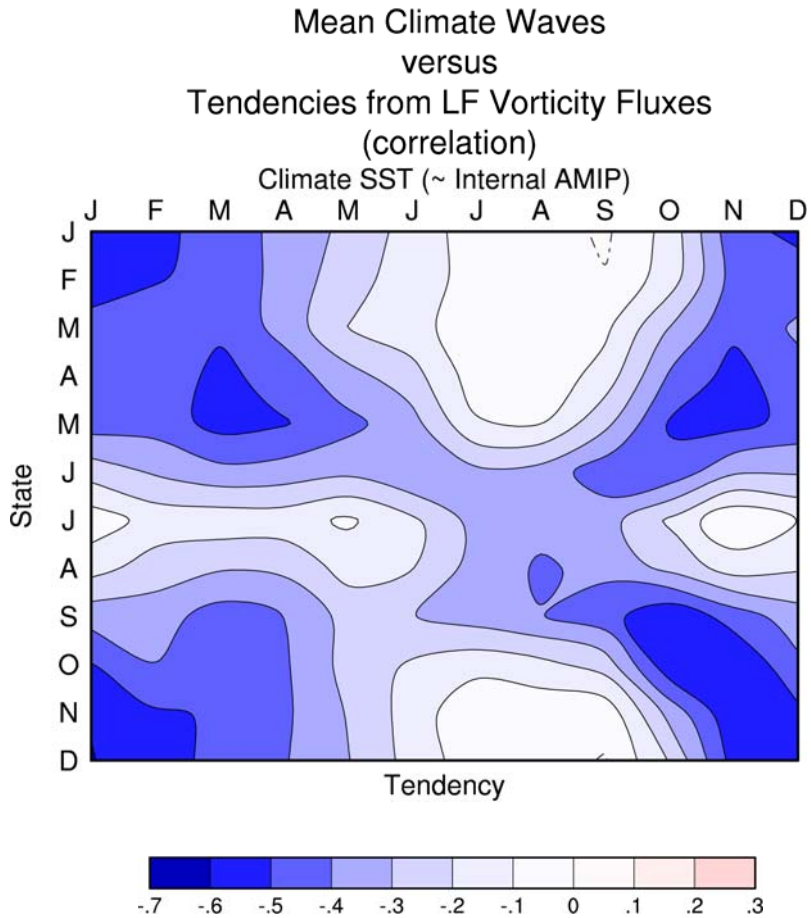
Psi300 Mean Eddies



$25x10^5 m^2 s^{-1}$


Psi300 Mean Tendencies
from Monthly Mean Anomalies
$-\nabla^{-2}\ \overline{\mathbf{V}_\psi' \cdot \nabla \zeta'}$
Jan
Jul
Apr
Oct
$1.5 m^2 s^{-2}$


Pattern Correlation between 2.22 86.60
zonal mean removed from field
J F M A M J J A S O N D J
38yrs.15d 45d 6per.keepZ psitend
L-.7001
H-.0206
H-.2005
H-.0124
40yrs psimean
-1 -.8 -.6 -.4 -.2 0 .2 .4 .6 .8 1
CONTOUR FROM -.6 TO -.1 BY .1 (x1)


Mean Climate Waves
versus
Tendencies from LF Vorticity Fluxes
(correlation)
Climate SST (~ Internal AMIP)
J F M A M J J A S O N D
State
Tendency
-.7 -.6 -.5 -.4 -.3 -.2 -.1 0 .1 .2 .3

Does the seasonal mean circulation affect the LF disturbances?

$$\frac{\partial \varsigma}{\partial t} = -\vec{v}_{\psi} \cdot \nabla(\varsigma + f) - \ldots$$

$$() = \frac{1}{T}\int_{0}^{T} () dt + ()'$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_{\psi} \cdot \nabla(\bar{\varsigma} + f) - \bar{\vec{v}}_{\psi} \cdot \nabla \varsigma' - \vec{v}'_{\psi} \cdot \nabla \bar{\varsigma} - \vec{v}'_{\psi} \cdot \nabla \varsigma' \ldots$$

$$\bar{\vec{v}}_{\psi} \cdot \nabla(\bar{\varsigma} + f) = -\overline{\vec{v}'_{\psi} \cdot \nabla \varsigma'} + \ldots$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_{\psi} \cdot \nabla \varsigma' - \vec{v}'_{\psi} \cdot \nabla \bar{\varsigma} - (\vec{v}'_{\psi} \cdot \nabla \varsigma' - \overline{\vec{v}'_{\psi} \cdot \nabla \varsigma'}) \ldots$$

$$= -\bar{\vec{v}}_{\psi} \cdot \nabla \varsigma' - \vec{v}'_{\psi} \cdot \nabla \bar{\varsigma} + damping + noise \ldots$$

$$\frac{\partial \varsigma}{\partial t} = -\vec{v}_\psi \cdot \nabla(\varsigma + f) - \ldots$$

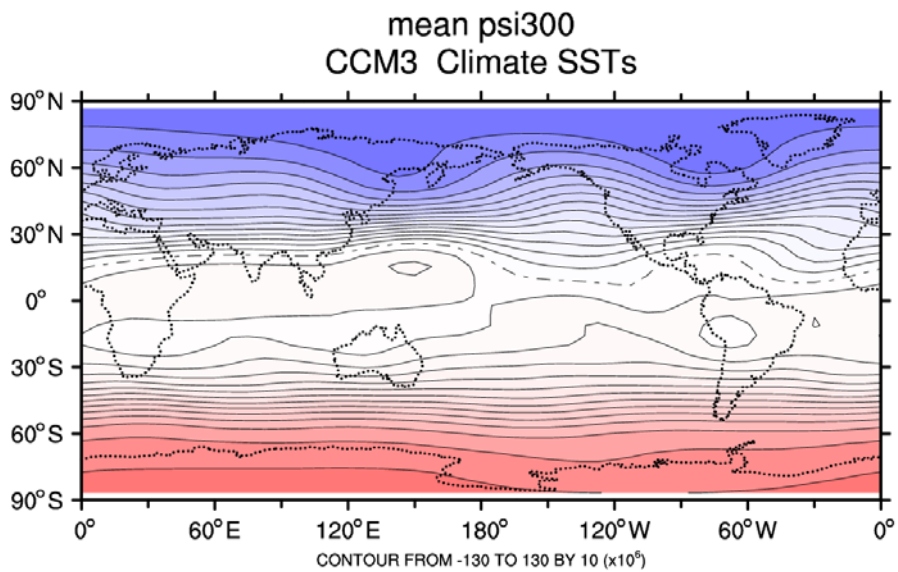
$$() = \frac{1}{T}\int_0^T ()dt + ()'$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_\psi \cdot \nabla(\bar{\varsigma} + f) - \bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} - \vec{v}'_\psi \cdot \nabla\varsigma' \ldots$$

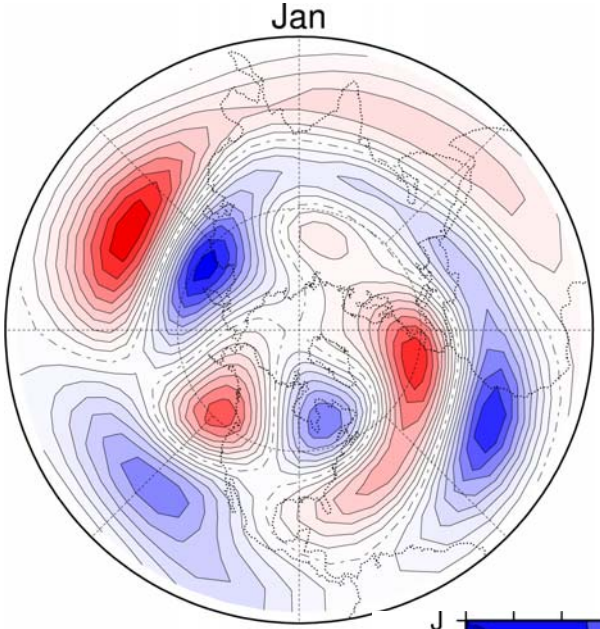
$$\bar{\vec{v}}_\psi \cdot \nabla(\bar{\varsigma} + f) = -\overline{\vec{v}'_\psi \cdot \nabla\varsigma'} + \ldots$$

$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} - (\vec{v}'_\psi \cdot \nabla\varsigma' - \overline{\vec{v}'_\psi \cdot \nabla\varsigma'}) \ldots$$

$$= -\bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} + damping + noise \ldots$$



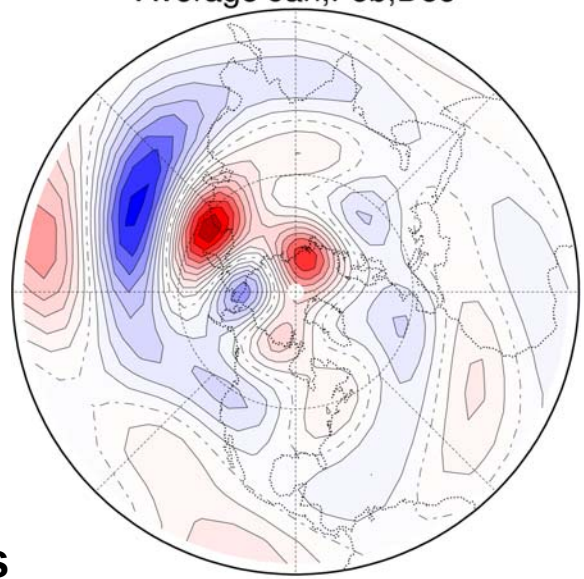
Psi300 mean eddies



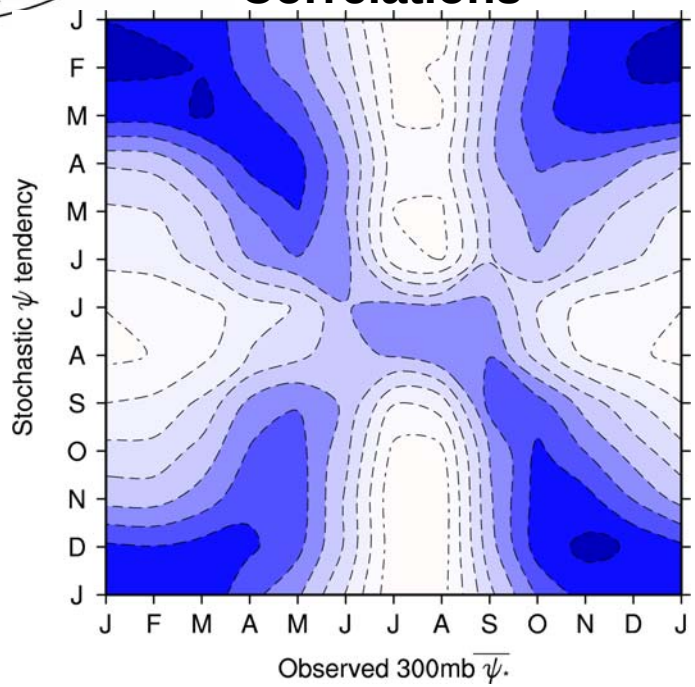
Psi tendency $-\nabla^{-2}\ \overline{\mathbf{V}_{\psi}' \cdot \nabla \zeta'}$

Nature basic state with random forcing

Average Jan,Feb,Dec

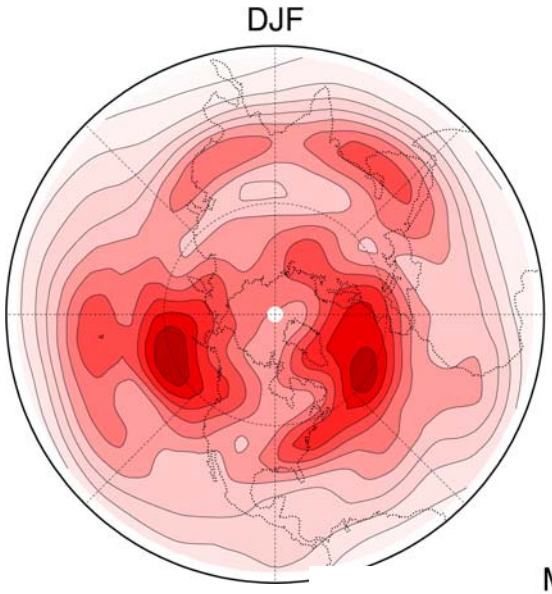


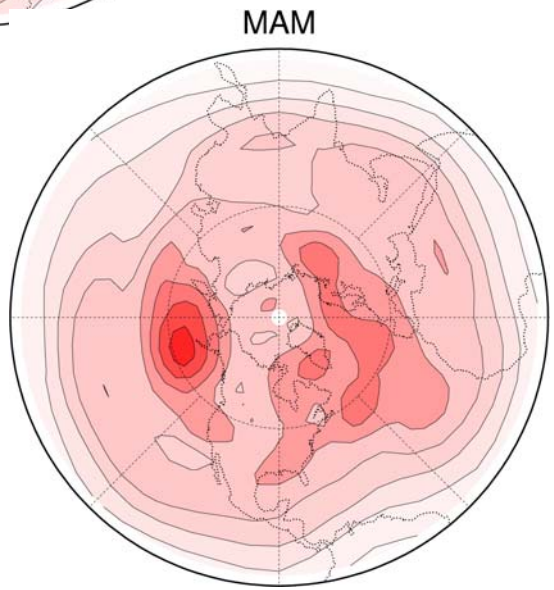
Correlations



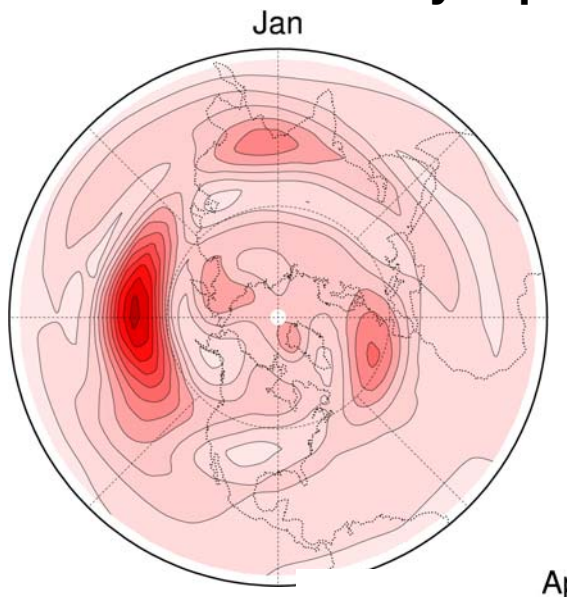
0.1

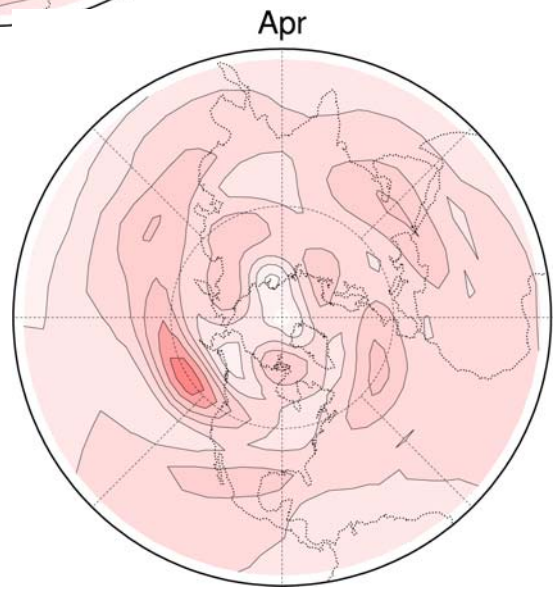
Observed Monthly mean Psi300 Variability





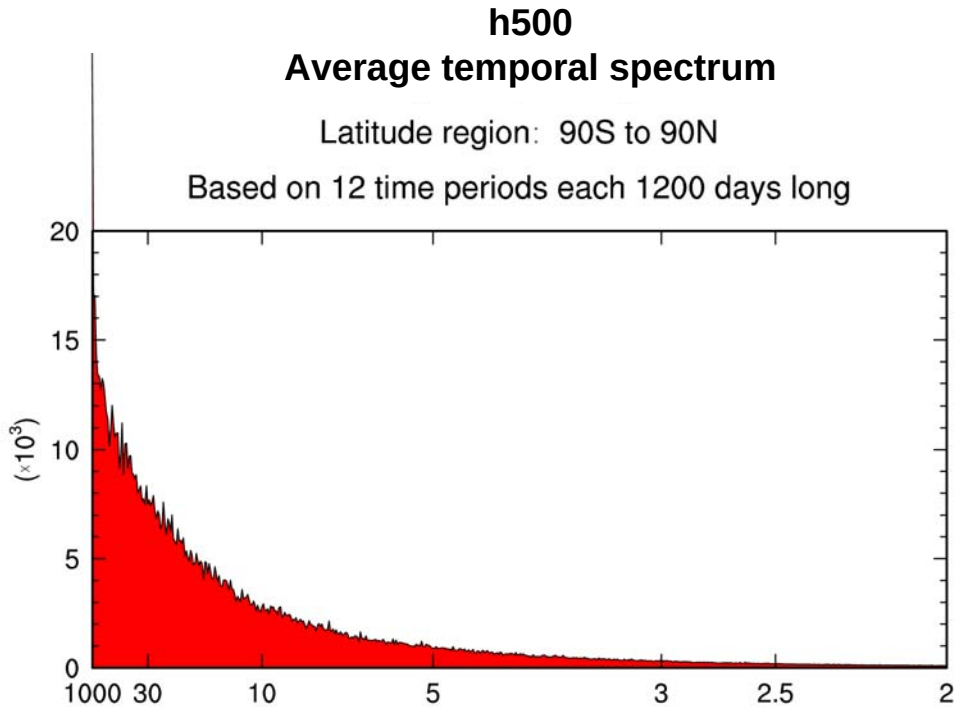
Stochastic Lin Baro Vorticity Eqn LFV



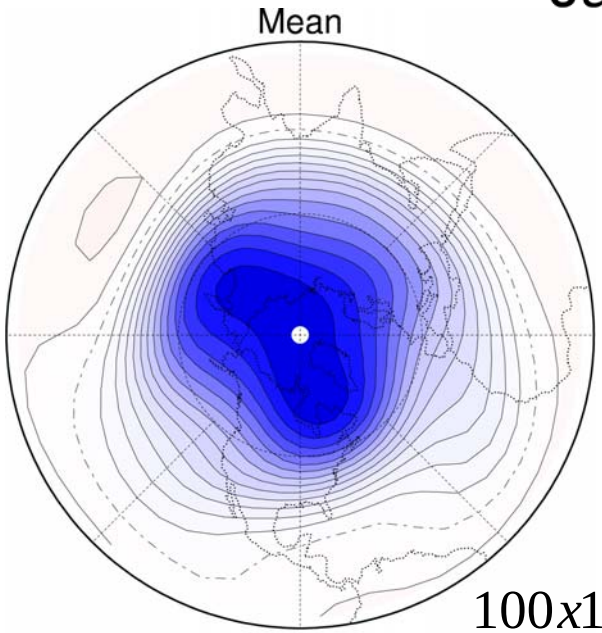


Interactions between seasonal mean and LF disturbances, and the transient eddies

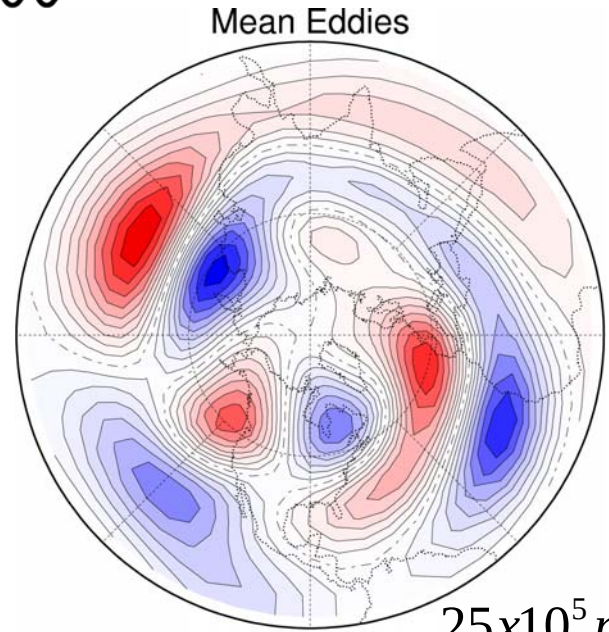
Do the transient eddies affect lower frequency fluctuations?



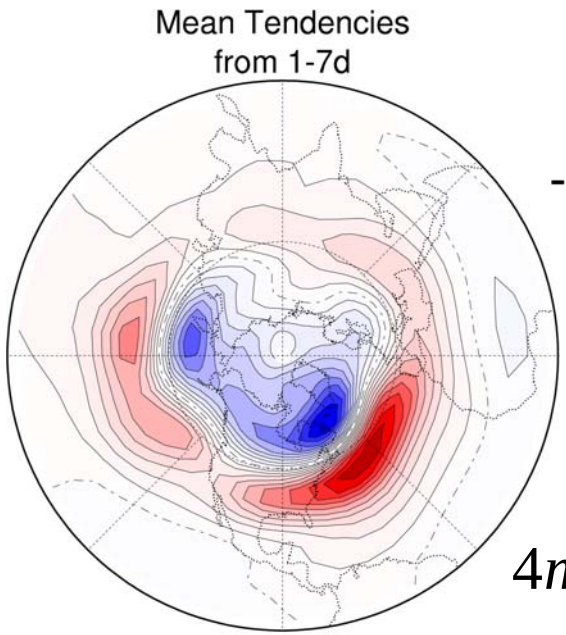
Jan Psi300



$100x10^5 m^2 s^{-1}$

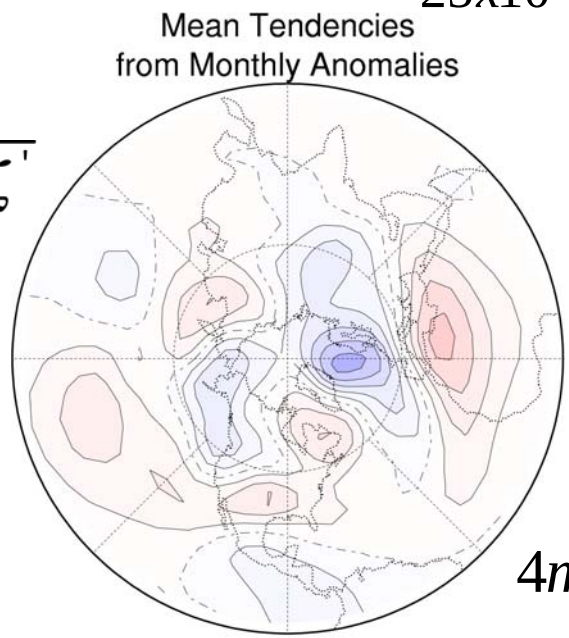


$25x10^5 m^2 s^{-1}$



$4m^2 s^{-2}$

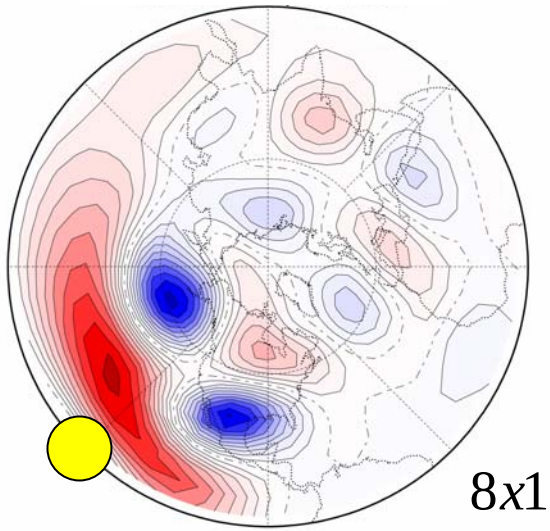
$$-\nabla^{-2}\ \overline{\mathbf{V}_\psi' \cdot \nabla \zeta'}$$



$4m^2 s^{-2}$

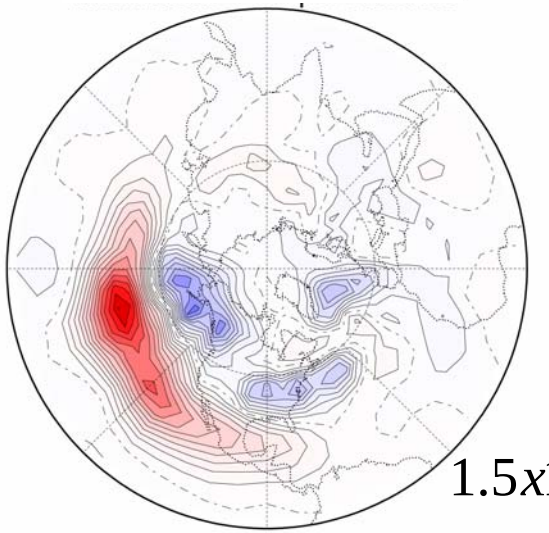
CCM3 DJF response to 135W,0N heating

Anomalous Psi300



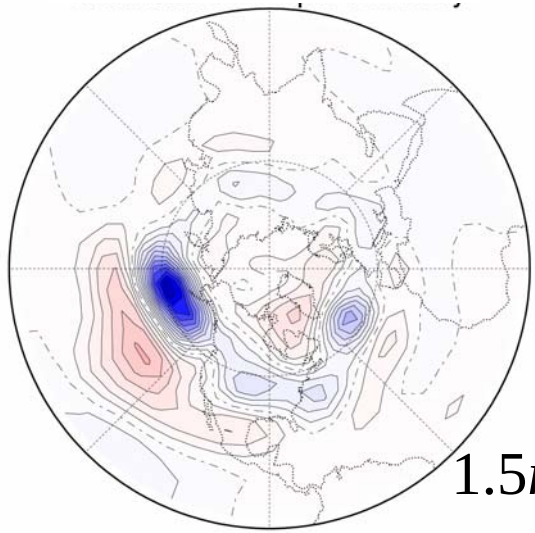
$8x10^5 m^2 s^{-1}$

Anomalous 1-7d psi300 variance



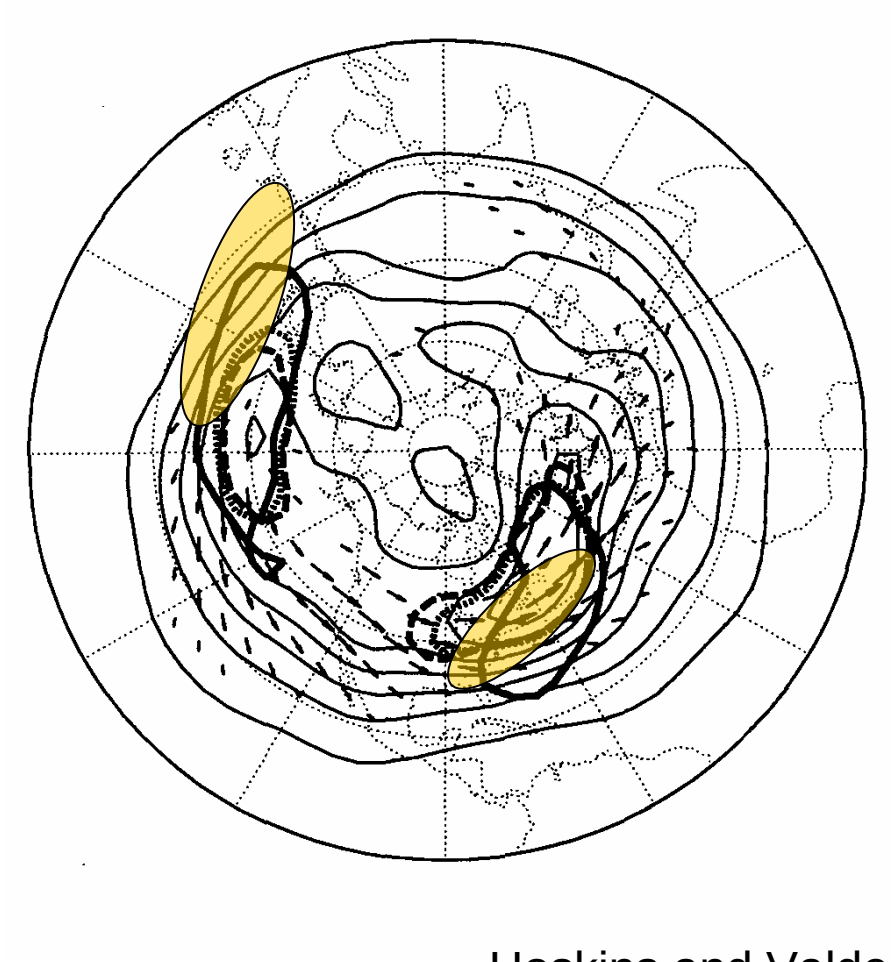
$1.5x10^{12} m^4 s^{-2}$

Anomalous $-\nabla^{-2} \overline{\mathbf{V}_\psi' \cdot \nabla \zeta'}$



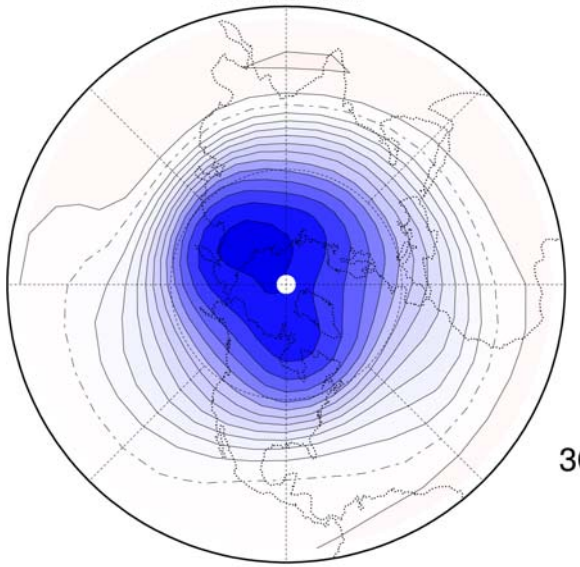
$1.5 m^2 s^{-2}$

Do the seasonal mean circulation and LF disturbances affect the transient eddies?

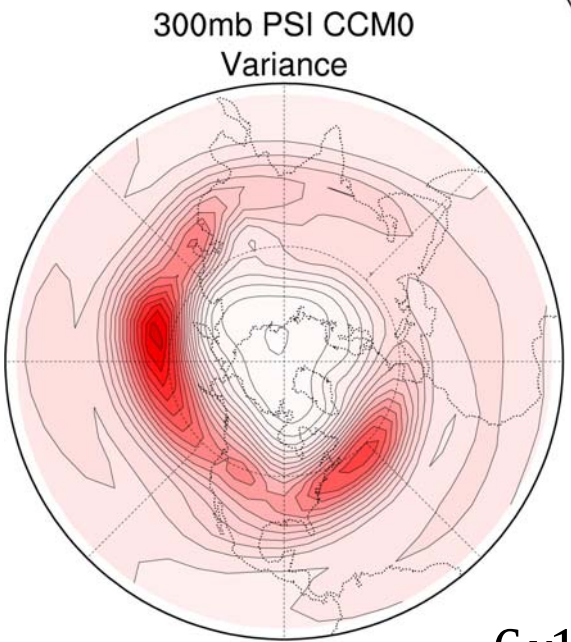


Hoskins and Valdes (1990)

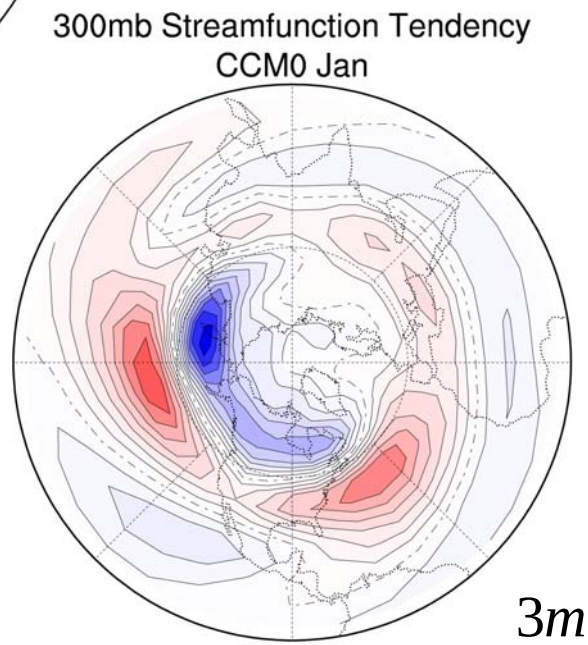
CCM0



$100x10^5 m^2 s^{-1}$

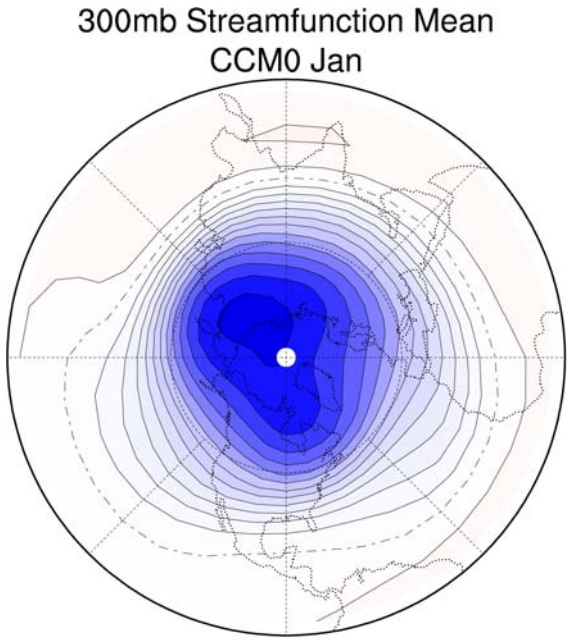


$6x10^{12} m^2 s^{-1}$



$3m^2 s^{-2}$

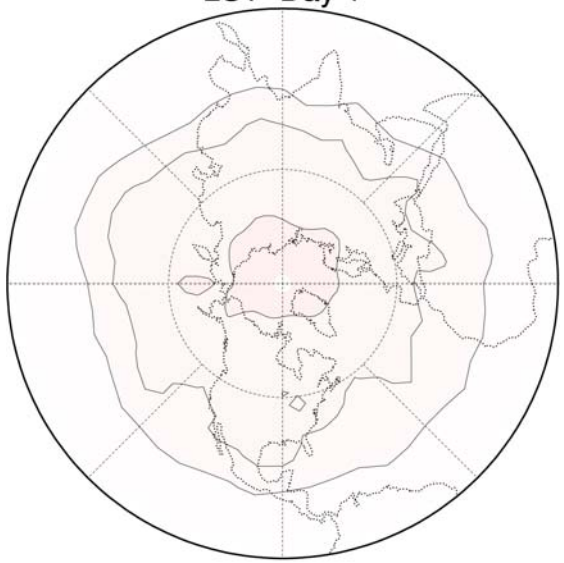
Linear Stormtrack Model



$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_\psi \cdot \nabla \varsigma' - \vec{v}'_\psi \cdot \nabla \bar{\varsigma} - (\vec{v}'_\psi \cdot \nabla \varsigma' - \overline{\vec{v}'_\psi \cdot \nabla \varsigma'}) \ldots$$

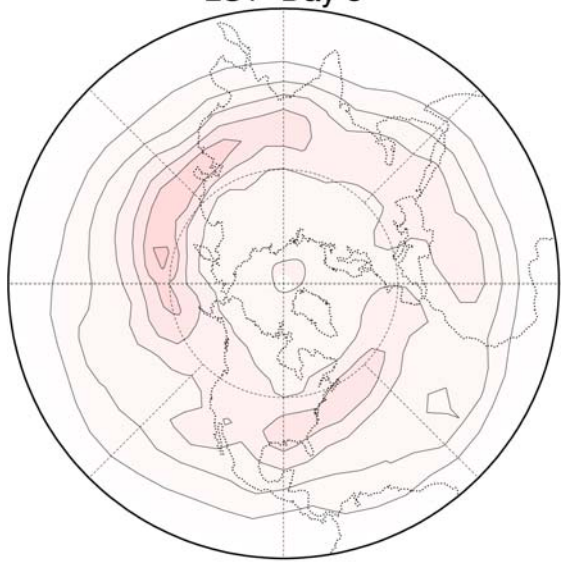
$$= -\bar{\vec{v}}_\psi \cdot \nabla \varsigma' - \vec{v}'_\psi \cdot \nabla \bar{\varsigma} + damping + noise \ldots$$

0.250 Streamfunction Variance
LST Day 1



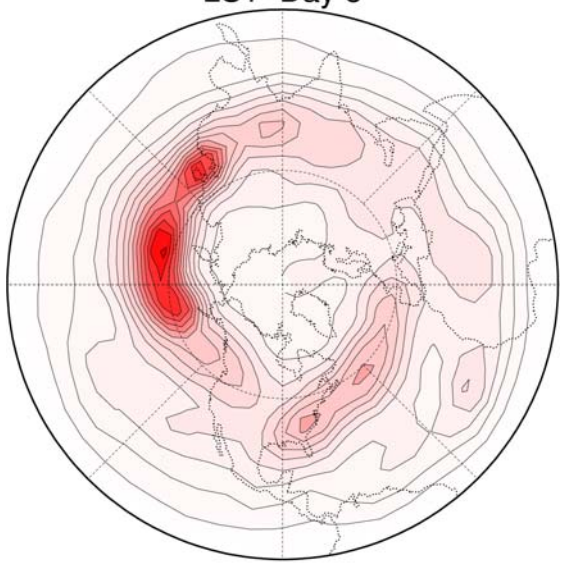
CONTOUR FROM 200 TO 600 BY 200 ($x10^{11}$)

0.250 Streamfunction Variance
LST Day 3



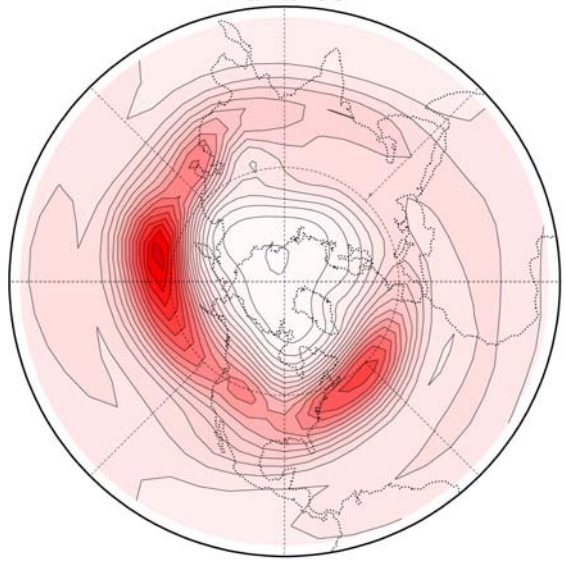
CONTOUR FROM 20 TO 120 BY 20 ($x10^{12}$)

0.250 Streamfunction Variance
LST Day 5



CONTOUR FROM 20 TO 280 BY 20 ($x10^{12}$)

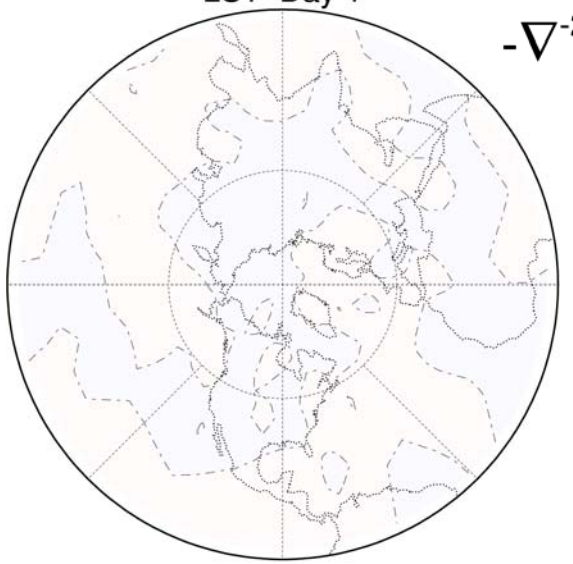
300mb PSI CCM0
Variance



CONTOUR FROM 6 TO 114 BY 6 ($x10^{12}$)

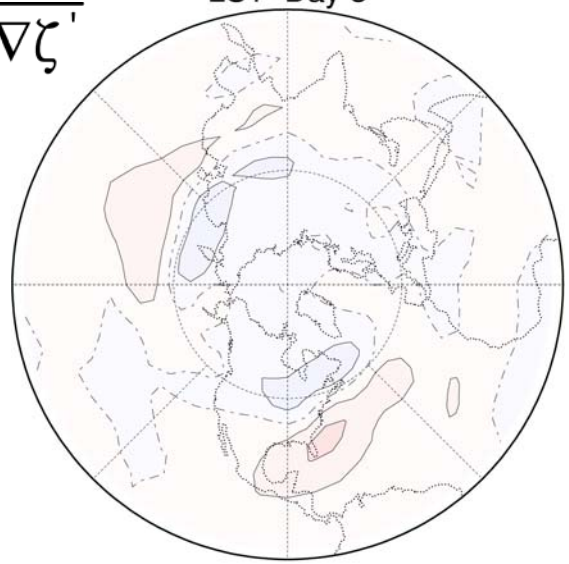
0.250 Streamfunction Tendency
LST Day 1

$$-\nabla^{-2}\,\overline{\mathbf{V}_{\psi}'\cdot\nabla\zeta'}$$



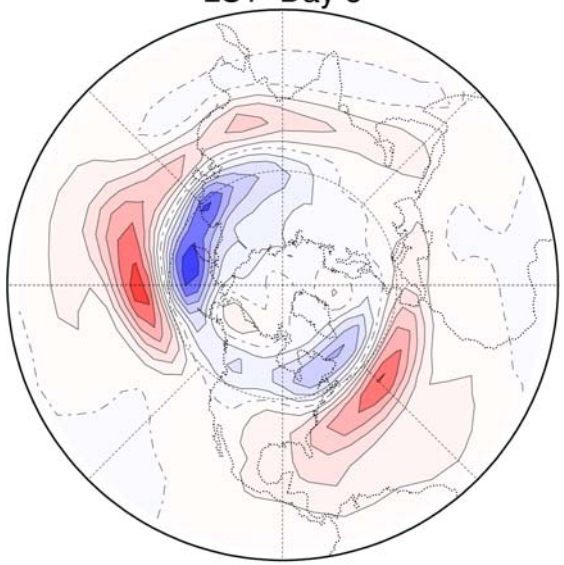
CONTOUR FROM 0 TO 100 BY 100 (x.1)

0.250 Streamfunction Tendency
LST Day 3



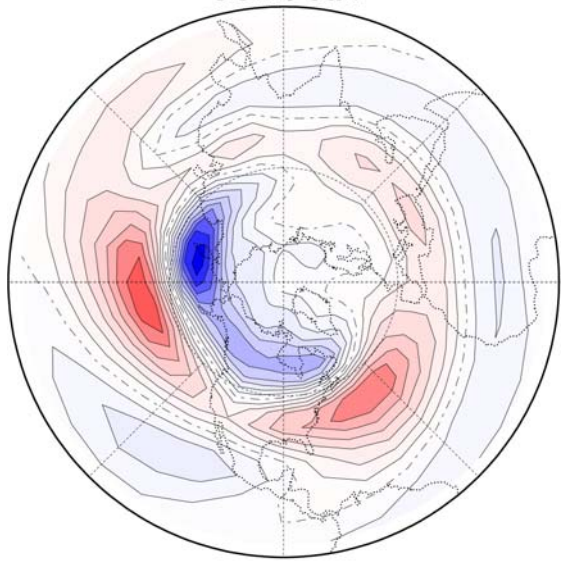
CONTOUR FROM -100 TO 200 BY 100 (x.1)

0.250 Streamfunction Tendency
LST Day 5



CONTOUR FROM -600 TO 600 BY 100 (x.1)

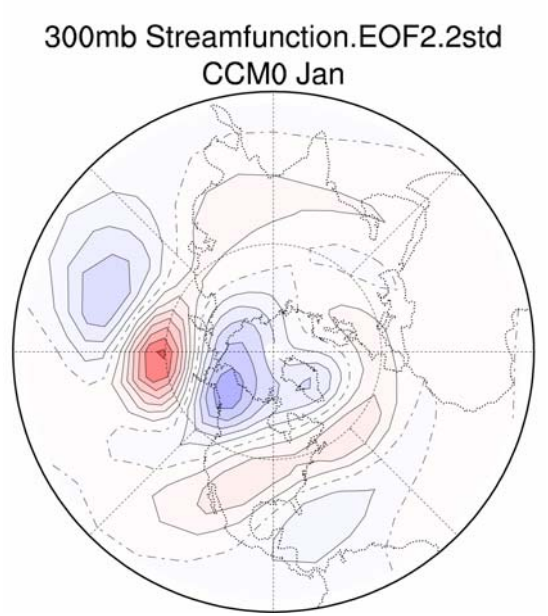
300mb Streamfunction Tendency
CCM0 Jan

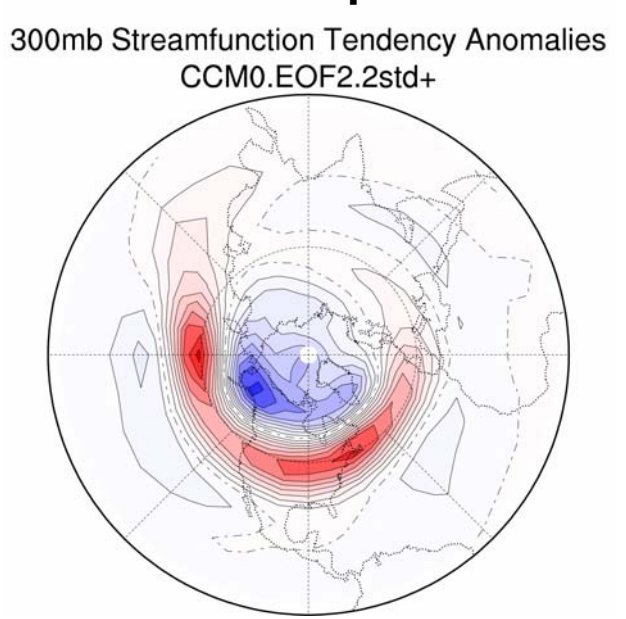


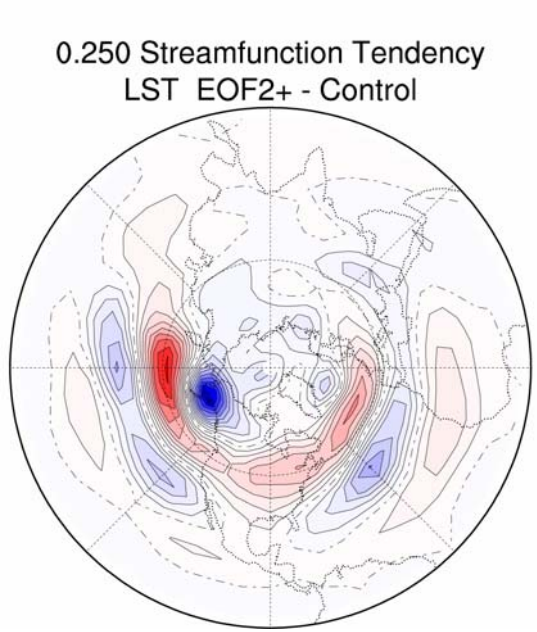
CONTOUR FROM -270 TO 210 BY 30 (x.1)

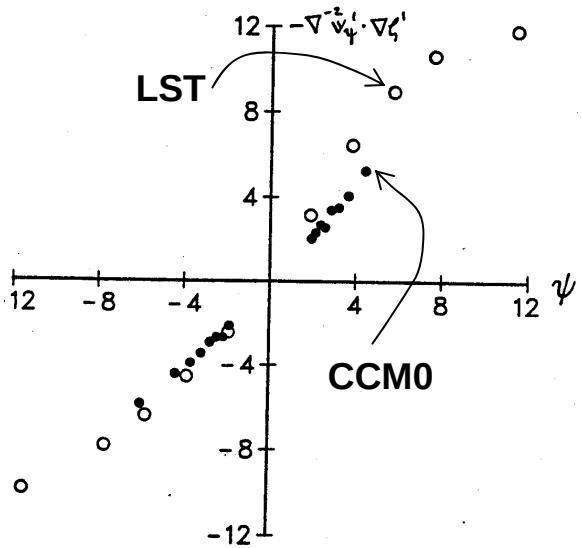
Transient eddies associated with CCM0 LF psi300EOF2

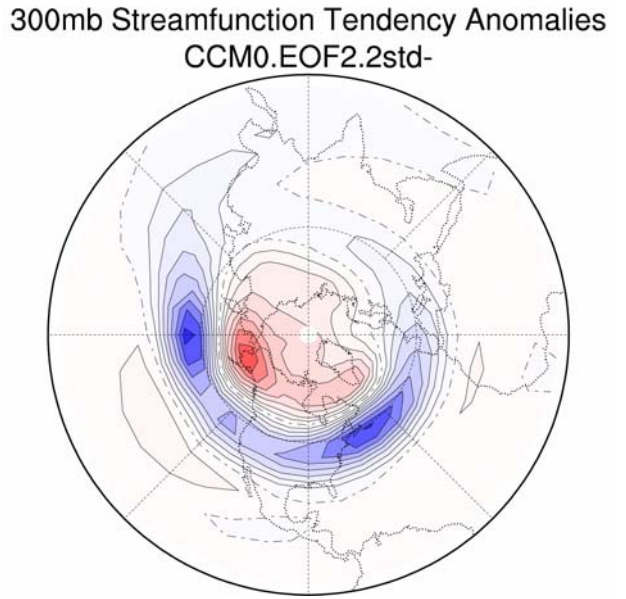
Lin Stormtk Model

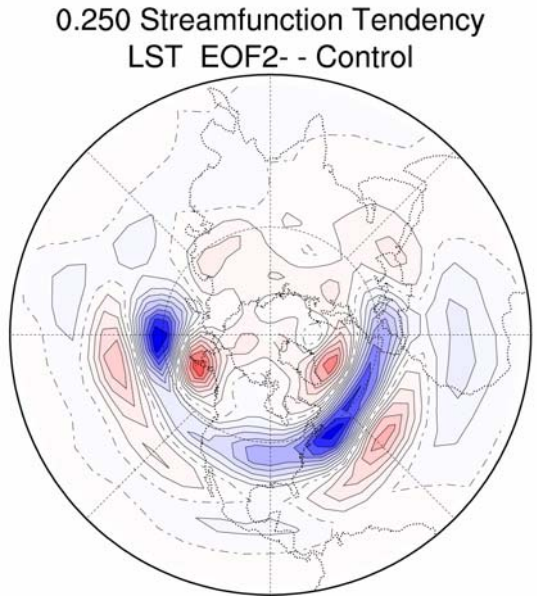












Effect of two way interaction

$$\frac{\partial \varsigma}{\partial t} = -\vec{v}_\psi \cdot \nabla(\varsigma + f) - \ldots$$

$$() = \frac{1}{T}\int_0^T ()dt + ()'$$

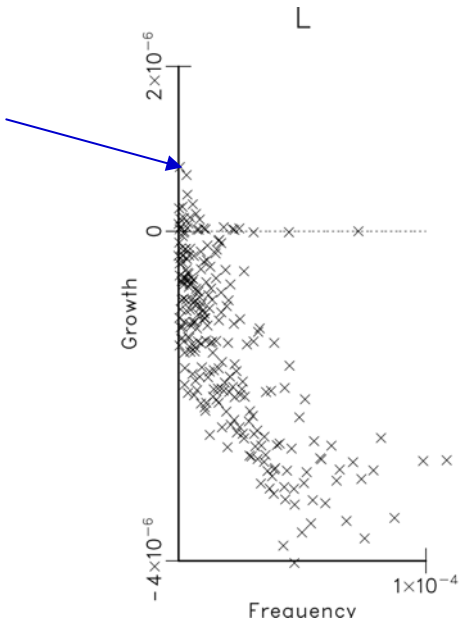
$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_\psi \cdot \nabla(\bar{\varsigma} + f) - \bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} - \vec{v}'_\psi \cdot \nabla\varsigma' \ldots$$

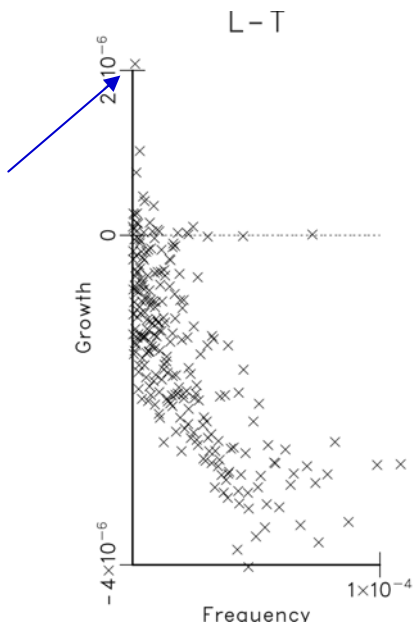
$$\bar{\vec{v}}_\psi \cdot \nabla(\bar{\varsigma} + f) = -\overline{\vec{v}'_\psi \cdot \nabla\varsigma'} + \ldots$$

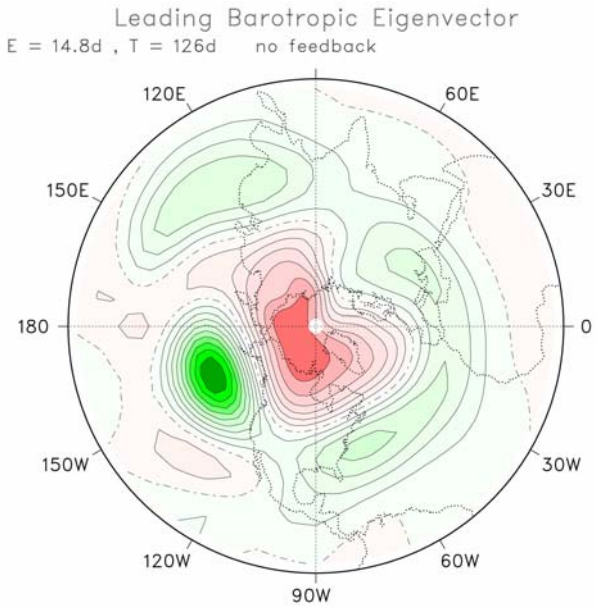
$$\frac{\partial \varsigma'}{\partial t} = -\bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} - (\vec{v}'_\psi \cdot \nabla\varsigma' - \overline{\vec{v}'_\psi \cdot \nabla\varsigma'}) \ldots$$

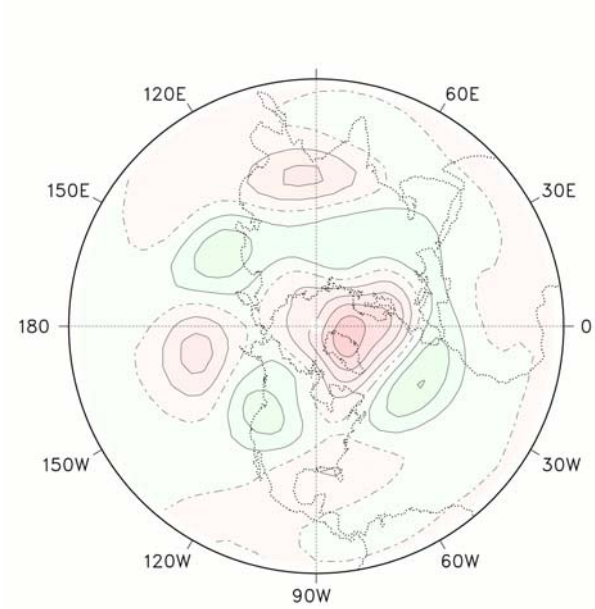
$$= -\bar{\vec{v}}_\psi \cdot \nabla\varsigma' - \vec{v}'_\psi \cdot \nabla\bar{\varsigma} + damping + noise \ldots$$

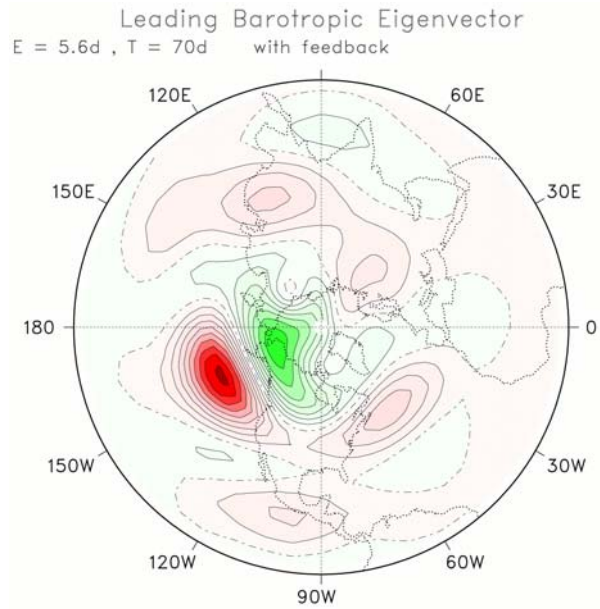
$$T\varsigma'$$

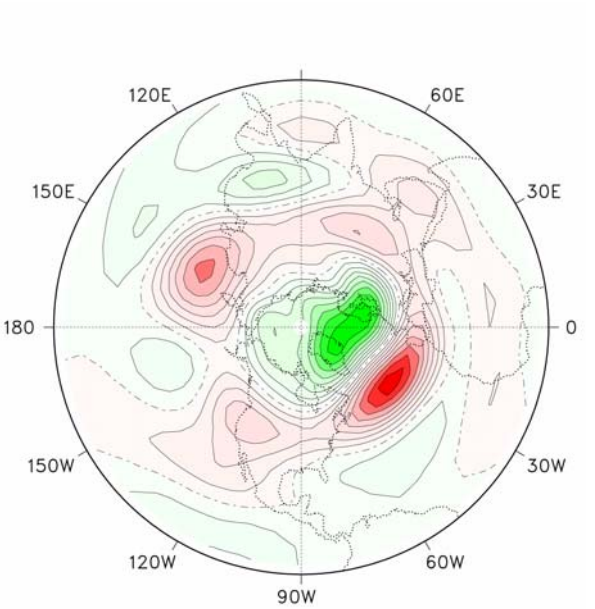

L
2×10⁻⁶
0
-4×10⁻⁶
Growth
1×10⁻⁴
Frequency


L – T
2×10⁻⁶
0
-4×10⁻⁶
Growth
1×10⁻⁴
Frequency

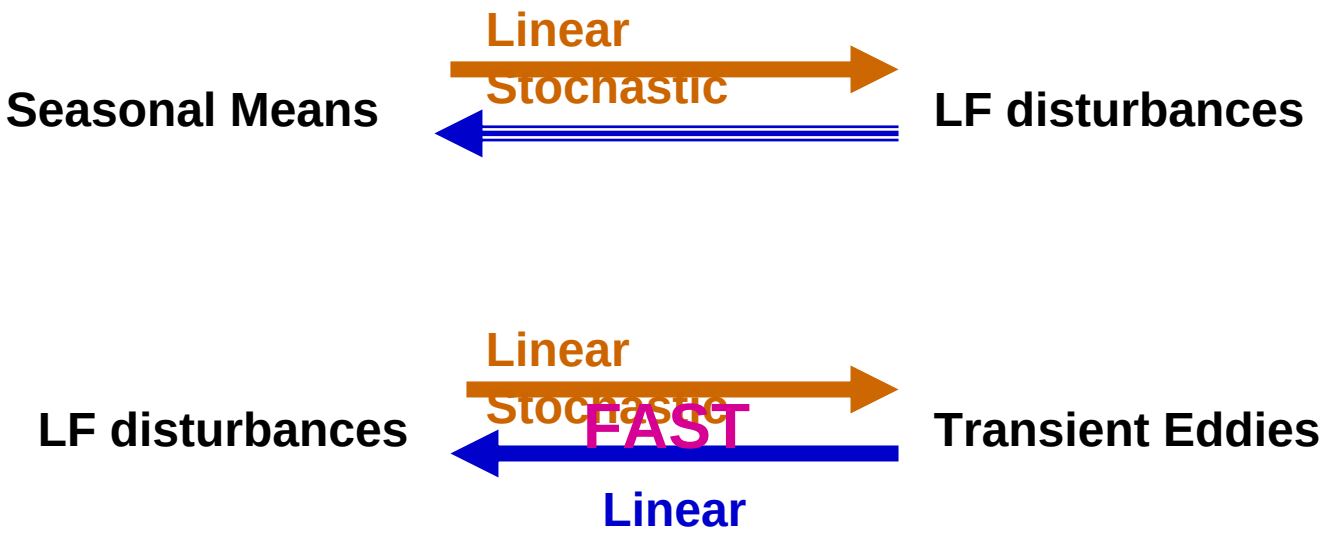

Leading Barotropic Eigenvector
E = 14.8d , T = 126d
no feedback
120E
60E
150E
30E
180
0
150W
30W
120W
60W
90W


120E
60E
150E
30E
180
0
150W
30W
120W
60W
90W


Leading Barotropic Eigenvector
E = 5.6d , T = 70d
with feedback
120E
60E
150E
30E
180
0
150W
30W
120W
60W
90W


120E
60E
150E
30E
180
0
150W
30W
120W
60W
90W

Summary


Linear
Stochastic
Seasonal Means
LF disturbances
Linear
Stochastic
FAST
LF disturbances
Transient Eddies
Linear