Periodic variability in the extratropical circulation

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The most robust forms of periodic variability in the climate system are found in association with *external* (orbital) forcing.

- Diurnal cycle; seasonal cycle; paleo timescaies

The most robust forms of quasi-periodic variability due to *internal climate dynamics* are found in the tropics.

- QBO; MJO; ENSO.

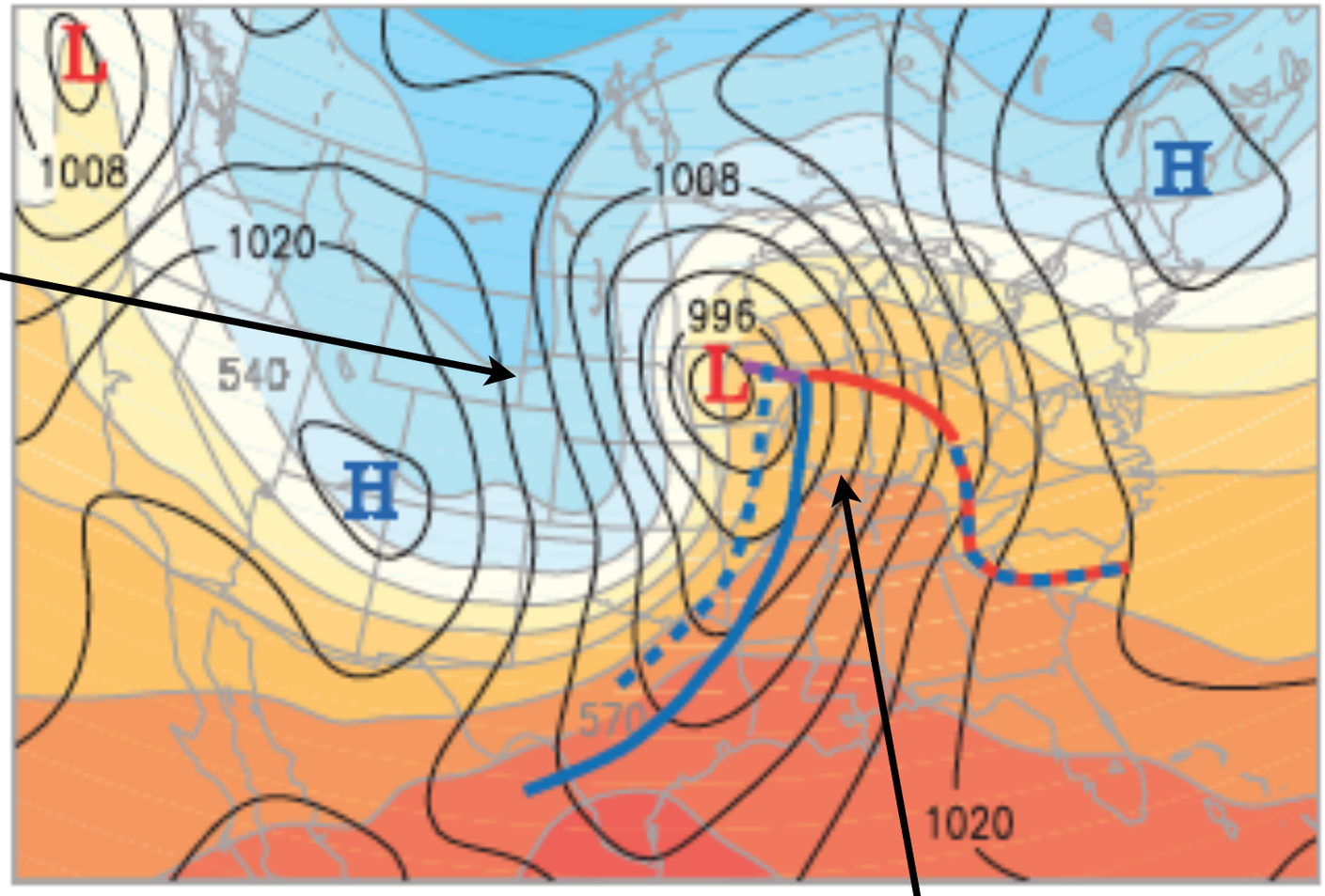
In the extratropics, periodic variability was theorized to arise in association with the index cycle during the 1940s (Rossby and Willet 1948).

But the notion of periodic variability in the index cycle was largely abandoned in the 1960s.

First.... baroclinic annular variability

Baroclinic waves are marked by poleward eddy fluxes of heat

cold air moving southward



warm air moving northward

From an energetics perspective, the eddy fluxes of heat lead to the generation of eddy kinetic energy

Zonal mean (available) potential energy

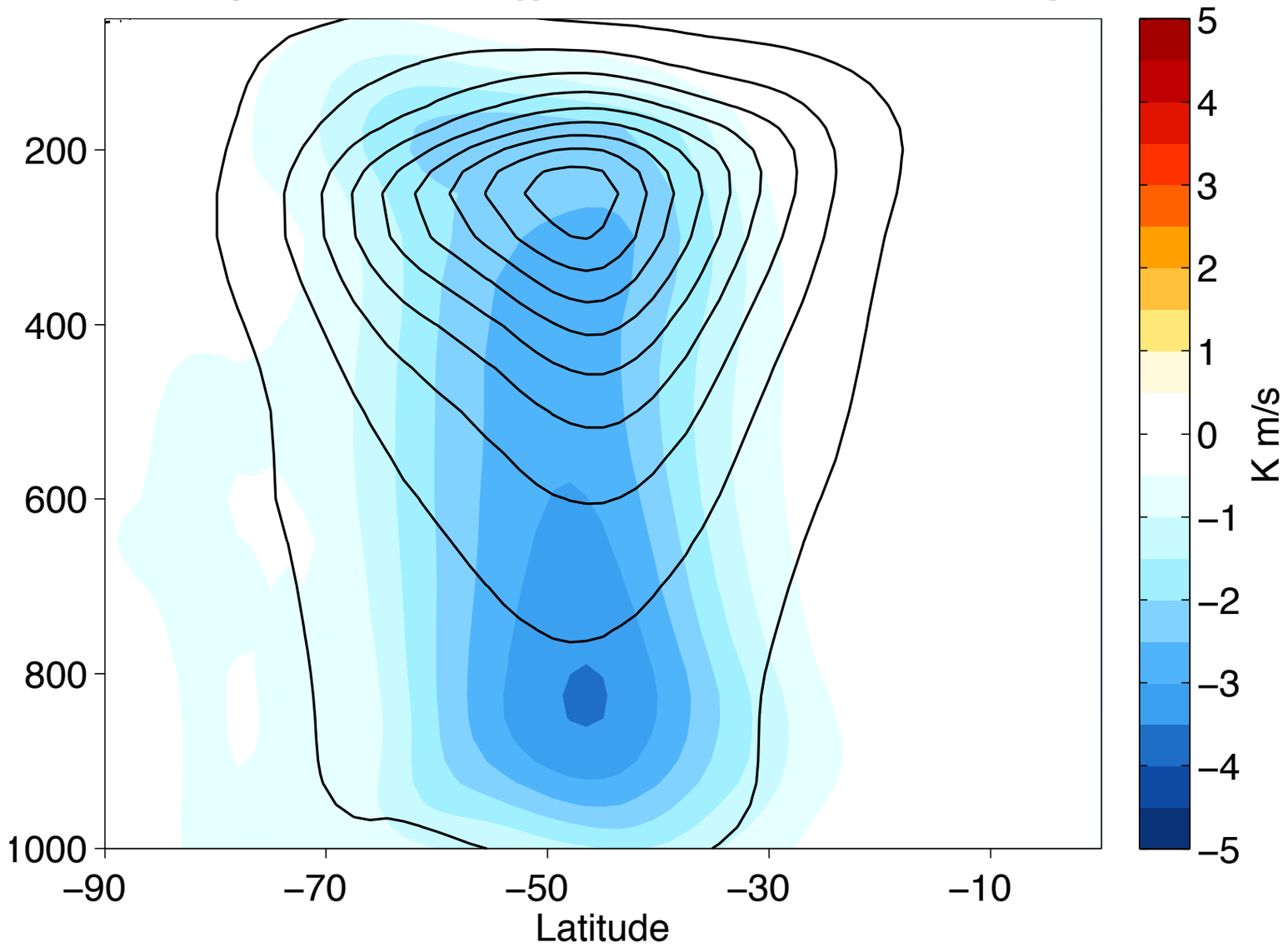
↓

Horizontal and vertical eddy fluxes of heat

↓

Eddy kinetic energy

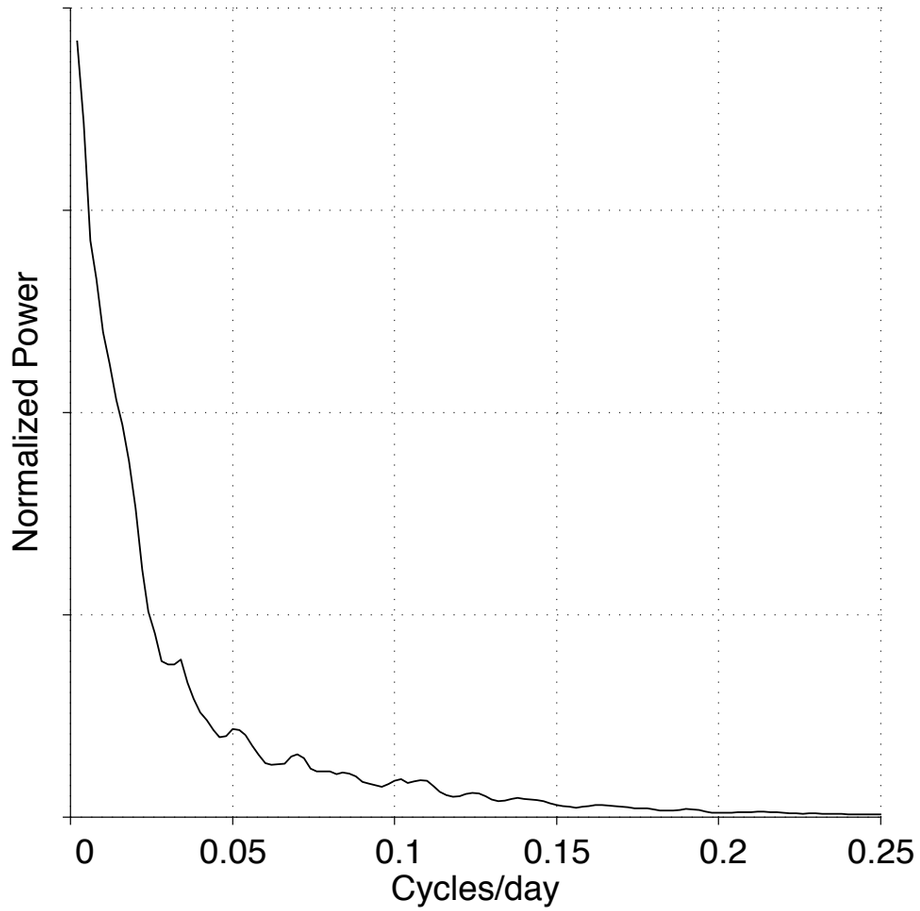
eg Lorenz 1955;Vallis 2006



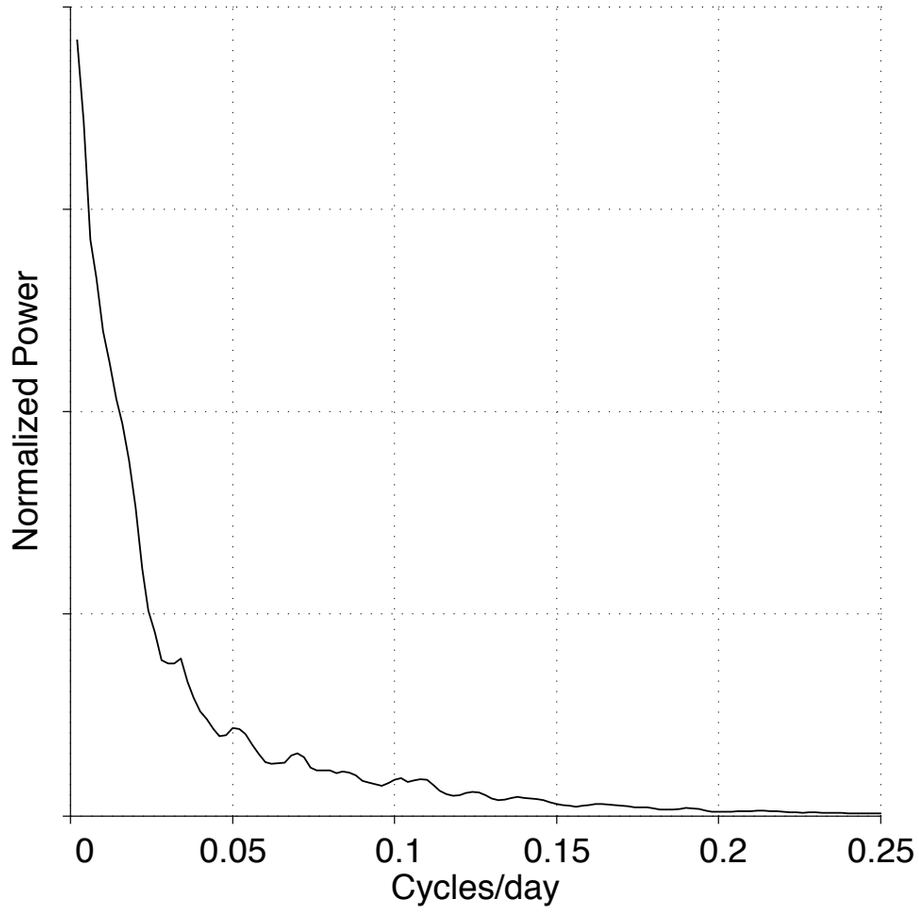
baroclinic annular mode is leading EOF of eddy kinetic energy

Results based on 6 hrly data from ERA Interim 1979-2010.

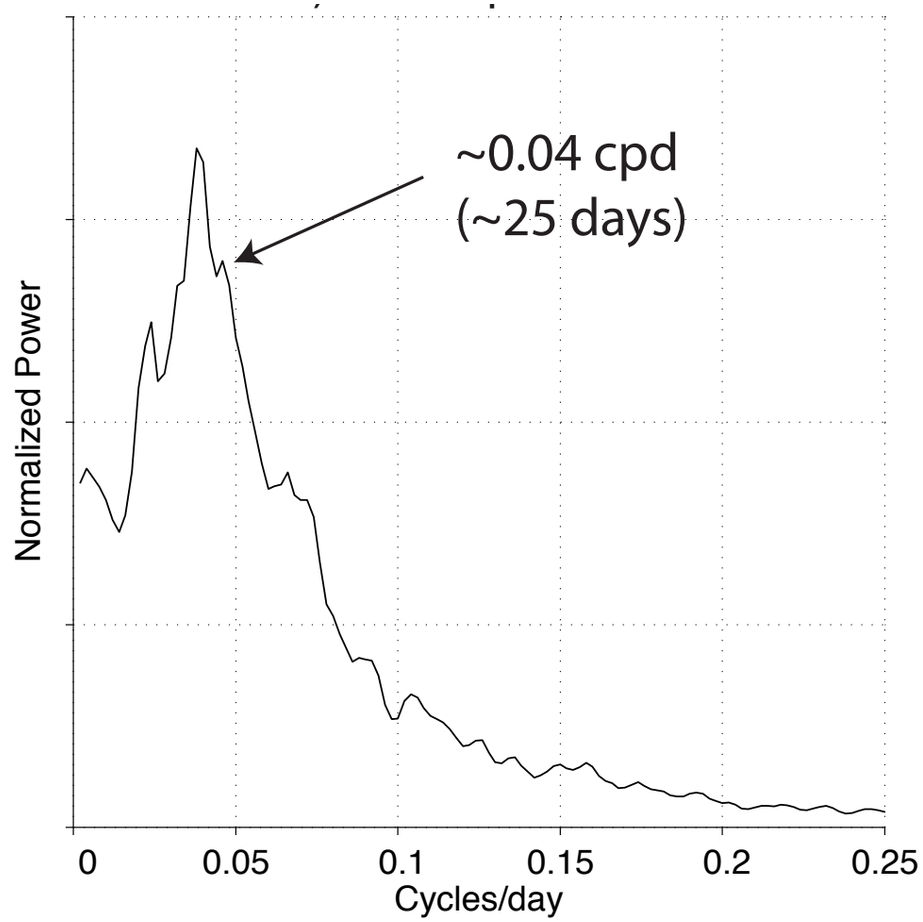
SAM spectrum



SAM spectrum

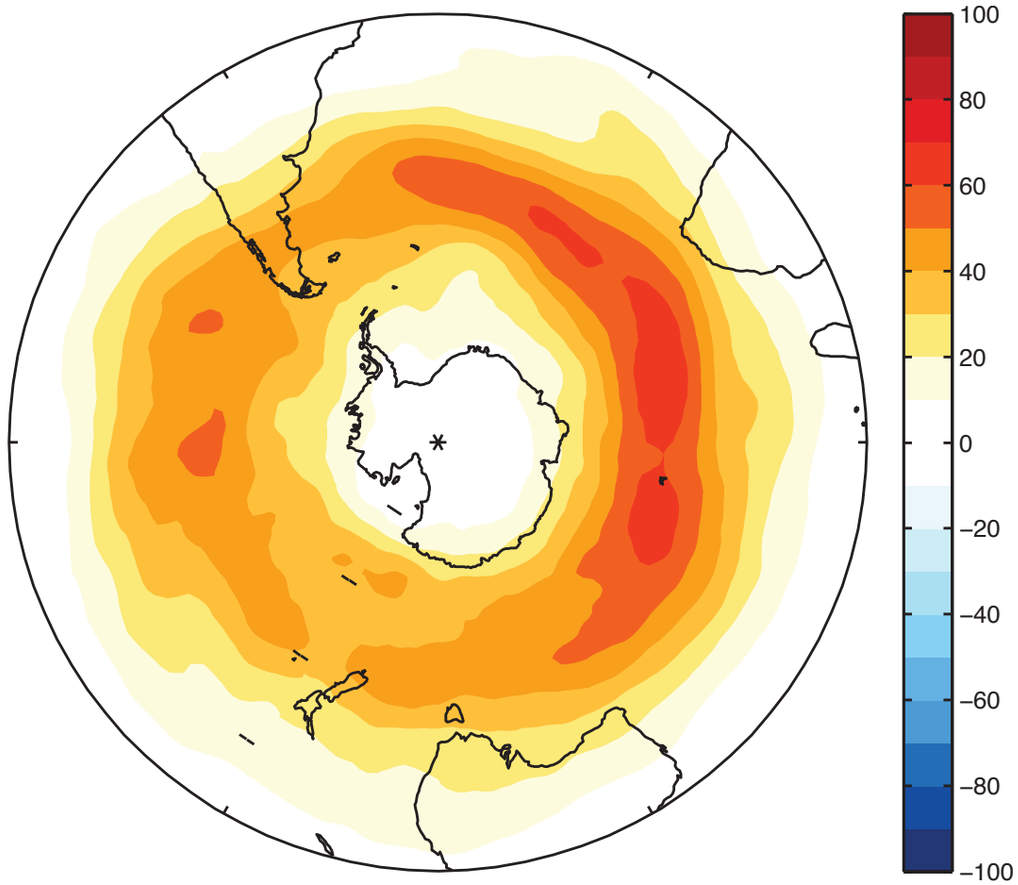


BAM spectrum

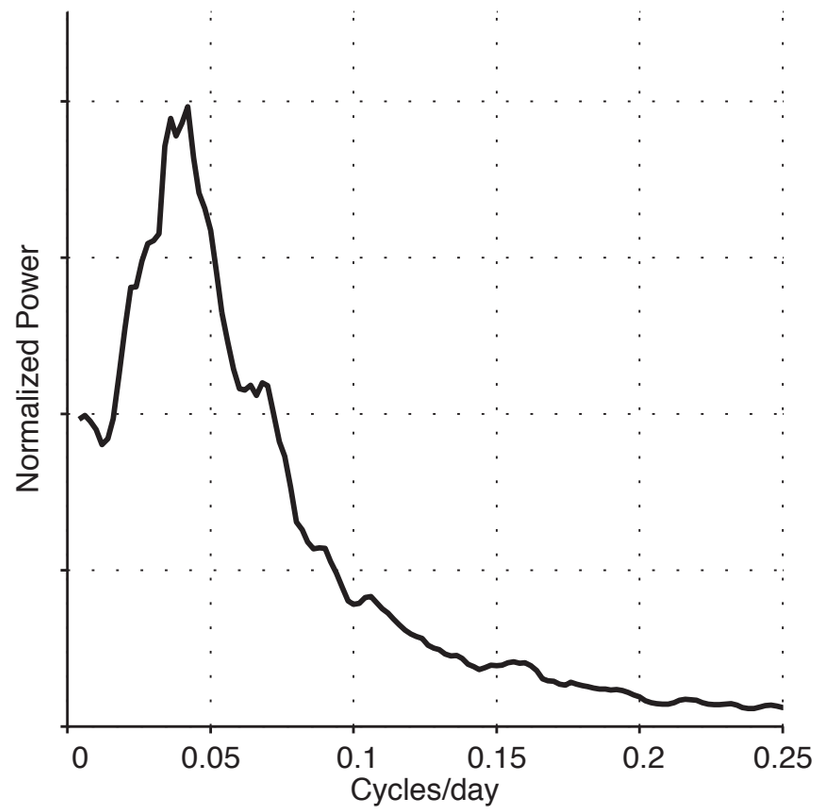


eddy kinetic energy at 300 hPa

spatial signature of BAM

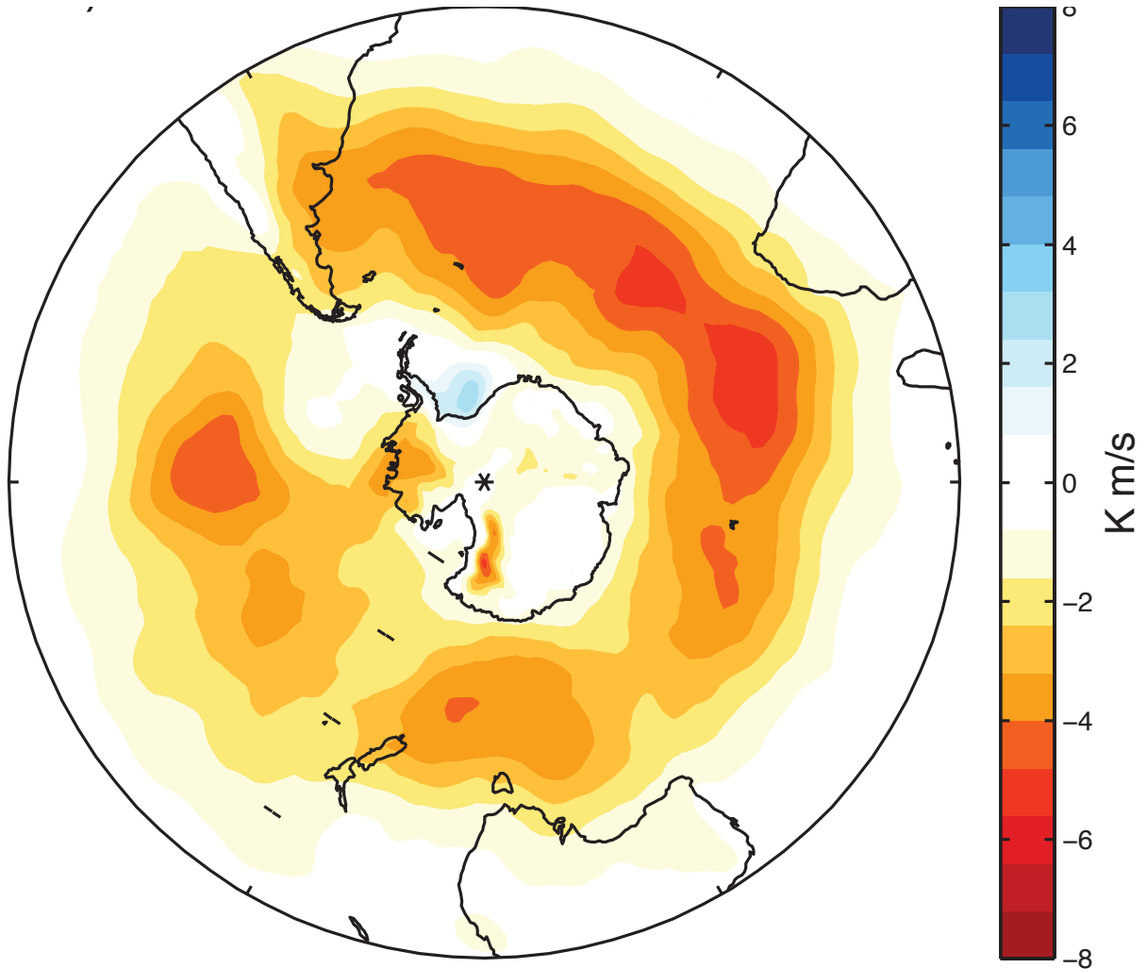


spectrum of field averaged 30-70S

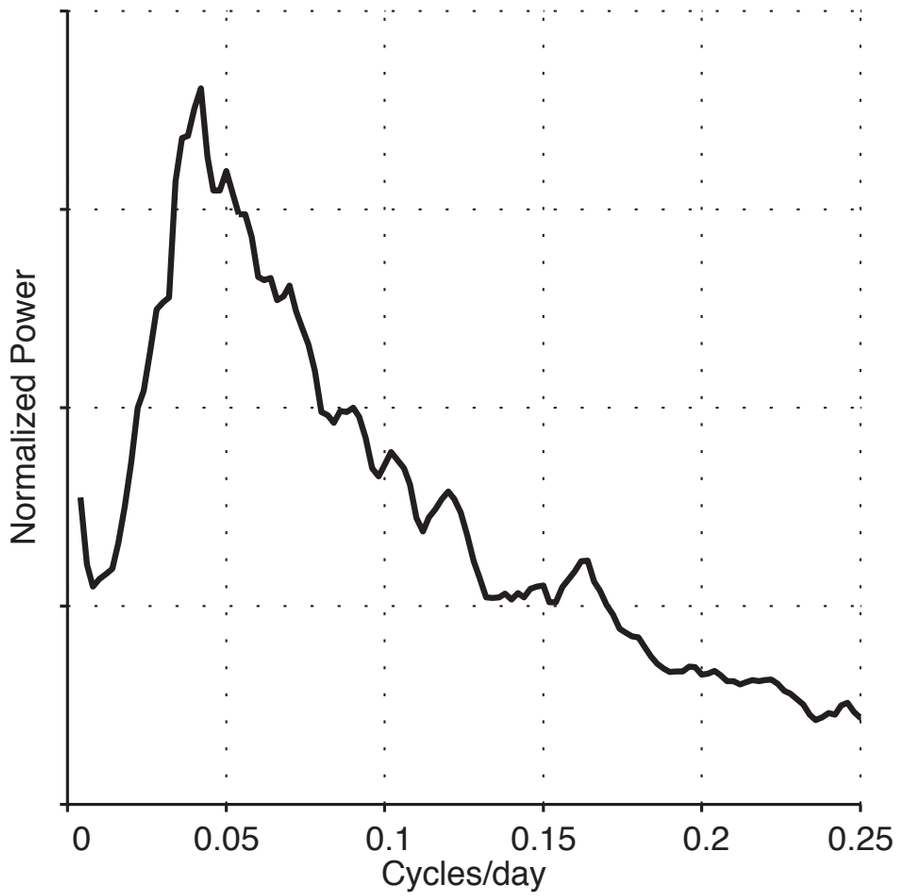


eddy heat fluxes at 850 hPa

spatial signature of BAM

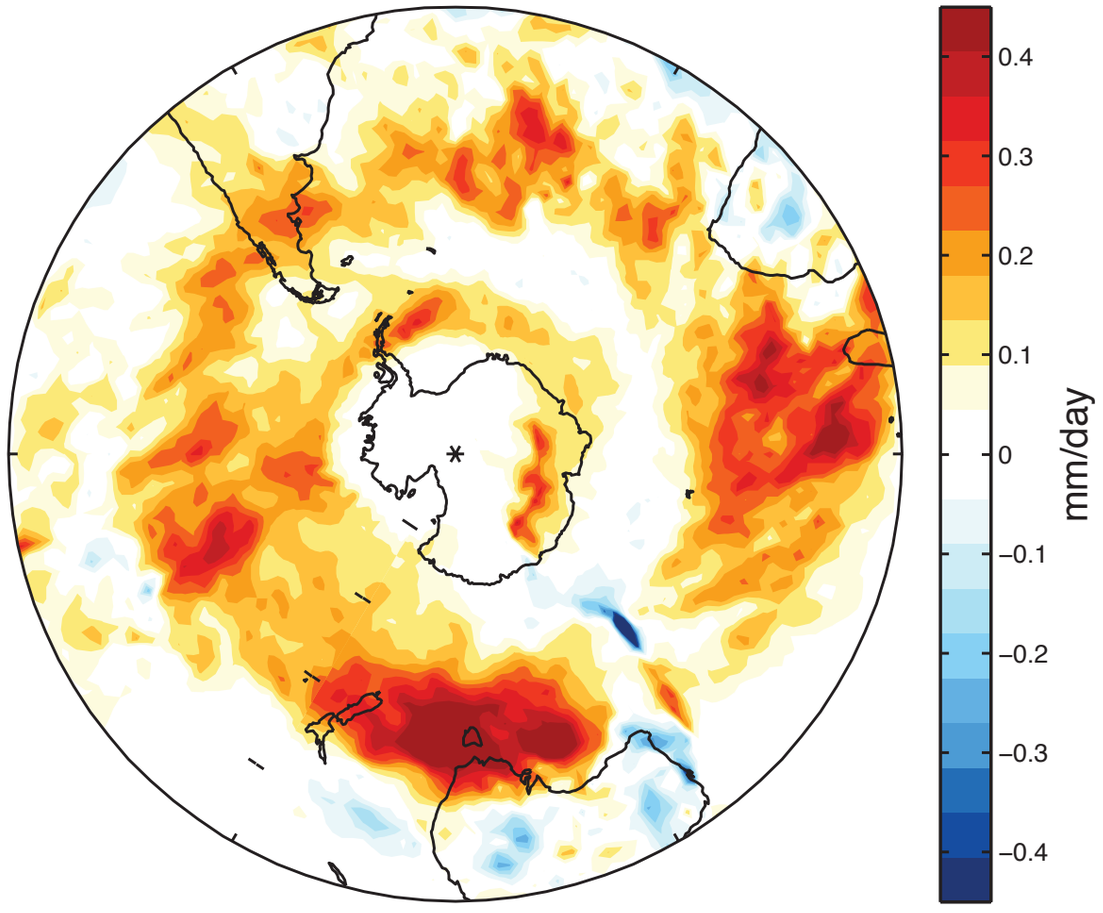


spectrum of field averaged 30-70S

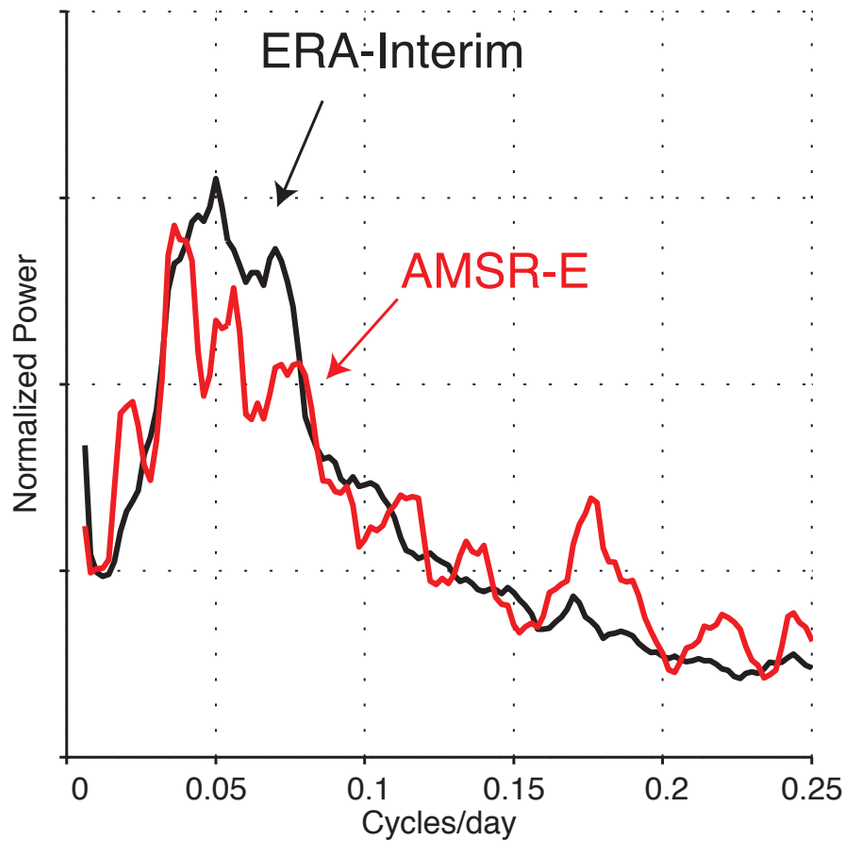


precipitation

spatial signature of BAM



spectrum of field averaged 30-70S



Mechanism for periodicity

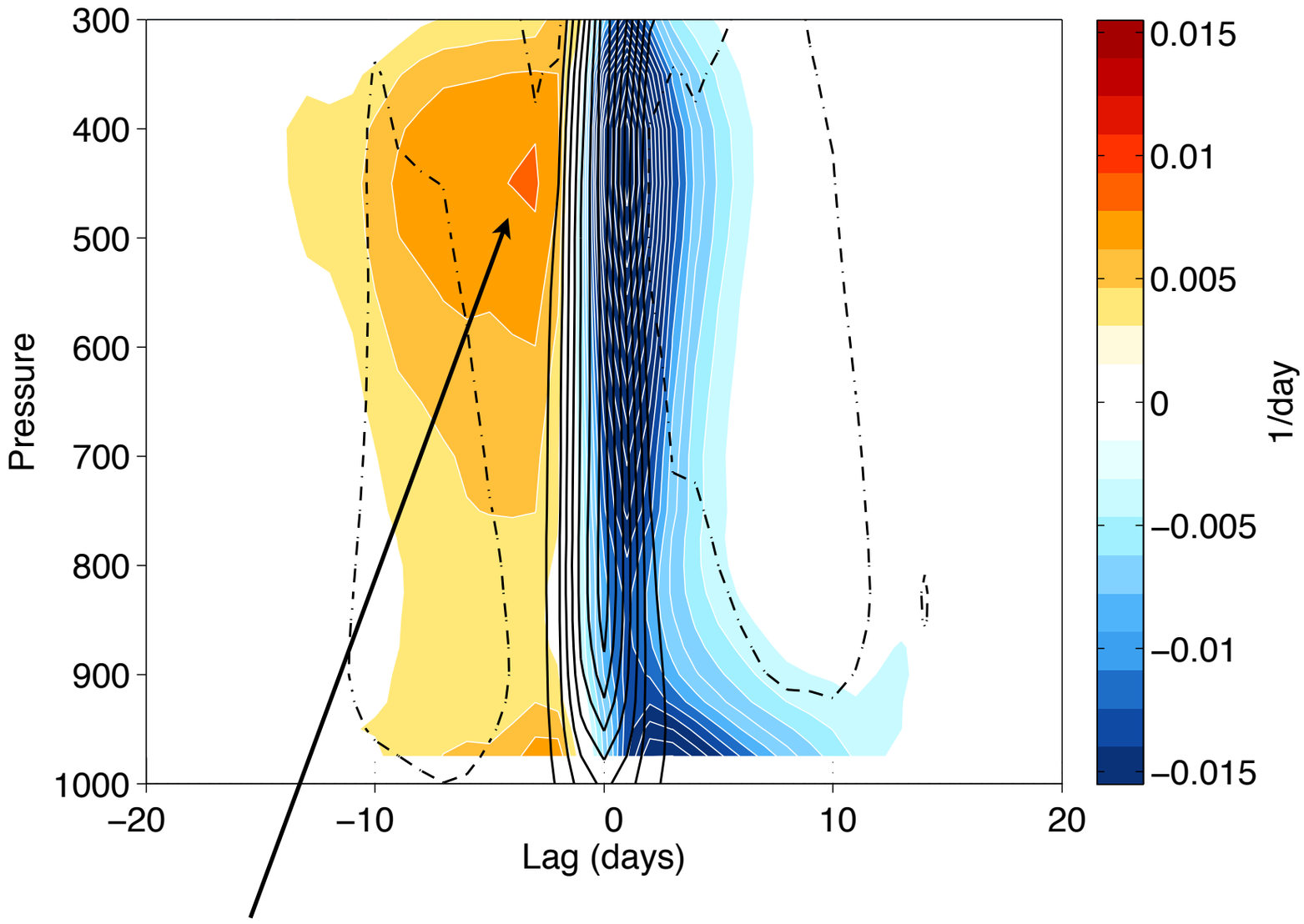
* Consistent with negative feedback between baroclinicity and the generation of baroclinic waves.

1) Increases in baroclinicity lead to increases in the generation of baroclinic waves

2) Increases in baroclinic wave activity lead to decreases in the baroclinicity

Regressions on SH mean [v*T*]

baroclinincity contours; [v*T*] contours



positive baroclinicity anomalies (warm shading) precede poleward heat fluxes (solid contours)

Simple model of oscillation:

Influence of baroclinicity on the heat fluxes

Time rate of change of eddy heat fluxes averaged over the SH baroclinic zone

Is proportional to the baroclinicity (b=dT/dy) + noise

$$\frac{\partial}{\partial t}\langle v'T' \rangle = \alpha \langle b \rangle + \varepsilon(t)$$

Simple model of oscillation:

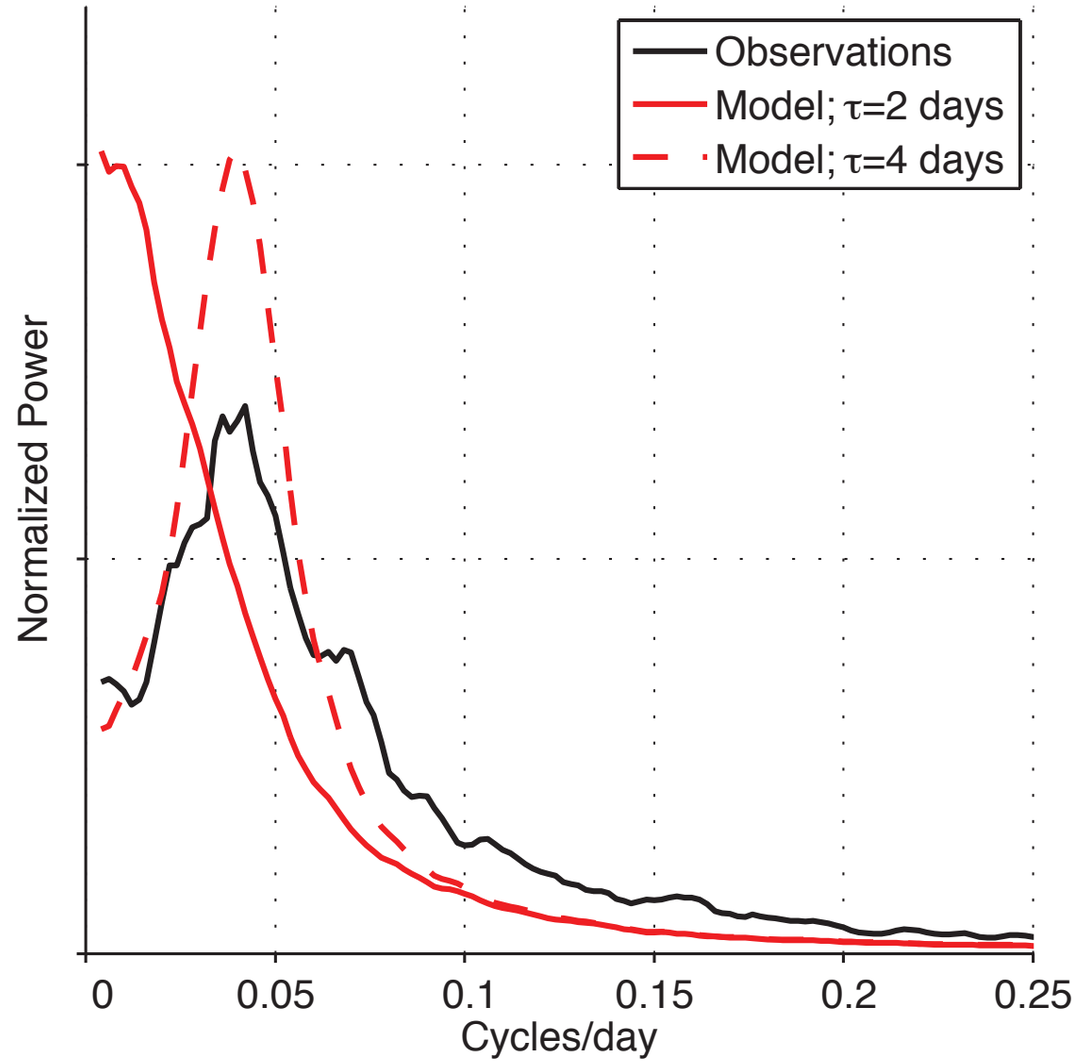
Influence of heat fluxes on the baroclinicity

Time rate of change of baroclinicity averaged over the SH baroclinic zone

Is proportional to the heat fluxes minus linear damping

$$\frac{\partial \langle b \rangle}{\partial t} = \beta \langle v'T' \rangle - \frac{\langle b \rangle}{\tau}$$

Model vs. theoretical spectra

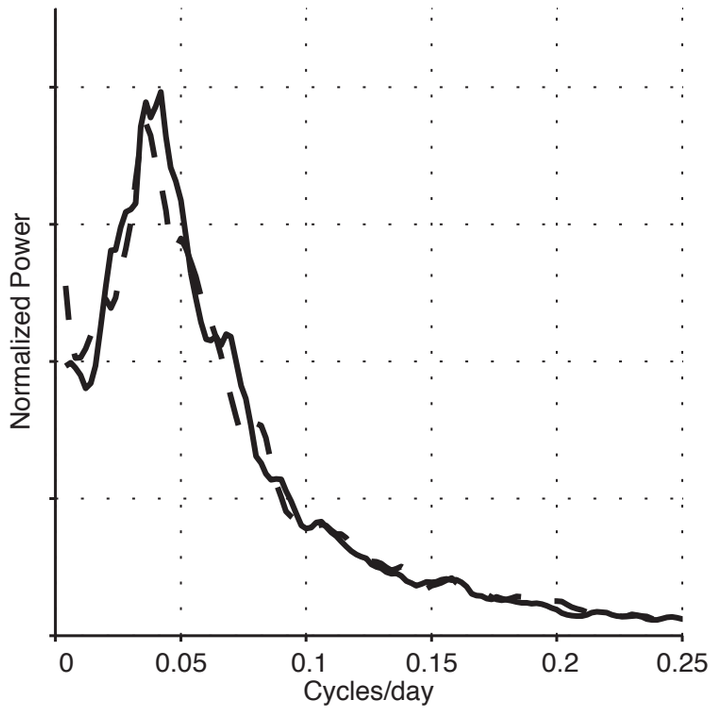


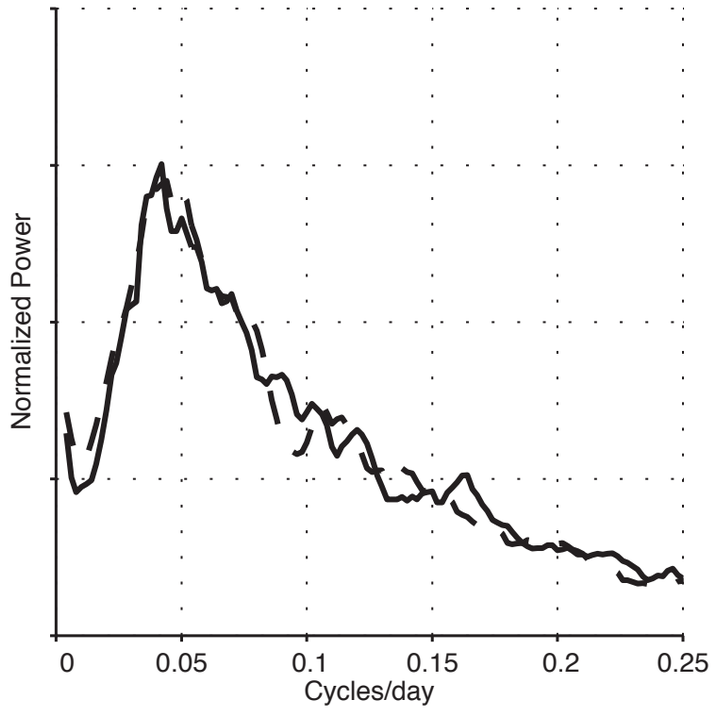
- *Frequency of oscillation increases as feedbacks increase*
- *No oscillation at short damping timescales*
- *alpha, beta, tau are found from observations*

Spectra for EKE 300

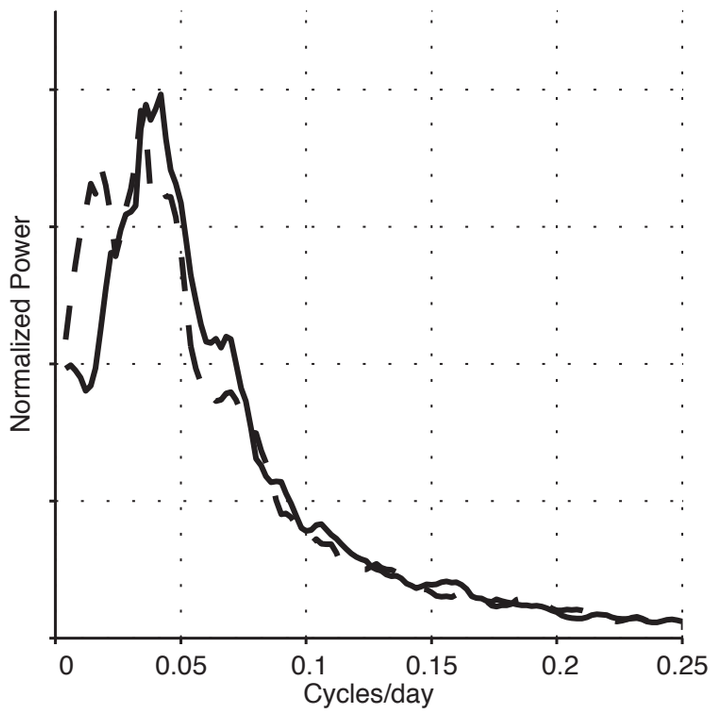
Spectra for [V*T*] 850

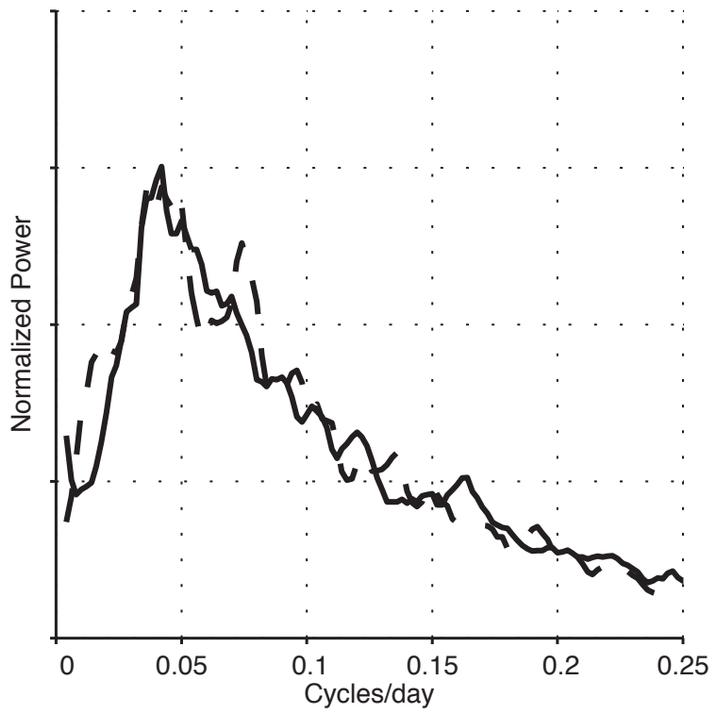
Observations (solid) and GFDL CM3 (dashed)





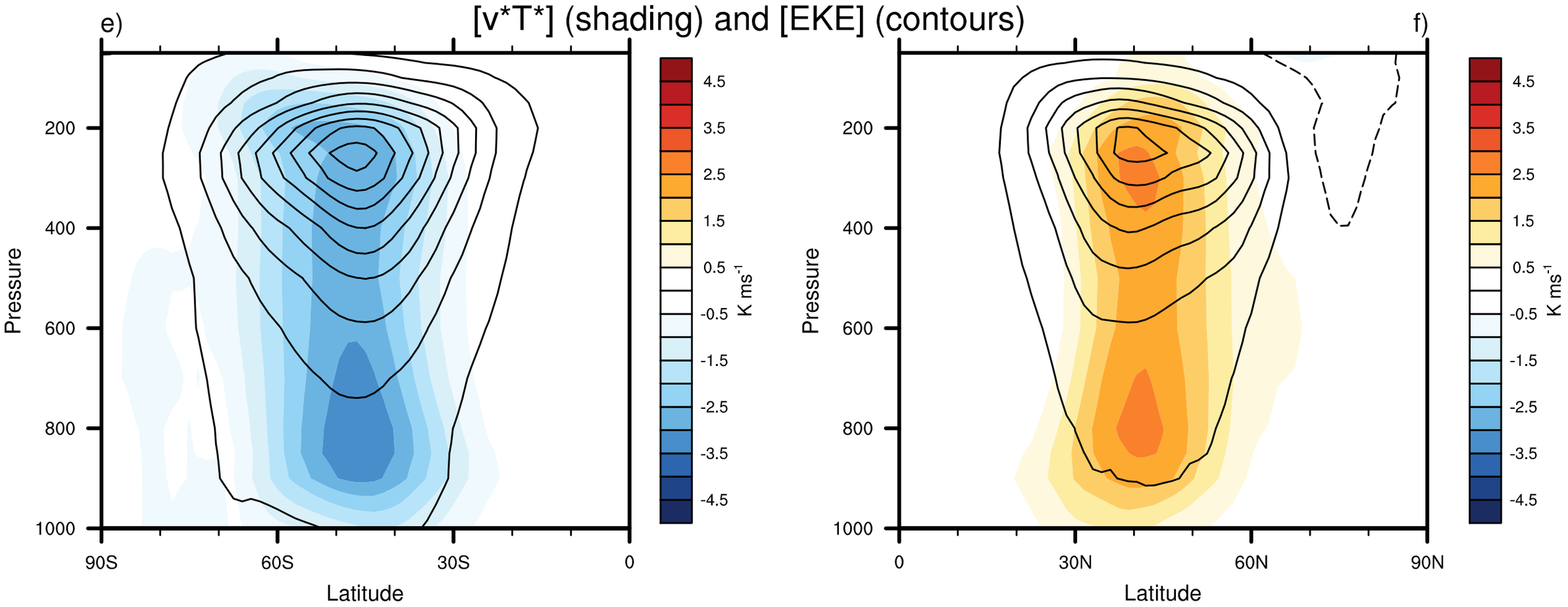
Observations (solid) and aquaplanet GCM (dashed)





SBAM

"NBAM"


[v*T*] (shading) and [EKE] (contours)
e)
f)
Pressure
200
400
600
800
1000
90S
60S
30S
0
0
30N
60N
90N
Latitude
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
-4.5
K ms-1

Variability in the zonal-mean SH circulation is characterized by two largely independent structures:

1) one that converts eddy to mean kinetic energy and dominates the zonal mean kinetic energy field (the SAM).

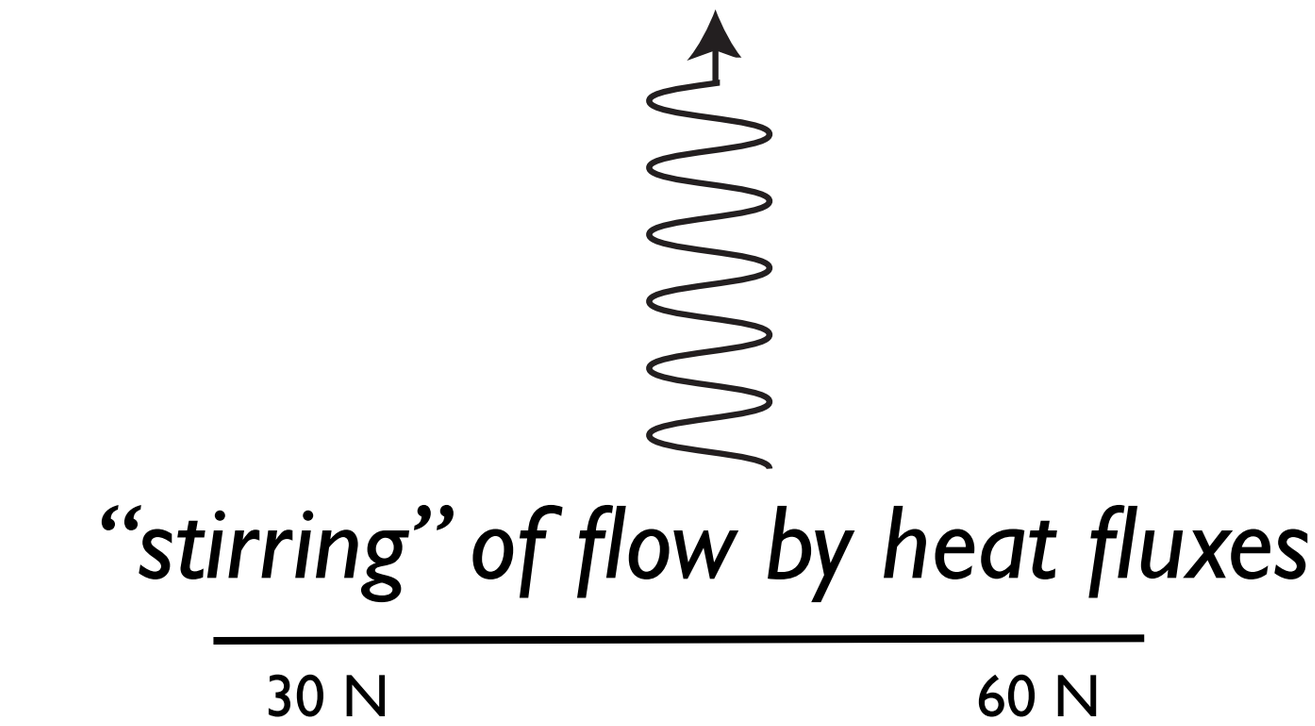
A "barotropic" annular mode. Linked to barotropic part of the flow. Red spectrum.

2) one that converts mean to eddy potential energy and dominates the eddy kinetic energy field (PC1 EKE).

A “baroclinic” annular mode. Linked to wave amplitudes.

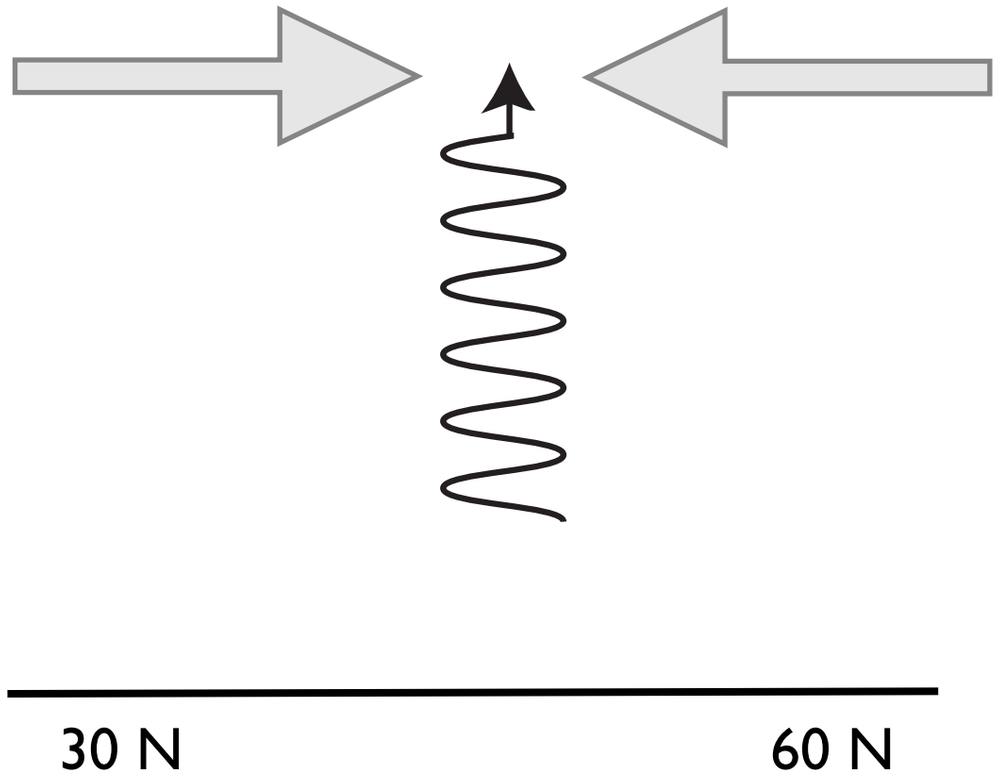
Quasi-periodic on timescales of ~20-30 days. Reminiscent of “index cycle”.

Extratropical eddies are also associated with momentum fluxes



Simmons and Hoskins 1978; Edmon et al. 1980

momentum fluxes converge in stirring region



Simmons and Hoskins 1978; Edmon et al. 1980

From an energetics perspective, the eddy fluxes of momentum convert eddy to zonal mean kinetic energy

eddy kinetic energy

↓

Horizontal eddy fluxes of momentum

↓

zonal-mean kinetic energy

eg Lorenz 1955;Vallis 2006

Prevailing view:

Patterns of large-scale variability in the extratropical circulation (e.g., the NAO; annular modes) are linked to variations in *both*:

1) the eddy fluxes of heat and eddy kinetic energy

2) the eddy fluxes of momentum and zonal-mean kinetic energy.

Results shown here suggest that:

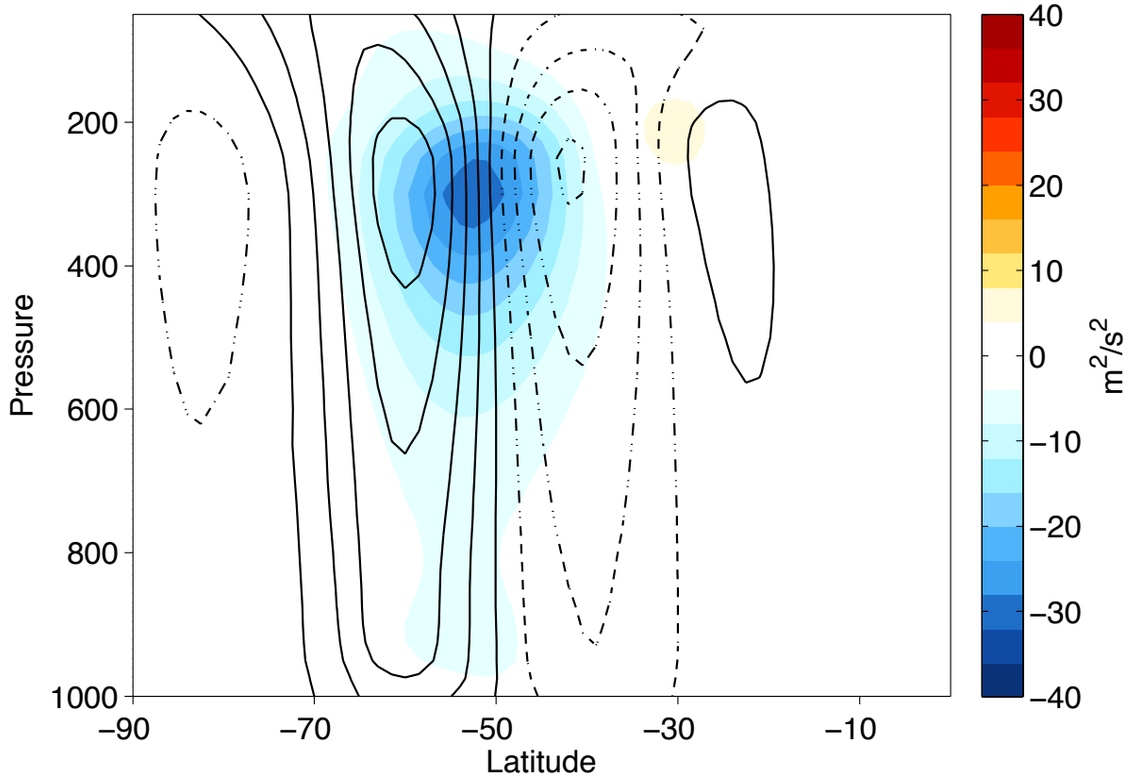
Patterns of large-scale variability in the extratropical circulation (e.g., the NAO; annular modes) are linked to variations in *either*:

1) the eddy fluxes of heat and eddy kinetic energy

2) the eddy fluxes of momentum and zonal-mean kinetic energy.

SAM

zonal wind contours; [u*v*] shading.



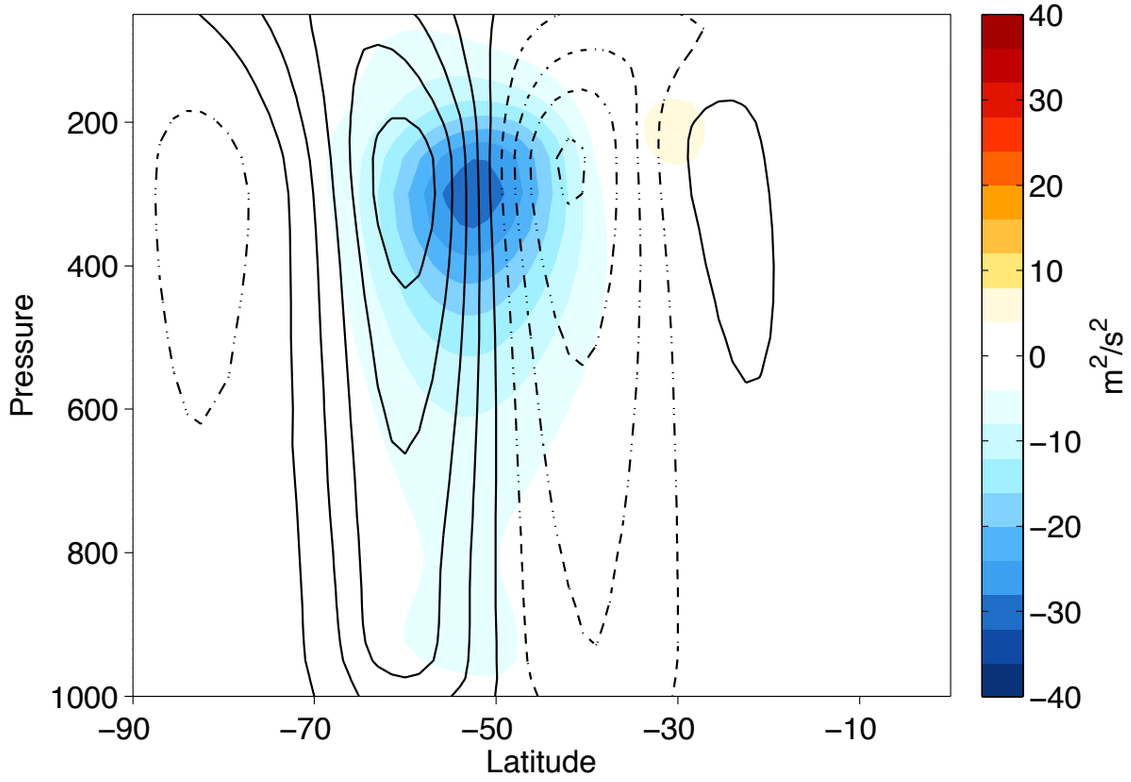
barotropic annular mode is leading
EOF of zonal-mean kinetic energy

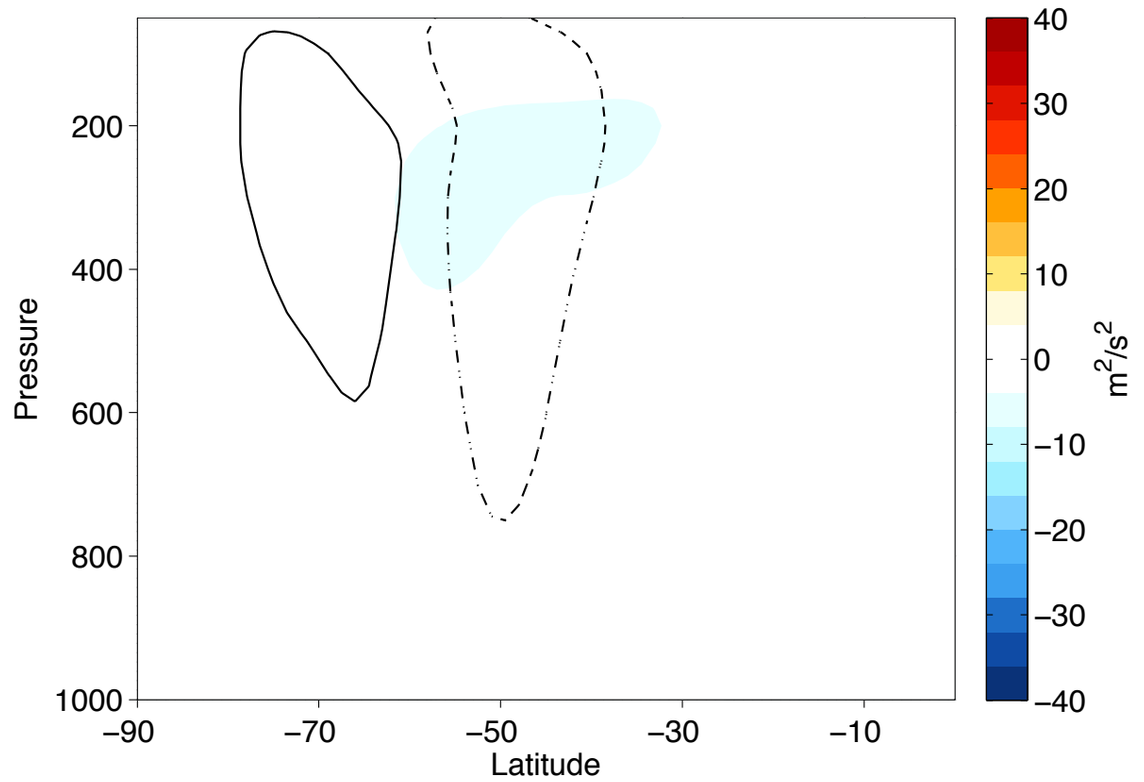
Results based on 6 hrly data from ERA Interim 1979-2010.
(As shown in dozens of papers. Early papers include those by Karoly, Kidson, Trenberth, Hartmann).

SAM

"BAM"

zonal wind contours; [u*v*] shading.

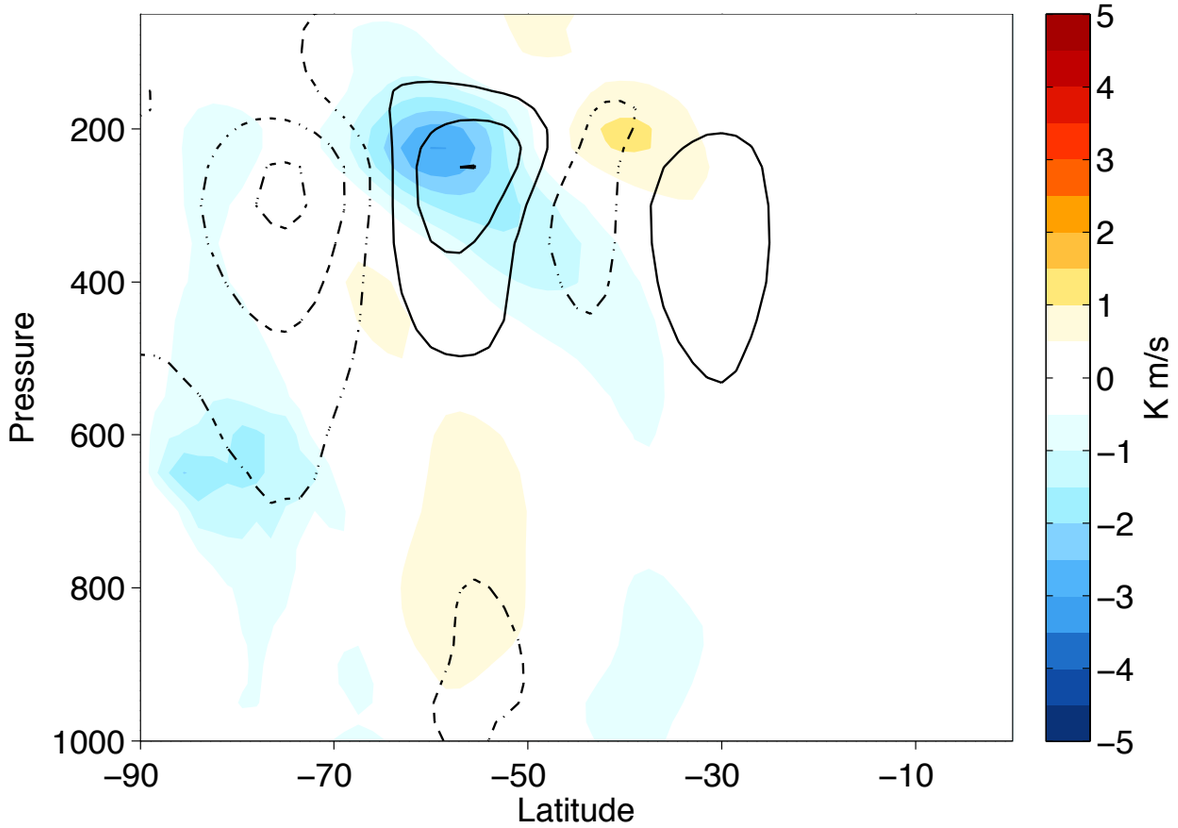




baroclinic annular mode is leading EOF of eddy kinetic energy

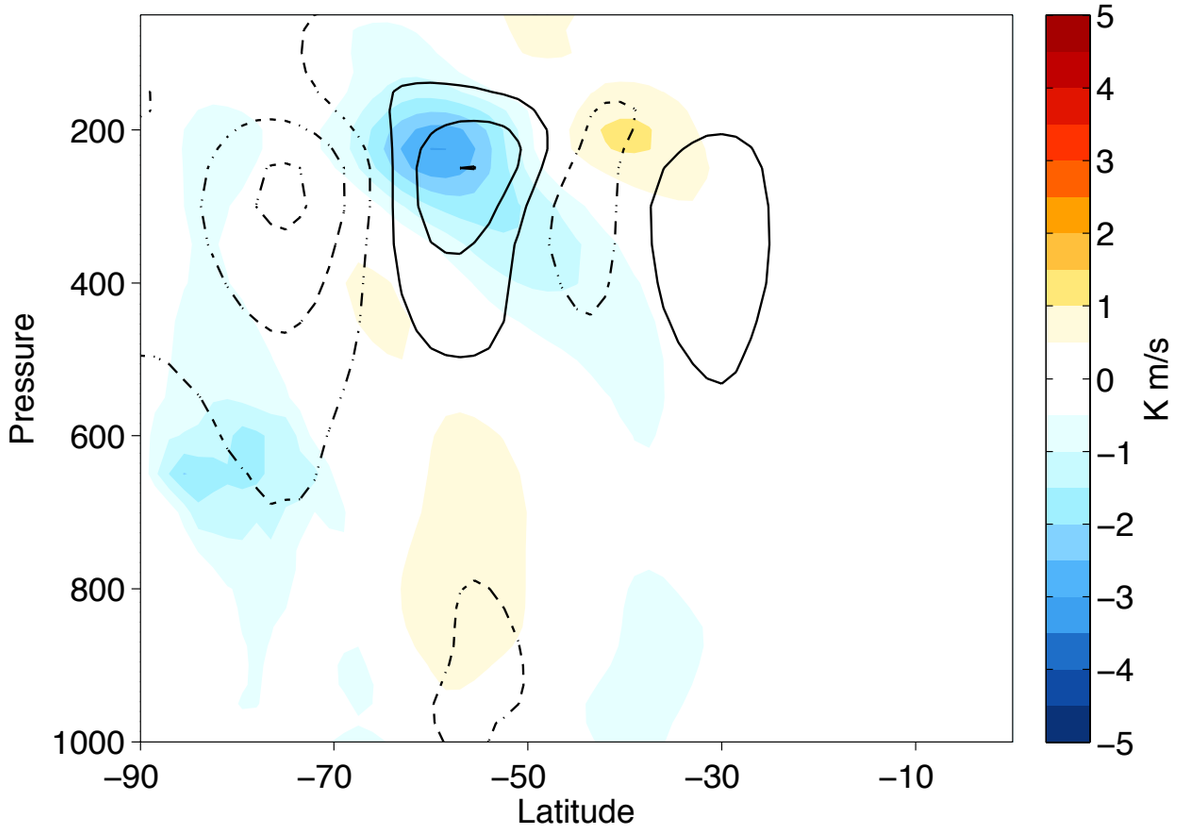
SAM

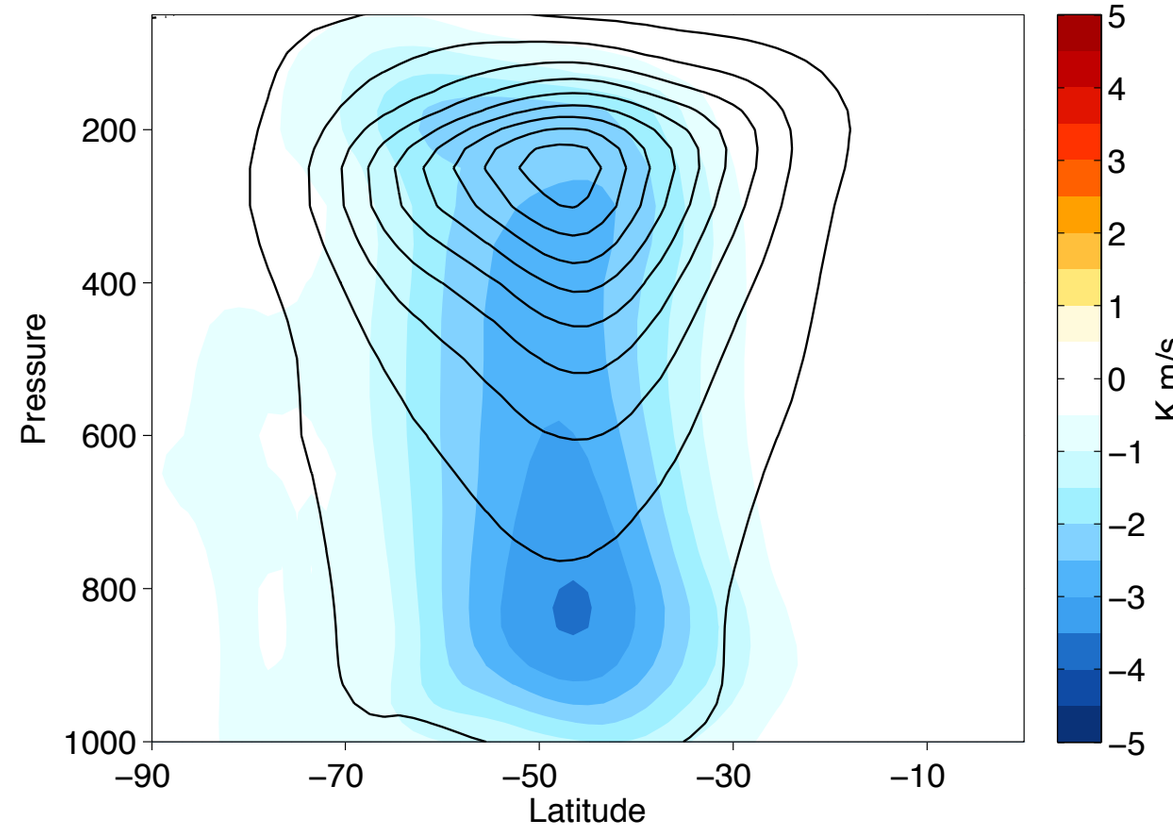
eddy kinetic energy contours; [v*T*] shading.



SAM *"BAM"*

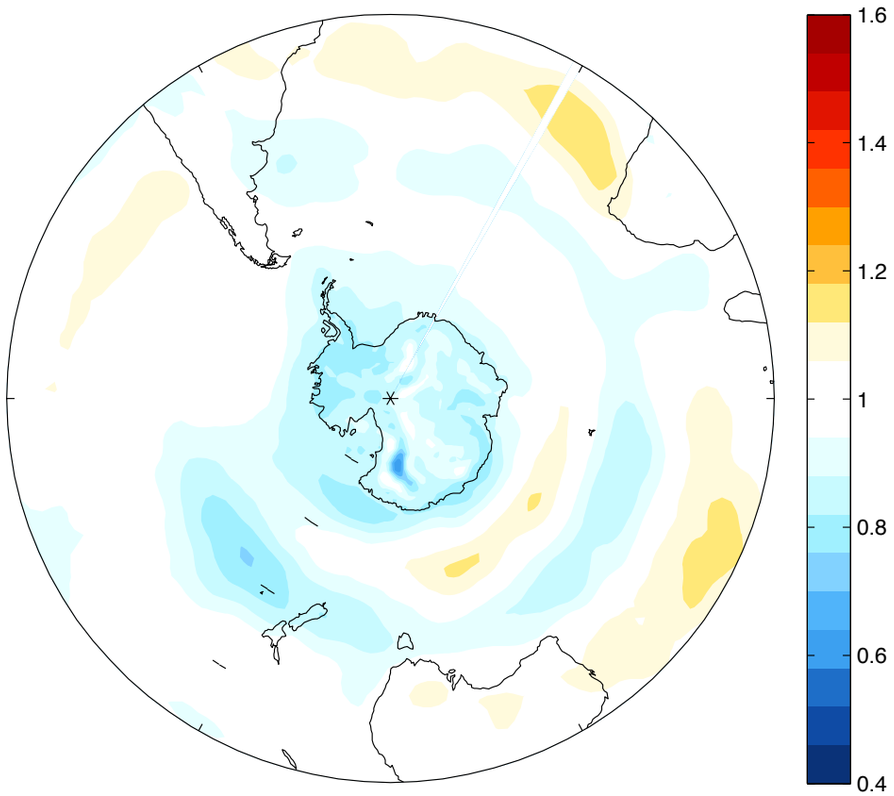
eddy kinetic energy contours; [v*T*] shading.





Ratios of variance in lower tropospheric temperatures

High/low polarity of PC1 Uwnd



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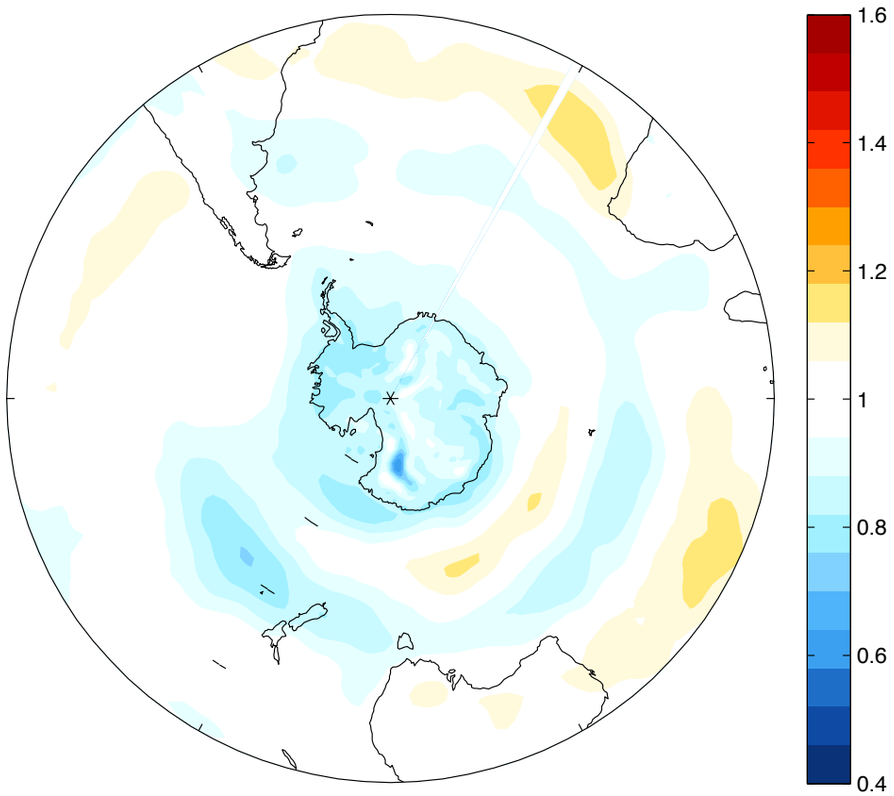
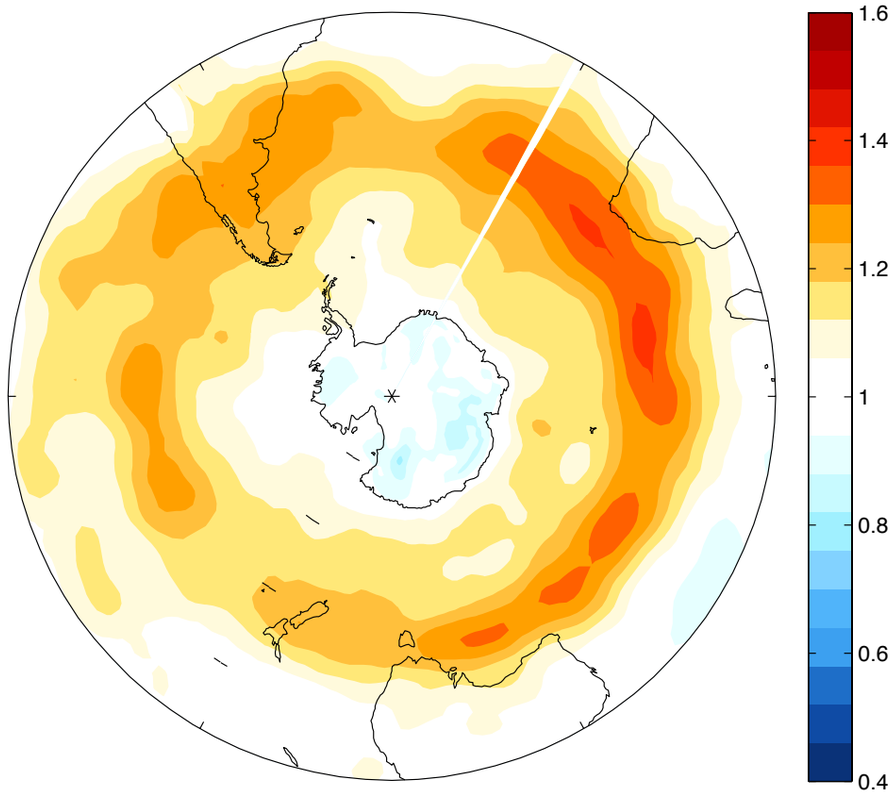
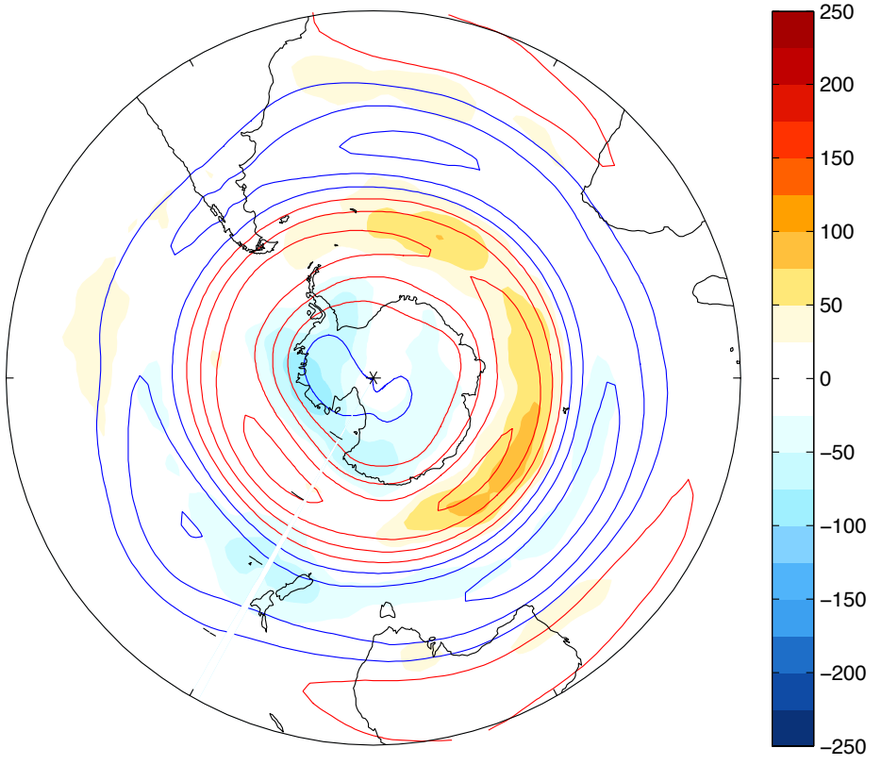


High/low polarity of PC1 EKE



Differences in eddy kinetic energy

High-low polarity of PC1 Uwnd



Differences in eddy kinetic energy

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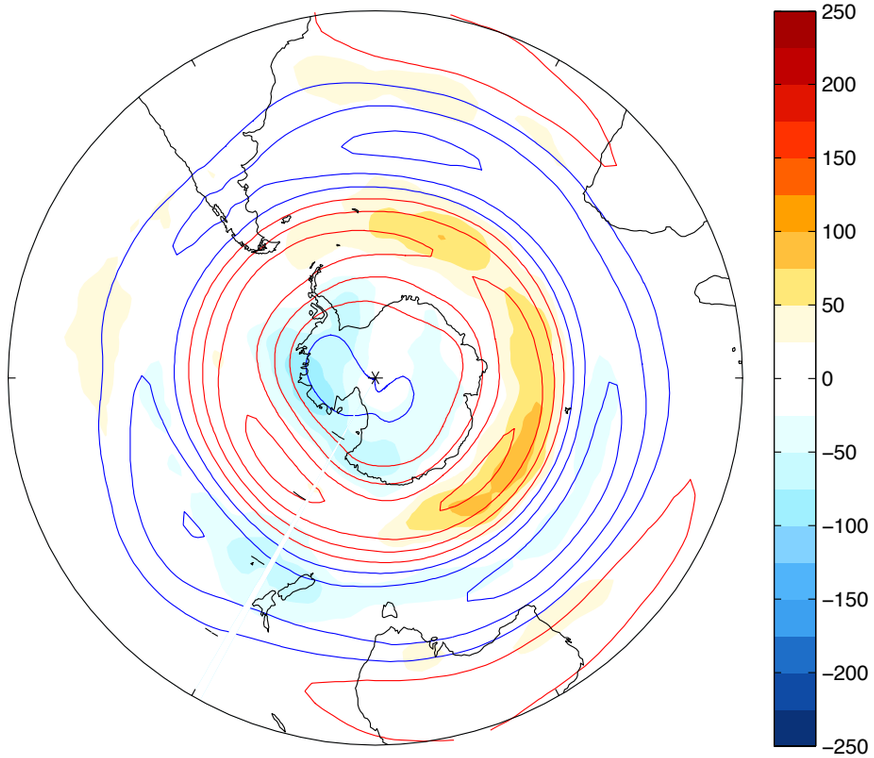

High-low polarity of PC1 EKE