Is the Brewer-Dobson Circulation driven by tropospheric baroclinic waves or by high latitude, upper stratospheric planetary waves

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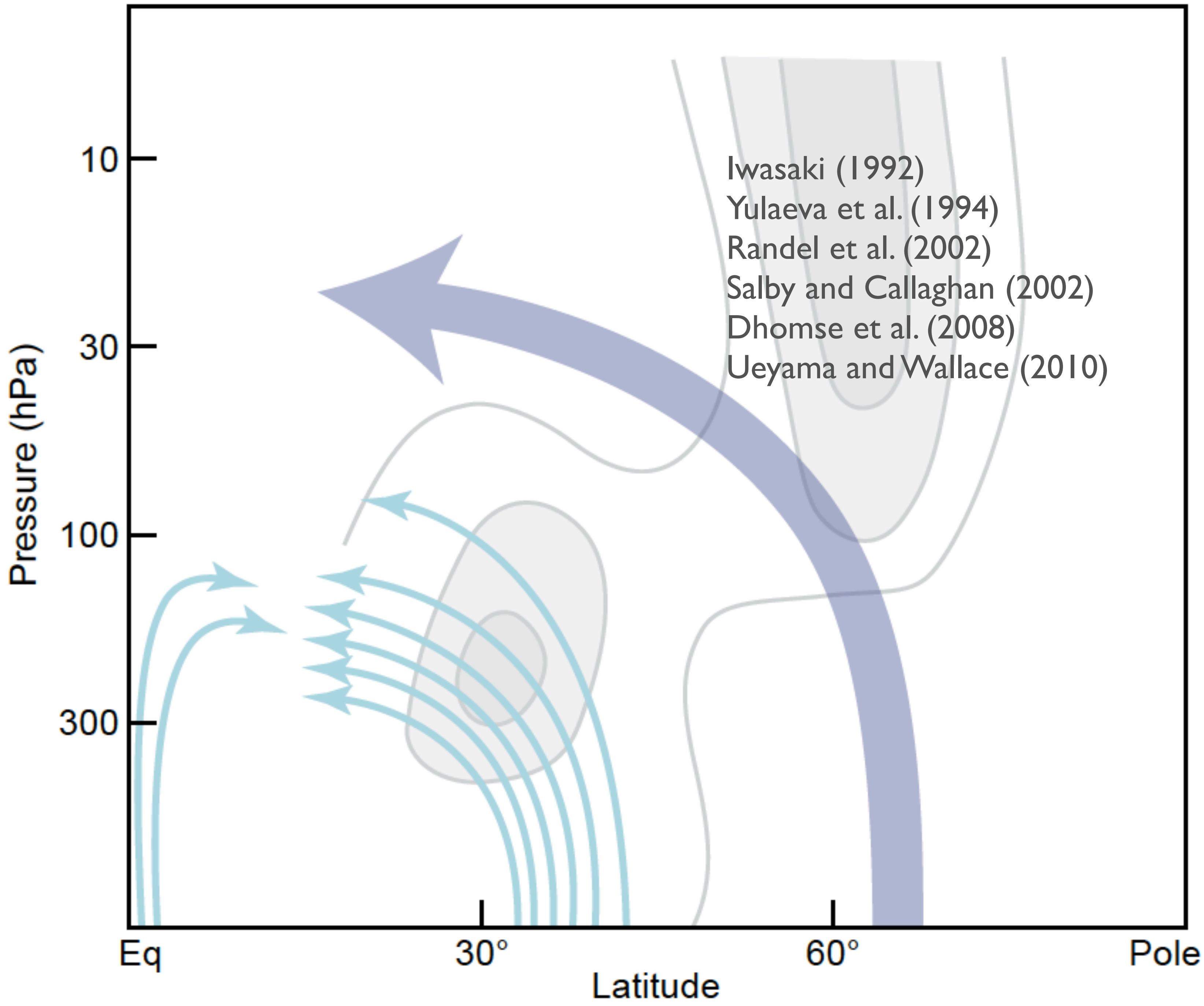
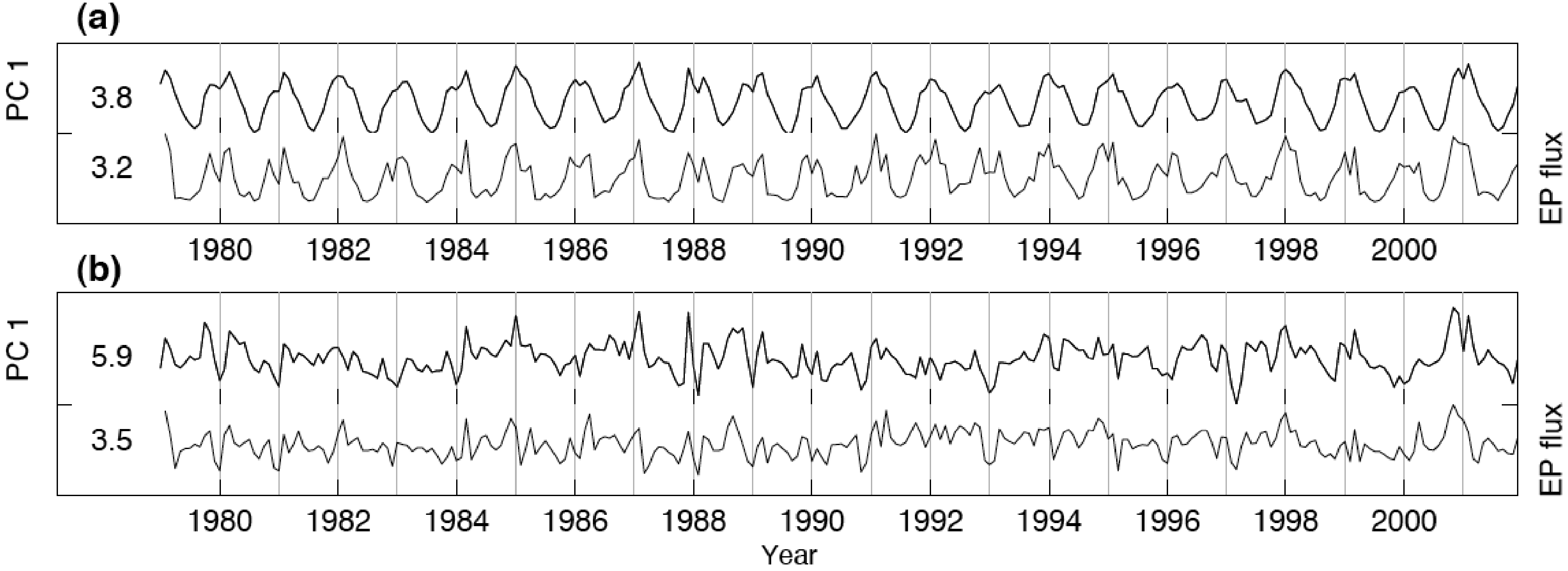
Background

general agreement that the Brewer-Dobson circulation (BDC) is forced by wave-breaking at stratospheric levels,

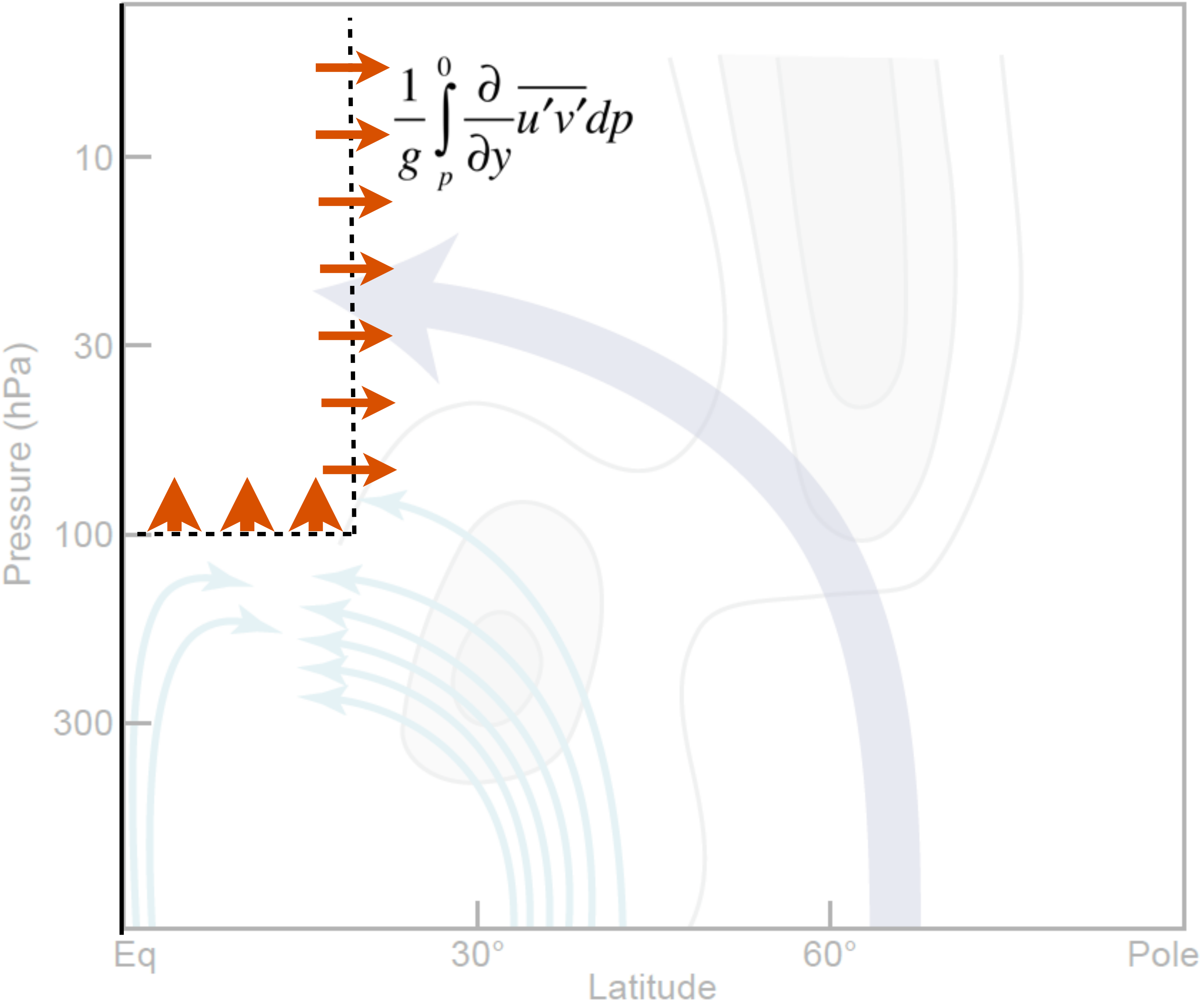
but conflicting interpretations of where the wave-breaking occurs



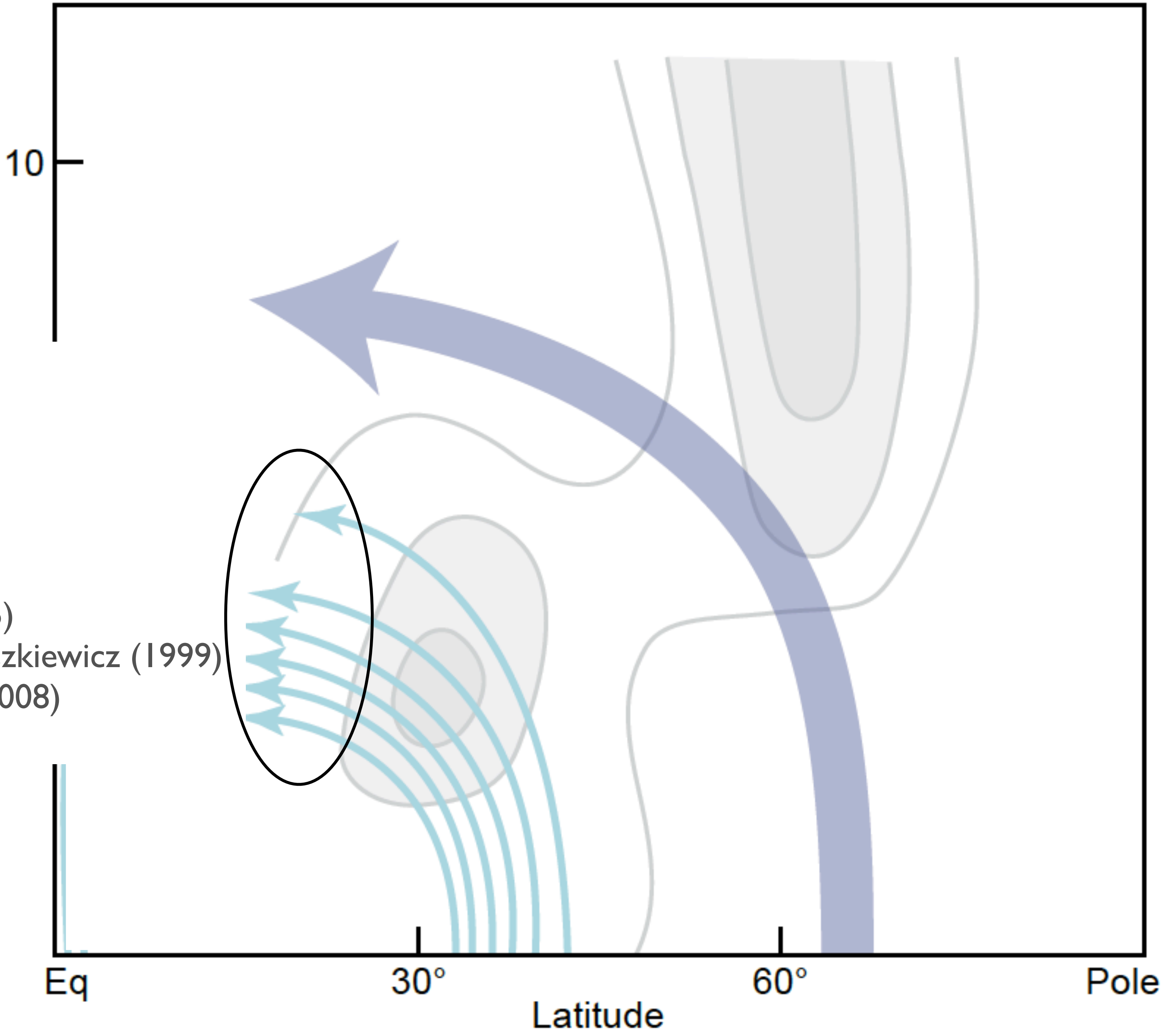
Iwasaki (1992)
Yulaeva et al. (1994)
Randel et al. (2002)
Salby and Callaghan (2002)
Dhomse et al. (2008)
Ueyama and Wallace (2010)



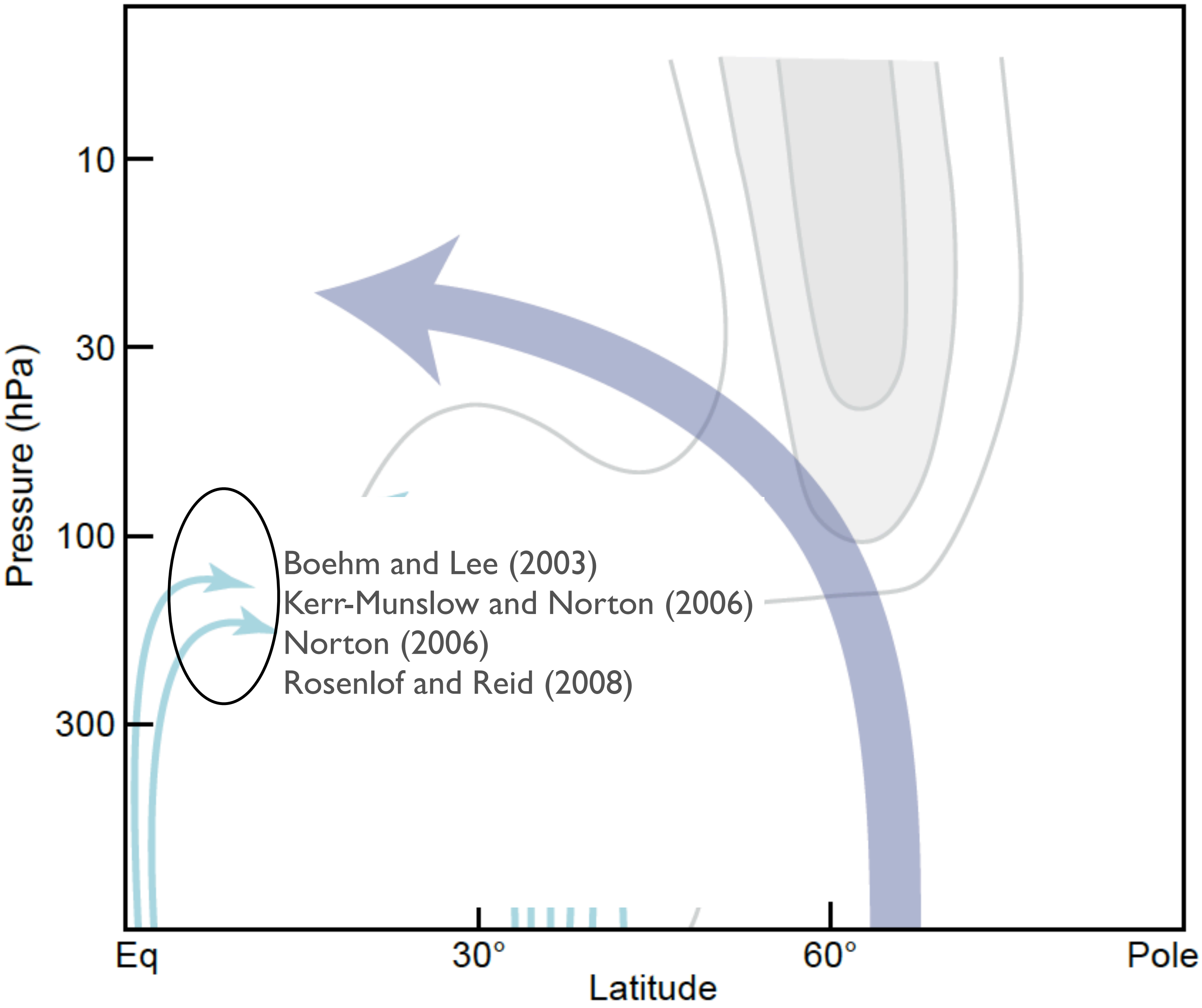
Ueyama and Wallace (2010)



$$\frac{1}{g}\int_{p}^{0}\frac{\partial}{\partial y}\overline{u'v'}dp$$



Rosenlof (1995)
Plumb and Eluszkiewicz (1999)
Randel et al. (2008)



Boehm and Lee (2003)
Kerr-Munslow and Norton (2006)
Norton (2006)
Rosenlof and Reid (2008)

Plumb (2002)

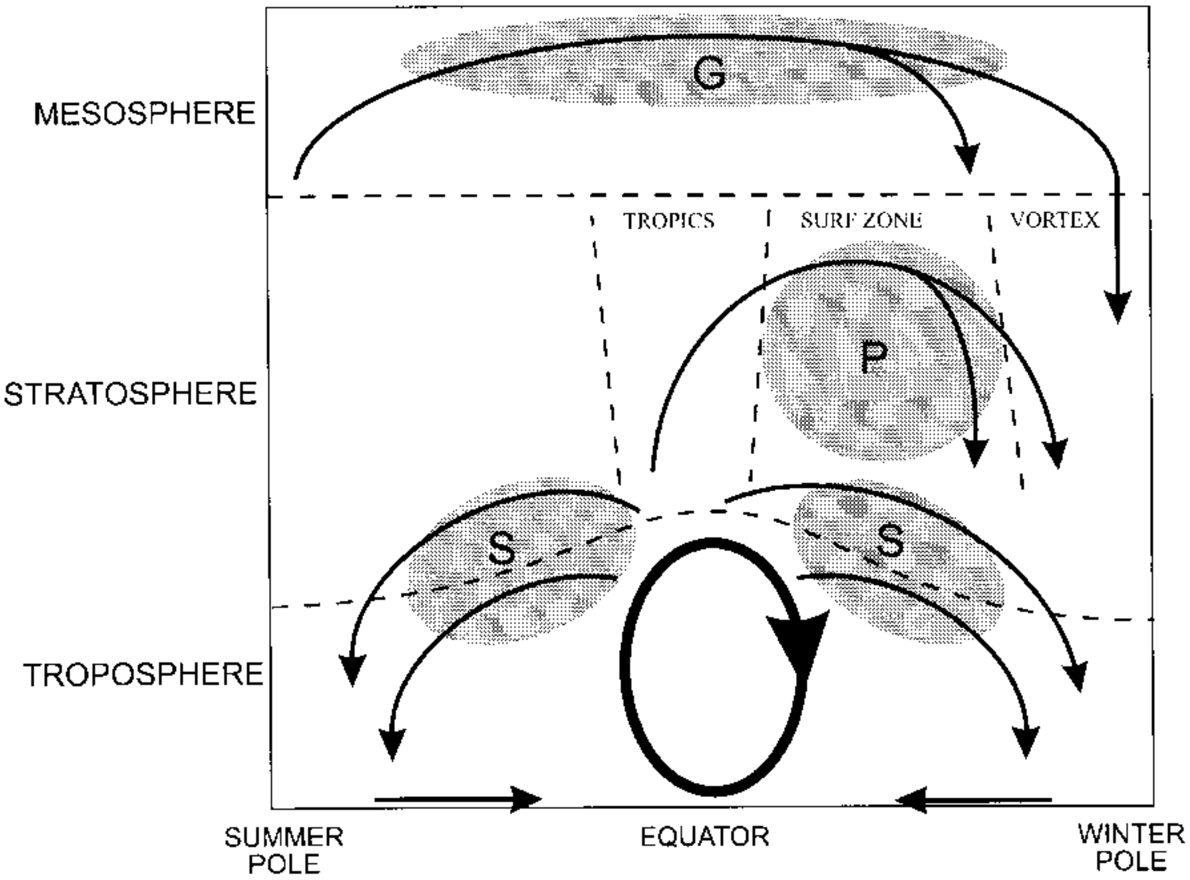


Fig. 2. Schematic of the residual mean meridional circulation in the atmosphere. The heavy ellipse denotes the thermally-driven Hadley circulation of the troposphere. The shaded regions (labelled “S”, “P”, and “G”) denote regions of breaking waves (synoptic- and planetary-scale waves, and gravity waves, respectively), responsible for driving branches of the stratospheric and mesospheric circulation.

Purpose of this talk

to confirm the existence of lower and middle cells with different sources of wave driving

to show that the breaking of high latitude planetary waves is important for the forcing of the BDC despite the lack of confirmatory evidence based on downward control diagnostics

Methodology

Side-by-side comparison of regression statistics and downward control diagnostics in the ERA-40 Reanalysis and in a simple dynamical model that is capable of simulating the sudden warming phenomenon

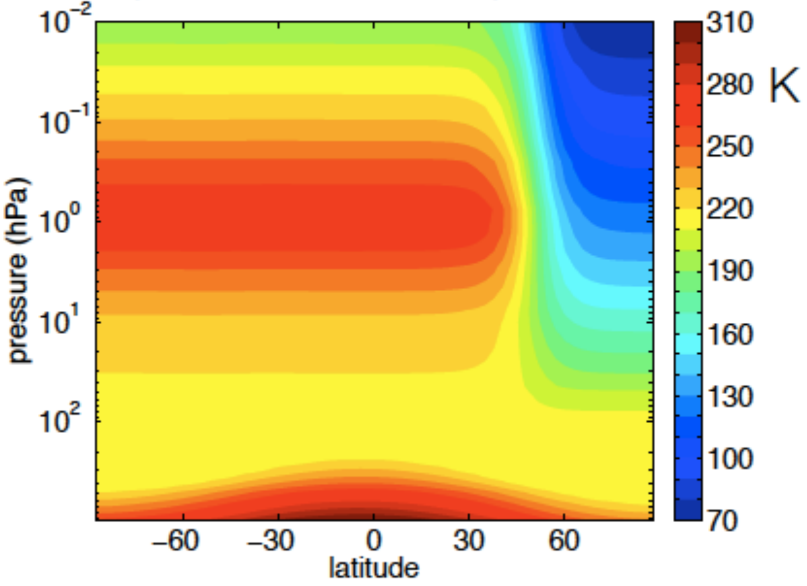
The ERA-40 Model--
work of Rei Ueyama

The simple dynamical model
work of Edwin Gerber

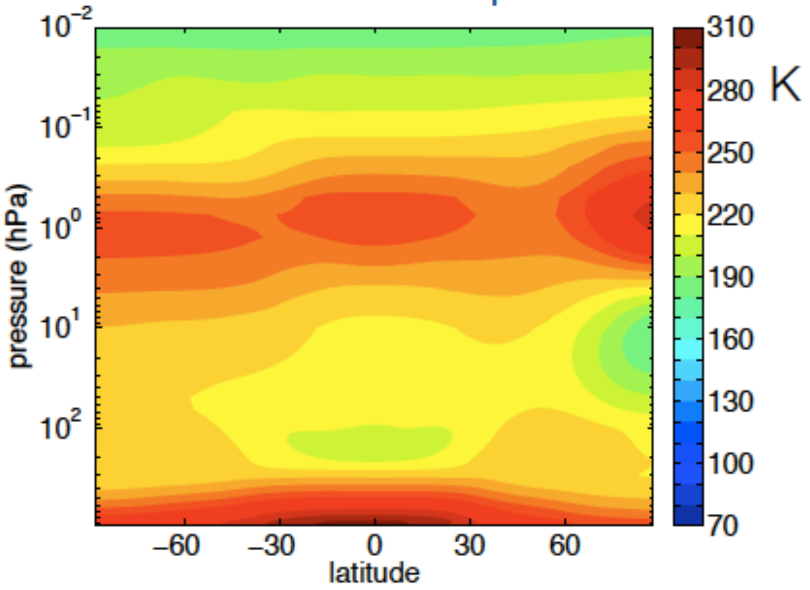
An idealized Atmospheric GCM

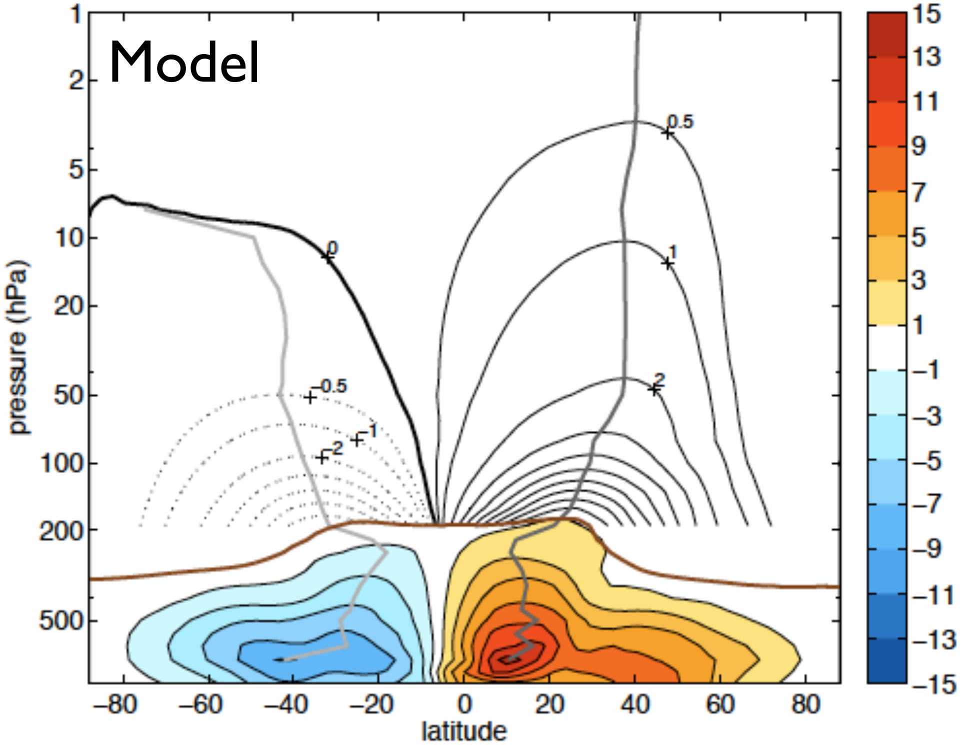
- dry primitive equations on the sphere
- Newtonian relaxation of temperature to radiative-convective equilibrium profile [Polvani and Kushner, 2002]
- Perpetual January-like conditions
- Simple large scale topography [Gerber and Polvani, 2009]
- Rayleigh friction at bottom (surface drag) and top (crude gravity wave parameterization)

radiative-convective equilibrium temperature



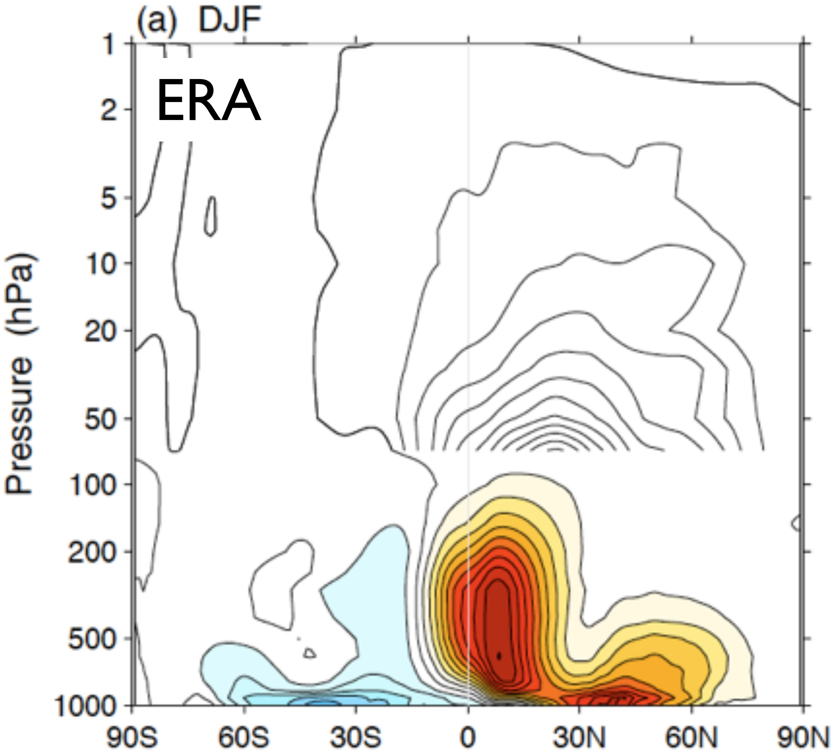
time mean temperature





Model

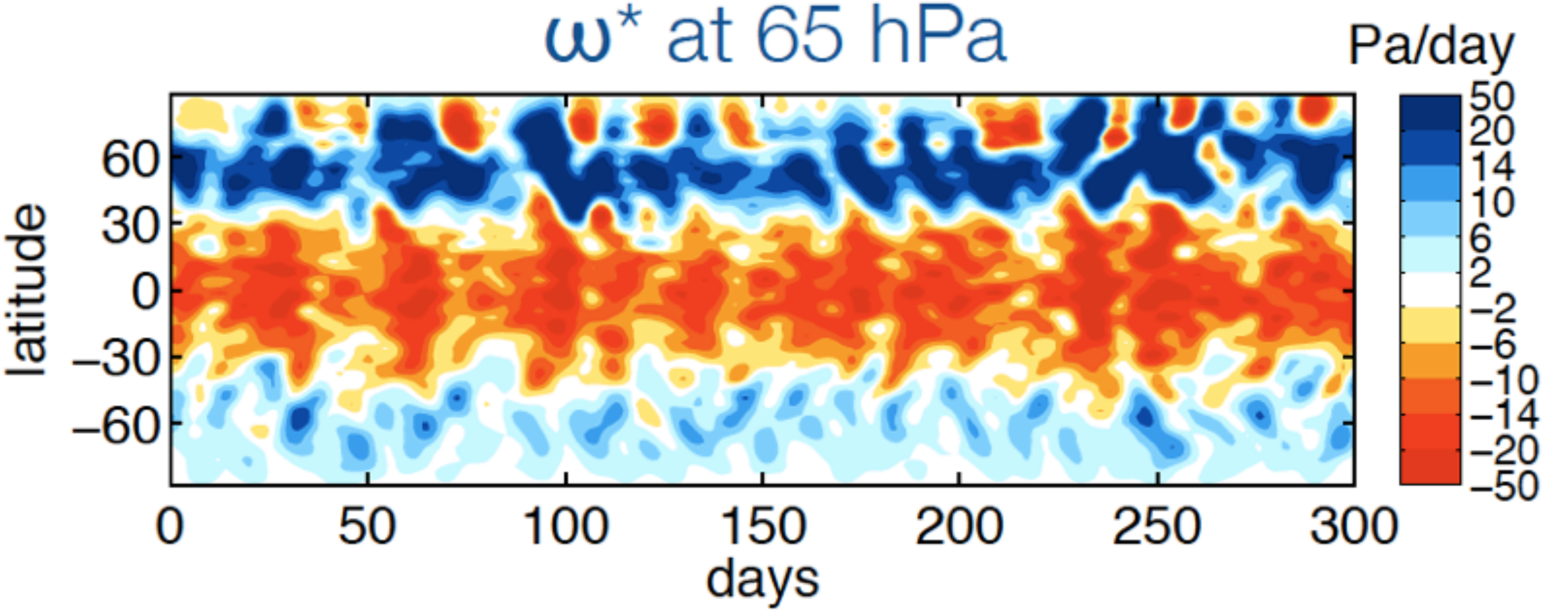
pressure (hPa)
1
2
5
10
20
50
100
200
500
latitude
−80
−60
−40
−20
0
20
40
60
80
0
−0.5
−1
−2
0.5
1
2
15
13
11
9
7
5
3
1
−1
−3
−5
−7
−9
−11
−13
−15



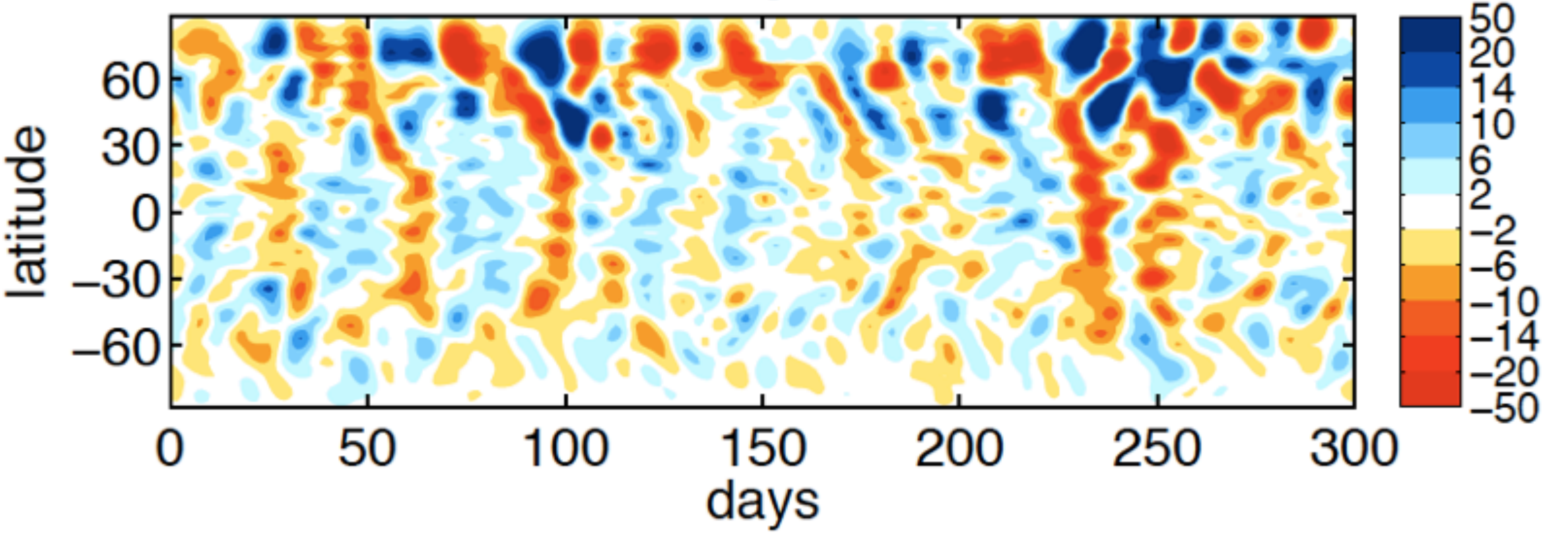
ERA

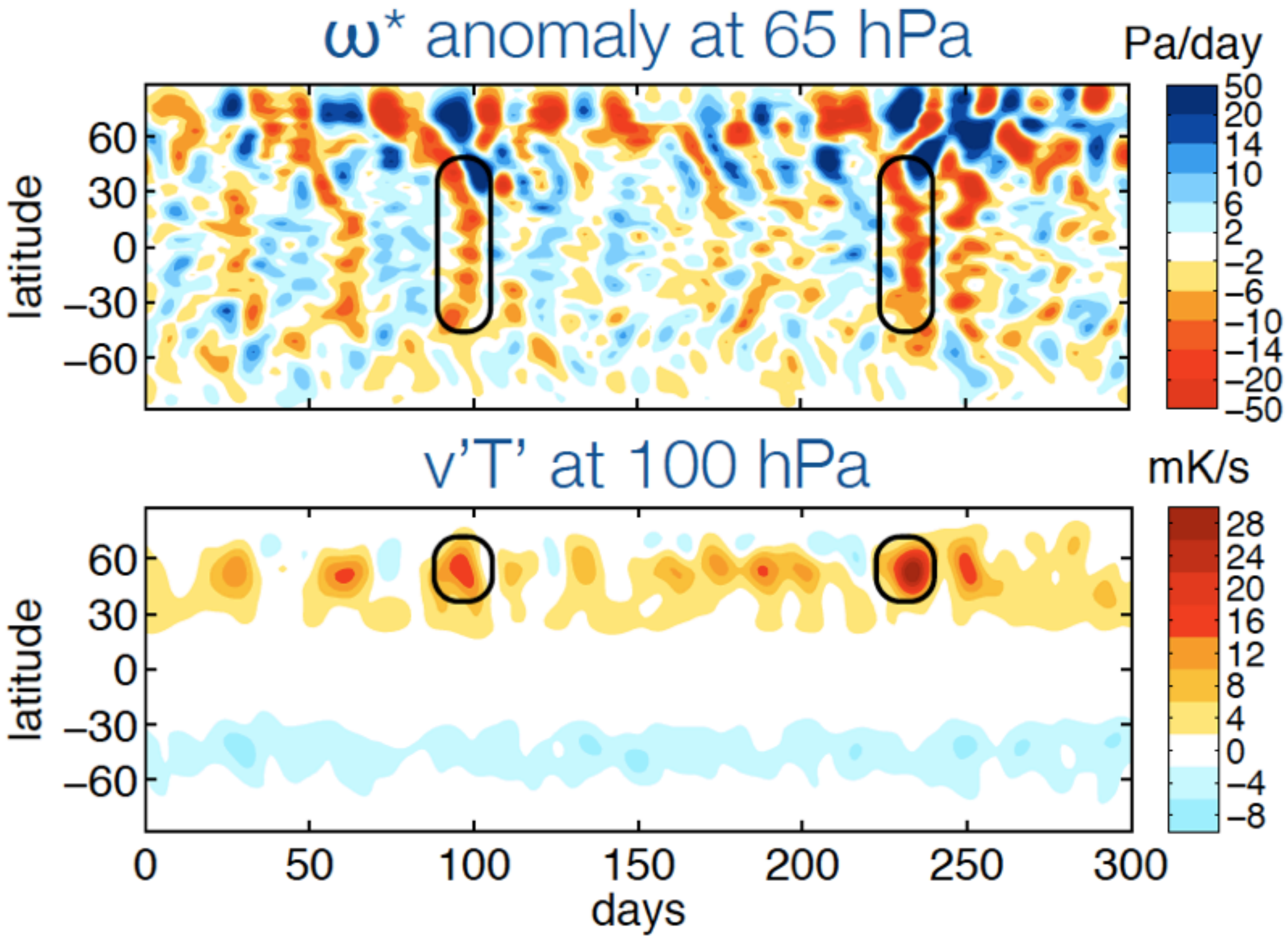
(a) DJF
Pressure (hPa)
1
2
5
10
20
50
100
200
500
1000
90S
60S
30S
0
30N
60N
90N

ω* at 65 hPa


Pa/day
50
20
14
10
6
2
−2
−6
−10
−14
−20
−50
latitude
60
30
0
−30
−60
0
50
100
150
200
250
300
days

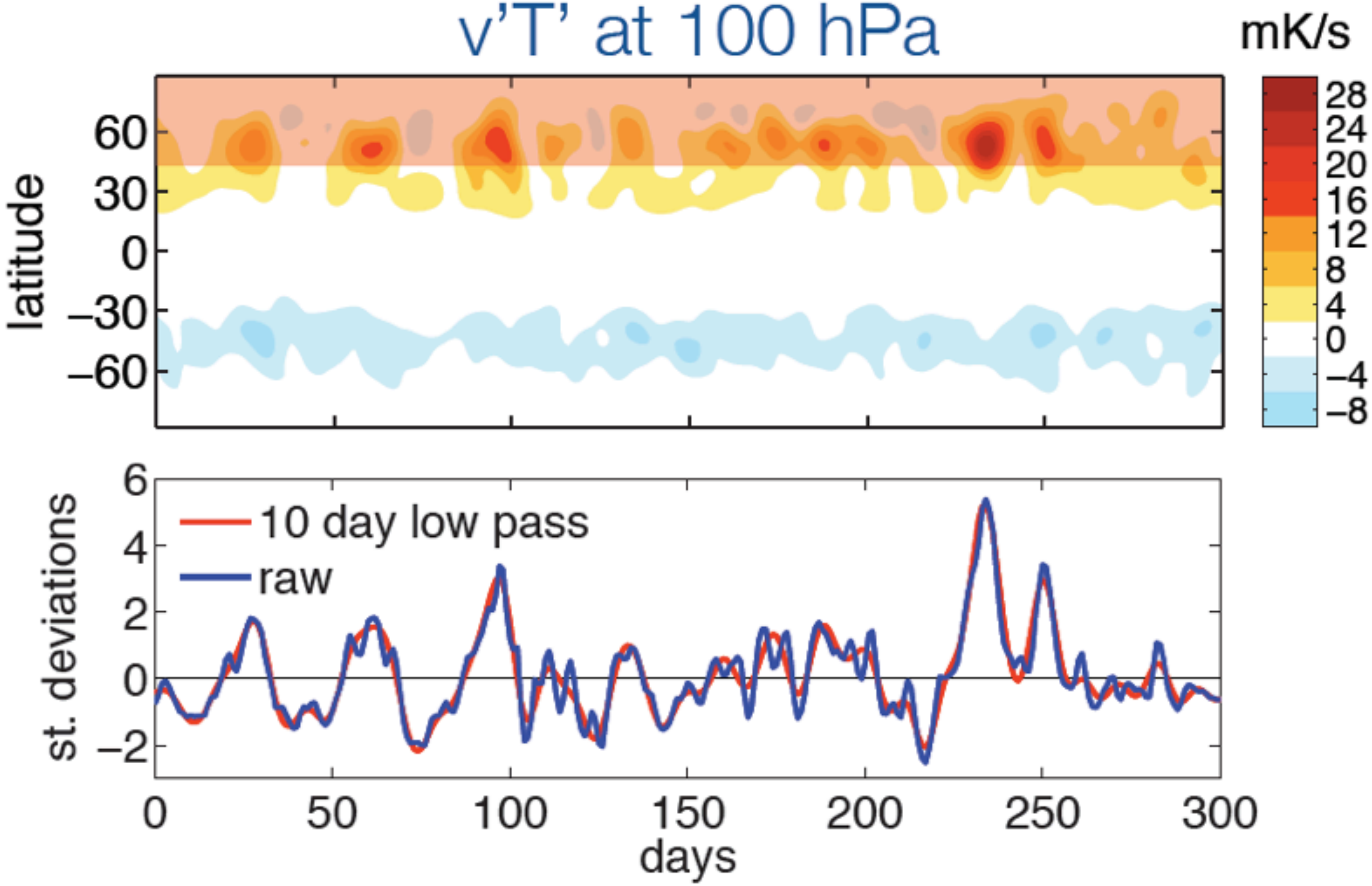
ω^* anomaly at 65 hPa




ω* anomaly at 65 hPa

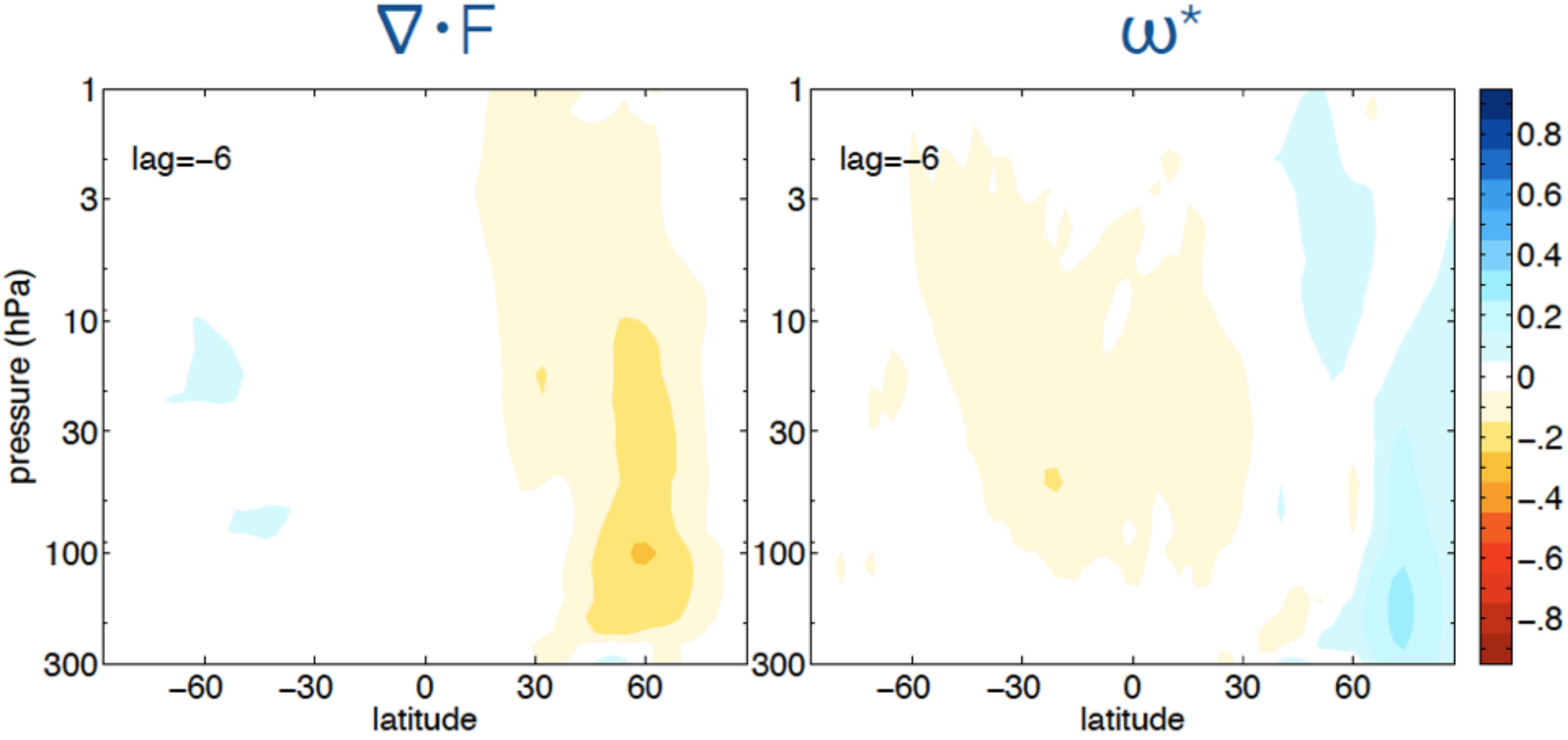
v’T’ at 100 hPa

v’T’ at 100 hPa



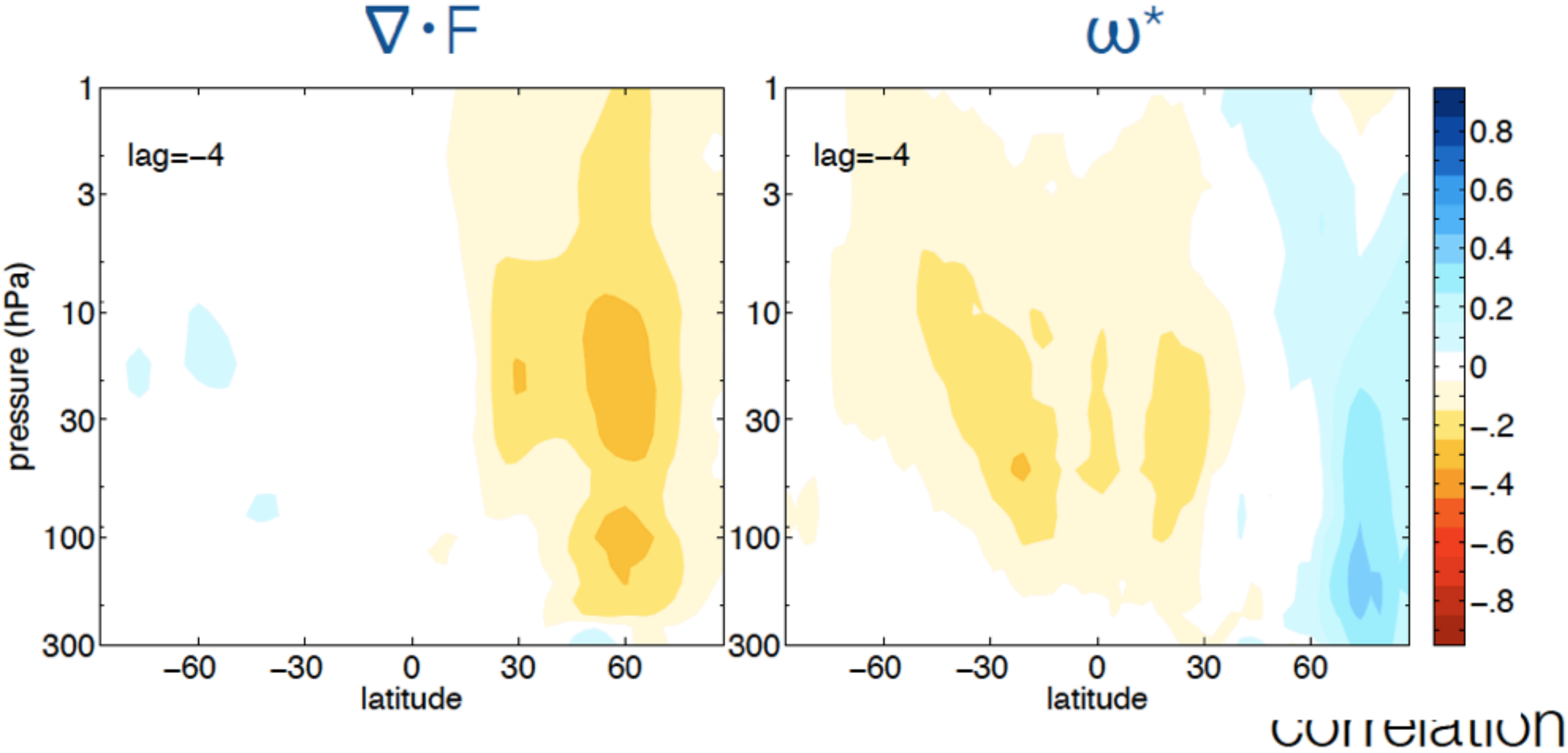
v’T’ index ∝ int_45^90 v’T’

Correlation of E-P flux divergence and $\boldsymbol{\omega}^*$ with extratropical v’T’ index

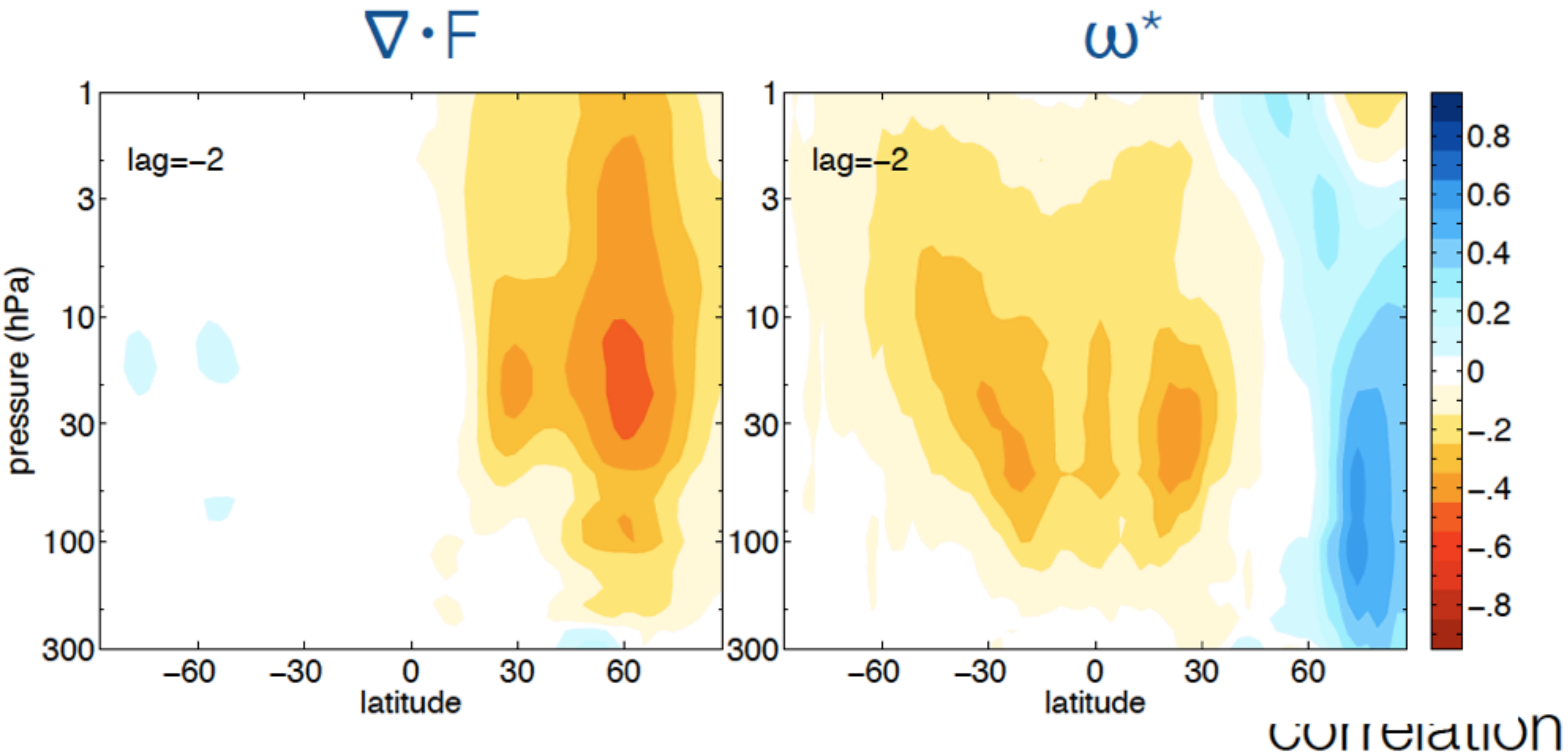


correlation

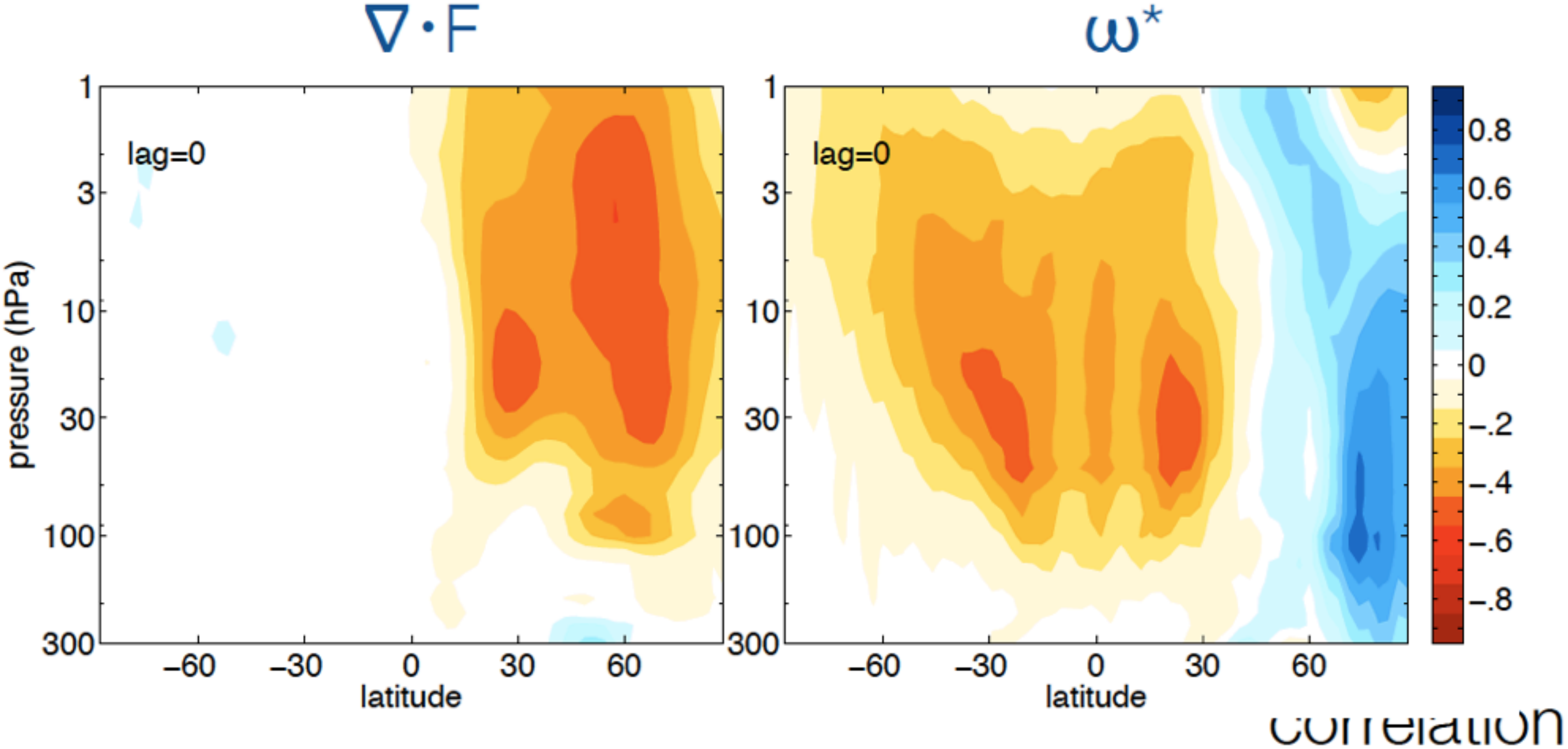
Correlation of E-P flux divergence and **ω***
with extratropical v'T' index



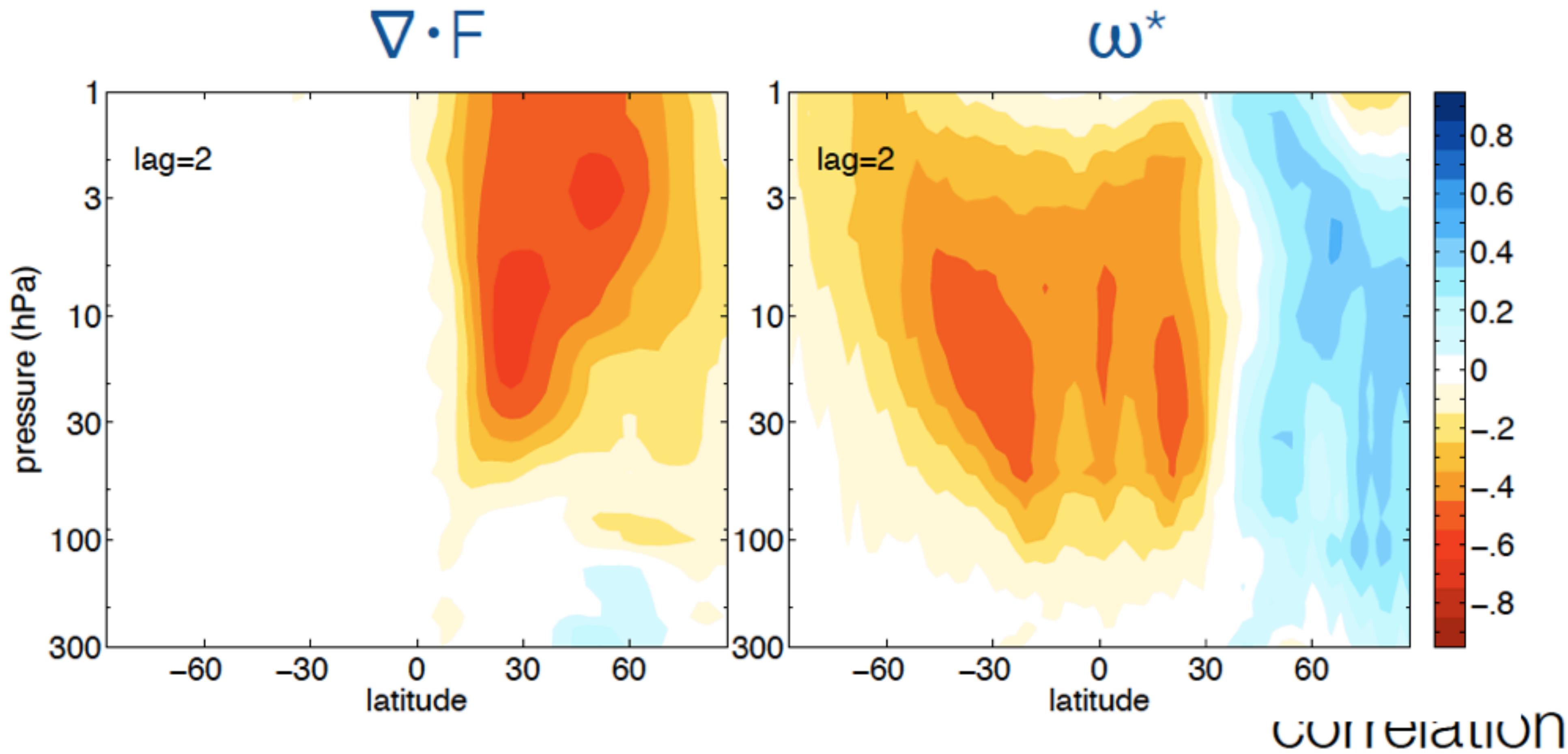
Correlation of E-P flux divergence and $\boldsymbol{\omega}^*$ with extratropical v'T' index



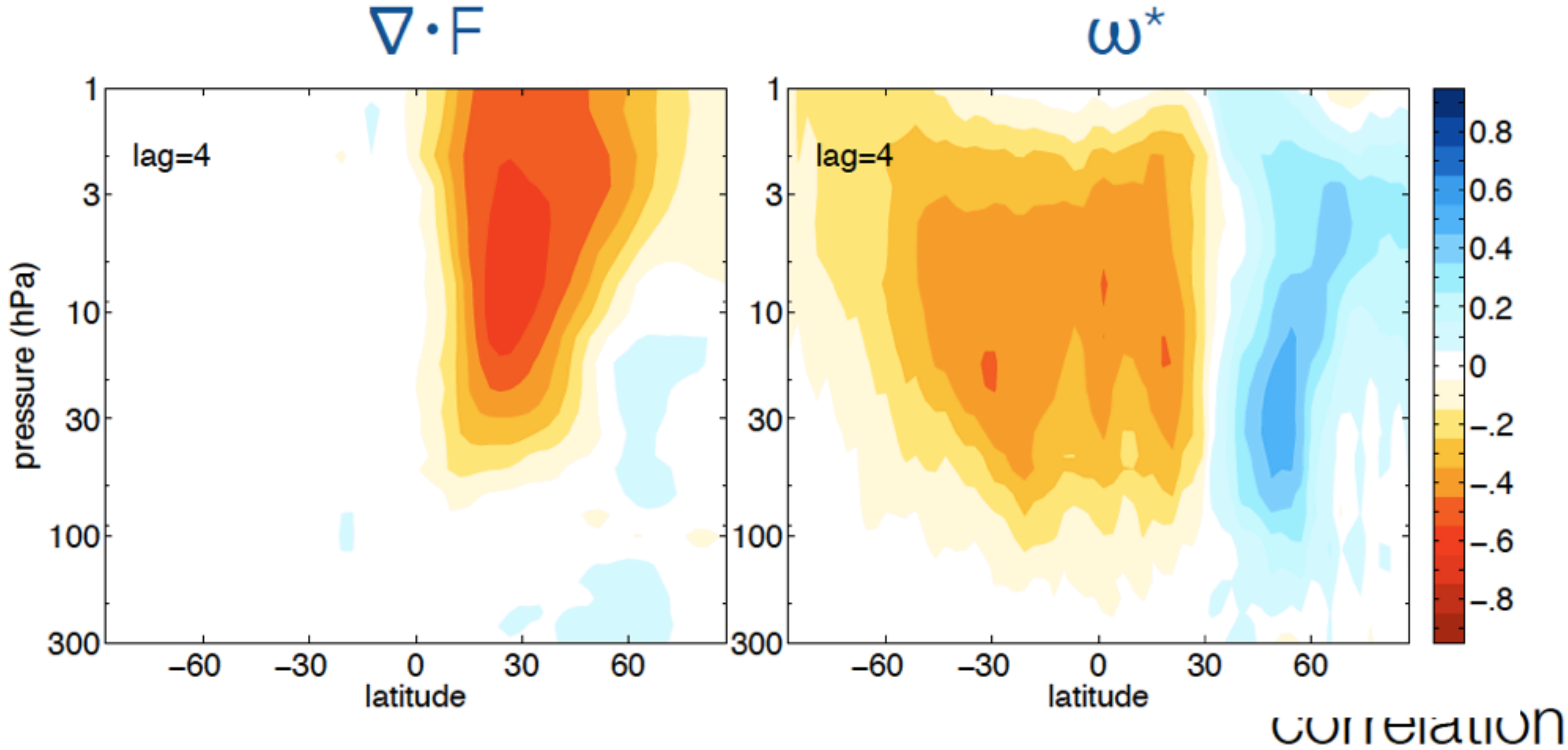
Correlation of E-P flux divergence and **ω*** with extratropical v'T' index



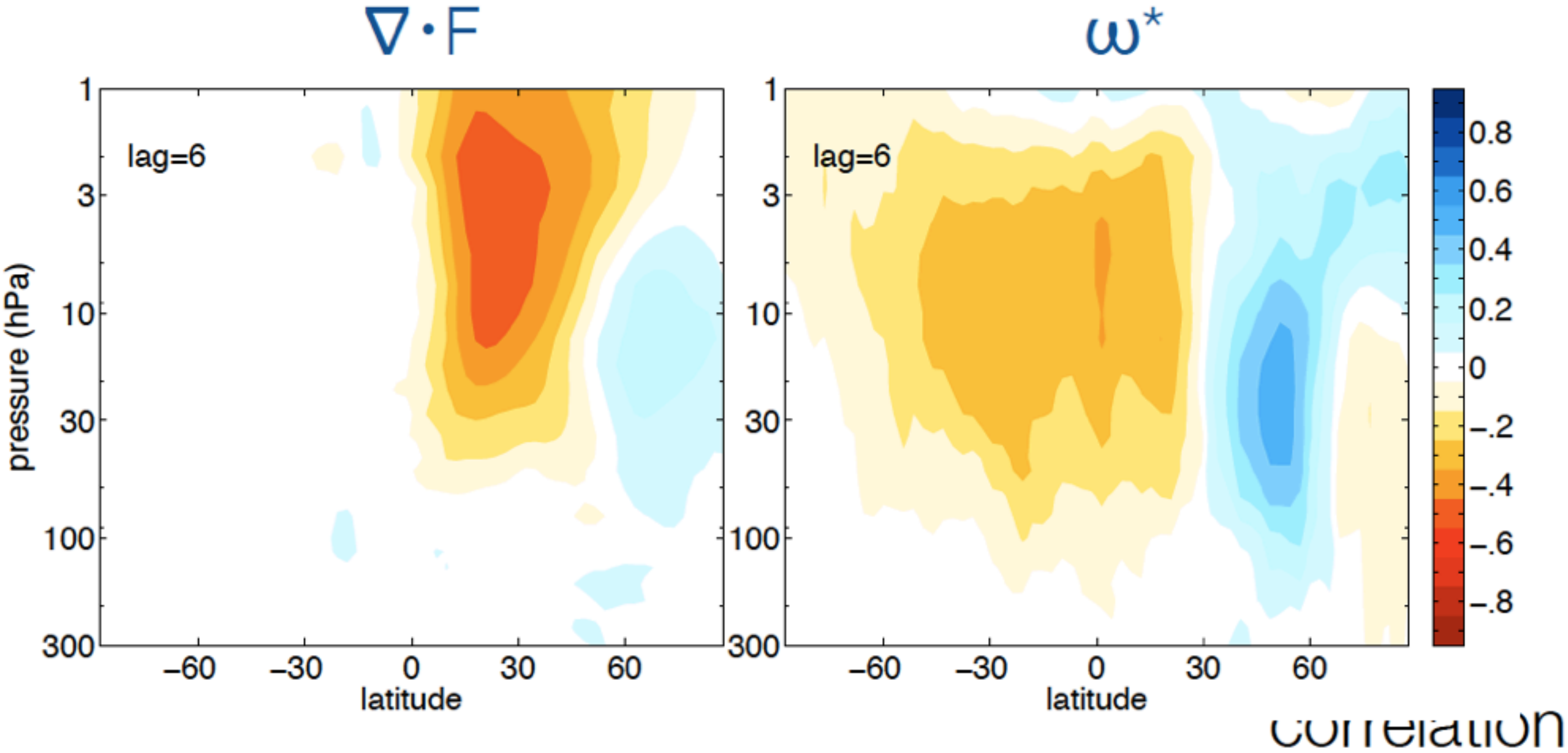
Correlation of E-P flux divergence and ω*
with extratropical v'T' index



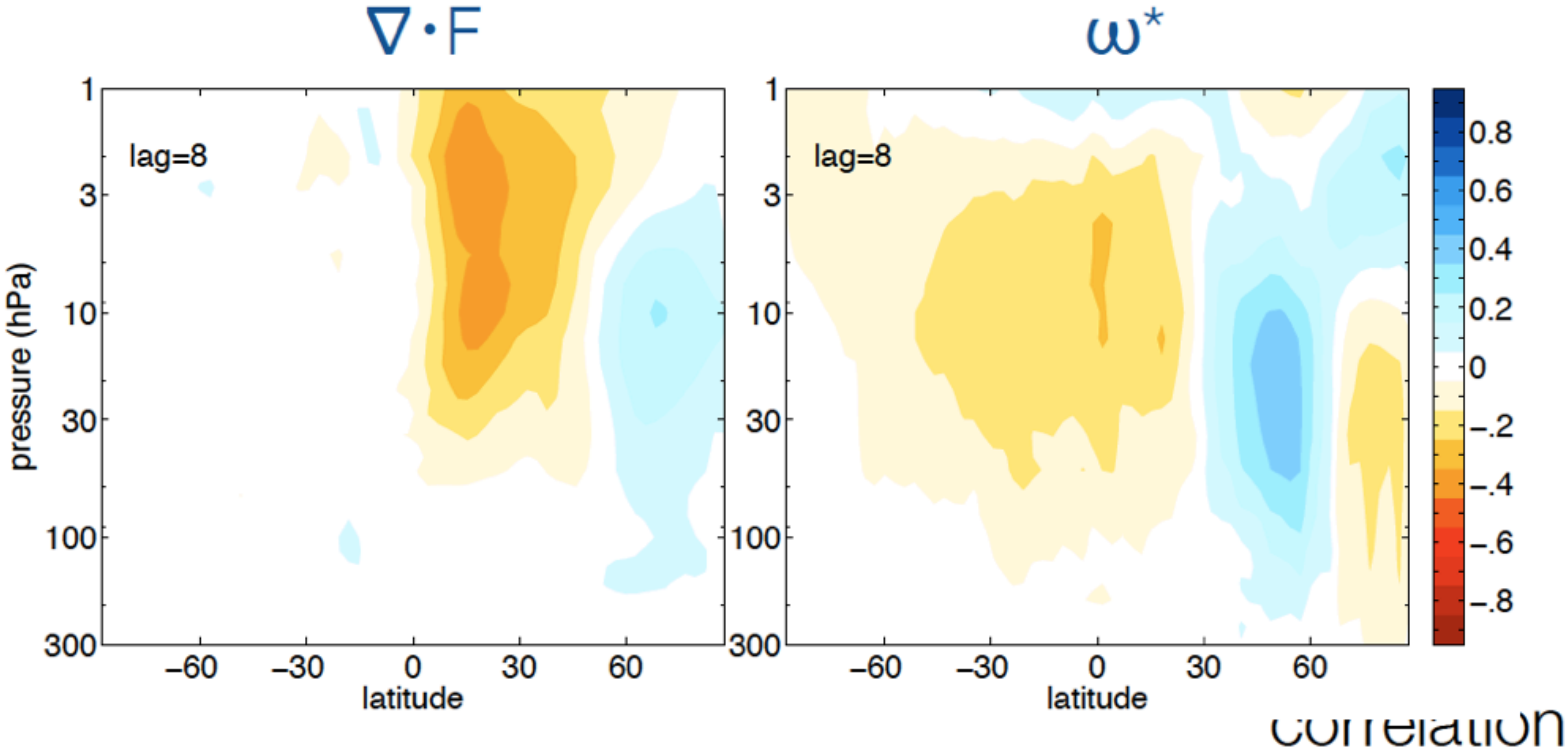
Correlation of E-P flux divergence and ω^* with extratropical v'T' index



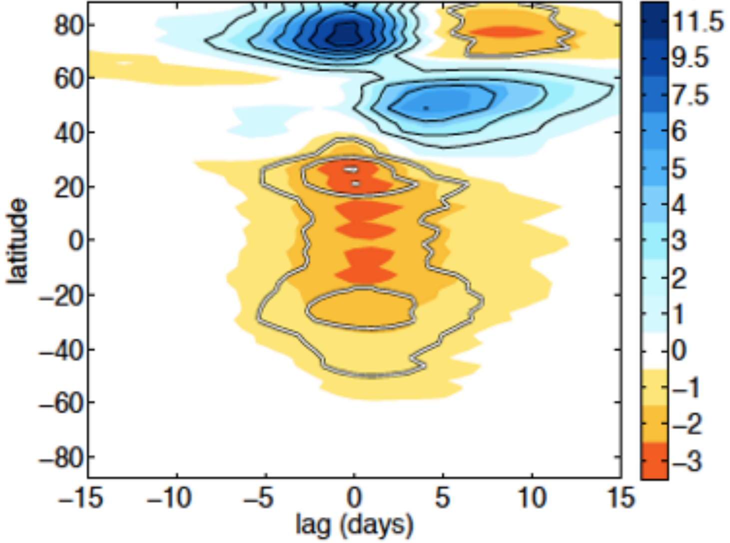
Correlation of E-P flux divergence and ω^* with extratropical v'T' index



Correlation of E-P flux divergence and ω^* with extratropical v'T' index



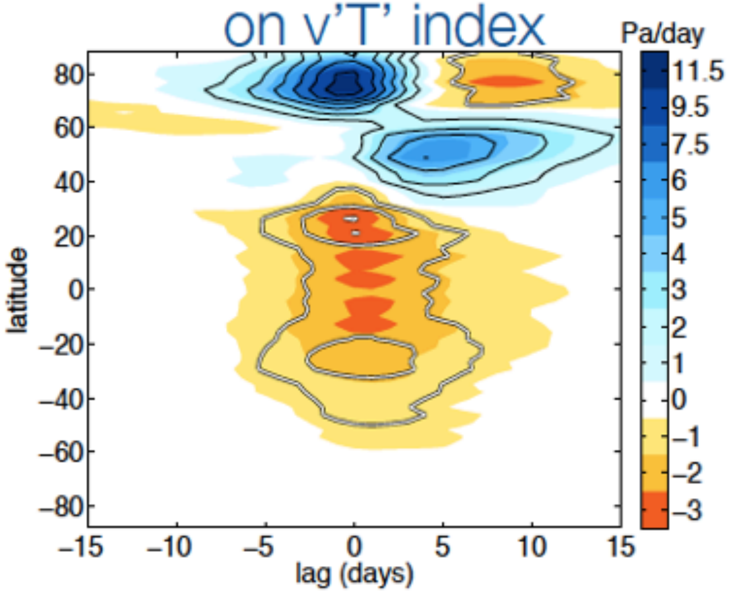
Winter hemisphere waves drive upwelling deep into summer hemisphere



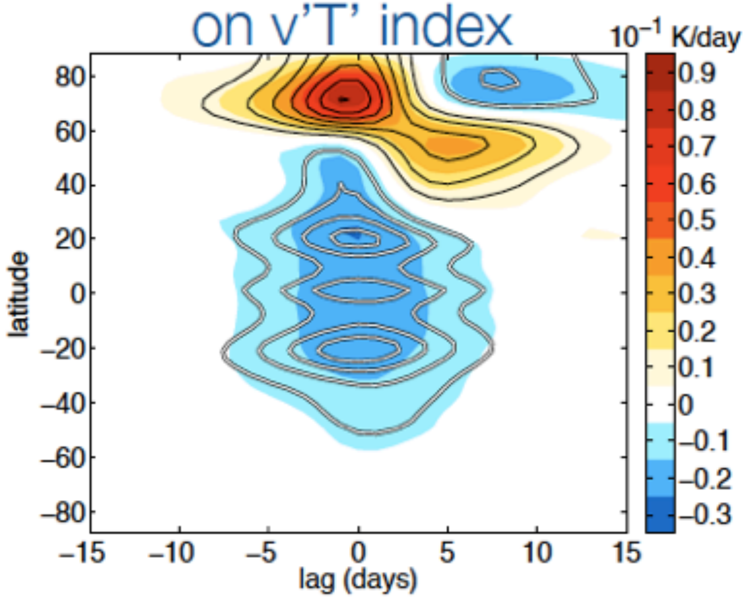
65 hPa ω* regressed on v’T’ index

When waves enter extratropical stratosphere, tropical upwelling begins almost instantaneously, spreading deep into the summer hemisphere.

Winter hemisphere waves drive upwelling deep into summer hemisphere, cooling the tropics!



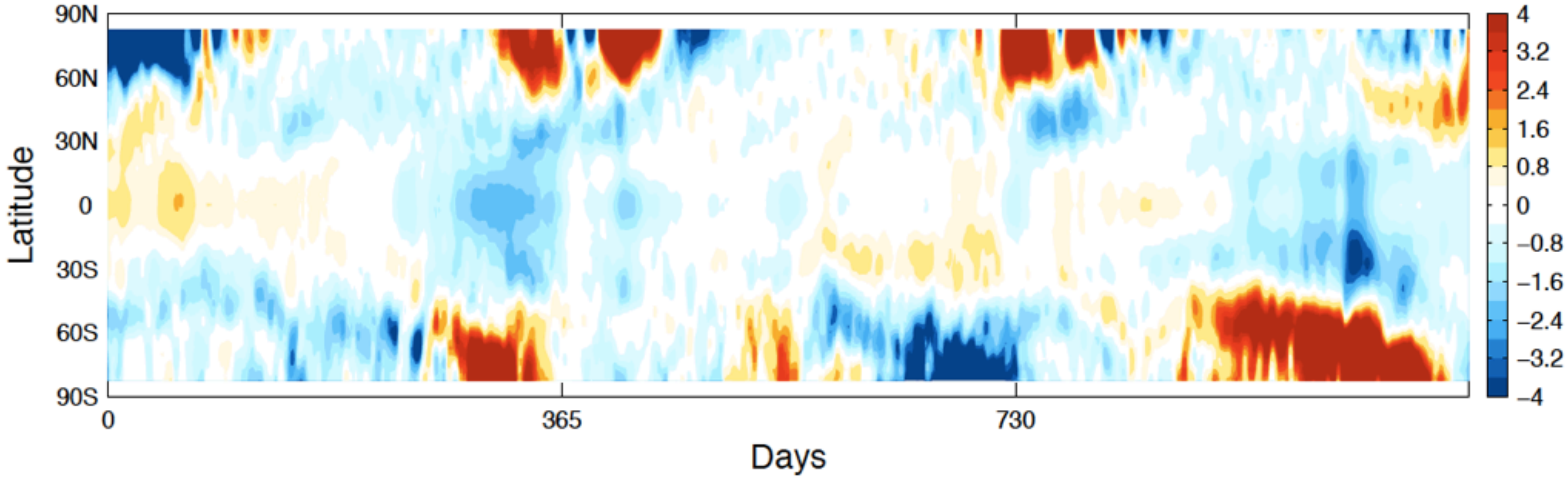
65 hPa ω* regressed on v'T' index

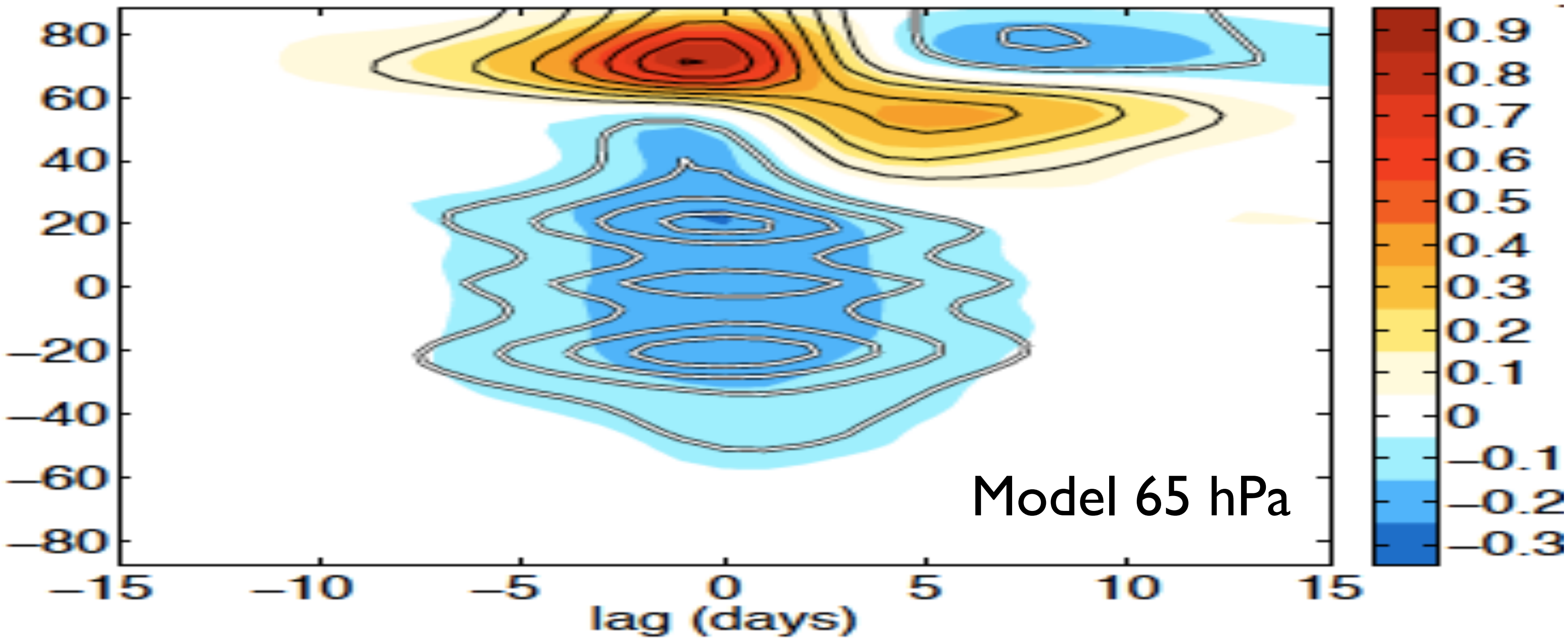


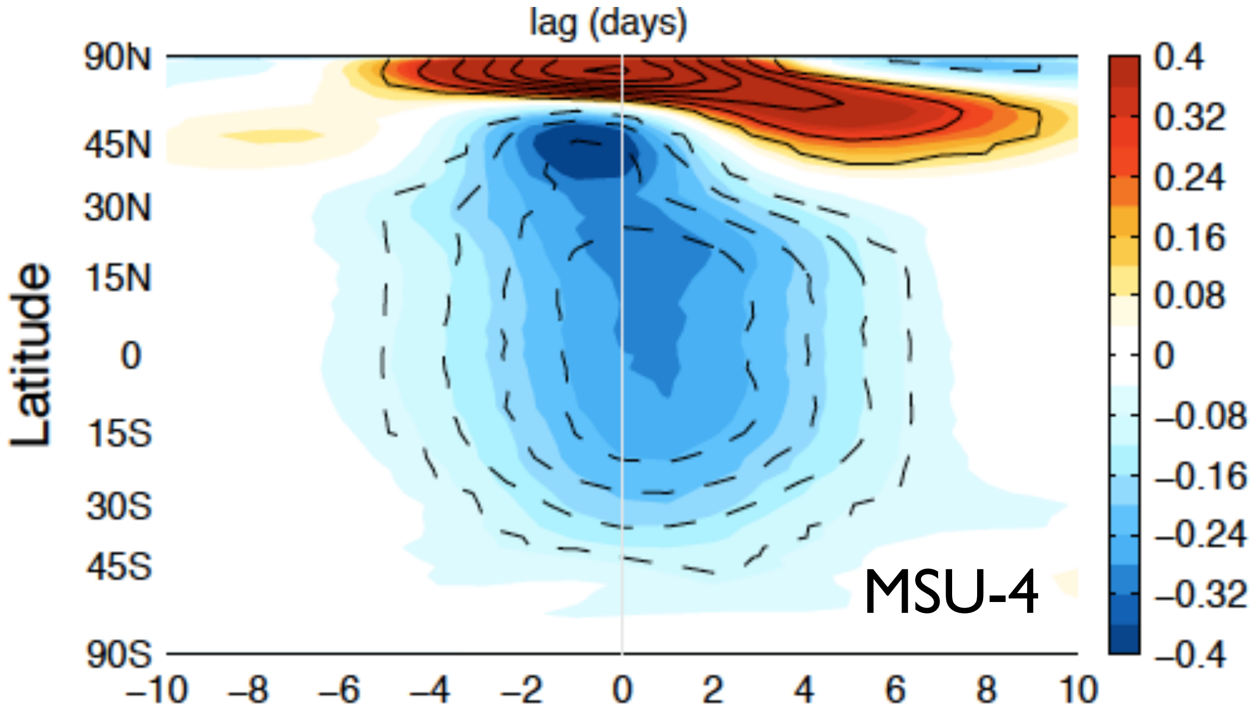
65 hPa dT/dt regressed on v'T' index

Upwelling induces low latitude cooling in both hemispheres

MSU-4 2000-2004



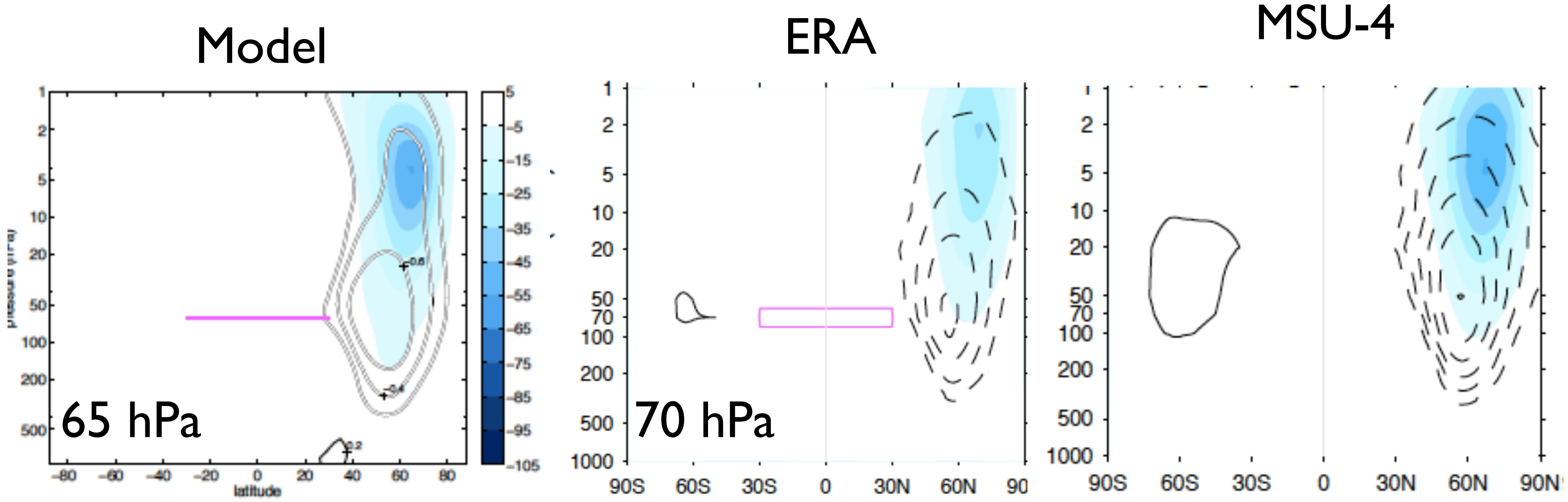




2-day $\frac{\partial T}{\partial t}$

regressed on

$\overline{v'T'}^{\,100\ \mathrm{hPa}}_{\,45\text{-}90°\mathrm{N}}$

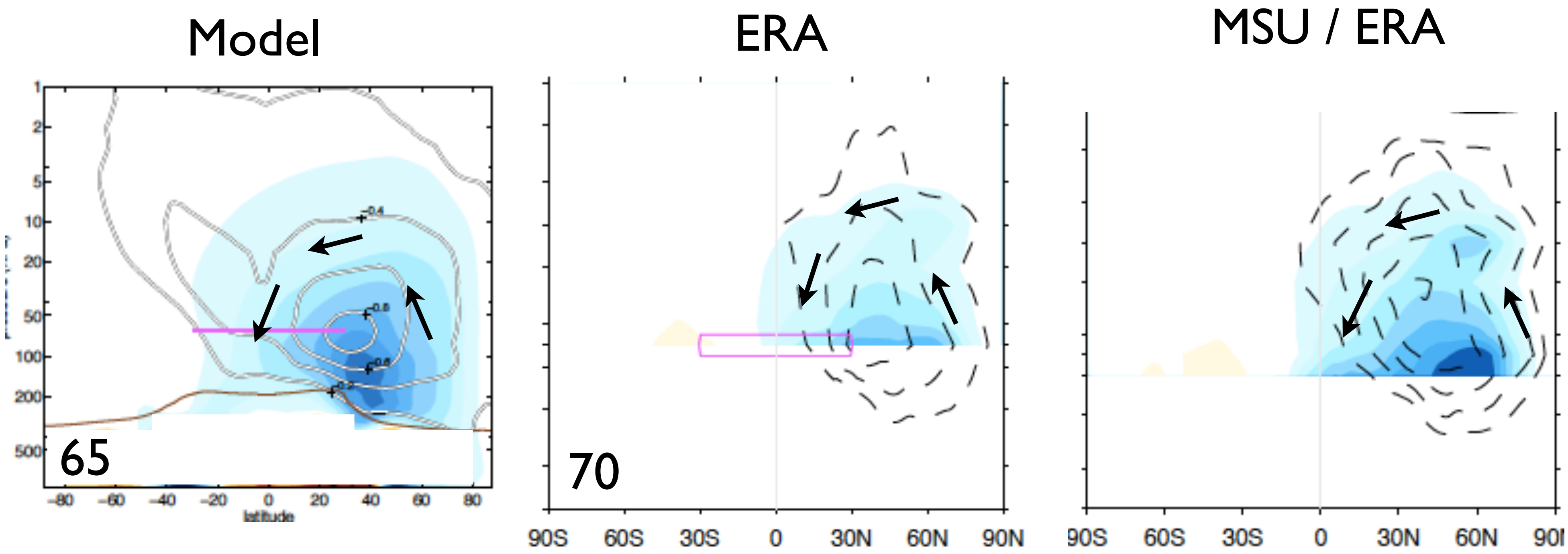


Model

ERA

MSU-4

$\overline{v'T'}$ upon daily $\frac{dT}{dt}_{30°S–30°N}$

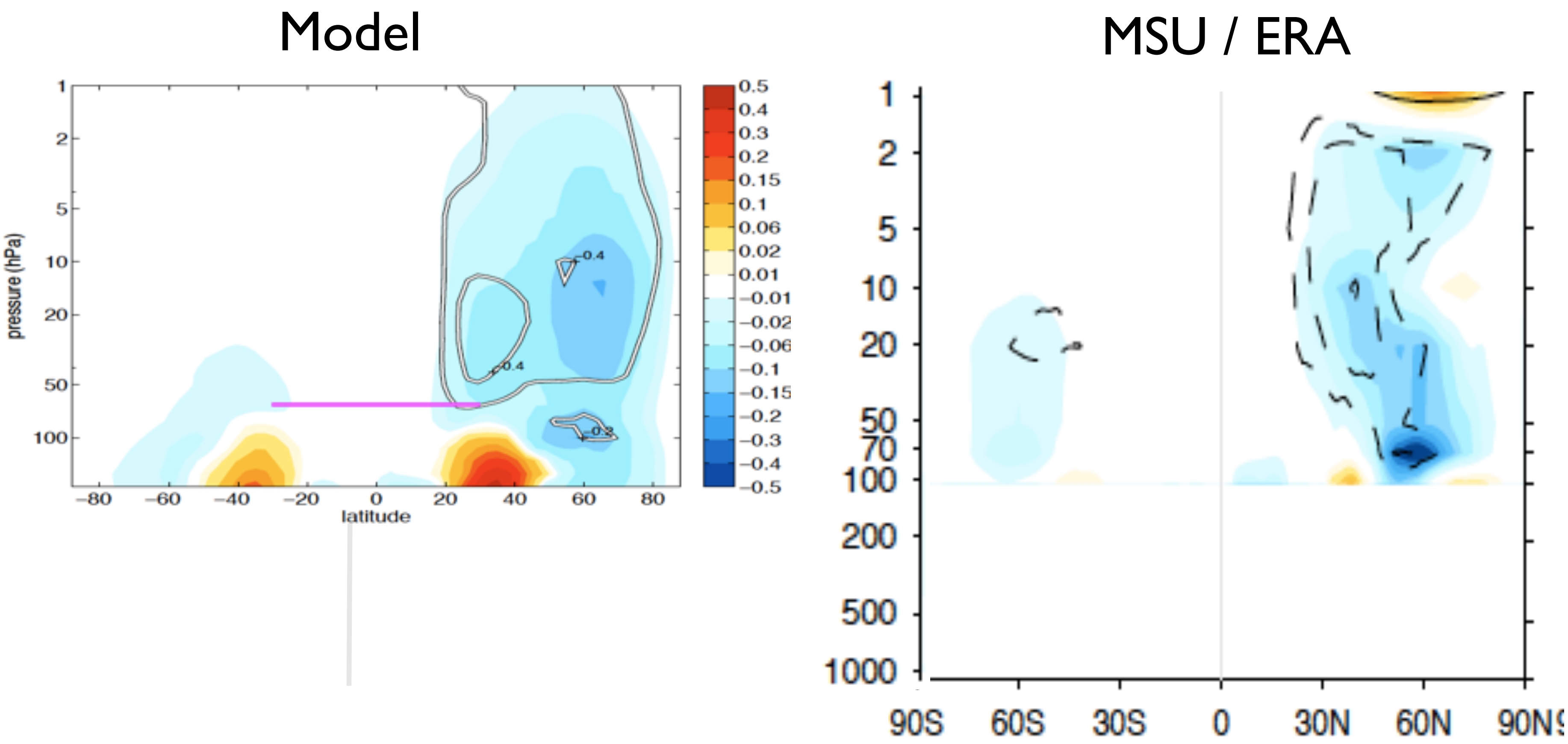


Model

ERA

MSU / ERA

ψ_{TEM} upon daily $\left.\frac{dT}{dt}\right._{30°\mathrm{S}–30°\mathrm{N}}$

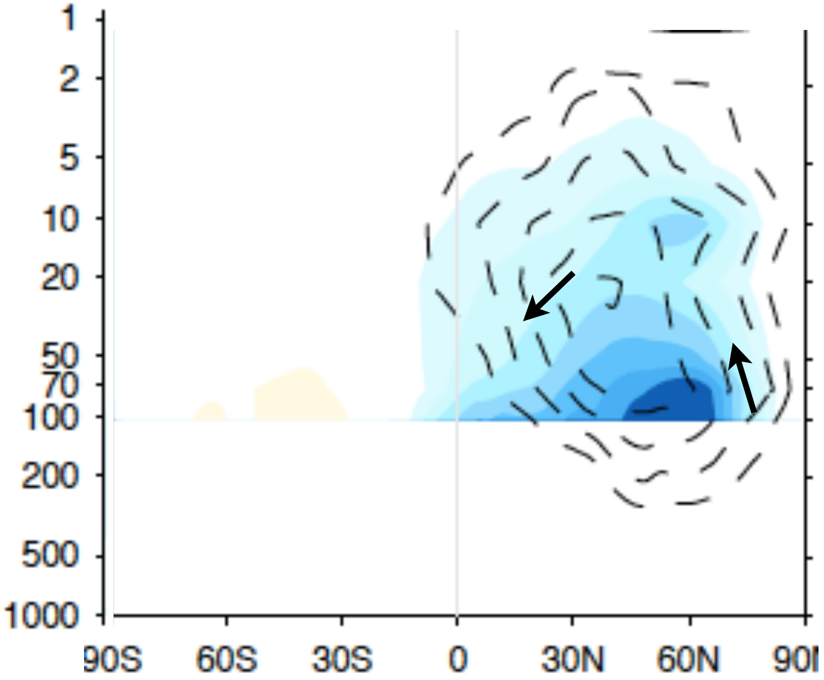


Model

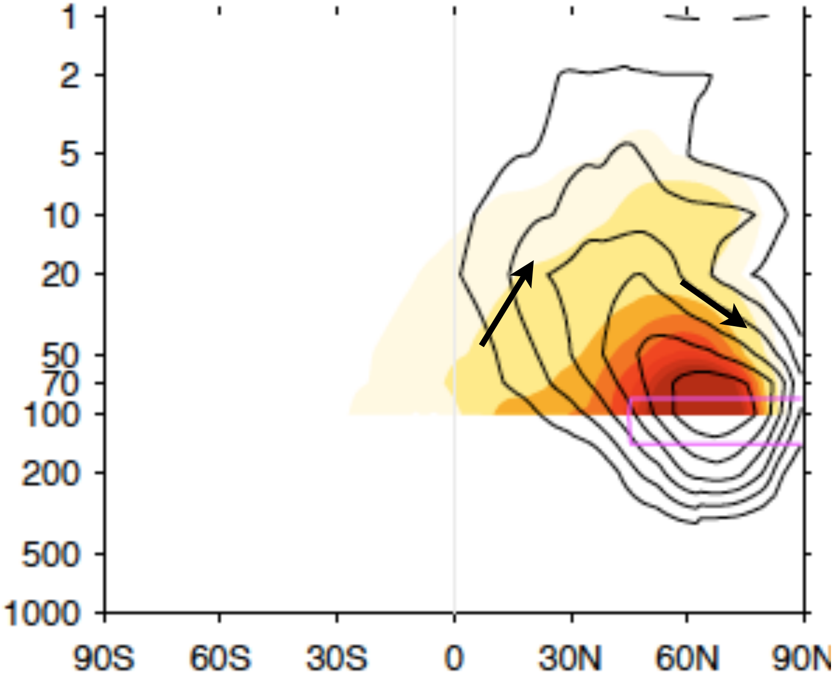
MSU / ERA

$$\nabla \cdot \vec{F} \quad \text{upon daily} \quad \frac{dT}{dt}_{\text{30°S–30°N}}$$

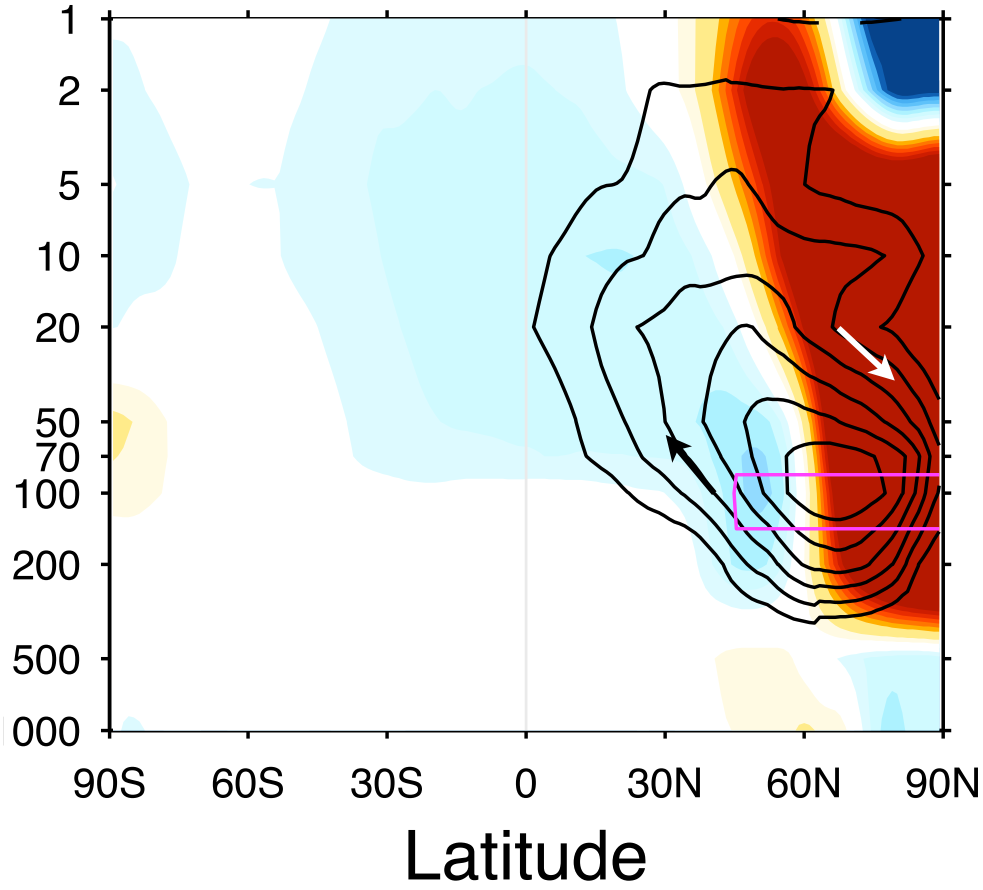
ψ_{TEM} ERA



upon daily $\frac{dT}{dt}^{\text{MSU-4}}_{30°\text{S}–30°\text{N}}$



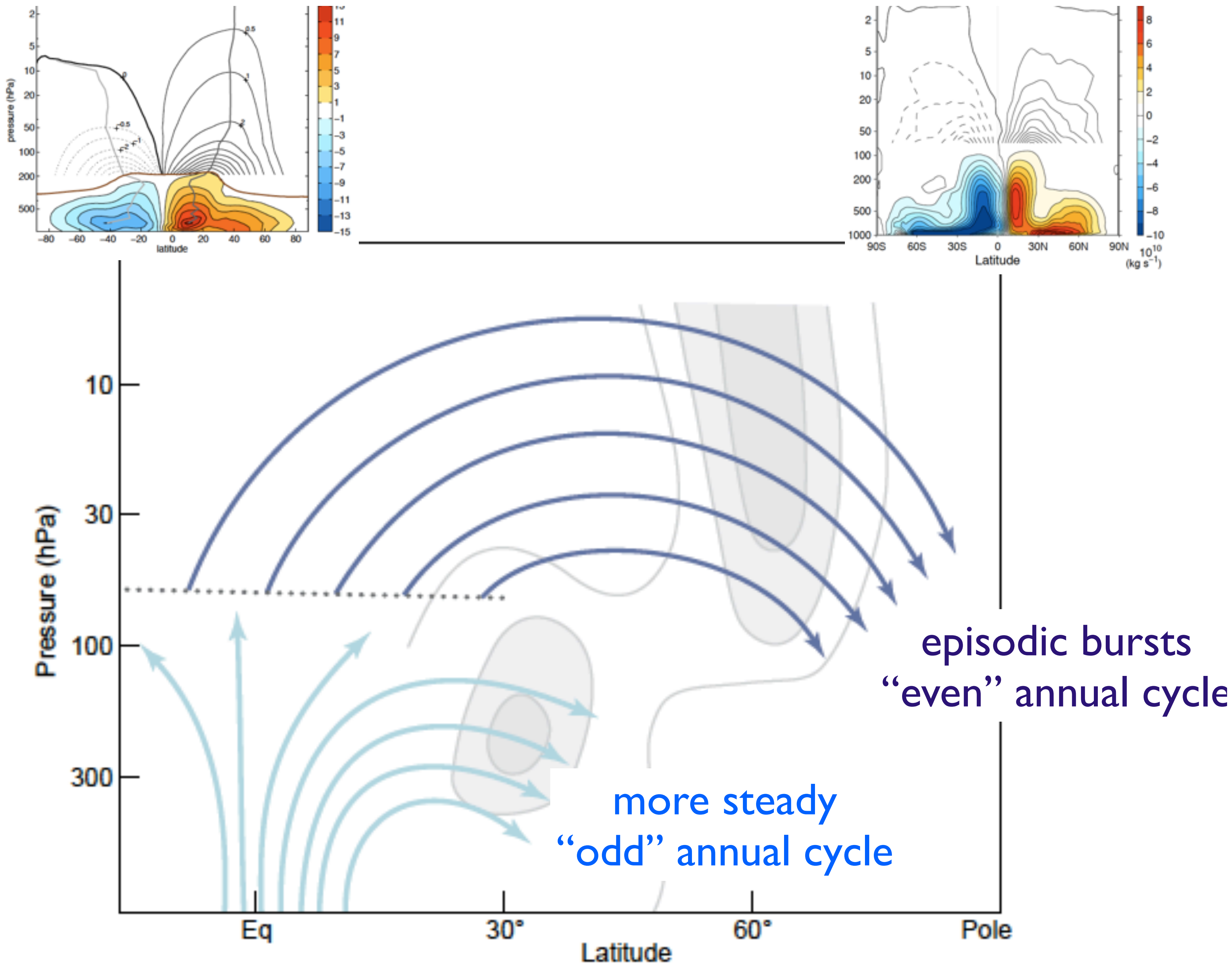
upon $\overline{v'T'}^{\text{100 hPa}}_{45°–90°\text{N}}$



color: *dT/dt*

contours: TEM ψ

regressed on $\overline{v'T'}^{\,100\ \mathrm{hPa}}_{45°\mathrm{S}–90°\mathrm{N}}$



episodic bursts
“even” annual cycle

more steady
“odd” annual cycle

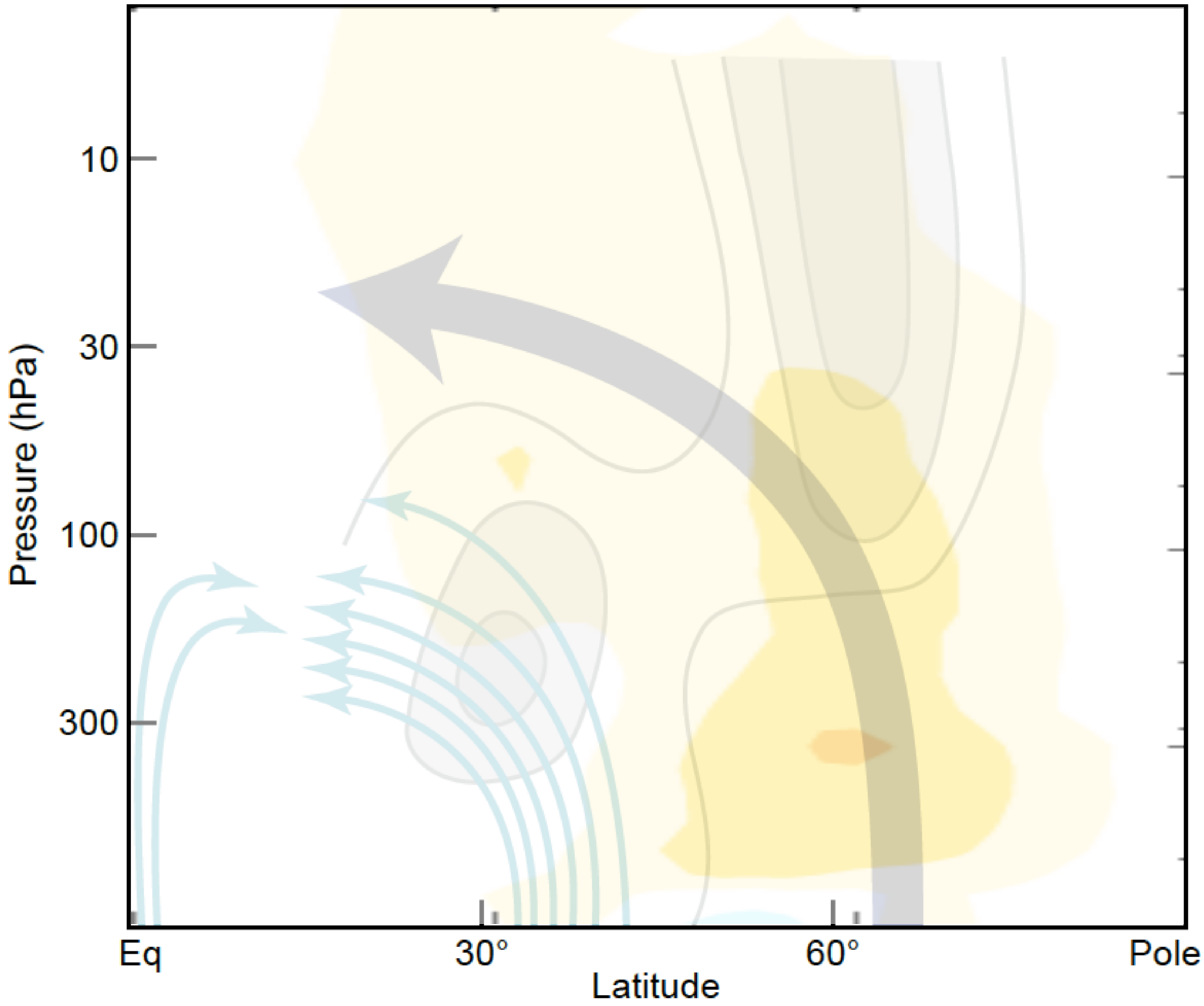
Conclusions

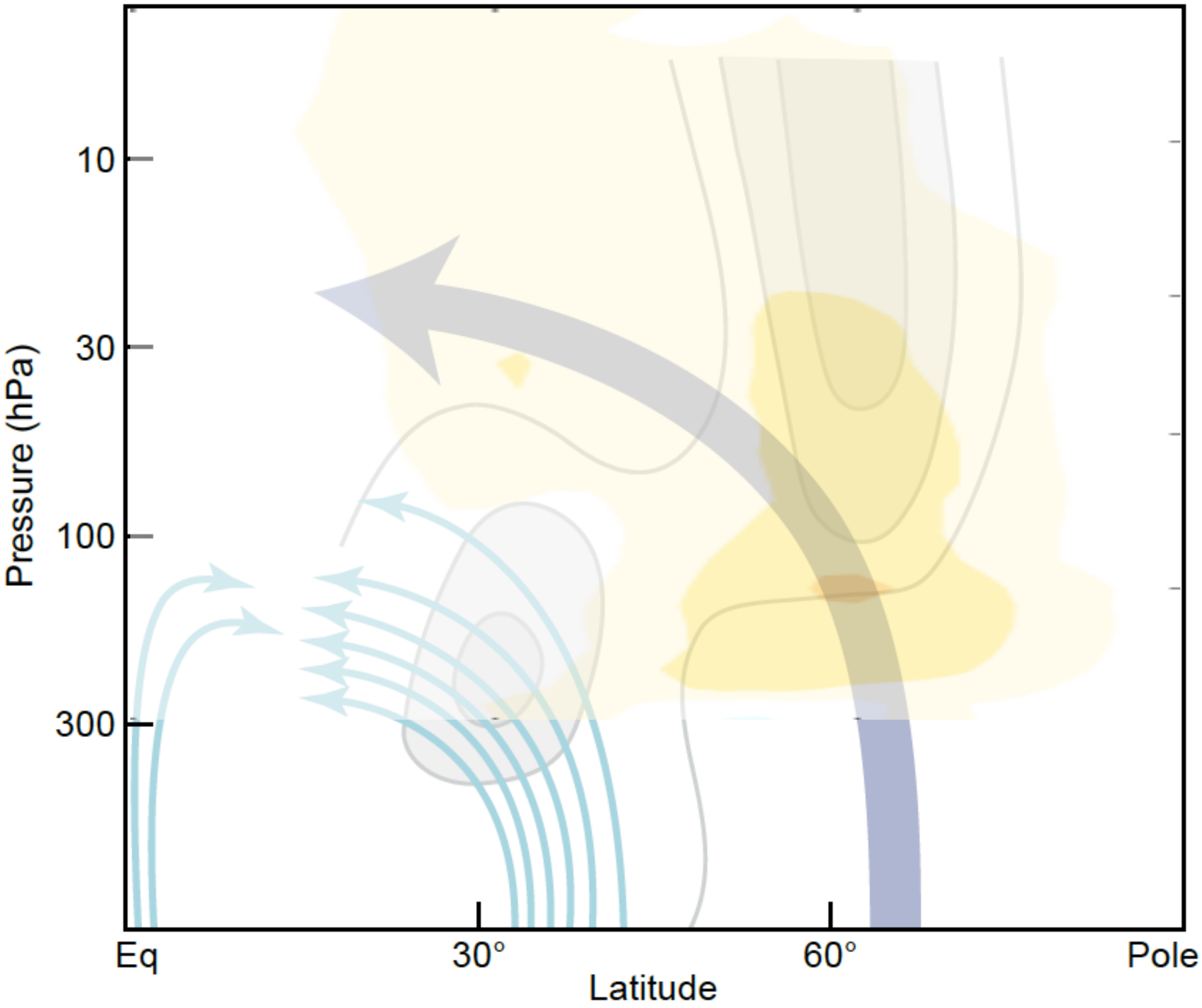
Tropospheric forcing is predominant at the cold point (100 hPa)
Stratospheric forcing predominant above 70 hPa

MSU-4 mainly samples the upper branch.
Cold point temperature mainly influenced by lower branch

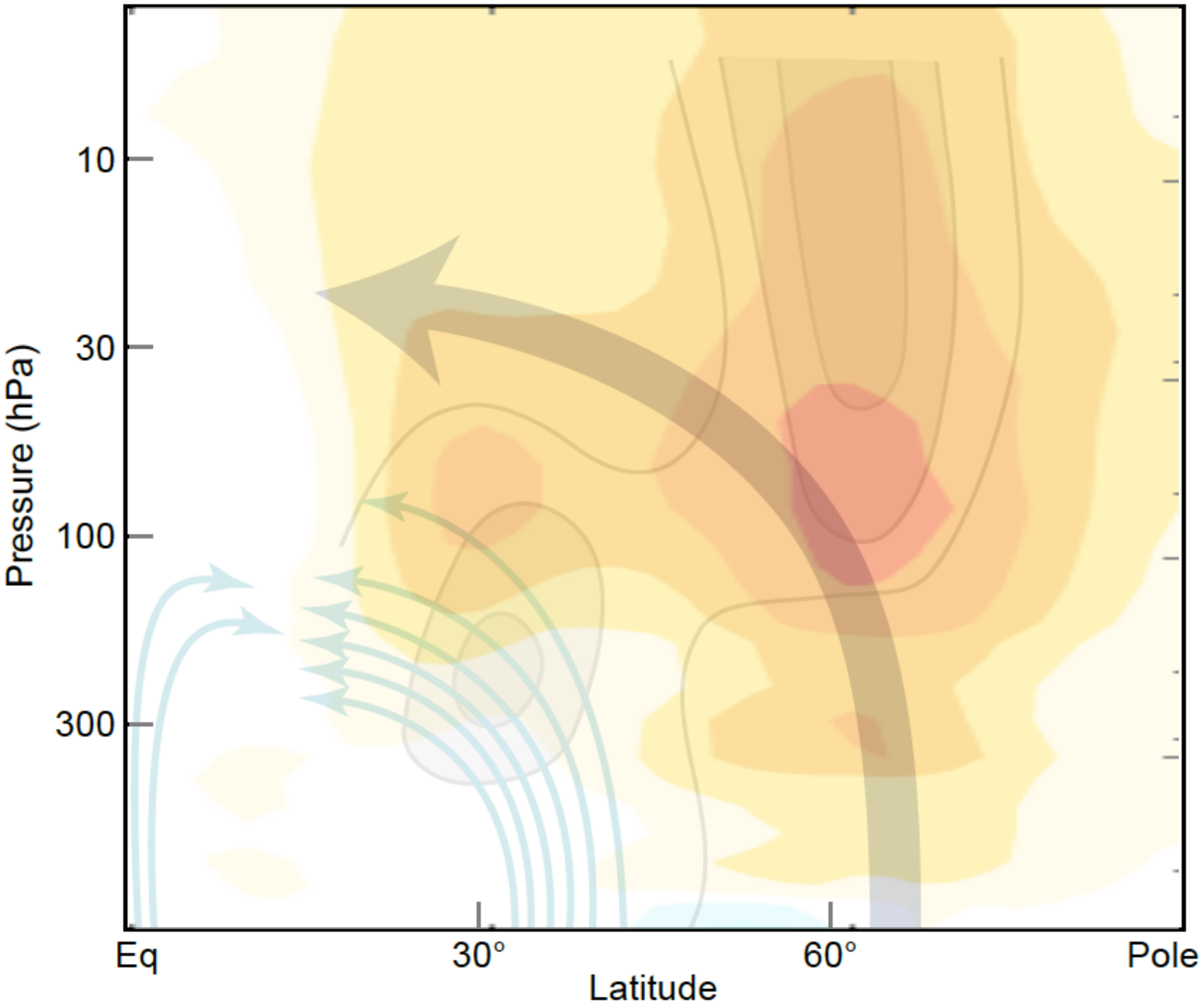
Low latitude wave-breaking in ERA reanalyses underestimated.

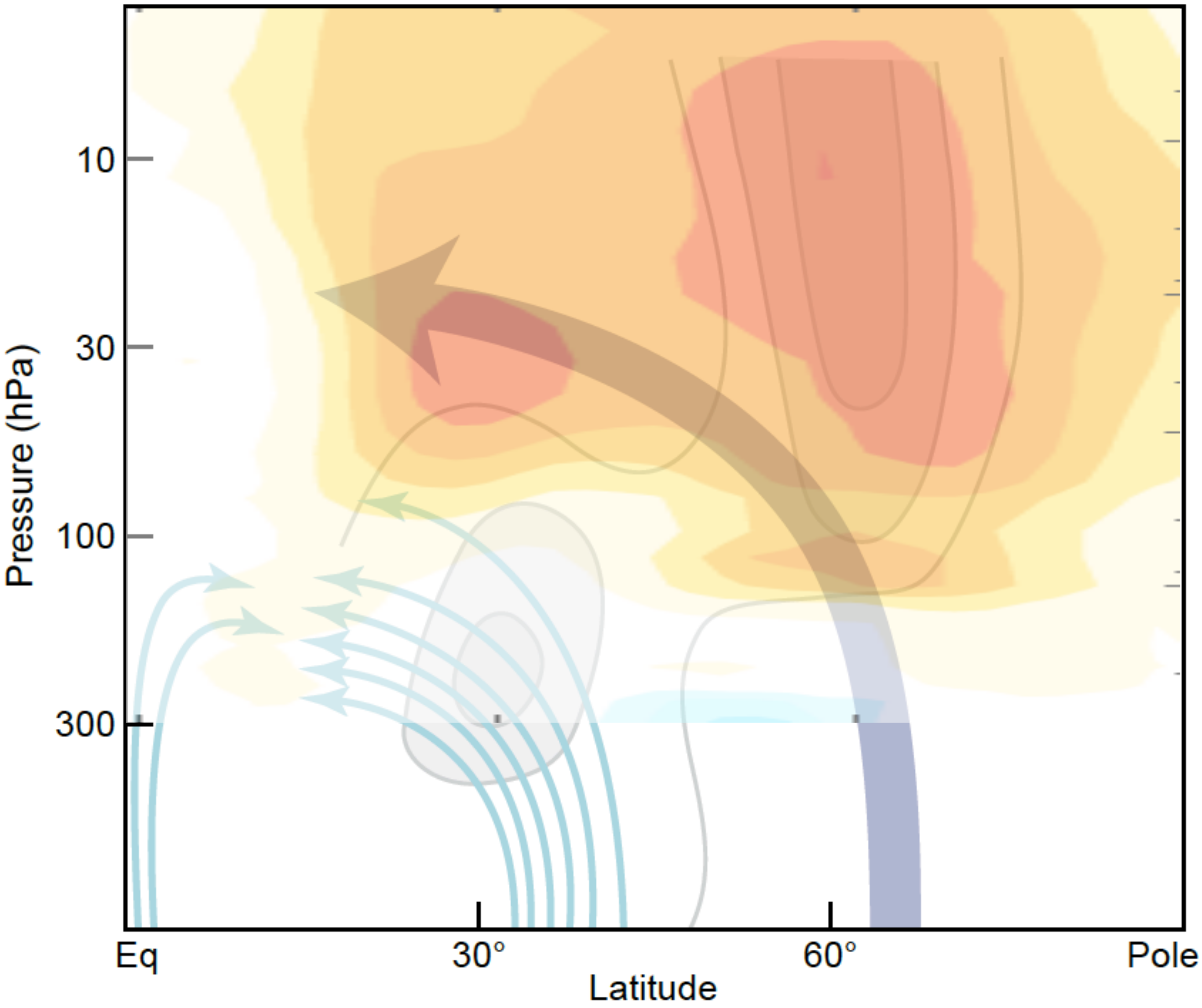
Forcing field is planetary in scale

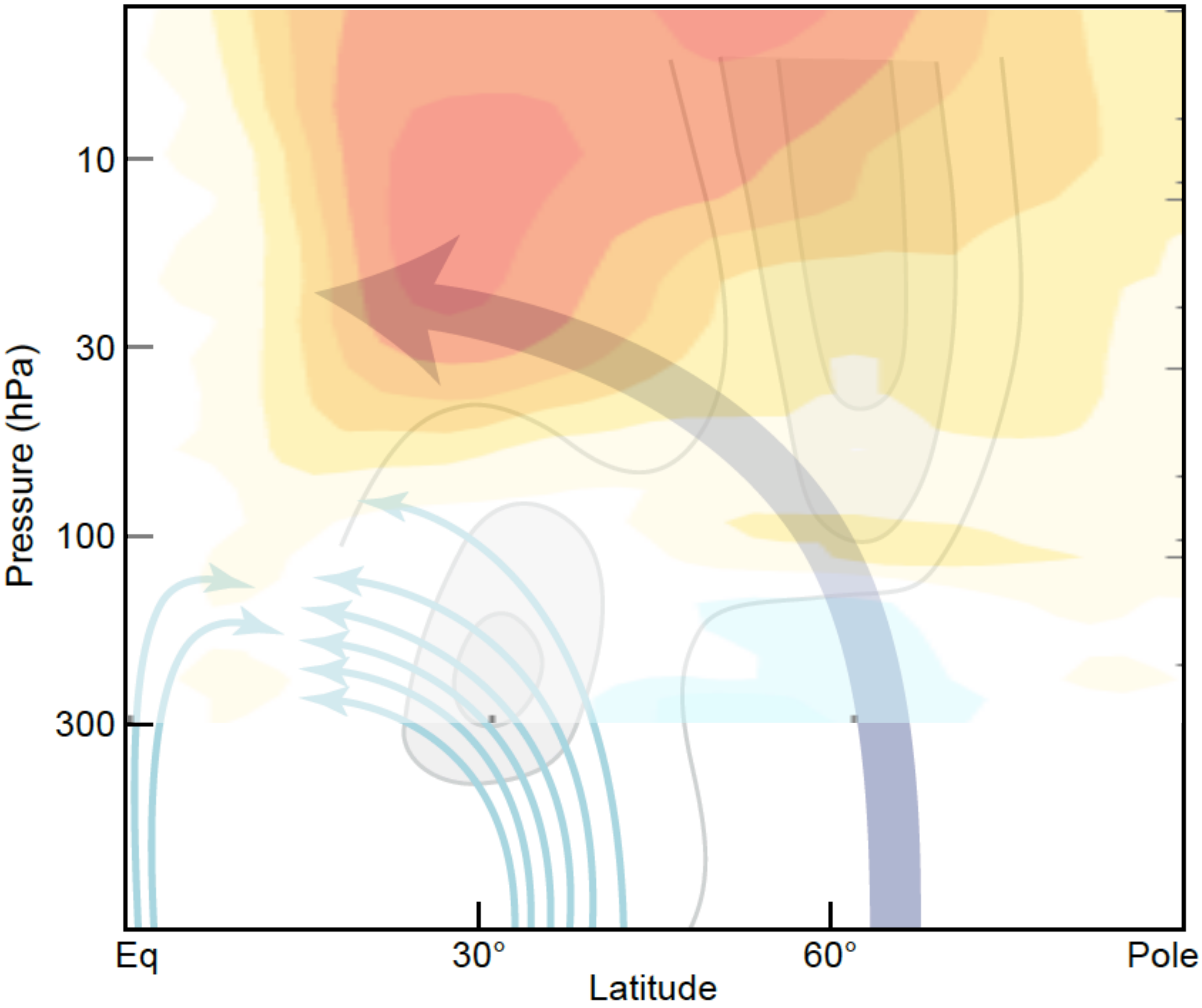

Pressure (hPa)
10
30
100
300
Eq
30°
60°
Pole
Latitude

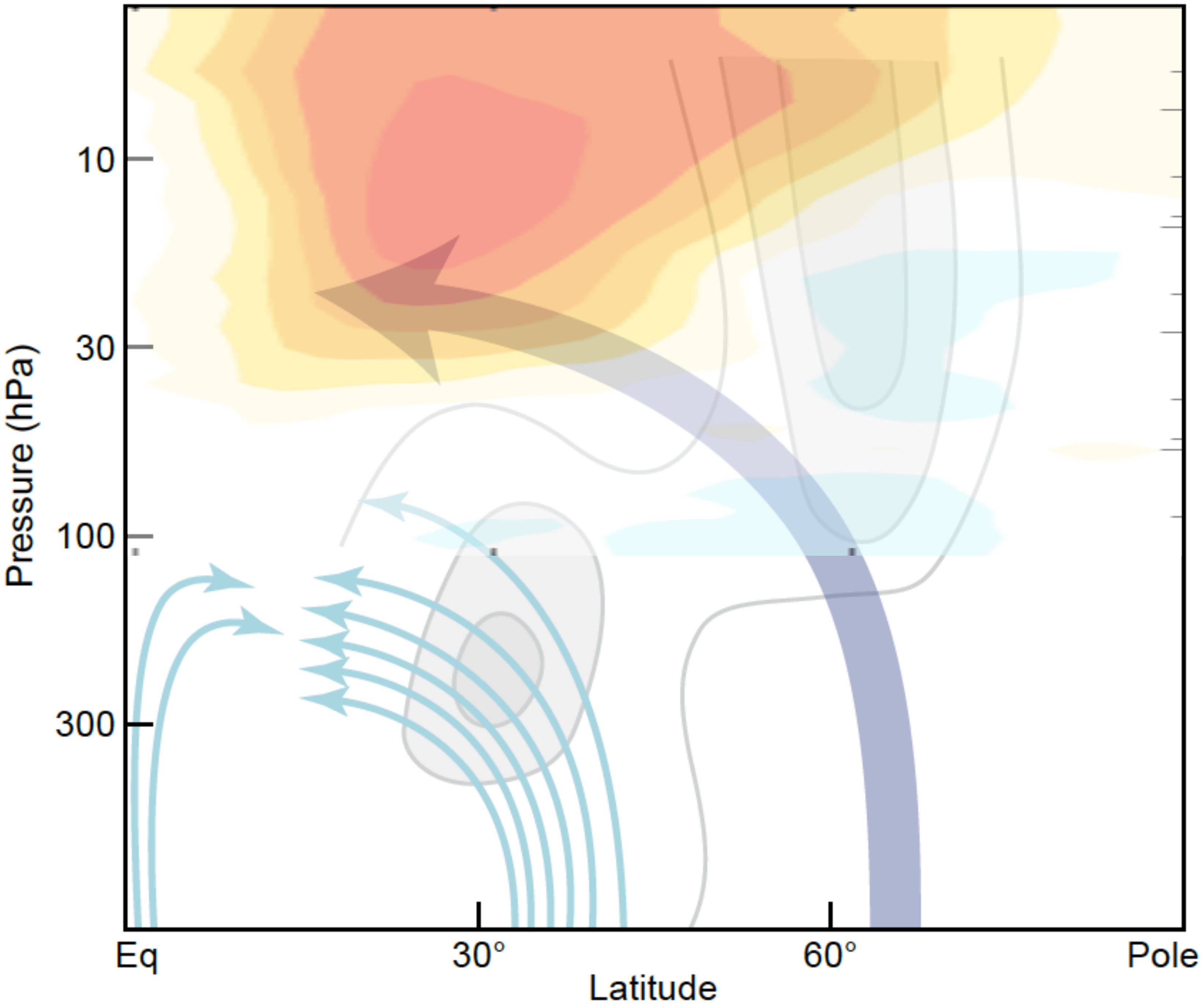


10
30
100
300
Pressure (hPa)
Eq
30°
60°
Pole
Latitude


Pressure (hPa)
10
30
100
300
Eq
30°
60°
Pole
Latitude


Pressure (hPa)
10
30
100
300
Eq
30°
60°
Pole
Latitude


10
30
100
300
Pressure (hPa)
Eq
30°
60°
Pole
Latitude


10
30
100
300
Pressure (hPa)
Eq
30°
60°
Pole
Latitude