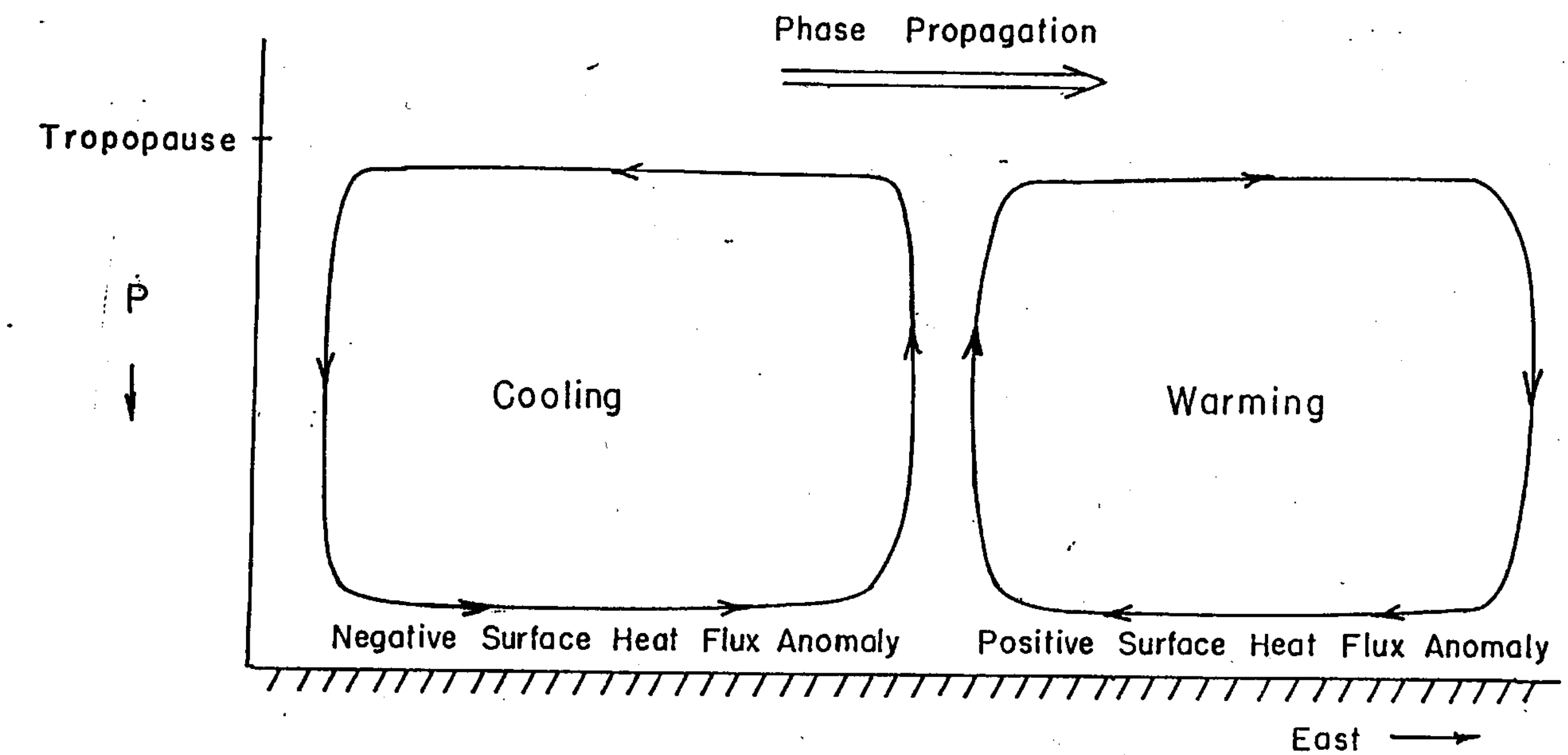
Intraseasonal Variability

- Stochastic excitation of the equatorial waveguide
- WISHE
- Moisture-convection feedback
- Cloud-radiation feedback
- Ocean interaction
- Self-aggregation on the equator

Wind-Induced Surface Heat Exchange (WISHE)



Add back WISHE term to linear undamped equations:

$$\frac{\partial u}{\partial t} = \frac{\partial s}{\partial x} + yv$$

$$\frac{\partial v}{\partial t} = \delta\left(\frac{\partial s}{\partial y} - yu\right)$$

$$\frac{\partial s}{\partial t} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \alpha u$$

First look for Kelvin-like modes with v=0:

$$\frac{\partial u}{\partial t} = \frac{\partial s}{\partial x}$$

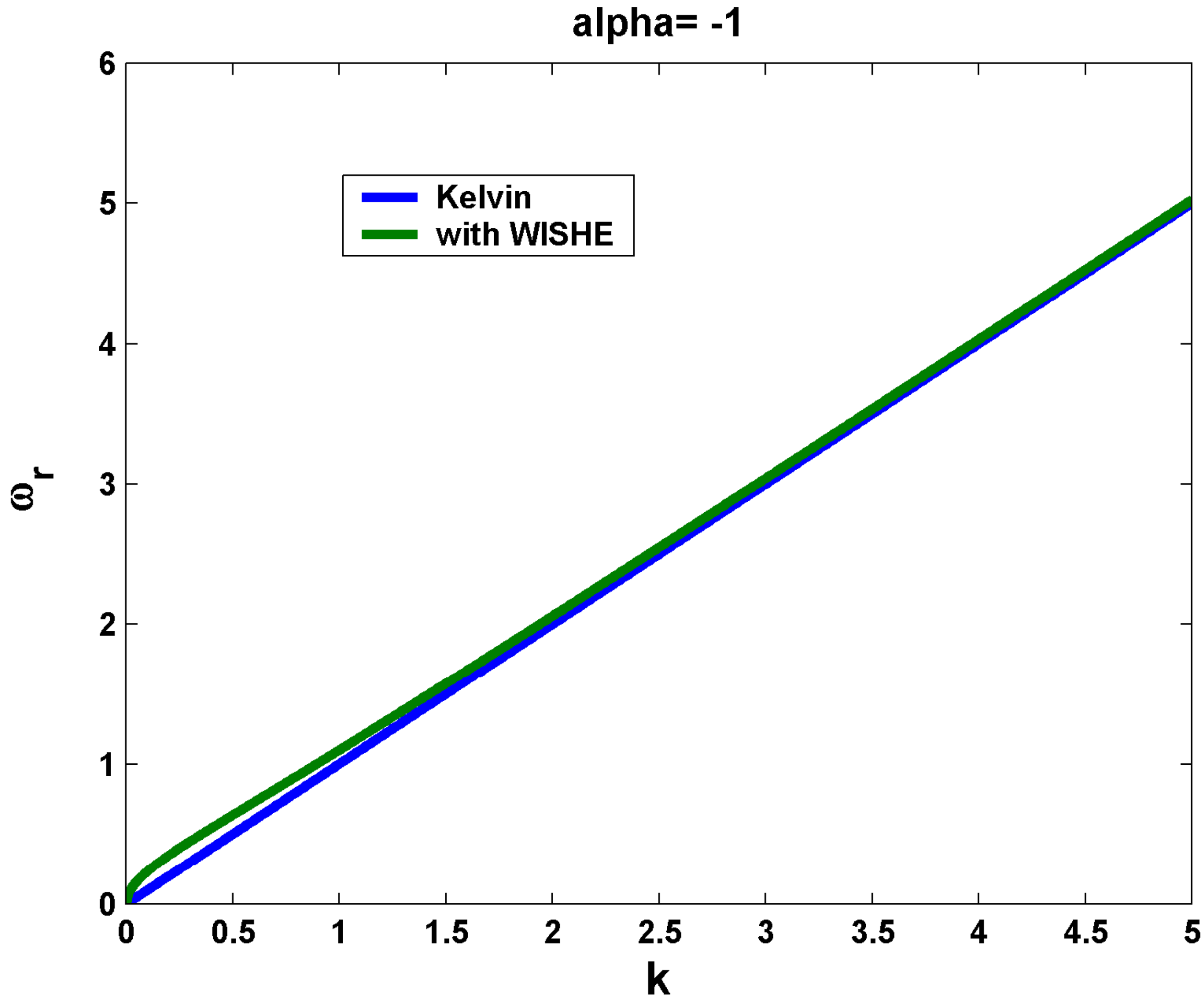
$$\frac{\partial s}{\partial t} = \frac{\partial u}{\partial x} + \alpha u$$

$$\rightarrow \frac{\partial^2 u}{\partial t^2} = \frac{\partial^2 u}{\partial x^2} + \alpha \frac{\partial u}{\partial x}$$

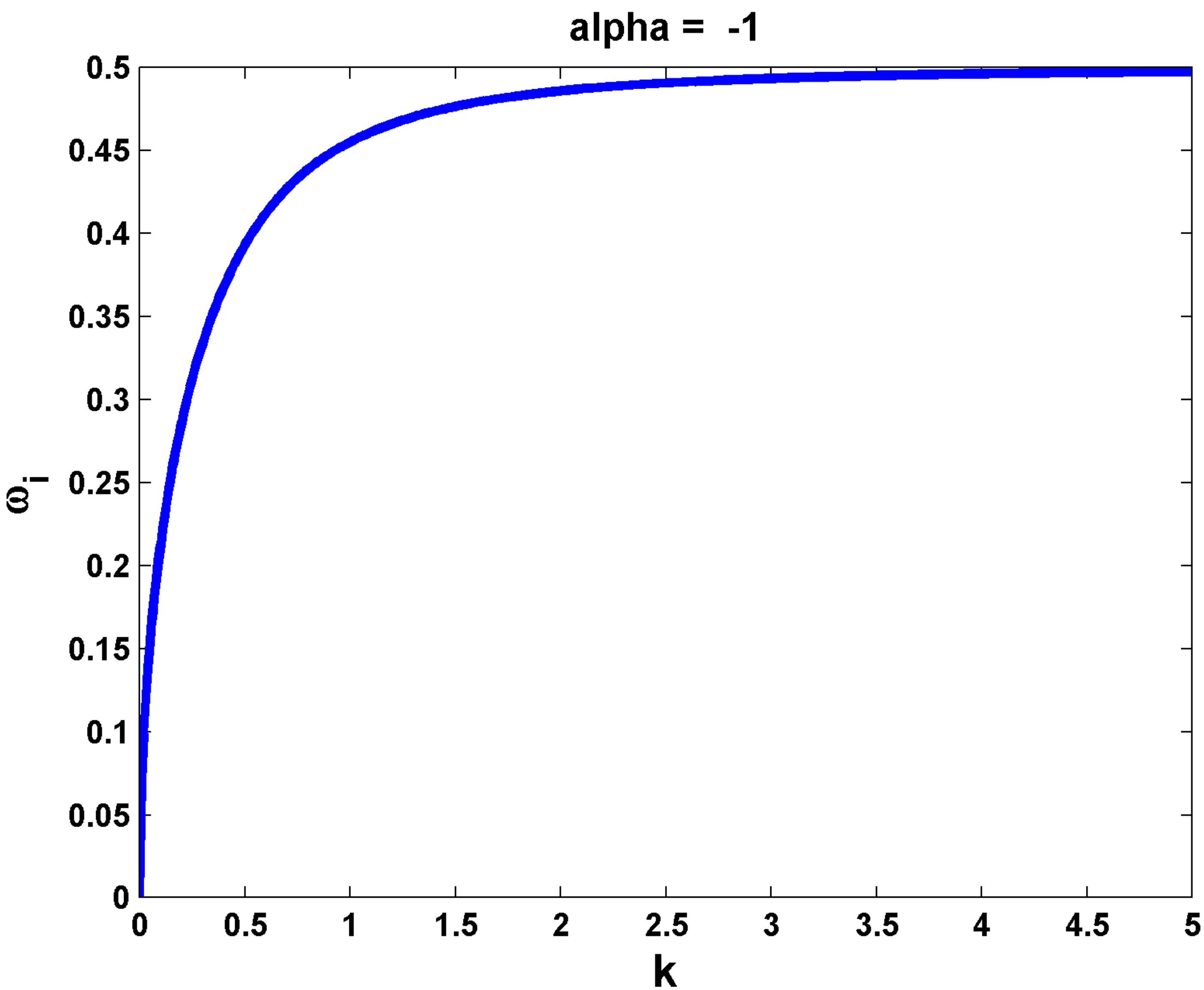
$$Let\ u = u_0 e^{ikx - i\omega t}\ :$$

$$\omega^2 = k^2 - i\alpha k$$

Note: α must be < 0 for $\omega_r > 0$ and $\omega_i > 0$



As k $\rightarrow \infty$ $\omega_i \rightarrow -\alpha/2$



Effect of Stratosphere (Yano and Emanuel, 1991)

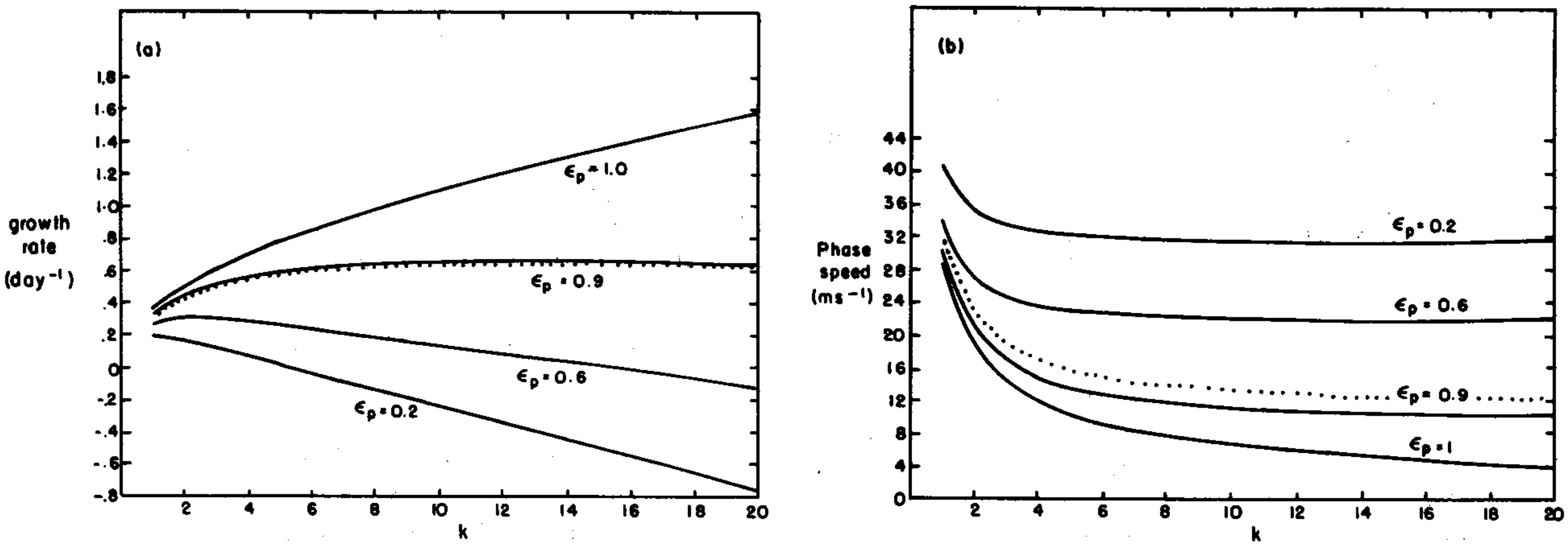


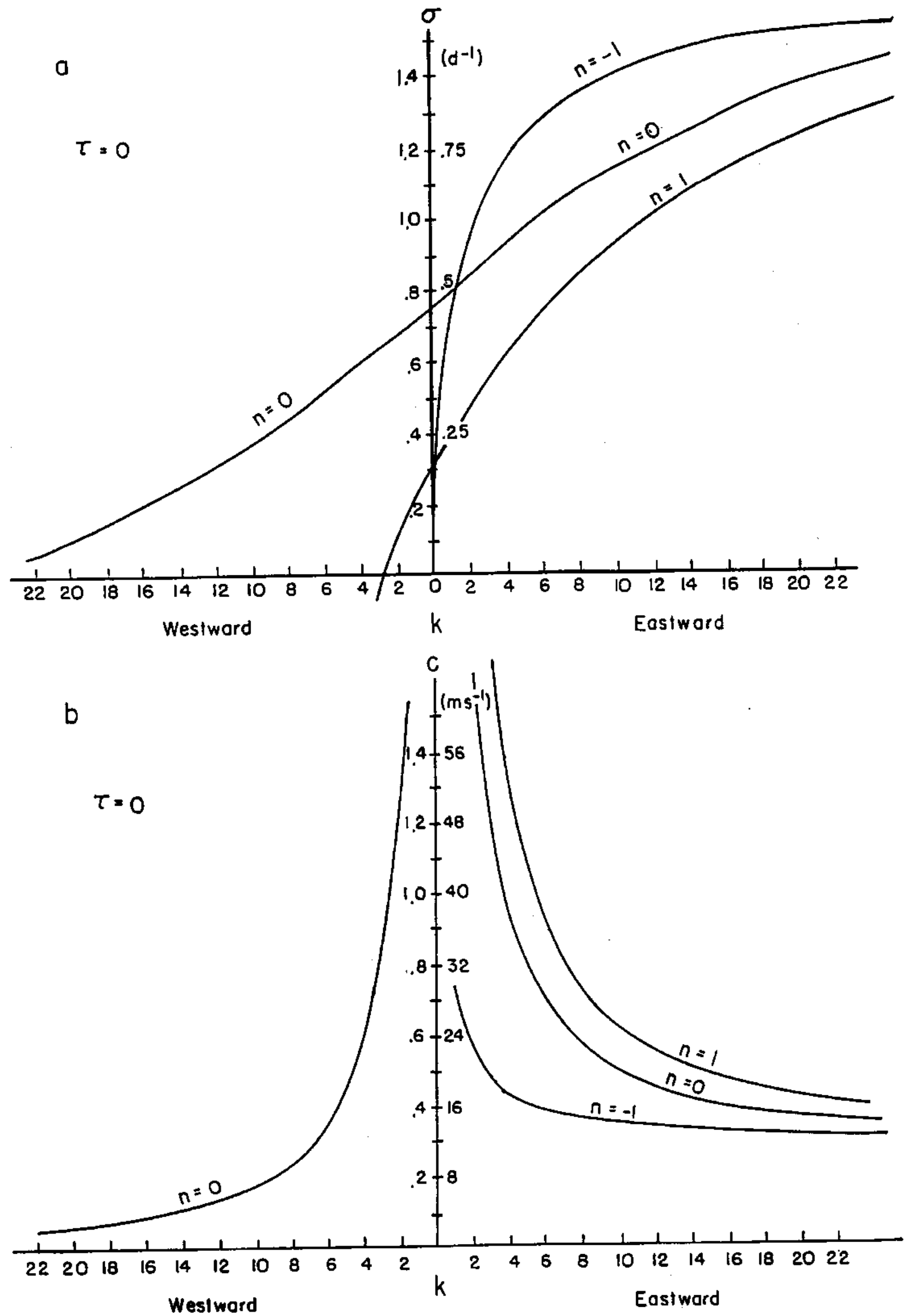
FIG. 5. The growth rate (a) and flow-relative phase speed (b) of WISHE modes with a coupled stratosphere for various values of the precipitation efficiency, ϵ_p. The other parameter values are $\lambda = 1$, $\nu = 3$, and $S^{1/2}H_e = 10.17$. Asymptotic solutions (34) for $\epsilon_p = 0.9$ are shown by dotted lines.

Effect of finite convective response time:

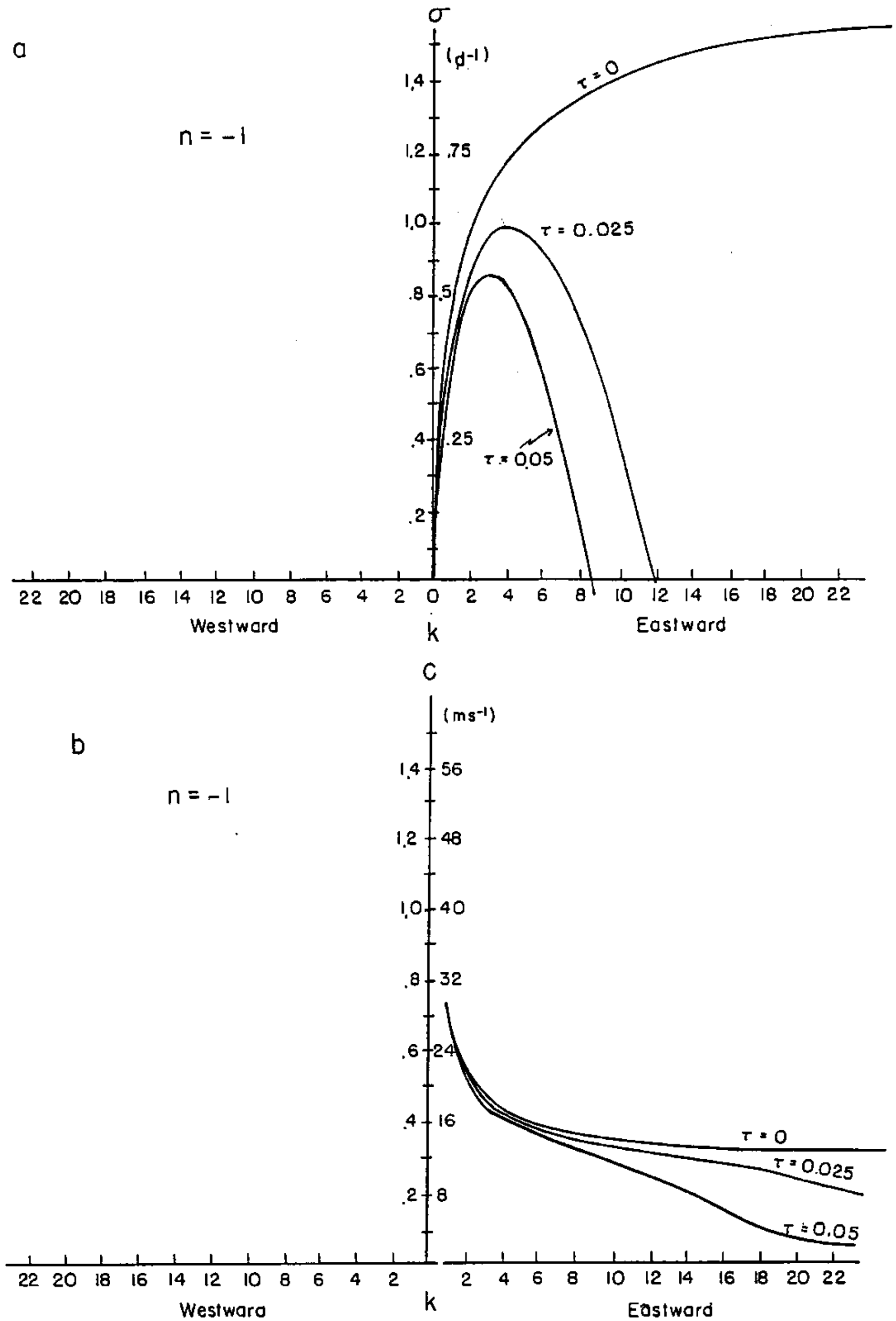
$$\frac{\partial s}{\partial t} = \frac{1}{1-\varepsilon_p}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + M$$

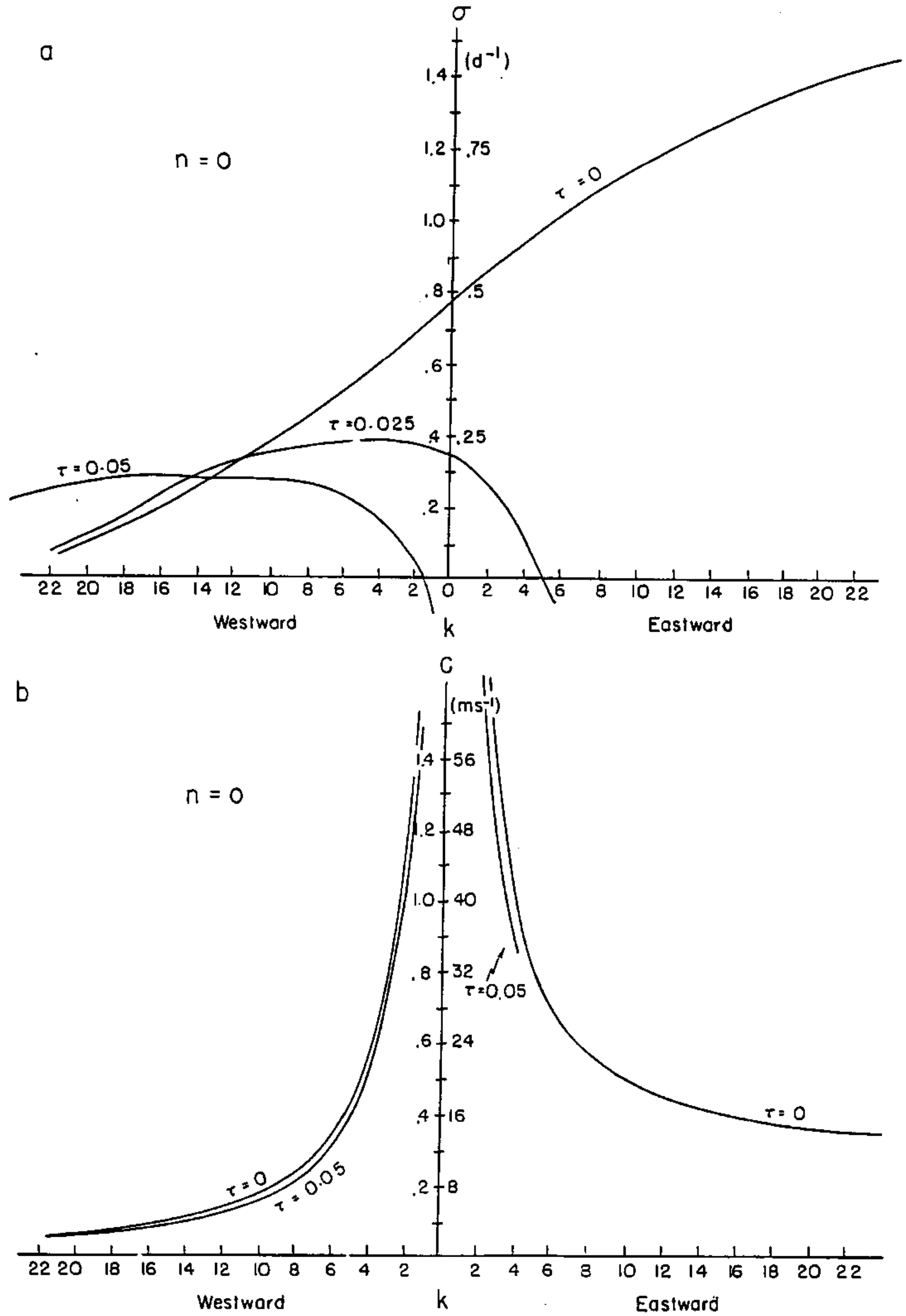
$$M_{eq} = \frac{-\varepsilon_p}{1-\varepsilon_p}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + \alpha u$$

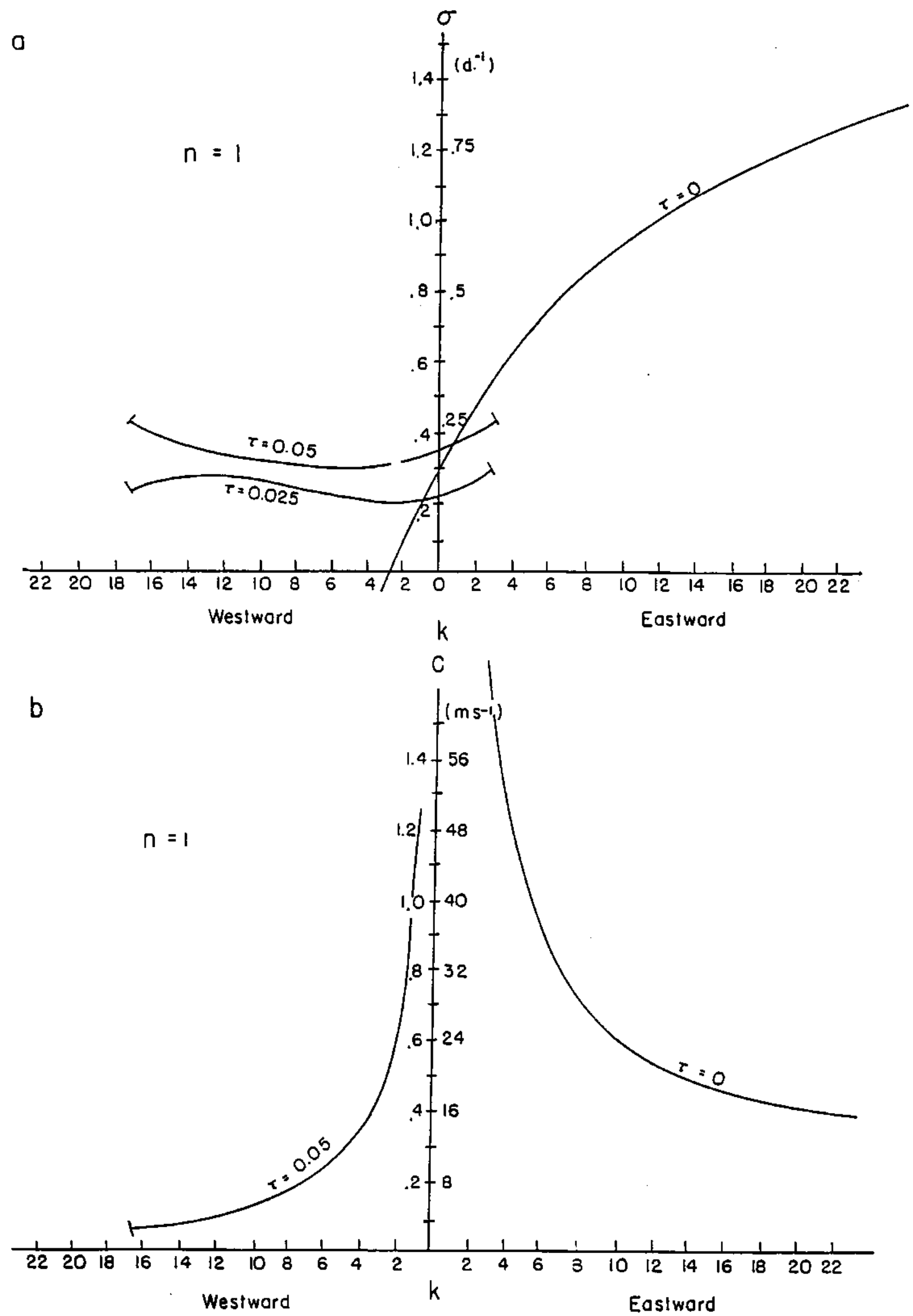
$$\frac{\partial M}{\partial t} = \frac{M_{eq} - M}{\tau_c}$$



a
τ = 0
σ
(d⁻¹)
1.4
1.2 .75
1.0
.8 .5
.6
.4 .25
.2
n = -1
n = 0
n = 1
n = 0
22 20 18 16 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14 16 18 20 22
Westward
k
Eastward
b
τ = 0
c
(ms⁻¹)
1.4 56
1.2 48
1.0 40
.8 32
.6 24
.4 16
.2 8
n = 1
n = 0
n = -1
n = 0
22 20 18 16 14 12 10 8 6 4 2 2 4 6 8 10 12 14 16 18 20 22
Westward
k
Eastward


a
n = -1
σ
(d-1)
τ = 0
τ = 0.025
τ = 0.05
Westward
Eastward
k
b
n = -1
c
(ms-1)
τ = 0
τ = 0.025
τ = 0.05
Westward
Eastward
k


a
σ
(d⁻¹)
n = 0
τ = 0
τ = 0.025
τ = 0.05
1.4
1.2
.75
1.0
.8
.5
.6
.4
.25
.2
22 20 18 16 14 12 10 8 6 4 2 0 2 4 6 8 10 12 14 16 18 20 22
Westward
k
Eastward
b
C
(ms⁻¹)
n = 0
τ = 0
τ = 0.05
1.4
56
1.2
48
1.0
40
.8
32
.6
24
.4
16
.2
8
22 20 18 16 14 12 10 8 6 4 2 2 4 6 8 10 12 14 16 18 20 22
Westward
k
Eastward


a
σ
(d.⁻¹)
n = 1
τ = 0
τ = 0.05
τ = 0.025
Westward
Eastward
k
b
C
(ms⁻¹)
n = 1
τ = 0.05
τ = 0
Westward
Eastward
k

Go back to dimensional, quasi-linear QE equations on β plane

Quasi-Linear β Plane System , Neglecting Barotropic Mode

$$\frac{\partial u}{\partial t} = \left(T_s - \overline{T}\right)\frac{\partial s^*}{\partial x} + \beta yv - ru$$

$$\frac{\partial v}{\partial t} = \left(T_s - \overline{T}\right)\frac{\partial s^*}{\partial y} - \beta yu - rv$$

$$\frac{\partial s^*}{\partial t} = \frac{\Gamma_d}{\Gamma_m}\left(\dot{Q}_{rad} + \frac{\partial s_d}{\partial z}\left(\varepsilon_p M - w\right)\right)$$

$$h\frac{\partial s_b}{\partial t} = C_k \,|\mathbf{V}|\left(s_0^* - s_b\right) - \left(M - w\right)\left(s_b - s_m\right)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{w}{H}=0$$

Define an equilibrum updraft mass flux from boundary layer QE:

$$M_{eq}\equiv w+C_k\,|\mathbf{V}|\,\frac{s_0*-s_b}{s_b-s_m}$$

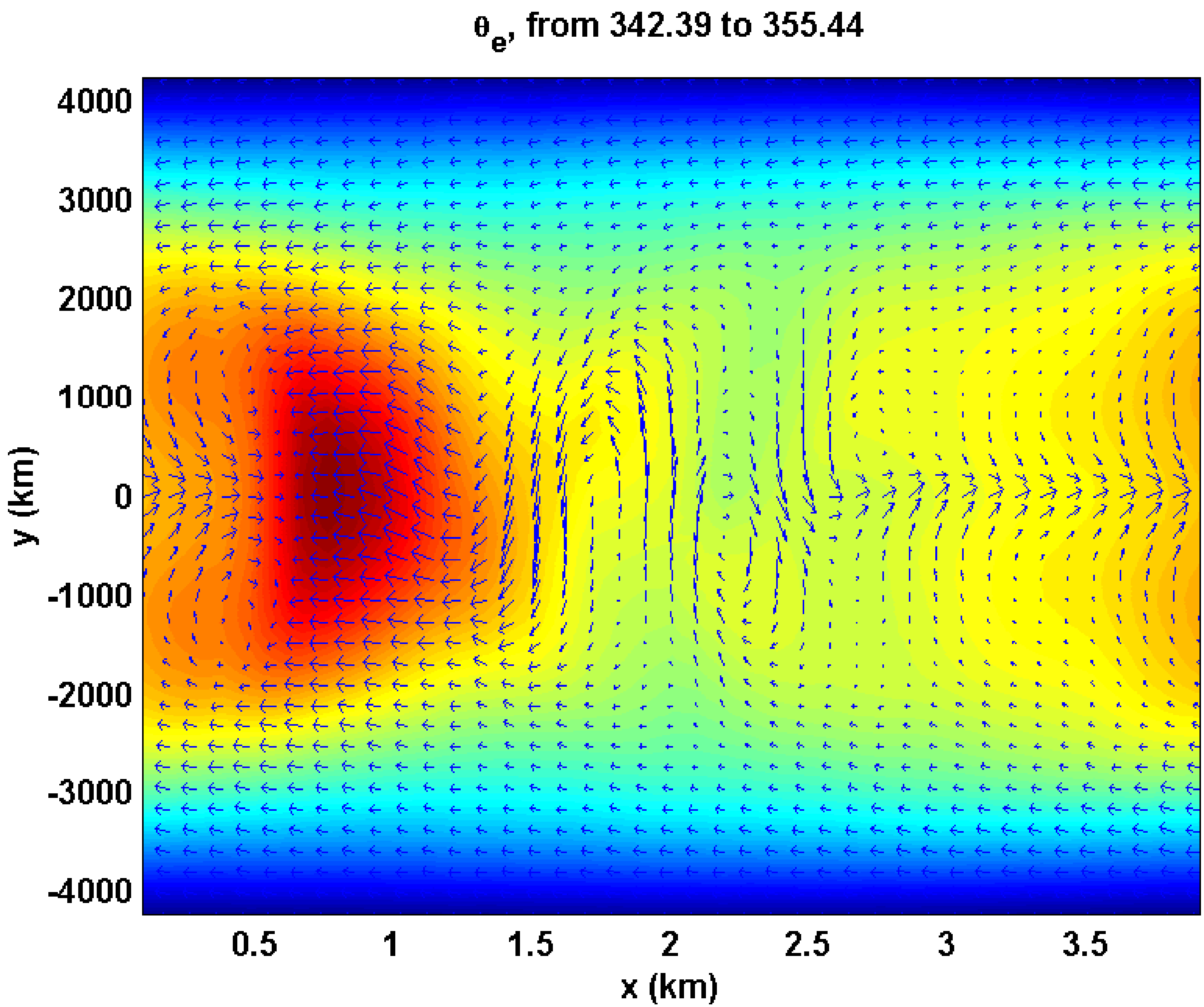
Relax to equilibrium over a finite time scale:

$$\frac{\partial M}{\partial t}=\frac{M_{eq}-M}{\tau_{convective}}$$

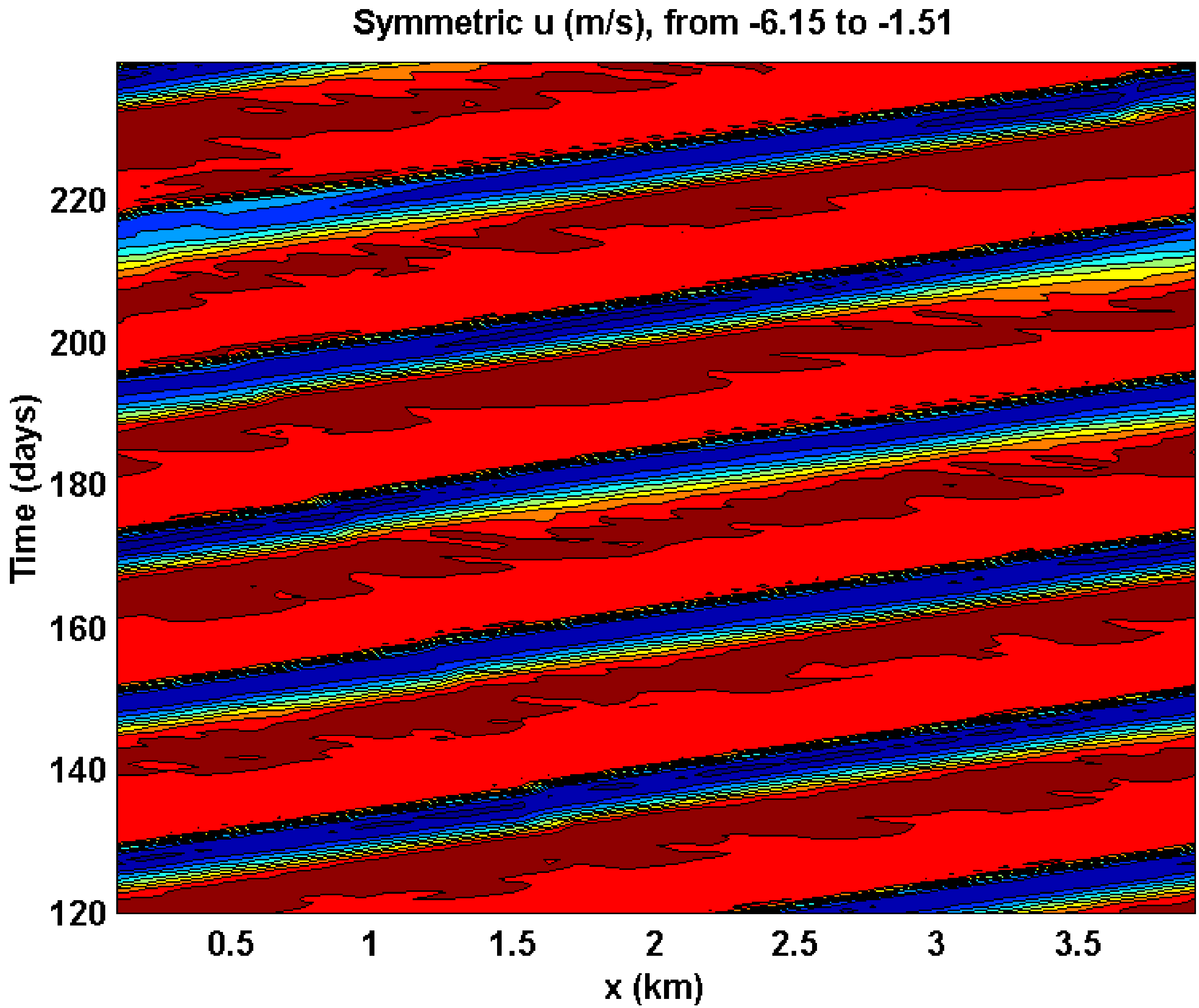
and enforce $M\geq 0$

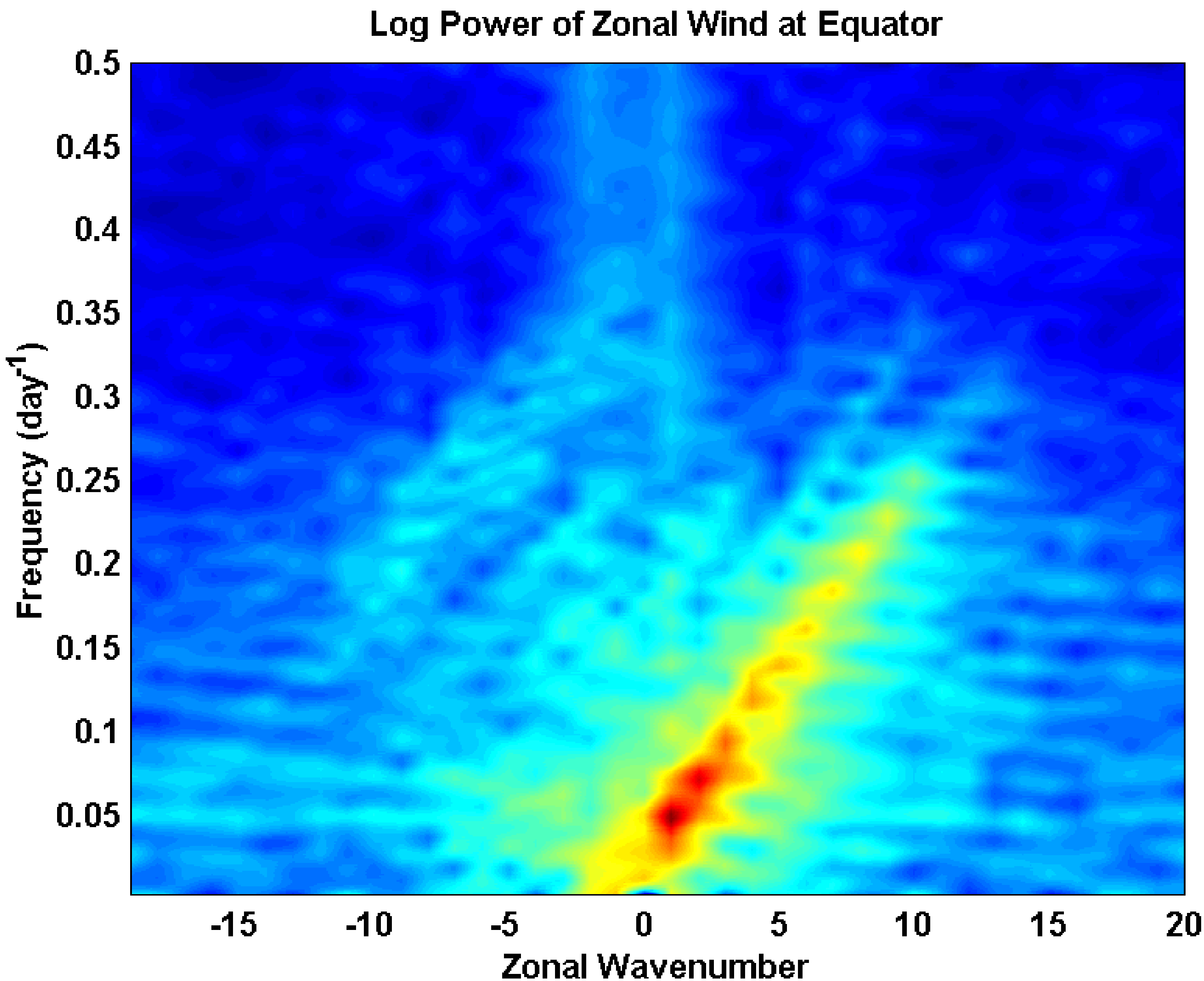
Numerical solution of β plane quasi-linear equations

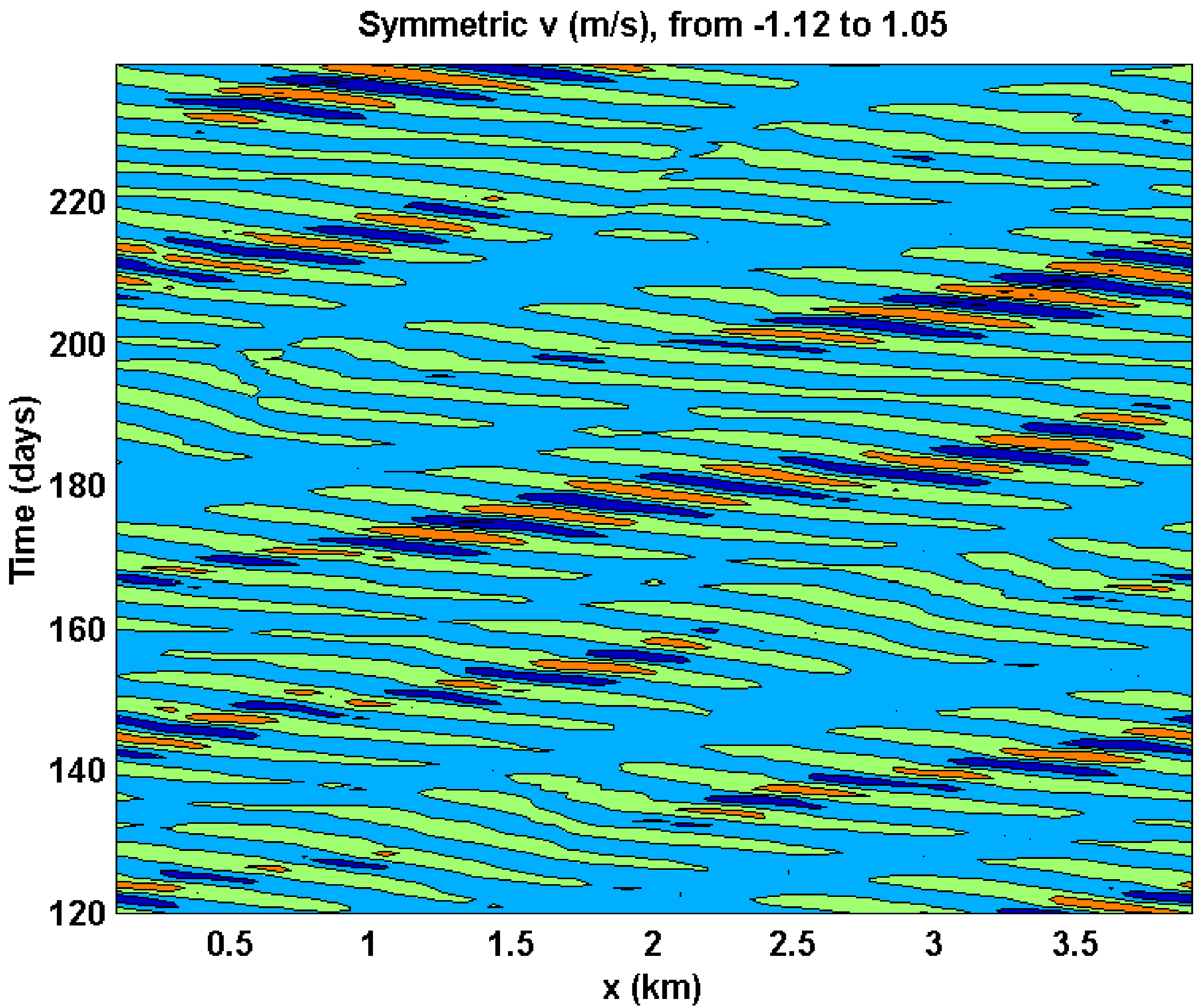
- Nonlinearity retained only in surface fluxes
- Zonally symmetric SST specified; also symmetric about equator
- Background easterly wind of 2 ms^{-1} imposed
- Convection relaxed to equilibrium over time scale of 3 hours

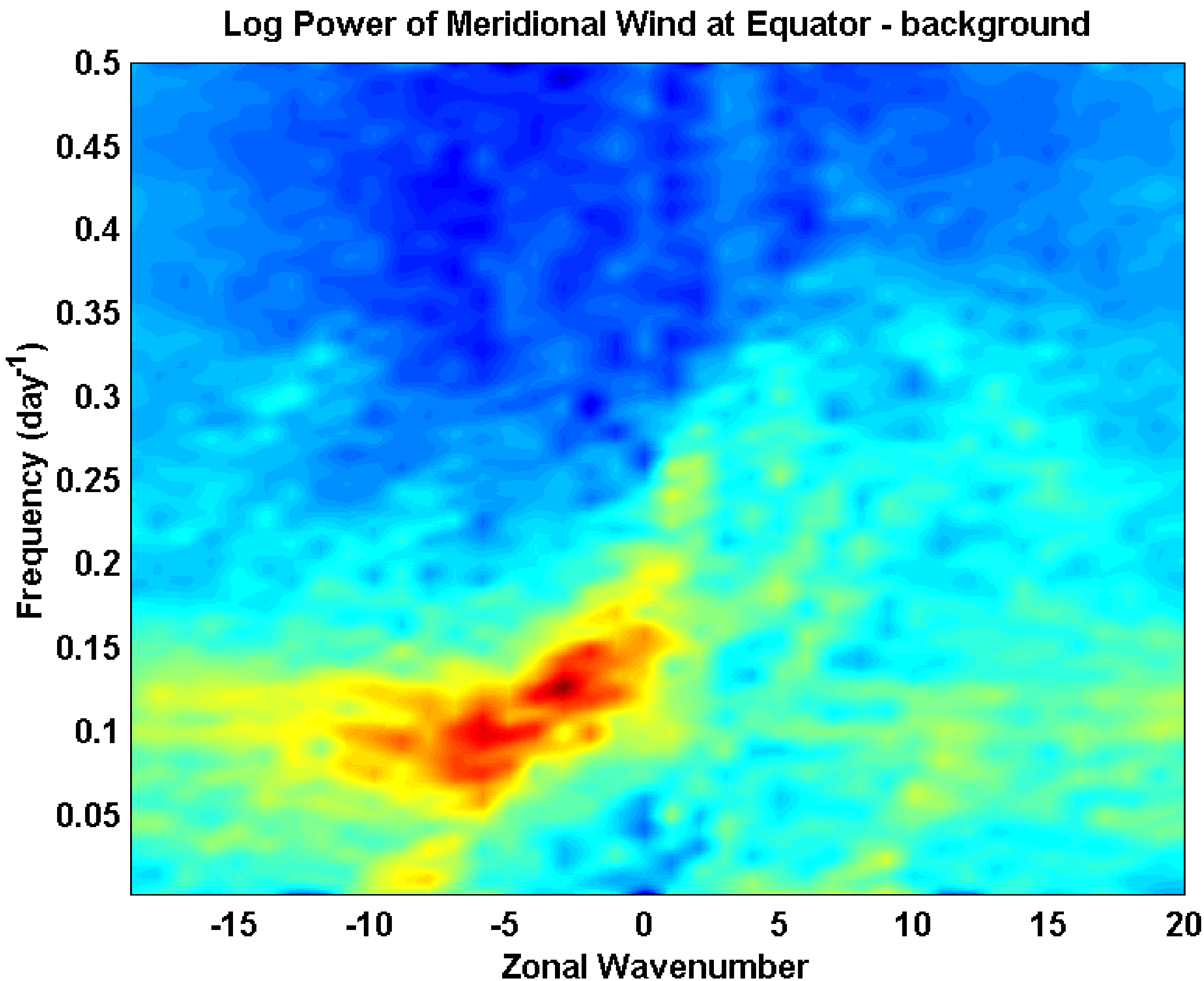


θ_e, from 342.39 to 355.44
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
y (km)
0.5
1
1.5
2
2.5
3
3.5
x (km)

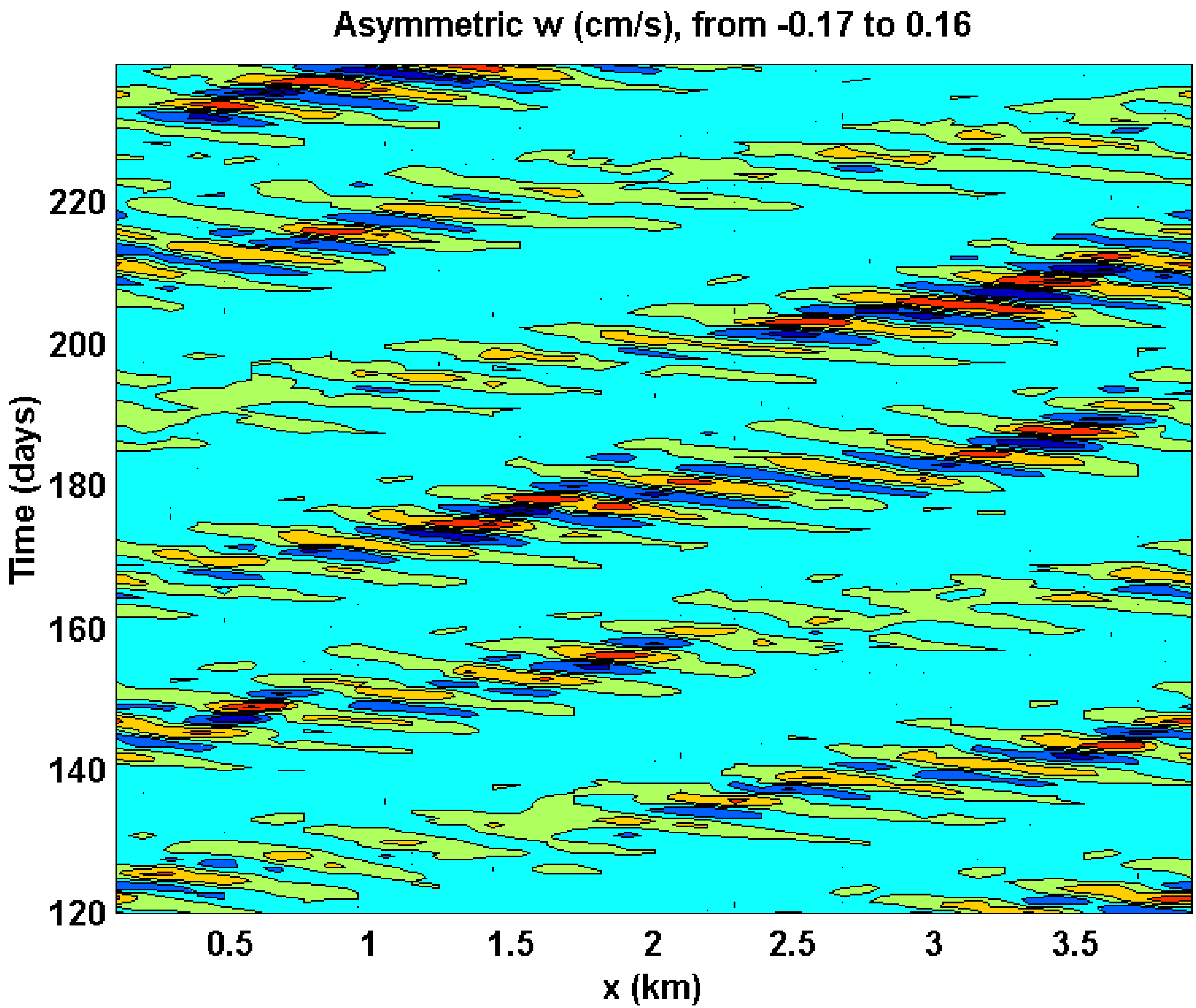

Symmetric u (m/s), from -6.15 to -1.51
Time (days)
220
200
180
160
140
120
0.5
1
1.5
2
2.5
3
3.5
x (km)


Log Power of Zonal Wind at Equator
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Frequency (day-1)
-15
-10
-5
0
5
10
15
20
Zonal Wavenumber


Symmetric v (m/s), from -1.12 to 1.05
Time (days)
220
200
180
160
140
120
0.5
1
1.5
2
2.5
3
3.5
x (km)

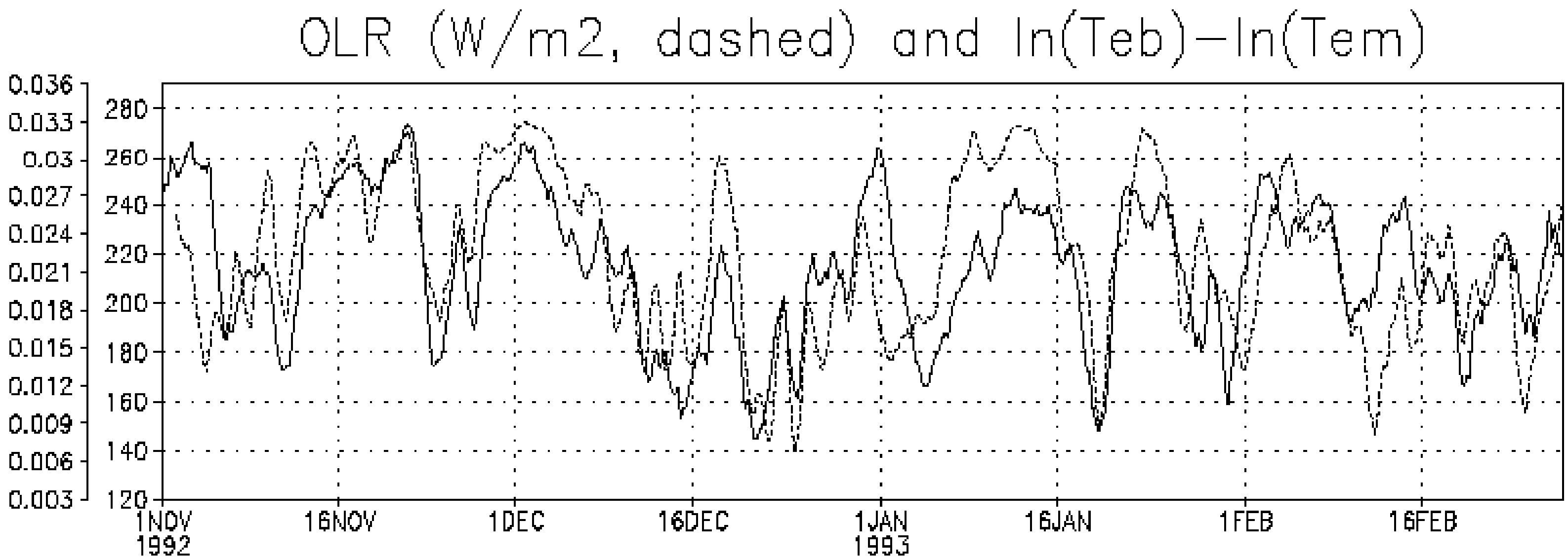


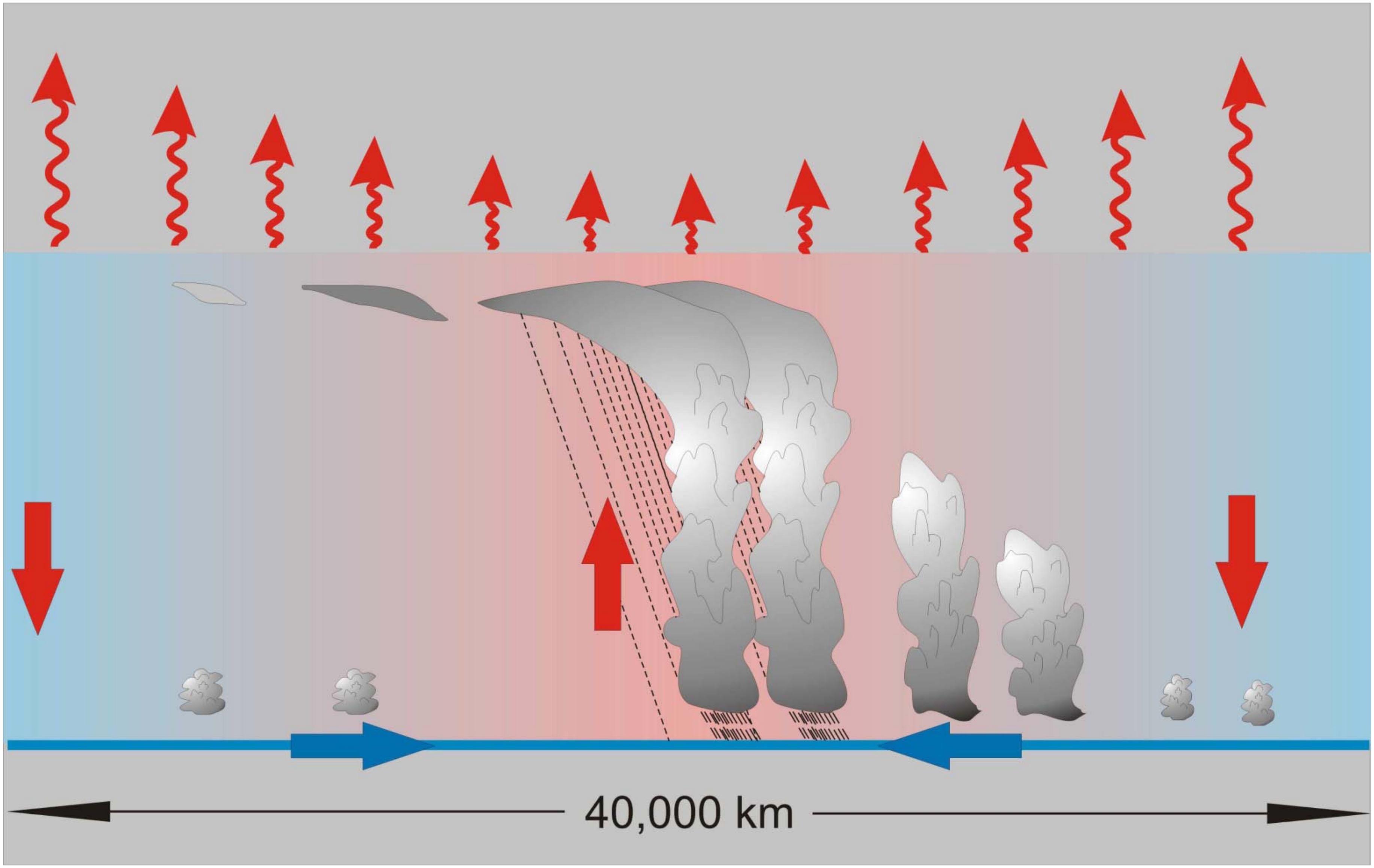
Log Power of Meridional Wind at Equator - background
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Frequency (day-1)
-15
-10
-5
0
5
10
15
20
Zonal Wavenumber

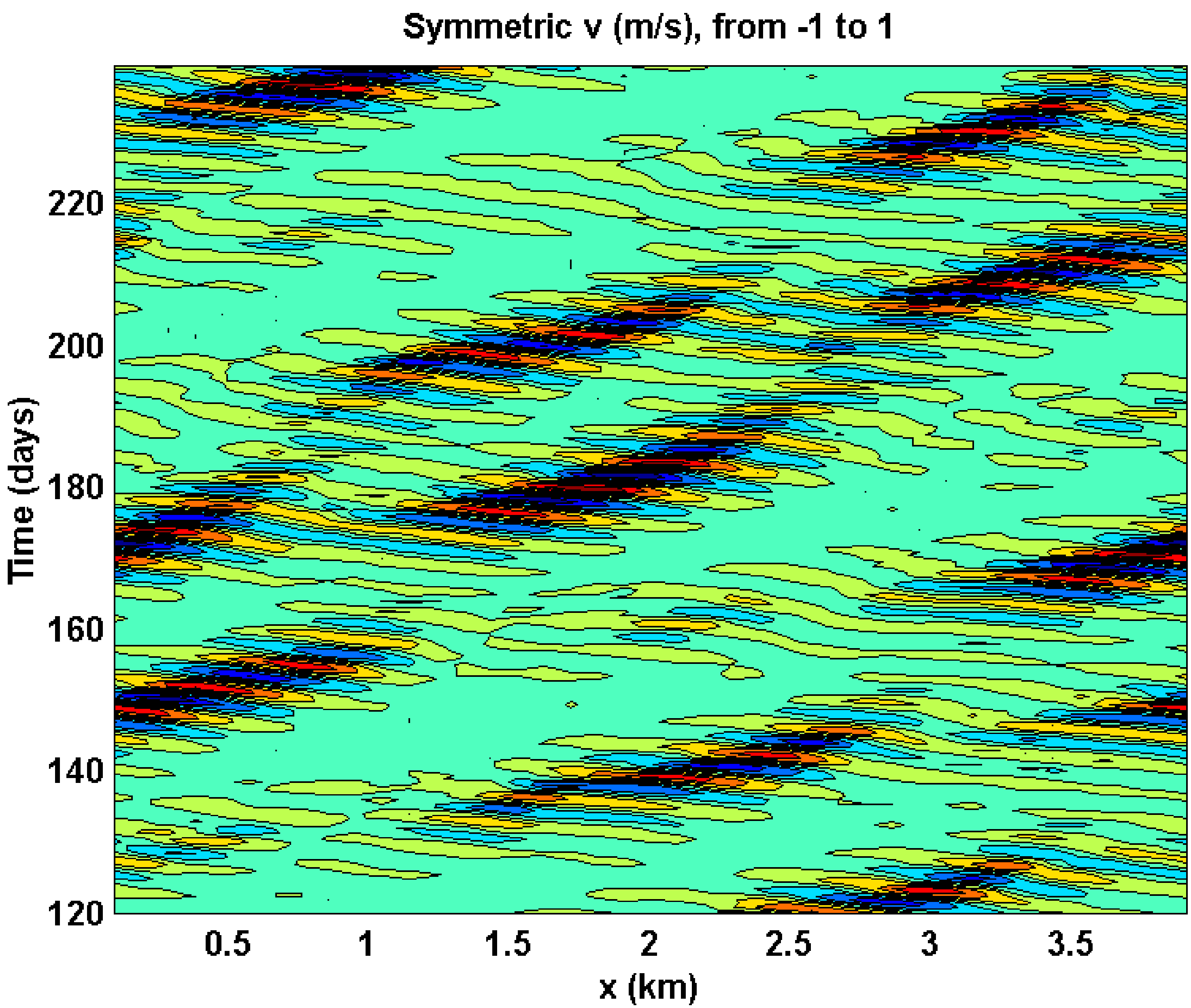

Asymmetric w (cm/s), from -0.17 to 0.16
Time (days)
220
200
180
160
140
120
0.5
1
1.5
2
2.5
3
3.5
x (km)

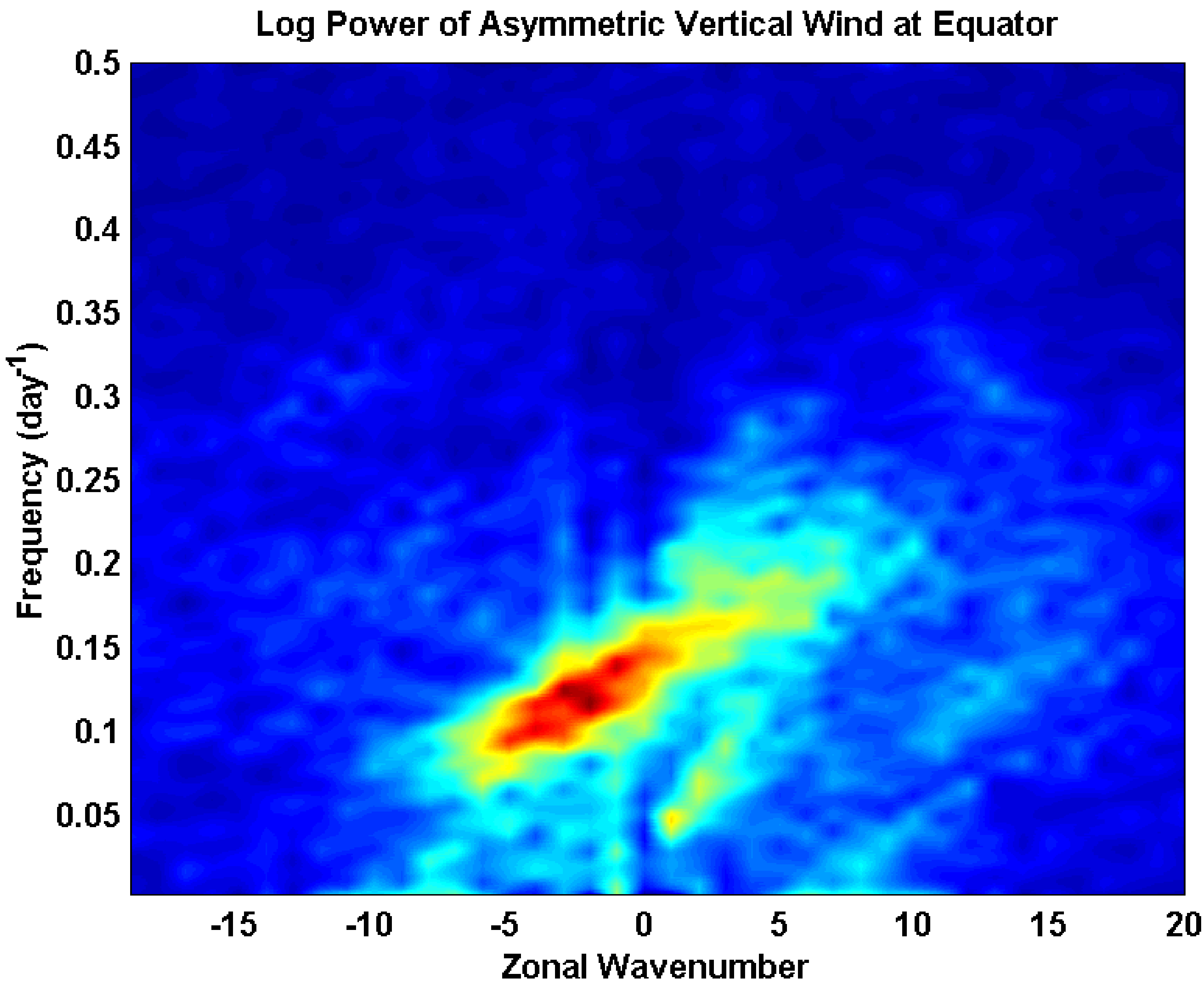
Cloud-Radiative Feedback

- **Set OLR proportional to difference in θ_e between boundary layer and mid troposphere (Sandrine Bony)**



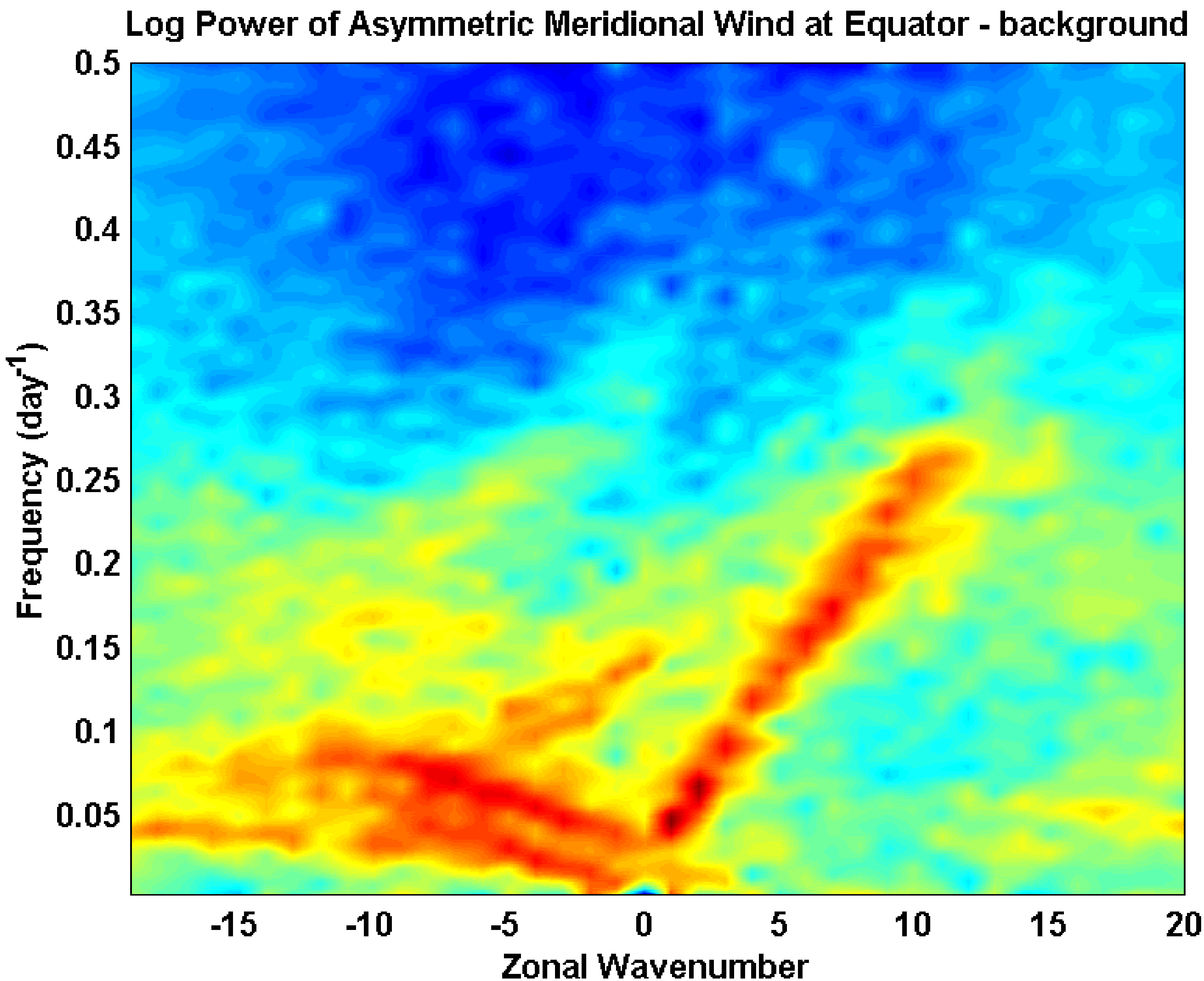

40,000 km


Symmetric v (m/s), from -1 to 1
Time (days)
220
200
180
160
140
120
0.5
1
1.5
2
2.5
3
3.5
x (km)

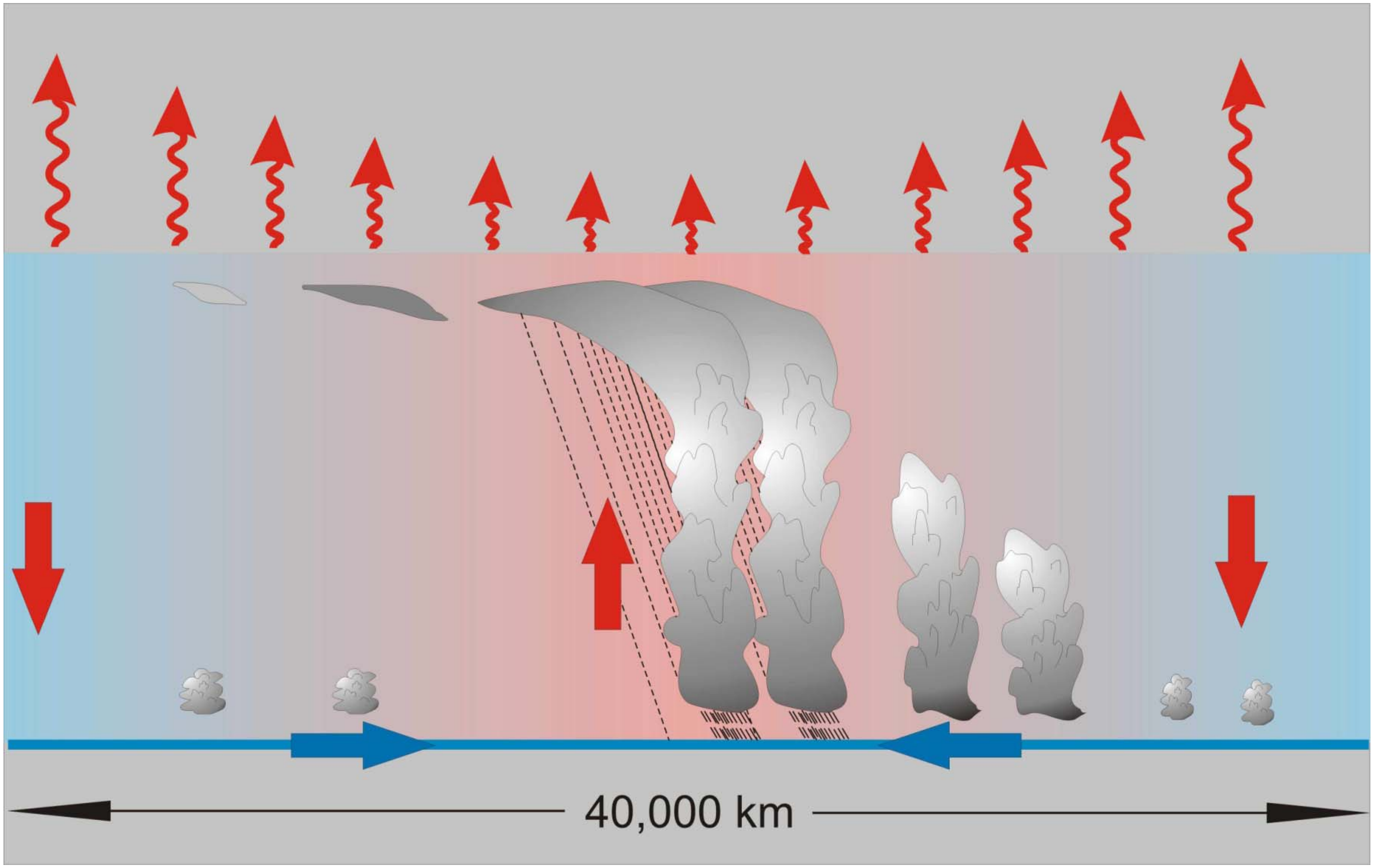

Log Power of Asymmetric Vertical Wind at Equator
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Frequency (day-1)
-15
-10
-5
0
5
10
15
20
Zonal Wavenumber

Moisture-Convection Feedback

- Allow precipitation efficiency to depend on relative humidity
- Greater heating/upward motion in moister air ⟶ upward motion moistens air
- Necessary for tropical cyclones
- Appears to excite planetary Rossby waves near equator


Log Power of Asymmetric Meridional Wind at Equator - background
Frequency (day^{-1})
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
-15
-10
-5
0
5
10
15
20
Zonal Wavenumber

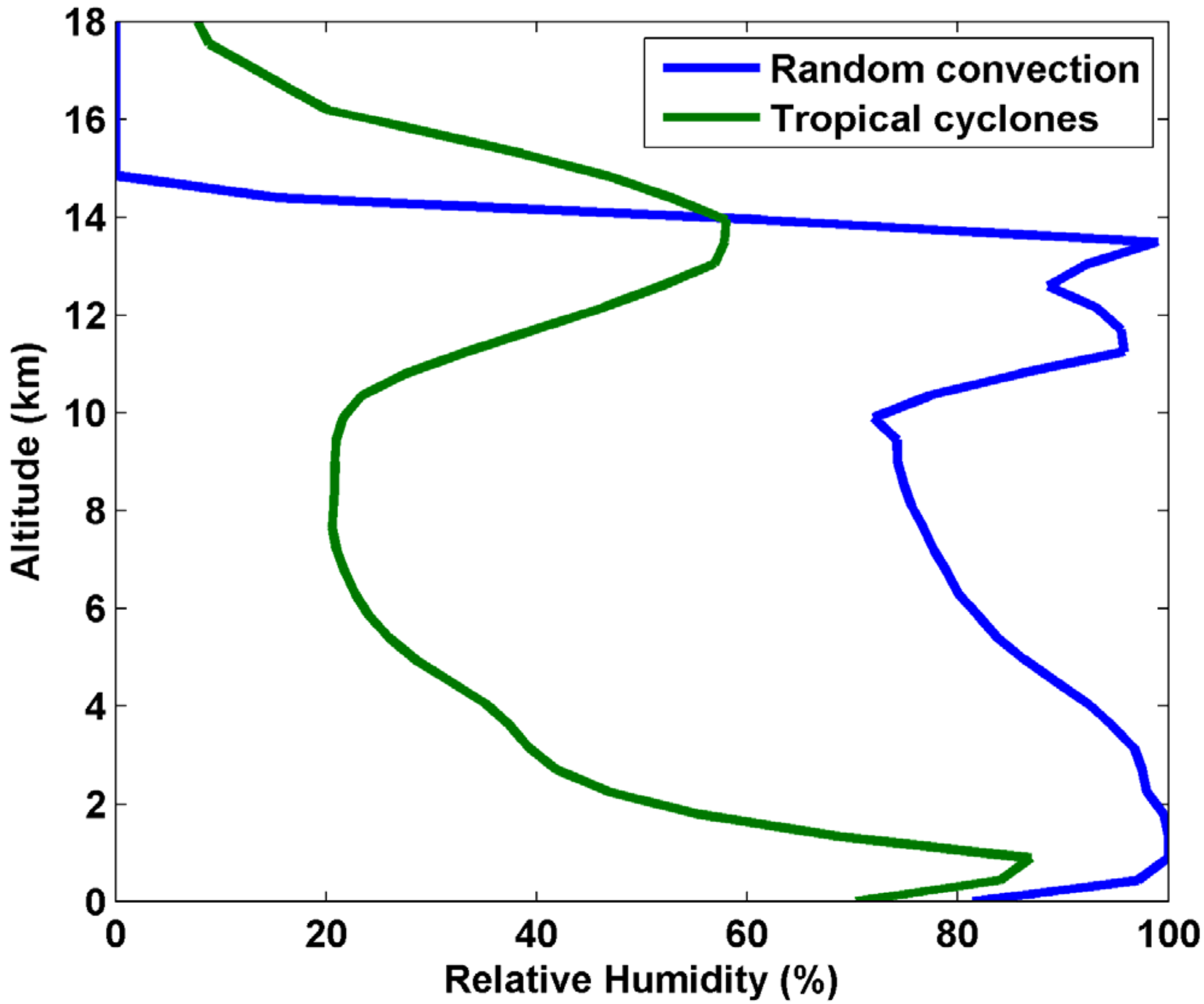
Possible effects of ocean response



Is the MJO an example of self-aggregated convection on the equatorial beta plane?

Explicitly Simulated Radiative-Convective Equilibrium

Nolan et al., QJRMS, 2007



Empirical Necessary Conditions for Self-Aggregation
(after Held et al., 1993; Bretherton et al., 2005; Nolan et al.; 2007)

- **Small vertical shear of horizontal wind**
- **Interaction of radiation with clouds and/or water vapor**
- **Feedback of convective downdraft surface winds on surface fluxes**
- **Sufficiently high surface temperature**

12.811 Tropical Meteorology
Spring 2011