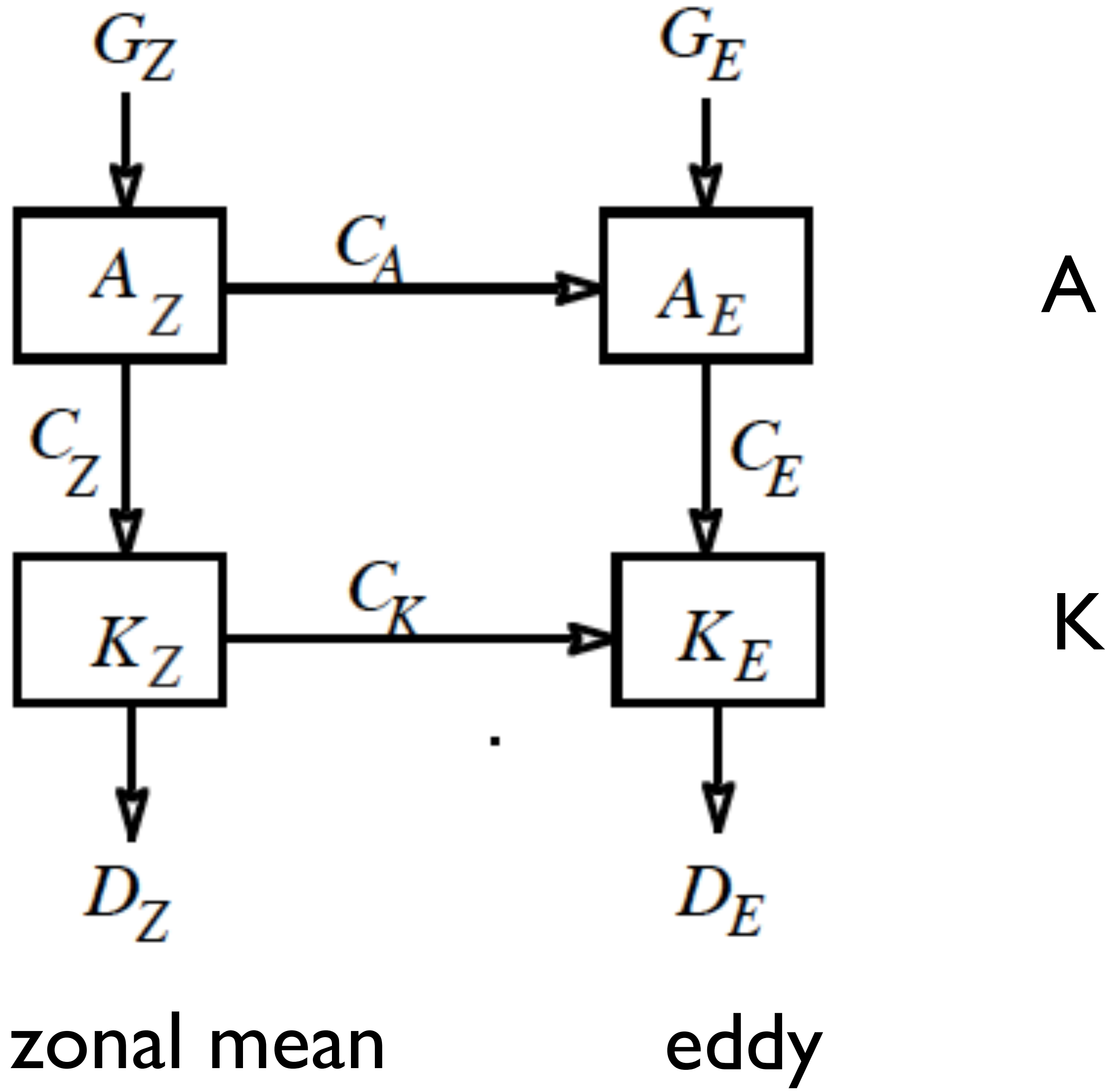
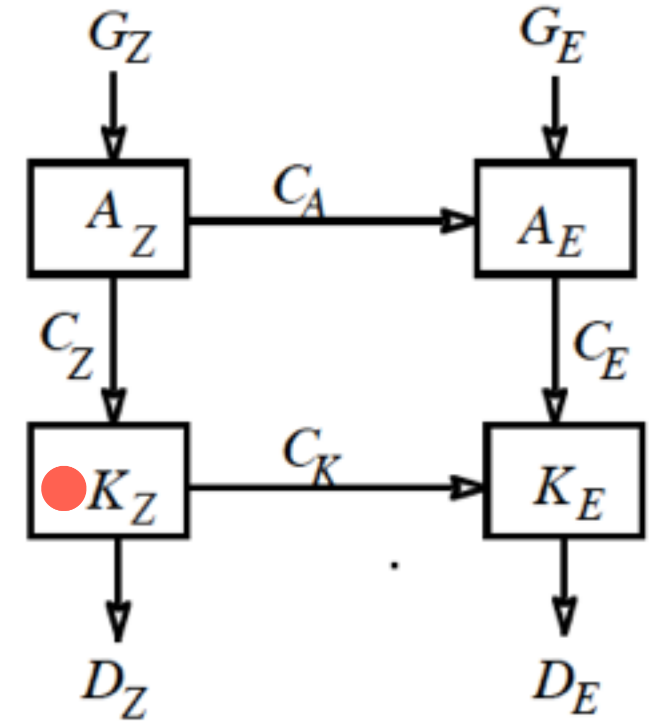



$$\frac{dA_Z}{dt} = G_Z - C_A - C_Z$$

$$\frac{dA_E}{dt} = C_A - C_E + G_E$$

etc.

# Zonal kinetic energy




$$\frac{\partial[u]}{\partial t} = [v]\left(f - \frac{\partial[u]}{\partial y}\right) + G + [F_x]$$

$$\frac{\partial \overline{K}_Z}{\partial t} = \frac{1}{g}\int_0^{p_0} f\overline{[u][v]}\,dp + \frac{1}{g}\int_0^{p_0} \overline{[u]G}\,dp + \frac{1}{g}\int_0^{p_0} \overline{[u][F_x]}\,dp$$

$C_Z$ $-C_K$ $D_Z$

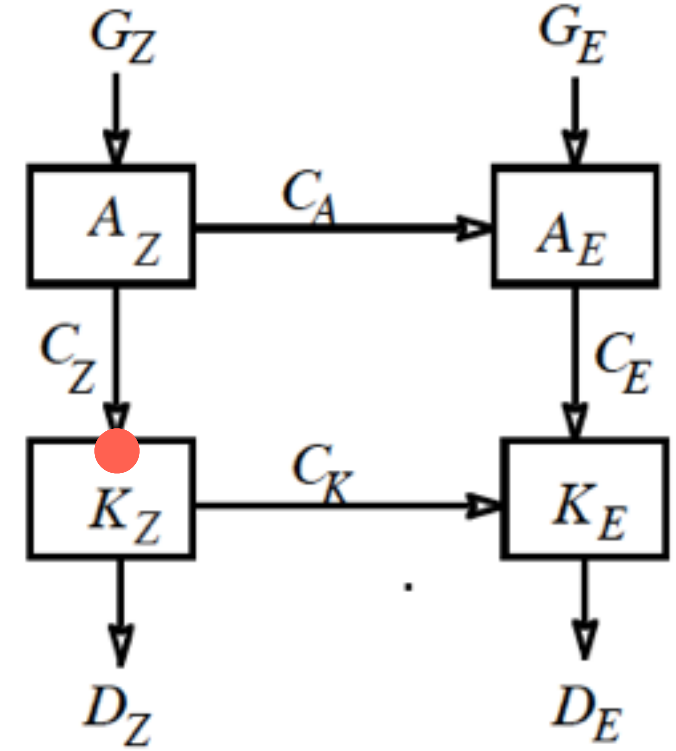
cross-isobar flow | eddy fluxes | friction

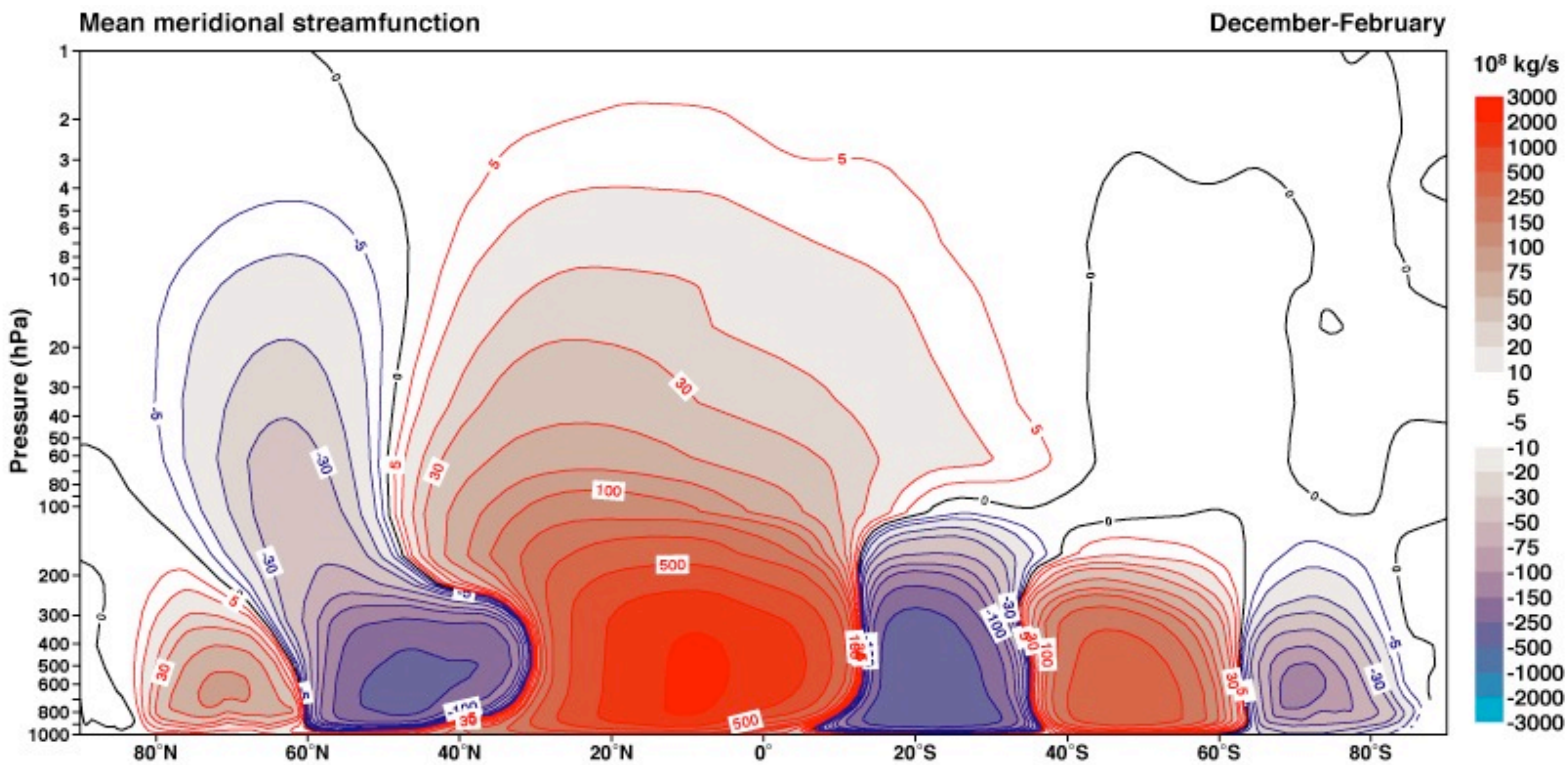
$$-[v]\frac{\partial[\Phi]}{\partial y}$$

Note that in this section overbars denote global averages.

$$\frac{1}{g}\int_0^{p_0} f\overline{[u][v]}dp$$

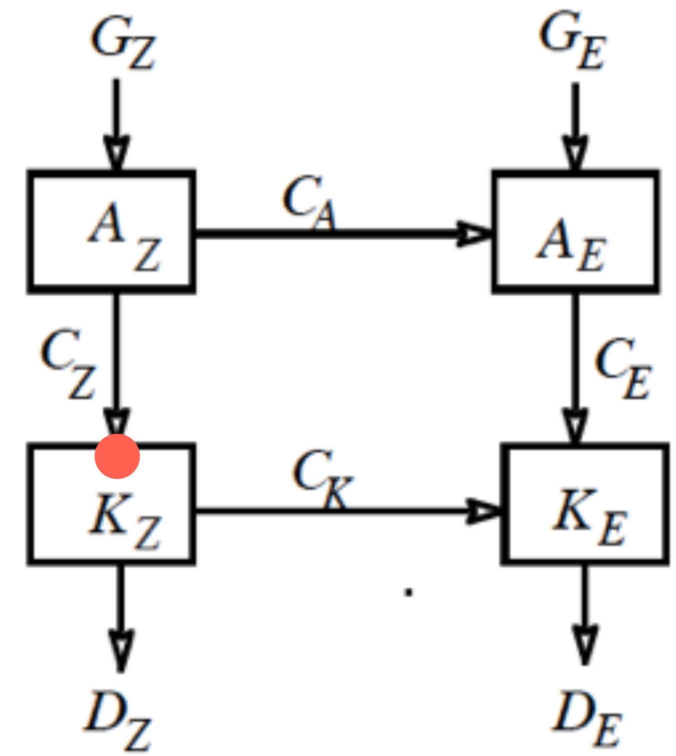
$$-[v]\frac{\partial[\Phi]}{\partial y}$$

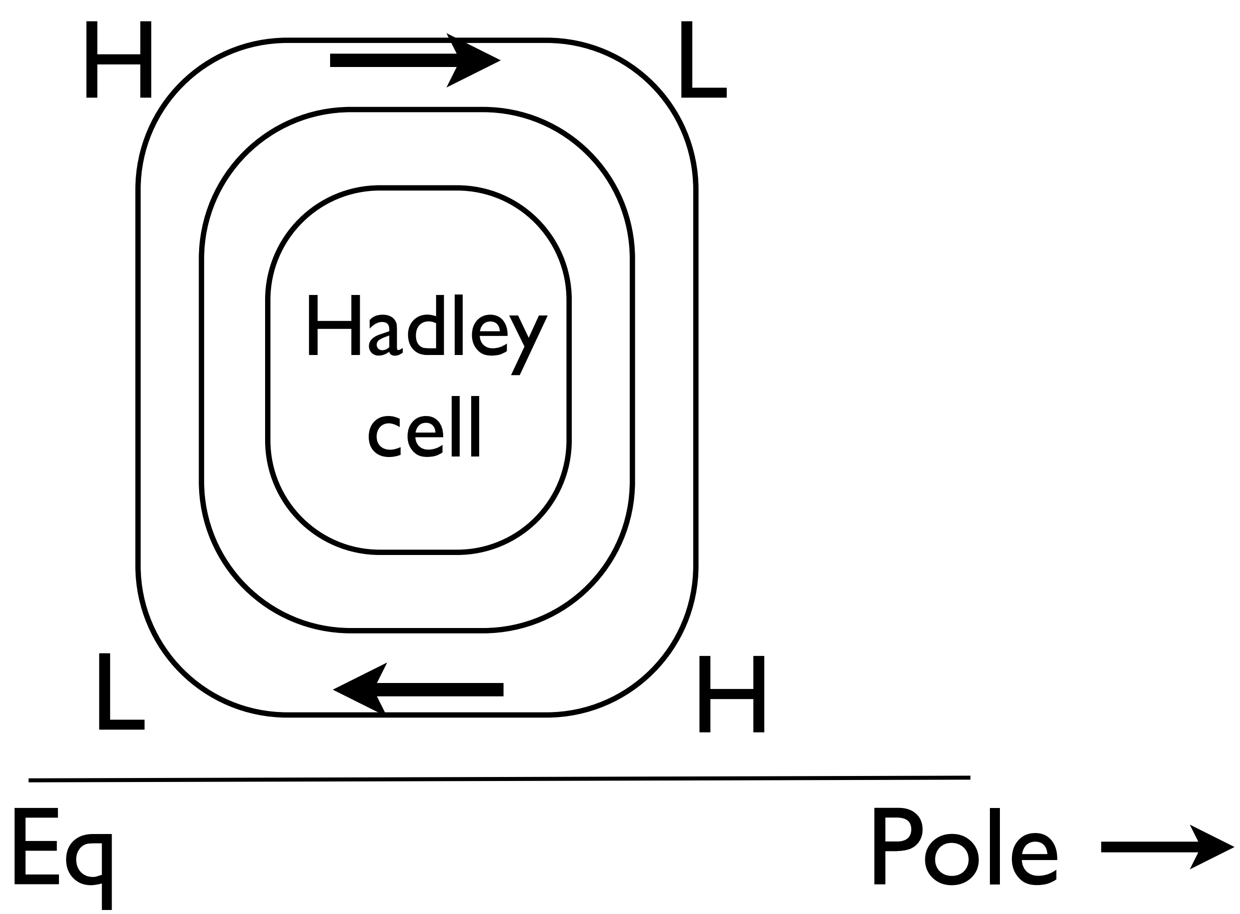


$$C_Z = \frac{1}{g}\int_0^{p_0} f\overline{[u][v]}\,dp$$

$$-[v]\frac{\partial[\Phi]}{\partial y}$$

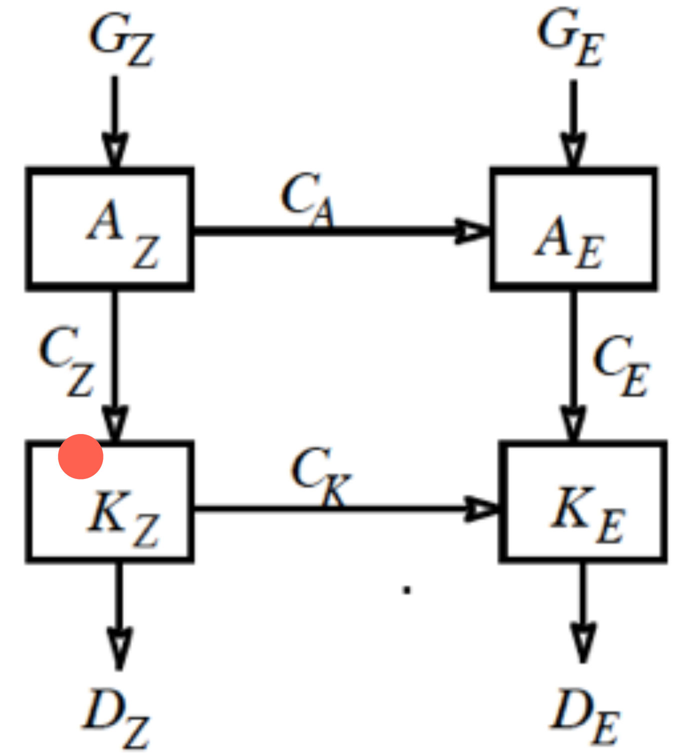


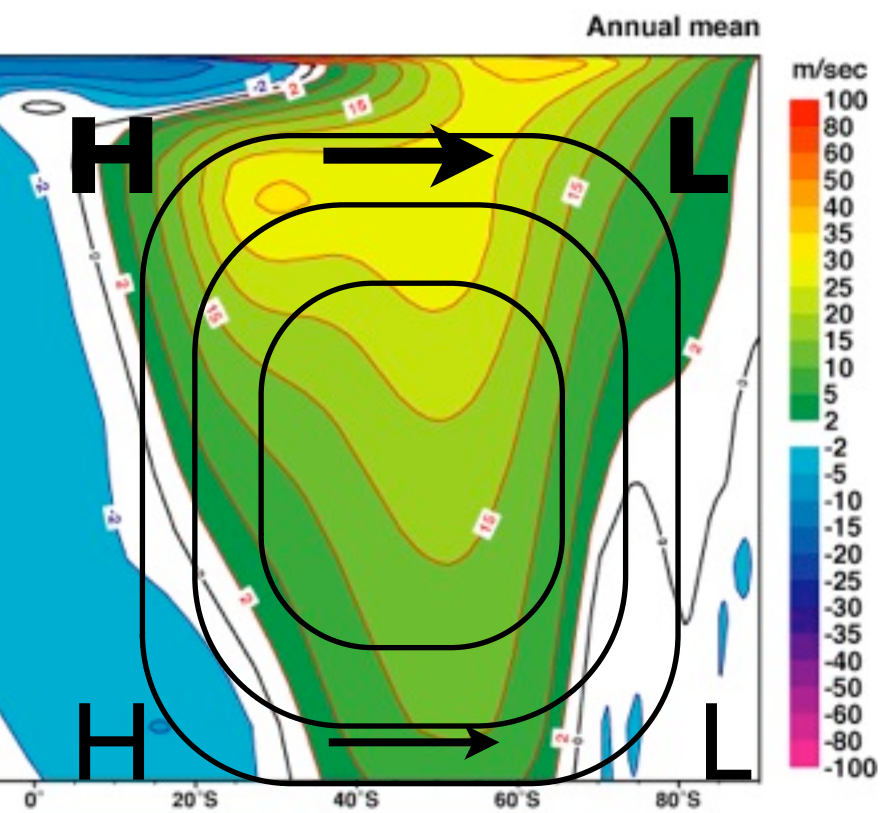



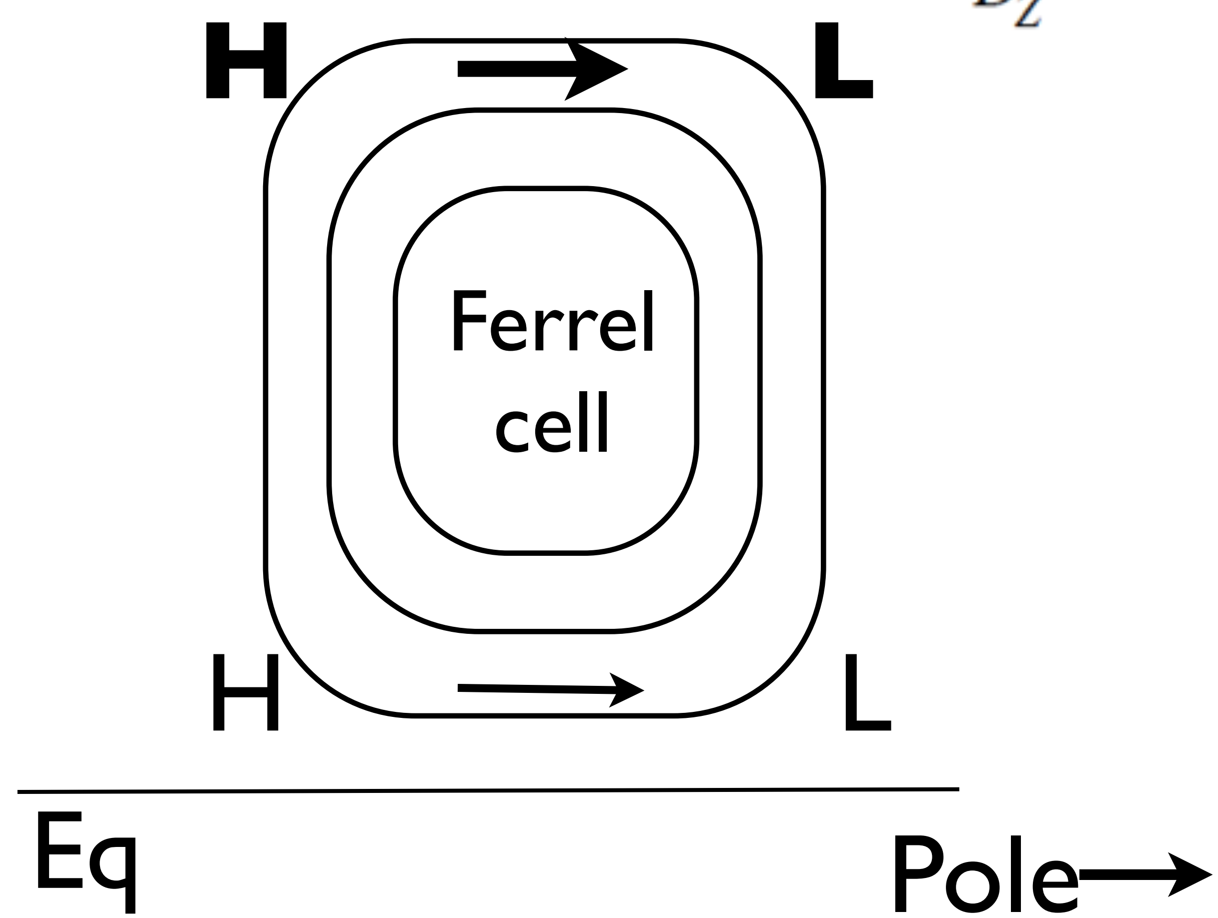

Hadley Cell $A_Z$ to $K_Z$ i.e., thermally direct

$$C_Z = \frac{1}{g}\int_0^{p_0} f\overline{[u][v]}dp$$

$$-[v]\frac{\partial[\Phi]}{\partial y}$$

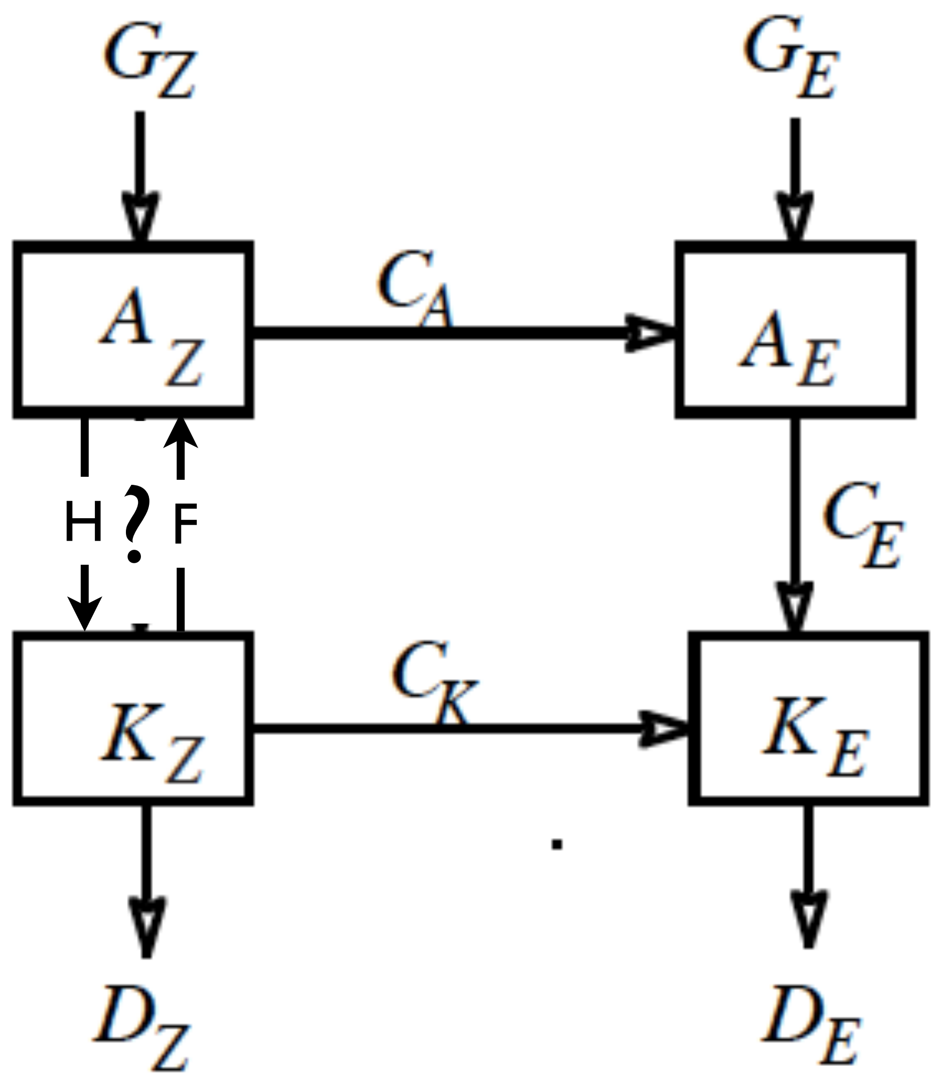


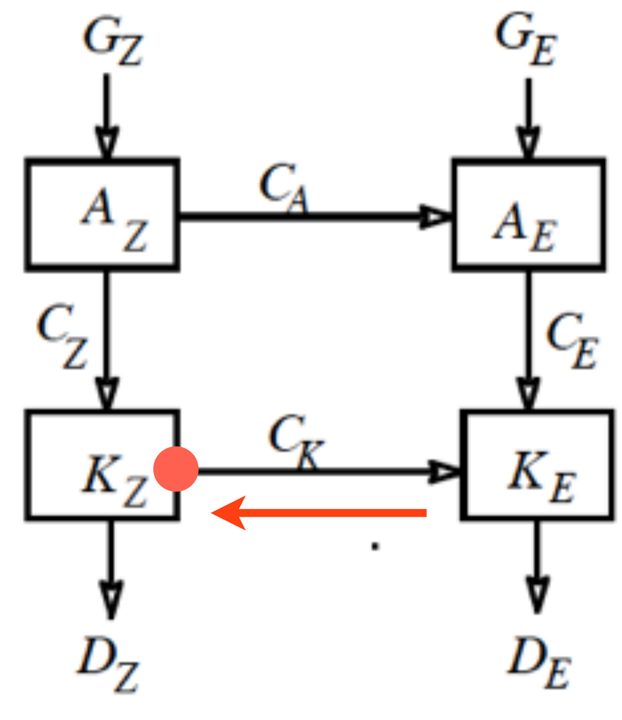




Ferrell Cell $K_Z$ to $A_Z$; i.e.,thermally indirect

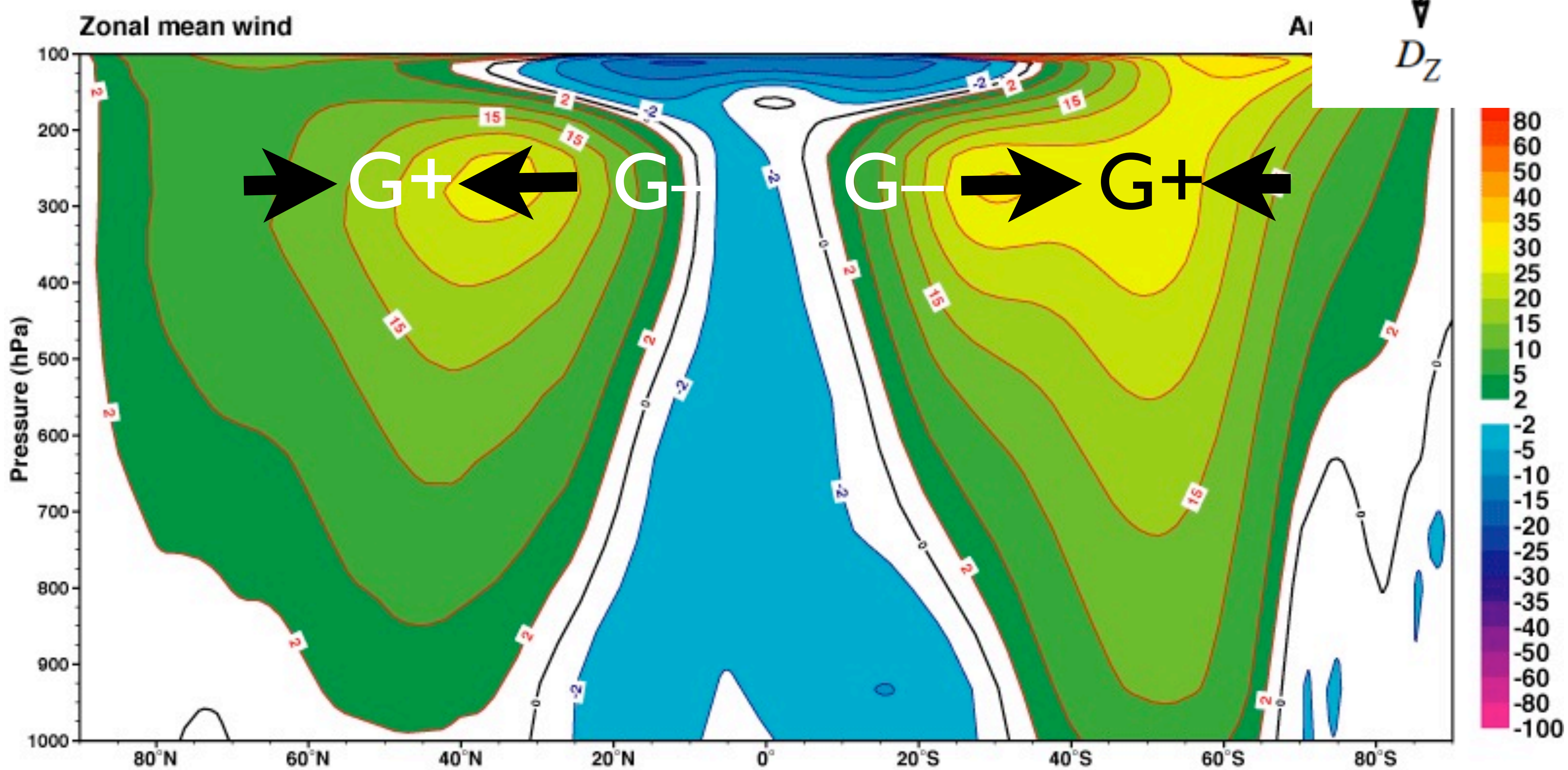
The conversions in the Hadley and Ferrell cells are nearly equal and opposite, so in the global-mean $C_Z$ is small and even of uncertain sign.



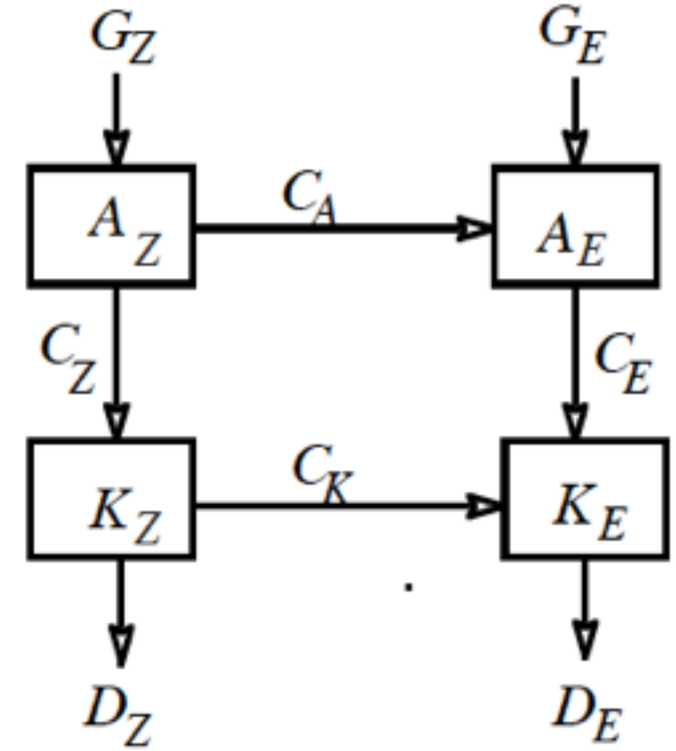
$$-C_K = +\frac{1}{g}\int_0^{p_0} \overline{[u]G}\,dp$$




$u$

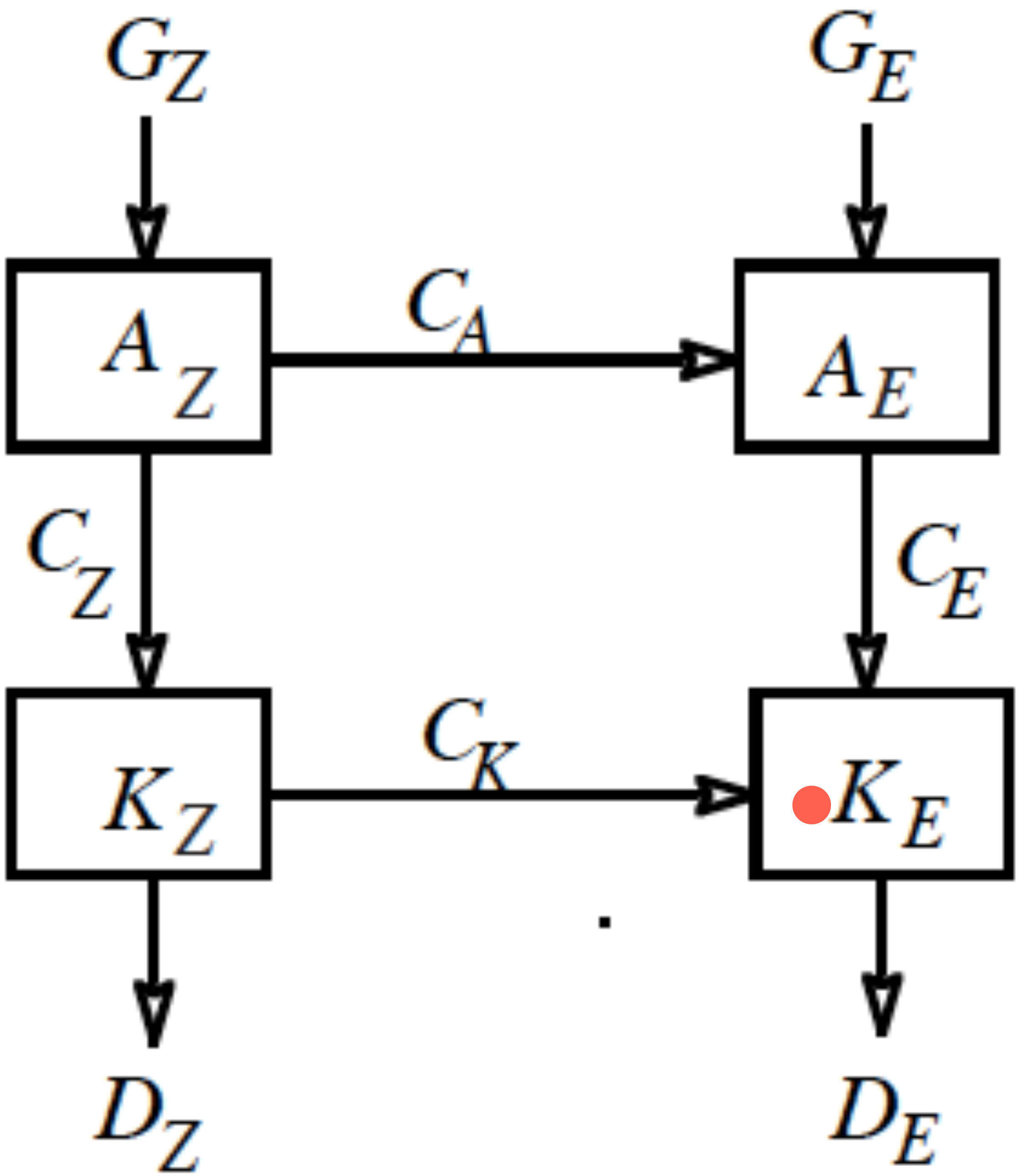



$G+$ where $u$ is more positive so $-C_K > 0$




$$D_Z = -\cdot\frac{1}{g}\int_0^{p_0}\overline{[u][F_x]}dp$$

Frictional drag always yields positive $D_Z$


$G_Z$
$G_E$
$A_Z$
$C_A$
$A_E$
$C_Z$
$C_E$
$K_Z$
$C_K$
$K_E$
$D_Z$
$D_E$

# Eddy kinetic energy

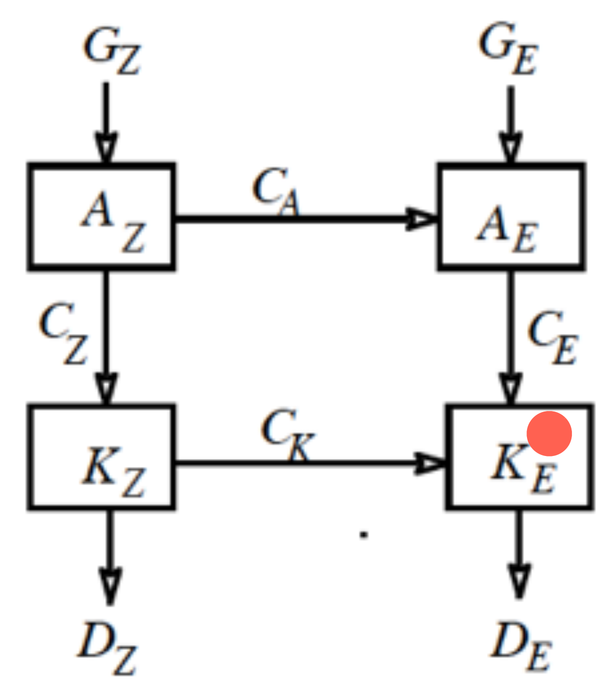
$$\frac{\partial \overline{K_E}}{\partial t} = -\frac{1}{g}\int_0^{p_0} \overline{[u^* v^*]\frac{\partial [u]}{\partial y}} dp - \frac{1}{g}\int_0^{p_0} \overline{\left[u^* \frac{\partial \Phi^*}{\partial x} + v^* \frac{\partial \Phi^*}{\partial y}\right]} dp - \frac{1}{g}\int_0^{p_0} \overline{\left[u^* F_x^* + v^* F_y^*\right]} dp$$

$C_K$ — downgradient momentum flux

$C_E$ — cross-isobar flow

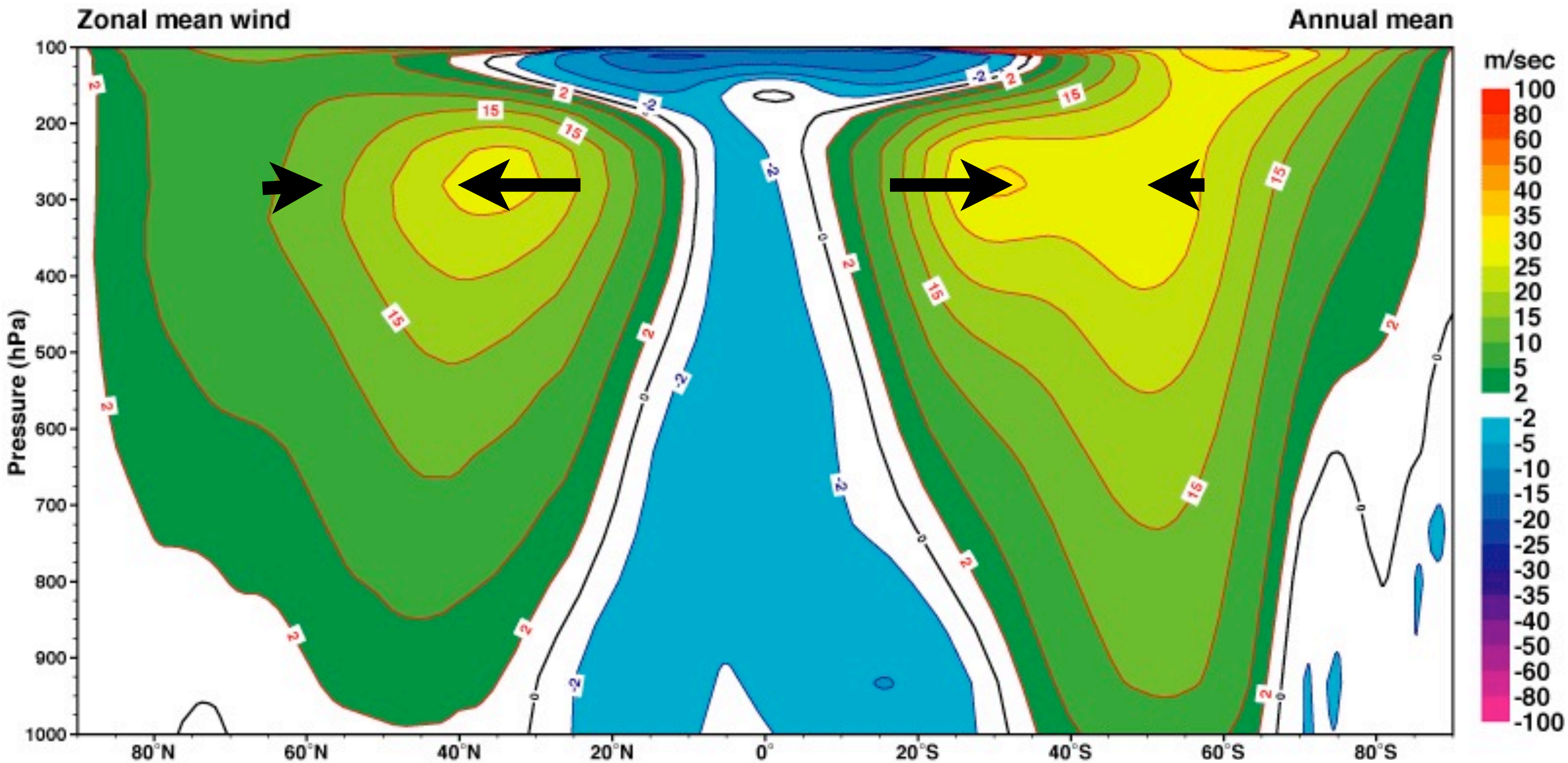
$D_E$ — frictional drag

See Appendix 5 for a derivation.

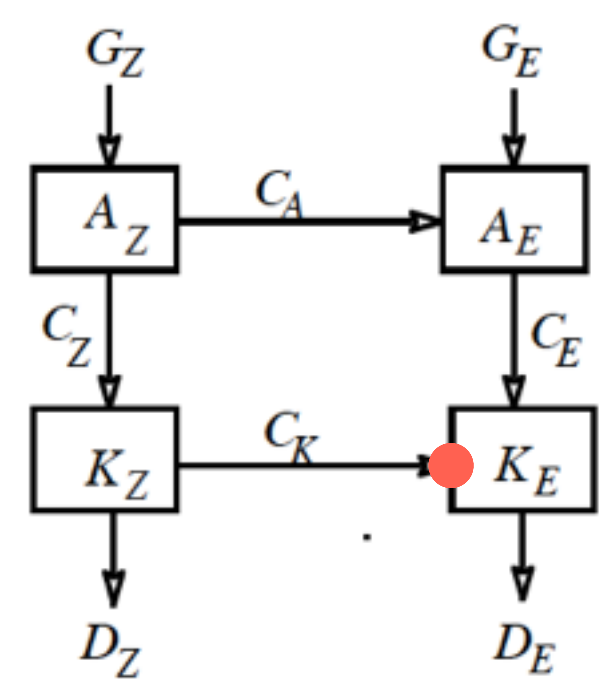


Note that the flux is primarily countergradient; i.e., toward higher $u$

$u$

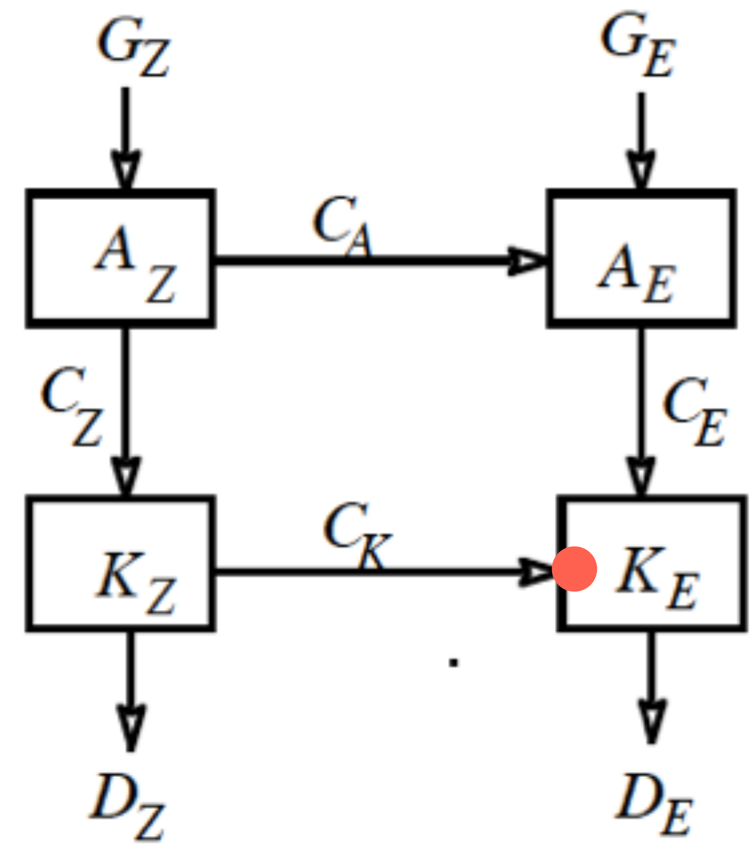



$$-\frac{1}{g}\int_0^{p_0}\overline{[u^*v^*]\frac{\partial[u]}{\partial y}}dp \quad < 0$$

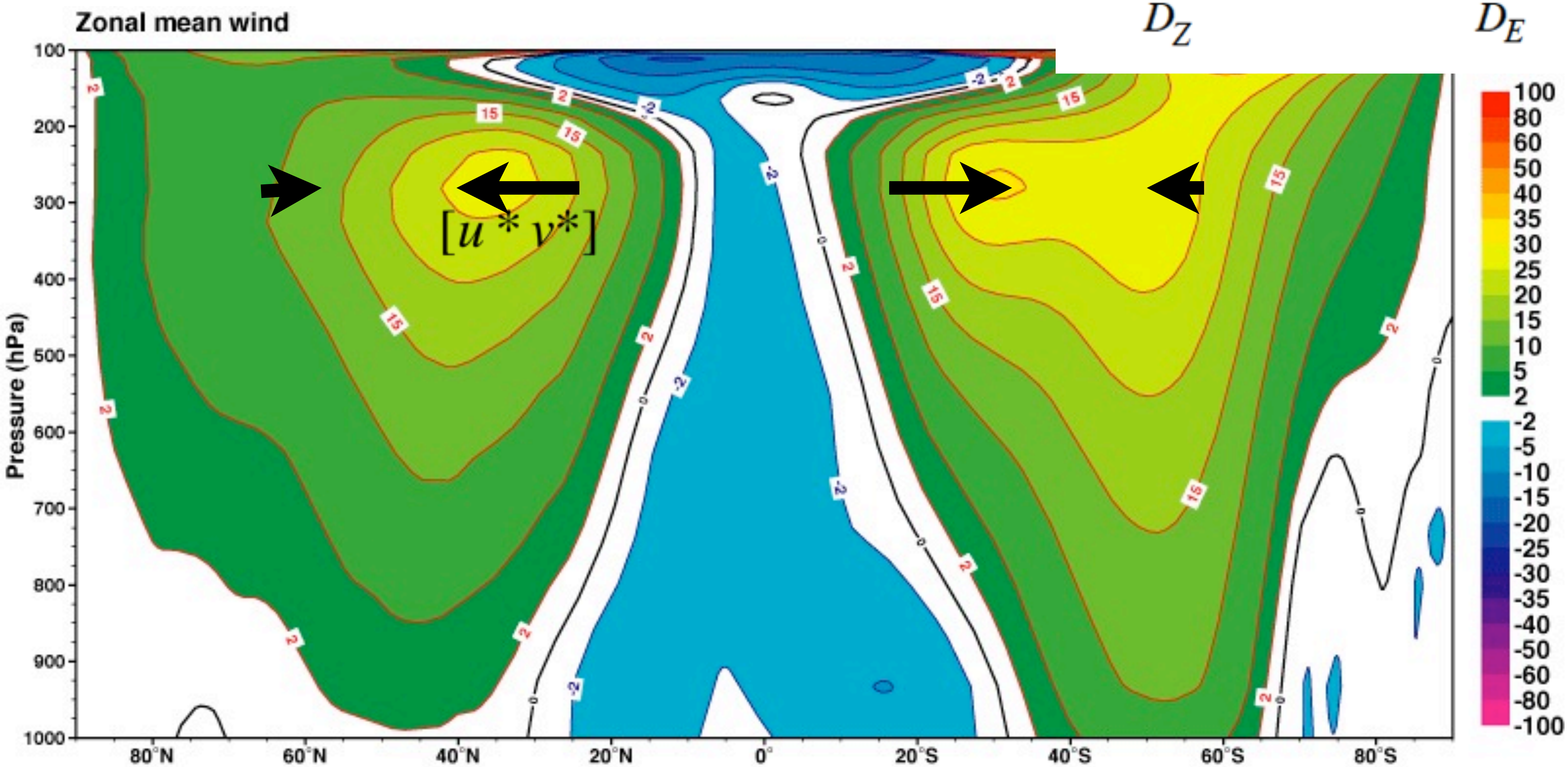


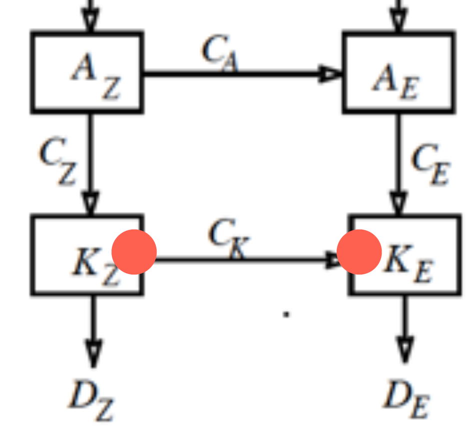
But the notion that mixing should be down-gradient doesn’t really apply to zonal momentum, which doesn’t behave as a passive tracer.

$$: -\frac{1}{g}\int_0^{p_0} \overline{[u^* v^*]\frac{\partial [u]}{\partial y}}dp$$




$u$






Note that

$$C_K = -\frac{1}{g}\int_0^{p_0} \overline{[u]G}\,dp = -\frac{1}{g}\int_0^{p_0} \overline{[u^* v^*]\frac{\partial [u]}{\partial y}}\,dp$$

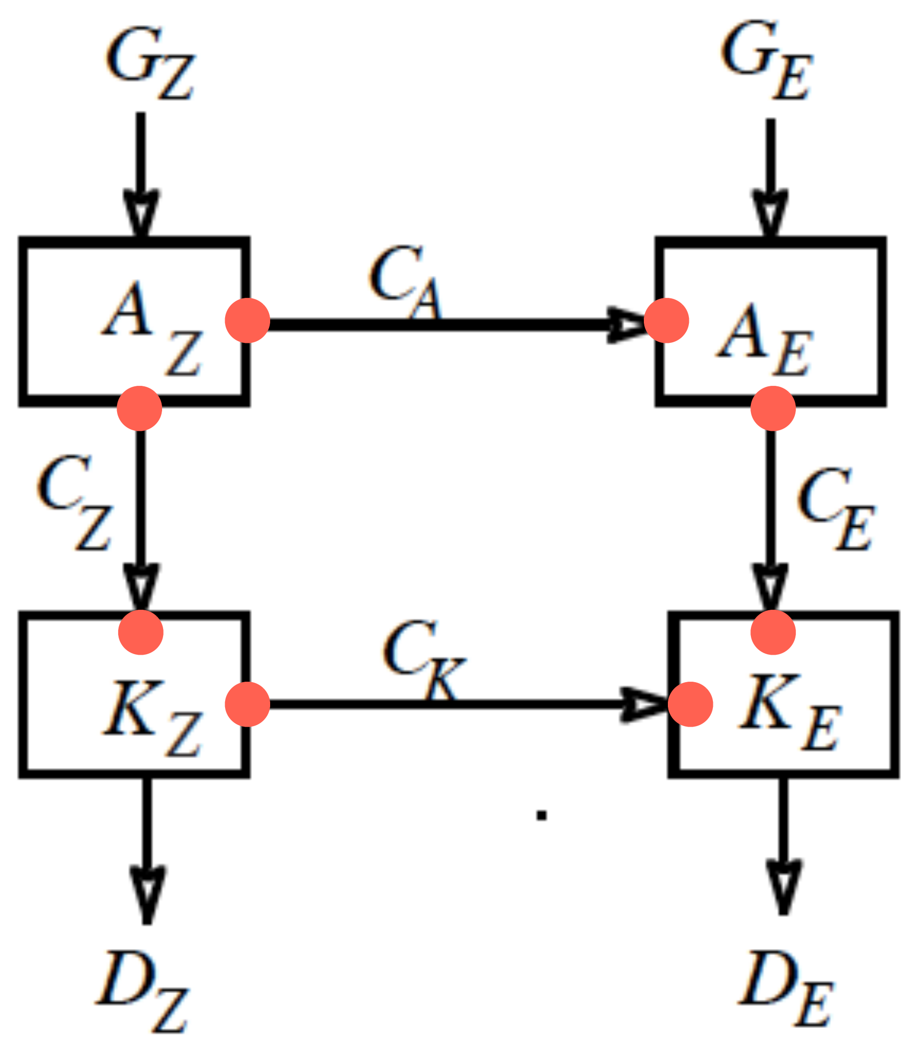
Verify this identity substituting $G = -\frac{\partial}{\partial y}[u^* v^*]$

and noting that $\int_{pole}^{pole} \frac{\partial}{\partial y}[u][u^* v^*]\,dy = 0$

It's only in the global average that the two expressions for $C_K$ are identical.


In my song *"Clouds"*, I stressed that things often appear different when viewed from differing perspectives. Is that also true of the conversions in the Lorenz KE cycle?


That's right!




We can look at them from both sides now.

In the song, the punch line is
*"It's clouds' illusions I recall*
*I really don't know clouds at all."*

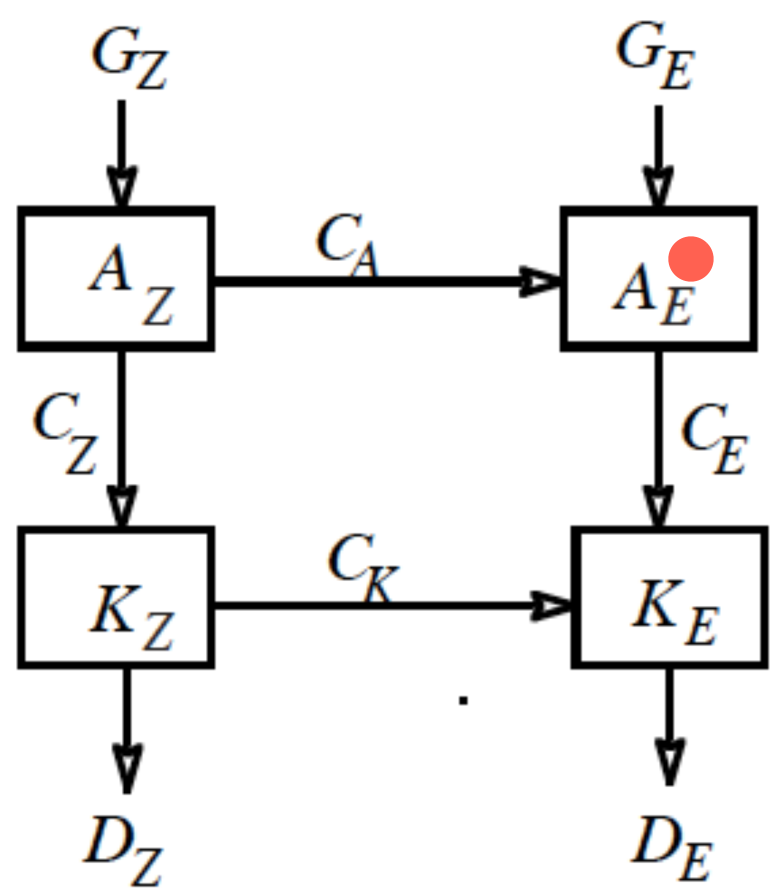

There are days when I wonder about that too.

But compared to clouds
the Lorenz KE cycle is simple.

For the eddy available potential energy, we have

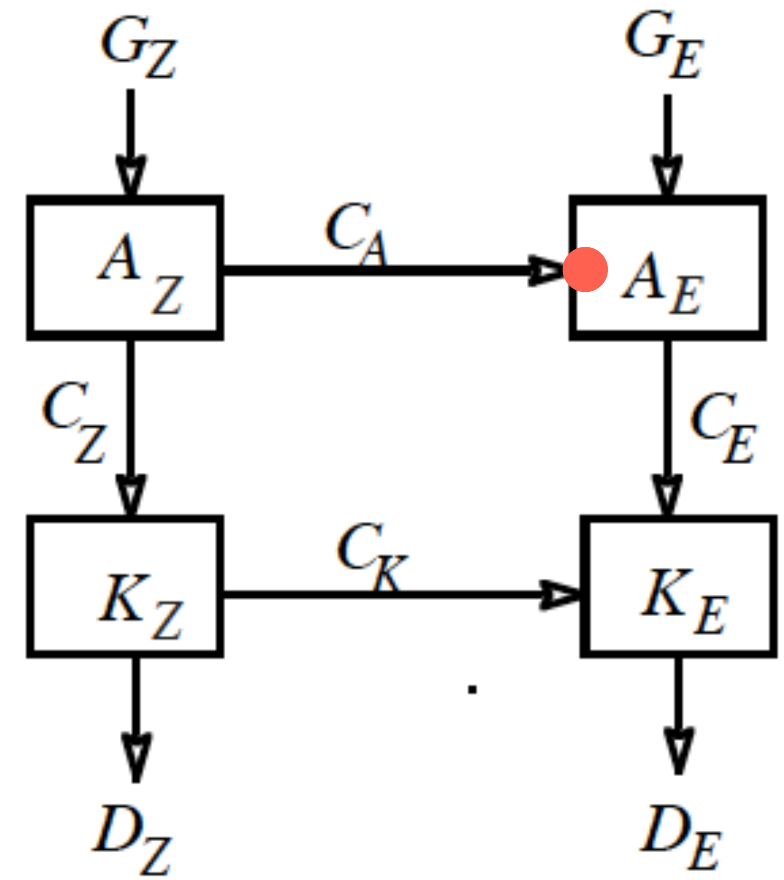
$$\frac{\partial A_E}{\partial t} = -\frac{1}{g}\int_0^{p_0} \overline{\frac{\left[v^*\alpha^*\right]}{\sigma}\frac{\partial \alpha}{\partial y}}dp + \frac{1}{g}\int_0^{p_0} \overline{\left[\omega^*\alpha^*\right]}dp + \frac{1}{g}\int_0^{p_0} \overline{\frac{\left[Q^*\alpha^*\right]}{\sigma}}dp$$

You should recognize the terms here.

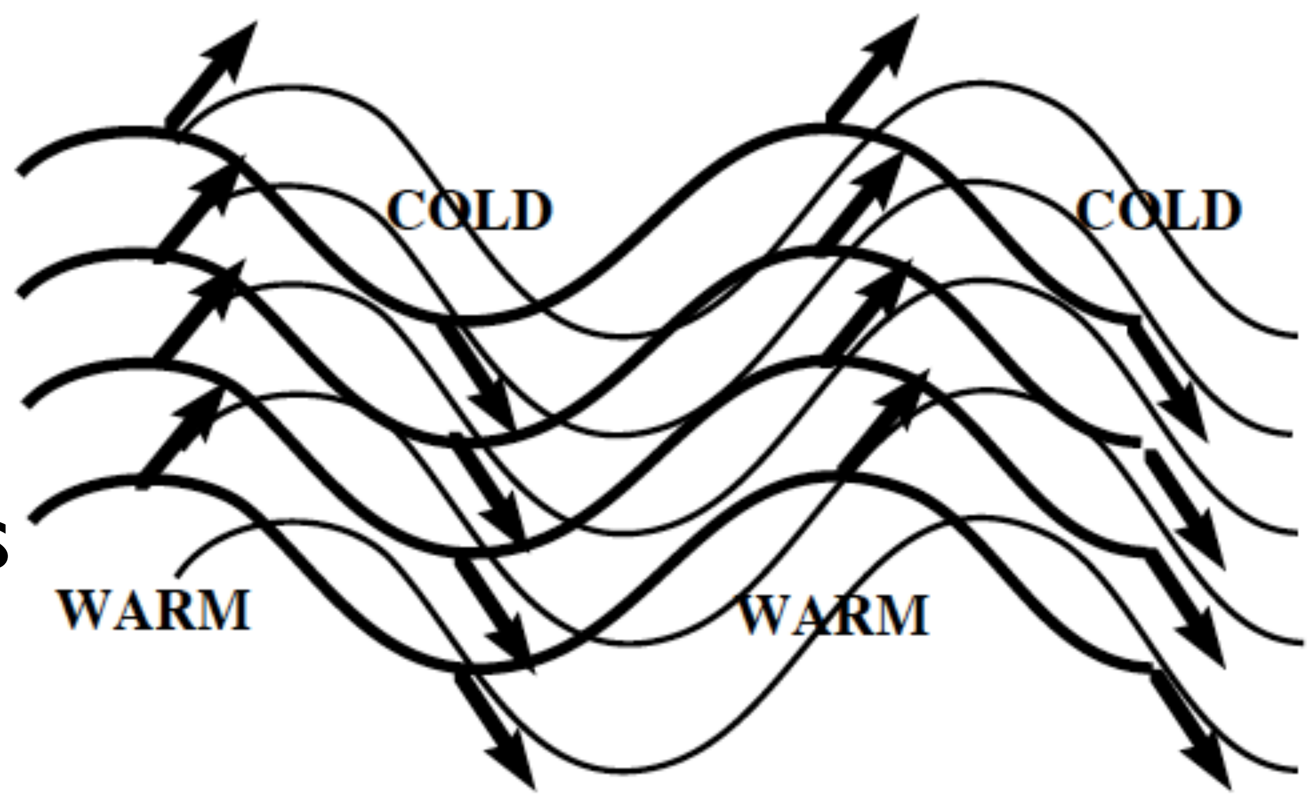


$$: -\frac{1}{g}\int_0^{p_0} \overline{\frac{[v^*\alpha^*]}{\sigma}\frac{\partial\alpha}{\partial y}} dp \cdot$$

the downgradient heat flux term



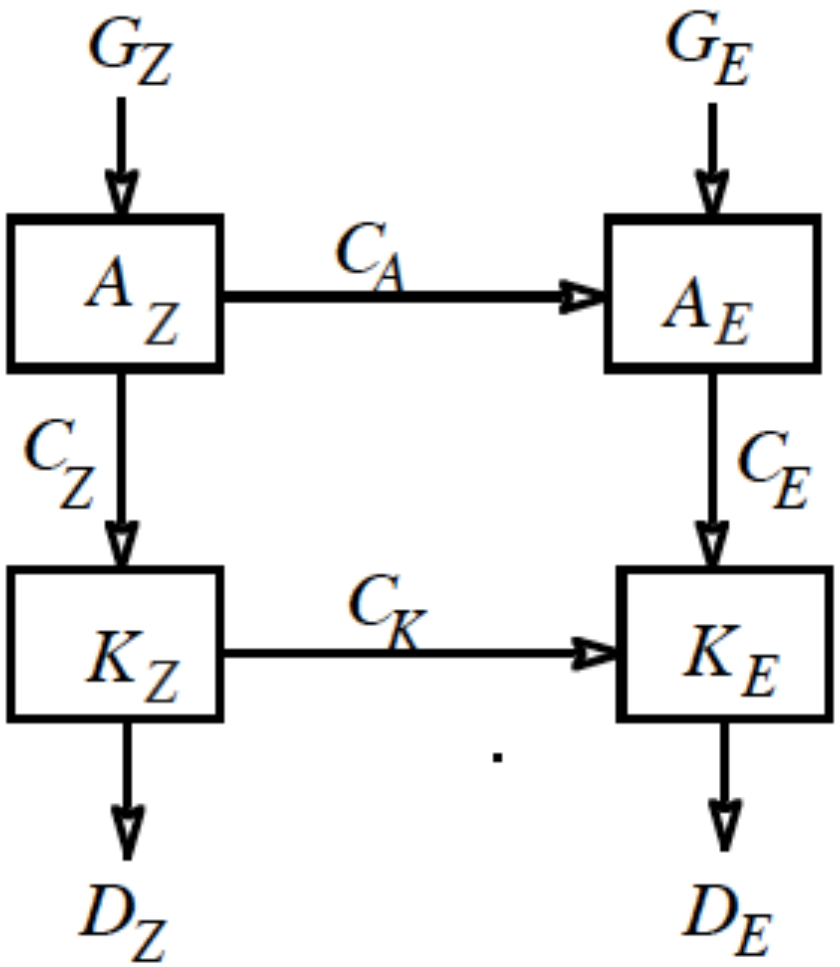

isotherms

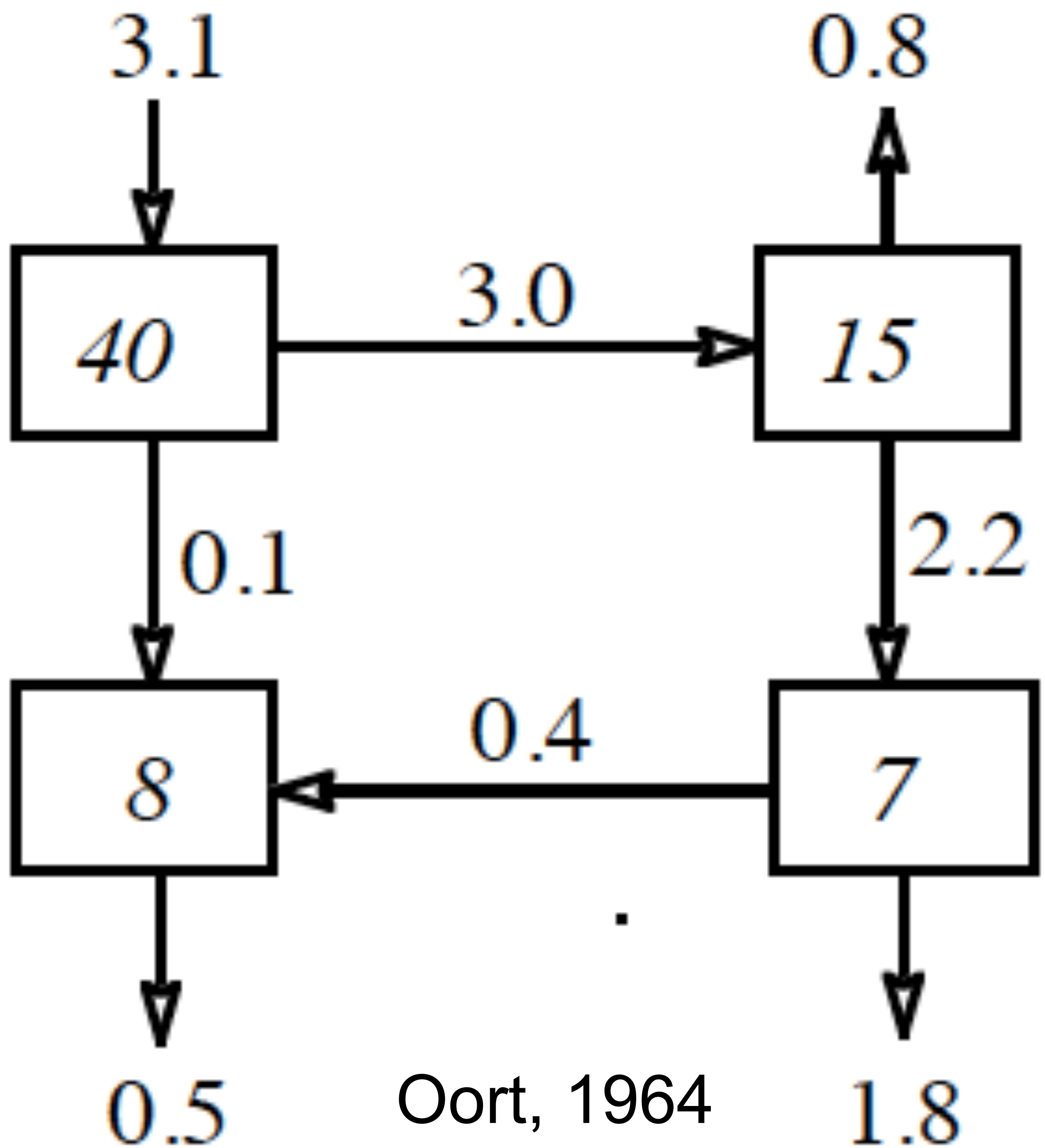



streamlines

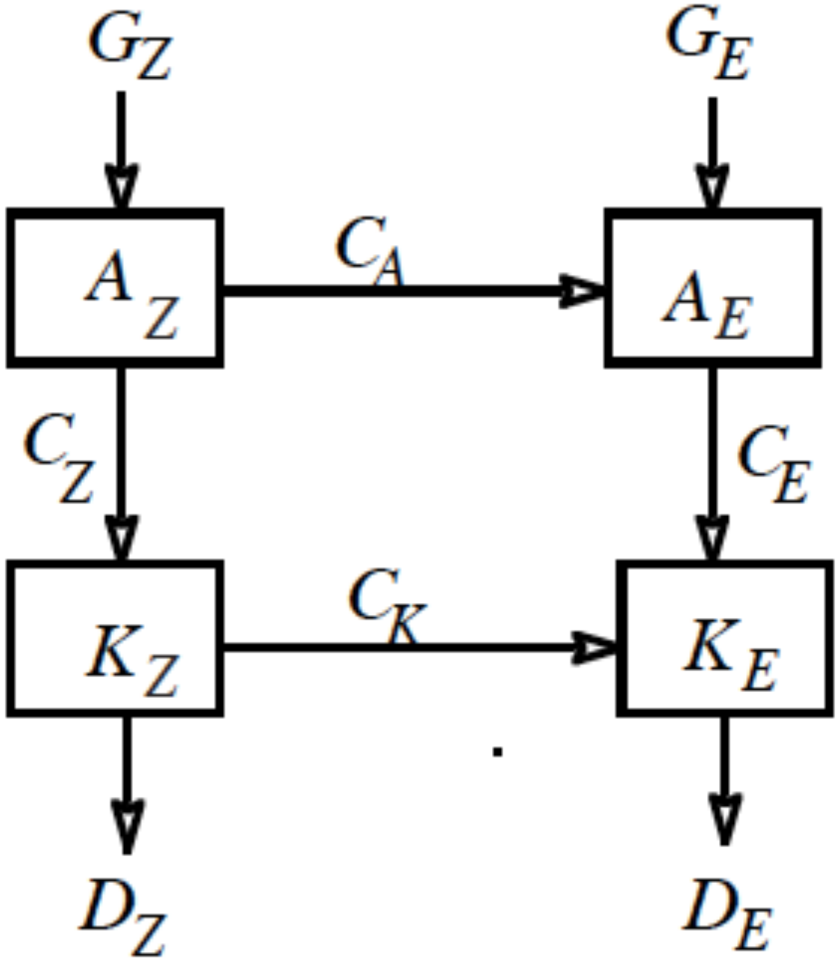
note how the flow is amplifying the waves in the isotherms

# Now let's do the numbers!



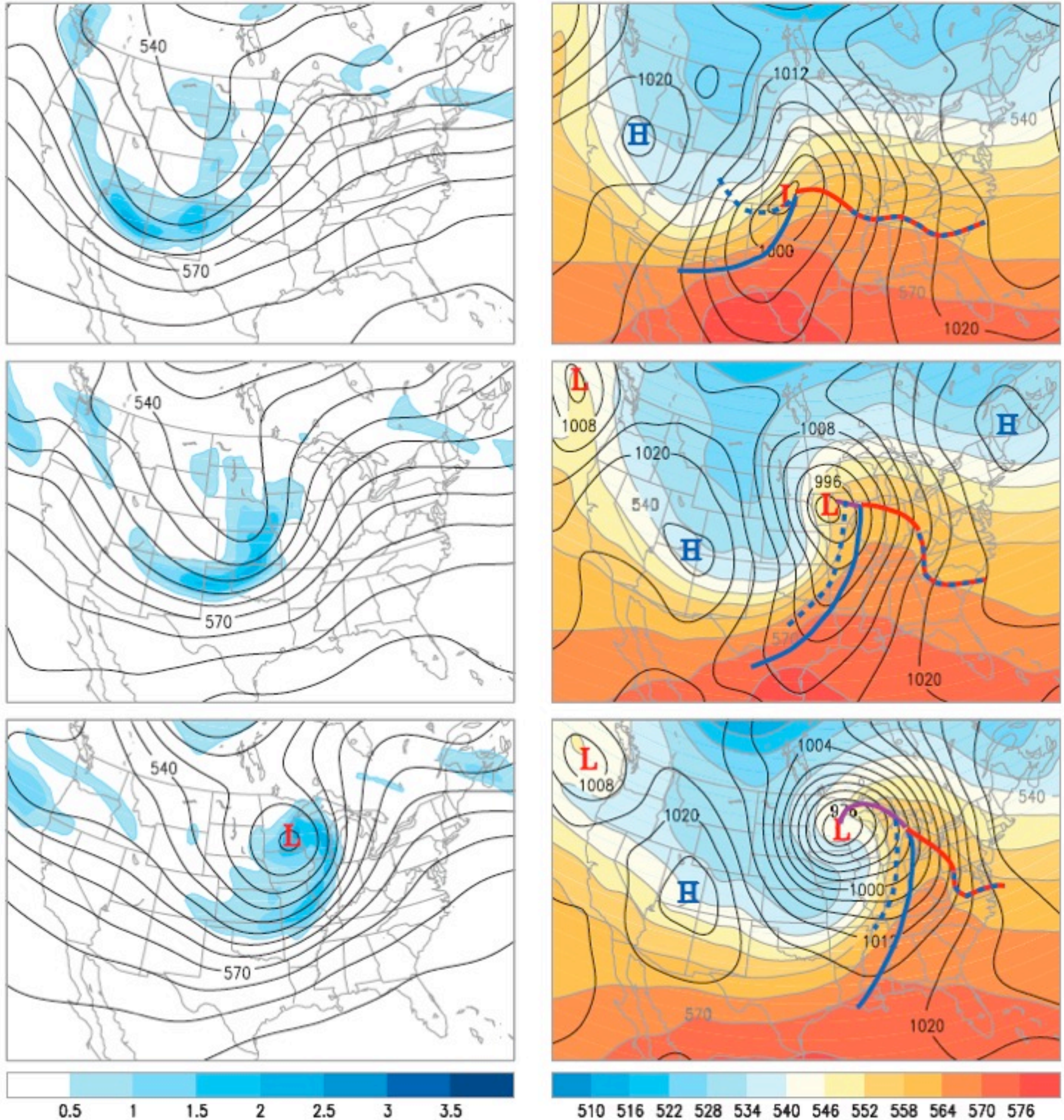

Oort, 1964



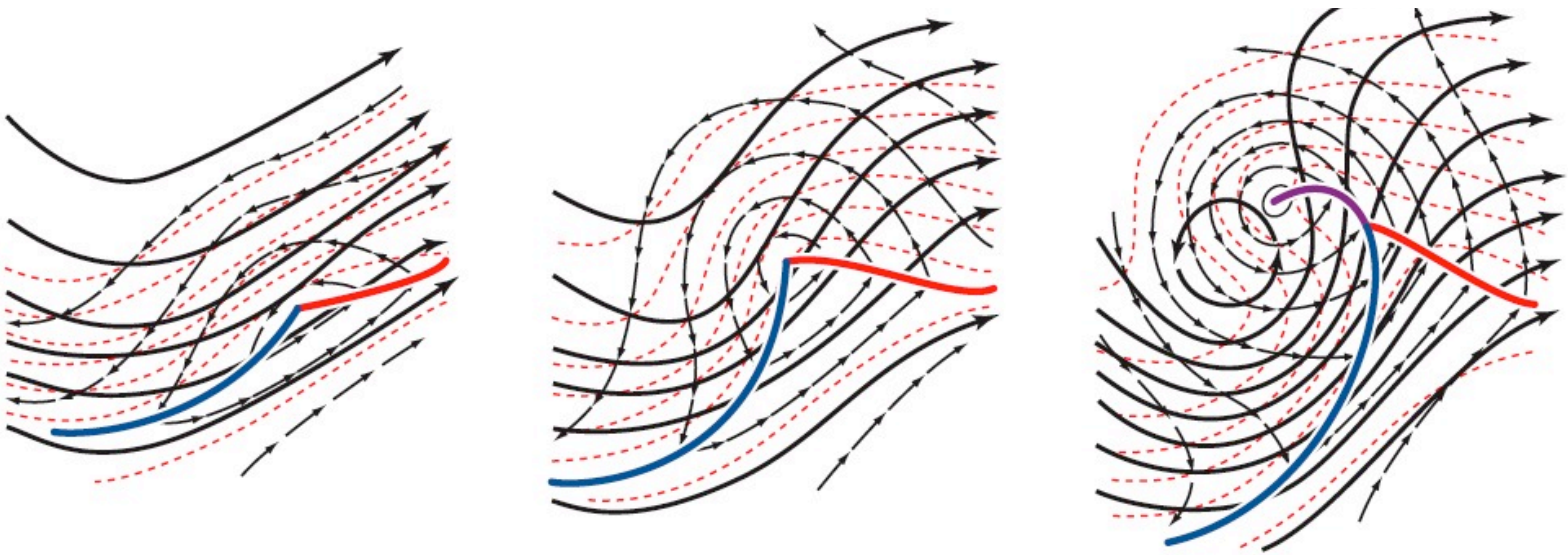

Tell us more about baroclinic waves and the KE cycle

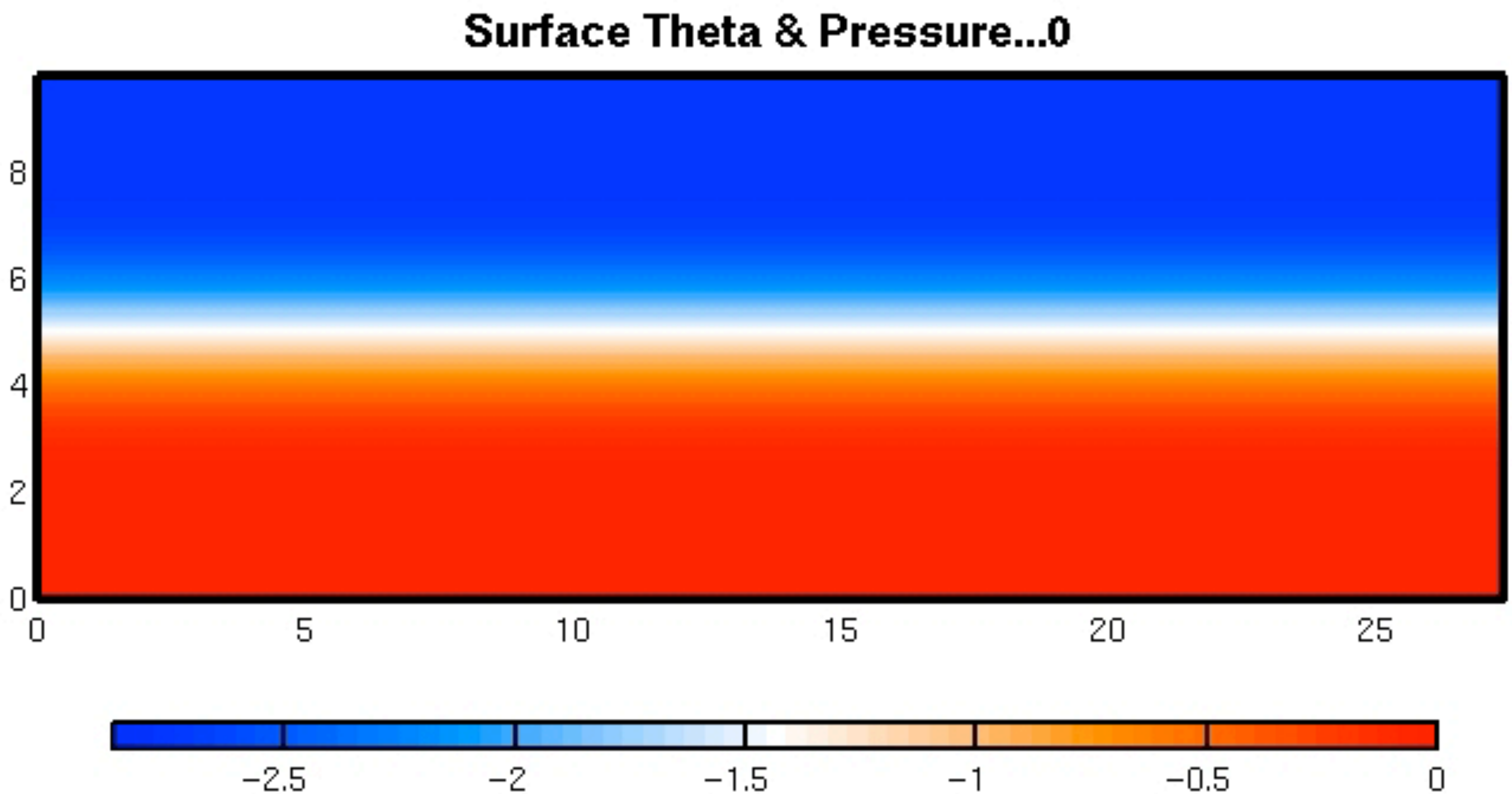
# Case Study

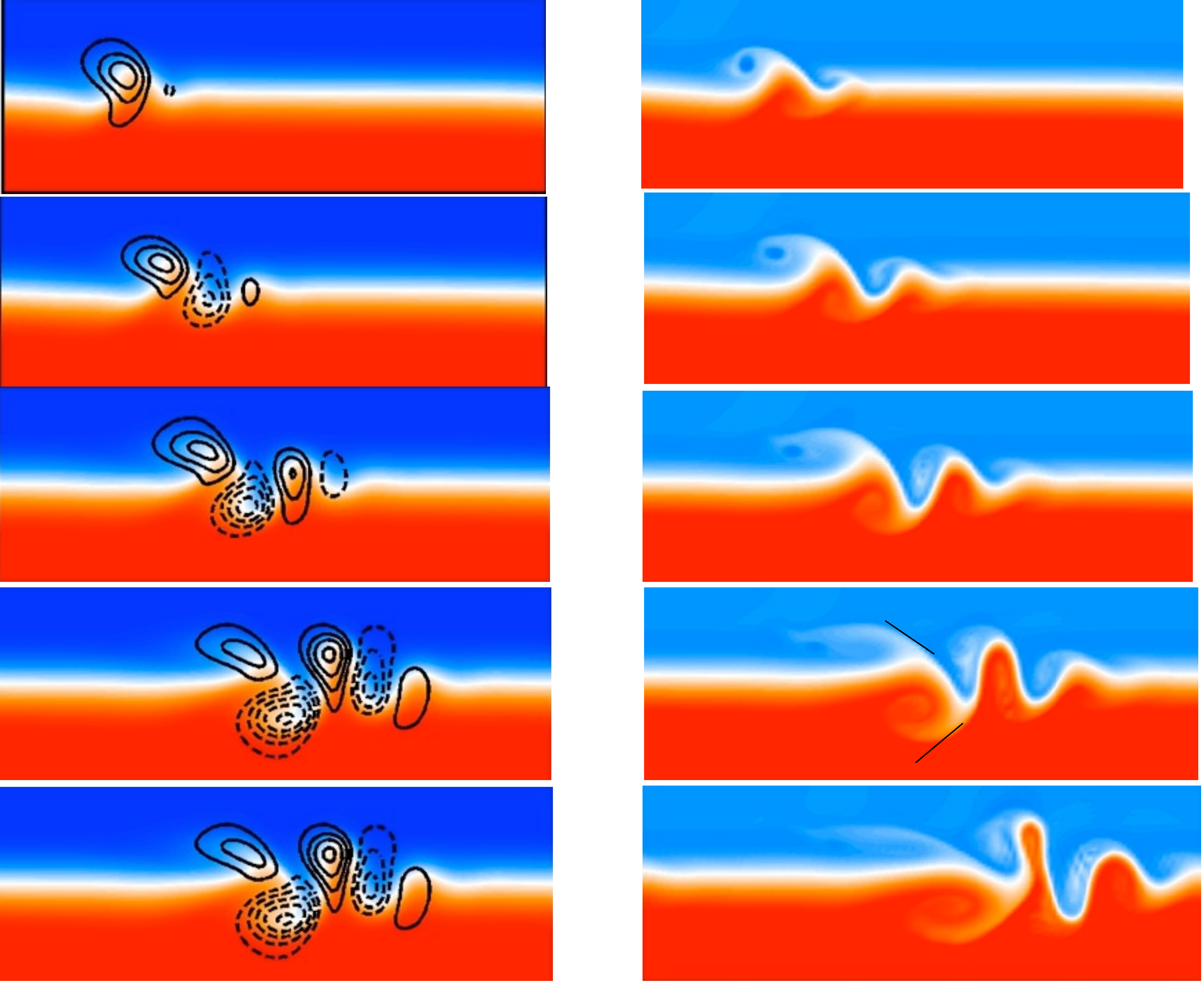
Nov. 10, 1998



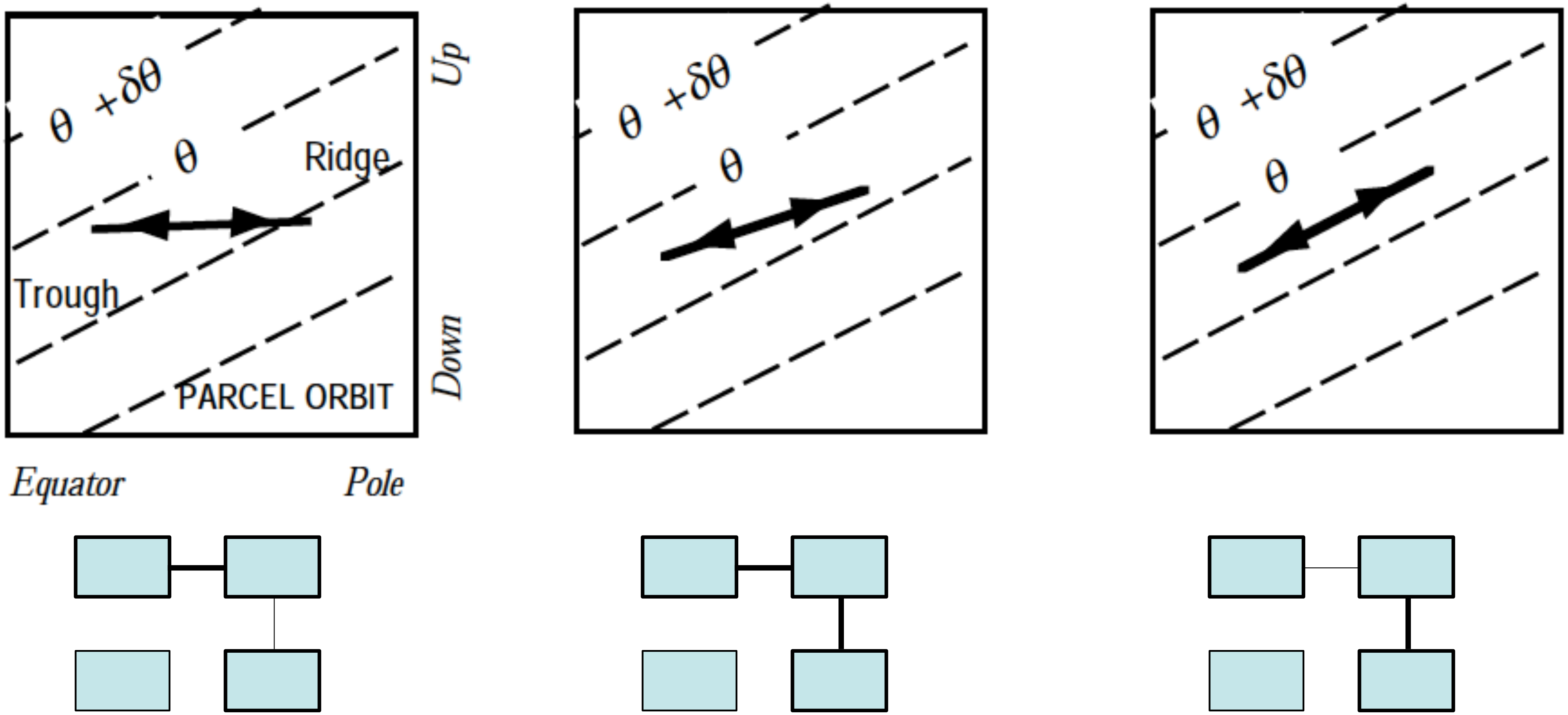
# Idealized model




Surface Theta & Pressure...0
8
6
4
2
0
0
5
10
15
20
25
-2.5
-2
-1.5
-1
-0.5
0


T sfc, SLP
Theta on tropopause

# KE cycle in developing baroclinic waves




$A_E$ generated

but little $K_E$

waves too long

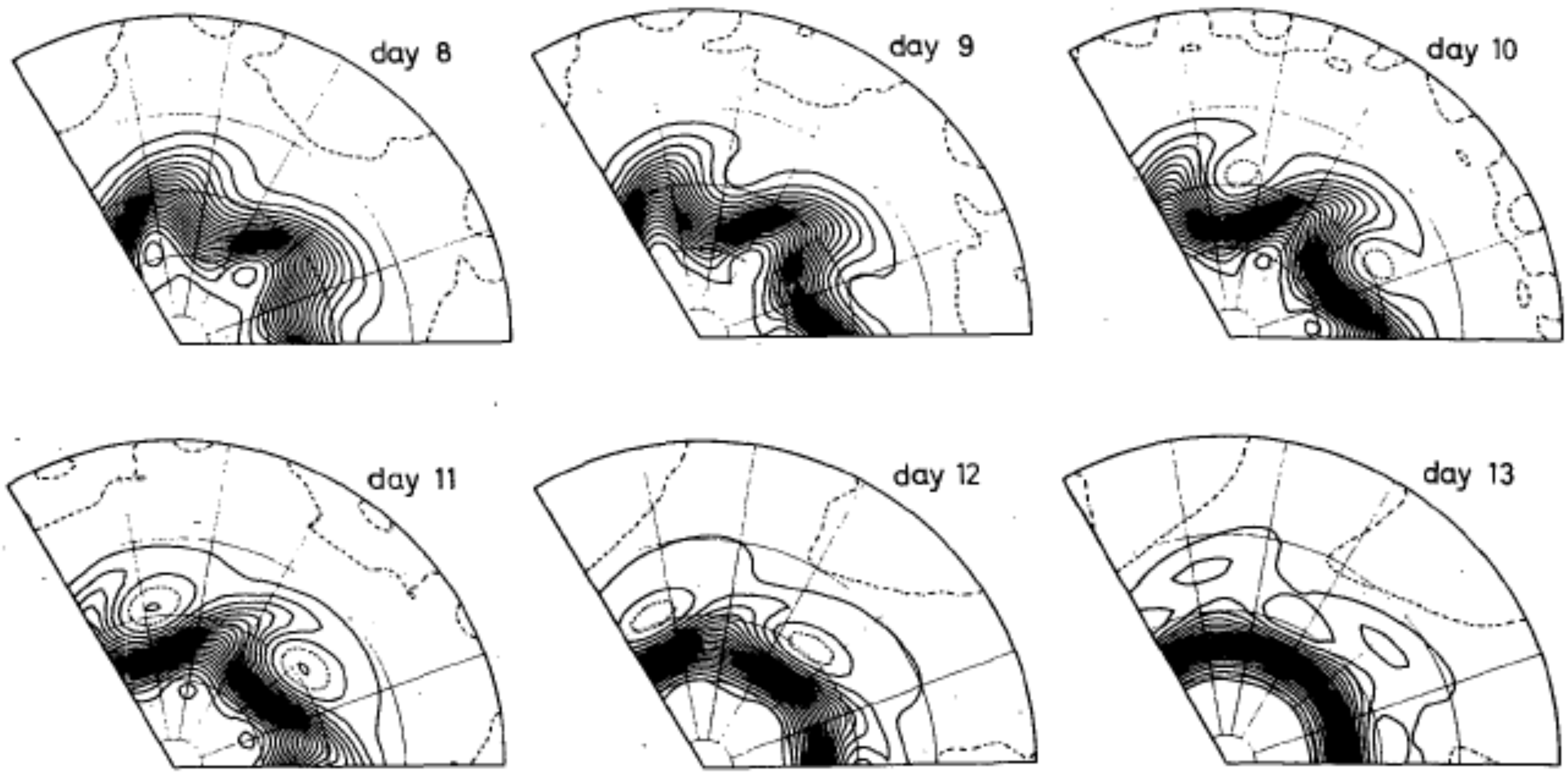
waves just right

$K_E$ generated

but little $A_E$

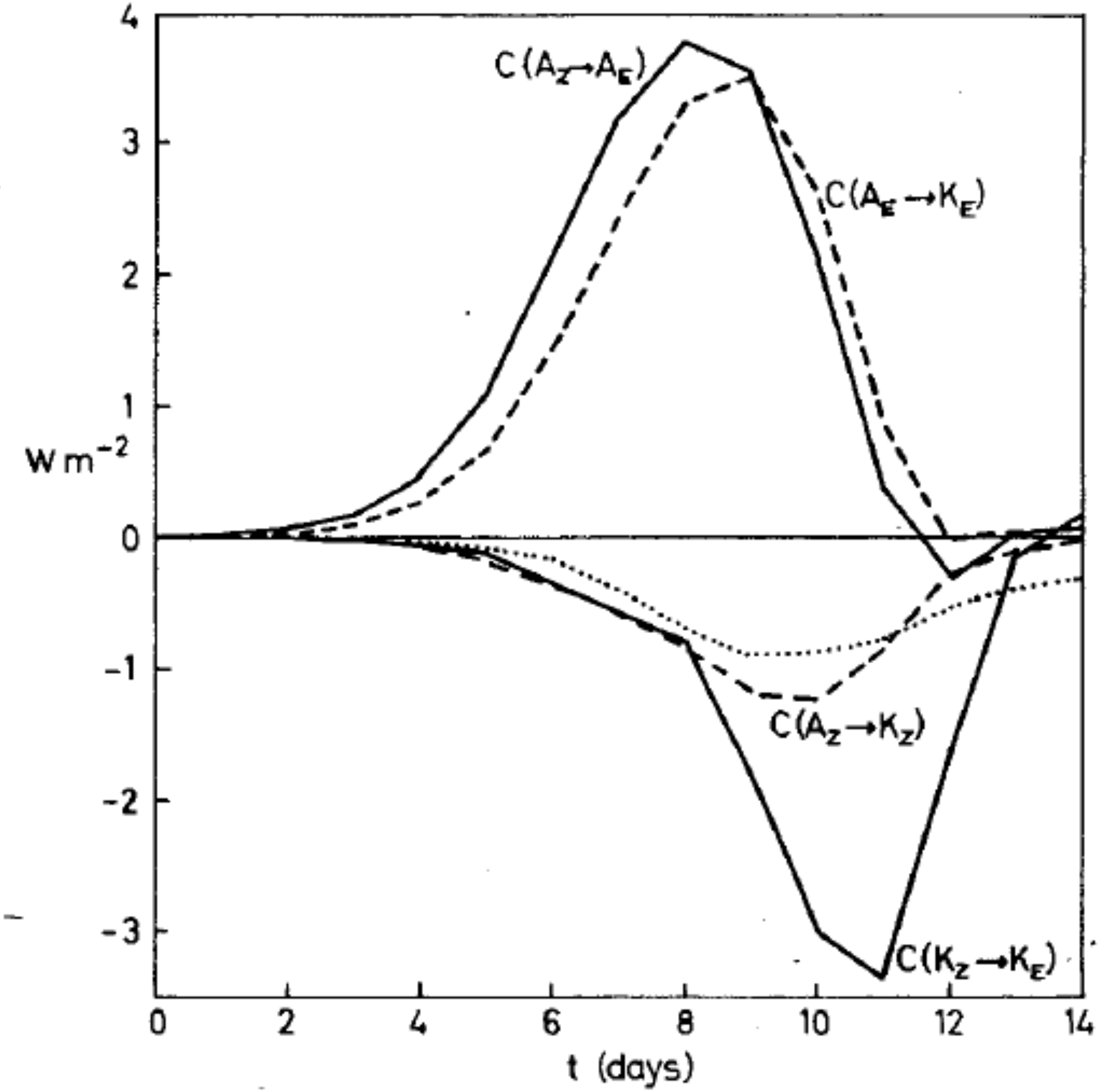
waves too short

300 hPa streamfunction

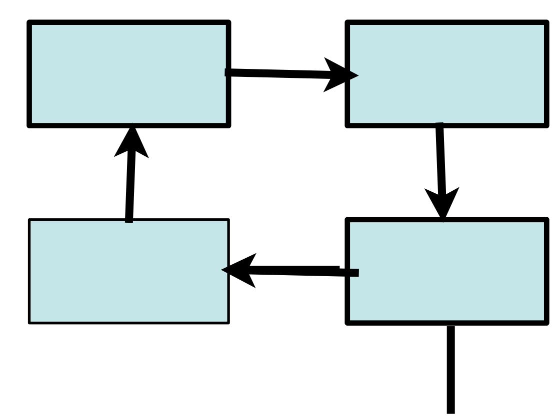



Simmons and Hoskins, JAS, 1978
idealized life cycle experiments

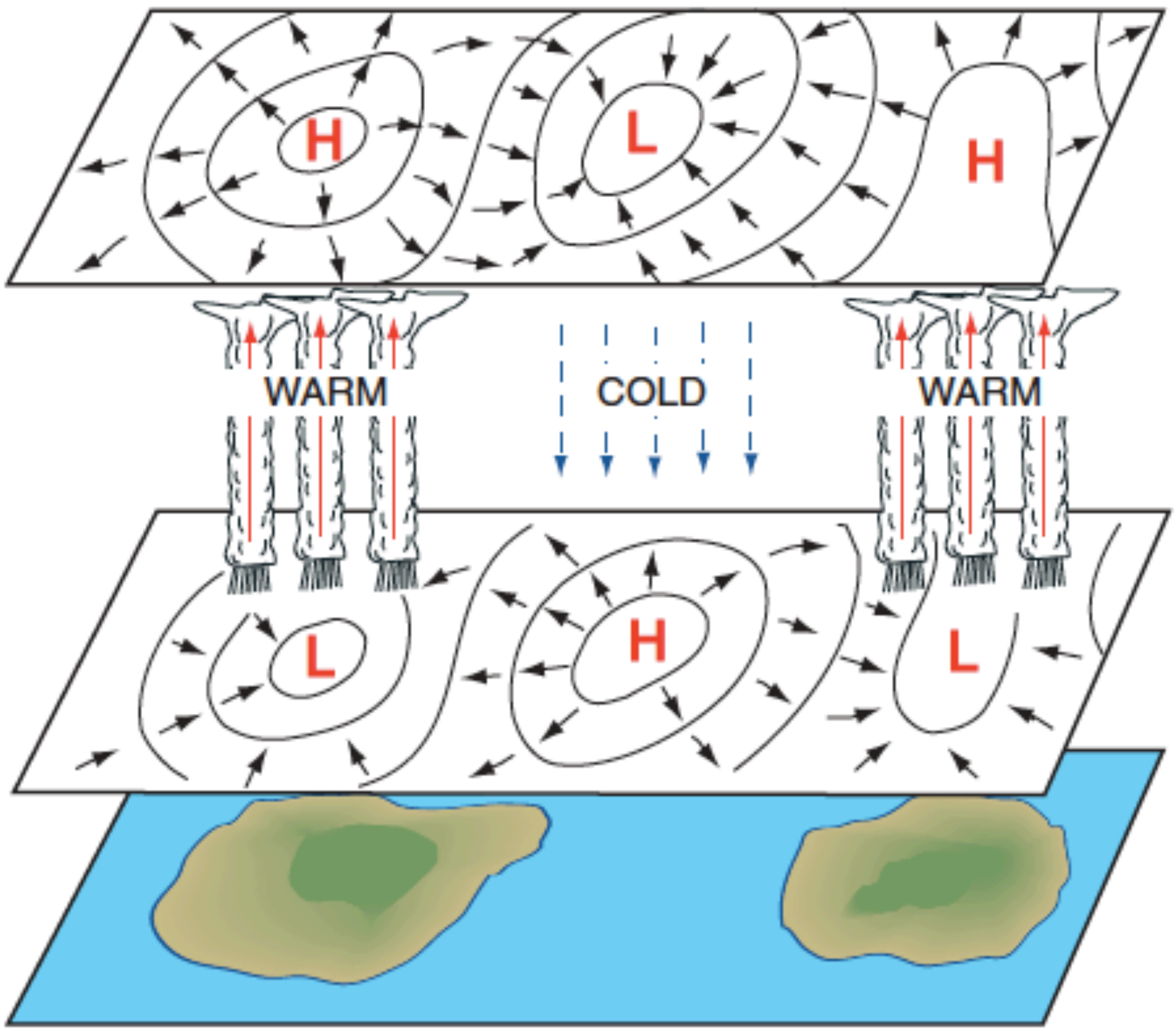
# KE cycle in baroclinic wave life cycle




Simmons and Hoskins, JAS, 1978

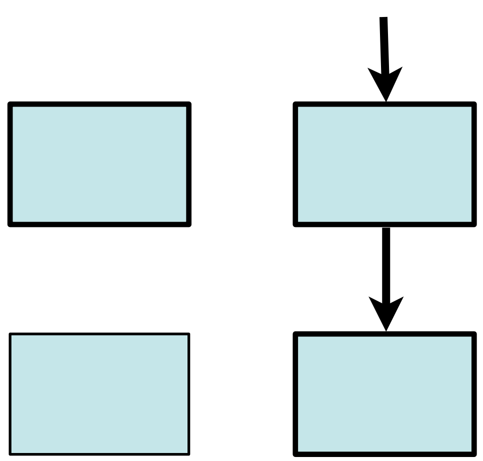


# KE cycle of the monsoons

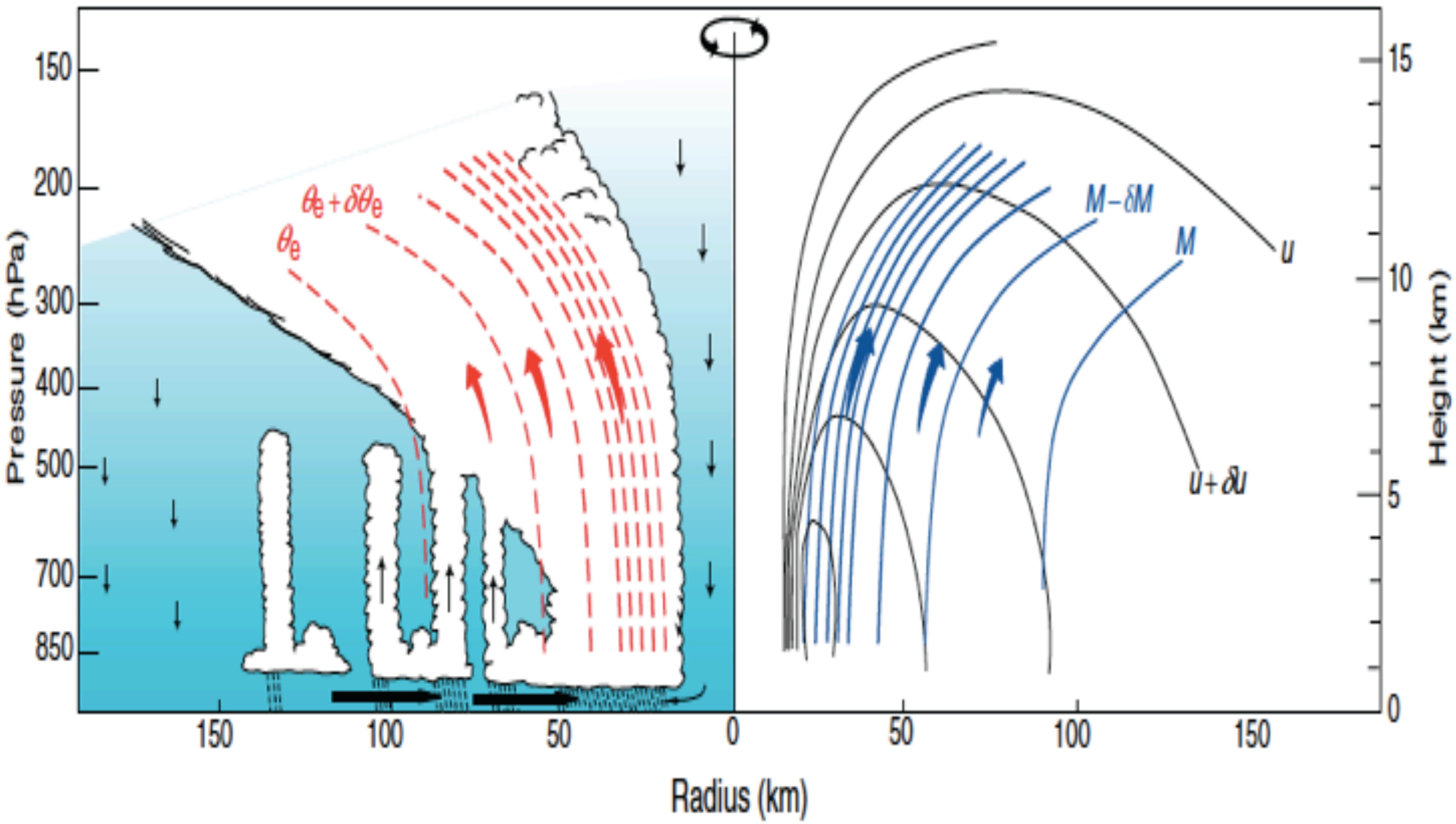



$$[Q^*T^*] > 0$$

$$[\omega^*T^*] < 0$$

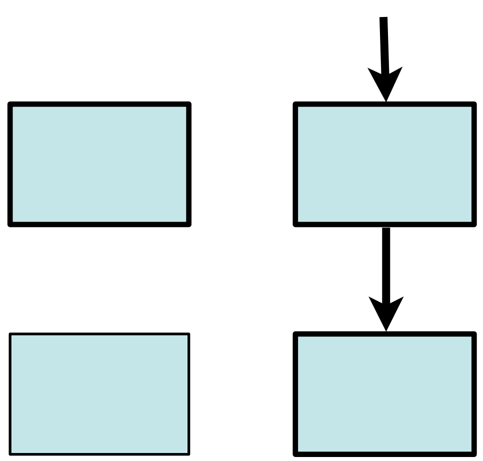


# KE cycle of tropical cyclones

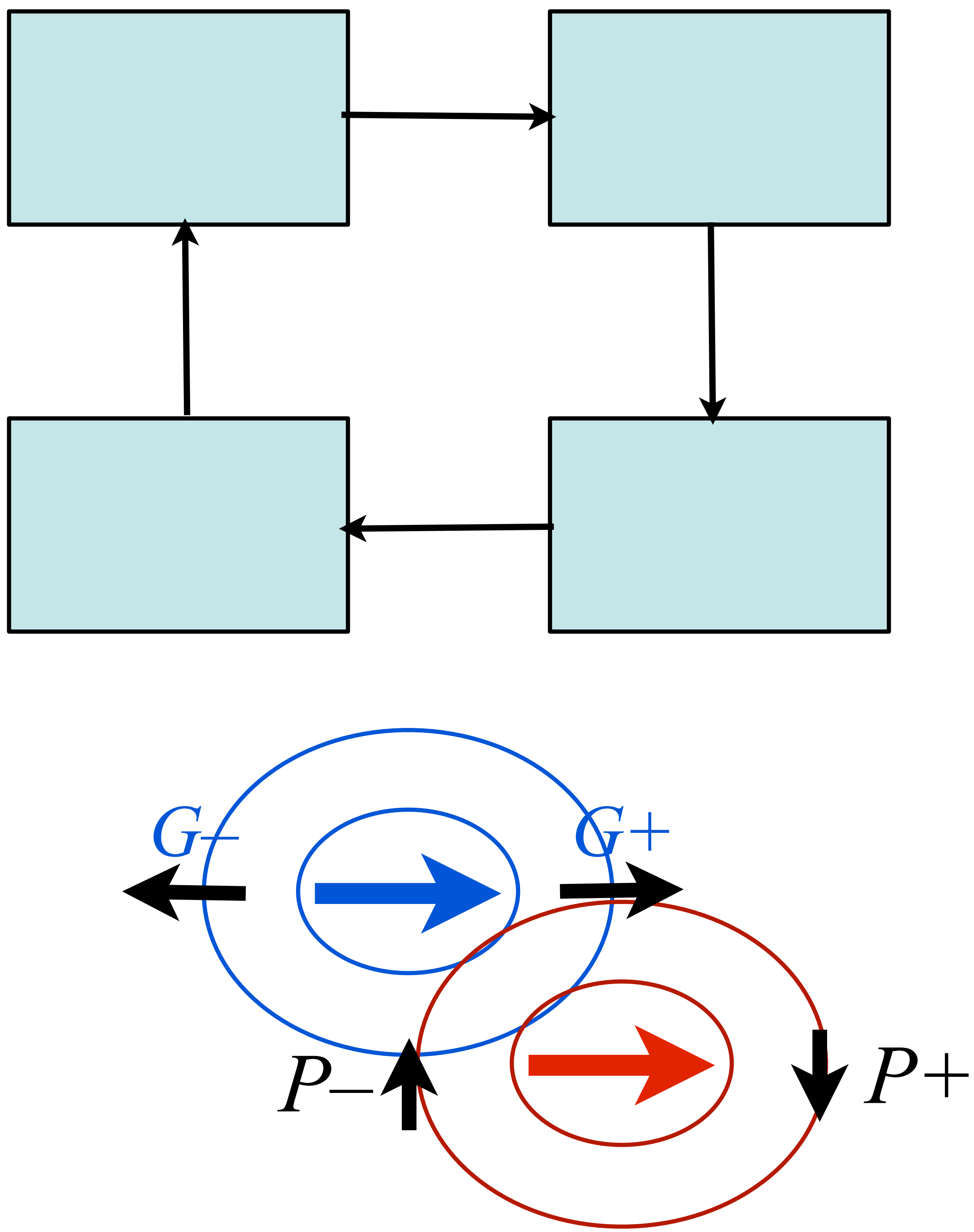



$$[Q^*T^*] > 0$$

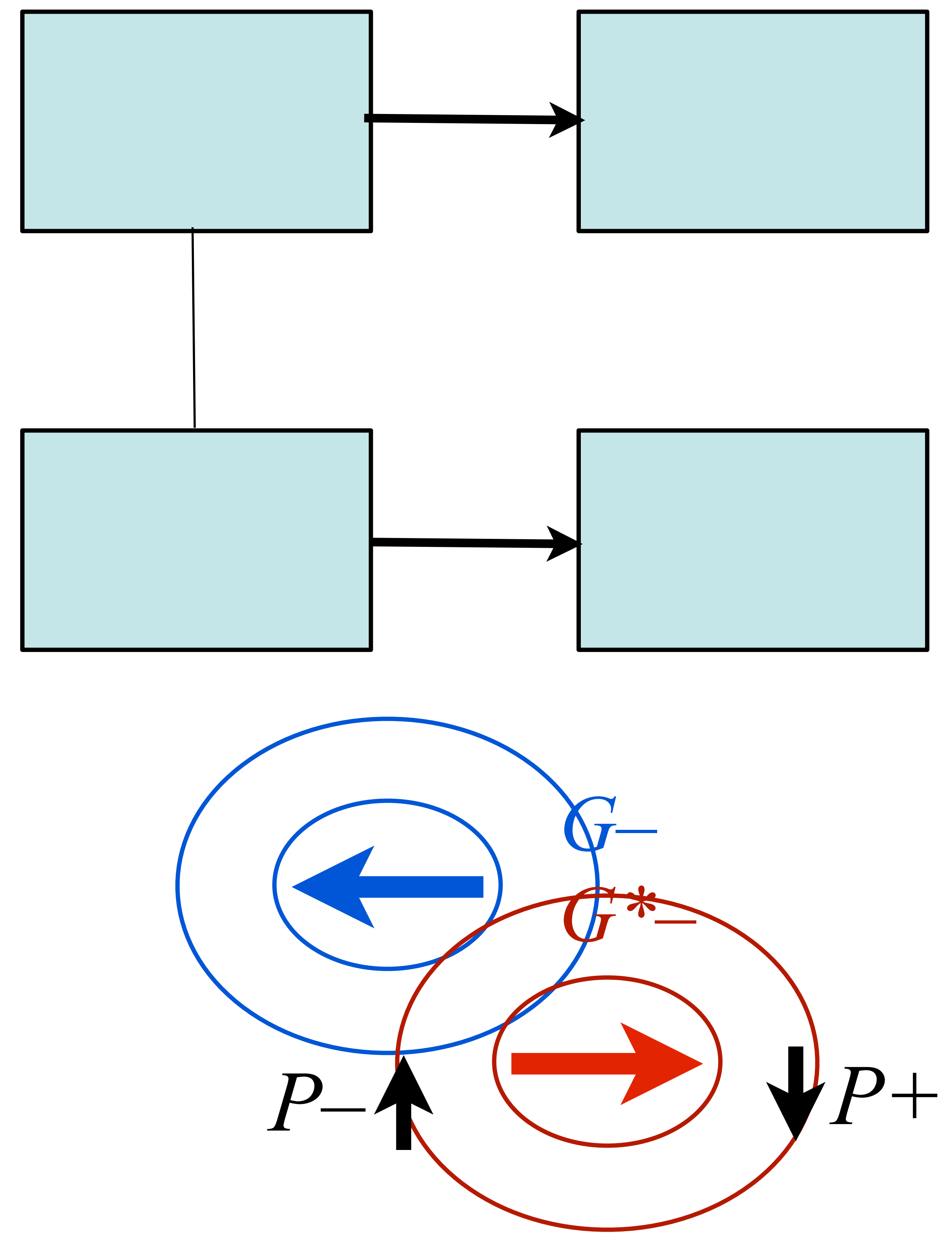
$$[\omega^*T^*] < 0$$



1. Quiescent regime with strong jet

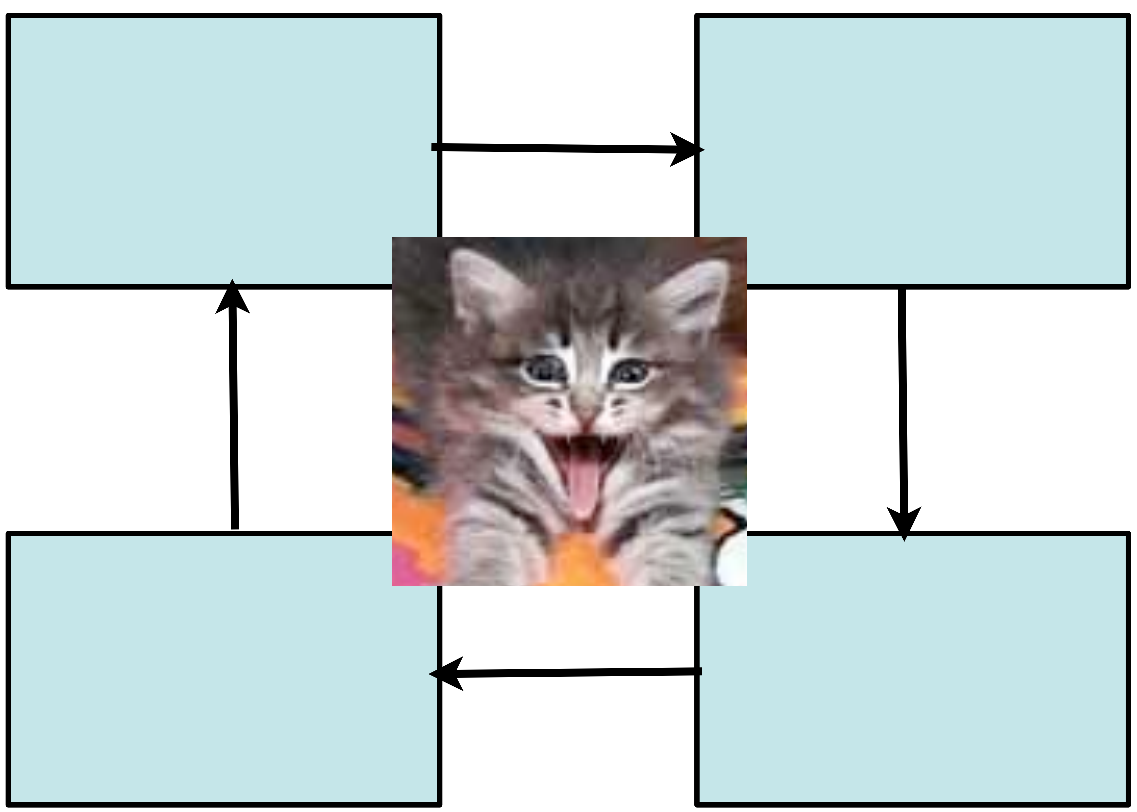



2. Sudden warming



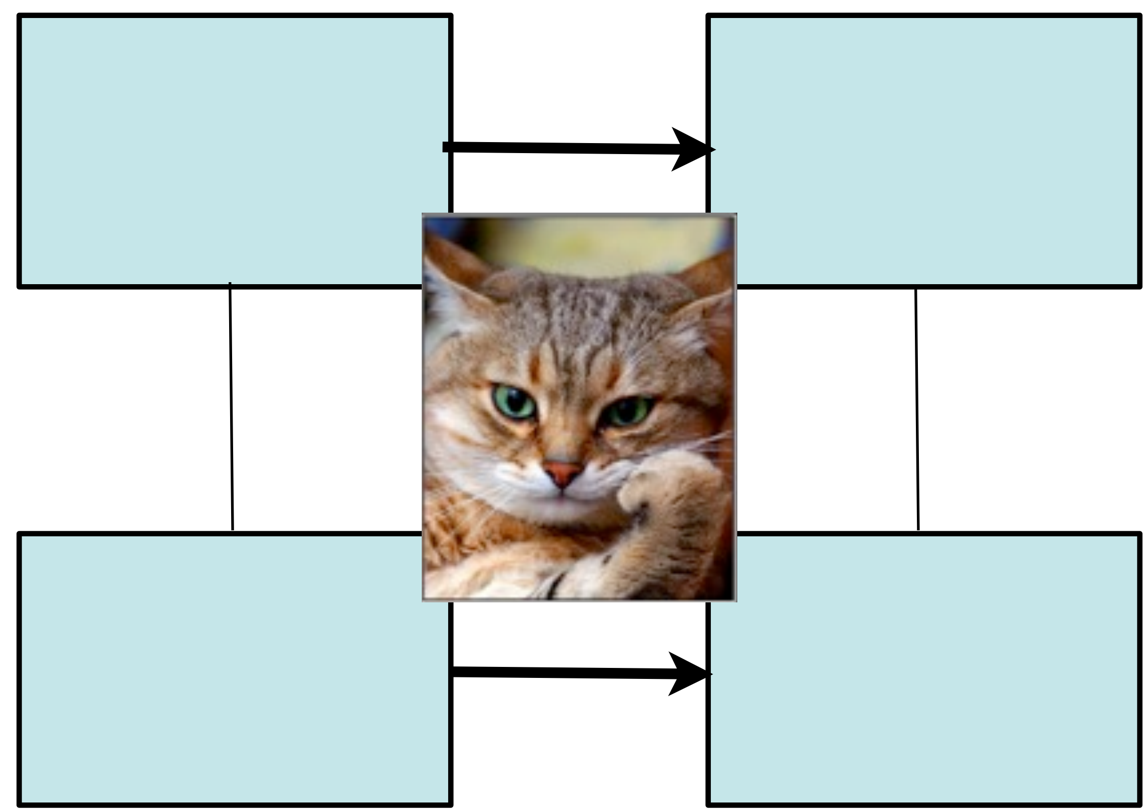
# KE cycle in the stratosphere

1. Quiescent regime with strong jet



awesome conversions
but nothing happens

2. Sudden warming



the MMC stand by idly
and let the jet collapse