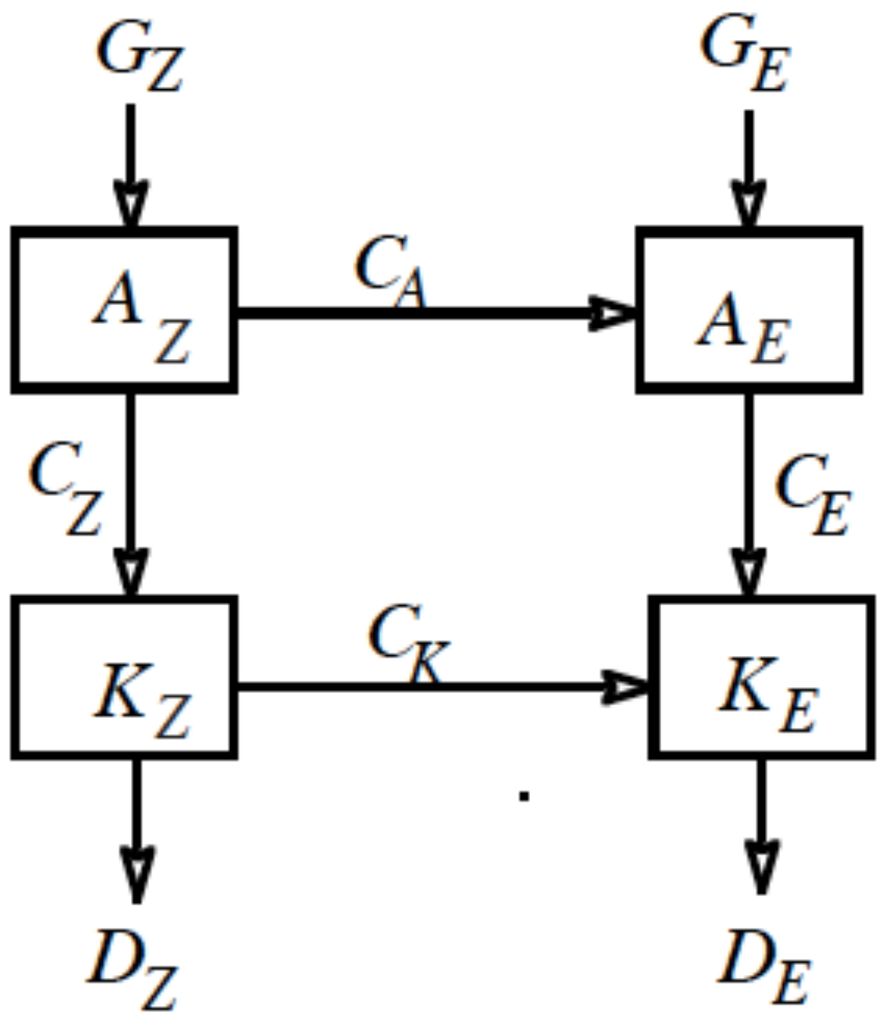
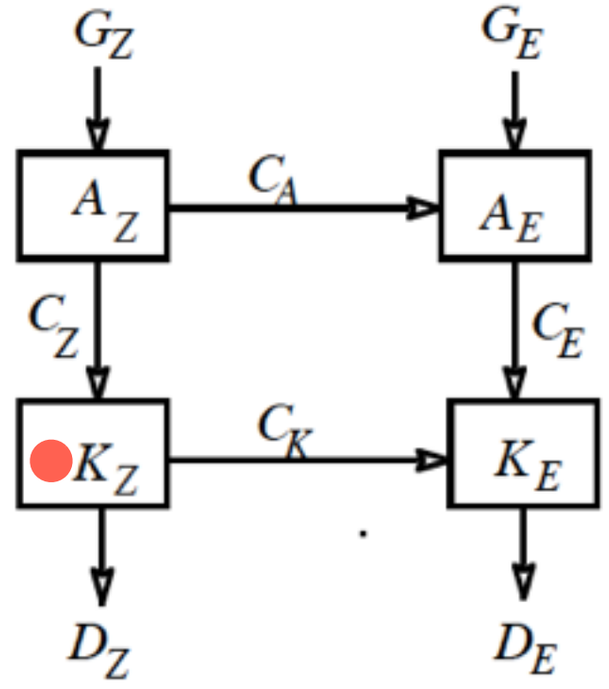


$$\frac{dA_Z}{dt} = G_Z - C_A - C_Z$$

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

etc.

Zonal kinetic energy



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

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

$$C_Z \qquad -C_K \qquad D_Z$$

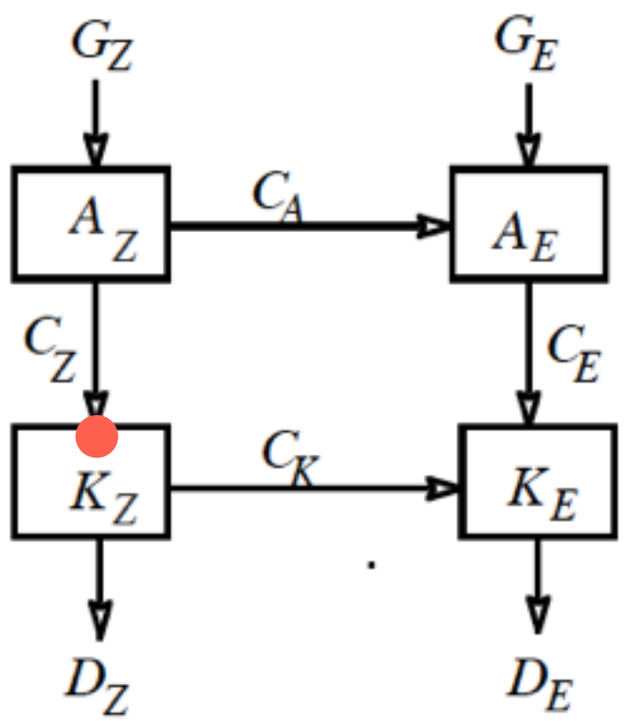
cross-isobar flow eddy fluxes friction

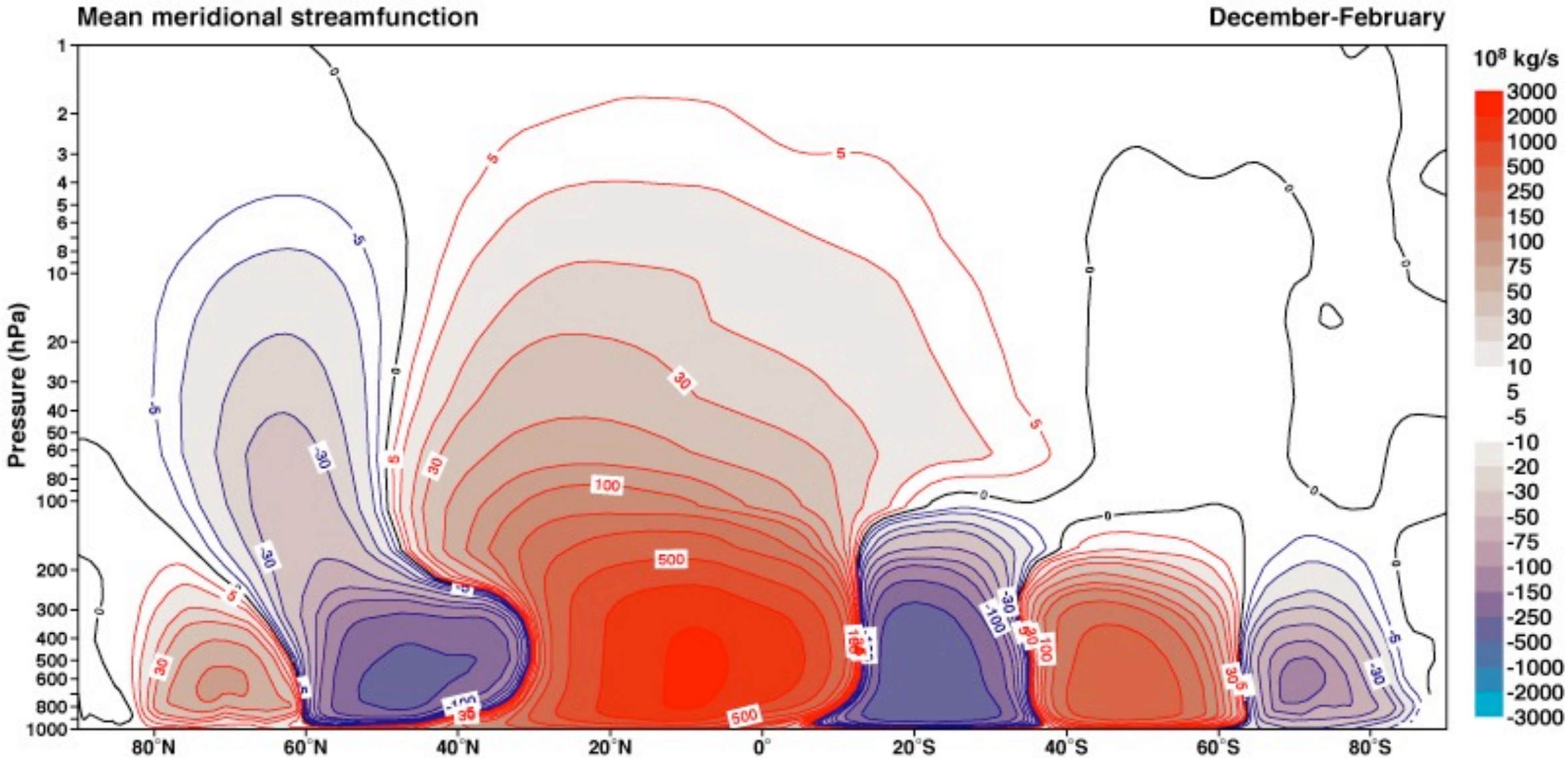
$$-[v]\frac{\partial[\Phi]}{\partial y}$$

Note that in this section overbars denote global averages.

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

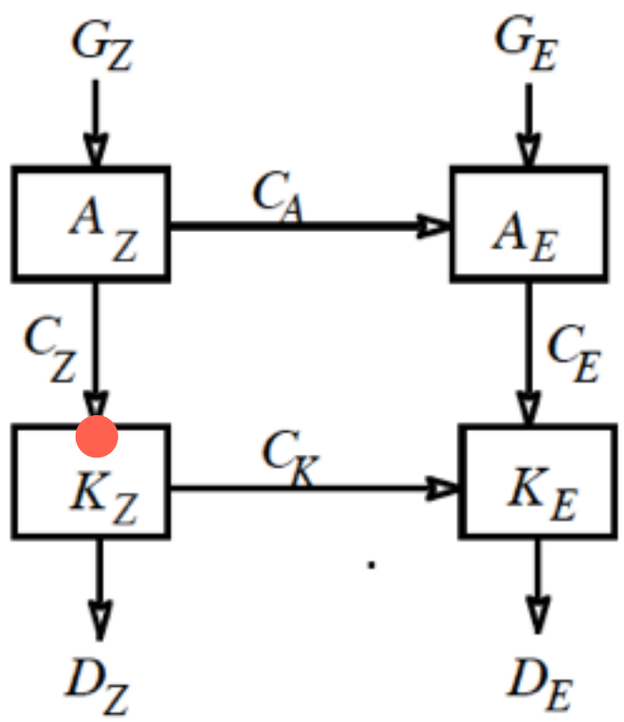
$$-[v]\frac{\partial[\Phi]}{\partial y}$$

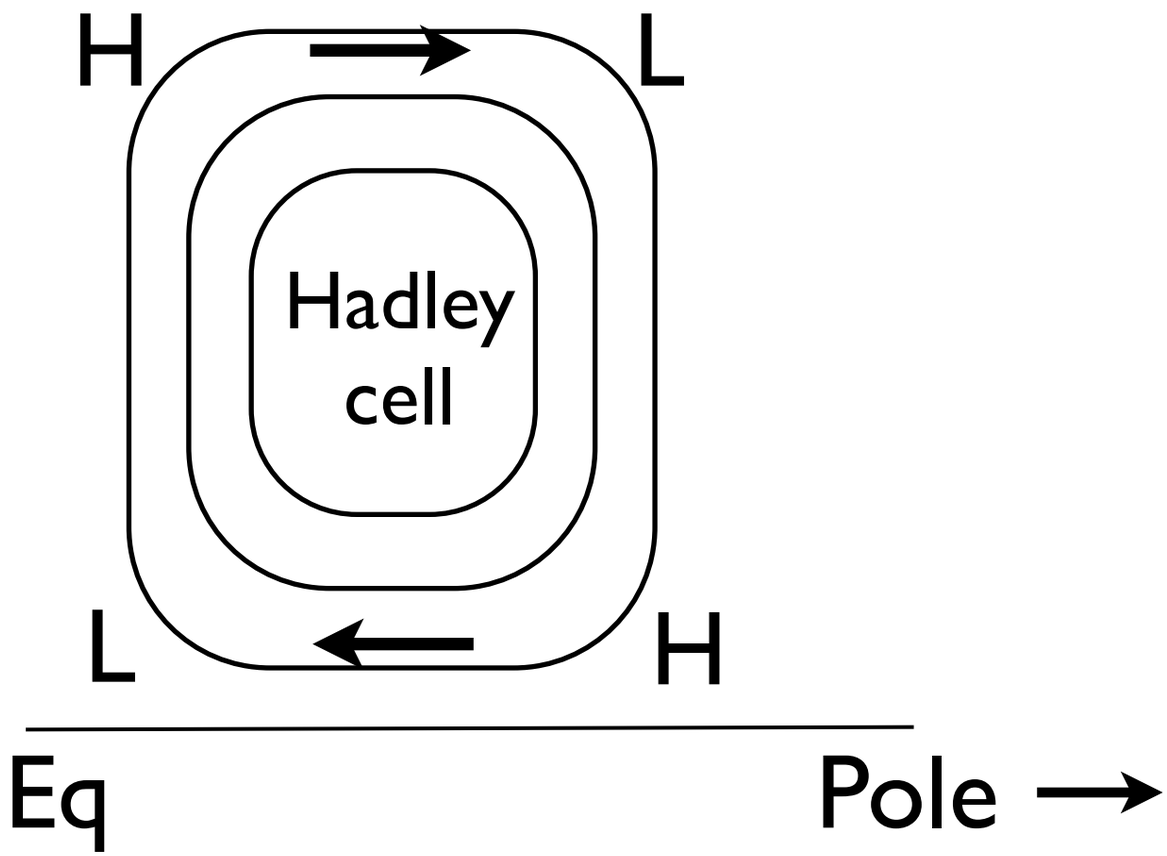




$$C_Z = \frac{1}{g}\int_0^{p_0} f\overline{[u][v]}dp$$

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

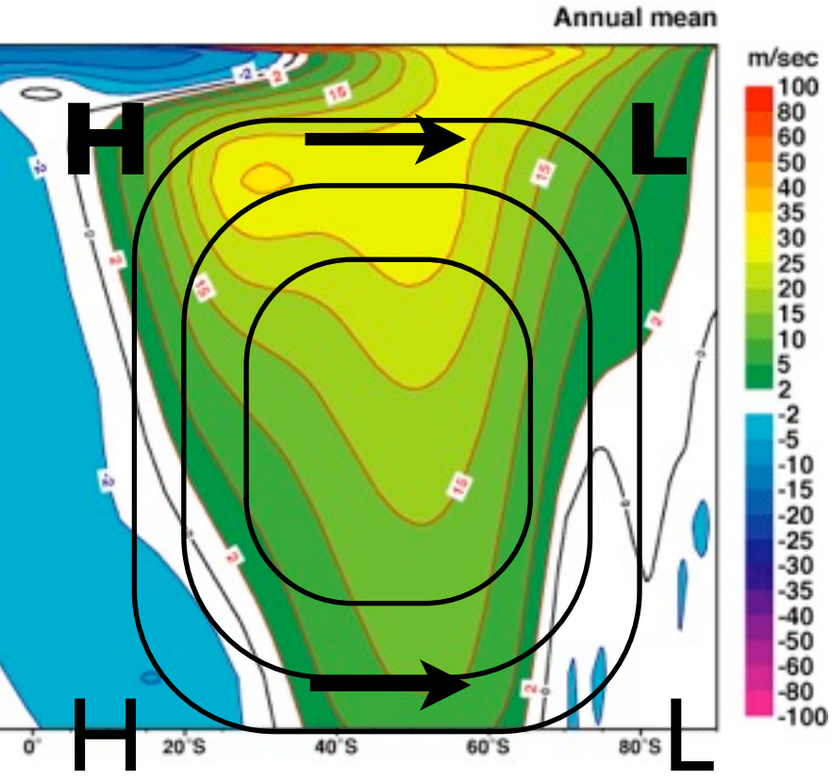


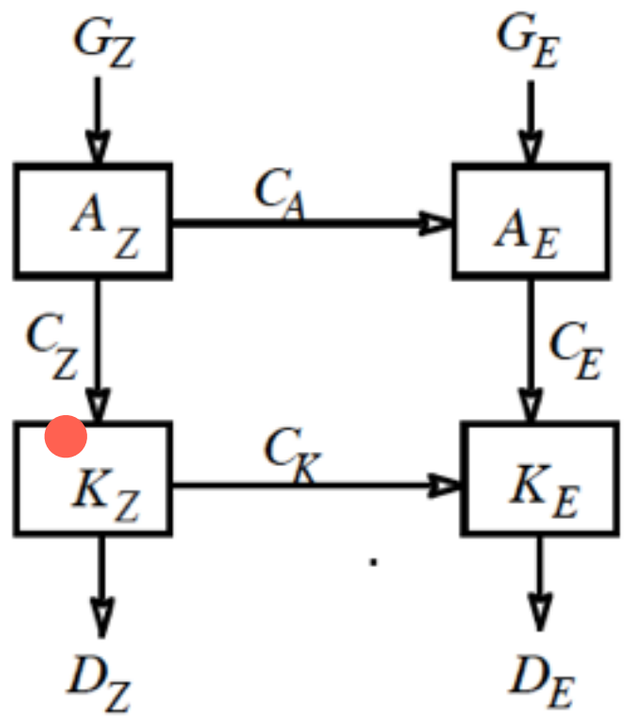


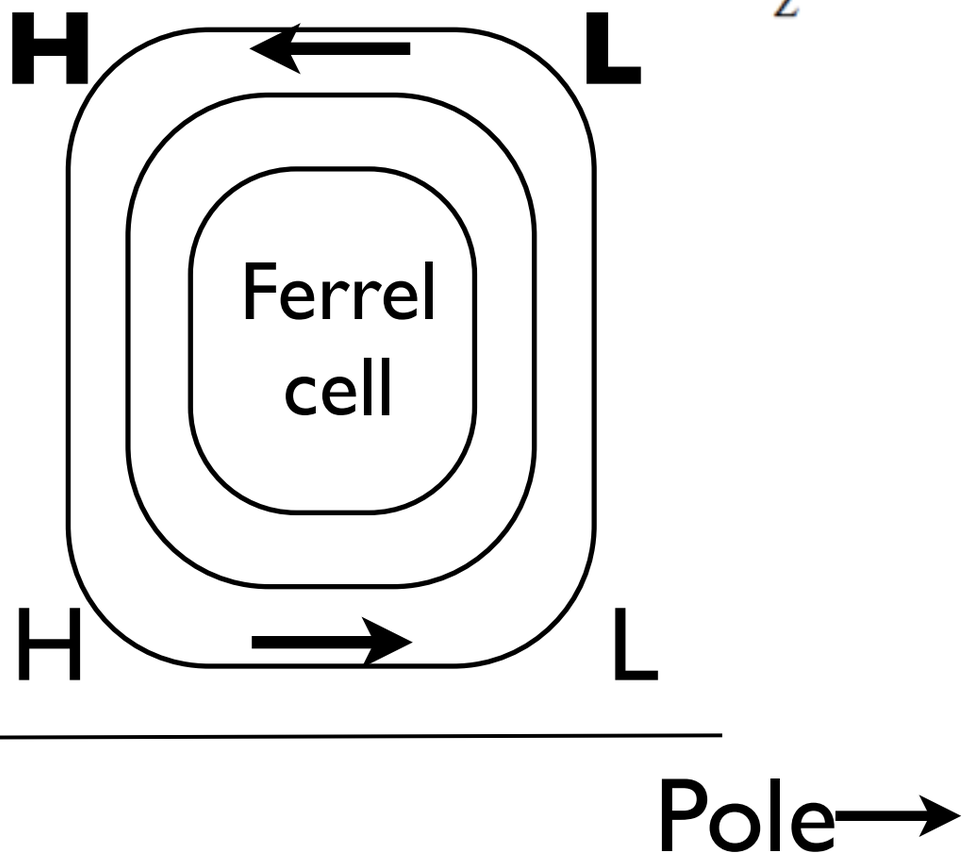
Hadley Cell A_Z to K_Z i.e., thermally direct

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

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



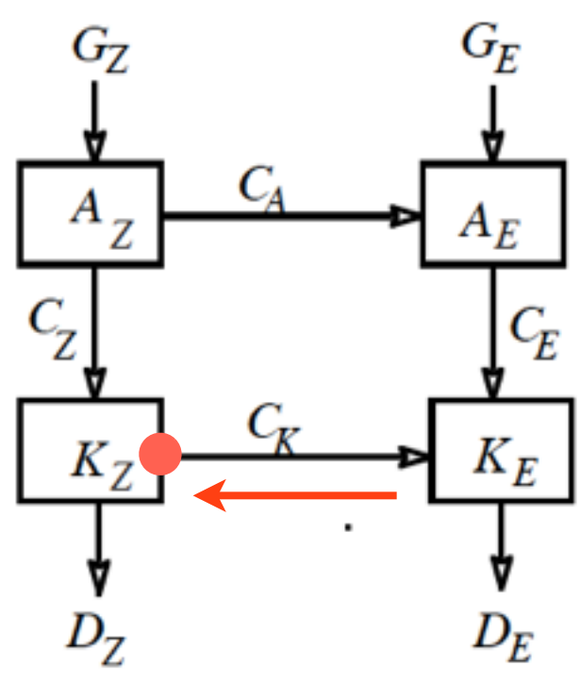




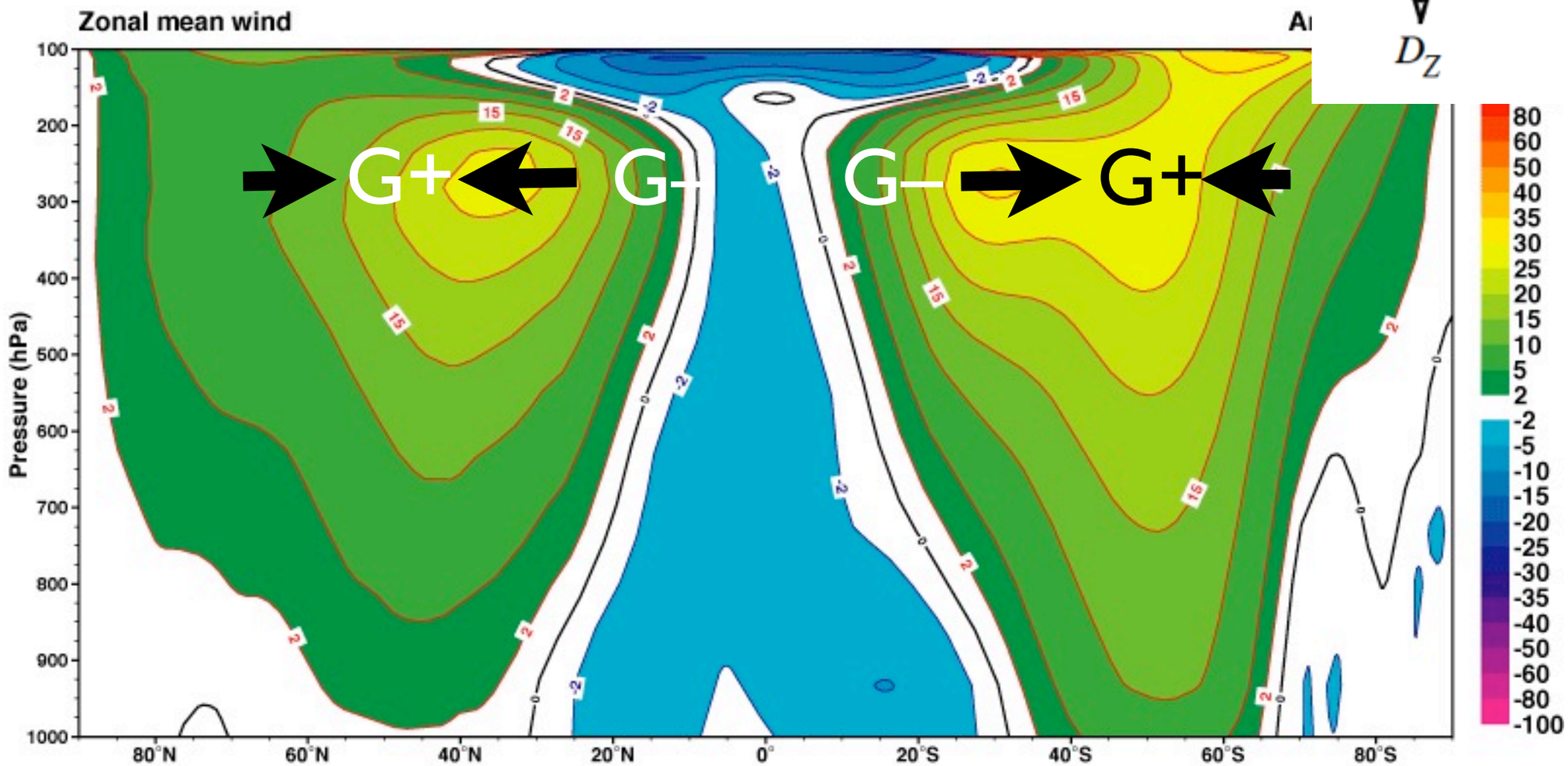
Ferrell Cell K_Z to A_Z; i.e.,thermally indirect

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.

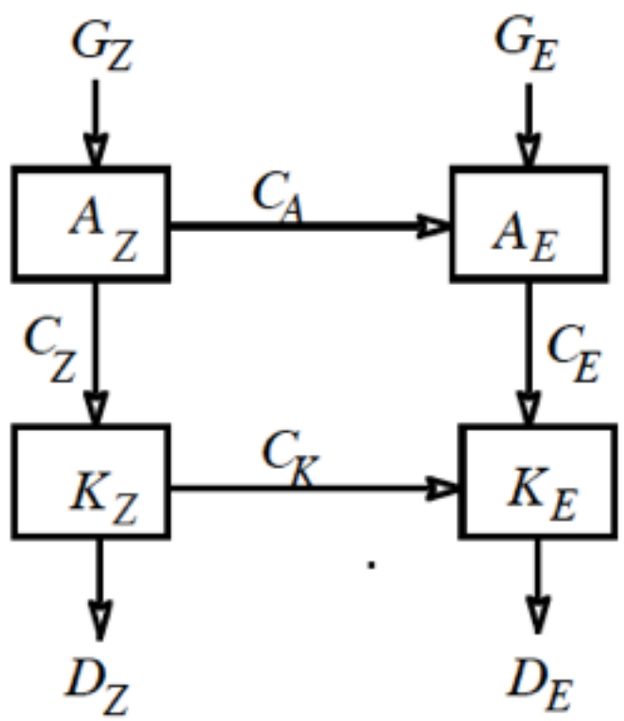
$$-C_K = +\frac{1}{g}\int_0^{p_0} \overline{[u]G}\,dp \,.$$



u

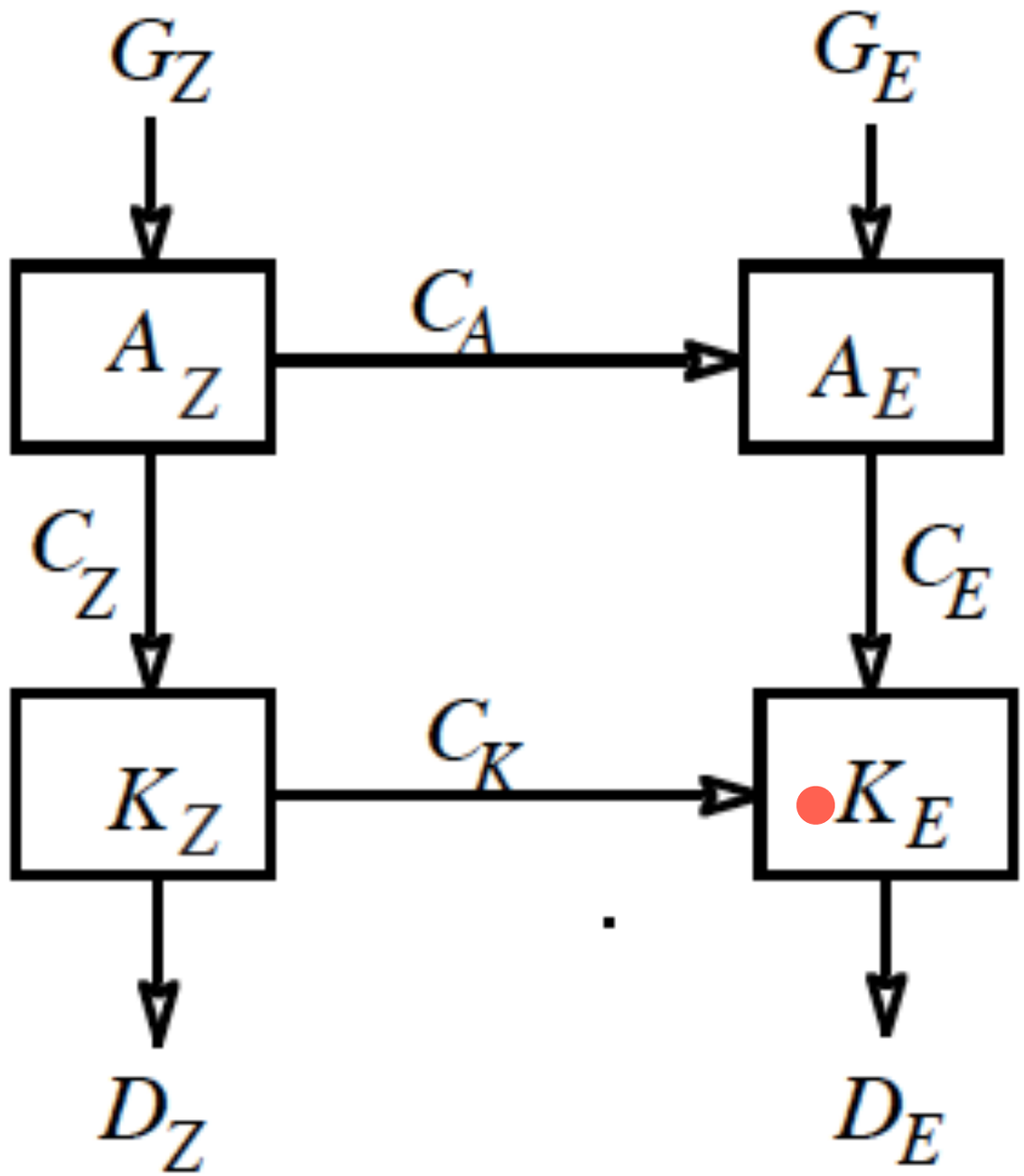


$G+$ where u is more positive so $-C_K > 0$



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

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

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

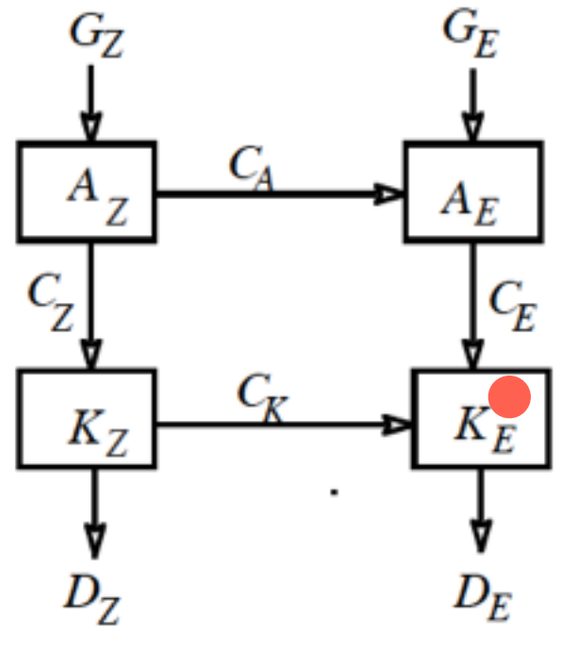
C_K C_E D_E

downgradient momentum flux

cross-isobar flow

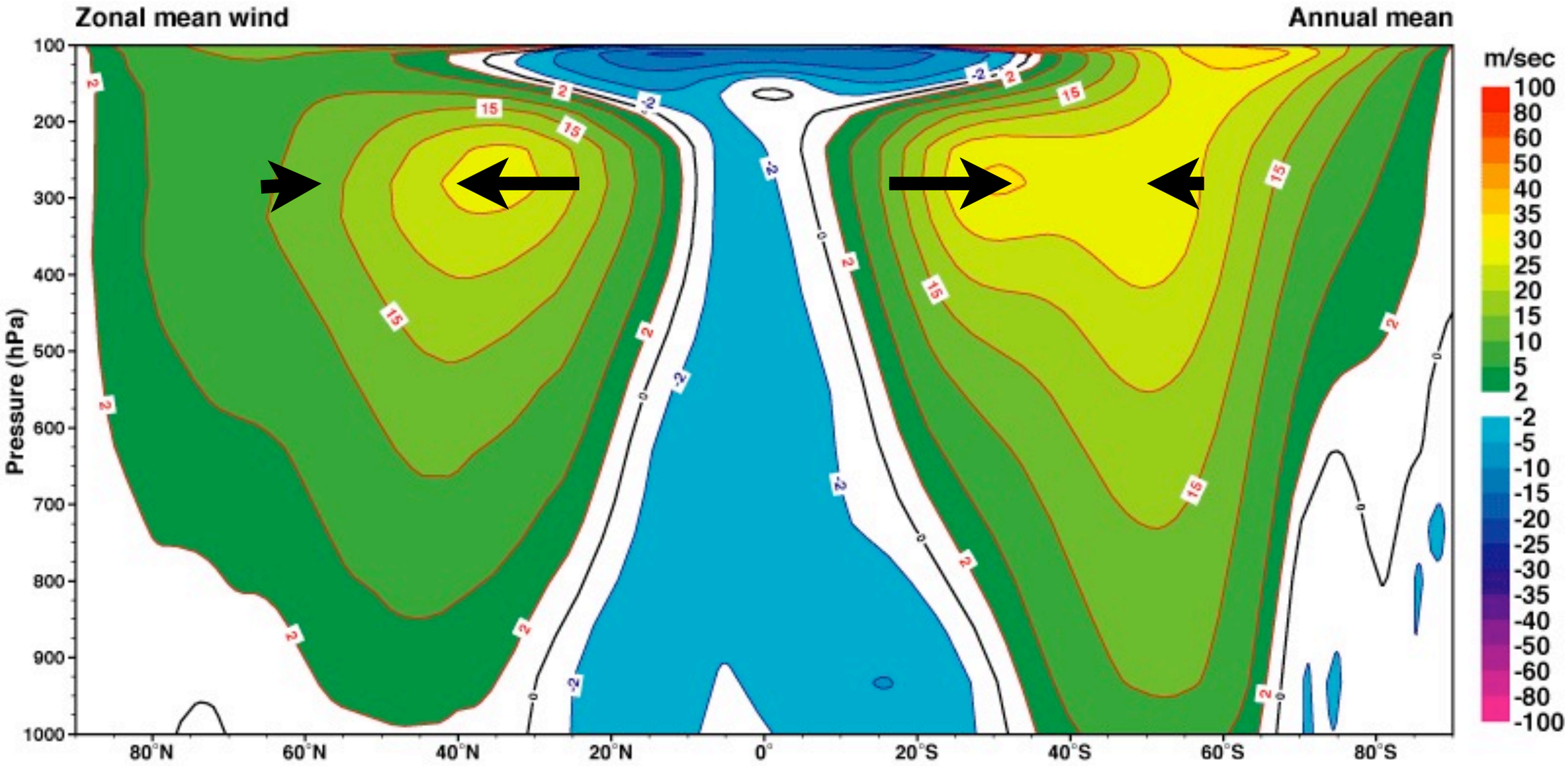
frictional drag

See Appendix 5 for a derivation.

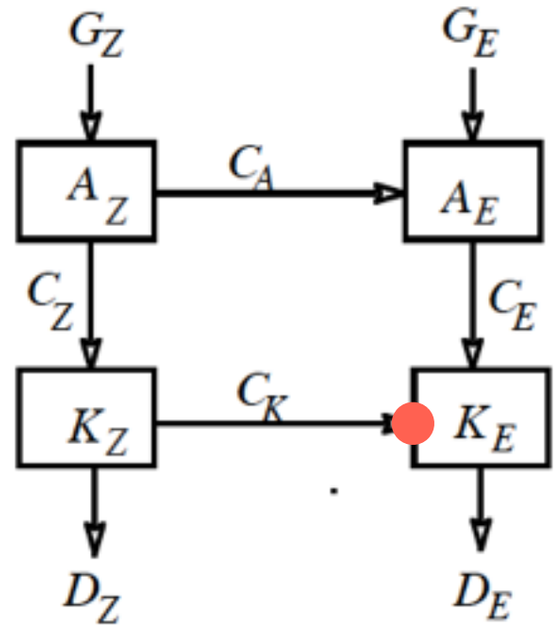


Note that the flux is primarily countergradient; i.e., toward higher u

u

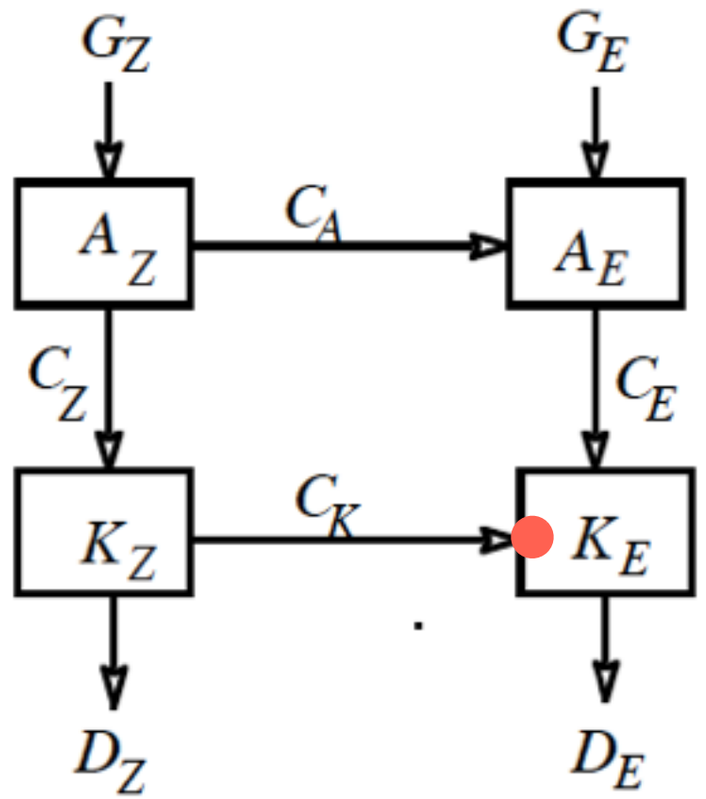


$$: -\frac{1}{g}\int_0^{p_0}\overline{[u^* v^*]}\frac{\partial [u]}{\partial y}dp \qquad < 0$$

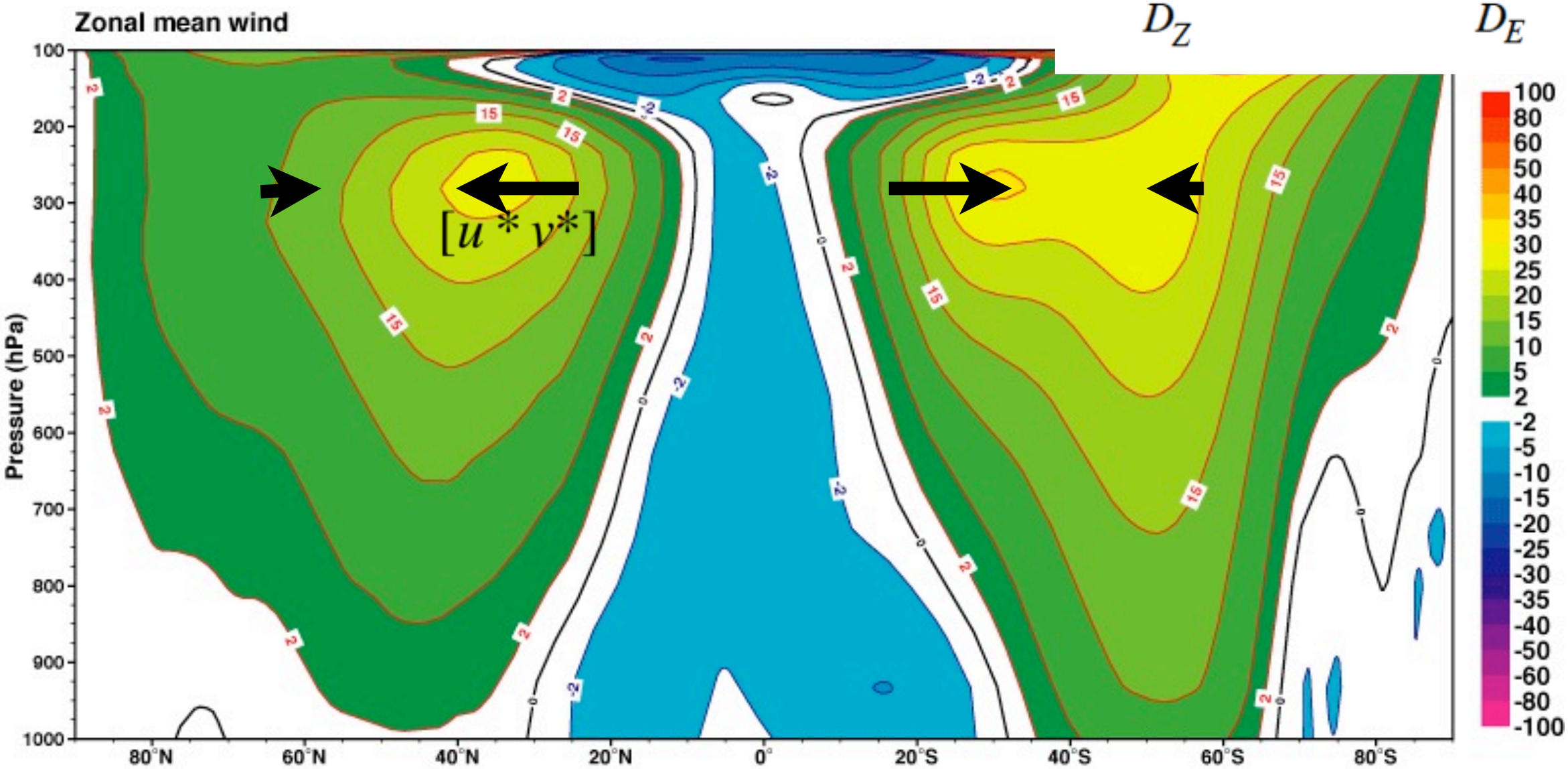


But the notion that mixing should be down-gradient doesn't really apply to zonal momentum, which doesn't behave as a passive tracer.

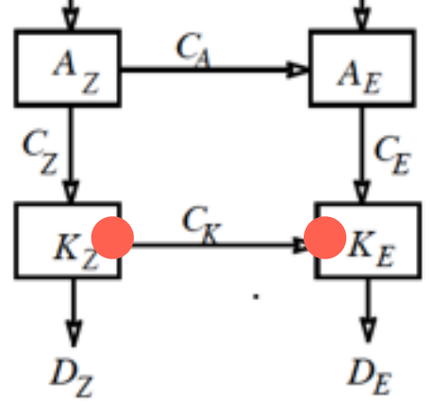
$$: -\frac{1}{g}\int_0^{p_0}\overline{[u^* v^*]}\frac{\partial[u]}{\partial y}dp$$



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

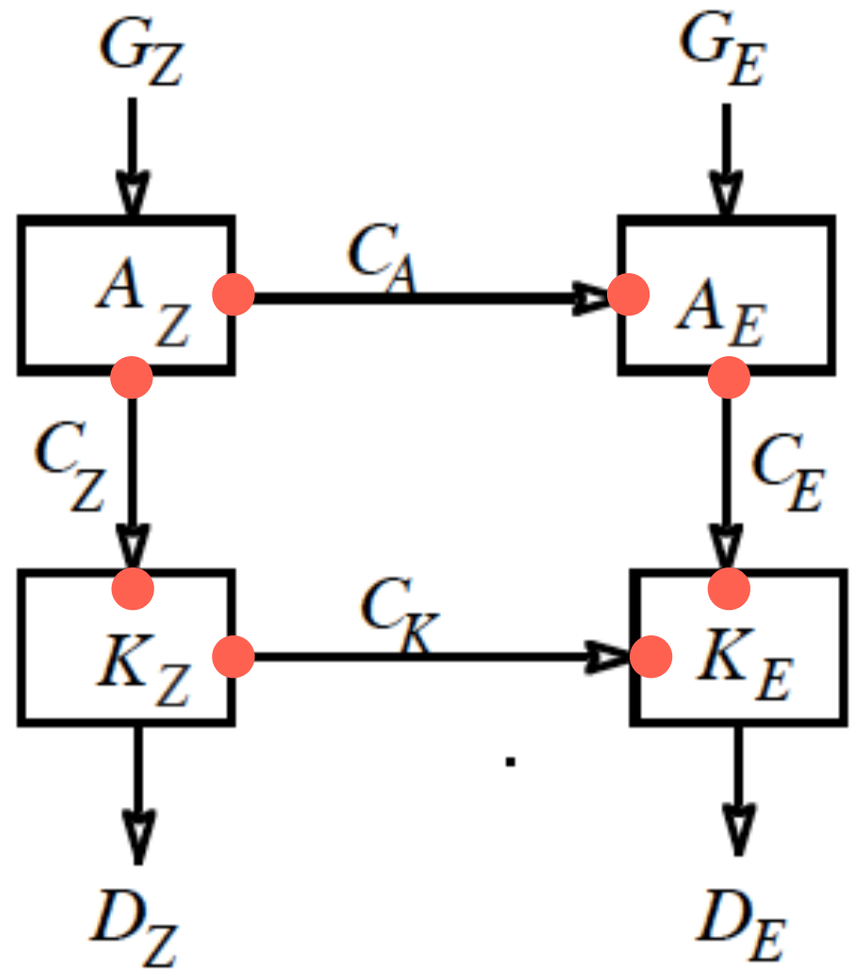
It's only in the global average that the two expressions for C_K are identical.



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."



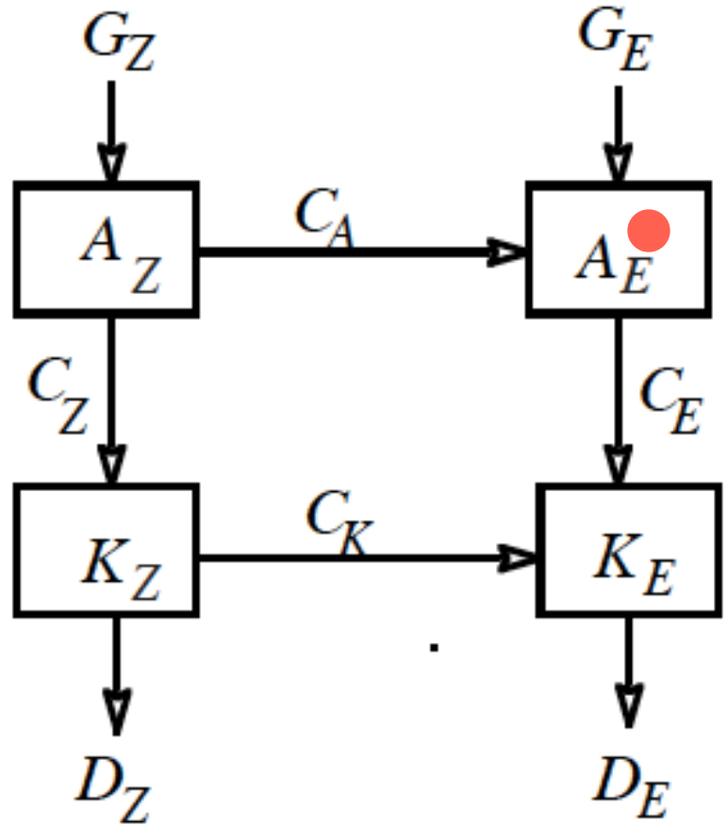
There are days when I wonder
about that too.

But compared to clouds
the Lorenz KE cycle is simple.

For the eddy available potential energy, we have

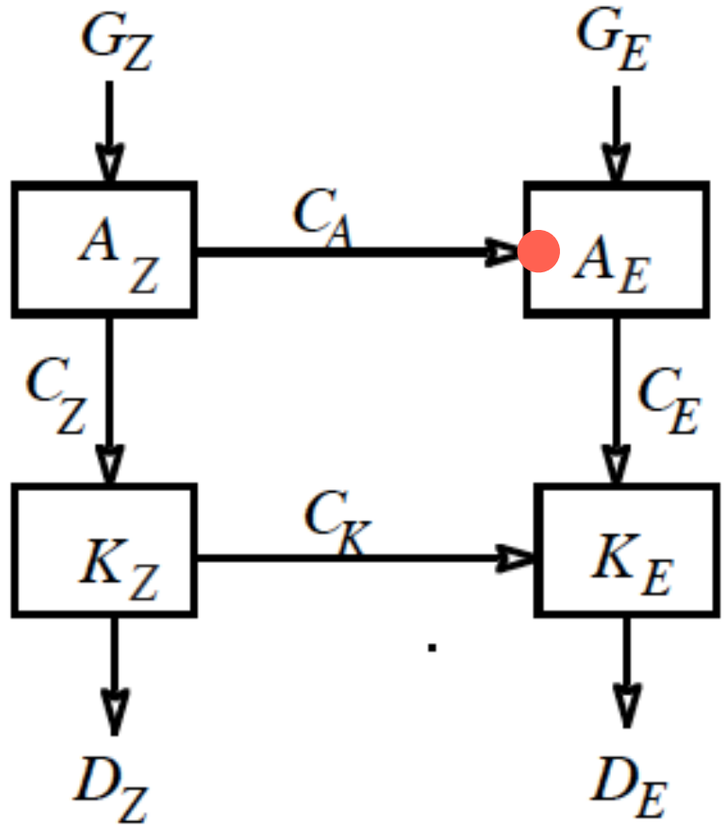
$$\frac{\partial A_E}{\partial t} = -\frac{1}{g}\int_0^{p_0} \frac{\overline{[v^* \alpha^*]}}{\sigma}\frac{\partial \alpha}{\partial y}dp + \frac{1}{g}\int_0^{p_0} \overline{[\omega^* \alpha^*]}dp + \frac{1}{g}\int_0^{p_0} \frac{\overline{[Q^* \alpha^*]}}{\sigma}dp$$

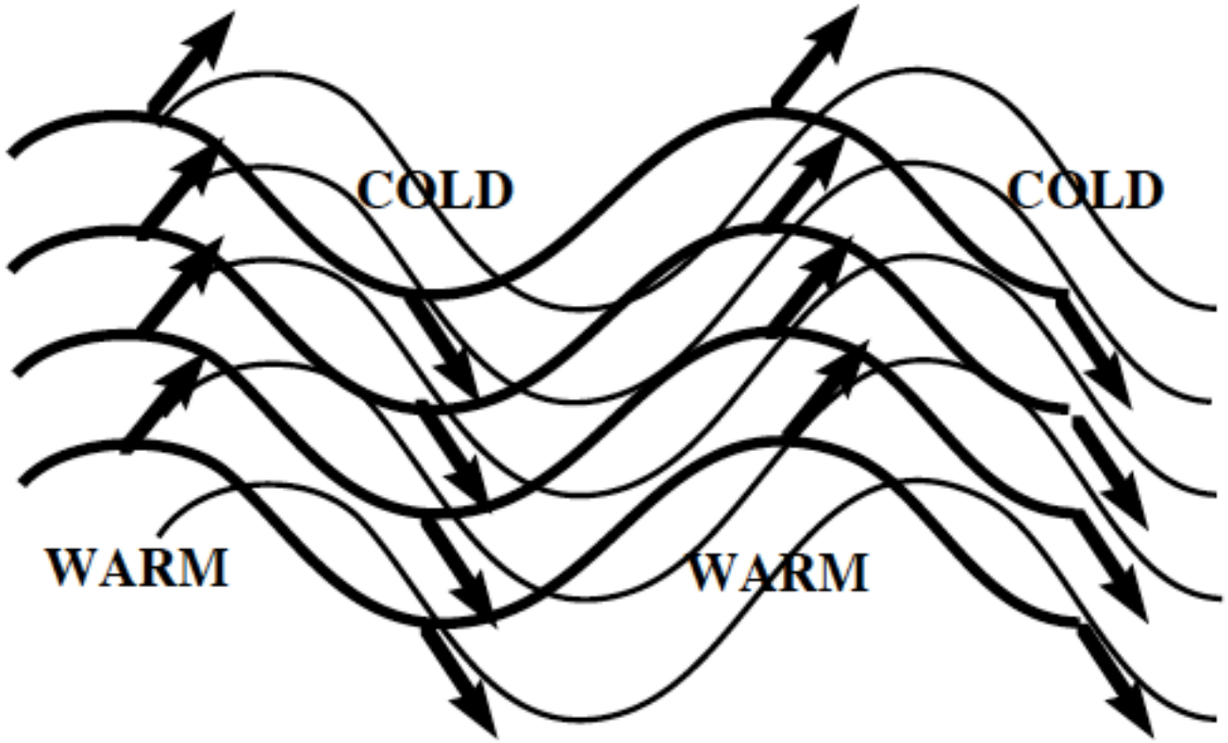
You should recognize the terms here.



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

the downgradient heat flux term

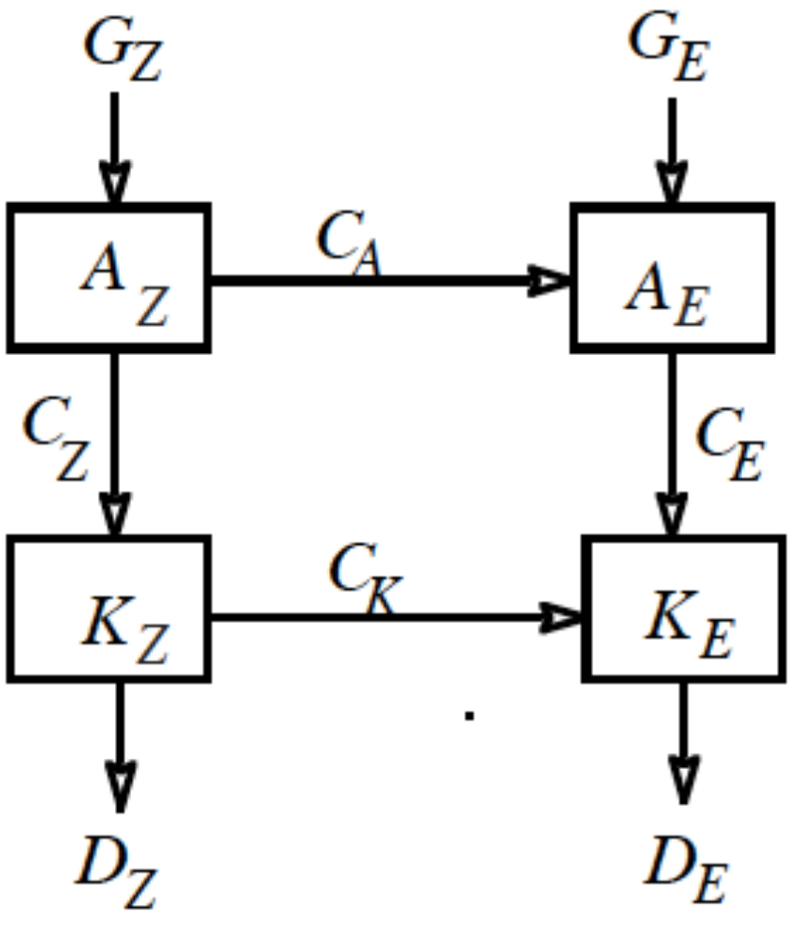




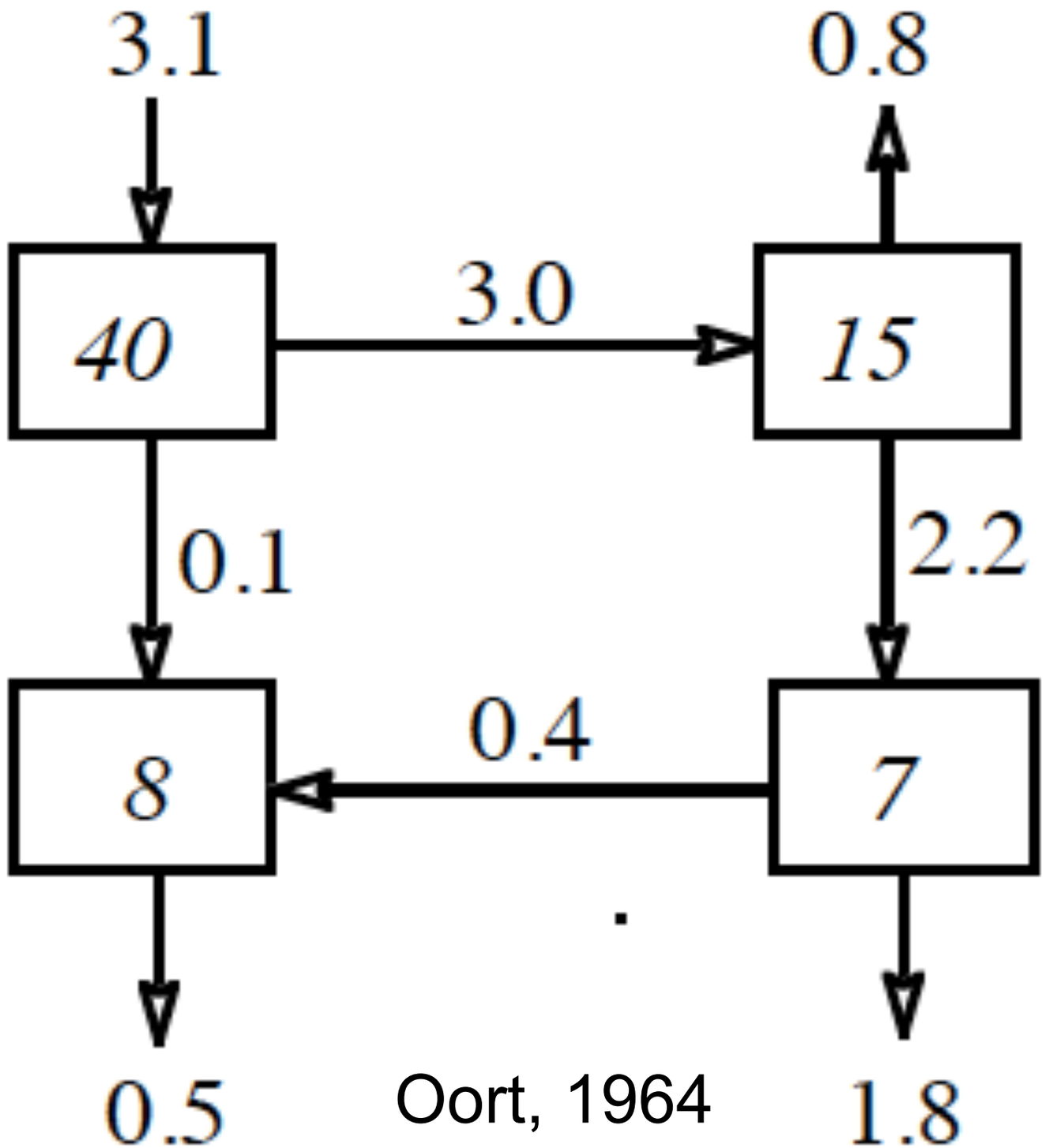
isotherms

streamlines

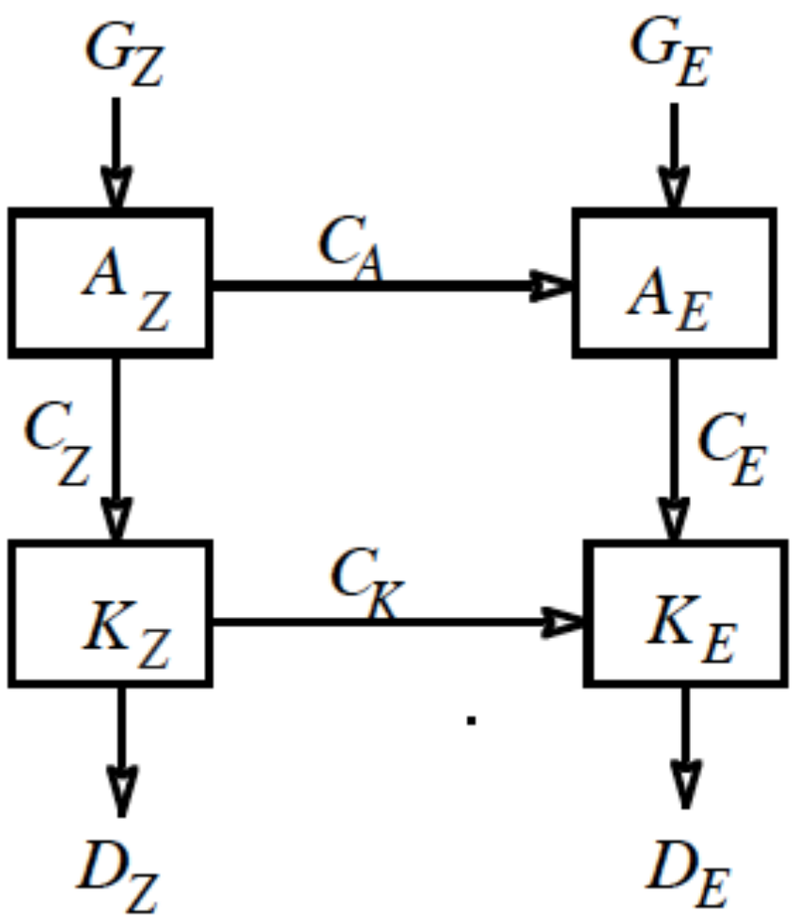
note how the flow is amplifying the waves in the isotherms



Now let's do the numbers!



Oort, 1964

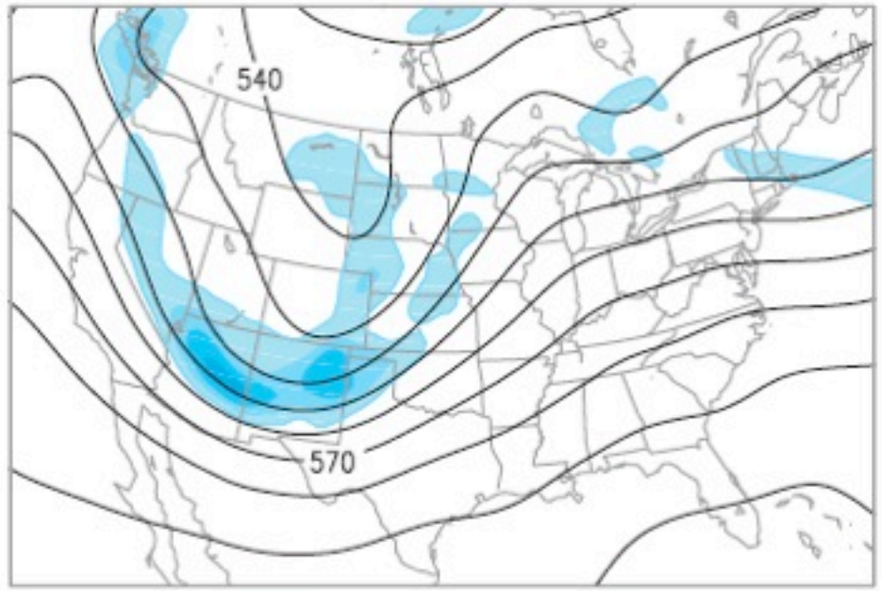


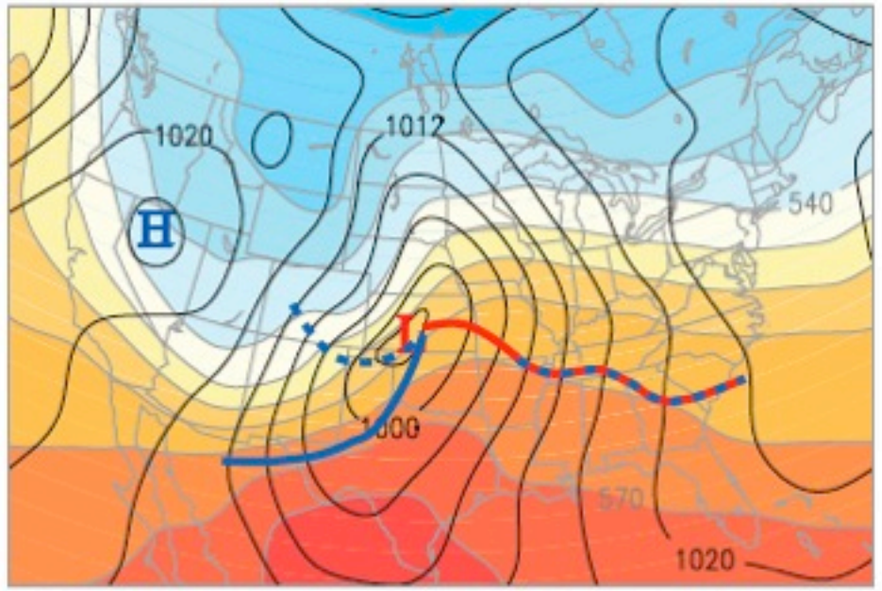


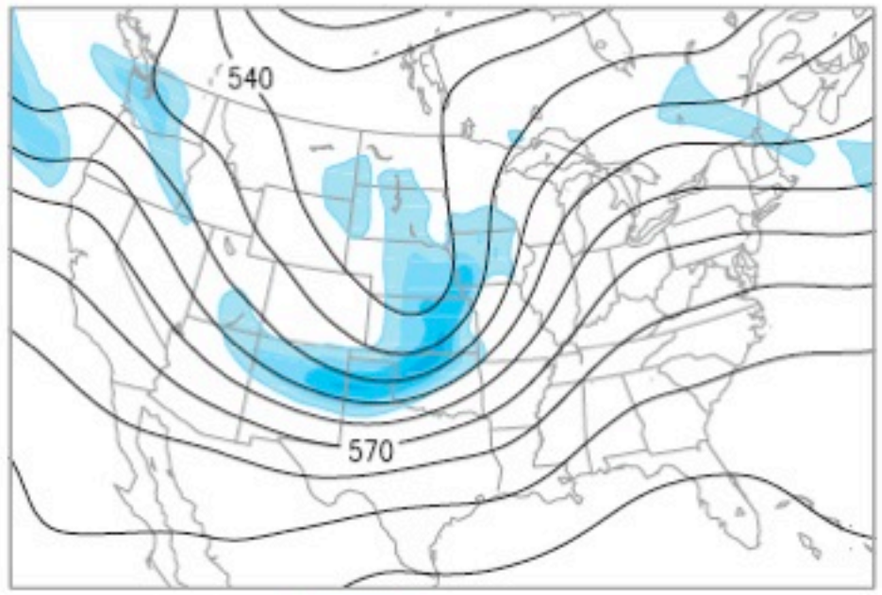
Tell us more about baroclinic waves and the KE cycle

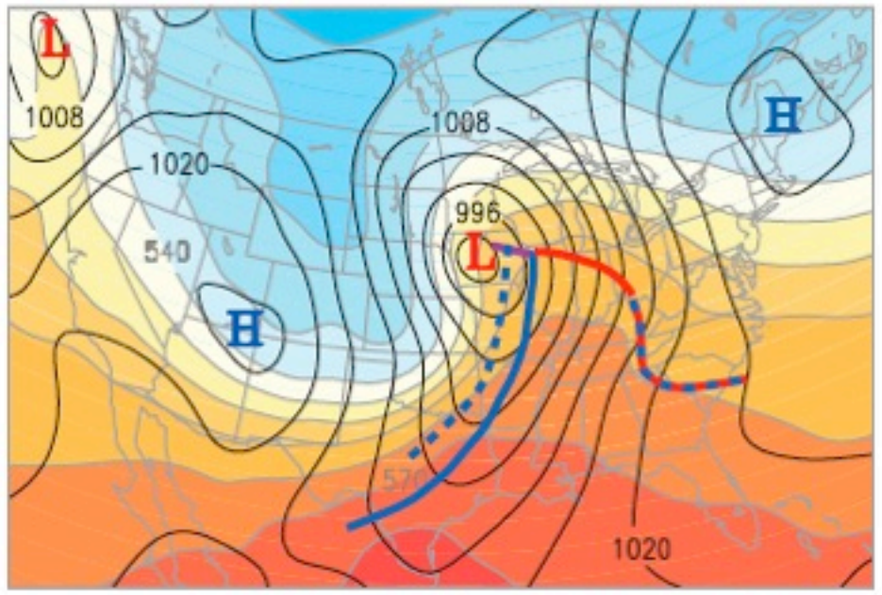
Case Study

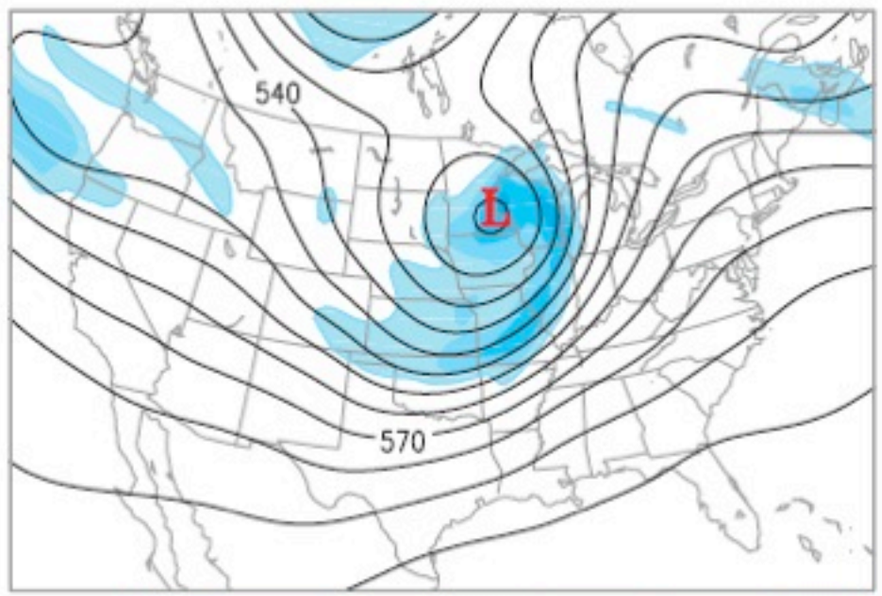
Nov. 10, 1998

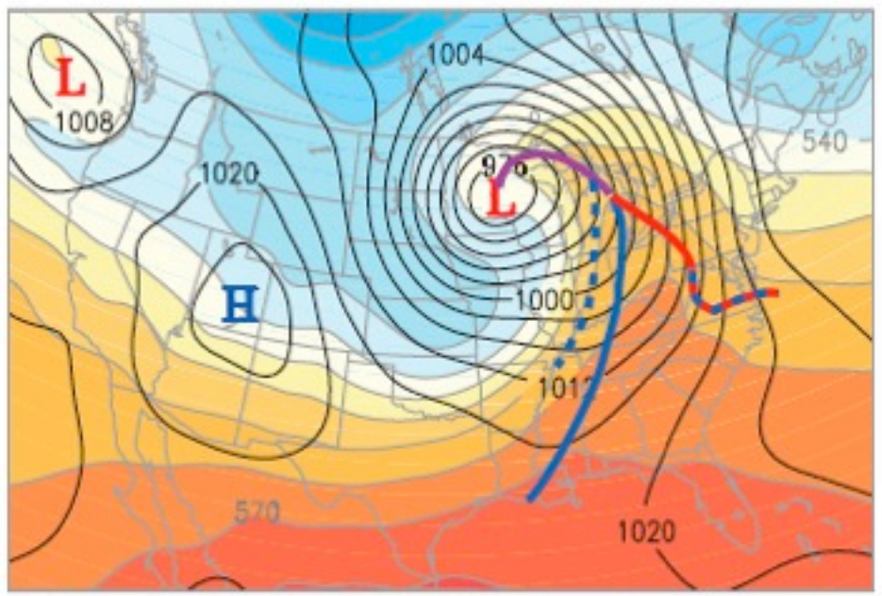




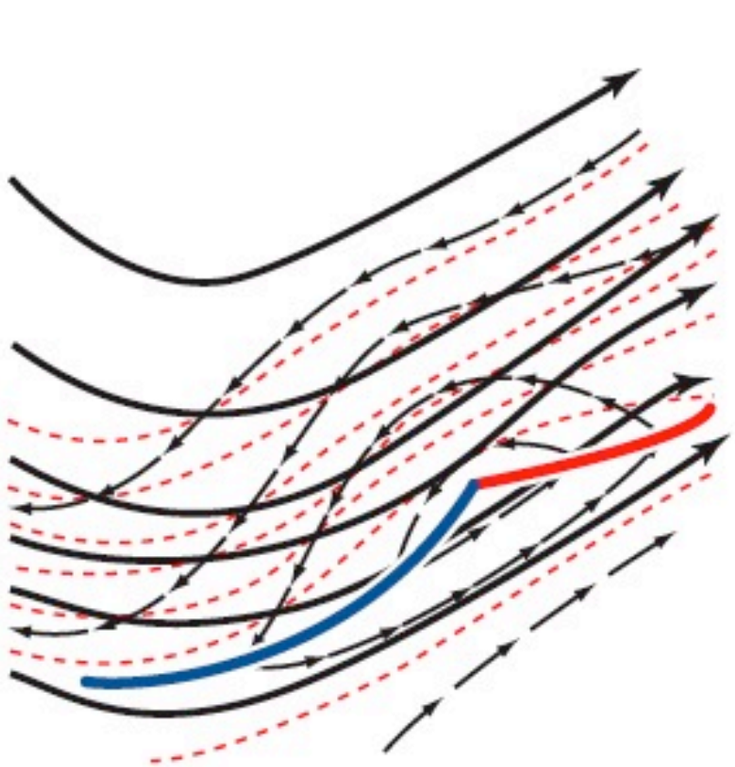


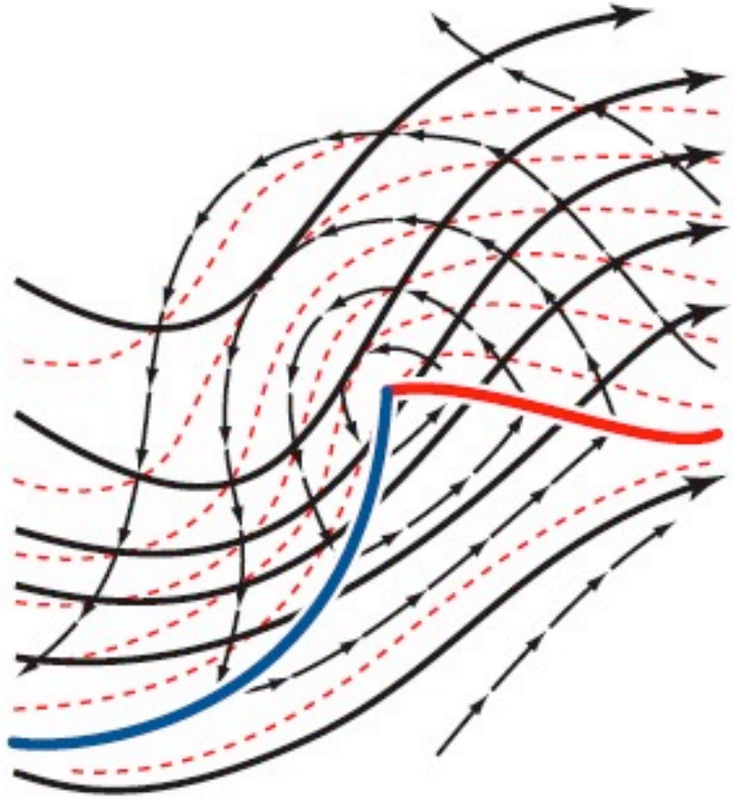


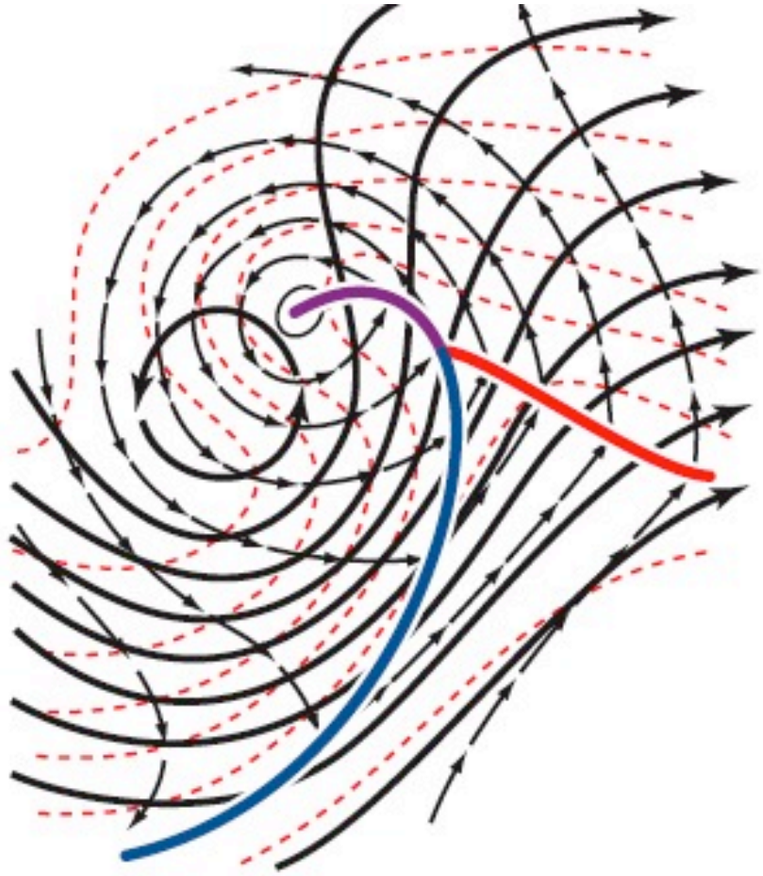




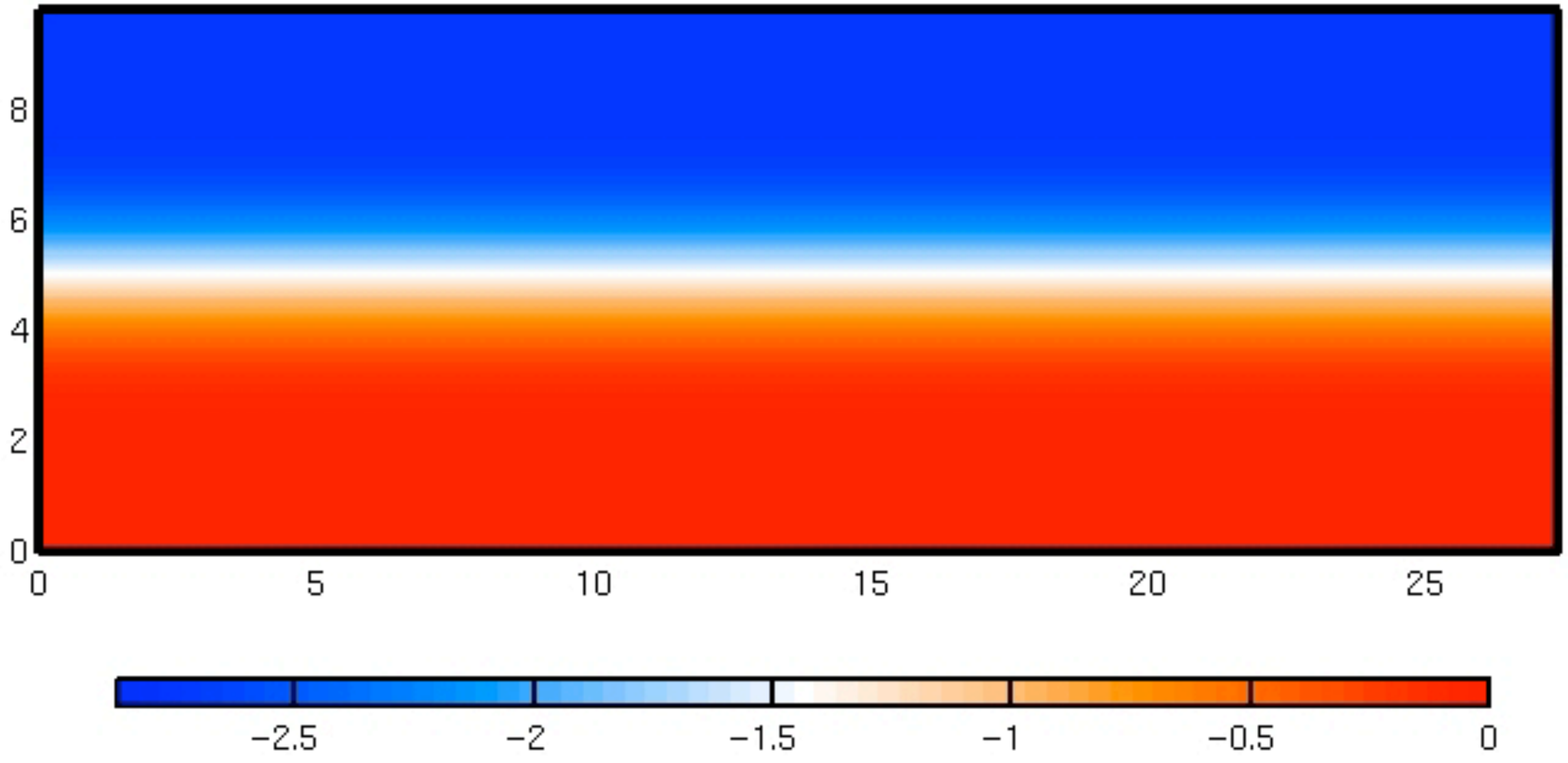
Idealized model

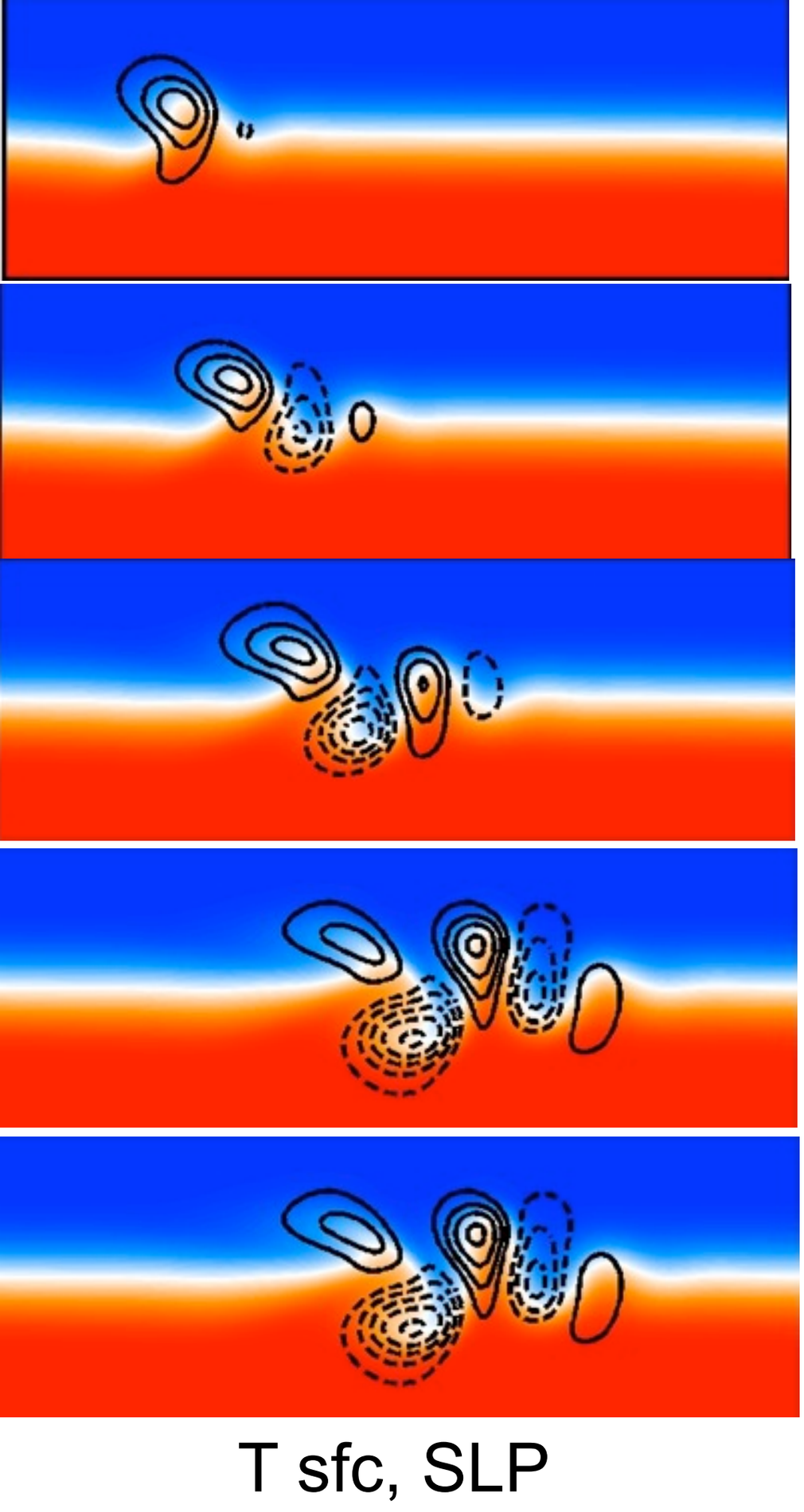




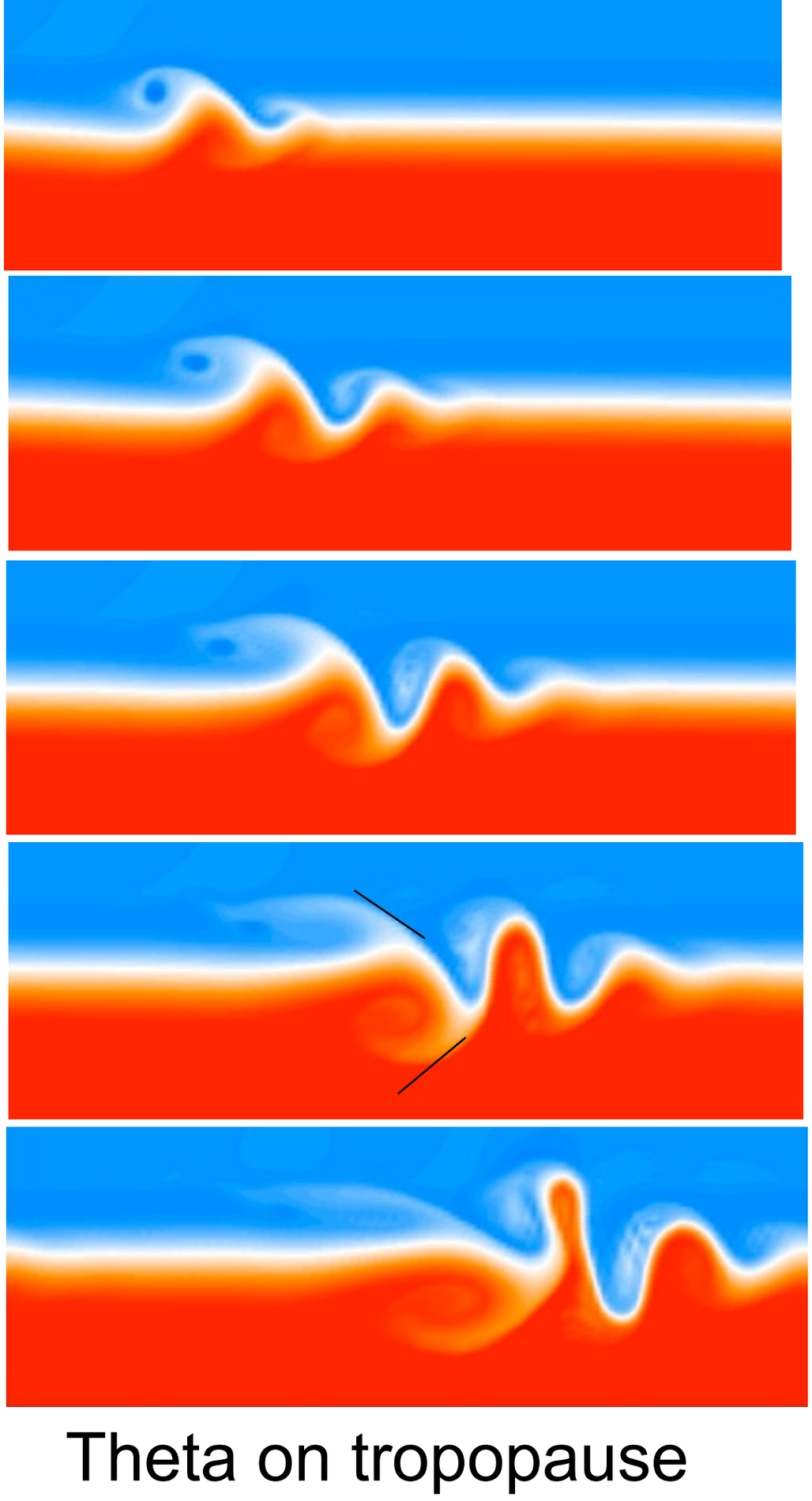


Surface Theta & Pressure...0



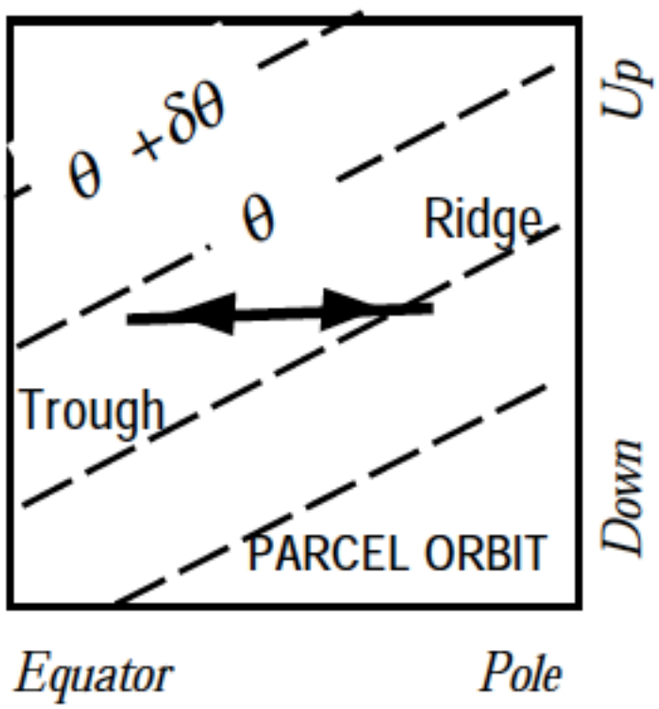


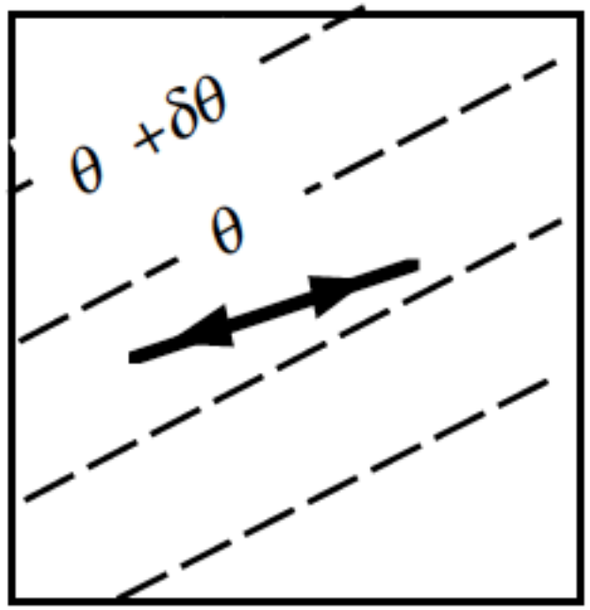
T sfc, SLP

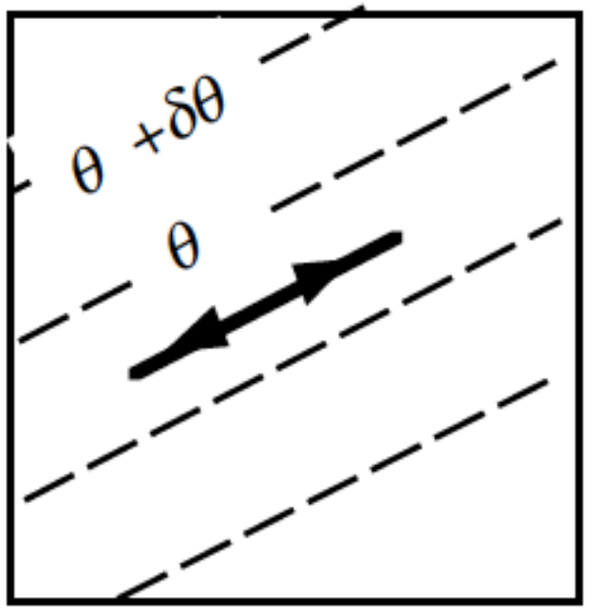


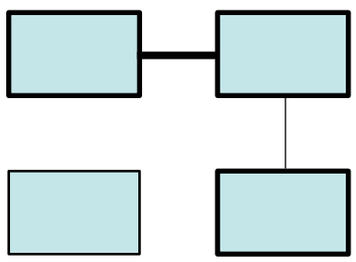
Theta on tropopause

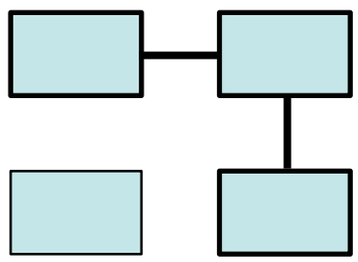
KE cycle in developing baroclinic waves

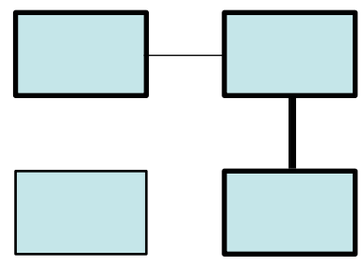












A_E generated

but little K_E



K_E generated

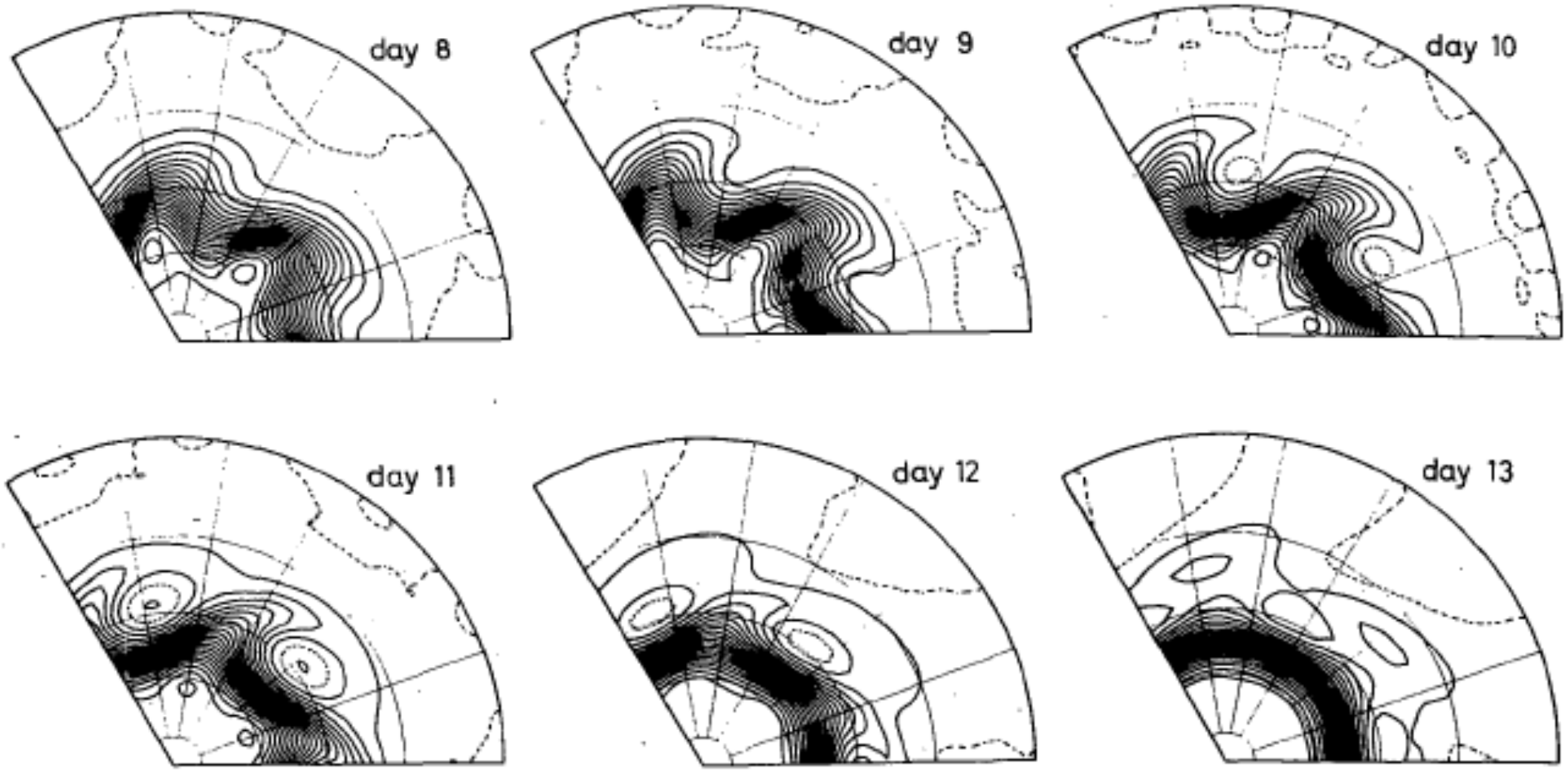
but little A_E

waves too long

waves just right

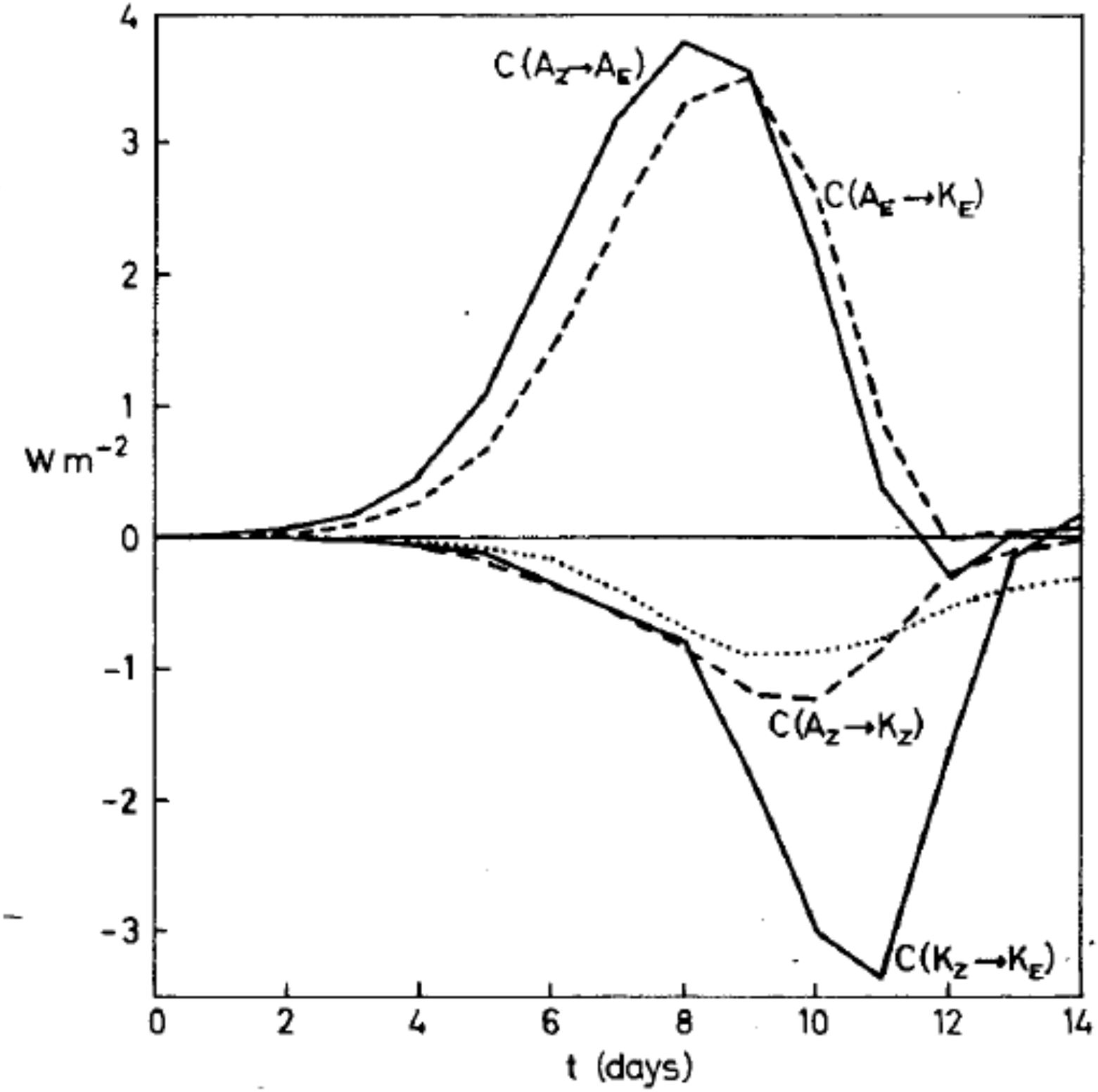
waves too short

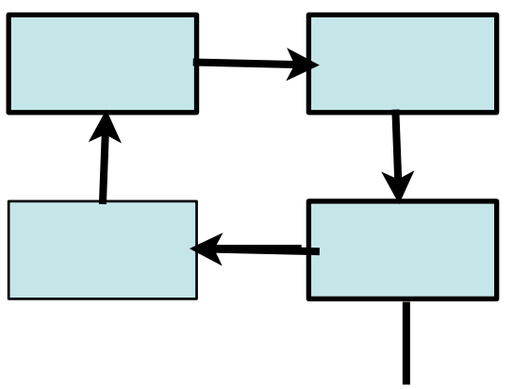
300 hPa streamfunction



Simmons and Hoskins, JAS, 1978
idealized life cycle experiments

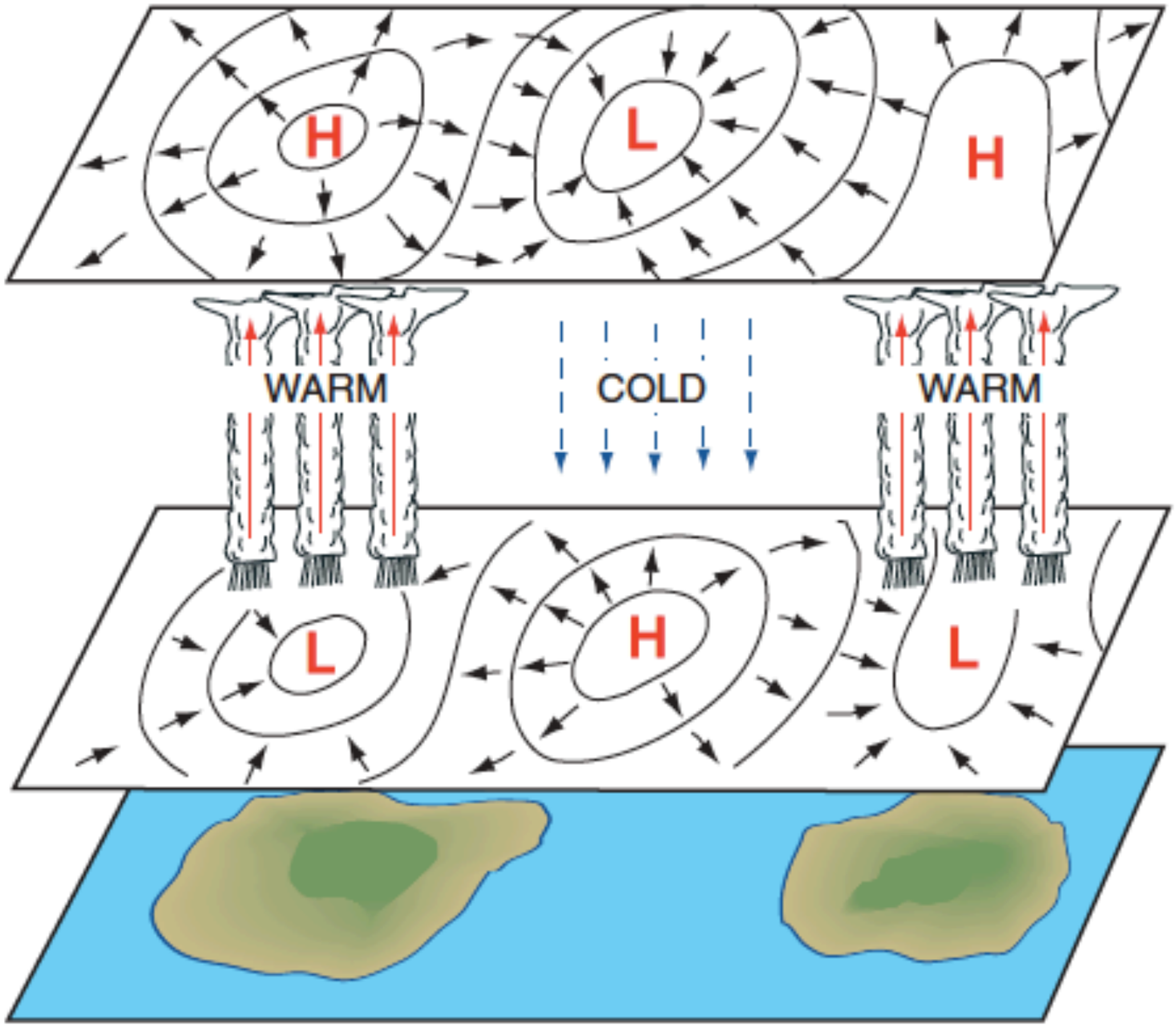
KE cycle in baroclinic wave life cycle





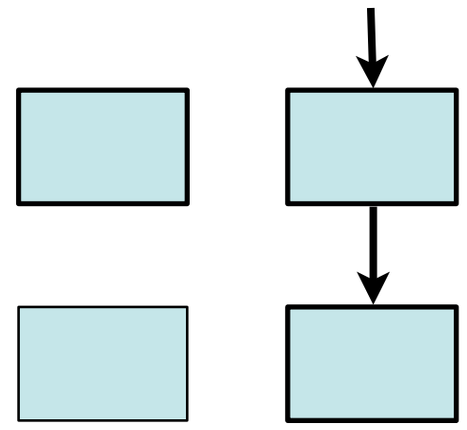
Simmons and Hoskins, JAS, 1978

KE cycle of the monsoons

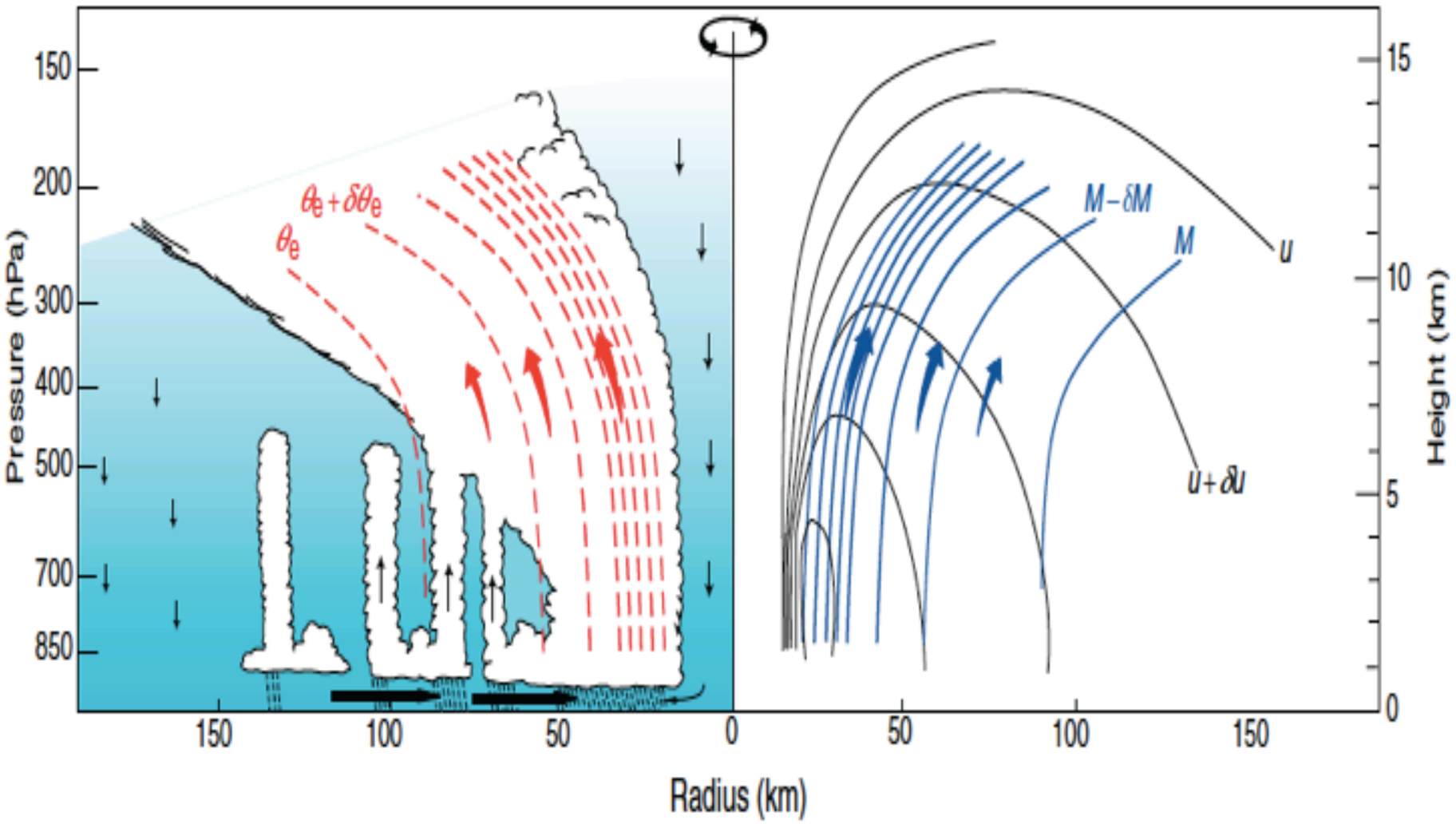


$$[Q^*T^*] > 0$$

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

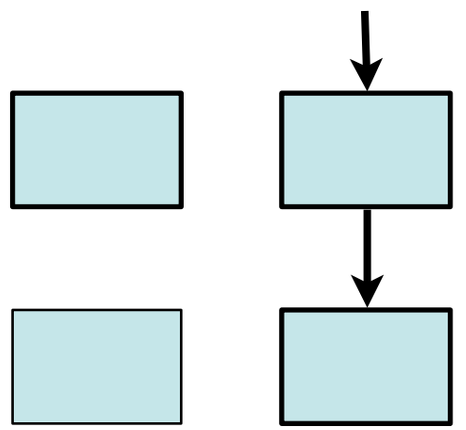


KE cycle of tropical cyclones

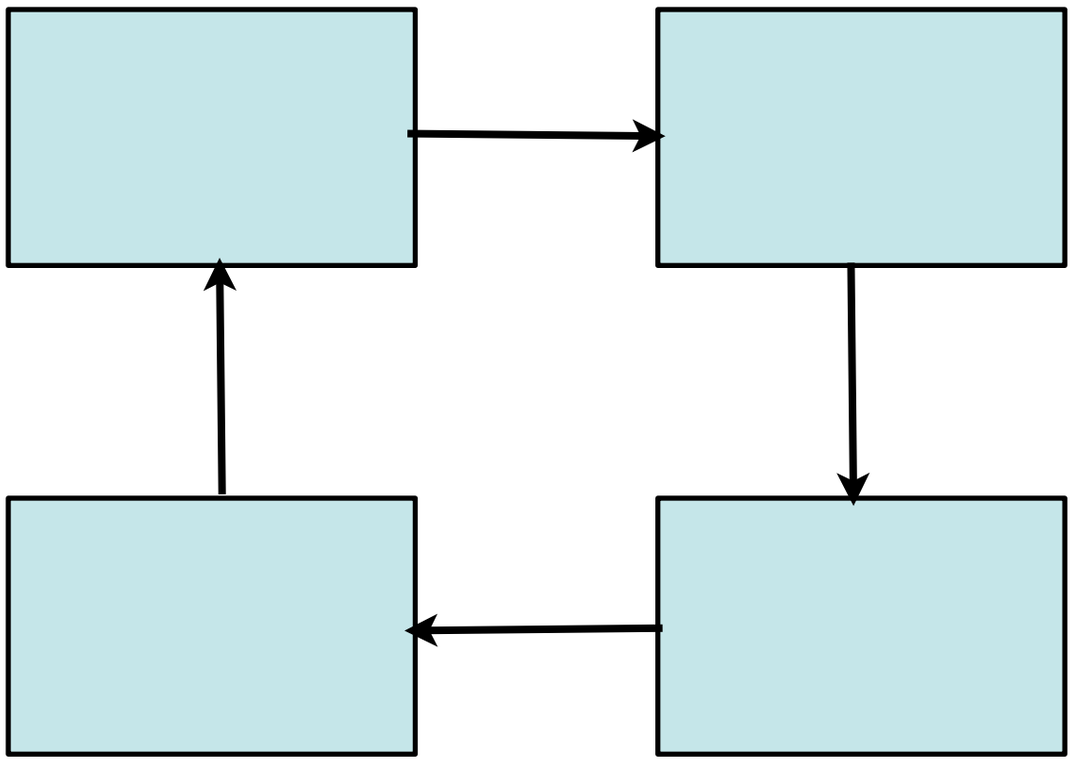


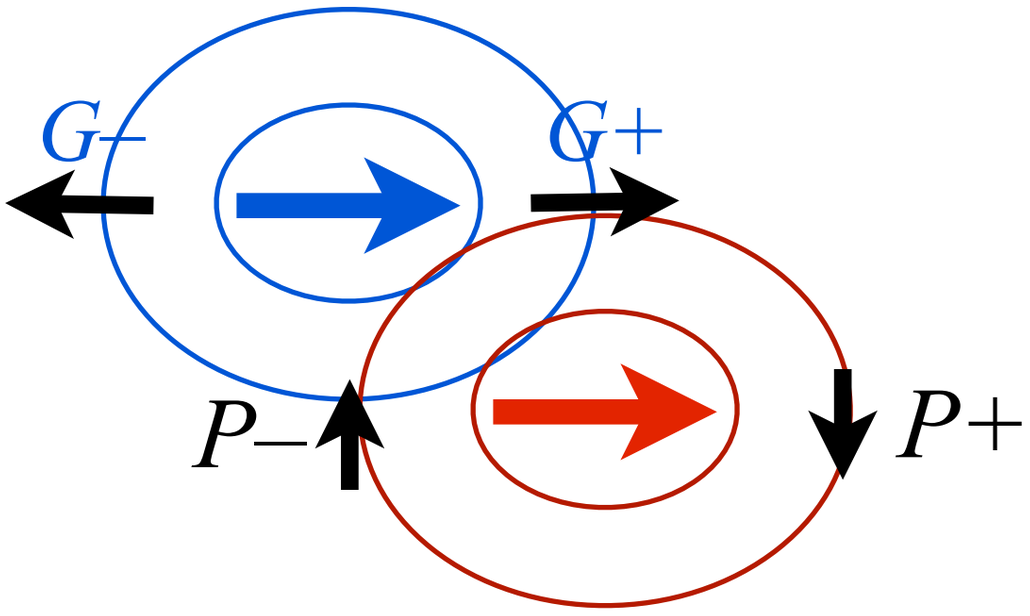
$$[Q^*T^*] > 0$$

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

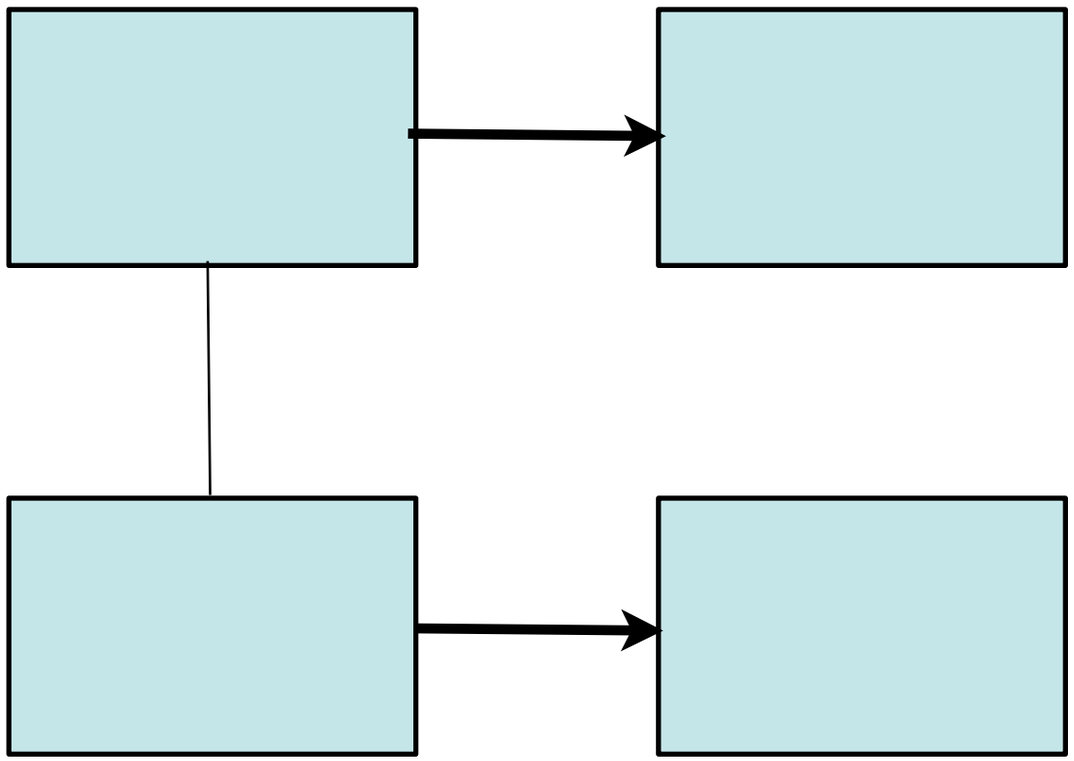


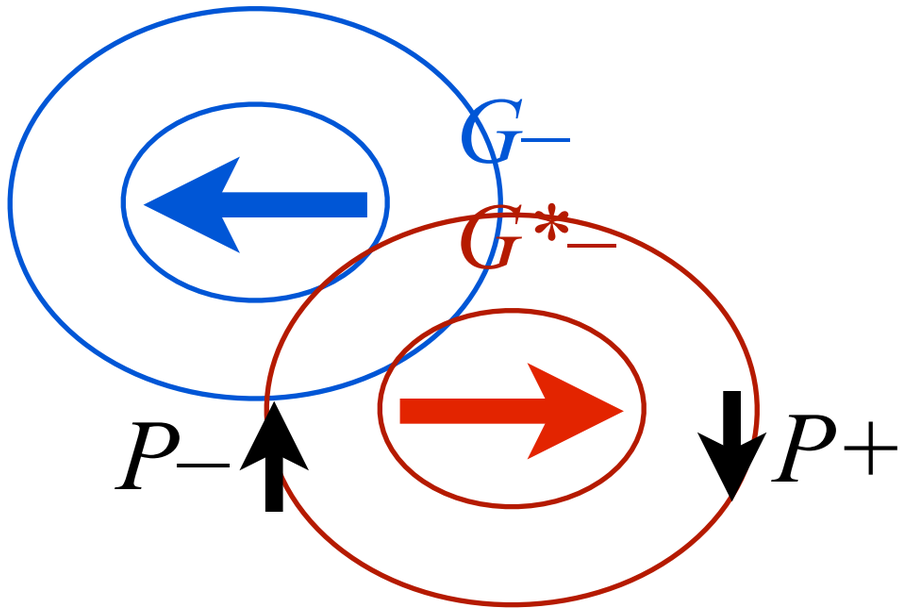
1. Quiescent regime with strong jet





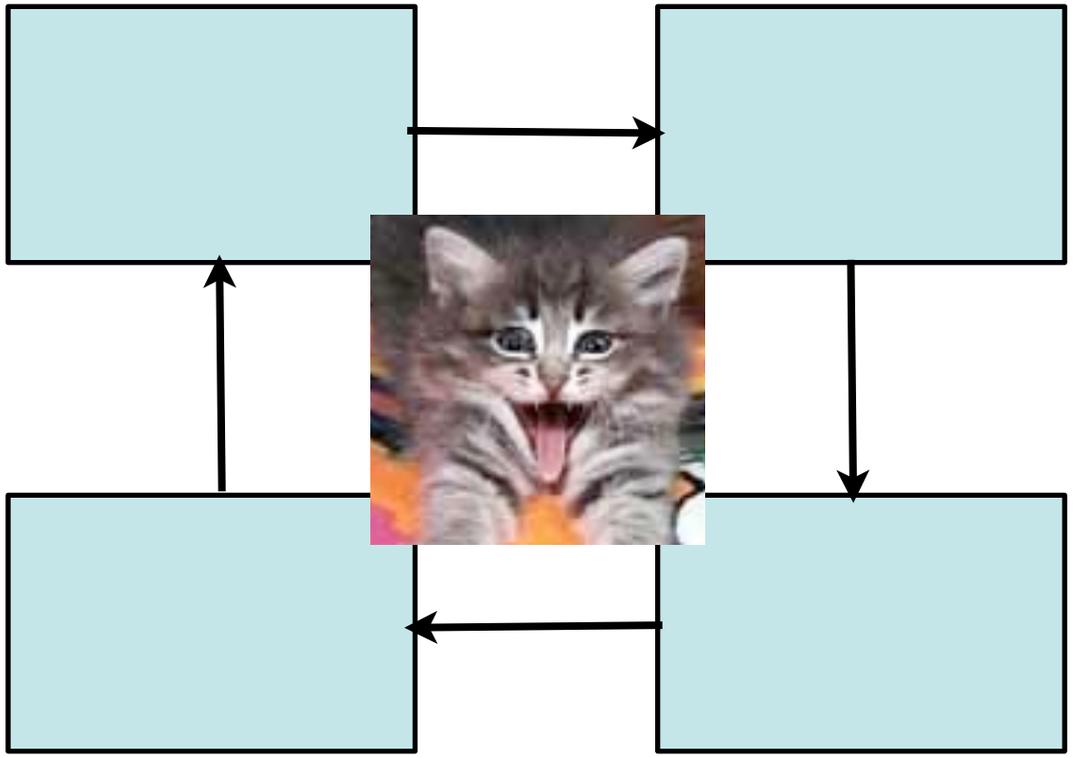
2. Sudden warming





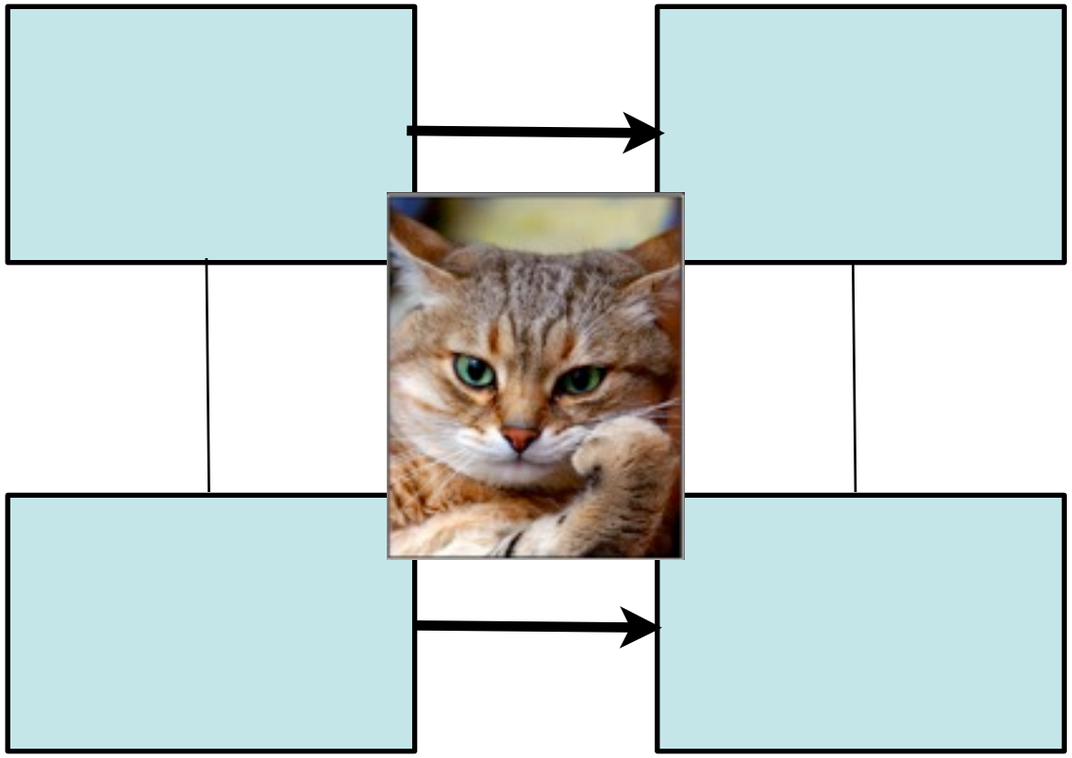
KE cycle in the stratosphere

1. Quiescent regime with strong jet



awesome conversions
but nothing happens

2. Sudden warming



the MMC stand by idly
and let the jet collapse