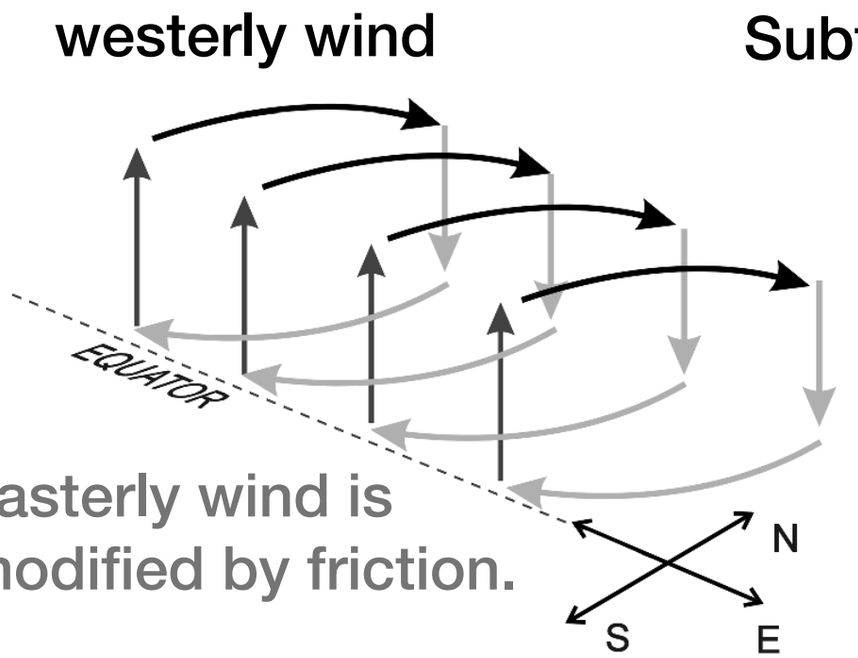
General circulation of the atmosphere, II

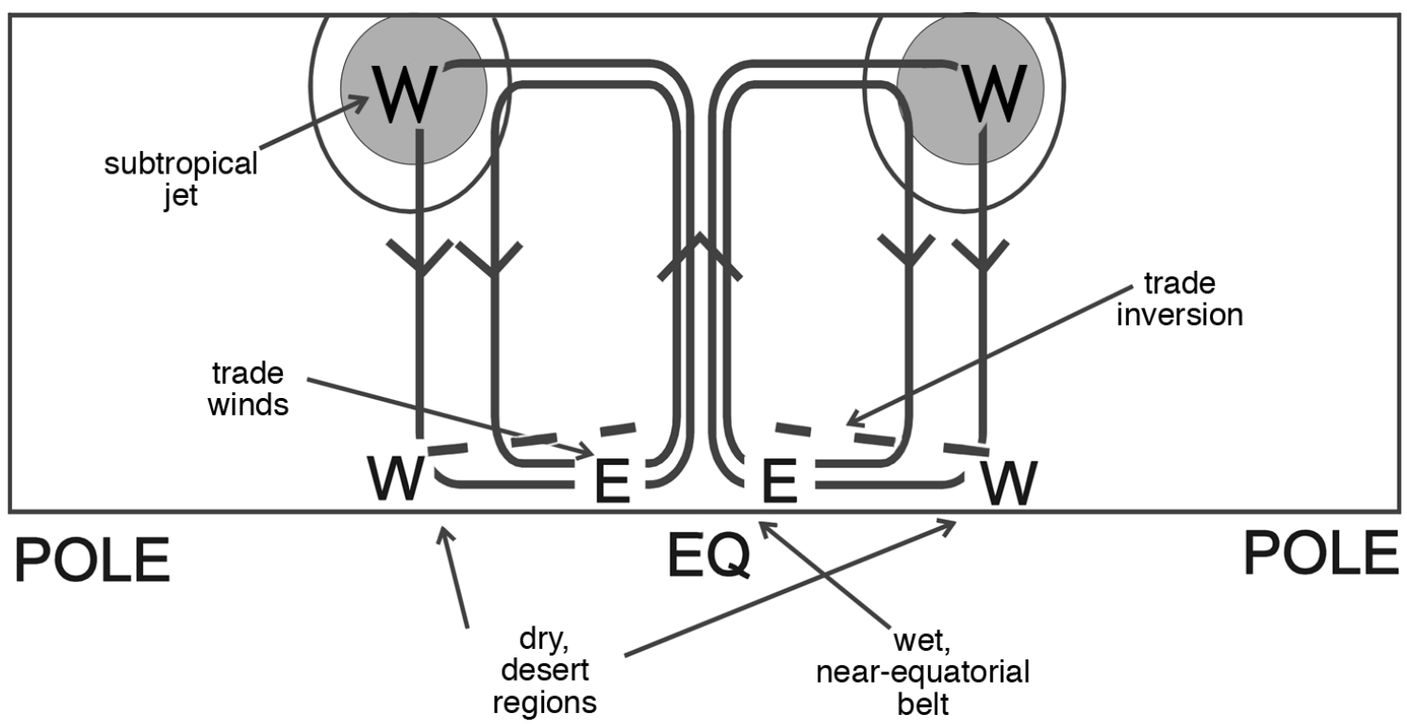
ATM2106

Last time



Subtropical jet is driven in large part by the advection of angular momentum by the Hadley cell.

When f is small



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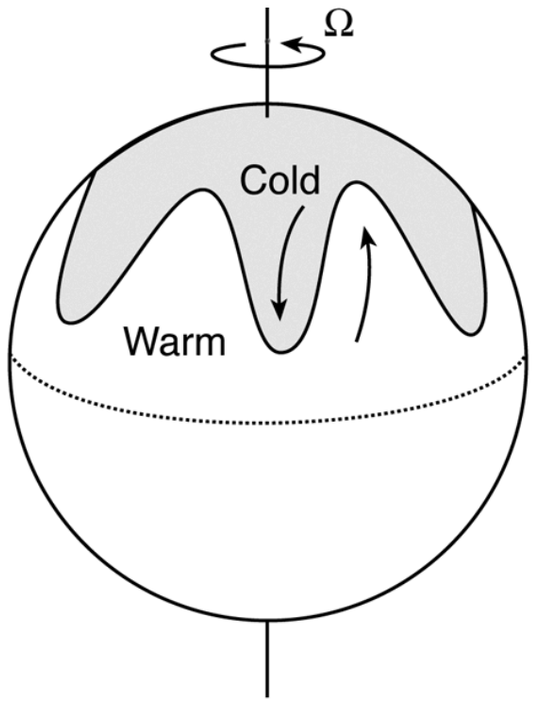
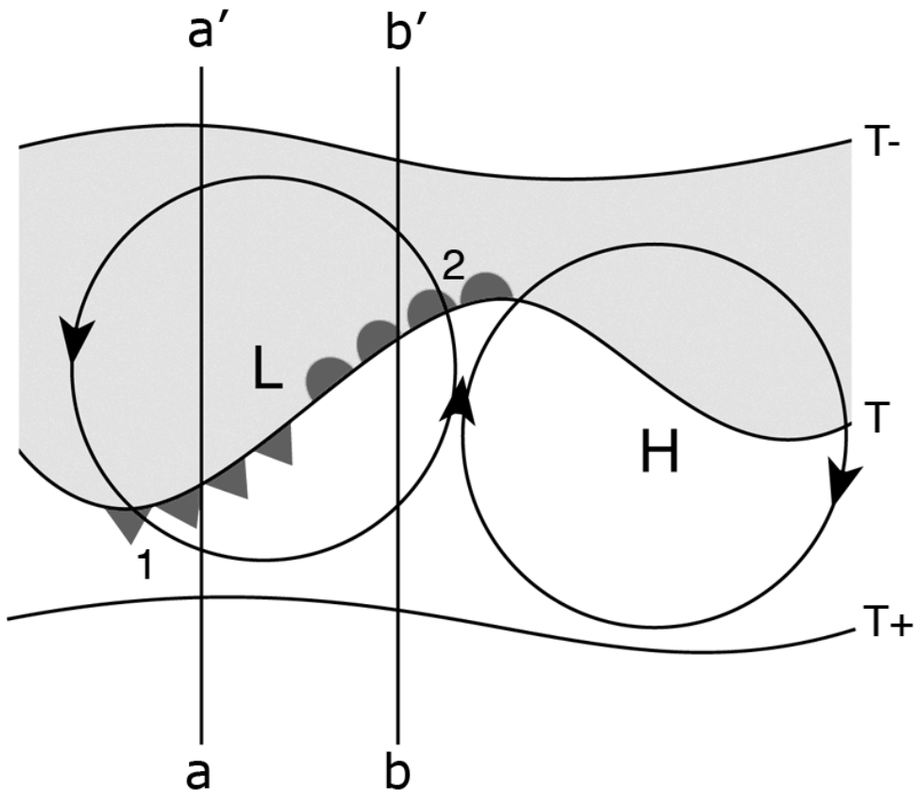
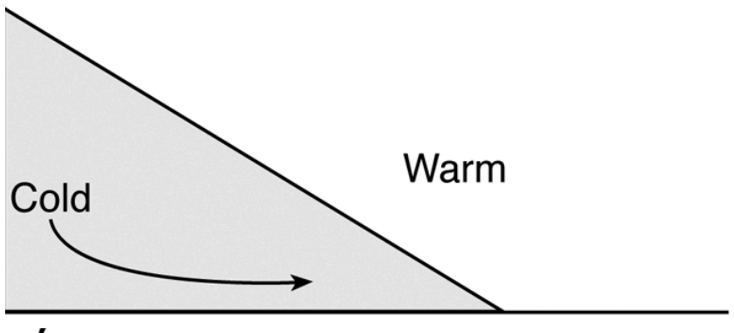
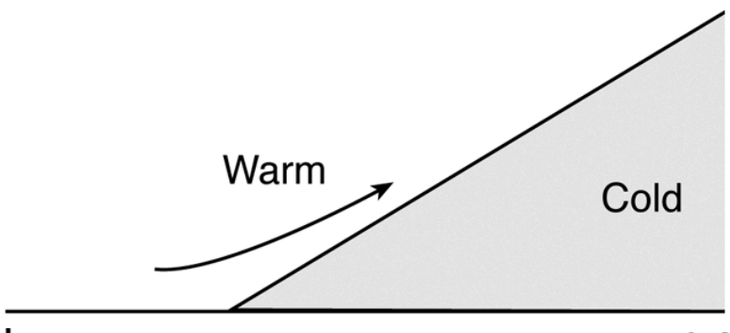


When f is relatively large

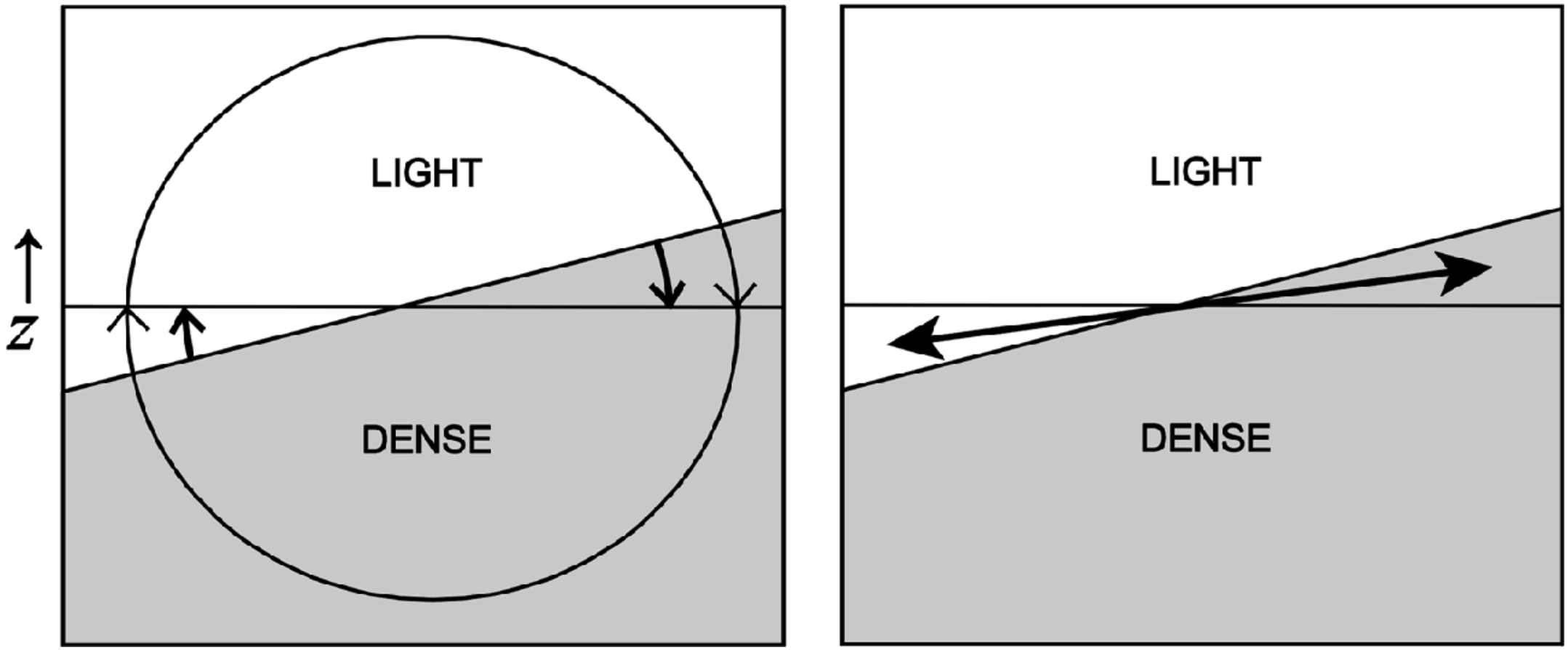






Last time

The release of available potential energy



Tropics

Extratropics

Today's topic

- Large-scale atmospheric energy transport
- Large-scale atmospheric momentum budget

1. Energy transport

- Total energy of the atmosphere = internal energy + potential energy + latent heat content + kinetic energy

$$E = c_p T + gz + Lq + \frac{1}{2}\mathbf{u} \cdot \mathbf{u}$$

- Energy transport by the atmosphere across the unit area

  $= \quad \rho v E \; dA$

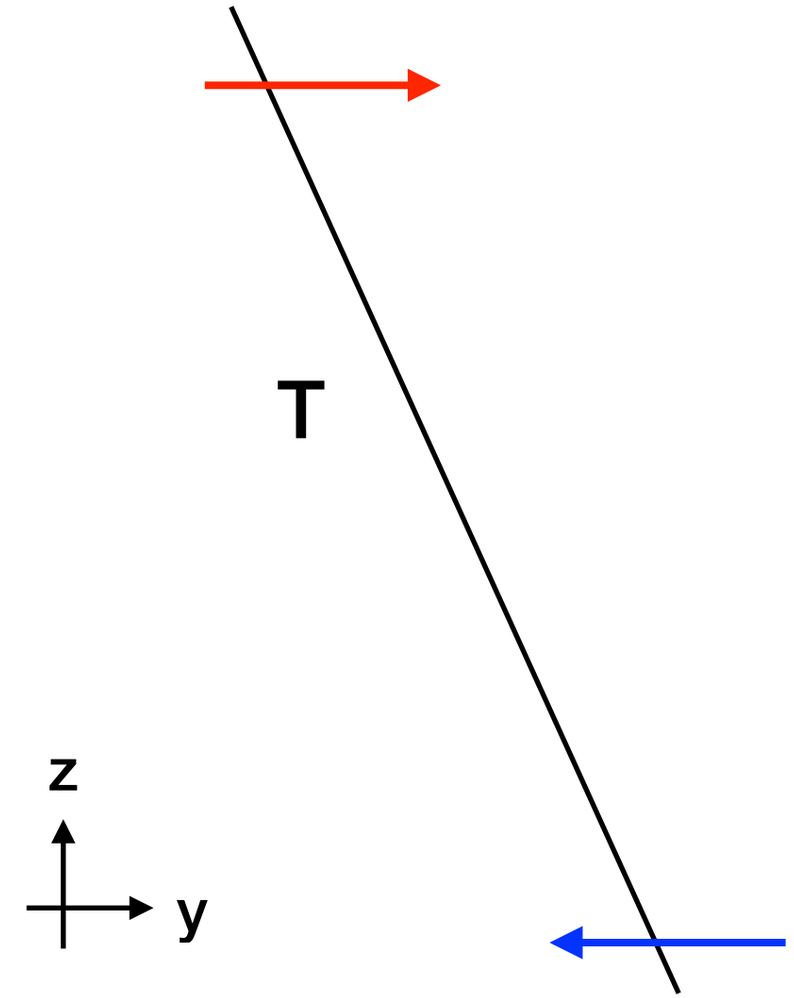
- Total meridional energy transport = $\iint \rho v E \; dx dz$

1. Energy transport, tropics

- The internal energy

$$\int_0^\infty \rho v c_p T \, dz < 0$$

Equatorward heat transport



The Hadley circulation carries heat toward the hot equator from the cooler subtropics!

1. Energy transport, tropics

- The internal energy + potential energy

$$\int_0^\infty \rho v(c_p T + gz)\, dz = c_p \int_0^\infty \rho v \left(T + \frac{g}{c_p} z \right) dz$$

$$= c_p \int_0^\infty \rho v \left(T - \left. \frac{dT}{dz} \right|_{dry} z \right) dz \quad > 0$$

The atmosphere is stale in dry adiabatic process, which makes this term positive.

The Hadley circulation carries (heat+potential) energy poleward.

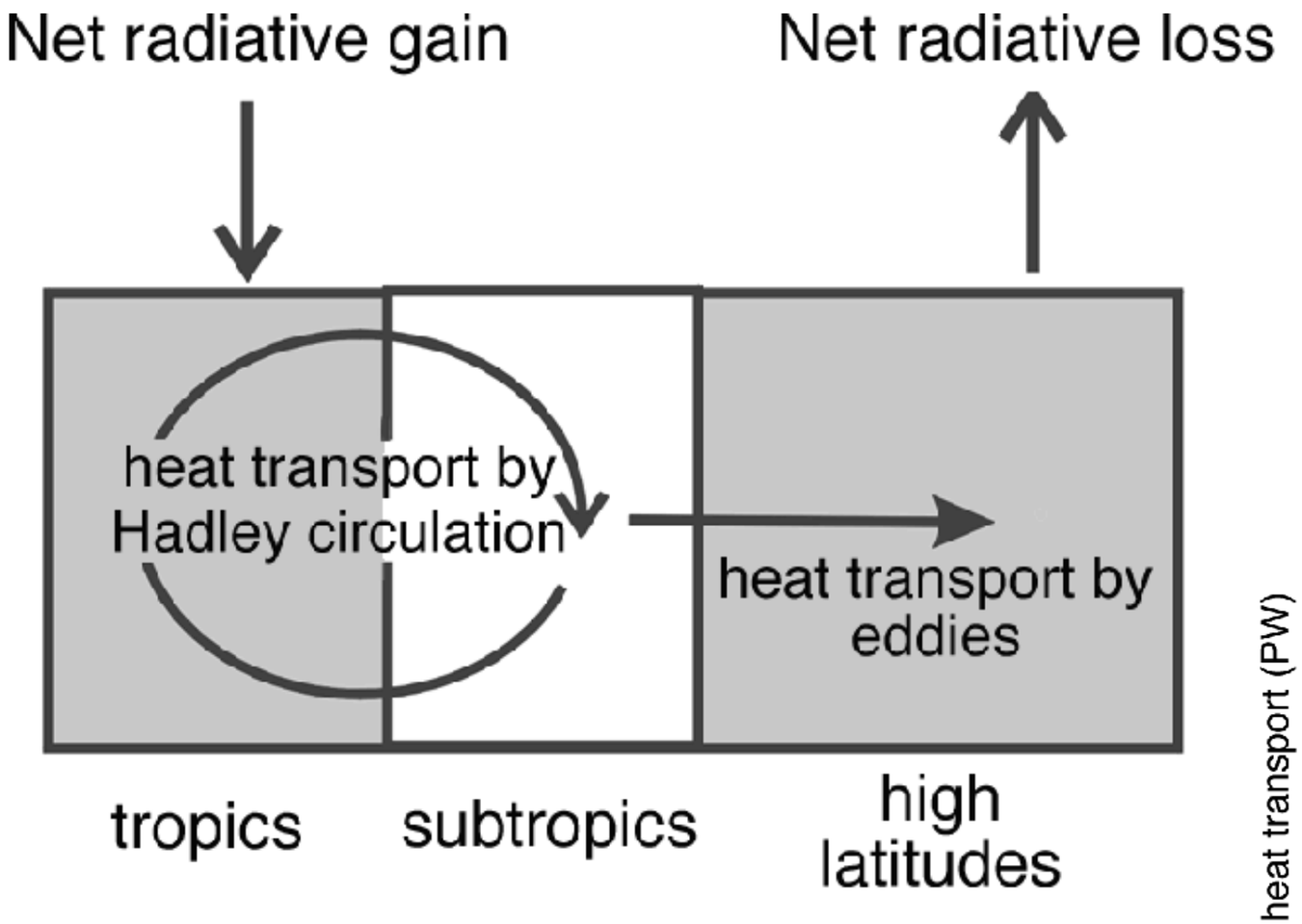
1. Energy transport, tropics

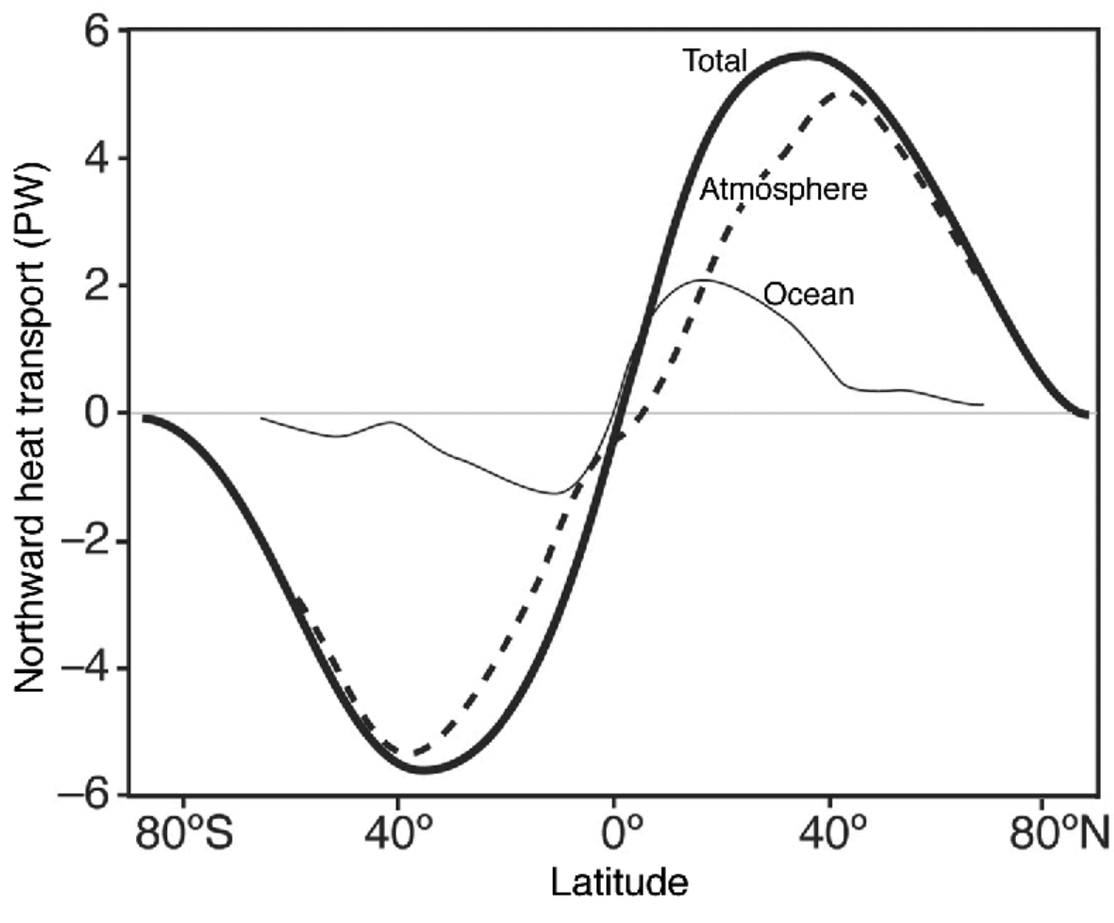
- Upper branch has far less moisture than lower branch of the Hadley cell.
- The net latent heat transport by the Hadley cell is equatorward.
- It turned out that poleward (heat+potential) energy transport and equatorward latent heat energy transport are in opposite sign with similar magnitude.
- The kinetic energy has negligible contribution to the total energy.
- In the net, then, the annually averaged energy flux by the Hadley cell is (weakly) poleward.

1. Energy transport, extratropics

- In the extratropics where the mean circulation is weak, the greater part of the transport is done by eddies.
- We saw that poleward/equatorward motions occur at almost the same altitude. → the vertical structure of the heat transport is not dominant.
- The heat transport, $\int_0^\infty \rho v c_p T \, dz$ is positive because the poleward winds are associated with higher temperature.
- The total energy transport in the midlatitude is poleward.

1. Energy transport





2. Momentum transport, tropics

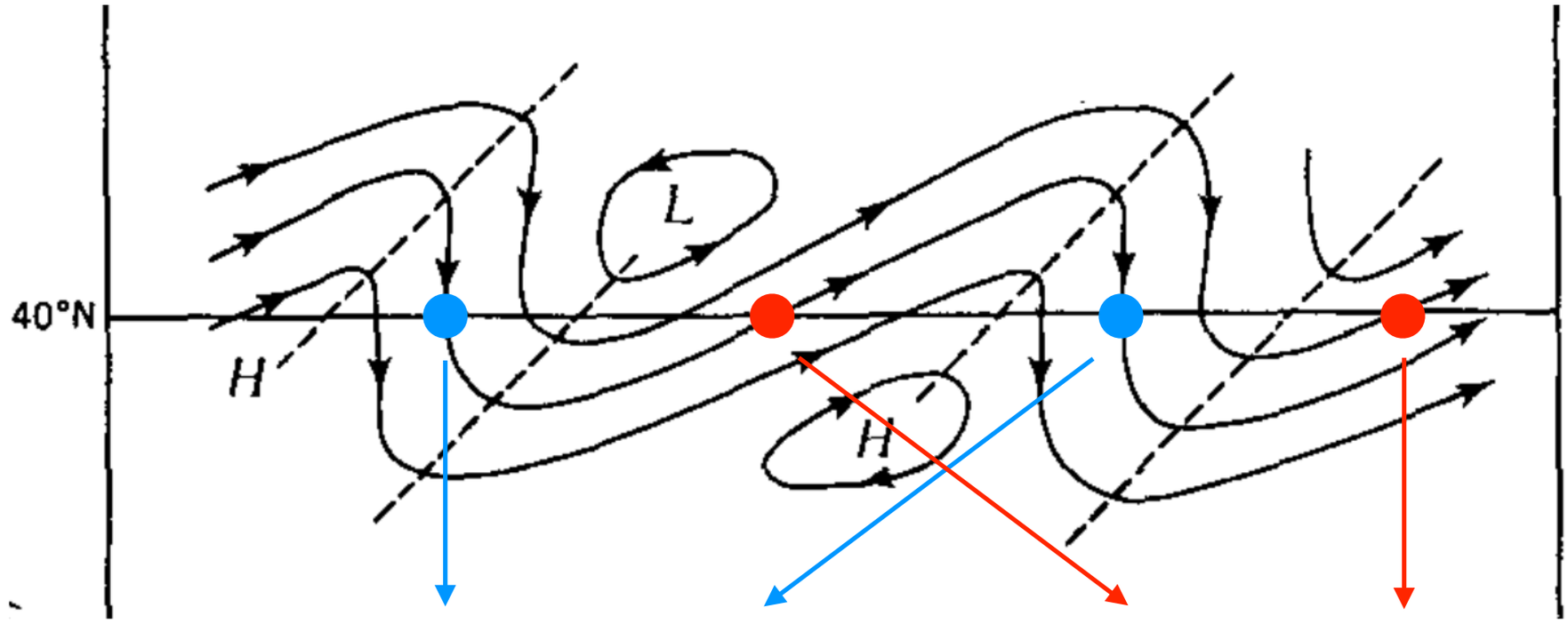
- Upper branch transports westerly angular momentum poleward.
- Lower branch transport easterly angular momentum equatorward.
- Because of the friction, the momentum transport in the lower branch is weaker than the upper branch.
- The Hadley cell does a poleward transport of westerly angular momentum.

2. Momentum transport, extratropics

- Eddies in the extratropics also transport westerly momentum to poleward, but how?

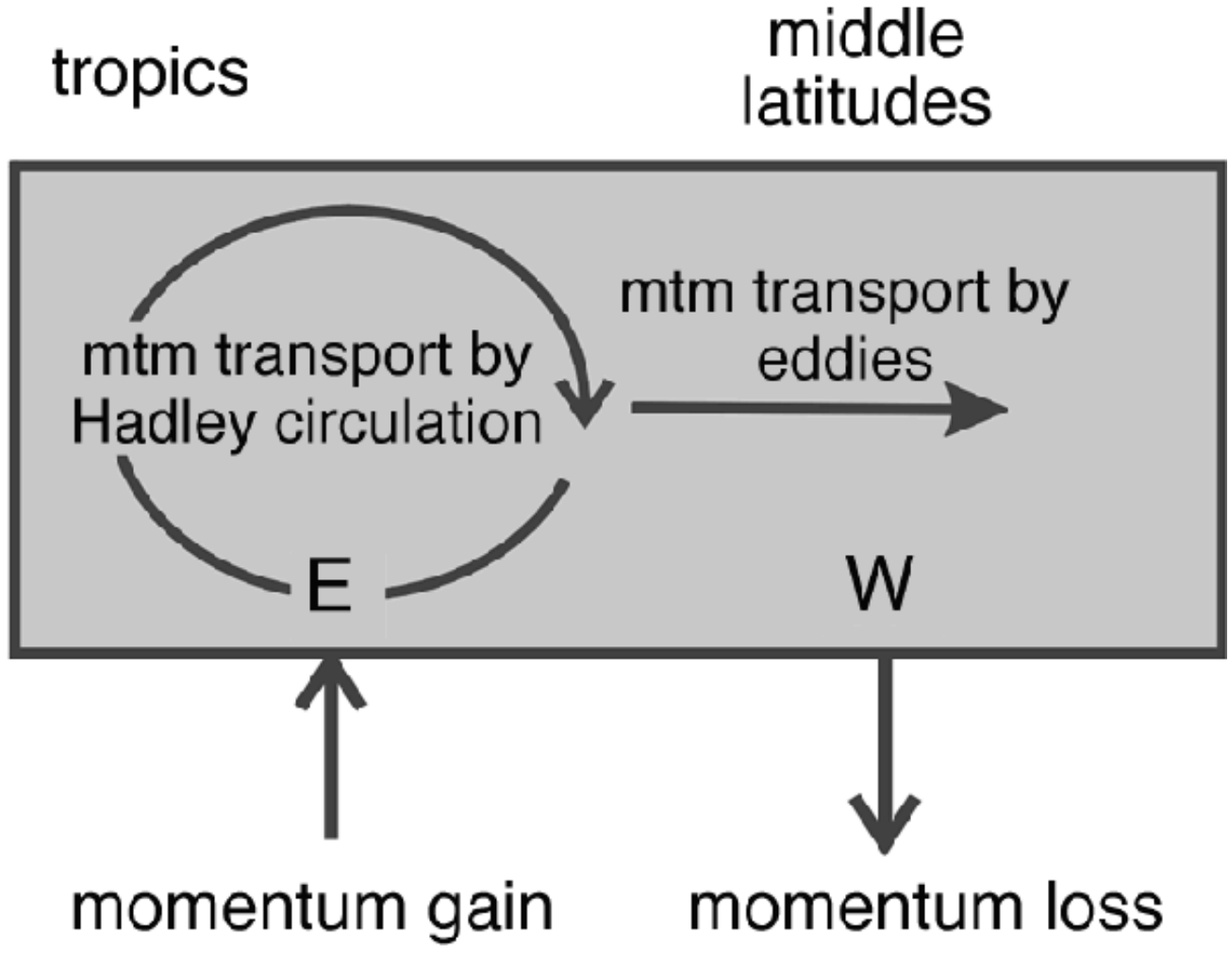
- The meridional momentum transport $= v(\Omega r^2 + ur)$

$= v\Omega r^2 + ruv$

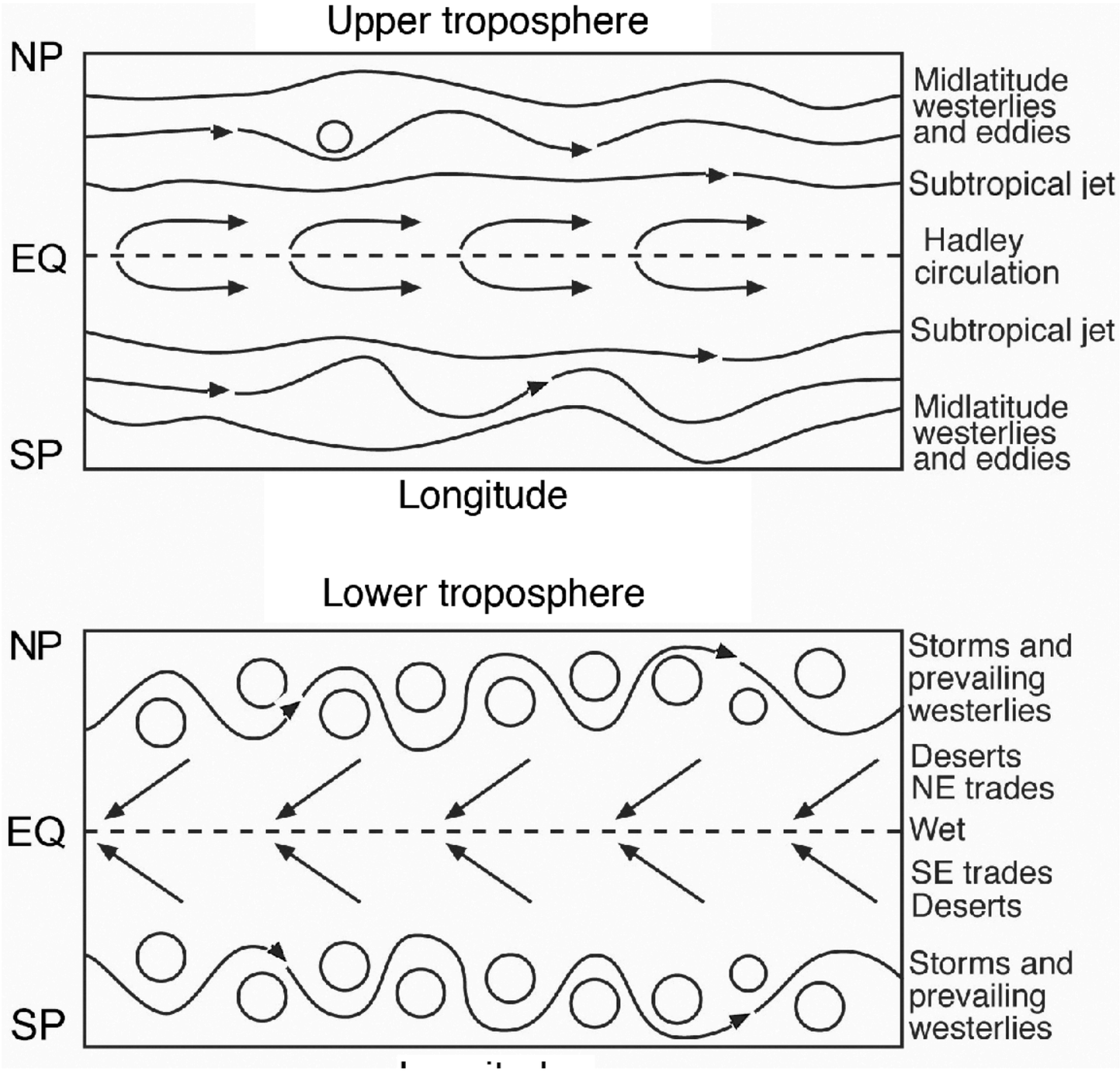


$u \sim 0,\ v < 0 \rightarrow uv \sim 0$ $\qquad$ $u > 0,\ v < 0 \rightarrow uv > 0$

2. Momentum transport, extratropics



3. Latitudinal variations of climate



@ tropics : convergence and upward motion → intense rainfall

@ midlatitude : sinking and warming → desert belt

@ midlatitude : eddies that go around the globe → control the weather patterns