General Atmospheric Circulation

SEA2004F

Week 4 Lecture 3

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What will you learn today?

- What is the Three Cell Model of General Atmospheric Circulation?
- What are the properties of the Hadley, Ferrel, and Polar Cells?

Review From Lecture 2

- Vertical distribution of mass in the atmosphere is determined by a balance between gravity and the pressure-gradient force
- When these forces are out of balance buoyant motions result

Part I. The Three Cell Model

Horizontal Flow

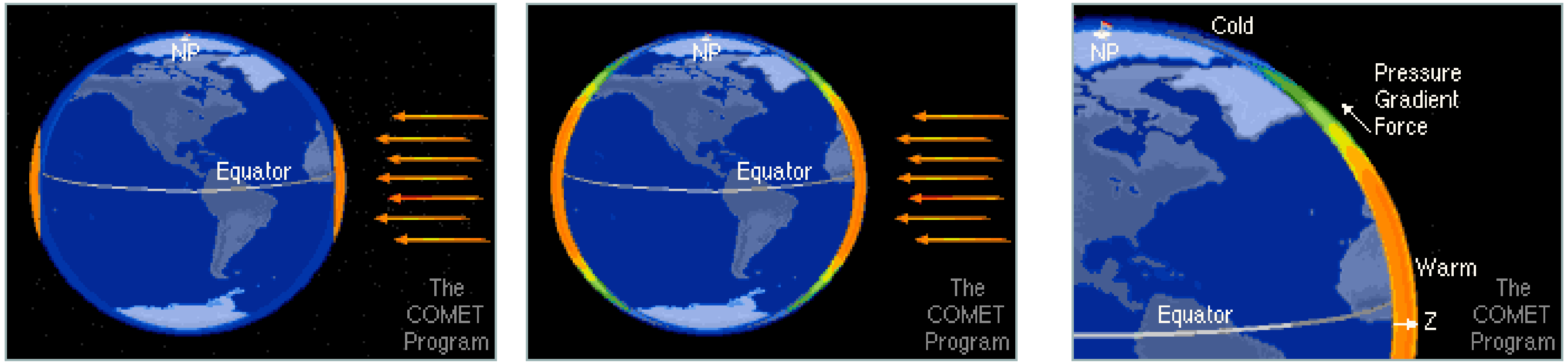
- Gravity does not operate in the horizontal direction
- Equilibrium of forces involves a balance between the pressure-gradient force and the Coriolis force – resulting in geostrophic flow
- Atmosphere is thinner in its vertical extent (what is typical H?) than its horizontal extent

Global Scale Circulation

Horizontal pressure gradients originate from differential heating of the Earth's surface

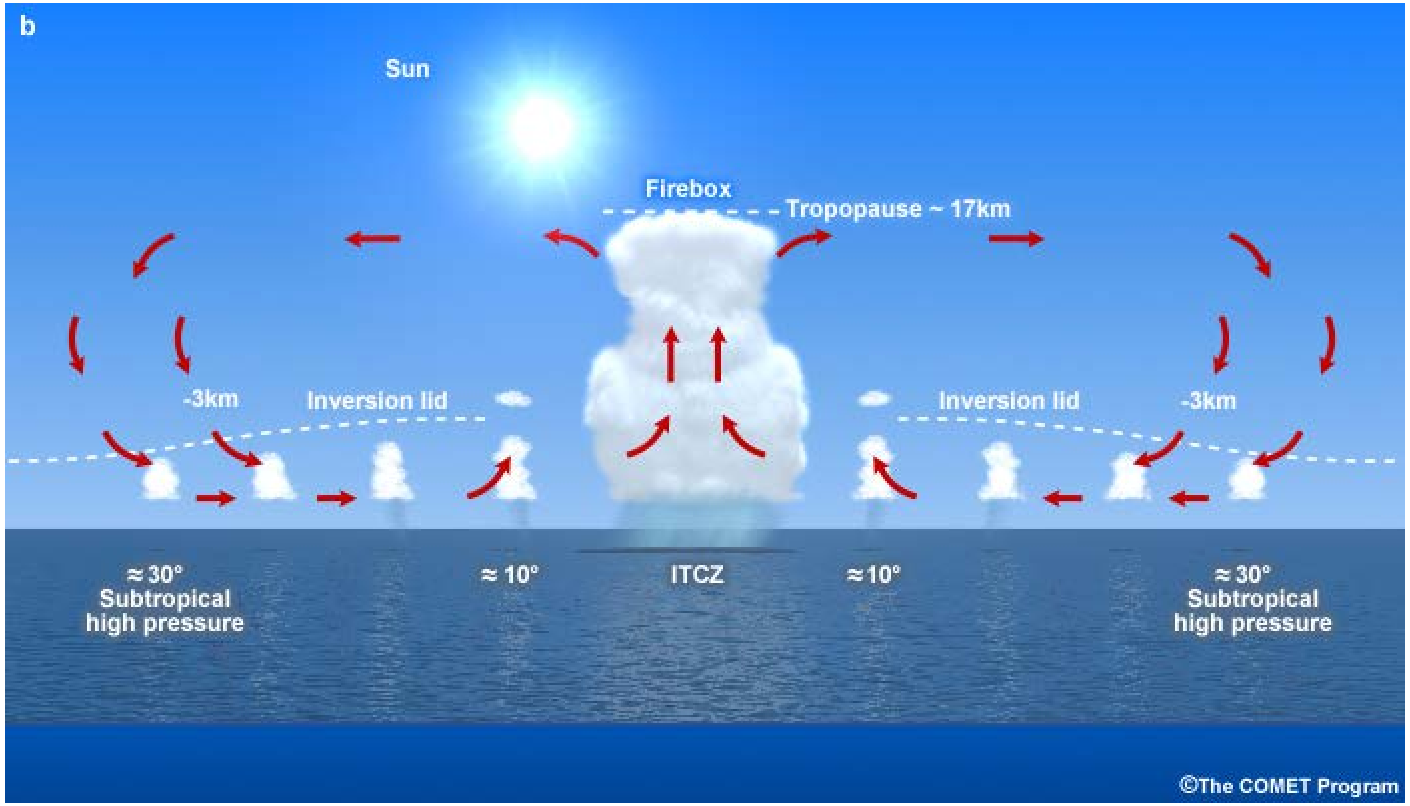
Surplus heating in the tropics and net cooling at the poles creates a horizontal temperature gradient in the atmosphere.

The consequent horizontal pressure gradients set the atmosphere into motion.



The fluid motions in the earth system, primarily the ocean and atmosphere, act to compensate for the radiative imbalance between the warm equator and the cold poles.

Fluid motion is a heat engine that helps to equilibrate the earth system.



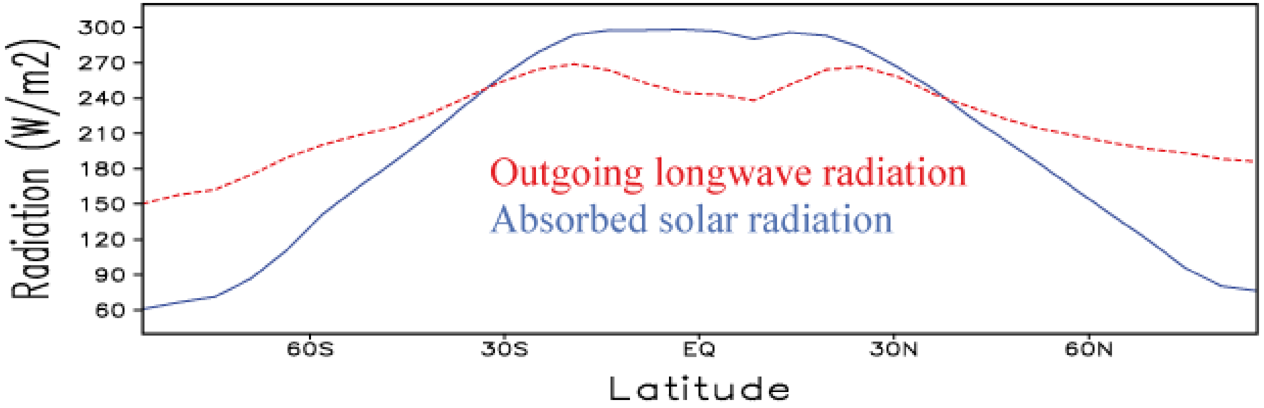
Global Scale Circulation

Horizontal pressure gradients originate from differential heating of the Earth's surface

Top panel:

At the top of the atmosphere in annual mean (W m^{-2})

- Zonal mean of the absorbed solar radiation
- Outgoing longwave radiation



Data from NCEP-NCAR reanalysis Kalnay et al., 1996

Global Scale Circulation

Horizontal pressure gradients originate from differential heating of the Earth's surface

Top panel:

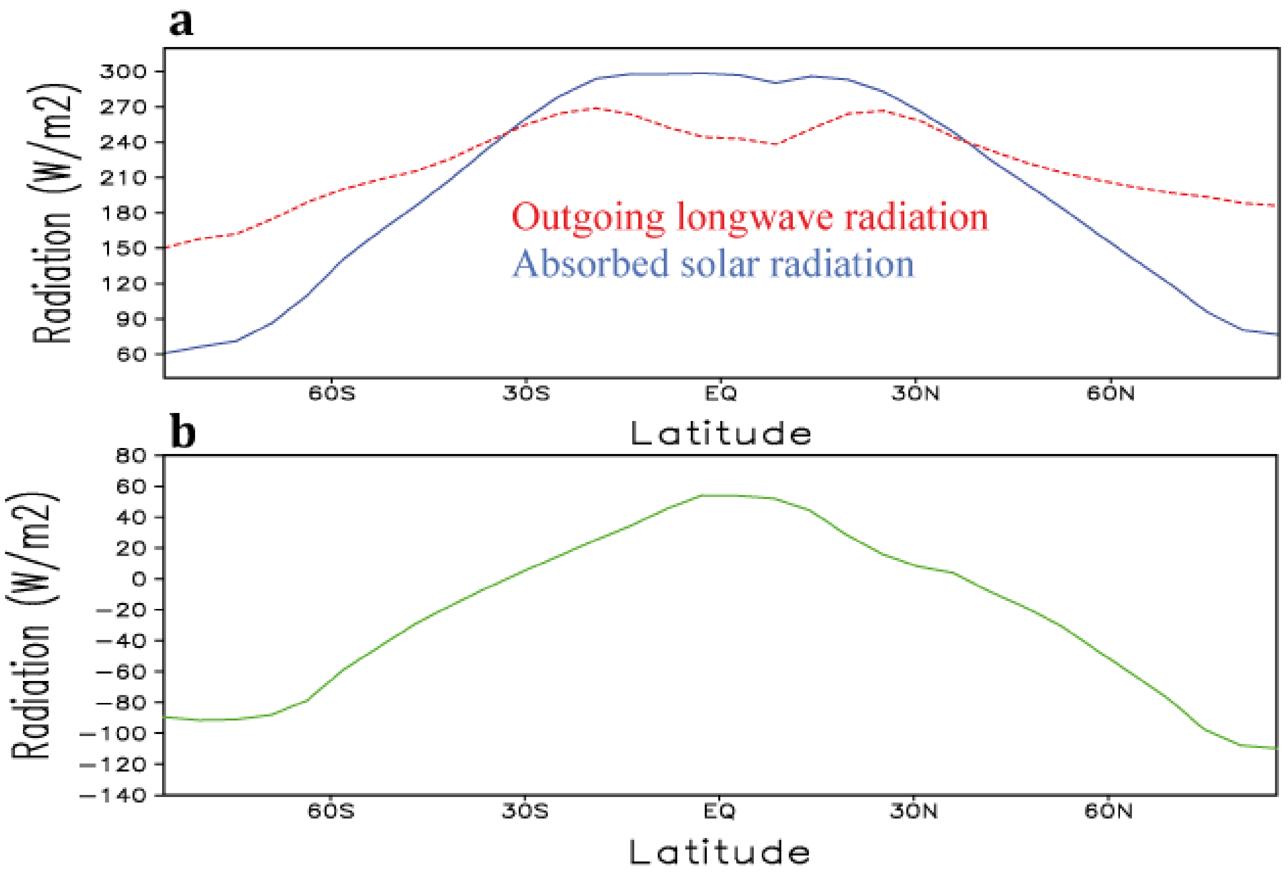
At the top of the atmosphere in annual mean (W m^{-2})

- Zonal mean of the absorbed solar radiation
- Outgoing longwave radiation

Bottom panel:

At the top of the atmosphere in annual mean (W m^{-2})

- Zonal mean of the difference between the absorbed solar radiation and the outgoing longwave radiation



Data from NCEP-NCAR reanalysis Kalnay et al., 1996

Large Scale Atmospheric Motions

- Horizontal scales of hundreds of km’s or longer
- Vertical scales on the order of the depth of the troposphere
- Timescales on the order of a day or longer

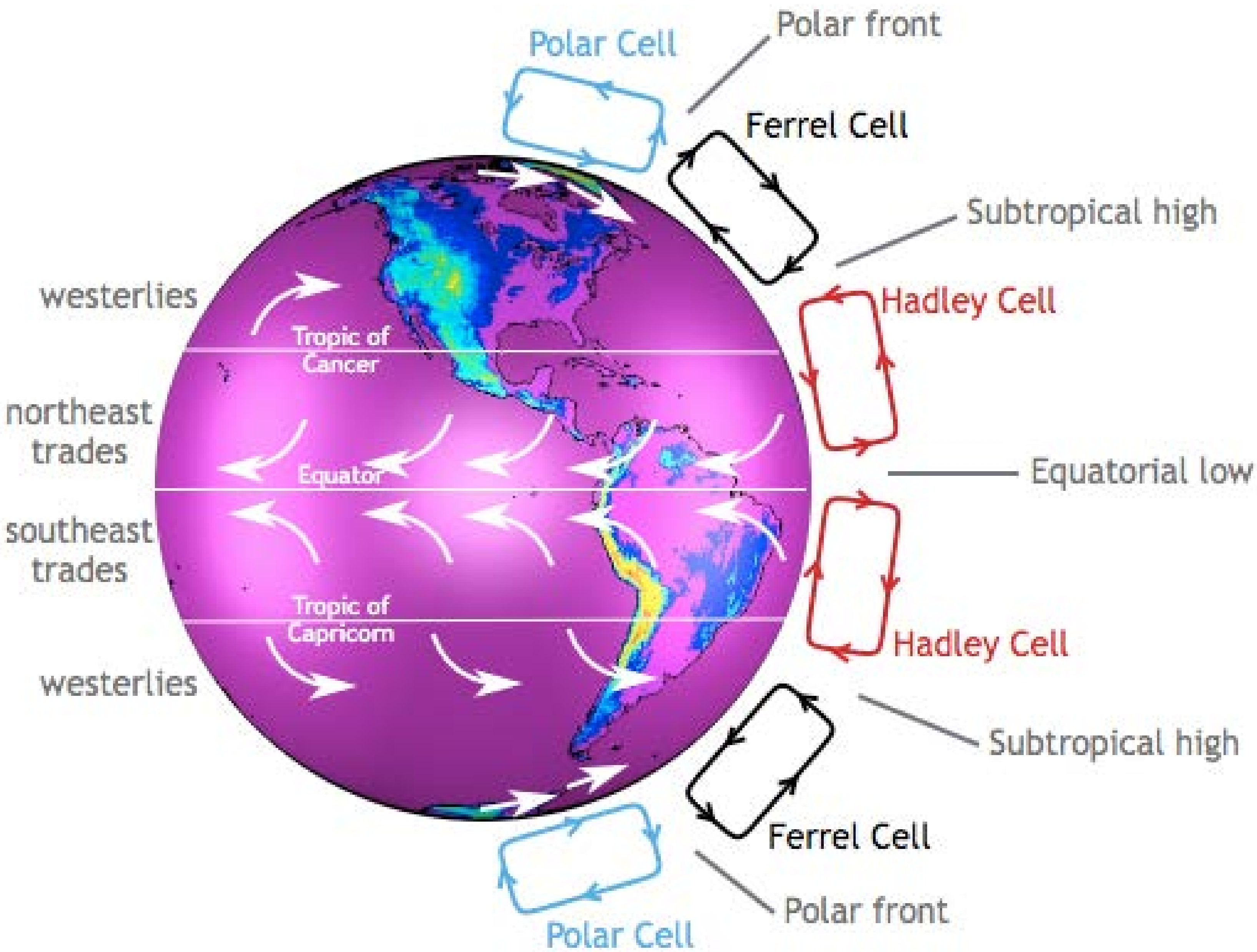
Motions on these scales are directly and strongly influenced by the Earth’s rotation

Coriolis Force

General Atmospheric Circulation

Without air moving, the equator would keep getting hotter and the poles would keep getting colder.

Air moves from warm to cold regions, and redistributes the incoming solar energy.



Hadley Cells: Step 1

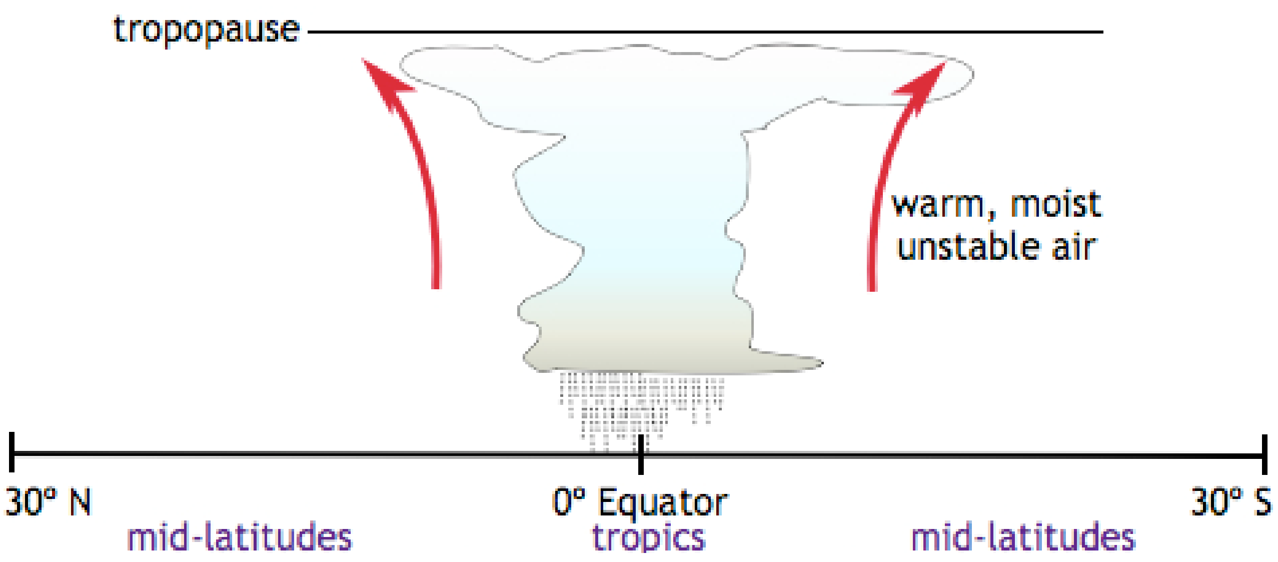
Convective towers in the tropics

Warm, moist air at the equator is unstable and rises to the top of the troposphere.

Rising air results in low surface pressure.

Surface winds are light, weather is monotonous, known as the "doldrums."

As the warm, moist air rises, water vapor condenses and forms the huge cumulus towers.



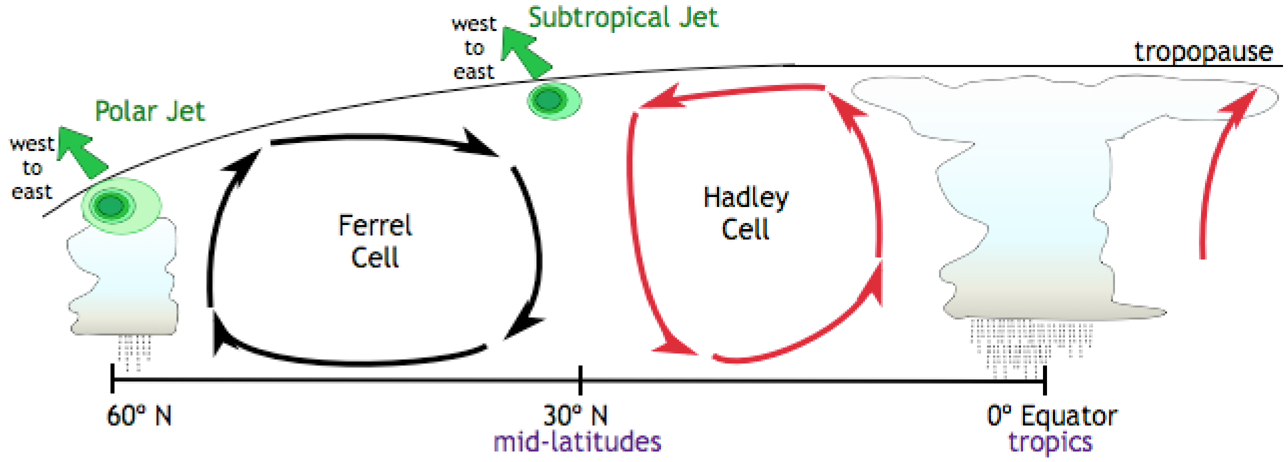
Hadley Cells: Step 2

The jet streams

The rising air reaches the stratosphere, where air temperature increases with height.

The rising air quickly becomes cooler than its surroundings and sinks. The tropopause is a lid for clouds! The air cannot rise anymore, so it spreads poleward.

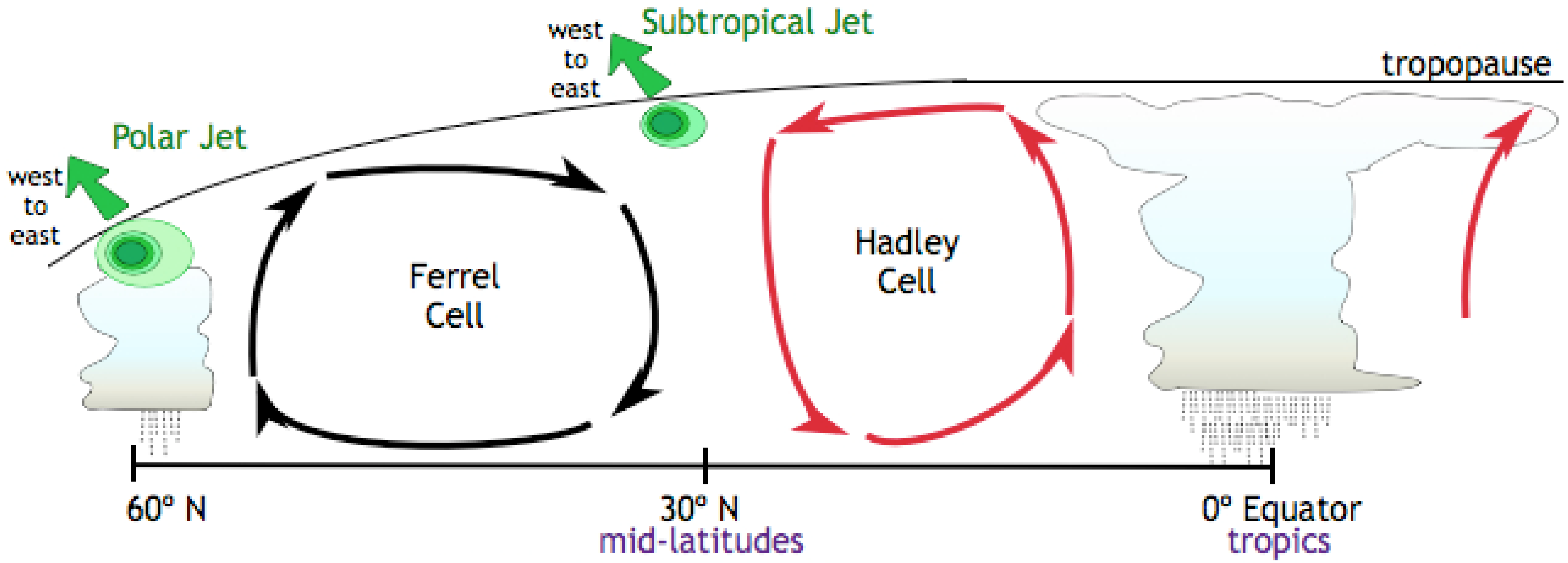
But, it is deflected by the coriolis force – poleward moving air becomes westerly winds.



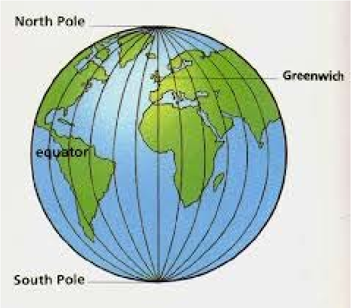
Hadley Cells: Step 2 cont.

The jet streams

- The westerly winds produce jet streams
- The Subtropical Jet Stream is at 30 degrees (N or S)
- The Polar Jet Stream is at 60 degrees (N or S)

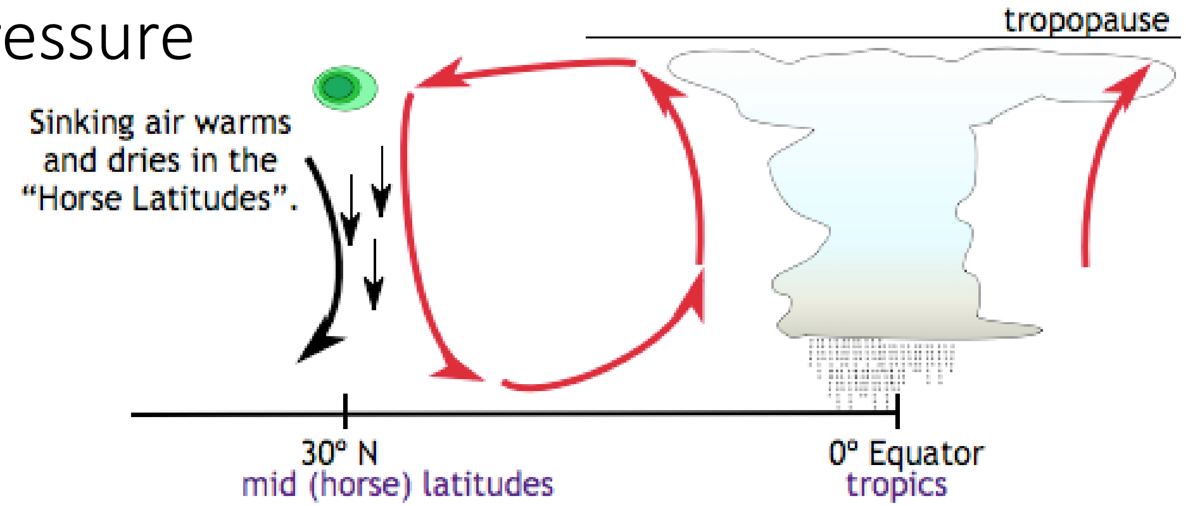


Hadley Cells: Step 3



Sinking air in the mid-latitudes

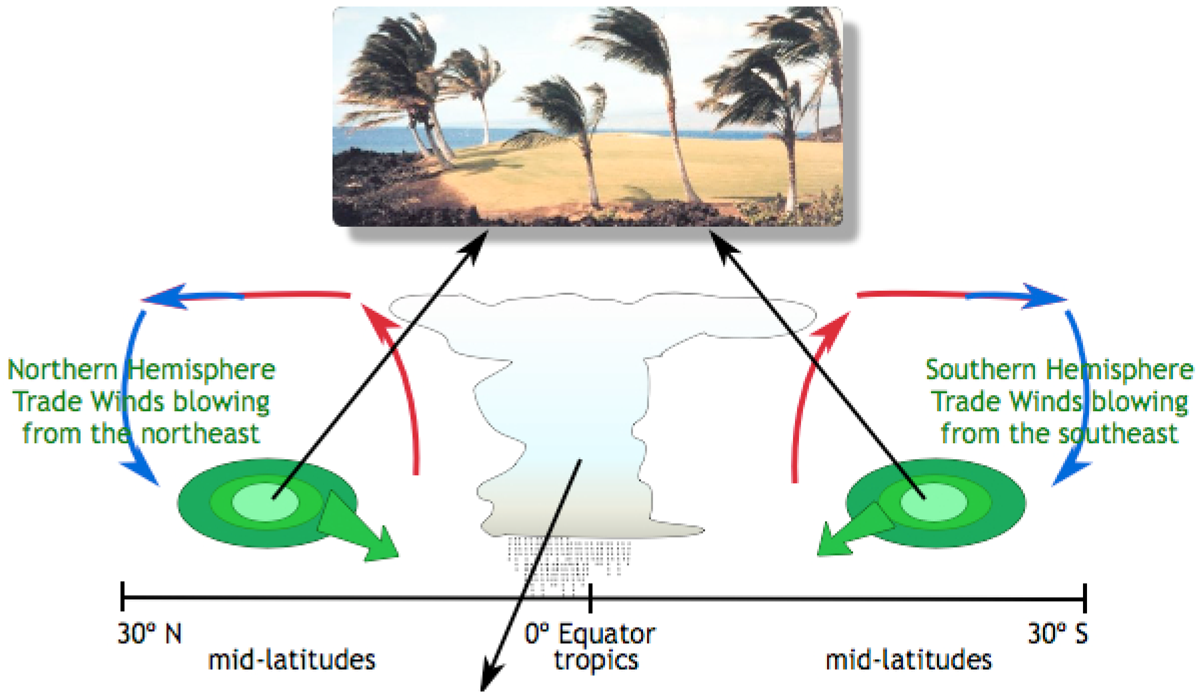
- As the air aloft moves poleward, it cools and bunches up (converges).
- At ~30 degrees latitude, the air sinks.
- The sinking air dries and warms.
- This results in a band of high surface pressure
- The Subtropical Highs



Hadley Cells: Step 4

Trade winds and the Intertropical Convergence Zone

- Some of the sinking air returns to the Equator from the subtropics.
- It gets deflected by coriolis, resulting in northeasterly winds (in the N. Hem; southeasterly in the S. Hem) known as the trade winds



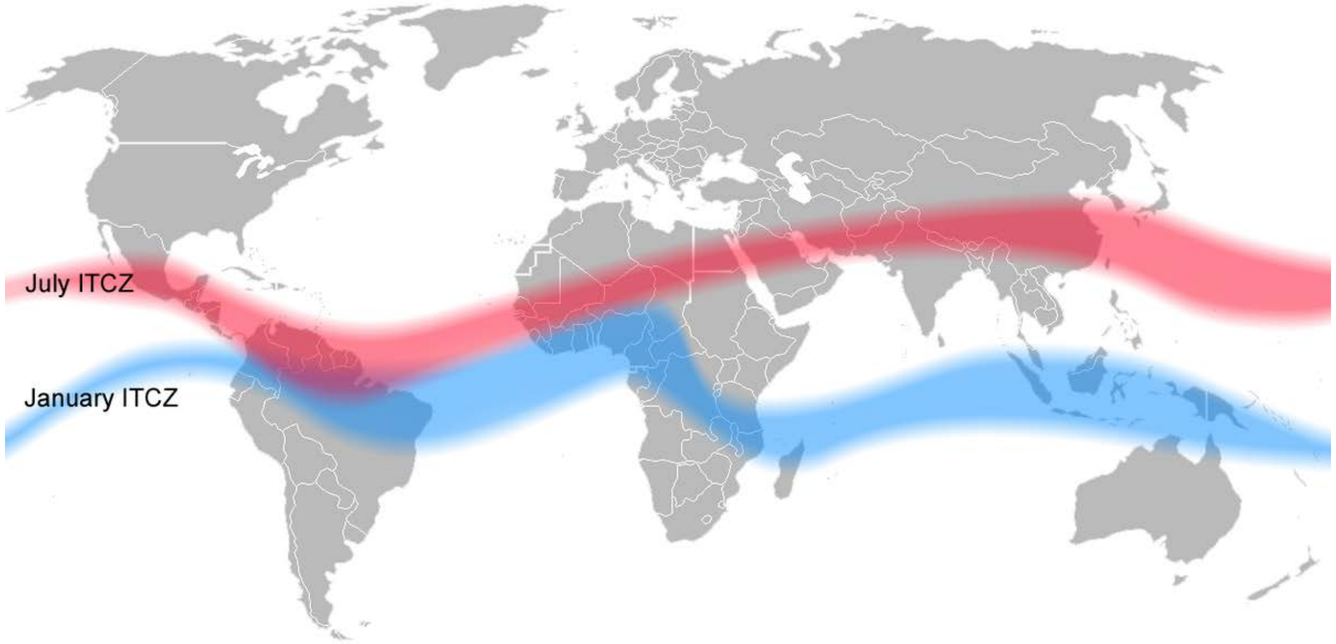
Hadley Cells: Step 4

Trade winds and the Intertropical Convergence Zone

- High levels of solar radiation and warm water hear the air in the ITCZ
- This raises its humidity and makes it buoyant
- The trade winds cause convergence, and the buoyant air rises
- As it rises it expands and cools, releasing the moisture in an almost perpetual series of thunderstorms

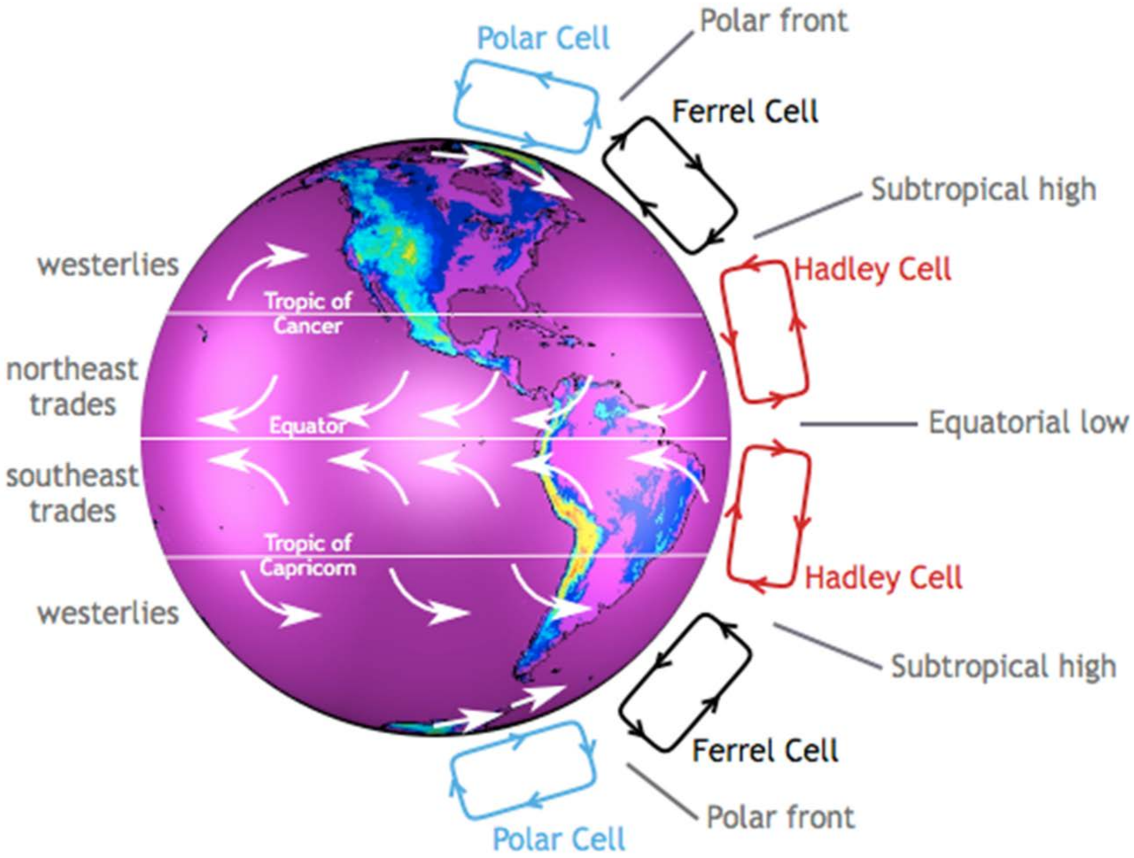
ITCZ

- Seasonal shifts in the location of the ITCZ drastically affects rainfall in many equatorial nations, resulting in the wet and dry seasons of the tropics rather than the cold and warm seasons of higher latitudes.
- Longer term changes in the ITCZ can result in severe droughts or flooding in nearby areas.



Hadley Cells Summed Up

Warm moist air in Equatorial regions rises in huge cumulus clouds, then travels poleward at very high altitudes, then sinks near 30 degrees (N or S), and returns Equator-ward at the Earth's surface.



Ferrel Cells: Step 0

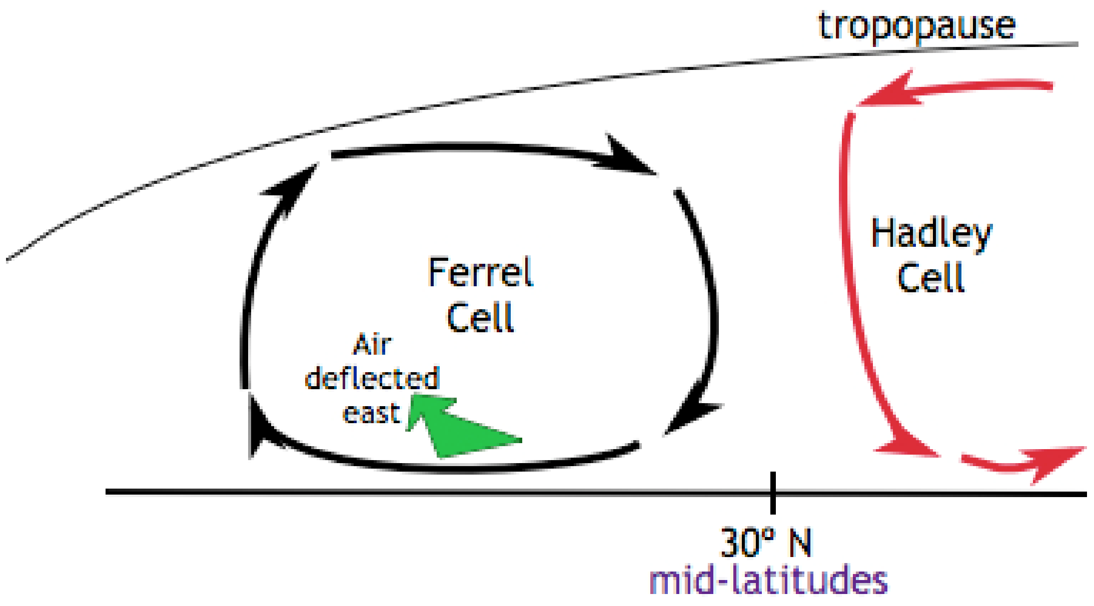
Brief eddy introduction

- An eddy is similar to a wave
- Eddies are the changes in the normal, or average, conditions in the atmosphere
- Eddies occur in regions of strong temperature gradients
- Eddies act to warm the cold area and to cool the warm area by mixing the air.

Ferrel Cells: Step 1

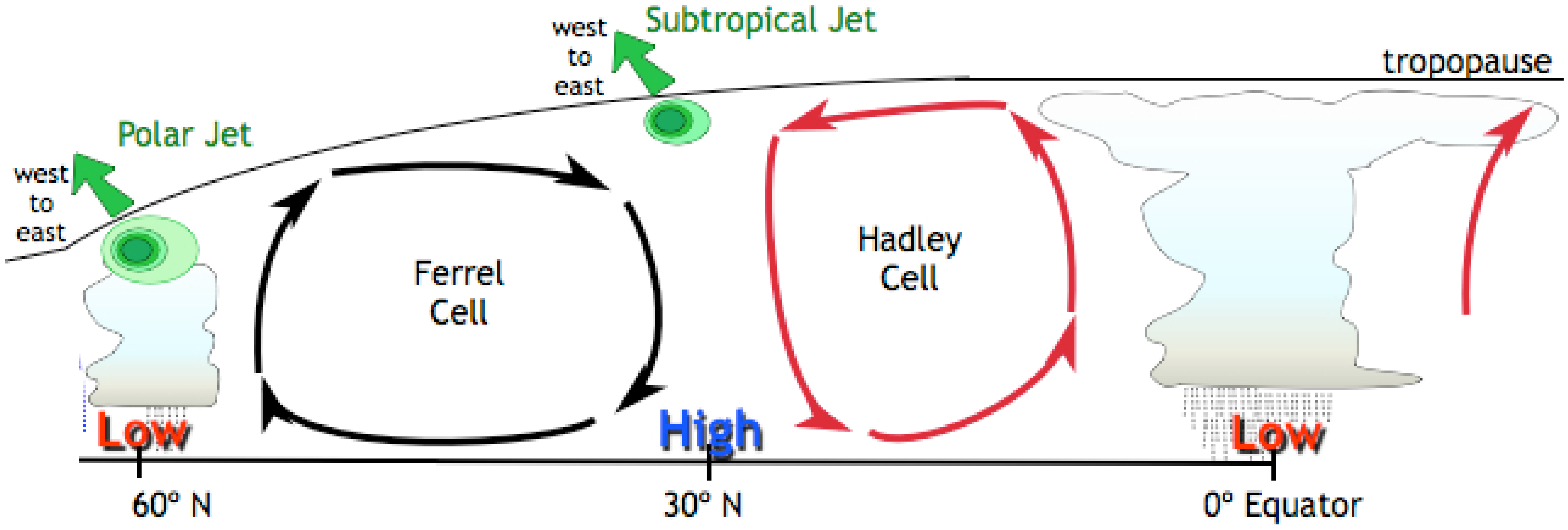
Why do we need to introduce eddies?

- Ferrel Cells have rising air where it is relatively cold and sinking air where it is relatively warm – this is different than what has been presented thus far



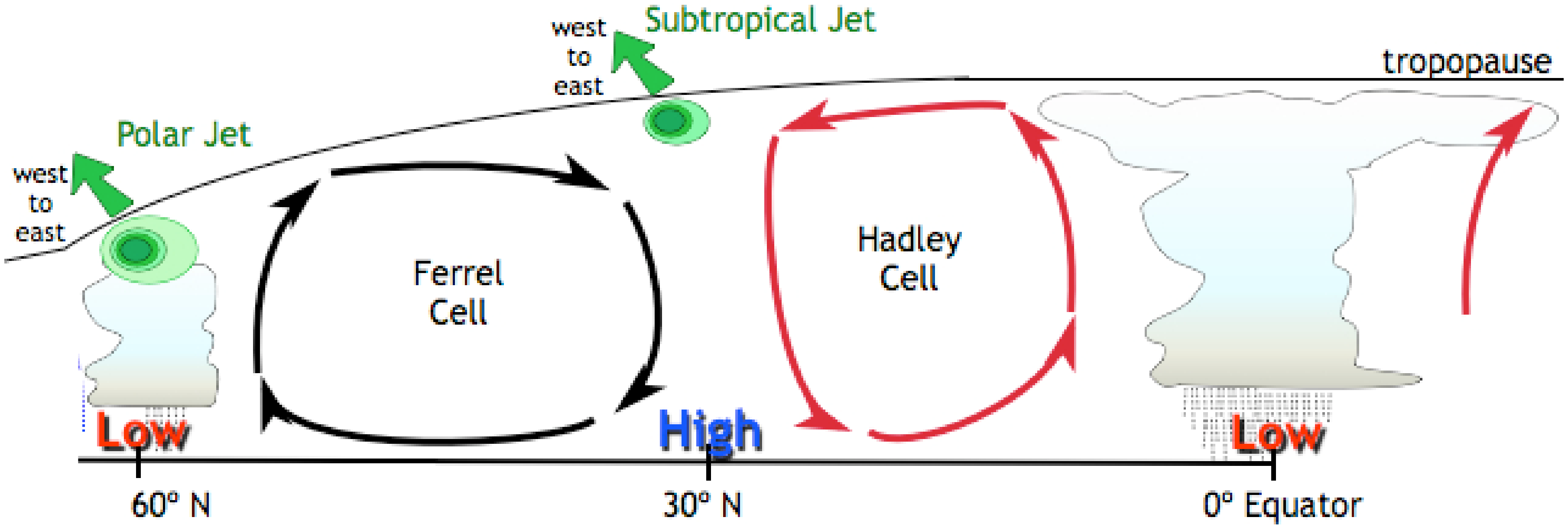
Ferrel Cells

- Mid-latitude eddies cool the subtropics – this results in sinking air
- Mid-latitude eddies warm the higher latitudes – this results in rising air
- The circulation pattern derives its energy from the strong temperature gradient that occurs in the mid-latitudes and results from warm tropical air meeting cold polar air



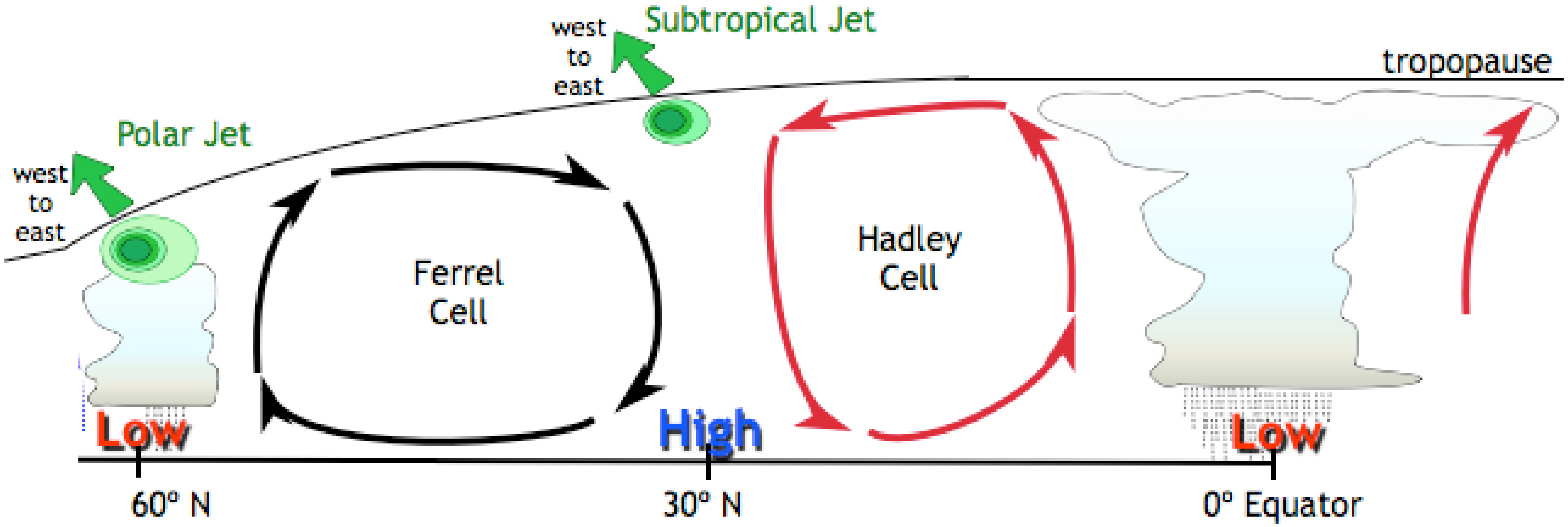
Ferrel Cells

- The sinking air in the subtropical highs moves poleward and is deflected to the east – this results in broad regions with westerly wind flow
- As a result of the prevailing westerlies, a flight from NYC to Europe is an hour faster than a flight from Europe to NYC



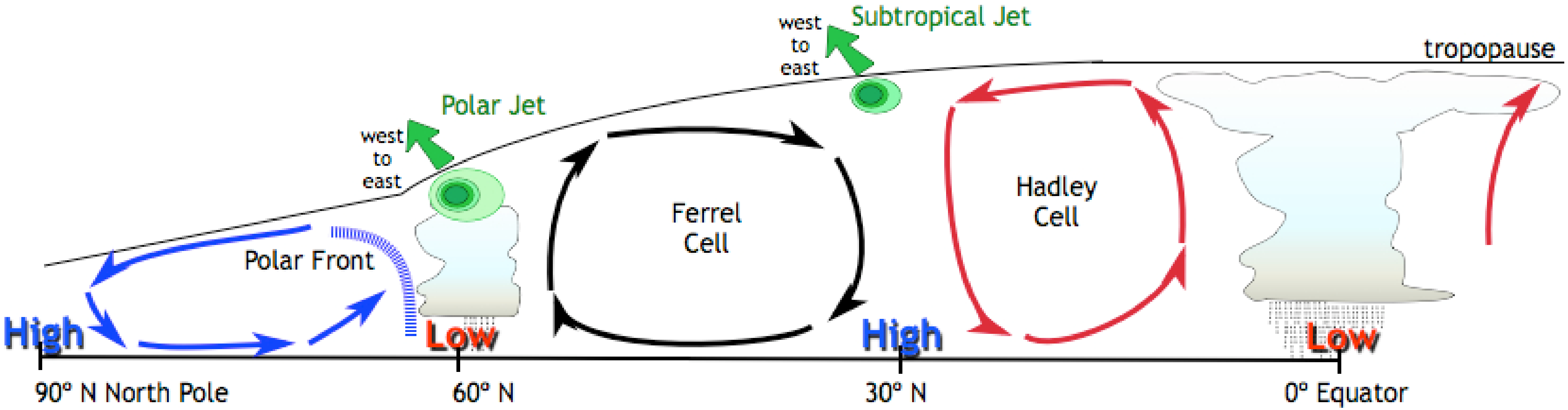
Ferrel Cells Summed Up

The Ferrel Cell is the average motion of air in the mid-latitudes. It is characterized by sinking air near 30 deg and rising air farther poleward. At the surface, air flowing poleward is deflected to the east by the coriolis force, resulting in westerly surface winds.



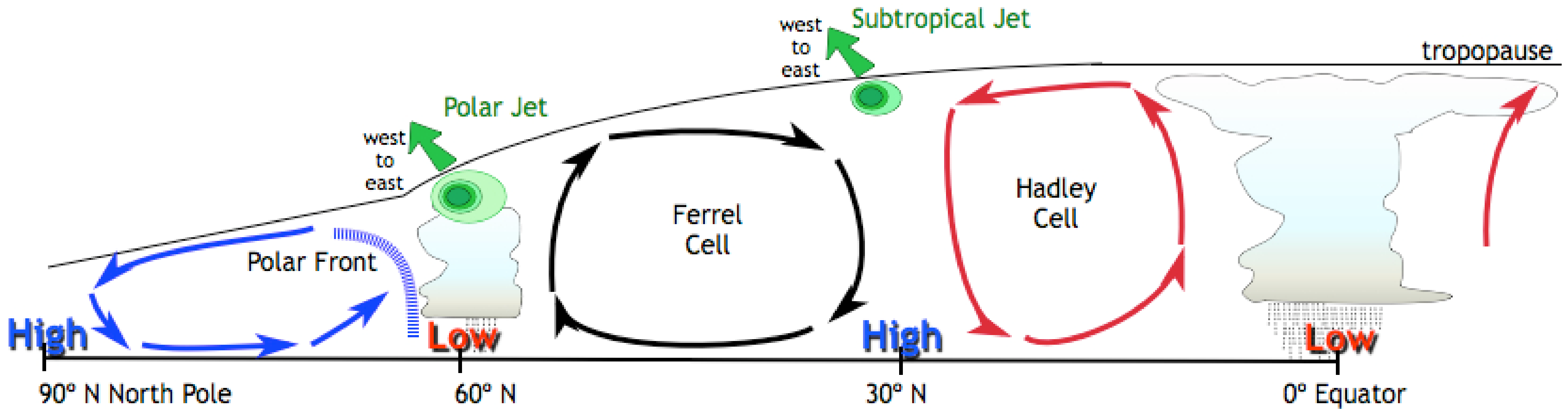
Polar Fronts

- Cold, dense air spreads away from the Poles
- The polar air mass moves along a boundary called the Polar Front
- On the other side is the relatively warm air from the subtropics
- When the two air masses meet, the warm air rises and storms develop
- Some of the air that rises returns toward the subtropics – completes the Ferrel Cell



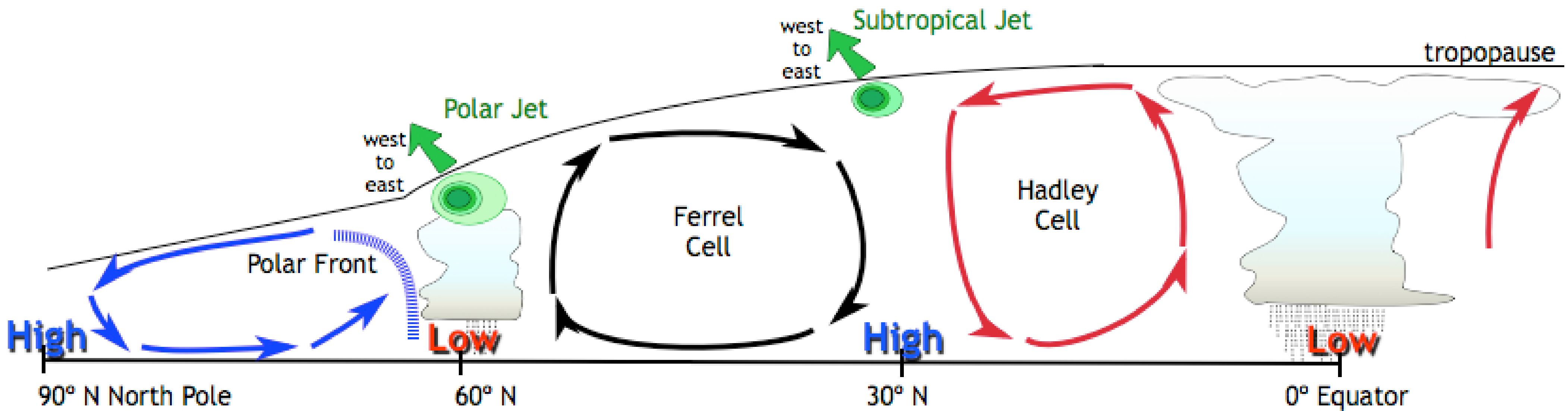
Polar Fronts

- The Polar Front occurs wherever the temperature gradient between the two air masses is greatest
- In the N. Hem summer it is ~ 60 degrees north, and in N. Hem winter it can be as far south as 30 degrees north.
- Storms typically occur along the Polar Front.

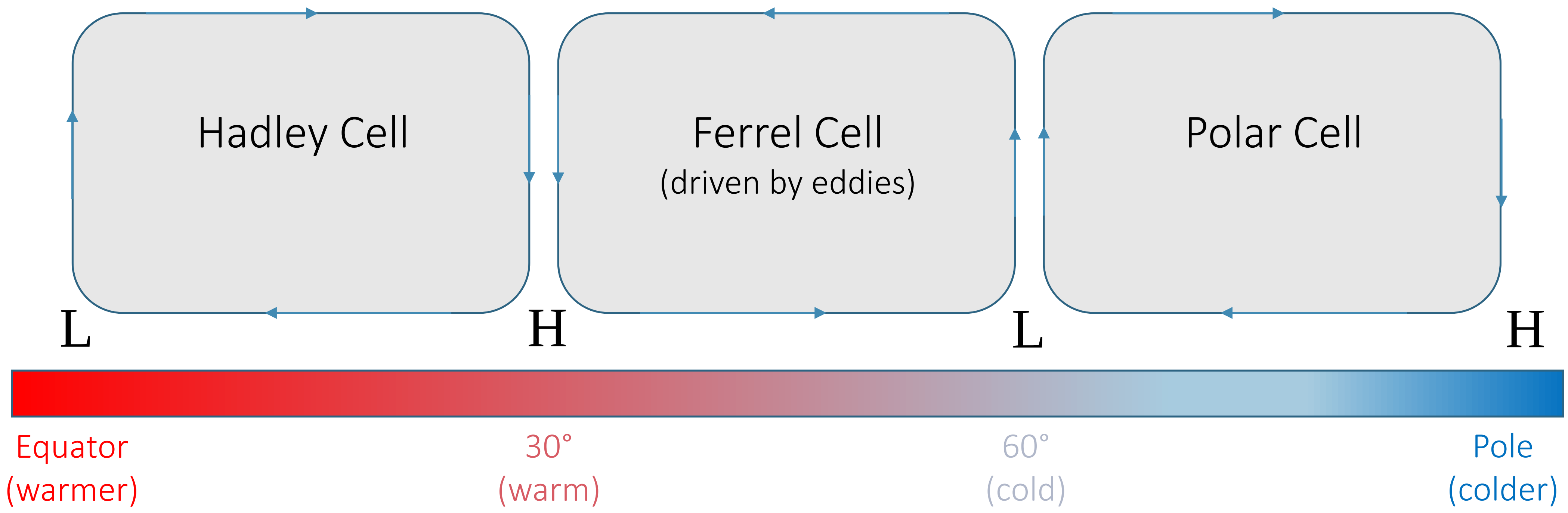


Polar Cells

- Sinking air at the poles warms and results in high pressure over the poles
- At the surface, the poleward moving air is deflected forming the polar easterly winds.
- The cold polar air meets the warm subtropical air moving poleward (Polar Front)
- The warm air from the subtropics pushes up over the cold equatorward moving polar air



The Three Cell Model for General Atmospheric Circulation



The Three Cell Model for General Atmospheric Circulation

Hadley and Polar Cells are Thermally Direct

- Rising branches over warm temperature zones and sinking branches over the cold temperature zones.

Ferrel Cell is Thermally Indirect

- Rising branch over cold temperature zone and sinking over warm temperature zone. Driven by eddy forcing, and not thermal forcing.