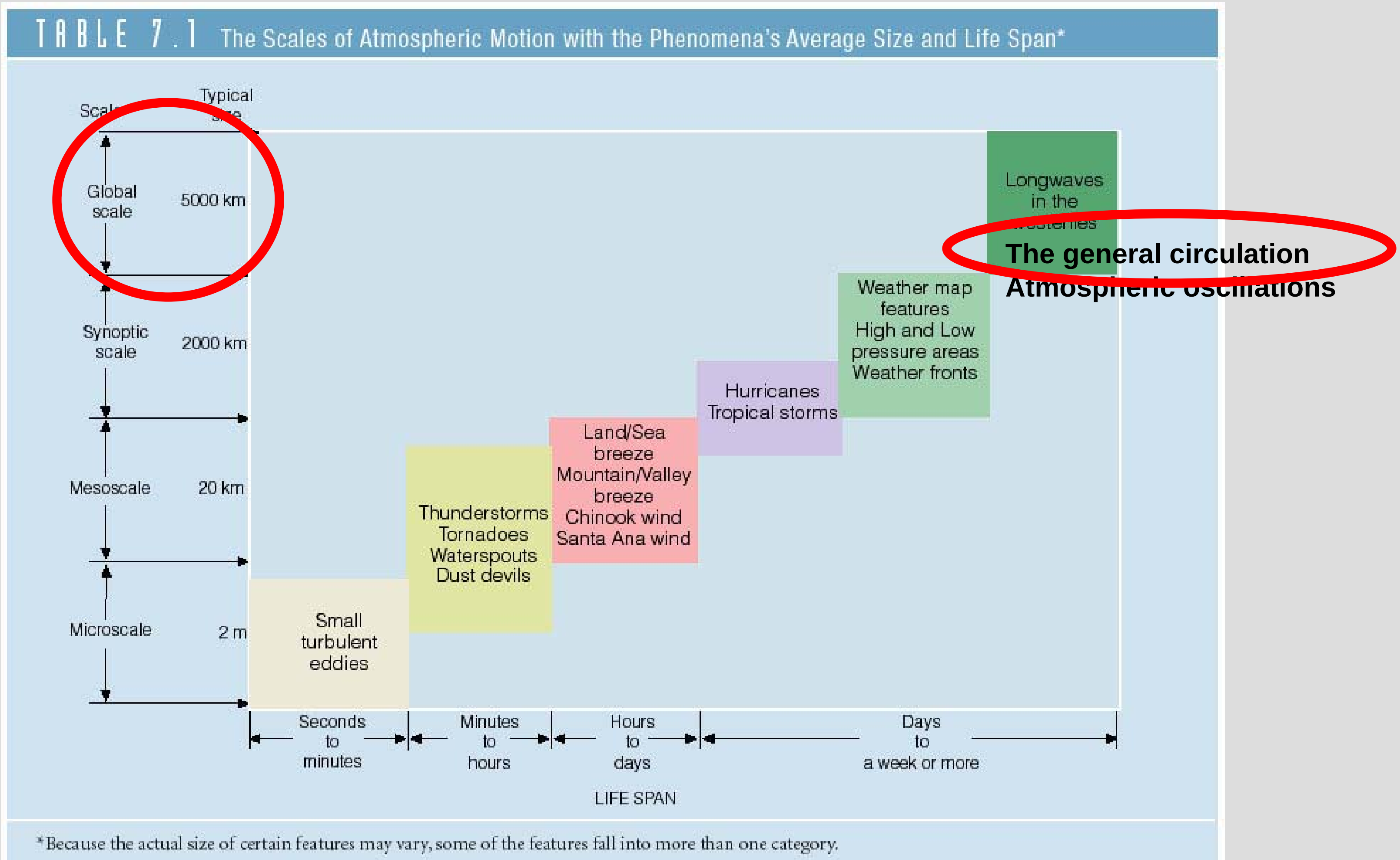
NATS 101
Section 13: Lecture 17

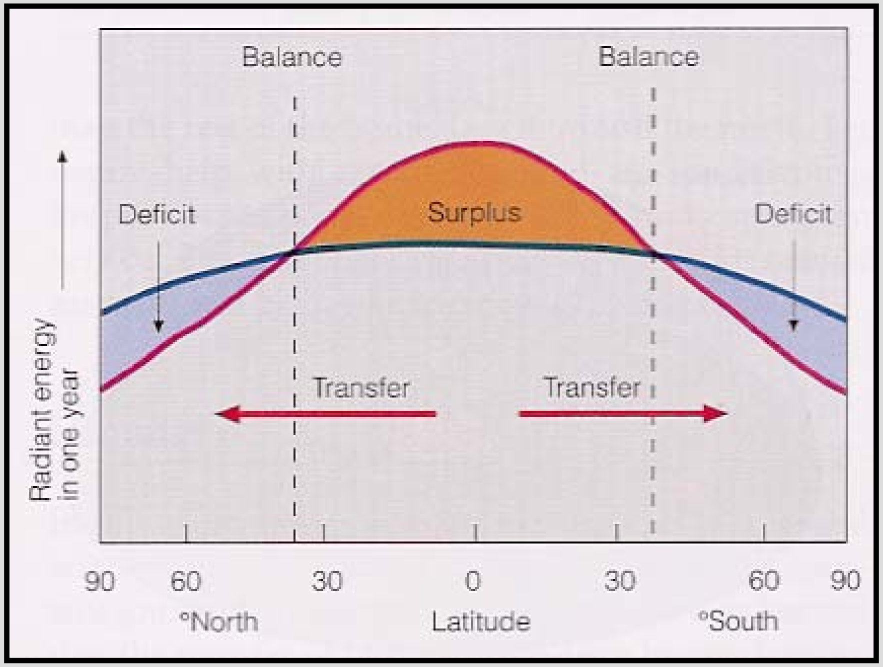
The General Circulation

Scales of Atmospheric Motion vs. Lifespan



The general circulation is on the global scale of atmospheric motion

Why does the general circulation exist? Flashback to Earth's net radiation balance



Red curve: Incoming solar radiation

Blue curve: Outgoing infrared radiation.

The equator doesn't keep getting warmer and warmer.

The high latitudes don't keeping getting colder and colder.

Therefore there must be ways that heat is transferred from equator to pole.

How is this accomplished?

Complicating factors for the general circulation

The Seasons

The __________ (or tilt of the Earth with respect to it's orbital plane): Causes annual differences in incoming solar radiation due to changes in the ____________________ and ___________________.

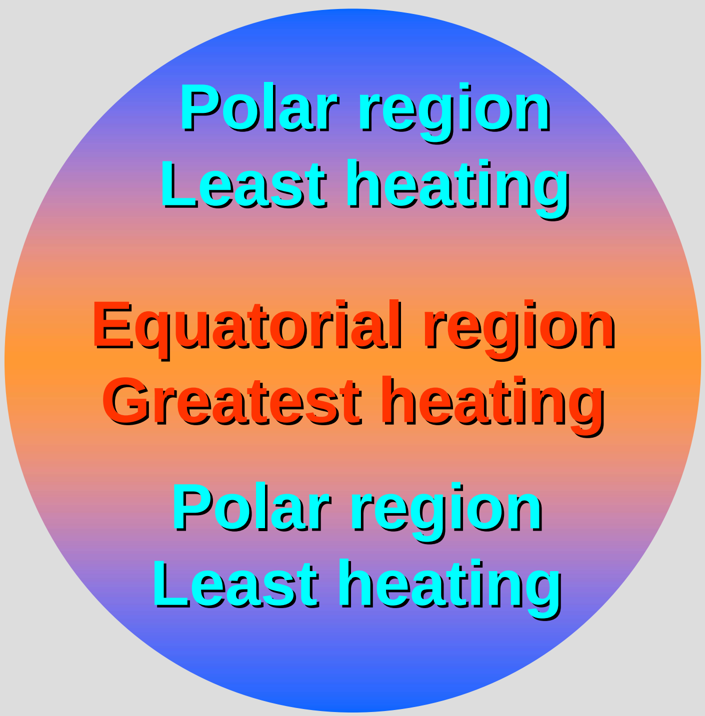
The Earth's Rotation

Affects how the wind blows because of the __________ force.

Land-Sea Contrasts

The presence of continents causes regional thermal contrasts which may seasonally reverse (e.g. monsoon). Why do these thermal contrast arise??

Waterworld: The general circulation without complications



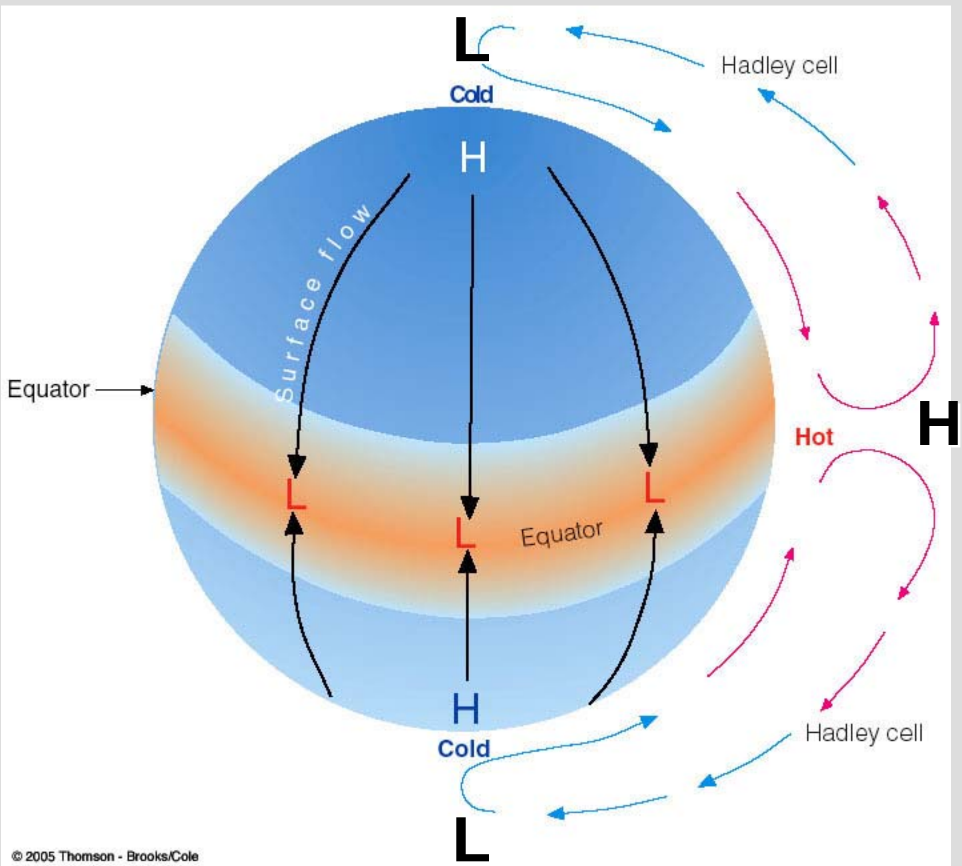
__Waterworld characteristics__

Earth's axis is not tilted, so the sun is always directly overhead at the equator all the time.

No rotation, so the only force to drive the wind is the pressure gradient.

An aquaplanet with no continents.

General Circulation of Waterworld



HADLEY CELL

A giant convection cell, or thermally direct circulation.

Warm air rises at the equator. Low pressure at surface, high pressure aloft.

Transport of warm air away from the equator aloft.

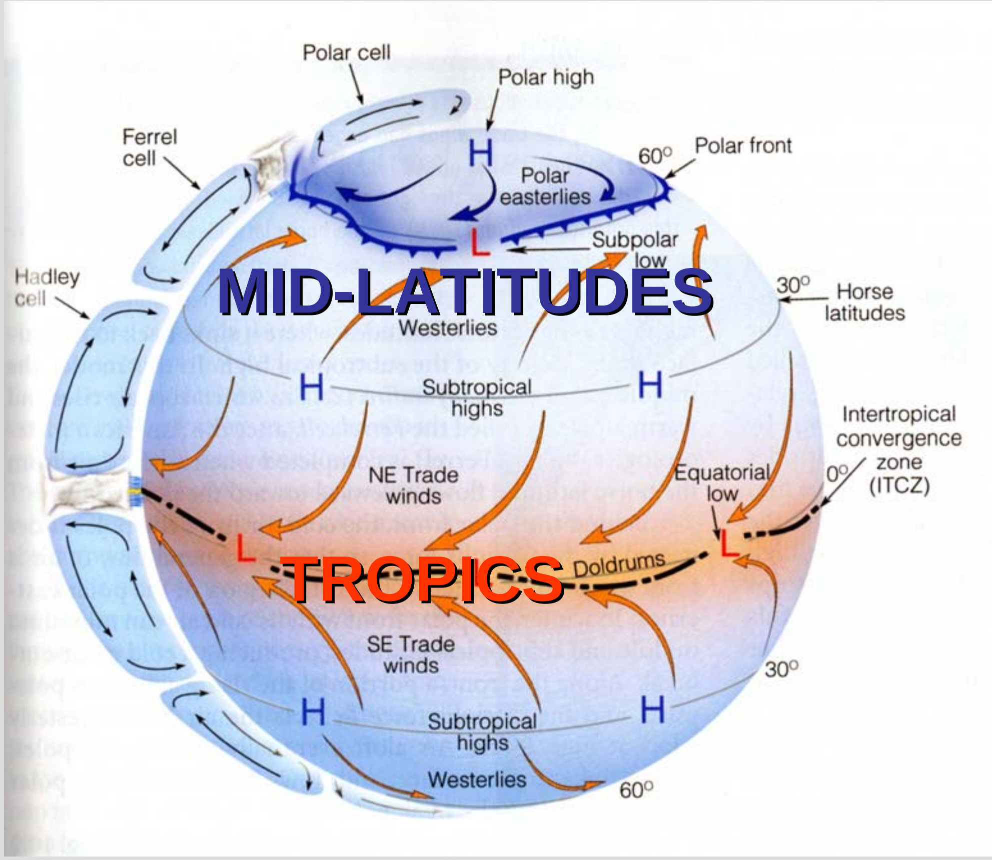
Cold air sinks at the pole. High pressure at the surface, low pressure aloft.

Transport of cool air toward the equator at the surface.

Now let's add Earth's rotation

It gets a bit more complicated…

Three-cell model of general circulation

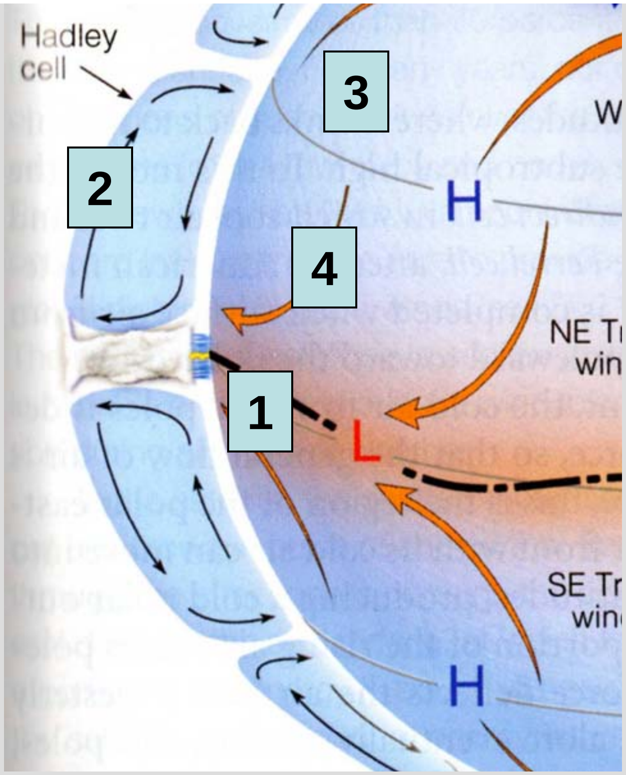


What mechanism transports heat poleward in each of these regions?

Mid-latitudes: 30° to 60° latitude

Tropics: 0 to about 30° latitude

General circulation: Hadley Cell in tropics



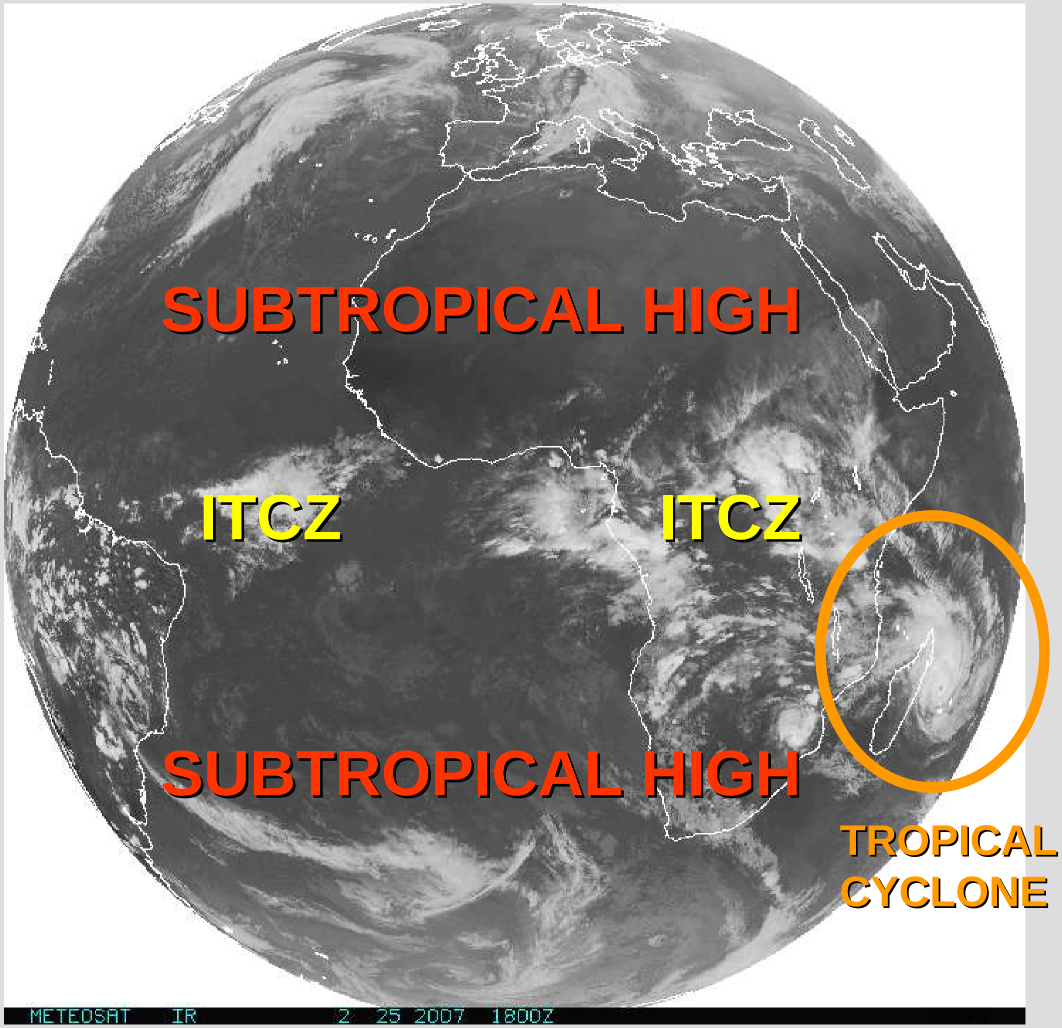
Path of air through the cell

1. **Equator: Air converges at the surface and rises to form a band of clouds, called the intertropical convergence zone (ITCZ). Releases latent heat.**

2. **Upper level winds transport heat away from the equator.**

3. **Air cools by radiating in the longwave to space, air sinks and warms (dry adiabatically) at about 30° latitude, forming a subtropical high.**

4. **Air returns to toward the equator at the surface, causing easterly trade winds.**



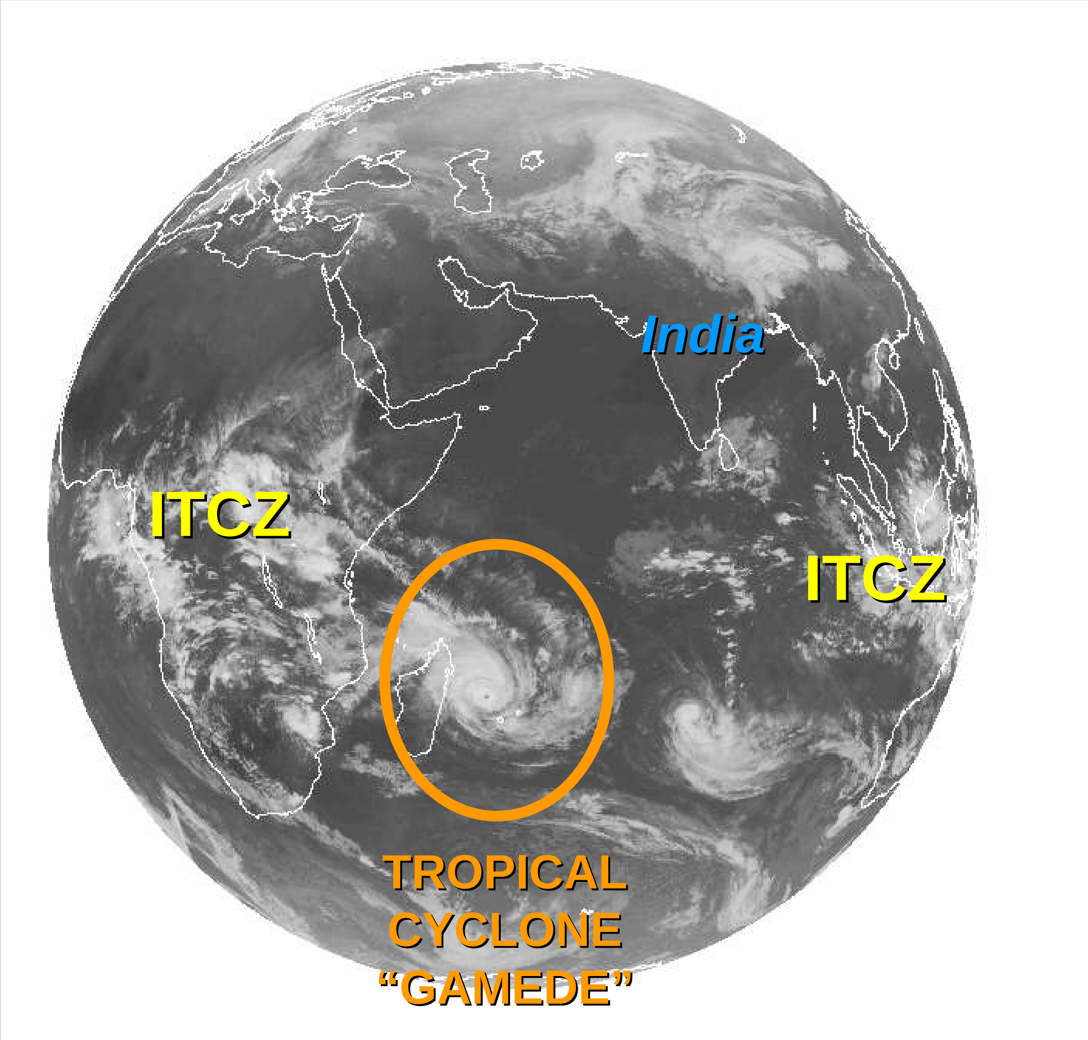
Meteosat IR Image

In the real world, the ITCZ is not a continuous band of clouds, but is patchy areas of thunderstorms.

Other interesting thing here:

When the ITCZ gets far enough away from the equator, it help to generate tropical cyclones—like off the coast of Madagascar.

View from Indian Ocean (Spring 2007)



Flashback to monsoon lecture:

It is winter in the northern hemisphere, so it is the dry season in India and there are no clouds there.

Subtropical jet stream
Result of angular momentum conservation

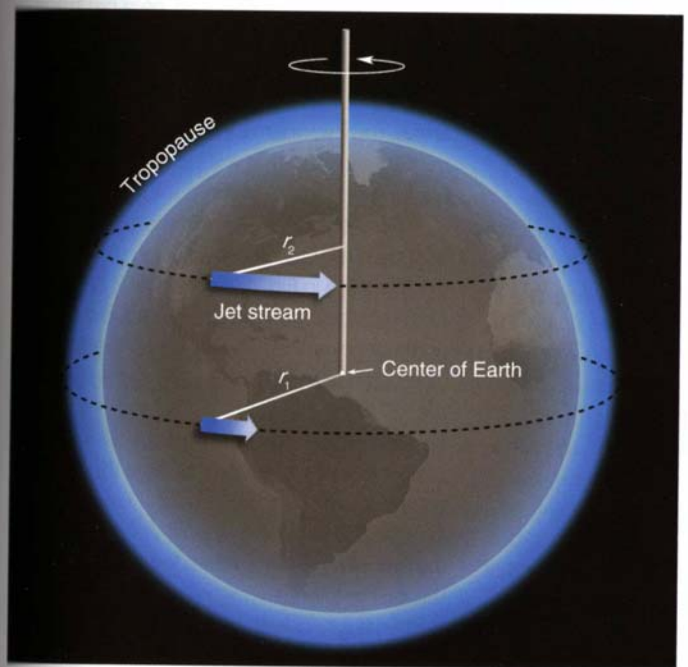


FIGURE 10.13
Air flowing poleward at the tropopause moves closer to the rotational axis of the earth (r_2 is less than r_1). This decrease in radius is compensated for by an increase in velocity and the formation of a jet stream.

Angular momentum = mvr

In the poleward branch of the Hadley cell, a subtropical jet stream occurs.

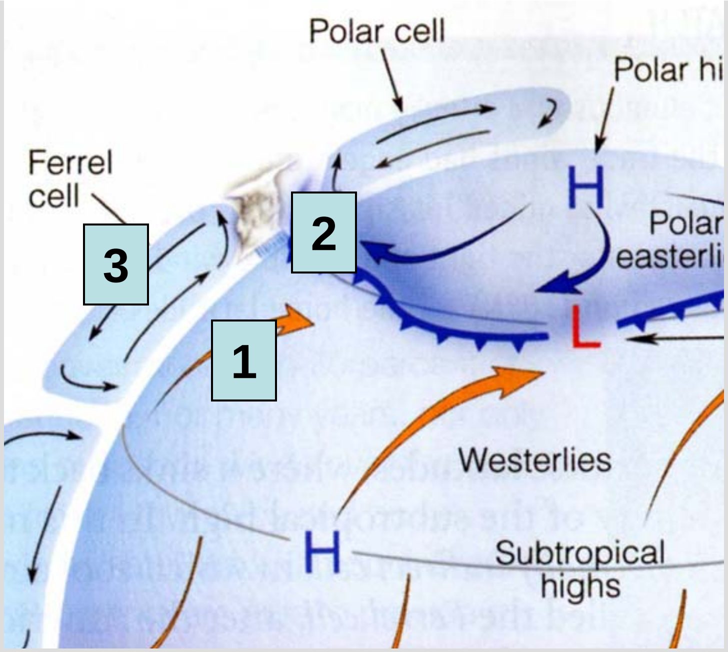
<u>Reason</u>

As air flows poleward, it moves closer to the rotational axis of the Earth (r).

By conservation of angular momentum, the wind speed (v) must increase.

Same idea as a spinning ice skater bring their arms inward and spinning faster and faster…

General circulation in mid-latitudes

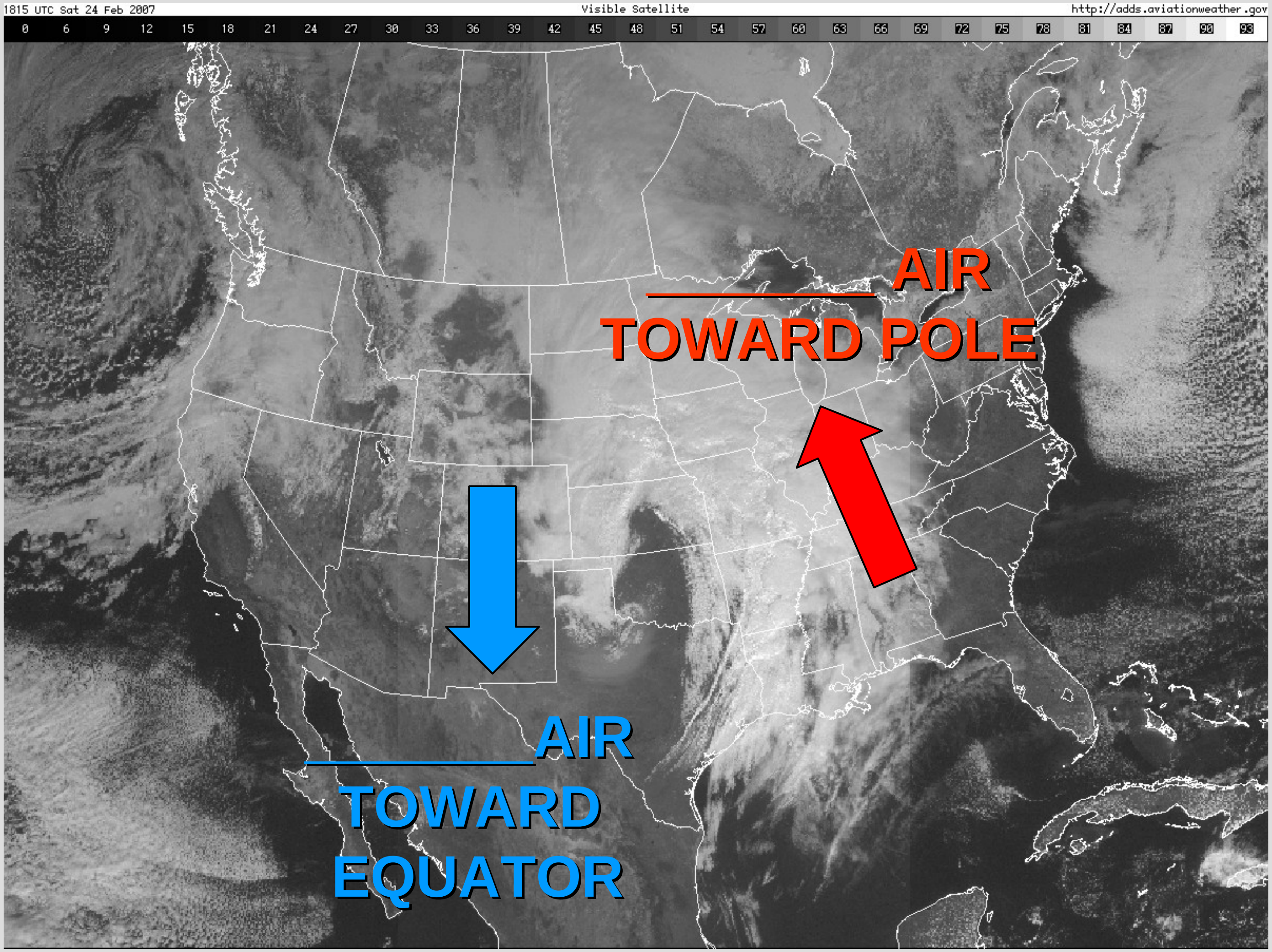


1. **Air flows away from the subtropical high toward the polar front, or boundary between warm subtropical air and cold polar air. Because of the Coriolis force, the winds are westerly.**

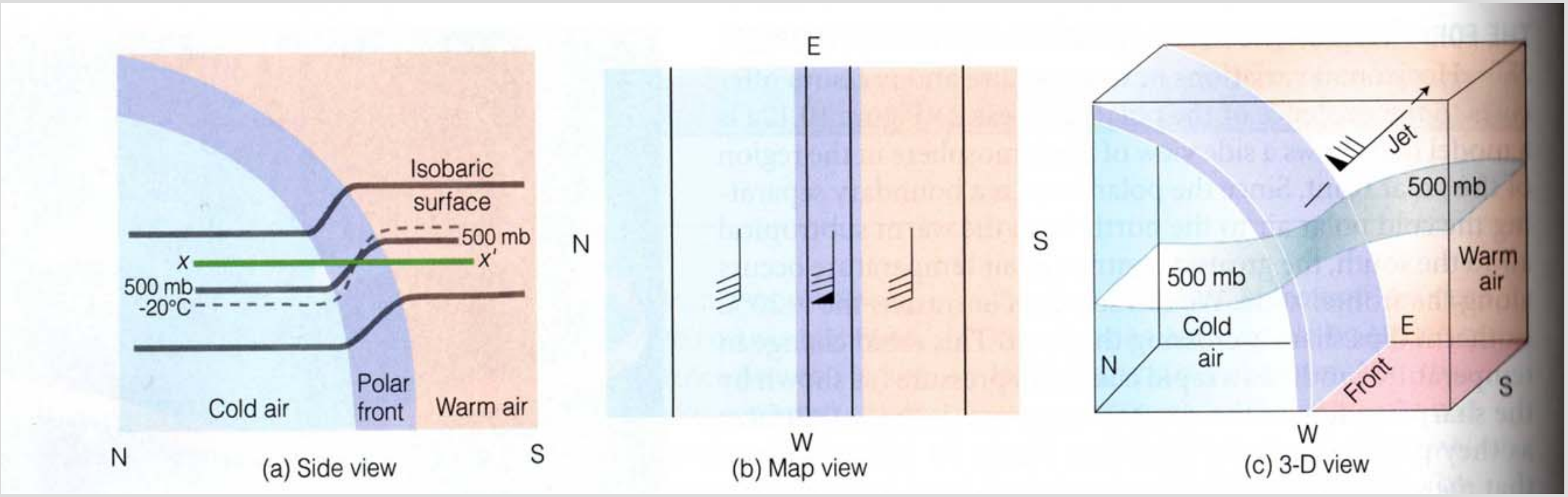
2. **Air converges and rises at the polar front. Mid-latitude cyclones (or areas of low pressure) develop along the polar front. The mid-latitude cyclones transport warm air toward the pole and cool air toward the equator.**

3. **Some of the air returns toward the subtropics, completing an indirect thermal circulation (Ferrel cell).**

Mid-latitude cyclone example (Major Midwest storm)



Polar Jet Stream
Result of the polar front boundary

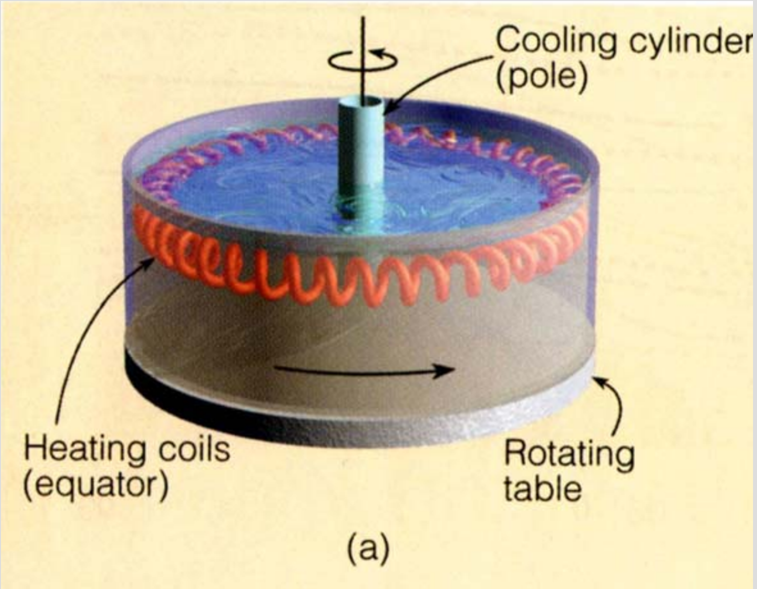


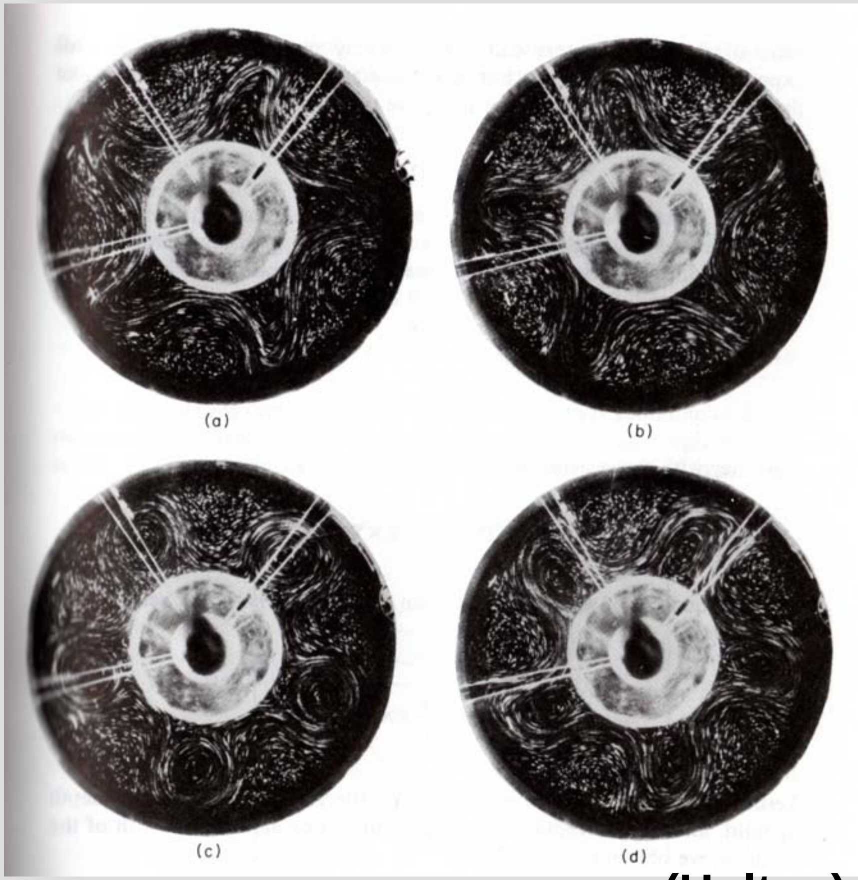
The rapid change between warm and cold air along the polar front results in a strong pressure gradient, and winds, there.

This upper-level wind is called the *polar jet stream*.

Dishpan experiment

View looking down on the rotating dishpan (in rotating frame)





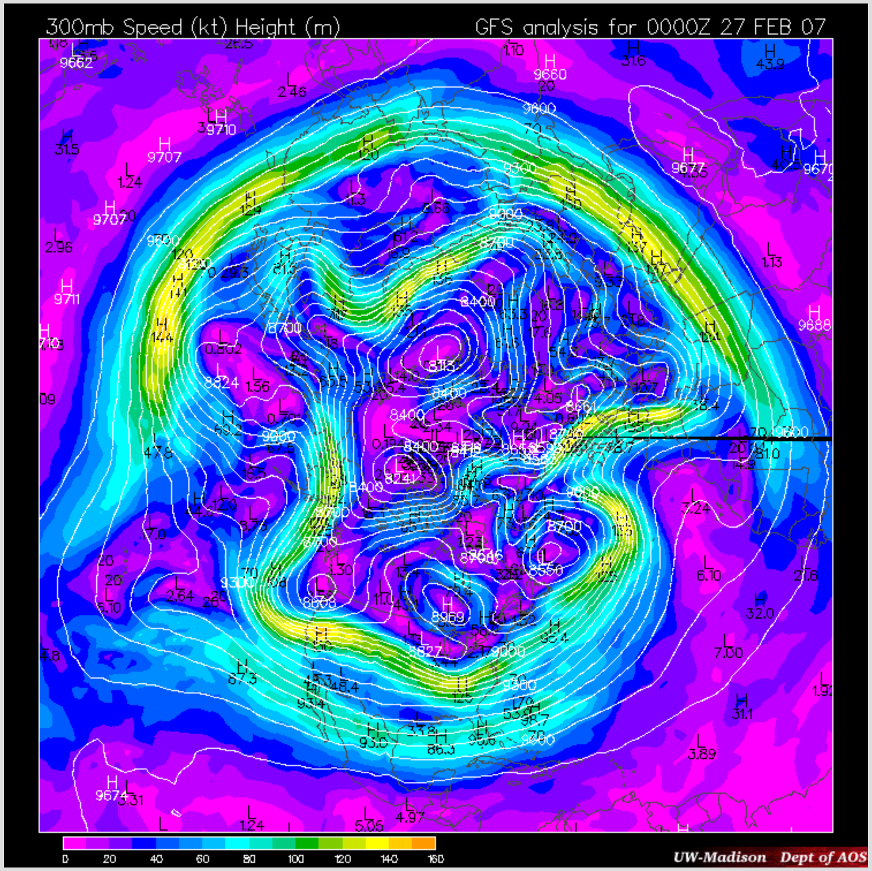
(Holton)

Heat applied to outer ring
Cooling applied to inner ring

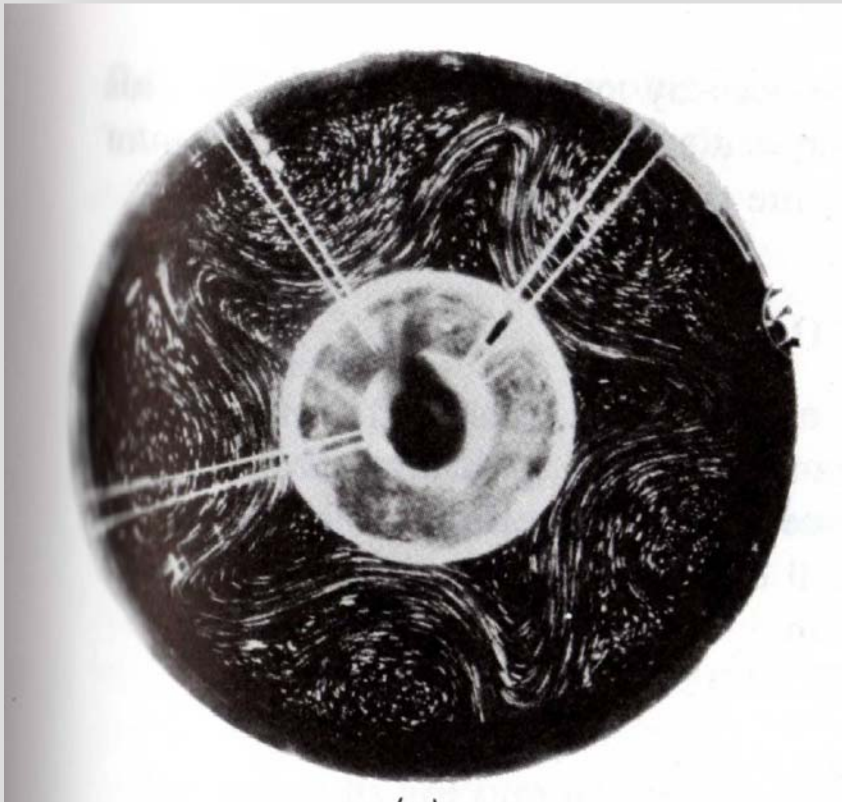
Add a particle tracer to the fluid…

SAME as mid-latitudes! Eddies transporting the heat from the outer ring toward the inner ring.

300-mb Height and Wind
View looking down on North Pole



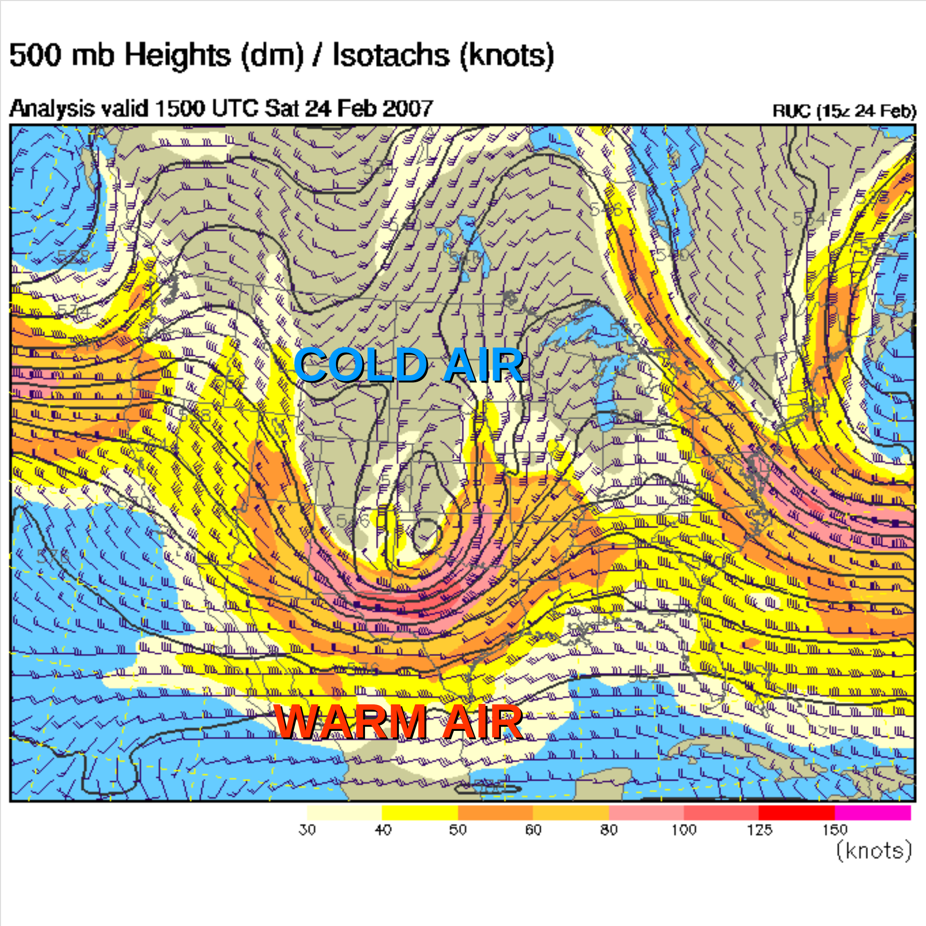
Rotating Dishpan



(a)

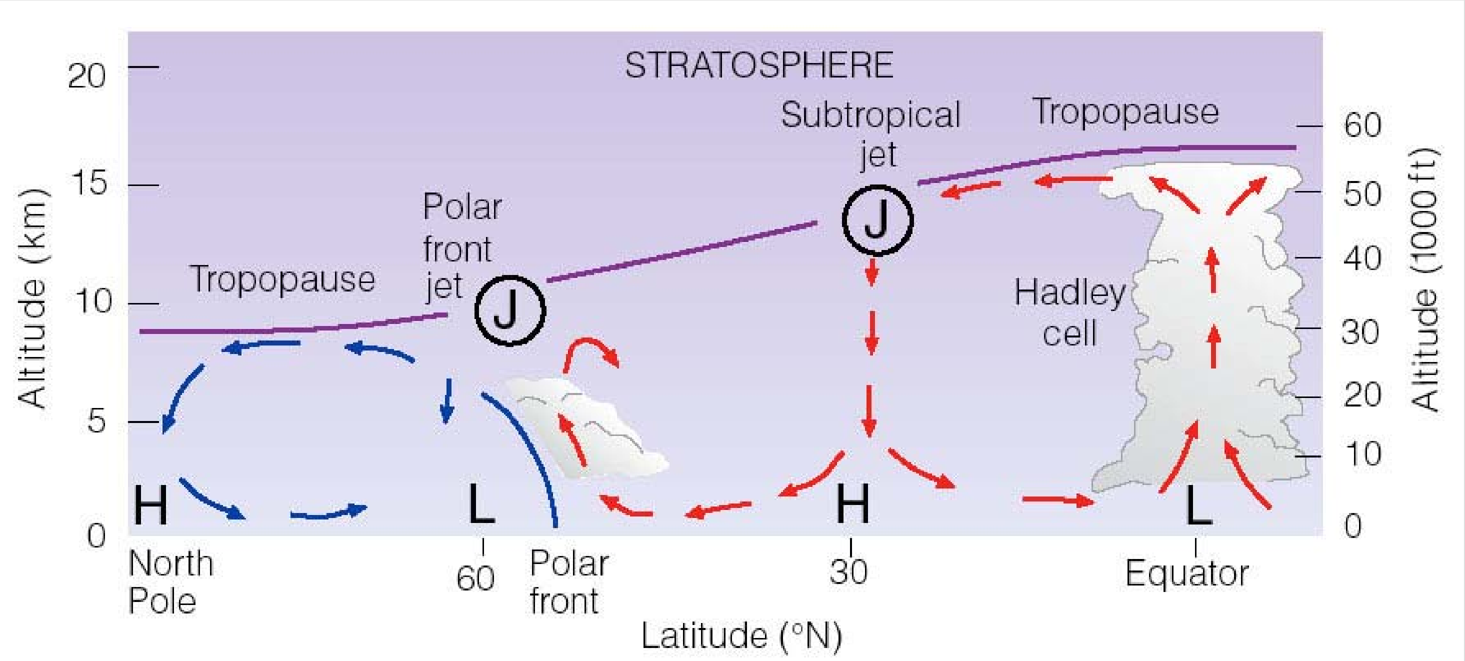
What are the eddies doing in both cases??

Polar jet stream in Midwest storm example



Note the very strong winds around the trough of low pressure.

Integrated picture of Jet Streams and the three-cell general circulation model.



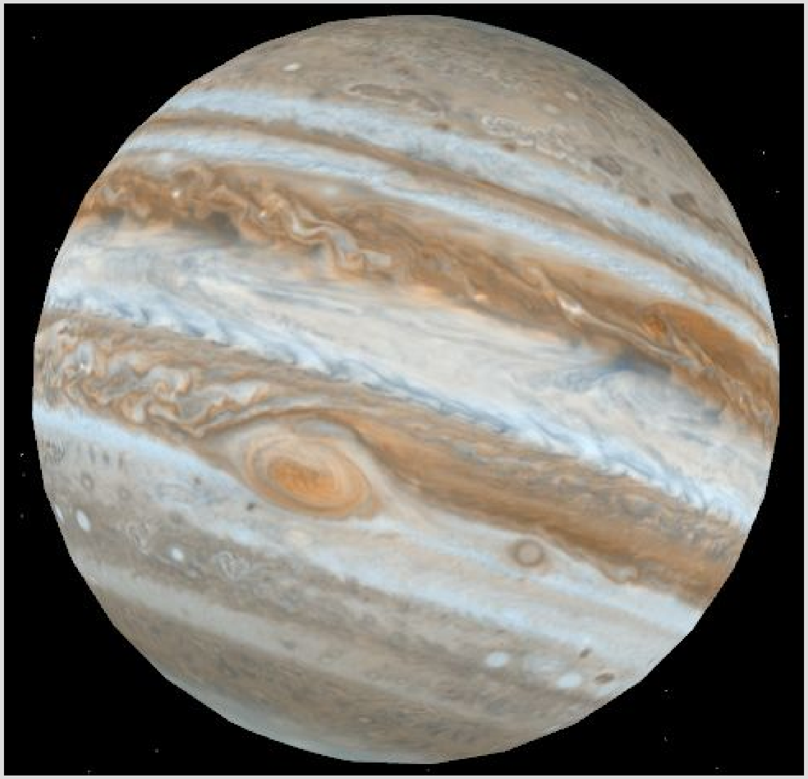
Jet streams occur near the tropopause.

Subtropical jet defines the limit of the Hadley Cell.

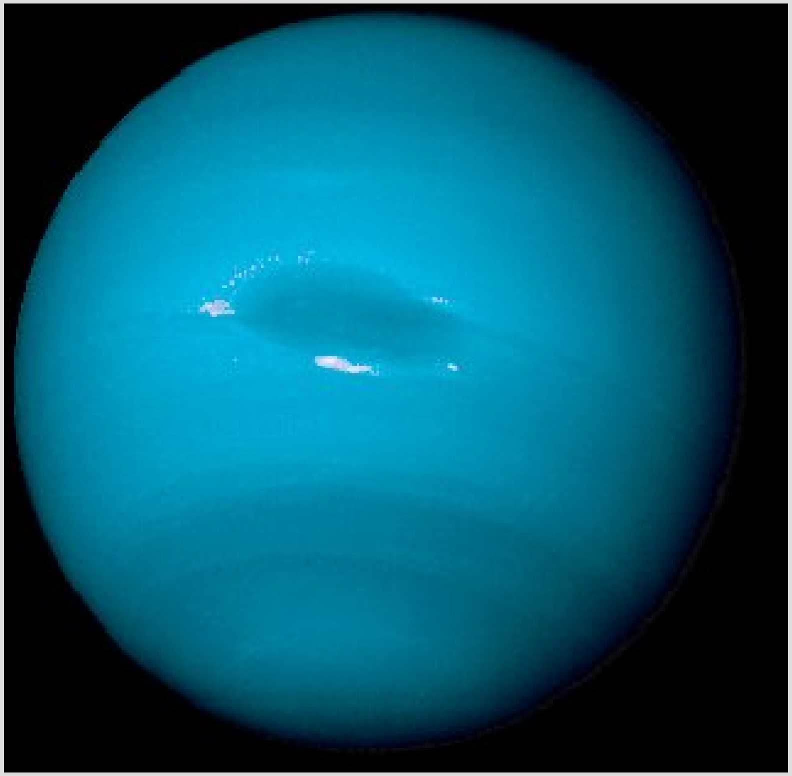
Polar jet is equatorward of the polar front.

Aside: What about other planets?

JUPITER: 10 hour day



NEPTUNE: 16 hour day



Because they have faster rotation rates than Earth, the general circulation of the gas giant planets has a more banded structure than Earth with a series of super strong jet streams. Neptune has winds of 1500 mph, the strongest in the solar system.

Add Seasonality + Land-Sea contrast
The final pieces of the puzzle

What can does this do?

Key idea (again…) is that land is going to heat and cool faster than water. Why??

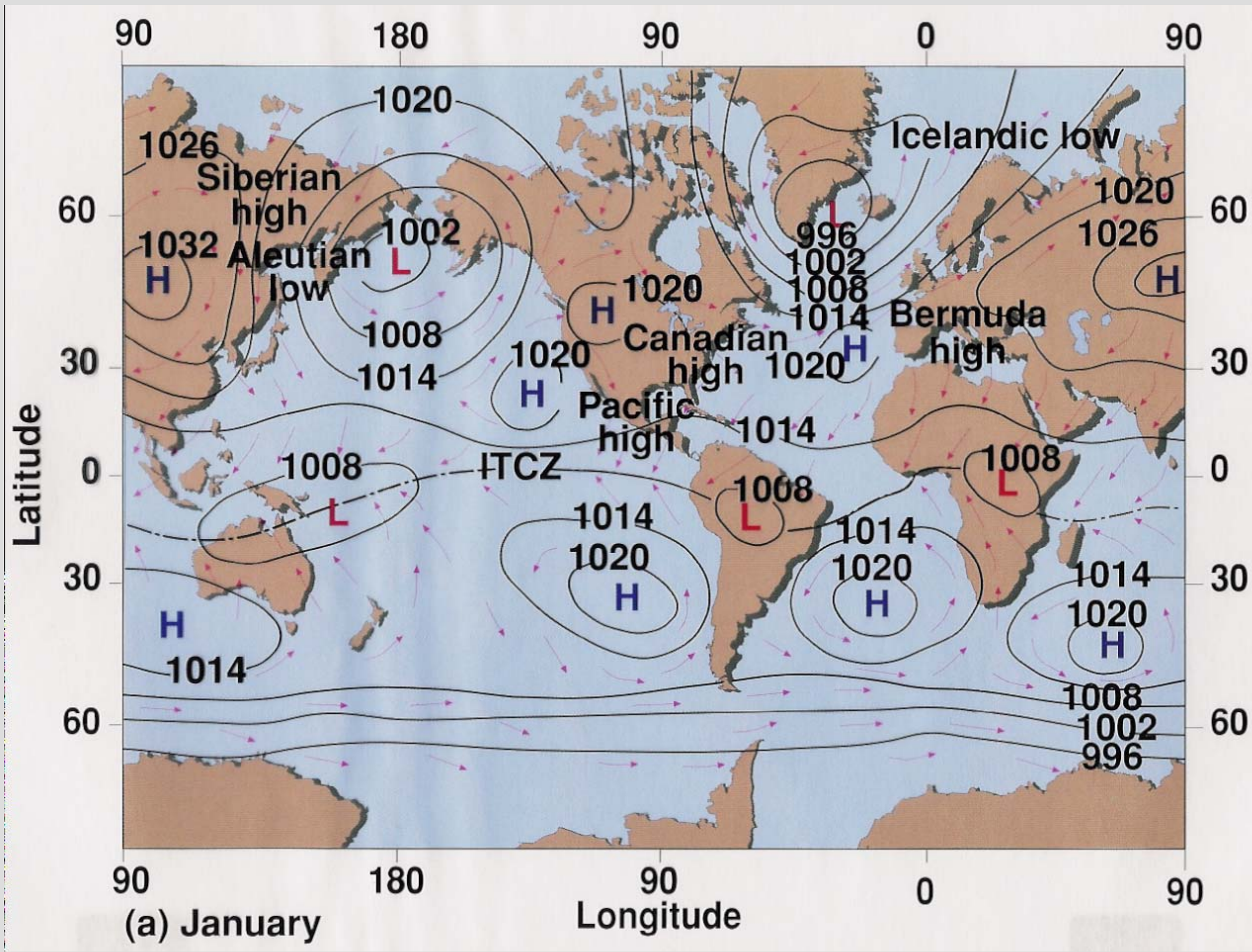
Winter

Cold air over continents, warm air over oceans
High pressure over continents, low pressure over oceans

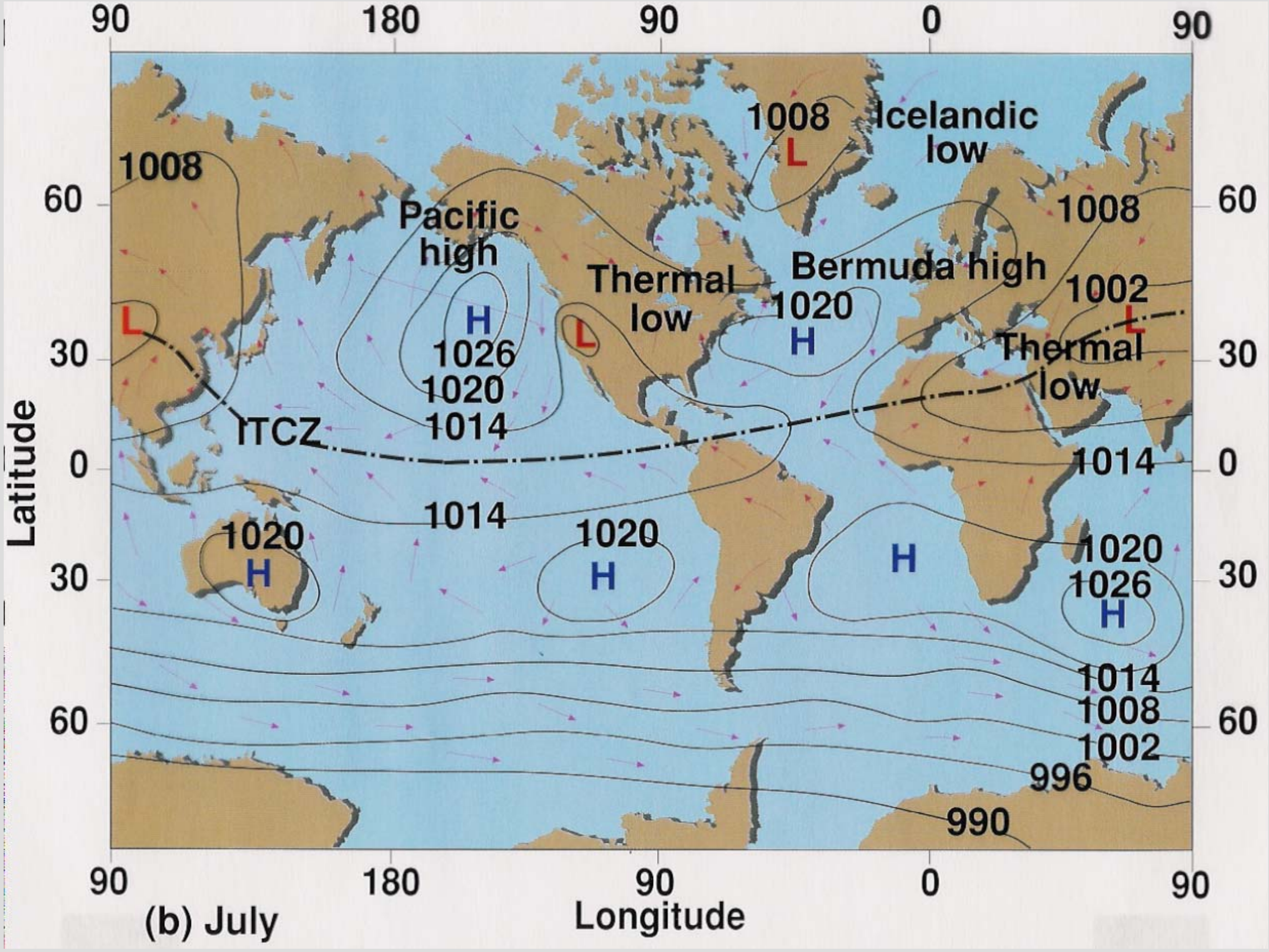
Summer

Warm air over continents, cold air over oceans
Low pressure over continents, high pressure over oceans

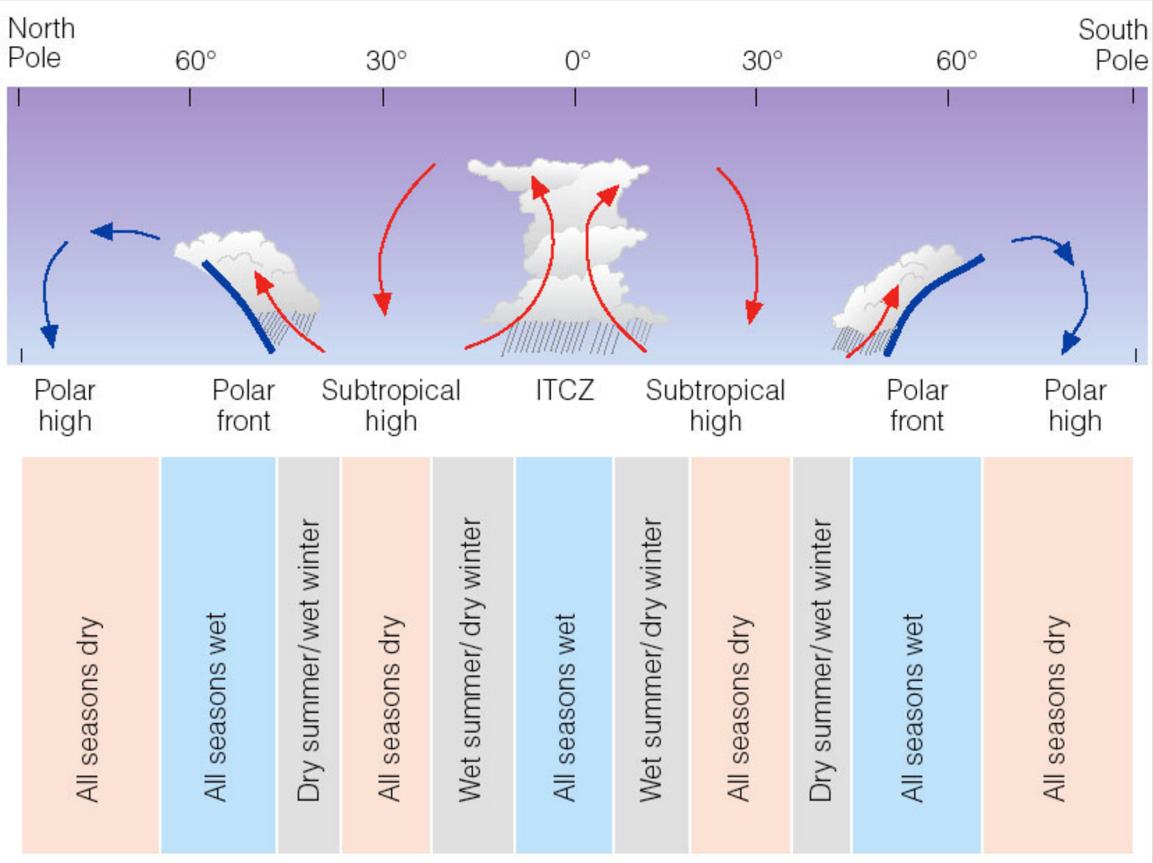
Northern Hemisphere Winter
Average surface pressure (mb)



Northern Hemisphere Summer
Average surface pressure (mb)



The global distribution of rainfall is largely explained by the general circulation



Vicinity of the ITCZ

Near constant rainfall

Tropical Rainforests

Subtropics

Wet-dry climates

Subtropical savannahs

Under subtropical high

Deserts: dry and hot

Mid-latitudes

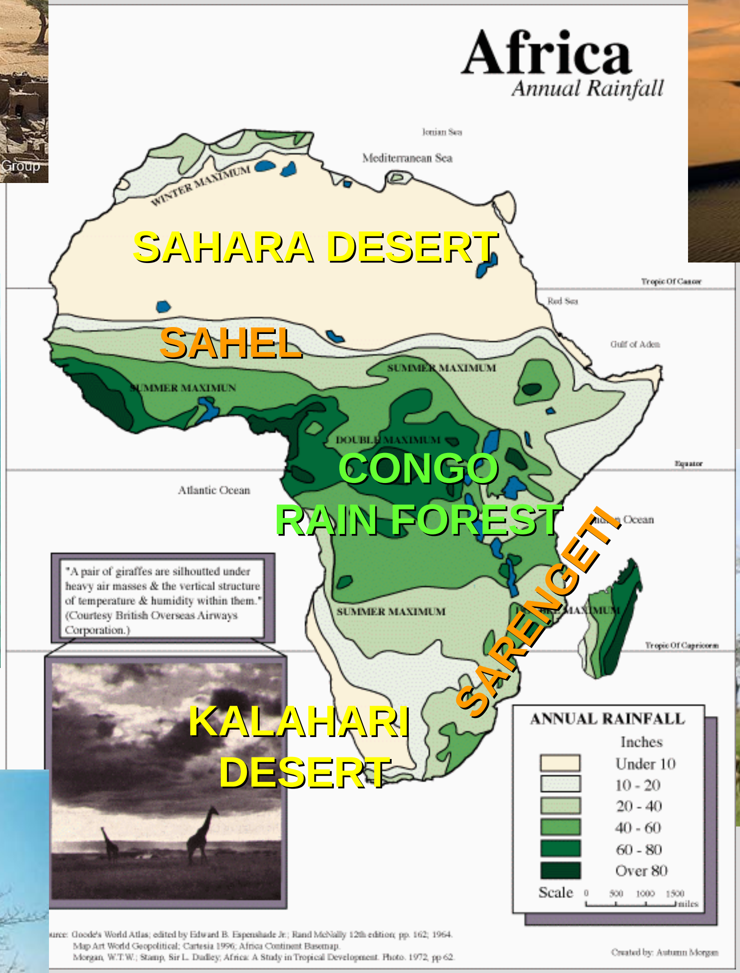
Strong seasonality, but seasons are wet for the most part

Polar

Dry and cold

SAHEL

SAHARA DESERT



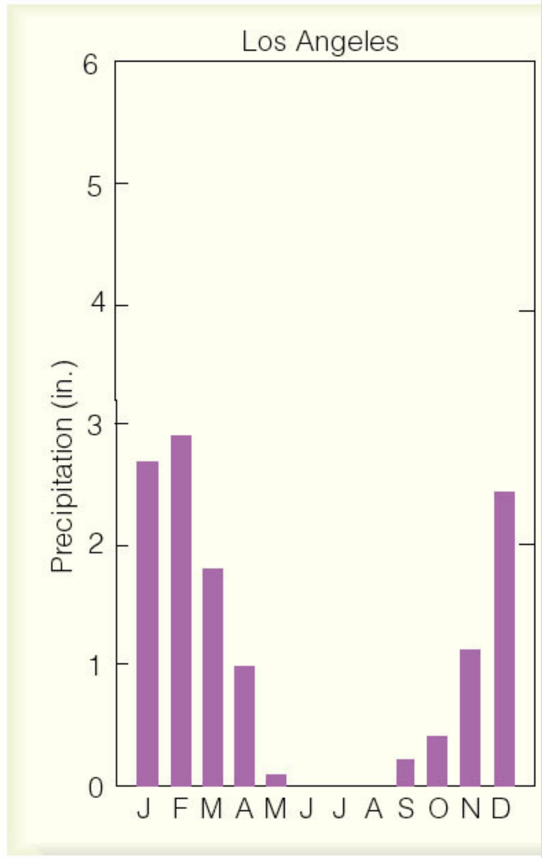
(UNC Charlotte)

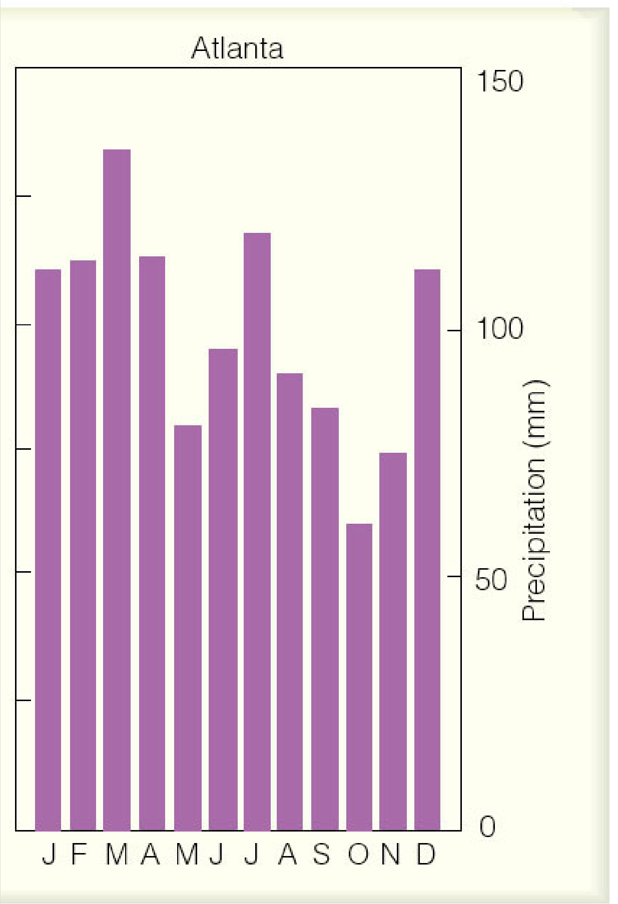
CONGO

SARENGETI

KALAHARI DESERT

Mid-latitudes:
West vs. East Coast Rainfall





Mid-latitudes
Continental Position vs. Rainfall

Summer Surface pressure (mb)

California

Mediterranean climate
Dry side of subtropical high
Little summer rainfall

Southeast

Moist Subtropical climate
Humid side of subtropical high
Abundant summer rainfall

Summary of Lecture 19

The purpose of the general circulation is to transfer heat from equator toward the pole. Without the complications of seasons, rotation, and land-sea contrast, the general circulation would just be a giant Hadley cell covering the whole Earth.

With rotation, the mechanisms of energy transport vary with latitude:

- Tropics: Hadley cell with ITCZ and subtropical highs
- Mid-latitudes: Mid-lat. Cyclones which form along polar front.

Two jet streams occur in the general circulation

- Subtropical jet: Conservation of angular momentum
- Polar jet: Temperature contrast (e.g. dishpan)

Seasonality and land-sea contrast cause reversals in the surface pressure patterns from winter to summer—because of the high specific heat capacity of water.

Global distribution of rainfall is largely explained by the general circulation. Africa is a good example.

Reading Assignment and Review Questions

Reading: Chapter 10, pp. 271-281 (8th ed.)
pp. 273-283 (9th ed.)

Chapter 10 Questions

Questions for Review: 1,2,3,4,6,7,8

Questions for Thought: 3,9