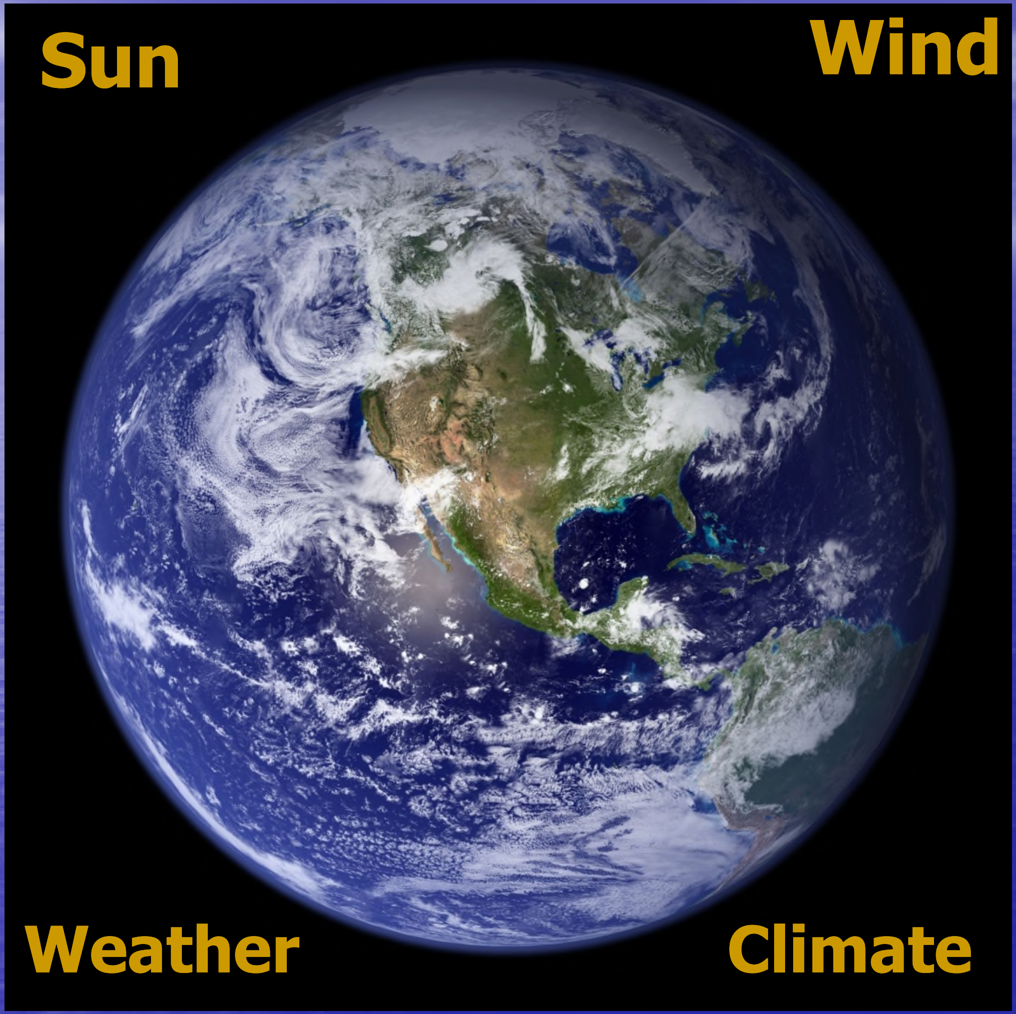
Meteorology Lab



EOSC 105 Lab

University of San Diego
Ray Rector: Instructor

Atmospheric Circulation

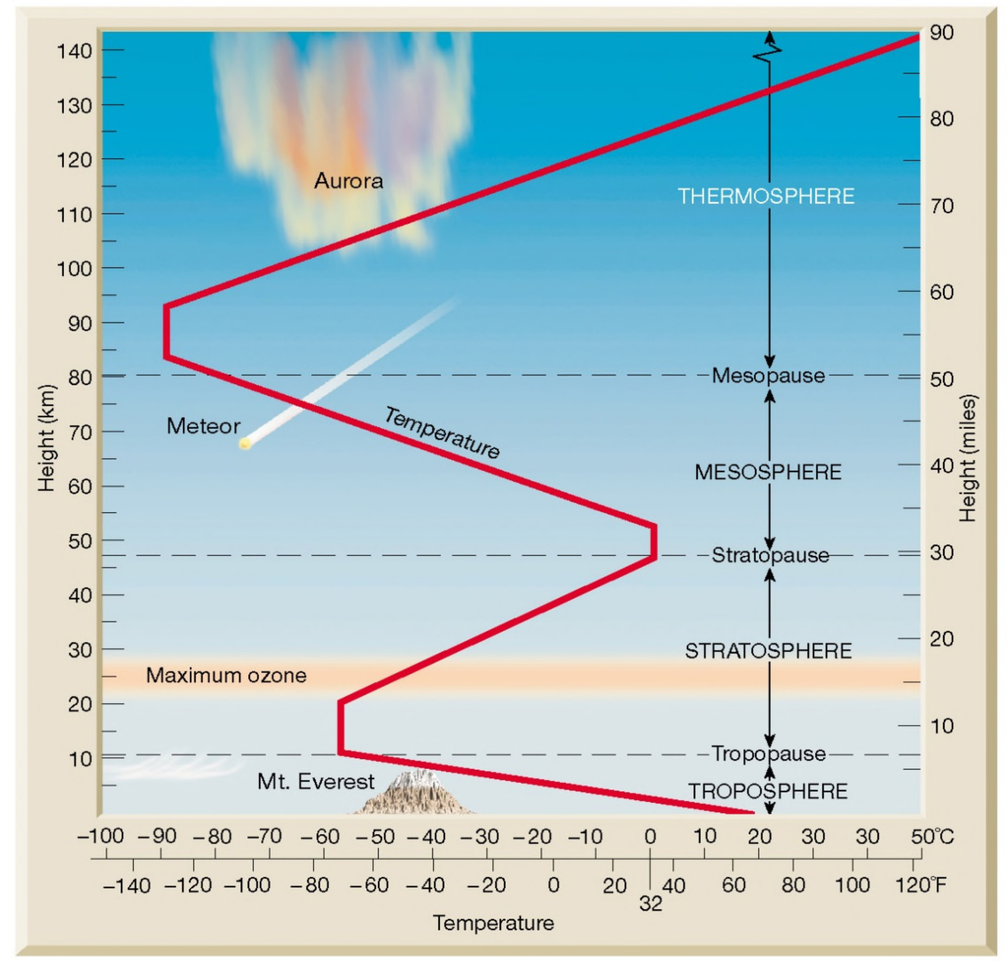
Key Topics

- Atmosphere Composition and Structure
- Thermal Behavior of Moisture
- Solar Heating and Convection
- The Coriolis Effect
- Wind Patterns
- Weather Fronts
- Weather Maps

Vertical Structure of Atmosphere

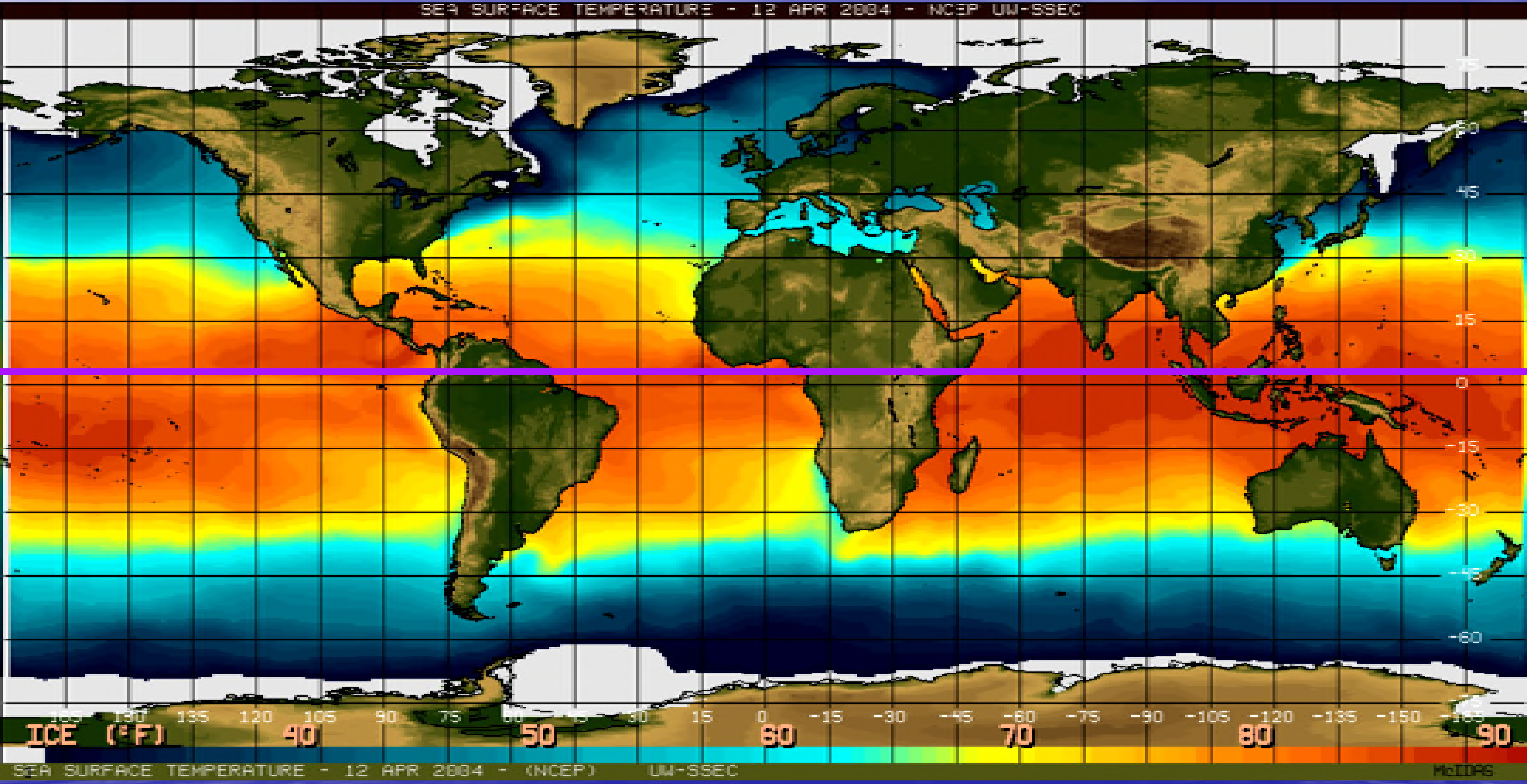
Key Ideas

- Atmosphere is stratified in both temperature and density
- Troposphere holds 90% of atmosphere
- Weather occurs in the troposphere
- Jet stream at top of troposphere
- Temperature decreases from bottom to top of troposphere
- Troposphere heated from the bottom up
- Protective ozone found in overlying stratosphere

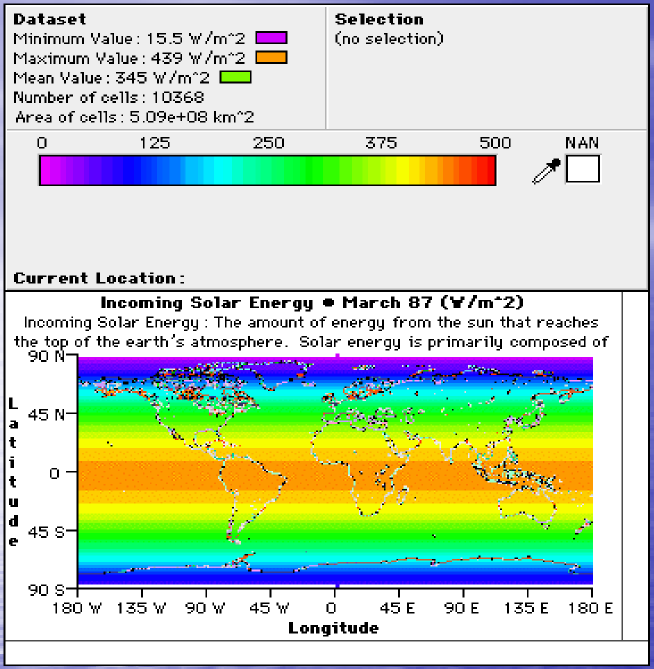


Solar Radiation is Unevenly Distributed

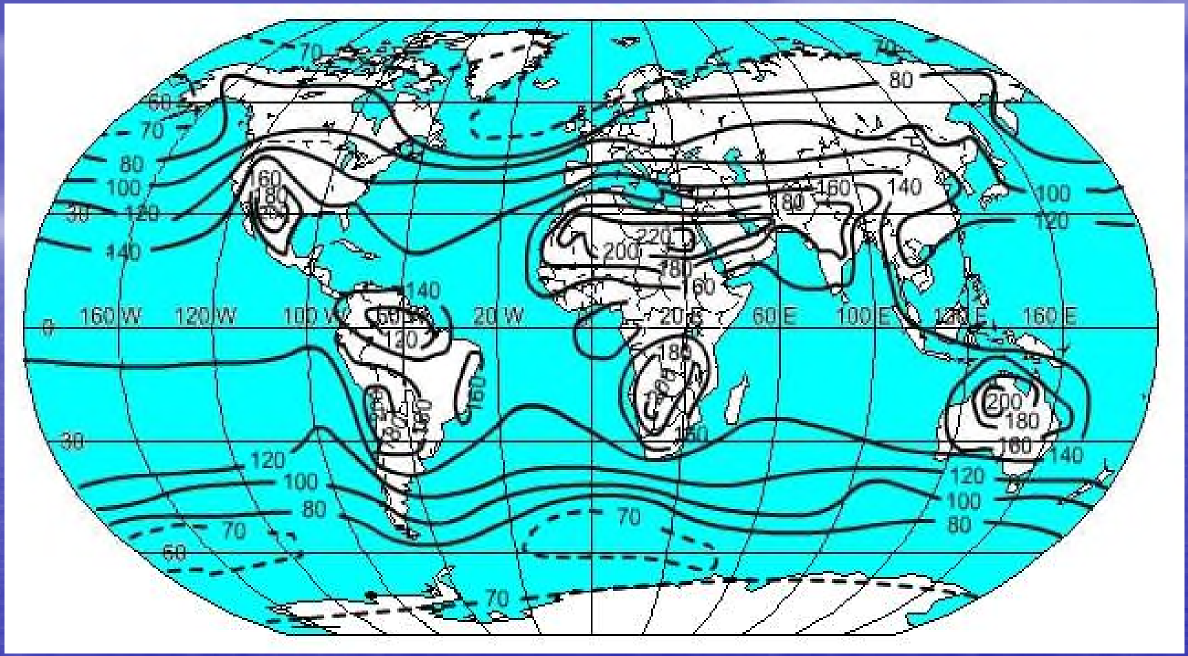
Why is it hot at the equator and cold at the poles?



Annual Solar Energy Striking Earth



Incoming Solar Radiation at Top of Earth's Atmosphere

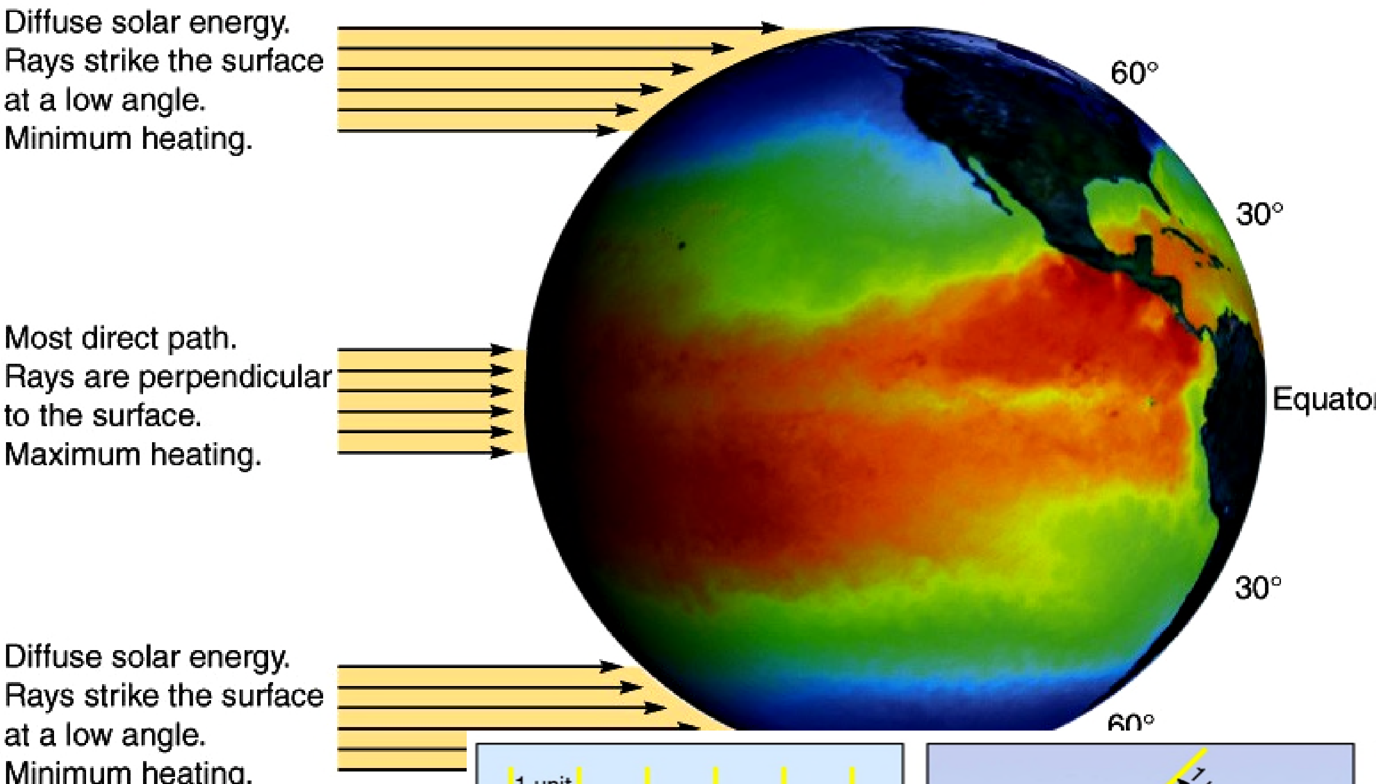


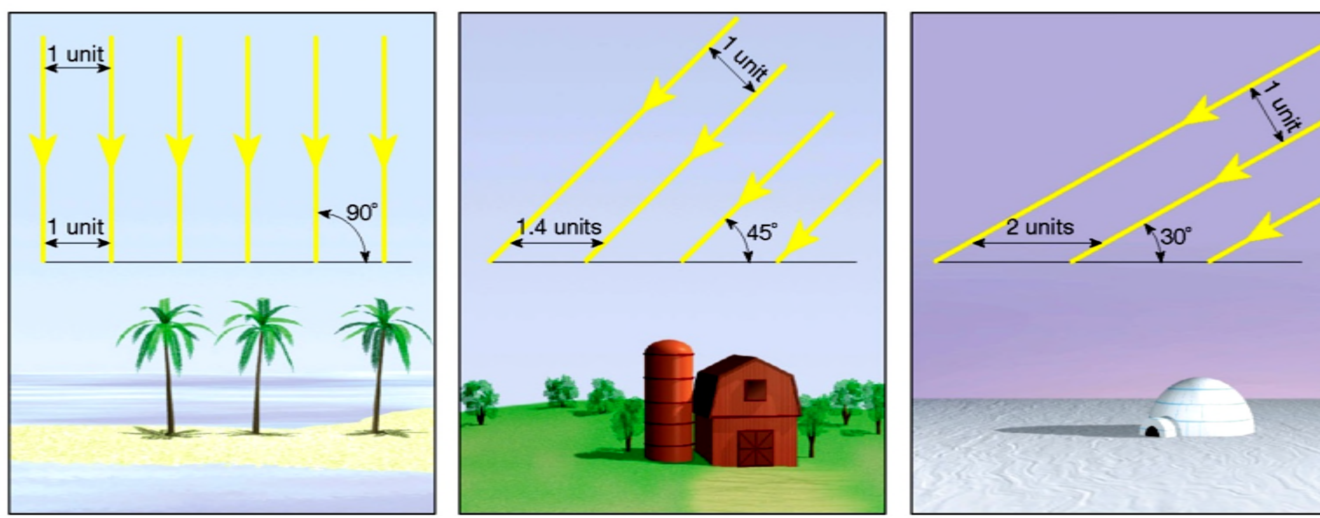
Annual Solar Radiation at Earth's Surface (kcal/cm2/year)

Key Idea:

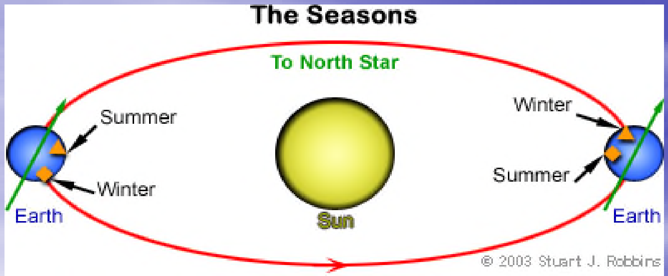
- Global variation in the amount of solar energy striking Earth's surface is controlled by the *latitude*, *season*, *atmospheric conditions*, and *altitude*.

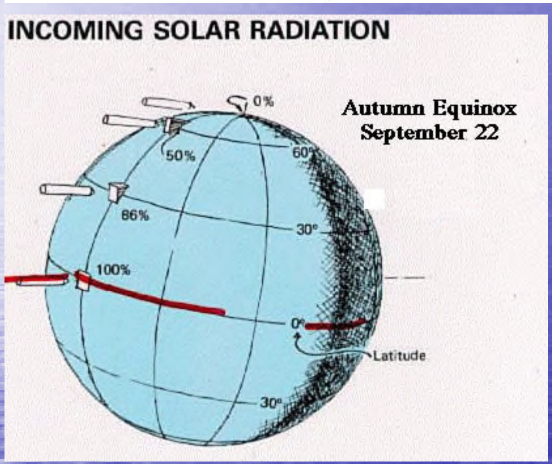
Earth is sphere

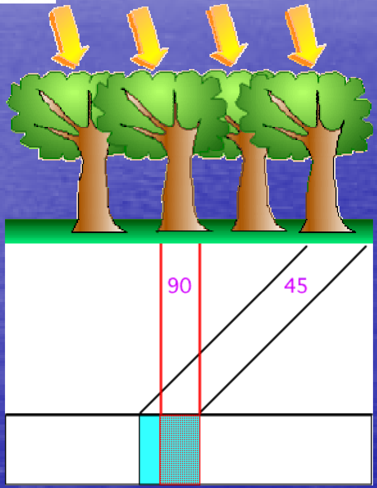


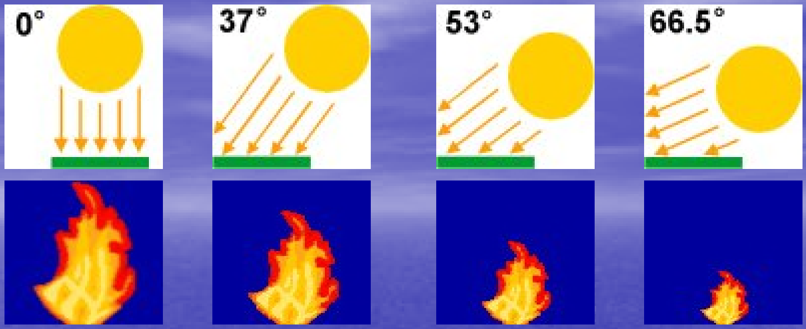


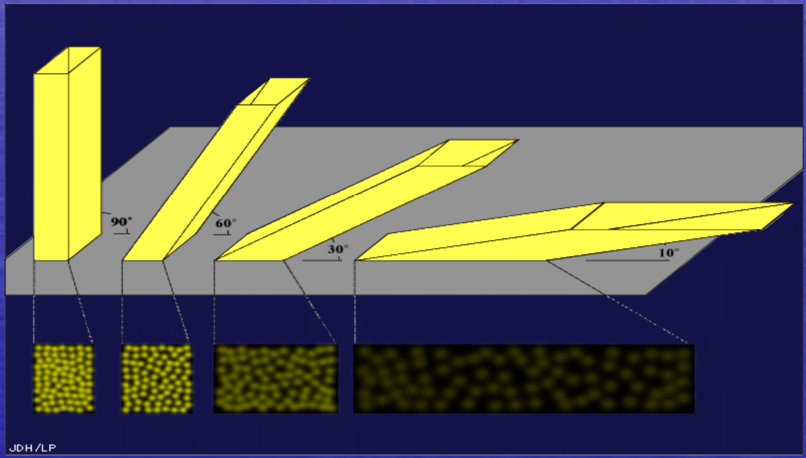
Differential Heating of Earth's Surface





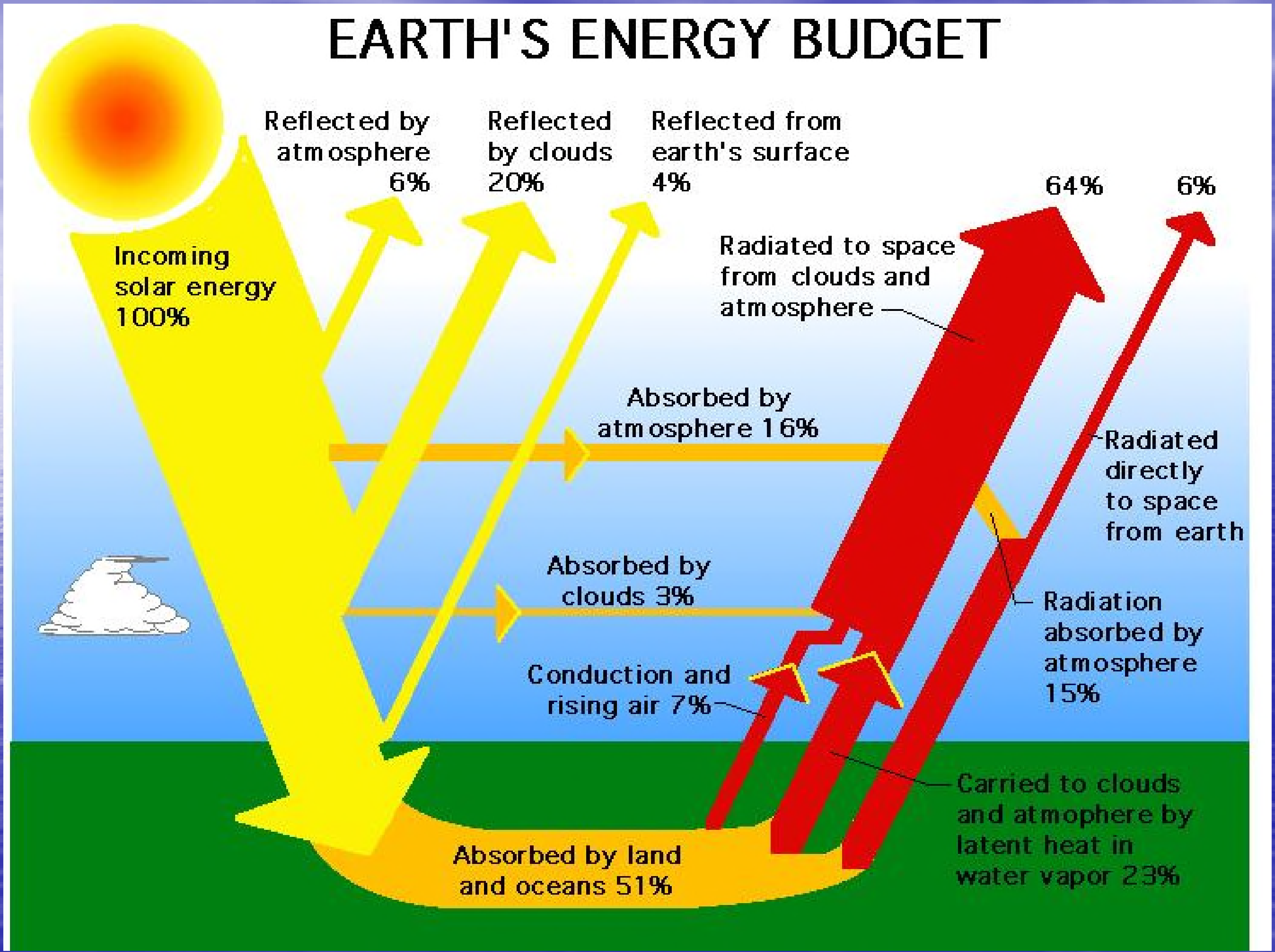




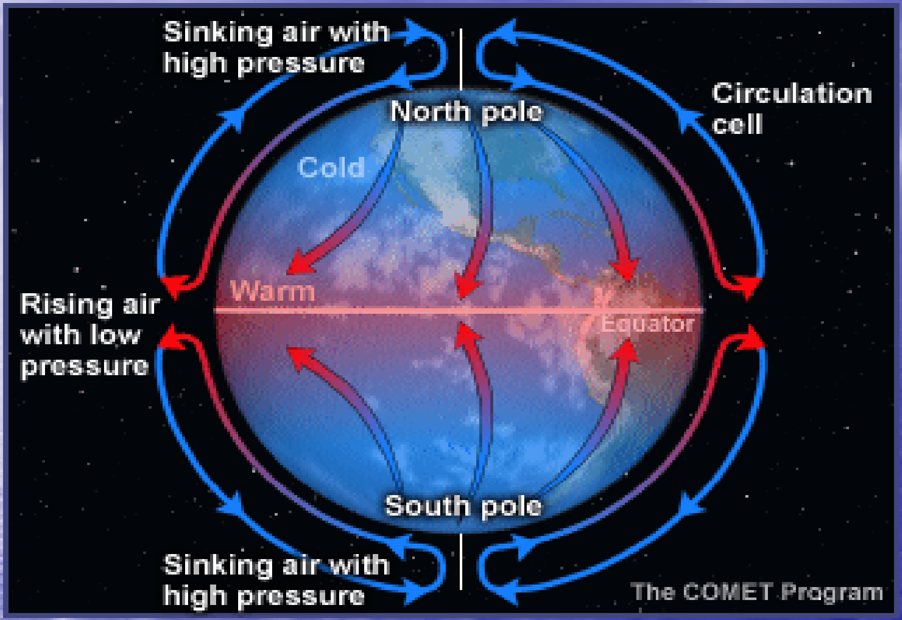


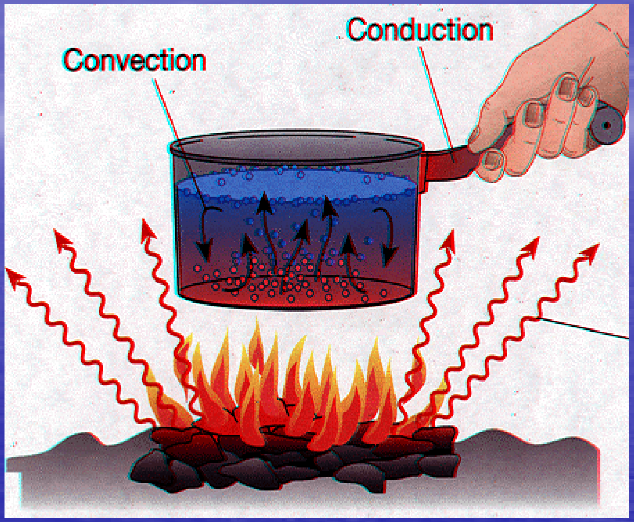
Key Idea

- **Insolation** is incoming solar radiation. The amount of insolation received at the surface of the earth is primarily controlled by the **sun angle.** Sun angle is a function of latitude and season.


EARTH'S ENERGY BUDGET
Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%
64%
6%
Incoming solar energy 100%
Radiated to space from clouds and atmosphere
Absorbed by atmosphere 16%
Radiated directly to space from earth
Absorbed by clouds 3%
Radiation absorbed by atmosphere 15%
Conduction and rising air 7%
Carried to clouds and atmophere by latent heat in water vapor 23%
Absorbed by land and oceans 51%

Uneven Solar Heating of Earth's Surface Causes Global-Scale Atmospheric Convection



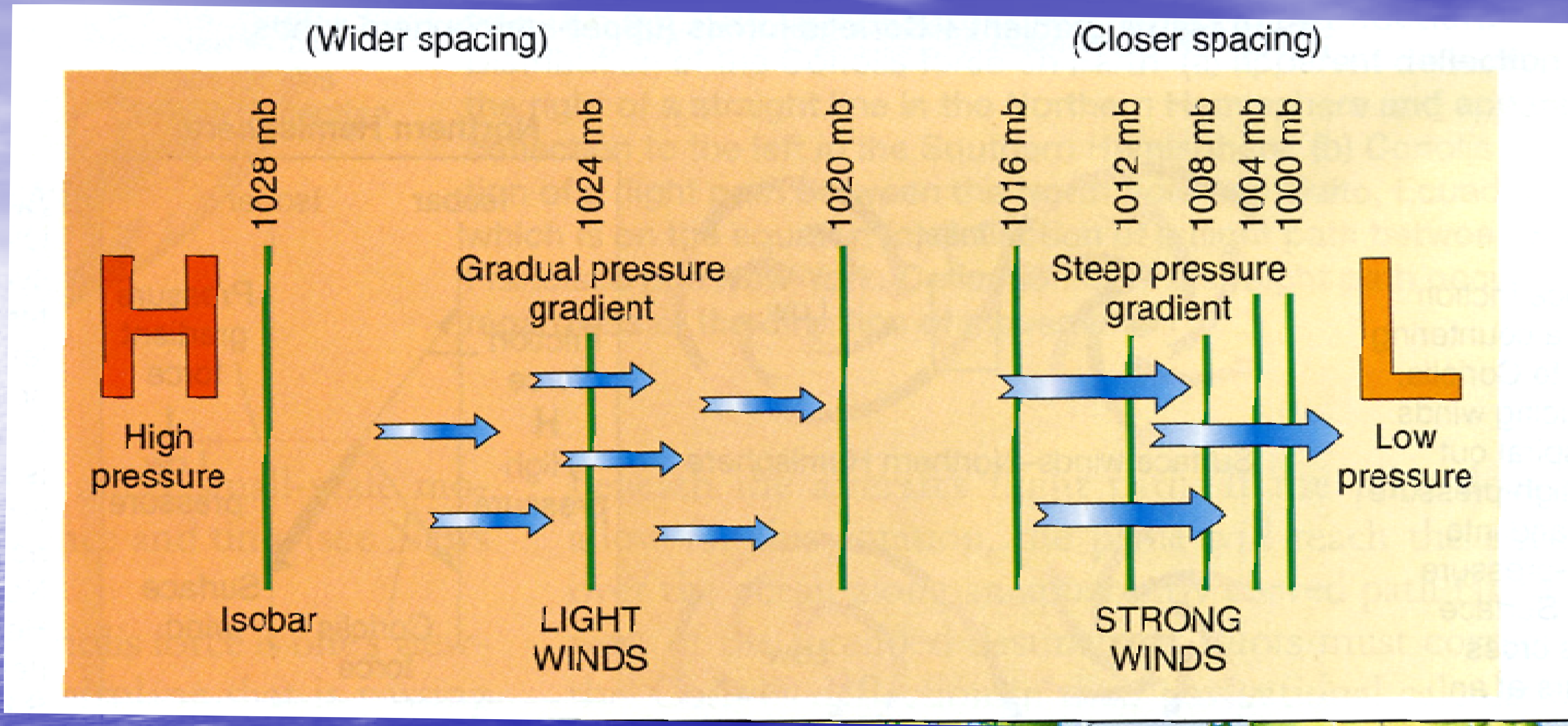


Human-Scale Convection Process

Global-Scale Convection Process

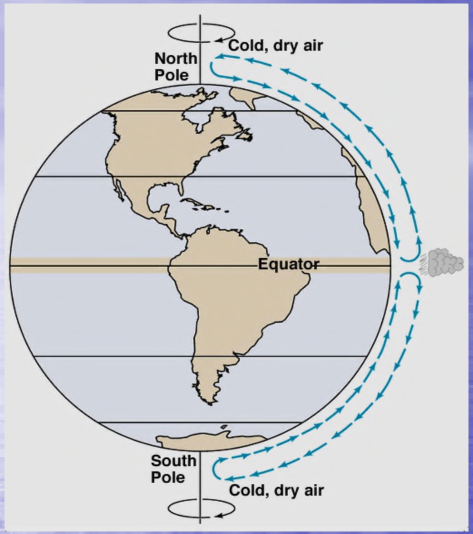
- ✓ Heat difference causes pressure differences in the overlying atmosphere
- ✓ Overheating of equatorial regions forms belt of low pressure
- ✓ Under-heating of polar regions creates centers of high pressure
- ✓ Pressure differences in lower atmosphere cause air masses to moves
- ✓ Air masses move from regions of high pressure to regions of low pressure

Pressure Gradients Causes Wind to Blow



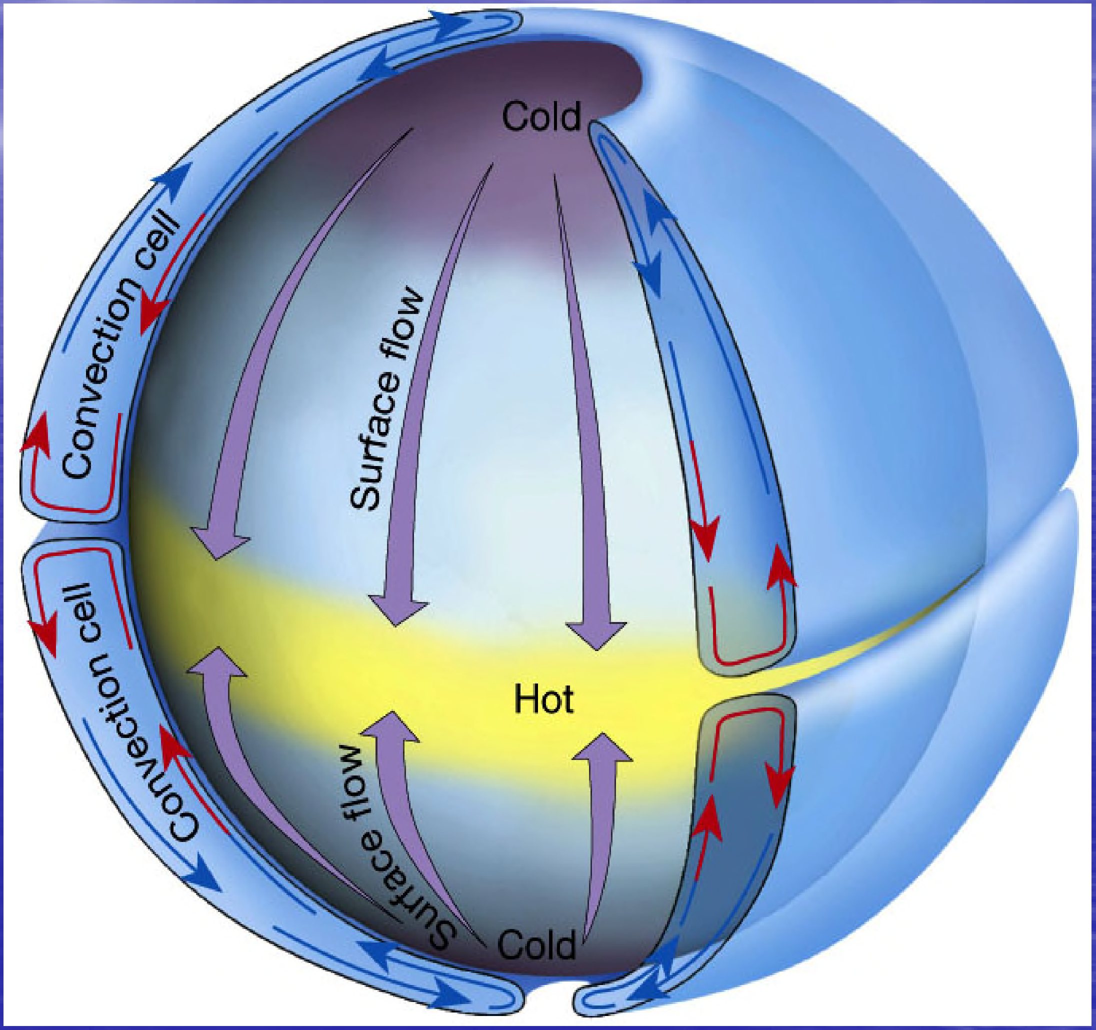
1) Air masses move from regions of high pressure to regions of low pressure
2) Severity of pressure gradient between adjacent regions of high and lows controls how strong of wind will blow between the high and low

Atmospheric Circulation Model of a *Non-Spinning* Earth



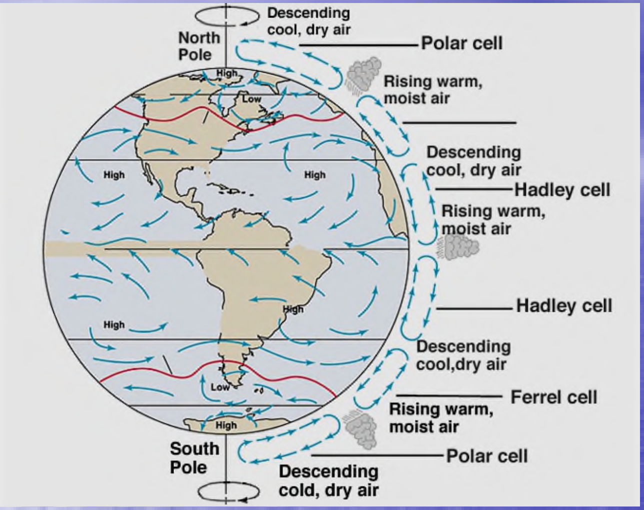
Key Ideas

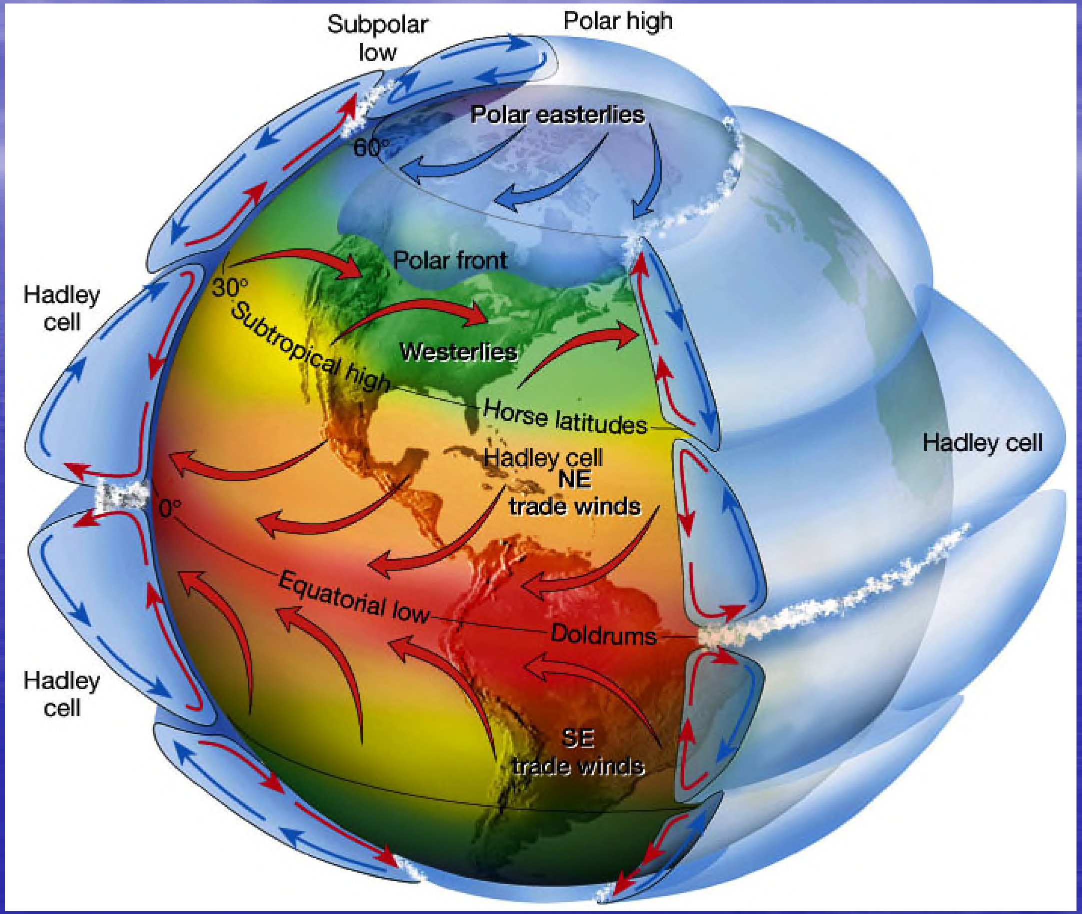
- ✓ One cell per hemisphere
- ✓ Overheated equatorial air rises and moves horizontally aloft toward the poles
- ✓ Overcooled polar air sinks and moves horizontally at surface towards equator



Single-Cell Hemispheric Convection Model

Atmospheric Circulation Model of a *Spinning* Earth





Key Ideas

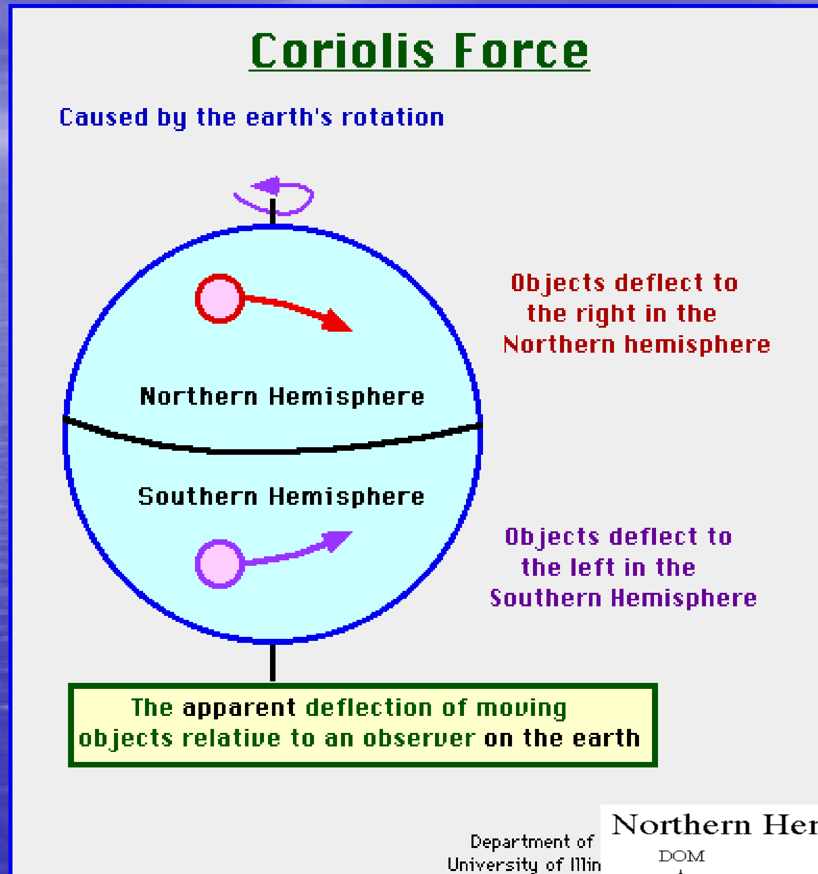
- ✓ Three cells per hemisphere
  - **Hadley, Ferrel, and Polar**
- ✓ Similar convection process
- ✓ Smaller convective cells
- ✓ Two surface convergence zones
- ✓ Two surface divergence zones

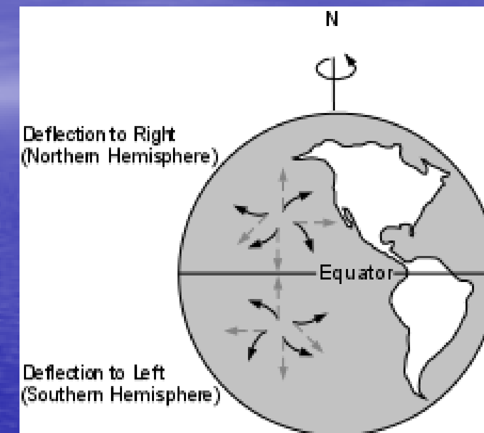
Triple-Cell Hemispheric Convection Model

- ✓ Spinning causes the Coriolis effect
- ✓ Coriolis effect deflects air currents

The Coriolis Effect

Deflection of Flying Projectiles

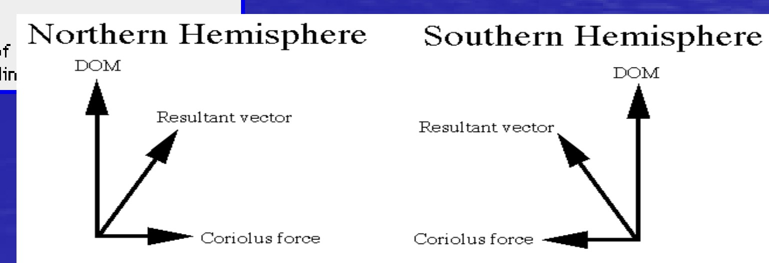




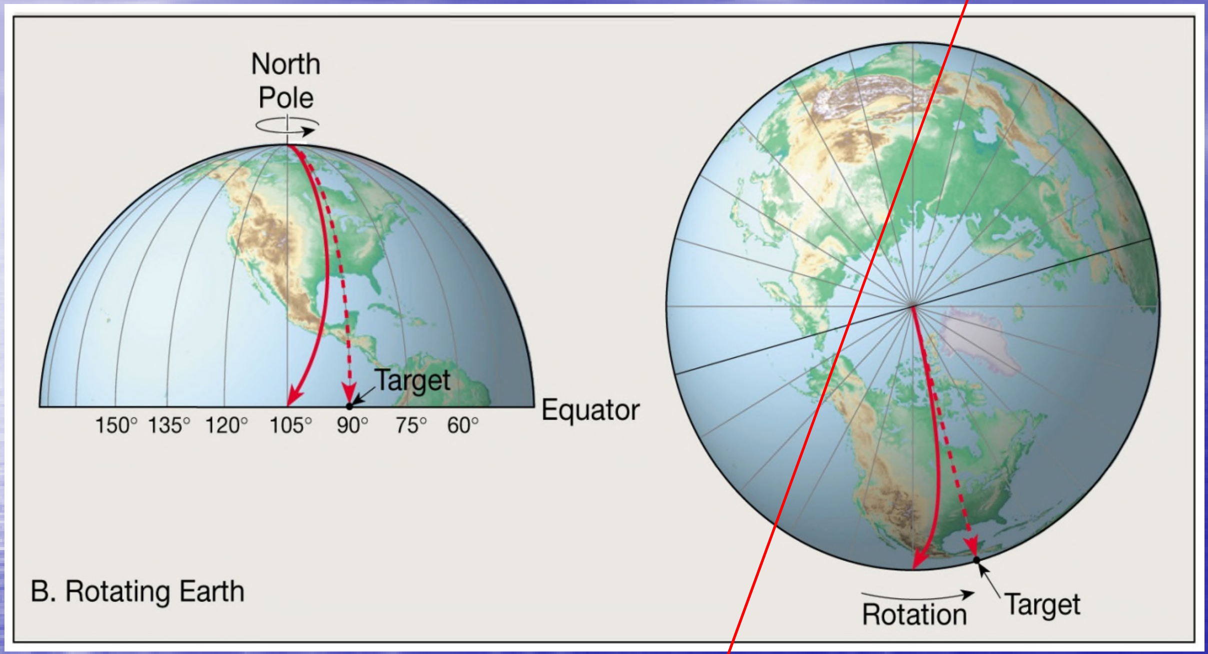
Deflection of Moving Air Masses

Key Ideas

- ✓ Objects deflect to the right in N. Hemi
- ✓ Objects deflect to the left in S. Hemi
- ✓ Moving air masses have curved paths

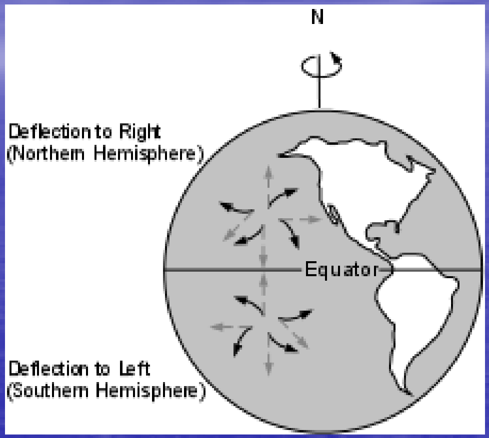


The Coriolis Effect

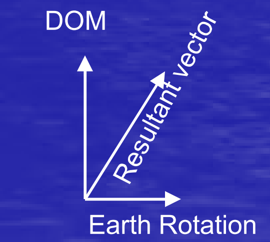


Deflection of Flying Projectiles

L I S = left in Southern Hemisphere



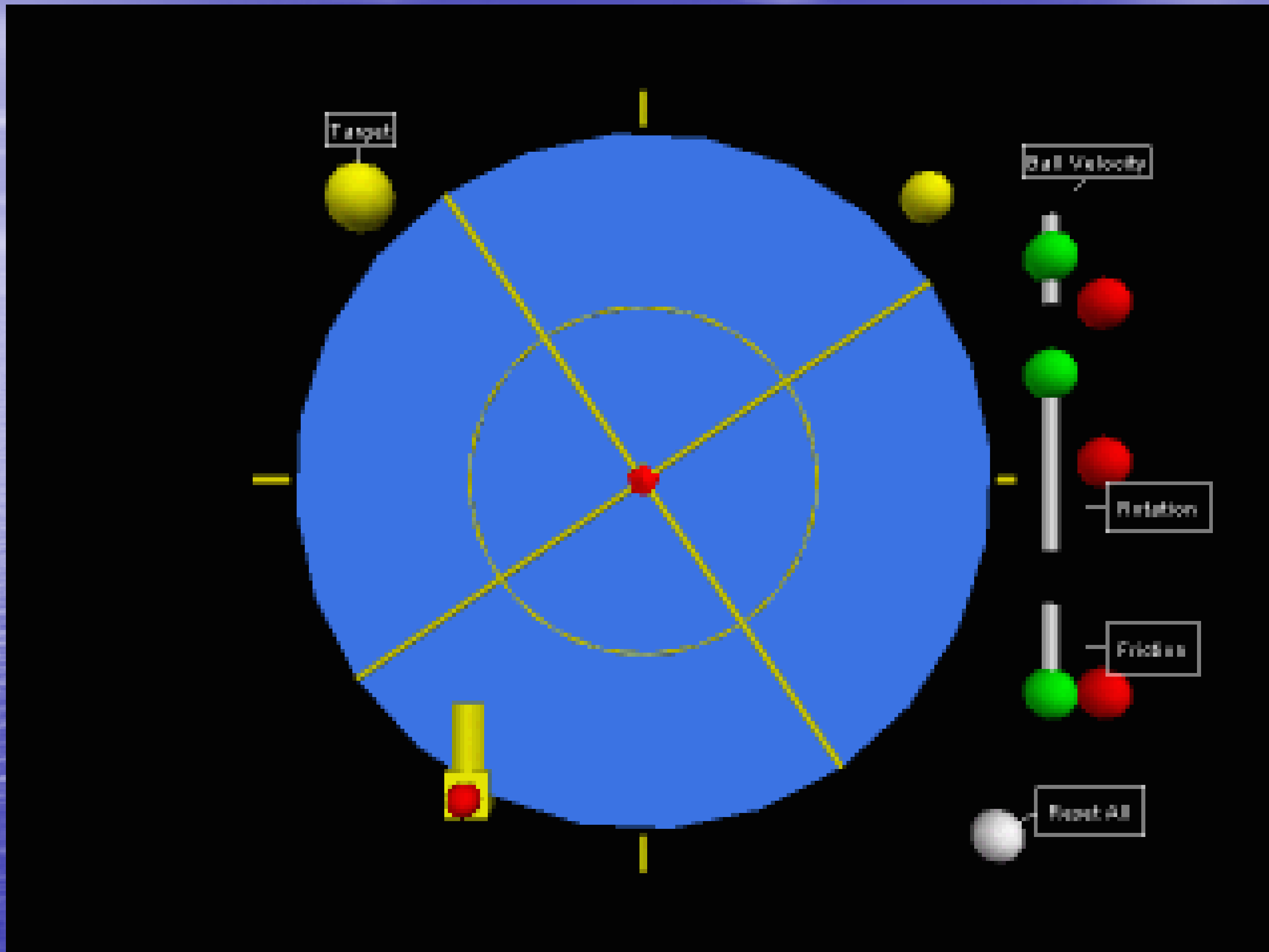
Deflection of Moving Air Masses



Key Ideas

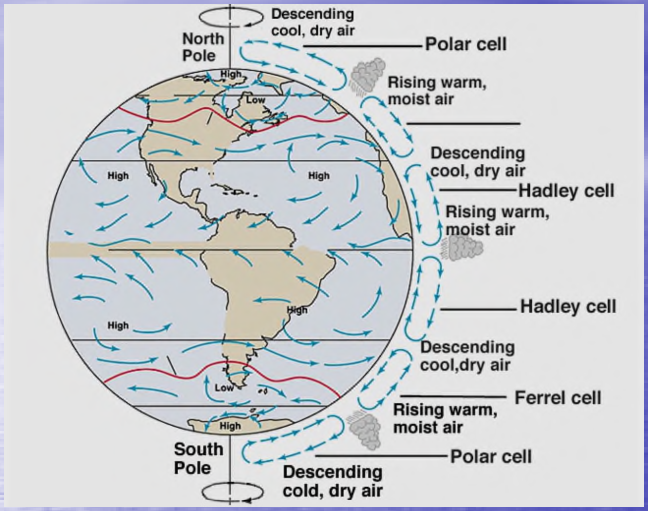
- ✓ Objects deflect to the right in N. Hemi
- ✓ Objects deflect to the left in S. Hemi
- ✓ Moving air masses have curved paths

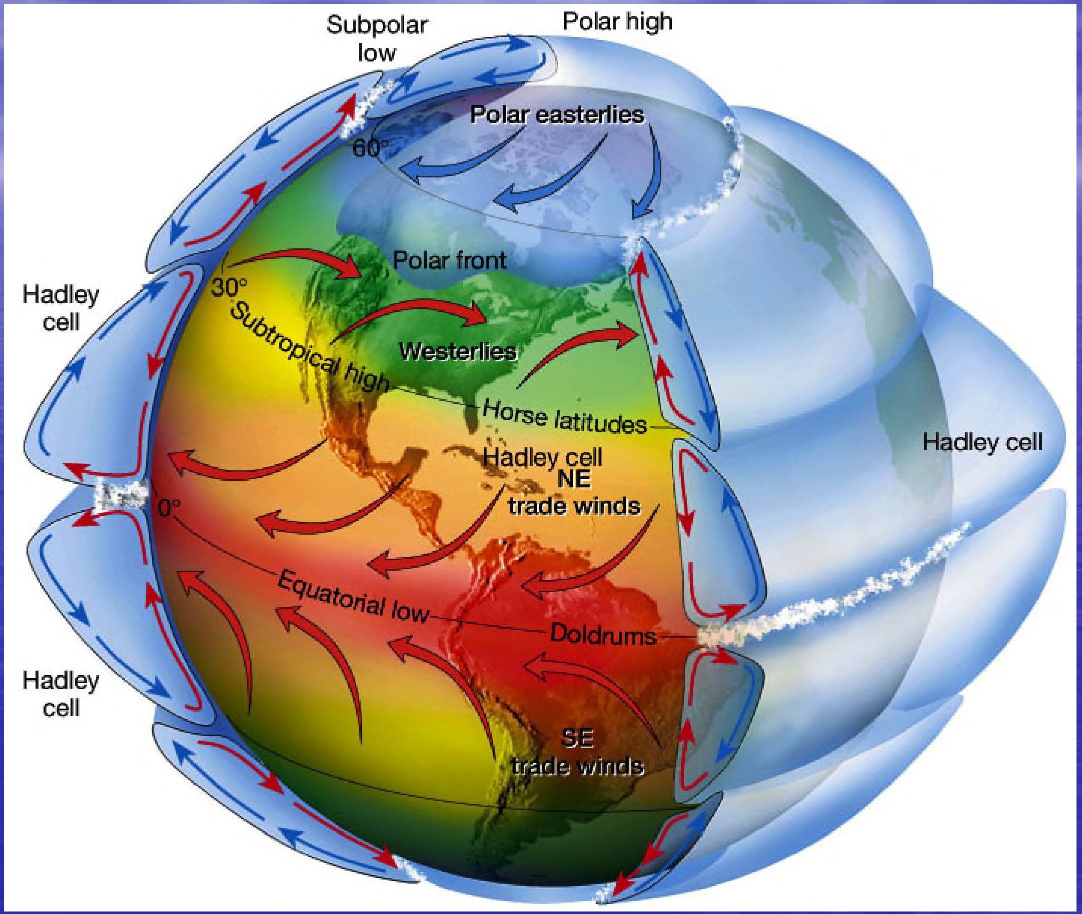
C o r i o l i s



http://lurbano-5.memphis.edu/GeoMod/images/2/2c/Coriolis.gif

Atmospheric Circulation Model of a *Spinning* Earth



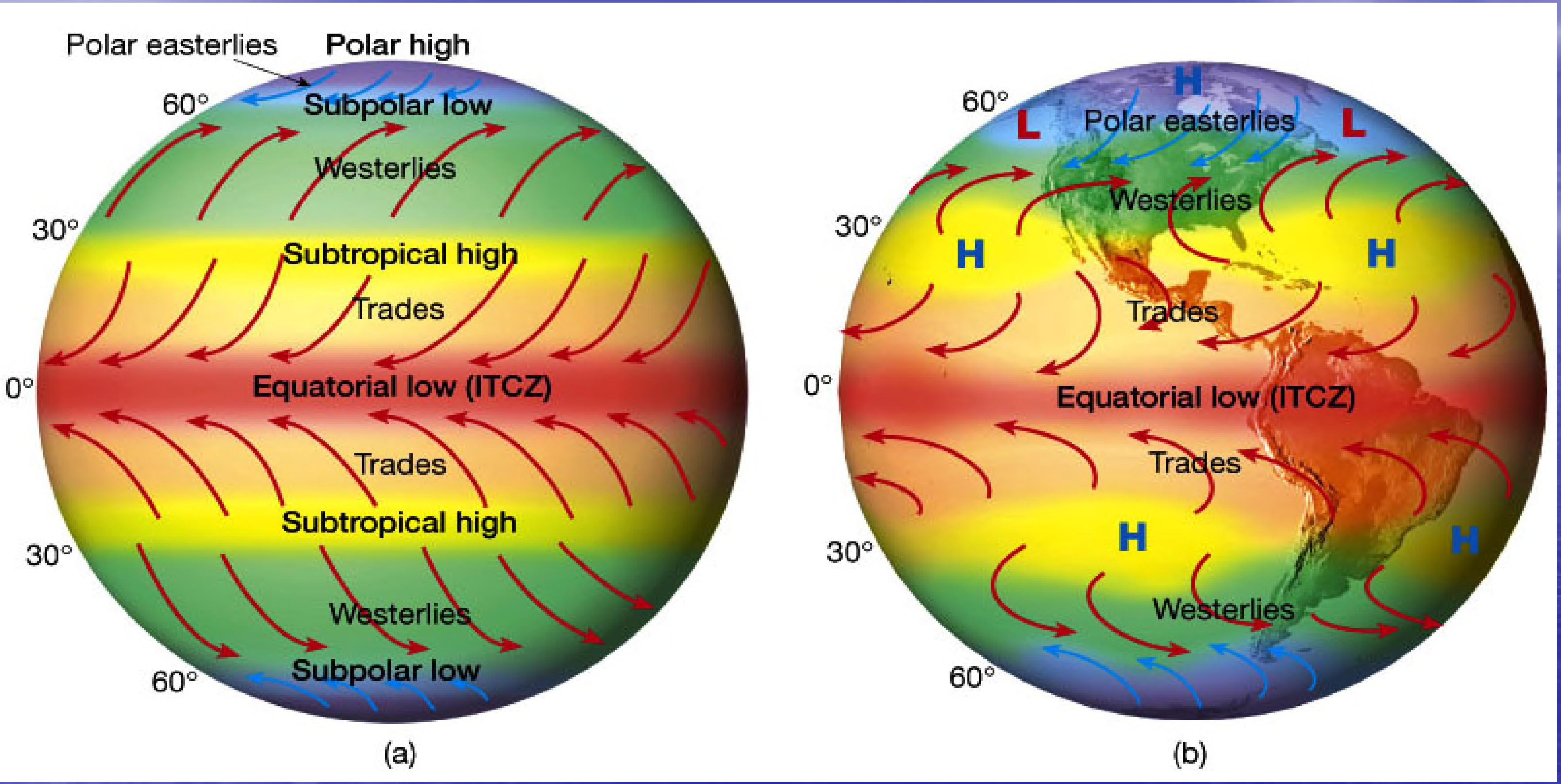


Triple-Cell Hemispheric Convection Model

Key Ideas

- ✓ Three cells per hemisphere
  - ➢ **Hadley, Ferrel, and Polar**
- ✓ Similar convection process
- ✓ Smaller convective cells
- ✓ Two surface convergence zones
- ✓ Two surface divergence zones

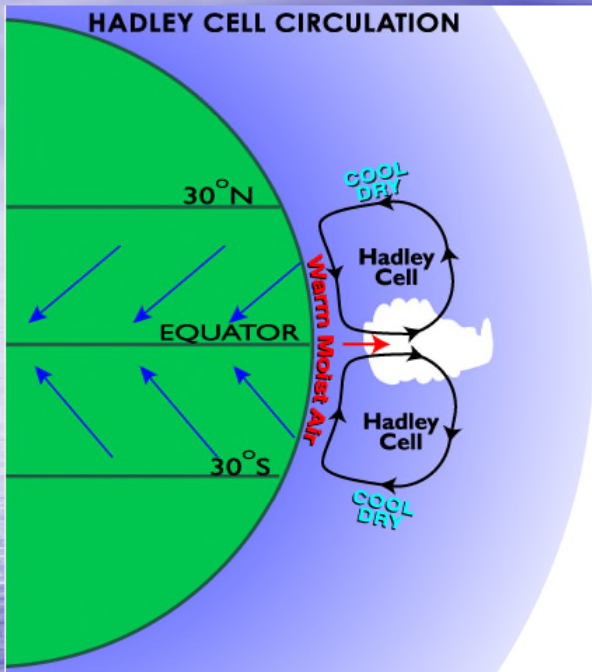
Earth's Surface Wind Belts



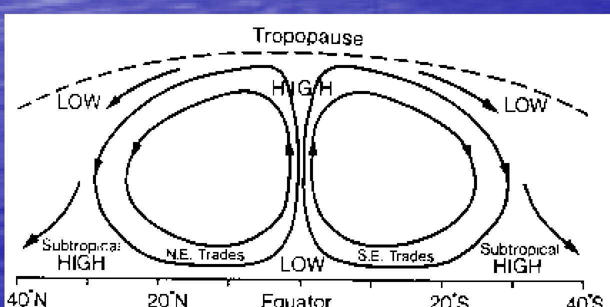
***Landless* Circulation Model** ***Landmass* Circulation Model**

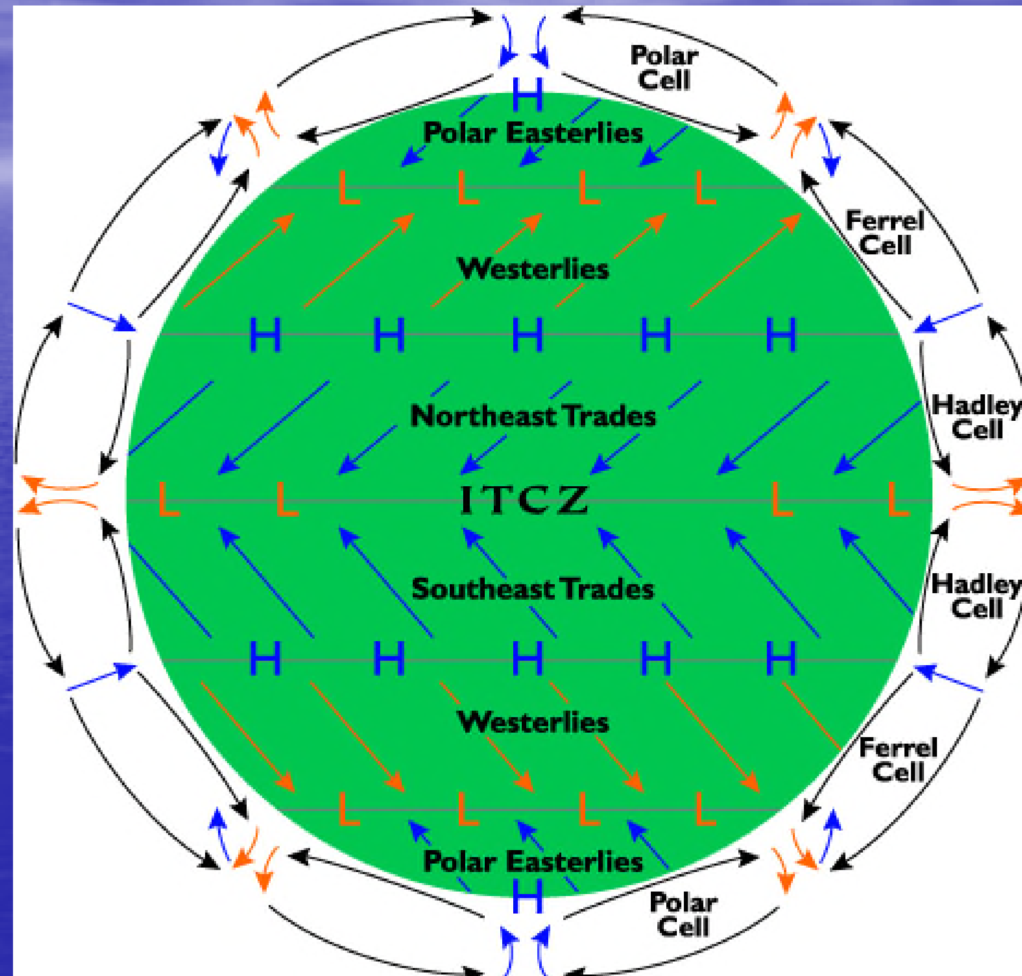
1) Polar Easterlies
2) Mid-latitude Westerlies
3) Tropical Easterlies = Trades

Convergence and Divergence Zones



Equatorial Convergence





Divergence = Blue Arrows
Convergence = Orange Arrows

Weather at Divergence and Convergence Zones

Polar Divergence

- ✓ **H**igh evaporation
- ✓ **V**ariable winds
- ✓ **C**old, **h**arsh, **d**ry weather

Subpolar Convergence

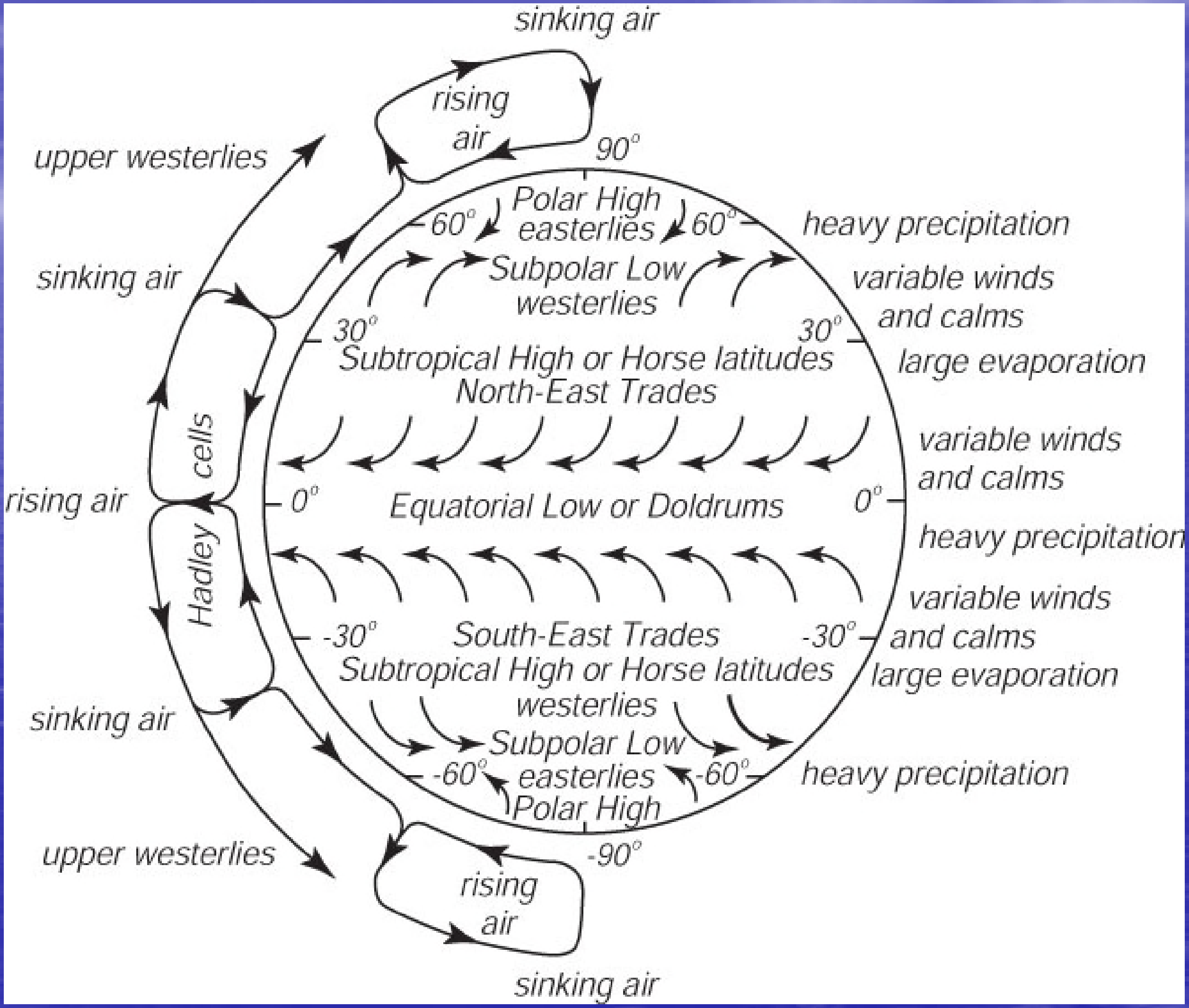
- ✓ **H**eavy precipitation
- ✓ **W**inter storm fronts
- ✓ **S**tormy, **w**et, **c**ool weather

Subtropical Divergence

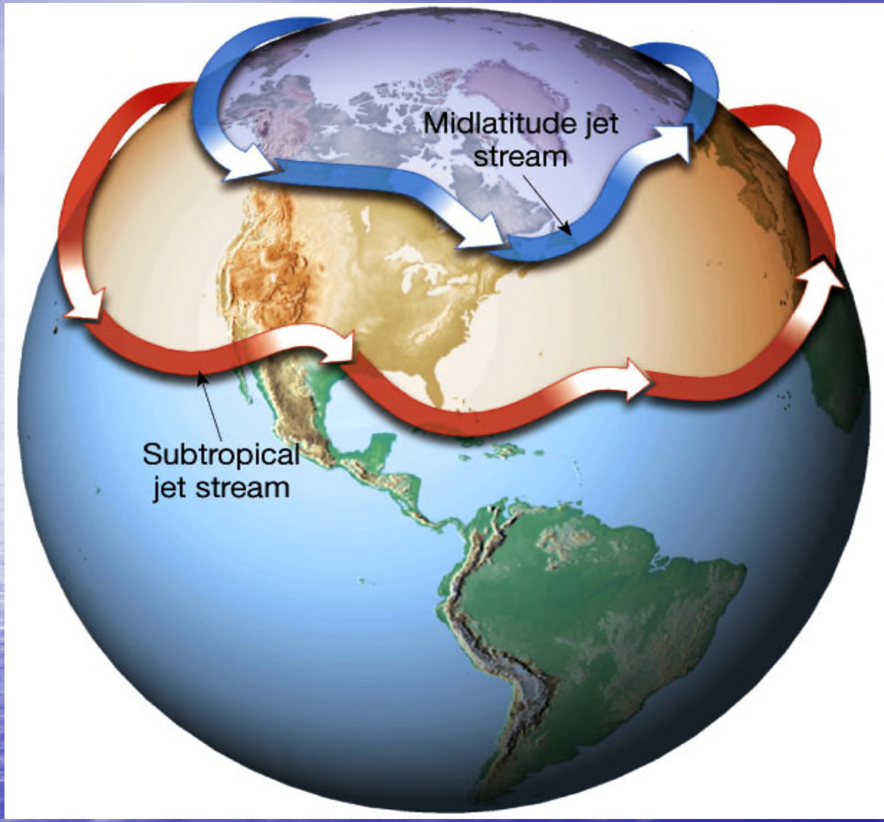
- ✓ **H**igh evaporation
- ✓ **V**ariable winds and **C**alms
- ✓ **W**arm, **m**ild, **d**ry weather

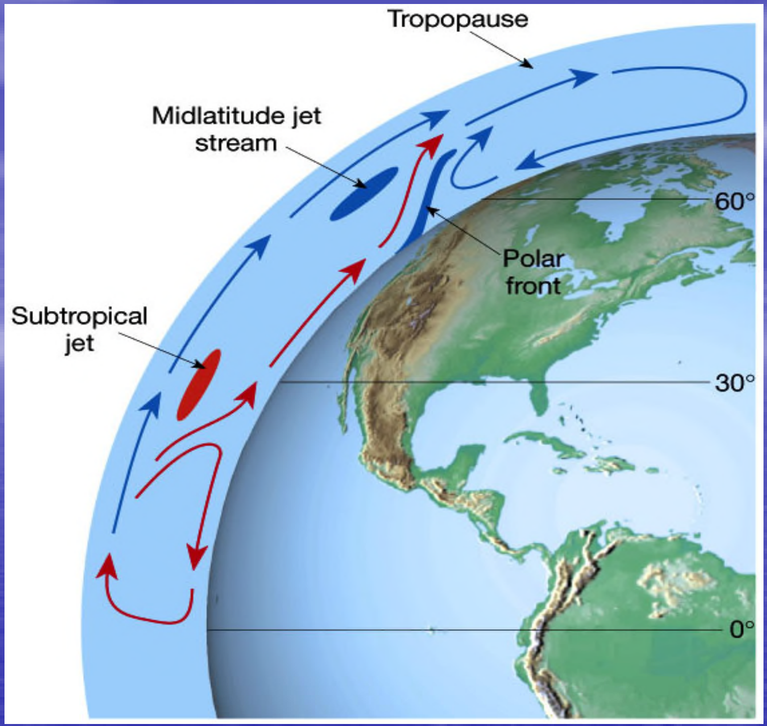
Tropical Convergence

- ✓ **H**eavy precipitation
- ✓ **L**ight winds and **C**alms
- ✓ **T**ropical cyclone nursery
- ✓ **S**tormy, **w**et, **h**ot weather



The Jet Stream



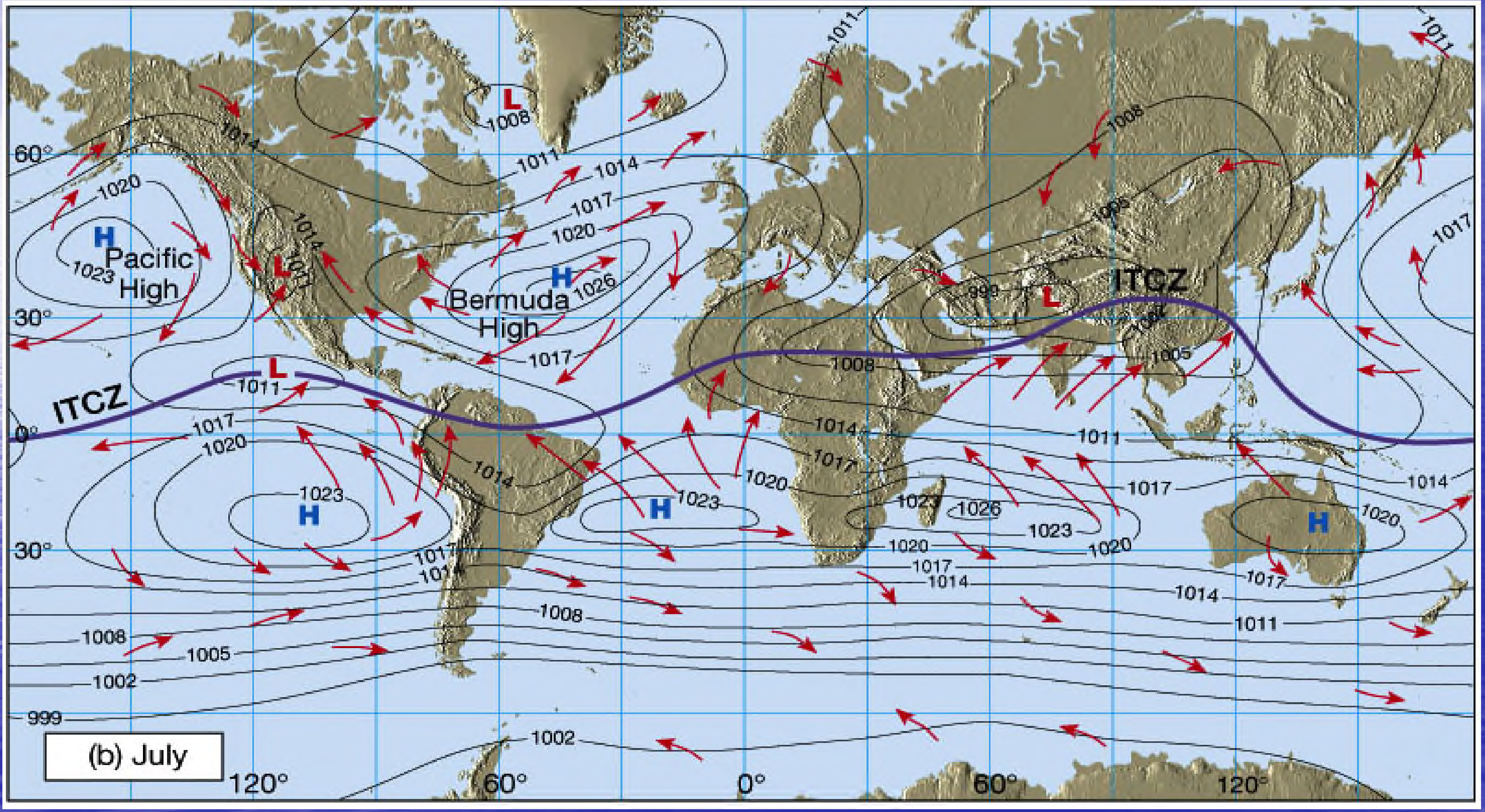


Key Ideas

- ✓ Narrow fast-moving ribbons of wind
- ✓ Travel west to east between cells
- ✓ Controls position and movement of high and low pressure systems

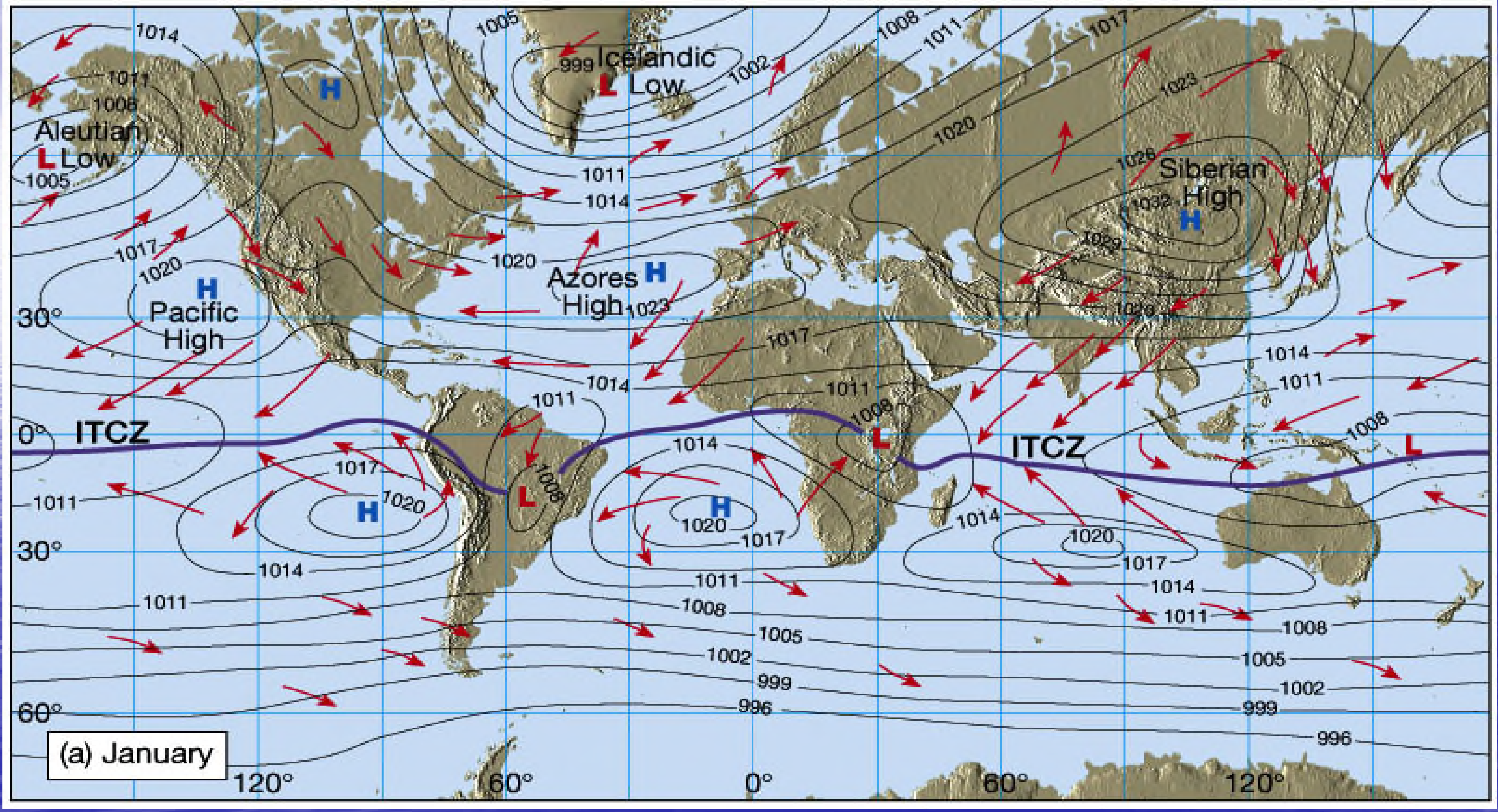
Wind Patterns and Pressure Systems

Averaged **July** Pattern

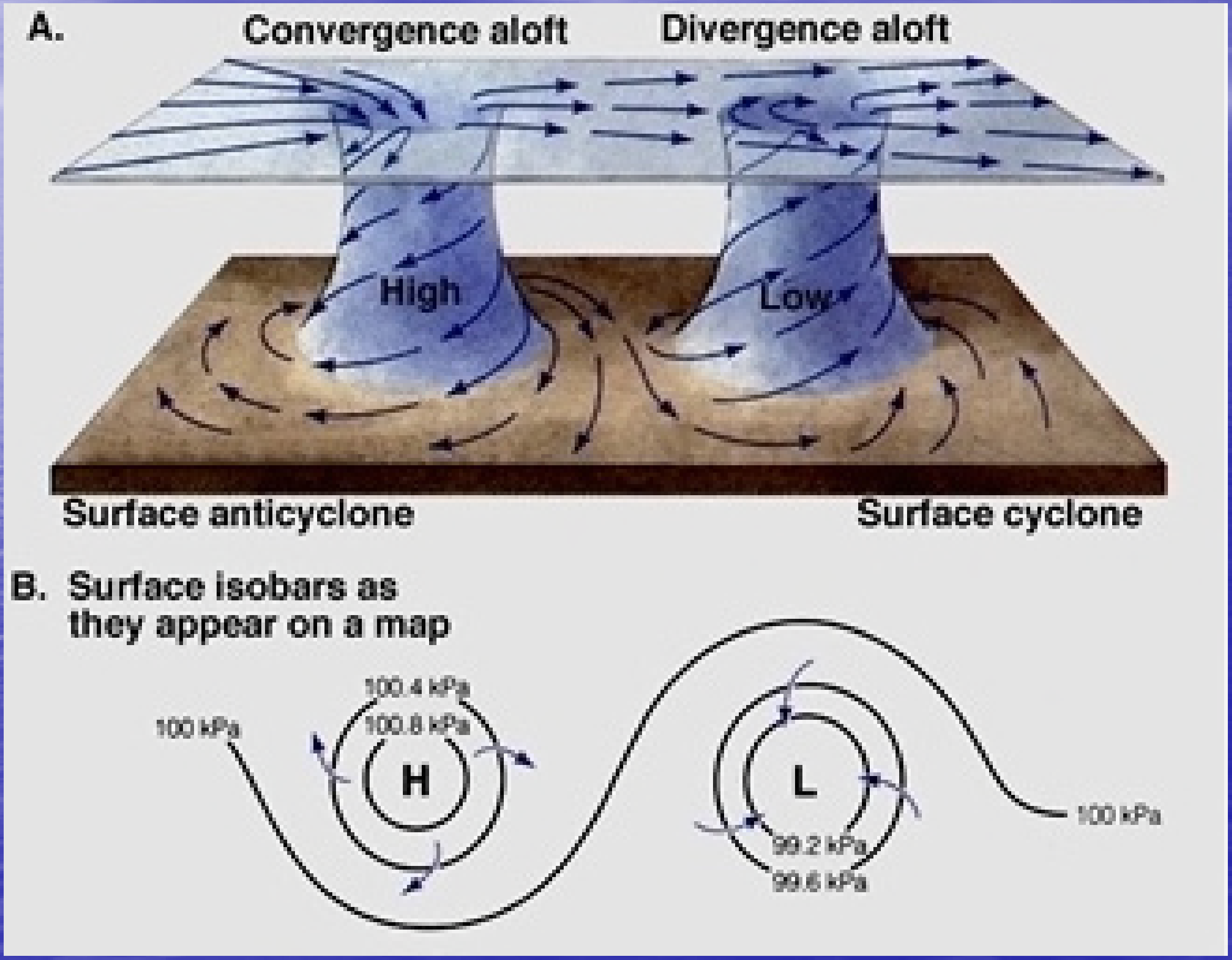


Wind Patterns and Pressure Systems

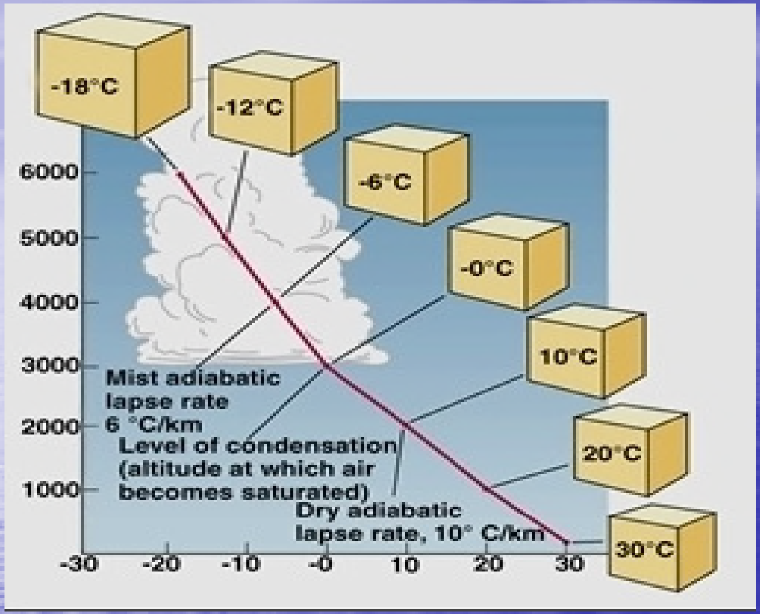
Averaged **January** Pattern



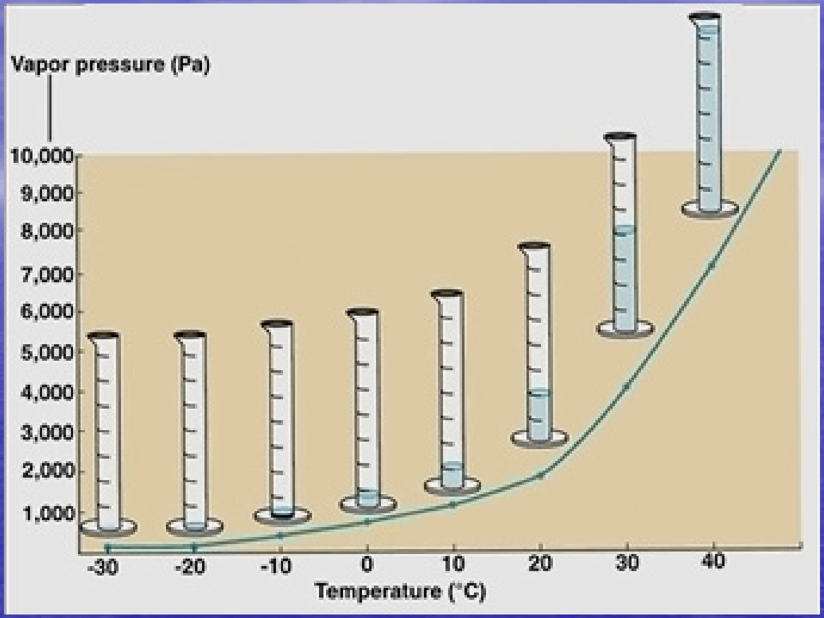
Divergence Versus Convergence Air Flow at High and Low Pressure Centers



Atmospheric Air Mass Properties



Adiabatic Changes in an Air Mass



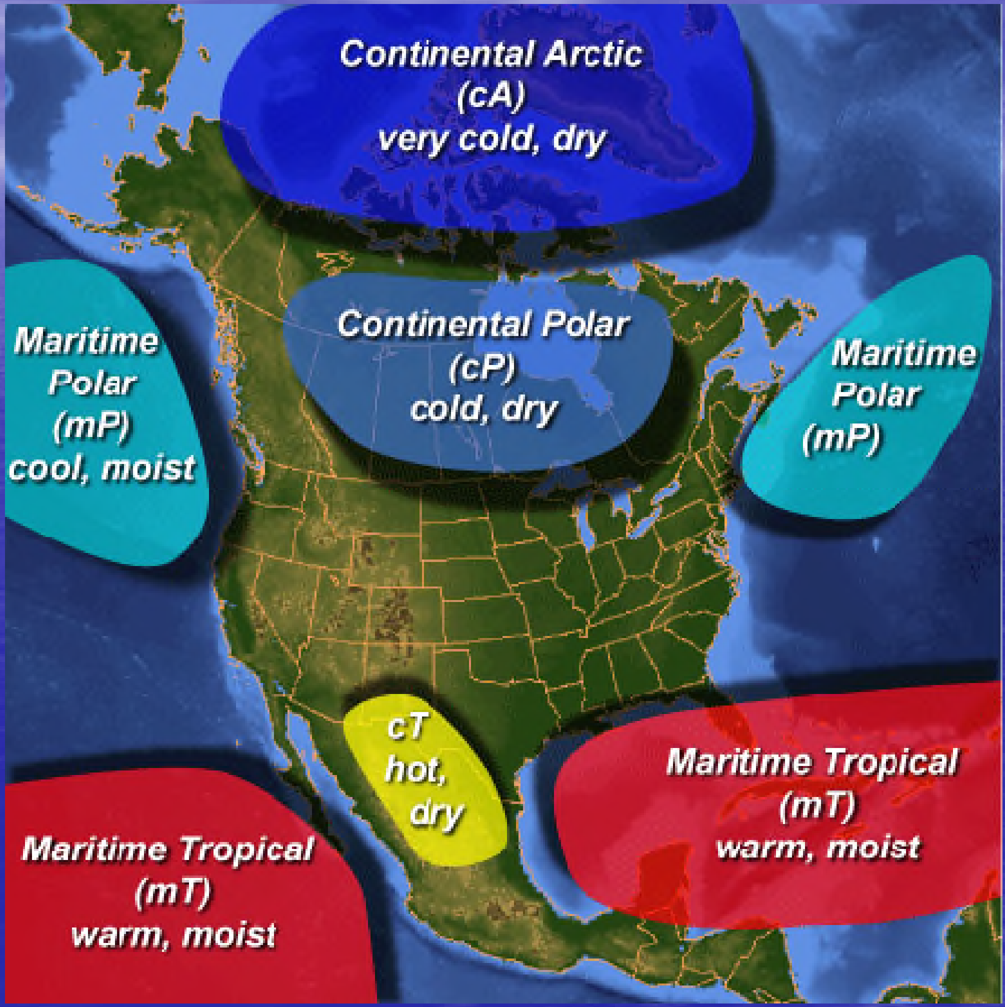
Vapor Pressure Changes in an Air Mass

Key Ideas

- ✓ Ascending (rising) air expands, cools, and becomes less dense
- ✓ Descending (falling) air contracts, heats, and becomes more dense
- ✓ Warm air can hold more water than cold air
- ✓ Water vapor in rising and cooling air will condense into clouds
- ✓ Further rising and cooling of cloud-rich air will lead to precipitation

Global-scale Air Masses

- Large body of air with uniform conditions
- Types
  - m = maritime
  - c = continental
  - T = Tropical
  - P = polar
  - A = Arctic
  - Combinations
    - mT
    - mP
    - cP
    - cA
    - cT

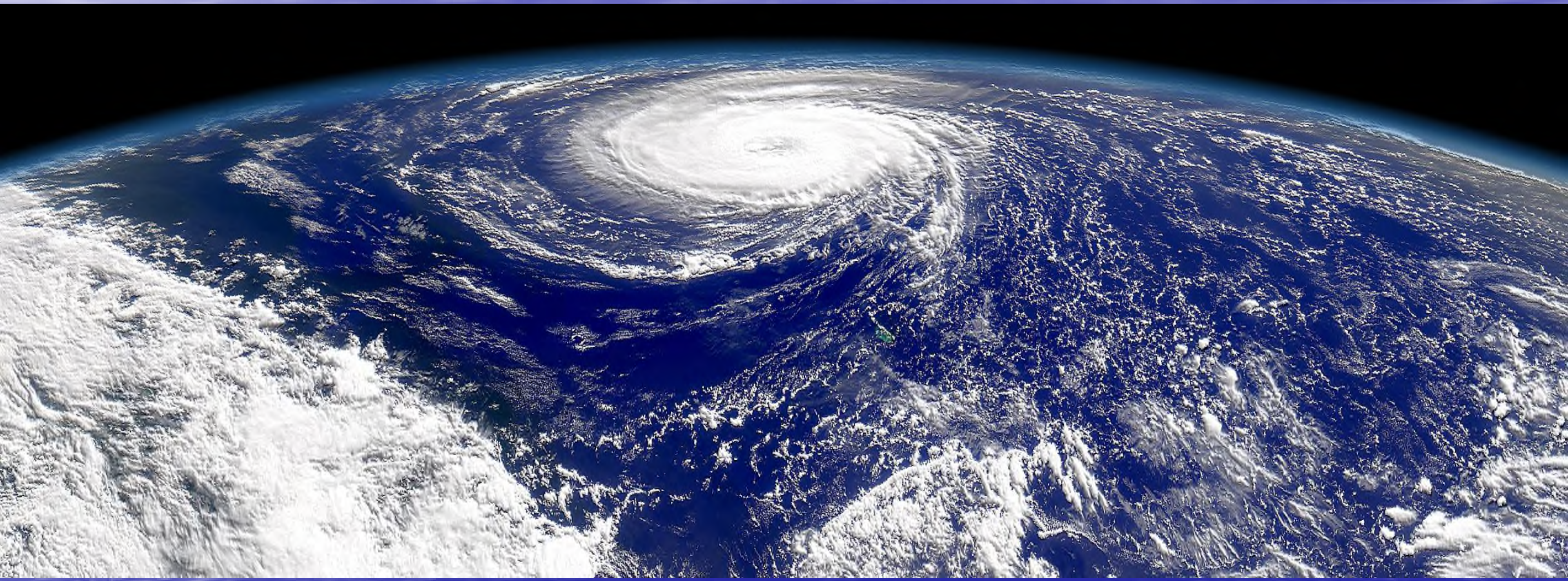


http://apollo.lsc.vsc.edu/classes/met130/notes/chapter11/graphics/airmass_map.gif

Earth's Surface Winds, Storms and Weather Features

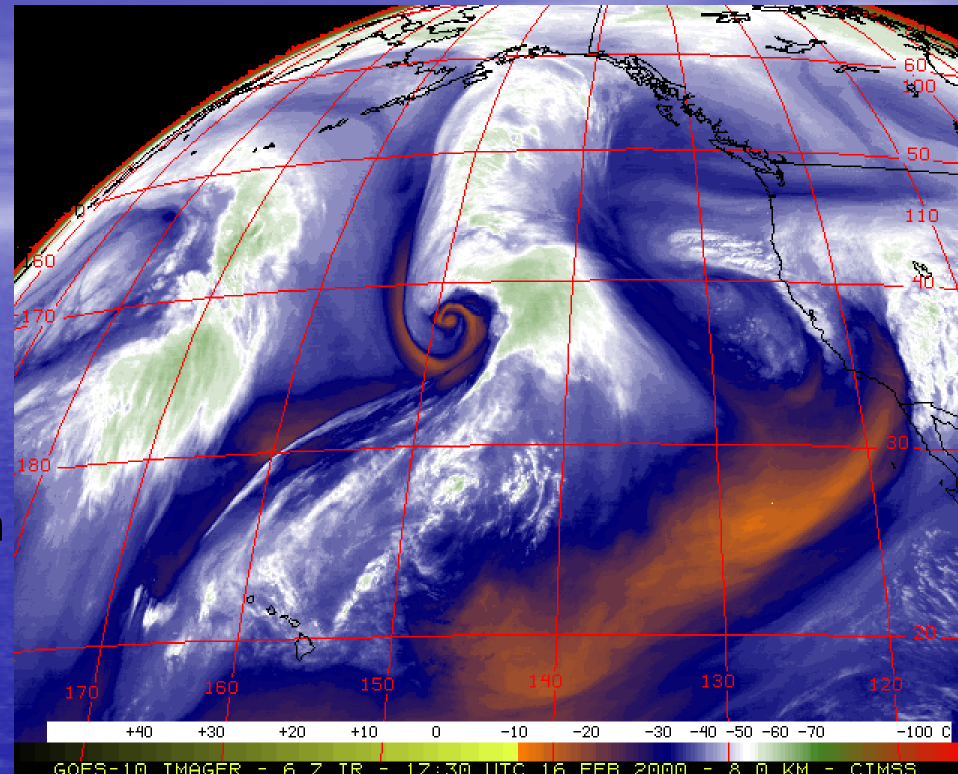



Storm Systems



- Spinning Air Mass Disturbances
  - Tropical Cyclones
  - Extratropical Frontal Systems

Extratropical Frontal Systems



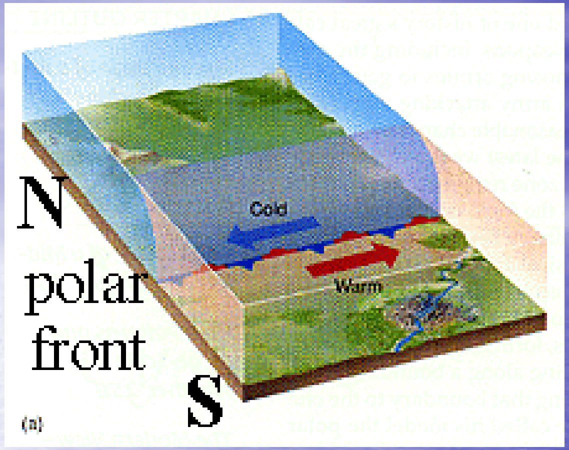
1) A mid- to high-latitude **regional-scale low pressure system** that features a cold air mass colliding with a warm air mass.

2) Frontal systems have cyclonic flow that move counterclockwise in the Northern Hemisphere – clockwise in the Southern Hemisphere

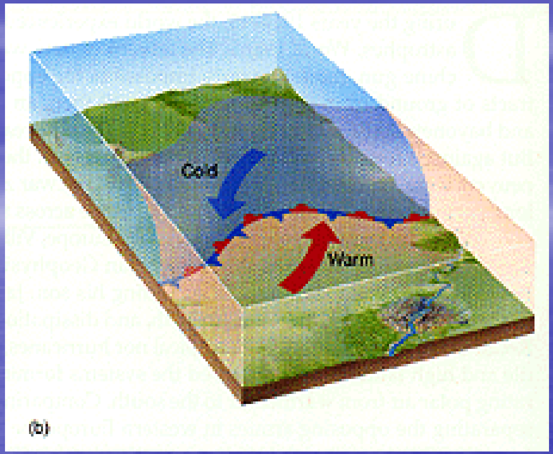
3) Typical size of frontal systems = 1000 to 5000 kilometers in diameter

4) Frontal systems move from west to east and track along jetstream paths

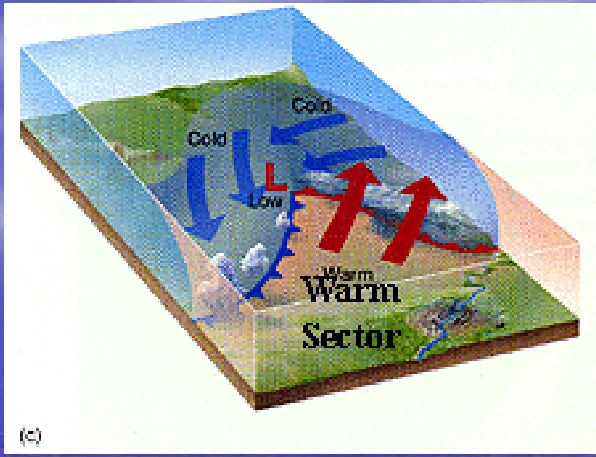
Development of Extratropical Storm Systems



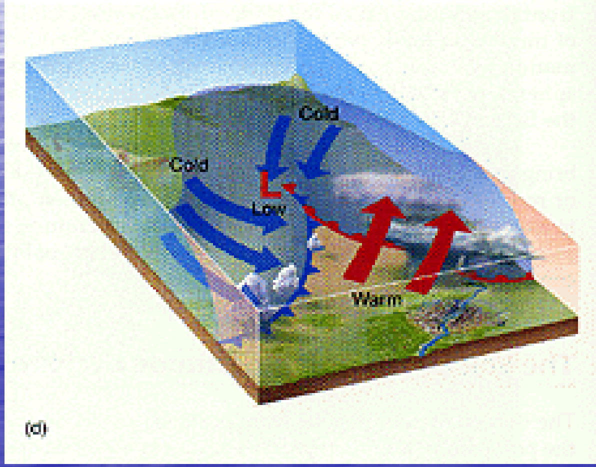
1) Frontal Wave Develops



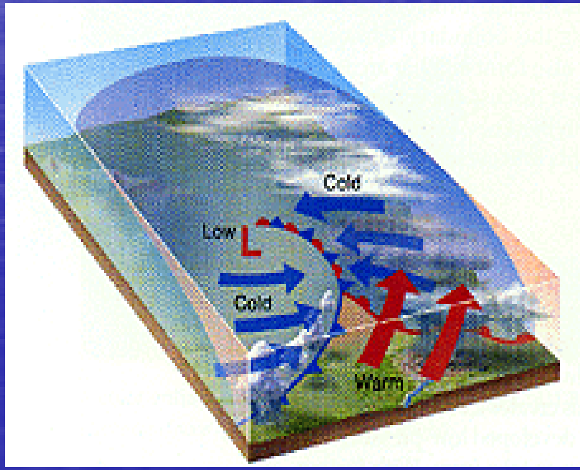
2) Instability "Kink" Forms



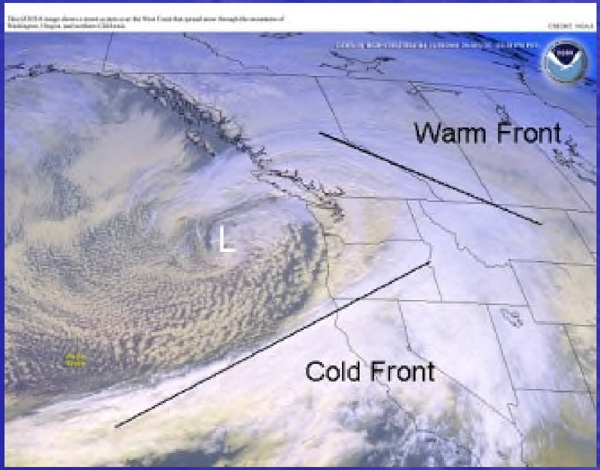
3) Fully-developed Cyclone



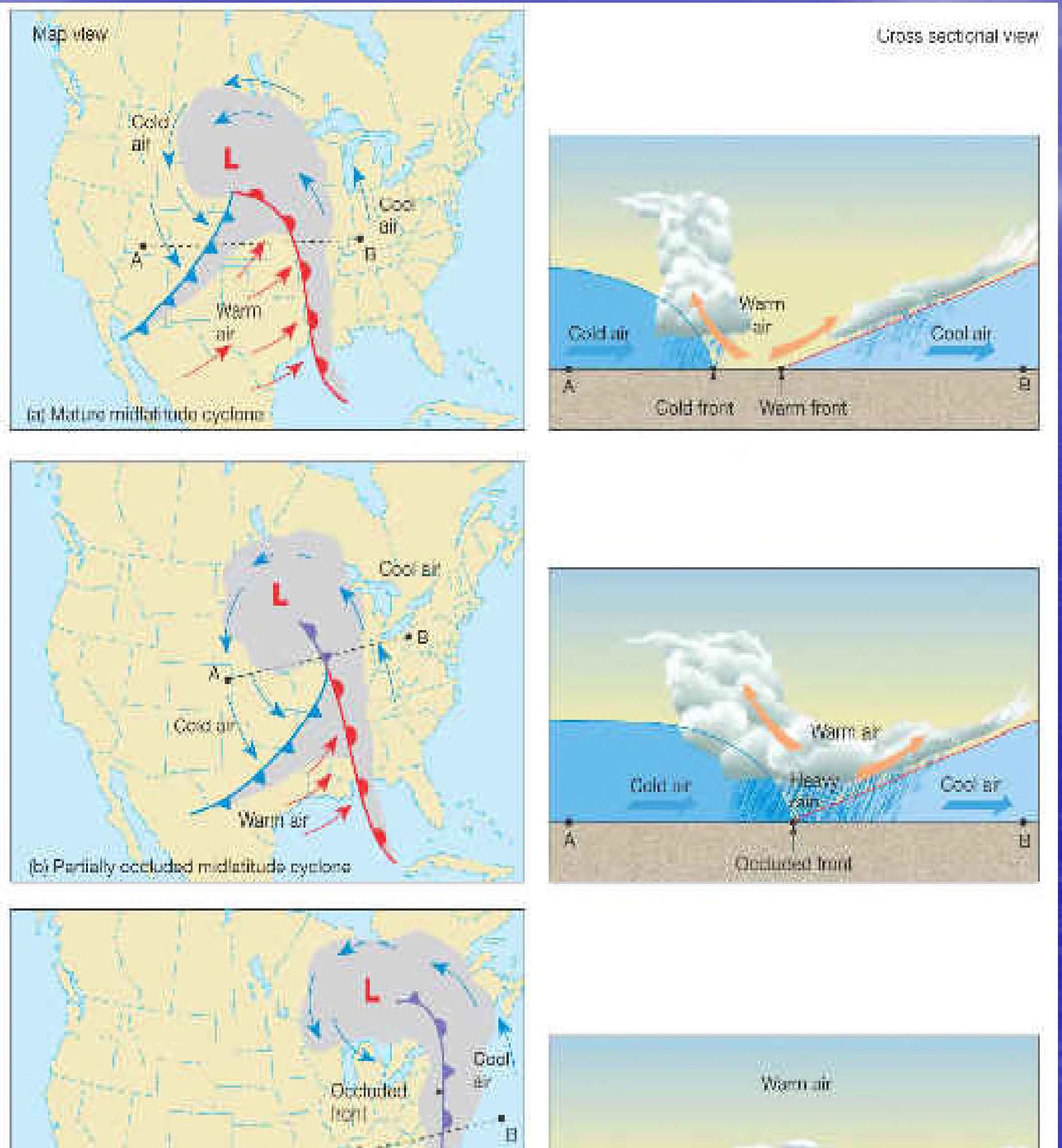
4) System Begins to "Occlude"



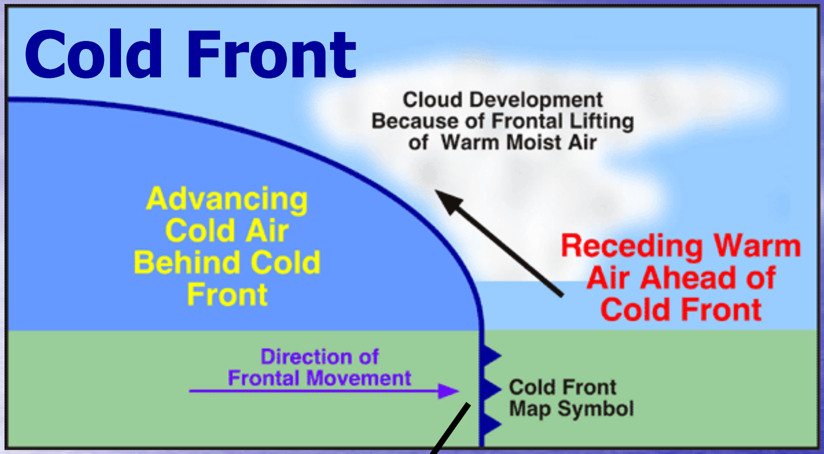
5) Advanced "Occlusion"

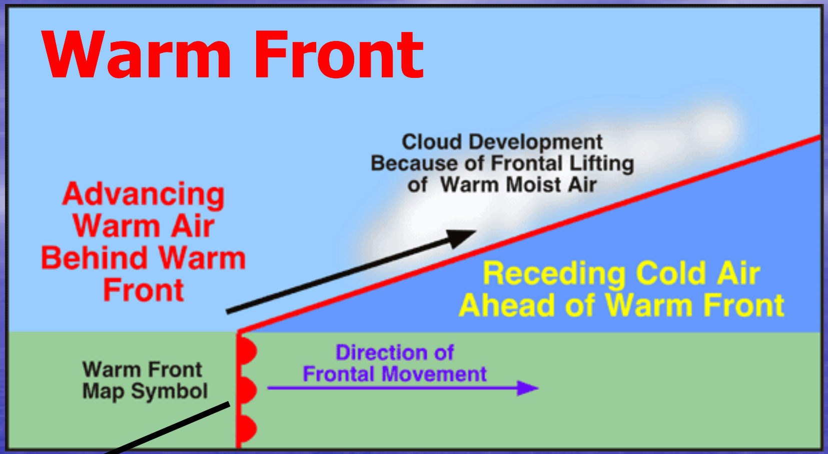


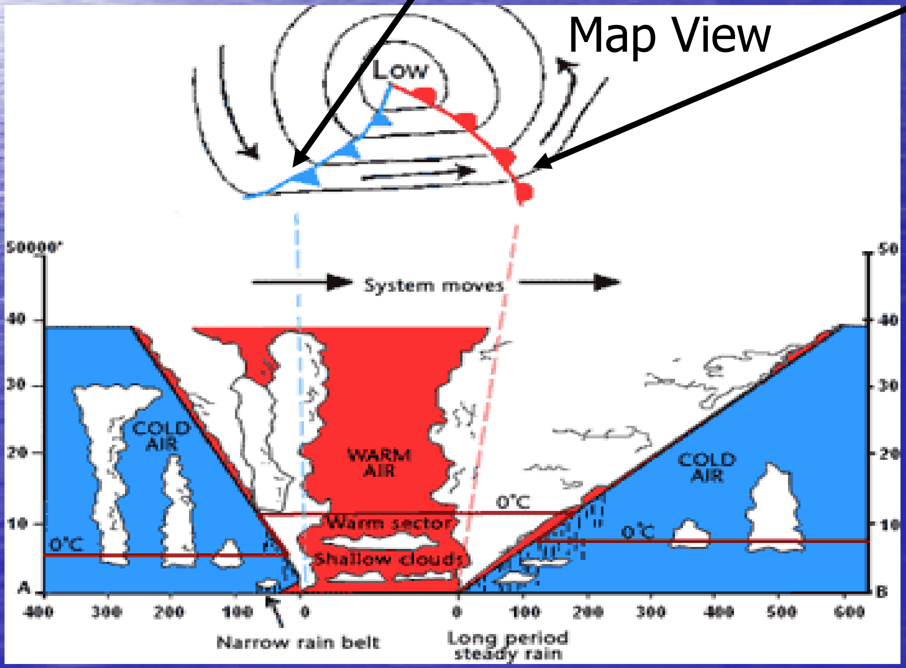
Example


Map view
Cross sectional view
Cold air
Cool air
Warm air
A
B
L
Cold front
Warm front
(a) Mature midlatitude cyclone
Cool air
Cold air
Warm air
Heavy rain
Occluded front
(b) Partially occluded midlatitude cyclone
Occluded front
Warm air

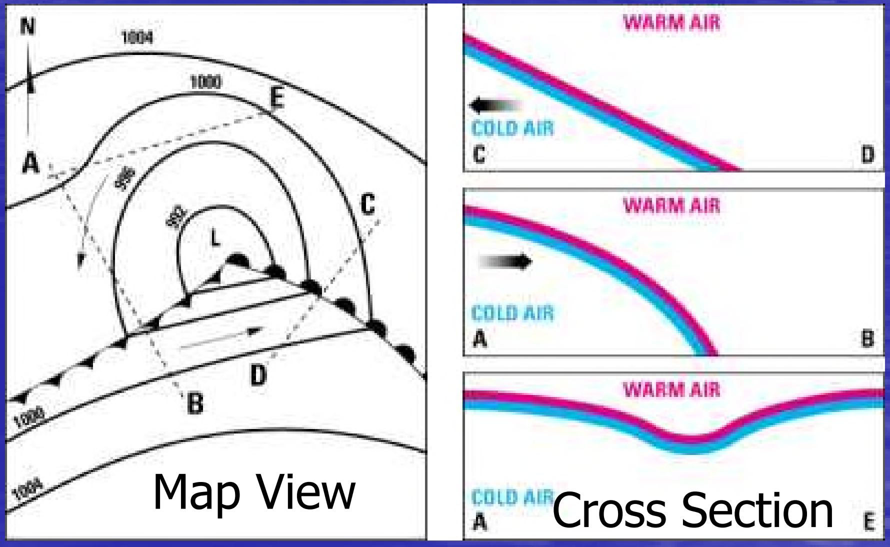
Cold and Warm Fronts



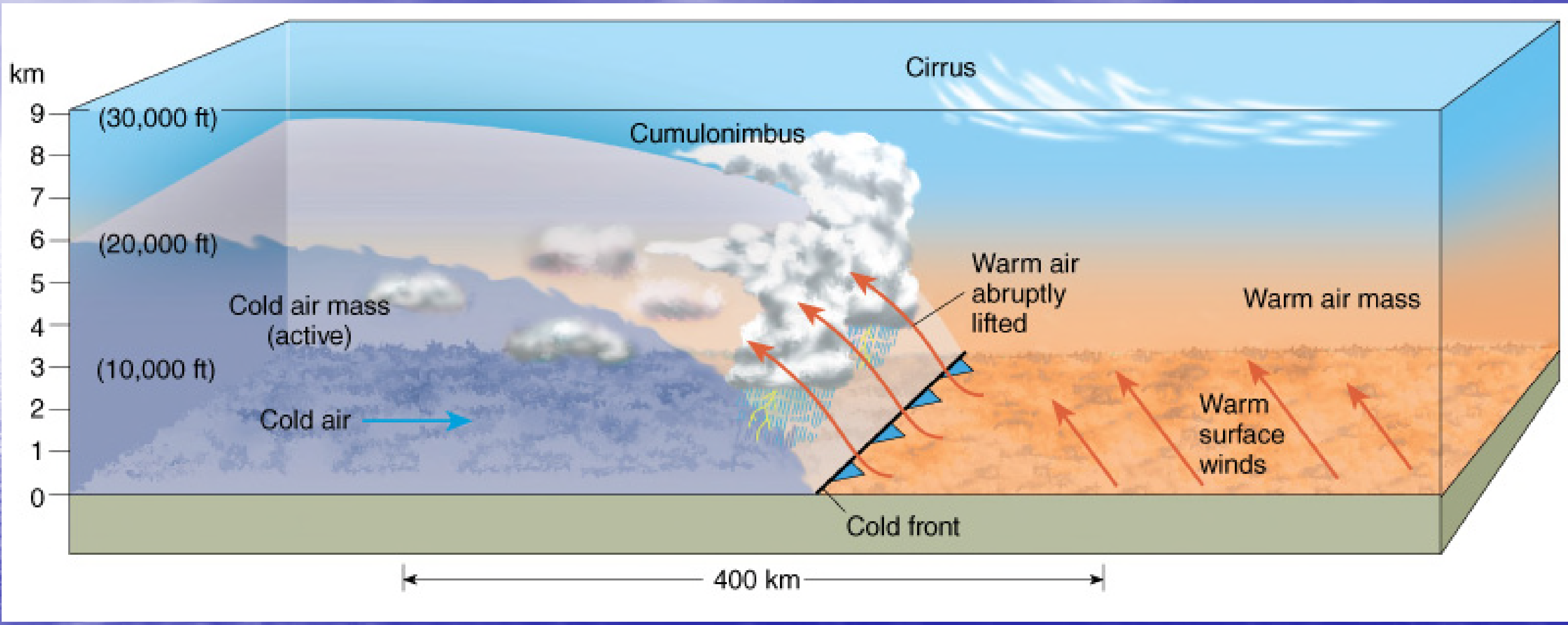




Cross Section View



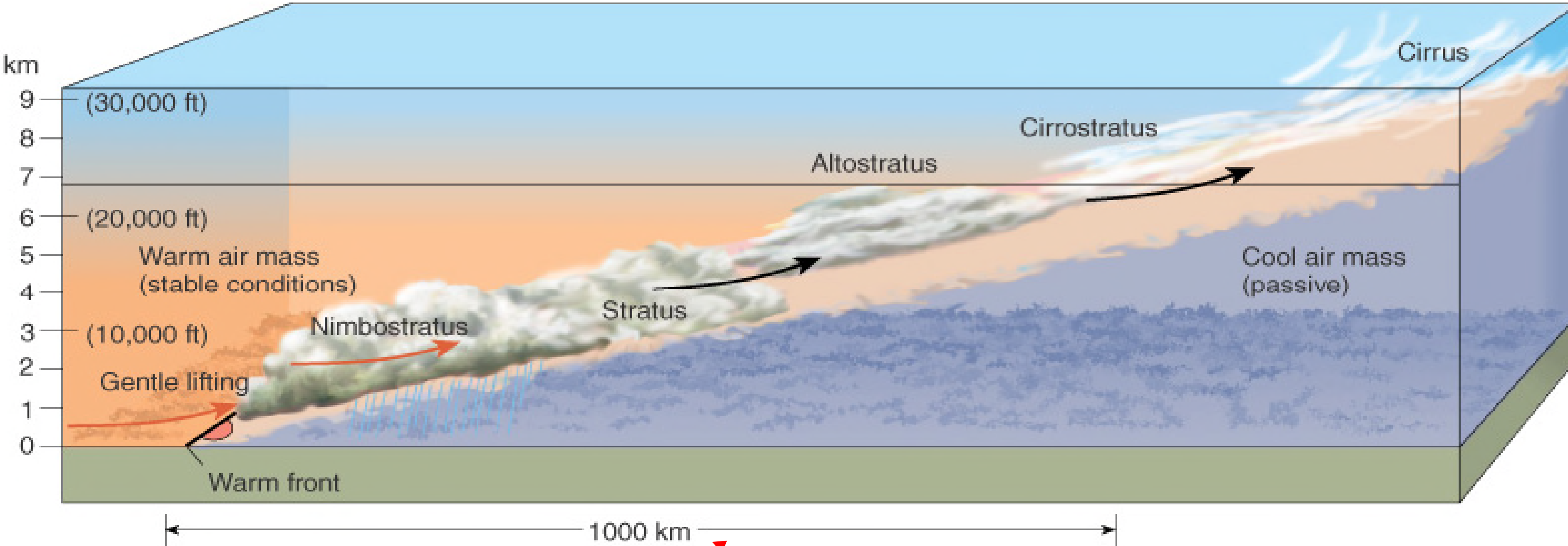
Advancing Cold Front



Note distance covered

05_CnWfronts_MnHcd.swf

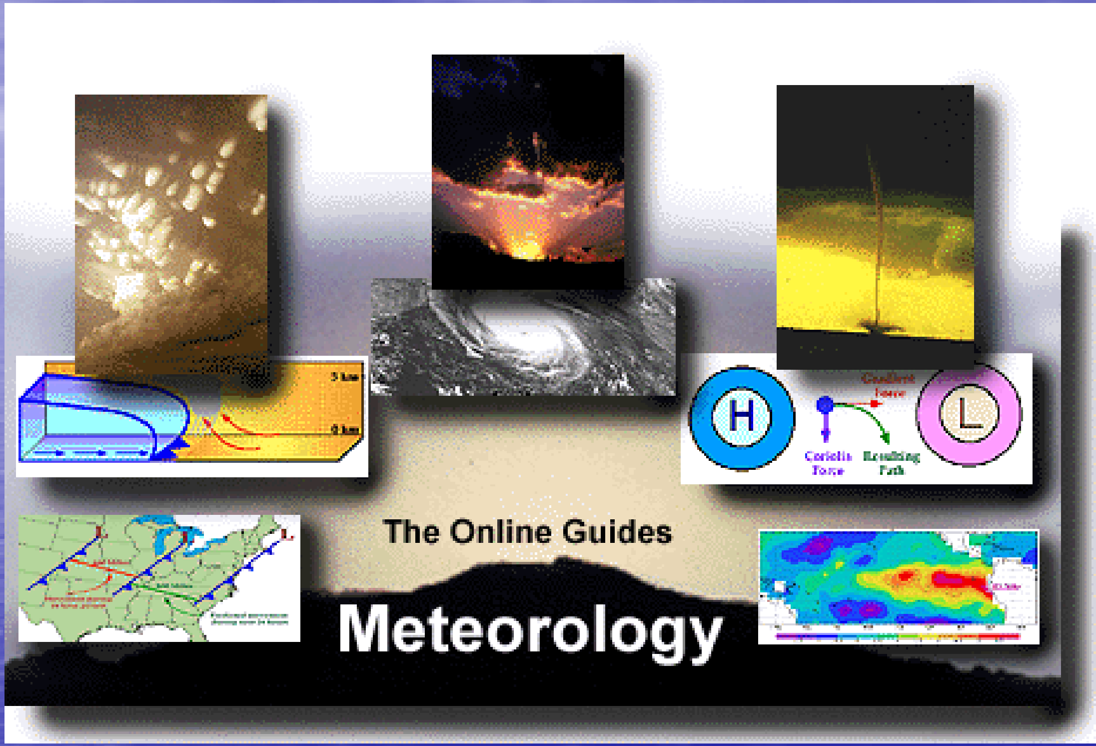
Advancing Warm Front



05_CnWfronts_MnHcd.swf

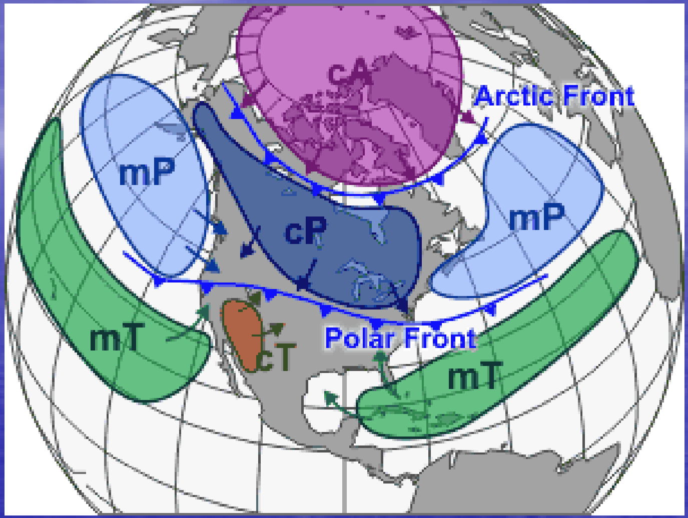
Note distance covered

Online Guide to Meteorology



- http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/home.rxml

Air Masses Over North America

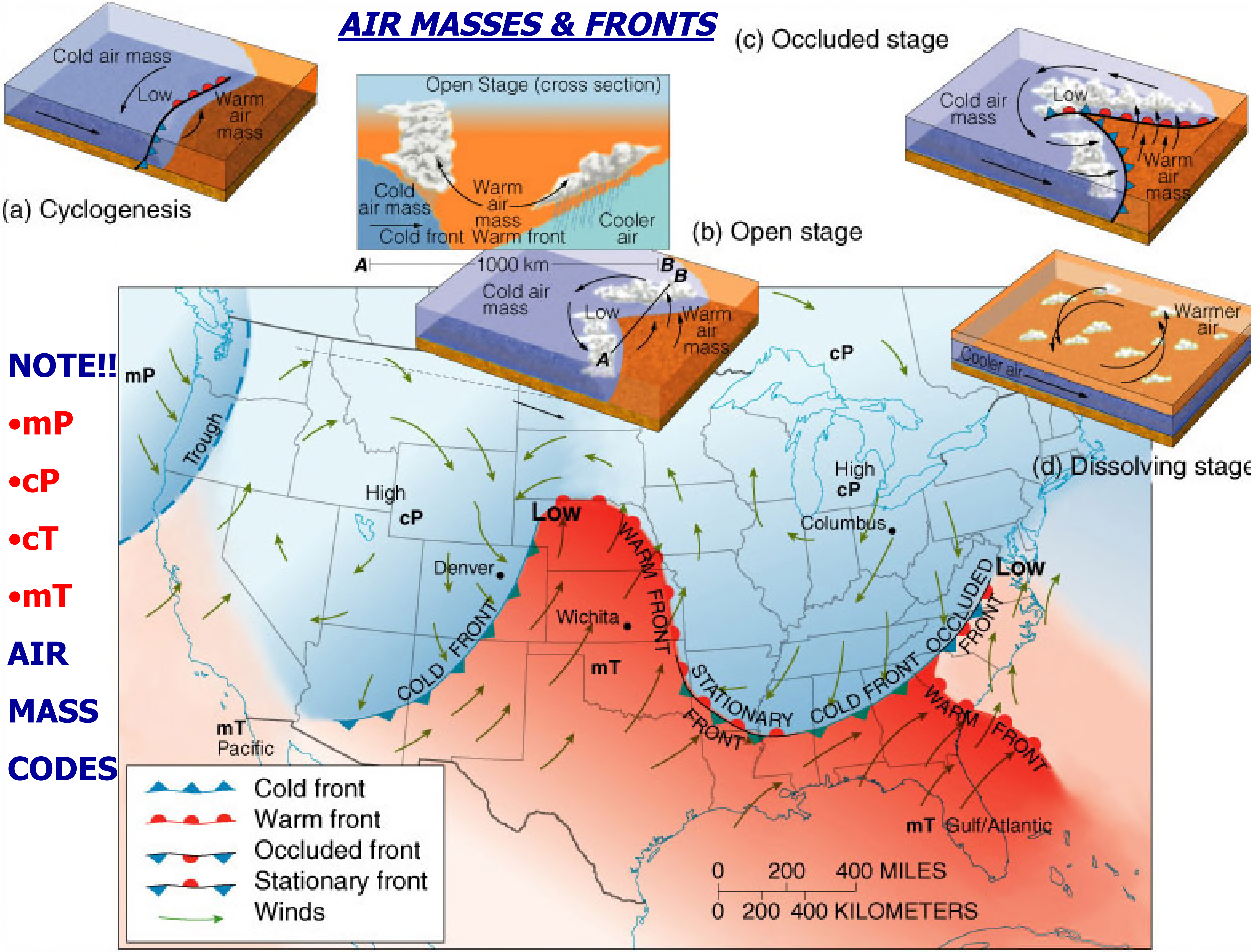


AIR MASSES & FRONTS

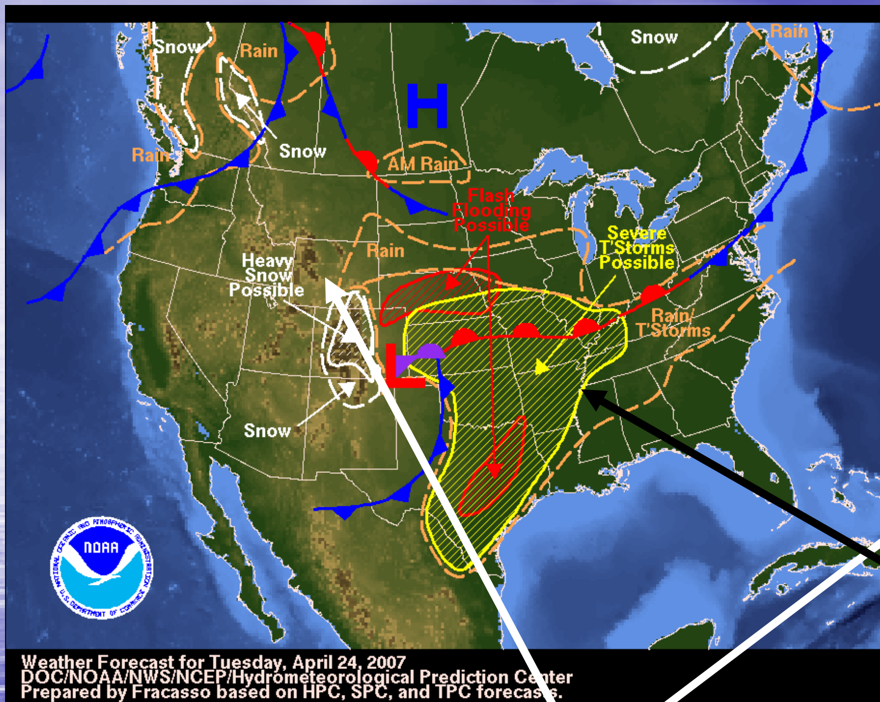
NOTE!!

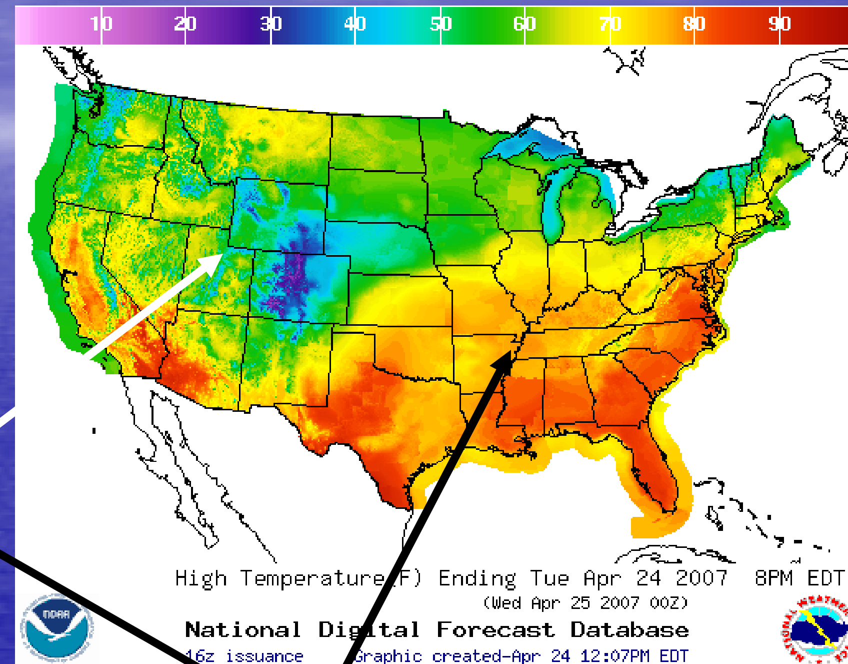
- **mP**
- **cP**
- **cT**
- **mT**

AIR MASS CODES



US Weather Map – April 24, 2007



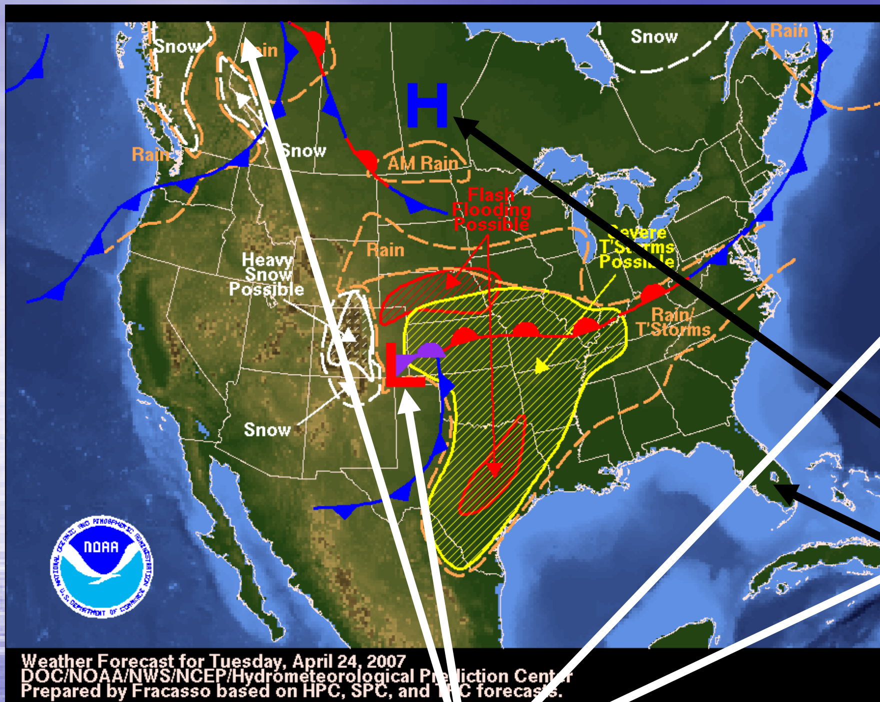


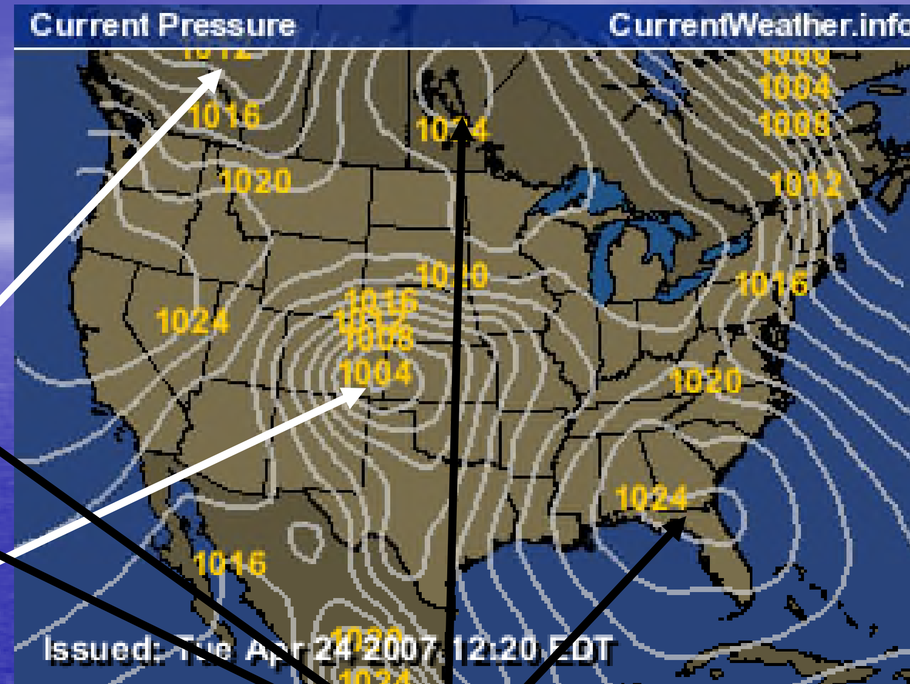
Cold Air Mass

Warm Air Mass

1) Blue lines with triangle hatchers are moving cold fronts
2) Red lines with semicircle hatchers are moving warm fronts
3) Mixed colored lines are stationary fronts

US Weather Map – April 24, 2007





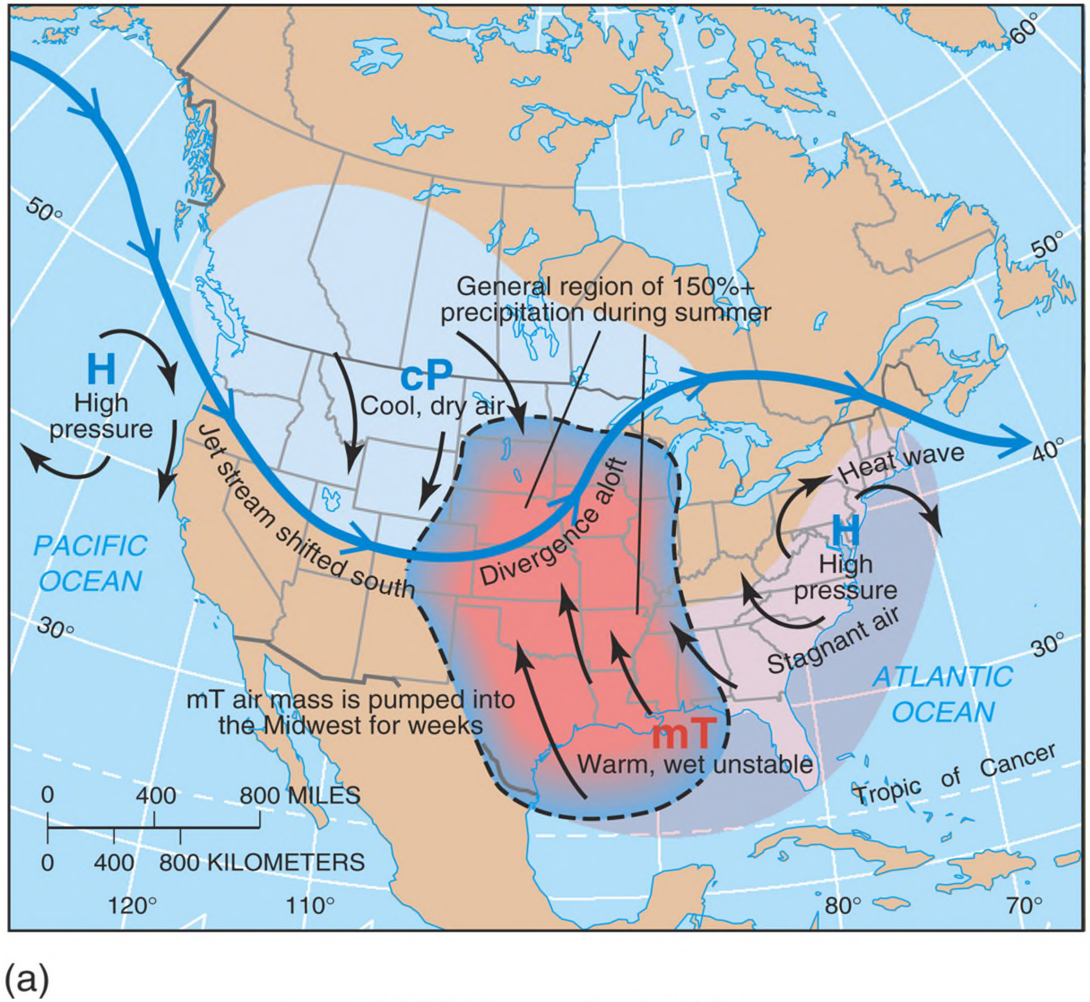
Low Pressure Centers

High Pressure Centers

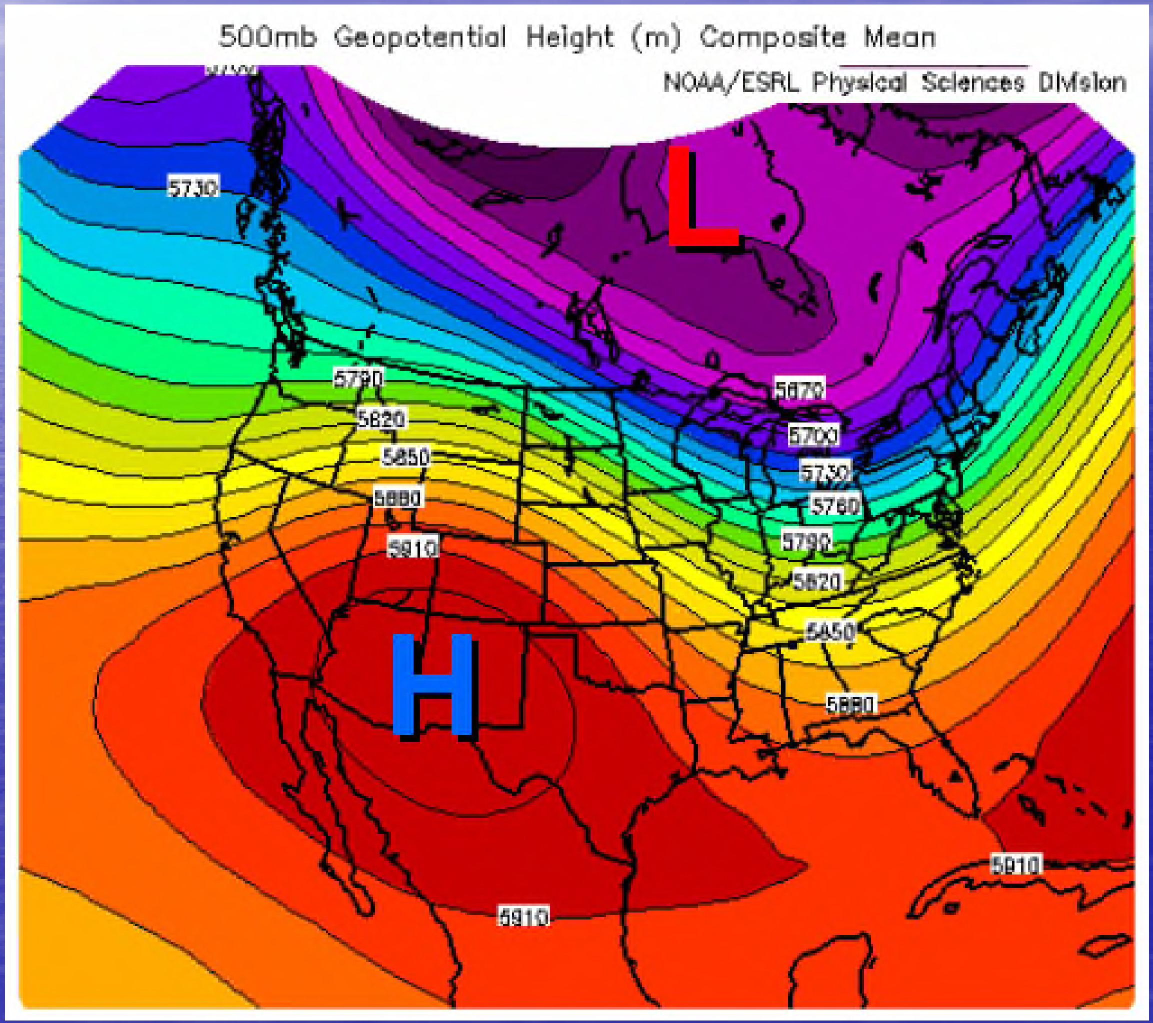
1) Red “L” symbols correspond to low pressure “bull's-eyes”
2) Blue “H” symbols correspond to high pressure “bull's-eyes”
3) The greater the number of tightly spaced isobars, the stronger the pressure system, the stronger the winds.

cP and MT air masses

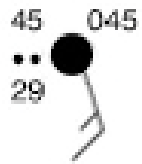
Is the coriolis effect working here?



Ridges and Troughs Along a Frontal System



Surface Station Model

Temp (F) Weather Dewpoint (F)		Pressure (mb) Sky Cover Wind (kts)	**Data at Surface Station** Temp 45 °F, dewpoint 29 °F, overcast, wind **from** SE at 15 knots, weather light rain, pressure 1004.5 mb

Notice shorthand method of recording pressure values - "045" to mean 1004.5mb.

Beware ! !

- Ranges of air pressure
  - 980 – 1050 mb
  - Extreme ranges

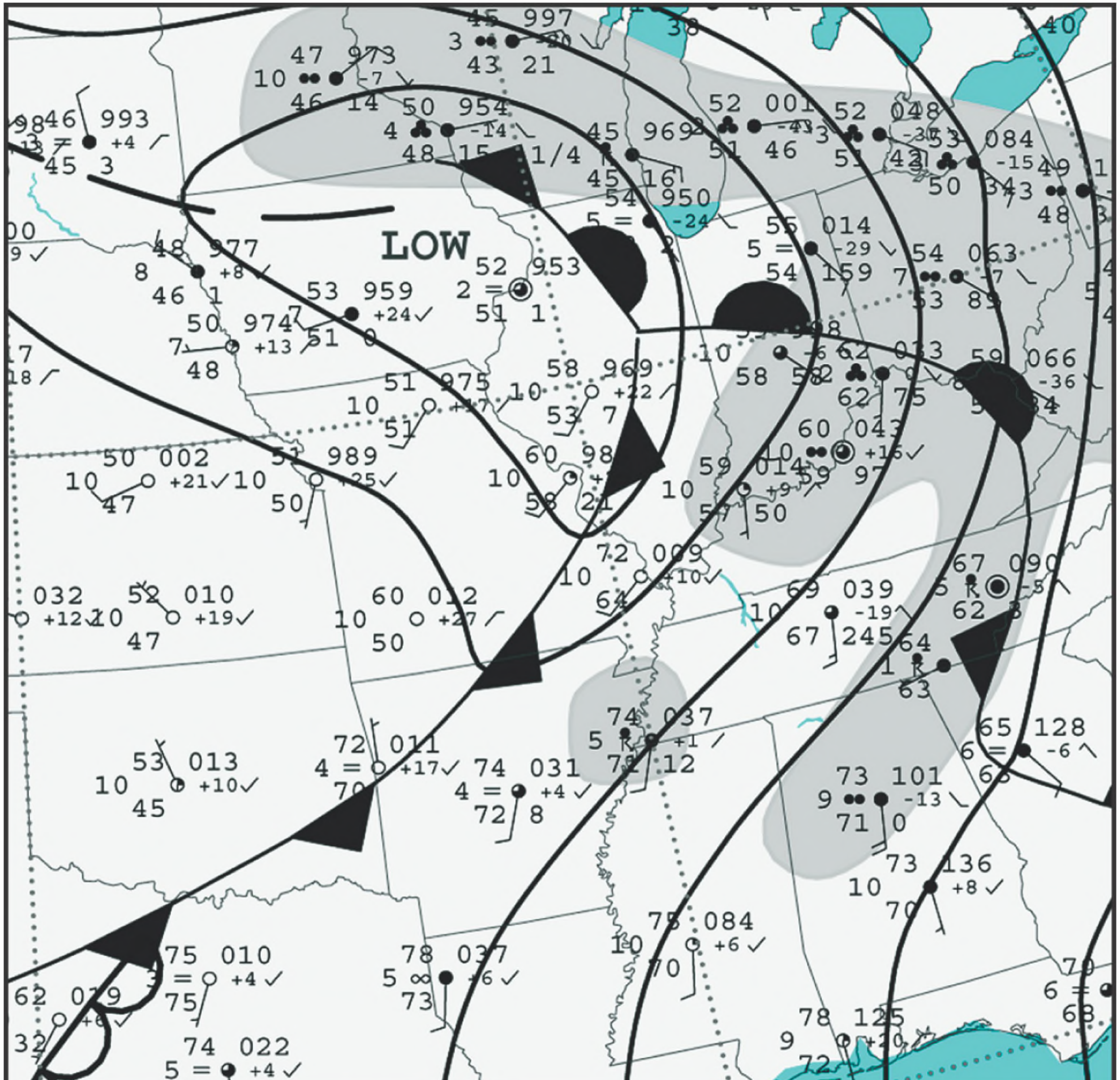
    Lowest: 870 mb, inside a typhoon/hurricane

    Highest: 1084 mb in Siberia

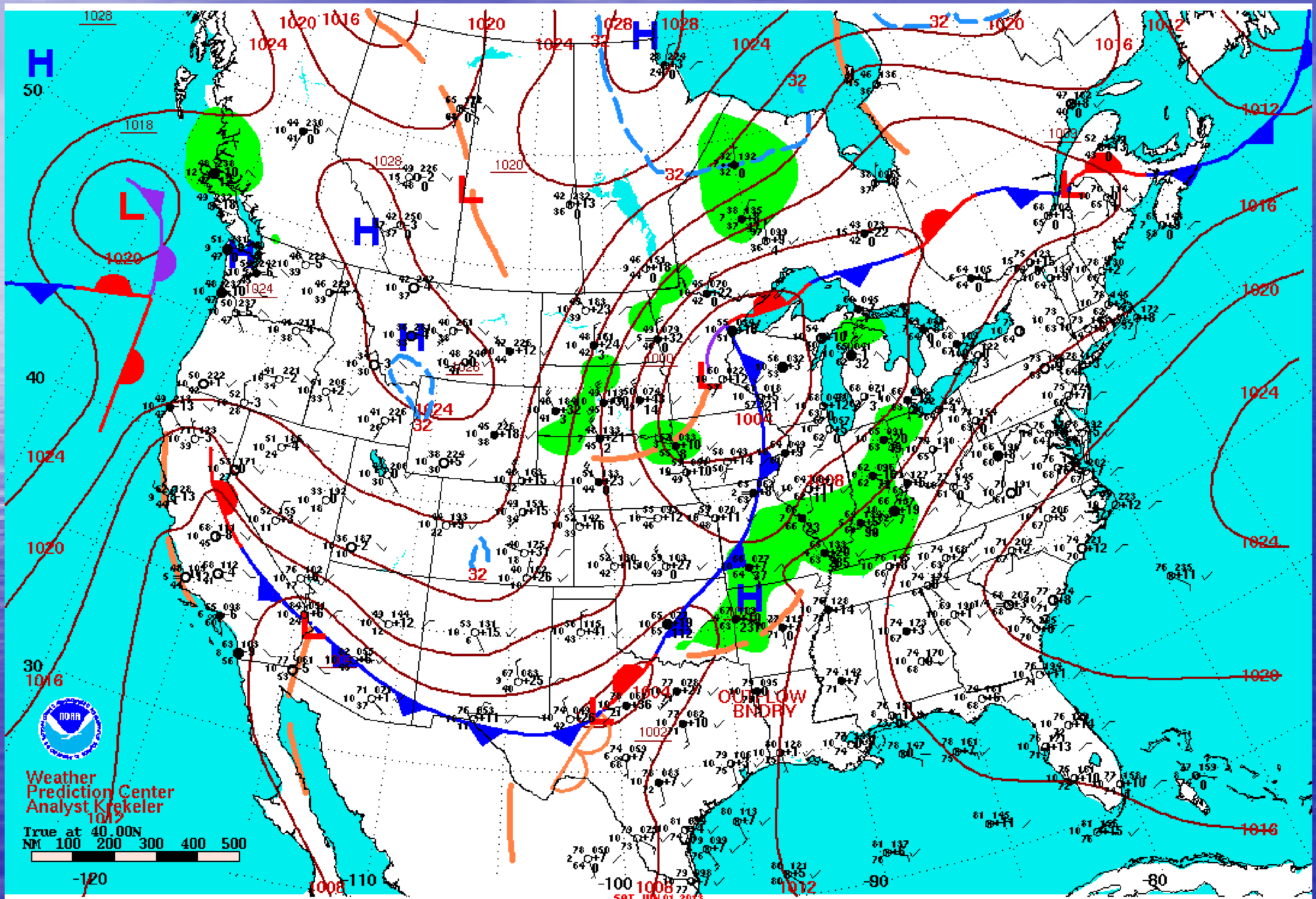
Wind Speed – ticks and flags on wind shaft

Map Symbols

Sky Cover	Wind	Fronts		Selected Weather Symbols
clear	Calm	cold front	warm front	Rain
1/8	1-2 knots (1-2 mph)	stationary front	occluded front	Rain Shower
scattered	3-7 knots (3-8 mph)	trough		Thunderstorm
3/8	8-12 knots (9-14 mph)	radar intensities 1 2 3 4 5 6		Drizzle
4/8	13-17 knots (15-20 mph)	tornado (T) #300 T 300		* or ← ← Snow
5/8	18-22 knots (21-25 mph)	severe thunderstorm (S) #287 S 287		Snow Shower
broken	23-27 knots (26-31 mph)			Freezing Rain
7/8	48-52 knots (55-60 mph)			Freezing Drizzle
overcast	73-77 knots (84-89 mph)			Fog
obscured	103-107 knots (119-123 mph)			Haze
missing	Shaft in direction wind is coming **from**			Smoke
				Dust or Sand
				Blowing Snow

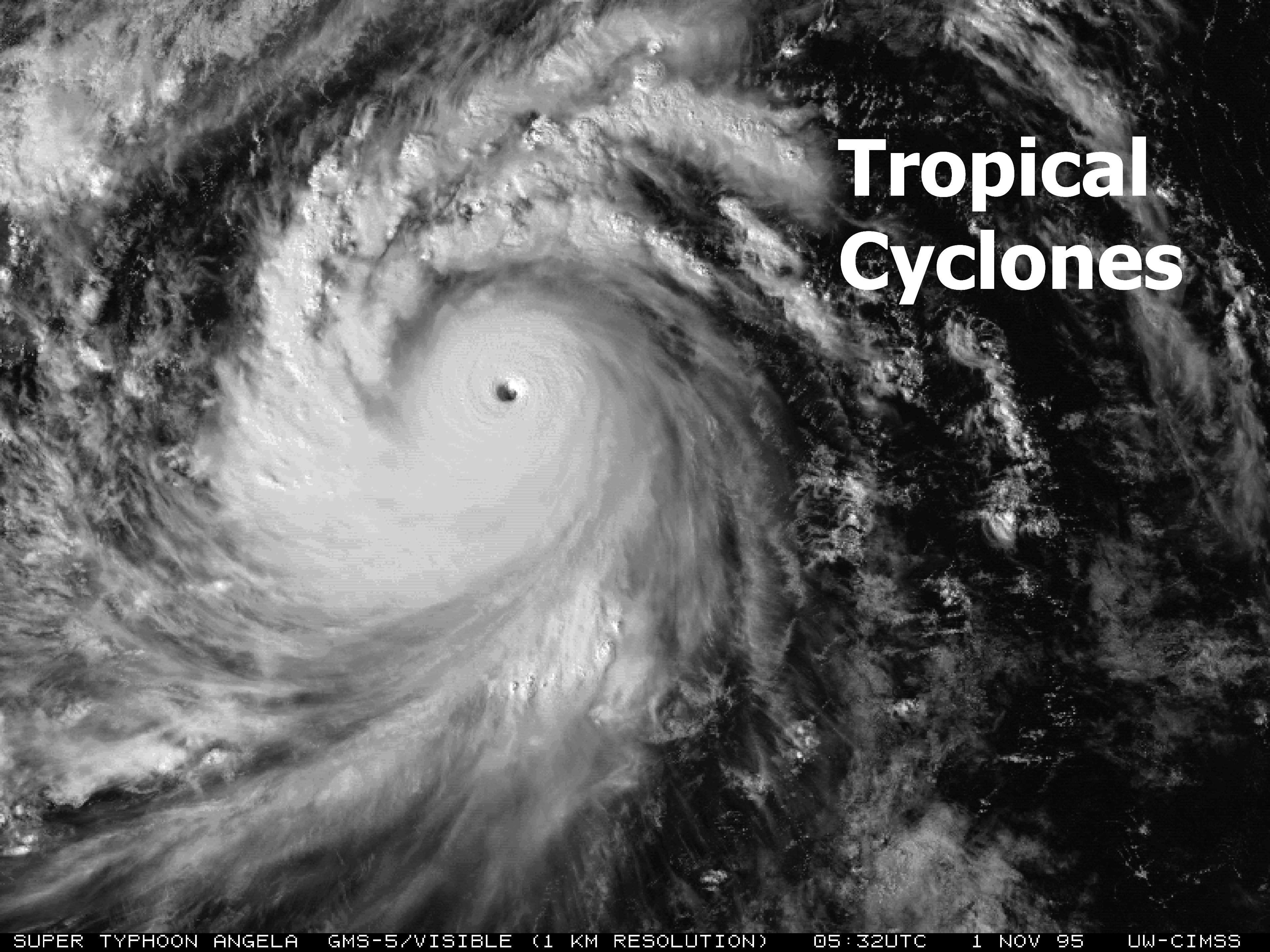

LOW

Weather Map of USA



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

Tropical Cyclones



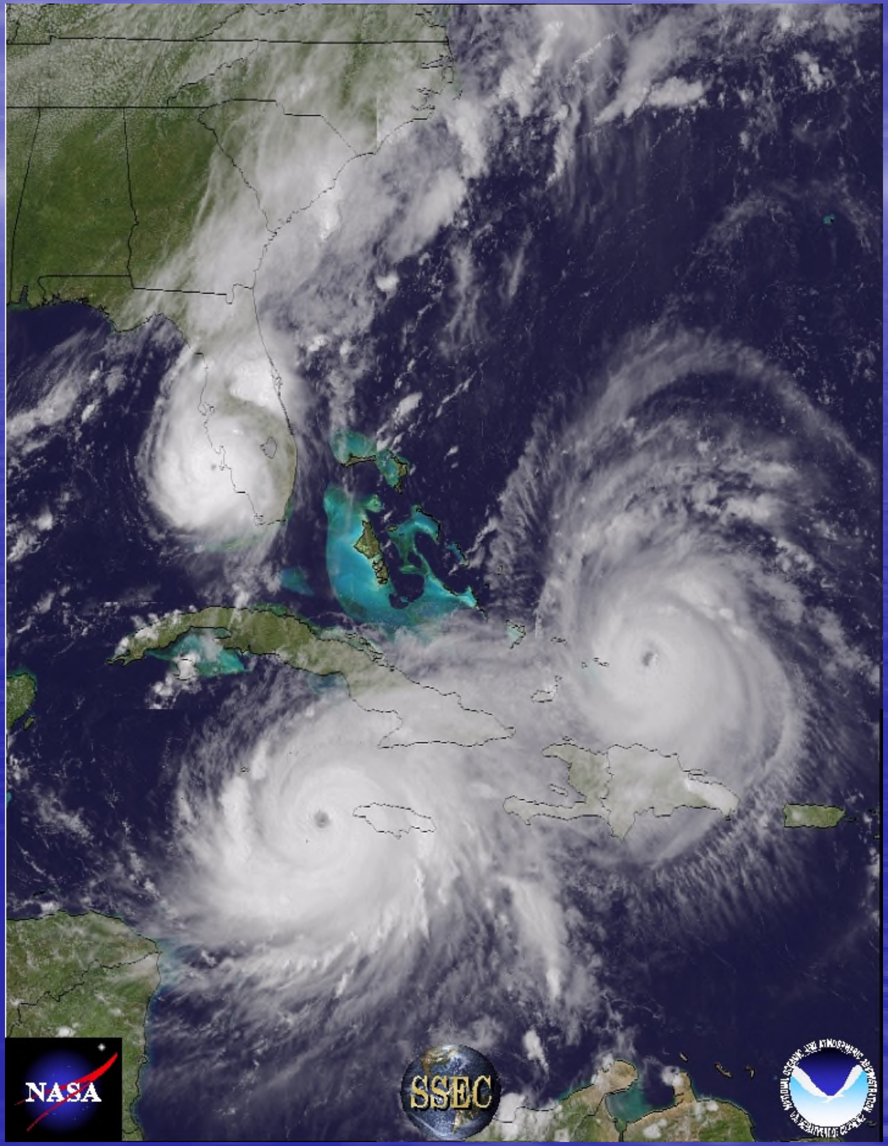
Tropical Cyclones

1) **Tropical Cyclones** are known as *hurricanes* in the Atlantic Ocean, *typhoons* in the Pacific Ocean and *cyclones* in the Indian Ocean.

2) Very extensive, powerful, and destructive type of storm.

3) This type of storm develops over oceans 8° to 15° North and South of the equator.

4) Hurricanes draw their energy from the warm water of the tropics and latent heat of condensation.



Necessary Conditions for Cyclone Development:

1) Must originate over ocean water that is least 26.5 °C.

- ✓ Hurricanes feed off the latent heat of water – hotter the better!

2) Have an atmosphere that cools quickly with height.

- ✓ This creates potentially unstable conditions that builds storms.

3) Low vertical wind shear.

- ✓ Winds at all levels of the atmosphere from the ocean up to 30,000 feet or higher are blowing at the same speed and from the same direction.

4) No closer than 500 kilometers to the equator.

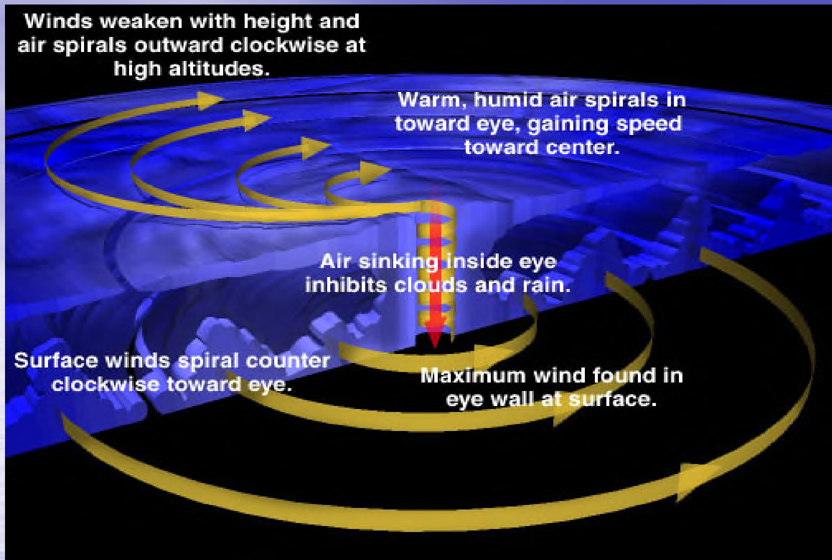
- ✓ The Coriolis Force is too weak close to the equator.
- ✓ It is the Coriolis Force that initially makes the cyclone spiral and maintains the low pressure of the disturbance.

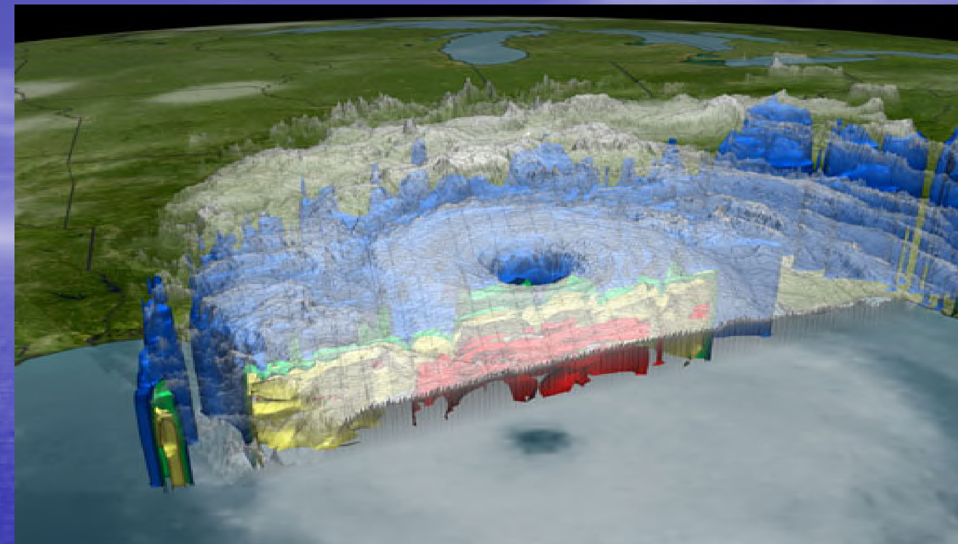
5) An upper atmosphere high pressure area above the growing storm.

- ✓ The air in such high pressure areas is flowing outward. This pushes away the air that is rising in the storm, which encourages even more air to rise from the low levels.

6) Hurricanes will not always form in these conditions. However, a will hurricane only form if these conditions are present.

Anatomy and Behavior of a Hurricane





1) Warm, humid surface winds spiral towards eye.

2) Strongest winds occur in the eye wall at the surface.

3) Air in the eye sinks which inhibits wind and cloud formation

4) Body of hurricane divided into concentric rain bands

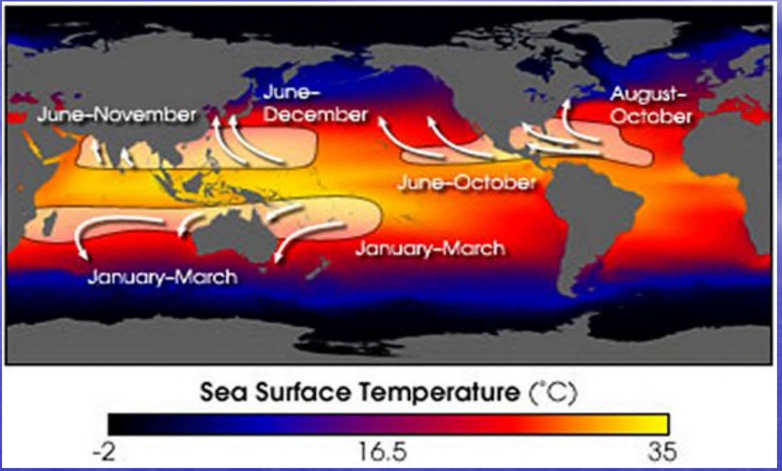
5) Surface rotation direction depends on hemisphere

6) All hurricanes move toward the west

Life Cycle of Tropical Cyclones

1) Formation

- ✓ Tropical Disturbance to Depression
- ✓ Weak to moderate winds
- ✓ Little to no rotation

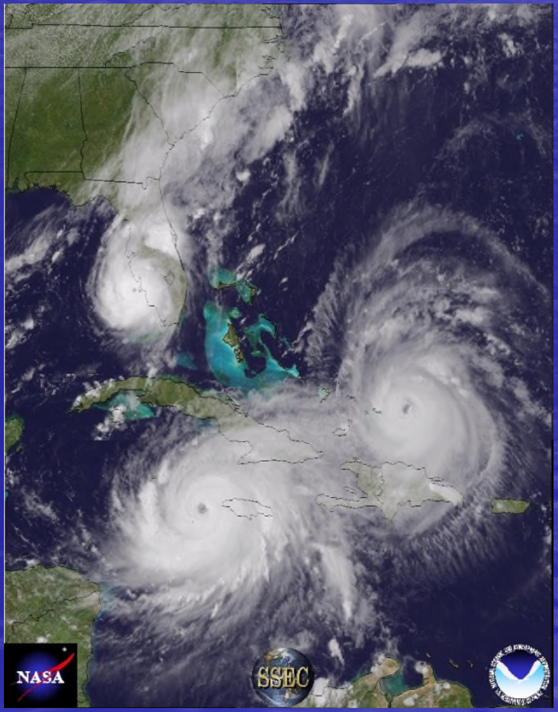


2) Prematurity

- ✓ Tropical Storm
- ✓ Moderate to strong winds
- ✓ Moderate rotation

3) Full Maturity

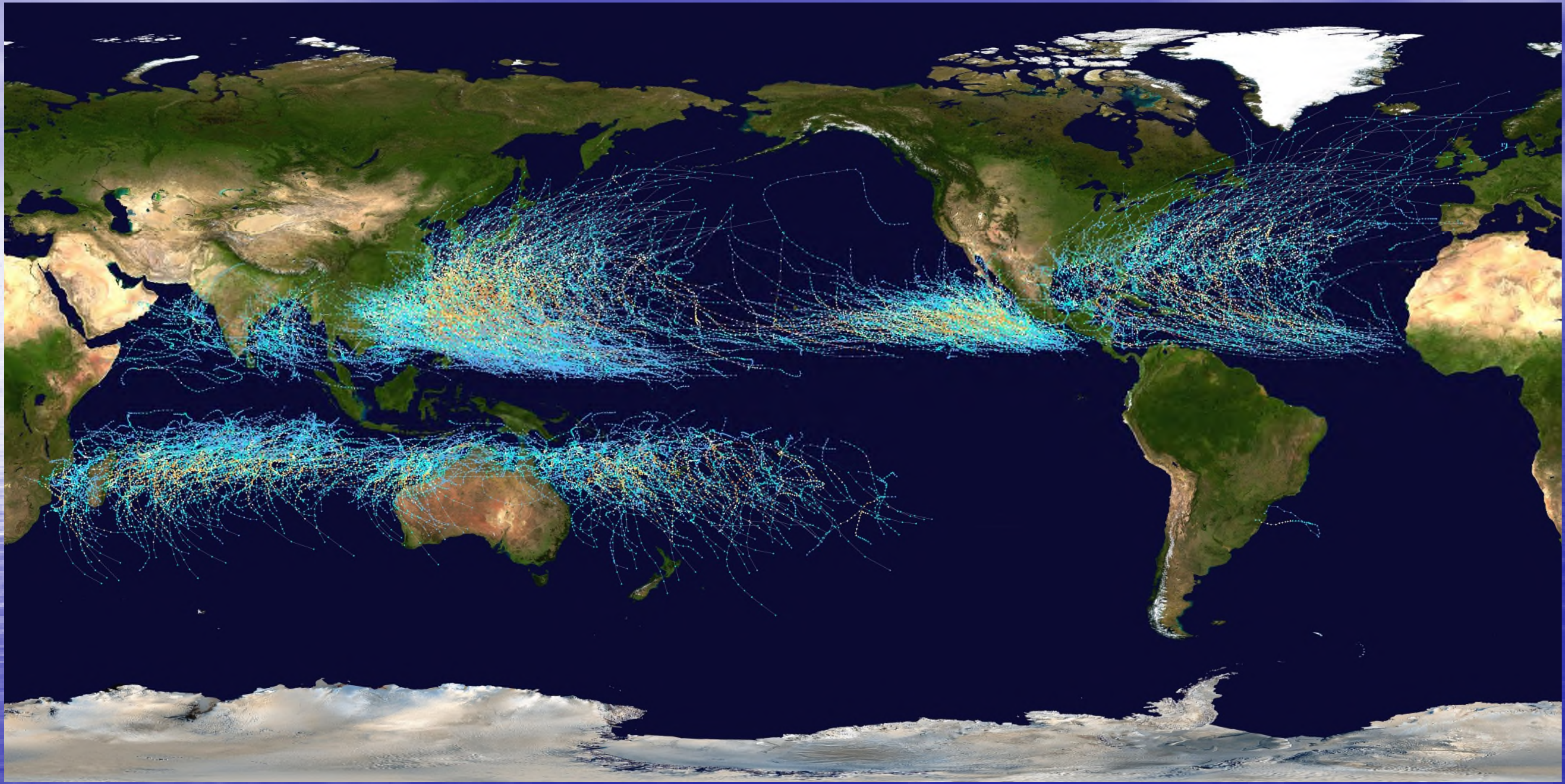
- ✓ Hurricane
- ✓ Very Strong winds
- ✓ Rapid rotation with eye



4) Decay

- ✓ Dissipation into weaker and weaker system
- ✓ Entire cycle typically lasts between 1 to 2 weeks

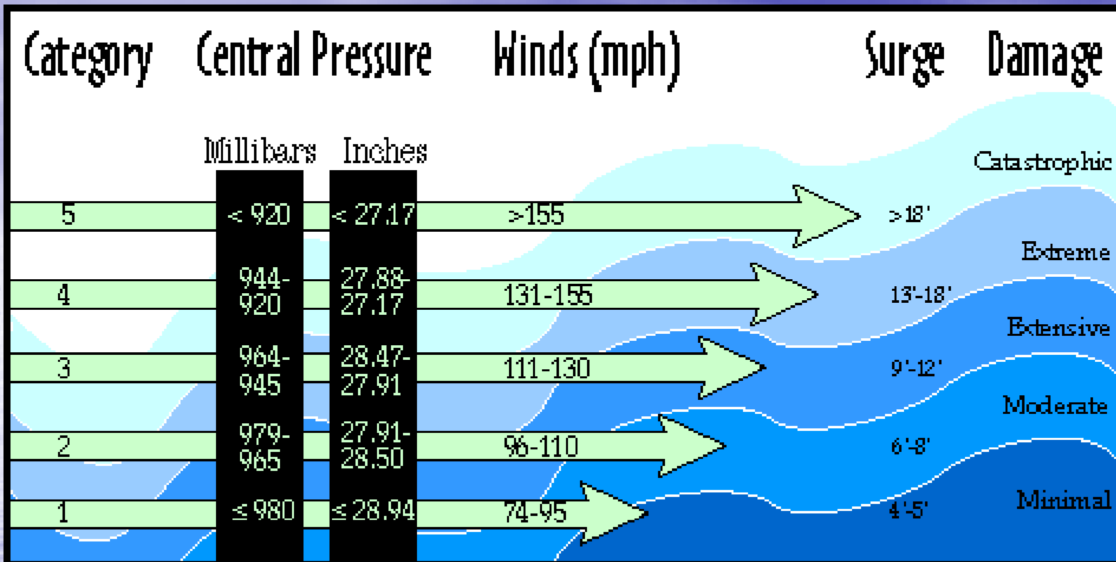
Global Tropical Cyclone Tracks

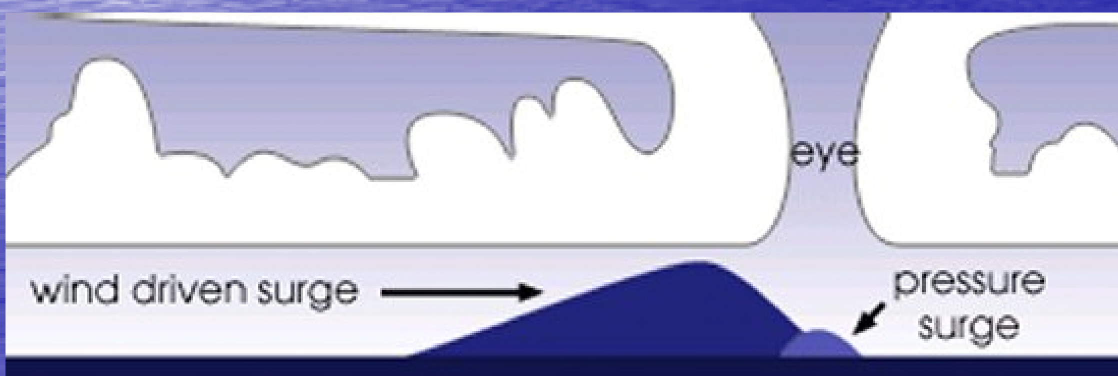


Which ocean basin has the most tracks? Why?

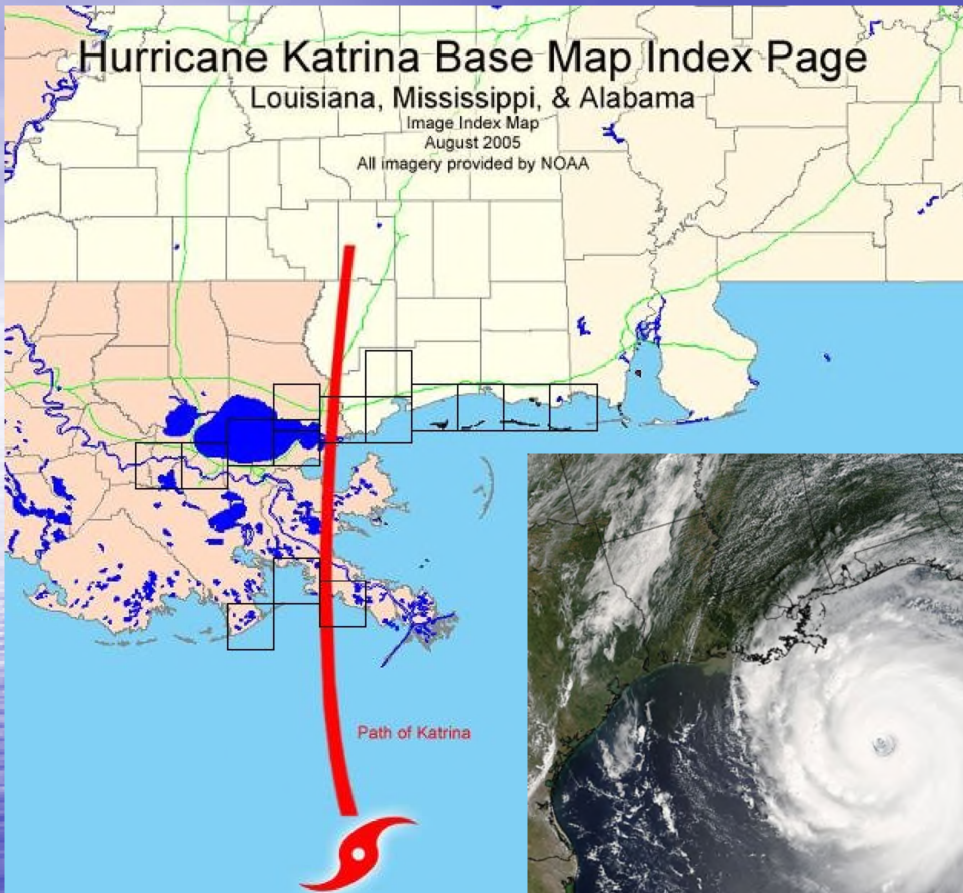
Which ocean basin has the least tracks?   Why?

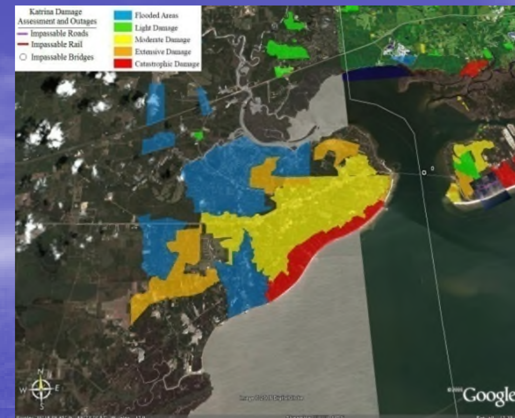
Hurricane Intensity Scale

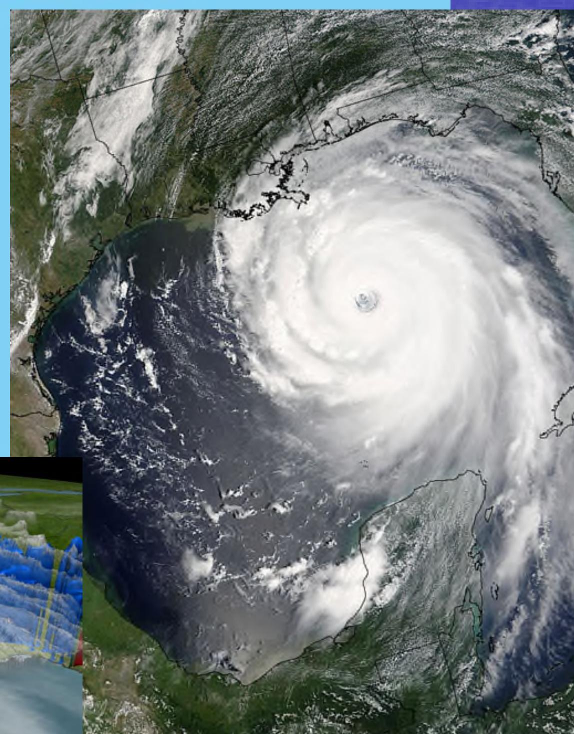


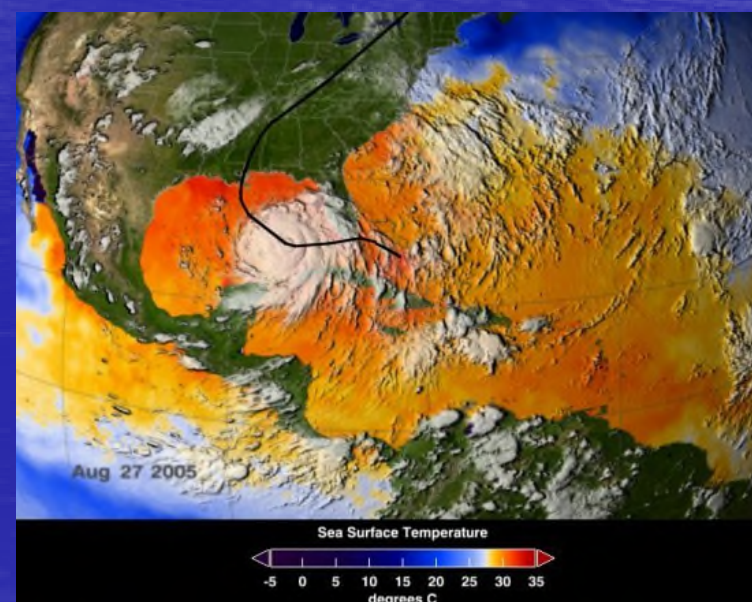


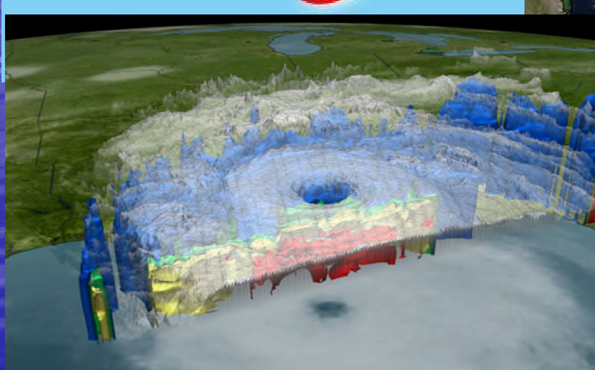
Hurricane Katrina



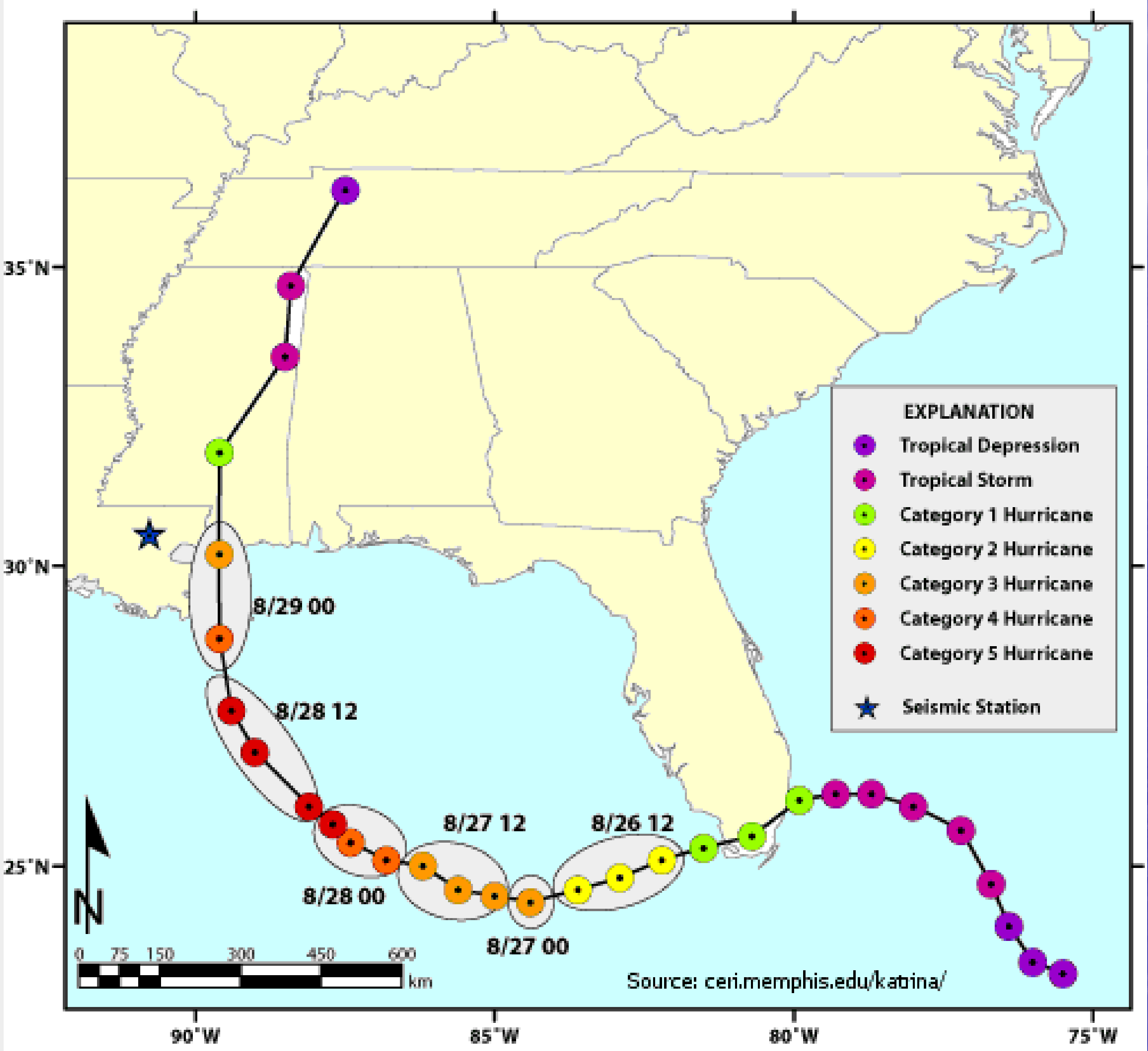








Path of Hurricane Katrina



Atmospheric Circulation

Review of Concepts

- Earth's atmosphere consists mostly of N_2 and O_2.
- Water in the ocean and atmosphere plays a paramount role in both, weather systems and moderating Earth's climate .
- Differential solar heating of Earth's surface produces an over-heated equator (low pressure) and under-heated poles (high pressure).
- Air pressure differences across Earth's surface power the winds.
- Earth's rotation causes moving air masses to curve – **left** in the N. Hemisphere and **right** in the S. Hemisphere, a.k.a. the **Coriolis Effect**
- The Earth has three major atmospheric wind belts in each hemisphere – a total of six around the planet
- Atmospheric circulation is responsible for the transfer of **2/3rds** of Earth's surface heat from the equator to the poles
- Colliding cold and warm air masses create cyclonic frontal systems
- Surface pressure and temperature maps used to track frontal systems
- Cold and warm fronts coincide with regions of stormy weather

Lab Discussion