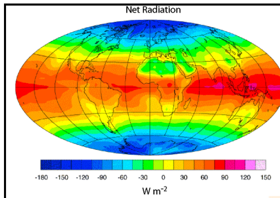
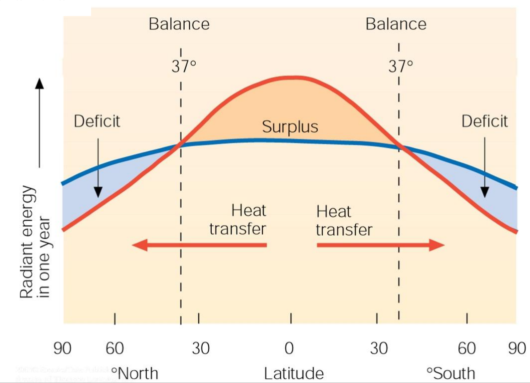
EXPLAIN

4. Horizontal Mixing by Winds & Currents

Energy Imbalances



Circulation of the atmosphere and oceans are driven by energy imbalances



What Makes the Wind Blow?

Three real forces (gravity, pressure gradient, & friction) push the air around

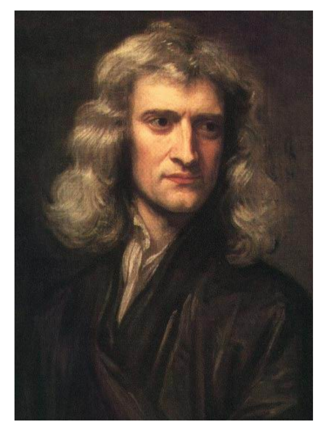
Two apparent forces due to rotation (Coriolis and centrifugal)

Large-scale flow is dominated by gravity/pressure and Coriolis … friction and centrifugal are also important locally

Newton

$$\sum \vec{F} = m\vec{a}$$

- Objects stay put or move uniformly in the same direction unless acted on by a force
- Acceleration is a result of the sum (net) of forces, in the vector sense



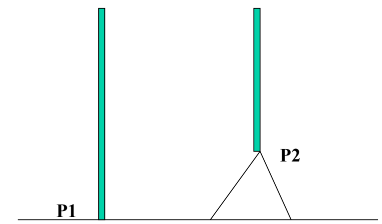
Forces Acting on the Air

- Pressure gradient force (pushing)
- Gravity (falling)
- Friction (rubbing against the surface)

- "Apparent" forces
  - The Coriolis Force
  - Centrifugal Force

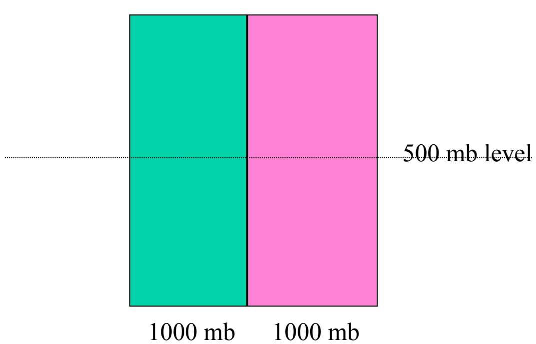
Why does pressure vary horizontally?

- Elevation changes cause pressure differences
- These are balanced by gravity and don't cause wind to blow
- *But why does pressure vary between locations which are at the same elevation?*

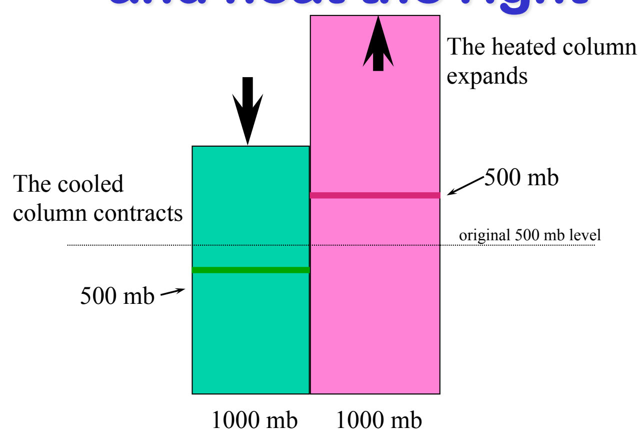


Thought Experiment:

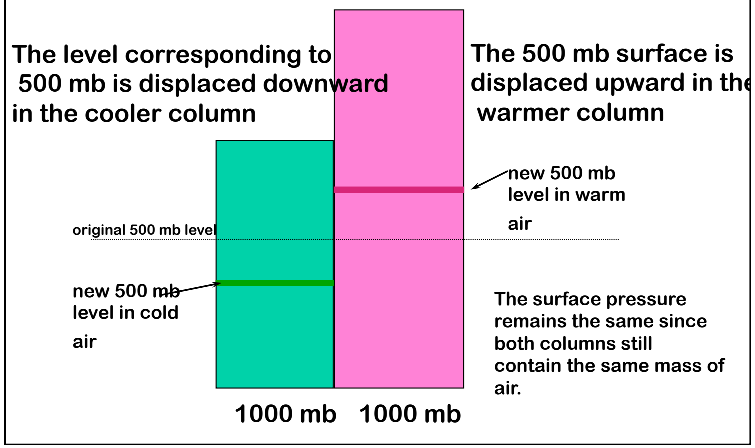
Consider two columns of air with the same temperature and distribution of mass



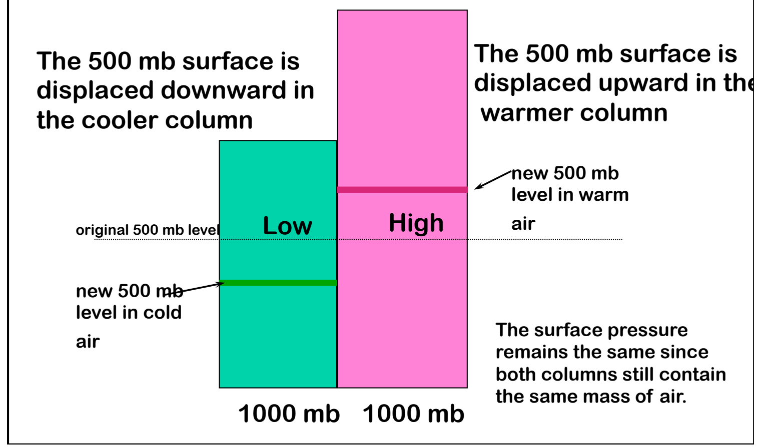
Now cool the left column and heat the right



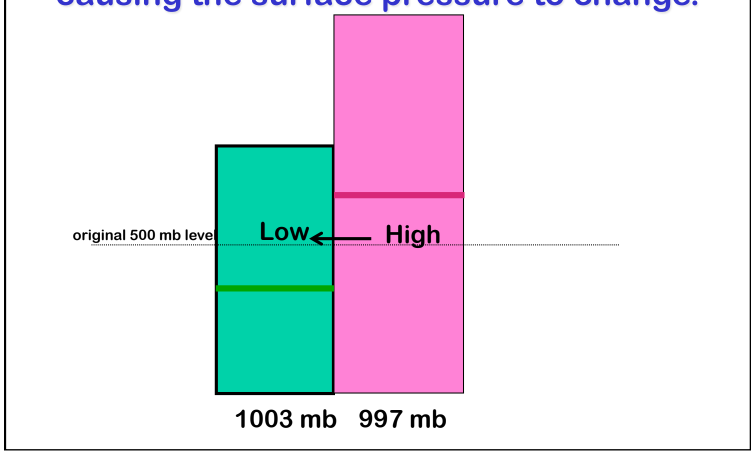
Height of the 500 mb surface changes; the surface pressure is unchanged



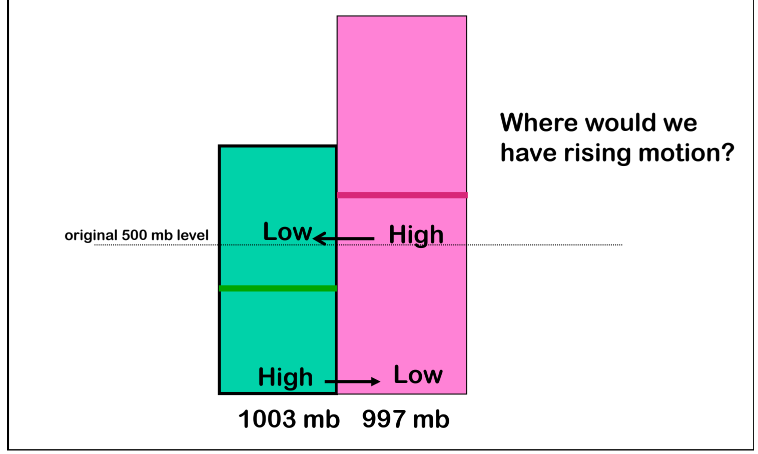
A pressure difference in the horizontal direction develops above the surface



Air moves from high to low pressure in the middle of the column, causing the surface pressure to change.



So air moves from high to low pressure at the surface…

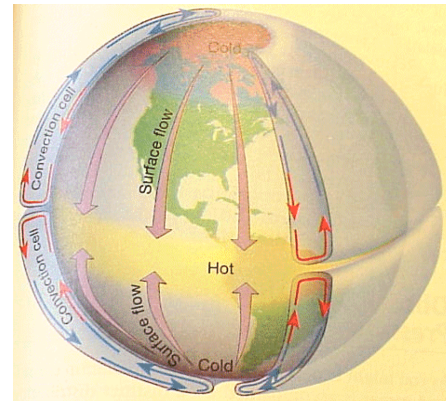


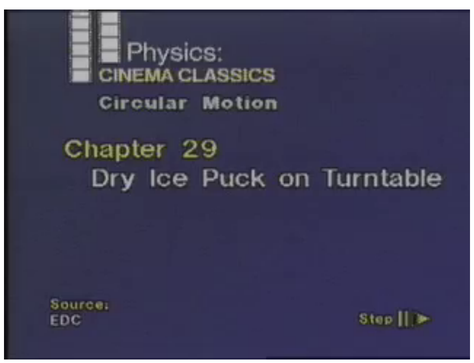
Thought Experiment Review

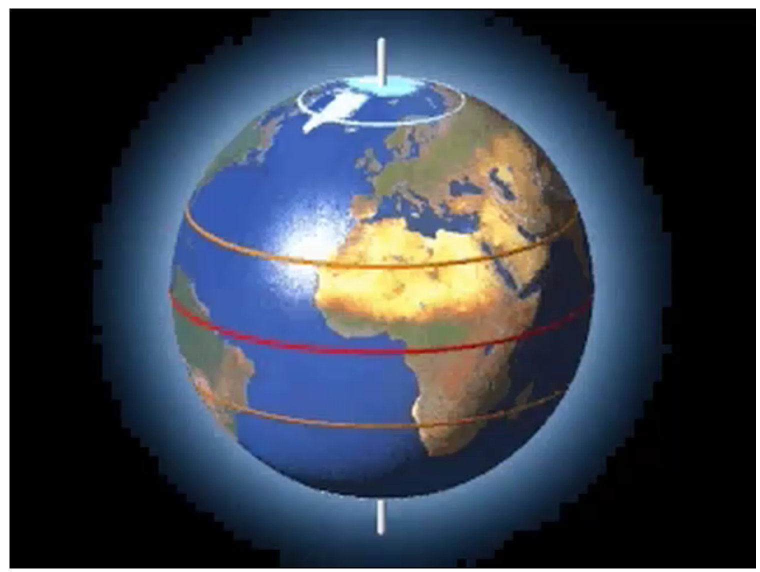
- Starting with a uniform atmosphere at rest, we introduced differential heating
- The differential heating caused different rates of expansion in the fluid
- The differing rates of expansion resulted in pressure differences aloft along a horizontal surface.
- The pressure differences then induced flow (wind!) in the fluid
- This is a microcosm of how the atmosphere converts differential heating into motion

If the Earth didn't rotate, it would be easy for the flow of air to balance the energy

- Thermal convection leads to formation of convection cell in each hemisphere
- Energy transported from equator toward poles
- Surface wind in Colorado would always blow from the North



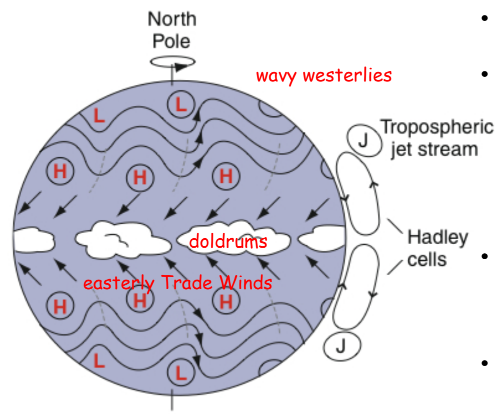




Coriolis Force

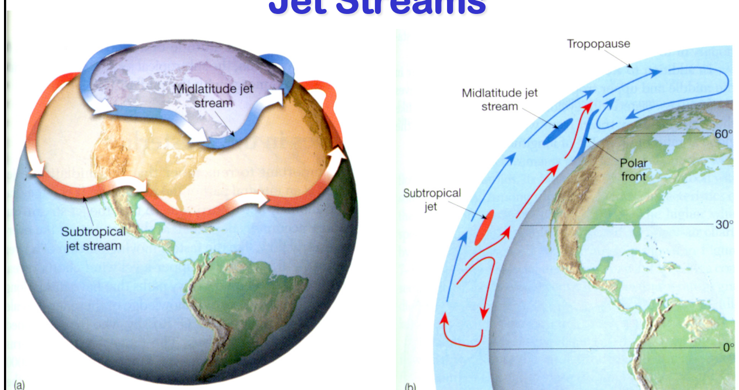
- Magnitude
  - Depends upon the latitude and the speed of movement of the air parcel
    - The higher the latitude, the larger the Coriolis force
      - zero at the equator, maximum at the poles
    - The faster the speed, the larger the Coriolis force
- Direction
  - The Coriolis force always acts at right angles to the direction of movement
    - To the right in the Northern Hemisphere
    - To the left in the Southern Hemisphere

Winds on the Rotating Earth



- Deep convective cells confined to tropics
- Condensation heating in rising branch of Hadley Cell lifts the center of mass of the atmosphere (converts latent to potential energy)
- Downhill slope toward winter pole produces jet streams in middle latitudes
- Jet is unstable to small perturbations, breaks down in waves we call winter storms

Jet Streams



- Subtropical Jet is zonal mean response to poleward flow in upper branch of Hadley Cell
- Polar front jet is response to south-north temperature differences

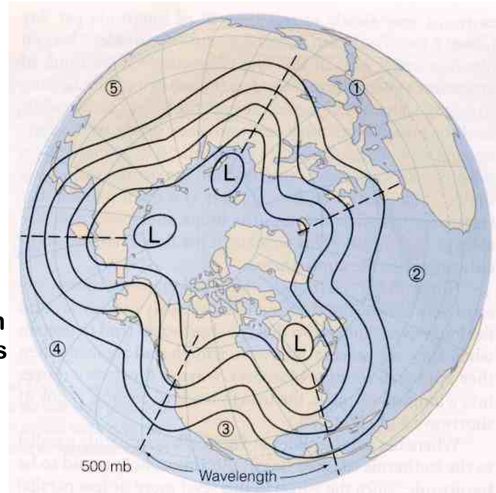
Eddies in the Jet Stream

- Momentum is *transferred from the earth* to the atmosphere in the *trade wind belt*.
- Momentum is *transferred from the atmosphere to the earth in the midlatitudes*.
- If the earth is always trying to slow down the midlatitude westerlies, why don't they weaken and disappear over time?
  - Eddies (storms) transfer momentum poleward in the upper troposphere.
  - This momentum transfer weakens the Hadley circulation, but drives the Ferrel cell.

Waves on the polar vortex

Hemispheric westerlies typically organized into 4-6 "long waves"

Wind blows through them, but the waves themselves propagate slowly (east to west!) or not at all



Polar Vortex

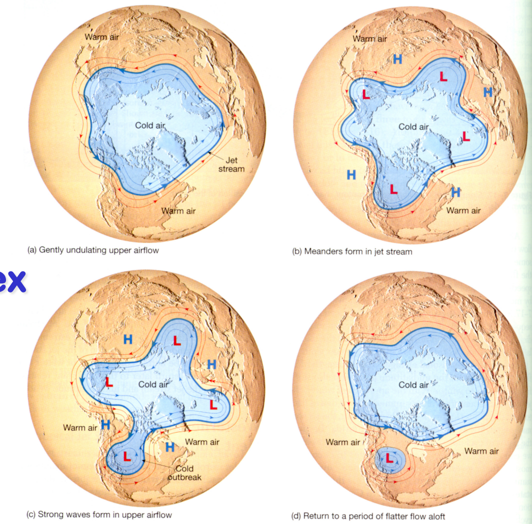
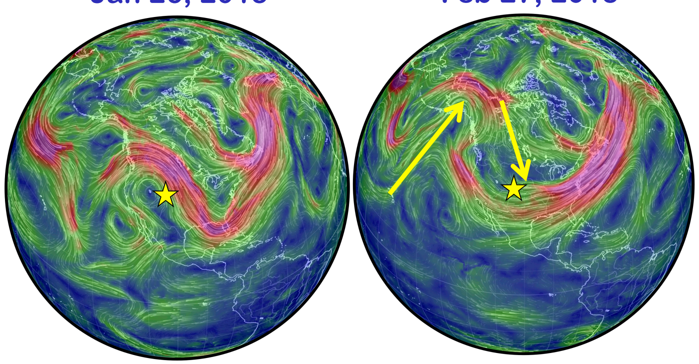


Figure 7–18 Cyclic changes that occur in the upper-level airflow of the westerlies. The flow, which has the jet stream as its axis, starts out nearly straight and then develops meanders and cyclonic activity that dominates the weather.

Changing Vortex

From http://earth.nullschool.net

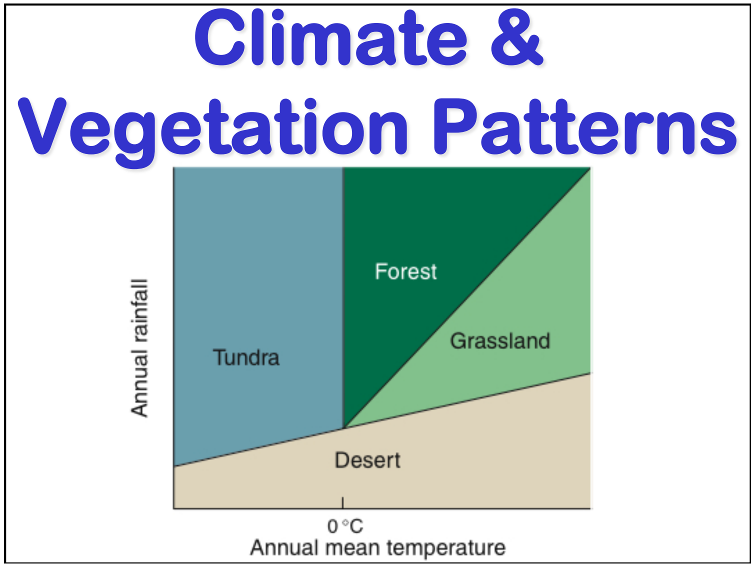
Jan 26, 2015 | Feb 27, 2015

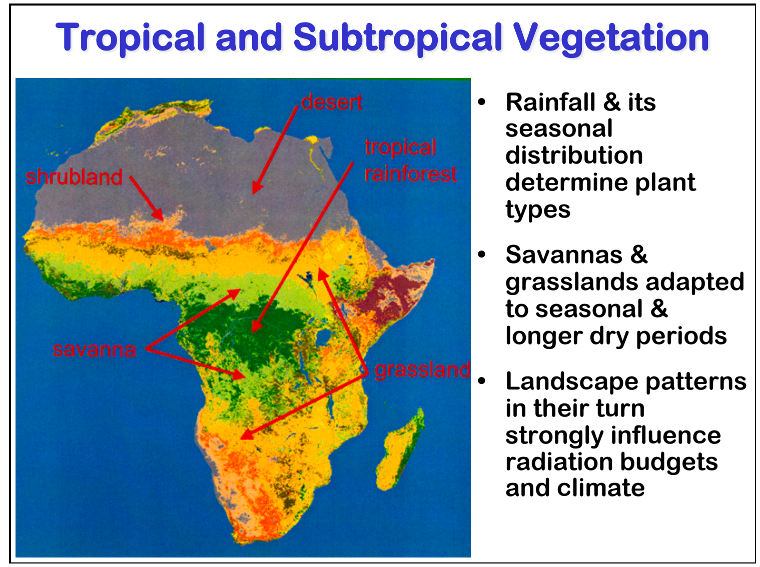


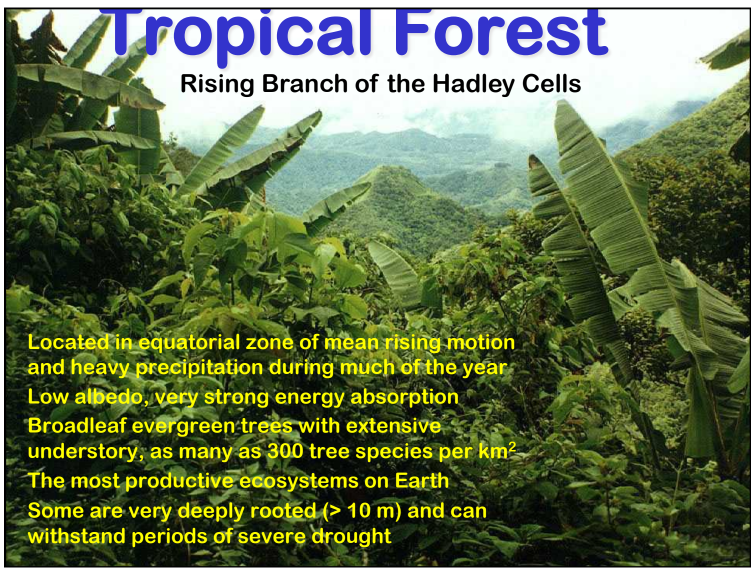
Fort Collins 75 °F | Fort Collins 20 °F

Atmospheric Circulation
in a nutshell

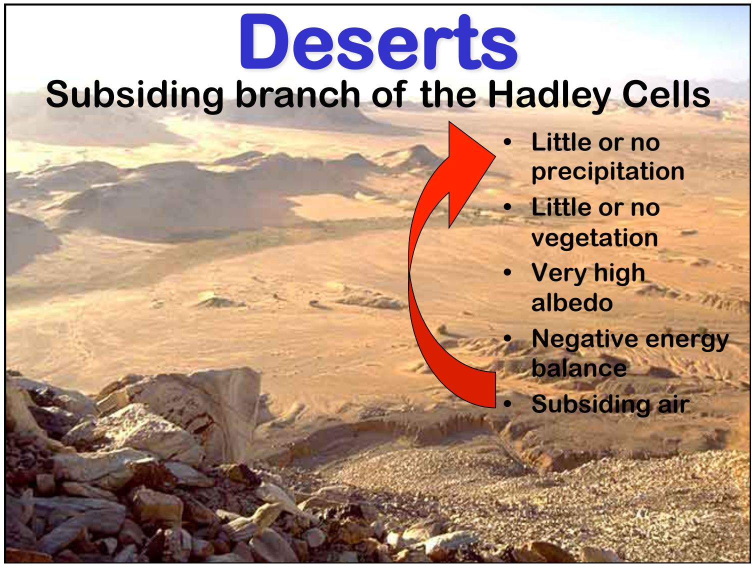
- Hot air rises (rains a lot) in the tropics
- Air cools and sinks in the subtropics (deserts)
- Poleward-flow is deflected by the Coriolis force into westerly jet streams in the temperate zone
- Jet streams are unstable to small perturbations, leading to huge eddies (storms and fronts) that finish the job

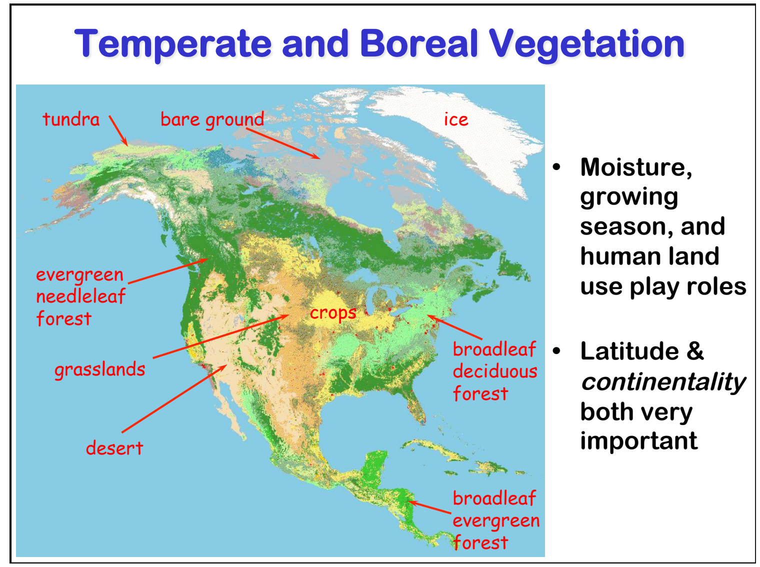

Climate &
Vegetation Patterns
Forest
Grassland
Tundra
Desert
Annual rainfall
0 °C
Annual mean temperature

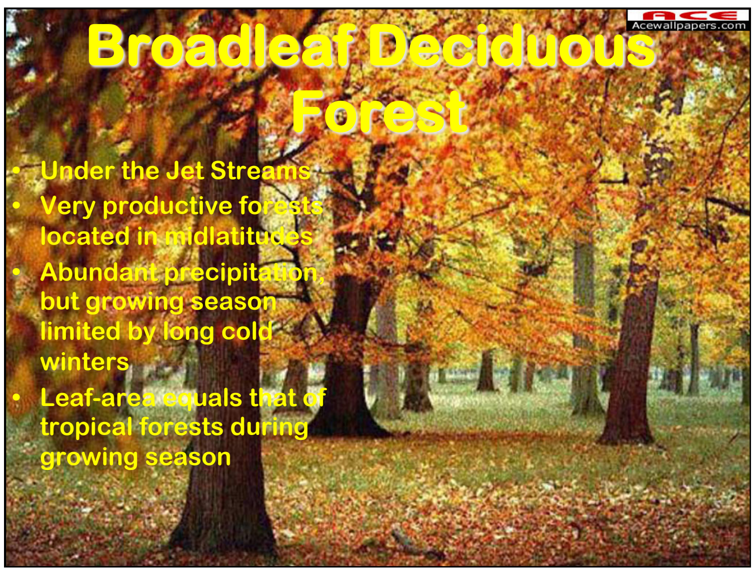

Tropical and Subtropical Vegetation
desert
tropical
rainforest
shrubland
savanna
grassland
• Rainfall & its seasonal distribution determine plant types
• Savannas & grasslands adapted to seasonal & longer dry periods
• Landscape patterns in their turn strongly influence radiation budgets and climate


Tropical Forest
Rising Branch of the Hadley Cells
Located in equatorial zone of mean rising motion and heavy precipitation during much of the year
Low albedo, very strong energy absorption
Broadleaf evergreen trees with extensive understory, as many as 300 tree species per km²
The most productive ecosystems on Earth
Some are very deeply rooted (> 10 m) and can withstand periods of severe drought


Grasslands & Savannas
• Seasonal Shifts of the Hadley Cells
• As much as 85% of biomass is belowground
• Highly adapted to drought, fire, and grazing
• May be very productive in rare wet periods


Deserts
Subsiding branch of the Hadley Cells
• Little or no precipitation
• Little or no vegetation
• Very high albedo
• Negative energy balance
• Subsiding air


Temperate and Boreal Vegetation
tundra
bare ground
ice
evergreen needleleaf forest
crops
broadleaf deciduous forest
grasslands
desert
broadleaf evergreen forest
• Moisture, growing season, and human land use play roles
• Latitude & *continentality* both very important

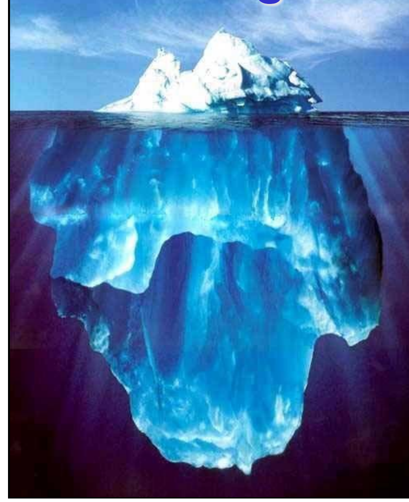

Broadleaf Deciduous Forest
• Under the Jet Streams
• Very productive forests located in midlatitudes
• Abundant precipitation, but growing season limited by long cold winters
• Leaf-area equals that of tropical forests during growing season


Boreal Forest
• Under the Jet Streams
• Mostly evergreen, needleleaf trees with little understory
• Short growing season, susceptible to drought and fire
• Low evaporative demand, so surface may be wet (bogs and fens)
• Very low albedo

Tundra

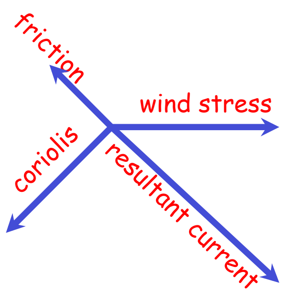
- Beyond the Jet Streams
- High latitudes: cold dry climates, but very little evaporative demand, so surface may be very wet
- Underlain by permafrost in many places
- Low-growing, non-woody plants
- Very short growing season
- Supports migratory mammals

Icebergs



- About 90% of an iceberg is under water
- Early sailors in N Atlantic (esp Vikings!) noticed that icebergs move 90° to right of the wind

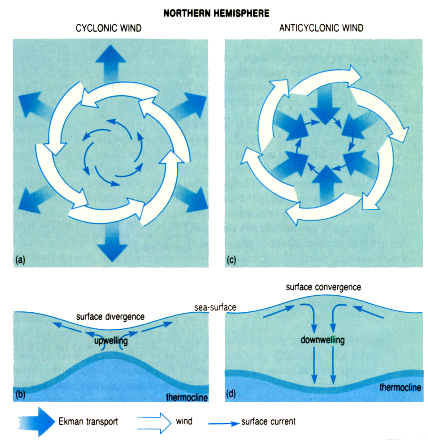
Force Balance



- Wind pushes surface water
- Friction couples surface to underlying water
- Friction always acts exactly opposite current motion
- Coriolis force is always perpendicular to current motion

RESULT: Surface current directed about 45° (right / left) of wind in (NH / SH)

"Ekman Pumping"



- Ekman flow in NH is 90° to the right of the wind stress
- Cyclonic wind (around low presure) forces divergence in water, and upwelling
- Anticyclonic wind (around high pressure) forces convergence and downwelling

Mid-Ocean Gyres

← 1000's of miles! →

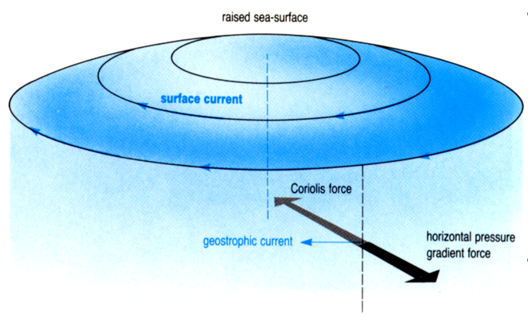
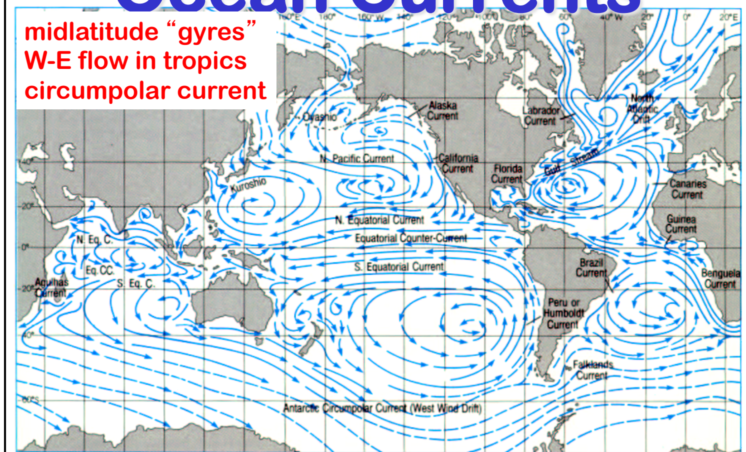


Figure 3.24 The generation of geostrophic current flow in a gyre driven by anticyclonic winds in the Northern Hemisphere. This current is driven by the wind only indirectly and persists below the wind-driven (Ekman) layer.

- Convergence of Ekman flow raises sea surface
- Rotating "dome" results

Ocean Currents

midlatitude "gyres"
W-E flow in tropics
circumpolar current



Gyres move A LOT of heat to poles!

Antarctica is isolated!

Remember

- More solar in than thermal out in tropics & vice versa at poles
- Job of the atmosphere & oceans is to move heat from tropics to poles!
- This is complicated by the rotation of the Earth (much worse on Jupiter!)
- Hadley Cells in tropics pass heat to jet streams in each hemisphere
- Ocean gyres move half the heat