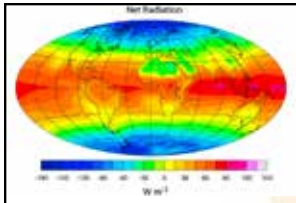
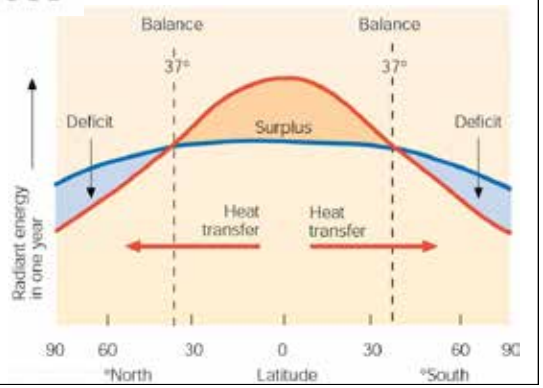
Winds and Weather

Please read Chapter 6 from Archer Textbook



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

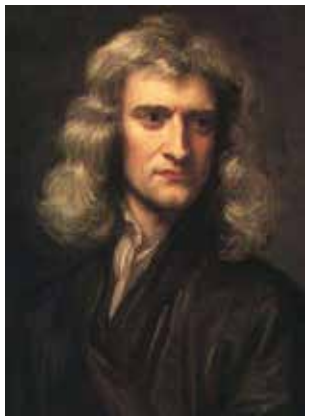
Two apparent forces due to rotation (Coriolis and centrifugal)

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



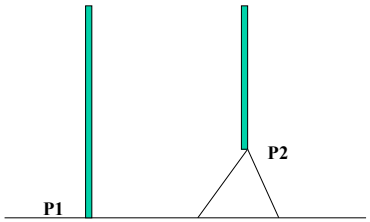
Forces Acting on the Air

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

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

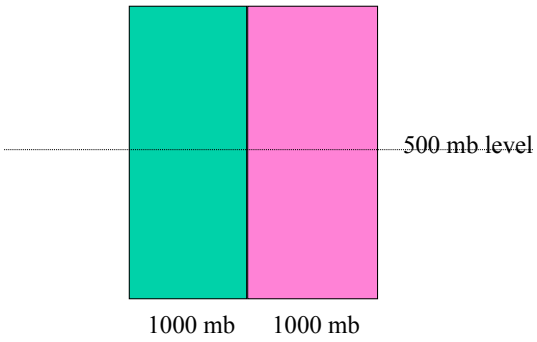
Why does pressure vary horizontally?

- 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?*

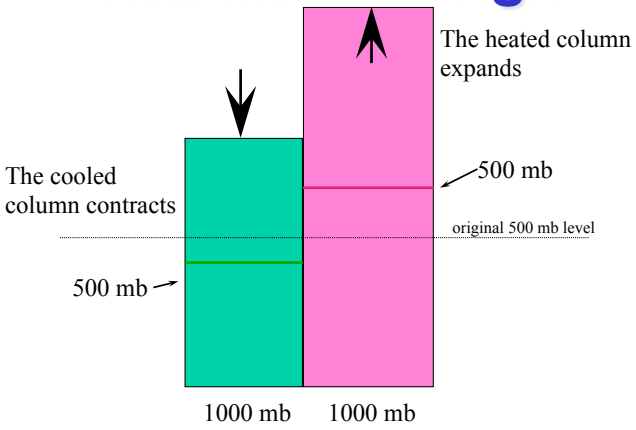


Thought Experiment:

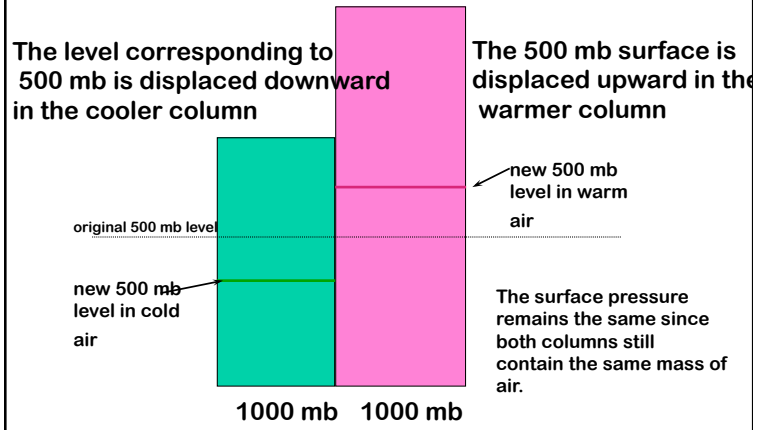
Consider two columns of air with the same temperature and distribution of mass



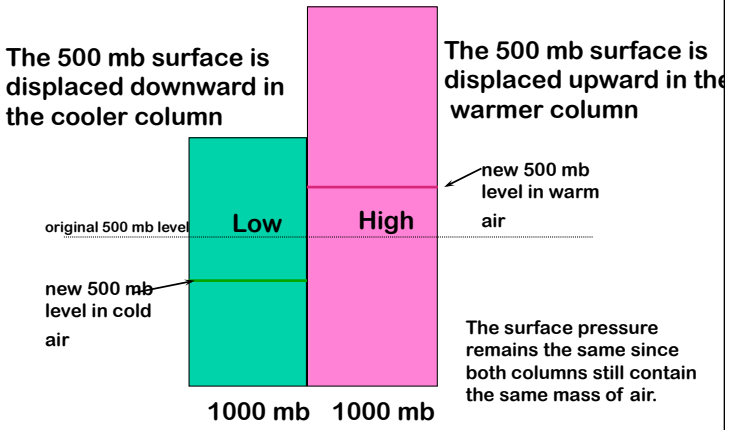
Now cool the left column and heat the right



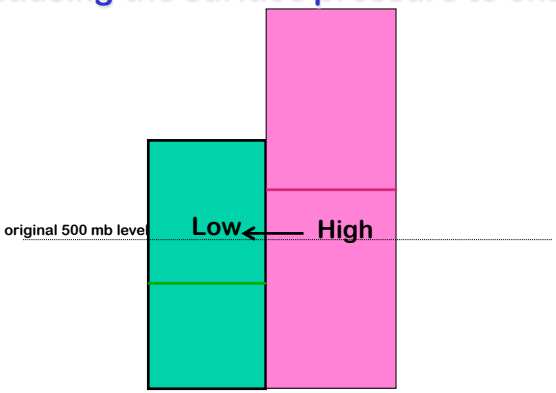
Height of the 500 mb surface changes; the surface pressure is unchanged



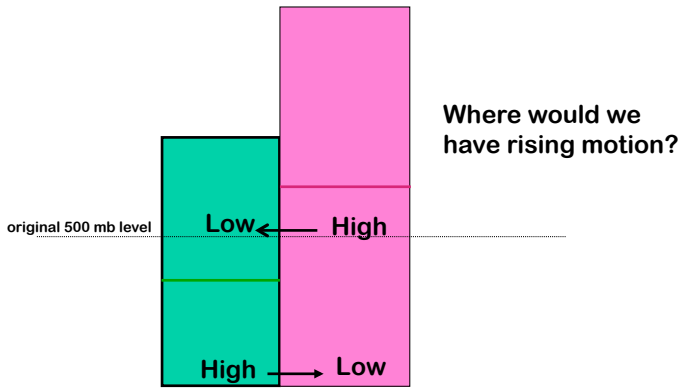
A pressure difference in the horizontal direction develops above the surface



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…

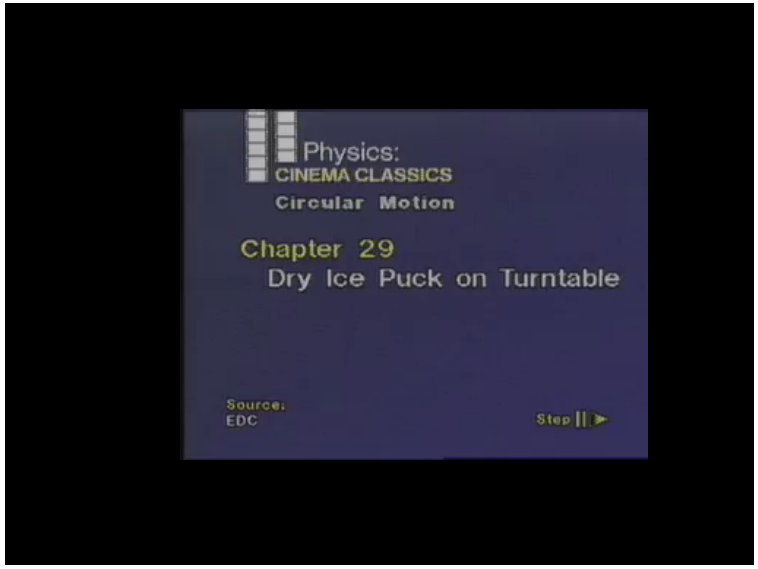


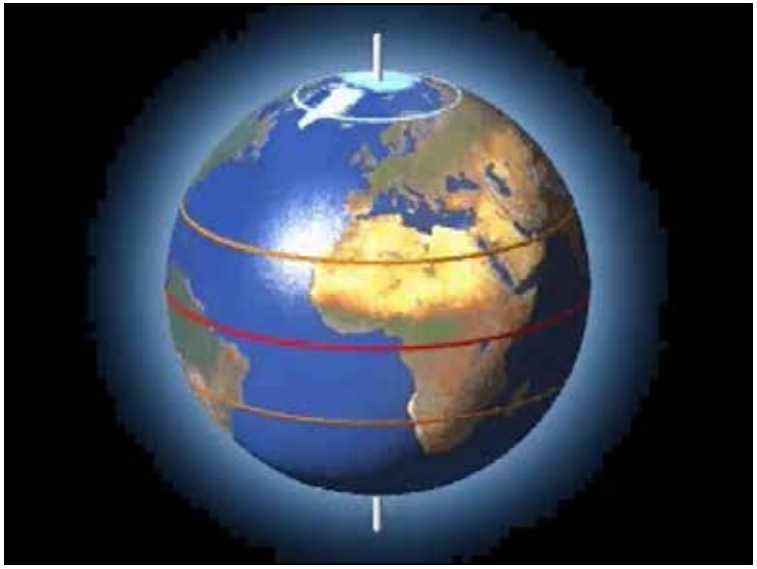
Thought Experiment Review

- 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

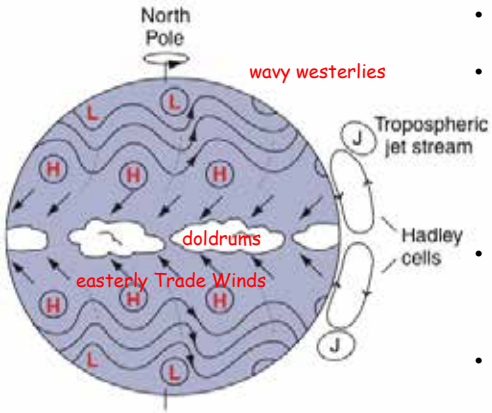




Coriolis Force

- 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

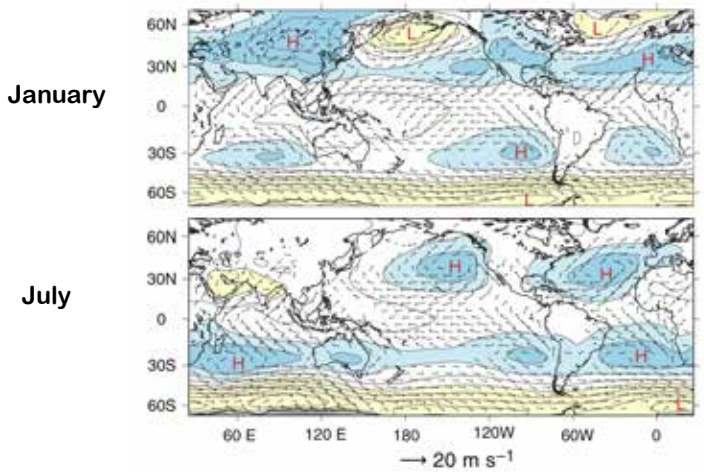


- Deep convective cells confined to tropics
- Condensation heating in rising branch of Hadley Cell lifts the center of mass of the atmosphere (converts latent to potential energy)
- Downhill slope toward winter pole produces jet streams in middle latitudes
- Jet is unstable to small perturbations, breaks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

Global Circulation

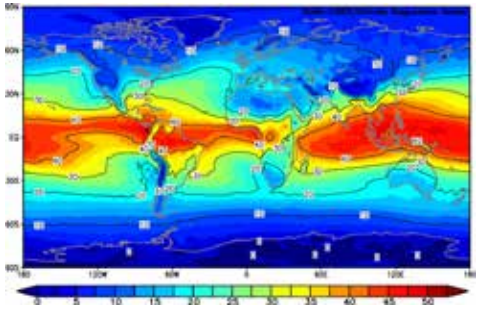
- Hadley cell (thermally direct cell)
  - driven by *N-S gradient in heating*
  - air *rises near equator and descends* near 30 degrees
  - explains deserts; trade winds; doldrums
- Ferrel Cell (indirect thermal cell)
  - driven by heat transports of *eddies*
  - air *rises near 60 degrees* and descends near 30 degrees
  - explains surface westerlies from 30-60
- Weak winds found near
  - Equator (doldrums)
  - 30 degrees (horse latitudes)
- Boundary between cold polar air and mid-latitude warmer air is the *polar front*

Surface Winds and Pressure



Atmospheric Water

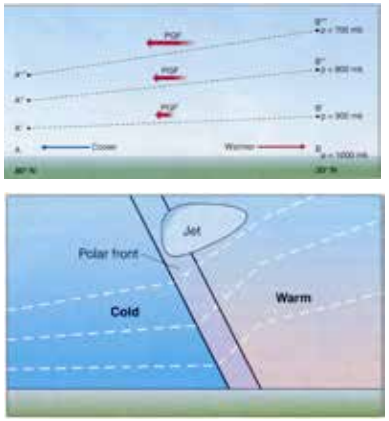
annual mean precipitatble water (mm)



- Mean ~ 25 mm (1 inch)
- Mean precip rate is about 2.6 mm/day
- Residence time ~ 9 days
- Very steady
- E ~ P ~ 2.6 mm/day

Source **http://www.cdc.noaa.gov/**
Reanalysis for *1968-1996*

Polar Front Jet



- Air density depends on temperature
- Warm air occupies more vertical space per mass (pressure depth)
- Tilt of pressure surfaces increases with height
- Coriolis force produces wind flow into screen
- Wind max (jet stream) occurs above steepest temperature gradient

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

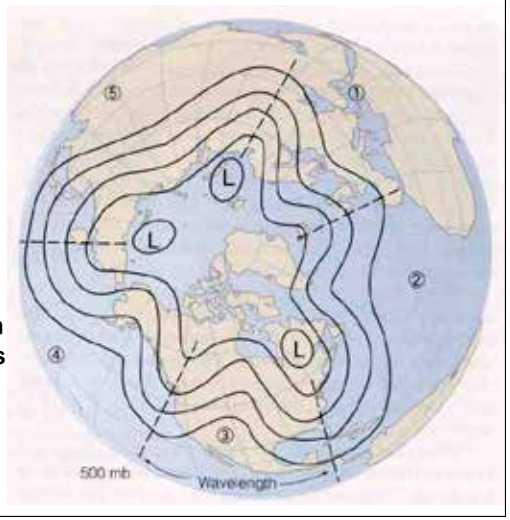
Eddies in the Jet Stream

- 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.

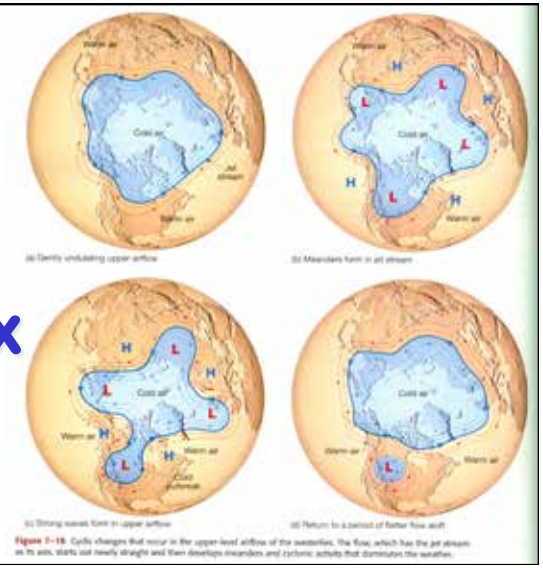
Waves on the polar vortex

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



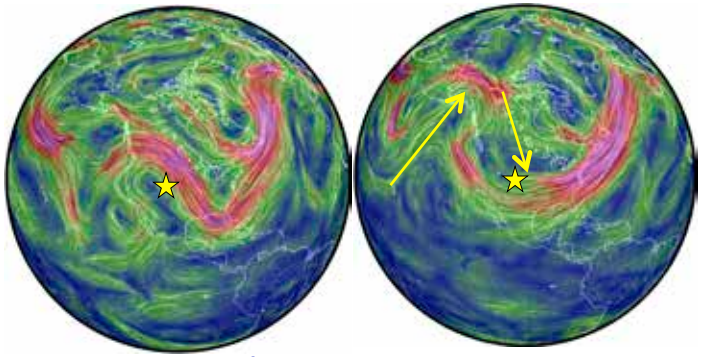
Polar Vortex



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