Lecture 15

This week (Week 5):

Continue describing another aspect of the "climate of the present", namely, atmospheric motions.

Today: Intro to concepts; Hadley circulation.

Next week:

Start "climate of the past".

Causes of air motion

Causes of air motion

1) Vertical motion

-Positive buoyancy (warm air rises)
-Negative buoyancy (cold air sinks)

2) Horizontal motion

- Pressure gradient force (air tends to move from high to low pressure)
- Friction, which slows down air movement
- Effect of Earth's rotation ("Coriolis effect")

Air circulation terminology

- convection/subsidence (vertical)
- convergence/divergence (horiz.)
- conservation of matter

Ultimate cause is the solar energy distribution

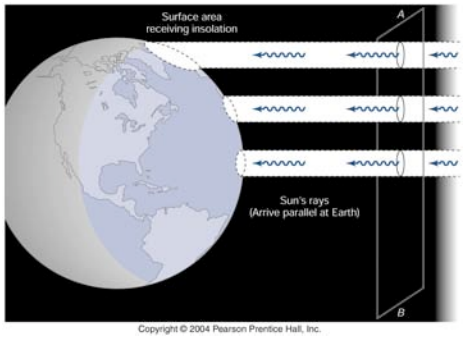
Layout of planet Earth

name	latitude range	portion of Earth surface
Tropics	0 to 30°	50%
Extratropics	30 to 90°	50%
Subtropics	~30°	
Midlatitudes	30-60°	37%
Polar Regions	60-90°	13%
Ocean		70%
Land		30%

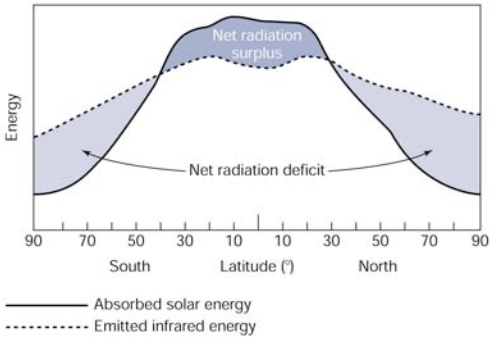
Note:
Most of Earth's surface: Tropics and/or Ocean. (These are the major components that a climate model needs to get right.)

Unequal distribution of solar energy with latitude: Fig 4-1

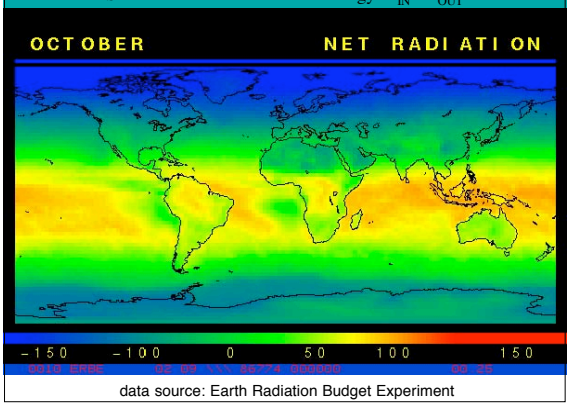
Recall: Flux is energy per unit surface area: (normal to the beam): W/m²



Net energy as a function of latitude: Fig 4-2

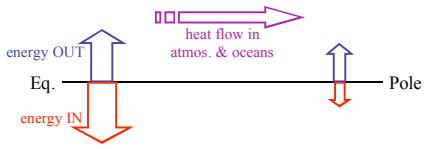


Satellite measurement of net energy: E_{IN} - E_{OUT}



data source: Earth Radiation Budget Experiment

Earth as a Heat Engine



With no atmosphere or ocean currents, low latitudes would continue to warm and high latitudes would continue to cool.

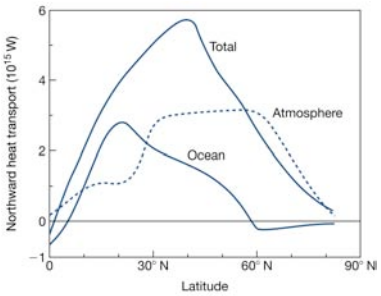
Atmosphere and ocean currents remove heat from Tropics and transport it to high latitudes. (Also from warm to cool regions on smaller scales - e.g. land/sea breezes.)

These currents cannot flow in one direction only - air and water would "pile up".

Result is "Circulation"
(warm currents poleward, cool currents equatorward)

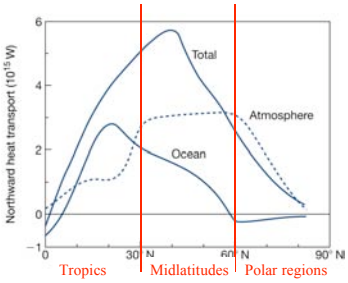
Heat transport from low to high latitude: Fig 05_16

Mechanisms:
(i) circulation of the troposphere
(ii) surface ocean currents
Note: These two are intimately connected.



Heat transport from low to high latitude: Fig 5-16

Questions:
1. What transports most heat in the tropics (ocean or atmosphere)?
2. What transfers most heat in the midlatitudes?



1. Oceans transport more heat than the atmosphere in tropics

2. Atmosphere transports most of heat in midlatitudes

Tropical Circulations

- Move heat from **source** regions to **sink** regions
- Have enormous consequences for regional/seasonal weather
- Three big ones...

Hadley circulation
- encompasses entire Tropics
- moves heat from low latitudes (near Equator) to higher latitudes (near 30°)

Monsoons
- move heat between land and ocean
- regional/seasonal

Walker circulation
- regional (but huge region)
- moves heat from warm Western Pacific to cooler Eastern Pacific
- strengthening and weaking of this is El Nino Southern Oscillation

George Hadley (1685-1768)

London lawyer and amateur scientist. Proposed the theory of planetary-scale circulation cells in a 1735 paper, "Concerning the Cause of the General Trade Winds"

Trade winds (or "trades") are easterly winds (i.e. blowing from the east) that occur most of the year in the tropics

Generally trade winds blow:
- from northeast in the northern hemisphere
- from southeast in southern hemisphere

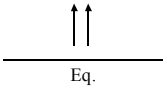
Winds within 30° of the equator were mapped in 1686 by Edmund Halley (of Halley's comet fame). But it took George Hadley to explain them.

Hadley Circulation - 1

buoyancy — rising and falling
(think of rubber ball in water vs rock in water)

density — mass per unit volume
less dense fluid rises
more dense fluid sinks

gas law — (see p. 57)
warm air is less dense



Hadley Circulation - 2

pressure gradient force

"gradient" refers to high and low pressure regions

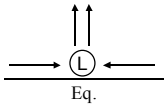
cause of horizontal air motions

induces air to flow from high pressure to low pressure

actual air motion is modified by:

friction

Earth rotation (Coriolis force)



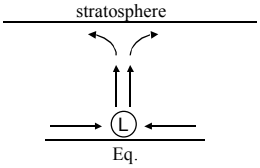
Hadley Circulation - 3

stratosphere

very stable region

vertical motion is inhibited

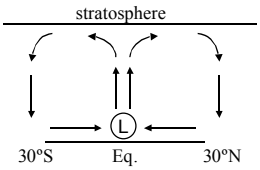
acts as a lid



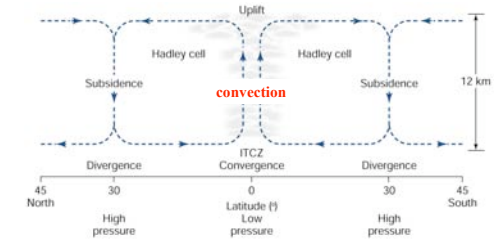
Hadley Circulation - 4

conservation of matter ... >>>>> **CIRCULATION**

The Hadley Circulation



Hadley Circulation - Fig 4-3



Horizontal motions

convergence: coming together

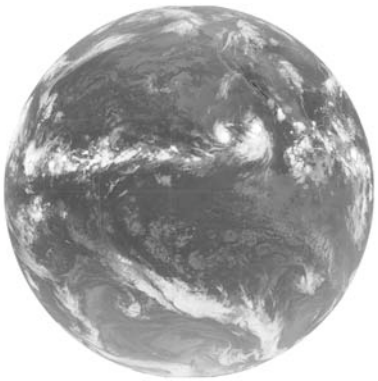
divergence: spreading apart

Vertical motions

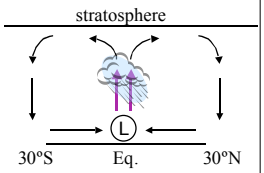
convection: rising air

subsidence: sinking air

IR satellite image ITCZ: Fig 04_07



Hadley Circulation - convection



Convection

- evaporation at surface
- phase change (liquid to gas)
- requires tremendous energy
- energy carried up as latent heat

specific heat of water: 4.2 J/g/°C

"It takes 4.2 Joules of energy to heat 1 gram of water by 1°C."

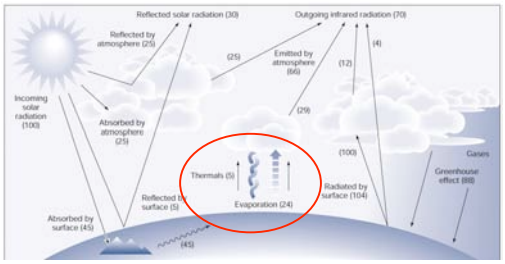
latent heat of water: 2500 J/g

"It takes 2500 Joules of energy to evaporate 1 gram of water."

- rising air expands and cools
- this causes water to condense when RH=100% (saturation)
- clouds form
- latent heat is released, causing the cloudy air to warm
- becomes less dense and more buoyant
- rises even faster >> towering cumulonimbus (thunderstorms)

Convection and the energy budget

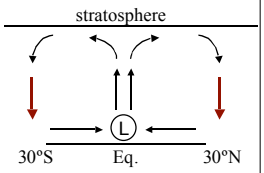
Huge amounts of energy (and moisture) are transported into the atmosphere by convection.



Hadley Circulation - subsidence & deserts

Subsidence & Subtropical 'High'

- sinking air compresses and warms
- this suppresses cloud formation
- absence of rain - deserts



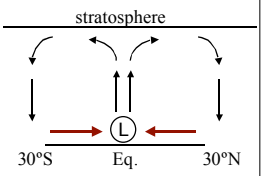
(c) Atacama

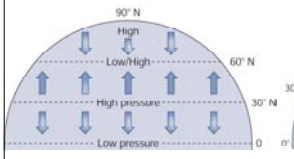
Atacama desert in northern Chile, one of the driest places on Earth.

Hadley Circulation - convergence

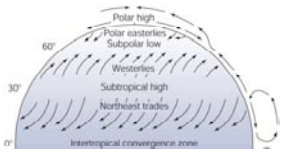
Low-level Convergence

- air forced upwards: "ITCZ" (Inter-Tropical Convergence Zone)
- horizontal motion modified by
  - friction
  - Earth's rotation (Coriolis Force)
- Coriolis: wind (or ocean current) veers right in N Hemi.





non-rotating planet



Earth