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

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 (horizontal)
   - Conservation of matter

Ultimate cause is the solar energy distribution

Layout of planet Earth:

<table>
<thead>
<tr>
<th>name</th>
<th>latitude range</th>
<th>portion of Earth surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropics</td>
<td>0 to 30°</td>
<td>50%</td>
</tr>
<tr>
<td>Extratropics</td>
<td>30 to 90°</td>
<td>50%</td>
</tr>
<tr>
<td>Subtropics</td>
<td>~30°</td>
<td></td>
</tr>
<tr>
<td>Midlatitudes</td>
<td>30-60°</td>
<td>37%</td>
</tr>
<tr>
<td>Polar Regions</td>
<td>60-90°</td>
<td>13%</td>
</tr>
<tr>
<td>Ocean</td>
<td></td>
<td>70%</td>
</tr>
<tr>
<td>Land</td>
<td></td>
<td>30%</td>
</tr>
</tbody>
</table>

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?

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 weakening of this is El Nino Southern Oscillation

Hadley Circulation

buoyancy rising and falling
(think of rubber ball in water vs rock in water)
density mass per unit volume
more dense fluid rises
less dense fluid sinks

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

George Hadley (1685-1768)


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.

1. Oceans transport more heat than the atmosphere in tropics
2. Atmosphere transports most heat in midlatitudes
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

stratosphere

Hadley Circulation - Fig 4-3

Horizontal motions
- convergence: coming together
- divergence: spreading apart

Vertical motions
- convection: rising air
- subsidence: sinking air

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: $4.2 \text{ J/g} ^\circ\text{C}$

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

latent heat of water: $2500 \text{ J/g}$

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

**Convection and the energy budget**

**Hadley Circulation - subsidence & deserts**

*Subsidence & Subtropical ‘High’*
- sinking air compresses and warms
- this suppresses cloud formation
- absence of rain - deserts

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

**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