Air moves towards ITCZ in tropics because of rising air - convection

Horizontal extent of Hadley cell is modified by
- Friction
- Coriolis “Force”

Speed from rotation

Objects at rest on Earth move at very different speeds depending on their latitude:

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poles (90°)</td>
<td>0</td>
</tr>
<tr>
<td>Seattle (47°N)</td>
<td>1400 km/hr</td>
</tr>
<tr>
<td>(1000 miles/hr)</td>
<td></td>
</tr>
<tr>
<td>Equator (0°)</td>
<td>1700 km/hr</td>
</tr>
</tbody>
</table>

Coriolis Effect

Toss a ball straight up while you are walking

Does it move horizontally “with you” as you walk?

What about when air at rest at latitude A is pushed toward latitude B?

Coriolis Effect for North-South Motions

Red Arrows represent motion of objects at rest on the surface
The yellow arrow shows the deflection to the right of the tip of the upper red arrow head
The green arrow shows the deflection to the left of the tip of the middle arrow head

Coriolis Effect for East-West Motions

Not expected to repeat argument for this one

Facts about the Coriolis Effect

- Displaces winds to the right in the NH (left in the SH) - Think tropical trade winds
- Only acts on something (like the wind) when it is in motion on a rotating body
- It is zero on the equator
- It’s a fictitious force, but a useful concept
- Doesn’t affect water in your sink

What if the Earth were a cylinder? Where would the Coriolis effect act?
Cold sinking air - leads to high pressure at surface. Surface flow is toward the tropics.

Surface flow causes polar front zone to slope
Front is wavy in the horizontal - high temperature gradient on rotating plane fuels atmospheric waves

Polar front causes jet stream
The J stands for jet stream
-Strong temperature gradient causes ...
-Large horizontal pressure gradient along the red dashed line
-Large pressure gradient must be balanced by Coriolis force

Horizontal Plane through Jet
Low pressure (to the north)
\[ P_G \uparrow \rightarrow V_G \]
High pressure (to the south)
\[ C \downarrow \rightarrow \]
Forces in balance give Geostrophic Flow
\[ P_G = C \]
The Jet Stream is a Geostrophic Wind

Like isobars

300 mb Height Map - Contours of topography of the 300mb pressure surface at a "snapshot"
-Wind direction is along contours
-Wind speed is highest where contours are close
-Winds, while meandering, are westerly
-Jet stream is very wavy
Surface Low - Storm

- Short-lived roughly circular isobars
- Geostrophic flow is circular
- But friction destroys geostrophic balance
- So actual flow is converges slightly into low.
- Air has to go somewhere, so it goes UP, making lows cloudy.
- Opposite for high

Earth-Sun relationship

**Eccentricity** = Difference of orbit from a perfect circle
- Earth’s orbit is slightly elliptical
- Closest to sun during January so sun is slightly brighter in SH than NH summer

**Obliquity** = Tilt of earth’s axis of rotation
- Causes seasons
- Currently 23.5°
- Anybody recognize that number?

**Fig 4-15**

Obliquity

Eccentricity

152 mi km

147 mi km

Wet season follows the ITCZ

**Seasonal movement of Hadley Circulation**

**Fig 4-16**

Land/Ocean Contrasts:

Ocean surfaces change temperature far more slowly than land surfaces

- Two main reasons:
  - Specific heat capacity of water is higher than soil
  - Turbulent transfer of heat (absent for land) mixes heat downward, away from surface

- Minor reasons:
  - Thermal conductivity of water is higher
  - Solar radiation is transmitted many meters into the ocean, transferring heat away from the surface

**Daily or diurnal effect: Fig 4-17**
Land/Ocean Contrasts and their implications

- Albedo - which is higher?
- Thermal inertia which is higher?
- Friction at interface with atmosphere - which is higher?

Implications

- Sea breeze on diurnal (daily) cycle
- Cold land - warm ocean in winter (vice versa in summer)
- Surface high over land - low over ocean in winter (vice versa in summer)

Continentality: Seasonal range of temperature extremes is much greater over land than ocean. The range is largest in the middle of large continents - Gobi Desert is largest of all.

Seasonal range of temperature is larger in the high latitudes than the midlatitudes, and midlatitudes over the tropics - Why?

Fig 4-19

Things to note about Fig 4-19

Highs over land and lows over ocean in winter (vice versa in summer)

So little land in southern hemisphere that it is more “zonal” (flow along latitude circles)

These are averages over a month - instantaneous pressure maps are more messy

Monsoon Circulations:

“seasonal reversal of the winds” - concentrated rainy season

Circulation explanation is same as for land/sea breeze but on seasonal timescale and larges spatial scale

Largest at about 10 deg N and S - location of ITCZ in summer (latitude of peak solar flux plus surface convergence)

Largest one is the Indian Monsoon owing to Tibetan Plateau a source of evaporation (and then condensation) at high elevation

Water cycle picture Fig 4-24a

Advection: Horizontal transport by atmospheric winds. Can transport things other than clouds too.
Rainy season is high in summer in continental climates due to convection.

One more desert:

*Antarctica* receives about 5 cm precipitation as water equivalent per year.

- So cold that humidity is low
- High elevation dries out air on upslope path
- Zonal flow in the Southern Hemisphere allows few storms to reach the pole

Circulation Drivers

- Heat transfer - sensible, latent, radiation
- Water transfer - evaporation and precipitation
- Momentum transfer - winds

All from the surface!

Wind Driven Circulations

- Gyres
- Ekman transport
**Surface winds** Fig 4-11

5-1

**Surface currents** Fig Simple Idealized Picture

**Fig 5-2 Gyres are not symmetric**

- Warm water
- Cold water
- Stagnant water

**Fig 5-3a Ekman drift (in the NH!)**

- Surface water is dragged along with the wind
- Deflected somewhat to the right by Coriolis effect
- Friction drags layers beneath
- Also deflected to the right by Coriolis effect
- Spiraling pattern
- Net transport of water to the right of the wind.

**NH Vertical slice**

PGF = Pressure Gradient Force - due to the sea surface height gradient

**Horizontal view**

**Vertical slice**

**Cycle in NH:**

- Pressure Gradient Force (PGF)
- Ekman transport
- Surface divergence
- Surface convergence
- Downwelling
- Upwelling
- Constant density lines
The Ekman mechanism is also responsible for coastal upwelling and downwelling.

North wind
- Water transported away from the coast
- Deeper water will be pulled up to compensate for the loss
- Coastal waters are COLD

Opposite for South wind

Northern Hemisphere

Equatorial Upwelling
- Trade winds blow toward the west
- Ekman flow transports water poleward in both hemispheres
- Upwelling cold water fills gap

West coast of North America in summer
Upwelling cold water
In what direction are the winds blowing?

How gyres get their shape

Circulation

Surface height

Driven by density gradients
Density is a function of both temperature and salinity.

- Temperature - thermal expansion
- Salt water is heavier than fresh (pure) water, so density increases with salinity.

Thermohaline Circulation
Thermohaline circulation or “conveyor belt” (also strengthens Gulf Stream)

Is conveyor belt a bad name?
It’s not a nice ribbon, downwelling in plumes, upwelling is messy, communication is not instant, etc

The ocean is heated from above.
- Because warmer water is lighter, this helps create a stable environment, with little vertical motion.
- Unlike the atmosphere!

With no vertical circulation
If we waited a long time...
What would happen to the temperature?

Fig 5-6 Vertical distributions of Density, Temperature, Salinity

Where is it cold?
Salinity is measured in parts per thousand

Where is it salty?

Sea ice influence on the ocean

- Reduces the influence of the winds
- Insulates the ocean (prevents it from losing heat)
- Rejects salt when it grows / Adds freshwater when it melts

Deep water production

Takes place at high latitudes during the wintertime
- Cold atmosphere extracts huge quantities of heat
- Sea ice expelled salt as it grows

If it becomes dense enough, it will sink to the depths of the ocean in small-scale “chimneys” or plumes
This dense water spreads throughout the global ocean
Eventually upwelling over such a large area that is nearly impossible to detect

Thermohaline Circulation Facts(?)

- Takes about 1000 years for a chunk of water to make the circuit
- Sinking occurs in North Atlantic not Pacific because (still debated) Atlantic has higher salinity, Better connected to Arctic Ocean, etc
- The Southern Ocean is also a site of deep water formation.

Heat transport by the ocean (in order from tropics)
- Ekman transport along the equator transports warm water poleward
- Gyre circulations (warm water goes poleward on western side of gyre, cool water goes equatorward on eastern side)
- Thermohaline circulation warm surface water moves poleward in the Atlantic
Ocean influence on climate:
Warm ocean (cold land) in winter keeps coastal areas warmer than continent interiors
Northern North Atlantic is warmer than it would be without the thermohaline circulation

So how can the ocean influence climate?
Short time scales (less than a few years)
The contrast in the heat capacity of the land and ocean has a profound effect on our climate’s seasonality and its response to increasing greenhouse gases.
The ocean plays a critical role in the El Niño phenomenon, a periodic climate "oscillation" centered in the equatorial Pacific.

Long time scales (greater than a few years)
Changes in the global thermohaline circulation, which warms the North Atlantic when it is strong, can affect temperatures in that region.
Long-term changes in sea ice coverage can affect the planet’s energy balance.
Changes in ocean ecosystems because of ocean circulation changes probably have a large influence on climate on time scales of hundreds to thousands of years. Ocean ecosystems help regulate CO₂ concentrations in the atmosphere, and hence the greenhouse effect.

Phytoplankton photosynthesize - use sunlight and intake CO₂ to produce O₂.
- Deplete surface waters of nutrients
- Deposit nutrients at depth when they die and sink
- So deep water is nutrient rich
- Hence phytoplankton serve as a marker for upwelling.

Ocean color from Seawifs satellite
“lighter colors” are high in phytoplankton indicating upwelling

Why are phytoplankton high in the northern North Atlantic?

Recall that the temperature (and density) of the high latitude ocean is relatively constant with depth. In addition to sinking plumes, the ocean here also allows deep mixing or "convection", which brings up nutrients.

Isotopes - are atoms of a given element that have different mass (or number of neutrons).
Carbon on Earth comes in ¹²C, ¹³C, and ¹⁴C (for example 12 is for 6 protons and 6 neutrons).
Unstable isotopes spontaneously (though perhaps slowly) change into another isotope or element via radioactive decay.
What does this have to do with climate?
Examples:
Evaporation of heavy water is more likely if the ocean is warmer
Photosynthesis consumes CO₂ isotopes at different rates depending on a number of things

\(^{14}\text{C}\) is all about its decay to \(^{12}\text{C}\). Live biota acquire \(\text{^{14}C}_2\text{O}\) from breathing. Once they die, the source of \(^{14}\text{C}\) is gone

Radiocarbon difference with respect to surface
Orange = most recently at surface

Half-life of \(^{14}\text{C}\) is 5730 years