Winds and Ocean Circulations

AT 351
Lab 5
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Sea Surface Temperatures
Temperature Structure of the Ocean

Ocean Currents
What causes ocean circulation?

- The direction of most ocean currents is determined largely by the wind
- Coriolis force acts to turn the moving water to the right (in the NH)
- Friction directly opposes motion
- Resulting current at the surface moves 45° to the right of the surface wind (in the NH)

Ekman Flow

- As you get deeper into the ocean, the flow is weaker and curved more toward the right
- Mean motion is 90° to the right of the wind
Ekman Pumping

- Ekman flow turns ocean to the right of the wind
- Cyclonic wind leads to divergence of water and upwelling in the center
- Anticyclonic wind leads to convergence of water and downwelling in the center

Ocean Gyres

- Idealized gyre is a rotating “dome” of water
- Real world gyres are asymmetric
- Eastern boundary current is wider and moves more slowly vs. faster western boundary current (e.g. the Gulf Stream)
Idealized vs. Real World

Coastal Upwelling

- Along west coast of U.S. prevailing wind is from the north
- Ekman pumping along western coasts leads to ocean moving away from the land
- Need upwelling to compensate – colder deepwater moves up near the coast
- Ocean temperatures off the coast of California are typically much colder than at similar latitudes on the east coast
Walker cell

- West Pacific has warmer water and deeper thermocline due to the easterly current near the equator
- Warmer water promotes convection
- Air diverges at the tropopause and cool, dryer air tends to sink in the East Pacific
- Goes hand in hand with the trade winds

el nino and la nina

- Typical trade winds keep the western Pacific warm and the thermocline deep
- When these trade winds relax, the water is allowed to move further east
- Other extreme is la nina
- During el nino (la nina) the Pacific has warmer (colder) than average sea surface temperatures
Impacts of el niño

- Convection over the Pacific shifts east
- Walker cell moves with convection, changing circulation patterns all over
- Warmer winter in United States
- Drought in northern Australia and Southeast Asia
- Intense rains and flooding in Peru and Ecuador
- Coastal upwelling shuts off near Peru, harming the fishing business

Thermohaline Circulation

- Circulation in the ocean is also caused by density differences
- Density differences come from differences in temperature (thermo) and salinity (haline)
- In the north Atlantic, freezing leads to high salinity content
- Cold, salty water sinks and forms NADW
- Warmer water moves in at the surface to replace the mass lost
Thermohaline Circulation

So, the winds move the ocean – Why are there winds?

- Winds are primarily driven by temperature differences
- Pressure is linked to temperature through the ideal gas law, so we typically look at differences in pressure
- Rotation of earth plays a role in determining patterns of wind
- Convection and advection act to transport energy in the vertical and horizontal, respectively
Pressure and Temperature

Another way of looking at it

- Because of the changes in air density, a surface of constant pressure (shaded gray area) rises in warm, less-dense air and lowers in cold, more-dense air.
- Where the horizontal temperature changes most quickly, the constant pressure surface changes elevation most rapidly.
- This means that we can show pressure changes by plotting height changes on a map of constant pressure.
Height vs. Pressure Surfaces

- When we look at a map of surface pressure, what is plotted is pressure contours on a constant height surface (sort of)
- When we look at the upper levels, what is plotted is height differences on a pressure surface

Pressure Gradient Force

- Air wants to move from areas of high pressure to low pressure
- The pressure gradient force is always pointed directly from high to low pressure
- A stronger pressure gradient will yield stronger winds (isobars packed more closely together on a map)
Coriolis Force

- Air is accelerated towards lower pressure by the pressure gradient force, but is turned to the right (in the NH) due to the rotation of the earth
- Coriolis force is strongest at the poles and weakest at the equator
- Coriolis force is also proportional to the wind speed – stronger winds are turned more

Geostrophic Wind Approximation

- If the pressure gradient force and coriolis force balance each other, the wind is said to be geostrophic
- Geostrophic wind moves parallel to isobars
- This can be a good approximation above about 1 km
**Centrifugal Force**

- An apparent force that occurs when the pressure gradient force and the coriolis force are not in balance
- Causes air to move in circular patterns around areas of high and low pressure
- Depends on the wind speed and radius of curvature
- Always directed away from the center of a circle
  \[ F = \frac{v^2}{r} \]

**Friction**

- Wind near the surface (lowest ~1km) is slowed down by friction caused by the ground
- Friction always acts opposite the direction of the wind
- Magnitude depends on the wind speed and the roughness of the surface
- Slows the wind so that the coriolis force no longer balances the pressure gradient force
What the real force balance looks like

- The net effect of all of the forces combined acts to turn the wind about 30° towards low pressure near the surface
- Winds converge toward lows and diverge around highs

- High pressure is typically associated with sinking motion and clear weather
- Low pressure is typically associated with rising motion and stormy weather
Turbulence in the atmosphere

- **Causes of turbulence**
  - **Thermal turbulence**
    - Caused by differential heating of the surface
    - Heating causes turbulence to extend higher in the atmosphere
  - **Mechanical turbulence**
    - Caused by ground roughness
    - Stronger at the surface than thermal turbulence, but does not extend as high
- Thermal and mechanical turbulence work together to magnify and influence each other
- More instability and turbulence can pull down higher velocity air from the upper atmosphere, increasing surface winds.
Small Scale Circulations: Land/Sea Breezes

- Solar heating raises land temperature more than water
- Air in contact with land warms and rises
- Cooler (denser) sea air moves in to replace rising air over land
- Air sinks over the water in response to surface air movement, producing return circulation (land-to-sea breeze) aloft
- Land breezes form at night due to stronger radiative cooling of the land surface leading to sinking and offshore flow of this cooler air mass with return flow aloft
- The presence of a sea breeze circulation can have significant impacts on the daily temperature cycle
Small Scale Circulations: Mountain/Valley Breezes

- Sunlight heats mountain slopes during the day and they cool by radiation at night
- A difference in air density is produced between air next to the mountainside and air at the same altitude away from the mountain
- Density difference produces upslope (day) or downslope (night) flow
- Daily upslope/downslope wind cycle is strongest in clear summer weather when prevailing winds are light

Small Scale Circulations: Downslope Windstorms (Chinook)

- Caused by the interaction of winds with topography (i.e. the Front Range)
- Air rises on the windward side of a mountain, as it rises it cools, and most of the water condenses (adding its latent heat to the air) and rains out
- On the leeward side, the air accelerates downward, warming as its pressure rises, leading to high winds that warm and dry the air
Dust Devils

- Dust devils (unlike tornadoes) usually form on clear sunny days
- Hot air at the surface becomes buoyant and begins to rise
- The presence of some kind of barrier causes the wind to be deflected and rotate the rising air
- While most dust devils are small and harmless, some have been known to cause significant damage to homes

Wind Shear

- Differences in temperature lead to tilting pressure surfaces
- Surfaces tilt more with height
- This means that the pressure gradient force is stronger, so the winds will increase with height
Jet Streams

- Subtropical jet is zonal mean response to poleward flow in upper branch of Hadley Cell
- Polar front jet is response to meridional temperature gradients

Monsoon circulations

- Monsoons work like a giant land/sea breeze phenomenon
- In the summer the land is much warmer and something like a sea breeze forms, bringing a huge increase in precipitation
- In the winter the circulation reverses, and dry weather dominates