Further Reading: Chapter 06 of the text book

Outline

- the hydrosphere and the hydrological cycle

- humidity

- consequences
Hydrosphere-2

- Only ~3% of water takes other forms
  - Most is trapped in the form of ice and glaciers
  - This leaves only 0.02% of all water which is “active” in that it actively cycles between the oceans, land, and atmosphere
The Hydrological Cycle-1

Represents the constant cycling and movement of water between the oceans, land and atmosphere
Humidity

- Specific Humidity:
  - How much water vapor is in the atmosphere
  - Given as kg(water)/kg(air)
**Saturation Humidity**

- **Saturation humidity**: Maximum amount of water the atmosphere can hold for a given temperature

  - Saturation humidity depends nonlinearly on temperature of the atmosphere
Relative Humidity

Ratio of Specific Humidity to Saturation Humidity

- Given as percentage
- Highest percentage is 100%, i.e., specific humidity is equal to saturation humidity
  - Atmosphere is saturated
  - If water is added, it must go into liquid, not vapor; i.e. it condenses out
Dew Point Temperature

- Given a fixed amount of water vapor, how much would we have to cool the parcel to have water begin to condense out
- Always less than or equal to the actual temperature
Further Reading: Chapter 06 of the text book

Outline

- adiabatic processes

- dry and wet adiabatic lapse rates

- ascent versus descent
**Adiabatic Processes**

- **Adiabatic process**: Process in which there is no external source or sink of energy
  - No solar heating
  - No longwave heating
  - There can be latent heating
  - Can allow latent heating because this represent internal energy within the atmosphere
  - Essentially, we are talking about process where the air parcel does not interact with the surrounding air
Pressure-Temperature Relation

- If we raise an air parcel, the pressure of the air around the parcel decreases
- The parcel expands and the temperature decreases
**Adiabatic Lapse Rate**

- **Adiabatic Lapse Rate:** The temperature change of a hypothetical parcel of air as it moves up in the atmosphere

- **Dry adiabatic lapse rate** - the temperature change of a parcel of unsaturated air

  - It is equal to 10-degrees/km
  - Constant
Lifting Condensation Level

- **Level at which clouds will form**

![Diagram showing lifting condensation level with temperature and altitude axes.](Image)
Moist Adiabatic Lapse Rate-1

- **Moist adiabatic lapse rate**: The temperature change of a parcel of saturated air as it rises.
Ascent vs Descent

- Let’s follow a parcel as it rises above the LCL then comes back down.
- Initially the parcel’s temperature changes according to the dry adiabatic lapse rate.
- Once it hits the LCL however, condensation releases latent heat that warms the parcel somewhat as it rises, hence it follows the moist adiabatic lapse rate and its temperature doesn’t change as much with height.
- As the parcel descends, however, there is no condensation so there is no gain or release of latent heat; hence the temperature change is purely due to pressure effects, i.e. it follows the dry adiabatic lapse rate as it warms.
- Note, when it reaches the bottom, it is warmer than when it started; this is due to warming as latent heat is released.
- Also, note that the specific humidity will be lower, as will the relative humidity, hence the parcel will be drier.
Further Reading: Chapter 06 of the text book

Outline

- stability and vertical motions

- five examples

- orographic precipitation
Introduction

- **Convection:**
  - Process in which we find localized *vertical motion* due to *instabilities* in the atmosphere
  - Key criteria is *stability*
Stability

- **Stability:**
  - When something tends to return to where it started
- **Instability:**
  - When something tends to continue in the direction it is initially moved

- What makes air stable or unstable?
- Need to consider one more **lapse rate**
**Lapse Rates**

- **Environmental lapse rate:**
  - The actual (or measured) temperature change of the air with respect to altitude

- **Density**
  - The number (or weight) of molecules in a given volume
  - $\rho=1/T$: Density is proportional to the inverse of temperature
  - If parcel is cooler (more dense) than surrounding air it will sink
  - If parcel is warmer (less dense) than surrounding air it will rise
Example: #1

- Dry Adiabatic Lapse Rate
- Moist Adiabatic Lapse Rate
- Environmental Lapse Rate

Absolutely Unstable

\( \gamma_e > \Gamma_d, \Gamma_m \)
Example #3

- Dry Adiabatic Lapse Rate
- Moist Adiabatic Lapse Rate
- Environmental Lapse Rate

Temperature vs. Height diagram showing:
- 3 km
- 2 km
- 1 km

Environmental Lapse Rate is greater than both the dry and moist adiabatic lapse rates in this region, indicating absolutely stable conditions:

\[ \gamma_e < \Gamma_d, \Gamma_m \]
The deepest cloud development occurs under unstable conditions with warm, moist air

- Common to tropics
- Also common to the southern, central and eastern US in the summer
Further Reading: Chapter 06 of the text book

Outline

- what is a cloud?

- cloud classifications

- clouds and precipitation
Cloud Type by Form

- **Clouds:**
  - Optically thick mass of suspended water drops or ice crystals

- One form of classification is based on **appearance or form**

**Cirrus:** Thin wispy clouds

**Stratus:** Layered clouds with fairly continuous coverage

**Cumulus:**

Individual clouds characterized by heaped, puffy appearance
Have vertical extent, from 1-3km up to tropopause
Cloud Type by Altitude-01

- Can also classify them based on their **altitude**
  - “Cirro”
  - “Alto”
  - “Strato”
  - “Fog”

**Cirro**
High clouds (7-18) km
Cold (<-25 C) with exclusively ice crystals

**Cirrus**: high, wispy clouds

**Cirrocumulus**: high, puffy clouds
Cloud Type by Rain

- Finally, we can classify them based on the presence of rain
- **Nimbus:** any cloud that rains

**Cumulonimbus:** vertical clouds that produce rain

**Nimbostratus:** low, flat clouds that drizzle
Further Reading: Chapter 07 of the text book

Outline

- vertical structure

- surface circulation

- 3D circulation
Vertical Structure

- Three main levels to the ocean
- These levels are stratified by temperature with warmer water on top and cooler water at the bottom
- **Upper mixed layer**
  - Well mixed by winds at the surface
  - Therefore it’s fairly homogeneous with respect to temperature
  - This is where oceans interact with the atmosphere (i.e. like in El Nino)
- **Thermocline**
  - Rapid transition to colder waters
  - Produces a strong barrier between surface waters and deep waters
- **Deep layer**
  - Extends to the bottom of the ocean
  - Has some variability in it but is also generally homogeneous
**Surface Circulation-1**

- Two types of circulation: **surface circulations and thermohaline circulations**
  - Circulations at the surface generally referred to as “**gyres**”
  - These circulations are produced by the frictional drag exerted by the winds
    - easterlies produce “westward” currents
    - westerlies produce “eastward” currents
  - They are also affected by the presence of continental barriers which deflects currents north and south
    - Note that in the southern hemisphere there are westward currents circling the entire globe
Thermohaline Circulation
Further Reading: Chapter 07 of the text book

Outline

- terminology

- characteristics of ENSO

- impacts
Terminology

- **El Nino**
  - Warming of the sea surface temperatures in the eastern tropical Pacific

- **La Nina**
  - Cooling of sea surface temperatures in the eastern tropical Pacific

- **Southern Oscillation**
  - Changes in surface winds/atmospheric circulations over the equator associated with El Nino

- **ENSO (El Nino/Southern Oscillation)**
  - The coupled response between ocean and atmosphere circulations over the tropical Pacific
Exceptionally intense trade winds come together in the Intertropical Convergence Zone (ITCZ), which is relatively far North, and the huge convective zone to the west of the date line, where sea surface temperatures exceed 28°C.

The eastward surface current between 3N and 10N, which is known as the North Equatorial Countercurrent because it flows counter to the prevailing winds, is relatively weak.

The westward South equatorial current is extremely strong, especially near the equator, where divergent motions cause intense upwelling and hence low sea surface temperatures.

The thermocline, the layer of large vertical temperature gradients that separates the warm surface waters from the cold waters at depth, slopes steeply to the west, where its depth is approximately 150 meters.
El Niño Conditions

The trade winds have collapsed, to be replaced in the west by westerly winds.

The eastward movement of the convective zone is associated with –

- an eastward expansion of warm surface waters,
- a thermocline that is elevated in the west and depressed in the east,
- an intensified eastward North Equatorial countercurrent,
- a weakened westward South Equatorial Current that is replaced by an eastward equatorial jet in the west,
- very weak equatorial upwelling
**Southern Oscillation Index (SOI)**

The *Southern Oscillation Index* (SOI) is defined as the difference in surface level pressure between Tahiti and Darwin (Australia).

During an El Nino there is high pressure at Darwin and low pressure area near Tahiti, in the mid-equatorial Pacific. The SOI is therefore **negative**.

Likewise, during the La Nina events, the SOI is **positive**.
Movement of Tropical Convection

- As the water moves east, the region of convection moves east
- In addition, the rainfall associated with the convection moves east -> find droughts over the western Pacific
- At the same time, rainfall increases over the eastern Pacific -> floods in Peru
Further Reading: Chapter 08 of the text book

Outline

- air masses

- air masses of the world and of N. America

- fronts: warm, cold and occluded
• **Air Masses**

  – Large bodies of air with (more or less) uniform properties (temperature and moisture)

  – Properties reflect properties of the source region

  – Described bases upon

    • **Latitude** (defines temperature)
    • **Surface type** (defines moisture content)
### Classification of Air Masses

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<td>Continental</td>
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<td>Continents</td>
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</table>

- Ex.: cA - Continental Arctic
  - mP - maritime Polar
Air Masses of the World

- The maritime tropical airmass (mT) and maritime equatorial air mass (mE) originate over warm oceans
  - high specific humidity
  - capable of producing heavy precip

- The continental tropical airmass (cT) originates over the subtropical deserts of the continents
  - substantial water vapor
  - low specific humidity

- Polar air masses (mP, cP) originate in the subarctic latitude zone
  - mP has low water vapor (moderate precip)
  - cP originates over N. America and Eurasia (low humidity and very cold)

- The continental arctic (cA) and antarctic (cAA) air masses are extremely cold and have little or no water vapor
– Warm air is less dense than cool air
– The warm air rises over the cool air
– As it does so, it goes through “adiabatic cooling” which allows moisture to condense into clouds and rain
– Typically there is gradual lifting leading to relatively mild precipitation
- Warm air is forced to flow over the cooler air
- As it does so, it goes through “adiabatic cooling” which allows moisture to condense into clouds and rain
- For these fronts, the boundary tends to be sharp with strong instability, leading to heavy precipitation
Occluded Front

- Similar to cold front in that warmer air is forced to rise over cold air
- Cold fronts move along the ground faster than warm fronts
- Thus, a cold front can overtake a warm front
- The warm air mass may be completely lifted off the ground
- For these fronts you may find hail and sleet -> as rain from the warm air falls through the cold air below it, it freezes and forms hail
Further Reading: Chapter 08 of the text book

Outline

- tornadoes

- tropical storms

- Storm surge
Tornadoes

- Usually these are very small phenomenon - approximately 300m in diameter
- Winds however can become very intense - approx. 300-400 km/h
- How they form
  - Usually there is strong wind shear - change in wind with height
  - This produces roll-like features
  - Now assume that there is also convective activity
  - The convection lifts one end of the roll and pushes down the other end, creating a vertical funnel

![Diagram of Tornado Formation](image)
Development of Tropical Cyclones-1

1) Warm, moist air spirals towards center of Hurricane

2) Convergence of air forces air to rise

3) As air rises, moisture condenses out, warming air and allowing it to continue rising

4) As air rises, it causes even lower pressures at the surface

5) As pressures decrease, winds intensify and even more warm moist air is forced to converge and rise

The Movie
Storm Surge

- Damage from hurricanes comes in many forms but by far the most destructive is the storm surge.
- High seas, large waves, and flooding associated with a rise of local sea level accompanying the passage of a hurricane.

- Storm surge movie:
  - Here we see that the storm surge is caused by two factors: one is the winds pushing water on shore, the other associated with water being lifted by the low pressure in the center of the storm.