

Water and Atmospheric Moisture

(Christopherson – Chapter 5)

I. Introduction - (What causes precipitation?): One of the fundamental questions we will answer in the next few sections is "What causes precipitation?" This is a complex and involved process, but includes some major, important steps.

- Evaporation
- Lifting of Air
- Cooling of Air (Adiabatic Cooling)
- Condensation
- Cloud Formation
- Precipitation Formation

II. Moisture Inventory

A. Water Covers 71% of the Earth's surface.

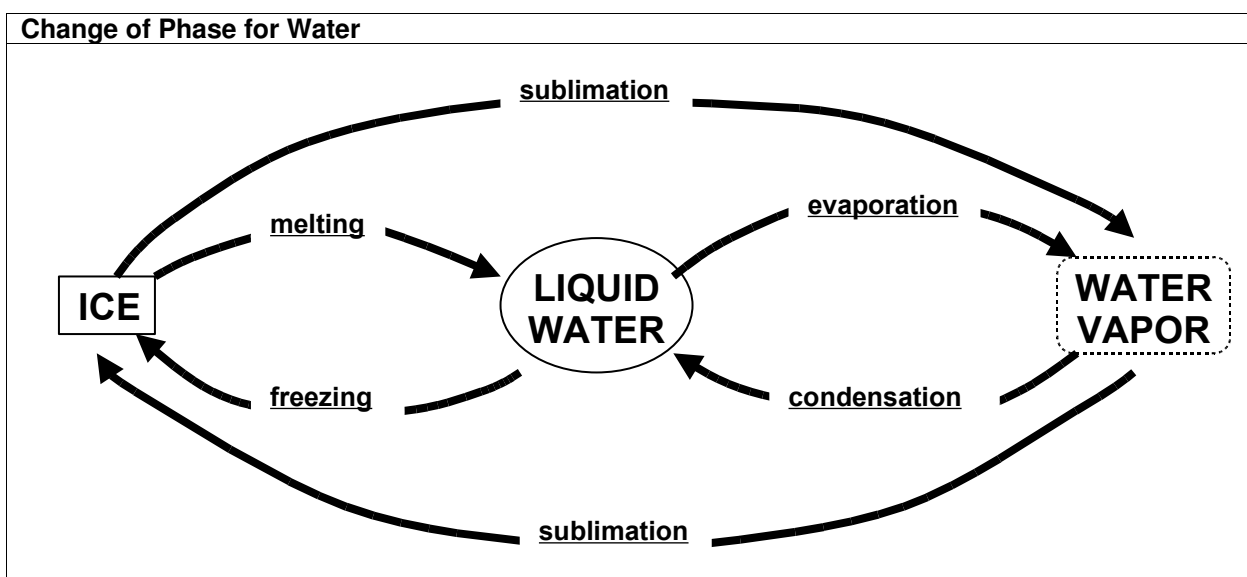
B. 97.22% of Earth's total water is ocean (saline)

C. Non-Ocean Water Includes:

1. 78% Surface (almost all glacial ice)
2. 11% Groundwater
3. 11% Deep groundwater
4. 0.2% Soil moisture

III. The Hydrologic Cycle Model (Figure 6.1): Note the general movements of water through the system. Most of the water vapor in the atmosphere comes from an ocean....

IV. Changes of Phase of Water: Water exists in three states; and routinely changes between these states. This is called "change of phase." Heat energy (called latent heat) is either absorbed or released during the changes of phase of water.



A. Hydrogen Bonds: Water molecules are naturally attracted to each other by hydrogen bonding. Ice has incredibly strong hydrogen bonds, whereas some of these bonds are broken in

liquid water. Finally, in water vapor the hydrogen bonds are entirely broken. It takes energy to break these bonds and keep them broken.

B. Latent Heat (or “Hidden” Heat): Latent heat is the energy which breaks the bonds. It holds the water molecules apart.

1. Melting and Evaporation (called cooling processes):

- Hydrogen Bonds broken!
- The water must absorb (or hide) the latent heat in order to break the bonds.
- Since the energy is “taken” from air or land, cooling occurs.
- For this reason these processes are called “cooling processes”.

2. Condensation and Freezing:

- Hydrogen Bonds formed!
- The water must release (or let go of) the latent heat in order to form the bonds.
- Since the energy is “given” to the air or land, warming occurs.
- For this reason these processes are called “warming processes”.

V. Humidity: Defined as the water-vapor content of the atmosphere.

A. Saturation: Air has a limited capacity to hold water vapor. When air is at the limit, it is said to be saturated.

B. Saturation and Temperature (see Fig. 5.11) : The most important thing to remember is that warm air has a much higher capacity to hold water-vapor than cold air!!

As Temperature Increases..... saturation capacity increases. The air can hold more water vapor.

As Temperature Decreases..... saturation capacity decreases. The air can hold less water vapor.

C. Specific Humidity: An important measure of water vapor content. Measured as grams of water vapor per kilogram of air. This is an actual measure of quantity of water in the air.

D. Relative Humidity: Relative humidity is the percentage of the observed amount of water vapor in the air compared to the capacity at saturation.

$$\frac{\text{Observed (actual) specific humidity}}{\text{Specific humidity at saturation}} \times 100$$

PROBLEM

Use Fig. 5.12 to calculate the relative humidity of a parcel of air as its temperature changes. Assume that its actual (observed) specific humidity remains constant at 10 grams H₂O vapor per kilogram of air (in other words, assume that the air doesn't gain or lose any vapor). The problem is set up for you with values that are intended to be easy to calculate. You will need to start by determining the specific humidity at saturation using the temperatures provided.

37 °C (99 °F)	24 °C (75 °F)	13 °C (56 °F)
10 gm/kg	10 gm/kg	10 gm/kg
$\frac{\quad}{\quad} \times 100$	$\frac{\quad}{\quad} \times 100$	$\frac{\quad}{\quad} \times 100$
?	?	?
Relative Humidity = ?	Relative Humidity = ?	Relative Humidity = ?

Final Question: What is the relationship between relative humidity and temperature?

1. Relationship Between Relative Humidity and Temperature (see Fig. 5.10)

- As the temperature increases Relative Humidity decreases. This is because it now has such a large capacity without gaining more water vapor.
- As the temperature decreases Relative Humidity increases toward 100%.

2. Dew point: The temperature at which the relative humidity reaches 100% (saturation).

3. Dew Point / 100% Relative Humidity / Saturation: Condensation will now occur.

VI. Atmospheric Stability (Adiabatic Heating and Cooling)

A. Physics Review: "An important principle of physics is that when a gas is allowed to expand, its temperature drops. Conversely, when a gas is compressed, its temperature increases."

B. Dry Adiabatic Processes (dry means clear air – no clouds)

1. Adiabatic Cooling (Ascending Parcels)

- NOTE: Think in parcels. Parcels are distinct units of air; have same temp and humidity.
- Parcel of air moves upward in the atmosphere.
- Parcel expands due to the decrease in the surrounding air pressure.
- Parcel cools because there are decreased molecular collisions in the expanded parcel.

2. Adiabatic Heating (Descending Parcels):

- Parcel of air moves downward in the atmosphere.
- Parcel compresses due to the increase in the surrounding air pressure.
- Parcel warms because there are increased molecular collisions in the compressed parcel.

(NOTE: Dry Adiabatic Rate (DAR) = $10^{\circ}\text{C}/1000\text{m}$ or $5.5^{\circ}\text{F} /1000 \text{ft}$)

C. Moist Adiabatic Processes (moist means inside a cloud)

- Similar to the process described above.
- As the parcel rises and cools, it eventually reaches the level of condensation.
- The process of condensation will release some latent heat.
- The result is that the rising parcel continues to cool, but not quite as fast (because latent heat is being added to the parcel through condensation).

(NOTE: Moist Adiabatic Rate (MAR) = $6^{\circ}\text{C}/1000\text{m}$ or $3.3^{\circ}\text{F} /1000 \text{ft}$)

Special Review

Normal Lapse Rate: Average temperature decrease as altitude increases

Environmental Lapse Rate: Actual/observed temperature decrease as altitude increases

Moist and Dry Adiabatic Rates: ONLY refers to ascending and descending air parcels

D. Stability of Air (see handout): To rise or not to rise; that is the question... (if you are a parcel)

- 1. Stable Air:** This is when a parcel of air is cooler (and denser) than the surrounding air at any level. It will resist rising, which means that clouds will not form.
- 2. Unstable Air:** Refers to a situation where, no matter how high the parcel rises, it remains warmer (and less dense) than the surrounding air. It keeps rising! This is called buoyancy (the tendency of something to rise in a fluid)!!!

Caused by: (1) extremely cold surrounding air and (2) very moist parcels.

Clouds, Precipitation, Air Masses, and Thunderstorms

(Christopherson – Chapter 5)

I. Introduction: As discussed earlier, precipitation is the result of the (1) lifting, (2) adiabatic cooling, and (3) condensation of moisture laden air masses. Three mechanisms cause lifting:

Orographic Lifting (Caused by mountain barriers): When moist air collides with a mountain barrier, it is forced up and subsequently cools and condenses.

Convective Lifting (Caused by surface heating): Heating at the ground surface which can cause moisture laden air to heat, rise, cool, and condense.

Frontal Lifting (Caused by colliding air masses): When two air masses collide, the warmer one is forced to rise, cool and condense.

II. Clouds: Clouds are a collection of small (20 - 50 μm) water droplets or ice particles

A. Formation Process (requires condensation nuclei): Droplets can form only when it is cold enough **and** when there is a surface on which to condense. These are tiny particles called condensation nuclei.

B. Cloud Types

1. **Cirroform (cirrus):** high altitude, wispy, ice crystal clouds

2. **Stratiform (stratus):** horizontal, layered clouds

3. **Cumuliform (cumulus):** globular, puffy clouds.

Nimbus = dark rain cloud

Cumulonimbus = vertical, dark, cumulus rain cloud

Nimbostratus = flat, layered dark rain cloud

III. Fog: Surface level cloud layers (clouds touching the ground)

A. Advection Fog (Central Coast Marine Layer): Forms along coastal areas (like the California coast), under the following circumstances.

Moist air moves over cold surfaces (usually cold ocean currents)

Air cools and condenses to fog

Fog then pushed or pulled to a new area

Why doesn't advection fog make it farther inland?

B. Radiation Fog:

Forms in flat, low areas at night.

Ground emits longwave toward space and cools (called radiation cooling)

Cold ground cools air to the DEW POINT

If the air is still, fog droplets will form.

C. Valley Fog: Occurs where cold air drains off of the mountain slopes, sits in the valley, and causes condensation.

IV. Precipitation Formation: Is any atmospheric water vapor which condenses and freezes and falls to earth. There are two types of precipitation processes:

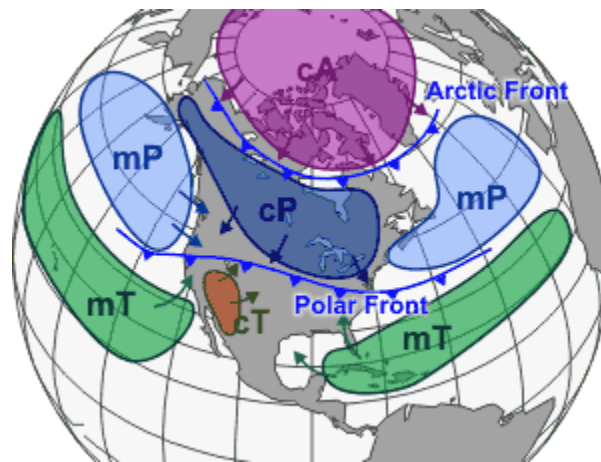
A. Collision-Coalescence Process

- Called the Warm cloud process: Common in equatorial and tropical regions.
- Process: Droplets collide and coalesce (join) until they have enough mass to overcome updrafts and friction.
- Drop size: Tends not to produce huge drops.

B. Bergeron Ice-Crystal Process

- Called the Freezing cloud process: Common at higher latitudes.
- Process: Supercooled droplets: Supercooled droplets collide with ice crystals (-10°C to -20°C) and freeze, or supercooled water vapor collects directly on the ice crystal through the process of sublimation.
- Precipitation: This can fall as snow or hail, or simply melt and fall as rain.
- Drop size: Tends to produce heavier precipitation; larger drops

- V. Air Masses:** These are large bodies of air with uniform temperature and moisture characteristics. The nomenclature is intended to describe the general moisture and temperature regimes of the source region, e.g., maritime Polar (mP).



- A. Source Region:** The place where an air mass forms. These characteristics are entirely dependent on the source region.
- B. Process (How is an air mass formed?):** A large mass of air stalls over an area long enough for the air mass to acquire moisture and temperature characteristics from the surface.
- C. Classification:** Air masses are classified by the latitudinal position and surface characteristics of the source region.
- 1. Surface:** Maritime air will consistently be more humid than continental air.
 - 2. Latitude:** Generally, the farther poleward the source region, the colder the air. Remember that cold air will have a lower specific humidity.

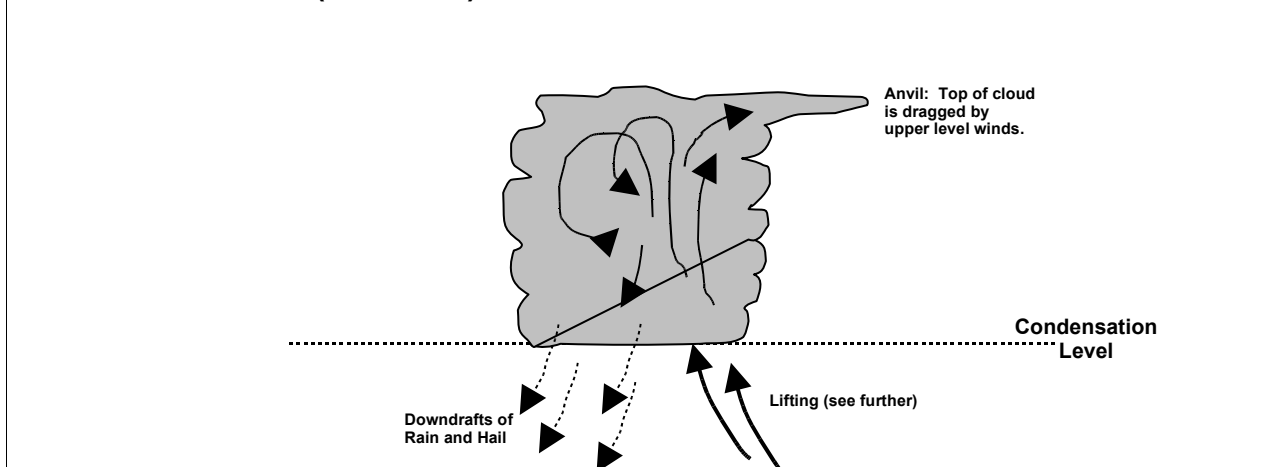
Surface	Latitude
Maritime (m) ocean surface	Arctic (A) highest latitude – near poles
Continental (c) land surface	Polar (P)
	Tropical (T)
	Equatorial (E) lowest latitude – near equator

Examples: A Maritime Polar air mass would be designated as mP; a Continental Tropical air mass would be designated as cT. Which would be the wettest and the driest?

VI. Thunderstorm Cell or Convection Cell: Occurs in unstable conditions where moist air is lifted rapidly. Lifting can be frontal, convective, or orographic.

Process: (1) Moist air lifted rapidly, (2) lifting condensation level is reached, (3) condensation occurs, (4) clouds and precipitation form, (5) rain and hail often caught in updrafts, (6) and massive buildup of rain and hail finally fall, creating down drafts. (7) Storm dissipates when no moisture remains.

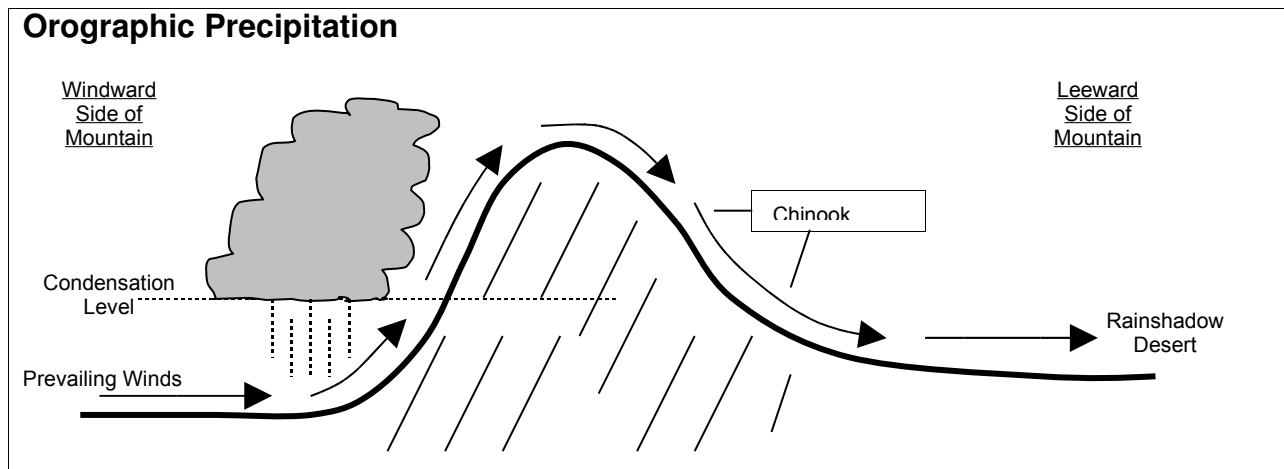
Thunderstorm Cell (side view)



VII. Lifting Mechanisms

A. Orographic Lifting

- 1. Mountain Barrier:** Warm, moist air is forced over a mountain barrier and cools due to the adiabatic process.
- 2. Prevailing Winds:** Prevailing winds is a term which means the most common or "average" winds for a given area.
- 3. Cloud Formation:** Rain clouds form at lifting condensation level
- 4. Precipitation:** Precipitation falls on the windward slope as the air mass passes over the mountain; the air mass then continues down the leeward slope.



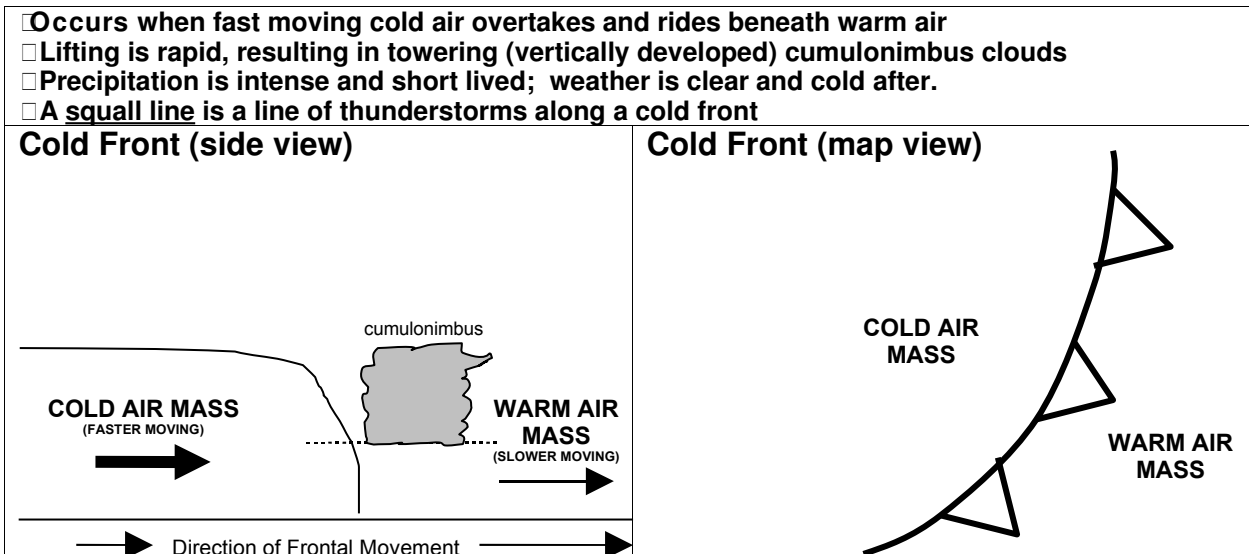
5. **Rainshadow Desert:** A desert which is located on the leeward side of a mountain. It is dry because the moisture cools, condenses, and falls as rain on the windward slope of the mountain. Air masses on the leeward side are generally dry.
6. **Chinook Winds:** When pressure differences cause air to be forced downslope (downhill), the air is heated through the force of compression (adiabatic heating). Also see Santa Ana example.....

B. Convective Lifting

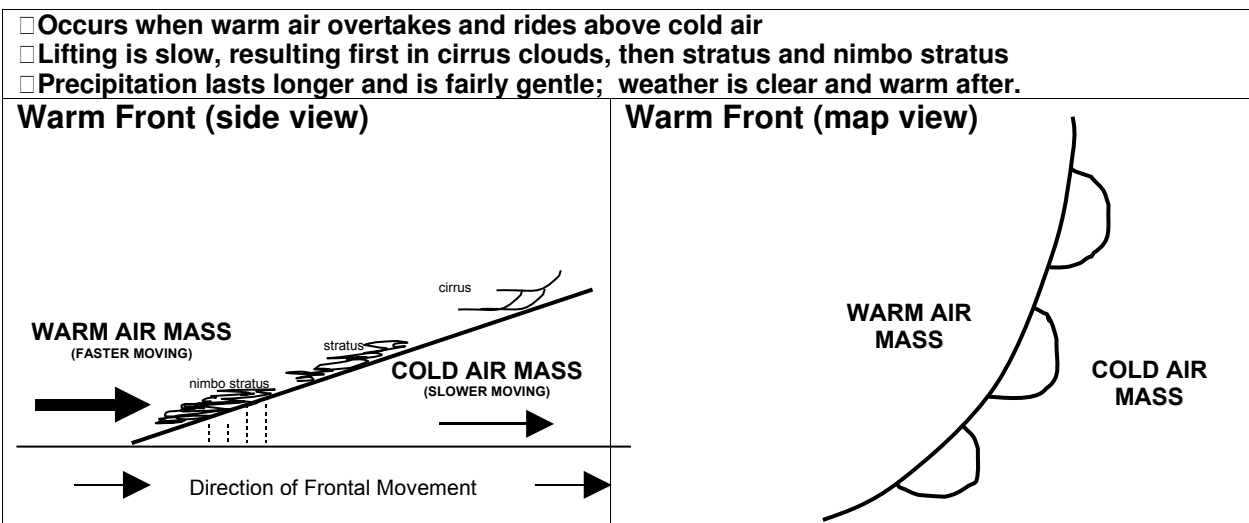
1. **Parcel Heats:** Land surfaces heat differentially; some surfaces will heat more quickly and reach higher temps. The parcel will expand.
2. **Parcel Rises:** Heated parcel at the surface will be less dense than the air around it, thus causing it to rise. This is a thermal low pressure.
3. **Followed by...?:**
 - Adiabatic Cooling
 - Condensation and Cloud Formation
 - Precipitation Formation
4. **Example (the Arizona Monsoon):** Late summer the Arizona Desert heats up, air rises often causing convergence of moist air from the Gulf of California. The moist air is then heated and lifted, resulting in convective precipitation.

- C. **Frontal Lifting:** When two air masses collide, the warmer air mass will always be forced up. The boundary between two air masses (where they meet) is usually sharply defined and referred to as a front.

Cold Front (see Figure 5.31)



1. Warm Front (see Figure 5.32)



Weather Systems

(Christopherson – Chapter 5)

I. Mid-Latitude Cyclones (or Traveling Wave Cyclones)

A. Form Along the Polar Front: Distinct global boundary between cold and warm air. May form in several places.

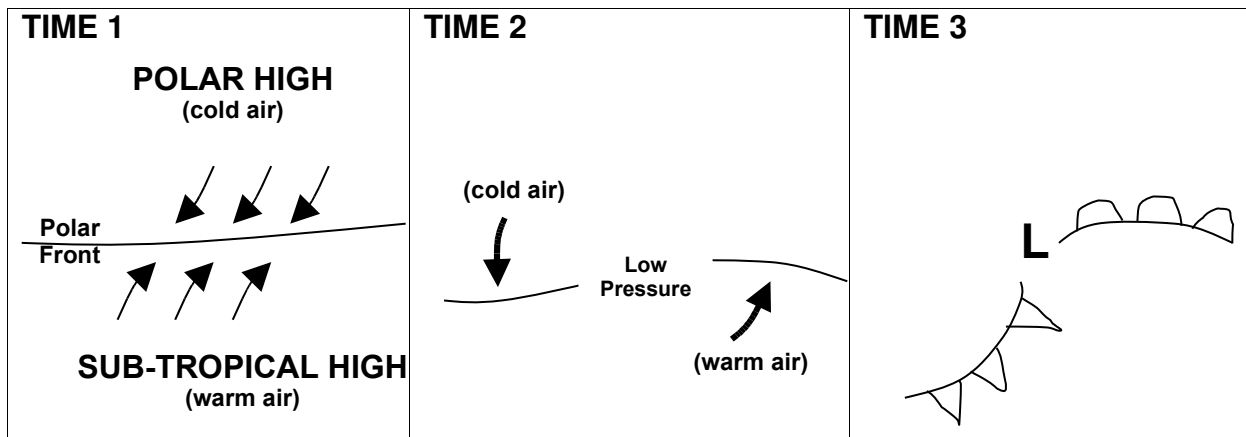
B. Causes for Cyclogenesis (Formation of a mid-latitude cyclone)

- Convergence at Surface: Fed by Polar Highs and Sub-tropical Highs
- Cyclonic Shear: Opposing airflow causes spiraling flow.
- Strong Upper Level Winds: Unusually strong Polar Front Jet Stream...
 - Literally act as a vacuum to strengthen cyclone.
 - May occasionally be the initial cause.

C. Frontal Development: Cold and warm fronts develop. (See Time 2 & 3)

D. Cyclone Migrates: Often called a Traveling Wave Cyclone. System spirals AND travels along the Polar Front Jet Stream.

Topview of Midlatitude Cyclone Development.



II. Tornadoes: Extremely intense, concentrated, small-scale low pressure cells.

A. Description and Function

1. **Rapid Uplift:** Associated with the rapid uplift along cold fronts or in hurricanes.
2. **Highly Contrasting Conditions:** Also associated with highly contrasting conditions: (cold/dry air masses versus warm/moist air masses)

- 3. Visibility:** due to rapid decrease in pressure resulting in adiabatic cooling and condensation.
- 4. Where Found:** They are most common in the south-central and south-eastern US, because of the proximity of the warm Gulf of Mexico. There is no such source region for the western states.

Tornado Vitals

- Winds up to 485kmh (300mph)
- Horizontal scale: 100 m – 1000 m
- Pressures <900mb?? (never measured)
- Duration: Few minutes to few hours

B. Damage

- 1. Wind Blown Debris:** Wind and windblown debris are by far the greatest cause of damage.
- 2. Fatalities:** Deaths from tornadoes have greatly decreased due to better prediction capabilities and tornado warnings.

III. Tropical Cyclones (called Hurricanes w/ winds >74mph): Large scale inward spiraling cyclonic storms characterized by high winds and high precip

A. Description and Function

- 1. Where Found:** They develop over tropical oceans between 8° and 20° N and S lat: (Never closer to the equator, as the coriolis force is not strong enough to drive a cyclonic storm).
- 2. The critical factor for formation:** High sea-surface temperatures; temps. over approx. 26°C are mandatory!!
- 3. Structure:** This huge low pressure system acts like a thunderstorm cell on a massive scale.
- 4. Air Movement:** Air converges and ascends
- 5. Release of latent heat:** Intense precipitation releases large amounts of latent heat, further fueling convective precipitation.
- 6. Role of upper level winds:** Hurricane strengthened by strong upper level winds, which act like a vacuum encouraging ascending air.

Hurricane Vitals

- Winds up to 200kmh (125mph)
- Horizontal scale: 100 km – 1000 km
- Pressures in the eye down to 900mb or lower
- Duration: Few days to a week

B. Damage

1. **Winds:** Cause damage

2. **Flooding: Four causes.....**

a) **High Precipitation:** Standard for a hurricane.

b) **High Tides:** The hurricane may coincide with the highest tides, causing even greater flooding.

c) **Surface Bulge:** . The low pressure actually causes the sea surface to rise (i.e. it literally sucks it upward like a vacuum) as much as 1m (3ft).

d) **Storm Surge:** Tropical cyclone winds generate a storm surge at the eye of the storm. This is wind driven water piled as high as 7.5 meters (25 feet) above the surrounding sea level. In 1737, 300,000 persons died in India as a result of such a storm surge.

C. Dissipation of Storm: When hurricanes reach land, they lessen and die for two reasons:

1. **Friction:** Friction from the earth's land surface slows winds

2. **Diminished source of moisture:** Land doesn't supply the needed source of moisture for the latent heat.

Hydrologic Cycle and Water Resources

(Christopherson – Chapter 6)

I. The Hydrologic Cycle Model (Figure 6.1): Note where and how water, in all its forms, moves through the environment. Specifically, note that 90% of all precipitation originates as water vapor FROM THE OCEAN!

II. The Water Balance Equation

$$\text{***Precipitation} = \text{Evapotranspiration} + \text{Runoff} \pm \text{Storage***}$$
$$(P = Et + R \pm St)$$

A. Precipitation: Total of all rain, snow, etc. to fall in an area

B. Evapotranspiration: Evaporation and transpiration (loosely defined as evaporation through plant leaves) combined.

C. Runoff: Total of all water which runs off over the surface or underground

D. Storage: Water held in the soil.

III. Subsurface Water: Any water below the soil surface.

A. Introduction

1. Infiltration: When water passes through the surface

2. Pore Spaces: Spaces between soil particles where the water exists

B. Soil Water: Any water in the zone accessible to plant roots.

1. Hygroscopic Water: Tightly bound to soil particles. Plants can't get; they will wilt.

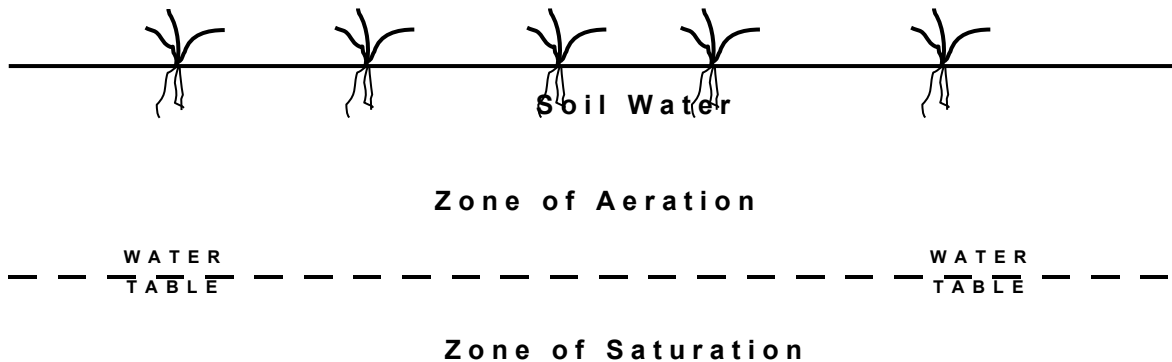
2. Capillary Water: Remains in pore spaces due to hydrogen bonding. Available to plant roots.

3. Gravitational Water: Moves downward under the force of gravity (called percolation).

C. Ground Water: Water which passes through the soil water zone under the force of gravity. It exists in the pore spaces of porous and permeable earth materials.

1. **Porosity (porous) and Permeability (permeable):** Amount of pore space available and ease with which water passes through, respectively.
2. **Zone of Aeration:** The zone where all pore spaces are **not** filled. There is space left.
3. **Zone of Saturation:** The zone where all pore spaces are filled.
4. **Water Table:** The water table is defined as the upper limit of the Zone of Saturation. It will slowly rise and fall after periods of drought or rain.
5. **Aquifer:** The porous and permeable rock layer which can hold usable amounts of ground water. Includes both zone of saturation and aeration.

Diagram of Ground Water (see Figure 6.14)



Self Study

What is an Aquiclude?

What is a Perched Water Table?

What is a Spring?

Sometimes the input of water to a stream is called effluent? Where does effluent come from?

IV. Surface Water (discussed later)

V. Problems with Human Use of Water

A. Ground Water Problems: Where rains and surface flows are not enough to provide for the demands of urban and agricultural use, ground water is accessed from wells. This raises two issues:

1. **Ground Water Depletion:** When water is extracted faster than it recharges, this results in ground water depletion.
 - a) **Cone of Depression:** Localized drop of water table. At a high volume well, this will cause drawdown and a cone of depression.
 - b) **Subsidence:** When pore spaces cave in. Entire land surface may fall (up to 30-40cm). This is a serious problem in the Central Valley of California, and to a lesser extent, around the oil regions of Texas (e.g., Houston). Groundwater cannot recharge; pore spaces disappear, land subsides.
 - c) **Ground Water Mining (page 206):** Where normal recharge would take 1000s of years, aquifer eventually disappears. (High Plains Aquifer)
2. **Ground Water Contamination:** When water flows through pollutants at the surface (landfills, leaking gas tanks, discarded industrial solvents, etc), contaminants are leached and carried downward to the water table and the saturated zone below.

B. Surface Water Problems

1. **Pollution/Contamination:** Water susceptible to pollution because both flow downhill. And because pollution travels easily in water.
 - a) **Point-Source Pollution:** Pollution from a single identifiable source. (e.g. drainage pipe from a factory, leaky chemical tanks, etc)
 - b) **Non-Point-Source Pollution:** Pollution from a wide area, not easily identifiable (e.g. city street grime, oil, gas, etc.)
2. **Soil Salinization:** When soils become too salty to support plant growth.
 - a) **Source of Salts:** Salts occur naturally in the soil, and possibly in irrigation water applied to the soil.
 - b) **Concentration of Salts:** As water evaporates from the surface, it leaves the salts behind (only pure water evaporates). This also draws more water (and more salts) to the surface.

Global Climate Systems

(Christopherson – Chapter 7)

I. Introduction:

Climate is what you expect. Weather is what you get...

Generally speaking, climate is the average weather of a region.

II. Two Main Climate Indicators: The annual patterns of (1) temperature and (2) precipitation. This, in turn, is primarily determined by:

III. Main factors affecting temperature and precipitation:

A. Latitude: Day length and sun angle (generally determines temp)

B. Proximity to oceans: Maritime or Continental air masses

C. Prevailing winds: Which way are the storms coming from?

D. Altitude: Normal Lapse Rate; high altitudes will be colder

IV. Global Precipitation Map (Fig. 7.2): (isohyets are lines of equal precip)

A. Recall the positions of:

- 1. Inter-tropical Convergence Zone (equatorial thermal low pressure trough):** high Convective rainfall
- 2. Hadley Cell**
- 3. Subtropical High Pressures:** 30° North and South Latitude; generally clear weather
- 4. Trade winds**
- 5. Westerlies:** (the track of extratropical cyclones; warm and cold fronts)

B. Review the following properties of global precipitation patterns:

- 1. Where is the highest precipitation and why?** Along the equator. ITCZ causes high convective precipitation
- 2. Why is there high precipitation in mountains?** Orographic lifting causes high precipitation
- 3. Why is there low precipitation along the tropics of Cancer and Capricorn?** Sub-tropical High Pressure influence
- 4. Why does the Andes' rain-shadow desert switch from east slope to west slope?** Because the prevailing winds are from the East at around 5-25° South Latitude and from the West at around 30-50° South Latitude.
- 5. Why are the interiors of N. America and Asia so dry?** They are far from maritime air masses.
- 6. Why are many midlatitude east coasts wetter than midlatitude west coasts?** East coasts receive tropical air masses, while west coasts receive polar air masses

V. Climograph: A graph showing annual patterns of average monthly temperature and precipitation.

VI. Climate Types (Modified Köppen Climate Classification): See figs 10-4 and 10-5.

A. Tropical Climates (warm season rains)

1. Tropical Rainforest (Af):

- a) **Where:** Along Equator. Equatorial South America, Africa, and Southeast Asia . World's largest rivers (Congo River in Africa and Amazon River in South America) are here.
- b) **Precip:** Consistent precipitation of the ITCZ. Generally high. in all months.
- c) **Temp:** Warm and humid with an extremely small annual temp. range.

2. Tropical Monsoon (Am):

- a) **Where:** SW India, NE Brazil, Thailand; often near Equator
- b) **Precip:** Extremely high precipitation when the ITCZ passes over; dominated the other months by a subtropical high, with much less precip.
- c) **Temp:** Highest temps. before and after the rain months, with a dip in the middle due to cloud cover.

3. Tropical Savanna (Aw):

- a) **Where:** Northern Australia, Southern Brazil, extensive in Africa)
- b) **Precip:** Similar to Tropical Monsoon with high ITCZ precip during a few months. Usually further from ocean, resulting in less rain. Dominated the other months by subtropical high, much less precip.
- c) **Temp:** Begins to show distinct seasonal pattern from the change in sun angle.

B. Dry Climates

1. Hot Low-Latitude Desert (BWh):

- a) **Where:** In the subtropical high pressure zone (15-30° North and South Latitude.) (Saharan Desert, Saudi Arabian Desert, Baja, Central Australia)
- b) **Precip:** Dominated almost entirely by sub tropical high pressure, little or no monthly rain.
- c) **Temp:** Hottest climate on earth; moderate annual temperature range.

2. Cold Mid-Latitude Desert (BWk):

- a) **Where:** Slightly higher latitude (poleward) than the Subtropical desert. (Great Basin and Mojave Deserts, Patagonian Desert, Gobi Desert)
- b) **Precip:** Dominated almost entirely by sub tropical high pressure, little or no monthly rain.
- c) **Temp:** Definite warm periods, but colder than hot desert because of higher latitude; large annual temperature range.

3. Cold Mid-Latitude Steppe (BSk**):

- a) **Where:** Poleward of the desert climates (40-50° North and South Latitude); often in the interior of continents (Interior N. America - the Great Plains - and interior Europe/Asia)

- b) **Precip:** More rain than a desert. Extratropical cyclones bring fronts, but air masses are often cP. TOO FAR FROM THE OCEAN FOR MOIST AIR.
- c) **Temp:** High annual temp. range with 1-2 months below freezing.

C. Mesothermal Climates (means "middle temperature" or mild)

1. Humid Subtropical (Cfa):

- a) **Where:** Eastern midlatitude coasts!!! (Southeast China, Southeast U.S., Southeast South America, East Australia)
- b) **Precip:** Significant precip in all months. Summer rain brought by the western edge of subtropical highs (mT air). Winter rain brought by extratropical cyclones.
- c) **Temp:** Warm, humid summer, cool humid winter; fairly low annual temp range due to maritime influence.

2. Mediterranean (Csa, Csb):

- a) **Where:** Western midlatitude coasts. Central California, Mediterranean Europe, SW Australia, SW South Africa)
- b) **Precip:** Dry summer (dominated by strong subtropical high pressure) and wet winter (dominated by extratropical cyclones)
- c) **Temp:** Generally low annual temp. range due to maritime influence.

3. Marine West Coast (Cfb and Cfc):

- a) **Where:** Very similar in position to mediterranean climate, but further poleward. (SW Chile, British Isles, New Zealand, Pacific North West U.S.)
- b) **Precip:** Cool-wet most of year (from extratropical cyclones - mP air). Lower summer precip. due to brief influence of subtropical high pressure.
- c) **Temp:** Generally cooler than Mediterranean; low annual range due to maritime influence.

D. Microthermal Climates (cool to cold)

1. Humid Continental (Hot Summer -Dfa** and Dfb**)

- a) **Where:** Higher latitude interior locations; some maritime influence. See map. Includes the circumpolar distribution of coniferous forest called **taiga**.
- b) **Precip:** Some precip in all months; causes are variable.
- c) **Temp:** High annual temp range; progressively colder poleward.

E. Severe Midlatitude and Polar Climates

1. Tundra (ET^{**}):

- a) **Where:** Highest latitude land masses of Northern Hemisphere. (Northernmost of Alaska, Canada, Scandinavia, Russia)
- b) **Precip:** Some in summer due to a few extratropical cyclones.
- c) **Temp:** Short cool season in summer; generally dominated by polar and Arctic air.

2. Ice Cap (EF^{**}):

- a) **Where:** Poles/Highest Latitudes. Greenland and Antarctica
- b) **Precip:** Negligible. Extremely dry. Recall that cold air holds little moisture.
- c) **Temp:** All months below freezing; generally high annual range.

F. Highland (Mountain) Climates (H^{**}):

- a) Thin atmosphere, cold, often glaciated, little vegetation.
- b) Equatorward there are drastic diurnal (daily) differences in temperatures with little annual change. Poleward there are drastic annual differences with little diurnal change.
- c) Almost always responsible for creating rainshadow deserts, or at least dry leeward slopes!!

Anthropogenic Climate Change

Possible Human Causes for Climate Change: There is significant evidence that humans are causing changes in local and global climate.

I. Global Warming Caused by Increases in Radiatively Active Gases: (Gases which are good absorbers of longwave radiation)

A. MAIN GASSES

1. Carbon Dioxide: Biggest problem, increasing at 0.4% per year

- a) **Combustion of fossil fuels:** Increases the concentration of CO₂ in the atmosphere.
- b) **Destruction of Forests:** Loss of forests means loss of global CO₂ consumer. Thus, there is more CO₂.

2. Methane (CH₄): Functions like CO₂. Increasing at 1% per year. Comes from things that rot or digest where oxygen isn't present.

- a) Livestock Intestines
- b) Rice Fields
- c) Vegetation Burning

3. Chlorofluorocarbons: Absorb shorter wavelengths; also involved in upper-atmospheric ozone chemistry, i.e., ozone-depletion.

B. POTENTIAL CONSEQUENCES: Shifting of climatic zones, ocean currents, weather and storm patterns, etc

1. Major Changes in Natural Plant Distributions

2. Agricultural Crop Failures

3. Rise in Sea Level: Future predictions are from a meter to six meters of rise.

a) Melting of Glaciers and Ice Sheets: Glacial ice turned to liquid water could raise sea level

b) Ocean Temperature: Expansion of water would raise sea level.

II. Theoretical Potential Cooling Caused by Nuclear Explosions (Nuclear Winter)

A. Volcanic Eruptions as Evidence: Volcanic ash in the atmosphere has been shown to block insolation and cause slight global cooling.

B. Nuclear Explosions: Have been hypothesized to drop global temps.

1. Smoke: Smoke from Firestorms would block insolation

2. Particulates: Particulate matter would be thrown into the atmosphere, again blocking insolation.

III. Other Human Impacts on Climate:

A. Ozone Depletion: Upper-atmospheric chemistry between chlorofluorocarbons, atmospheric ozone, cloud ice, and sunlight.

B. Deforestation: Removal of large tracts of forest lands (mostly tropical) negatively impacts the ability to remove atmospheric CO₂, as well as the ability to generate precipitation, retain soil moisture, etc.

C. Soil Erosion: Results from non-sustainable agricultural practices, such as the over-use of chemical fertilizers, poor irrigation design and water management, and a general failure to understand how natural systems affect human activities.