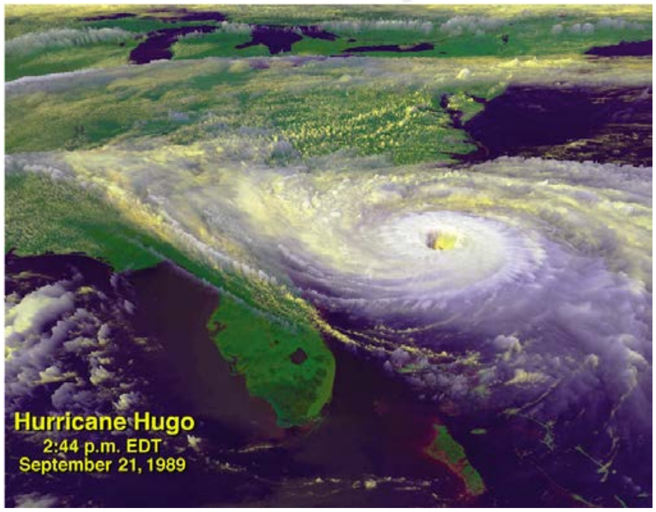
CE/SC 10110-20110

Atmosphere & Climate



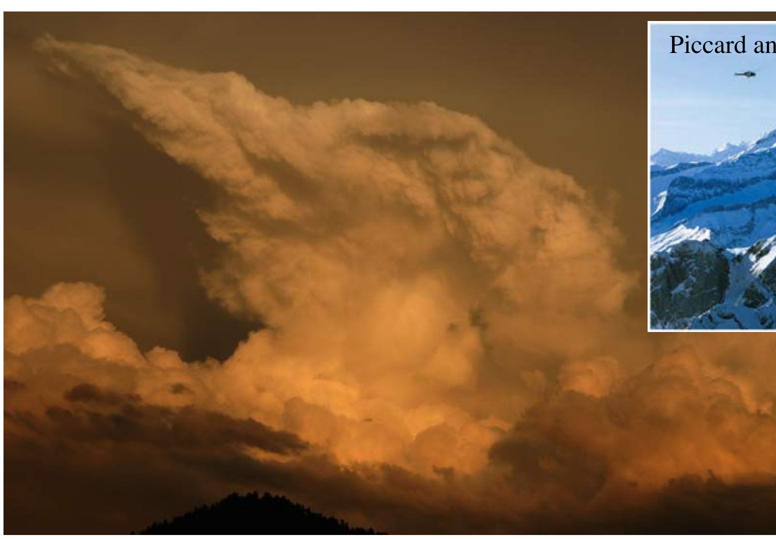
Earth

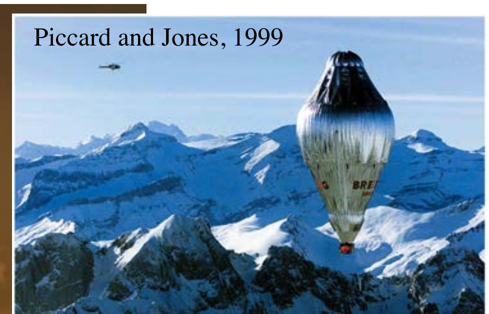
Portrait of a Planet
Fifth Edition

Chapter 20

Air = mixture of gases. Balloons rise because of the atmosphere.
Wind = movement of air from high to low pressure.
Weather: physical conditions (temperature, pressure, moisture content, wind strength and direction).
Climate = average weather conditions during the year.

The Atmosphere



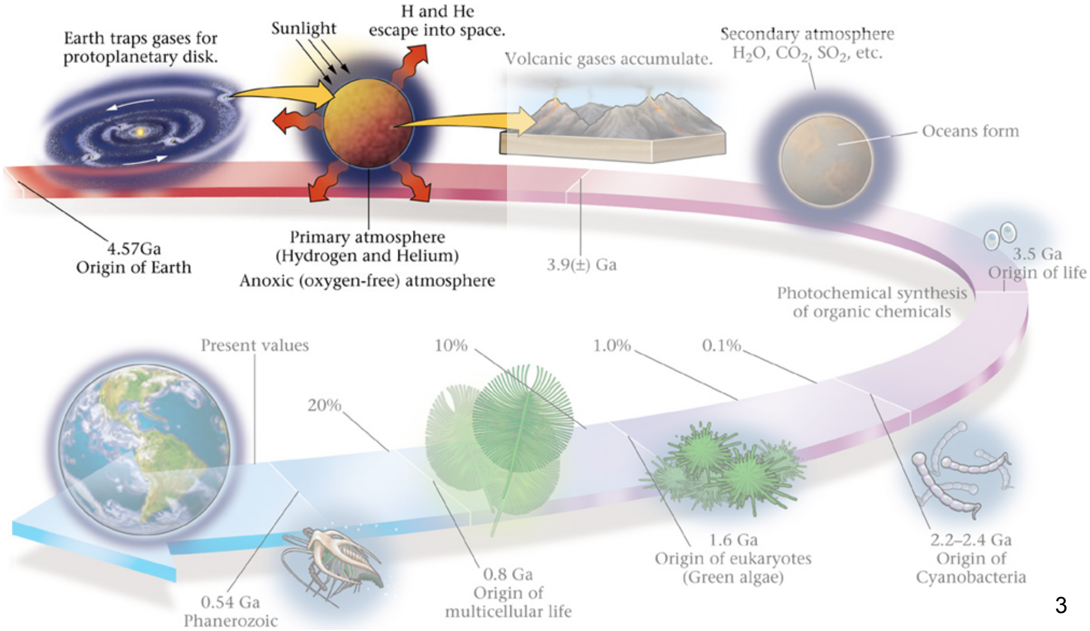


Piccard and Jones, 1999

Earth has a well-developed atmosphere comprised of a mixture of gases called air. Density and pressure variations cause air motion: wind.

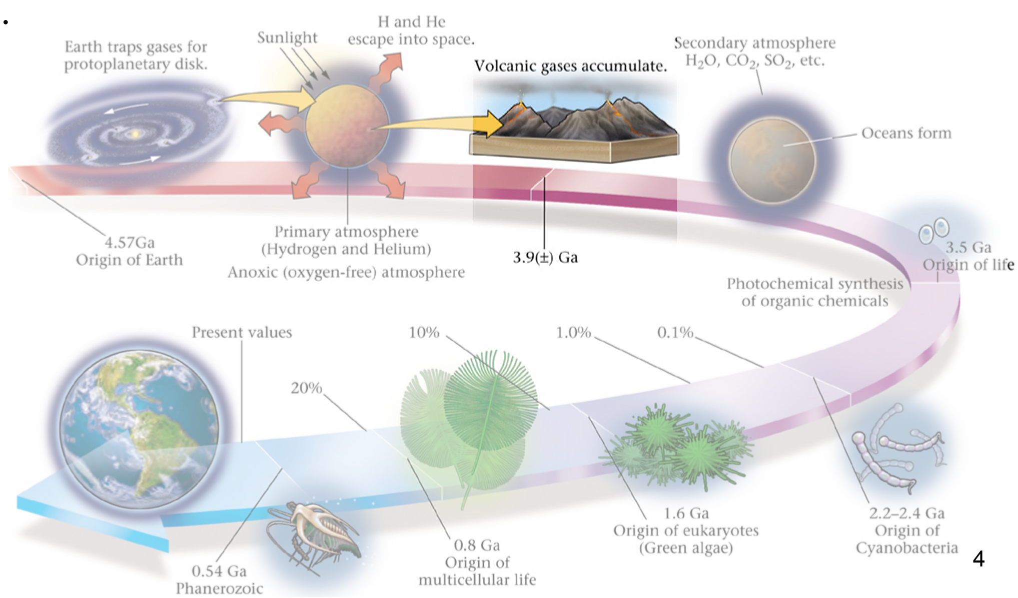
Atmosphere Formation

Primary atmosphere (H, He): accumulated with the initial Earth. This was “blown away” when the Sun ignited.



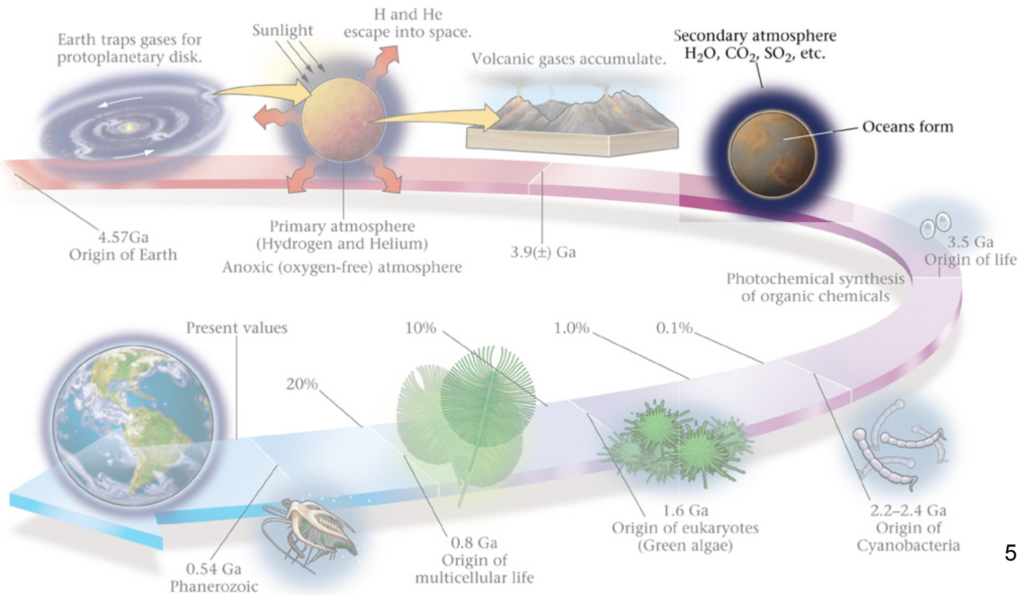
Atmosphere Formation

Gaseous elements that were bonded to minerals were released by volcanic emissions to produce a secondary atmosphere.
Secondary atmosphere: 70-90% H_2O, lesser amounts of CO_2, SO_2, N_2, NH_3.



Atmosphere Formation

When the Earth cooled, liquid water formed the oceans and the amount of CO_2 in the atmosphere decreased. Chemical weathering increased.



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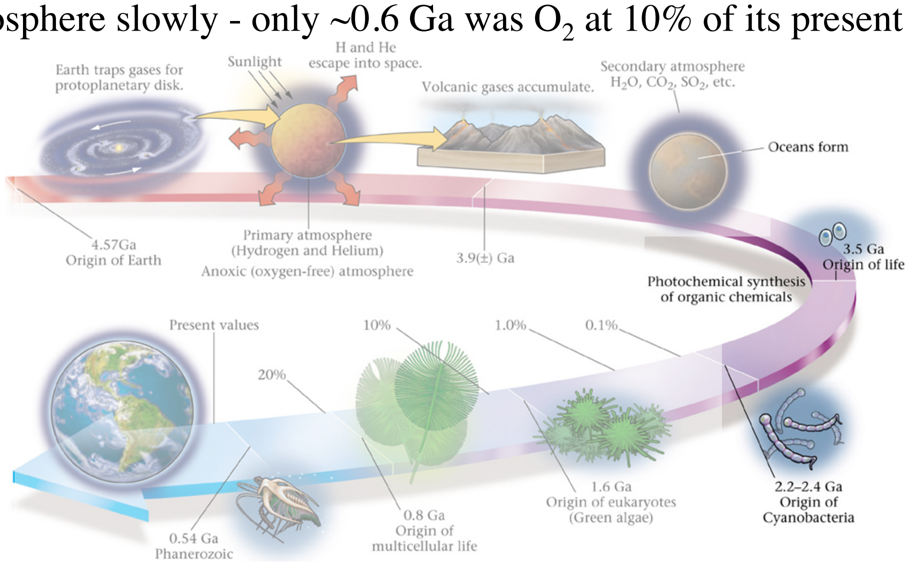
Atmosphere Formation

Ultraviolet light split NH_3 into N and H - formation of N_2 molecules meant the nitrogen content of the atmosphere gradually increased. H formed H_2O and went to the oceans. Photosynthesis produced O_2 (cyano-bacteria or blue-green algae), but this increased in the atmosphere slowly - only ~0.6 Ga was O_2 at 10% of its present level.



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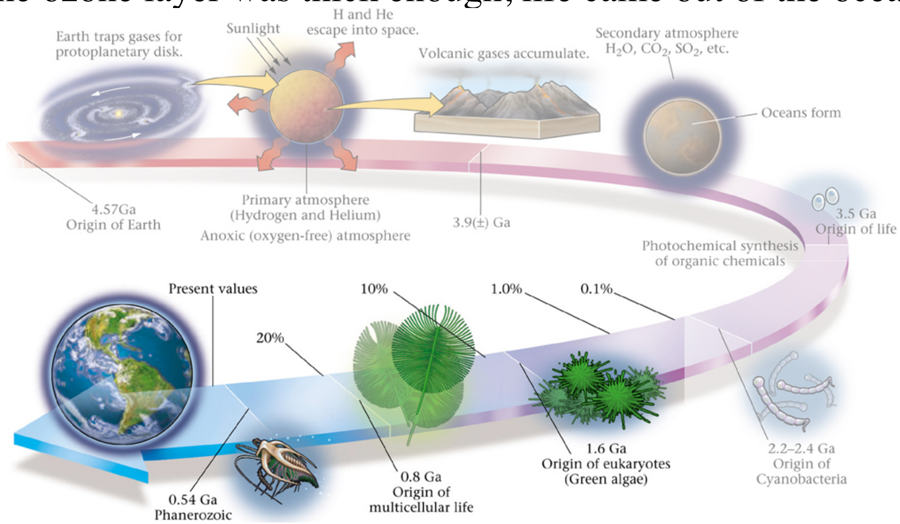
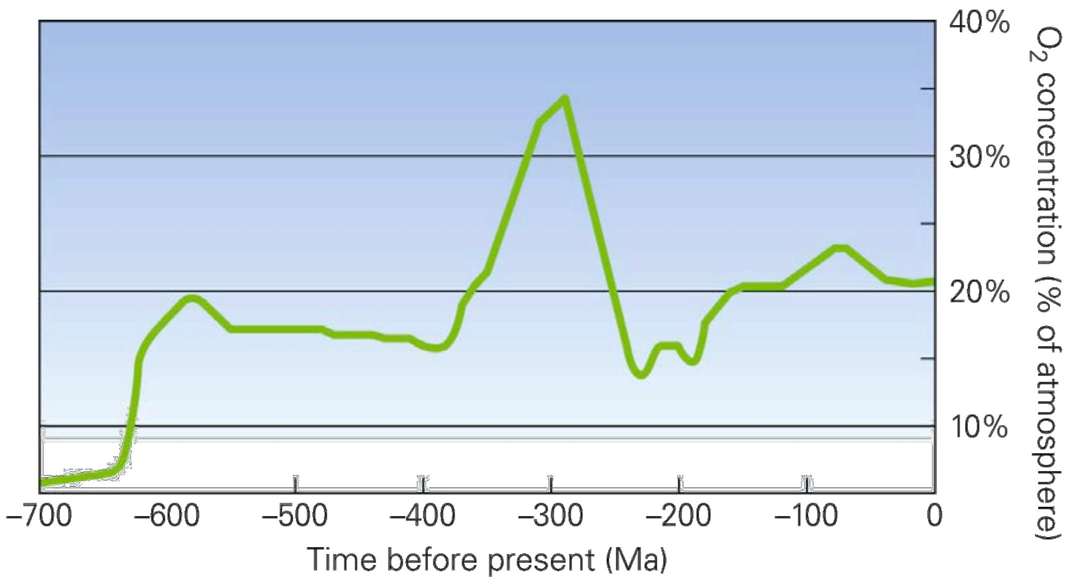
Atmosphere Formation

Oxygen is important because it allows complex multicellular organisms to breathe and also to form ozone (O_3). Ozone absorbs short wavelength UV. Ozone forms at ~30 km by a two-step reaction: O_2 + energy (from Sun) --> 2O; O_2 + O --> O_3

When the ozone layer was thick enough, life came out of the oceans.

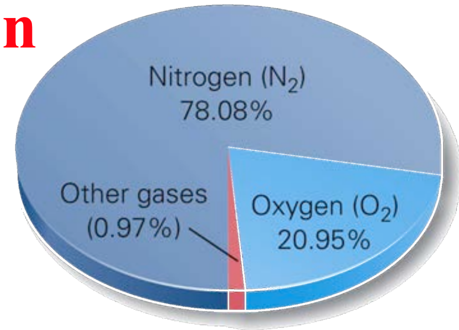


Formation of the Atmosphere



During the Phanerozoic, oxygen composition was varied. It was unusually high during the Carboniferous and the Permian.

Air Pollution



The Atmosphere

78.08% $N_2 + H_2O$
20.95 % O_2
0.97 % Ar, CO_2, CH_4, O_3

Materials cycle through the atmosphere as they do the oceans.

Inert gases have an almost infinite residence time.

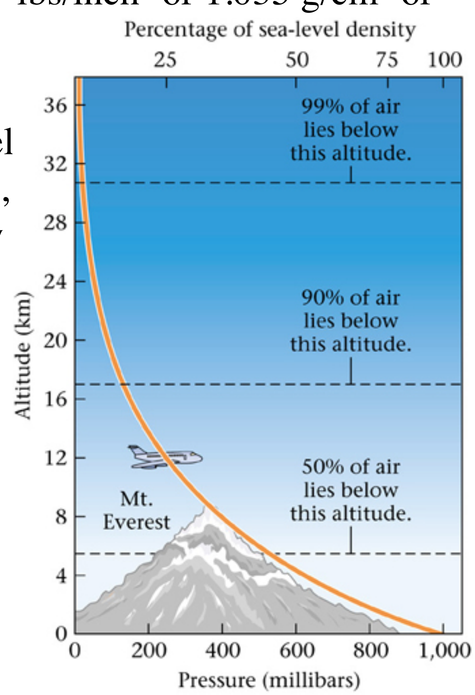
Aerosols: <1 µm particles that can remain suspended in air. Sea salt, volcanic ash, clay, soot, pollen, water & acid droplets.

Pollutants: SO_4^{2-}, NO_3^- react with water to form acid rain.
CO_2 from fossil fuel burning - greenhouse gas.
Chlorofluorocarbons (CFCs) - destroy ozone. Accumulates over the poles to form "ozone holes".

Other sources of pollutants, especially CO_2?

The Atmosphere

Air pressure is greatest at sea level (~14.7 lbs/inch^2 or 1.035 g/cm^2 or 1 bar = 0.986 atmospheres).



At the top of Mt. Everest, atmospheric pressure is about one third that at sea level 50% of the atmosphere lies below 5.6 km, 90% below 16 km, 99.99997% lies below 100 km.

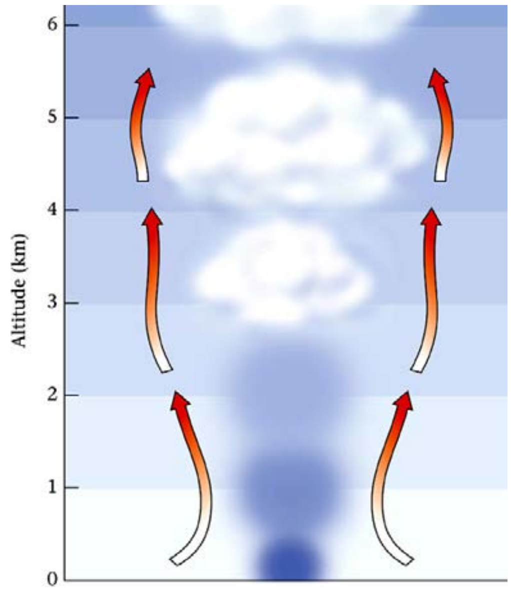
Adiabatic Cooling: air moves from high to low pressure, without adding or subtracting heat, it expands and cools.

Adiabatic Heating: air moves from low to high pressure, without adding or subtracting heat, it is compressed and heats up.

The Atmosphere

Relative Humidity: Ratio between the measured water content and the maximum amount of water the atmosphere can hold.

Dewpoint Temperature: The temperature at which air becomes saturated with water so it precipitates.
Adiabatic cooling forms clouds.

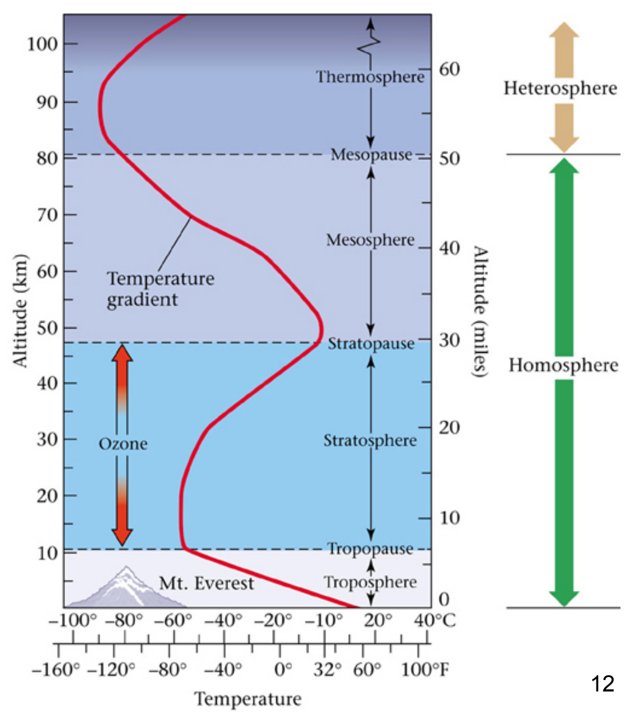


The Atmosphere

Separated into layers depending on a change of temperature decrease to increase and vice versa.

Troposphere: up to 9 km at the poles and 12 km at the equator. Temperature decreases to ~-55˚C. Base is heated by infrared radiation causing convection, which causes the weather.

Stratosphere: temperature stays about the same for ~10 km then increases to ~0˚C at ~47 km. This layer doesn't convect. Heating occurs because O_3 absorbs solar radiation.



The Atmosphere

Mesosphere: temperature decreases to -85˚C from 47 km to 82 km as this layer doesn't absorb solar radiation. Meteors start to burn up in this layer.

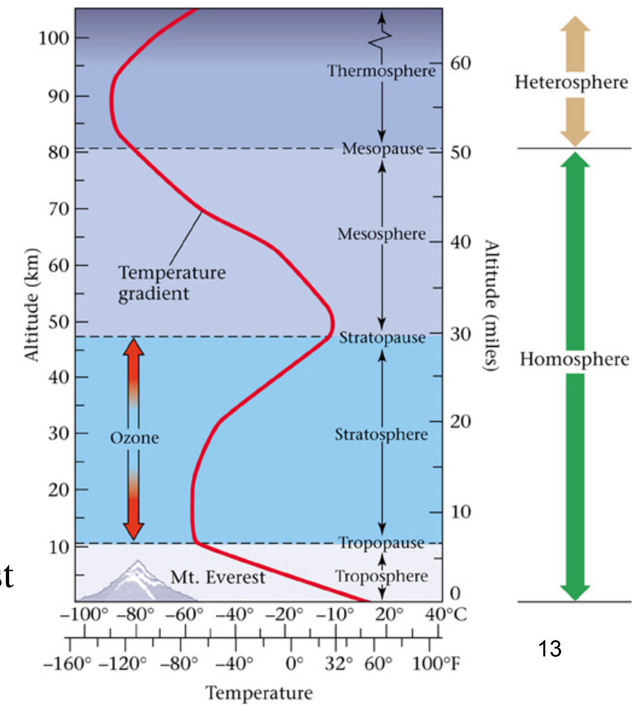
Thermosphere: <1% of the atmosphere resides here, but gases absorb short-wavelength solar radiation.

Homosphere: comprises Mesosphere, Stratosphere, Tropopause and each layer has the same composition.

Heterosphere: layered - heaviest at the base (N), then O, He, H.

Why this layering?

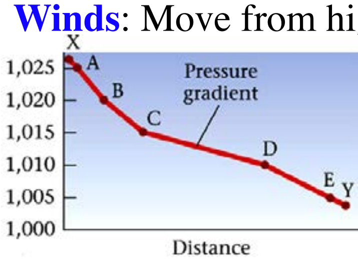
Exosphere: above Heterosphere

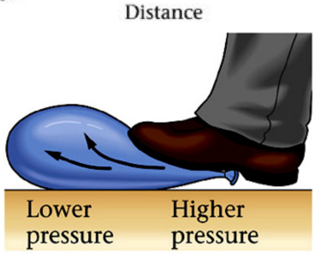


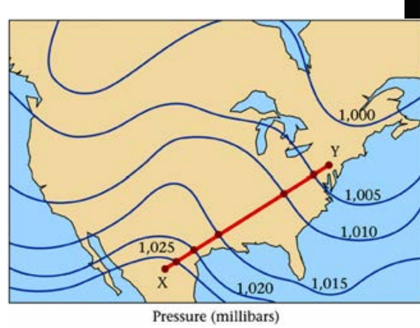
The Atmosphere

Ionosphere: 60-400 km (mostly Exosphere) where solar radiation strips N and O of their electrons. This layer reflects radio transmissions (short-wave). The aurora boreallis (northern) and aurora australis (southern) form here.

Winds: Move from high to low pressure.







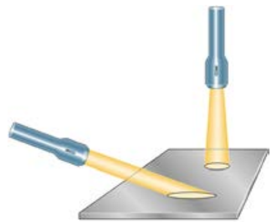
Pressure represented on maps by isobars.

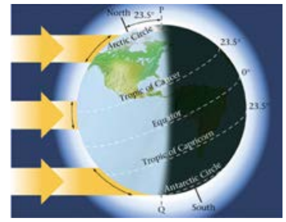
How can isobaric maps show wind speed?

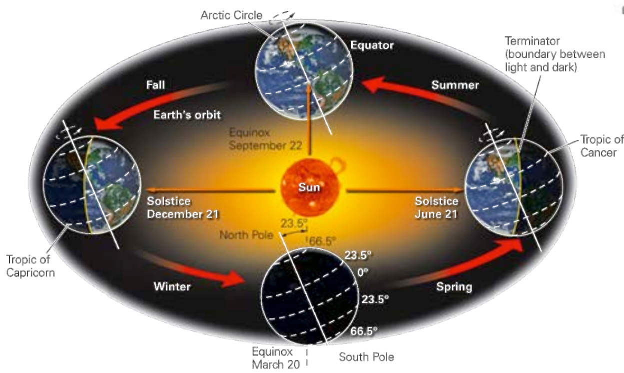
The Atmosphere

Energy from the Sun (**insolation**) heats the atmosphere either directly or indirectly via absorption by land and re-radiation back as infrared radiation, which can be retained by greenhouse gases.

Amount of insolation depends on how the suns rays hit the Earth.



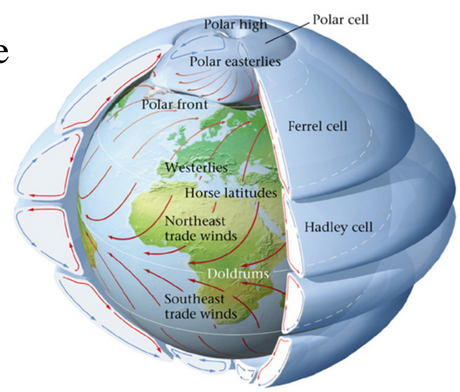


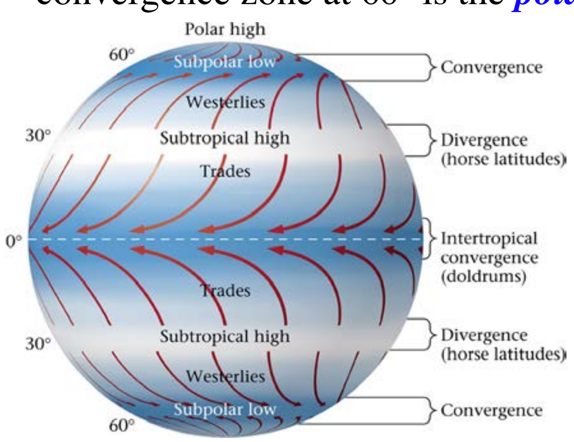


Earths rotation axis and orbit changes the angle that the Sun hits the Earth at different times of the year.

The Atmosphere

Convection in the troposphere produces the ***Hadley***, ***Ferrel*** and ***Polar Cells*** that are offset by the rotation of the planet - the ***Coriolis Effect***. Limbs of these cells rise due to heating (*convergence zone*) and fall due to cooling (*divergence zone*). The convergence zone at 60˚ is the ***polar front***.

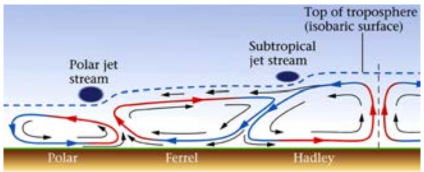


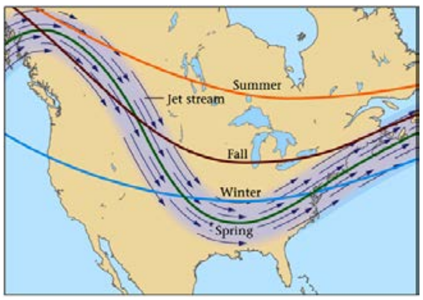


Divergence and Convergence zones = weak, erratic winds. Prevailing Surface Winds = trades or westerlies; polar easterlies >60˚.

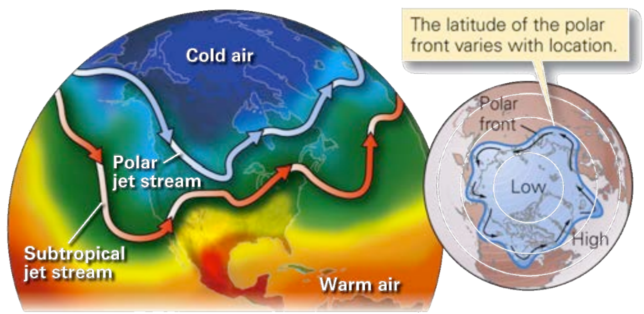
The Atmosphere

Air is thicker and warmer at the top of the troposphere over the equator compared to the poles. This causes the higher altitude air to flow north (or south). The Coriolis Effect makes these “high-altitude westerlies” that move at 200-400 km/hr. These are “**jet streams**”.





The polar jet stream is faster and more important for weather.



The Weather

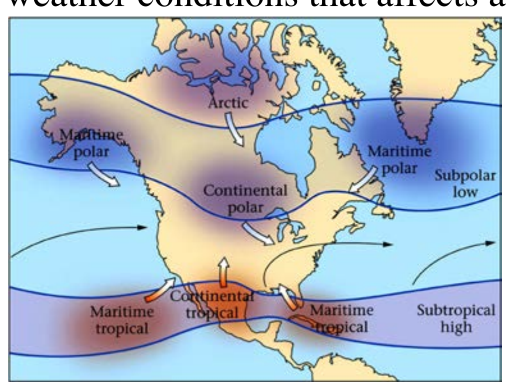
Weather: local scale conditions defined by temperature, air pressure, relative humidity and wind speed.

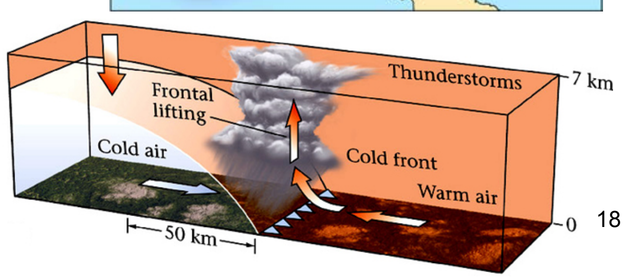
Weather System: a specific set of weather conditions that affects a region for a period of time.

Air Mass: a body of air (at least 1,500 km across that has recognizable physical characteristics.

Boundary between air masses is a ***front***.

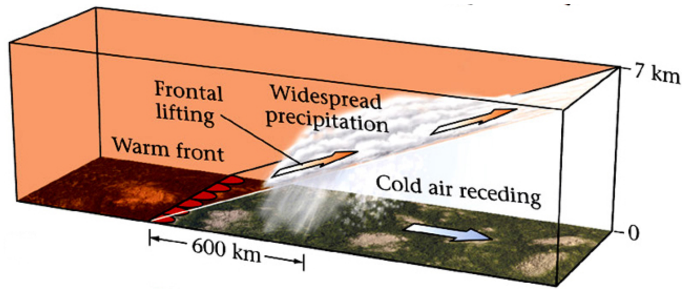
As a cold front moves in, cold air mass pushes below a hot air mass, the hot air rises, cools adiabatically, and water condenses and heavy rains ensue.

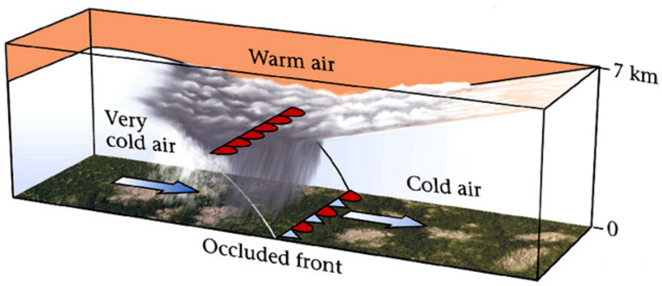




The Weather

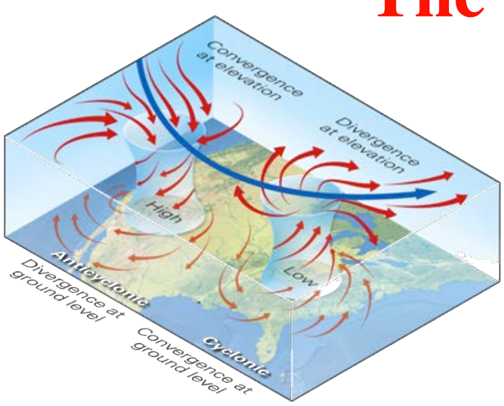
As a warm front moves in, warm air slowly rises over the cool air and clouds form because a warm front has a gentler slope than a cold front.





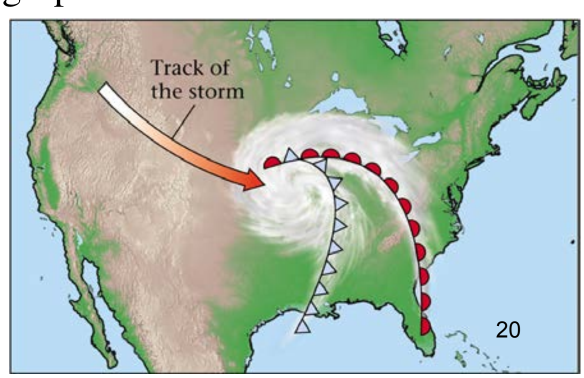
Typically cold fronts move faster than warm fronts and overtake them. The cold front lifts up the base of the warm front, such that the warm front is no longer in contact with the ground. This is called an "**occluded front**".

The Weather

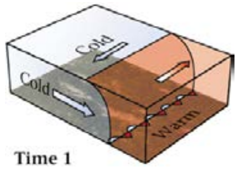


Air flowing from high to low pressure is affected by the Coriolis Effect. In the Northern Hemisphere, the air moves counterclockwise (creating a cyclone) around a low-pressure mass, and clockwise (creating an anticyclone) around a high-pressure mass.

In the mid-latitudes (including the USA and Europe), the weather usually reflects the movement of a large low-pressure air mass (moving west to east). Counterclockwise moving air creates a wave cyclone.



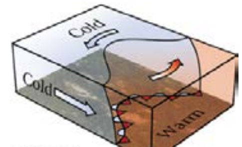
The Weather



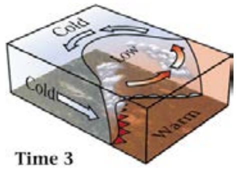
Time 1

Wave cyclones develop when air on one side of the cold front shears sideways past air on the other side.

This warps the face of the front into the shape of a wave - warm air starts to move north and up and over the cold air mass, creating a warm front.



Time 2



Time 3

Cold air circles around and starts to move south and downward, pushing the cold front forward.

The two fronts meet in a “V”, the point of which lies near the center of the low-pressure mass, forming a huge spiral mass of clouds.

Time 4

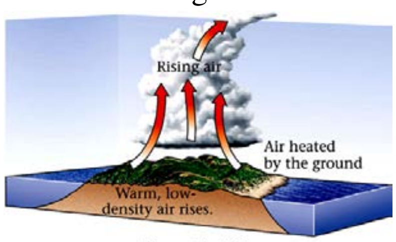
Time 5

The cold front of a wave cyclone moves faster than the warm front, so the warm front becomes occluded and the cyclone dies out.

The Weather

Clouds

Clouds at the surface = fog.
Require condensation nuclei (aerosols).
Air rises through several mechanisms:

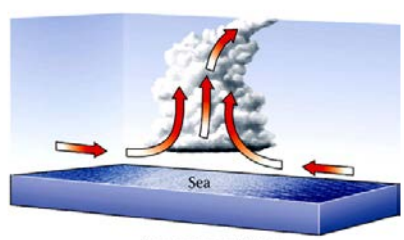


Convective lifting

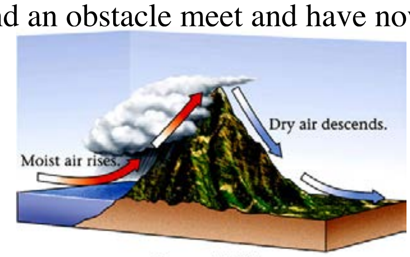
Convective Lifting: ground warms the air and it rises, cooling adiabatically.

Frontal Lifting: warm air rises over cold.

Convergence Lifting: air converges - spirals up in a low-pressure zone or where 2 winds that have been deflected around an obstacle meet and have nowhere to go but up.



Convergence lifting



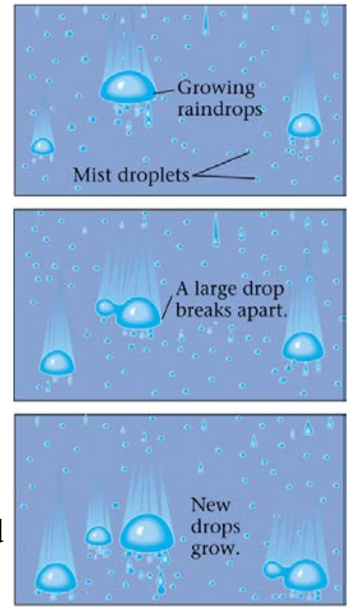
Orographic lifting

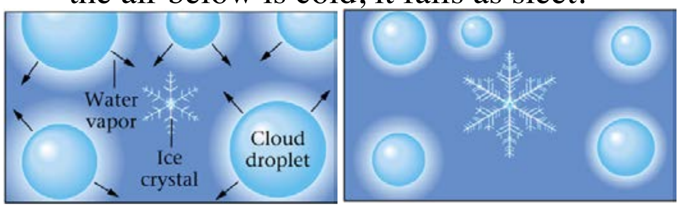
Orographic Lifting: Air rises over landmass/mountain range.

The Weather

Precipitation occurs in two ways:

1) Collision & Coalescence: warm clouds, tiny droplets collide and stick to form larger drops until they are too large to remain suspended. If the air below is cold, it falls as sleet.



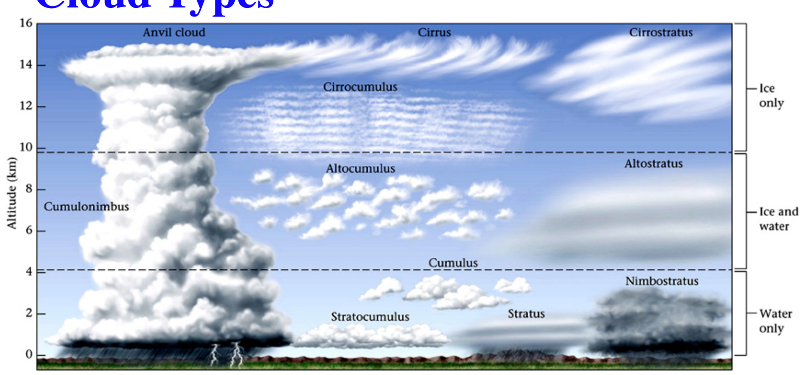


2) Bergeron Process: cold air, tiny ice crystals form and lead to growth of snow flakes. If the air below is very cold, it falls as powder snow; if the air is close to 0˚C, it falls as “wet snow”; if the air is >0˚C, it falls as rain.

Which type of snow is best for making snowballs and snowmen? Why?

The Weather

Cloud Types



Three basic types based on shape:

Cumulus: puffy, cotton-ball/cauliflower-shaped;

Stratus: relatively thin, stable layers (layered structure);

Cirrus: wispy shape.

Add a prefix to indicate elevation:

Cirro: high altitude (>7 km); **Alto**: mid latitude; Low altitude (<2 km) have no prefix.

Add the suffix “***nimbus***” or the prefix “***nimbo***” if the cloud produces precipitation.

Large cumulonimbus clouds flatten out at the tropopause to form “***anvil clouds***”.

Cumulus clouds are puffy, cotton ball, or cauliflower shaped.

Stratus clouds have a sheet-like or layered appearance.

Cirrus clouds are high and have a wispy shape

Storms

Storms, episodes of severe weather, may be dangerous, bringing lightning, high winds, torrential rain, hail, sleet, and snow. A thunderstorm can drench an area with rain and attack it with lightning.

Storms

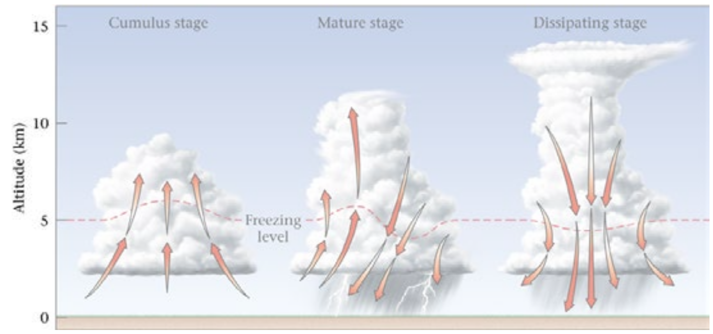
Storm: episode of severe weather.

Thunderstorms

Local episode of intense rain + strong winds & lightening.
Occur when warm, moist air meets cold, dry air (mid-USA during the summer).
Convective lifting driven by solar radiation or orographic lifting.

Latent heat of condensation enhances the lifting eventually allowing anvil clouds to form.
Hail forms if updrafts are strong enough to take water to levels where it freezes.

Precipitation indicates storm is in the “mature stage”, as falling rain pulls air down with it creating strong downdrafts. Interaction of updrafts and downdrafts produces strong, gusty winds. Once downdrafts predominate, storm dissipates.



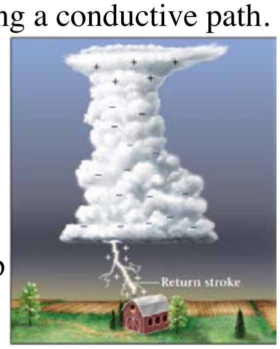
Lightening

The Weather

Speculation: rubbing of water & air molecules creates positively charged ice and H that drift to the top of a cloud. Negatively charged OH^- sink to the base, creating a zone of positive charge on the ground.

As air is a good insulator, the charge separation can become very large, until a lightening flash jumps across the gap. This begins when electrons incrementally leak from the negatively charged cloud base to the ground creating a conductive path.

When the charges meet, the “return stroke” carries positive charge up to the cloud.



Positive ions flow upward to the cloud through conducting materials (trees, buildings, etc.).

Lightening creates heat (8,000-33,000˚C) and surrounding air rapidly expands, producing an explosion.
As light travels faster than sound, lightening precedes the thunder clap.

The Weather

Tornadoes

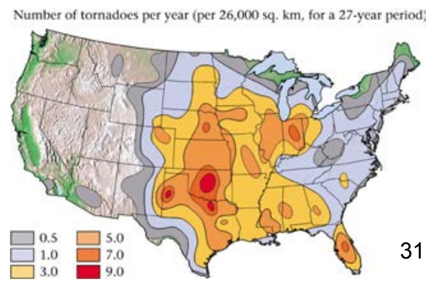
Near vertical funnel-shaped cloud that funnels air up the center (low pressure). Rotates counterclockwise in the Northern Hemisphere.

Fujita Scale: estimates of wind speed based on the damage caused.

TABLE 20.2 Enhanced Fujita Scale for Tornadoes

Scale	Category	Wind Speed km per Hour (mph)	Average Path Length; Average Path Width	Typical Damage
EF0	Weak	104–137 (65–85)	0–1.6 km; 0–17 m	Branches and windows broken
EF1	Moderate	138–177 (86–110)	1.6–5.0 km; 18–55 m	Trees broken; shingles peeled off; mobile homes moved off their foundations
EF2	Strong	178–217 (111–135)	5–16 km; 56–175 m	Large trees broken; mobile homes destroyed; roofs torn off
EF3	Severe	218–266 (136–165)	16–50 km; 176–556 m	Trees uprooted; cars overturned; well-constructed roofs and walls removed
EF4	Devastating	267–322 (166–200)	50–160 km; 0.56–1.5 km	Strong houses destroyed; buildings torn off foundations; cars thrown; trees carried away
EF5	Incredible	over 322 (over 200)	160–500 km; 1.5–5.0 km	Cars and trucks carried more than 90 m; strong houses disintegrated; bark stripped off trees; asphalt peeled off roads

"Tornado Alley"



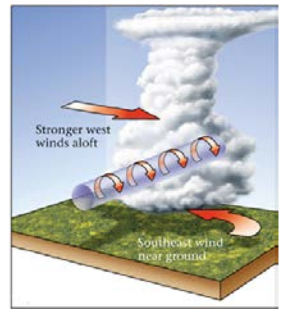
The Weather

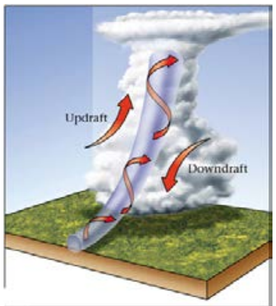
Tornadoes

The Weather

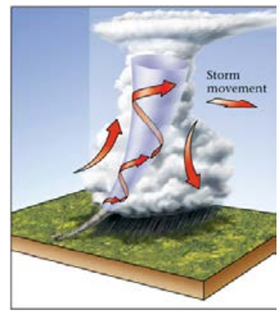
Tornadoes

Formation (in USA): strong upper level westerlies interact with strong southeast surface winds (Gulf moisture). Interaction produces shearing such that the air rotates in a horizontal cylinder.





Updrafts and one end and downdrafts at the other move the funnel vertical.



Initially white/grey clouds form, but when the funnel hits the ground, clouds become back due to entrained debris.

Nor' easters

Wave cyclones affect Atlantic coast - winds out of the NE. Huge storms ("perfect storm") can build seas to 11 m.

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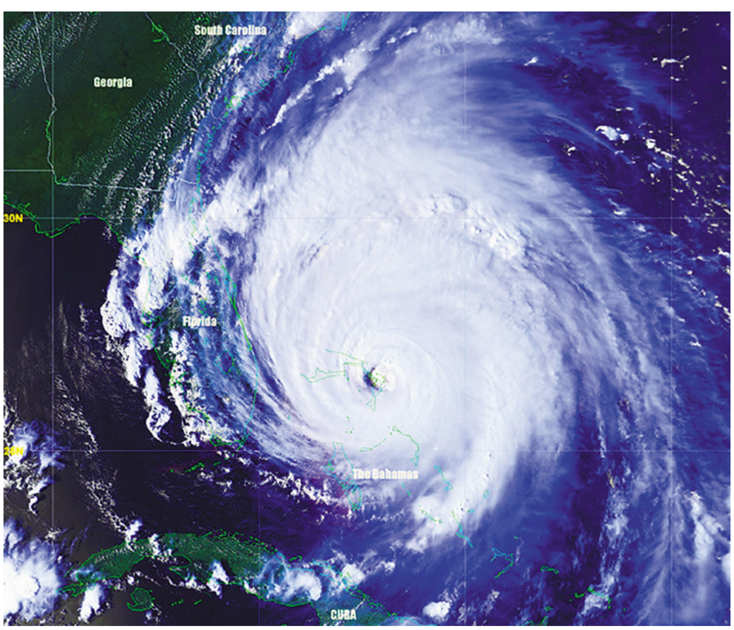
The Weather

Hurricanes



Originate during summer/early fall in the Atlantic off Africa (latitude ~20˚N) over warm tropical water. If water >27˚C, a lot of moisture is in the air that rises and the latent heat of condensation promotes further rise and more moist air takes its place. *Coriolis Effect* causes the mass to rotate counterclockwise.

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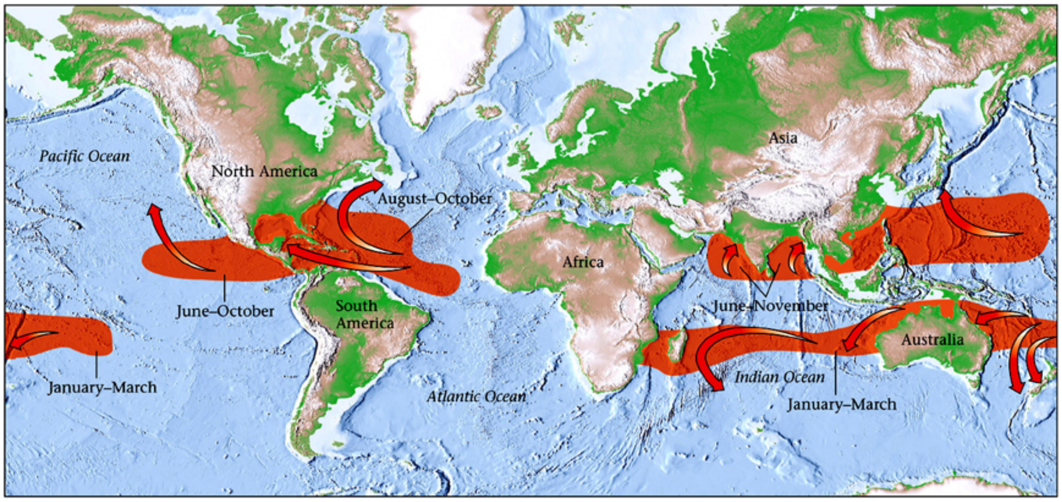
The Weather

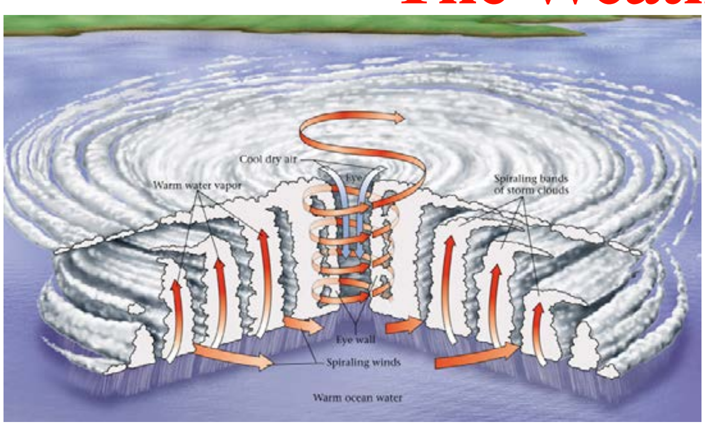
Hurricanes

Hurricanes in the Atlantic; **Typhoons** in the Pacific; **Cyclones** in the Indian Ocean.

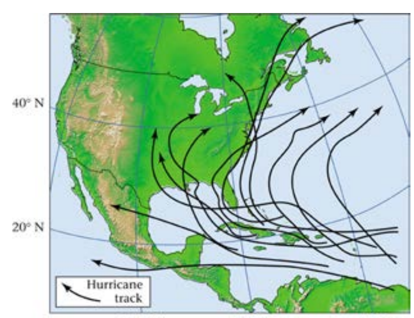
Tropical Depression: >38 mph; ***Hurricane***: >74 mph.



The Weather



Consist of several spiral arms (rain bands) extending inward to the eye (zone of relative calm). The eye wall is where the winds are strongest.



Hurricanes move west in the Atlantic - winds on the N-side are relatively faster than those on the S-side.

Damage is caused by:

Wind; Waves; Rainfall (flooding and associated mass wasting); Storm Surge.

The Weather

Storm Surge: the side of a hurricane where winds blow onshore piles up the sea over a 60-80km region and pushes it on land (e.g., Katrina).

If a storm reaches tropical depression status, it is given a name. Names of particularly notorious storms are never used again, but names of lesser storms are.
Hurricanes classified using the ***Saffir-Simpson*** scale.

Saffir-Simpson Scale for Hurricanes

Scale	*Category*	*Wind Speed (km/h)*	*Air Pressure in Eye (millibars)*	*Damage*
1	Minimal	119–153	980 or more	Branches broken; unanchored mobile homes damaged; some flooding of coastal areas; no damage to buildings; storm surge of 1.2–1.5 m.
2	Moderate	154–177	965–979	Some roofs, doors, and windows damaged; mobile homes seriously damaged; some trees blown down; small boat moorings broken; storm surge of 1.6–2.4 m.
3	Extensive	178–209	945–964	Some structural damage to small buildings; large trees blown down; mobile homes destroyed; structures along coastal areas destroyed by flooding and battering; storm surge of 2.5–3.6 m.
4	Extreme	210–250	920–944	Some roofs completely destroyed; extensive window and door damage; major damage and flooding along coast; storm surge of 3.7–5.4 m. Widespread evacuation of regions within up to 10 km of the coast may be necessary.
5	Catastrophic	over 250	less than 920	Many roofs and buildings completely destroyed; extensive flooding; storm surge greater than 5.4 m. Widespread evacuation of regions within up to 16 km of the coast may be necessary.

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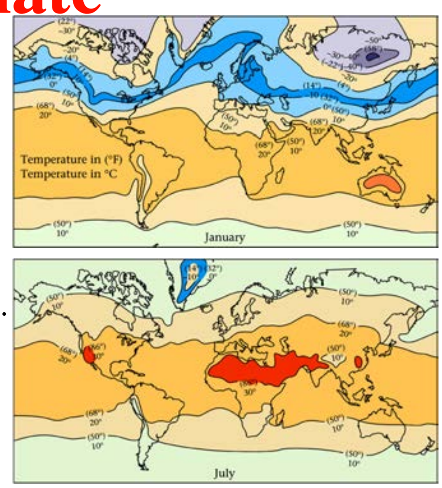
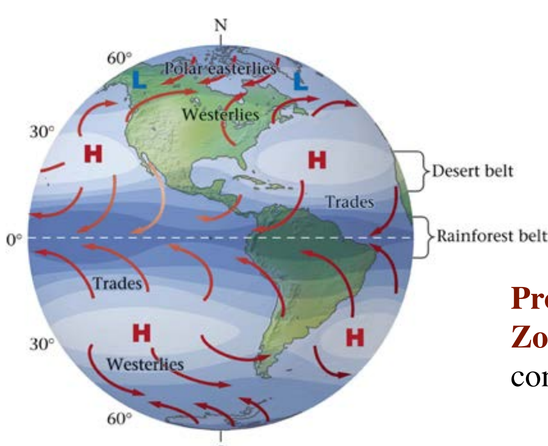
Global Climate

Several factors control climate:

Latitude: determines the amount of solar radiation that reaches a given region (along with the season).
Altitude: higher = cooler.
Proximity of Water: Moderating affect.
Proximity to Ocean Currents: North Atlantic Drift.
Proximity to Orographic Barriers: Mountain ranges.





Proximity to High- or Low-Pressure Zones: zones of divergence or convergence.

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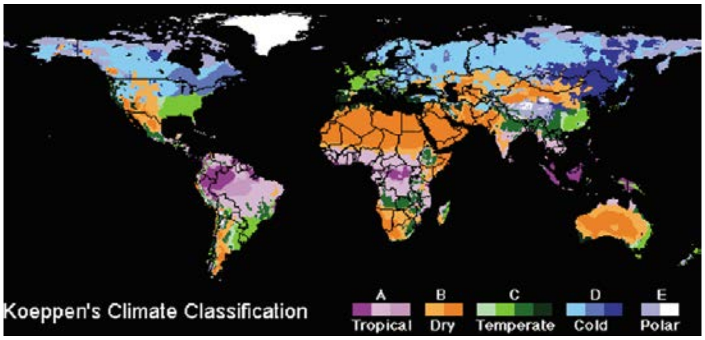
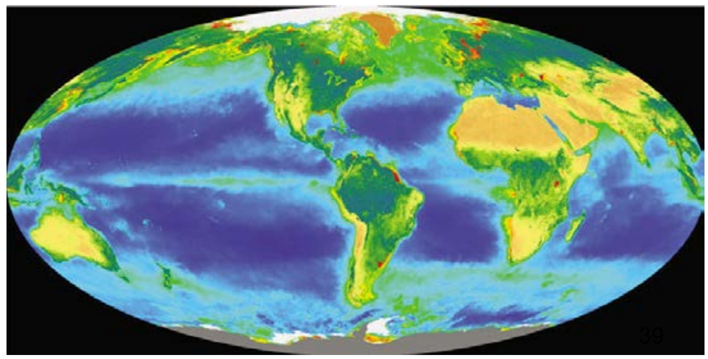
Global Climate



Biosphere: Land = vegetation; Sea = Chlorophyll production



Southern Oscillation, El Niño.

Typical high & low pressure locations, summer & winter are reversed.

For example, tropical Pacific in winter is normally under a low pressure system just to the north of Australia and a high pressure system is just off the western coast of South America. Trade winds drag warm water across the Pacific and "pile" it up on the western side.

At intervals of 3-8 years, these high and low pressure systems reverse so winds blow in the other direction = Southern Oscillation. Occurs around Christmas = El Niño current.

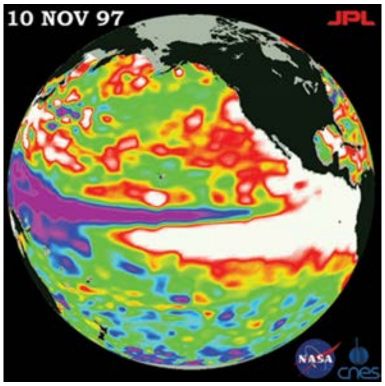
Effects:

Sea level rises in E. Pacific by ~20 cm, sea temperature increases by up to 7˚C.

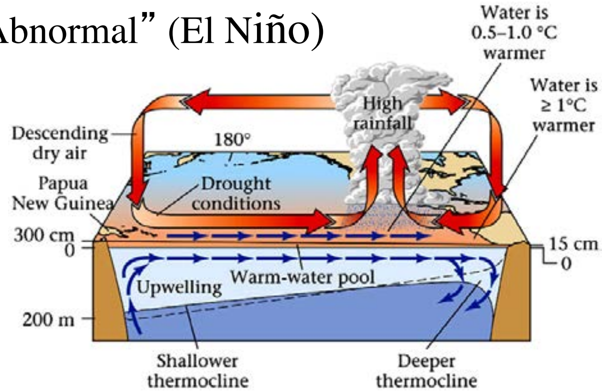
More evaporation = rain increased in South and Central America, storms are more intense. Drought in Australia.

Causes – unknown! Heating by mid-ocean ridges??

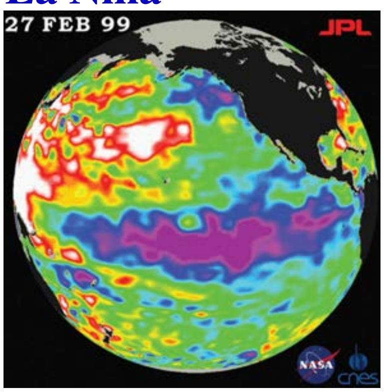
El Niño



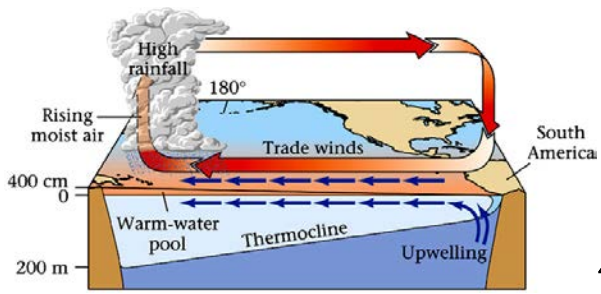
"Abnormal" (El Niño)



La Niña



"Normal" (La Niña)



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Summary

Atmosphere Formation: Primary and Secondary Atmospheres; Current Atmosphere Composition.

Air Pollution: Aerosols; Acid Rain; Greenhouse Gases; CFCs.

The Atmosphere: Adiabatic Cooling & Heating; Relative Humidity; **Dewpoint**; Cloud Formation; Troposphere (Tropopause); Statosphere (Stratopause); Mesosphere (Mesopause); Thermosphere; Homosphere; Heterosphere; Ionosphere; Insolation (latitudinal & seasonal variations); Hadley, Ferrel, and Polar Cells; Convergence & Divergence Zones; Coriolis Effect; Polar Front; Jet Streams.

The Weather: Air Mass; Cold & Warm Fronts; Cyclone; Wave Cyclone; Convective, Frontal, Convergence, Orographic Lifting; Precipitation Processes.

Cloud Types: Cumulus, Stratus, Cirrus; Cirro; Alto; Nimbus; Nimbo; Anvil Clouds.

Thunderstorms: Thunder and lightening;

Tornadoes: Formation; Fujita Scale.

Nor'easters.

Hurricanes (Typhoons, Cyclones): Tropical Depression; Damage.

Global Climate: Latitude; Altitude; Proximity of Water; Proximity to Ocean Currents; Proximity to Orographic Barriers; Proximity to Low- & High-Pressure Zones; El Niño.

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