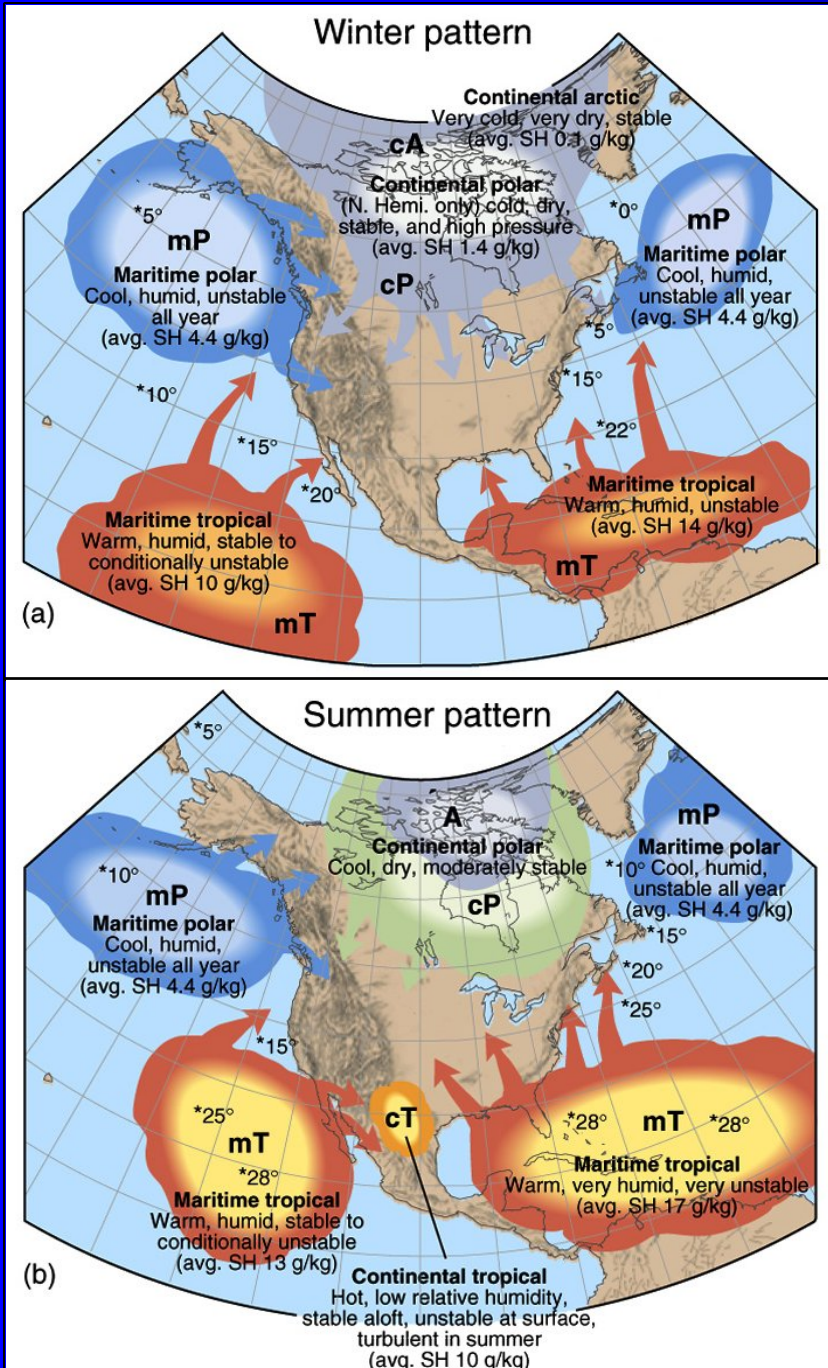
The Earth System - Atmosphere IV

Air Masses, Weather Systems and Hurricanes



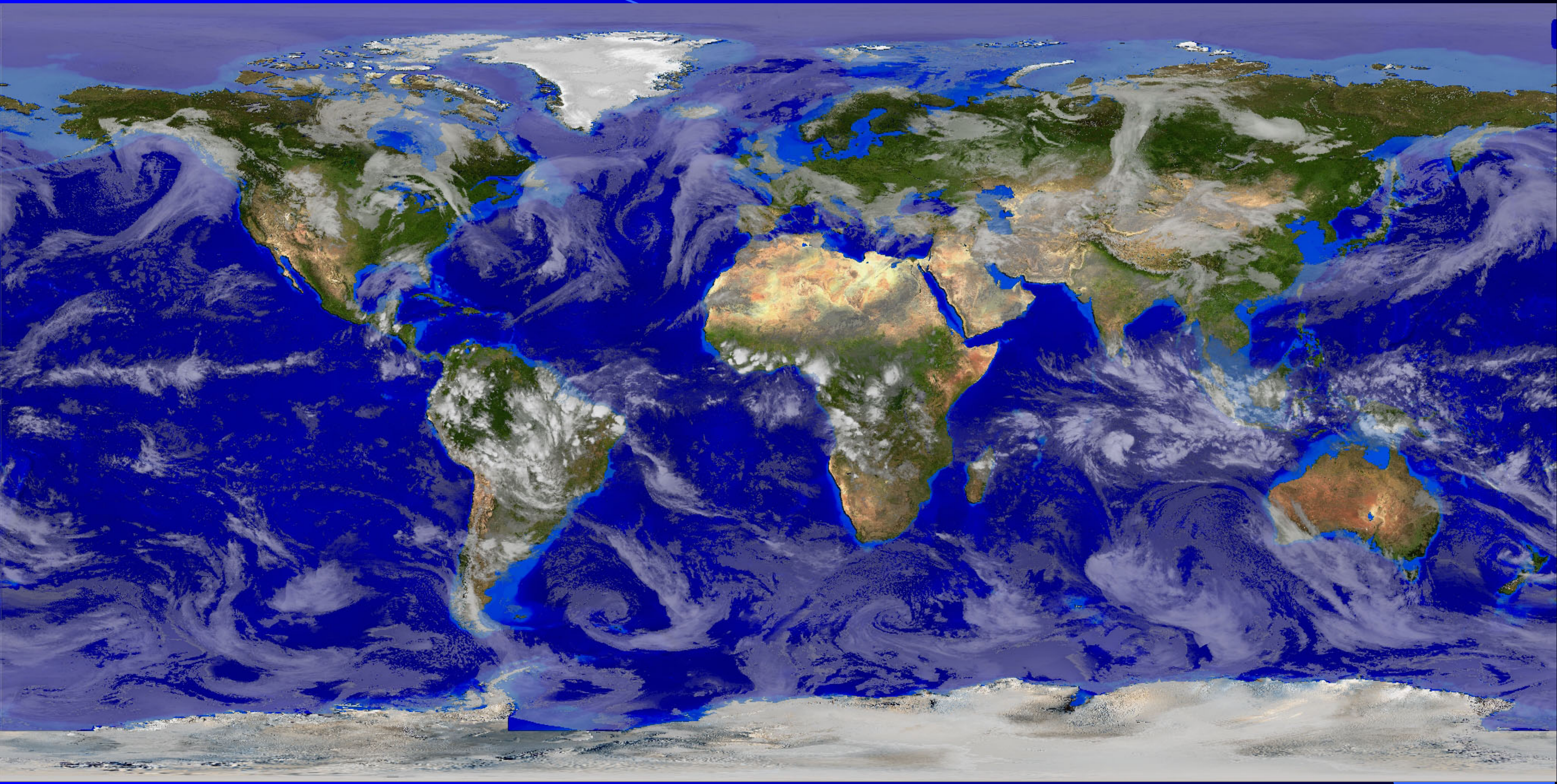
Air mass – a body of air which takes on physical characteristics which distinguish it from other air.

Classified on the basis of moisture content [continental (c) and maritime (m)] and temperature [Arctic (A), Polar (P), and Tropical (T)].

Table 8–1 Weather characteristics of North American air masses

Air Mass	Source Region	Temperature and Moisture Characteristics in Source Region	Stability in Source Region	Associated Weather
cA	Arctic basin and Greenland ice cap	Bitterly cold and very dry in winter	Stable	Cold waves in winter
cP	Interior Canada and Alaska	Very cold and dry in winter	Stable entire year	a. Cold waves in winter b. Modified to cPk in winter over Great Lakes bringing "lake-effect" snow to leeward shores
mP	North Pacific	Mild (cool) and humid entire year	Unstable in winter Stable in summer	a. Low clouds and showers in winter b. Heavy orographic precipitation on windward side of western mountains in winter c. Low stratus and fog along coast in summer; modified to cP inland
mP	Northwestern Atlantic	Cold and humid in winter Cool and humid in summer	Unstable in winter Stable in summer	a. Occasional "nor'easter" in winter b. Occasional periods of clear, cool weather in summer
cT	Northern interior Mexico and southwestern U.S. (summer only)	Hot and dry	Unstable	a. Hot, dry, and cloudless, rarely influencing areas outside source region b. Occasional drought to southern Great Plains
mT	Gulf of Mexico, Caribbean Sea, western Atlantic	Warm and humid entire year	Unstable entire year	a. In winter it usually becomes mTw moving northward and brings occasional widespread precipitation or advection fog b. In summer, hot and humid conditions, frequent cumulus development and showers or thunderstorms
mT	Subtropical Pacific	Warm and humid entire year	Stable entire year	a. In winter it brings fog, drizzle, and occasional moderate precipitation to N.W. Mexico and S.W. United States b. In summer this air mass occasionally reaches the western United States and is a source of moisture for infrequent convectional thunderstorms.

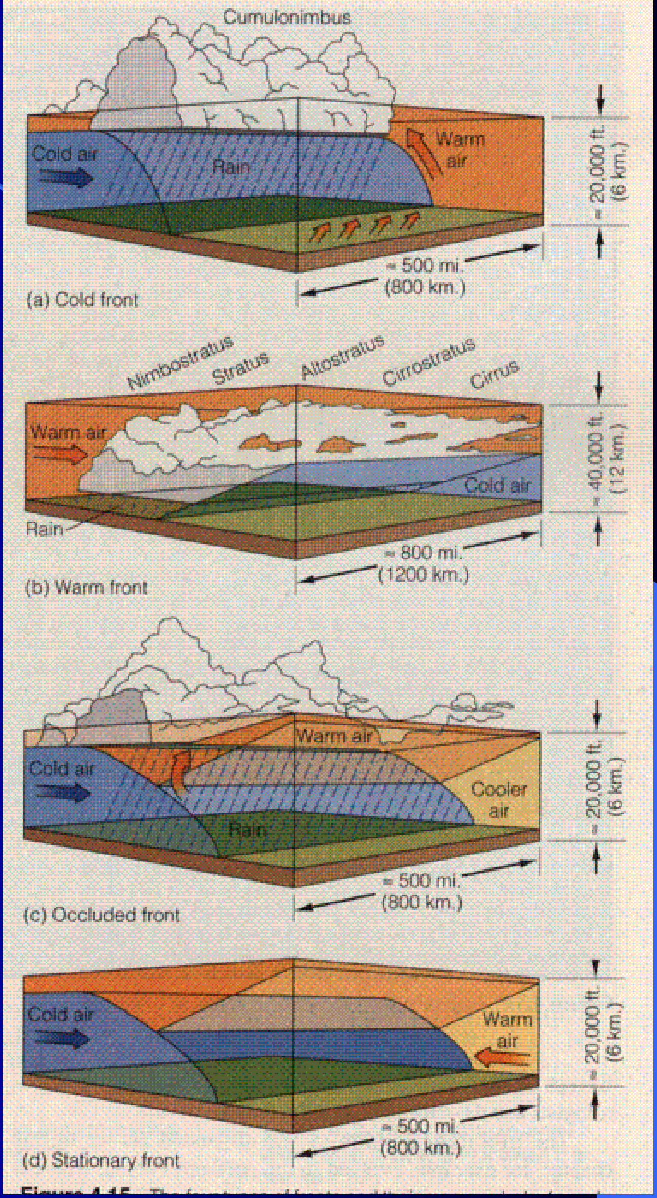
Weather Patterns



1. The primary weather producer at mid-latitudes (e.g., North America) is the mid-latitude cyclone.
2. Weather is interpreted in terms of the polar front or Norwegian Cyclone Model.

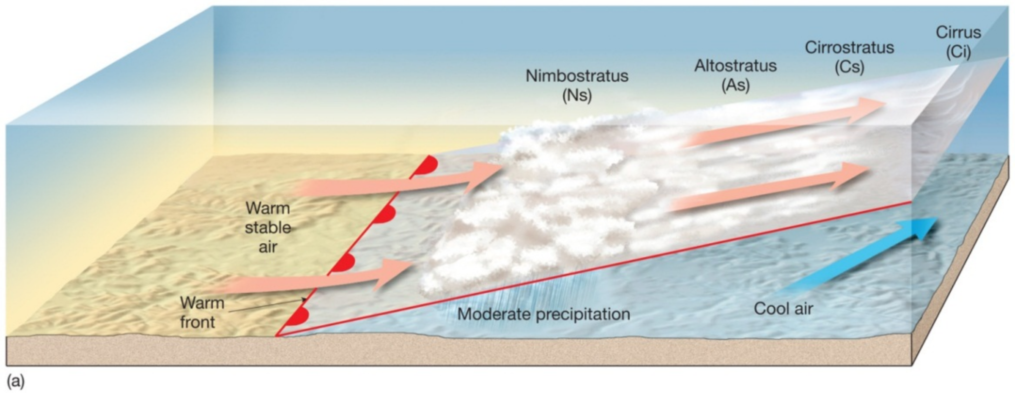
Fronts

1. In general, Fronts are boundary surfaces that separate air masses of different densities.
2. A polar front separates cold Arctic air from warm subtropical air.
3. It is always the warmer, less dense air that is forced aloft.
4. Cool air acts as a wedge on which lifting takes place. Called overrunning.
5. Types of fronts are: warm, cold, stationary, occluded



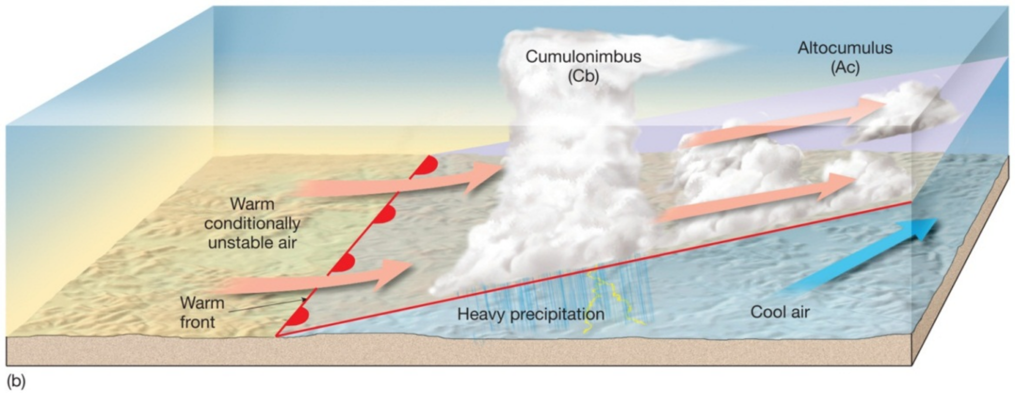
Warm Fronts

A warm front forms when warm air moves into cold air and is forced aloft. The boundary between the two air masses is the frontal surface. The intersection of the frontal surface with the ground is the front.



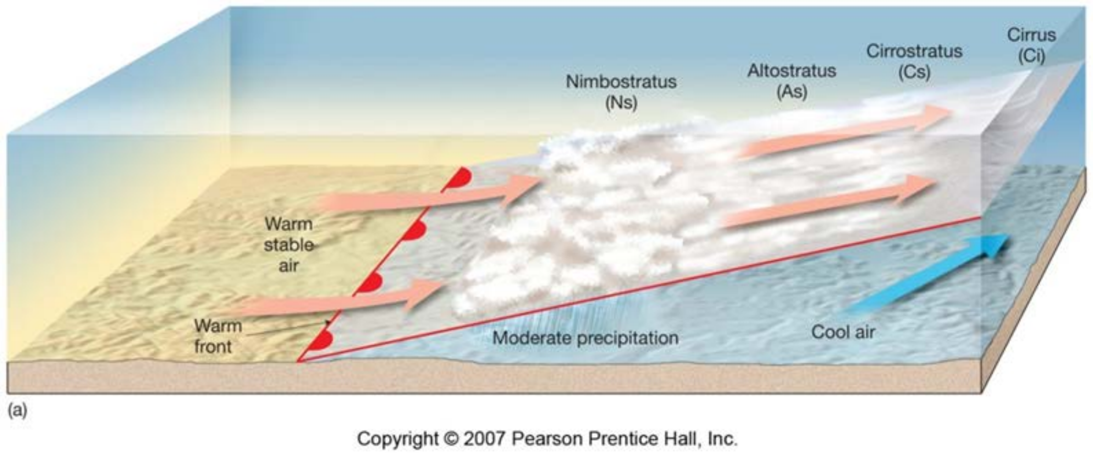
Warm stable air

Warm conditionally unstable air



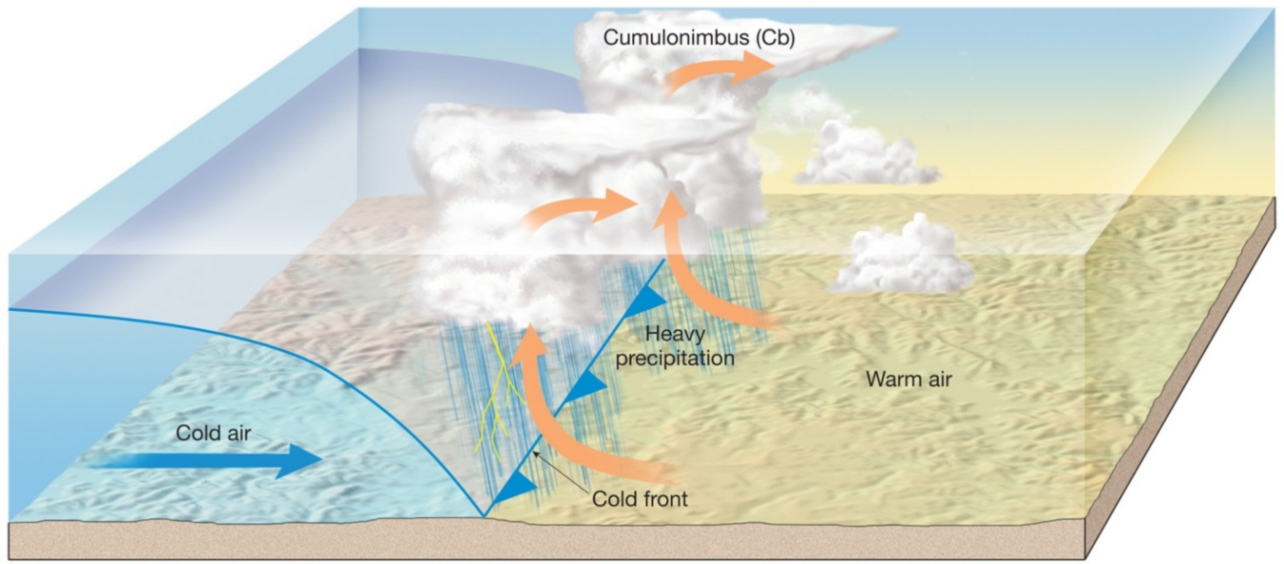
Warm Fronts

1. As the warm air rises over the cold air, it expands and cools adiabatically, causing condensation and precipitation
2. The first sign of an approaching front is cirrus clouds, which form where the overrunning warm air has ascended high up the wedge of cold air. The surface front could be 1000 km behind. Warm fronts normally produce light to moderate precipitation over a large area for an extended period.
3. As the front approaches a given point, the cirrus clouds grade into cirrostratus, then thicker stratus, and then nimbostratus clouds, which bring the rain.
4. Precipitation occurs well ahead of the surface location of the front.



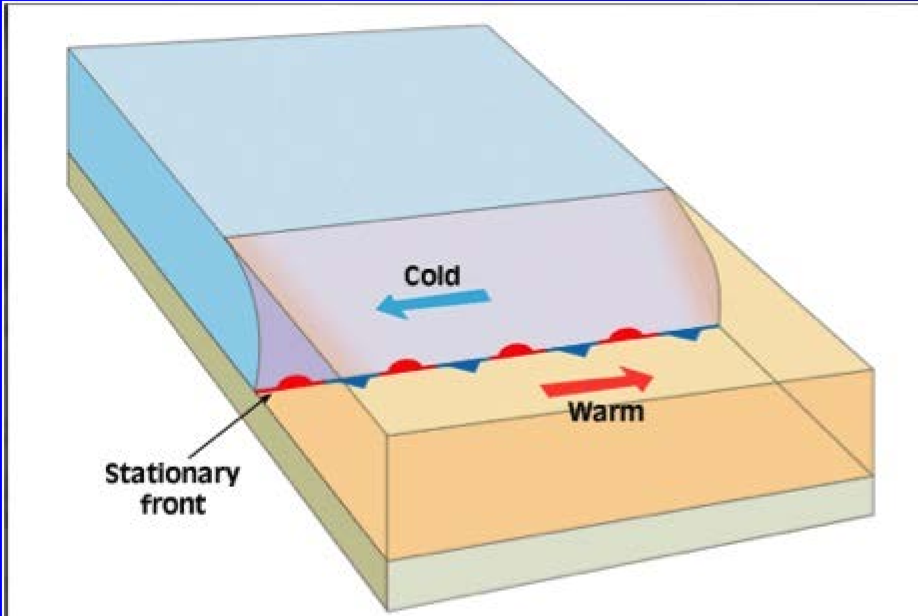
Cold Fronts

1. Cold air moves into warm and forces the warm air to rise.
2. The arrival of a cold front is often preceded by altocumulus clouds, followed by cumulonimbus clouds and rain.
3. Cold air behind the front is usually subsiding, so the weather is clear (and cold). Cold fronts are about twice as steep as warm fronts, and move about 50% faster. Consequently cold-front weather is more violent than warm-front weather.
4. Intensity of precipitation is greater than for a warm front, and has a shorter duration.



Stationary Fronts

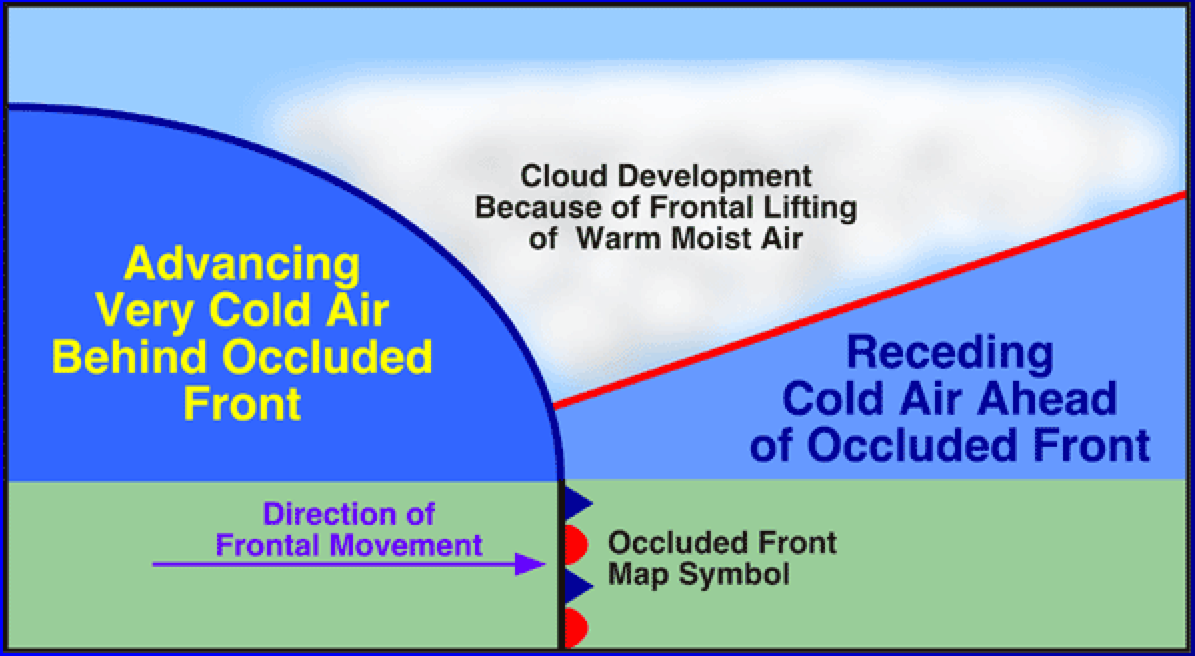
1. Sometimes neither the warm air or cold air wins the battle, and we get a **stationary front** (stalemate).
2. Air flow is parallel to the line of the front.
3. Gentle to moderate precipitation, but possible floods if the front remains in the one place for too long.

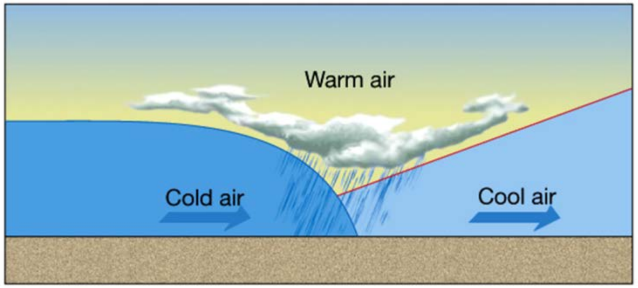


A stationary front does not move or is almost motionless and winds blow parallel to the front but in opposite directions on either side.

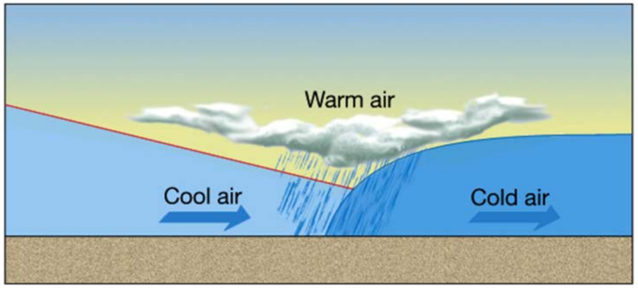
Occluded Fronts

1. One front overtakes another.
2. Cold-type occluded front - cold front overtakes warm front. e.g. East of Rockies. Expect heavy rain - warm air is forced aloft.
3. Warm-type occluded front - warm front overtakes cold front. e.g. Along the Pacific coast. Mild maritime polar air invades frigid continental polar air.





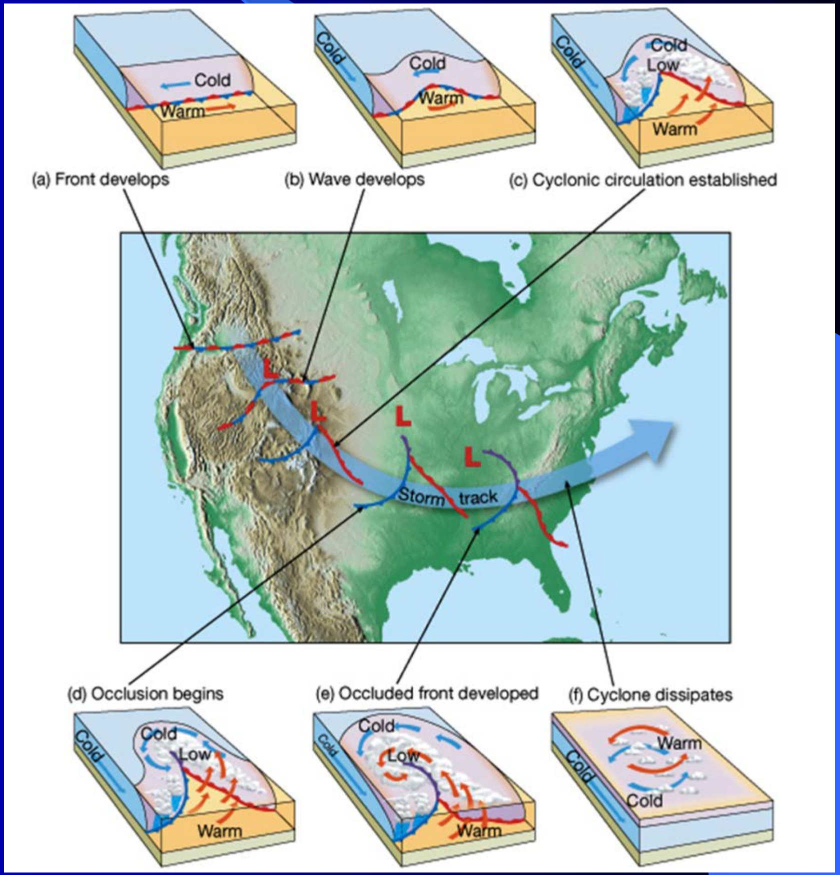
(a) Cold-type



(b) Warm-type

Mid-Latitude Cyclone

1. Development and intensification of a mid-latitude cyclone is explained in terms of the "polar-front" theory .
2. Cyclones form along fronts. Life cycle last about 3 to 7 days.
3. Six stages:
   1. Formation (cyclogenesis)
   2. Development of wave in the front
   3. Cyclonic circulation established
   4. Occlusion begins
   5. Occluded front develops
   6. Cyclone dissipates

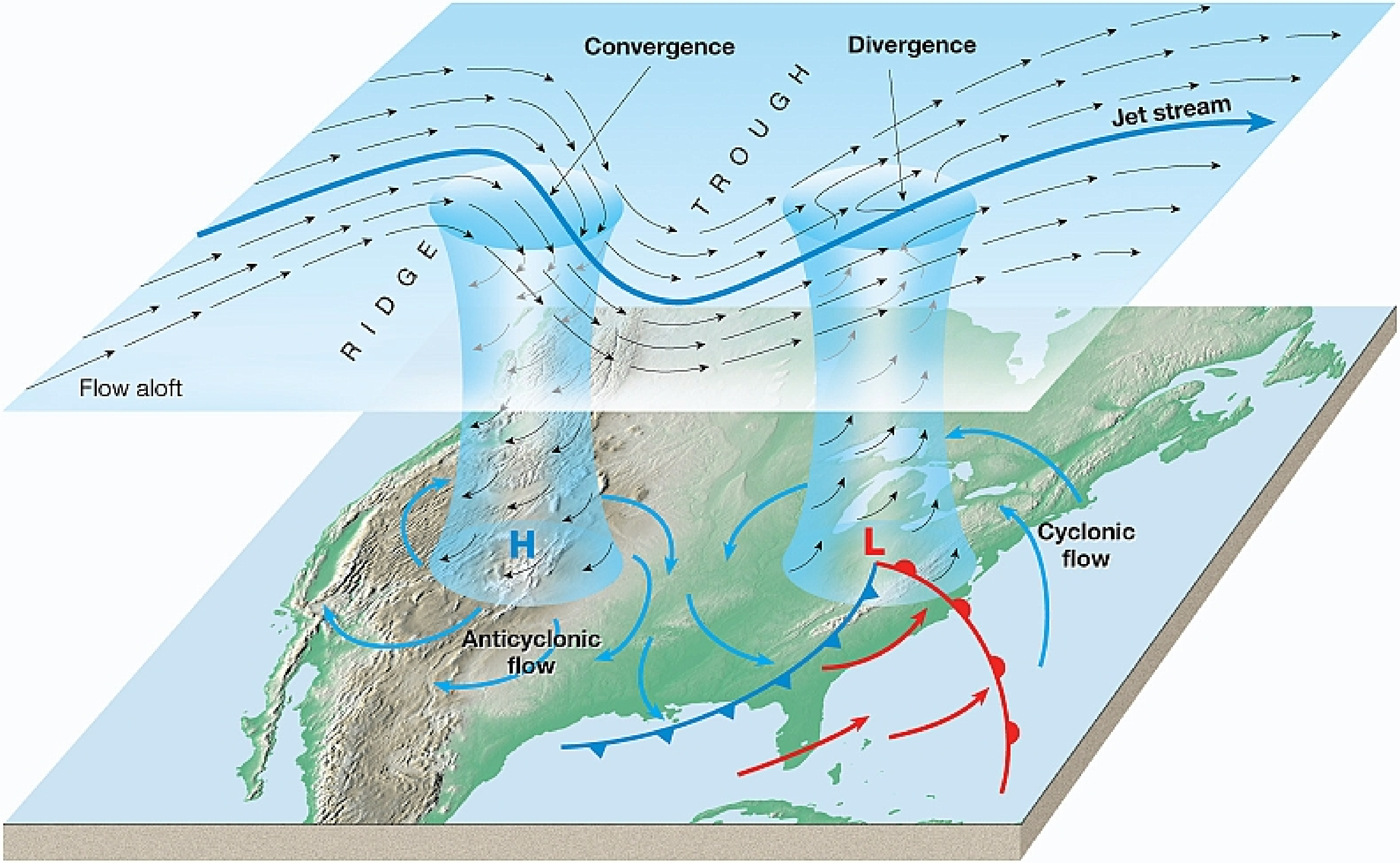


Mid-Latitude Cyclone

1. Stage 1. Two air masses of different densities and temperatures are moving parallel to the front, and in opposite directions. Typically - cP associated with polar easterlies on the north of the front, mT driven by westerlies on the south
2. Stage 2. Under suitable conditions, the front takes on a wave shape that is usually several hundred km long.
3. Stage 3. For a cyclone to develop, the wave must steepen and "break". The warm moves pole-wards into the cold air, establishing a warm front, while cold air moves equator-wards, establishing a cold front. This sets up a circular flow pattern in a counterclockwise direction - the cyclone.
4. Stage 4. Cold front normally travels about 50% faster then the warm front, and overtakes it, causing occlusion. Ends of the fronts in center of cyclone occluded first.
5. Stage 5. The size of the occluded front grows in length, displacing the warm front aloft. The storm usually intensifies, the central pressure falls, and wind speeds increase. During Winter, can get heavy snowfalls and blizzard-like conditions (because of the high winds).
6. Stage 6. Once all the warm air has been displaced, we have just the cold air and no temperature gradient. There is thus no energy left to drive the cyclone, which therefore dissipates.

Cyclogenesis / Formation

1. **Polar-front model** - cyclone formation occurs where a frontal surface is distorted into a wave-like discontinuity.
2. Wave is caused by surface factors, such as topographic irregularities, temperature contrasts, ocean currents.
3. The flow aloft is usually intensified before the formation of a surface cyclone, so the flow aloft is a very important contributor to cyclone formation.
4. When the flow aloft is generally zonal (east to west), little cyclonic activity occurs at the surface.
5. When the upper air forms waves, these waves drive the air north and south as well as east-west and set up alternating troughs and ridges. Surface cyclones tend to form below such regions.
6. When surface cyclones form, they are usually centered below the jet stream, and downwind from an upper level trough.

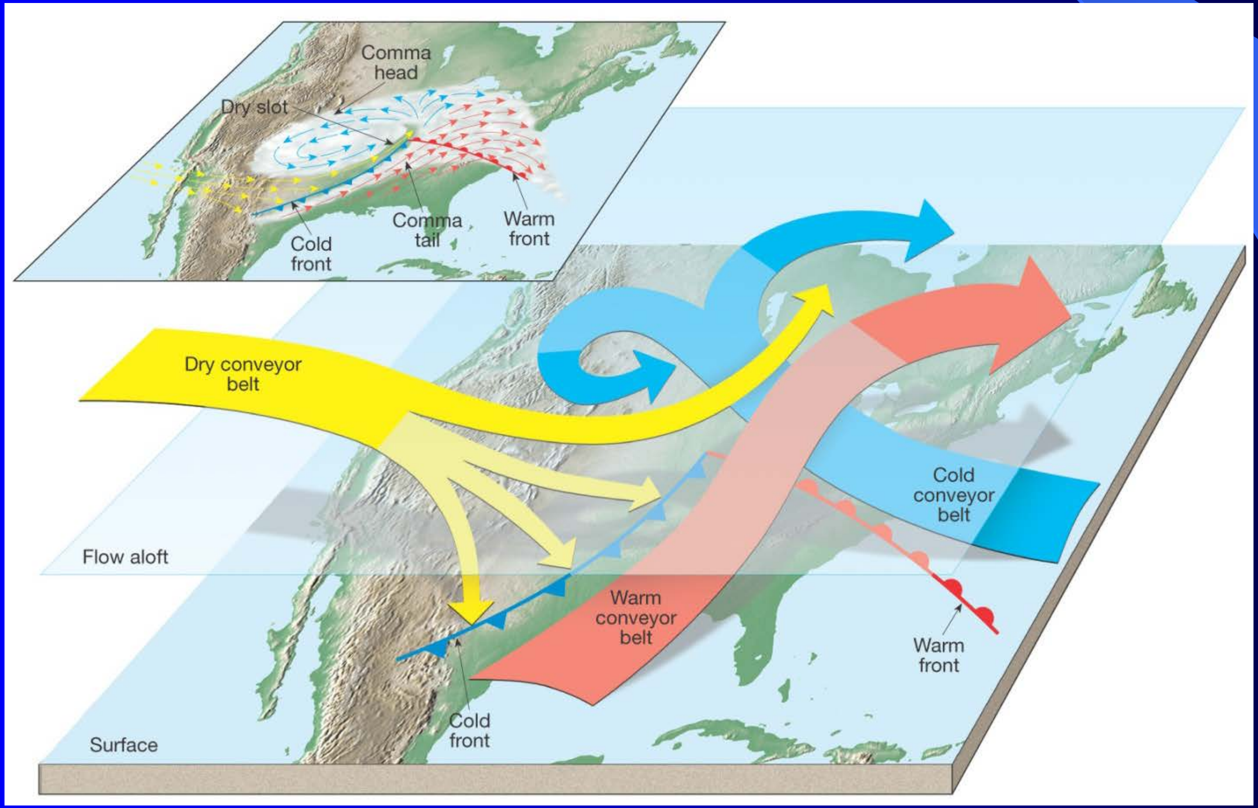

Convergence
Divergence
TROUGH
RIDGE
Jet stream
Flow aloft
H
L
Anticyclonic flow
Cyclonic flow

Cyclogenesis

1. Cyclonic & Anticyclonic Circulation - cyclones & anticyclones generally appear in pairs, below the jet stream .
2. The surface air that flows into the low pressure center of a cyclone is forced aloft where it diverges. On the other hand, the air above an anticyclone converges, sinks to the surface, and becomes the outflow from the anticyclone.
3. Divergence & Convergence Aloft - divergence aloft tends to flow generally west to east along sweeping curves. (At the surface, divergence is in all directions over the surface.) This flow is controlled by the jet stream.
4. On entering the zone of high wind speed around the jetstream, air accelerates and stretches out (divergence).
5. On entering a zone of low wind speed, air slows down and piles up (convergence).
6. Upper level divergence and surface cyclonic flow around a Low generally develop downstream (to the east) from an upper level trough.
7. Upper level convergence and surface anticyclonic flow around a High generally develop downstream (to the east) from an upper level ridge.

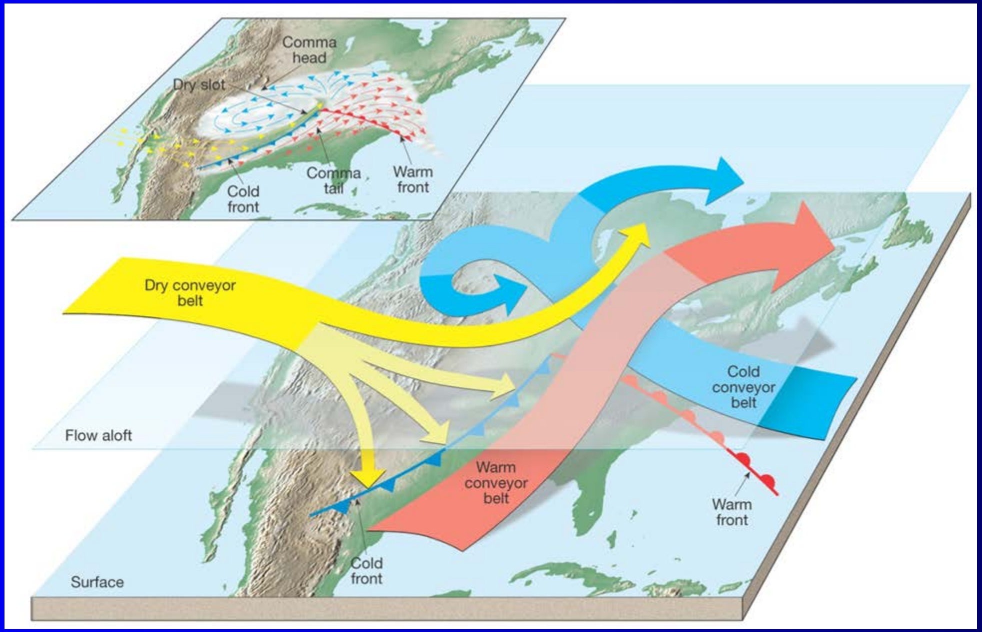
Conveyor Belt Model

1. Norwegian (polar front) model talks about conflicts between air masses along frontal boundaries.
2. Conveyor Belt model consists of 3 interacting air streams - Two that originate near the surface, and ascend aloft; One that originates in the upper troposphere.



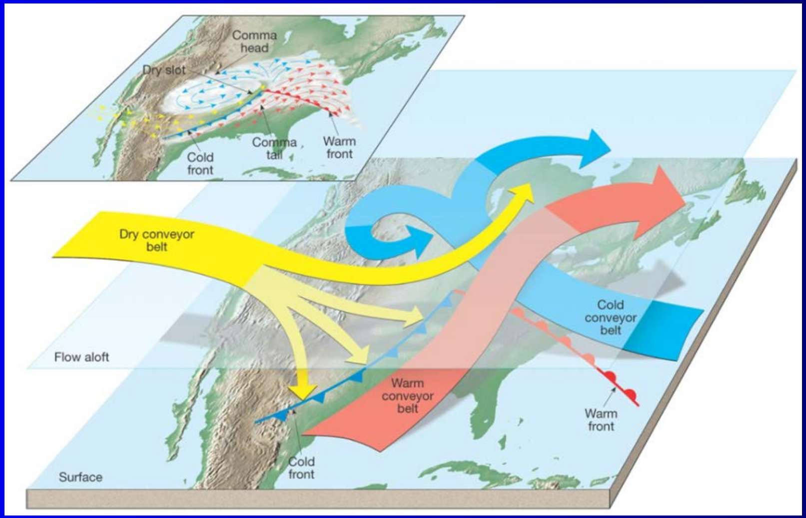
Warm conveyor belt

1. Warm conveyor belt carries warm air from Gulf of Mexico northward into warm sector of cyclone. Convergence causes it to rise.
2. When it reaches the warm front, it rises even more rapidly over the cold air.
3. Adiabatic cooling of warm moist air gives clouds and precipitation.
4. When this air reaches the middle troposphere, it turns right and joins the general west to east flow.



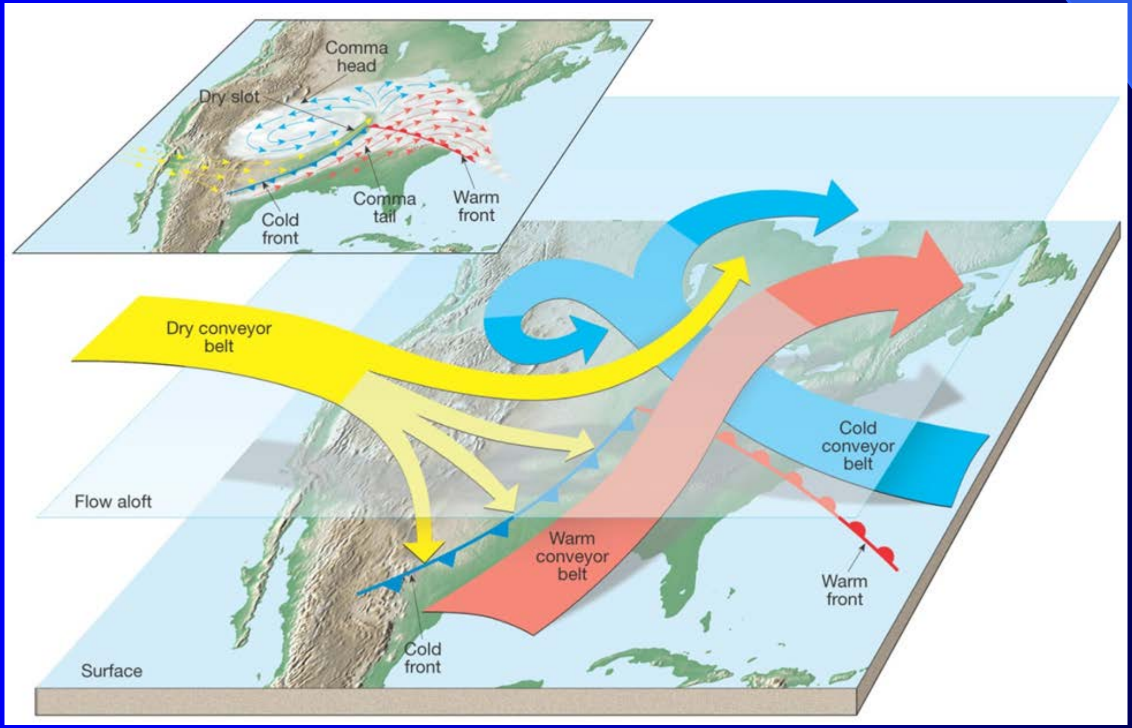
Cold conveyor belt

1. Cold conveyor belt is airflow that starts at the surface ahead of the warm front, and flows westward towards the center of the cyclone.
2. Air is moistened by evaporation of moisture falling through it.
3. Airstream rises because of convergence, becomes saturated, and contributes to the overall precipitation. When this air reaches the middle troposphere, some of it rotates cyclonically around the low to produce the "comma head" of the mature storm system.
4. Remaining air turns right (clockwise) and joins the general west to east flow.
5. Runs parallel to the warm conveyor belt, and may generate precipitation.



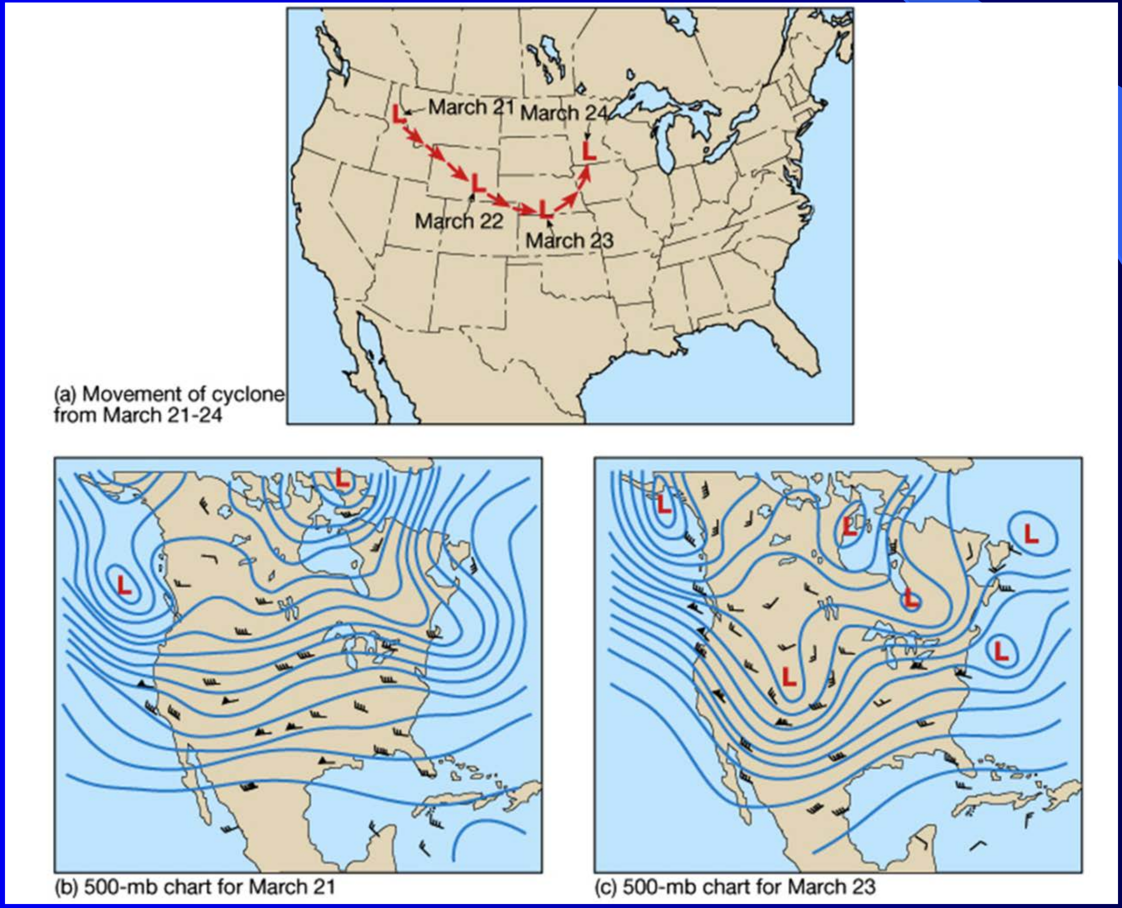
Dry conveyor belt

1. Dry conveyor belt (yellow) originates in upper troposphere, where it is part of the general west to east flow.
2. This air is relatively cold and dry.
3. As this airstream enters the cyclone, some descends behind the cold front, and provides clear, cool conditions.
4. Other branch of this airstream flows west, and forms the dry slot (no cloud)



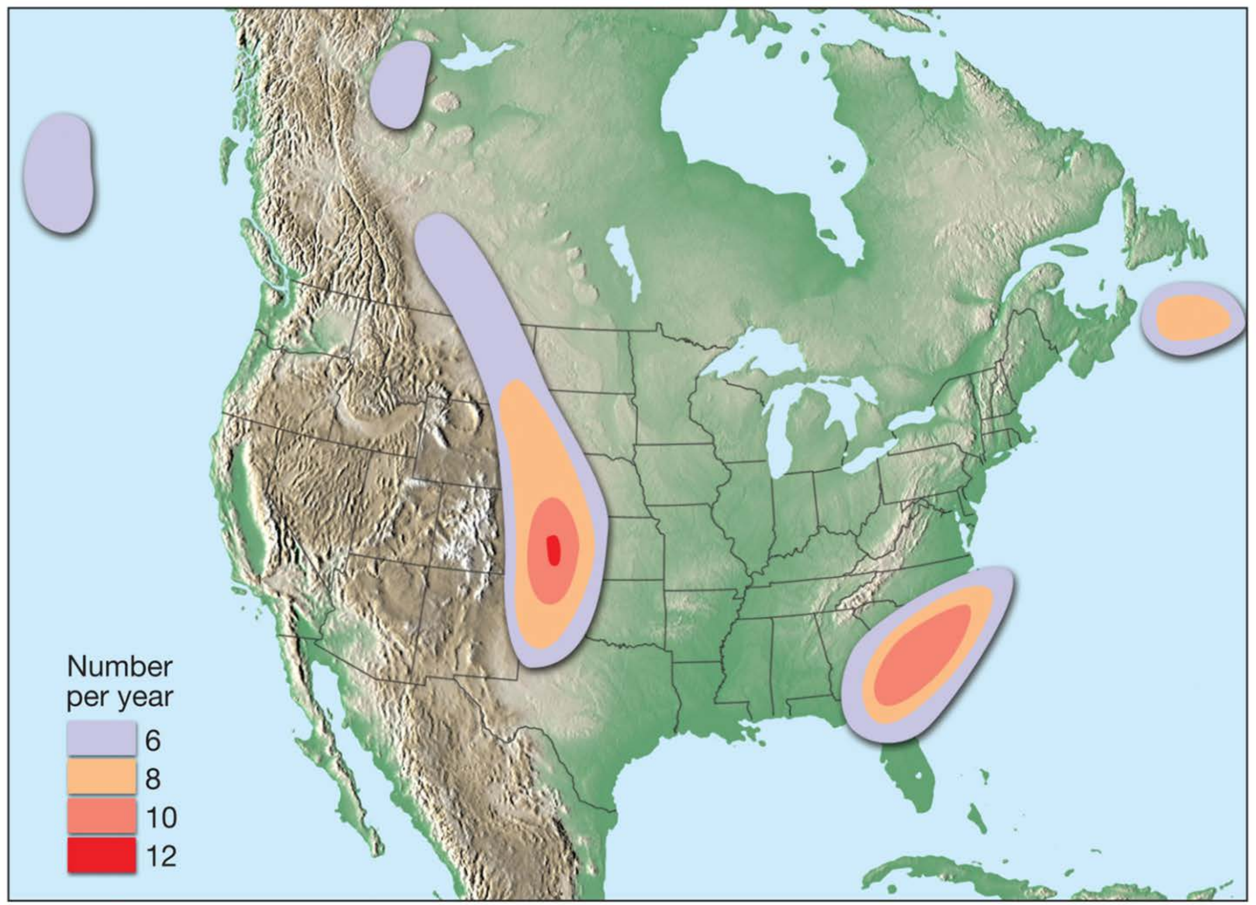
Travelling Cyclones

1. Cyclones generally move over the surface of the Earth at about 25 to 50 kph.
2. The path of a cyclone is controlled to a large extent by the air flow aloft (500 mb level). The upper level flow "steers" the surface cyclone.



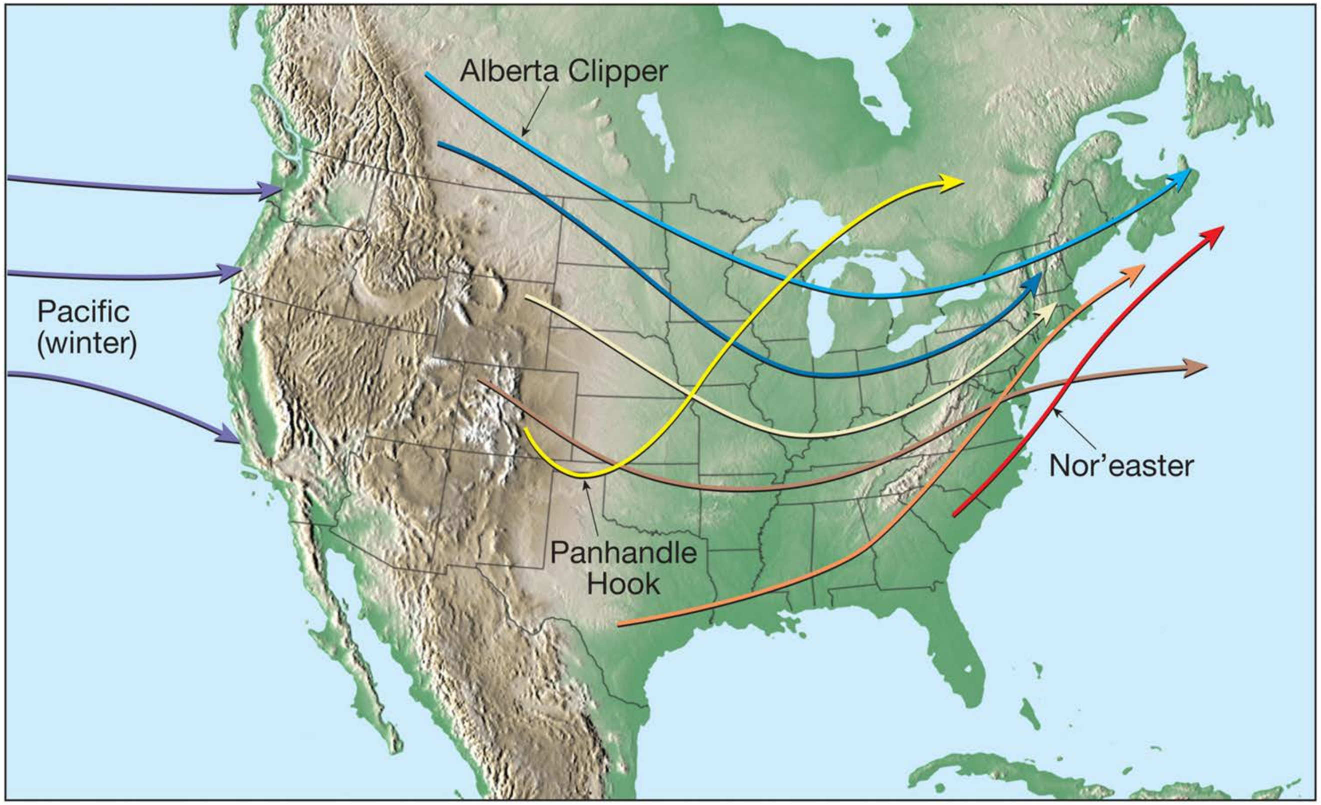
Travelling Cyclones

1. In general, cyclones form where large temperature contrasts occur in the lower troposphere.
2. Main sites for cyclone formation: lee side of Rockies; along Atlantic coast, east of the Appalachians; North Pacific; North Atlantic.



Patterns of Movement

1. Cyclones that form east of the Rockies tend to migrate to the east, and then northeast.
2. Cyclones that influence western North America originate over the Pacific, and move northeastwards towards the Gulf of Alaska, where they merge with the Aleutian low.

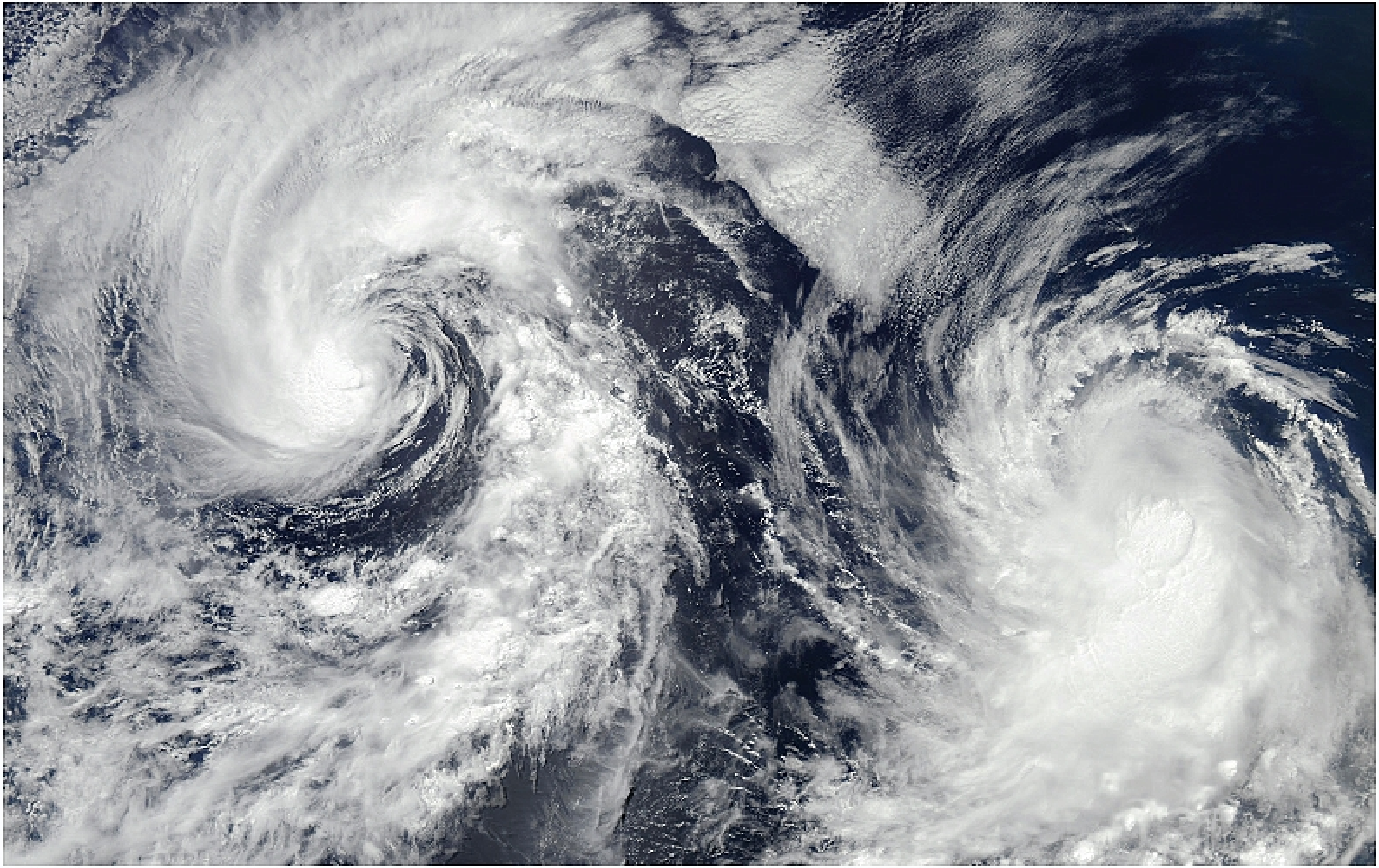


Hurricanes

Galveston, 1900

(a)

(b)



Tropical storms Boris and Christian, 2008


Katrina

New Orleans after Katrina

Crystal Beach, Texas. Hurricane Ike, Sep 2008

TABLE 11–1 The 10 Deadliest Hurricanes to Strike the U.S. Mainland 1900–2008

Rank	Hurricane	Year	Category	Deaths
1.	Texas (Galveston)	1900	4	8000*
2.	SE Florida (Lake Okeechobee)	1928	4	2500–3000
3.	Katrina	2005	4	1833
4.	Audrey	1957	4	At least 416
5.	Florida Keys	1935	5	408
6.	Florida (Miami)/Mississippi/Alabama/Florida (Pensacola)	1926	4	372
7.	Louisiana (Grande Isle)	1909	4	350
8.	Florida Keys/South Texas	1919	4	287
9. (tie)	Louisiana (New Orleans)	1915	4	275
9. (tie)	Texas (Galveston)	1915	4	275

Source: National Weather Service/National Hurricane Center NOAA Technical Memorandum NWS TPC-5.
*This number may actually have been as high as 10,000–12,000.

Hurricanes

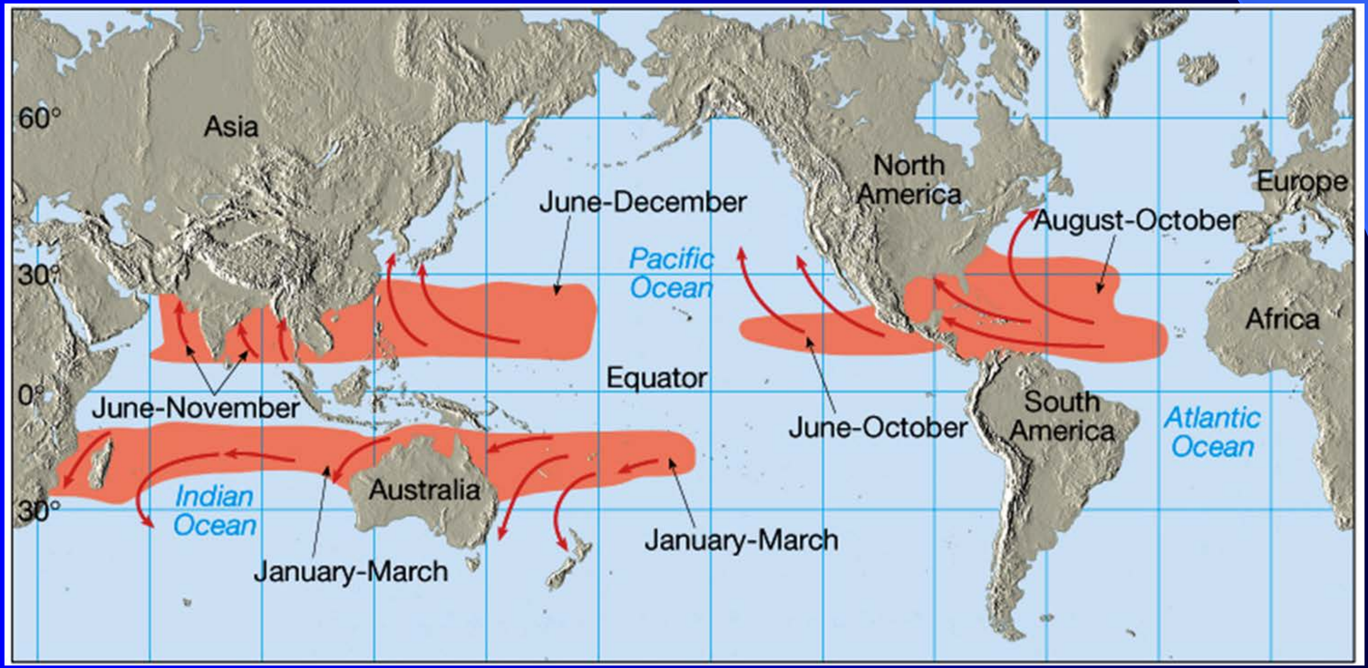
- Tropical depressions have sustained winds below 61 km/hr.
- Tropical storms have winds between 61 and 119 km/hr.
- Hurricanes are tropical cyclones that have sustained winds that exceed 119 km/hr. (74 mi/hr.) and that have a rotary circulation about the center (counter-clockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere).

Formation of Hurricanes

1. A hurricane is a heat engine that is fueled by the **latent heat** liberated when huge quantities of water condense.
2. The warm air rises, and surface air flows into the hurricane
3. The water temperature must be 27°C or higher, to provide the necessary heat and moisture
4. Hurricanes do not form over the relatively cool waters of the South Atlantic and the eastern southern Pacific Ocean.
5. Hurricanes do not form within 5 degrees of the equator because the Coriolis force is too weak to start the necessary rotation.

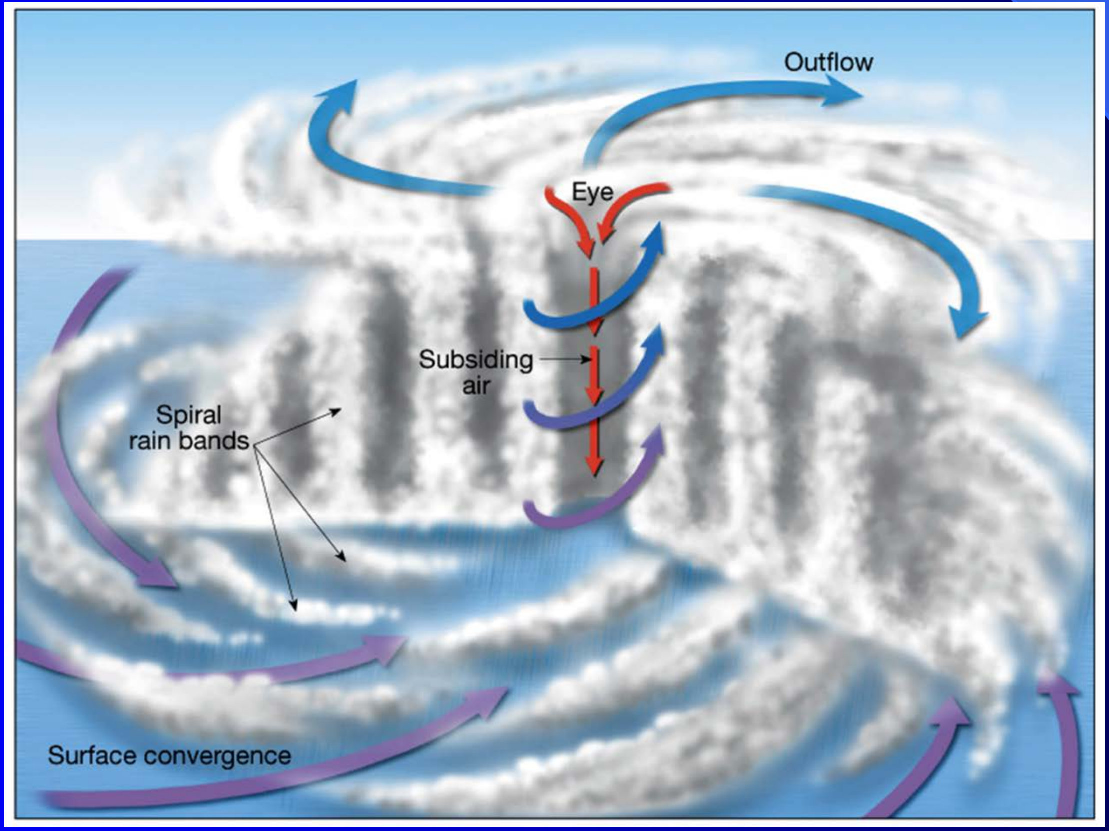
Hurricanes

1. Hurricanes are formed from simple complexes of thunderstorms called tropical disturbances
2. Most hurricanes form between the latitudes 5 and 20 degrees over the tropical oceans except the South Atlantic and the eastern South Pacific (which are too cold).
3. North Pacific has maximum occurrence- about 20 per year. Typhoons.
4. Large hurricanes are about 600km across (range from 100 to 1500 km)



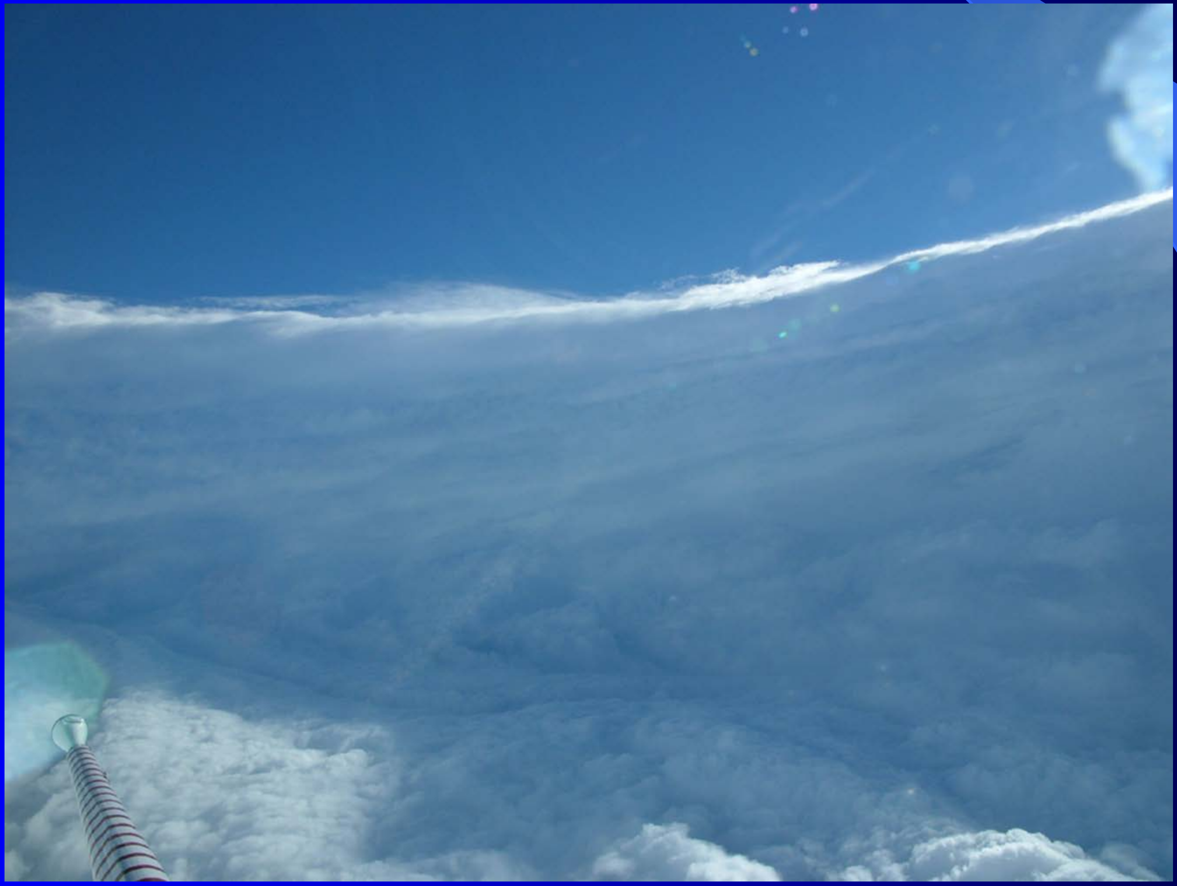
Hurricanes

1. Barometric pressure can drop by as much as 60 mb from edge to center
2. A steep pressure gradient generates the rapid, inwards spiralling winds of a hurricane. These winds get faster towards the center (conservation of angular momentum)
3. As warm, moist surface air approaches the core of the storm, it turns upwards and ascends in a ring of cumulonimbus clouds.



Hurricanes

1. The eye wall is the doughnut shaped wall of intense convective activity surrounding the center of the storm.
2. Strongest winds and heaviest rainfall occur at the eye wall.
3. Surrounding the eye wall are spiral bands of clouds.



Hurricanes

1. Near the top of the hurricane the airflow is outwards, carrying the rising air away from the storm center (divergence), making room for more inward air flow (warm & moist air) at the surface (convergence).
2. At the center of the hurricane is the eye - winds drop and precipitation stops.
3. The air within the eye gradually descends, and is warmed by compression - warmest part of the storm.

Hurricane Decay

1. Hurricanes decay when
   (1) They move over a region that cannot supply the required warm, moist tropical air
   (2) They move onto land
   (3) They reach a location where the large-scale flow aloft is unfavorable

2. Surface roughness over land reduces the speeds of the surface winds, which causes them to flow more directly into the low, decreasing the pressure gradient.

Hurricane Destruction

Three classes of damage - Storm Surge, Wind Damage & Inland flooding

Saffir-Simpson scale is used to rank the relative intensities of hurricanes - 1 is least severe storm, and 5 is the worst storm possible

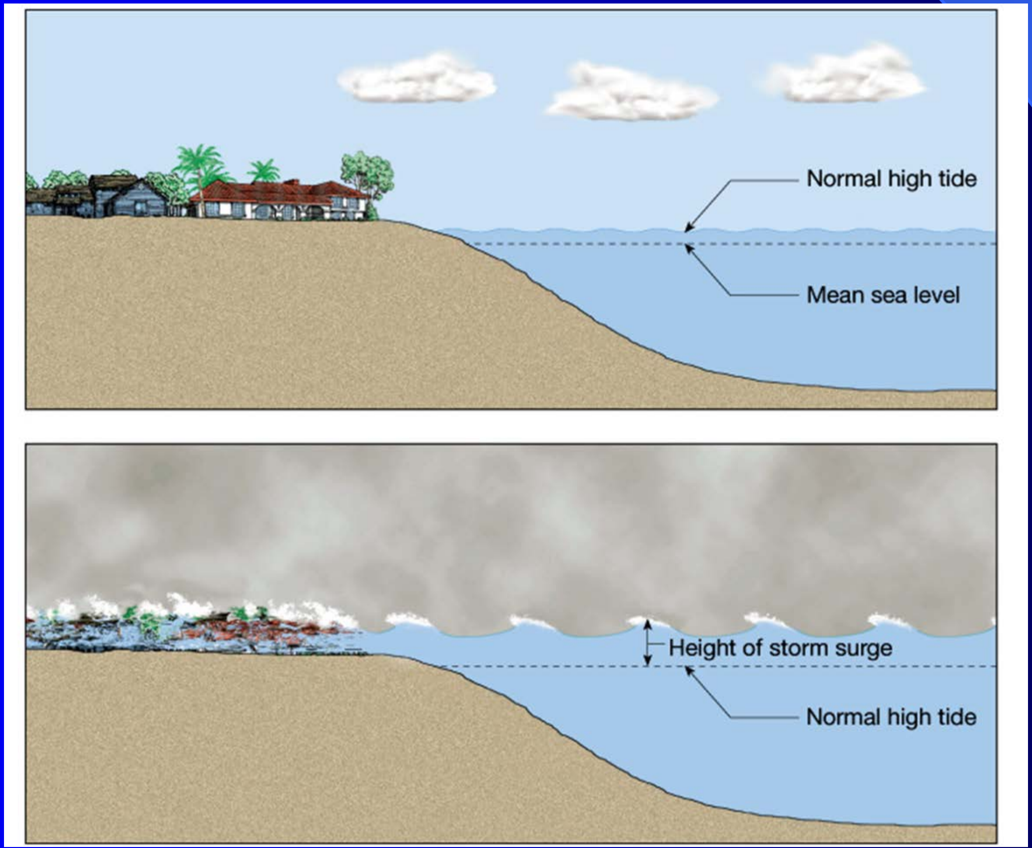
TABLE 11–2 Saffir-Simpson Hurricane Scale*

Scale Number (category)	Central Pressure (millibars)	Winds (km/hr)	Storm Surge (meters)	Damage
1	≥980	119–153	1.2–1.5	Minimal
2	965–979	154–177	1.6–2.4	Moderate
3	945–964	178–209	2.5–3.6	Extensive
4	920–944	210–250	3.7–5.4	Extreme
5	<920	>250	>5.4	Catastrophic

*A more complete version of the Saffir-Simpson hurricane scale may be found in Appendix F, p. 485.

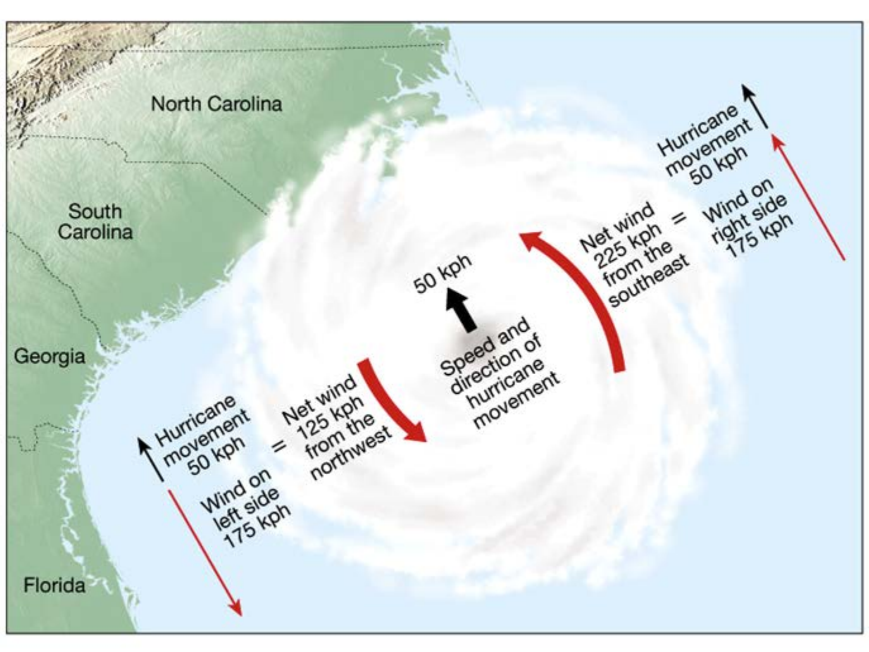
Storm Surge

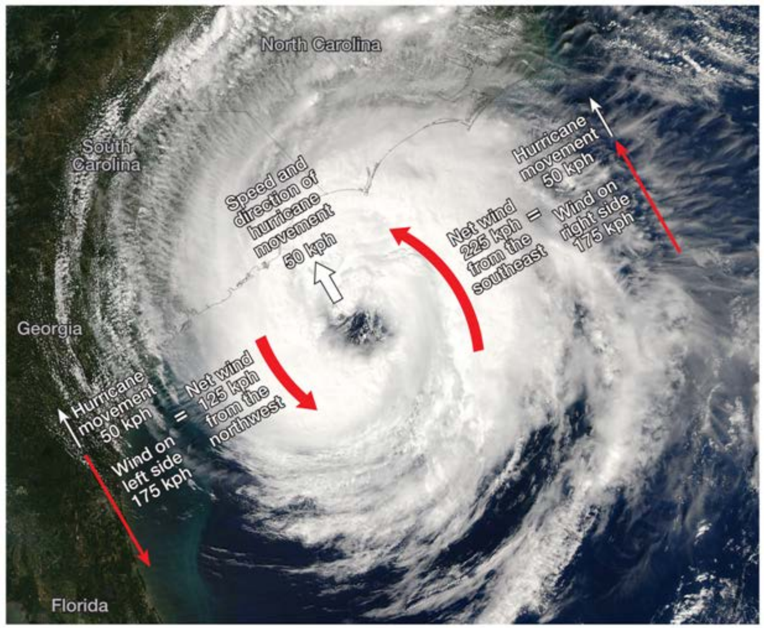
1. Cause the most devastating damage in coastal regions.
2. A storm surge is a dome of water 65 to 80 km wide that sweeps across the coast near where the eye makes landfall. Produces a higher water level than normal and tremendous wave activity.



Storm Surge

1. Storm surge has two causes:
   (1) Piling up of ocean water by strong onshore winds
   (2) Storm has lower atmosphere level than normal
2. Storm surge is most intense on the right side, where winds are blowing towards the shore
3. Forward movement of the hurricane on this side of the storm also contributes to the storm surge
4. On the left side of the storm, the speed of the winds blow in the opposite direction to the movement of the storm, cancel each other out to some extent.





Wind Damage

1. Destruction caused by wind is the most obvious type of hurricane damage.
2. Affect a much larger area than the storm surge, and can cause huge economic damage.
3. Tornadoes spawned by hurricanes represent another aspect of wind damage.

Inland Flooding

1. Caused by the torrential rains that accompany hurricanes
2. Can occur hundreds of km inland, and last for days after the hurricane has gone.

Hurricane Watches & Warnings

1. Hurricane watch - hurricanes pose a possible threat within the next 36 hours
2. Hurricane warning - sustained winds of 119 km/hr are expected within a specified coastal area within 24 hours
3. Important factors in the watch & warning process:
   1. Adequate lead times must be provided
   2. Over-warning must be kept to a minimum – don't cry "Wolf!"