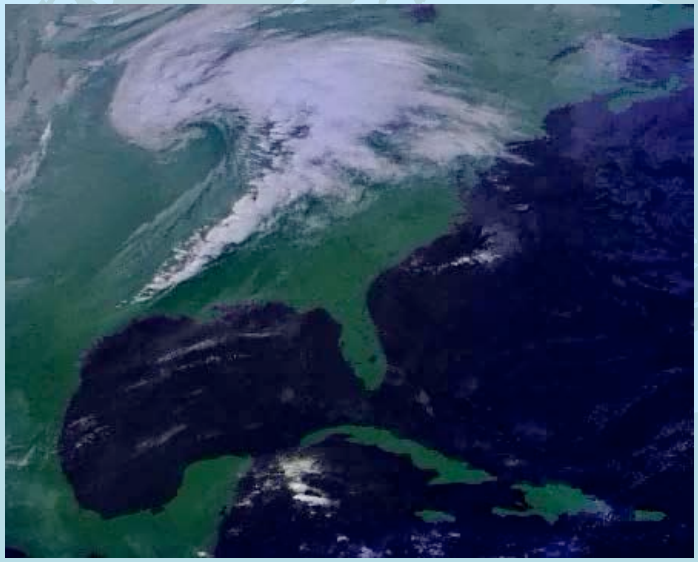
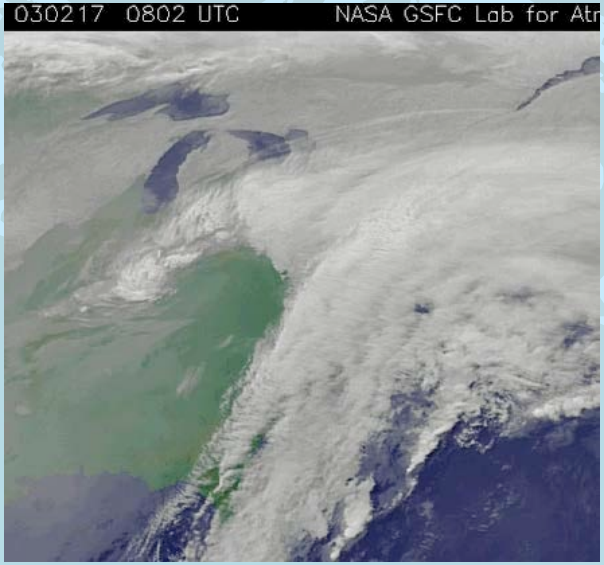
MET 200 Lecture 19
Midlatitude Cyclones



Hallow's Eve Mask

Lecture 19 Midlatitude Cyclones



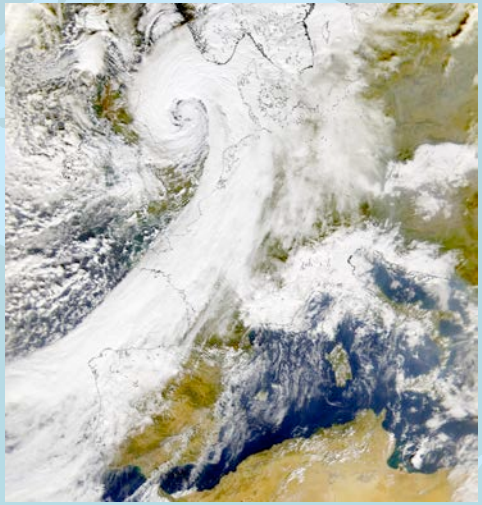
Midlatitude Cyclones or Winter Storms

- Cyclogenesis
- Energy Source
- Life Cycle
- Air Streams
- Vertical Structure
- Storm Hazards

Previous Lecture

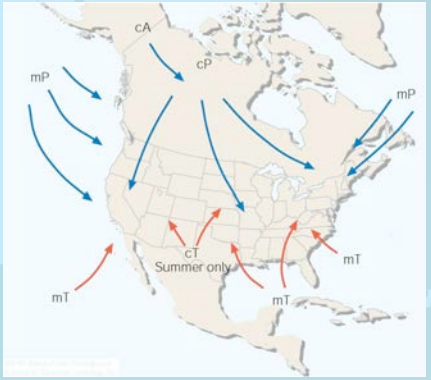
Air masses and Fronts

- Air mass formation
- Types of air masses
- Types of Fronts
- Identifying Fronts
- Formation of Fronts
- Cyclogenesis Stages



Air Mass Classifications

- cP - continental Polar
  - Cold, dry, stable
- A - Arctic
  - Extremely cold cP air mass may be designated Arctic
  - Cold, dry, stable
- mP - maritime Polar
  - Cool, moist, unstable
- mT - maritime Tropical
  - Warm, moist, usually unstable
- cT - continental Tropical
  - Hot, dry
  - Stable air aloft, unstable surface air
- E - Equatorial
  - Hot, very humid
  - unstable through deep layer



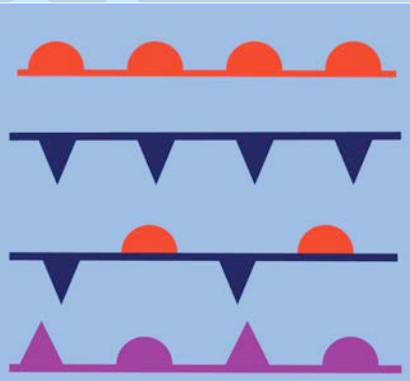
Four Types of Fronts

Warm Front

Cold Front

Stationary Front

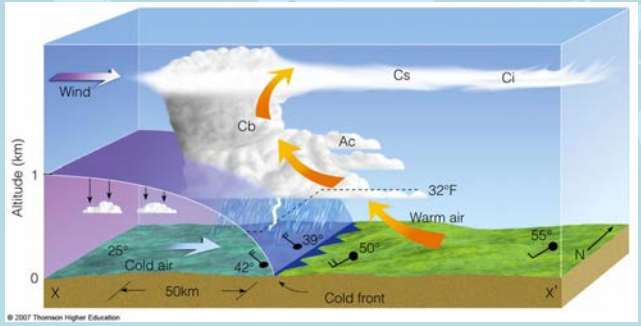
Occluded Front



Frontal symbols are placed pointing in the direction of movement of the front (except in the case of the stationary front).

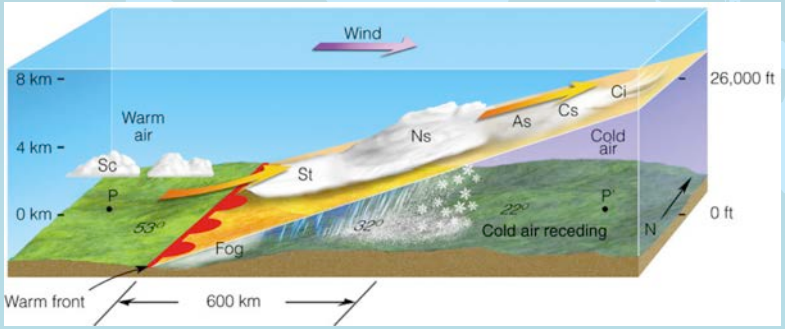
Typical Cold Front Structure

- Cold air replaces warm; leading edge is steep in fast-moving front shown below due to friction at the ground
  - Strong vertical motion and unstable air forms cumuliform clouds
  - Upper level winds blow ice crystals downwind creating cirrus and cirrostratus
- Slower moving fronts have less steep boundaries and less vertically developed clouds may form if warm air is stable

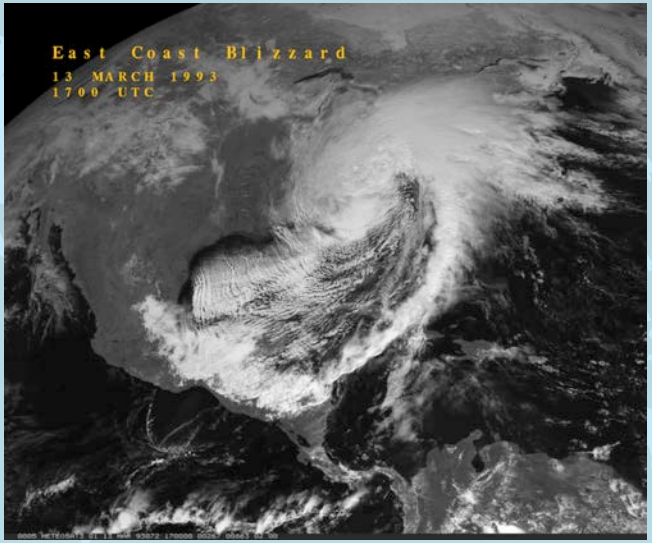


Typical Warm Front Structure

- In an advancing warm front, warm air rides up over colder air at the surface; slope is not usually very steep.
- Lifting of the warm air produces clouds and precipitation well in advance of boundary.
- At different points along the warm/cold air interface, the precipitation will experience different temperature histories as it falls to the ground (snow, sleet, freezing rain,& rain).

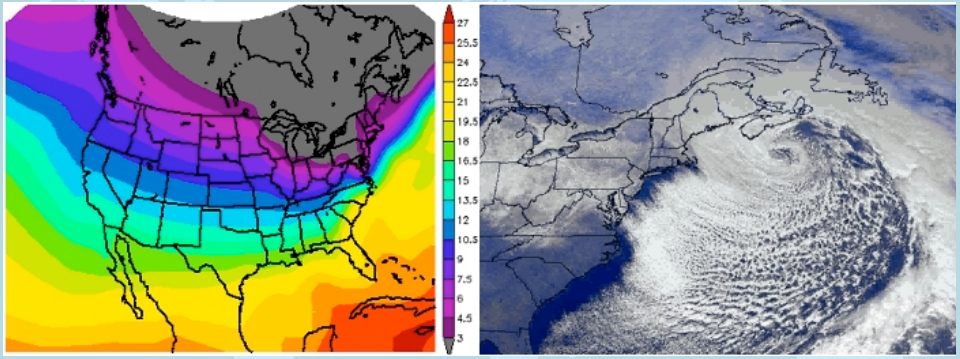


Midlatitude Cyclone or Winter Storm



Cold, heavy air sinks, displacing warm air, which rises, thus converting potential energy into kinetic energy in the form of a cyclonic wind circulation.

Energy Source for Winter Storms



Temperature Gradients Fuel Cyclogenesis

Cold, heavy air sinks, displacing warm air, which rises, thus converting potential energy into kinetic energy in the form of a cyclonic wind circulation.

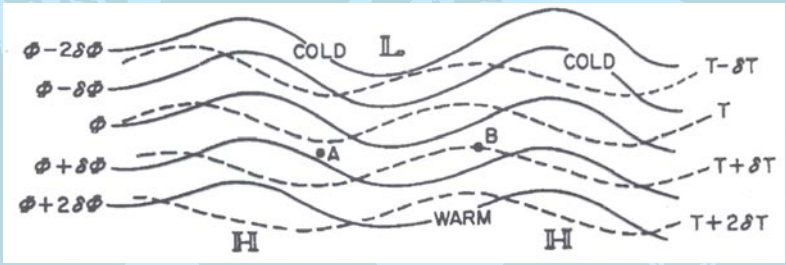
Midlatitude Cyclones

- Midlatitude cyclones, aka winter storms are the dominant synoptic-scale phenomenon of middle latitudes.
- Winter storms derive their energy from baroclinic instability, an instability of the sheared zonal current.
- Baroclinic vorticity generation occurs whenever there is a density gradient along surfaces of constant pressure.
- Potential energy of the mean state is converted to kinetic energy as cold air sinks and warm air rises.
- Short waves in the jet stream provide the initial perturbation that allows midlatitude cyclones to form

Baroclinic Instability

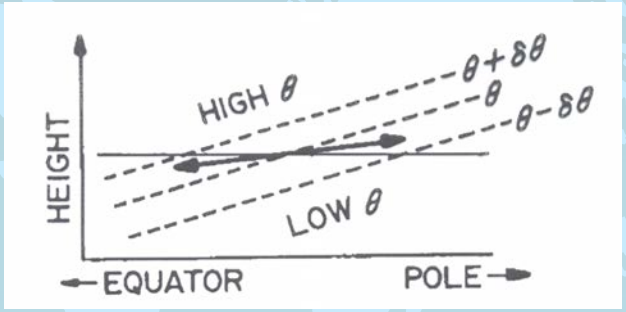
- Baroclinic instability is the dominant mechanism shaping the cyclones and anticyclones that dominate weather in mid-latitudes.
- The most important feature of baroclinic instability is that it exists even in the situation of rapid rotation (small Rossby number) and strong stable stratification (large Richardson's number) typically observed in the atmosphere.
- The energy source for baroclinic instability is the potential energy in the environmental flow. As the instability grows, the center of mass of the fluid is lowered. In growing waves in the atmosphere, cold air moving downwards and equatorwards displaces the warmer air moving polewards and upwards.

Baroclinic Instability



Distribution of geopotential height (solid) and temperature (dashed) on a constant pressure surface in a developing baroclinic wave in the Northern Hemisphere. The pressure surface is located near the level where the speed of the wave is the same as the speed of the mean zonal flow.

Baroclinic Instability



Idealized meridional cross section through a developing baroclinic wave showing slope of typical air parcel trajectories in relation to the slopes of the zonally averaged isentropes.

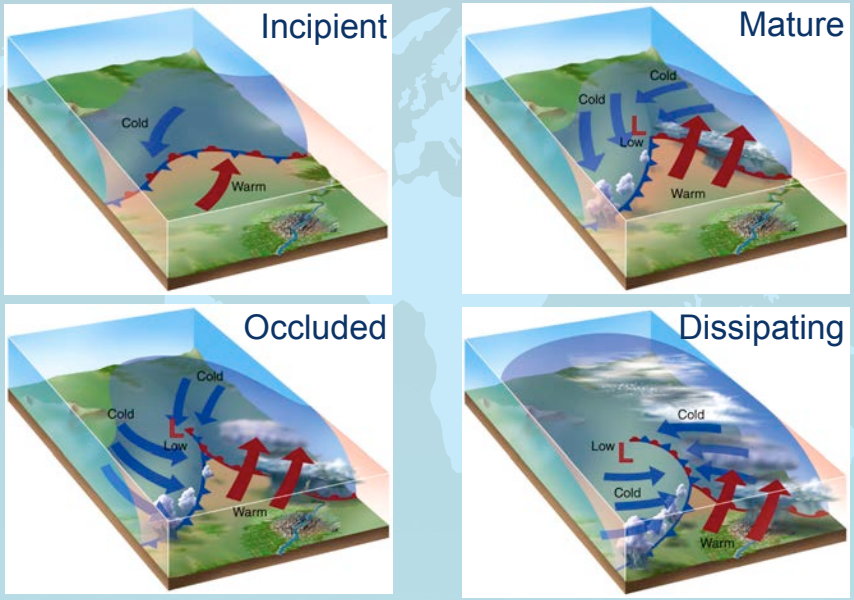
Baroclinic Instability

- Assume a wave-like perturbation (think short wave) in an otherwise zonal flow. Assume the wave is moving at the same speed as the flow (air is not passing through the wave). Now view the motion in a coordinate system moving with the wave (zonal flow vanishes). In this frame the only motion we need to consider is the meridional velocity.
- How will these meridional motions distort the isotherms?

$$\delta T/\delta t = -v(\delta T/\delta y)+w((kT/P)-(\delta T/\delta P))$$

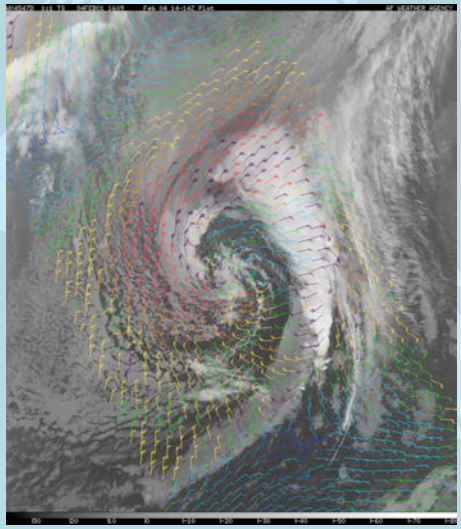
Advection Adiabatic warming & cooling

Life Cycle Stages of Midlatitude Cyclone



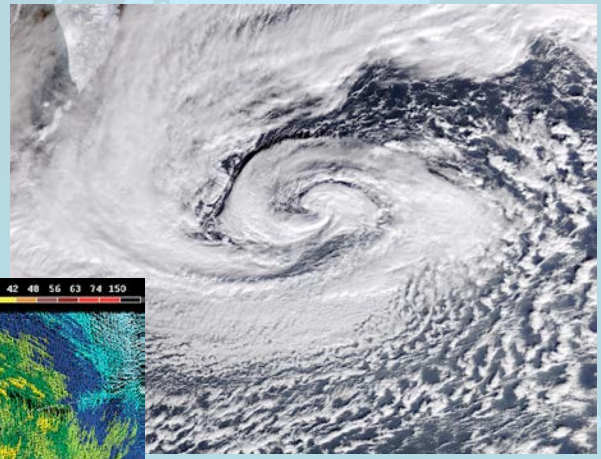
Occluded Stage

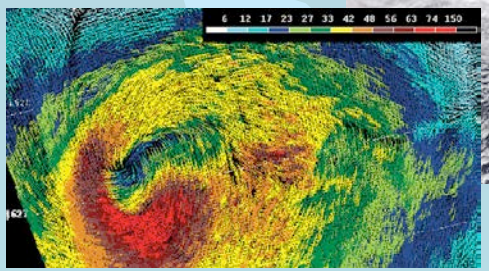
- Cyclone is mature, precipitation and winds are most intense.



Occluded Stage

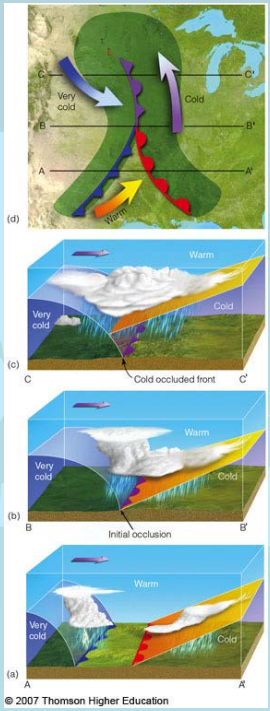
- Cyclone is mature, precipitation and winds are most intense.





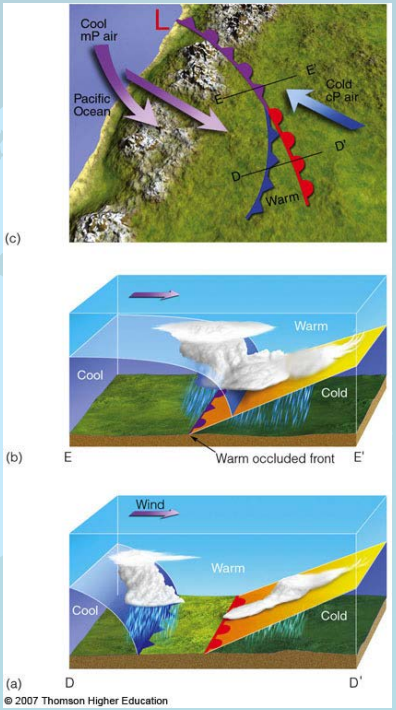
Formation of Occluded Fronts

East of the Rockies - Cold Occluded Fronts

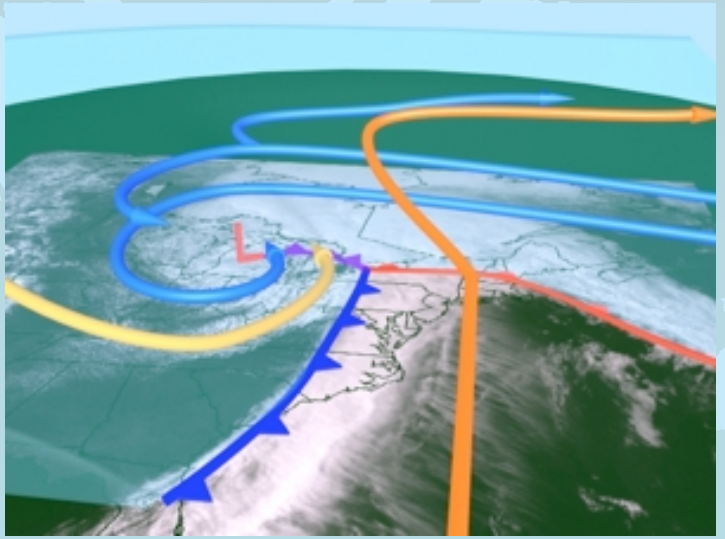


Formation of Occluded Fronts

West of the Rockies -
Warm Occluded Fronts



Three Air Streams in Winter Storms

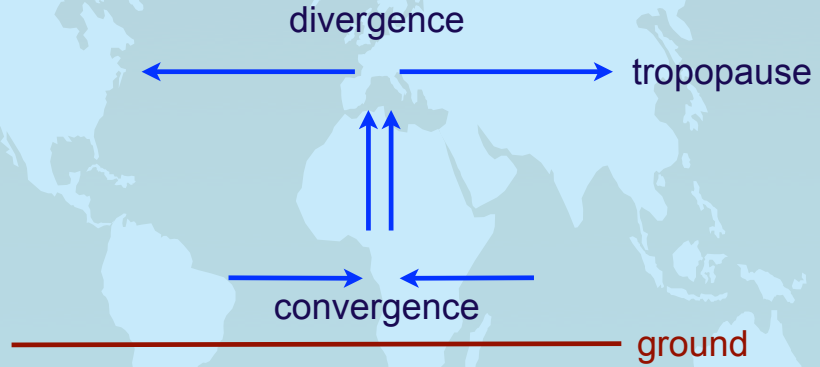


Warm (rising), Cool/Cold, Dry (sinking)

Air Steams in Midlatitude Cyclones are Three Dimensional

- Warm air stream brings warm moist (mT) air in the warm sector and lifts it over the warm front.
- Cold air stream brings cold moist (mP) air westward to the north and beneath the warm front to the low pressure center.
- Dry air stream brings cold dry (cP) air from the north west and descends behind the cold front.

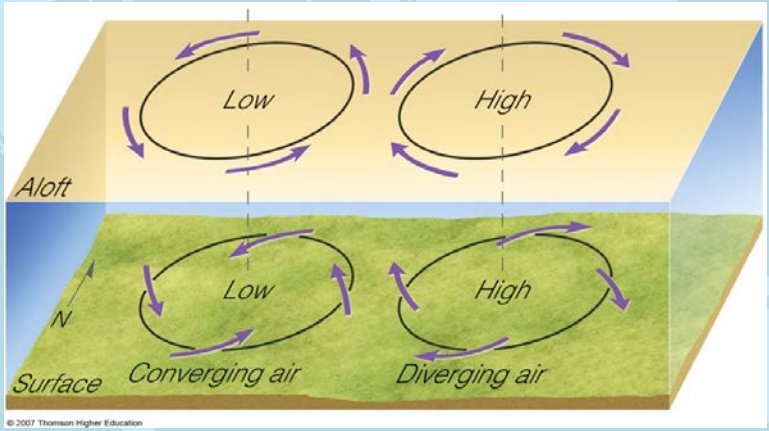
What Causes the Surface Low to Form?



When upper-level divergence is greater than lower-level convergence, more air is taken out at the top than is brought in at the bottom. Surface pressure drops, and the low deepens.

What maintains the surface low?

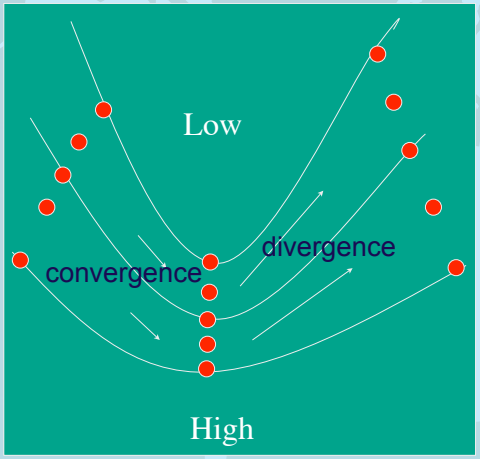
Without upper level divergence surface low fills.



Surface convergence "fills in" the low

Surface divergence "undermines" the high

What Causes the Surface Low?

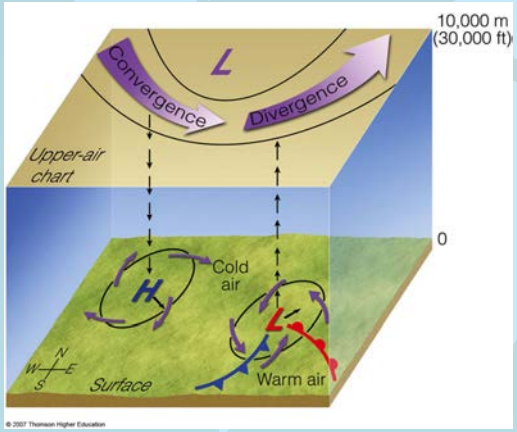


convergence and divergence aloft

When upper-level divergence is stronger than lower-level convergence, more air is taken out at the top than is brought in at the bottom. Surface pressure drops, and the low intensifies, or "deepens."

Upper-level height contours

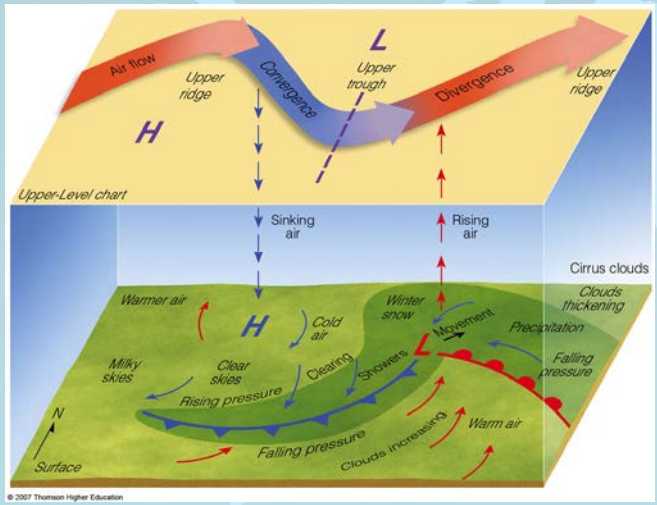
Vertical Structure of Midlatitude Cyclones



Upper-level divergence initiates and maintains a surface low.

Upper-level low is tilted westward with height with respect to the surface.

Cyclogenesis



Upper level shortwave passes.

Upper level divergence leads to sfc low.

Cold advection throughout lower troposphere.

Cold advection intensifies upper low.

Leads to more upper level divergence.

Temperature advection is key!

Storm Track

Storms are steered by flow in the upper troposphere. The location and strength of the jet-stream flow is governed in part by the distribution of sea surface temperature. Thus, el niño influences the storm track.

Weather Hazards in Winter Storms

Hazards associated with Midlatitude Cyclones

Winter Storm - Hazards

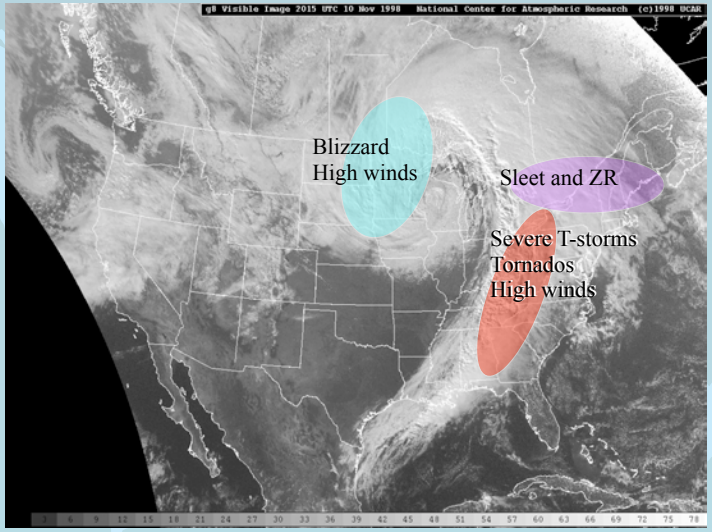
- High Winds
  - Nor'easter, Blizzard Conditions, Turbulence
- Frozen Precipitation
  - Blizzard Conditions, Snow, Sleet and Freezing Rain, Aircraft Icing, Riming, Snow Avalanches
- Heavy Rain
  - Flooding, Flash Floods, Land/Mud Slides
- Large Ocean Swell and Waves
  - High Surf, Storm Surge
- Severe Thunderstorms
  - Tornados, Large Hail, High Winds, Lightning

Motivation: Societal Impact of Winter Storms

- Deaths due to exposure, exertion, traffic accidents, high seas.
- Insurance losses due to wind and water damage, shipping containers lost overboard, ...
- Impact on transportation: snow and ice reduce traffic, cancelled flights, school closures, shipping....

- Reduction in retail activity, loss of wages, ...
- Clean-up costs, snow and ice removal, repair to power lines, ...

Weather Hazards



Where are the hazards?

Hazards – High Winds

High Winds: Where do they Occur?

Where do we find the strongest winds in a midlatitude cyclone?

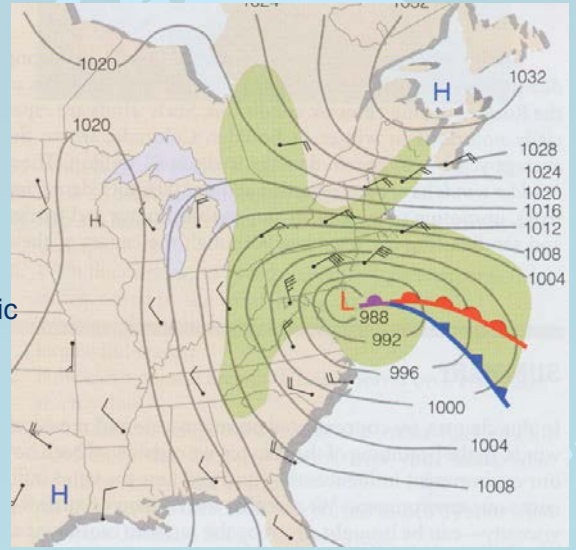
- Surface
  - Where the pressure gradient is largest, often on NW side of storm.
  - Near the fronts
  - Near convective clouds (including tornados)
- Upper Air
  - Where the temperature gradient and thus pressure gradient is largest (associated with fronts and thermal wind)
  - In pulses superimposed on the jet stream
  - these pulses are called jet streaks
  - turbulence is found near jets in regions of large wind shear

Where do the High Winds Occur?

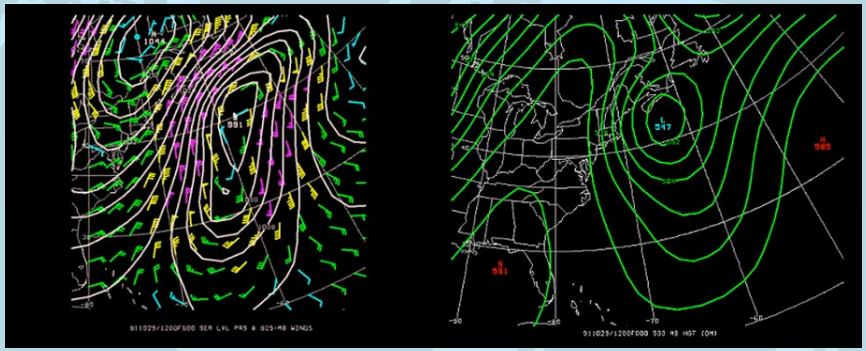
Blizzard conditions occur N and NW of surface-low center.

Nor'easters

- Strong low pressure systems moving up Atlantic seaboard
- Strong winds and heavy precipitation (blizzards).



October's the "Perfect Storm"



The storm—created from a collision between a high pressure system, a low pressure system and the remnants of a dying hurricane—sent high winds and Atlantic Ocean waves crashing into the East Coast, from New England to North Carolina. The Andea Gail sank in this storm on 10/28/91.

Hazards – Large Waves

Oahu, North Shore
January 1998.

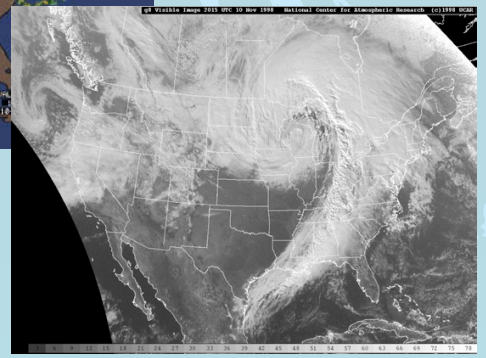
Peggotty Beach, Massachusetts
February 9, 1978

Hazards – Large Swell

Surf's up!
Heavy surf on the Columbia River bar tests a Coast Guard vessel approaching the mouth of the Columbia River.

Where do the Heavy Rains Occur?

Radar View of Precipitation



Where does air rise?

- Along the fronts
- In areas of convection
- Around the surface low center

Hazards – Heavy Rain and Flooding

An ice storm in New York also caused flooding of water front properties in the region, January 1998.

Hazard – Freezing Rain & Sleet

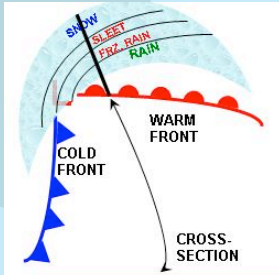
Kansas City, MO, January 31, 2002.

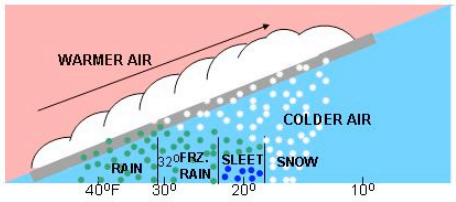
Freezing rain and sleet cause significant disruption of transportation and resulting economic impact.

Where does the Sleet and Freezing Rain Occur

The Rain – Snow Line

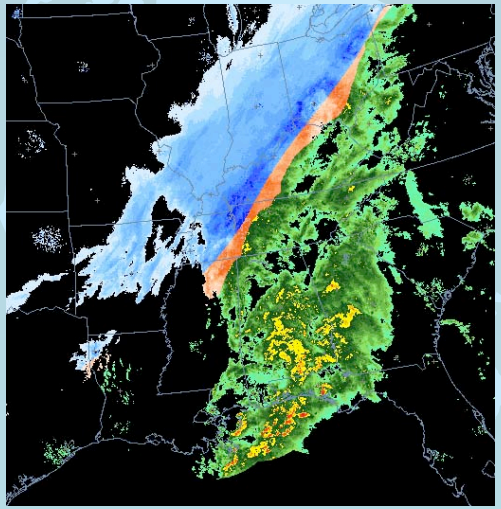
- North of the warm front there is a transition from rain to snow called the rain-snow line.
- Freezing rain and sleet fall on the warm side of this line.



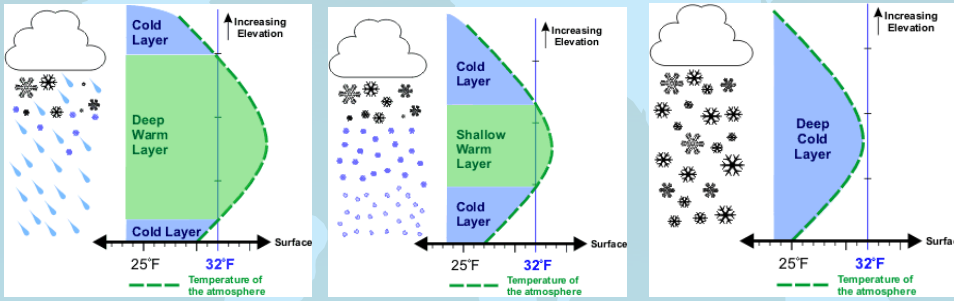


The Rain-Snow Line

- North of the warm front there is a transition from rain (green and yellow) to snow (blue) called the rain-snow line.
- Freezing rain and sleet fall on the warm side (red/pink) of this line.



Hazards – Sleet and Freezing Rain



S Freezing Rain Sleet Snow N

As the depth of the cold air near the ground increases north of the warm front, precipitation changes from rain to freezing rain to sleet to snow.

Freezing Rain

Television Tower
Raleigh, NC
January 1990

Freezing Rain

Television Tower
Raleigh, NC
January 1990

Hazards – Blizzard

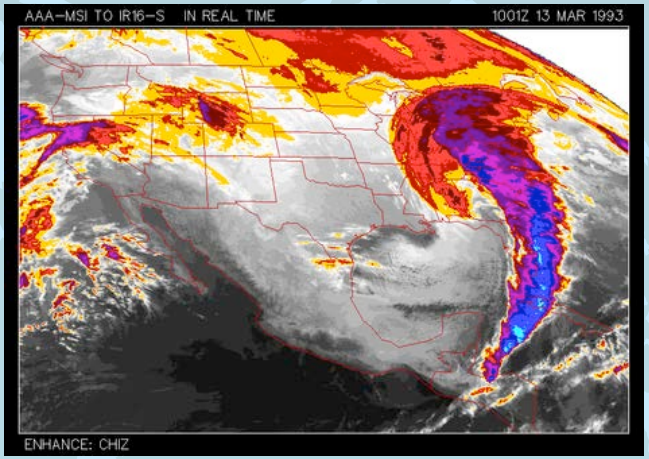
Blizzard conditions include winds ≥35 mph and visibility less than 1/4 mi.

Hazards – Blizzard

Blizzard conditions include winds ≥35 mph and visibility less than 1/4 mi.

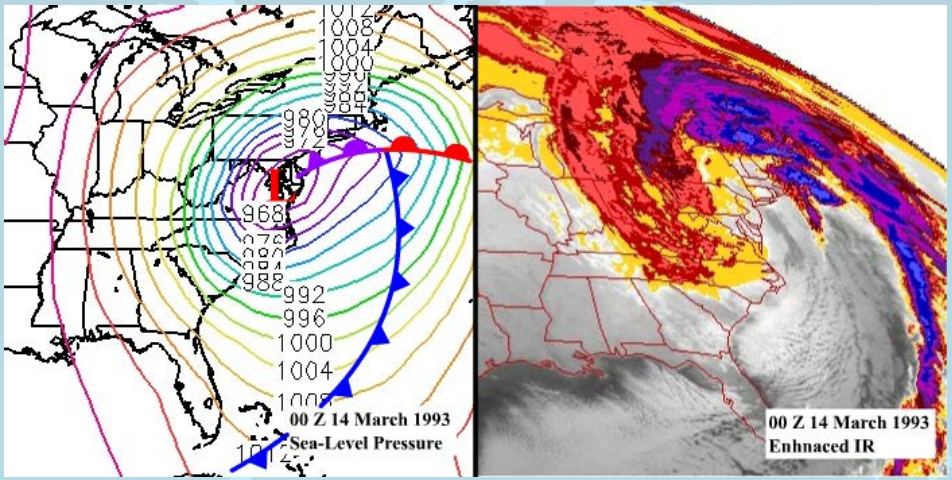
North Dakota: A March 1966 blizzard nearly buried utility poles.

Superstorm of March 1993



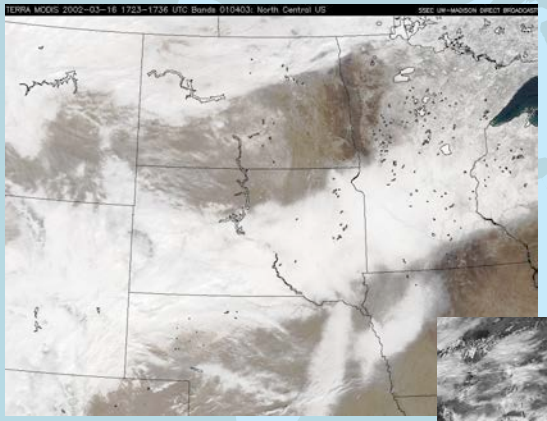
This enormous winter storm spawned blizzard conditions, hurricane force winds, 25 tornados, and a storm surge, killing over 250 people and canceling 25% of the United States' flights for two days.

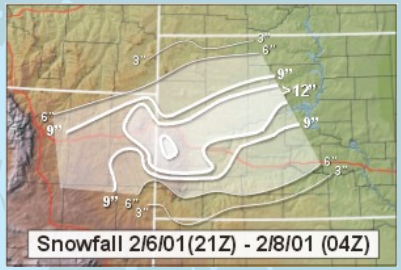
1993 Blizzard



Blizzard conditions include heavy snowfall and blowing snow with strong winds. Note the tight spacing of isobars at left.

Hazards – Heavy Snow



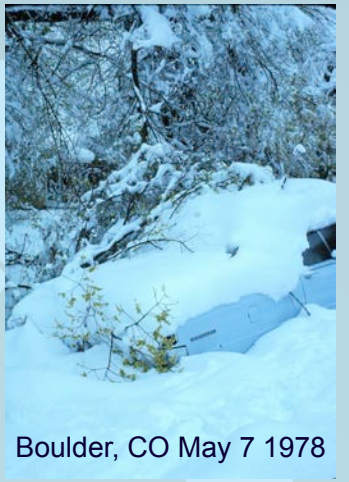


Snowstorms leave a band of heavy snow in their wake.

Where is my dog?

February 17, 2003 in New York City

Hazards – Heavy Snow



Boulder, CO May 7 1978

Death in blizzards comes from exposure to cold.

Equivalent Temperature (°F)

Wind Speed MPH	Calm	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
		COLD																
	5	32	27	22	16	11	6	0	-5	-10	-15	-21	-26	-31	-36	-42	-47	-52
	10	22	16	10	3	-3	-9	-15	-22	-27	-34	-40	-46	-52	-58	-64	-71	-77
	15	16	9	2	-5	-11	-18	-25	-31	-38	-45	-51	-58	-65	-72	-78	-85	-92
	20	12	4	-3	-10	-17	-24	-31	-39	-46	-53	-60	-67	-74	-81	-88	-95	-103
	25	8	1	-7	-15	-22	-29	-36	-44	-51	-59	-66	-74	-81	-88	-96	-103	-110
	30	6	-2	-10	-18	-25	-33	-41	-49	-56	-64	-71	-79	-86	-93	-101	-109	-116
	35	4	-4	-12	-20	-27	-35	-43	-52	-58	-67	-74	-82	-89	-97	-105	-113	-120
	40	3	-5	-13	-21	-29	-37	-45	-53	-60	-69	-76	-84	-92	-100	-107	-115	-123
	45	2	-6	-14	-22	-30	-38	-46	-54	-62	-70	-78	-85	-93	-102	-109	-117	-125

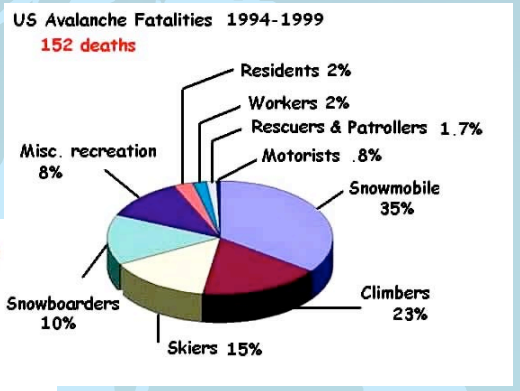
VERY COLD
BITTER COLD
EXTREME COLD
WIND CHILL CHART

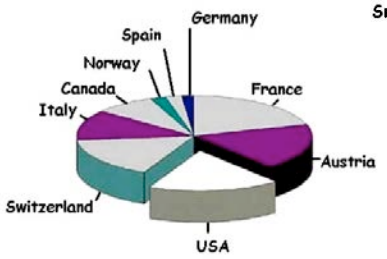
Hazard – Snow Avalanche

Western U.S. mountains generally record over 100,000 avalanches every winter. Some avalanche slides can reach speeds of over 100 miles per hour.

Hazard – Snow Avalanche

In US roughly 25 deaths per year due to snow avalanches.

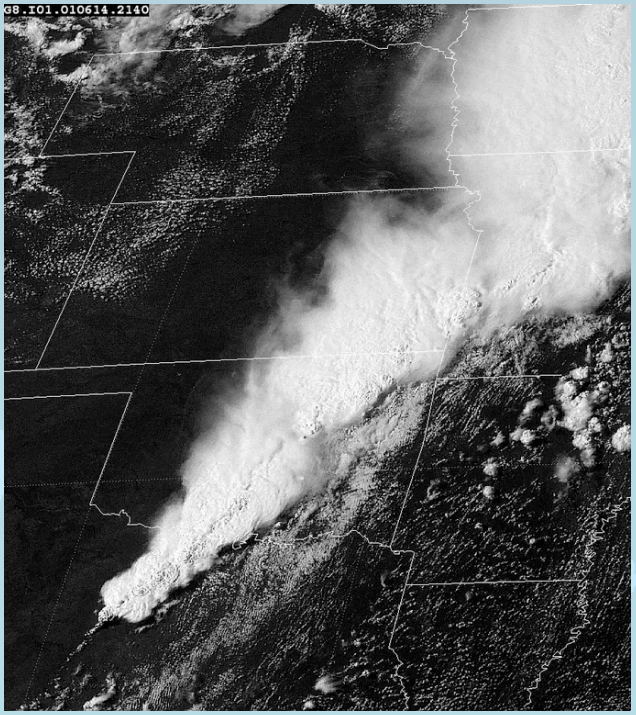




Large Hail
Tornados
High Straight-line winds

Hazards – Severe Thunderstorms

Severe Thunderstorms associated with a cold front.



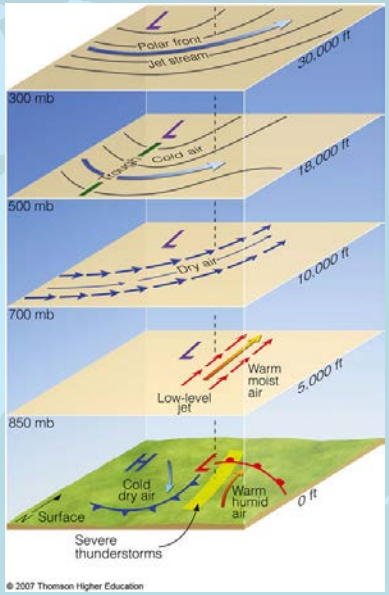
Where do the Severe Thunderstorms Form?

Severe Thunderstorms Produce:

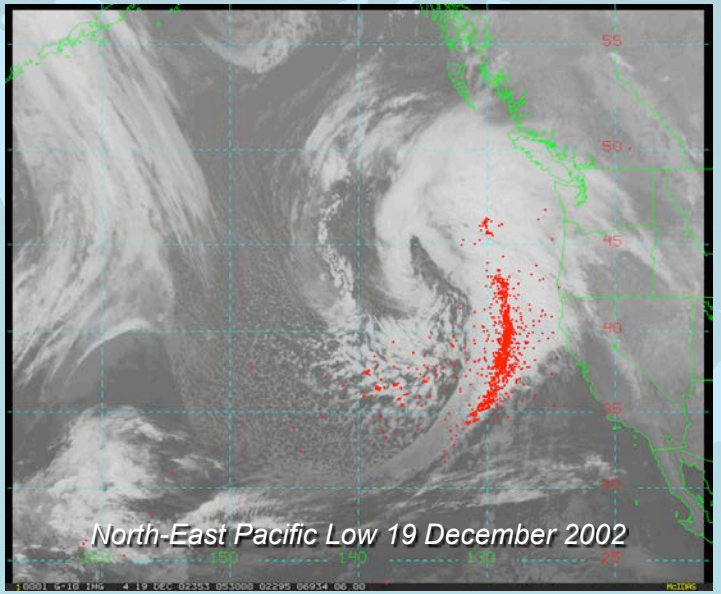
- Tornados
- Large Hail
- Strong Straight-line Winds

(Lightning and Flooding)

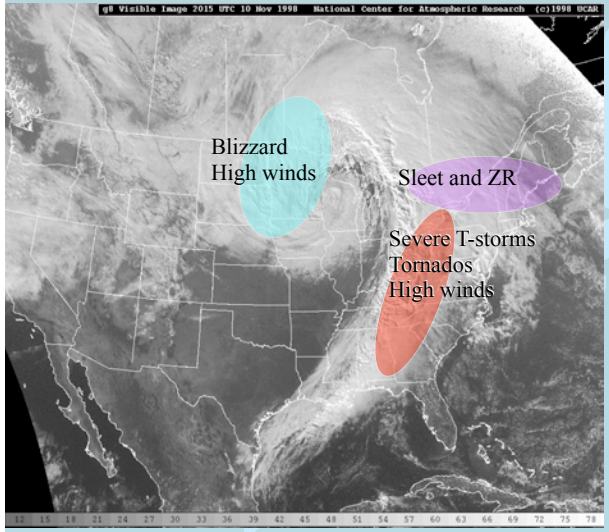
Occur where jet stream crosses the cold front.

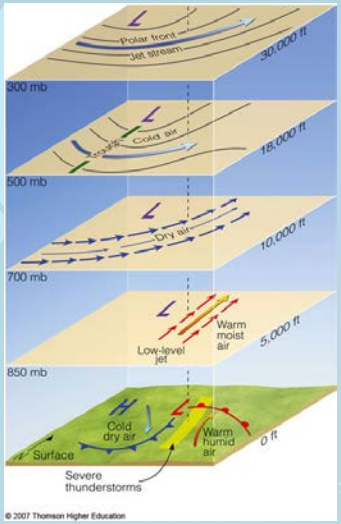


Lightning in Winter Storm



Questions?





Three areas with distinct hazards in winter storms.