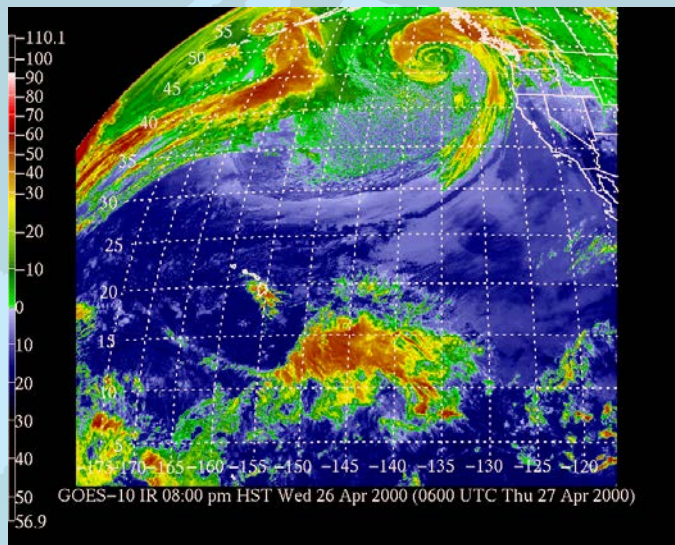


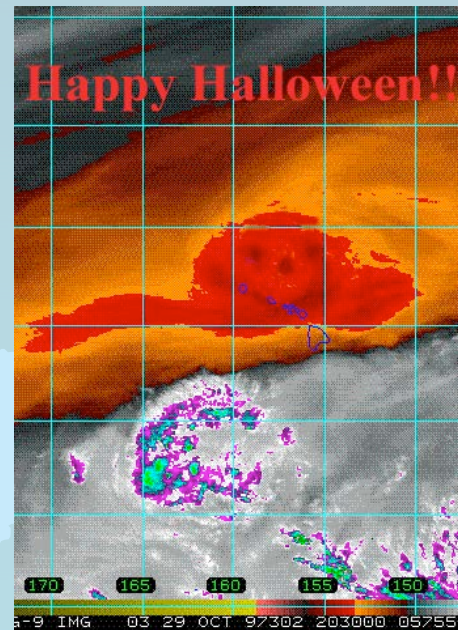
Lecture 18 Air Masses and Fronts

- Air Masses
- Air Mass Modification
- Fronts



Ahrens Chapter 8

1



2

Glad to be in HI



My B&B in Boulder, CO 10/27/11
Note: no power!

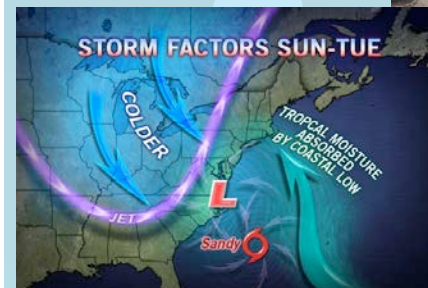


Snow - water equivalent

3

Hurricane Sandy

This storm was another "perfect storm" killing more than 100 people and causing more than \$60 billion in damage along the East Coast.



4

Almost Perfect Forecast for a More Perfect Storm



Jersey Shore



NYC Metro



Brooklyn

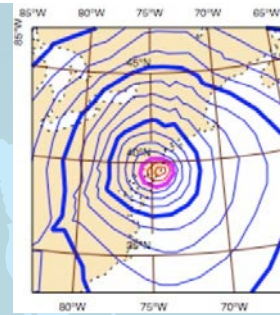


Ground Zero

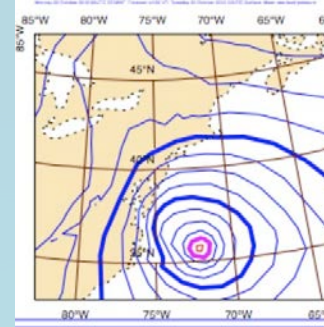
The forecast for Sandy was a technological and scientific triumph, one that could not have happened a decade ago.

5

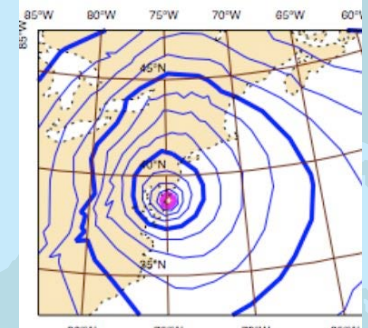
Sea-Level Pressure Forecast



verification at 5 PM on October



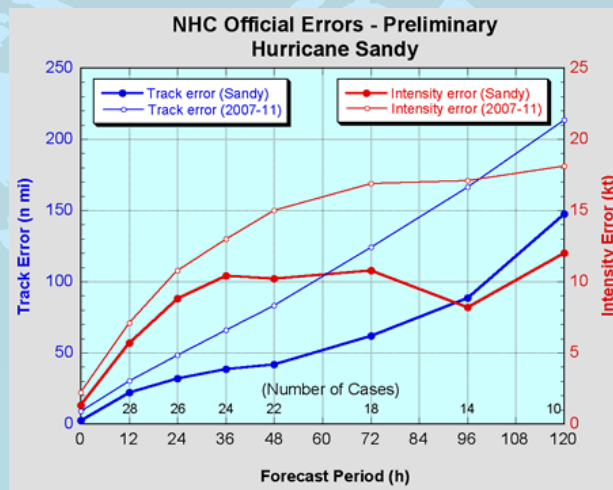
8.5 days before landfall, it had a major storm, but it was about 12h too slow.



But by 5.5 days before landfall, the prediction was nearly perfect in placement...and it held on to that solution until landfall.

6

NHC Forecast Errors for Sandy

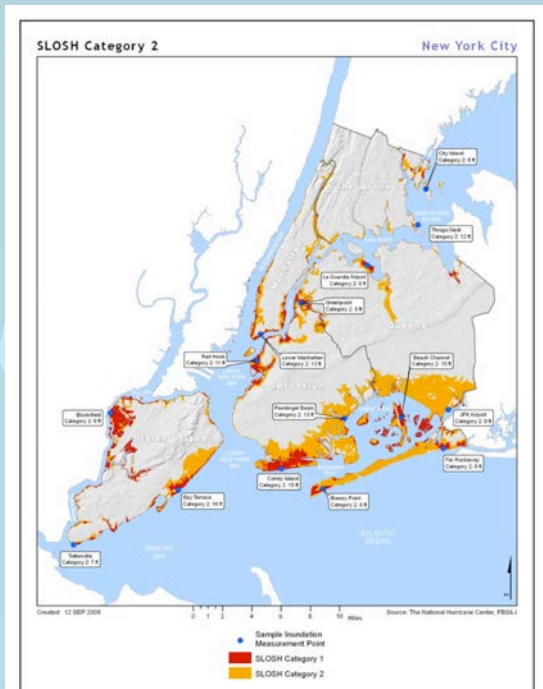


For the last two days before landfall their track error was less than 50 nautical miles, far better than the average track error for 2007-11, and the intensity error was 12 knots or less for entire period shown. Very impressive.

7

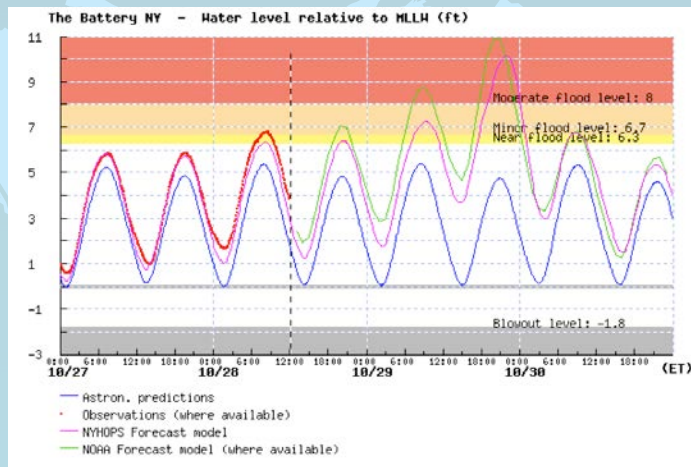
Slosh Model Forecast

The forecasting process included feeding the projected path and intensity into models of the coastal water level, using tools such as the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model. This model predicted historic flood levels on the 29th and clearly identified the areas in risk.



8

Slosh Model Forecast



SLOSH) model predicted **historic flood levels** on the 29th and clearly identified the areas in risk. A big question is whether the seriousness of these objective forecasts were properly communicated to the public and local officials.

9

Forecast SNAFU

A major communication snafu occurred with Sandy. As the storm approached the coast, it was losing its tropical characteristics and becoming more like a midlatitude storm (the fancy name for this is *extratropical transition*). So right before landfall, the National Weather Service downgraded Sandy to a *post-tropical cyclone* and responsibility for forecasting it was handed off to local Weather Service forecast offices. Hurricane watches and warnings were dropped, as one of the most dangerous storms of the century approached the Northeast coast. Keep in mind that the storm was still as strong as a hurricane, with maximum winds of 85 mph. And Sandy was much larger than the typical hurricane. The name change was terribly confusing to the media and many local authorities, some of which started to downplay the storm. Big mistake. The National Weather Service recognizes these problems in the post-storm review and has changed its strategy...next time the Hurricane Center will stay with such storms through landfall, and the warnings/watches will continue.

10

Previous Lecture The Simple Science of Flight



Steven Businger SOEST/UHM

11

The Simple Science of Flight



Some quick definitions used in this lecture

Velocity – distance per unit time, m/s

Acceleration – change in velocity per change in time, m/s^2

Force – mass times acceleration, Newton, $\text{kg}\cdot\text{m/s}^2$, $1\text{N} = 102\text{g}$

Energy (Work) – force over a distance: Joule, $\text{J} = \text{Nm} = \text{kg}\cdot\text{m}^2/\text{s}^2$

Power – energy per time, Watt = $\text{J/s} = \text{Nm/s} = \text{force} \times \text{speed}$

12

First-Class Lift



Airbus A380

$$\text{Lift } L = \alpha \rho V^2 A \text{ kg m/s}^2 \text{ or newtons}$$

At 12 km the air density is 1/4 that at sea level, you will have to fly twice as fast to obtain the same lift.

To support horizontal flight, lift = weight (W). So we can write:

$$L = W = 0.3 \rho V^2 A \text{ newtons,} \quad (1)$$

where the constant 0.3 is valid for long distance flight with an average angle of attack of 6° .

13

Lift, Weight, and Speed

If we divide both sides of Eq 1 by the wing area A and replace the variable density ρ by its value at sea level where birds fly, we get:

$$W/A = 0.38 V^2$$

This formula tells us that the greater a bird's wing loading, the faster the bird must fly.



14

Lift, Weight, and Cruising Speed



Common tern
 $V = 18 \text{ mph}$



Common gull
 $V = 21 \text{ mph}$



Herring gull
 $V = 26 \text{ mph}$



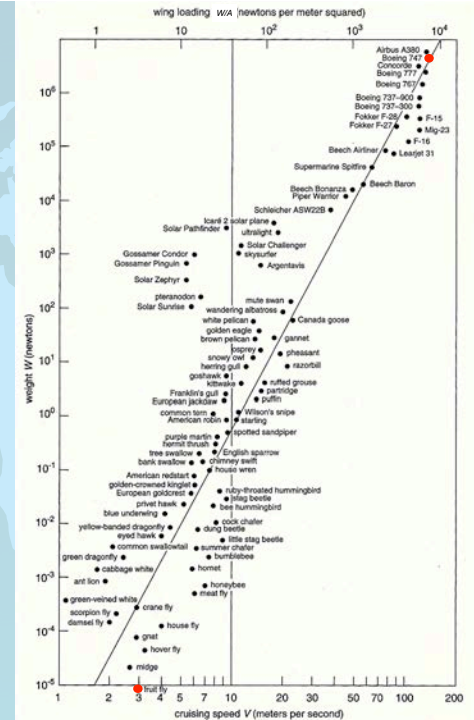
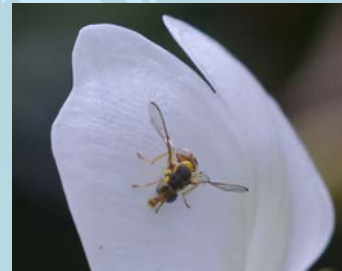
Wandering Albatross $V = 43 \text{ mph}$



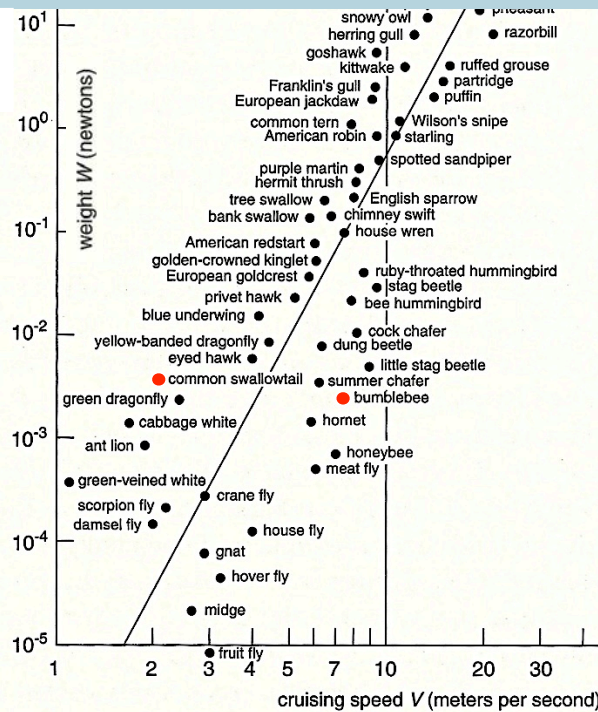
Laysan Albatross $V = 36 \text{ mph}$

15

The Great Flight Diagram

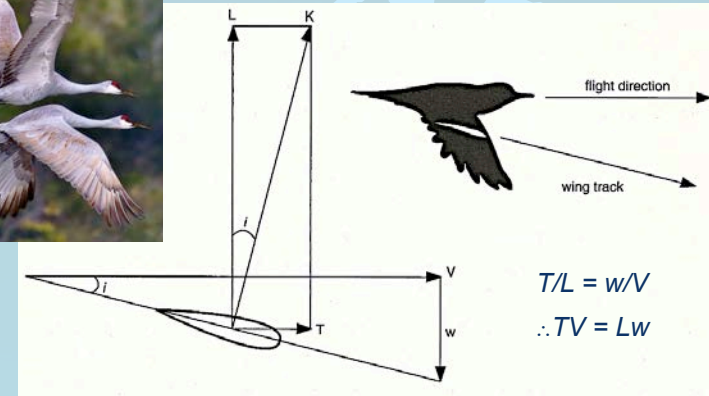


The Great Flight Diagram



17

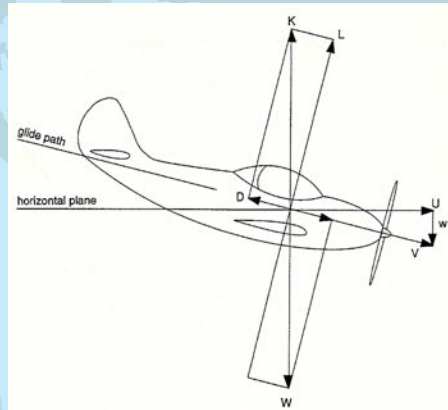
The Flier's Edge



As the wing moves down, the lift force generates power. This power, the product of L and w, is transmitted in its entirety to the propulsive effort, the product of T and V.

18

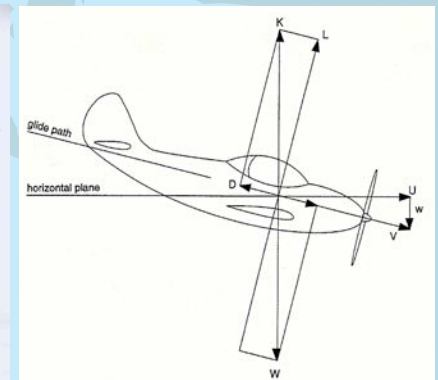
Gliding with Finesse



The force and speed triangles again have the same proportions. Thus, $w/V = D/W$, and $Ww = DV$. The power DV required to overcome the aerodynamic drag is supplied by the large force of gravity W acting on the small downward speed w .

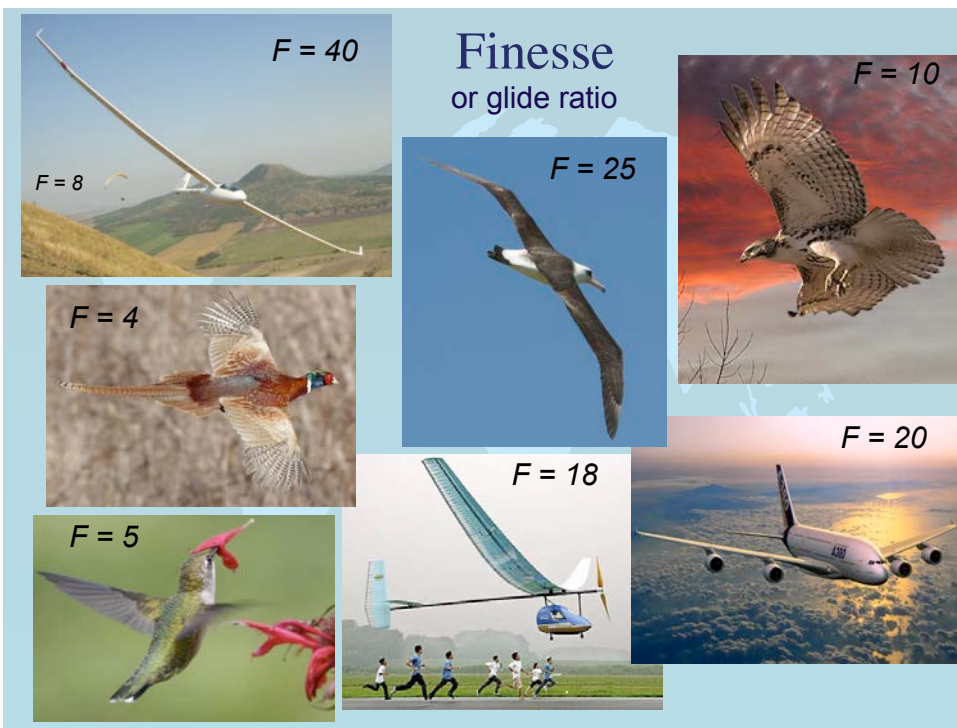
19

Finesse

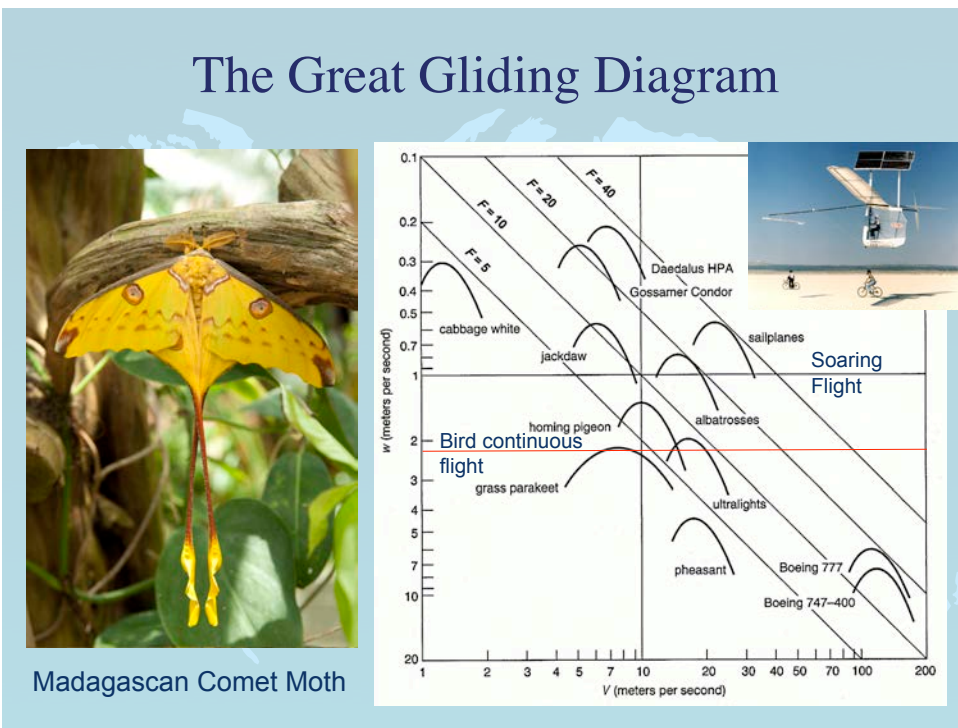


The force and speed triangles also provide useful information on the distance that can be covered in a glide. If U equals the horizontal component of the airspeed, the ratio between it and the rate of descent w must be equal to the ratio of the lift L to the drag D . $L/D = U/w$, determines how many meters a gliding bird or plane can travel for each meter of descent. This is called the finesse of the bird/plane.

20



21



22

What is an Air Mass

Air Masses are large regions of air with similar temperature and moisture content.

23

Air Mass

Air masses form over areas with

- (1) **Uniform underlying surface properties** and
- (2) **High surface pressure**, where **divergence** of surface winds decrease contrasts in temperature and humidity.

© 2001 Brooks/Cole Publishing/TP

24

Air Mass Properties

- Air masses take on the properties of the underlying surface.
- Air masses are classified according to their location of "origin".
- Geographical Characteristics
 - Tropical, Polar, Arctic.
- Surface Properties
 - maritime, continental.
- Source region characteristics are most well defined if the air mass remains over a source region for a long time.

25

Air Mass Classification

- Classified according to temperature and moisture characteristics.
 - Continental (dry) - c
 - Maritime (moist) - m
 - Equatorial (extremely humid) - E
 - Tropical (warm) - T
 - Polar (cold) - P
 - Arctic (extremely cold) - A

26

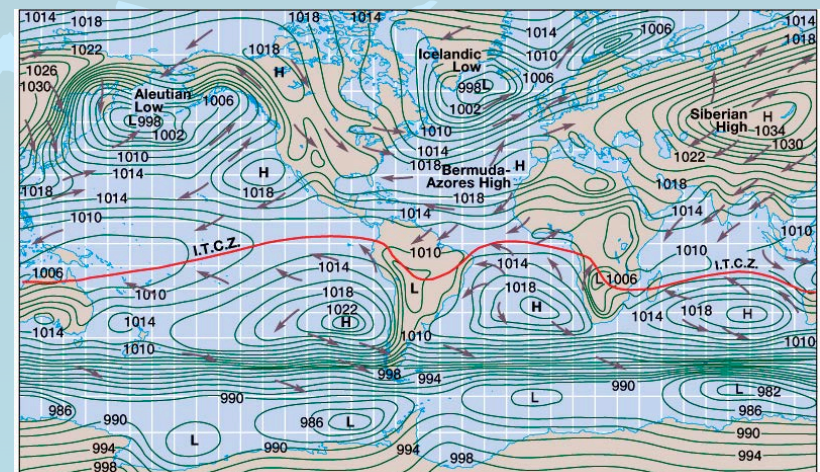
Air Mass Classifications

- 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



27

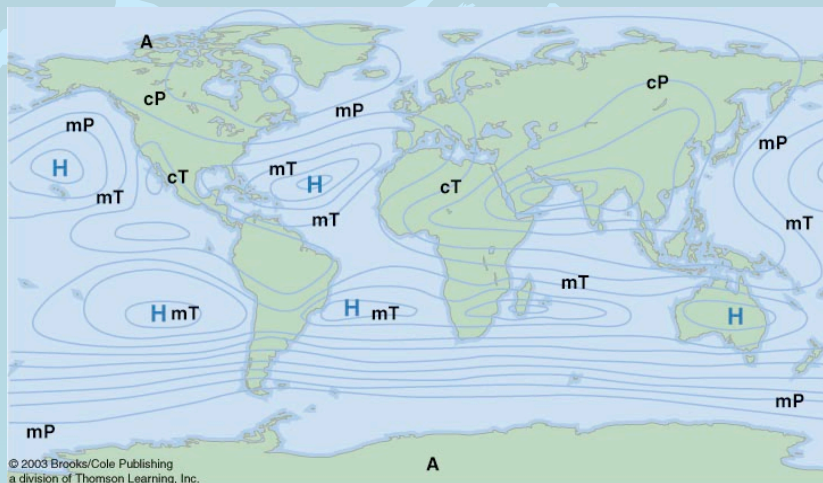
Air Mass Source Regions



Mean sea-level pressure map, January: Air Masses form where areas of high pressure prevail.

28

Air Mass Source Regions



Mean sea-level pressure map, July: Air Masses form where areas of high pressure prevail.

29

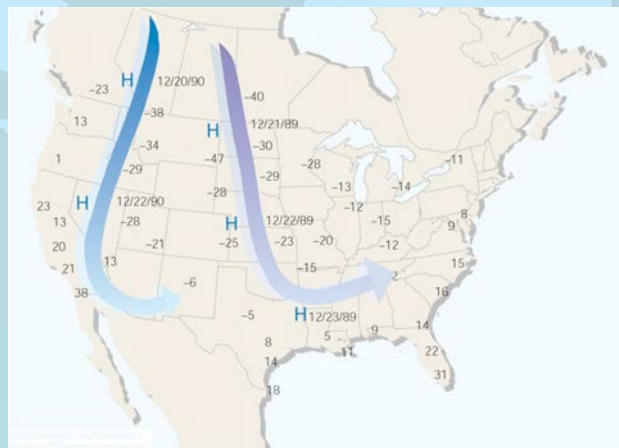
Air Mass Modification



30

Air Masses Modify When they Move

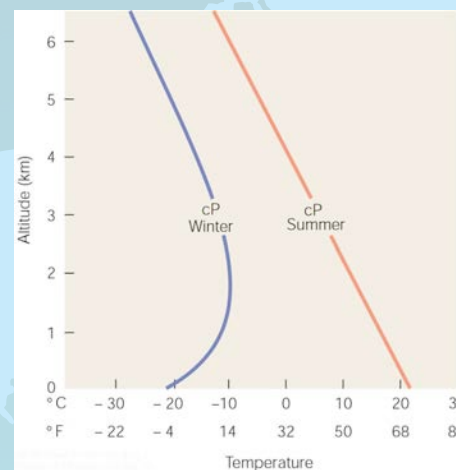
cP air from Canada gradually warms as it is carried across warmer ground on its way to the southern US.



31

Air Masses Modify with Seasons

cP air from Canada gradually warms as the sun becomes stronger (more overhead) in spring and summer.



32

Air Mass Modification I

cP air from Canada is carried across the United States and reach the Gulf Stream. Contact with the ocean warms and moistens the air near the surface, transforming it to an unstable mP air mass.



33

Modification by Surface Fluxes

- Time required for the surface fluxes to modify the boundary layer
- Using the Bulk formula for the sensible heat flux, H_s :

$$H_s = \rho c_p C_d u \Delta\theta = \rho c_p (d\theta/dt) h(t)$$

$$h(t) = C_d u \Delta\theta / (d\theta/dt)$$

where:

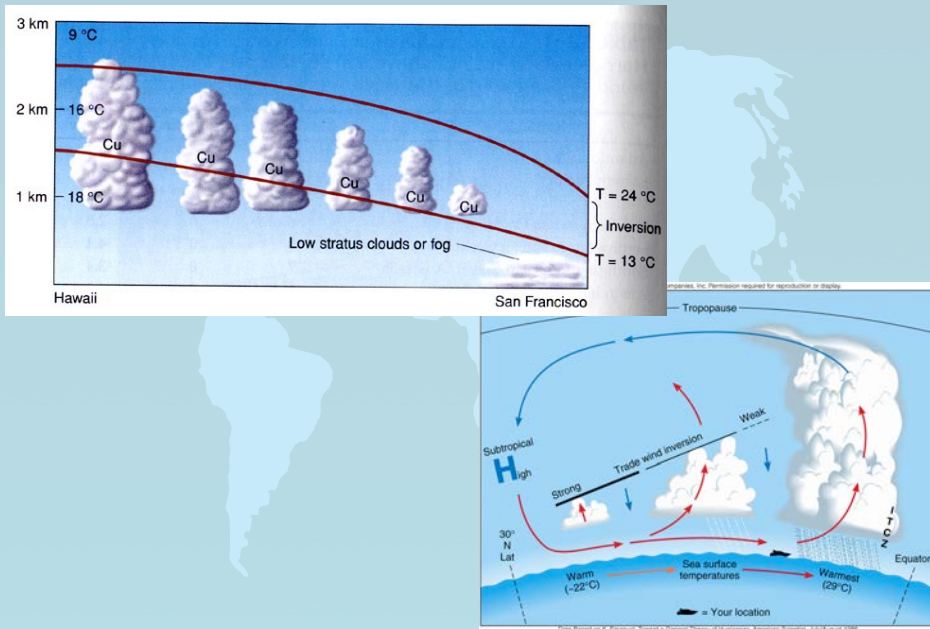
ρ = density of air c_p = heat capacity at constant pressure

C_d = drag coefficient u = wind speed $\Delta\theta$ = air-sea temp. difference

θ = temperature in boundary layer h = height of the B-L inversion

34

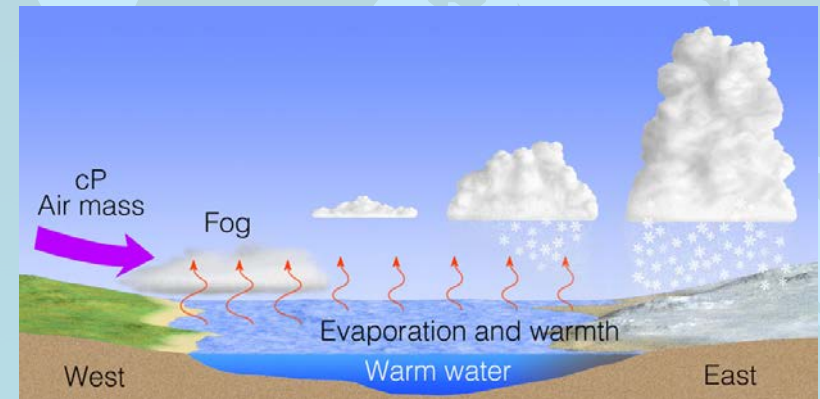
Evolution of Trade Wind Inversion



35

Air Mass Modification I

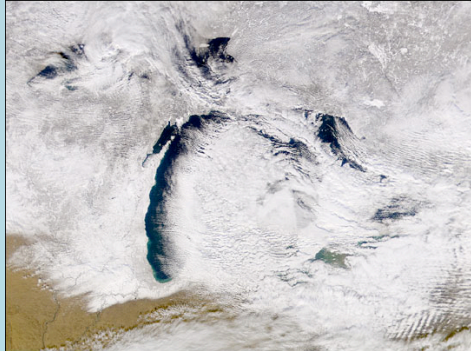
- cP air from Canada is carried across the Great Lakes.
- Contact with the lakes warms and moistens the air near the surface, transforming it to an unstable mP air mass, and resulting in lake-effect snow showers.



36

Air Mass Modification I

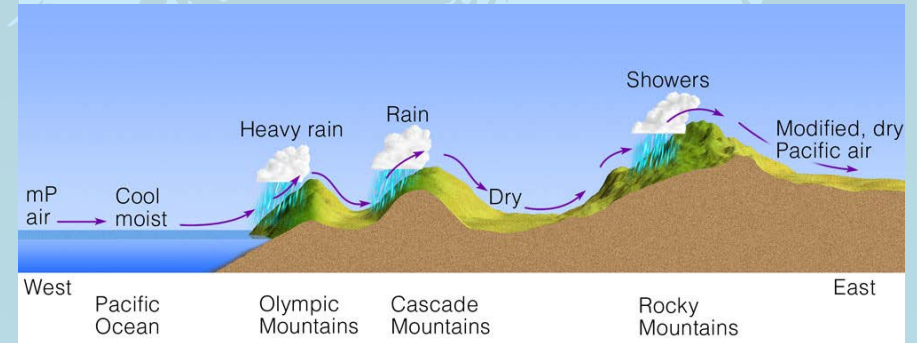
- cP air from Canada is carried across the Great Lakes.
- Contact with the lakes warms and moistens the air near the surface, transforming it to an unstable mP air mass, and resulting in lake-effect snow showers.



Annual average snowfall totals.

37

Air Mass Modification II

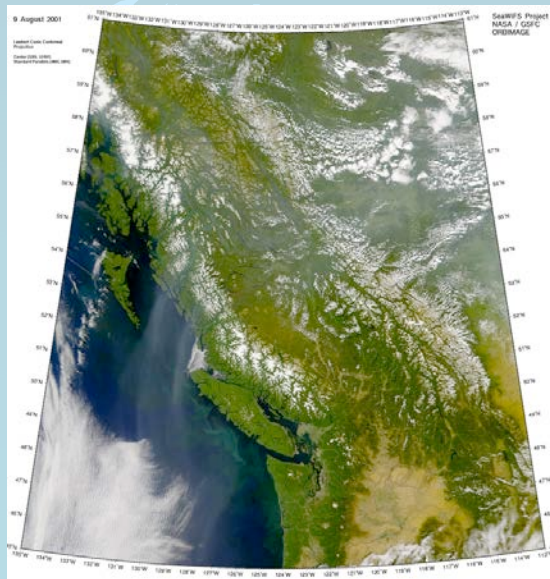


When mP air enters the West Coast and moves inland it crosses several mountain ranges, removing moisture as precipitation.

38

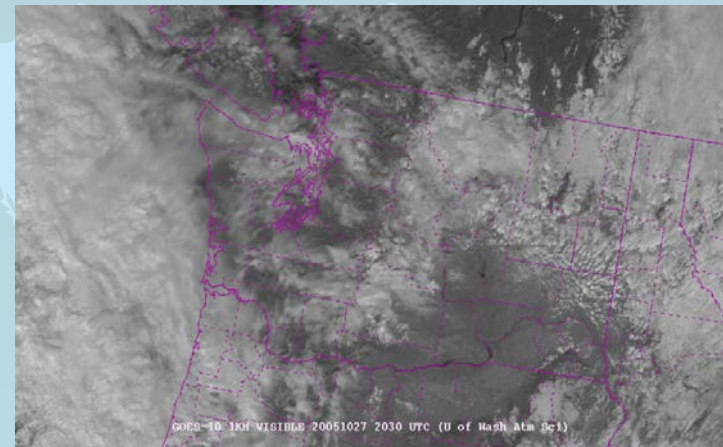
Air Mass Modification II

When mP air enters the West Coast and moves inland it crosses several mountain ranges, removing moisture as precipitation.



39

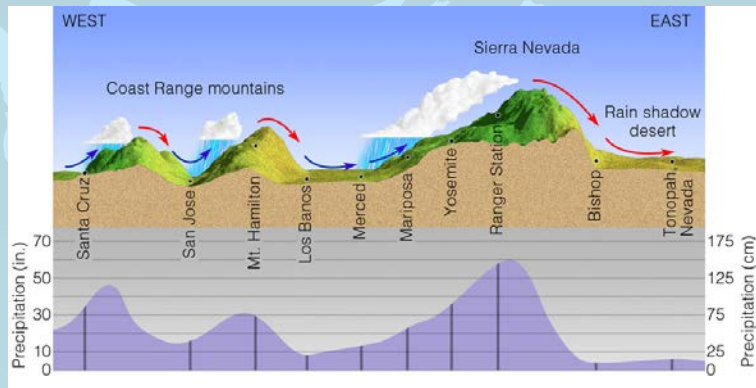
Air Mass Modification II



When mP air enters the West Coast and moves inland it crosses several mountain ranges, removing moisture as precipitation.

40

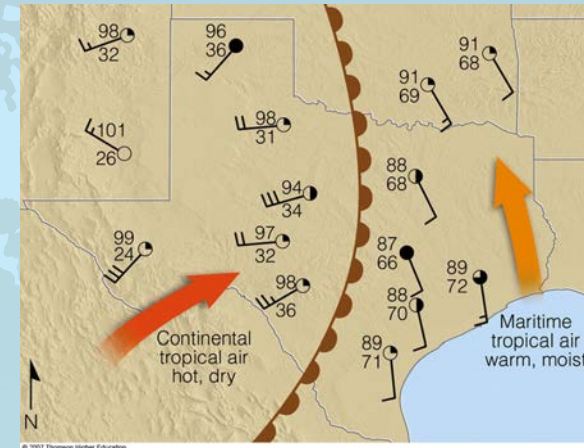
Air Mass Modification II



When mP air enters the California Coast and moves inland it crosses several mountain ranges, removing moisture as precipitation.

41

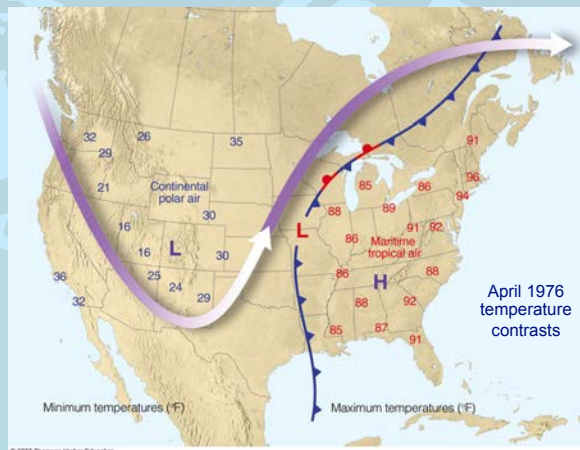
Air Mass Modification and the Dry Line



- Dry air entering eastern Texas from the west encounters warm moist air moving north from the Gulf of Mexico, resulting in the formation of a dry line.

42

Air Masses Modify When they Move



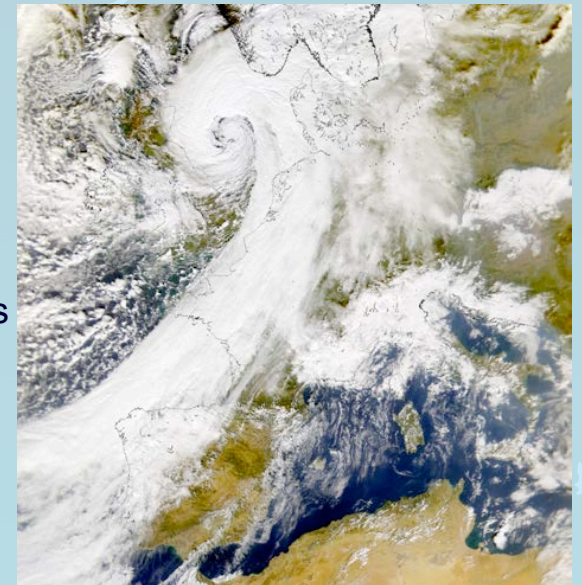
A wave in the jet stream brings cP air southward and mT air northward, resulting in large temperature differences.

43

Fronts

Fronts

- Types of Fronts
- Identifying Fronts
- Formation of Fronts



44

A Front is a Conceptual Model

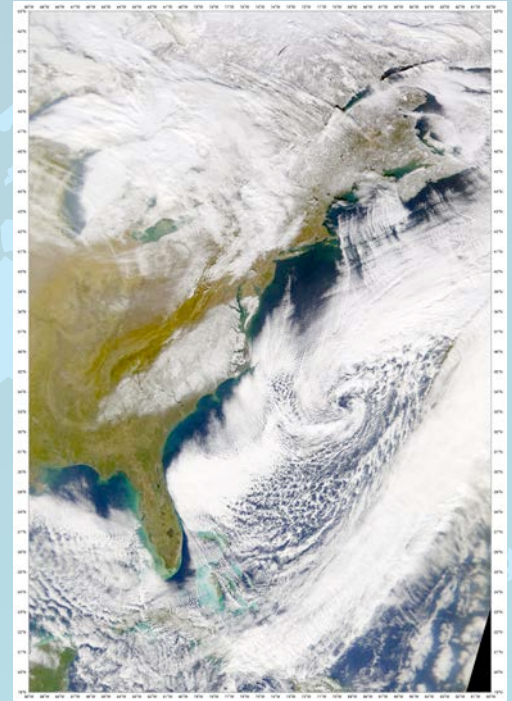


A paradigm for optimal scientific methods of inquiry: physical understanding and conceptual representation through the union of theory, diagnosis, and observations.

45

Fronts

A Front - is the boundary between air masses.
Thus, a front is characterized by a zone of contrasting temperature and moisture.



46

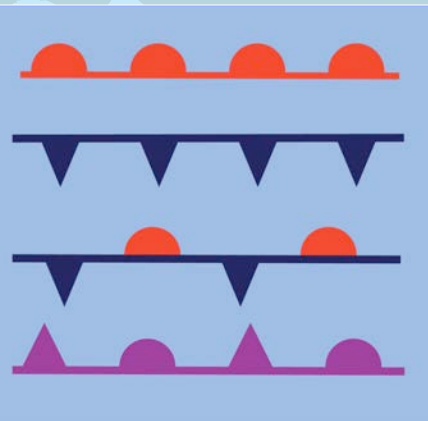
Four Types of Fronts

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).

47

How do we determine what kind of front it is?

From the vantage point of the ground:

- If warm air replaces colder air, the front is a warm front.
- If cold air replaces warmer air, the front is a cold front.
- If the front does not move, it is a stationary front
- Occluded fronts are boundaries between cold and cool air, with warm air pushed aloft.

48

Identifying Fronts

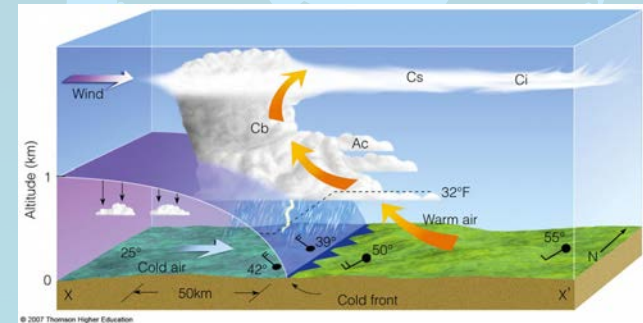
Across the front - look for one or more of the following:

1. Change of Temperature
2. Change of Moisture characteristic (RH, T_d)
3. Change of Wind Direction
4. Change in pressure readings (falling vs rising pressure)
5. Characteristic Precipitation Patterns
6. Characteristic Cloud Patterns

49

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



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50

Cold Front Passage



51

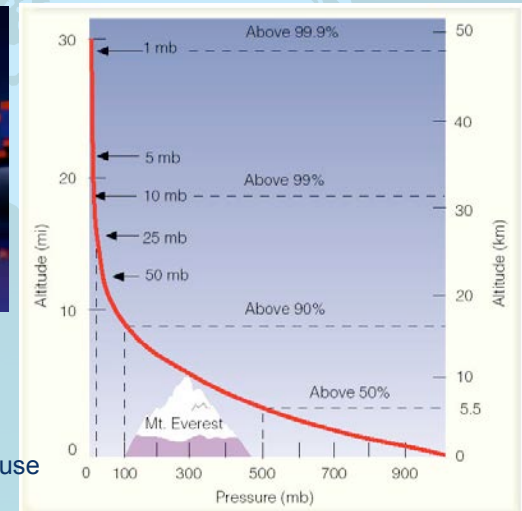
Al Gore: Did Altitude throw Obama off at the Denver Debate?



What is the altitude/pressure at Denver?

Did candidates acclimatize?

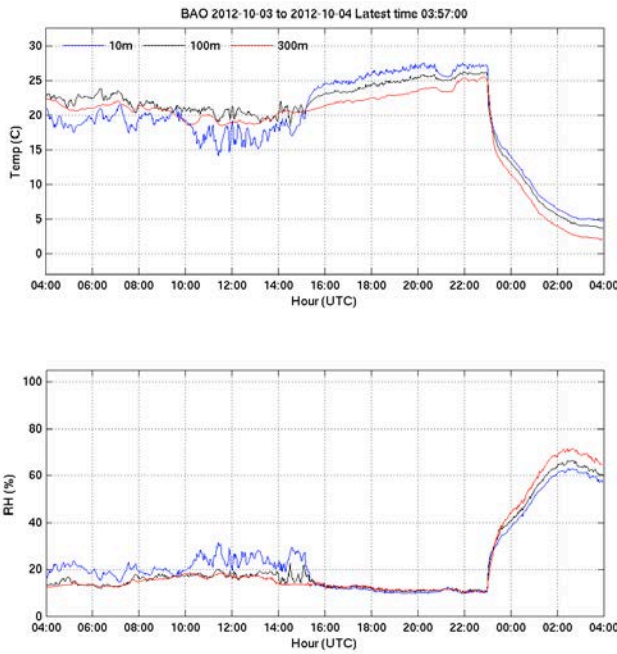
Does Denver altitude potentially cause cognitive loss?



52

If it wasn't Pressure, What was it?

Severe cold front
passage with 40-50 kt
wind gusts.

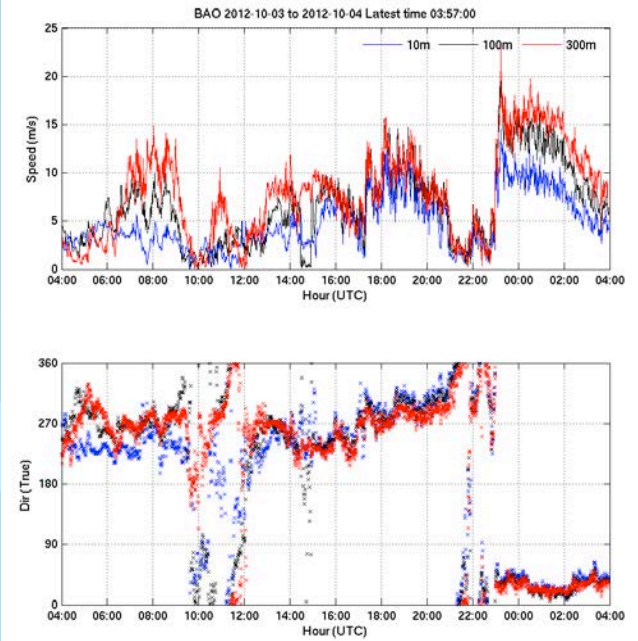


Temperature and Relative Humidity

53

If it wasn't Pressure, What was it?

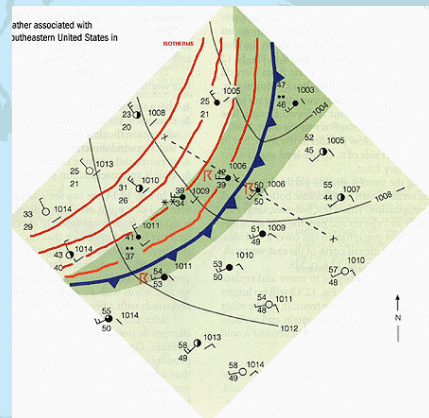
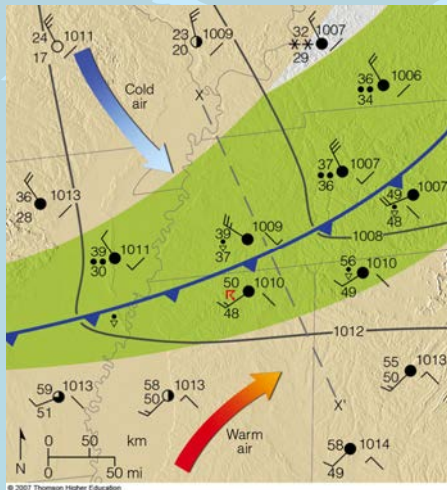
Severe cold front
passage with 40-50 kt
wind gusts.



Wind Speed and Direction

54

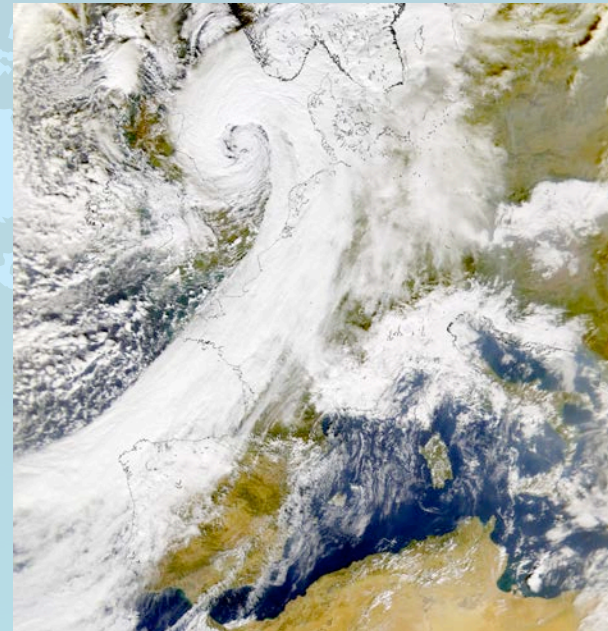
Cold Front on Weather Map



Note that the front is located at the leading edge of the colder air

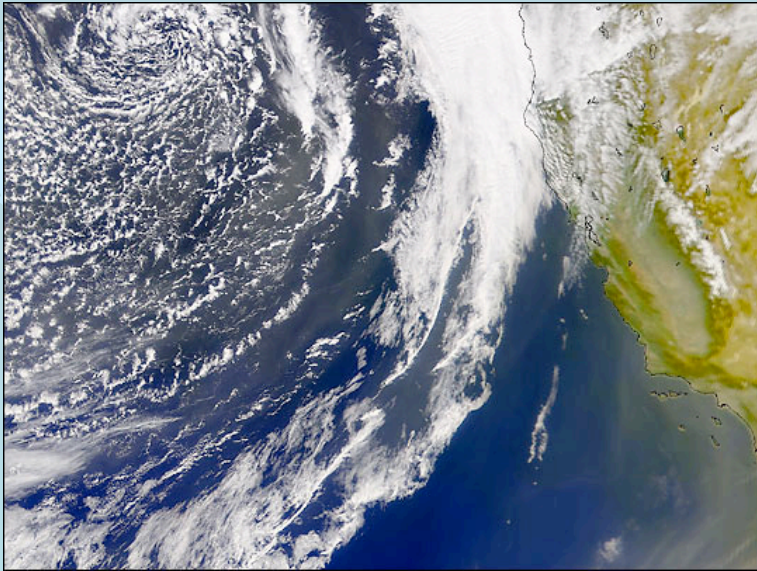
55

Strong Cold Front Striking Europe

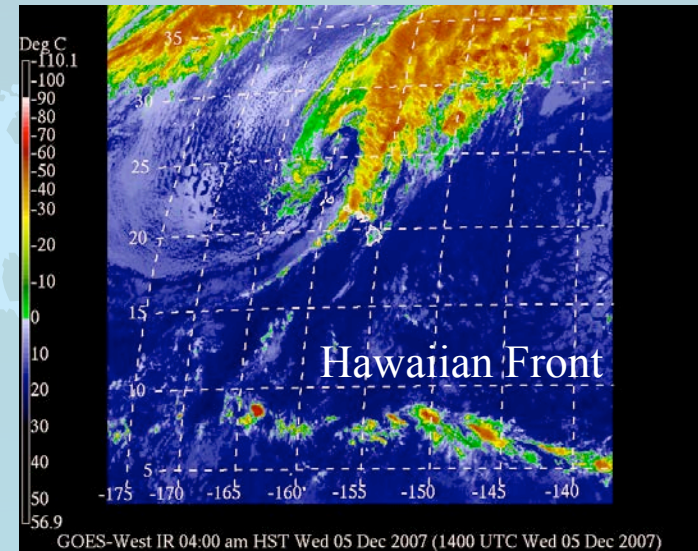


56

Weaker Cold Front Striking West Coast



57

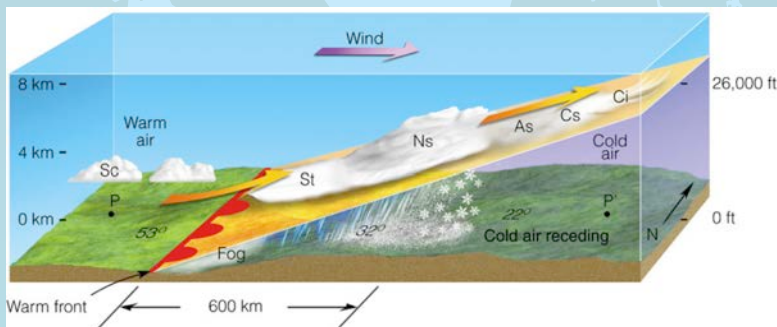


A Front - is the boundary between air masses. Thus, a front is characterized by a zone of contrasting temperature and moisture; normally where this interface intersects the ground.

58

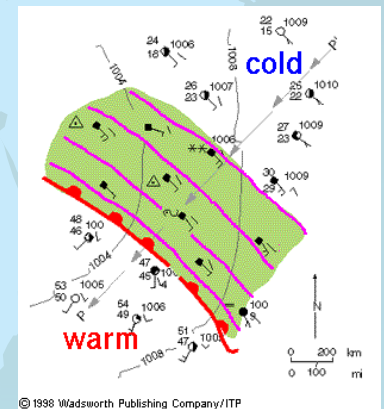
Typical Warm Front Structure

- 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).



59

Warm Front on Weather Map

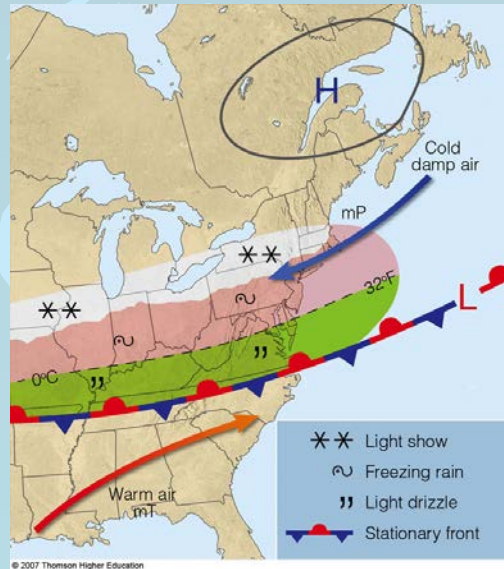


The warm front is located on the warm air side of the colder air. Note the transition from rain to snow across the boundary, this is an example of a rain-snow line.

60

Stationary Fronts can bring Sleet Storms

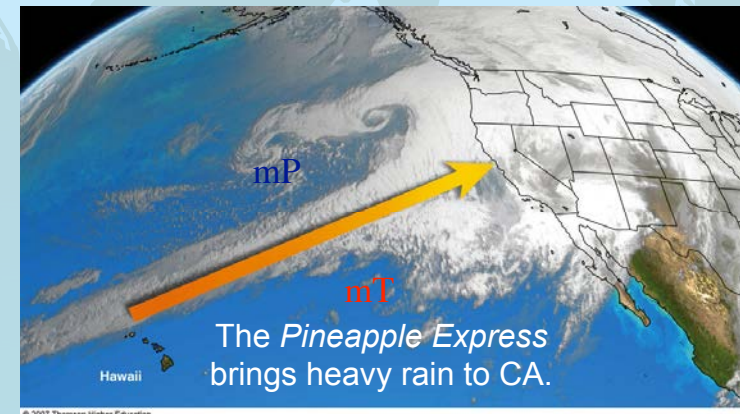
- Stationary fronts across the eastern US can cause prolonged ice storms. Once again, note the rain-snow line.



61

Stationary Fronts can bring Flooding

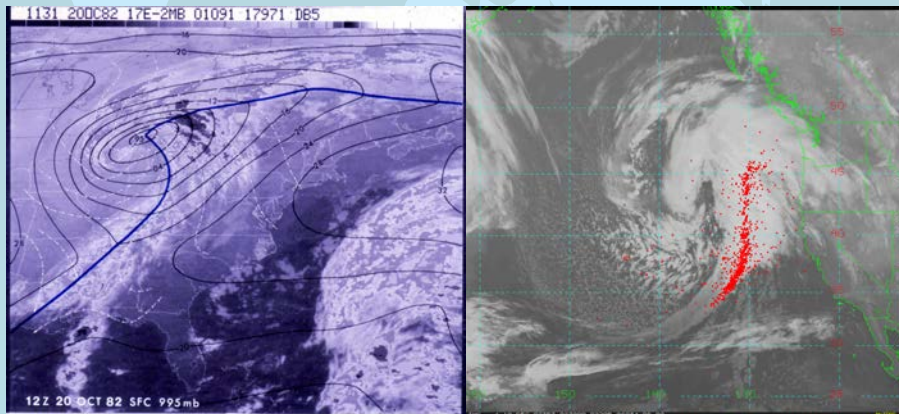
- Warm, moist mT air moves into California on Jan. 1, 1997
- Heavy flooding caused 100,000 people to flee their homes
- Yosemite NP experienced nearly \$200 million in damages and was closed for two months



62

Frontogenesis: Formation of Fronts

- Fronts form when air of differing origins converges (e.g., tropical vs polar).
- Convergence of air happens in areas of low pressure.
- Frontogenesis is the hallmark of midlatitude cyclones.



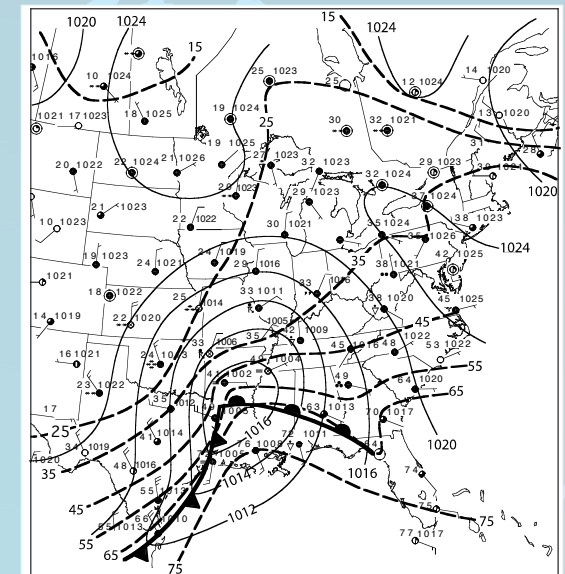
63

Weather Map of a Winter Storm

Temperature - dashed lines

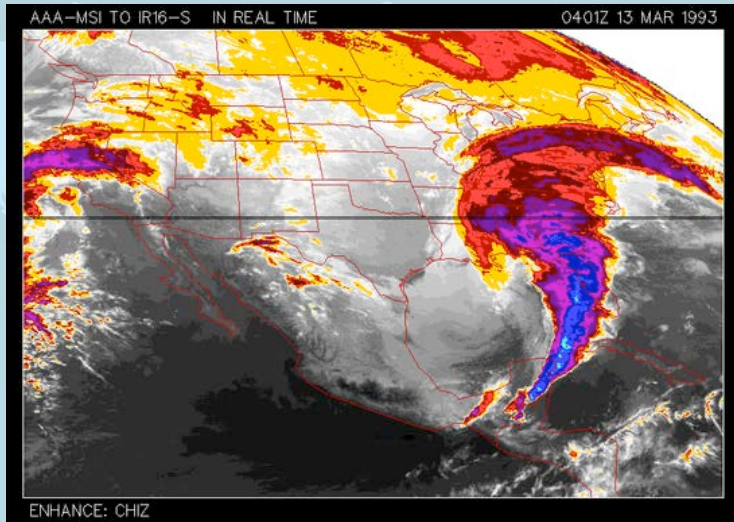
Pressure - solid lines

Fronts - heavy lines with barbs



64

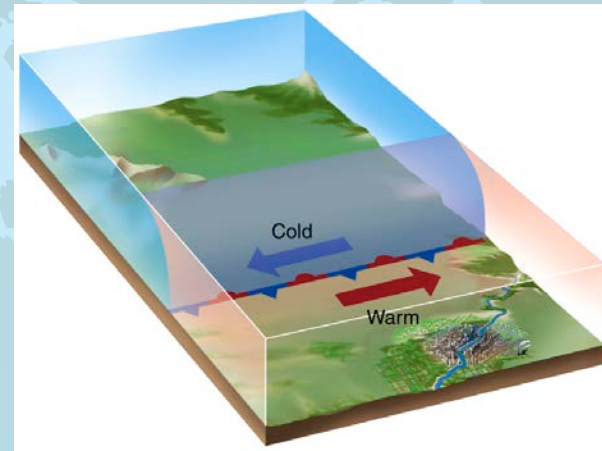
Frontogenesis: Formation of Fronts



Fronts are an fundamental part of winter storms

65

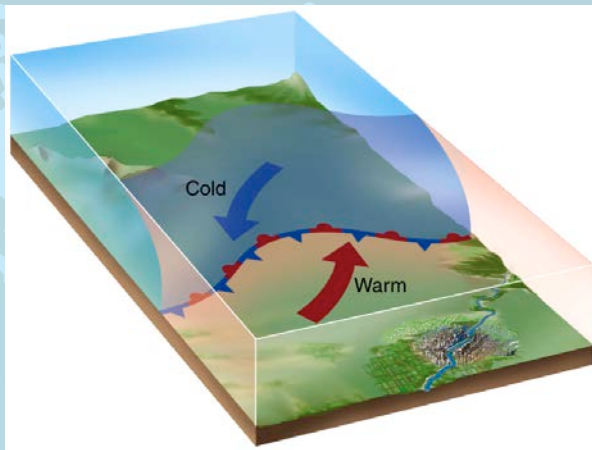
Mid Latitude Cyclone Life Cycle



Polar front separates cold easterlies and westerlies.

66

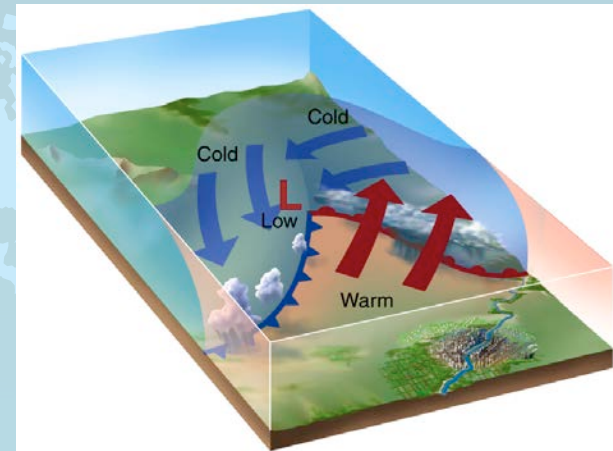
Incipient Stage



A kink forms on the front and cold air starts to move southward. Warm air starts to move northward.

67

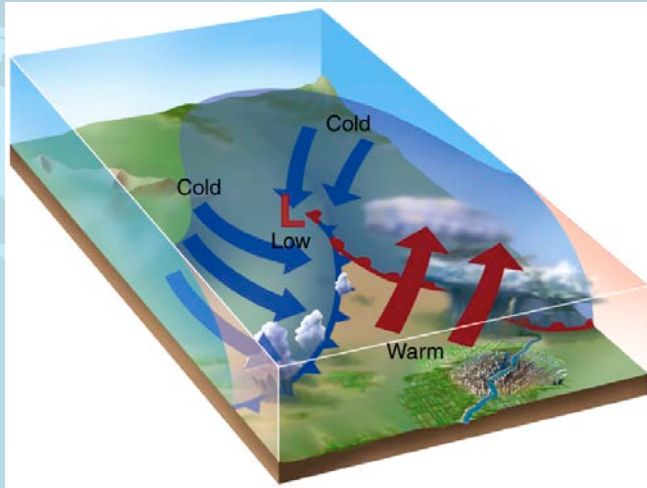
Mature Stage



Cold air continues to move south, and warm air north. Fronts strengthen and low pressure develops in the center.

68

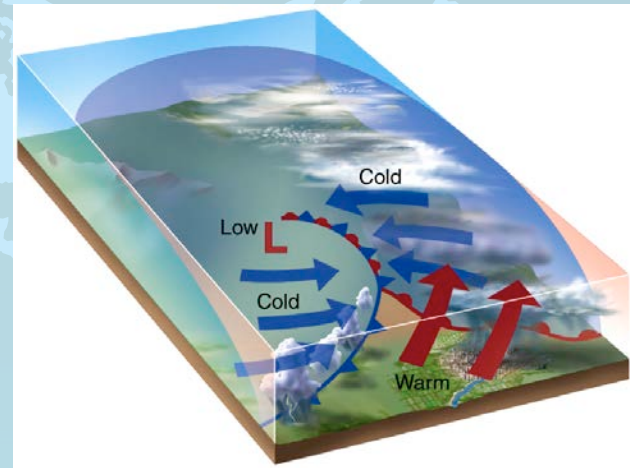
Occluded Stage



Cyclone matures, precipitation and winds become more intense.

69

Dissipating Stage

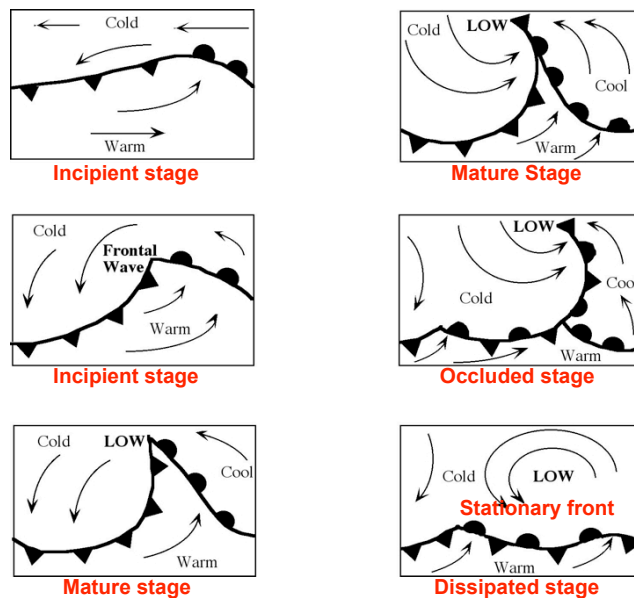


Cyclone continues to occlude (end of life cycle) and cyclone dissipation starts

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Lifecycle of Midlatitude Cyclone

The lifecycle takes several days to a week, and can move 1000's of km during this time.



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Shear Line

A shear line is a line of cyclonic shear that results from prolonged frontolysis acting on a cold front as it travels southward or southwestward over the ocean. Frontolysis is the result of greater surface fluxes acting on the cold-air side of the front and more cloudiness there as well.

Shear lines are characterized by a line of enhanced clouds and embedded showers in a region of confluent flow.

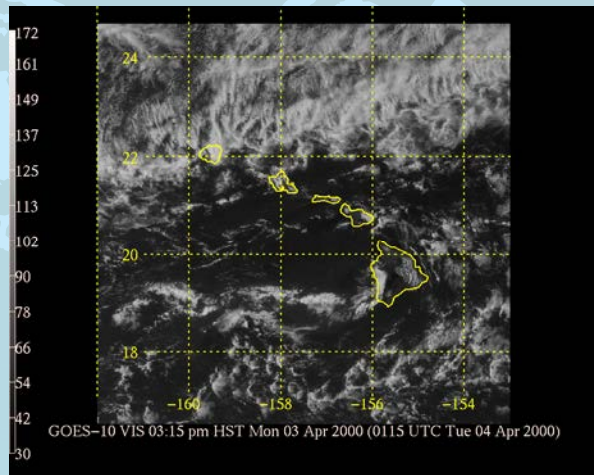
Cyclonic vorticity in shear lines is due to speed shear, winds increasing northward across the line.

Shear lines tend to have weak temperature gradients and relatively small wind shifts in wind direction across the line.

Larger changes in wind speed and dew point temperature can occur.

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Shear Line



Visible satellite image of a shear line approaching the Hawaiian Island chain.

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Shear Line

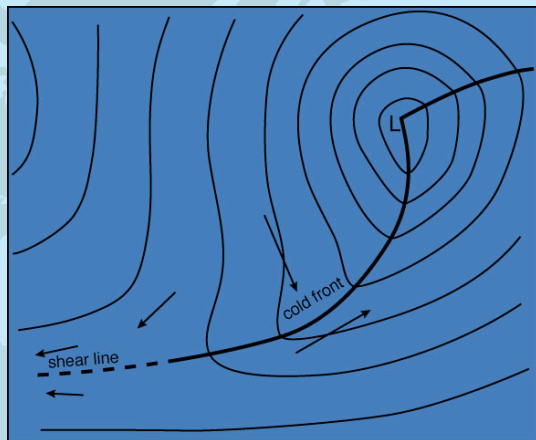
The motion of a shear line, similar to that of a cold front, is determined by the component of the flow perpendicular to the shear line on the cold-air side of the line.

The point along a surface trough at which a cold front becomes a shear line is somewhat subjective.

However, a rule of thumb is to take the location of the inflection point in the surface isobars where the curvature switches from cyclonic to anticyclonic.

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Shear Line

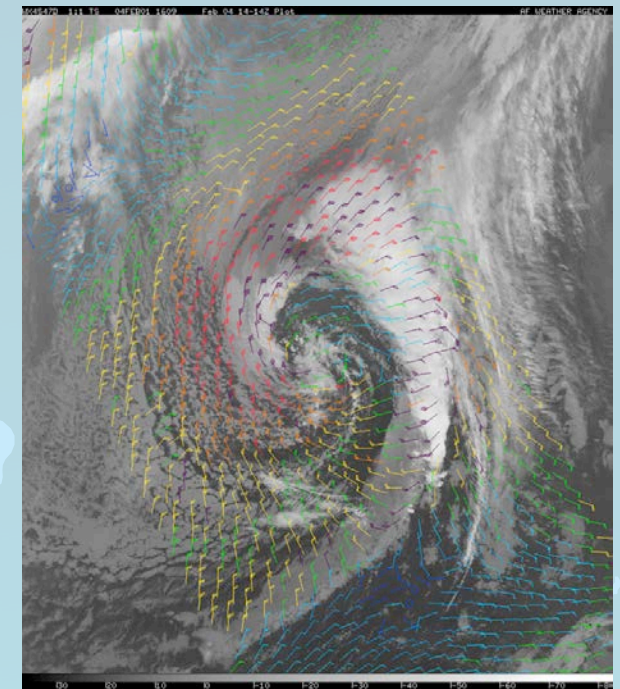


Conceptual model of a shear line analysis.

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Midlatitude Storm with Shearline

Quikscat
Surface
Winds



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Frontolysis in the Subtropics

$$F_H = \frac{d}{dt} \left(\frac{-\partial \theta}{\partial y} \right) = \frac{\partial \theta}{\partial y} \left(\frac{\partial v}{\partial y} \right) + \frac{\partial \theta}{\partial z} \left(\frac{\partial w}{\partial y} \right) - \frac{\partial}{\partial y} \left(\frac{\partial \dot{\theta}}{\partial t} \right)$$

Total F_H = (confluence + tilting terms - diabatic) < 0
in the subtropics.

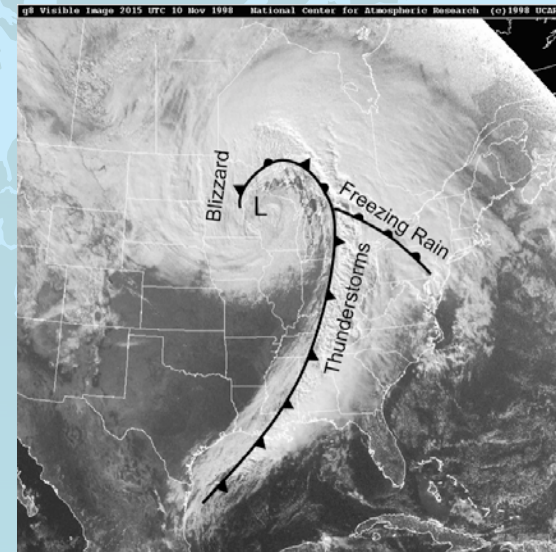
Confluence term acting on existing baroclinicity tends to be small but > 0.

Tilting term tends to be < 0, with a thermally direct circulation along the front (cold air sinking and warm air rising).

Differential diabatic term tends to be < 0, due to greater surface fluxes and cloudiness north of line.

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Location of Hazards in a Midlatitude Cyclone



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Questions?



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Quiz 3 on Thursday November 14th



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