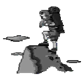
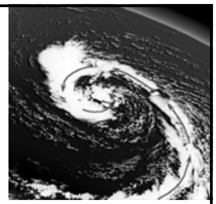
Climatology

Geography 520
SP06

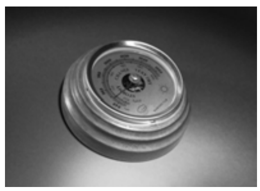




Lecture 13:

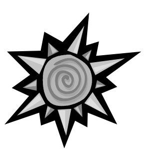
The Atmosphere in motion: Pressure & mass

Surface map

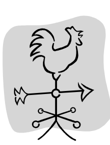


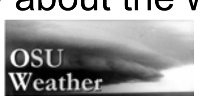
Looking ahead…

- Weather notebook: due Friday 26 May
- We're now getting into dynamics…how the atmosphere moves (winds)…on local and global scales
- Remember our fundamentals of energy, mass, forces, gas laws

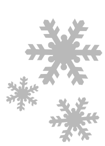


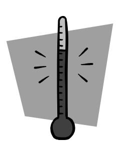
Hey, how about the weather?





GEOG 520





Recap: Precipitation formation and types

- Cloud droplets are too small to fall as rain
- The smaller the drop, greater curvature, more likely to evaporate
- In above freezing air, cloud droplets can grow larger as faster-falling, bigger droplets collide & coalesce with smaller droplets
- In ice-crystal (Bergeron) process, both ice and liquid droplets must coexist at below-freezing T. The diff in saturation vapor pressure causes water to diffuse from liquid droplets (which shrink) toward ice crystals (which grow)
- Most of rain fall in mid-lats starts as snow
- Precipitation reaches sfc in various forms, depending on atmospheric conditions

Molecules from Water to Ice

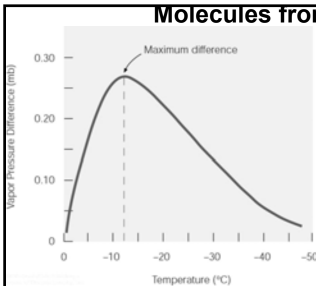


Figure 8.8

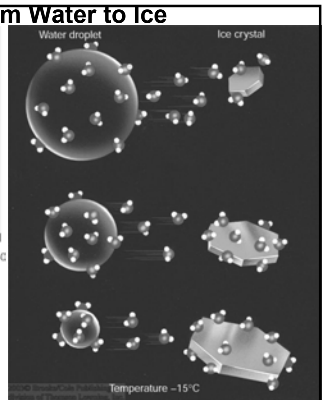


Figure 8.9

Ice crystals have lower saturation vapor pressures than liquid droplets, creating a gradient of high to low water molecules from liquid to ice that encourages ice growth. This growth is critical to the ice-crystal precipitation process.

Sleet & Freezing Rain - II

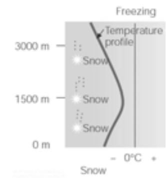


Figure 8.22A

Figure 8.22B

Four vertical temperature profiles are shown to illustrate the phase change that a snowflake may experience in its path toward earth's surface.

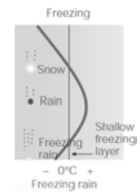


Figure 8.22C

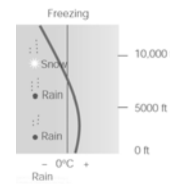


Figure 8.22D

Symbols for precipitation types

Table 8.5 Summary of Precipitation Types

PRECIPITATION TYPE	WEATHER SYMBOL	DESCRIPTION
Drizzle	’’ (light)	Tiny water drops with diameters less than 0.5 mm that fall slowly, usually from a stratus cloud
Rain	•• (light)	Falling liquid drops that have diameters greater than 0.5 mm
Snow	✱✱ (light)	White (or translucent) ice crystals in complex hexagonal (six-sided) shapes that often join together to form snowflakes
Sleet (ice pellets)	△	Frozen raindrops that form as cold raindrops (or partially melted snowflakes) refreeze while falling through a relatively deep subfreezing layer
Freezing rain	~ (light)	Supercooled raindrops that fall through a relatively shallow subfreezing layer and freeze upon contact with cold objects at the surface
Snow grains (granular snow)	△	White or opaque particles of ice less than 1 mm in diameter that usually fall from stratus clouds, and are the solid equivalent of drizzle
Snow pellets (graupel)	◊ (light showers)	Brittle, soft white (or opaque), usually round particles of ice with diameters less than 5 mm that generally fall as showers from cumuliform clouds; they are softer and larger than snow grains
Hail	◊ (moderate or heavy showers)	Transparent or partially opaque ice particles in the shape of balls or irregular lumps that range in size from that of a pea to that of a softball; the largest form of precipitation. *Large hail* has a diameter of ¾ in. or greater; hail almost always is produced in a thunderstorm

Chapter 9: The Atmosphere in Motion: Air Pressure, Forces, & Winds

This chapter discusses:

1. Measurement and meaning of surface (sfc) and upper-level air pressure
2. Effect of pressure and other forces on surface and upper-level winds

Why does the wind blow?
How can one tell wind direction from weather charts?

Atmospheric Pressure Basics

Pressure = The weight (mass) of air above a given level;

Always decreases with elevation

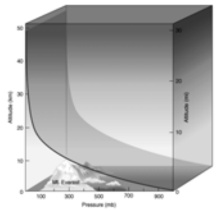
Units: force/area*

The earth's atmosphere has a greater density of gases at its base due to gravity; the gases are compressible

Horizontal differences in pressure cause winds to blow, moving air

Pressure can be increased by:

- increasing density at constant temperature
- Increasing temperature at constant density



*Units: Pascals (Pa) or millibars (mb) (1 mb = 100 Pa)

Average surface pressure over globe: 1013.2 mb.

Atmosphere obeys the gas law (equation of state)

Pressure (p) = temperature (T) x density (ρ) x constant

p v = T ρ constant or **p ~ T x ρ**

At the *same T* (p ~ **ρ)**, air at higher *pressure* is more *dense* than air at lower pressure. Therefore:

- *Air above a region of sfc H pressure is more dense then air above a region of L pressure*
- For sfc H-pressure areas (anticyclones) and sfc L-pressure areas (mid-latitude storms) to form, air density above them must change.
- Surface air pressure: increases as wind moves more air into a column than is able to leave (net convergence); decreases when air leaves (net divergence)

Consider a MODEL of atmosphere

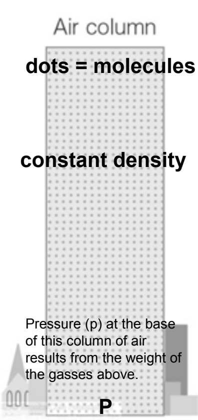


Figure 9.1

An abstraction of reality;

Make simplifying assumptions:

1. The air molecules in our column are not crowded close to the sfc and, unlike the real atmosphere, the air density (ρ="row") remains constant from sfc to top;
2. The width of the column does not change with height

If we forced more molecules in, and keep temperature constant, the column would get more dense, and increase sfc pressure & vice versa.

More on gas law… ($p = T \times \rho \times C^*$)

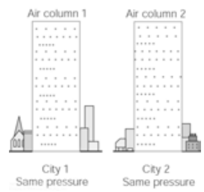
- At a constant pressure, gas becomes less dense as T goes up; hence:
  - *At a given atmospheric pressure, air that is cold is more dense than air that is warm*
- Using gas law, we can calculate:
  - Average T at a certain level (pressure), if we know air density…
  - Average pressure if we know T and density

(*Constant = 2.87 when p is in mb, T in K, and density in kg/m^3)

SO, at average sfc T (15°F), what is average sea-level pressure (SLP) if aver density = 1.226 kg/m^3?

Temperature & Elevation

•When two columns of air are equal in elevation and density, they are at equilibrium.
•Adjusting temperatures by cooling (or heating) increases (or decreases) air density.
•At the surface, equilibrium is maintained, but the taller column has greater upper-level pressure, and winds are generated; air moves, lowers sfc pressure in City 2.



It takes a shorter column of cold, more dense air to exert same sfc p as taller column of warm, less dense air

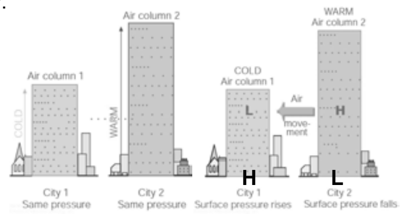
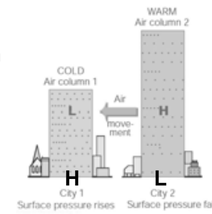


Figure 9.2

More on p, T, elevation

- Above the upper level H in warm column, there are more molecules than above the L in the cold column
- Warm air aloft is normally associated with high (H) atmospheric pressure, and cold air aloft is associated with low pressure
- The horizontal difference in T creates a horizontal difference in p.
- It is this pressure difference (gradient) that establishes a force (**pressure gradient force**) that causes the air to move from H to L



Heating or cooling a column of air can set up pressure gradient causing wind

Diurnal Pressure Fluctuations

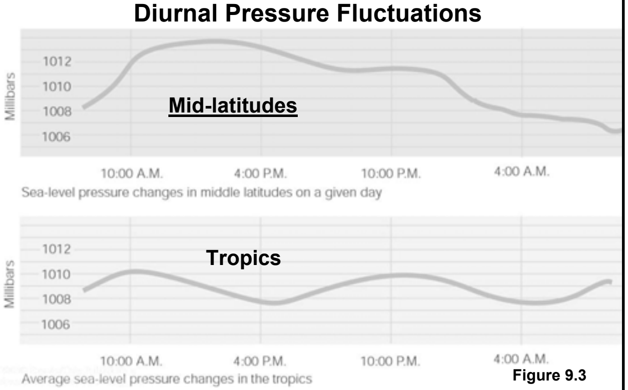


Figure 9.3

Solar heating of ozone gasses in the upper atmosphere, and of water vapor in the lower atmosphere, can trigger oscillating thermal tides of sea-level pressure change in the tropics.

Pressure Scale & Units

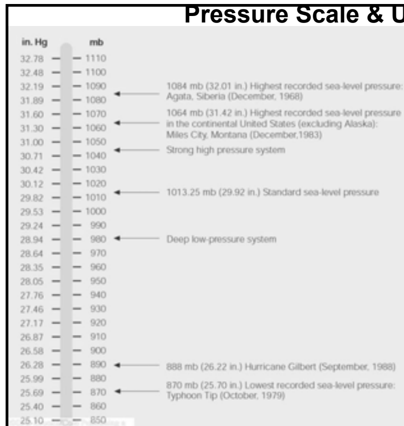


Figure 9.4

Many scales are used to record atmospheric pressure, including inches of mercury (Hg) and millibars (mb).

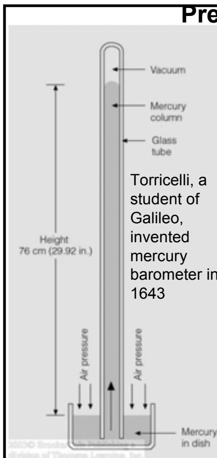
The National Weather Service uses mb, but will convert to metric units of hectopascals (hPa).

The conversion is simply 1 hPa = 1 mb.

Barometer & units

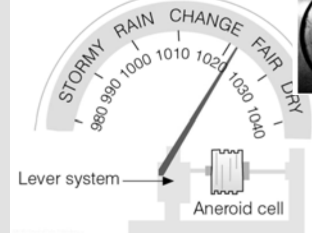
- Literally, instrument that measures bars (unit of pressure)
- 1 bar = 100,000 Newtons (N) (force) acting over 1 sq meter (area) = 100,000 N m^{-2}
- 1 bar = 1000 mb
- 1 Pascal (Pa) = force of 1 N over 1 sq m (N m^{-2})
- 100 Pa = 1 mb
- 1 kilopascal (kPa) = 10 mb
- 1 hectopascal (hPa) = 1 mb

Pressure Measurement



Torricelli, a student of Galileo, invented mercury barometer in 1643

Figure 9.5



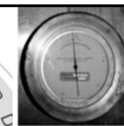


Figure 9.6

Changes in atmospheric pressure are detected by a change in elevation of a barometric fluid or change in diameter of an aneroid cell, which indicates changing weather.

Standard atmospheric pressure at sea level = 29.92" Hg = 1013.25 mb.

Pressure Trends

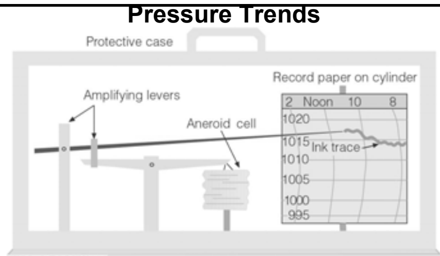


Figure 9.7

Barographs provide a plot of pressure with time, and are useful in weather analysis and forecasting.

Altimeters convert pressure into elevation, and are useful in steep terrain navigation or flying.

Both use aneroid cells.

Station pressure

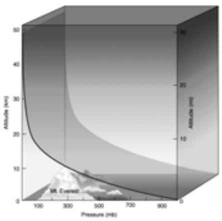
Recall that making a measurement of pressure (e.g. with a mercury barometer) has errors:

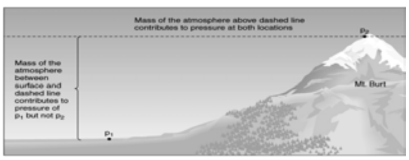
1. Mercury is fluid, sensitive to T
2. The earth's gravity changes, and effects height of mercury
3. Instrument error: built in, due to actual sfc tension

After being corrected for errors, a barometer reading at a particular place and elevation is termed station pressure

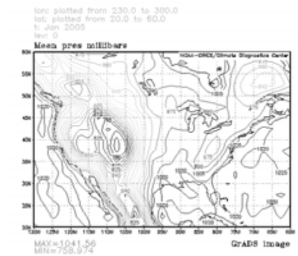
Vertical Pressure Distribution

- pressure decreases non-linearly w/ height
  - Why? Because air is compressible
- pressure will be less at P2 than at P1 due to pressure decreasing with height
- Station pressures are reduced to <u>sea level pressure</u> equivalents so we can compare pressures on a *constant elevation surface*

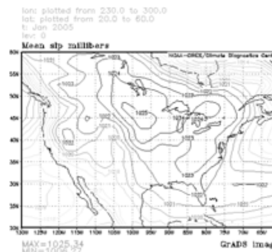




Station (surface) pressure vs. Sea Level Pressure



Surface Pressure
(this is measured by the barometer – strongly related to elevation – doesn't tell you much about the weather)



Sea Level Pressure
(this is calculated from surface pressure…this is what meteorologists are interested in because it omits effects of elevation)

Pressure Reading & Reporting

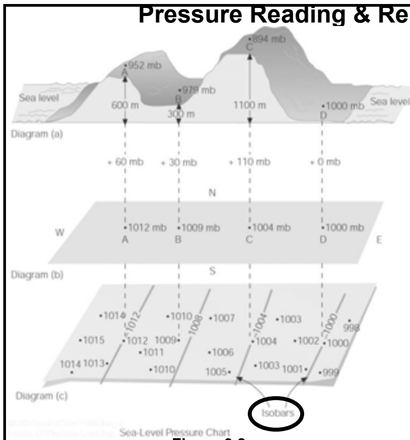


Figure 9.8

Increase terrain elevation → decrease column of air above (lower p).

To remove the effect of elevation, station pressure is readjusted to sea level pressure at ~10mb/100m.

Isobars show geographic trends in pressure, and are spaced at 4 mb intervals.

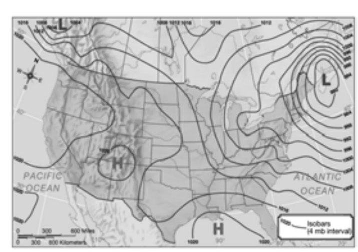
The Distribution of Pressure

- Pressure maps depict <u>isobars</u>, lines of equal pressure
- Through analysis of isobaric charts, pressure gradients are apparent
  - Steep <u>pressure gradients</u> are indicated by closely spaced isobars
  - Steep pressure gradients = strong winds

A weather map depicting the sea level pressure distribution for March 4, 1994

Small gradient over country

40 mb change in 3000 km →
Gradient = 1 mb/75 km
= 0.012 mb / km



Smoothed Isobar Maps

Continental maps of station recorded sea-level pressure are often smoothed and simplified to ease interpretation.

Smoothing adds error to those already introduced by error in instrument accuracy.

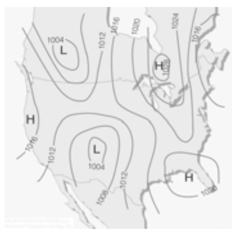


Figure 9.9

Constant Height Chart

Maps of atmospheric pressure, whether at sea level or 3000 m above sea level, show variations in pressure at that elevation.

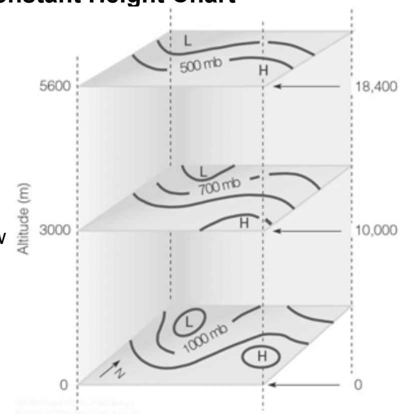


Figure 9.10

Constant Pressure (Isobaric) Chart

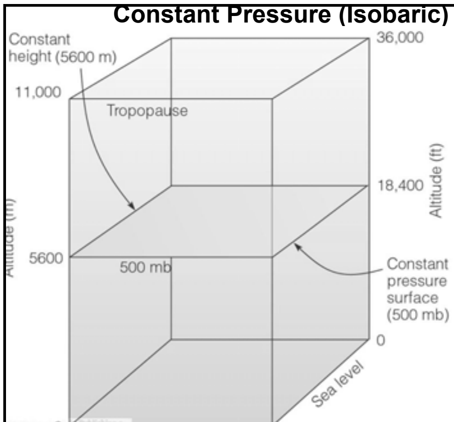


Figure 9.11

Maps of constant pressure provide another means for viewing atmospheric dynamics.

In this example, there is no variation in elevation for a pressure of 500 mb.

Variation in Height

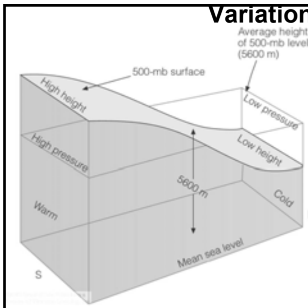


Figure 9.12

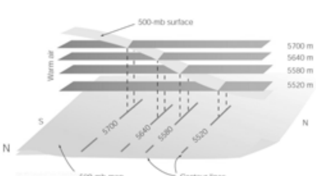
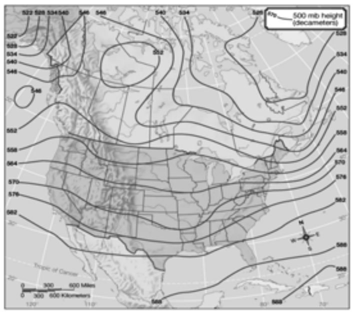


Figure 9.13

Isobaric (constant pressure) surfaces rise and fall in elevation with changes in air temperature and density.
A low 500 mb height indicates denser (colder) air below, and less atmosphere and lower pressure above.
Contour lines indicate rates of pressure change.

Example of typical 500 mb height chart

- Height contours analogous to the pressure gradient
- Small changes over large regions: approximate 10% difference across North America
- More contour lines in an interval represent greater amounts of T (pressure) change (larger gradient).
- Generally in N Hemisphere, colder air to north means lower heights, so isobars usually decrease in value from S to N.



500 mb height contours for May 3, 1995

Ridges & Troughs

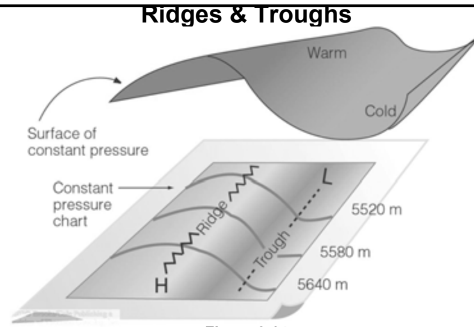


Figure 9.14

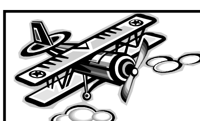
Upper level areas with high pressure are named ridges, and areas with low pressure are named troughs.

These elongated changes in the pressure map appear as undulating waves.

Common Isobaric Charts

Table 9.1 Common Isobaric Charts and Their Approximate Elevation above Sea Level

ISOBARIC SURFACE (MB) CHARTS	APPROXIMATE ELEVATION (m)	(ft)
1000	120	400
850	1,460	4,800
700	3,000	9,800
500	5,600	18,400
300	9,180	30,100
200	11,800	38,700
100	16,200	53,200



Flying on constant pressure surface

High to low, look out below!

- Aircraft altimeters are barometers that convert pressure to approximate elevation, and need to be calibrated
- Air pressure is influenced by temperature, and so will the elevation indicated by altimeter
  - Flying into warmer air column → altimeter will register altitude that is LOWER than true elevation
- Flying into a region of lower pressure can be dangerous, especially in mountainous terrain

Surface & 500 mb Maps

Surface maps chart pressure contours, highs and lows, and wind direction.

Winds blow clockwise around highs, called anticyclones, in N Hemisphere

500 mb maps reveal patterns that on average are 5600 m above the surface, where westerly winds rise and fall across ridges and troughs. (isotherms)

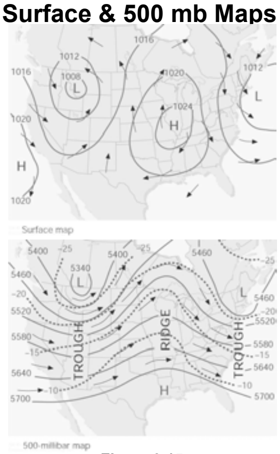


Figure 9.15

Pondering the winds

- Why do the surface winds cross the isobars, whereas the upper level winds blow parallel to the contour lines?
- We must address the FORCES that affect winds…

Newton's laws of motion

1. An object at rest will remain at rest and an object in motion remain in motion as long as no FORCE is exerted on it.
2. The FORCE exerted on an object equals its mass times acceleration produced

$F = ma$

Acceleration = change in velocity

Velocity specifies both speed and direction

Forces on wind

TO determine the direction the wind blows, we must consider the net balance of all forces acting:

1. Pressure gradient force
2. Coriolis force
3. Centripetal force
4. Friction

Forces & Motion

Pressure forces are only one influence on the movement of atmospheric air.

Air responds similarly as water to this force, moving from higher pressure to lower pressure.

The greater the pressure difference, the stronger the force, and the faster the flow of water

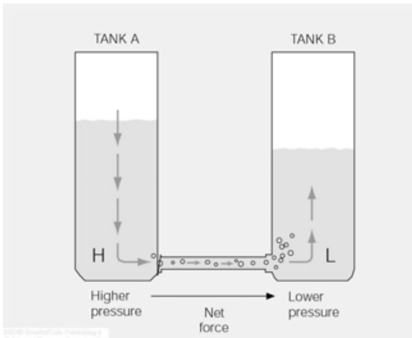


Figure 9.16

Pressure Gradient

Pressure gradient (PG) = $\frac{\text{difference in pressure}}{\text{distance}}$

$$PG = \Delta p / d$$

Pressure Gradient Force

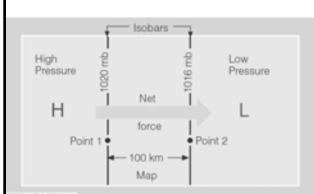


Figure 9.17

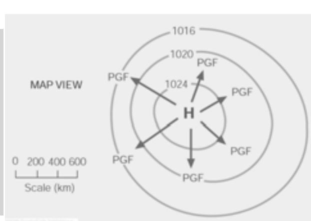


Figure 9.18

- •Change in pressure per change in distance determines the magnitude of the pressure gradient force (PGF).
- •PGF is directed from H to L pressure, at right angles to isobars
- •Greater pressure changes across shorter distances creates a larger PGF to initiate movement of winds.

PGF vs. Cyclonic Winds

Pressure gradient force (PGF) winds acting alone would head directly into low pressure.

Surface observations of winds, such as the cyclonic flow around this low, reveal that PGF winds are deflected by other forces.

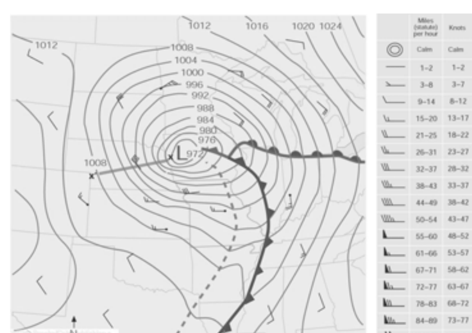


Figure 9.19

Tightly packed isobars = strong winds, big storm (November 10, 1998)