Lecture 14
Meteorology

Winds are the energy transportation network of the atmosphere.

Pressure, density, temperature, and volume are used to describe gases.

Pressure = \( \frac{\text{force}}{\text{area}} \) or \( \frac{\text{weight}}{\text{area}} \) and as an area is a two-dimensional thing, pressure is also two-dimensional.

Density = \( \frac{\text{mass}}{\text{volume}} \) or mass per unit volume. Volume is a 3-dimensional quality and so density relates to 3 dimensions.

A thin layer of dense air may exert a pressure equivalent to a thick layer of less dense air.

The gas law states that pressure is proportional to temperature \( \times \) density or \( P \propto T \rho \)

To make this proportion into an equation, you must use a "constant". This is a number that literally stays constant and that doesn't change the meaning of the equation, except to make the different units in the equation work out correctly. The "constant" in this case is the Universal Gas Constant "\( R \)" and is equal to \( 8.317 \times 10^7 \) ergs/mole K⁰.

Thus, now with our constant, we can write:

\[
P = \rho R T
\]

And because we know that density = mass \( \div \) volume ( \( \rho = \frac{M}{V} \) )

We can write the equation as

\[
P = \frac{M}{V} R T
\]

Because mass usually remains constant unless you get way to great heights, you can eliminate it from the equation.

And the equation will become

\[
P = \frac{1}{V} R T \quad \text{or} \quad P = \frac{R T}{V}
\]

Oftentimes a physicist or meteorologist will forget the exact value of the gas constant \( R \) because if you work with a gas under two different situations, you can eliminate the \( R \) very simply using fundamental algebraic manipulations. The trick is simply to get the quantity you wish to eliminate from the equation alone on one side of the equation thus making it equal to everything else on the other side of the equation, then substitute.
So \( P = \frac{RT}{V} \)

If you do something to one side of the equation, you must do the same thing to the other side.

\( V \cdot P = \frac{(V)RT}{V} = RT \) *Something multiplied & divided by the same number is equal to the original number before the processes of multiplication and division occurred. Thus, essentially, the processes cancel themselves out if their quantities are the same.*

\( \frac{VP}{T} = R \) Thus, every time we see an \( R \), we can substitute \( \frac{VP}{T} \) for it.

So let's take a situation where the air is in a certain condition and then do something to change the characteristic of the air and call that situation #2. How can we relate these two situations to each other by means of this formula??

**Situation 1:** \( \frac{P_1V_1}{T_1} = R \)

**Situation 2:** \( \frac{P_2V_2}{T_2} = R \)

So by substituting the pressure, temp., and volume of situation #1 into the equation for situation #2 for "R", we can easily relate them to each other --- and eliminate "R" as a bonus!

\[ \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \]

Now, if you're still uncomfortable with the alphabet soup and you can't understand its relationships at all, don't worry. You can describe the same situations in English.

If you're describing gas in an open container in the atmosphere, you can think about a balloon with no elastic properties enclosing it. Thus will the pressure be held constant ---or will stay the same between the gas inside the balloon and outside the balloon. So for this arrangement, "P" can be eliminated from our equation giving us:

\[ \frac{V_1}{T_1} = \frac{V_2}{T_2} \]
If you're working with a gas in a closed container, the volume is held constant with respect to the rest of the atmosphere and thus you're working only with pressure and temperature. The resulting equation: \[
\frac{P_1}{T_1} = \frac{P_2}{T_2}
\]

Remember now that pressure is force per unit area, or the number of collisions that the molecules in the gas make with the surface area of the container.

Temperature excites the molecules to a higher kinetic energy, or makes them move faster and thus bump each other and their confining surface more and harder.

The atmosphere acts like an open container because it's only singly bounded by the ground and so acts like a balloon.

A helium balloon rises because it is less dense than air.

A hot air balloon isn't a closed balloon like the helium balloon.

With the increase in temperature of the air rising into the balloon, there is an increase in the K.E. (motion) of the gas molecules and a decrease in the density of the gas --- the gas within essentially becomes lighter than the gas without, the pressure within wants to equalize itself with the pressure without, so the balloon acquires "lift". Thus, for more lift, you stoke the fire and boil out a few more gas molecules from within.

Do you know what will happen if the atmospheric pressure suddenly dropped by 1 pound per square inch? The average tornado passing over a building, for instance, changes the atmospheric pressure by 2lbs per square inch, and the building won't survive. It'll blow up, because the lifting force that will be on the roof (say a roof 10'x 20') will be 4.32 tons! (To figure out this for any roof, take the surface area of the roof and multiply it by the change in pressure, in this case, 2lbs/in².)
It's the difference in pressure, in fact, in a room that is what blows up a room when a bomb goes off in it. It's this same pressure difference that blows up houses which are in the vicinity of tornadoes. Thus, when a tornado comes by, open up the doors and windows wide to help to equalize the pressure between the inside and the outside.

Now, we've already established that hot air rises and cold air sinks, but what happens when a gas expands or contracts? All gases cool by expansion when they rise, and descending air is compressed and therefore warms as it sinks.

The gas from an aerosol can is let out of a small area & expands and thus feels cool. But pumping a gas into a confined volume causes a compression of the gas which warms it.

Car tires in the desert: friction causes heat which increases the pressure inside the tire. If you let out some of this pressure when you stop for gas, then when you resume your journey, there will be increased friction and more flexing of the tire than before causing a higher heat and perhaps a blow-out. .. . The way you can tell the tire with the lowest pressure, is to see which one feels hottest.

So why is it hot today meteorologically? Pressure! Just off the coast there's a high pressure area that's draining extra air down onto us, causing our own local environment to be warmed by compression. Just remember that mountains of air tend to equalize themselves with the valleys to either side of them; the air comes down, is compressed and compresses that air which its coming down on, and warms through that compression.

What's this have to do with the inversion level? It puts a lid on it & pushes it down.

What causes inversions? A high pressure aloft and a low pressure in the surface because of hot air rising (from sand, etc) held down by highs moving in. Or cold air coming off the surface of the ocean, held down by a high. In a high pressure system, most movement is downward, not horizontal (no wind).
1. Sun at equinox
2. Sun heats earth, earth by conduction heats air, air by convection rises when warm
3. If hot air is rising, the air is leaving so the pressure goes down causing a thermal low.
4. When the air has expanded itself to a high elevation, it begins to cool & wishes to sink, however, just as in a N.Y. subway station at rush hour, it is impossible to turn around & go back — but it is possible to go sideways.
5. At 30°N or 30°S the air is free to sink. As it does so, it is warmed by compression.
6. This air is then drawn back toward the equator by the low there, thus completing the convective cell or Hadley cell.
7. Some of this air at #5 is not drawn to the equator but toward the poles, compressed it is warm & heavy.
8. At the polar front or cyclone belt it meets the polar air coming from the polar high (9.)
Three Types of Winds:
Primary - Global
Secondary - Continental
Tertiary - Local

The diagram to the right shows wind patterns under the conditions that:
1. The earth is made of the same stuff all over.
2. The earth doesn’t rotate or move in any way.
3. There are no seasons.

In the diagram below, the earth rotates toward its own east.
Looking from the North, it rotates in a counterclockwise direction;
Looking from the South, it rotates in a clockwise direction.

How fast does a person standing at the Equator travel? The circumference of the earth every 24 hours. And the circumference \(= \pi \times \text{diameter} \), which is about 8,000 miles. So \( C = \pi \times 8,000 \text{ miles} \). \( C = \pi \times 3.14 \times 8,000 \text{ miles} \). Thus the speed is 25,000 miles \( \div 24 \text{ hours} \) or 1050 miles per hour. The speed at our 37° Latitude is about 640 mph. Now, the difference in this rotational speed at different latitudes cannot be ignored because energy is conserved. You can use these speeds to advantage by making use of the winds they produce in launching rockets, for instance. The Russians must use much more fuel than we do because they are further north, further from the equator, than we are.
It's much like what happens when you get out of a moving car ---
you have a residual kinetic energy (energy of motion) which keeps
impelling you forward even though you personally might want to stop.
Well, the air in the earth's atmosphere is going around with the
earth at over 1000 mph and helps to fairly fling the rocket off into
space --- and the closer the rocket is shot off to the equator, the
faster the environmental air is moving, the bigger the final fling---
the less the fuel.

The air deflection is known as the Coriolis effect.
In the Northern Hemisphere, the Coriolis effect is a rightward effect,
or a deflection to the right of intended motion. In the Southern
hemisphere it is a deflection to the left of intended motion.

The Coriolis effect is a tendency
which is stronger northward because
the latitudinal circles there describe
much wider variations in the measure-
ments of the circumferences of the
circles which are right next to each
other than those circumferences of
the latitudinal circles at or around
the equator.
Empirically, the strength of the effec-
t of Coriolis can be tested by counting
the number of times water spirals down
a drain in a counterclockwise direction
as compared to a clockwise direction
for different latitudes. At Rhode
Island, experiments show that eight
out of ten times water spirals down
the sink counter-clockwise; here about
6 or 7 times out of 10; and in Mexico
City only about 5 out of 10 times,
which is a "pure chance" relationship.
The Coriolis effect is not only present in the atmosphere causing its characteristic deviations and in sinks swirling down the drains, but also in the meandering of the rivers, the right hand erosion of river banks in the northern hemisphere, the wearing of the right front brakes on a car, the wearing of the right hand rail for train tracks in a round house (train tracks on which a train travels in one direction only), and the rotation of air within a tornado and a hurricane. Incidentally, a hurricane cannot cross the equator and remain a hurricane for that reason. If it does cross, it simply fizzles out because the curling of the winds due to the Coriolis effect are diametrically opposed.

Meteorologists name the wind from whence its coming

Most of the above names were coined by sailors traveling from Europe to the New World and back.

The deserts are located around 30° N and 30°S at the highs -- which are naturally hot and dry.
Air always wants to go out of a high pressure area and wants to go into a low pressure area.

Air leaves a high in a clockwise direction in the northern hemisphere and in a counterclockwise direction in the southern hem.

Memorize: counter-clockwise into the low in the northern hemisphere.
To illustrate the gas laws, we shall now discuss how a refrigerator works.

Compressor puts air under pressure making it compressed. It is then warmer due to that compression. This extra warmth is radiated off or out by means of conduction, convection, and radiation into the outside environment.

At the expansion area the gas is allowed to expand. It therefore cools due to this expansion, sometimes below the freezing point of water.

The Refrigerator Cycle depends on: Compression—Heating Environmental Cooling Expansion Cooling of the gas.

The refrigerator consumes at least 4 times its cost in electricity during its lifetime. To keep this operating cost at a minimum,

1. Have plenty of air circulation around the radiator.
2. Keep radiator clean of dirt as dirt is a good insulator.
3. Must have less that ½" of ice on the expansion tube within or will lose efficiency because ice is an excellent insulator due to the fact that it has a great deal of air in it.

Incidentally, more heat is generated by a refrigerator (and an air conditioner also) than cool because neither is 100% efficient.

To get a full fill of oxygen in scuba tanks, you must fill them in water --- the water acting to cool down the tanks---because when you’re compressing air, it heats up and the temp. caused by the compression adds to the pressure therein. So to lower this added pressure, cool the tank off and you can add more of the pressure you want -- air pressure.
Do not use air conditioners in close quarters --- efficiency lack but heats the air and makes only the electric and air conditioning companies happy.

Lows fill up from the bottom. When air enters a low, it does so from the surface. Air leaves a high by spiraling.

Check the station model of page 325. It shows that each weather station records the barometric pressure at its location. These readings are then placed on geographical maps in their proper locations as a dot and a number. Then all the dots of equal pressure are connected by a line and this line of equal pressure is called an isobar.
There are basically three types of winds: 
The Geostrophic Wind 
The Gradiant Wind 
The Friction Wind

In order to understand these winds, we must look briefly into vector analysis. A good example of vectors analogous to those causing the simplest of the above winds, the geostrophic wind, are those vectors showing the forces in a bow and arrow.

The force of gravity & the pressure gradient force are not dependent on velocity --- they simply are. But to have the "force" of Coriolis, you must have something moving, that is there must be a velocity present. If you increase the pressure gradient, you will correspondingly increase the Coriolis effect and increase the resultant wind.

With the introduction of the Centrifugal force, then you have a Gradient Wind. The Centrifugal force is the pull which wants to pull the layers away from the central high or low. The closer in you get to the high or low, the more curve you get, the more the Centrifugal force.
The closer the wind gets to the ground, the more it will encounter a frictional force which will impede its flow. The more its flow is slowed, the weaker the Coriolis force becomes, the more direct air movement into the low the wind will blow. This is because the pressure gradient force is unaffected by friction and is not dependent upon velocity, as the force of Coriolis and centrifugal force is.

So, the pressure gradient force is still pulling the air in to the central low and the force of Coriolis and the centrifugal force are still pulling it back, but the latter's combined efforts are reduced by the force of friction. This reduction manifests as both a change in magnitude and a change in direction of the resulting wind... Now, for the first time, you get winds crossing over the isobars. And now you can see why air from highs spiral all the way down to the surface before they can begin to fill the lows, and why lows always fill from the bottom up.

Bi Ballot's Law states that if you turn your back to the wind in the northern hemisphere, then the low will be at your left. Only one trouble, while standing down on the ground, you must adjust for frictional forces which have modified the right hand pull of the Coriolis effect by about 45° --- so you must simply turn yourself about 45° toward the right, put out your left arm, and you're pointing to the low.

Now, because storms generally move from west to east across the globe, if your back is to the wind and your left happens to be to the west, you know that the storm's still a comin', but if your left hand is pointing to the east, then the storm's a goin'!

Returning for a moment to our previous discussion, we were told that there is a change in speed and direction of the wind through or because of the friction layer. There's actually a pattern that the velocities at different elevations generally make and this pattern is called the Eckmann Spiral. The spiral works in oceans as well as in the air.
Now usually if you see by your barometer that you're under a HIGH, you expect fair weather or better.

And if you check the barometer and it reads LOW, you expect bad weather, clouds, and/or rain, because of the rising, cooling air mass.

BUT, don't depend on your barometer too much, because there are many situations that can arise that will "fool" it. The situations pictured below illustrate the definite need that there is to have upper level readings --- to send up radiosonde balloons in order to find out how high and how deep the HIGH or LOW is by checking the upper level atmosphere. Now, if the standard millibar reading at sea level reads 1013.25 m.b. pressure, then halfway up through the atmosphere the millibar reading would be about 500 m.b. . . . The weather service records pressure here and also at 300 m.b. and the 200 m.b. level in order to provide a better accuracy to their reports.

If cold compacted air is below, it weighs more and thus reads a high on the barometer --- BUT if there's a high level low on top of the high and a nice high mountain to help the warm air of the low rise quickly you're blessed with clouds and rain.

"Ah, the storm's passed. My barometer is beginning to rise." !!!
METEOROLOGY
Lecture 17

When emptying big bottles, spin the liquid therein causing a counterclockwise vortex before you begin to pour out the contents, and the air will come up inside the vortex and the liquid will flow evenly down the sides of the bottle. Thus you're using the Coriolis force and the vortex to help you.

WEATHER: The whole thing is basically a thermal energy transfer machine beginning with the sun producing the primary winds which change with the seasons in positions due to the tilt of the axis.

The Jet Streams: are geostrophic in nature. They are upper level winds without friction and therefore travel at high speeds -- eastward. They oscillate like a hose -- which splits in half sometimes. Jet Streams are usually located right above differing air masses --- where cold air meets warm air.

As the jet streams fluctuate north and south, so do storms fluctuate north and south ---but they do not determine storms. They are as much controlled by highs and lows as they apparently control highs and lows. There is not a cause and effect relationship here. BUT, when a jet stream is above a storm, it acts like a vacuum cleaner. When air comes into a low, the low eventually is going to fill up, the air will rise and cool by expansion, and if the filling is at a reasonably efficient rate, then you'd expect the low and resulting storm should last for a day or two then it would be time for the low to go up. . . Yet some storms start at the Gulf of Alaska and don't die till 5 or 7 days later over the Atlantic. What happens is that the jet stream sucks out the excess air "fill" so that the low continues on and on, thus the jet stream helps maintain the storm longer and make it stronger --- that is, if the jet stream is above the storm. And when a jet stream leaves a storm area, the storm is doomed to die within a very short time.

Jet Streams are affected by the high pressure areas just as they affect them --- a partnership interrelationship so to speak.
Storm tracts are basically caused by primary circulation and the seasons because primary circulation determines where the semi-permanent highs are located and the seasons just shift them around a bit --- which determines the ability of the storm to track in one direction or another. Primary winds which are influenced by the seasons and fired by the sun determine the ability of the movement of air that the storms track through.

Secondary Winds are winds that don't operate on the global scale but on a continental scale --- but before we can talk about these kinds of winds, we must know about specific heat.

C stands for specific heat, and specific heat is the ability of an object to warm up or cool off based on the stuff of which that object is made. You give some energy to something and it's going to warm up --- but some objects take longer to warm up than others --- and that's where the specific heat ratio comes in.

\[ C = \frac{\text{change of heat applied to object}}{\text{change of temperature of the object}} \]

Now if I give one calorie of heat to one gram of ______ it will raise its temperature by ______ degrees and the ratio of the first blank to the second blank in the above statement, is what's known as the specific heat ratio.

Now we'll state the same thing by means of equations:

\[ C_{H_2O} = \frac{\Delta H}{\Delta T} = \frac{1 \text{ cal/gm}}{1^\circ \text{ centigrade}} = 1 \]
\[ C_{\text{hydrogen}} = 3 \text{ so a lot of heat is needed here to raise the temp. of H and He.} \]
\[ C_{\text{silver}} = \frac{\Delta H}{\Delta T} = \frac{1 \text{ cal/gm}}{10^\circ \text{ centigrade}} = 0.1 \]
\[ C_{\text{helium}} = 2 \]
\[ C_{\text{dirt}} = \frac{\Delta H}{\Delta T} = \frac{1 \text{ cal/gm}}{5^\circ \text{ centigrade}} = 0.2 \]

Note that the lower the number of the specific heat, the quicker and hotter an object will become when a certain heat is applied to it.
So the specific heat ratio is an inverse relationship --- the higher the specific heat, the slower something heats up. *see footnote

\[
C = \frac{\Delta H}{\Delta T}
\]
given out or applied to something
degrees of the object

Now a sort of side track piece of information that touches on specific heat in that it shows what lack of knowledge of it can do to distort temperature data in an experiment.

The experiment dealt with temperature differences inside solar homes and outside solar homes and the greenhouse effect produced by a special type of solar panel. The experimenter had a normal glass thermometer which was backed by a brushed aluminum mounting, a model home about 6 or 7" high, and cellophane windows so that the hot air within the house could not escape. The house was put in the sunlight and the thermometer was put thru a slit in the roof. The outside air temperature in the shade was 74°F. The inside air temp. for the house with the bulb of the thermometer in the shade was 114°F (though much of the rest of it was exposed to the sun), and with the bulb of the thermometer exposed to the sun it read 124°F. . . An incredible difference due to this greenhouse effect wouldn't you say --- time to buy into solar furnaces! BUT was it the greenhouse effect that was really making the temperature go up so drastically? NO. Unfortunately our experimenter failed to take into account the specific heat of the glass of the thermometer and the aluminum backing adjacent to it and when he held it in view of the sun, the thermometer naturally read the temperature that the glass & aluminum was absorbing and conducting to it --- which was much greater than that temperature of the surrounding molecules of air. . . Dr. Balogh had a remedy for this situation however, by simply taking a sheet of aluminum foil and shading the outside of the thermometer with it while poking just the bulb inside the house and keeping it also in the shade therein, he came out with a more accurate reading of 86°F as the inside temperature.

Back to class. Up to now, we've had certain assumptions or certain reservations that we've kept in mind when we put together our schematic diagram of the global weather pattern. The first two reservations that the earth doesn't move nor go thru seasons have been removed, and now it's time to remove the third, that the earth is made of the same stuff

* Specific heat at constant volume is not the same as specific heat at constant pressure. \( C_p \) always exceeds \( C_v \) --- therefore you must ask if it's in an open container or a closed container. When something can expand & contract, it will take more heat & thus have a higher \( C \) to raise its temp. than if its volume were kept constant (\( C_v \)).
70% of the surface of the earth is covered with water.

The earth is composed of 70% water.

\[ C_{H_2O} = \frac{1}{1^\circ \text{centigrade}} \text{calorie/gram} \]

\[ C_{\text{dirt}} = \frac{1}{5^\circ \text{centigrade}} \text{calorie/gram} \]

Which says that dirt will warm up 5x faster than the same amount of water using the same amount of energy in both cases.

Therefore, if you wanted to store heat and you had the option of storing it in salt, rocks, or water, which would you choose?

Water is better than dirt or rocks because you would need 5x more rocks than you’d need water to affect the same heat storage ability. It’s not only a more efficient way by volume, but also more efficient because you wouldn’t have to raise the temperature of the water as high as you would that of the rock. You see, the rock has a lower specific heat and therefore heats up faster --- but because of the law of conservation of energy, that which heats up quickly, also loses its heat quickly. This is why you would expand the volume of rock so that each rock wouldn’t radiate out its heat to the air as fast but would radiate out to other rocks.

To insulate a wall you’d need about a thickness of about 4” of rock to get the same effect as 1” of wood. Why? Specific heat again.

Now let’s take a trip to the beach. It’s a nice hot day and our feet fairly burn while we walk down to the water on the sand --- but the water’s cold. Actually, here at Santa Cruz the temperature difference in the water between summertime and wintertime is between 7 & 100°F and changes less than a degree between night and day, whereas the temperature of the sand can vary as much as 60 or 70°F between night and day. Why. The specific heat variation between the two, and that convection transfers heat in the ocean, and in the ocean light can penetrate deeper (between 100-150 ft if the water is clear). On the ground only the top surface is warmed and there’s no solar penetration (light) below 4mm, and from there all heat transfer to below is done by conduction, the least efficient method of heat transfer.
At 6 feet below the surface of the ground, there is no change of temperature throughout the year, so at 6 feet below you can get the average temperature of that dirt throughout the whole year. At 3 feet below the surface of the ground there is no change of temperature between night and day, but there is a difference between the temperature read off in summer and that read in winter. At this 3 foot level, the warmest time that you can measure is during winter (January-February) in the northern hemisphere. This is due to the heat-transfer lag of the dirt.

By day, the sun warms the land at least 5x faster and radiates out this warmth correspondingly. Thus a thermal low is produced over the land relative to the sea and a relative high is produced over the ocean as compared to land.

By night, the land cools quickly and the ocean stays about the same, so a relative high is created over the land which fills the low created over the ocean on cold nights.

Secondary Winds are continental in size. A good example of a second order, or secondary wind, is our mid-latitude Extra-Tropical Cyclone which we Californians think of as simply a "storm".
**Extra-tropical means out of the tropics, and Cyclone is a low or counterclockwise circulation of air. These extra-tropical cyclones are characterized as secondary circulations because their size is huge, at times extending clear from the Great Lakes all the way to Houston.**

A monsoon is another example of a second order wind. Actually the word monsoon denotes a seasonal reversal of the winds — there being a wet monsoon, about which everybody hears, and a dry monsoon. What happens is this:

**Summertime in Mongolia is hot on the ground, causing a thermal low which pulls in air from over the ocean. Any air over the water for 3 days or more comes to thermal and hydrologic equilibrium — that is, it will come to the same temperature and evaporate all the moisture from the water it can. So the low causes an on shore wind of hot moist air. This air must flow over India’s high mountains, then due to orographic lifting, it goes up, cools by expansion, clouds form, then storm.**

This whole pattern reverses in the winter time, when the ground in Siberia gets cold (about -30 degrees) creating a high relative to the Arabian Sea causing off shore winds and the dry monsoon, as the air arrives cool & dry.
Once again, in the summertime there's a low created by the high temperatures in Mongolia pulling in air from the high which is over the Pacific. When this warm moist air starts to cross over Japan, it meets the mountains midway. The air rises orographically, cools, clouds, & rains on the eastern or windward half of the island.

When the reverse of this weather pattern occurs in winter and the northern lands become quite cold, the winds blow out of China & Manchuria across the warmer Sea of Japan until they encounter the high volcanic mountains of Japan where they are deflected upward and over the western side of the island dump their load.

Thus half of the year, the eastern side of Japan is the windward and stormy side, and the other half the western side of Japan is the windward and rainy side.

We have a similar condition here in the states. In the summertime, warm moist air comes up from the Gulf of Mexico, air that's a translation of the Bermuda High. It keeps to the southwest and crosses no big mountains all the way up past Houston and El Paso, heats up in the central states, and then meets the high mountains of the Sierra Nevada right around Yosemite and dumps its wet load on the east side of them.
WINDS ARE THE HORIZONTAL MOVEMENT OF AIR FROM A HIGH PRESSURE SYSTEM TO A LOW PRESSURE SYSTEM.

SEASONS WEAKENS THE SEMI-PERMANENT HIGHS.

THE WET TROPICS --- WHEN THE SUN'S AT ITS HIGH, IT RAINS MORE AND THUS IT'S THE WET SEASON IN THE TROPICS.

THE DRY TROPICS --- WHEN THE SUN'S AT ITS LOW ANGLE, IT'S THE DRY SEASON IN THE TROPICS.


REFERRING TO THE ASIATIC MONSOON, IN SUMMERTIME, THE WINDS BLOW ON SHORE FROM ALL DIRECTIONS TO FILL THE LOW IN MONGOLIA. . . MONSOONS DURING THEIR SUMMER, "RAINY" SEASON, DO NOT ALWAYS PRODUCE CONTINUOUS RAIN. SOMETIMES A COUPLE OF WEEKS ARE COMPLETELY CLEAR IN THE MIDDLE OF THE SEASON.

AFRICA, JAPAN, ASIA, THE PHILIPPINES, AND AUSTRALIA ARE SOME OF THE PLACES AFFECTED BY MONSOONS.
The only way the air can get moisture is through transpiration from plants and from evaporation from the oceans --- so if air sits over an ocean for any period of time, it will pick up all the moisture it can. Also, a thermal equilibrium will set up between them within 3 days.

An onshore flow from the Gulf of Mexico in the summer, brings thunderstorms to Arizona, New Mexico, and the eastern side of the Sierra Nevadas.

Tertiary or third order winds

1. The land-sea breeze is the most important wind on the coast of California. A daily reversal of the winds.

Land breezes are only about one tenth as strong as sea breezes.

A wind is named from whence it comes and so the above is a sea breeze because it blows from the sea.

The ocean is just a straight man with the land going through all the fluctuations of temperature.

Actually, the difference in pressure causes the wind, and the greatest difference in pressure would result from the greatest difference in temperature --- thus, the greatest land-sea breeze would result from the relative proximity of hot land and cold water. Deserts and hot valleys furnish the hot land, and cold ocean currents, the cold water. Evaporation from the ocean, the circulation in the oceans, and the specific heat of water are three significant factors keeping oceans cool.

The eastern side of land masses almost always have warm currents adjacent to them, and the western side almost always, a cold current.
This relationship has to do with the "Force of Coriolis". The cold current comes down from the poles, and while going to the equator, is deflected by the Coriolis force to the right (in the northern hemisphere) so runs into and along the western shores. The same logic applies to the warm currents coming from the equatorial region.

The strongest sea breeze on the globe is found in northwest Africa where, between hot deserts and a cold ocean current, winds blow to storm intensity — about 40 mph — and to a height of approx. 2,000 meters or over 6,000 feet inland.

Our Santa Cruz sea breeze is usually about 5 mph and our coastal sea breezes blow on the average of 8 mph.

What will the temperature of the water do to the sea breeze coming off the coast. The water's temperature regulates the breeze's temp. and furthermore, a thermal equilibrium will possibly be reached between the coast land and the water. Take, for instance, San Diego when the sea breeze is strong. The temperature of the city is 70°F when the temperature of the water is 70°F., especially on cloudy days. Here, right on the coast in Santa Cruz, if 55°F in water, 55°F on land or within a few degrees — unless an unusually hot day.

A warm inland region makes all the difference in the sea breeze. This region is the root of the thermal low which is the pulling power of our breeze. The Mojave desert is the hot spot for southern California, and the great central valley for northern California. The deserts of Washington and Oregon are elevated (higher in altitude) and so are not so hot, thus generating a weaker thermal low and therefore a weaker sea breeze. . . Incidentally, it seems that when you run out of hot valley (that is either the heat or the valley!) you run out of sea breeze.

Now let's look at Los Angeles's sea breeze. L.A. is a big, flat area, a broad basin. At about 8 a.m. the sea breeze starts (5-10 mph). 8:30-8:45 a.m. it arrives at Santa Monica College, about 18 blocks from the beach. Between 9 or 10 o'clock, it arrives in West L.A., about 7 miles from the beach. By noon, at Griffith Park, 12 miles
FROM THE BEACH, YOU'RE ABOVE THE INVERSION LAYER AND CAN SEE IT BLOWING ALL THE CRUD AHEAD OF IT. SOMETIMES YOU CAN SEE THE SHEAR LINES. BY 2 OR 3 P.M. IT'S PAST EAST L.A. AND ALL THE INDUSTRIAL PARKS AND IS BLOWING INTO THE WALNUT AND SAN GABRIEL VALLEYS WHERE ALL THE POLLUTION HAPPENS TO ACCUMULATE ON ITS WAY TO THE MOJAVE. AT THIS POINT IT MUST GO THROUGH THE SAN GREGORIO AND CAHON PASSES IN THE SAN JACINTO MOUNTAINS, WHERE, FOR THIS REASON, YOU'LL ALWAYS FIND IT WINDY.

SO, IF YOU'RE UNFORTUNATE ENOUGH TO HAVE TO LIVE IN THE L.A. AREA, WHERE WOULD YOU GO??-- AS NEAR THE BEACH AS YOUR POCKET BOOK CAN AFFORD. UNFORTUNATELY I GAVE THESE LECTURES AT UCLA, AFTER WHICH TIME MARINA DEL RAY WENT 35 STORIES UP, OLD VENICE WENT INTO NEW VENICE, AND THE PROPERTY VALUES AT CULVER CITY JUST AIN'T WHAT THEY USED TO BE.

THE COLDEST TIME OF THE YEAR IN SAN FRANCISCO IS SUMMERTIME DUE TO THE THERMAL LOW CREATED IN THE CENTRAL VALLEY. THIS THERMAL LOW IS TRYING TO SUCK AIR IN FROM ALL DIRECTIONS. THE TROUBLE IS THAT IT'S SURROUNDED BY MOUNTAINS --- BUT THERE'S A TREMENDOUS BREAK OR BREACH IN THE COASTAL MOUNTAIN RANGE --- RIGHT AT THE GOLDEN GATE --- AND THAT'S JUST WHERE SAN FRANCISCO IS LOCATED ON A NICE LOW FLAT PIECE OF LAND.

IF FRESNO, OR SOMEOTHER CITY LOCATED IN THE CENTRAL VALLEY, HAPPENS TO BE ABOUT 20° WARMER THAN THE TEMPERATURES FOUND ON THE COAST, YOU CAN FORECAST ON SHORE WINDS, OR A SEA BREEZE. AND AS SOON AS THE VALLEY COOLS OFF, YOU CAN FORECAST THE CESSATION OF THE SEA BREEZE.

THE TYPICAL SEA BREEZE SITUATION RUNS AS FOLLOWS:

**Day 1:** The Central Valley is just getting warm.

**Day 2:** The Central Valley is getting quite a bit warmer.

**Day 3:** In the C.V., it's getting downright hot and the sea breeze is just beginning.

**Day 4 & 5:** The valley's getting so hot that the winds are getting rather strong, reaching all the way to around Travis Air Force base.

**Day 5, 6, & 7:** The winds are now entering and cooling the valley.
Off the West Coast is a cold current known as the California Current. Both air and water temperatures are lowered by it several degrees. This thermal lowering of already saturated air makes a fog deck just off the coast, running all the way from Baja California to Washington state. Before the wind blows on shore across California, however, it runs into some upwelling, caused by approaching land. The upwelling produces a warming along the immediate coastal vicinities which evaporates the lowest 200 feet of fog, making the fog a cloud deck. As the day progresses, the sea breeze gets stronger and the top of the sea breeze pushes the clouds back off shore (about 2 or 3 P.M.) and the mountains don't allow the clouds to come in too far so they just wait there till they're burned off.
The Valley gets more heat than a plain, because it gets heat from early morning & evening sunlight on its mountains and also there's a focusing of energy by the mts. (sunlight gets bounced toward the center of the valley by the mountains).

Wind comes from the valley center to replace or fill up the low, thus THE VALLEY BREEZE.

The updraft or thermal blows up the side of the mountain or the side of a cliff. Hawks and eagles rise in the air by circling in them.

At Night, due to specific heat differences, the land cools faster than does the air, the cold air on the floor sinks & the air above it follows. When the cool air drains into the valley from the mountains, it's called a MOUNTAIN BREEZE.

Urban Heat Island LIKE PUTTING A DOME OF HEAT OVER THE AREA. GETS OWN HEAT; GETS OWN POLLUTION!
At bottoms of valleys are rivers, creeks, etc. The water therein is colder than both land & air & thus will cool air even more at night and pull it down faster resulting in a bigger colder wind.

Cold air drains downhill into the hole that's how you get frost pockets and fog pockets.

Check for sale signs: more along creeks than along higher lands because of cold air drainage.

Micrometeorology deals with the very small changes in local situations.

If your car has an old radiator with an overheating problem, wait to climb the mountains at night time when the cold wind is blowing downhill in the direction of your radiator.
Air rises up slope in the day and down the slope at night. Do not build a fire upslope or downslope of your tent or you will fumigate it. Build it the same approx. level as the tent but away from it. Have tent flaps facing down slope.

DESERTS

Hot air rises in a big bubble which pulls in air from all directions around it. Usually when the air that left in the bubble is replenished, the winds surrounding that small area cease. But in the meantime, some other place on the desert is getting quite hot and another bubble is forming. Thus do these bubbles give rise to "fitful winds". Within a half hour after sunset, convection will stop so the winds will stop. These "bubbles" occur in the central valley, the Salinas valley, over freshly plowed ground, and over bare ground as well as in deserts.

If the sun beats down so much at a local spot that it becomes very hot, the air will form a sort of current of continuous bubbles of low pressure whose nature is to rise and keep rising. But this flow of bubbles cannot rise in a vertical column of air because of the Coriolis force, so they spiral and rise, spiral and rise, spiral and rise, spinning from the bottom to the top, picking up local dust and debris. They are known as Dust Devils --- local penetrative convection. They are dependent on heat, albedo, and geography for their formation. The sides of canyons are good for dust devil formation.
Sometimes the surface of the ground is extremely cold just due to the nature of the ground, if, for instance, the ground happens to be a glacier or field of snow, and this will make the air sink. When the air sinks, there's heat produced due to compression, but the ice will absorb all the heat it can get, so the air will continue on its way down the ice field as a cold wind. This gravity induced wind, due to losing heat to the surface is called a Katabatic wind. Thus does a katabatic wind result from the environment greatly changing the temp. of the air.

In Greenland and Antartica, freezing Katabatic winds have been clocked at 100 mph.

In Yugoslavia, this wind is called the Bora wind.

Snow camping is becoming rather popular. If you decide to try it, don't camp on a steep and open slope, but camp in the trees at night.

**Compressional Heating Wind:** When air goes down, it warms by compression, and air goes from a high to a low in the friction layer, that is under 2000 feet and with the help of surface friction. Air in a valley can be 10° warmer due to compression than on the mountain from which it came, just due to the fact that the air is blowing down the mountain.

If I allow air to rise or sink and if air doesn't make a cloud up there in the process and if it doesn't mix with the heat or cold of the environment, then we can use the dry adiabatic lapse rate to find out how much the air will warm or cool from one point to another.

**The dry adiabatic lapse rate = 5.5°F per every 1000 feet**

= **1.0°C per 100 meters**

The word "adiabatic" means 'environmentally unaffected', 'environmentally isolated' --- that is, not affecting air temp. whereas "katabatic" means 'environmentally induced'.
The Santa Ana (or San Tana meaning 'devil wind') is an example of a compressional heating wind.

It originates from Salt Lake City, Utah, elevation 4000 feet msl and terminates off the coast of Los Angeles, elevation 000 - 50 feet msl. Naturally, the air will try to move from a high to a low elevation but it can't do it as easily at high elevation as down low by the ground. And it just so happens that the few mountains running in between the area separating Salt Lake from L.A. are oriented in the north-south direction with beautiful passes in between --- thus no orographic lifting and cooling takes place. Also, there are no lakes or large bodies of water for this flowing air to pass over on the way so it can't pick up water. Thus can we use our DRY ADIABATIC LAPSE RATE to find out how warm the air coming to L.A. will be.

\[
\text{Difference in elevation} = 4000 \text{ ft.} \\
\text{change of temp per 1000 ft} = 5.5^\circ F \\
\text{Temperature at Salt Lake} = 70^\circ F \\
5.5^\circ F \times 4 + 22^\circ F \\
22^\circ F \quad 92^\circ F \text{ at Los Angeles}
\]

But because of its dryness, it dries out plants real fast which creates a fire hazard for the area.

The Santa Ana actually isn't a big (wide) wind but a strong narrow one that affects only a small part of southern Cal., approximately 100 square miles only. Depending where the center of the low is off the coast determines where the air (or wind if you will) will finally strike the ground. If the Low shifts a little bit, it will change the balancing point where the winds are touching the ground before then can enter the Low. . . . The Santa Ana blows during fall, winter, and spring.

---PREICTION --- one day during Christmas vacation, Long Beach will record the highest temp. of the nation --- due to these Santa Ana winds.

Mono Winds are rare winds that blow from the deserts over the tops of the Sierras about every 5 or 10 years.

Avalanches occur in the Alps just about the time of the onset of the Föhn or Foehn. The FÖHN is a compressional heating wind that comes down the slopes of the high Alps.

The SOROCO Winds of North Africa come out of the Atlas Mts. and cook Italy and the French Rivera.
The CHINOOK is another example of a compressional heating wind that takes place east of the Rockies in the winter time. In a little town east of the Rockies, the bright temperature of a winter day happens to be about 30° below zero --- then suddenly a wind comes from the top of the mountains which is hot and dry and the temperature goes up to 50°F --- then after about 4 hours, the wind stops and all the melted water (which has seeped itself into the ground next to trees, telephone poles, houses etc.,) gets refrozen, expanding in the process, to produce all sorts of havoc.

The CANTABURY-NORWESTER in New Zealand's famous compressional heating wind.
WIND CHILL FACTOR

A short look at equations: F=MA and E=\frac{1}{2}MC^2 are theoretical equations, that is, derived from a theory that held, and as such they are simple and logical to the mind, providing you know what the symbols stand for.

An empirical equation is all together different from a theoretical equation. It is based on a collection of data, that is, after getting some data about something, you make up an equation to fit the data. Looking logically at this type of data usually tells the human mind nothing reasonable. You must work with it and put it into its 'original state' by plotting your points, etc. in order to be able to see what it's trying to tell you. For instance, the equation for wind chill factor is:

\[ H = (V_{1000} + 10.45 - V)(33 - T_a) \]

which tells you nothing, except to look at the graph & read on!

While you are here sitting in class you are generating a certain amount of heat and warming an envelope of air around your body, first by conduction and then by convection. But if you went outside on a windy day, this heat envelope would be displaced by the wind causing a net loss of heat to the body corresponding to the temperature difference between the air and the body --- and the faster the wind blows, the faster the heat loss --- to a limit --- dependent upon the temp. change of the air & body and upon how much heat the body can feel and generate.

In 1941, the first "Wind Chill" experiments were conducted by Simpall and Passel in the Antarctic and came up with an index of the cooling power of the wind there, which came to be known simply as Wind Chill. Their index was determined by using the freezing rate of water sealed in plastic containers. The only obvious problem here, relating their findings to a human situation, is that the body has a certain heat generating capacity that water in plastic does not.
In order to put the human factor into the "Wind Chill Factor", new and more modern experiments were carried out to arrive at a graph similar to that shown on the previous page. In the newer experiment, a person sits almost naked in a cold room, say about 30 degrees below zero Fahrenheit and is told to remember exactly how cold he feels, then the operator warms up the room and turns on the wind machine, while, little by little, he turns down the temperature. In the meantime, he tells the subject to tell him when it feels as cold as it did when it was -30°F. And when the poor subject tells him, he puts a dot on the graph which corresponds to the air temperature and the wind speed at that point in time.

Thus, currently, Wind Chill is subjectively determined in terms of the equivalent temperature in still air and is only to be considered on uncovered or exposed flesh. In other words, it is a subjectively determined index which combines the temperature and the wind speed and suggests what their combined effect will be in terms of still cold air on the unprotected human body.

Of course, in determining the relevance of the T.V. weatherman's announcement of the wind chill factor of Buffalo as being a 30 below equivalent, you should consider then how many Buffalo-ans will be running around the city with little or no clothes on to experience this equivalent.

Winds form the transportation network of the planet, transferring energy through the atmosphere from energy rich equatorial regions to energy deficient regions by the poles.

Water is clearly the most important single element involved in this heat transfer process. Actually, the whole story of weather is "Energy and water in the air" -- because it's water that is the energy carrying passenger on the transportation network of the winds.

Water: \[ \text{H}_2\text{O} = \text{H}^+ + \text{OH}^- \]

Hydrogen ion (H+) and hydroxide ion (OH-) are represented with a 105° angle, which is greater than the 90° angle but less than 180°.
Because of the sharing by oxygen of the two atoms of hydrogen, and because of the polarized nature of each atom relative to the other atoms, the molecules grow and hold themselves together.

The more negative side of the molecule is near the oxygen atom and the more positive side is near the hydrogen atoms. Actually this water molecule acts much like a bar magnet, and thus has been referred to by chemists and physicists alike as a dipolar molecule...

When the orientation is correct, the molecules will want to come together and stick together. This nature of water produces a certain affinity between molecules, therefore energy must be expended to separate them. In other words, a certain energy is required to break these dipolar bonds or dipolar attraction. And it takes more of this energy to get something from a liquid state into a gaseous state than it takes to get from a solid state into a liquid state. Thus, a liquid state is a higher energy state than the solid state of the same material and a gaseous state of the same thing is a much higher energy state than the former two.

A solid manifests itself in a framework of crystalline material which exhibits itself in a definite order. The solid becomes a liquid when you break enough of these bonds of attraction so that at any one time there is a sufficient number of bonds broken or unbonded that the thing 'slumps' or rather, is mobile. A gas has such a high energy state that each molecule has more energy in itself or each of its atoms than do any of the attractive forces possess --- thus is each molecule free to make perfectly elastic collisions (theoretically).

So gas occupies the shape of the container in which it is. Liquid does too, but it has an interface between itself and the gaseous media, usually on top of it... But a gas will just keep on spreading out if you increase the boundary dimensions --- it fills all space.
Water is the only material than can exist in all three states, vapor, liquid and ice, in the atmosphere or in nature at one time. An example of this, other than a snow storm, is a puddle of water with ice in it that's being evaporated by the sun.

The amount of water that the air is holding occupies between .001% to 6% by volume of the content of the atmosphere. Thus, it is either the third or fifth or sixth most prevalent gas in the atmosphere depending on where you're at.

Now then, returning to our dipolar bonds, to get these bonds to break, you must give the water molecule more energy than you would need to if it wasn't dipolar. Actually, you can't sense or feel this energy until it's required or released. It's said to be sleeping or latent in the molecule and is thus called latent heat or latent energy --- which simply means that it's there, but not apparent.

The amount of energy that it takes to change ice into water, to break the necessary bonds, depends both on the temperature of the molecules initially and the latent heat required to make the change of state, in this case, the temperature + 80 calories per gram (latent heat).

Ice (solid) → Water (liquid) → Vapor (gas)

@ 0°C = 80 cal/gm
@ 20°C = 586 cal/gm

It takes 100 calories to raise 1 gram of water 100°Celsius --- because the definition of a calorie states that a calorie is the amount of heat energy needed to raise 1 gm of H2O 1°C --- so you multiply that by 100 (degrees) & there you are!

Winter campers often forget that it takes almost twice as much energy to get warm water from ice or snow as it does to warm 0°C water from its liquid state, because for every gram of ice that melts they must put in 80 calories (latent heat) of energy before it will even begin to warm up.

Of course, you can also use this 80 calories for your benefit on a hot day. For instance, for every gram of ice that melts, you're taking 80 calories of heat energy from the outside world --- perhaps from a Pepsi, so it will cool the drink & you also without diluting the drink very fast.
When driving from Tucson to Los Angeles in 120° weather in my non-air-conditioned car, I (Mr. Balogh) used to stop at a Dairy Queen and get a Mr. Misty, made with mostly ice with syrup in it, the large size, and drink off all the liquid in it, put the cup down in the van for a while, drink off all the liquid again a little later, and in such fashion, nurse it all the way from Hialeah Bend to Yuma, some 2 to 3 hours drive... You drain off the liquid because the liquid is a better conductor than still air so that the ice doesn't melt so fast. The purpose here is to give you a freezing liquid drink as long as possible to cool the body on a hot day.

If you do not happen to have ice water handy to cool your body down on a hot day, worry not, your body has its own temperature regulating device: prespiration. Prespiration is simply organic water that's evaporating off of your body, and evaporation cools because for every gram of water evaporated at 20° Centigrade (normal room temp.), to get from a liquid phase to a vapor phase, water pulls 586 calories from the body and the air. Incidentally, the latent heat of vaporization (or evaporation) changes with temperature also, so if the air temp. happened to be that 120°F (50°C), the amount of latent heat required would be only about 556 calories and so the cooling effect to your body would be slightly less than on a cooler day.

On days like the above, 120°, watering down the roof or sides of buildings makes living a little more comfortable because as the water evaporates, it pulls 555 calories (per gram of water evaporated) of heat energy out of the woodwork, which thus cools down the building, sometimes as much as 30°.

What happens when your body gets too cold? You shiver. Your body is making you do mechanical work to generate heat to keep warm.

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<th>Required</th>
<th>Released</th>
<th>(*it = change state)</th>
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<td>you've got to get it in order to do it! *</td>
<td>it gives it up when its done it!</td>
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<tr>
<th>Latent Heat of Melting</th>
<th>Latent Heat of Fusion</th>
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<tr>
<td>@ 0°C = 80 cal/gm</td>
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<tr>
<th>Latent Heat of Vaporization</th>
<th>Latent Heat of Condensation</th>
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<tr>
<td>@ 20°C = 586 cal/gm</td>
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It's very important to note on the previous chart that the same amount is required to change the state from a lower energy phase to a higher energy phase as that which is given up or released when changing from a higher energy state to a lower energy state. Provided that the initial and final temperatures are the same and that we're working with the same amount of H$_2$O. . . . For instance, it takes 686 calories to get one gram of ice into the vapor state, from 0°C to 100°C, and 686 calories are given up when 1 gram of water vapor becomes one gram of ice.

But how does this idea of latent heat affect the energy transfer in the atmosphere?? To explain this, let me tell you a little story in which I shall play the part of a gram of water.

My home is in the tropics, in a very warm and comfortable ocean current. It's so beautiful here with the sun shining so brightly that I feel a little lazy, so, floating on the surface of the water, I fall asleep. As I lay there, I absorb 580 calories and wake up with a splitting headache --- I really am split because I've absorbed so much energy that I no longer am water. I've come apart at the seams and I now am a gas --- and since I'm a gas, I am able to see all the other molecules of gas in the atmosphere --- all kinds of nitrogen and oxygen and an occasional argon floating around, even a big C O$_2$ molecule once in awhile. But they keep on bumping me, pushing me --- it seems as if they're in a sort of a migration. "O.K! O.K! I'm going!"

'Humm, it's getting cooler.' Now we're over Schenectady, New York, and it's getting really rather cold. Down from the cold regions of the north, cold air is coming, and cold air is more dense so that the molecules around me are more closely packed together. . . ."If there's one thing I can't stand to be, it's to be crowded and it's getting pretty tight up here and I can't stand it!" So I release a lot of my energy and I become liquid. (You see, nitrogen, oxygen, argon and other gases found in the atmosphere cannot liquify under normal temperatures and pressures found in nature --- only water can.) "Yes, I'm the only one who can do it --- so I did and so now I'm a raindrop."
Now, I'm moving downward as a raindrop to the base of the cloud where it's really cold — so cold that I can't take it — so I release a little more of my energy, another 80 calories to be specific, and become a snowflake heading down to downtown Schenectady. ——Oh! I forgot to tell you about George! He's been following me all the way from the tropics, to the cloud, and then as a drop of rain — and now he too is a snowflake, but he's headed toward the park. . . But, back now to me, for I'm just now falling on Main Street and, Oh No! Here comes the mayor's car —— and is George ever howling with laughter —— oh — splat — mud! I've become almost the lowest form of water life —— slush.

But when the sun comes out, I feel a little bit better. I see George, but he's not laughing anymore, because he's in the park and he knows that he's not going to melt because he's pure as the driven snow! (What's the albedo of snow? 90% But what's the albedo of dirty old slush? Maybe only about 40% or so.) . . So I absorb the sun's energy more efficiently and pretty soon I absorb the 80 cal. I need to melt into water. ~See you George —— maybe next spring—~ cause here comes the next snow storm and he's going to get buried —— and me? Down I go into the drain, out this little creek and into a river, and from the Hudson River, I pick myself a nice cold current heading south, and never again will I fall asleep on the surface anymore.

END OF STORY

So what happened is that water evaporated at the tropics, carried as a gas and holding the latent heat of vaporization, condenses into a cloud over New York. At that time and at that point, about 580 calories of heat energy were released into the atmosphere over New York. . . The wind carried the water vapor but the change of state was the actual transfer of energy process. And when he turned to snow, he released another 80 calories, but he took that back when he melted— which is important, because when it rains or when it snows, the sun's energy is used to either melt or evaporate the snow or water before it does much to warm the air. That's why it feels so cold when the sun's out on a cold winter day.
Remember that the energy transfer is done during the change of state—
that's how the excess energy from the hot equatorial regions gets
transferred to the temperate and polar areas of the globe.

Actually, our story was over-simplified for reasons of clarity.
The average water molecule changes state about five times on its
way across the United States. It's carried and dropped; picked up,
carried and dropped, but generally migrates.

Have you ever heard the expression: 'It's too cold to snow'?
Just before it starts to snow, the air temperature goes up 2° or 3°
from the latent heat given out while making the change of state
from water to ice and this will warm the whole envelope of air all
the way from the clouds down to the thermometers on the ground.
And depending on how fast and how much that temperature rises, you
can tell how big the snow storm will be.
METEOROLOGY
Lecture 21

The story that I told you last lecture about latent heat and the transfer of energy was rather idealized, in as much as very few molecules make the whole circuit at once. Most start out in an ocean, however, and through evaporating and condensing, bounces from ocean to sky to river to sky to puddle to sky, etc. across the United States. It takes about 5 bounces on the average to get across the United States and more across Asia.

Even if the sun is shining in the winter, after a rain, it's so cool because all the energy is going to do something --- evaporate the water (especially from large flat puddles) --- before it begins to heat the air. Also, the sun is lower in the sky and is going through more atmosphere. And finally, if you're living in the snow, there's a high albedo surrounding you which is reflecting a great deal of the sun's heat energy away. Of course, it would help a great deal to wear dark clothing and be directly in the sunlight at this time, for then you would absorb as much energy as possible yourself.

Latent Heat is not sensible to you until a change of state actually occurs, and then, and only then, does it manifest itself to you. Once again, the reason it doesn't warm up after a rain is that all the sun's energy is going to evaporate the water instead of heat the air --- so you can tell that something's going on --- by the fact that the sun isn't warming you as you'd expect --- that's when Latent Heat makes itself apparent to you. Conversely, if the air warms up for no apparent reason, the sun may not even be out, then you know that a great deal of water vapor is condensing in your immediate area and that its latent heat went to warm the air.

So then, heat is going into a change of state in the tropics, and being released in the north when it goes through another change of state. And the mechanism that operates this great machine is water vapor. The sun deposits energy in water molecules which is carried by them as latent heat in the south to later become sensible heat in the north when they release it.

Water is the only thing in our environment that can express itself in all three changes of state or phases naturally.
MEASURES OF WATER VAPOR CONCENTRATION
(no standard notation has been adopted)

1. **Vapor pressure**, $e$ (mb): pressure exerted by water vapor.
   actual vapor pressure, $e_a$: pressure of vapor actually present.
   saturation vapor pressure, $e_s$: pressure of vapor in equilibrium with
   a plane water surface, both at the same temperature, $t_d$

2. **Saturation deficit**: $e_s - e_a$.

3. **Relative humidity**, $U$: (Z): $100 \frac{e_a}{e_s}$, where $e$ applies at the actual temperature $t_a$.

4. **Absolute humidity**, vapor concentration, or vapor density, $w$ or $q$ (g/m³): mass of
   water vapor in unit volume. Actual vapor density, $w_a$ or $q_{wa}$, corresponds to
   actual vapor pressure, saturation vapor density, $w_s$ or $q_{ws}$, to saturation
   vapor pressure.

5. **Specific humidity**, $q$ (Zo or g/kg): ratio of mass of water vapor in a unit volume
   to the total mass of all gases in the volume.

6. **Mixing ratio**, $r$ (Zo or g/kg): ratio of mass of water vapor in a unit volume to
   the total mass of all other gases in the volume, $r = w/q$.

7. **Dewpoint**, $t_d$ (C or F): temperature at which saturation vapor pressure would
   equal existing vapor pressure ($e_a = e_s$), or at which $w_a = w_s$.

8. **Virtual temperature**, $t_v$ (C or F): temperature at which dry air would have the
   same density, at the same pressure, as the existing moist air.

9. **Wetbulb temperature**, $t_w$ (C or F): lowest temperature to which a free water surface
   can be cooled by evaporation into existing moist air.

10. **Precipitable water**, $W$ (cm or inch): total amount of water vapor in a column of
    air if completely condensed into liquid.

    $$e = \frac{r_p}{r + 0.622} \quad \text{or} \quad r = \frac{0.622 e}{p - e}$$

    $$(p = \text{total pressure, mb})$$

    $$w = \frac{\dot{e} v}{R_w T_w}$$

    $$(R_w = \text{gas constant for water vapor, } 4.6150 \times 10^6)$$

    $$(T_w = \text{absolute temperature (K) of water vapor})$$
Short Table of \( e \), the saturation vapor pressure (mb) over water.

(Smithsonian Meteorological Tables, 6th ed., pp. 351-353)

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<th>°C</th>
<th>0</th>
<th>1</th>
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Short table of \( w \) or ev, the absolute humidity, vapor concentration, or density of saturated water vapor, in grams per cubic meter.

(Smithsonian Meteorological Tables, 6th ed., pp. 382-383.)

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RELATIVE HUMIDITY: THE AMOUNT OF WATER VAPOR PRESENT IN THE AIR CHANGES WITH THE AVAILABILITY OF MOISTURE IN THE AIR AND THE TEMPERATURE.

The two limiting factors that determine the amount of moisture in the air are:

1. The availability of the moisture --- that is, if it's not there, you can't get it! How can you get water or moisture for the air? Evaporate it from oceans, lakes, rivers, reservoirs, etc., from the transpiration of trees and plants, and from volcanic gases... but if there is no source of moisture for the air in the vicinity, it cannot get it.

2. The upper limiting factor is temperature --- that is, the amount of moisture the air is capable of holding is determined by the temp. of the air. When the temperature of the air becomes lower, the air increases in density, and if it becomes too crowded, some of the water molecules condense. When this condensation begins to take place, the air is full of all the moisture it can take and it's said to be saturated. This point is said to be the dew point temperature and also the temperature of 100% humidity. Logically, you cannot evaporate moisture into air which is holding all the moisture it can --- it's saturated, like the sponge in the kitchen sink when it's full.

But air will evaporate moisture at a specific rate depending on how much moisture it already has in it --- that is it will evaporate moisture less efficiently if it's already carrying a load. Specifically, air that's 80% humid will not evaporate moisture as fast as air that's 7% humid because that air that's 7% humid is
Dying to get some water. A sling psychrometer is used to measure this rate. Two thermometers are used concurrently in the psychrometer, a normal mercury thermometer, and another identical one with a piece of wet muslin wrapped securely around its bulb. When wind hits upon the wet bulb, moisture from the bulb wants to evaporate into the air at a rate corresponding to the humidity of the air at that time and temperature. This rate of evaporation can be detected by registration of the amount of latent heat energy which is being pulled out of the air and the thermometer --- latent heat which is necessary in the evaporation process---lowering the temperature of the wet bulb thermometer. But, be aware that the wet bulb reading is not the dew point temperature. You must use tables or graphs or calculators to get the dew point temperature or relative humidity. The second principle behind the sling psychrometer (the first being the use of the 580 calories of latent heat needed for evaporation) is that dry air cools the wet bulb faster and more than moist air at the same temperature.

When air is completely saturated, it is said to have reached the dew point temperature.

Vapor pressure: Air pressure is the weight of air over your head.

Dalton’s law of partial pressures says:

The total pressure of the gases of the air equals the sum of the partial pressures of all the gases that make up the air.

Actual vapor pressure, written as $E_A$, is that part of the total air pressure exerted by the water vapor that’s in the air.

Saturated vapor pressure, $E_S$, is the total amount of vapor pressure that’s possible for the air to exert --- or another way of looking at it, the total amount of moisture that the air can hold by weight. Both of these definitions are temperature dependent.
Absolute Humidity refers to the density of the vapor — for example, in grams per cubic meter — it's the weight of the vapor — it tells you how much you've got specifically. Absolute humidity will be emphasized in this class.

Of the two tables handed out concerning absolute humidity, the one dealing in terms of the weights of the vapor pressure (gms/m³) will be used in preference to the saturated vapor pressure (mb). Both work equally well, however, but most people are more comfortable thinking in weights per volume than in pressures.

A SHOWER of meteorological thoughts: What happens when you take a shower? When the shower is first turned on, the heat from the water raises the temperature of the air in the room which increases the rate of evaporation of water off of your body, and until you really warm the air, this evaporation will cool your body down. Once you get the shower stall hot, however, then that warm, moist, saturated air goes to the rest of the bathroom whose air is relatively cold and where there are cold environmental surfaces like mirrors which have a low specific heat. There, the air will be cooled below the dew point and then water will begin to condense on the mirror, the ceiling, the walls, etc. — actually, you've made convection fog — steam. This is a prime example of saturation in your lives.

One can make an interesting analogy between what happens in the bathroom during a shower and what happens on the global scene with regards to the transference of energy and resulting weather. The shower stall we shall consider equivalent to equatorial latitudes. In the shower, hot moist air transfers heat and condensation occurs within a few feet on the other side of the bathroom — with the equator, however, the warm moist air from the oceans must travel miles, however, to fog, rain, or in some other way condense in the North. The mirror and wall, across the bathroom, are like Schenectady, New York. The coolness you felt at first is the equivalent of evaporation and the recondensation later warms
THE BATHROOM UP DUE TO LATENT HEAT GIVING ITSELF UP. SO, WITHIN LIMITS, YOU CAN SEE THE ANALOGY BETWEEN THE EARTH'S ATMOSPHERIC SYSTEM AND THE SHOWER --- BUT NORMALLY ON EARTH, IT'S THE COOLING OF THE AIR BELOW THE DEW POINT THAT IS SIGNIFICANT, NOT THE INJECTING OF A LOT OF WARM MOIST AIR AS IN THE BATHROOM. OF COURSE, THIS DOES HAPPEN AS MOISTURE IS INJECTED INTO THE AIR AT THE TROPICS, AS PER OUR STORY.

RELATIVE HUMIDITY

THE FORMULA FOR RELATIVE HUMIDITY IS IN ENGLISH SIMPLY "HOW MUCH MOISTURE YOU'VE GOT" DIVIDED BY "HOW MUCH IT CAN HOLD AT THAT TEMP.," PUT INTO PERCENT:  

\[ R.H. = \frac{\text{how much moisture you've got}}{\text{how much moisture it can hold at that temp.}} \times 100 \]

OR WRITTEN IN MATHEMATICAL SHORT HAND:  

\[ U = R.H. = \frac{E_a}{E_s} \times 100 \]

WHERE \( U \) STANDS FOR RELATIVE HUMIDITY  
\( E_a \) FOR ACTUAL MOISTURE IN THE AIR  
AND \( E_s \) FOR SATURATED VAPOR PRESSURE OR HOW MUCH IT CAN HOLD AT THAT TEMPERATURE.

NORMALLY THE FRACTION \( \frac{E_a}{E_s} \) WILL BE LESS THAN 1.00

AND REMEMBER THAT RELATIVE HUMIDITY IS TEMPERATURE DEPENDENT BECAUSE \( E_s \) IS ALWAYS BASED ON THE AMOUNT OF MOISTURE THE AIR IS CAPABLE OF HOLDING AT A SPECIFIC TEMPERATURE.

BECAUSE \( E_s \) IS BASED ON TEMPERATURE AND BECAUSE IT HOLDS THE POSITION IT DOES IN THE RELATIVE HUMIDITY EQUATION AS THE DENOMINATOR OF A FRACTION, SOMEONE WHO HAS DEVELOPED A FEELING FOR EQUATIONS COULD SEE THAT WHEN THE TEMPERATURE GOES UP, THE RELATIVE HUMIDITY GOES DOWN (UNLESS YOU ADD MORE MOISTURE TO THE AIR IN THE MEANTIME).

SO, IF NO MORE MOISTURE HAS BEEN ADDED TO THE AIR, THE TEMP. WHERE IT WAS LAST SATURATED (WHICH DIRECTS YOU TO THE PLACE TO LOOK AT ON THE CHART) WILL DETERMINE THE PERCENT OF HOW MUCH MOISTURE IT HAS IN IT RIGHT NOW (ACCORDING TO THE PLACE ON THE CHART DETERMINED BY THE CURRENT TEMP.).
So now let’s play a little bit with the chart and the equation with a couple of problems.

1. If the air is holding 10 grams of water vapor per cubic meter but is capable of holding 20 grams per cubic meter, what is the relative humidity?

\[ \text{R.H.} = \frac{E_a}{E_s} \times 100 = \frac{\text{air is holding}}{\text{air could hold}} \times 100 = \frac{10 \text{ gm/m}^3}{20 \text{ gm/m}^3} \times 100 = 50\% \]

Please note that there are no units to worry about in the answer because they cancel each other out.

2. If the air is holding 10 grams of water vapor per cubic meter and the temperature is 20°C (68°F), what is the relative humidity?

The solution to this problem is exactly the same as that of the previous one with one extra step involved. First of all, you’re given \( E_a \) as 10 gm/m³ but you’re only given a temperature for \( E_s \). Thus you must look at the chart and at that temperature of 20°C you will find the number 17.30. This is your \( E_s \) in grams per cubic meter. Hence:

\[ \text{R.H.} = \frac{E_a}{E_s} \times 100 = \frac{\text{air is holding}}{\text{air could hold}} \times 100 = \frac{10 \text{ gm/m}^3}{17.3 \text{ gm/m}^3} \approx 58\% \]

3. Referring to the chart, we see that to hold 20 grams/m³ of moisture, the air needs to be at a temperature of about 22°C or about 73°F. If the air is holding 10 grams/m³ of moisture, to what temperature do I need to lower the air to get to the dew point?

This problem simply requires you to look at the chart in the reverse way that you did before, when you had the temp. and wanted the density --- for now you have the density and want the temperature. It also is dependent on your knowledge that the dew point temperature = the temperature of condensation which equals the saturation temperature, or \( E_s \).

To hold 10 grams of moisture, you need a temperature of 11°C or 52°F. If the temperature of the air is currently 22°C (73°F) we would have to lower the temperature 11°C or 21°F to reach the dew point. . .Who cares about the dew point temperature you say —— Farmers for one, who want to know when to cover their crops, especially if the temperatures and dew points are around freezing which would mean frost and a possible financial loss.
Pilots are also interested in dew point temperatures because fog usually occurs at the dew point temperatures and carburator icing can also manifest itself in the engine and these can be avoided with a little foreknowledge and flight planning by skirting an airport with an outside air temp. That is within a couple of degrees of the dew point temperature. Also, knowledgeable drivers can avoid the dangers of driving in toulie fog by checking the proximity of the actual temp. and the dew point temperature and then either stopping for the night or pushing on rapidly.

From the above discussion, we’ve deduced that fog occurs at dew point temperatures --- that is in saturated air --- and saturated air has a relative humidity of 100%. Therefore, if you happen to know what the temperature was when it was foggy, then you can figure out how much moisture the air is holding at a later time and probably higher temperature.

4. Fog has covered the morning sky at Santa Cruz and the temperature is a wet 54°F. By noon, however, the sky is clear and the temp. is a lovely 70°F. What is the dew point temperature and the relative humidity at noon?

The first thing you must do to solve the problem, is to remember that fog occurs at the dew point temperature which is also the saturated air temp. $E_s$ on the chart... Then, to solve the relative humidity, step one would be to change the fahrenheit temperatures to celsius temperatures by using the lowest chart entitled Fahrenheit scale to centigrade. After converting 54°F to 12°C and 70°F to 21°C, we get our corresponding data from our $E_s$ chart and plug it into our relative humidity equation.

$$\text{R.H.} = \frac{E_a}{E_s} \times 100 = \frac{\text{air is holding}}{\text{air can hold at certain temp.}} \times 100 = \frac{10.66 \text{ gm/m}^3}{17.0 \text{ gm/m}^3} \times 100 = 61\%$$

And the dew point temperature is still at noon time what it was earlier in the morning---54°F.

Sometimes these relative humidity percentages can be confusing if you don’t consider well the temperatures they were based on---For instance, consider a typical day at Tuscon Arizona. You wake up to the radio announcer saying: The temperature is 28°F today and the relative humidity is 85%. Then around 1:00 p.m. while
YOU'RE OUTSIDE SWEATING THROUGH YOUR LUNCH BREAK AND WAITING TO GET BACK INTO YOUR AIR CONDITIONED BUILDING CAUSE IT FEELS LIKE SOMEWHERE BETWEEN 85 AND 100 DEGREES OUT, YOU HEAR THAT THE RELATIVE HUMIDITY IS NOW ONLY 6%. Actually, the air is holding the same amount of moisture as it did this morning, but the difference in temperature is what's making the change in the relative humidity percentages reported.

RELATIVE HUMIDITY TELLS YOU HOW CLOSE THE AIR IS IN PERCENTAGES TO BEING SATURATED AT SPECIFIC TEMPERATURES AND WHENEVER AN ENVIRONMENTAL SURFACE DROP BELOW AIR SATURATION TEMPERATURE, IT FORMS DEW ON IT.

A SURFACE WITH A LOW SPECIFIC HEAT CONDENSES WATER OUT ON IT FIRST--- FOR INSTANCE, ON GLASS, MIRRORS, AND METAL BEFORE GRASS, WOOD OR CONCRETE.

DEW DOES NOT FALL --- IT IS PRODUCED DIRECTLY ON THE SURFACE WHERE IT IS LOCATED --- IT IS DIRECT CONDENSATION.

ABSOLUTE HUMIDITY = HOW MUCH MOISTURE YOU'VE GOT = \( E_a \)

RELATIVE HUMIDITY = \( \frac{E_a}{E_s} \) IN PERCENTAGES.

Remember that the temperature should always be told in conjunction with relative humidity.

With this information, you can compute the absolute humidity and then further compute the dew point. For example:

5. THE RELATIVE HUMIDITY IS CURRENTLY 50% WITH THE TEMPERATURE AT 72°C.

WHAT IS THE DEW POINT TEMPERATURE?

\[ \text{R.H.} = 50\% = \frac{E_a}{E_s} \times 100 \quad \text{The Temp} = 72^\circ F = 22^\circ C \]

AT 22°C, THE TABLE OF THE DENSITY OF SATURATED VAPOR PRESSURE \( (E_s) \) READS 19.43 GM/M³ --- WHICH BECOMES OUR \( E_s \). SO NOW WE HAVE:

\[ \frac{E_a}{19.43 \text{ GM/M}^3} \times 100 = 50\% \quad \text{GETTING RID OF:} \quad \frac{E_a}{19.43 \text{ GM/M}^3} = .50 \]
MULTIPLYING OUT, THE EQUATION BECOMES: 
\[ 0.50 \times 19.43 \text{ gm/m}^3 = E_a \]
so \( E_a = 9.72 \text{ gm/m}^3 \) ...

NOW BECAUSE THE DEW POINT TEMPERATURE EQUALS THE SATURATED AIR TEMP.,
you simply let the current \( E_a = E_s \) AND YOU'VE GOT THE \( T_d \) OR THE
DEW POINT TEMPERATURE BY REFERRING TO THE CHART.

WITH 9.72 GM/M\(^3\), THE \( T_d \) IS A LITTLE MORE THAN 10\(^\circ\)C OR 51\(^\circ\)F.

6. THE AIR WAS LAST SATURATED OVER THE COAST RANGE AT A TEMPERATURE
OF 65\(^\circ\)F. THE TEMPERATURE AT THAT TIME WAS 75\(^\circ\) IN SAN JOSE. WHAT
WAS THE RELATIVE HUMIDITY THERE THEN?

\[ \text{R.H.} = \frac{E_a}{E_s} \times 100 \]

\[ 65\(^\circ\)F = 18.3\(^\circ\)C \]
\[ 75\(^\circ\)F = 23.9\(^\circ\)C \]

\[ \text{R.H.} = \frac{9.4 \text{ gm/m}^3}{15.5 \text{ gm/m}^3} \times 100 = 70\% \]

7. THE AIR IS HOLDING 9.4 GM/M\(^3\) OF WATER VAPOR
AND THE TEMPERATURE IS 20\(^\circ\) CENTIGRADE. WHAT IS THE RELATIVE HUMIDITY?

Looking at the chart, corresponding to 20\(^\circ\)C, you find an \( E_s \) of 17.3 GM/M\(^3\).
You've already been given an \( E_a \) of 9.4 GM/M\(^3\) --- so you just put these quantities
into your equation: \[ \text{R.H.} = \frac{9.4 \text{ gm/m}^3}{17.3 \text{ gm/m}^3} \times 100 = 54\% \]

Now, let's say we have 20\(^\circ\)C SATURATED AIR WHICH IS COOLED TO 10\(^\circ\)C.
WHAT WILL HAPPEN? AT 20\(^\circ\)C THE AIR CAN HOLD 17.3 GM/M\(^3\) OF MOISTURE;
AT 10\(^\circ\)C THE AIR CAN ONLY HOLD 9.4 GRAMS/METER\(^3\) --- SO
THE AIR WILL GET RID OF ALMOST 8 GRAMS/METER\(^3\) OR
MOISTURE IN A CLOUD OR AS RAIN. ALSO, IF 8 GM/M\(^3\)
ARE CONDENSED, THERE WILL BE A LATENT HEAT OF
8 \times 580 CAL PER CUBIC METER TO WARM THE AIR.
8. Refer back to the bottom of page 6 of this lecture where it states that sometimes relative humidity percentages can be confusing and let's see just how hot the temperature at 1:00 p.m. had to be to bring down the relative humidity ratio to only 6%.

Given: the morning temperature of 28°F and a corresponding relative humidity of 85%, we proceed as follows:

28°F = -2.2°C

-2.2°C is capable of holding 4.2 grams of water per meter³ but it is only holding 85% of this or \[
\frac{4.2 \times 0.85}{E_s} = \frac{E_a}{3.57 \text{ grams/m}^3}
\]

Thus our \( E_a \) or actual humidity is 3.57 grams/cubic meter.

If this 3.57gm/m³ is only 6% of the amount of water vapor that the air can hold at 1:00 p.m., then we find out that the \( E_s \) is:

\[
R.H. = 6\% = \frac{E_a}{E_s} \times 100\%
\]

\[
\frac{0.06}{E_s} = \frac{3.57 \text{ gm/m}^3}{E_s}
\]

\[
E_s = \frac{3.57 \text{ gm/m}^3}{0.06} = 58.3 \text{ gm/m}^3
\]

Therefore referring to the chart, we see a corresponding temperature of 42°F C which equals approximately 108°F.

Most likely the reason that our friend judged the temperature to be lower than it actually was, was because he cooled himself off at lunch with a Mr. Misty!