

Weather and Climate
Jim Keller & Paul Belanger

Classroom assistant: Fritz Ihrig


Week 3: January 29TH , 2019

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Announcements

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 **Week 3: January 29TH, 2019**

 Lecture Chapters
 About the Professor

Meteorology: An Introduction to the Wonders of the...

LECTURE 7 An Introduction to Atmospheric Moisture

LECTURE 8 Bringing Air to Saturation

LECTURE 9 Clouds, Stability, and Buoyancy, Part 1

LECTURE 10 Clouds, Stability, and Buoyancy, Part 2

LECTURE 11 Whence and Whither the Wind, Part 1

LECTURE 12 Whence and Whither the Wind, Part 2

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White Board Definitions:

Lecture 7 & 8:

- Chinook
- Diabatic
- Isobaric = equal pressure
- Latent heat: Fusion/Freezing/melting- 80calories per gram; Evaporation/Condensing/boiling – 540 calories/gm
- Wet bulb temp -air is cooled by evaporating H2O. Cooling towers take 100F water and 100F air and evaporate the water cooling both the air and the water, to, say, 80F for a 5F approach to a dew point of 75F
- <https://www.fossilconsulting.com/2018/06/04/cooling-tower-factors/>
- Wet Bulb T
- Dry Bulb T
- Dew point T

Lecture 9

- Lapse Rates - changes of temperature with height
- DALR = Dry adiabatic lapse rate
- ELR = environmental (troposphere) lapse rate
- MALR = moist adiabatic lapse rate
- Prefixes
- Strato – low
- Alto – middle
- Cirro - high
- Suffixes
- Cumulus
- Stratus
- Nimbo - contains rain
- Wind Shear later

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First look at role of Moisture

Lecture 7

An Introduction to Atmospheric Moisture

- Static electricity
- Grams H₂O per Kilogram of Air (g/kg)


The ability of air to hold water is a very strong function of temperature.

vapor capacity (VC)
vapor supply (VS)
mixing ratio

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relative humidity (RH): ratio of vapor supply to capacity

Vapor Capacity (VC)
Vapor Pressure (VP)
Vapor Supply (VS)
Relative Humidity (RH)



vapor supply (VS)
10 grams of water vapor per kilogram of dry air – 10g/kg

vapor capacity (VC)	relative humidity (RH)
10 g/kg	100%
20 g/kg	50%
30 g/kg	33%

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Water vapor

The amount of water vapor
that the atmosphere can hold
DOUBLES FOR EVERY 10°C

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Table 1 Specific humidity of a kilogram of air (at average sea level pressure)

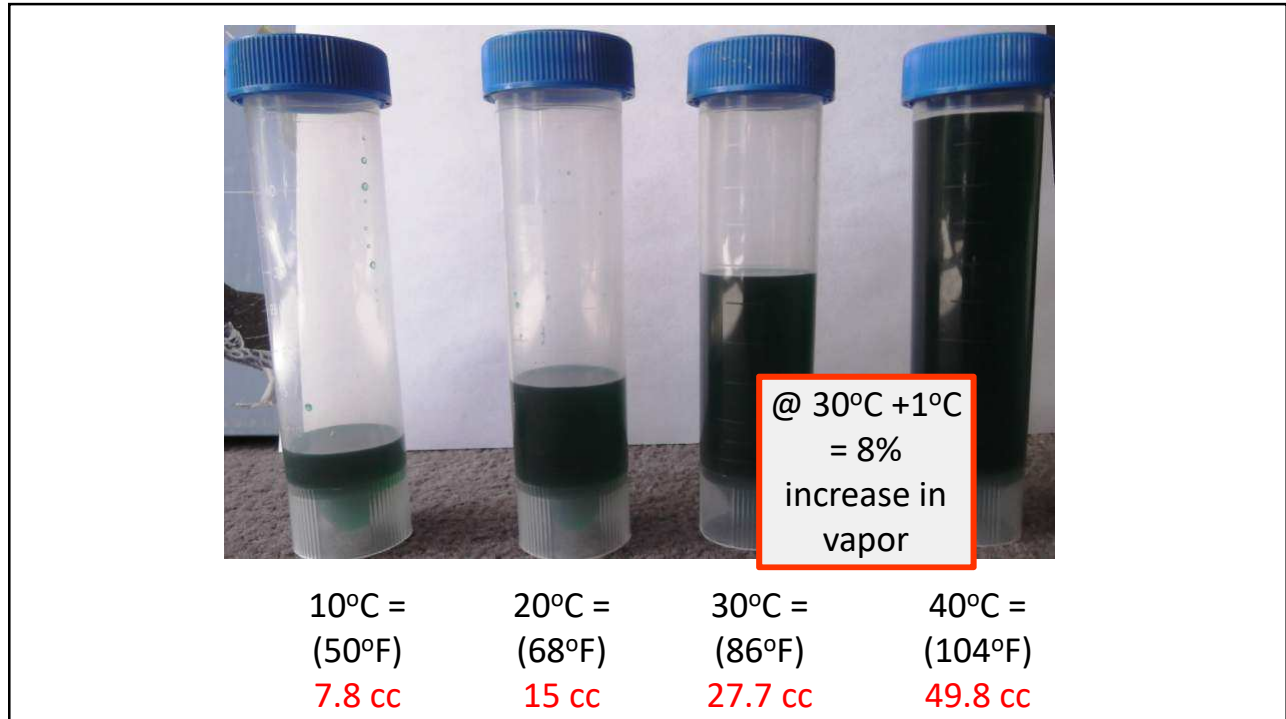
Temp. (°C)	Temp. (°F)	Grams of water vapor per kg of air (g/kg)
-40	-40	0.1
-35	-31	0.2
-30	-22	0.3
-25	-13	0.51
-20	-4	0.75
-10	14	1.8
0	32	3.8
5	41	5
10	50	7.8
15	59	10
20	68	15
25	77	20
30	86	27.7
35	95	35
40	104	49.8

What is the volume of 1 kg of air?

Answer: 0.844 m³

(94.5 cm x 94.5 cm x 94.5 cm)

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The CO₂ greenhouse gas effect is concentrated in the polar regions !!!



The large H₂O greenhouse effect is controlled by temperature – H₂O saturation doubles with every 10°C increase. CO₂ and other greenhouse gases are evenly distributed throughout the atmosphere. As a result it is concentrated in the lower atmosphere of the tropics.

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Water Vapor Capacity -Roughly doubling per 10 degrees C (18 degrees F)	Celsius	Fahrenheit	Vapor Capacity
	• 1 kg air ~ .84 cubic meter at sea level	-20° C	-4° F
• Vapor supply is low at cold temperatures	-10° C	14° F	2 g/kg
	0° C	32° F	4 g/kg
	10° C	50° F	8 g/kg
	20° C	68° F	15 g/kg
	30° C	86° F	28 g/kg
	40° C	104° F	50 g/kg

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Water Vapor Capacity (VC)

- Minnesota 14° F VC 2g/kg – 100% 2/kg
- Death valley 104° F, VC = 50g/kg
 - @5%RH - 2.5 g/kg VS

Vapor Capacity (VC)
 Vapor Pressure (VP)
 Vapor Supply (VS)
 Relative Humidity (%RH)
 = VS/VC

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Dry adiabatic vs wet adiabatic

- Electric shock <20% RH
- Humidify the air to avoid
- Wet adiabatic is $\sim 5^\circ \text{C/km}$
- Dry adiabatic is $\sim 10^\circ \text{C/km}$

50°F VC = 8g/kg	110°F VC \approx 50g/kg
VS = 8g/kg	VS = 8g/kg
RH = 100%	RH \approx 16%



$T = 14^\circ \text{F}$
 $\text{RH} = 100\%$
 $\text{VS} = 2 \text{ g/kg}$
 $\text{VC} = 2 \text{ g/kg}$
 indoor $T: 68^\circ \text{F}$
 $\text{VS} = 2 \text{ g/kg}$
 $\text{VC} = 15 \text{ g/kg}$
 $\text{RH} = 2/15 \approx 13\%$

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Diabatic – change temperature by heating or cooling instead of adiabatic pressure change

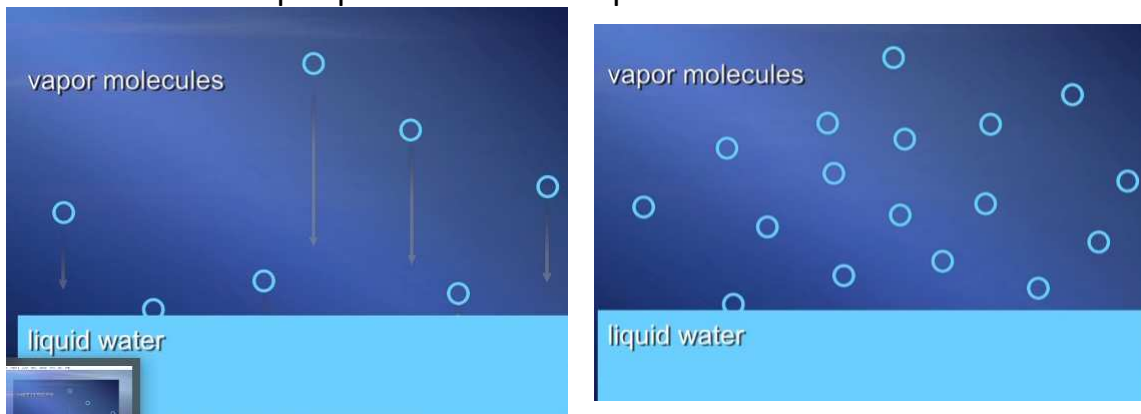
- Air has less capacity for water vapor at lower temperatures

We can increase relative humidity by lowering the temperature.

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Water: vapor, liquid, solid

- Vapor pressure (VP)
- Increase in vapor pressure with temperature



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Evaporation vs condensation

- Saturation – $VS = VC$
- Subsaturation = VS less than VC
- Supersaturation = $VS > VC$
- As temperature rises more VP needed to make $VS = VC$

Vapor Capacity (VC)

Vapor Pressure (VP)

Vapor Supply (VS)

Relative Humidity (RH)

The ability of air to hold water vapor is really the ability of vapor to avoid condensing.

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Condensation

- Water vapor needs a surface to condense on
- Condensation nuclei
- Better surfaces - hygroscopic nuclei
 - Salt one of the best
 - As low as 75% RH
- Hydrophobic nuclei - Oil, Teflon, wax

collision coalescence process
warm rain process

homogeneous nucleation
spontaneous freezing

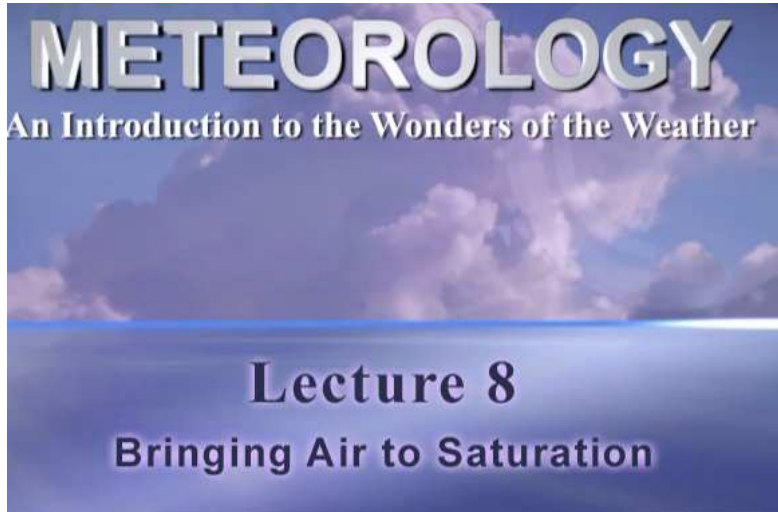
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Ice nuclei

- Ice nuclei not as common as one would expect
- Often have supercooled liquid in clouds
- Bonds of solid (ice) stronger than liquid water and even more so than water vapor

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Lecture 8



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Bringing air to saturation

- Force air to rise
- Expanding air cools
- Lift it to point where condensation will occur

- Dew point temperature

Vapor Capacity (VC)

Vapor Pressure (VP)

Vapor Supply (VS)

Relative Humidity (RH)

dew point temperature
wet bulb temperature
dry bulb temperature

$T = 20^{\circ}\text{C} = 68^{\circ}\text{F}$
 $\text{VC} = 28 \text{ g/kg}$

$T = 10^{\circ}\text{C} = 50^{\circ}\text{F}$
 $\text{VC} = 15 \text{ g/kg}$

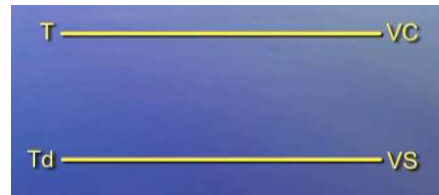
Dew point (T_d)
tells us the air's
vapor supply.

if $\text{VS} = 15 \text{ g/kg}$
then $T_d = 10^{\circ}\text{C}$

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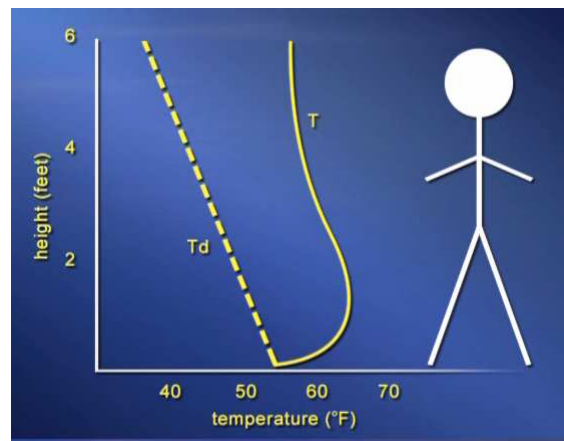
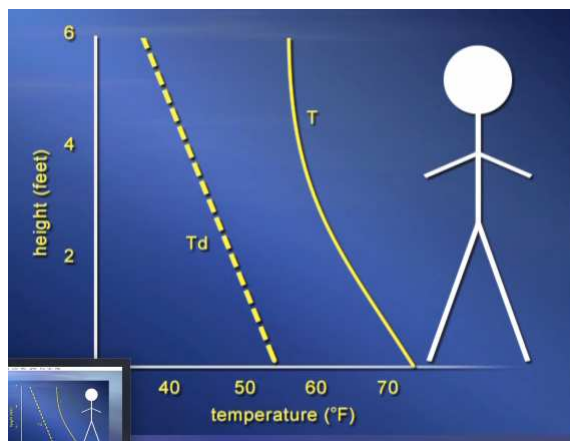
As you cool the air

- Vapor Capacity (VC)
- Vapor Pressure (VP)
- Vapor Supply (VS)
- Relative Humidity (RH)
- $VS = VC - \text{Saturation}$



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Dew Point reached with cooling over night



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Black ice

- Transparent ice
 - Difficult to see
 - Slippery – because friction easily melts a thin layer
 - No trapped bubbles
- Ice cube –
 - Freezes from outside to inside

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Once dew point is reached, change to lower temperatures slows greatly from latent heat of condensation

- Latent heat of condensation and evaporation – 540 calories per gram of water
- Condensation warming reduces the decrease of cooling of a rising parcel of air after it is saturated ($V_S = V_C$)

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Evaporation

- A cooling process
 - E.g. stepping out of shower or
 - Or with wind
- Why we sweat – to cool ourselves
- Why in desert climate if you have enough water you have Evaporative cooling = Swamp coolers



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evaporation wet bulb temperature

Vapor Capacity (VC)

Vapor Pressure (VP)

Vapor Supply (VS)

Relative Humidity (RH)

= $8/28 = 29\%$

$T = 30^{\circ}\text{C} = 86^{\circ}\text{F}$

$T_d = 10\text{C} = 50\text{F}$

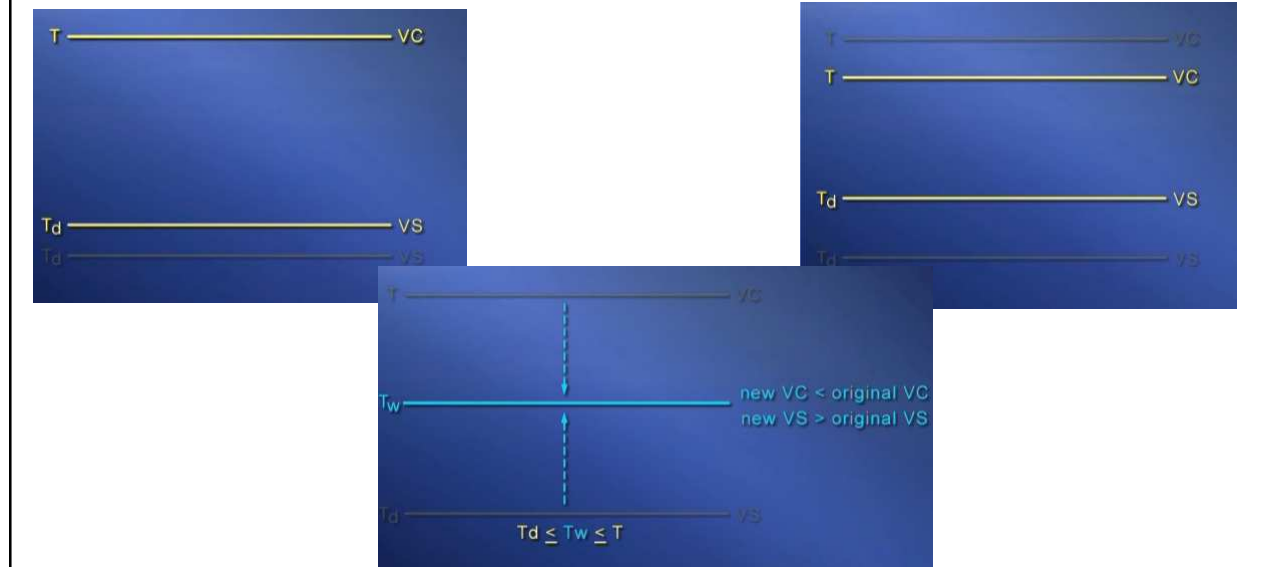
$\text{VC} = 28 \text{ g/kg}$

$\text{VS} = 8 \text{ g/kg}$

20 g/kg
short of
saturation

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Achieving the wet bulb temperature – evaporation of water cools air but raises dew point.



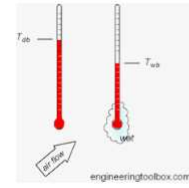
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3 temperatures

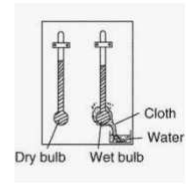
dry bulb temperature (T)
 dew point temperature (T_d)
 wet bulb temperature (T_w)

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Sling psychrometer



Temperatures - Dry Bulb/Wet ...
weather.gov



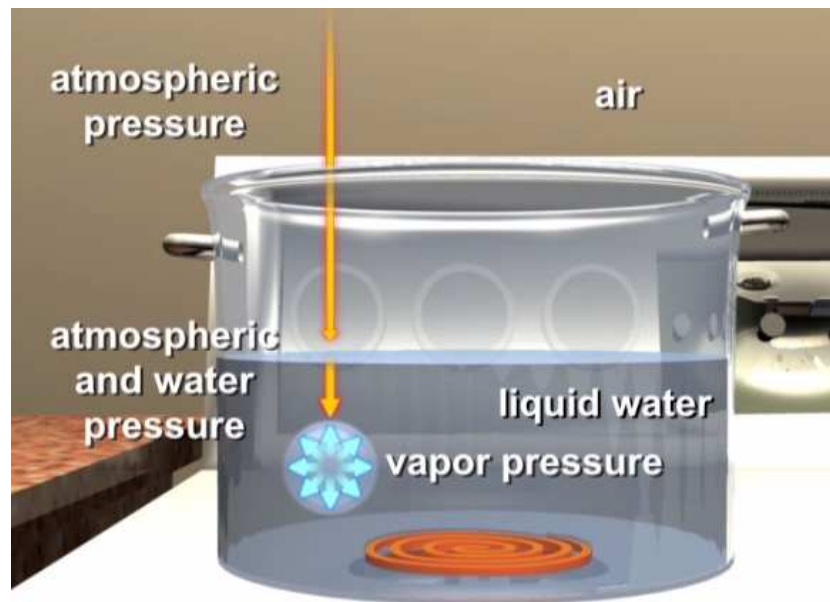
Wet bulb temperature | Arti...
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Boiling

- Rapid evaporation



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Why boiling point decreases with elevation

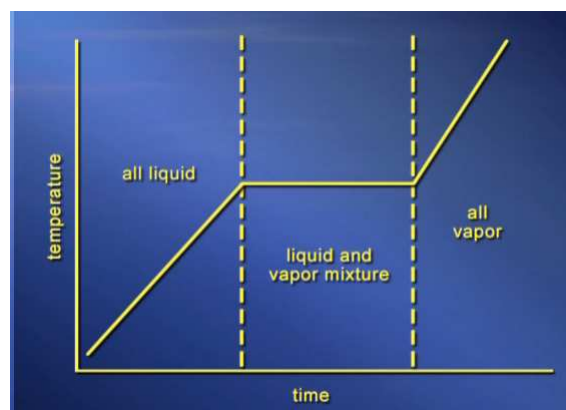
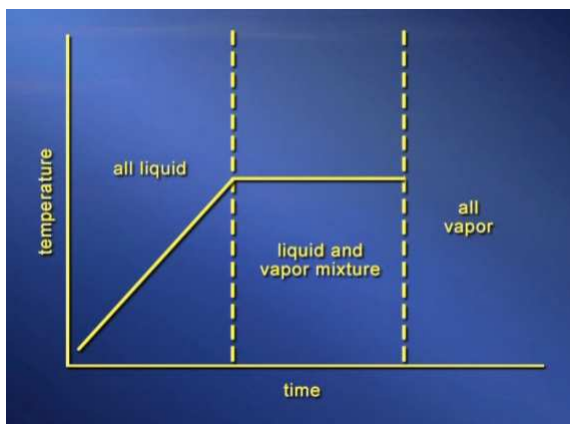
- Air Pressure decreases with Elevation
i.e. the pressure decreases:
Diagram tries to show that



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Phase change

- Boiling/vaporization – no T change until all liquid is vaporized



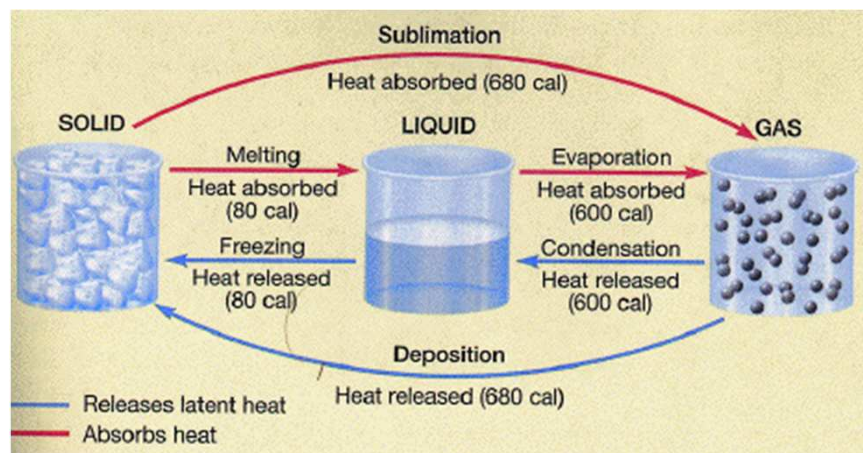
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The Energy involved with WATER VAPOR

- To melt ice (solid to liquid) = 80 calories / gram
- To heat water 1° C = 1 calorie / gram
- To go from 100° C liquid to 100° C steam/vapor – 540 calories / gram

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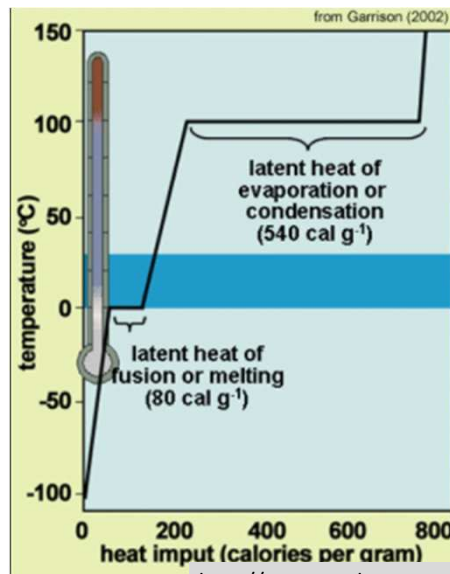
The Energy in phase changes



<http://www.uh.edu/~jbutler/physical/chapter6notes.html>

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The Energy in phase changes



http://www.aqob.com.au/details.php?p_id=371

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TAKE AWAY:

- IF YOU INCREASE THE AVERAGE ATMOSPHERIC TEMPERATURE YOU INCREASE THE AMOUNT OF WATER VAPOR IT HOLDS
- IF YOU DO THAT YOU INCREASE THE AMOUNT OF ENERGY IN THE ATMOSPHERE

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latent heat of fusion

- = melting

The latent heat of melting is 7 1/2 times smaller than the latent heat of vaporization.

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Lecture 9

Clouds, Stability, and Buoyancy
Part 1

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Examination of Clouds

- Concept of air parcels
- Lapse rates
 - Positive or
 - Negative buoyant clouds

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Clouds

- Cloud Dynamics
- Sometimes benign
- Crepuscular rays – because of our eyes – sun rays are straight
- Make for beautiful sunrises and sunsets
 - Cumulus, lenticular, waves (oceans in the sky), bands, rows
 - Rotor clouds
 - Short lived elements – cells
 - Anvil clouds
 - Wall clouds
 - Mammatus – water laden

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Classifying clouds

- Low middle or high
- Prefixes
 - Strato-
 - Alto-
 - Cirro-
- Suffixes
 - Stratus
 - Cumulus
- Subtypes
 - Altocumulus lenticularis
 - Stratocumulus undulates
 - Cumulus humilis
 - Nimbostratus
 - cumulonibus

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Cloud recipe

- Air Parcel
- Assumptions
 - Dry
 - Flexible sides
 - Dry Closed and insulated

- moist

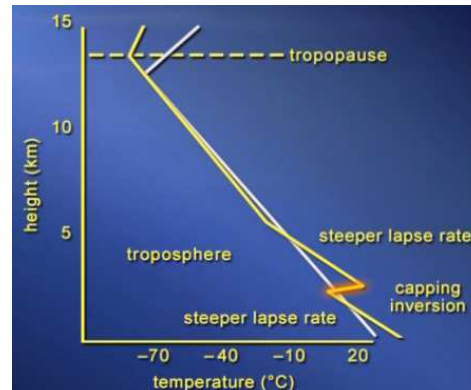
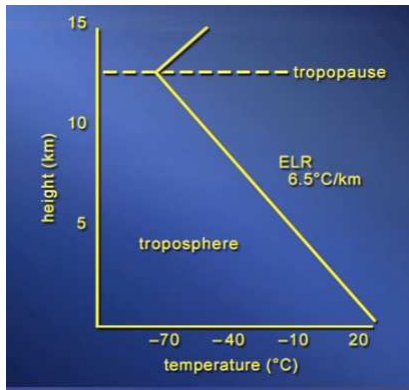


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Lapse rates

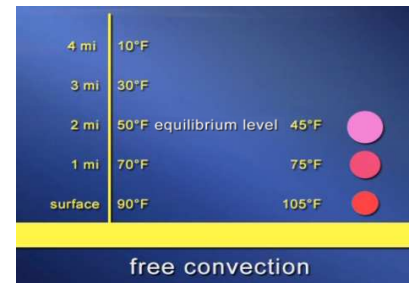
lapse rates
A lapse rate quantifies how temperature changes with height.

- DALR – dry adiabatic lapse rate
- ELR – Environmental lapse rate
 - Negative in troposphere



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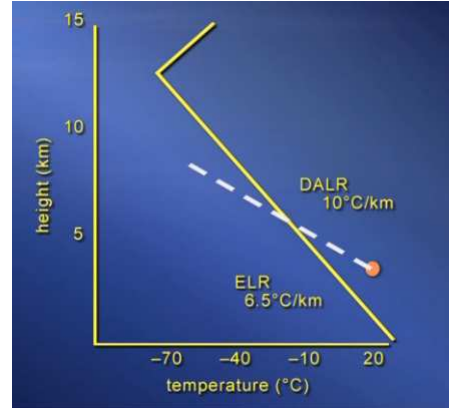
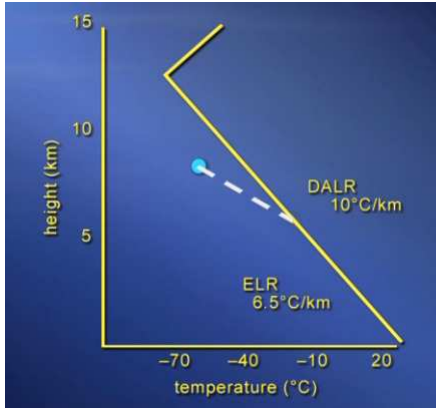
- The difference between DALR and ELR is important
- Example of air and parcel from car let free
- Starts 15 more, then only 5 more and then 5 less –
- Beyond this it needs to be forced and would become much colder in the process -



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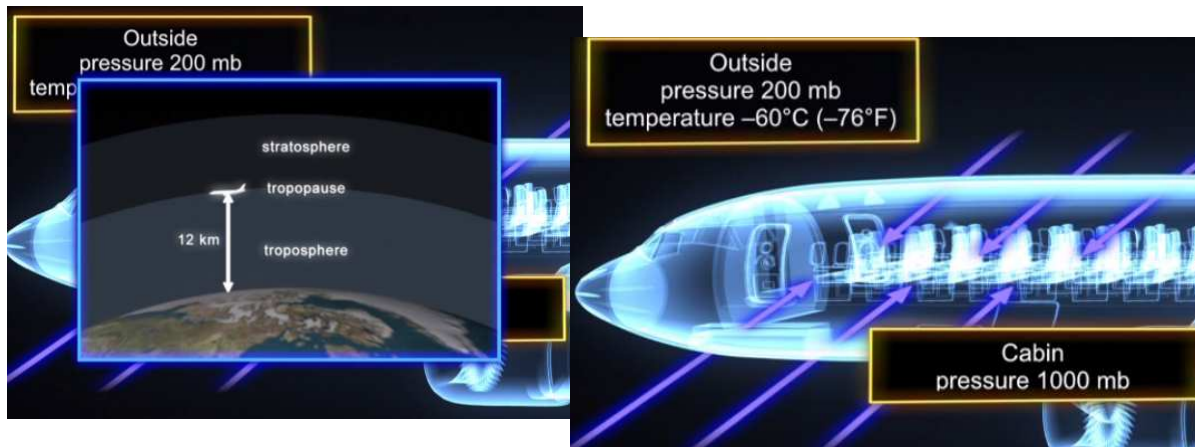
Atmospheric stability

- Forces up or forced down examples
- Wants to be absolutely stable



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Airplane example – added very cold air must be compressed, which makes it very hot



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Moist air

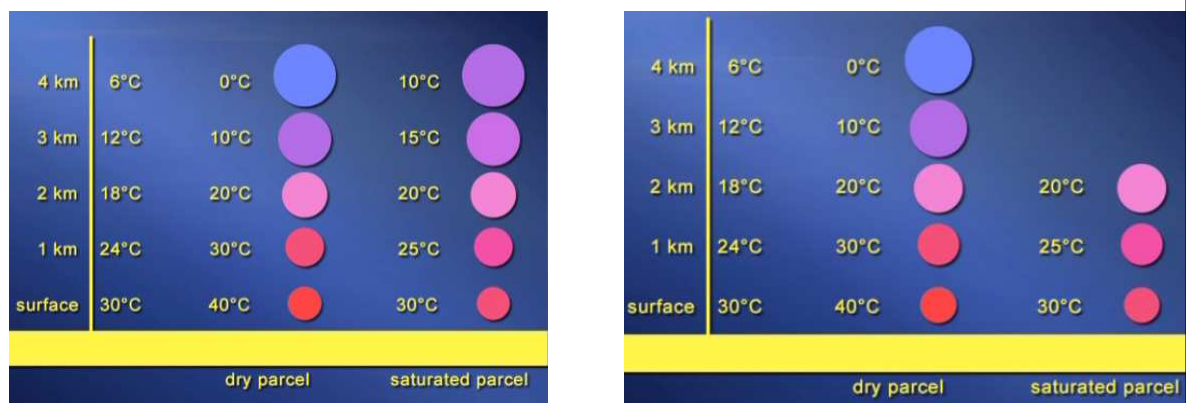
- Sub-saturated
- Saturated
- Supersaturated
- Condensing warms
- Evaporation cools

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MALR vs. DALR

moist adiabatic lapse rate (MALR)
dry adiabatic lapse rate (DALR)

Moisture condenses from rising saturated air adding heat, reducing its lapse rate and providing buoyancy.



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SUMMARY

- Clouds – benign or not
- Air parcels
 - Subsaturated – cools quickly until saturation and condensation of moisture
 - Saturation – condensation warming – slows lapse rate
- Water vapor complicates matters and helps make weather