ATMOSPHERIC MOISTURE

I. INTRODUCTION

A. Water Vapor accounts for 0-4% of atmospheric composition by volume
  1. Water Vapor: most important gas in atmosphere
    a. Fundamental component of hydrologic cycle
    b. High heat capacity: important for heating and heat transfer in atmosphere
    c. Controls weather patterns, cloud formation, meteorlogical phenomena

B. Precipitation Patterns
  1. control climate, vegetation, human habitation, surface geological processes
  2. Vary from geographic location to location

II. CHANGES OF STATE: WATER VAPOR

A. Water Vapor
  1. Three states of matter
    a. gas
    b. liquid
    c. solid

  2. Unlike N, O and CO_2 (stable gases at all earth surface temps); water vapor is very temp. sensitive and readily changes states depending on heat energy in atmospheric system

B. Water Vapor and States
  1. Evaporation- converting liquid water to water vapor-gas
  2. Condensation- converting water vapor/gas to liquid
  3. Freezing- converting liquid water to solid ice
    a. Melting- solid changed to liquid
  4. Sublimation- converting water vapor/gas directly to solid ice

C. Thermal Budget and States
  1. States of matter a function of amount of heat in system, which in turn influences the vibrational rates of molecules
    a. gas - high rate of vibration, high heat condition
    b. liquid- medium rate of vibration, medium heat system
    c. solid- low rate of vibration, low heat system

  2. Heat Energy
    a. measured in calories
      (1) amount of energy required to raise the temperature of 1 gram of water 1 degree C

  3. Heat and State Transformation

    a. Evaporation: water liquid to vapor = system must absorb 600 Cal of energy
      (1) energy absorbed by molecules, > rate of vibration to allow phase change

(2) latent heat of vaporization = "stored heat" that is exchanged to cause phase change

b. Condensation: water vapor to liquid = system must lose 600 Cal of energy
(1) < vibratory motion
(2) latent heat of condensation
(3) Condensation/heat transfer
(a) drives storm systems
(b) affects climate
(c) transfers heat from equator to poles
(d) results n cloud phenomena

c. Melting: solid ice changed to liquid = system must gain 80 calories of energy

d. Freezing: liquid to solid = system must lose 80 calories of energy
(1) latent heat of fusion for water

e. Sublimation: solid to gas or gas to solid = system must gain 680 cal of energy or lose 680 cal of energy respectively for transformation to occur

(1) e.g. dry ice sublimates to gaseous carbon dioxide with no intervening liquid phase

III. HUMIDITY

A. Terminology

1. Humidity- amount of water vapor in air
2. Vapor Pressure- total atmospheric pressure that can be attributed to water vapor content
3. Vapor Saturation- maximum amount of water vapor the air can hold,
a. rate of evaporation = rate of condenstation
b. "Vapor Capacity"- measure of amount water vapor air can hold
c. Temperature dependent
(1) >T, air can hold more moisture (>expansion of volume, > motion of molecules)
(2) <T, air can hold less moisture (< expansion of volume)

Temp. C	Vapor Capacity (gm/kg)
-40	0.1
-20	0.75
0	3.5
10	7
20	14
30	26.5
40	47

(3) Thus by taking an unsaturated system to lower temperature, system can become saturated

4. Specific Humidity- amount of water vapor contained in unit of air (expressed as wt. of vapor/mass of air = gm/kg)
   a. not affeted by changes in pressure or temperature

5. Relative Humidity- ratio of airs water vapor content to its water vapor capacity at a given temperature

for given temp.

$$\text{R.H.} = \frac{\text{water vapor}}{\text{vapor capacity}} \times 100\%$$

E.g. referring to table above, given a temp of 20 C, vapor capacity of air is 14 gm/kg. Assume a specific humidity of 7 gm/kg, relative humidity = 7/14 x 100% = 50%

a. Temperature influence on relative humidity

Relative humidity changes with temperature according to vapor capacity of air. In example above at 20 C, vapor capacity is 14 gm/kg, assuming a specific humidity of 7 gm/kg, relative humidity = 7/14 x 100% = 50%.

By decreasing the temperature to 10 C, vapor capacity of air is now 7 gm/kg, assuming the same specific humidity of 7 gm/kg, the relative humidity = 7/7 x 100% = 100% humidity.

Vapor capacity must be exceeded to oversaturation for condensation/precipitation to occur

(1) In sum: a decrease in air temperature will result in an increase in relative humidity, and an increase in air temperature will result in decrease in relative humidity

(2) <T, > R.H.; >T, < R.H.

(3) In terms of absolute air moisture...
   (a) cold air contains less specific humidity than warm air, although cold air relative humidity and warm air relative humidities may be identical (e.g. 85%), the vapor capacities are different, and the warm air will have much more moisture than cold air at same relative humidity

6. Dew Point Temperature

   a. Temperature at which air would have to be cooled in order to reach saturation
      (1) at temperatures colder than dew point, air vapor capacity is exceeded and condensation would occur

IV. CONDITIONS FOR CONDENSATION

A. Condensation of water vapor in atmosphere to liquid state; result:
   1. dew
   2. fog
   3. clouds

B. Necessary condition:
   1. air must reach vapor saturation for condensation to occur
      a. via temp. drop below dew point (most common)
      b. addition of water vapor to air (less common)

   2. Must be surface upon which water vapor can condense
      a. condensation nuclei or hygroscopic nuclei
         (1) particulate matter in atmosphere which serves as surface for water vapor to condensate
            (a) microscopic dust, smoke, salt particles from ocean

C. Cloud Formation
   1. condensation on particulate matter/condensation nuclei
   2. droplets form on millions of tiny particles
   3. clouds = fine condensed droplets that remain suspended in air
      a. different than much larger rain drops which fall to ground

V. CONDENSATION, CLOUDS, ADIABATIC TEMP. CHANGES

A. Cloud and fog formation require cooling of air to its dew point

B. Adiabatic Heat Changes in Air

   1. Air Pressure, Temperature and volume are inter-related

      a. As air volume expands, pressure decreases, and temperature decreases (i.e. air cools)
      b. As air volume contracts, pressure increases, temperature increases (air warms)

   2. Rising Air: experiences Pressure < at higher elevations, volume of air expands ----- net result = cooling of air
      a. cooling of air below dew point = cloud formation

   3. Dry adiabatic rate = temperature gradient of rising air to dew point

      a. dry adiabatic rate = 10 C/1000m altitude (i.e. cools 10 C for every 1000m rise in altitude)

   4. Wet Adiabatic Rate = temperature gradient of rising air after clould formation begins (i.e. past dew point)
      a. wet adiabatic rate = 5C/1000m altitude

VI. ATMOSPHERIC STABILITY

A. Controls on vertical movement of air masses a function of temperature of air relative to surrounding ambient air

1. Stable air: temperature of rising (adiabatic) air mass < temperature of upper elevation air, air mass will tend to resist vertical motion

2. Unstable air: temperature of rising (adiabatic) air mass > temperature of upper elevation air, air mass will tend to rise vertically like a hot air balloon

a. at >T, D air < (rises)
b. at <T, D air > (sinks)

B. Stability and Weather

1. Stable forced air aloft, widespread cloud formation relatively thin, little precipitation, drizzle-dreary day

2. Unstable air forced aloft: billowing clouds represent hot air surging upward

VII. FORCEFUL LIFTING

A. Air may be forced upward regardless of stability of air mass or adiabatic processes

B. Methods of Forceful lifting of air

1. Convergence- flowing of air masses together, occupies less space, air column forced to rise vertically
a. air forced to rise upward
b. enhances instability
c. E.g. Florida: on warm summer days
(1) Atlantic air flow westward over land
(2) Gulf air flow eastward over land
(a) convergence + vertical uplift + intense solar heating = high rate of thunderstorm occurrence (greatest occurrence in U.S.)

2. Orographic Lifting- sloping terrain/mountain slopes act as barriers to air flow, forces air to ascend
a. Rain fall on windward side, rising moist air masses, <Temp during ascent, >saturation point.... rain
(1) e.g. Mt. Waialeale Hawaii: 38 Ft rain/yr

b. Lee sides: dry air descends... orographic deserts
(1) Rain shadow deserts
(2) e.g. Columbia Basin of Wash, Mojave of Calif.

3. Frontal Wedging- cool air acts as a barrier over which warm, less dense air rises
a. Responsible for rainfall patterns over much of continental U.S.

(1) Cold Fronts moving in from w-nw, forcing warm continental air above
(a) Arctic/Canandian cold fronts moving into US

(2) Warm Fronts moving in from w-nw, riding over cold

b. Cloud Process
(1) Warm stable air over wedge of cold air
(a) frontal lifting, widespread thin cloud cover, light rains and drizzle

(2) warm unstable air over wedge of cold air
(a) frontal lifting, billowing clouds/thunderheads

VIII. CLOUDS

A. Clouds- condensated water vapor, comprised of aggregates of very small droplets of water or thin crystals of ice

B. Cloud Classification: based on appearance and height

1. Three Basic Forms
a. Cirrus- high, white and thin
(1) veil-like patches and wispy fibers

b. Cumulus- cotton ball masses, "cauliflower like" structure

c. Stratus- sheets or layers that cover much or all of the sky, no distinct individual cloud units

C. Elevation of Clouds

1. High Clouds- bases above 6000 m
2. Middle Clouds- bases between 2000 - 6000 m
3. Low Clouds -bases below 2000 m
4. Clouds of vertical development- transcend to high elevations: e.g. unstable thunderheads

IX. FORMATION OF PRECIPITATION

A. General
1. If all clouds are water vapor, then why do only some lead to rain?

a. cloud drops very small: D = 10 micrometers
b. small drops held in suspension by air mass
c. growth through condensation is very slow
d. evaporation is occurring as well

2. Rain Droplets
a. 1 million times more volume than cloud droplet

b. to form: must coalesce cloud drops to form rain drops
(1) must fall through air column without evaporation

B. Rain Drop Formation

1. Collision-coalescence process
a. cloud droplets must be >20 um for rain drops to form
b. condensation nuclei required for coalescence of vapor
(1) (dust, particulates)

c. water droplets fall and coalesce with other droplets, growing in size
(1) drops must be large and plentiful to survive evaporation before reaching the earth's surface
(2) rain = larger drops
(3) drizzle = fine drops

X. SLEET, GLAZE AND HAIL

A. Sleet- particles of ice produced by warm air over freezing air, rain falls from warm air through freezing... frozen rain drops
1. winter phenomena

B. Glaze- freezing rain
1. supercooled rain drops that become frozen upon impact with trees, branches and surfaces

C. Hail- hard rounded pellets of ice

1. may have concentric internal structure, D = 1-10 cm
a. largest recorded in Kansas D = 14 cm, 1.5 lbs.

2. Destructive to property and crops

3. Form from rising unstable air masses, towering thunderheads (cumulonimibus clouds)

a. supercooled water drops "recycled" through cloud many times owing to strong updraft
(1) ice fall, updraft, lifting, ice fall, accumulation until mass > updraft shear

XI. FOG

A. Fog- cloud with base at or very near ground, same general structure as cloud
1. visibility hazard: dense fog can severely reduce visibility

B. Formation Mechanisms

1. Advection Fog- warm, moist air blown over a cool surface
    a. e.g. Cape Disappointment, WA: warm moist Pacific air blown over cool California Current

2. Radiation Fog- forms by rapid cooling of earth's surface (common on very clear nights where surface heat escapes readily)
    a. air above ground surface cooled below dew point
    b. air cools, sinks to low-lying areas/valleys

3. Evaporation Fog- cool air moves over warm water, "steam" rises from water as evporation from water occurs, air above reaches saturation point
    a. e.g. lakes/rivers