COMPOSITION, STRUCTURE AND TEMPERATURE OF ATMOSPHERE

I. WEATHER AND CLIMATE

A. Meteorology- study of weather and atmosphere
   1. Aristotle "Meteorologica" = "Discourse on Things Above"

B. Weather- state of atmospheric conditions at a particular place for a short period of time
   1. changes by hour, day, season

C. Climate- average composite of atmospheric conditions for a given area over a long period of time
   1. Influences
      a. vegetation, land use, soil types, surface geology, geomorphology, shape and feel of landscape, human habitation

D. Descriptive Properties of Atmosphere
   1. air temperature
   2. humidity
   3. type and amount of cloudiness
   4. type and amount of precipitation
   5. air pressure
   6. speed and direction of wind

II. COMPOSTION OF ATMOSPHERE

A. Average composition of elemental gases in dry air
   1. Nitrogen (N_2)= 78%
   2. Oxygen (O_2)= 21%
   3. Argon (inert) = 0.93%
   4. Carbon Dioxide (CO_2) = 0.035%

      a. Ability to absorb heat in atmosphere from energy radiated from earth's surface, helps keep the atmosphere warm

   5. All Others = trace

B. Water Vapor
   1. range of water vapor content in air: 0-4% by volume
   2. Important source of clouds, precipitation, water budget
   3. Like CO_2 has ability to absorb heat given off by earth's surface as well as solar energy
      a. important for warming atmosphere

   4. Water vapor has high heat capacity, and can absorb and release heat

      a. important agent of heat transfer in atmosphere from one region to another

      b. latent heat in water vaport provides energy for driving storms

C. Dust/Particulate Matter

1. fine mineral dust, pollen, spores, seeds, man-made pollution
   a. derived from earth's surface
   b. abundant in lower atmosphere, also carried to upper portions of atmosphere

2. Particulates necessary for nucleation of water droplets (condensation) in clouds to form precipitation

3. Under extreme conditions of volcanic eruptions, volcanic dust high in the atmosphere may reflect incoming solar radiation, resulting in short term atmospheric cooling.

4. Dust creates colors of sunsets/sunrise

D. Ozone (O_3)

1. triatomic form of oxygen, occurs in very low amounts, concentrated to upper atmosphere known as stratosphere (10-50 km above the surface, 6-31 miles)

2. Formation: at high altitudes in atmosphere

   a. O_2 absorbs incoming ultraviolet radiation from sun (harmful to life on planet in high doses).
   b. O_2 splits into single atoms of oxygen
   c. $O + O_2$ + neutral catalyst molecule = O_3 (ozone).... "ozone layer"

3. Ozone acts as filter absorbing harmful ultraviolet radiation from sun, if ozone layer were depleted, life may be rendered uninhabitable on the planet.

   a. CFC's = chlorofluorocarbons used in aerosol sprays, freon/refrigerants, plastics and cleaning solvents

   b. CFC's inert in lower atmosphere, readily travel to upper atmosphere undegraded

   c. UV radiation breaks CFC's into components in upper atmosphere, Chlorine atoms released react to destroy ozone molecules

   d. "Ozone Hole" - diminished levels of O_3 detected over the southern polar region by Antarctic Scientists in 1979, fluctuates seasonally especially low during southern hemisphere spring (Sept. to Oct.)

III. EXTENT AND STRUCTURE OF ATMOSPHERE

A. Atmosphere divided according to thermal structure/temperature

1. Lower Limit of Atmosphere = air/water, air/land interface at earth's surface

2. Troposphere (0-12 Km altitude = 0-7.4 miles on avg.)
   a. bottom layer of atmosphere
   b. vertical mixing of air
   c. clouds, precipitation and storms restricted to troposphere ("weather sphere")
   d. "Normal Lapse Rate": temperature decreases systematically upward in troposphere
      (1) temp. gradient = 6.5 C/km altitude = 3.5 F/1000 Ft

3. Tropopause: boundary between underlying Troposphere and overlying Stratosphere

4. Stratosphere (12-50 km)
   a. temp. constant from 12-20km, then gradual increase in temp to height of 50 km
   b. Ozone concentrated in stratosphere, hence the reason for the temperature increase (O3 absorbing UV from Sun)

5. Stratopause: boundary between underlying stratosphere and overlying thermosphere (at ~50 km)

6. Mesosphere (50 km to 80 km)
   a. Temperatures decrease with increasing altitude

7. Mesopause (80 km) boundary between mesosphere and overlying thermosphere
   a. Temp. at 80 km =~ -90 C

8. Thermosphere 80 km - ???

   a. contains only minute fraction of earth's atmospheric gases, very rarefied air, low pressure.

   b. Temp. again increases with > altitude due to solar energy absorption by atoms of oxygen and nitrogen

      (1) "Temp" = 1000 C max (i.e. measure of molecular motion)

         (a) however, there are so few atoms of oxygen and nitrogen that heat is generally not transferred, hence satellites in this region are cool.

B. Altitude vs. Air Pressure

Altitude (km)	Percent of Air Press. at Sea Level (avg = 1000 mbar = 1 kg/sq. cm)
0	100 (full column of air)
5.6	50
16.2	10
31.2	1
48.1	0.1
65.1	0.01
79.2	0.001
100	0.00003

IV. EARTH-SUN RELATIONSHIPS

A. General

1. The earth's dependence on the sun for solar energy is essential for all life, drives biosphere, atmosphere, and hydrosphere.

2. Movements of the Earth: Rotation vs. Revolution

a. Rotation- the earth rotates on its axis from west to east (counter clockwise direction viewed from top), complete revolution of 360 ° every 24 hrs.

(1) Sidereal Day: view of revolution of the earth with respect to astronomical view of stars: takes 23 hrs 56 mins and 4.1 secs

(2) Since the earth spins from west to east, the moon and sun and stars appear to relatively move (rising and setting) in the opposite sense: east to west.

(3) Speed of rotation of the earth is greatest at the equator and decreases to 0 at the poles, function of revolving different diameters about a pole.

b. Effects of the Rotation of the earth

(1) Constancy of the earth's rotation results in coriolis effect in which the flow of air and water on the earth's surface is deflected by the centrifugal forces

(2) rotation brings varying portions of the earth into increasing and decreasing gravitational fields relative to the moon and sun, thus driving diurnal tidal fluctuations

(3) rotation results in diurnal variation of lightness and darkness, as the earth turns relative to the position of the sun

c. Revolution Around the Sun: earth revolves around the sun in a similar west to east rotation, once every 365.25 days (known as the tropical year)

(1) The path of the earth's orbit around the sun is not a circle but an ellipse with varying radius of orbit.

(2) Perihelion- position on January 3, the earth = 91,445,00 miles from the sun

(3) aphelion - position on July 4, the earth = 94,555,000 miles (farthest from the sun in our summer).

Perihelion and aphelion are oriented at 180° to one another: do not so significant effects on seasonal temperature variation.

B. Season Temperature/Weather/Insolation Changes

1. Plane of the ecliptic- the plane the passes through the sun and earth, enscribing the orbital path of the earth around the sun.

2. The axis of the earth and the plane of the equator is tilted approximately 23.5° with respect to the plane of the ecliptic (i.e. polar axis is not perpendicular to the plane of the ecliptic).

a. The axis of the earth is always parallel to itself, pointing at all seasons of the year towards polaris the north star..

b. The rotation, revolution, and tilt of the earths axis is such that the amount of insolation or energy the hits the earth is at different angles throught the year of revolution.

THE MORE DIRECT THE STRIKE OF THE SUN'S RAYS, THE EFFECTIVE IS THE HEATING OF THE EARTH'S SURFACE

THE MORE OBLIQUE THE STRIKE OF THE SUN'S RAYS, THE MORE DIFFUSED THE ENERGY IS OVER A LARGER LAND SURFACE.

3. Latitudinal changes in insolation with seasons

a. SUMMER SOLISTICE: NORTHERN HEMISPHERE

(1) Tropic of Cancer- 23.5° north latitude, marks the northernmost location reached by the vertical/direct rays of the sun in annual revolution pattern (occurs on the summer solistice in the northern hemisphere, June 21)

(2) At solistice, all points lying north of the Arctic Circle (66.5° N.) are placed within the circle of illumination for 24 hours continuously

(3) At northern solistice, all points south of the anarctic circle (66.5° S) are placed in continual darkness, outside the circle of illumination

b. WINTER SOLISTICE: NORTHERN HEMISPHERE

(1) Tropic of Capricorn- 23.5° S. latitude, marks the southernmost location reached by the vertical/direct rays of the sun in annual revolution pattern (occurs on Dec. 21, more or less).

(2) At winter solistice, all points lying south of the Anarctic Circle lay continually within the circle of illumination, whereas, points north of Arctic circle lay within continual darkness.

c. EQUINOXES: (spring March 20, and fall: sept. 22)

(1) The perpendicular rays of the sun strike the equator

(2) The circle of illumination just touches both poles

(3) The periods of daylight and darkness are each 12 hours long all over the earth

(4) equinoxes represent midpoints in the shifting of direct rays of the sun between the Tropic of Cancer and the Tropic of Capricorn

V. RADIATION

A. Sun emits EM Radiation (spectrum presented previously)
1. EM radiation travels through vacuum of space at 186,000 mi/sec
2. Long waves : infrared radiation- can't be seen but felt as heat
3. short waves: ultraviolet radiation- sunburn wavelengths

B. Basic concept: absorption of EM radiation
1. When objects absorb EM radiation, > molecular motion, resulting in increase in temperature

VI. MECHANISMS OF HEAT TRANSFER

A. Conduction- transfer of heat through matter by molecular activity

1. e.g. spoon left in hot pan, heat conducted to spoon
2. Good conductor: metals
3. Poor Conductor: air/fiberglass insulation

B. Convection- transfer of heat by the movement of mass from one place to another (takes place primarily in liquids and gases)
1. Atmospheric convection - primary mode of heat transfer, i.e. transfer of heat with air

a. Atmospheric convection = vertical mass movement
b. Atmospheric advection = horizontal mass movement (winds)

C. Radiation- passage of radiant energy as wave energy, e.g. radiation from sun in vacuum of space
1. conduction or convection is not possible in space

VII. HEATING THE ATMOSPHERE

A. Solar Radiation Relationships with Earth

1. Absorbed radiation- solar radiation absorbed by atmosphere
a. Gases are selective absorbers of particular portions of the EM spectrum, depending on chemical composition

(1) N_2 poor absorber
(2) O_2 and O_3 good absorbers of UV radiation
(3) Water vapor good absorber

b. 20% of total incoming solar radiation absorbed by atmosphere and clouds

c. Atmospheric gases do not absorb visible light portion of spectrum thus all of it reaches the earth's surface

(1) atmosphere most effectively absorbs terrestrial radiation from the earth's surface (reflected and directly from the earth).

(2) Atmospheric absorption of terrestrial radiation primary mechanism of heat transfer and weather phenomena

d. "Greenhouse Phenomena": Water vapor and CO_2 allow shorter wavelength solar radiation to enter atmosphere, where it heats earth's surface inside, the earth's surface re-radiates longer wavelength terrestrial radiation, which is trapped by the water vapor and CO_2, thus heating the air of the lower atmosphere

(1) Greenhouse necessary to point, however runaway greenhouse effect could be detrimental in terms of severe global warming.

e. Climatic examples

(1) arid southwest, US
(a) high daily temp. fluctuation, low humidity, rapid warming of air, but also rapid heat loss due to low water vapor content (low absorptive capacity)
(2) humid northeast, US
(a) high humidity, high absorbtive capacity, daily temperature fluctuation at a minimum

VIII. CONTROLS OF TEMPERATURE

A. Land and Water

1. Land has lower heat capacity than water

a. land heats more rapidly and to higher temps. than water, and cools more rapidly and to lower temps. than water

2. Reasons for differential heating of land compared to water

a. water has high specific heat (i.e. it takes more energy to raise temp. of water than similar volume of land)

b. Land surfaces are opaque, thus heat only absorbed at surface. Water is transparent and allows heat to penetrate throughout body

c. Water transfers heat by convection, thus distributing the heat through a larger mass

d. Evaporation (a cooling or heat loss process) from water bodies is greater than that for land

3. Example Coastal Areas

a. ocean bodies can have a buffering effect on local climates, due to high heat capacity and lag in heat transfer, warming air above ocean and influencing air temps inland.

B. Altitude

1. > altitude, < atmospheric content, < heat capacity, < T

C. Geographic Position (Latitudinal Position with Respect to Sun)

1. Latitudinal influences on amount of incoming solar radiation

a. Tropics vs. arctic

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.

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

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

PRESSURE AND WIND

I. PRESSURE MEASUREMENT

A. Air Pressure: important factor in controlling wind, wind speed, advective air movement, storm patterns

B. Air Pressure Relationships

1. Air Pressure = force exerted by the weight of the air above

2. Altitude Relationships
    a. with > altitude, < air column, < Pressure

Altitude (km)	Altitude (mi)	Pressure (mb)
0	0	1013
1	0.6	899
2	1.2	795
3	1.9	701
4	2.5	617
5	3.1	540
10	6.2	265
20	12.4	55
30	18.6	12
40	24.8	3

C. Units of air pressure
1. at sea level
    a. Pressure = 1 kg/sq. cm = 1013.2 millibars (mb) = 29.92 inches of mercury = 76 cm of mercury

D. Mercurial Barometer
1. Barometer
    a. filled glass tube with liquid mercury
    b. inverted in base dish with pool of mercury
    c. mercury flowed out of tube until column of mercury was balanced by weight of the air column pushing on the pooled dish of mercury
        (1) wt. of air column = wt. of mercury column in tube
2. Increasing Air Pressure: pushes mercury higher in tube
3. Decreasing Air Pressure: mercury falls in tube

II. FACTORS AFFECTING WIND

A. General
1. Wind = horizontal movement of air (advective motion)
2. Wind and Pressure
    a. basic gas law: air of higher pressure moves towards air of lower pressure
    b. wind = drive toward equilbrium of air pressure

3. Pressure Differences on Earth's Surface
    a. Caused by unequal heating of atmosphere by sun
    b. Variable solar insolation due to tilt of earth, orbital path, latitudinal changes

B. Factors Influencing Air Motion
1. General : if earth did not rotate and there were no friction of air motion, wind would be simply controlled by air motion from high pressure to low pressure

2. Influencing factors
    a. Pressure Gradient Force- degree of pressure changes per unit distance
    b. Coriolis Effect- motion on rotating objects/centrifugal force
    c. air friction- resistance to flow

C. Pressure Gradient Force

1. Pressure variation = wind
    a. > press. diff, > wind speed
2. Mapping air pressure
    a. pressure contour maps
    b. isobars = lines on constant air pressure

3. Pressure Gradient = $\frac{\text{change in pressure}}{\text{unit distance}}$
    a. gradient to hill
        (1) steeper the hill (pressure gradient)
            (a) > press. gradient, > wind acceleration
            (b) > close spacing of isobars

        (2) gentler the hill slope (pressure gradient)
            (a) < press. gradient, < wind acceleration
            (b) widely spaced isobars

4. Coriolis Effect
    a. Coriolis = apparent shift due to rotation
        (1) Earth rotating in counterclockwise direction as viewed from north pole
        (2) Net result:
            (a) Northern Hemisphere: air deflected to right in the direction of travel
            (b) Southern Hemisphere: air deflected to left in direction of travel

    b. View from north pole
        (1) counter clockwise rotation
        (2) air deflection to right, due to coriolis

    c. View from south pole
        (1) clockwise rotation
        (2) air deflection to left, due to coriolis

d. Coriolis relationships
(1) deflection always directed at right angles to direction of airflow
(2) deflection affects only wind direction, not wind speed
(3) deflection affected by wind speed
(a) > speed, > deflection

5. Friction
a. friction of air motion with earth's surface/topography
b. acts to slow wind velocity
(1) tends to deflect wind via "refraction"
(2) friction effects prominent to 2000 Ft altitude
c. rough mountainous landscape: > friction
d. smooth ocean surface: < friction

6. Air motion and Isobars

a. in frictionless, non-rotating environment, air motion perpendicular to isobars
b. Coriolis + friction effects ------
(1) Upper level (high altitude) airflow parallel to isobars
(a) Jet stream: "rivers of air" flowing at 75-150 mph at upper altitudes (reduced friction > speed)
(2) near-surface air flow winds cross isobars at an acute angle

III. CYCLONES AND ANTICYCLONES

A. General
1. Cyclones: low pressure center
2. Anticyclones: high pressure center

B. Cyclonic and Anticyclonic Winds
1. Cyclones
a. Northern Hemisphere
(1) low pressure center (influenced by coriolis and friction)
(2) winds blow inward and counterclockwise around the low
b. Southern Hemisphere
(1) winds blow inward and clockwise

2. anticyclones
a. Northern Hemisphere
(1) high pressure center
(2) winds blow outward and clockwise around the high
b. Southern Hemisphere
(1) winds blow outward and counterclockwise

C. Weather Generalizations about Highs and Lows
1. Rising air: associated with clouds/precipitations
2. subsiding air: adiabatic heating and clearing conditions
3. Cyclone: low pressure system

a. inward flow of air
b. winds converge to center
  (1) air pile up
  (2) pushes air upward
  (3) > pressure due to rising column of coverged air (a paradox, low pressure results in > pressure)
  (4) rising air cools adiabatically---- clouds/condensation---precipitation associated with low pressure system

4. Anticyclone: high pressure system
  a. outward flow of air
  b. winds diverge from center
    (1) air descends and thins
    (2) pushes air downward
    (3) descending air is compressed and warmed
    (4) air moisture vaporizes and clears

5. Short range weather predictions
  a. barometric tendency
    (1) rising barometeter: high pressure system approaching, clearing weather
    (2) falling barometer: low pressure system approaching, clouds and rain
  b. Cyclones---- rain
  c. Anticyclones---- clear

IV. GENERAL CIRCULATION OF ATMOSPHERE
  A. Causes of Air Motion
    1. Unequal heating of earth's surface
      a. Tropical Regions/Low Latitudes = receive > solar radiation, less reflection
      b. Polar Areas = receive < solar radiation, > reflectance/albedo

    2. General Circulation (ideal on a non-rotating earth)
      a. Heat Imbalance: high at equator, low at poles
        (1) warm air rises from equator and circulates symmetrically to north and south pole
        (2) cold air sinking at the poles, circulated back to equator for reheating/circulation

      b. Complications to the ideal model
        (1) friction/turbulence
        (2) coriolis: effects of air motion due to centrifugal force on a rotating planet
        (3) secondary ocean current influences

** Result: breaks air flow into smaller cells of circulation, mid-latitude circulation shows complex airflow patterns

    3. Idealized Global Circulation of Air on a Rotating Planet

a. Standard terminology for wind direction
   (1) Easterly wind: blowing from east to west
   (2) Westerly wind: blowing from west to east
   (3) Southwesterly: blowing from southwest to NE,... etc.

b. Equatorial Low
   (1) Low pressure Zone at Equator
   (2) Warming/Rising Air
   (3) Convergence of Northeasterly Trade Winds and Southeasterly Trade Winds
   (4) Abundant Precipitation/Tropical Climates

c. Subtropical High

   (1) Zone of subsiding, adiabitically warming air at 30 N and S latitudes
   (2) Warm/arid areas
      (a) World deserts in this belt
         i) Australian Desert
         ii) Arabian Peninsula
         iii) Sahara Desert
         iv) Gobi Desert

   (3) Divergent air at subtropical high, adiabatic warming, air diverging pushed to the south and north at 30 degree high
      (a) Trade Winds: reliable steady winds
         i) N. Hemisphere: northeasterlies pushed back to soutwest towards equator
            a) Deflected to right (SW) due to coriolis

         ii) S. Hemisphere: southeasterlies pushed back to the northwest towards equator
            a) Deflected to left (NW due to coriolis

      (b) Mid-latitude Westerlies: North and south of 30 degrees N. and S. latitude
         i) remainder of diverging, subsiding air (in Hadley cell) forced north and south respectively
         ii) Northern Hemisphere: air pushed to north, deflected to the right in an eastward direction--- forming westerlies

d. Subpolar Low

   (1) Northern portion of mid-latitude cell with air rising, < pressure to form subpolar low
   (2) Polar Easterlies
   (3) Polar Front
      (a) contact between cold polar air and warm mid-latitude air
      (b) Forms stormy northern belt

e. Polar High
  (1) At poles: high pressure
  (2) cold subsiding dry air forced equatorward

f. Summary
  (1) Four Pressure Zones
    (a) Subtropical and Polar highs
      i) dry subsiding air pushed equatorward
    (b) Equatorial and Subpolar Lows
      i) converging and upward moving airflow
      ii) sites of precipitation/instability

V. CIRCULATION IN MID-LATITUDES (Between 30 and 60 Latitude)

A. Complexities in the zone of the westerlies (mid-latitude)

1. Does not fit convective model well

2. west to east flow interrupted by migration of cyclones (low-press, counterclockwise systems) and anticyclones (high press, clockwise systems)
  a. cyclones: precipitation
  b. anticyclones: clear skies
3. Complicated upper airflow patterns

B. Seasonal Variations in upper air flow
1. Wind Speed
  a. cool season: increased wind speed in upper air flow
2. Temperature Gradient
  a. steeper in winter months
3. Fluctuation in position of polar jet stream
  a. winter: cool arctic air pushed further south
    (1) may be pushed as far as central Fla... freezing in Fla.
  b. summer: more northward

C. Erratic behavior of upper level air, makes longer range predictions of weather uncertain at mid-latitudes

VI. LOCAL WINDS
A. Seas and Land Breezes
1. Variation in coastal winds daily due to water having higher heat capacity than land
  a. i.e. land warms and cools faster than ocean on daily basis
  b. Differential heating
2. Daytime: Sea breezes (towards land)
  a. cool sea air directed inland
  b. land and air above heats faster than ocean
  c. land air---warm, rises, circulates out to sea
  d. sea air relatively cool, descends and pushed towards land

3. Nightime: Land breezes (towards sea)

a. land and overlying air cools/loses heat faster than ocean
b. land air cools, subsides and forced in oceanward direction
c. ocean air warms and rises circulating landward

B. Valley and Mountain Breezes
1. Differential heating
a. Day: valley air warms rises up mountain slopes (valley breezes)
b. Night: upslope air cools and subsides down mountain slopes (mountain breezes)

C. Chinook and Santa Ana Winds
1. Chinooks: warm dry winds on eastern slopes of Rockies
a. adiabatic warming of air as it compresses and descends down leeward (east) side of Rockies
b. leeside warm, dry air
c. common in winter, spring, although inherently not that warm, warm enough to moderate freezing temps. and to melt snow
2. Santa Ana Winds
a. hot dry winds from east that flow into southern California
b. Descend down western slopes of Sierras
(1) >fire hazard

ATMOSPHERE: WEATHER PATTERNS AND STORMS

I. AIR MASSES
   A. General
      1. Air Mass - immense body of air, characterized by homogeneity of temperature and moisture at any given altitude
         a. 1000 miles or more in breadth
         b. Passes through area over the course of days
            (1) e.g. Summer: heat wave, high temps, high humidities
               (a) ends with series of thunderstorms and few days of cooler weather
            (2) e.g. Winter: frigid clear, subzero cold spell
               (a) ends with thick stratus clouds, rising temps. and snowfall.

      2. Front: boundary between two adjoining air masses having contrasting characteristics
         a. passage of a front marks a change in weather

   B. Source Regions

      1. Source Region: area of earth's surface over which air masses assume their distinguishing characteristics
      2. Types of Air Masses
         a. Classified According to Latitude and Temperature
            (1) Polar (P) air masses
               (a) originate in high latitudes
               (b) cold air mass temps.
            (2) Tropical (T) air masses
               (a) originate in low latitudes
               (b) warm air mass temps
         b. Classified According to Geographic Source and moisture
            (1) Continental (C) designates land source
               (a) On the dry side
            (2) Maritime (M) designates ocean/water source
               (a) On the wet side

         c. Four Basic Types of Air Masses
            (1) Continental Polar
               (a) On dry and cold side
            (2) Continental Tropical
               (a) On dry and warm side
            (3) Maritime Polar
               (a) On wet and cold side
            (4) Maritime Tropical
               (a) On wet and warm side

   C. Weather Associated with Air Masses
      1. Relationships in U.S. East of Rockies (most influenced by Cp and Mt)

a. Continental Polar Masses
   (1) Originate in northern Canada, AK and Arctic
   (2) Cool and Dry Air
   (3) High Pressure, few clouds
      (a) Winter: clear cold arctic air
      (b) Summer: clear cool air

   (4) Local Effects
      (a) Great Lakes
         i) "Lake Effect"
            a) winter: cold arctic air, over warmer moisture air above Great Lakes
            b) Lee side of lakes = wet, humid unstable air.... snow showers, heavy accumulation (Buffalo, Erie, etc.)

b. Maritime Tropical Air Masses
   (1) Originate in Gulf of Mexico, Caribbean/Atlantic
   (2) Warm, moisture laden, unstable
   (3) Responsible for most of rain in eastern 2/3's of US
      (a) Summer: Mt into central and east US
         i) heat, high humidity

2. Pacific Northwest
   a. Heavily influenced by Maritime Polar air masses from NW in Pacific
   b. west side Cascade/orographic rainfall

3. Southwest
   a. Continental Tropical Air
      (1) Dry, warm, arid
      (2) locally contained to Southwest

4. New England
   a. Northeaster
      (1) maritime polar air mass from northeast off N. Atlantic
         (a) snow and frigid temps

II. FRONTS
A. General
   1. Fronts- boundaries that separate air masses of different densities
      a. one warmer and often higher in moisture
      b. avg. 15-200 km wide, narrow compared to breadth of air mass

   2. Vertical Configuration
      a. Warm air: less dense
         (1) warm air over cold air (more dense)
         (2) warm air/cold air interface often sloping/wedge shaped at low angle
      b. Fronts often collisional in nature
      c. Always warm air forced aloft, with colder bottom air acting as a wedge

B. Warm Fronts
1. warm air moves over wedge of cold air
a. map symbol: line with semi-circles extending into cold air
2. Average slope of warm front: 1:200 (V:H)
3. Ascending Warm Air
a. cooling by adiabatic expansion
b. often clouds and precipitation
(1) several hours of gentle precipitation over large region
(a) gentle slope of front does not encourage convective activity
c. Increase in temperature

C. Cold Fronts
1. cold air moves into region of warm air
a. map symbol: line with triangular barbs extending into warm air
2. Average slope of cold front: 1:100 (V:H)
a. steeper than that of warm front
b. cold fronts in general advance more rapidly than warm fronts

3. Actively forces warm air aloft
a. cold fronts produce more violent weather
(1) sudden downpours
(2) wind gusts
(3) >intensity, < duration compared to warm front

4. Behind Front
a. cold air mass, subsiding air
b. Often clear and cold behind the front

D. Occluded Fronts
1. Cold front over takes a warm front
2. Wedging of warm air aloft between two cold air masses
3. Complex weather patterns/ heavy or light rain possible

III. MIDDLE LATITUDE WAVE CYCLONES (LOW PRESSURE SYSTEMS)
A. General
1. At Middle Latitudes (Like U.S.)
a. Cold and Warm Front Activity Commonly Associated with Low Pressure Systems
(1) Cyclone = low pressure system, counterclockwise rotation
(a) Common Harbringer of Rainfall to Central and Eastern U.S.
(2) "Wave" Cyclone- refers to a low pressure system comprised of cold and warm air, with the front commonly bending into a swirling low pressure system

B. Role of Upper Level Jetstream in Maintaining Low Pressure System
1. Cyclone: low pressure system with converging air drawn inward
a. with inward flow, if there were no mechanism for air escape, the low pressure area would eventually "fill up" with converging air and cease to exist

(1) However, we know that low pressure systems can exist for low periods of time, migrating across U.S.

2. Upper level air flow
   a. With converging air into low pressure system, air is piped to higher altitudes aloft, where it escapes the low pressure zone into the upper jetstream
      (1) "piping" of air through the low to the jet stream allows low pressures to be maintained in the cell over longer periods of time
         (a) otherwise the cell would "fill up" and the pressure would rise

   b. Air flow aloft also helps direct and mobilize cyclonic systems through shear flow

3. Moral of the story: air flow aloft, is important in maintaining and influencing lower level weather patterns

IV. THUNDERSTORMS
   A. Thunderstorms
      1. lightening, thunder, localized intense rain fall, high energy events
      2. associated with billowing cumulonimbus clouds

   B. Formation and Associations
      1. T-storms associated with cumulonimbus clouds
         a. U.S. common associated with Mt air masses derived from Gulf of Mexico and migrate northward
         b. Also: associated with cold fronts and forcful lifting of unstable air

      2. Process
         a. warm moist air lifted aloft
            (1) heat loss and instability with > altitude
            (2) common in afternoon and early evening at max. surface temperatures

         b. Towering cumulonimbus clouds
            (1) upward of 12,000 m in height
            (2) requires continual supply of warm moist air
               (a) cumulative effect to reach great heights
            (3) strong updrafts up to 62 mph
            (4) at point of moisture/drops > updrafts = cloud burst of rain
               (a) upon release of moisture: strong downdrafts, wind gusts, intense rainfall
               (b) life of cumulonimbus clouds ~1 hour between origination and down pour
         c. Lightening
            (1) cloud discharge of electricity
               (a) Process
                  i) associated with movement of precipitation in cloud

ii) Charge accumulation
- a) Upper portion of cloud = positive charge
- b) lower poriton of cloud = negative charge
- c) charges build to millions/hundreds of millions of volts before lightening is discharged

iii) Discharge/lightening
- a) charge buildup until discharge
- b) rapid multiple strokes of electrical charge from cloud to ground or from cloud to cloud
- c) 1/10th of sec. to discharge lightening bolt

(2) Thunder
- (a) lightening---rapid heating of air upon passage----violent expansion of superheated air
  - i) explosive air expansion = thunder
- (b) "heat lightening" = lightening occurring too far away to hear thunder (>20 km)

V. TORNADOES

A. Tornado =
1. local storm of short duration
2. violent wind storm emanating from a funnel-shaped spiraling column of air
3. Low pressure centers, up to 10% lower than outside column
4. Rapid convergence of air to low pressure center
   - a. swirling inrushing air
   - b. high pressure gradients = air flow up to 300 mph
5. tied to cumulonimbus cloud, form in association with thunderstorms
6. Dimensions/velocity
   - a. D = 500-2000 Ft, Vel up to 28 mph
   - b. Tornado tracks up to 16 miles long

B. Frequency and Occurrence
1. dominant in U.S. in April through June
2. Avg. 780/yr in U.S.
3. Tstorms and tornadoes commonly associated with middle-latitude cyclone development from above
   - a. Cp air from canada mixing with Mt air from Gulf of Mexico
     - (1) intense temp. differences
     - (2) commonly meet in central U.S.
     - (3) most common point of occurrence for Tstorms and tornadoes

VI. HURRICANES

A. Hurricanes- whirling tropical cyclones with wind speeds up to 185 mph
1. highly destructive because of high winds in coastal areas
2. may form 50 "storm surge" waves

B. Character
1. Form in tropical waters between 5 and 20 Latitude
   - a. Atlantic = "Hurricanes"
     - (1) U.S. avg. = 5/yr

- b. Pacific = "typhoons"
  - (1) N. Pacific highest no. of occurrence =20/yr
- c. Indian = "Cyclones"

2. Characteristics
   - a. wind speed = > 74 mi/hr
   - b. rotary counterclockwise circulation
   - c. Dimensions
     - (1) D=375 mi
     - (2) Height = up to 40,000 Ft altitude
   - d. Low pressure centers
     - (1) outside press. - inside press. = 60 millibars
     - (2) steep pressure gradient
     - (3) inward, converging, spiraling winds
   - e. Upper level air flow
     - (1) divergent and outward, maintaining the low pressure center of the storm

3. Morphology
   - a. Eye of Hurricane
     - (1) low pressure center of cyclone
       - (a) avg. 12 mile in Diameter
       - (b) zone of calm and scattered clould cover
       - (c) warm zone
   - b. swirling rotation of storm function of coriolis effect

4. Process
   - a. Hurricane = heat energy built up and liberated by release of water vapor
   - b. hurricanes form over oceans in late summer, with abundant warm moist air plentiful
     - (1) water temps to 80 F, warm moist overlying air
     - (2) can not form in cool water temps, hence limited latitudinally
   - c. Storm Progression
     - (1) Tropical depression- cyclone with wind speed < 38 mi/hr
     - (2) Tropical Storm- cyclone with wind speed 38-74 mi/hr
     - (3) Hurricane - cyclone with wind speed > 74 mi/hr
     - (4) Land docked hurricane
       - (a) loses moisture source
       - (b) frictional effect of land slows winds
       - (c) pressure gradient dissipated

C. Identification
1. weather satellit imagery
2. storm tracking and prediction
3. emergency management and contingency in coastal areas

D. Destructive Force
1. high winds/wind shear
2. Storm surge in coastal areas