Moisture, Clouds, and Precipitation

Changes of state of water

❖Heat energy
- Measured in calories – one calorie is the heat necessary to raise the temperature of one gram of water one degree Celsius
- Latent heat
  - Stored or hidden heat
  - Not derived from temperature change
  - Important in atmospheric processes

Changes of state of water

❖Three states of matter
- Solid
- Liquid
- Gas

❖To change state, heat must be
- Absorbed, or
- Released

Changes of state of water

❖Processes
- Evaporation
  - Liquid is changed to gas
  - 600 calories per gram of water are added – called latent heat of vaporization
- Condensation
  - Water vapor (gas) is changed to a liquid
  - Heat energy is released – called latent heat of condensation

Changes of state of water

❖Processes
- Melting
  - Solid is changed to a liquid
  - 80 calories per gram of water are added – called latent heat of melting
- Freezing
  - Liquid is changed to a solid
  - Heat is released – called latent heat of fusion

Changes of state of water

❖Processes
- Sublimation
  - Solid is changed directly to a gas (e.g., ice cubes shrinking in a freezer)
  - 680 calories per gram of water are added
- Deposition
  - Water vapor (gas) changed to a solid (e.g., frost in a freezer compartment)
  - Heat is released

Humidity

❖Measuring humidity
- Relative humidity
  - Ratio of the air's actual water vapor content compared with the amount of water vapor required for saturation at that temperature (and pressure)

Humidity

❖Measuring humidity
- Relative humidity
  - Expressed as a percent
  - Saturated air
    - Content equals capacity
    - Has a 100% relative humidity
  - Relative humidity can be changed in two ways
    - Add or subtract moisture to the air
      - Adding moisture raises the relative humidity
      - Removing moisture lowers the relative humidity

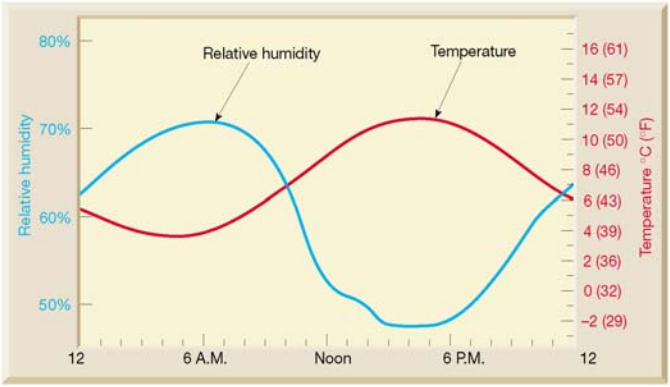
Humidity

❖Measuring humidity
- Relative humidity
  - Relative humidity can be changed in two ways
    - Changing the air temperature
      - Lowering the temperature raises the relative humidity
  - Dew point temperature
    - Temperature to which a parcel of air would need to be cooled to reach saturation

Humidity

❖Measuring humidity
- Relative humidity
  - Dew point temperature
    - Cooling the air below the dew point causes condensation
      - e.g., dew, fog, or cloud formation
      - Water vapor requires a surface to condense on

Typical daily variations in temperature and relative humidity



Adiabatic heating/cooling

❖Adiabatic temperature changes occur when
- Air is compressed
  - Motion of air molecules increases
  - Air will warm
  - Descending air is compressed due to increasing air pressure
- Air expands
  - Air parcel does work on the surrounding air
  - Air will cool
  - Rising air will expand due to decreasing air pressure

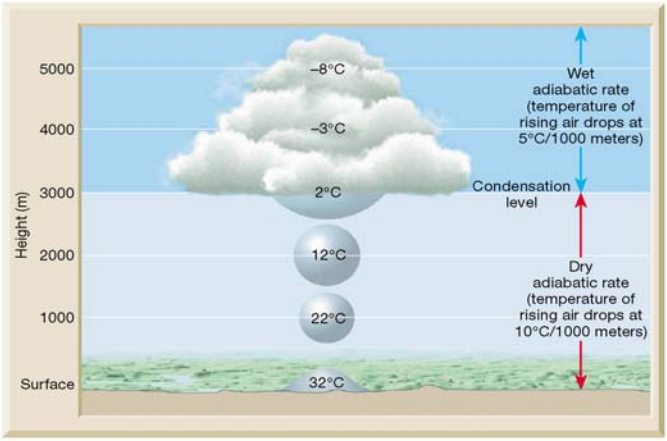
Adiabatic heating/cooling

- ❖Adiabatic temperature changes occur when
  - Adiabatic rates
    - Dry adiabatic rate
      - Unsaturated air
      - Rising air expands and cools at 1˚C per 100 meters (5.5˚F per 1000 feet)
      - Descending air is compressed and warms at 1˚C per 100 meters

Adiabatic heating/cooling

- ❖Adiabatic temperature changes occur when
  - Adiabatic rates
    - Wet adiabatic rate
      - Commences at condensation level
      - Air has reached the dew point
      - Condensation is occurring and latent heat is being liberated
      - Heat released by the condensing water reduces the rate of cooling

Adiabatic cooling of rising air



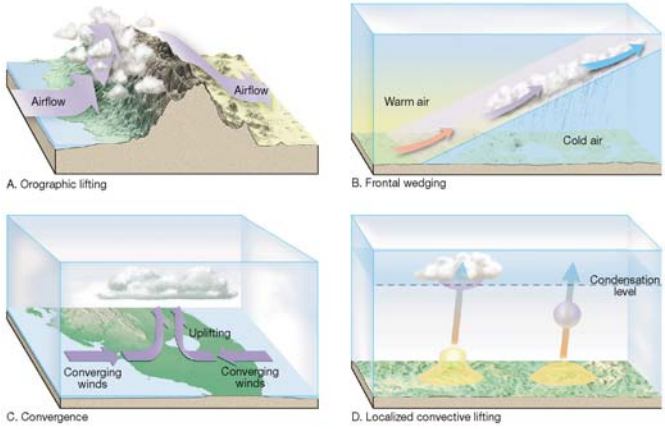
Processes that lift air

- ❖Orographic lifting
  - Elevated terrains act as barriers
  - Result can be a rainshadow desert
- ❖Frontal wedging
  - Cool air acts as a barrier to warm air
  - Fronts are part of the storm systems called middle-latitude cyclones

Processes that lift air

- ❖Convergence where the air is flowing together and rising (low pressure)
- ❖Localized convective lifting
  - Localized convective lifting occurs where unequal surface heating causes pockets of air to rise because of their buoyancy

Processes that lift air



Stability of air

❖Types of stability

- Stable air
  - Resists vertical displacement
    - Cooler than surrounding air
    - Denser than surrounding air
    - Wants to sink
  - No adiabatic cooling
  - Absolute stability occurs when the environmental lapse rate is less than the wet adiabatic rate

Stability of air

❖Types of stability

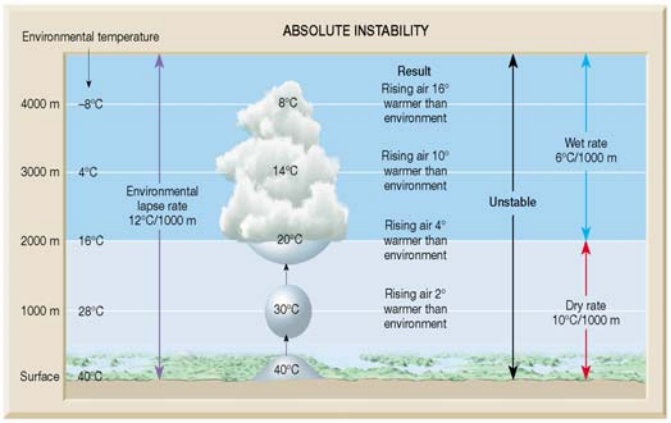
- Stable air
  - Often results in widespread clouds with little vertical thickness
  - Precipitation, if any, is light to moderate
- Absolute instability
  - Acts like a hot air balloon
  - Rising air
    - Warmer than surrounding air
    - Less dense than surrounding air
    - Continues to rise until it reaches an altitude with the same temperature

Stability of air

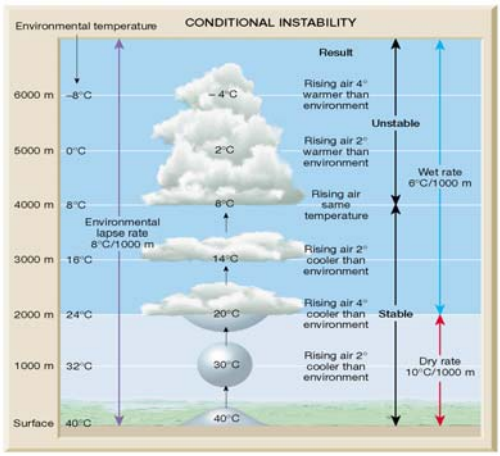
❖Types of stability

- Absolute instability
  - Adiabatic cooling
  - Environmental lapse rate is greater than the dry adiabatic rate
  - Clouds are often towering
  - Conditional instability occurs when the atmosphere is stable for an unsaturated parcel of air but unstable for a saturated parcel

Absolute instability



Conditional instability



Stability of air

❖Determines to a large degree

- Type of clouds that develop
- Intensity of the precipitation

Condensation and cloud formation

❖Condensation

- Water vapor in the air changes to a liquid and forms dew, fog, or clouds
- Water vapor requires a surface to condense on
  - Possible condensation surfaces on the ground can be the grass, a car window, etc.
  - Possible condensation surfaces in the atmosphere are tiny bits of particulate matter
    - Called condensation nuclei
    - Dust, smoke, etc
    - Ocean salt crystals which serve as hygroscopic ("water seeking") nuclei

Condensation and cloud formation

❖Clouds

- Made of millions and millions of
  - Minute water droplets, or
  - Tiny crystals of ice
- Classification based on
  - Form (three basic forms)
    - Cirrus – high, white, thin
    - Cumulus - globular cloud masses often associated with fair weather
    - Stratus – sheets or layers that cover much of the sky

Cirrus clouds

A. Cirrus

Altostratus clouds

E. Altostratus

Cumulus clouds

G. Cumulus

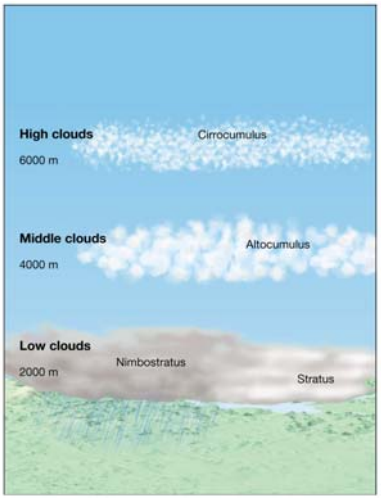
Condensation and cloud formation

❖Clouds

- Classification based on
  - Height
    - High clouds - above 6000 meters
      - Types include cirrus, cirrostratus, cirrocumulus
    - Middle clouds – 2000 to 6000 meters
      - Types include altostratus and altocumulus
    - Low clouds – below 2000 meters
      - Types include stratus, stratocumulus, and nimbostratus (nimbus means "rainy")

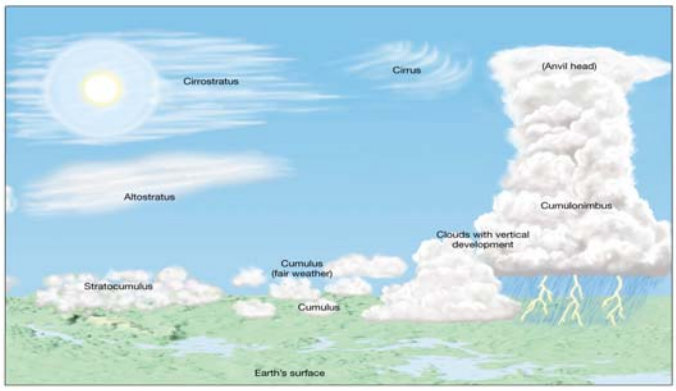
Condensation and cloud formation

- Clouds
  - Classification based on
    - Height
      - Clouds of vertical development
        - From low to high altitudes
        - Called cumulonimbus
        - Often produce rain showers and thunderstorms



Classification of clouds according to height and form

Classification of clouds according to height and form (continued)



Fog

- Considered an atmospheric hazard
- Cloud with its base at or near the ground
- Most fogs form because of
  - Radiation cooling, or
  - Movement of air over a cold surface

Fog

- Types of fog
  - Fogs caused by cooling
    - Advection fog – warm, moist air moves over a cool surface
    - Radiation fog
      - Earth's surface cools rapidly
      - Forms during cool, clear, calm nights
    - Upslope fog
      - Humid air moves up a slope
      - Adiabatic cooling occurs

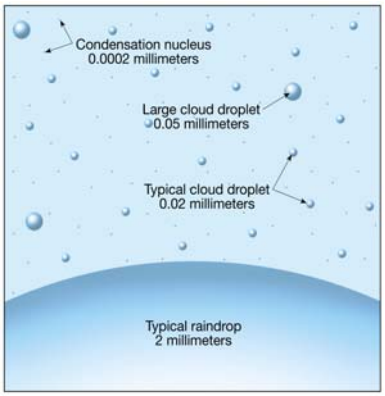
Fog

- Types of fog
  - Evaporation fogs
    - Steam fog
      - Cool air moves over warm water and moisture is added to the air
      - Water has a steaming appearance
    - Frontal fog, or precipitation fog
      - Forms during frontal wedging when warm air lifted over colder air
      - Rain evaporates to form fog

Precipitation

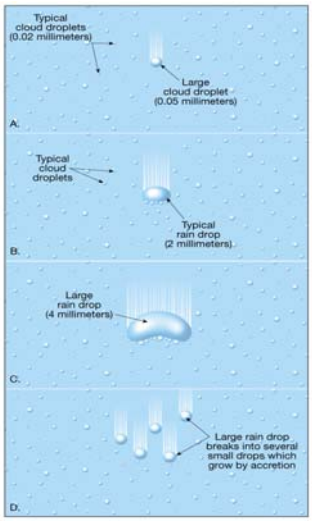
❖Cloud droplets
- Less than 20 micrometers (0.02 millimeter) in diameter
- Fall incredibly slow

Particle sizes involved in condensation and precipitation



Precipitation

❖Formation of precipitation
- Collision-coalescence process
  - Warm clouds
  - Large hygroscopic condensation nuclei
  - Large droplets form
  - Droplets collide with other droplets during their descent
  - Common in the tropics

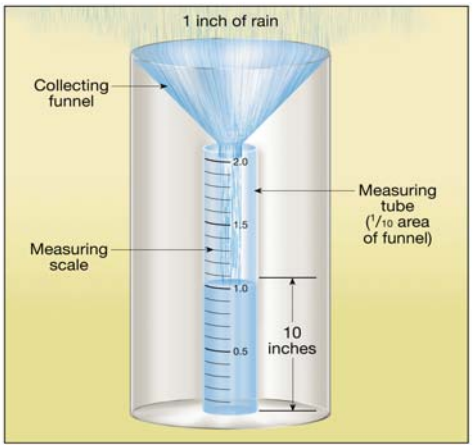


The collision-coalescence process

Precipitation

❖Forms of precipitation
- Hail
  - Hard rounded pellets
    - Concentric shells
    - Most diameters range from 1 to 5 cm
  - Formation
    - Occurs in large cumulonimbus clouds with violent up- and down drafts
    - Layers of freezing rain are caught in up- and down drafts in the cloud
    - Pellets fall to the ground when they become too heavy

The standard rain gauge



Precipitation

- Measuring precipitation
  - Snow has two measurements
    - Depth
    - Water equivalent
      - General ratio is 10 snow units to 1 water unit
      - Varies widely
      - Radar is also used to measure the rate of rainfall