Chapter 6
Atmospheric Moisture and Precipitation
The Hydrosphere

- **Hydrosphere** – water in the earth-atmosphere system
  - Oceans and Salt Lakes \(97.6\%\)
  - Ice Caps and Glaciers \(1.9\%\)
  (Not available for humans) \(99.5\%\)
  - Subsurface Water (soil, groundwater) \(0.5\%\)
  - Surface Water (rivers, freshwater lakes) \(0.02\%\)
  - Atmosphere \(0.0001\%\)

- If all land were flat, the oceans would cover it to a depth of 3 km
- If all atmospheric water were precipitated, it would cover the earth to a depth of 25 mm (1 inch)
- Holt, MO -- 12 inches of rain in 42 minutes!
The Hydrosphere

- Over 70% of the planet is covered by water
- Water is unique in that it can simultaneously exist in all three states (solid, liquid, gas) at the same temperature
- Water is able to shift between states very easily
The diagram illustrates the water cycle, showing the transitions between different states of water:

1. **Gaseous state (Water vapor)**
   - Latent heat absorbed (Sublimation)
   - Latent heat released (Deposition)

2. **Liquid state (Water)**
   - Latent heat released (Freezing)
   - Latent heat absorbed (Melting)

3. **Solid state (Ice)**
   - Latent heat released (Freezing)
   - Latent heat absorbed (Melting)

The cycle is closed with the release of latent heat during freezing and the absorption of latent heat during melting, and vice versa for sublimation and deposition.

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Hydrologic cycle defines the movement of water among the great global reservoirs

- Positive balance over land = more precipitation than evaporation
- Negative balance over water = more evaporation than precipitation
Evaporation

- Molecules escape liquid water as water vapor.
- Water vapor increases in air as surface water evaporates.
- **Condensation** begins and water returns to the surface.
  - Water vapor molecules become liquid.
Atmospheric Humidity

- **Humidity** – the amount of water vapor in the air
- When saturated, warm air contains more water vapor than cold air
- Thus, we erroneously say that warm air can “hold” more water vapor than cold air
- So, we would expect deserts near the poles due to the cold air temperatures
Atmospheric Humidity

PHYSICALLY IMPOSSIBLE!

Temperature (°C)

Saturation vapor pressure (mb)

Saturation specific humidity (gm/kg)
Atmospheric Humidity

- **Relative Humidity** – the amount of water vapor in the air relative to the amount at saturation

- If air is saturated, we say that it has a relative humidity of 100%

- A relative humidity of 50% implies that the air has only half as much water vapor as it would have when saturated
Atmospheric Humidity

- Since at saturation, warm air contains more water vapor than cold air, relative humidity is inversely related to air temperature.

- As air temperature rises and the amount of moisture in the air remains the same, the relative humidity decreases.

- As air temperature falls and the amount of moisture in the air remains the same, the relative humidity increases.
**Atmospheric Humidity**

- **Dew Point** -- the temperature the air must reach for the air to become saturated. If you lower the air temperature until the relative humidity reaches 100%, you have reached the dew point. Lowering the air temperature below the dew point will result in condensation.
PHYSICALLY IMPOSSIBLE!
Atmospheric Humidity

- Relative humidity is strongly dependent on the air temperature; the dew point is a more conservative measure of the moisture content of the air.

- Therefore, dew point is a better way to represent the moisture content of the air.
Atmospheric Humidity

- Relative humidity is inversely related to air temperature; the dew point is not.
- The highest value of relative humidity usually occurs just after sunrise.
- The lowest value of relative humidity usually occurs in the mid-afternoon.
(a) Relative humidity

(b) Air temperature and Dew point

Time of day:
- Midnight
- 6 A.M.
- Noon
- 6 P.M.

Temperature, °C:
- 0
- 5
- 10
- 15
- 20
- 25
- 30

Temperature, °F:
- 32
- 40
- 50
- 60
- 70
- 80

Data from National Weather Service.
Air Temperature and Height
Air Temperature and Height

- In the troposphere, air temperature decreases with height
- Rising air expands due to the decreasing atmospheric pressure and cools as it expands
- Similarly, descending air will warm as it compresses due to the increasing atmospheric pressure
The process by which changes in air temperature occur solely as a result of changes in atmospheric pressure is called an \textit{adiabatic process}.

When air is heated or cooled adiabatically and no condensation occurs, air temperature will follow the \textit{dry adiabatic lapse rate} which equals about 10°C per kilometer (or about 5.5°F per 1000 feet).
Air Temperature and Height

- However, rising air will cool and it is possible that it will reach the dew point temperature (a relative humidity of 100%)

- At that point, or the lifting condensation level, moisture will condense from the air and the air temperature will follow the wet adiabatic lapse rate which ranges from between 4°C and 9°C per kilometer

- The wet adiabatic lapse rate will be lower for warmer air since there is more moisture to condense
Figure 4-2: A parcel of air which is forced to rise to a height of 1 kilometer when it is not saturated (left) and when it is saturated (right).
Consider air flowing over a mountain that is 4 kilometers high (13,123 feet)

For simplicity, we will assume the wet adiabatic lapse rate is 6°C per kilometer

At sea level on the windward side of the mountain, the air temperature is 30°C and the dew point is 10°C
At Sea Level, Windward Side:
Air Temperature = 30°C
Dew Point = 10°C
At 1km, Windward Side:
Air Temperature = 20 °C
Dew Point = 10 °C
At 2km, Windward Side:
Air Temperature = 10 C
Dew Point = 10 C
At 3km, Windward Side:
Air Temperature = 4 C
Dew Point = 4 C
At the Summit, Leeward Side:
Air Temperature = -2 C
Dew Point = -2 C
At 3km, Leeward Side:
Air Temperature= 8 C
Dew Point= -2 C
At 2km, Leeward Side:
Air Temperature = 18 C
Dew Point = -2 C
At 1km, Leeward Side:
Air Temperature = 28˚C
Dew Point = -2˚C
At Sea Level, Leeward Side:
Air Temperature = 38 C
Dew Point = -2 C
Air Temperature and Height

- This demonstrates the **rainshadow effect** of mountain ranges.
- Precipitation occurs on the windward side.
- Warmer and drier conditions are found on the leeward side of the mountain range (e.g., Washington, Oregon, California).
- Downslope winds can be warm and dry – sometimes called **Chinook Winds**.
PHYSICALLY IMPOSSIBLE!

Atmospheric Humidity

Temperature (°C)

Saturation vapor pressure (mb)

Saturation specific humidity (gm/kg)
Precipitation
To get precipitation, you need:

- Moisture in the Atmosphere
- Mechanism to Release the Moisture
  - Every Mechanism Causes Air to Cool Below the Dew Point Temperature
PHYSICALLY IMPOSSIBLE!
To get precipitation, you need:

- Moisture in the Atmosphere
- Mechanism to Release the Moisture
  - Every Mechanism Causes Air to Cool Below the Dew Point Temperature
  - The Easiest Mechanism is to Force Air to Rise
  - There are 4 Basic Mechanisms for Precipitation and 1 for Condensation
To get precipitation, you need:

1) Moisture in the Atmosphere
   - Clouds are the source of precipitation
   - In warm clouds, liquid droplets condense and collide
   - When the droplets become large enough, they fall as rain
Precipitation Causing Mechanisms
Precipitation Causing Mechanisms

- Orographic Precipitation
1) Orographic Precipitation

- Warm moist air is forced over a mountain barrier
- It cools adiabatically
- At the LCL condensation (and often precipitation occurs)
Precipitation Causing Mechanisms

- Orographic Precipitation
- Convective Precipitation
2) Convective Precipitation

- Convection = upwards motion of heat air (convection cells)
- Caused by uneven surface heating
- Parcel of warmer, less dense air rises
- As the parcel rises, it cools
2) Convective Precipitation

- If the air is quite moist, the release of latent heat will ensure that the parcel of air remains warmer than the surrounding air.

- If conditions remain favorable, the rising thermal will grow into a thunderstorm.
Precipitation Causing Mechanisms

- Orographic Precipitation
- Convective Precipitation
- Cyclonic Precipitation
3) Cyclonic Precipitation

- Pressure differences cause air motion (wind)
- A low pressure cell at the surface causes convergence
- Low level convergence causes upward vertical motion, and therefore precipitation
Precipitation Causing Mechanisms

- Orographic Precipitation
- Convective Precipitation
- Cyclonic Precipitation
- Frontal Precipitation
4) Frontal Precipitation

- Frontal uplift – air can be forced upward through the movement of air masses

- **Air masses** = a large body of air, with a set of relatively uniform temperature and moisture properties
4) Frontal Precipitation

- When a colder, more dense air mass advances on a warmer, less dense air mass (a cold front), it is forced to rise over the cold air mass.
Precipitation Causing Mechanisms

- Orographic Precipitation
- Convective Precipitation
- Cyclonic Precipitation
- Frontal Precipitation
Atmospheric Lifting Mechanisms

(a) Convergent

(b) Convectional (local heating)

(c) Orographic (barrier)

(d) Frontal (e.g. cold front)
Clouds
Clouds are instrumental to the Earth’s energy and moisture balances.

Most clouds form as air parcels are lifted and cooled to saturation.

Different lifting mechanisms exist to lift air and form clouds through condensation.

In the 1700s, a British Pharmacist developed a cloud classification scheme that we still use today.
Clouds and Cloud Formation

- Clouds are classified on the basis of the presence or absence of vertical development.
  - *Cumuloform* clouds exhibit significant vertical development.
  - *Stratiform* clouds do not exhibit significant vertical development.
Clouds and cloud formations

- **Cirrus** – thin, wispy clouds of ice
- **Nimbus** – rain producing clouds
Cumuloform Clouds

- **Cumulus Clouds**
  - 1-2 km thick, 600-1200 meters high
Formation of fair weather cumulus

Zone of rising air  Zone of sinking air  Zone of rising air
Cumuloform Clouds

- **Cumulus** Clouds
  - 1-2 km thick, base is 600-1200 meters high
- **Cumulus Congestus**
  - 3-5 km thick
Cumuloform Clouds

- **Cumulus** Clouds
  - 1-2 km thick, base is 600-1200 meters high

- **Cumulus Congestus**
  - 3-5 km thick

- **Cumulonimbus**
  - 6-12 km thick – thunderstorm clouds

- Progression occurs with development
Stratiform Clouds

- Classified on the basis of height

*High Clouds* – more than 6 km high
*Middle Clouds* – between 2 and 6 km high
*Low Clouds* – less than 2 km high
Stratiform Clouds

**High Clouds** – more than 6 km high
- Composed entirely of ice crystals
- Whitish appearance
- Temperature is around -35°C
- Little water vapor (0.025 g/m³)

- High clouds –
  - Cirrus: fine and wispy
Cirrus clouds with fall streaks
Stratiform Clouds

**High Clouds** – more than 6 km high
- Composed entirely of ice crystals
- Whitish appearance
- *Cirrus* – fine and wispy
- *Cirrostratus* – forming a complete layer
When viewed through a layer of cirrostratus, the Moon or Sun has a whitish, milky appearance but a clear outline. A characteristic feature of cirrostratus clouds is the *halo*, a circular arc around the Sun or Moon formed by the refraction (bending) of light as it passes through the ice crystals.
Stratiform Clouds

*High Clouds* – more than 6 km high
- Composed entirely of ice crystals
- Whitish appearance
- **Cirrus** – fine and wispy
- **Cirrostratus** – forming a complete layer
- **Cirrocumulus** – light puffy clouds
  - “Mackerel Sky”
Stratiform Clouds

**Middle Clouds** – between 2 and 6 km high

- Composed of a combination of ice crystals and water droplets
- Thicker due to higher temperatures
- *Altostratus* – forming a near complete layer
Stratiform Clouds

Middle Clouds – between 2 and 6 km high

- Composed of a combination of ice crystals and water droplets
- Thicker due to higher temperatures

- Altostratus – forming a near complete layer

- Altocumulus – rows of puffy clouds
Stratiform Clouds

*Low Clouds* – less than 2 km high

- Composed primarily of water droplets
- Thicker and somewhat darker

*Stratus* – a nearly unbroken layer of gray
Stratiform Clouds

**Low Clouds** – less than 2 km high

- Composed primarily of water droplets
- Thicker and somewhat darker
- **Stratus** – a nearly unbroken layer of gray
- **Stratocumulus** – rows of puffy clouds
Cumulus or Stratocumulus?

- **Cumulus**
  - flat bottoms
  - occur when significant lifting is present

- **Stratocumulus**
  - rounded bottoms
  - occur when vertical motions are minimal
Low *Clouds* – less than 2 km high

- Composed primarily of water droplets
- Thicker and somewhat darker
- *Stratus* – a nearly unbroken layer of gray
- *Stratocumulus* – rows of puffy clouds
- *Nimbostratus* – stratus cloud from which rain is falling
### Classification of Clouds According to Height and Form

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<tr>
<th>Cloud Type</th>
<th>Height</th>
<th>Notes</th>
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<tr>
<td>High clouds</td>
<td>12 km (about 40,000 ft)</td>
<td>Cirrus, Cirrocumulus, Cirrostratus</td>
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<tr>
<td>Middle clouds</td>
<td>6 km (about 20,000 ft)</td>
<td>Altostratus, Cumulus, Altostratus</td>
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<td>3 km (about 10,000 ft)</td>
<td>Nimbostatus, Stratocumulus, Stratus</td>
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<td>Clouds with</td>
<td>1.5 km (about 5000 ft)</td>
<td>Cumulus of fair weather, Cumulonimbus</td>
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<td>Vertical Development</td>
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<td>Anvil head</td>
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Lenticular Clouds

- Form downwind on mountain barriers
- Have a curved (lense-like) shape
altocumulus standing
lenticularus

Lenticular Clouds
Stratiform Clouds

- **Fog** – stratus cloud at the ground
- **Advection Fog** – moving air over a colder surface
  - (e.g., the Grand Banks of Newfoundland)
- **Radiation Fog** – motionless air that cools below the dew point due to longwave radiation loss at night
Radiation Fog in the Central Valley of California
Stratiform Clouds

- **Fog** – stratus cloud at the ground
- **Sea Fog** – forms when a cool moist air parcel comes in contact with cold ocean

Occurs along the coasts of continents where cold currents move toward the equator (e.g. California, Peru)
What is the difference between the environmental lapse rate and the dry adiabatic lapse rate?
Environmental Lapse Rate vs. DALR/WALR

- Is the average temperature lapse rate, an expression of how temperature of still air varies with altitude.

- This rate will vary from time to time and from one place to another, depending on the state of the atmosphere.

- No motion if air is implied for the environmental lapse rate (both DALR and WALR rely on motion).