Water, Weather, and Climate Systems

Atmospheric Water

Water and Atmospheric Moisture

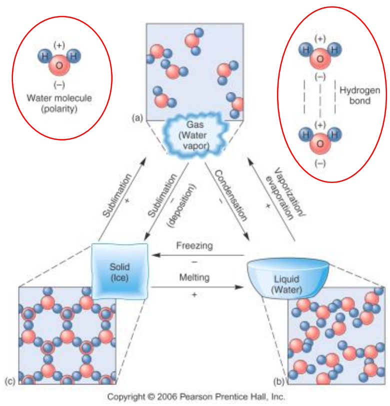
- **Water on Earth**
- **Unique Properties of Water**
- **Humidity**
- **Atmospheric Stability**
- **Clouds and Fog**

Three Phases of Water

- **Water vapor is the gas phase:**
  - **Each molecule moves independently**
  - **Compressible gas**
- **Water is the liquid phase:**
  - **Water reaches it's greatest density at 4 ºC (39º F)**
  - **Density decreases below this temperature**
- **Ice is the solid phase:**
  - **Solid ice less dense than liquid water (ice floats)**
- **For phase changes, heat energy must be added or released:**
  - **Sublimation: direct change of water vapor to ice or ice to water vapor**

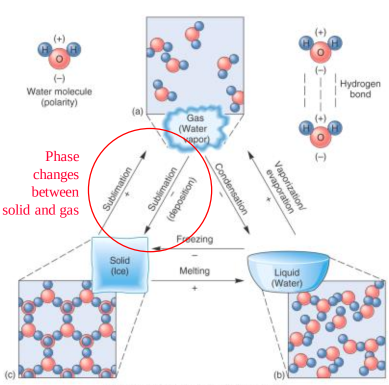
Water molecule is polar

Three States of Water

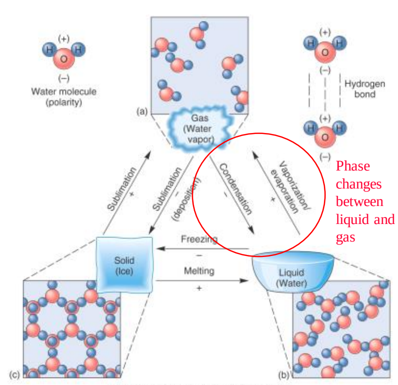


Three States of Water

Phase changes between solid and gas

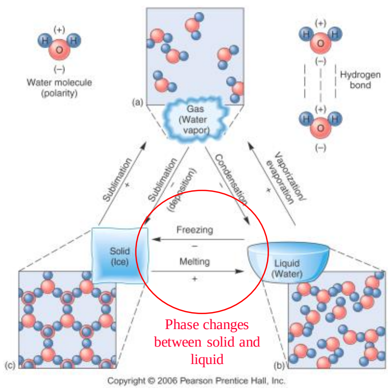


Three States of Water

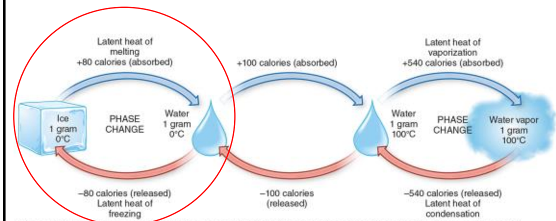


Phase changes between liquid and gas

Three States of Water

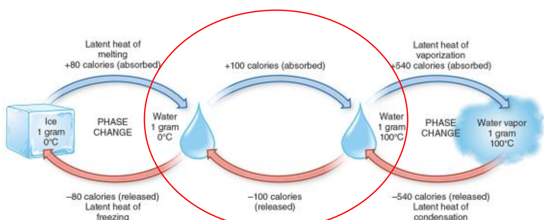


Water's Heat Energy Characteristics



(a) Latent heat absorbed or released in phase changes between ice and water and water vapor. To transform 1 g of ice at 0°C to 1 g of water vapor at 100°C requires 720 cal: 80 + 100 + 540.

Water's Heat Energy Characteristics



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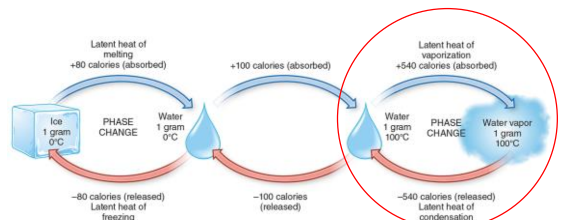

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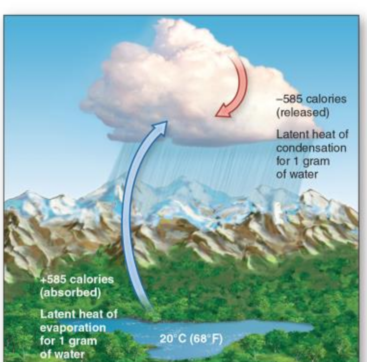
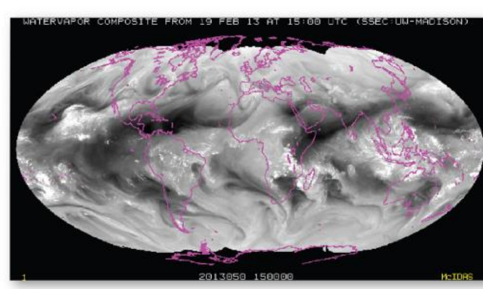


(b) Latent heat exchange between water in a lake at 20°C and water vapor in the atmosphere, under typical conditions.

Global Water Vapor in the Atmosphere



HUMIDITY

- Specific Humidity g/kg
- Relative Humidity %
- Dew Point ºC or ºF
- Wet Bulb/Dry Bulb ºC or ºF
- Vapor Pressure mb

Specific Humidity

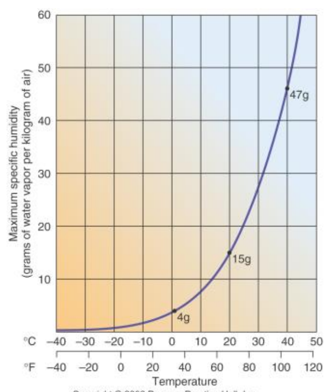
- Specific Humidity = Mass of water vapor (in grams) per mass of air (in kilograms) at a given temperature:

$$\frac{\text{Grams of water vapor}}{\text{Kg of air}}$$

Maximum Specific Humidity at Saturation

How is maximum specific humidity related to temperature?

Maximum specific humidity increases with temperature. Warmer air can hold more water vapor.
More water vapor is required to saturate warmer air

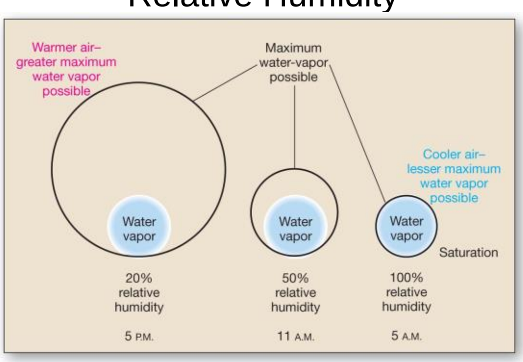


Relative Humidity

- Relative Humidity (RH) expressed in percent =

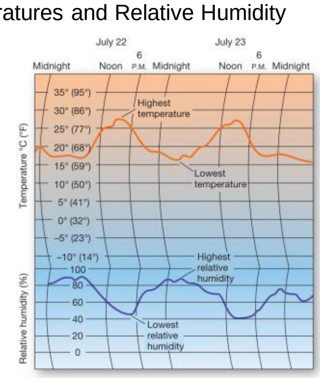
$$\frac{\text{Mass of Water in Air} \times 100}{\text{Mass Of Water Air Can Hold}}$$

Relative Humidity



Daily Temperatures and Relative Humidity

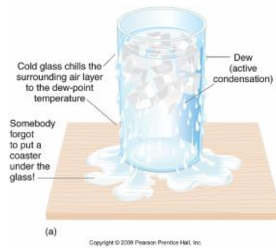
Relative humidity decreases at higher temperatures; increases at lower temperatures



Dew Point

Temperature at Which Water Vapor Begins to Condense

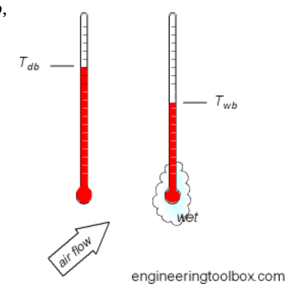
Dew Point Temperature Examples



Dry Bulb / Wet Bulb Used To Determine Dew Point

Dry-bulb temperature - *Tdb*, can be measured using a normal thermometer freely exposed to the air

Wet bulb temperature – *Twb*, is indicated by a moistened thermometer bulb exposed to air flow



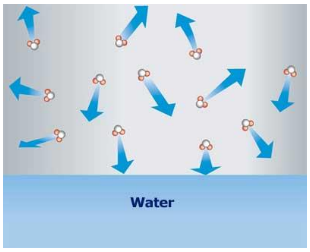
Dewpoint Temperatures (°C)

Dry-Bulb Temperature (°C)	Difference Between Wet-Bulb and Dry-Bulb Temperatures (C°)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
−20	−20	−33														
−18	−18	−28														
−16	−16	−24														
−14	−14	−21	−36													
−12	−12	−18	−28													
−10	−10	−14	−22													
−8	−8	−12	−18	−29												
−6	−6	−10	−14	−22												
−4	−4	−7	−12	−17	−29											
−2	−2	−5	−8	−13	−20											
0	0	−3	−6	−9	−15	−24										
2	2	−1	−3	−6	−11	−17										
4	4	1	−1	−4	−7	−11	−19									
6	6	4	1	−1	−4	−7	−13	−21								
8	8	6	3	1	−2	−5	−9	−14								
10	10	8	6	4	1	−2	−5	−9	−14	−28						
12	12	10	8	6	4	1	−2	−5	−9	−16						
14	14	12	11	9	6	4	1	−2	−5	−10	−17					
16	16	14	13	11	9	7	4	1	−1	−6	−10	−17				
18	18	16	15	13	11	9	7	4	2	−2	−5	−10	−19			
20	20	19	17	15	14	12	10	7	4	2	−2	−5	−10	−19		
22	22	21	19	17	16	14	12	10	8	5	3	−1	−5	−10	−19	
24	24	23	21	20	18	16	14	12	10	8	6	2	−1	−5	−10	−18
26	26	25	23	22	20	18	17	15	13	11	9	6	3	0	−4	−9
28	28	27	25	24	22	21	19	17	16	14	11	9	7	4	1	−3
30	30	29	27	26	24	23	21	19	18	16	14	12	10	8	5	1

Vapor Pressure

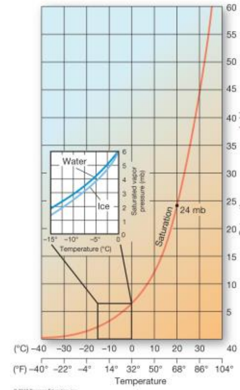
The Amount of Pressure Exerted By Water Vapor in the Atmosphere

As more water vapor enters the atmosphere, the amount of pressure exerted by that water vapor increases. When the vapor pressure maximum is reached, no more water can enter the atmosphere and the atmosphere is saturated.

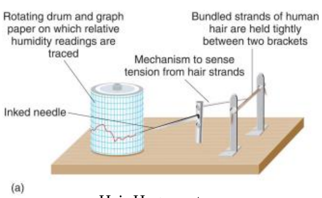


Saturation Vapor Pressure

The higher the temperature, the greater the saturation vapor pressure



Humidity Instruments



Hair Hygrometer

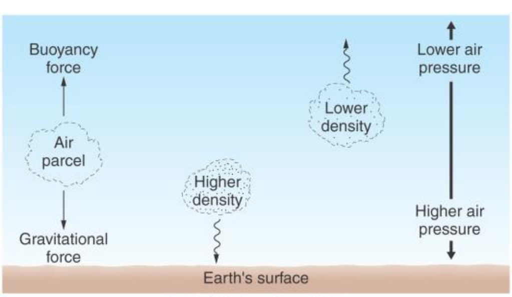
Sling psychrometer with wet and dry bulbs

(b)

Atmospheric Stability

- **Differences in temperature create changes in density within an air parcel:**
  - **Warmer air: lower density**
  - **Cold air: higher density**
- **Two opposing forces work on a parcel of air:**
  - **Upward buoyancy force**
  - **Downward gravitational force**
- **A parcel of lower density air will rise (more buoyant) while denser air will descend (less buoyant)**

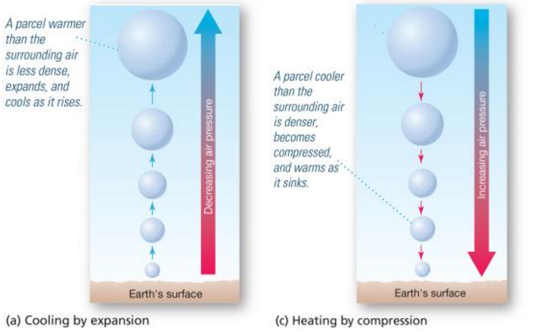
Buoyancy and Gravity



Adiabatic Processes

- **The warming and cooling rates for a parcel of expanding or compressing air are termed adiabatic:**
  - **Ascending air parcel cools by expansion in response to reduced pressure at higher altitudes**
  - **Descending air heats by compression due to increasing pressure at lower altitudes**

Adiabatic Processes



(a) Cooling by expansion (c) Heating by compression

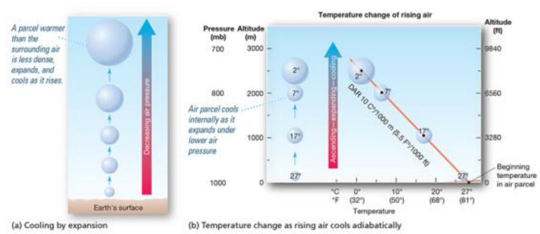
Adiabatic Rates

- Dry adiabatic rate (DAR) is the rate at which "dry" air cools by expansion or heats by compression
- Moist adiabatic rate (MAR) is the average rate at which ascending air that is moist (saturated) cools by expansion:
  - Latent heat of condensation in moist air is liberated as sensible heat, reducing the adiabatic rate of cooling
  - MAR less than DAR

Adiabatic Processes

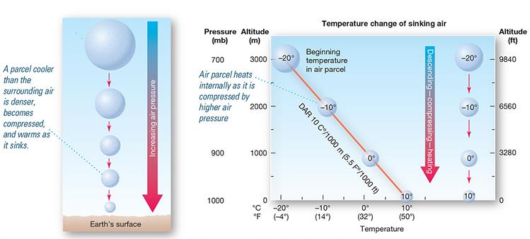
- Dry adiabatic rate
  - 10 C°/1000 m
  - 5.5 F°/1000 ft
- Moist adiabatic rate
  - 6 C°/1000 m
  - 3.3 F°/1000 ft

Adiabatic Cooling



(a) Cooling by expansion (b) Temperature change as rising air cools adiabatically

Adiabatic Heating



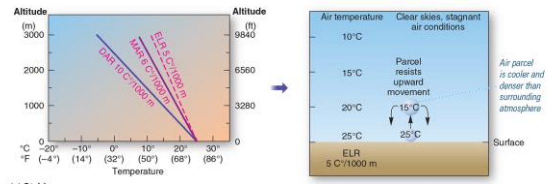
(c) Heating by compression (d) Temperature change as sinking air heats adiabatically

Atmospheric Stability

Stability of Atmospheric Conditions

- **Normal lapse rate: Average drop in temperature with increasing altitude (6.4 C° per 1000 m) for still, calm air**
- **Environmental lapse rate: Actual lapse rate for air at a particular place and time:**
  - **Can be lower or higher than the normal lapse rate depending on conditions**

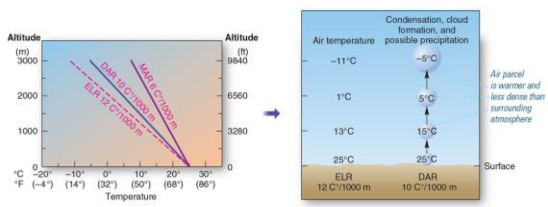
Stable Atmospheric Conditions



(a) Stable

- Environmental lapse rate less than both the DAR and MAR
- Both moist and dry air parcels have adiabatic rates higher than the environmental lapse rate
- Both parcels remain cooler than surrounding atmosphere and are forced to settle back to original positions

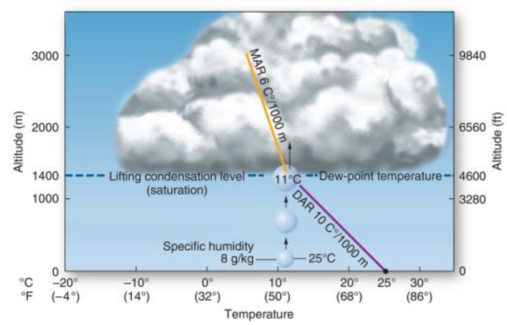
Unstable Atmospheric Conditions



(b) Unstable

- Rising air parcel has a lower adiabatic rate than the environmental lapse rate of the surrounding air
- Air parcel always warmer than surrounding atmosphere
- Parcel continues to rise, leading to saturation and cloud formation

Unstable Atmospheric Conditions

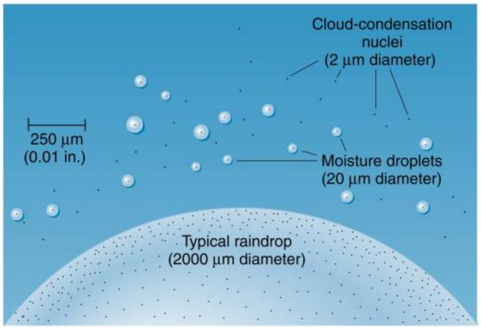


Atmospheric Stability

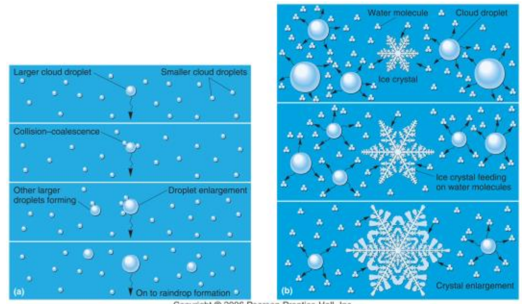
Clouds

- **A cloud is an aggregation (grouping) of moisture droplets and ice crystals suspended in air:**
  - **Rising air parcel cools to dew point**
  - **Further lifting causes active condensation of water vapor around condensation nuclei (dust, soot, ash, etc.)**
  - **Cloud initially composed of microscopic moisture droplets**
  - **A million or more moisture droplets aggregate to form a rain drop**

Moisture Droplets



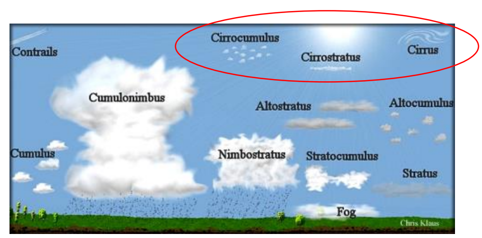
Raindrop and Snowflake Formation



Clouds Defined By Form And Altitude

- **Three basic forms:**
  - **Stratiform: Develop horizontally as flat and layered clouds**
  - **Cumuliform: Puffy and globular clouds**
  - **Cirroform: Wispy**
- **Cloud altitudes:**
  - **Low clouds: Surface up to 2,000 m**
  - **Middle: 2,000 – 6,000 m (preface *alto*-)**
  - **High: Above 6,000 m**
  - **Vertically developed**

High Altitude Cirrus-Type Clouds

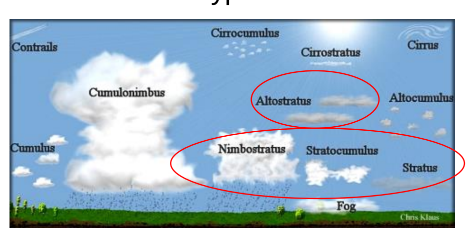


- Cirrus are high altitude clouds composed of ice crystals
- Exhibit thin, wispy forms
- Often associated with an approaching storm

Cirrus

(b)

Stratus-Type Clouds



- Stratus clouds usually low to middle altitude
- Composed of water droplets
- Appear dull, gray, and featureless
- Nimbostratus clouds yield precipitation where showers typically fall as drizzling rain

Stratus

(f)

Nimbostratus

(e)

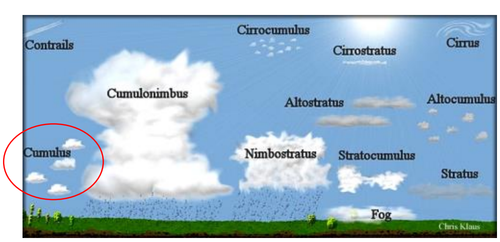
Altostratus

(g)

Cirrostratus

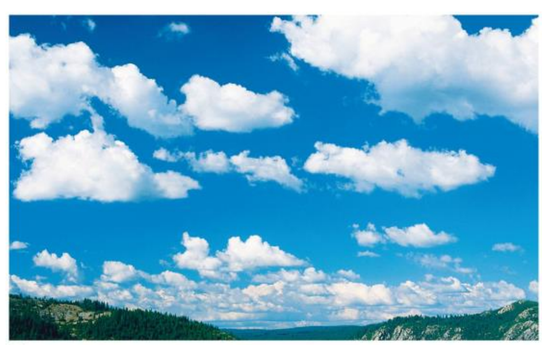
(c)

Cumulus-Type Clouds



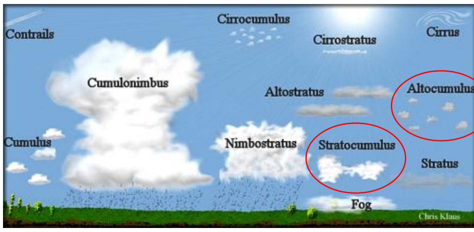
- Cumulus are low-level puffy clouds composed of water droplets
- Associated with fair weather

Cumulus



(h)

Cumulus-Type Clouds

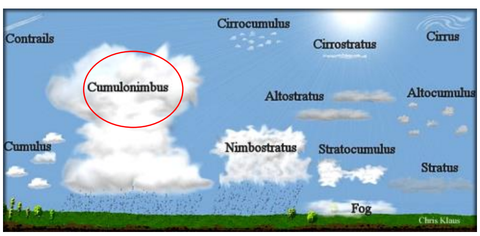


- Stratocumulus clouds are lumpy, grayish, low-level clouds that sometimes indicate clearing weather
- Altocumulus clouds are middle-level clouds that appear in patchy rows or wave patterns

Altocumulus

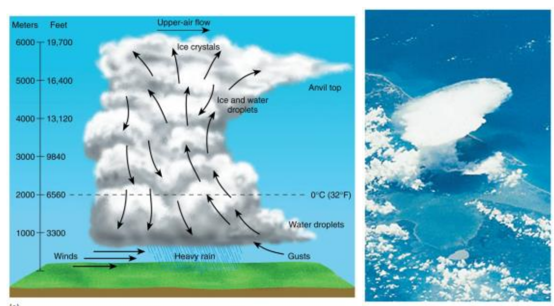
(a)

Cumulonimbus Clouds



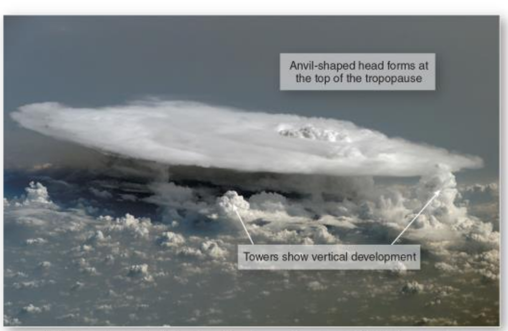
- Towering giant, vertical clouds often called thunderheads
- Associated with strong storms, thunder and lightening
- High-altitude winds may shear the top into the characteristic anvil shape

Cumulonimbus Development



(a)

(b)



(b) A dramatic cumulonimbus thunderhead over Africa at 13.5° N latitude near the Senegal–Mali border.

Fog

- **Fog is a cloud layer on the ground that restricts visibility to less than 1 km**
- **Several types:**
  - **Advection fog**
  - **Evaporation fog**
  - **Upslope fog**
  - **Valley fog**
  - **Radiation fog**

Advection Fog

- Advection fog forms when air in one place migrates to another place where conditions cause saturation
- Warm, moist air moves over cooler ocean currents, lake surfaces or snow masses
- Air layer directly above the cooler surface is chilled to the dew point

Evaporation Fog

- Evaporation fog forms when water molecules evaporate from the water surface into cold, overlying air
- Also known as steam fog or sea smoke

Upslope Fog

- A type of advection fog where moist air is forced to higher elevations along a hill or mountain
- Adiabatic expansion results in cooling and condensation
- Resulting upslope fog forms a stratus cloud at the level of saturation
- Common in winter and spring along the Appalachians and eastern slopes of the Rockies

Valley Fog

- Cool, dense air settles in low-lying areas
- Valley fog forms as a chilled, saturated layer near the ground

Radiation Fog

- Radiation fog forms when radiative cooling of a surface chills the air layer directly above the ground to the dew-point temperature
- Often occurs on clear nights over moist ground