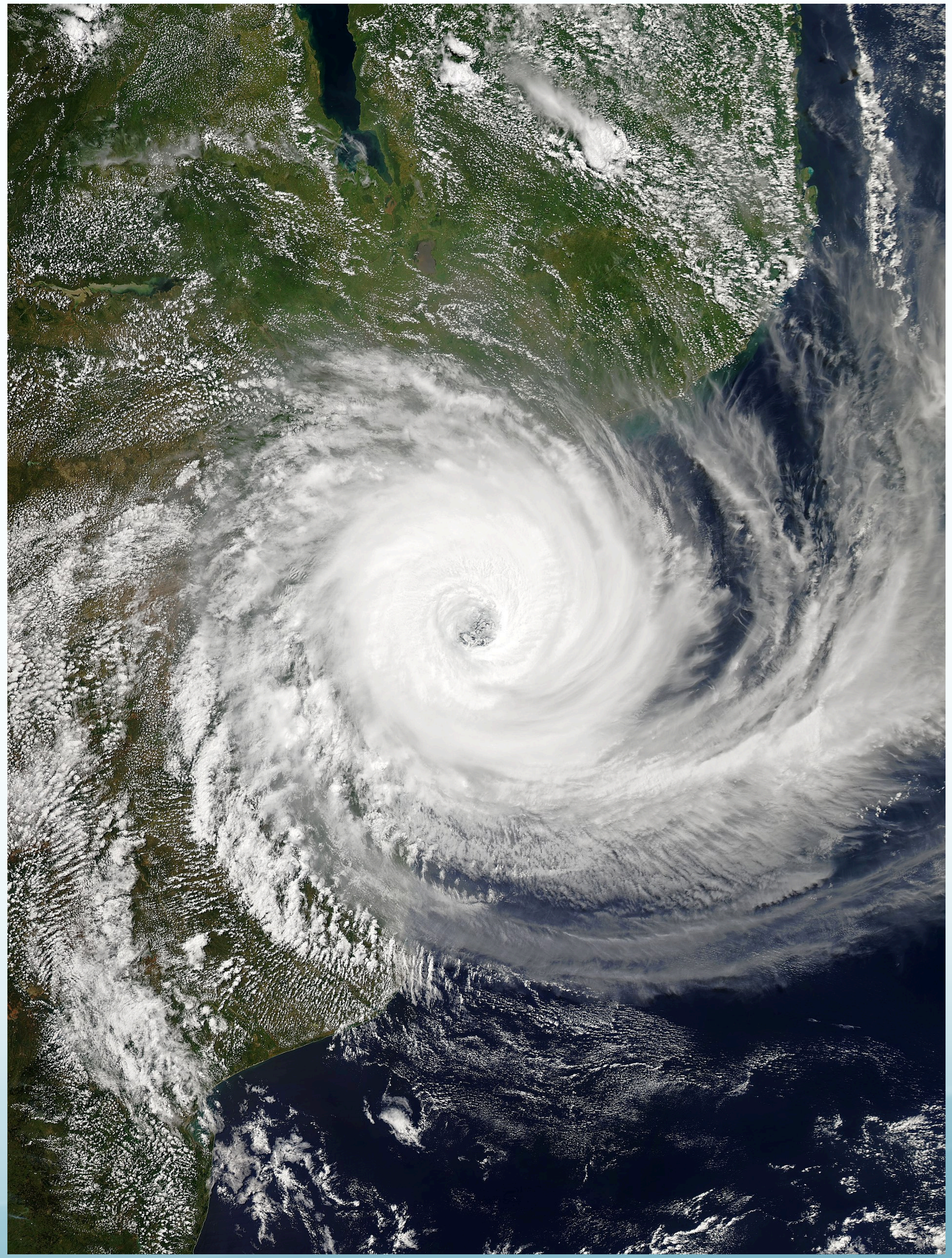
ATM S 103

Hurricanes and Thunderstorms

Their Science and Impacts

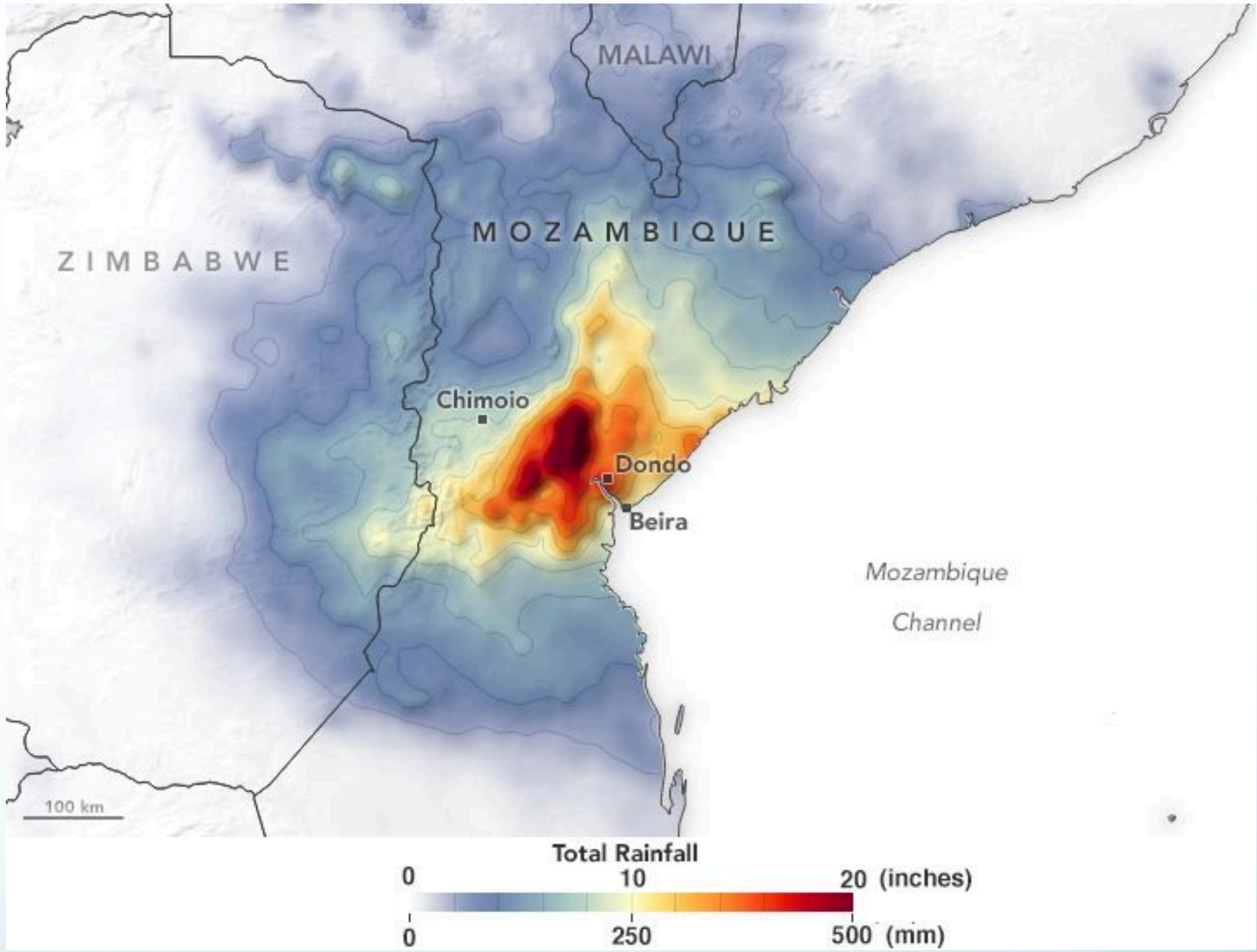
Cyclone Idai

- Forecast made on March 14th



Cyclone Idai

- Made landfall on March 14 as a Category 2 storm with 110 mph winds just north of Beira, Mozambique (population 530,000) near the time of high tide
- Heavy rainfall, storm surge, and high-wind damages
- Death toll so far: 826
  - 3rd Deadliest Southern Hemisphere Cyclone on Record
  - 17th deadliest weather disaster in African history
- More on Friday



Seven-day total rainfall (13-20 March, 2019)

Water in the Atmosphere

Vapor (gas)

Liquid

Ice (solid)

At which phase of water almost all molecules are connected by bonds?

- Vapor (gas)
- Liquid
- Ice (solid)

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Total Results

Answer: Ice

Vapor (gas): all bonds between molecules are broken

Liquid: some broken bonds between molecules

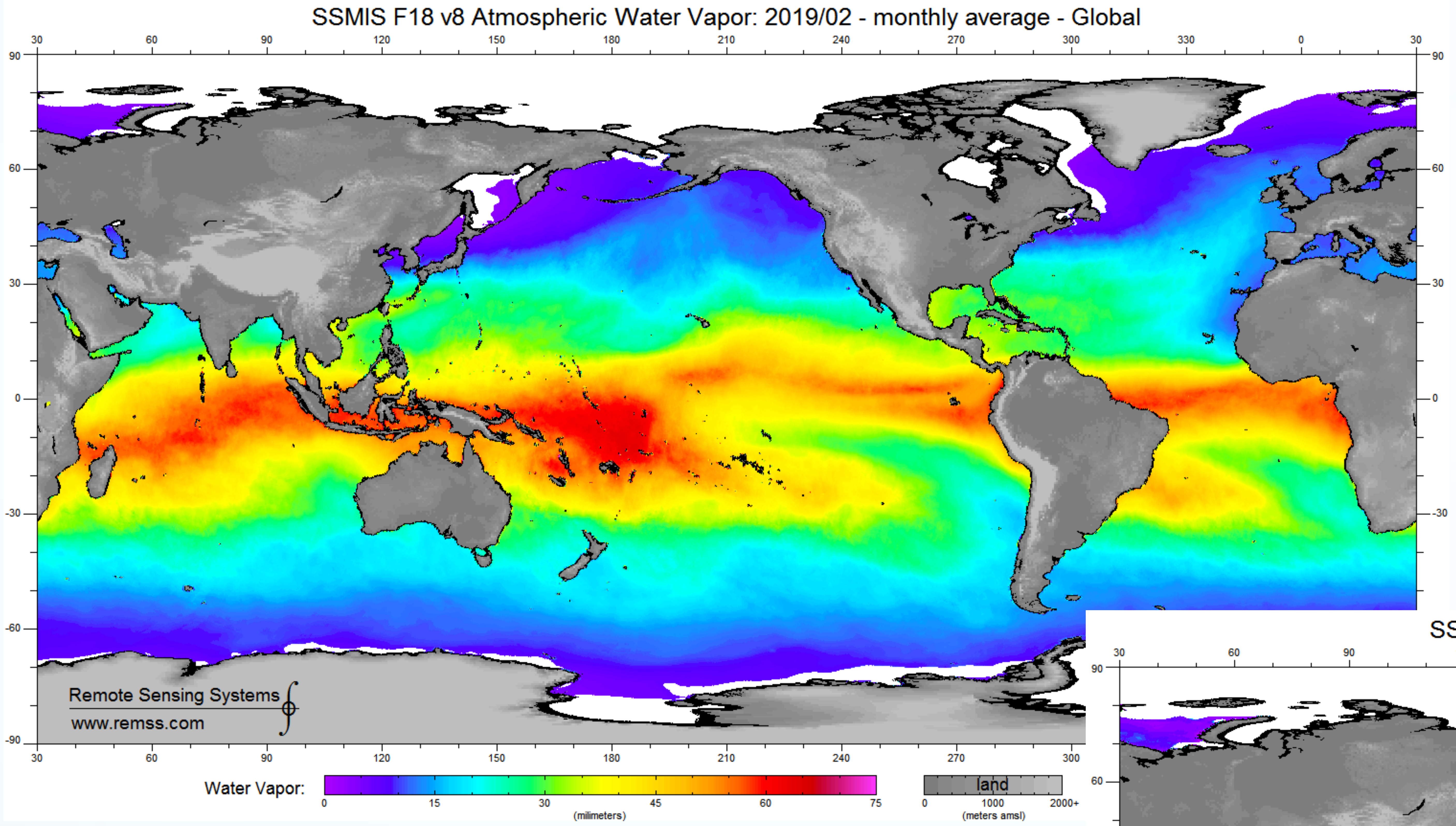
Ice (solid): almost no bonds broken between molecules

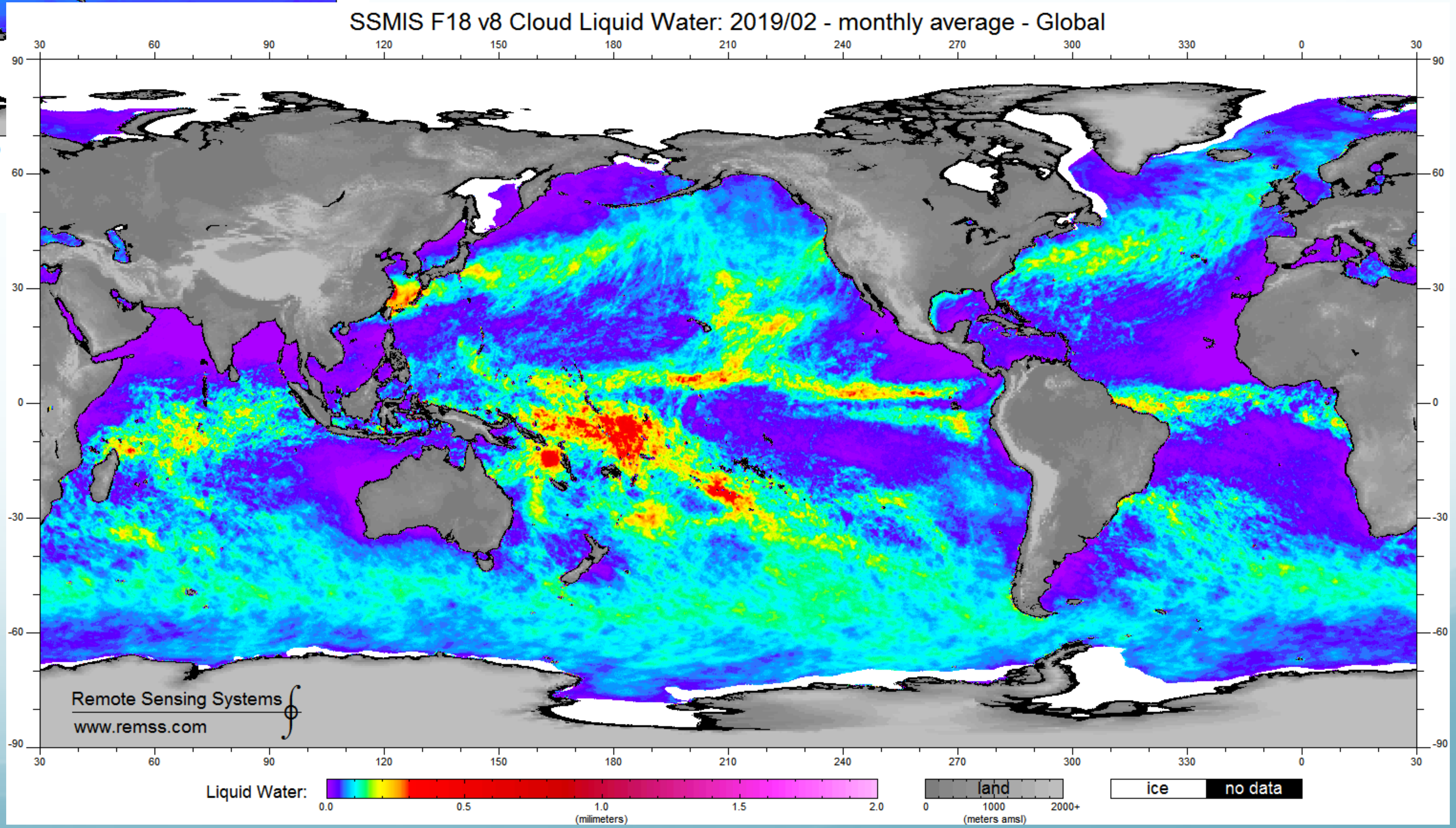
Today's topic

Water vapor → Condensation → Liquid

- When do clouds form?
- What are the measures of humidity?

Satellite observed “column” water vapor (left) and cloud liquid water (bottom)





more water vapor, more clouds?

Cloud formation: phase change of water

Water vapor → Condensation → **Liquid**

- Condensation occurs when the air parcel is "**saturated**"
- What do we mean by an air parcel is **saturated**?

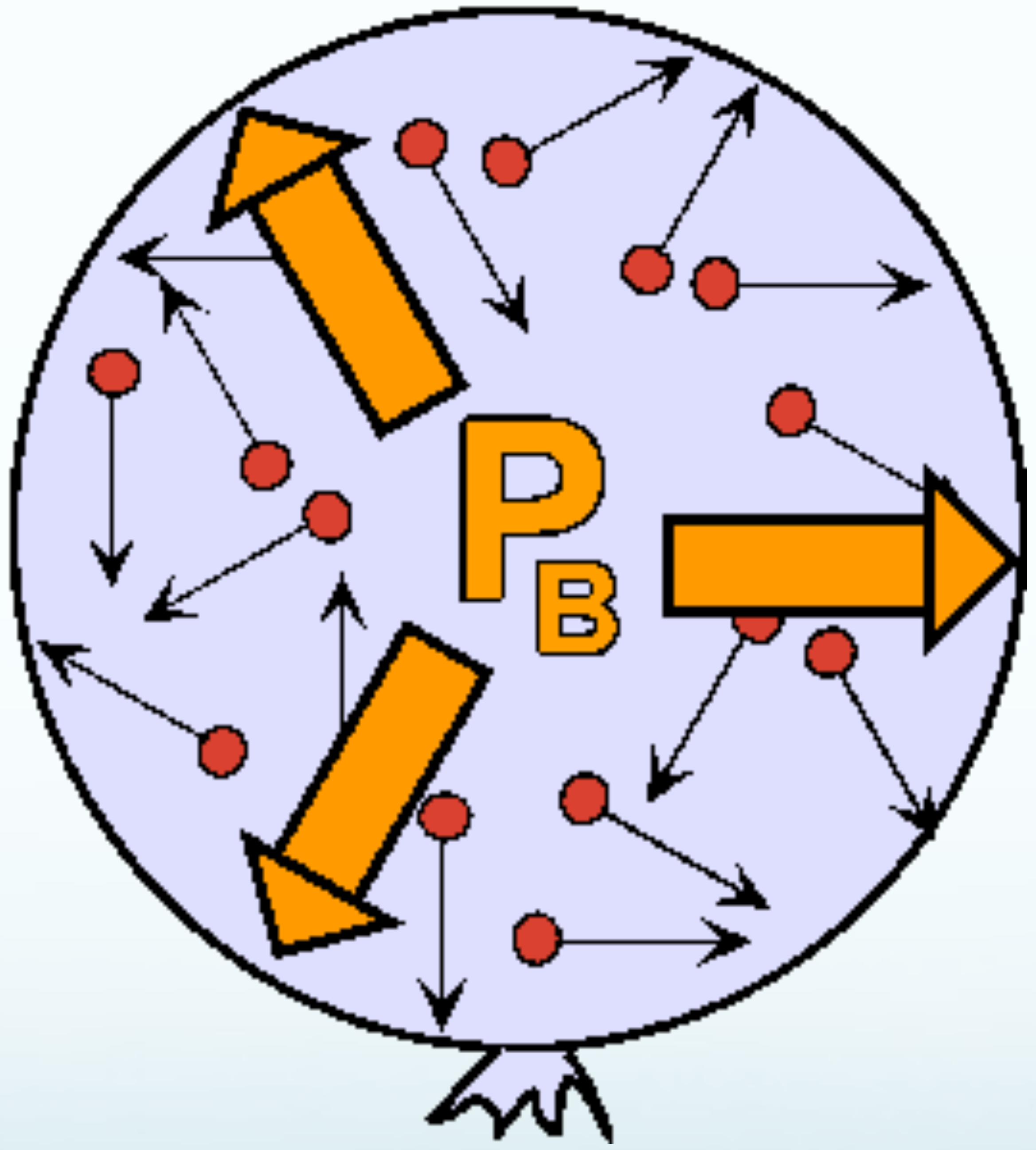
Saturation

- When an air parcel is saturated, any additional vapor added to the air parcel will condense if it gets the chance.
- An air parcel is saturated when its vapor pressure exceeds its saturation vapor pressure.

Pressure

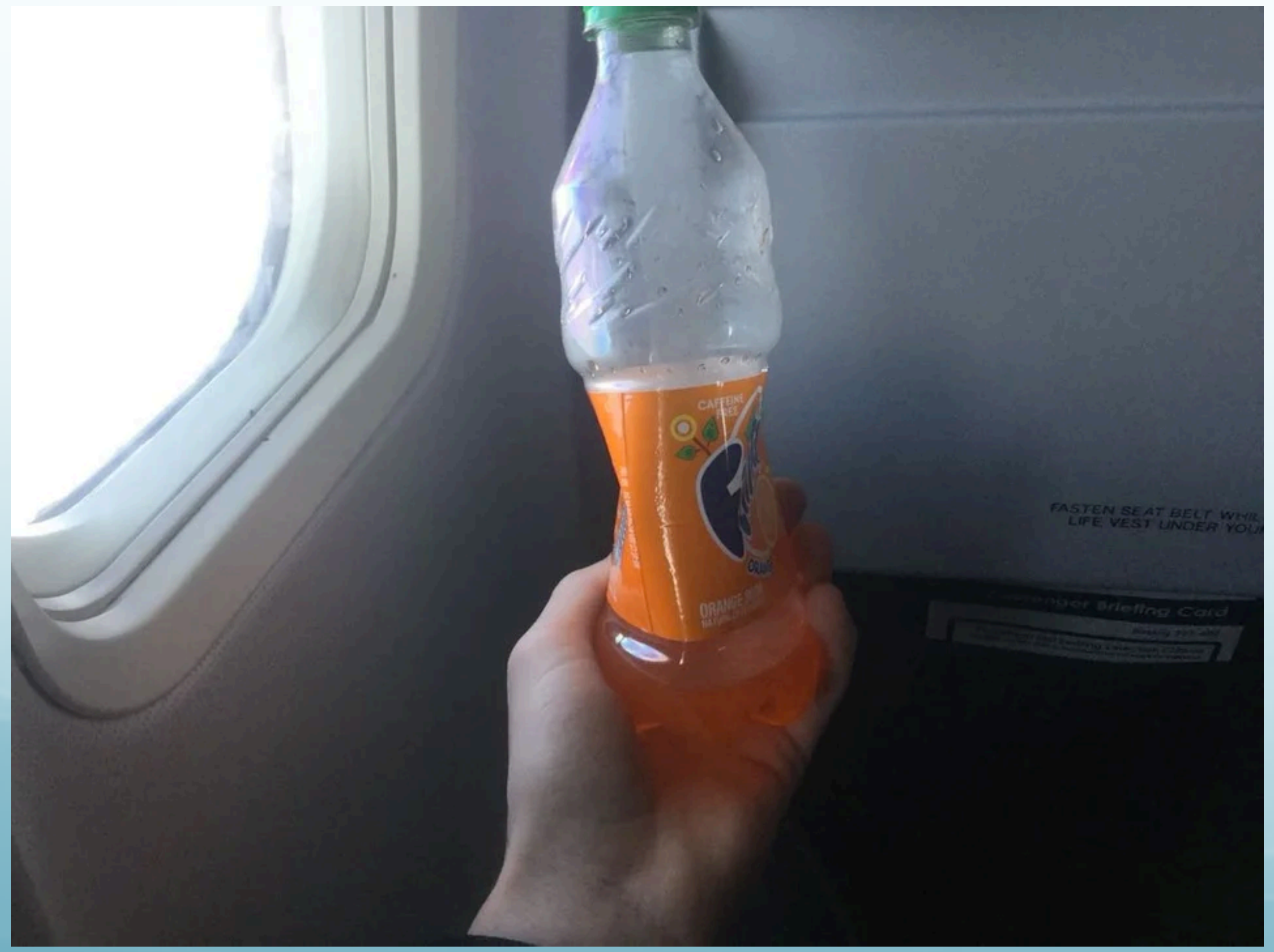
- The net force per unit area exerted by molecules in a gas or liquid colliding with a surface.

Molecules exerting pressure inside a balloon.

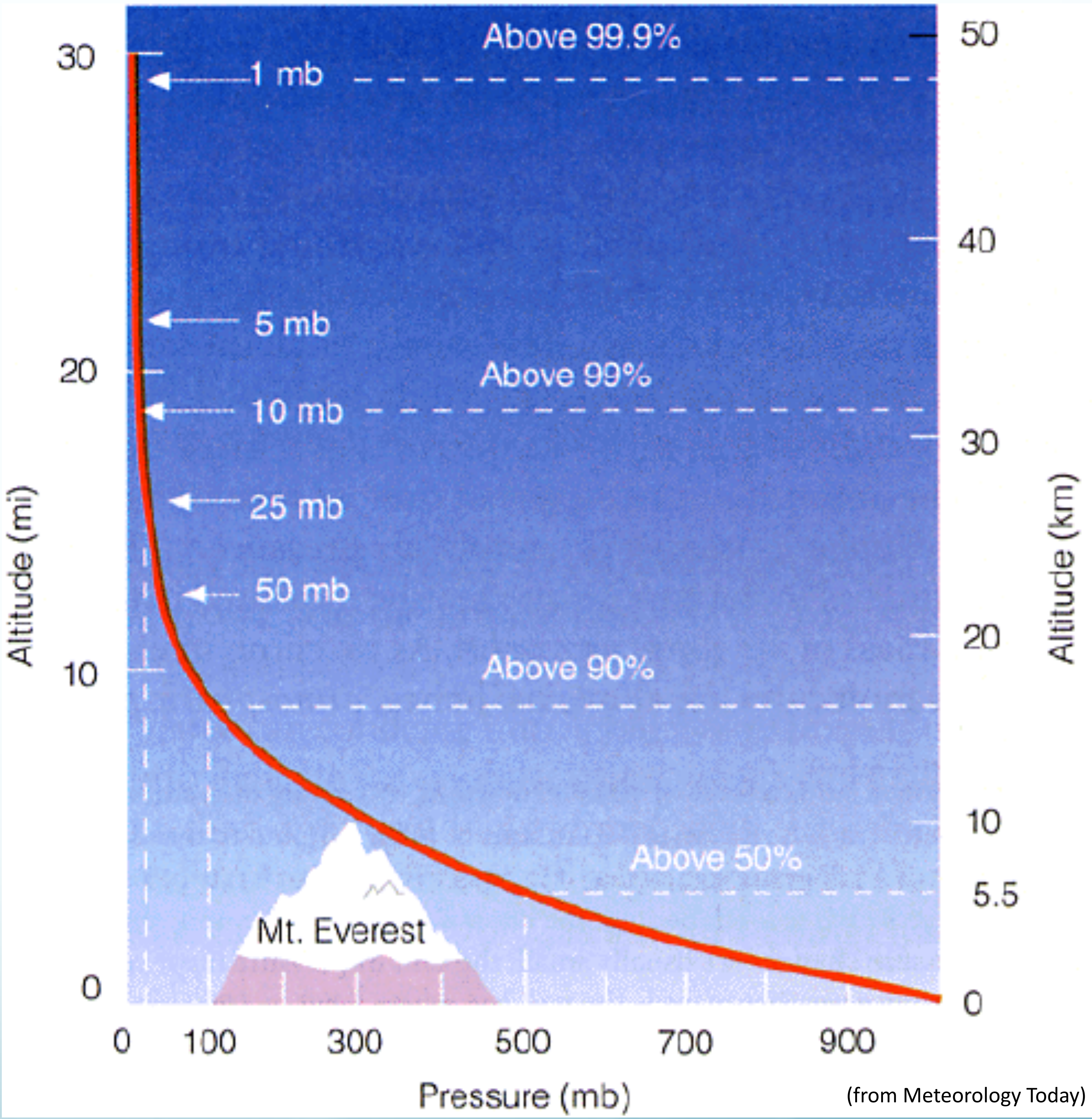


Pressure in a Motionless Fluid

- Equals the weight of the overlying fluid. (1000 kg or 2200 lbs per m^2 at the surface)
- Pressure decreases with height in the atmosphere
  - As you ascend, there is less air above to weigh down on you



As your flight heads down



(from Meteorology Today)

Vapor Pressure

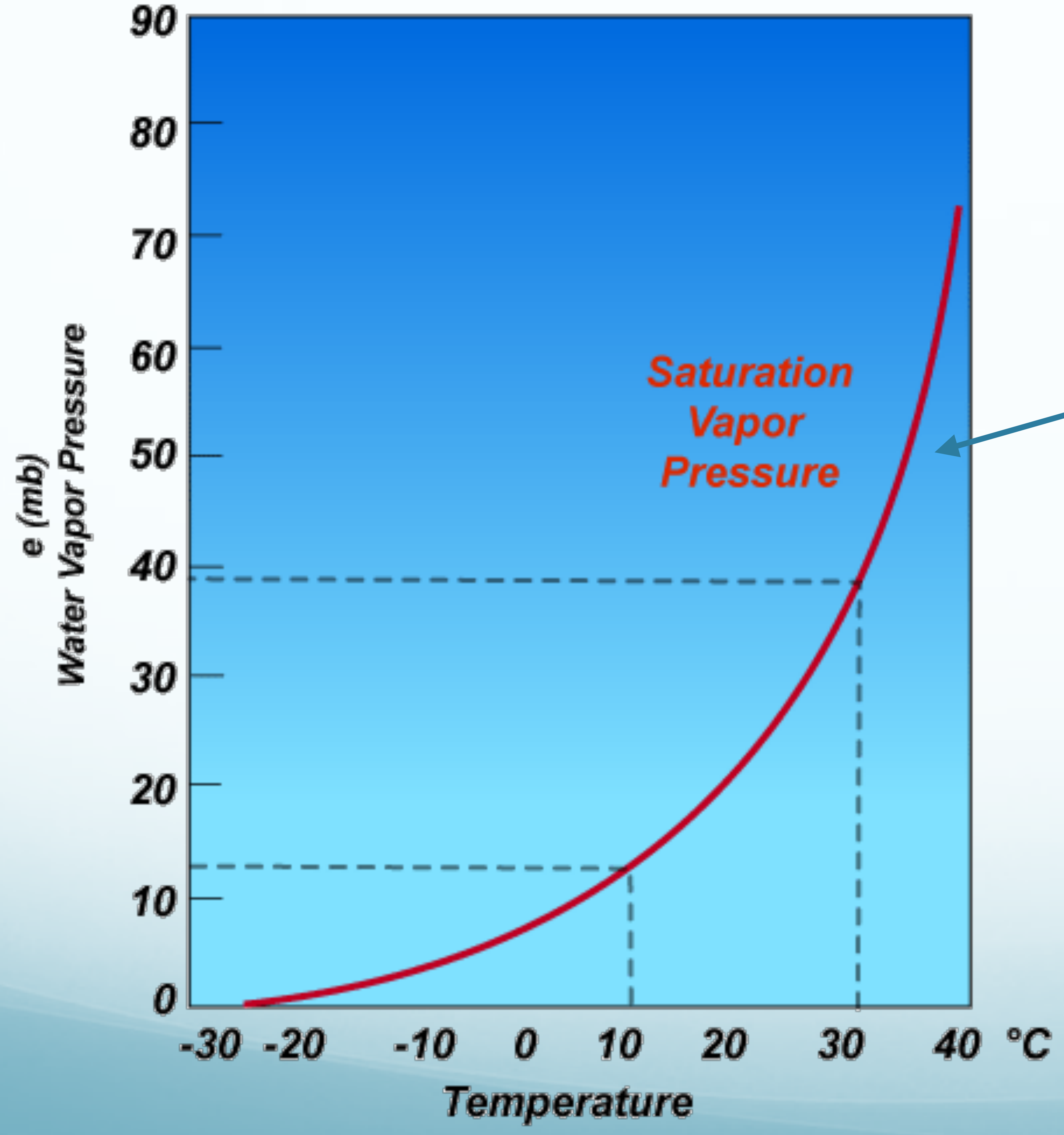
- The net force per unit area exerted by molecules of **water vapor** in a parcel of air.
- **Saturation vapor pressure**: the pressure exerted by water vapor when the air is saturated.

Saturation

- An air parcel is saturated when its vapor pressure exceeds its saturation vapor pressure.
- Or, its relative humidity becomes greater than 100%.
  - the ratio of actual vapor pressure to saturation vapor pressure (times 100%)
  - the ratio of water vapor content to water vapor capacity (expressed in percent)

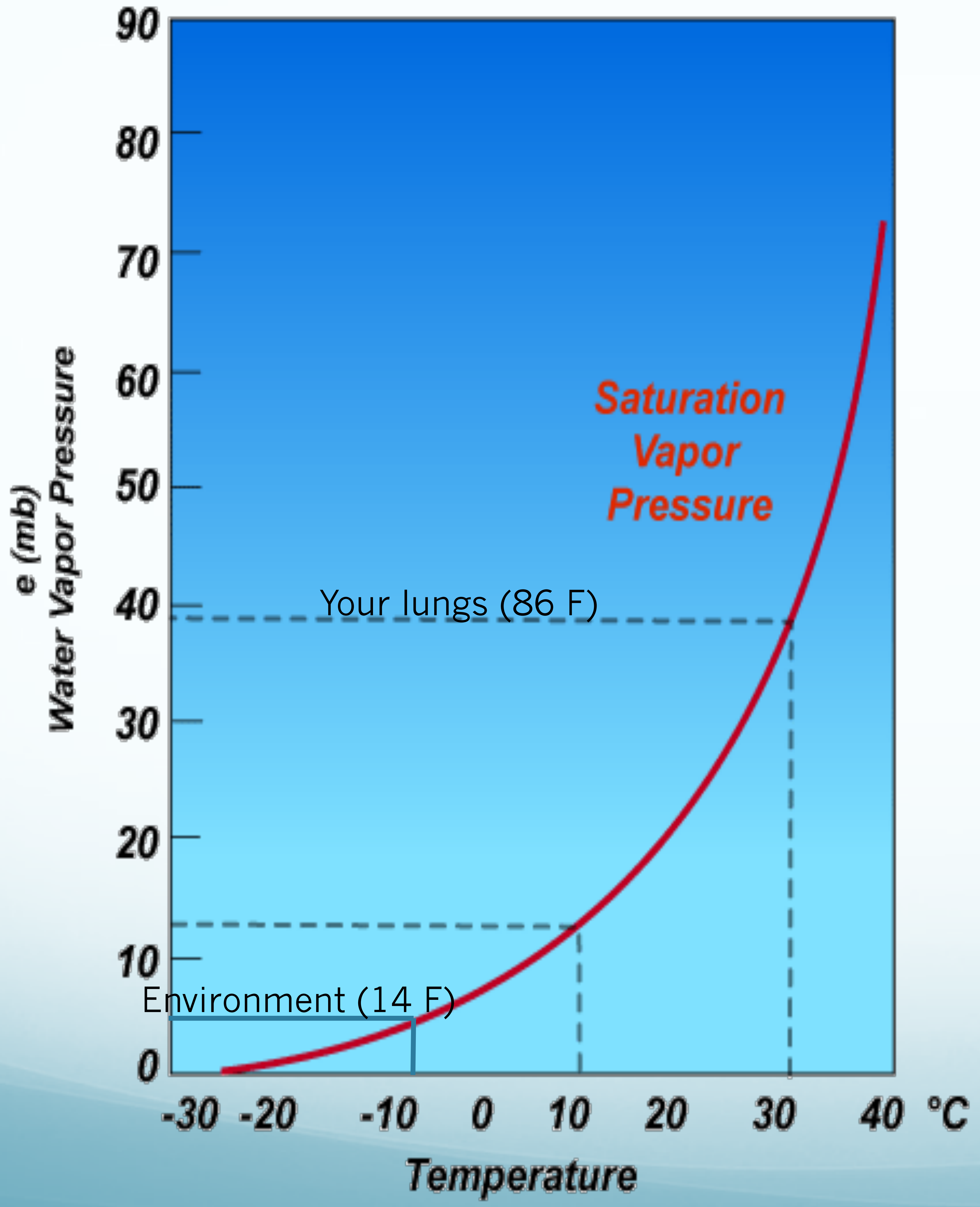
$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

Saturation vapor pressure depends only on temperature



$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

Why is your breath visible on a *very* cold day?



Saturation vapor pressure increases rapidly with temperature

$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

When the air parcel comes out of your mouth

Temperature ↓

Saturation vapor pressure ↓

Relative humidity ↑

Cooling down an air parcel will saturate it eventually (if it contains water vapor molecules)

Saturation as an equilibrated state

Condensation →

Water vapor ⇄ **Liquid**

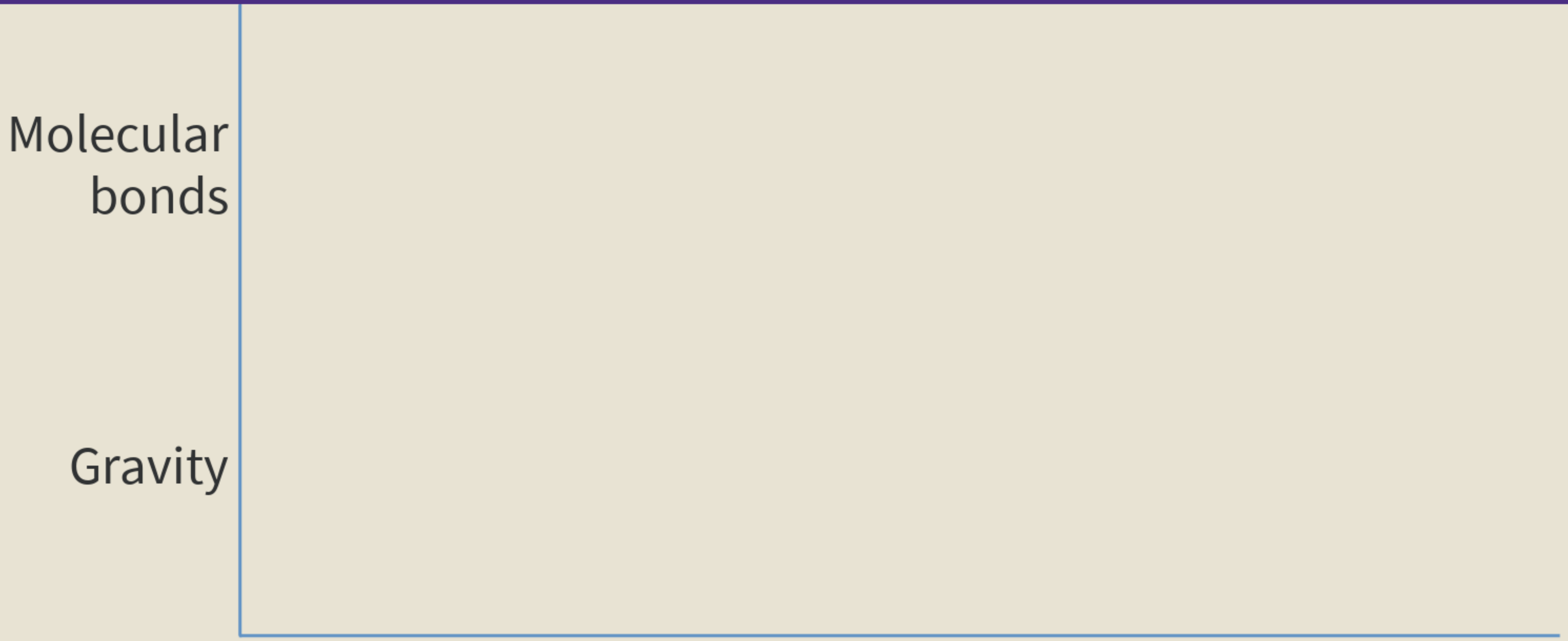
← Evaporation

- Saturation will occur if
  - Liquid water is also present
  - The amount of liquid and vapor is not changing
    - The vapor and liquid are at *equilibrium*.

Melting and evaporation at the molecular level

- Simulation made by Mike Daniel

What is inhibiting the water molecules on the liquid surface from flying off as vapor?



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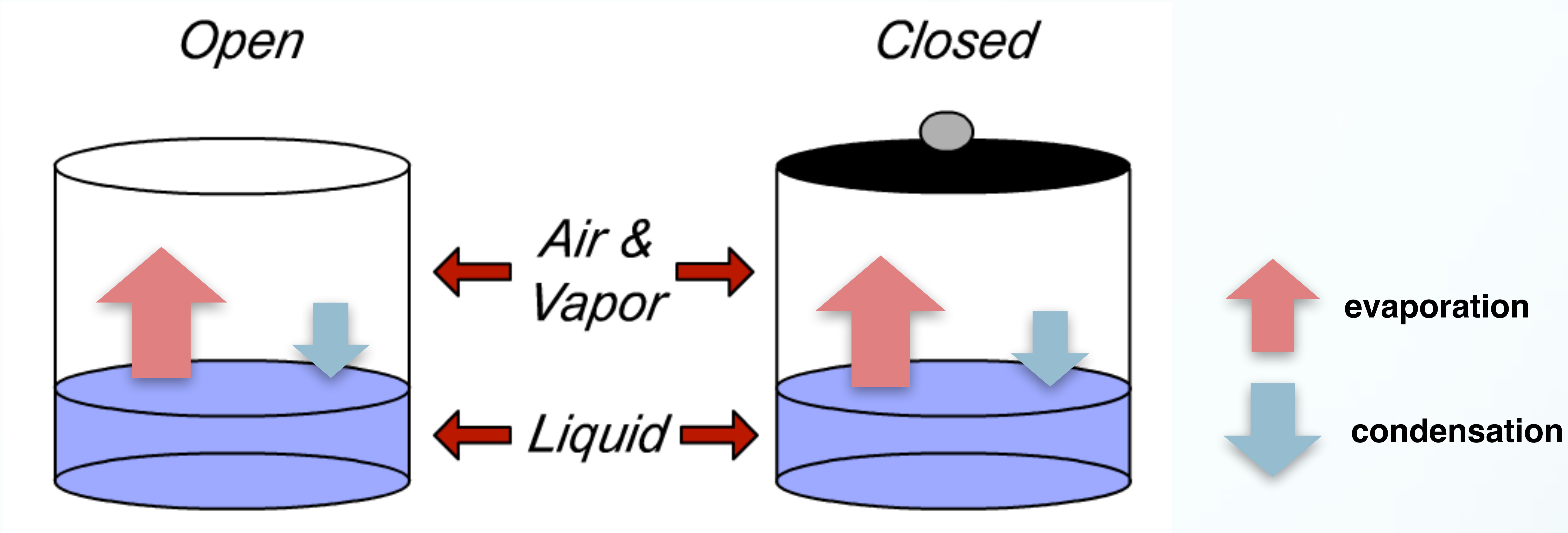
Total Results

Answer: Molecular bonds inhibit evaporation.

Similar behavior takes place on the bottom side of rain and cloud droplets.

More on saturation

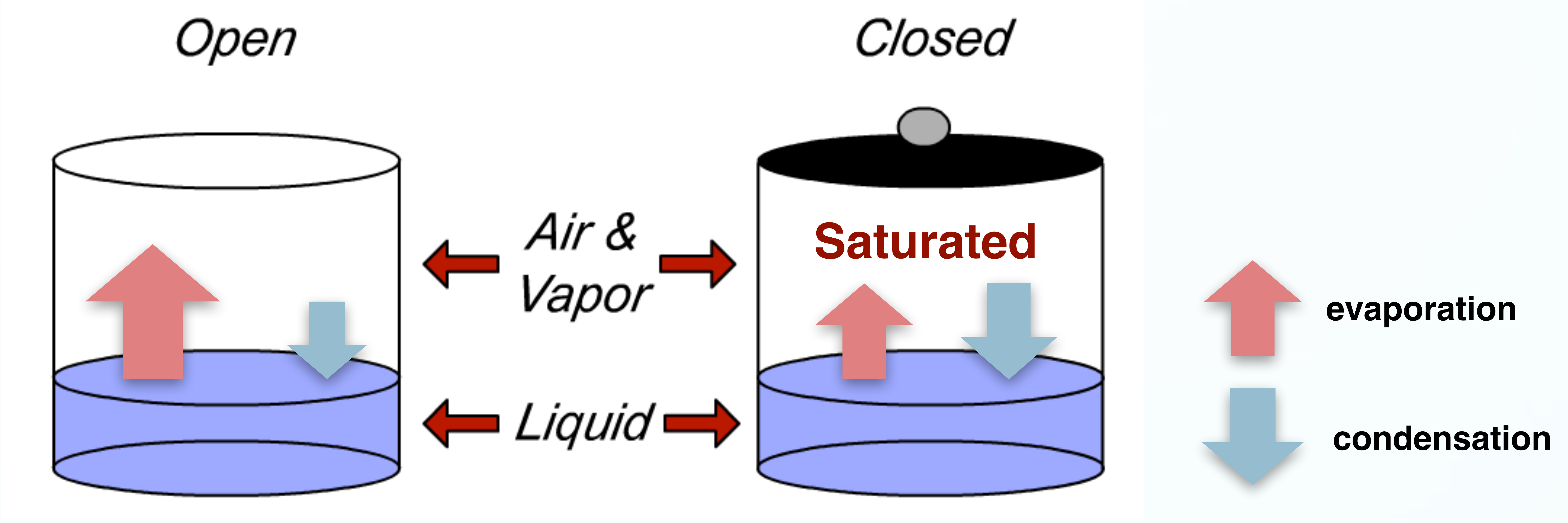
Two Jars at 70°F (21°F)



- Initially, there will be net evaporation (evaporation > condensation) in both cases.
- But relative humidity of the air in the jar will increase much more rapidly in the closed case.

Which jar can be in equilibrium?

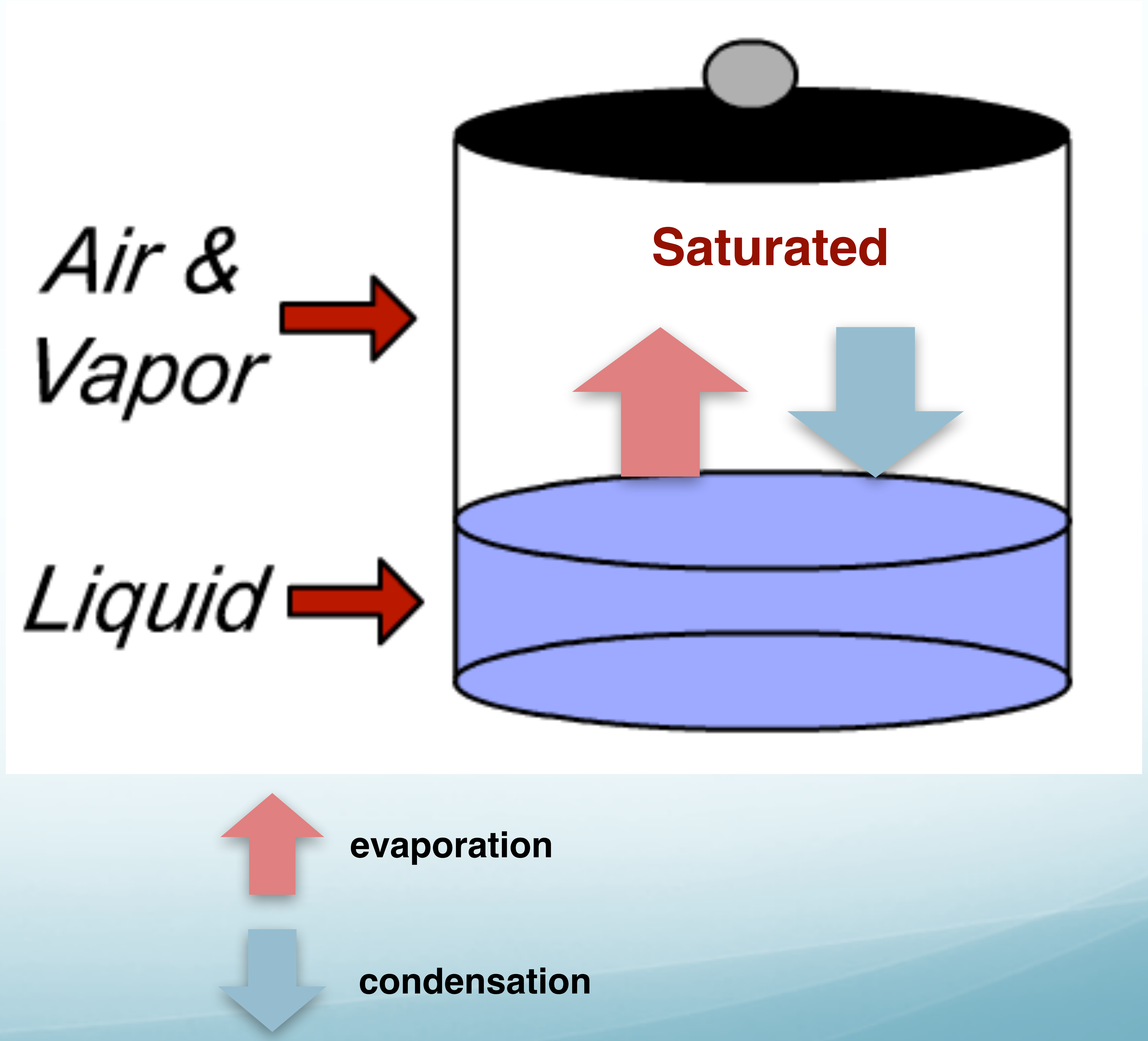
After some time



- Since the air in the covered jar is more humid, more vapor condenses onto the surface of the liquid in that jar.
- If the air in the covered jar is saturated, the rate of condensation on the water surface matches the rate of evaporation from that surface.
  - No net change in the amount of liquid water

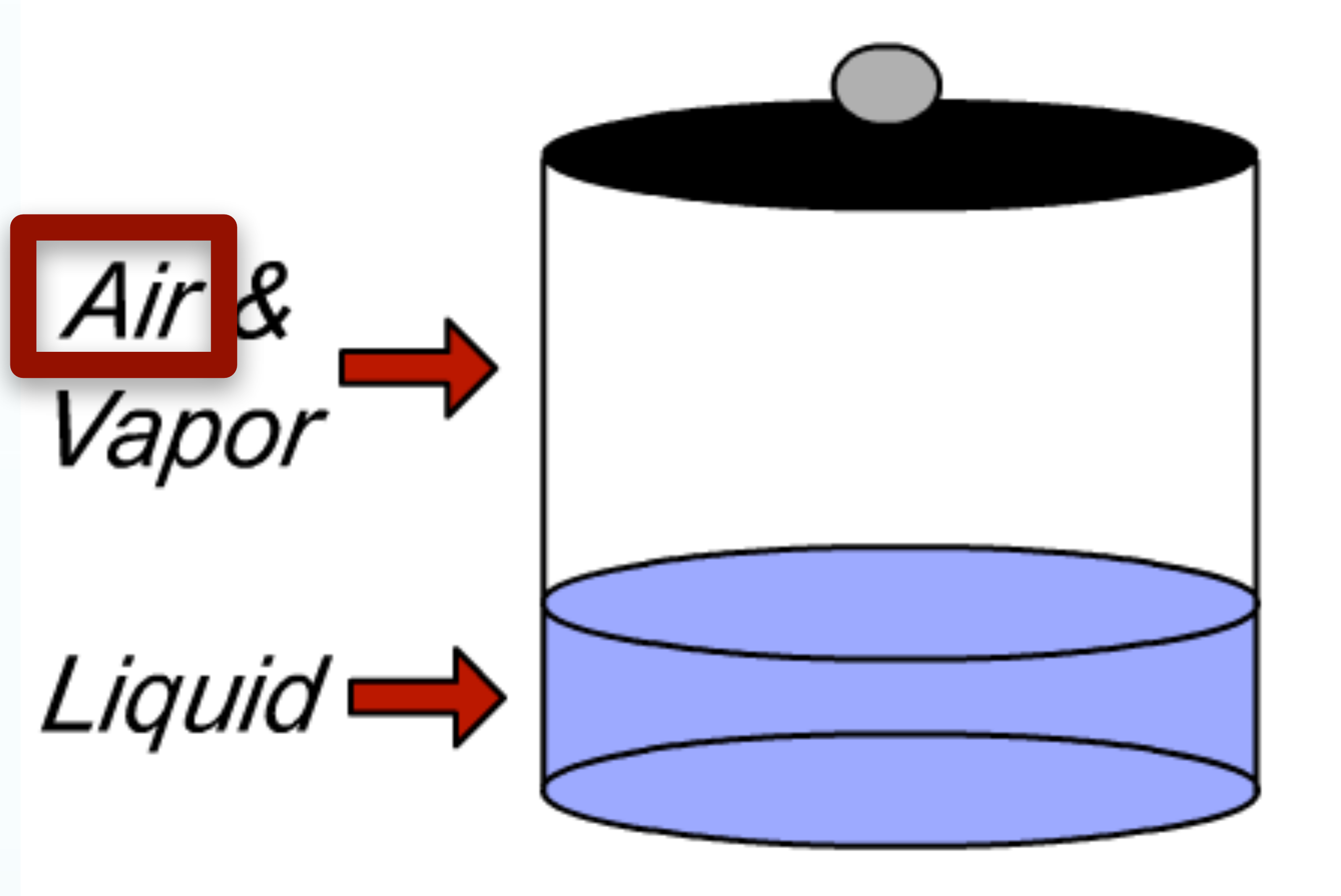
Equilibrium: More Details

- All evaporation and condensation does not stop when the air in a covered jar reaches saturation.
- Instead there is a balance and no net evaporation or condensation.



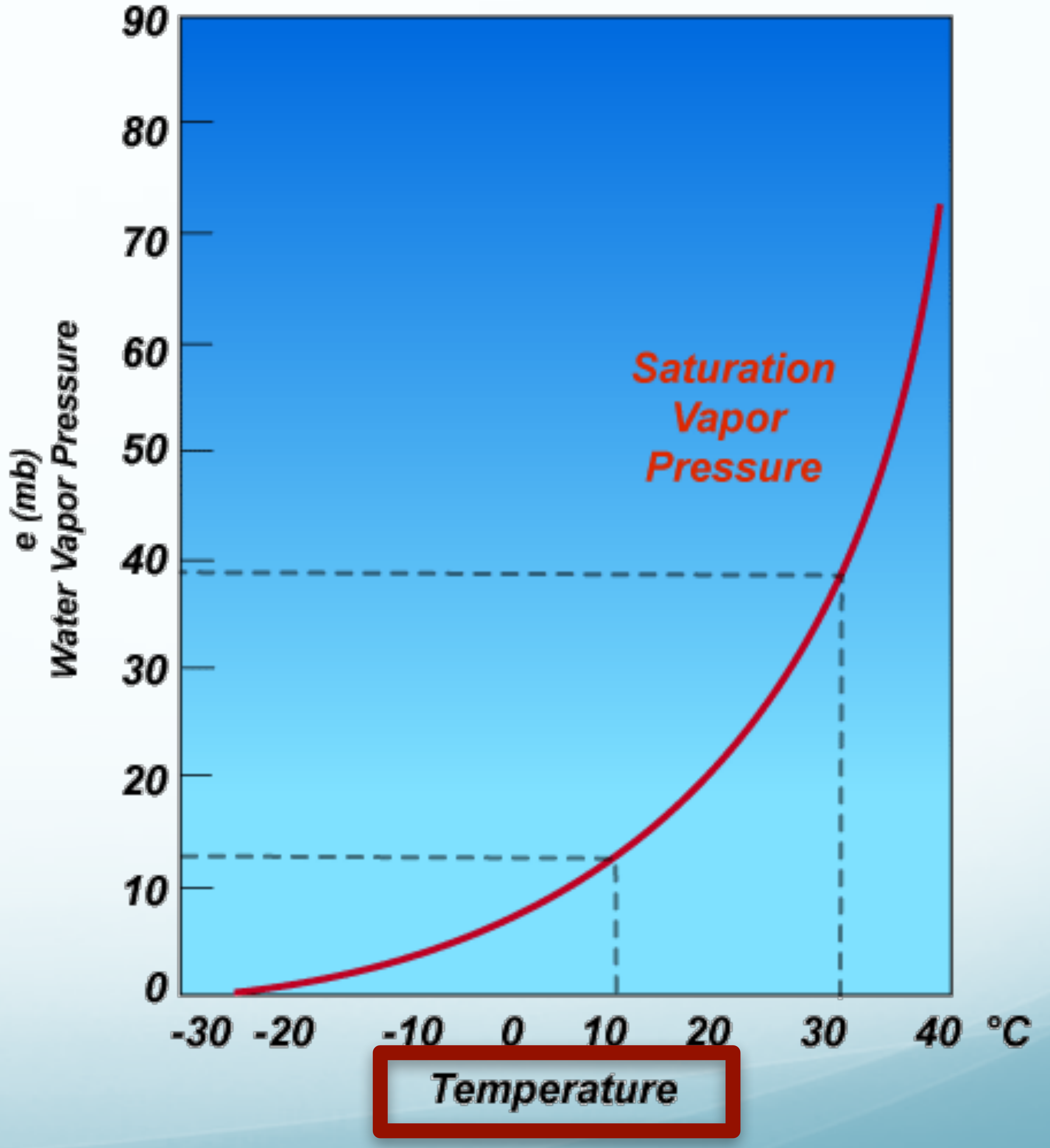
What does the dry air do?

- The nitrogen and oxygen molecules play no role in
  - Maintaining the equilibrium
  - Setting the saturation vapor pressure.
  - Saturation vapor pressure depends only on the temperature.
- But the temperature of the water vapor follows that of the dry air. Why?



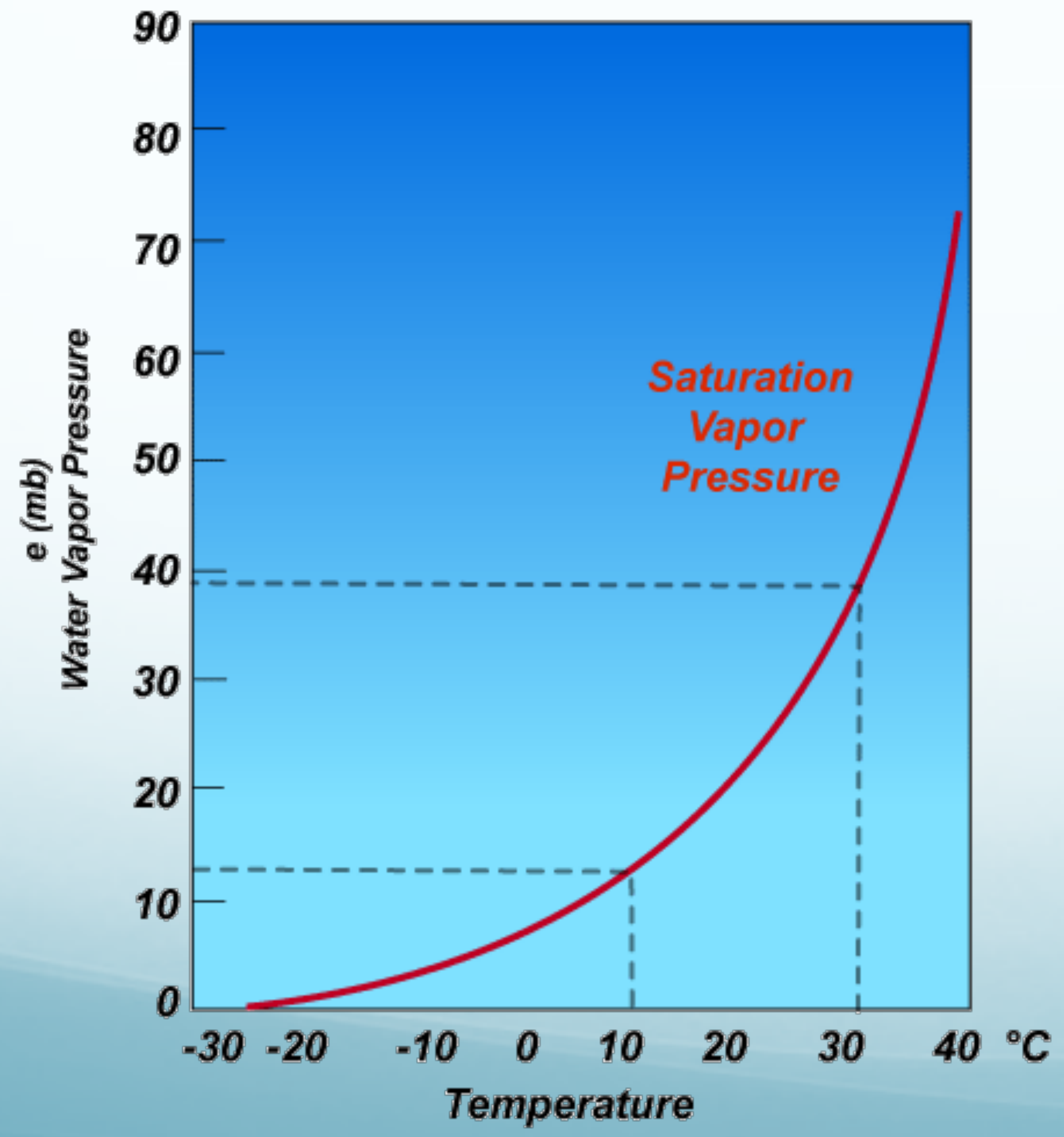
Dry air rules the temperature!

- Air in the atmosphere contains only 1-4% water vapor by mass.
  - The dry air determines the temperature of the water vapor.
  - Warm saturated air contains more water vapor than cold saturated air.



Measures of Humidity

- *Relative humidity* and the *dew point*
- Saturation vapor pressure ('capacity') or relative humidity doesn't tell you about the actual humidity

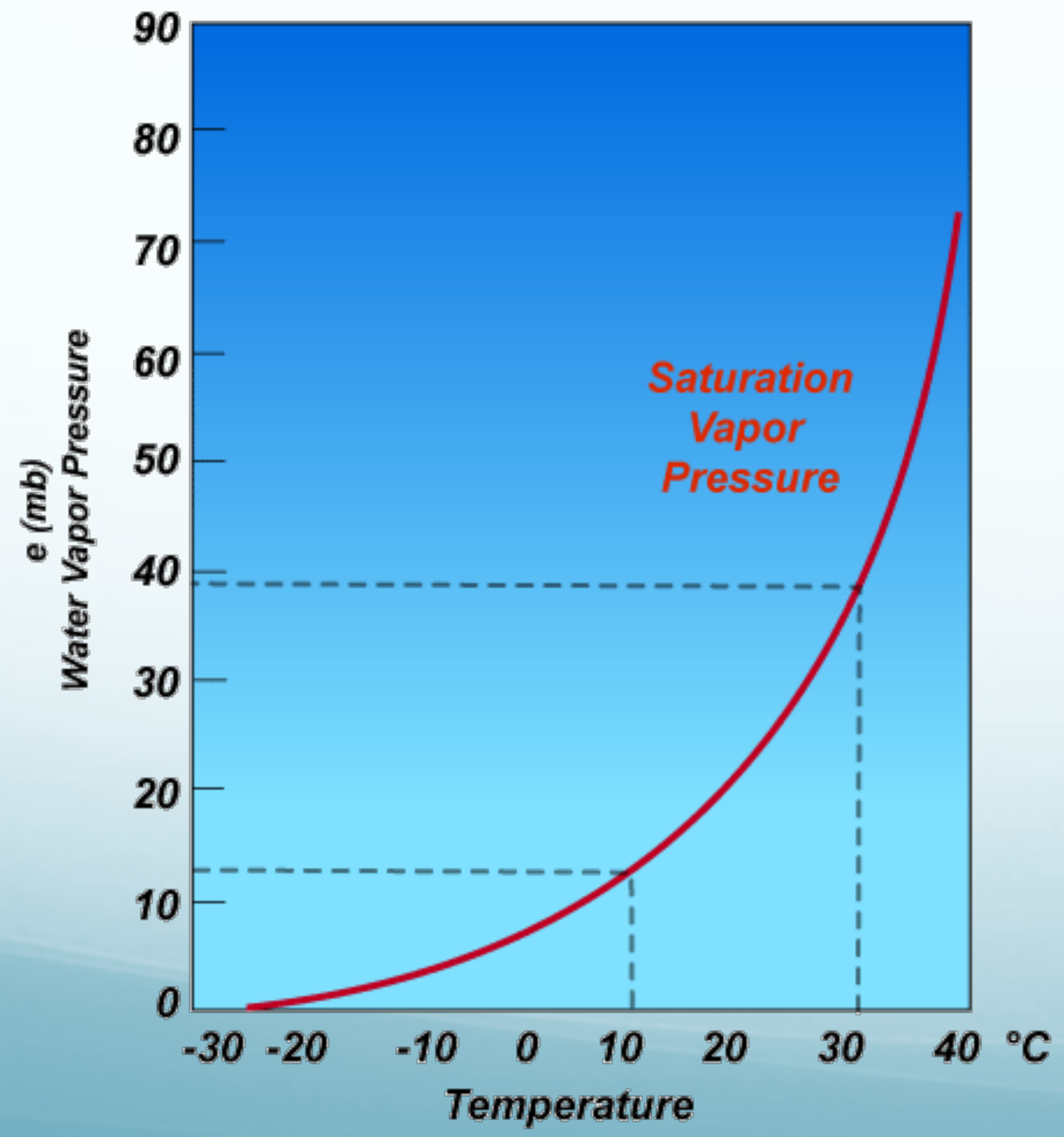


$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

Why not just one measure?

Comparing two equal-sized volumes of air, we use

- *Relative humidity (in %)* to determine which is closer to saturation
- *Dew point (in ^oC or ^oF)* to determine which holds more water vapor molecules



$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

If the vapor pressure is 20 mb and temperature is 30^{o}C

Relative humidity: 20/~40 x 100 = ~50%

Relative Humidity (RH)

- Conceptually it's the ratio of water vapor content to water vapor capacity (expressed in percent)
- Mathematically it's the ratio of actual vapor pressure to saturation vapor pressure (times 100%)
- RH decreases if air is heated without adding or removing water vapor.
  - The actual vapor pressure stays the same.[1]
  - The saturation vapor pressure increases with the increase in temperature.
  - The RH drops.

[1] If the air is heated at constant pressure, the most meteorologically relevant case.

If air is cooled without adding or removing water vapor, the

RH drops

RH stays the same

RH increases

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Total Results

Answer: the RH increases

- The actual vapor pressure stays the same.
- The saturation vapor pressure decreases with the decreasing temperature.
- RH = (actual VP)/(saturation VP) increases

Why do we care about changes in relative humidity?

Clouds are formed by processes that bring the RH in previously unsaturated air to 100%

Relative humidity does not tell all.

- No direct way to determine the mass of water vapor (number of molecules) in an air parcel from its RH.
- Why might we care about the amount of water vapor?
  - Rainfall totals depend on the mass of water vapor available for condensation and precipitation.
  - Mass of water vapor determines the amount of latent heat available during condensation.
  - (Water vapor is an important greenhouse gas.)

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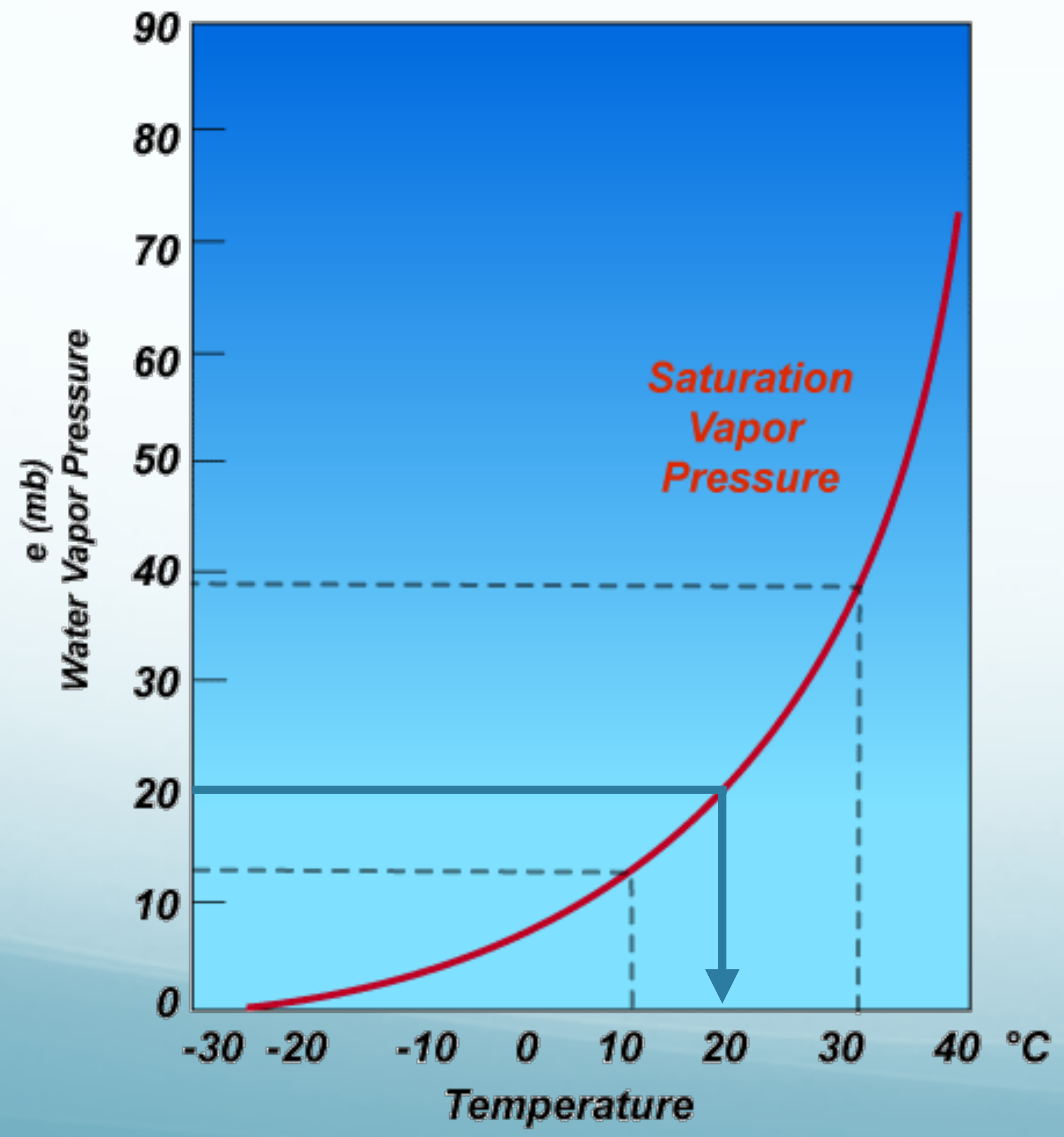

$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

If the vapor pressure is 20 mb and temperature is 30^{o}C

Dew point: ~20^{o}C

The Dew Point

- Is the temperature to which air must be cooled, without changing the pressure or the number of water vapor molecules, to cause saturation.
- Depends only on the amount of actual water vapor: a higher dew point means a higher number of water vapor molecules
- Can be used to compare the mass of water vapor in two equal-volume parcels having the same pressure.
  - We can compare dew points of parcels of air near the surface to compare their dew points.

Increasing the temperature without adding water vapor decreases the dew point

True

False

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Total Results

Answer: False

- If we need to cool a parcel to 40°F to achieve saturation, the dew point is 40°F.
- The dew point is the same whether the temperature before cooling starts at 50°F or 100°F.

Which parcel is drier?

Temperature: 18°F, dew point 18°F, RH=100%

Temperature = 92°F, dew point = 35°F, RH=12.5%

No clear answer; question needs to be more specific.

- Which parcel will produce a bit of condensed water or ice after just a little cooling?
- Which parcel will produce the most condensed water or ice after substantial cooling?