ATM S 103

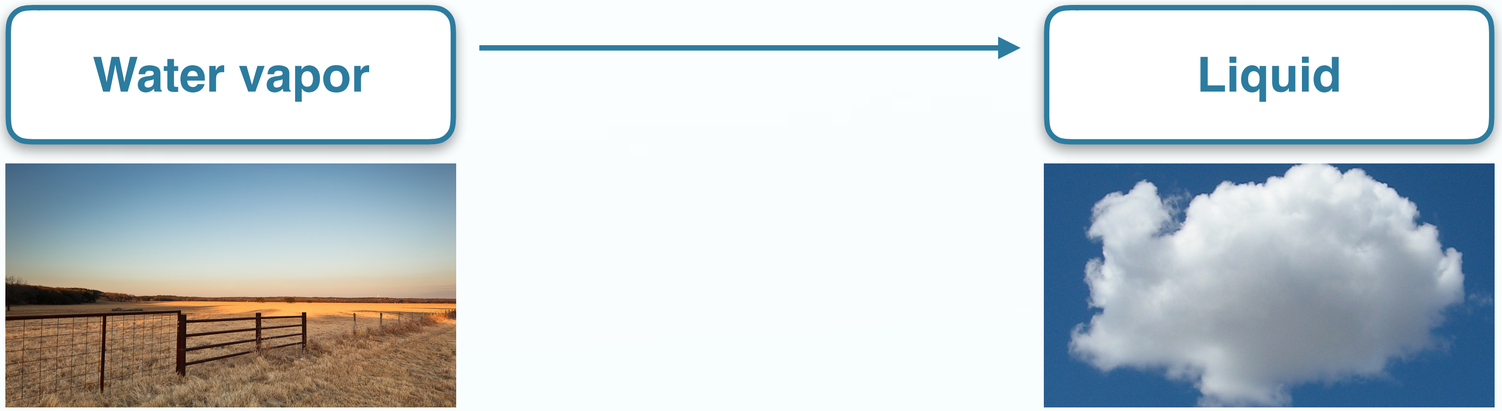
Hurricanes and Thunderstorms

Their Science and Impacts

Announcements

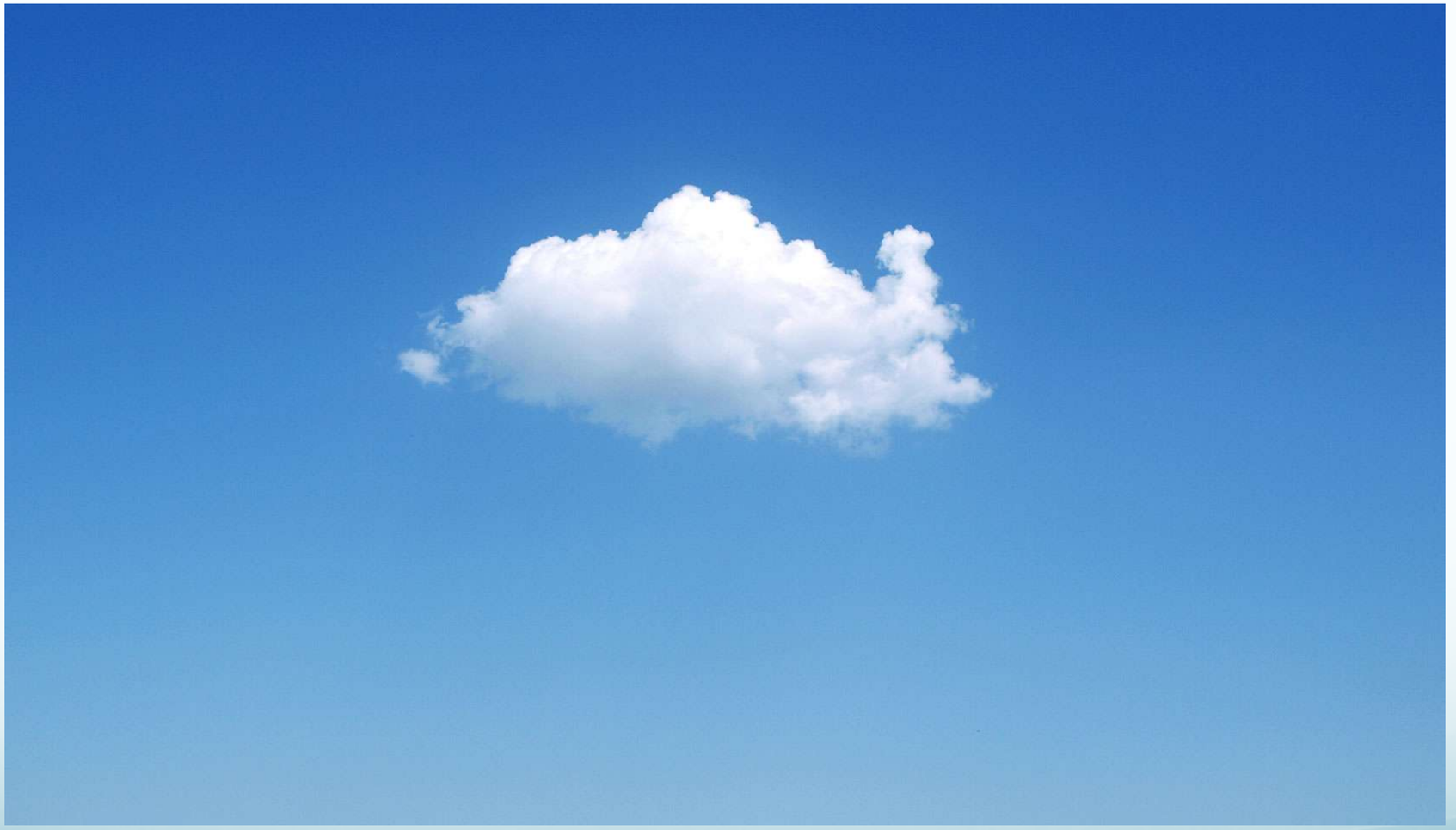
- First set of homework problems published (due Apr 12)
- Lecture slides are available from the canvas website

Today's topic



- When do clouds form?
- What is the role of cloud condensation nuclei?

Forming a Cloud



Most clouds form when

Water vapor is added to air without changing the temperature

Air is warmed without adding water vapor

Air is cooled without adding water vapor

Answer: Most clouds form when air is cooled without adding water vapor

- Condensation can be produced by adding water vapor to air at constant temperature, but well above the ground there is no good water source.
- Steam fogs form near the surface by adding moisture to the air.

Condensation produced by adding water to the air

Steam fog

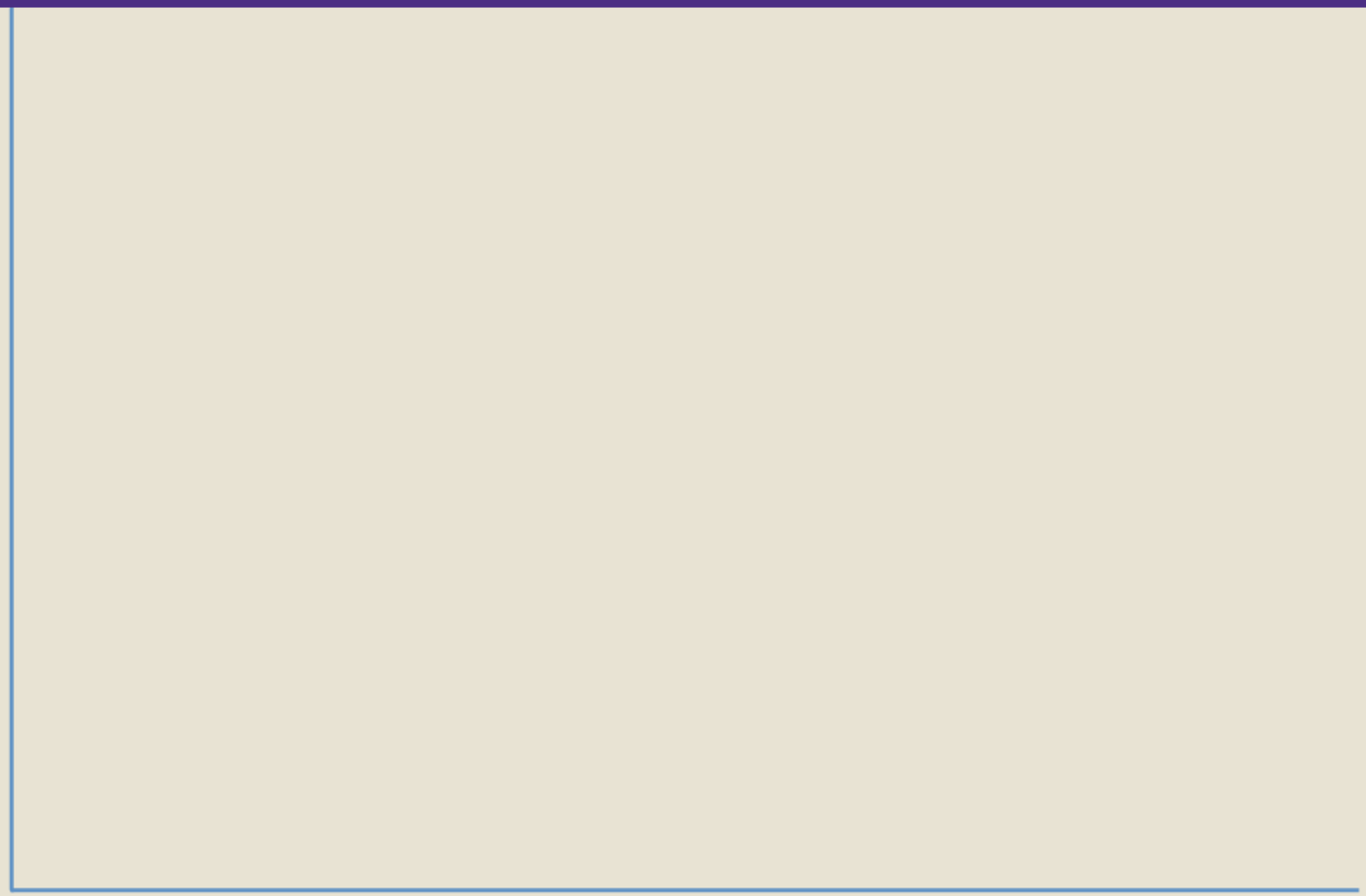
Steam fog tends to form over water when

The sky is blue

Atmospheric pressure are unusually low

The air is very cold

Music is playing



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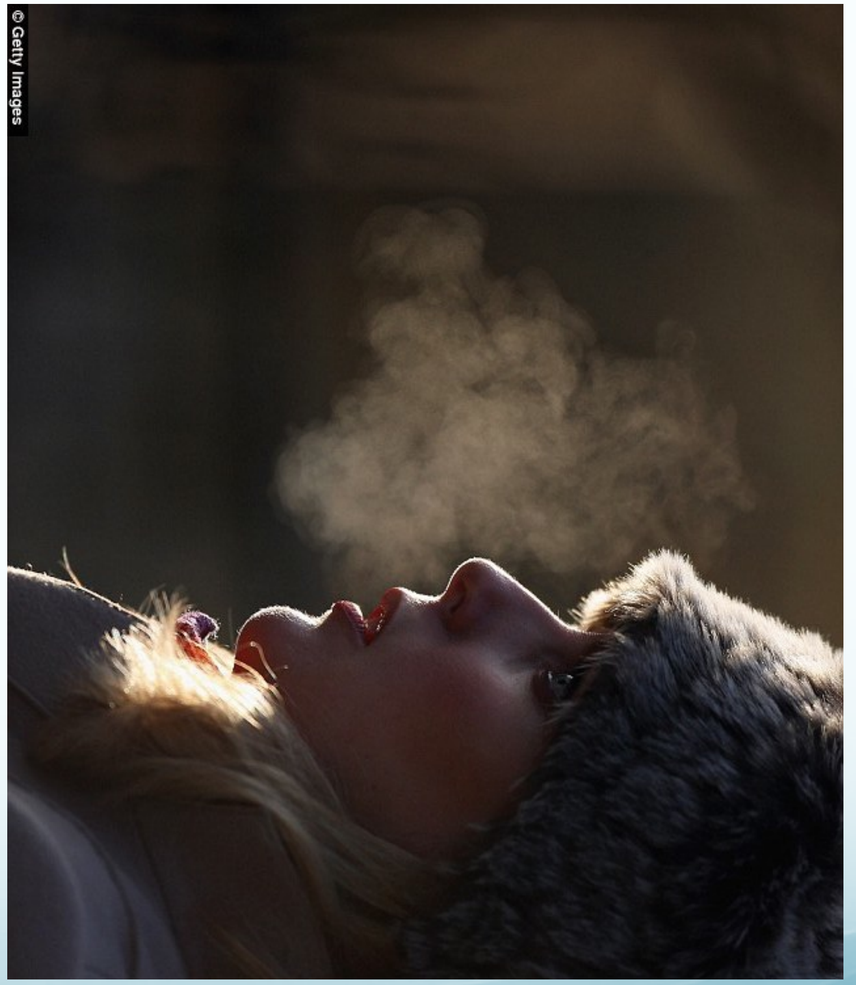
Total Results

Answer: Steam fog tends to form when the air is very cold.

Steam Fog

- Warm moist air just above the water rises and mixes with very cold dry air above.
- Mixture becomes saturated and water droplets condense.
- Same process that makes your breath visible on a very cold day.



Condensation in Midair

Cloud in a Bottle (with captions)

Cloud in a Bottle (original)

Steve's Demo

- What we've learned
  - Condensation occurs when vapor pressure exceeds saturation vapor pressure

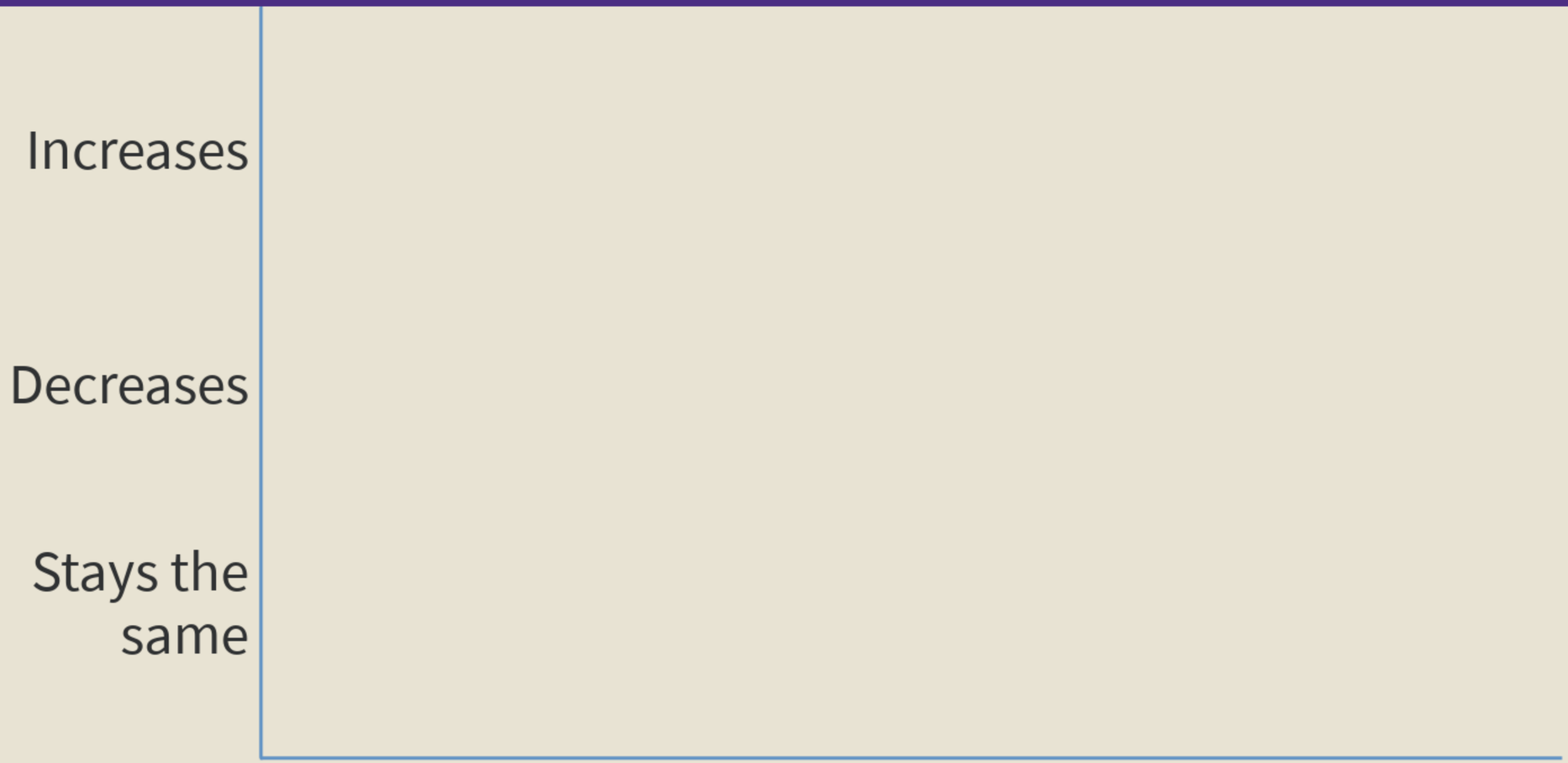
$$\text{Degree of saturation}^* = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

*In this case, about alcohol, not water molecules

  - Saturation vapor pressure increases with temperature

- What happens when Steve pumps air into the bottle?

As Steve pumps air into the bottle, the temperature in the bottle



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Total Results

Answer: the temperature increases.

Pumping up the pressure warms the air in the bottle (compressing the air into a constant volume)

Steve's Demo

- When the air in the bottle is released,

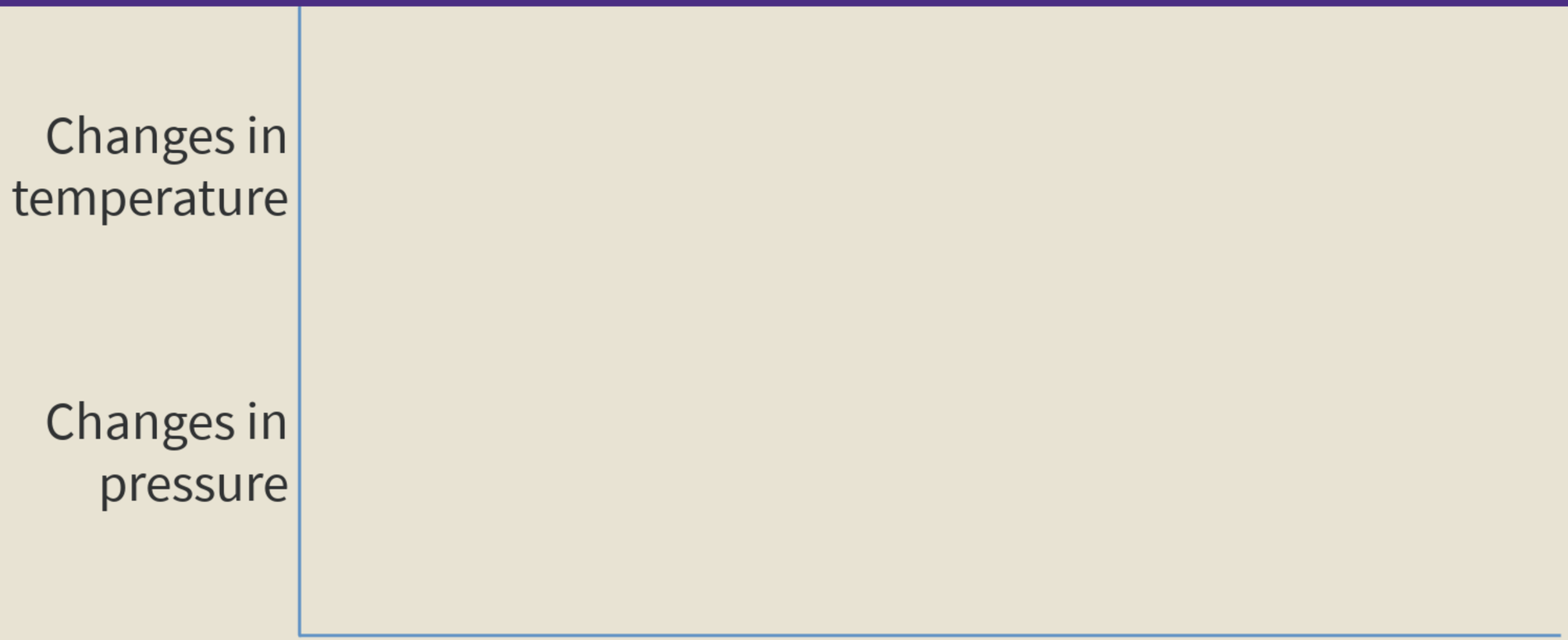
Temperature ↓

Saturation vapor pressure ↓

Degree of saturation ↑

$$\text{Degree of saturation} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

What is most FUNDAMENTALLY responsible for condensation and evaporation of the alcohol droplets in the bottle?



Answer: Temperature

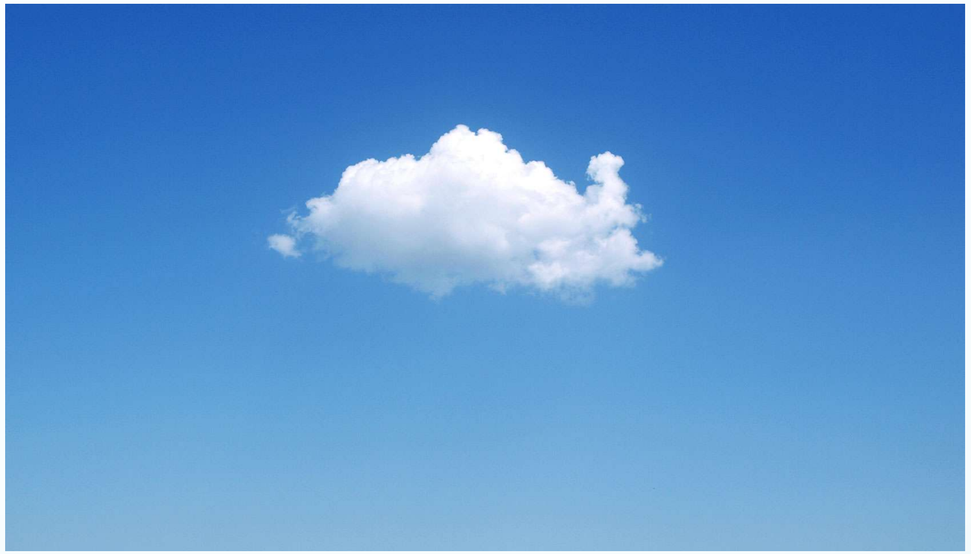
Saturation vapor pressure depends only on temperature!

Steve's Demo - Summary

- Pumping up the pressure warms the air in the bottle (compressing the air into a constant volume).
- Liquid alcohol in the bottle evaporates, raising the number of molecules of gaseous alcohol
- Popping the stopper in the top of the bottle reduces both the pressure and the temperature.
  - *Air expands adiabatically*
- Saturation occurs as saturation vapor pressure becomes lower than vapor pressure.
- Alcohol gives a more dramatic result because its vapor pressure is higher than that of water.

Ingredients for making a cloud

- Water vapor
  - High humidity means high dew point
- Cooling
  - Cooling air down to the dew point means the relative humidity is 100%
- Cloud condensation nuclei
  - What is it?

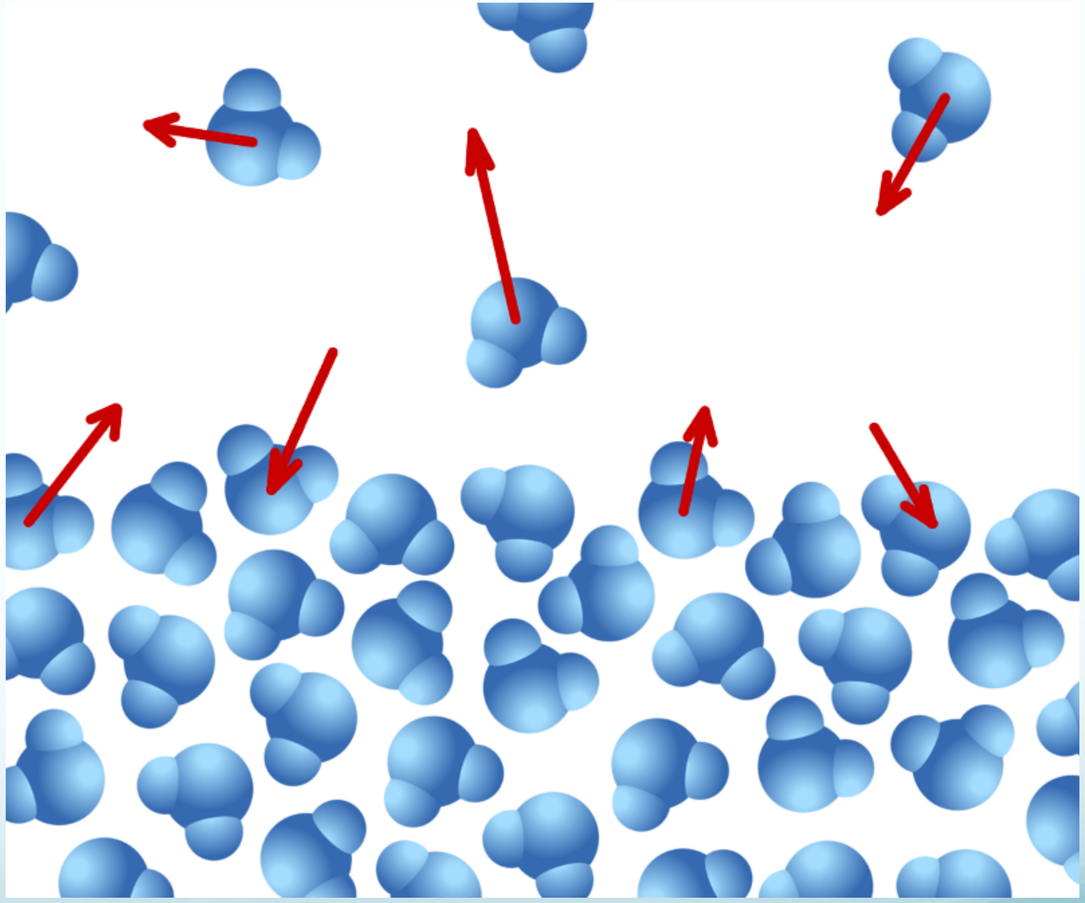


Cloud Condensation Nuclei — 1

Molecules continually evaporate from and condense onto a liquid surface.

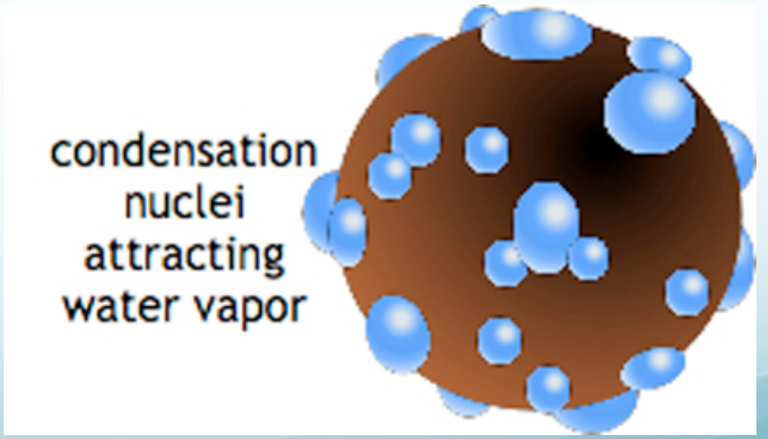
Water vapor condenses more easily if a droplet is larger than a few molecules.

- Easier for vapor to re-bond with other molecules
- Harder for molecules in liquid to break away



Cloud Condensation Nuclei — 2

- Water vapor condenses into liquid more easily if the droplet is larger than a few molecules.
- Water vapor condenses on tiny particles of sand, dust, smoke, sea salt, …
  - Particle diameters are 1/1000 to 1/10 the width of a human hair (0.1 to 10 microns)
  - These are cloud condensation nuclei (CCN)



Cloud in a bottle without alcohol

Cloud in a bottle, take 2

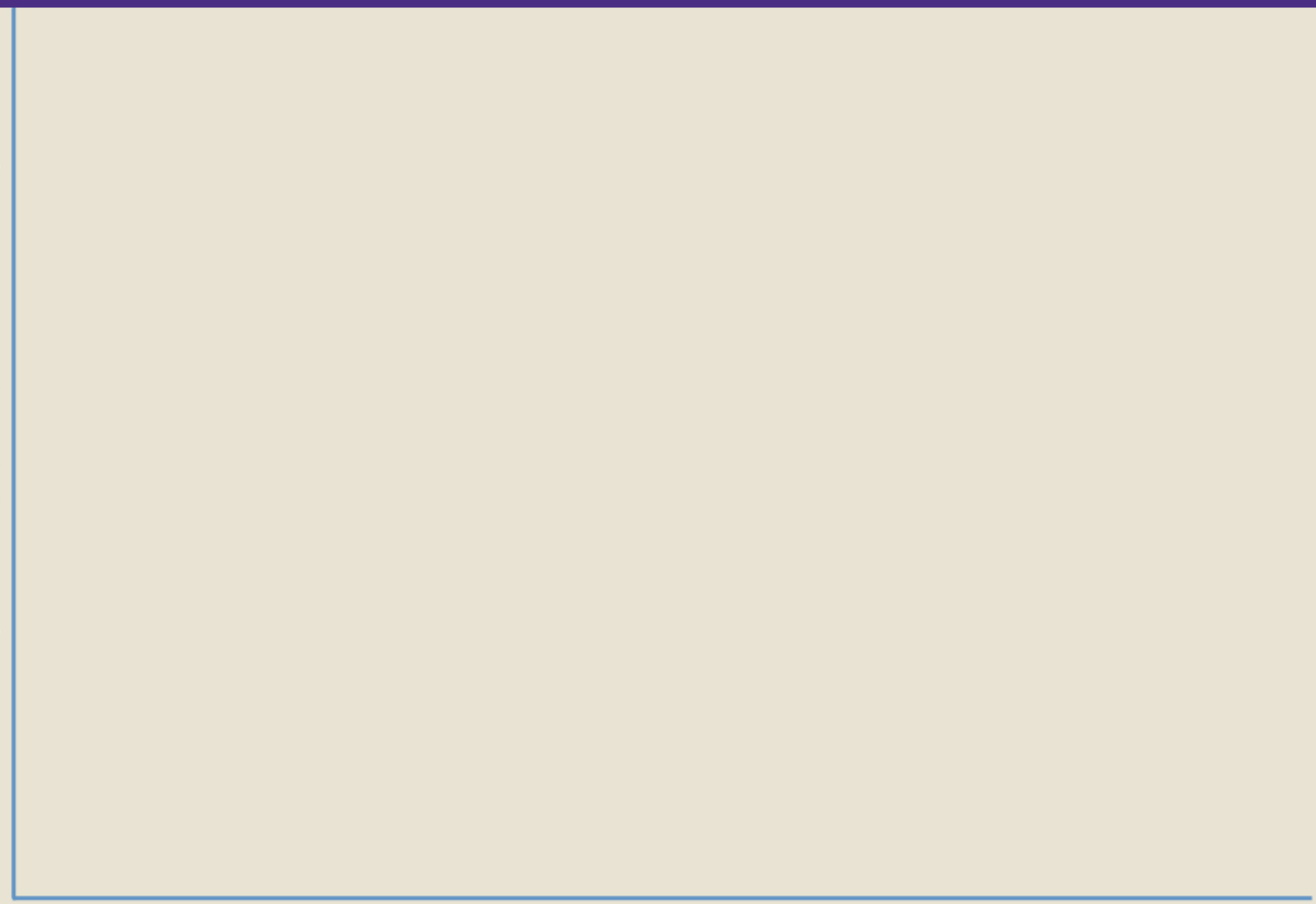
- by UW Department of Atmospheric Sciences Outreach group
- Cloud experiment from 2:22

Why is the match injected into the bottle?

To heat the air

To make the experiment look more interesting

To increase the number of cloud condensation nuclei in the bottle

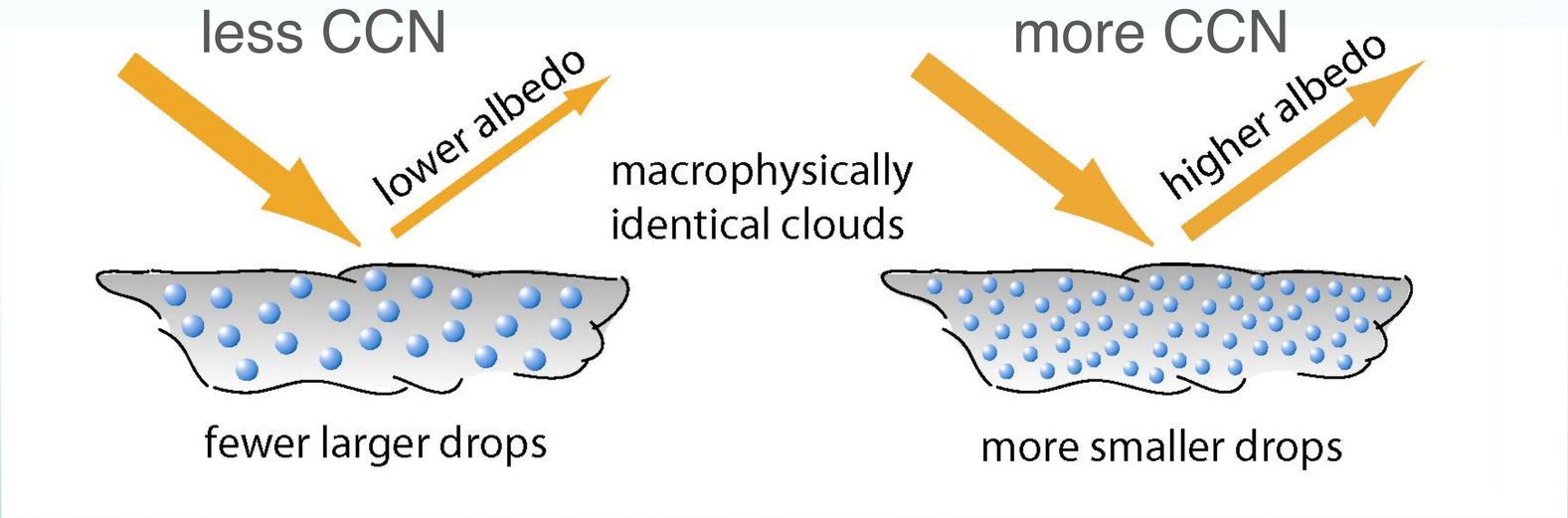


Answer

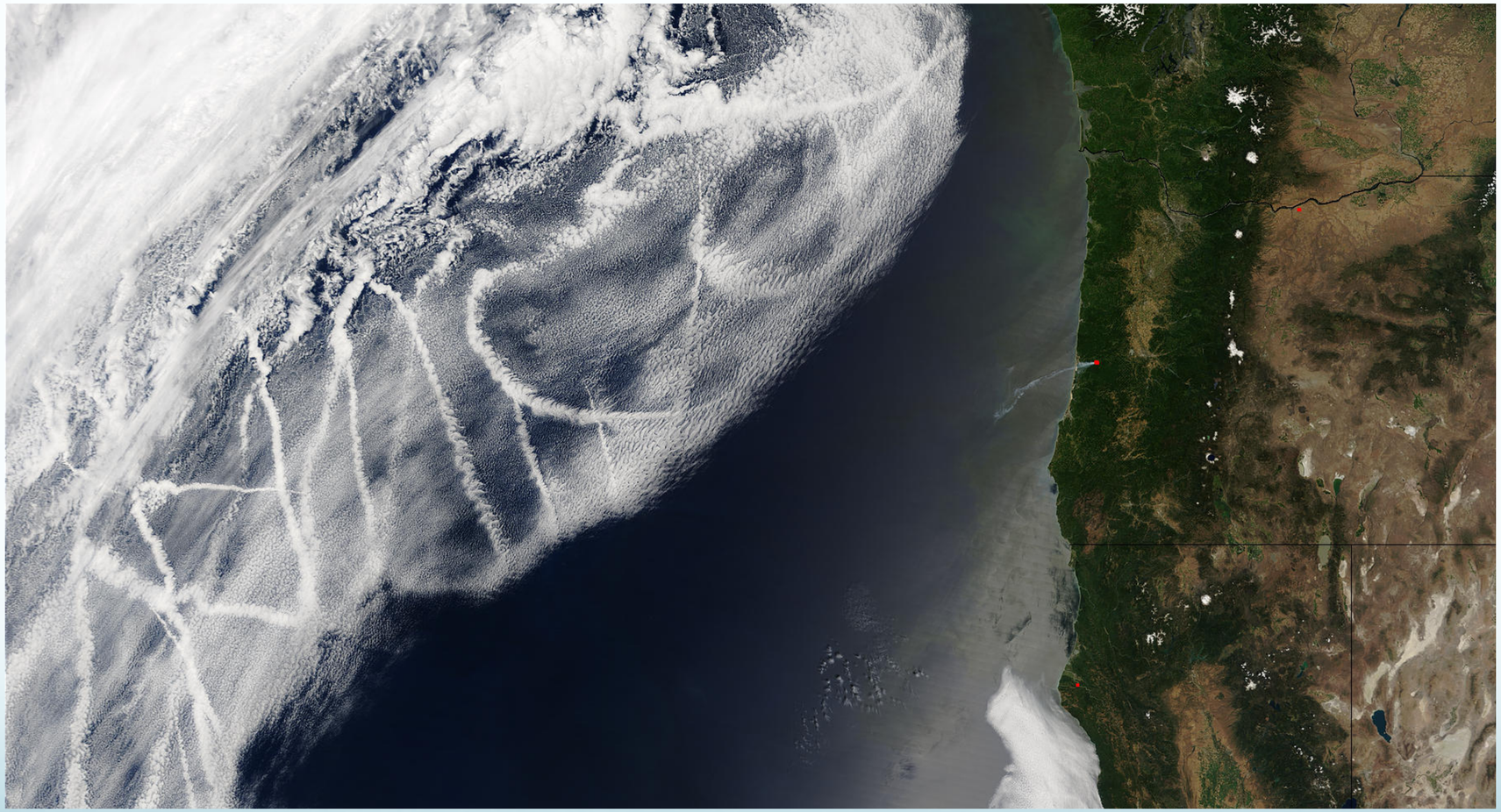
The smoke particles from the match increase the number of CCN making the cloud thicker and more visible.

Thick clouds (hard to see through) and CCN concentrations

- Clouds are harder to see through when their liquid water is distributed among lots of smaller droplets instead of a few larger droplets.
- This happens when there are more cloud condensation nuclei (CCN).



Ship tracks caused by enhanced CCN



Bright part indicates that more light is reflected by the clouds

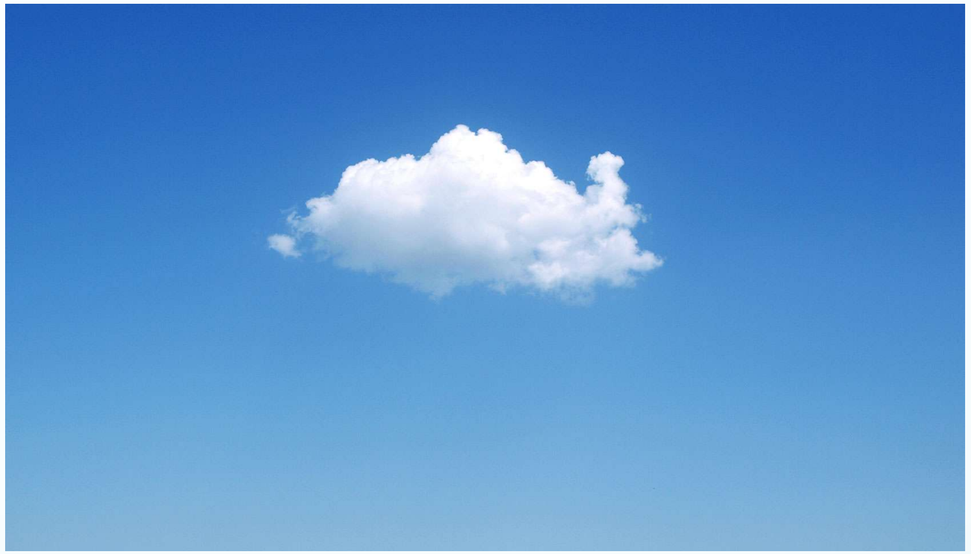
Fog thickened by high CCN from pollution

Why is this important?

- There are always enough CCN present to ensure that water vapor condenses into liquid droplets as soon as the air saturates.
- But the same is not true for the transition between cloud droplets and ice crystals.
  - Ice nuclei (IN) that will kick-start the freezing process in a droplet at 0° C are extremely rare.
  - More on this later.

Ingredients for making a cloud

- Water vapor
  - High humidity means high dew point
- Cooling
  - Cooling air down to the dew point means the relative humidity is 100%
- Cloud condensation nuclei
  - It helps if the water has something to stick to
  - Makes the cloud more visible too



Forming a Cloud

- Clouds form when air is cooled to saturation.
- The cooling occurs as the air rises.
- Why does rising air cool?
  (next week)