Clouds: Introduction

- Strongly influence Earth's radiative energy balance
- Key components of the global cycle of water through precipitation

- Influence and influenced by atmospheric circulation
- Highly complex cloud processes

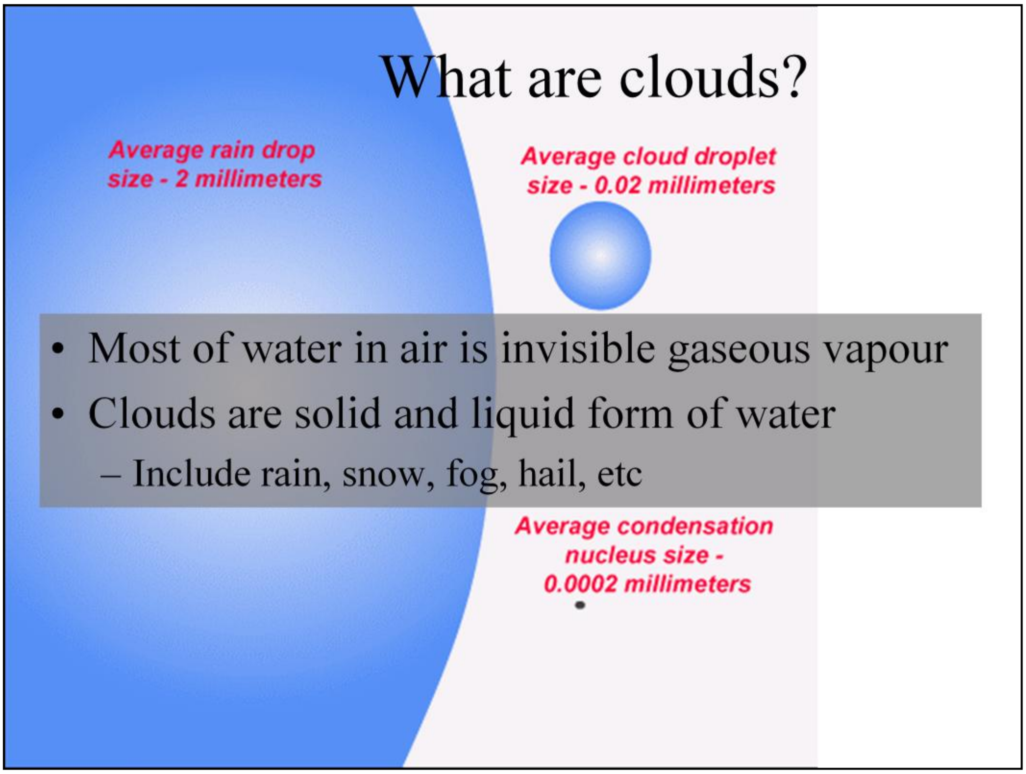
Clouds are integral to the climate system.

They are a crucial component of the global water cycle, vital to humans and to ecosystems which depend upon fresh water.

They are important signals of the atmospheric circulation that aid our ability to predict the weather.

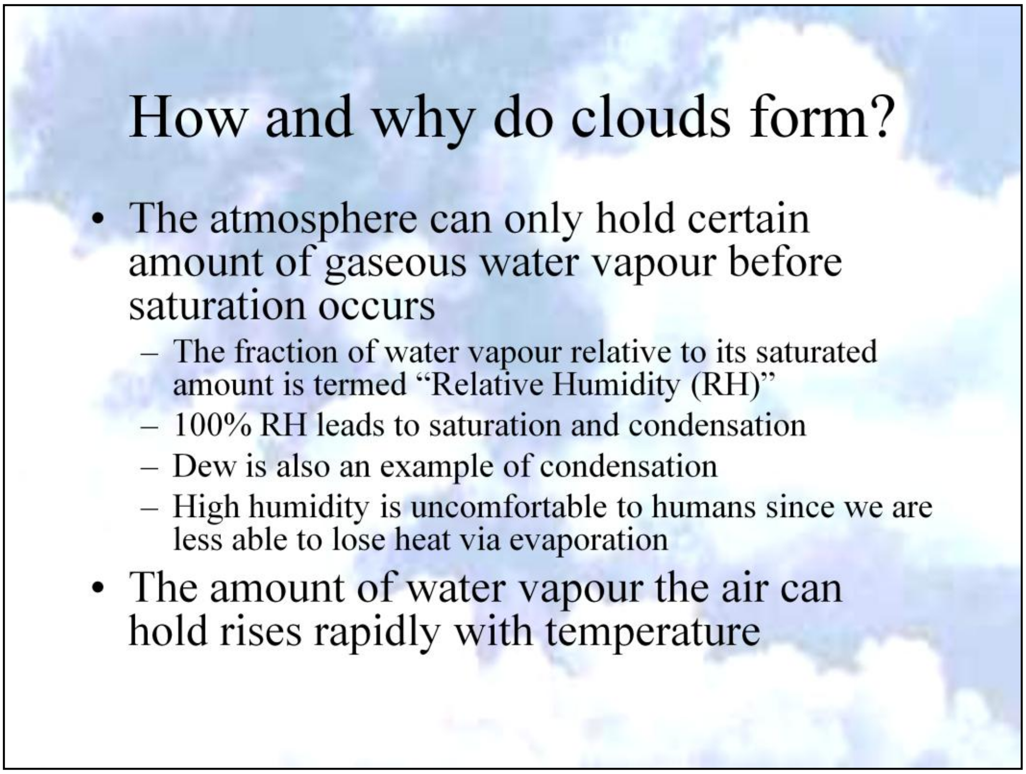
Clouds are also crucial for climate and climate change. In addition to their powerful role in the hydrological cycle, they strongly interact with the Earth's radiative energy balance. They cool the surface by shading it from the direct solar beam but almost as strongly enhance the greenhouse effect of the atmosphere by reducing the efficiency by which the surface can cool to space through thermal emission.

Their formation processes and radiative properties are complex and thus predicting how they will respond and influence climate change is an extremely difficult challenge.



Clouds (along with rain, snow, fog, haze, etc.) are wet atmospheric aerosols. They are made up of tiny spheres of water from 2-100μm which fall with terminal velocities of a few cm/sec. With a concentration of a few hundred droplets/cm3, a small cubic cloud, 1km on a side, contains 10^{17} droplets (100,000,000,000,000,000).

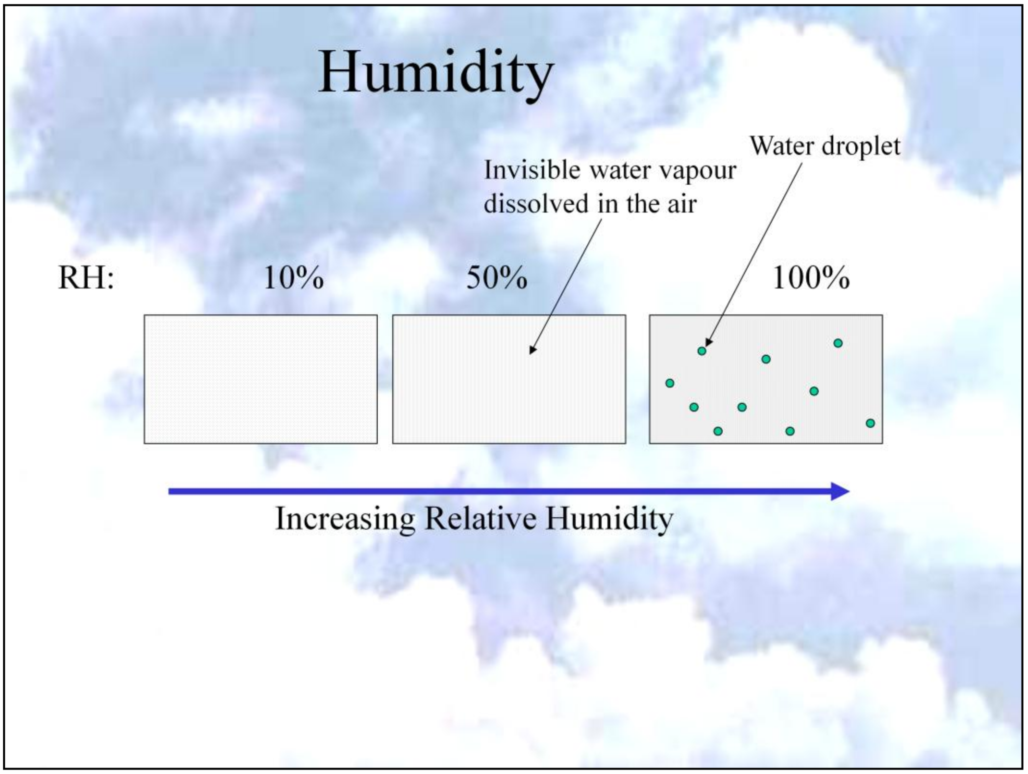
Most of the water in the atmosphere is dissolved as gaseous water vapour. Clouds are just the "tip of the ice-berg" but are particularly visible to us because they interact strongly with visible wavelengths of solar radiation that our eyes are sensitive to.



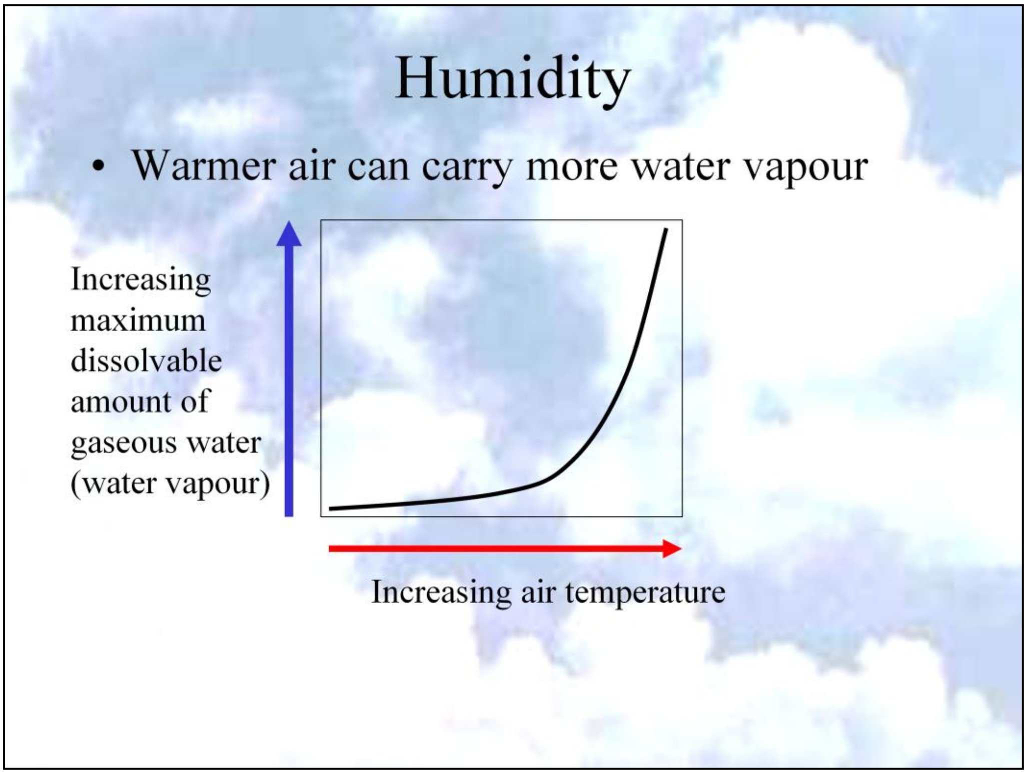
Clouds form because the air can only hold a certain amount of gaseous water vapour, just like water can only dissolve a certain amount of salt.

If there is more water vapour in the air than the air can hold, condensation of cloud droplets and ice may occur which are the clouds we observed. Crucially, the amount of water the air can dissolve is dependent on the temperature of the air.

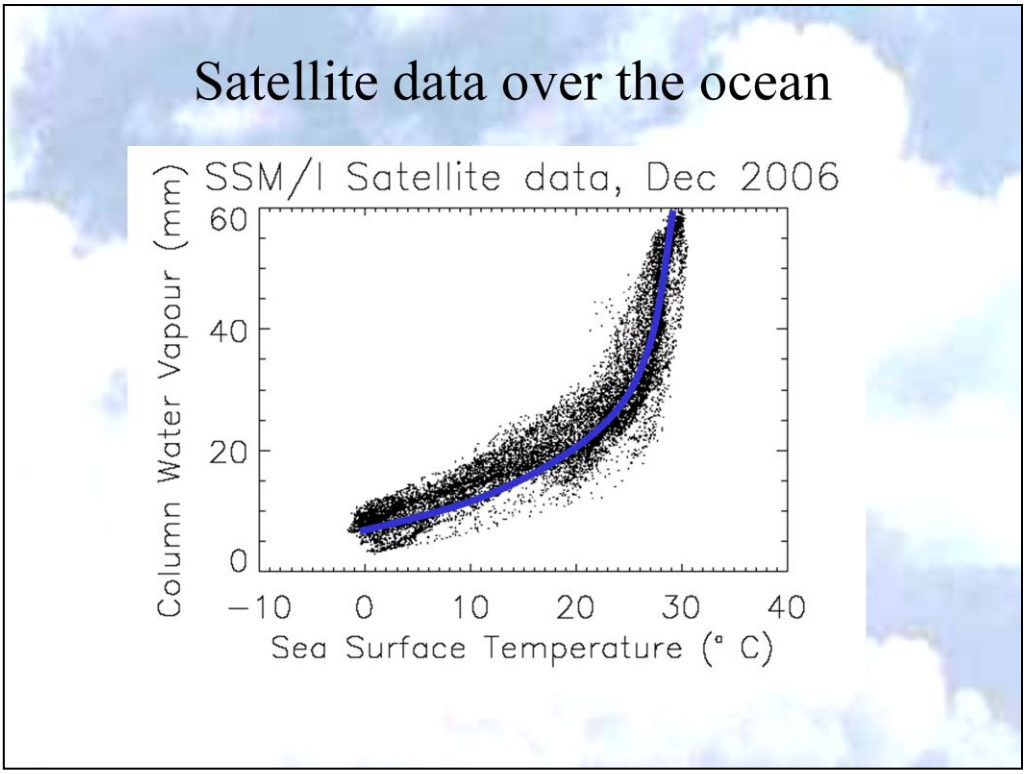
Condensation also requires a surface on which to act, for example, condensation on vegetation as is the case for morning dew. Clouds form on condensation nuclei, tiny particles in the atmosphere such as sea salt, dust and other aerosols. Sometimes "super-saturation" can occur: the air is so pristine that cloud cannot form due to the lack of condensation nuclei.



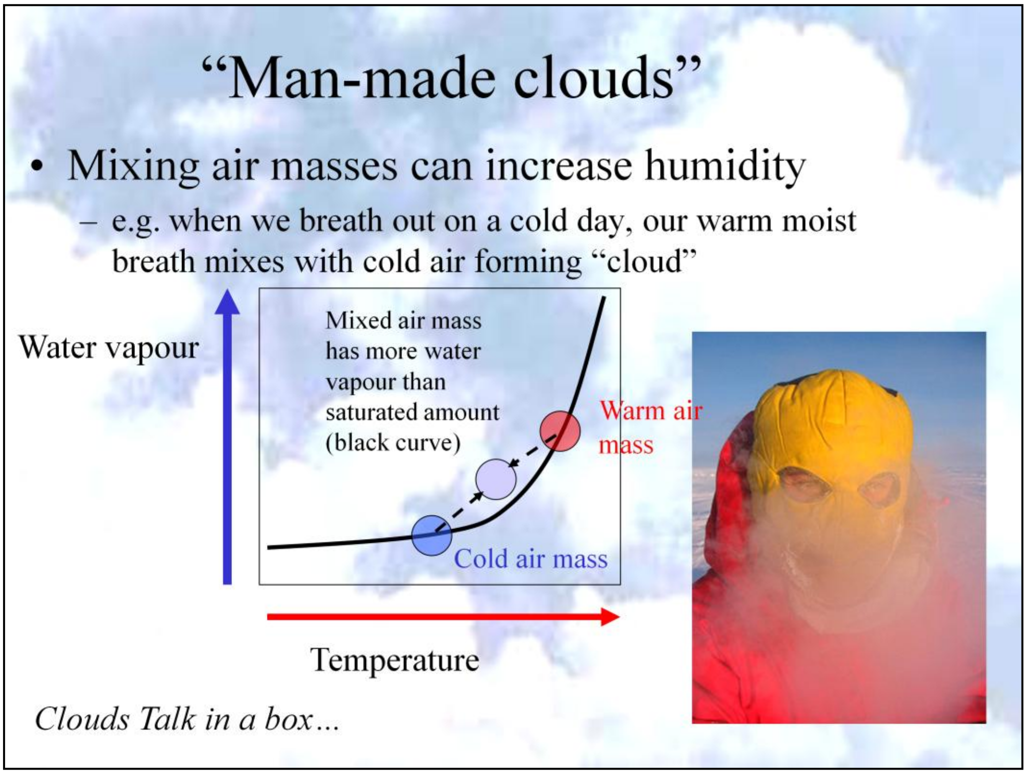
If relative humidity (RH) is 100%, the amount of water vapour in the air is equal to the maximum the air can hold before condensation of water droplets takes place. If RH is 50%, the amount of water vapour in the air is about one half of the saturated amount. Therefore cloud amount is fundamentally linked to relative humidity (more relative humidity increases the likelihood of cloud formation).



As air temperature rises the amount of water vapour the air can hold before saturation and condensation occurs rises rapidly. Therefore, if air is cooled and water vapour stays constant, the relative humidity will rise and eventually saturation will take place causing condensation and the formation of water or ice droplets depending on the temperature.



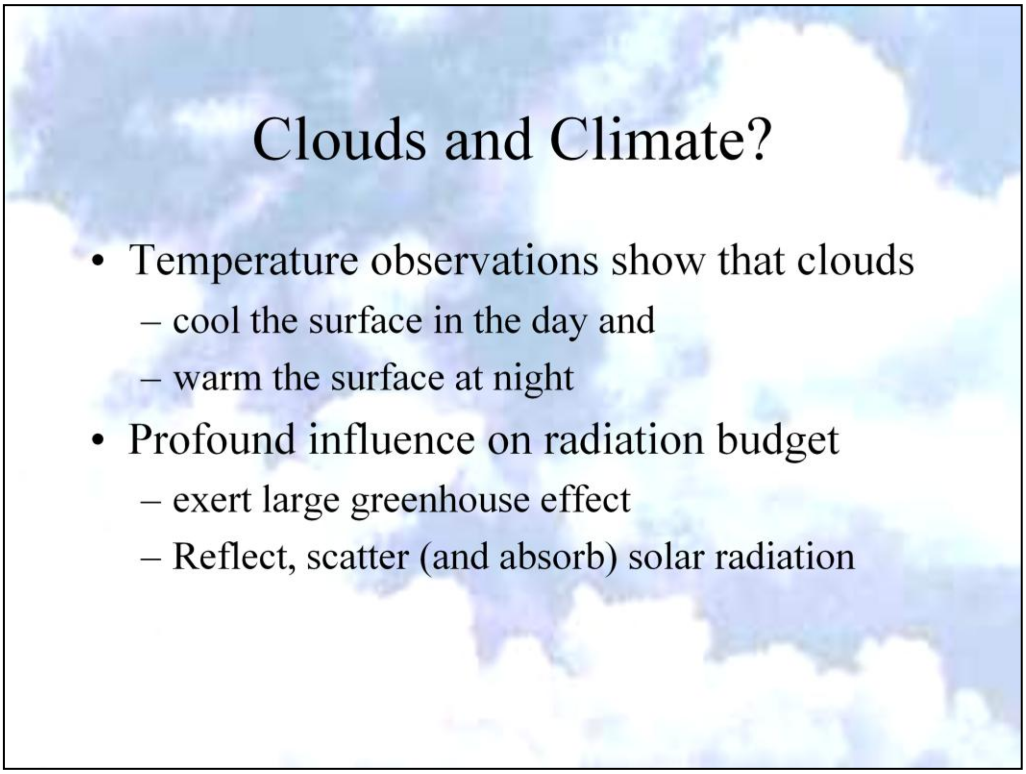
Satellite derived estimates of total column amount of water vapour over the ocean show a rapid rise with sea surface temperatures. This figure was created with recent passive microwave water vapour data.



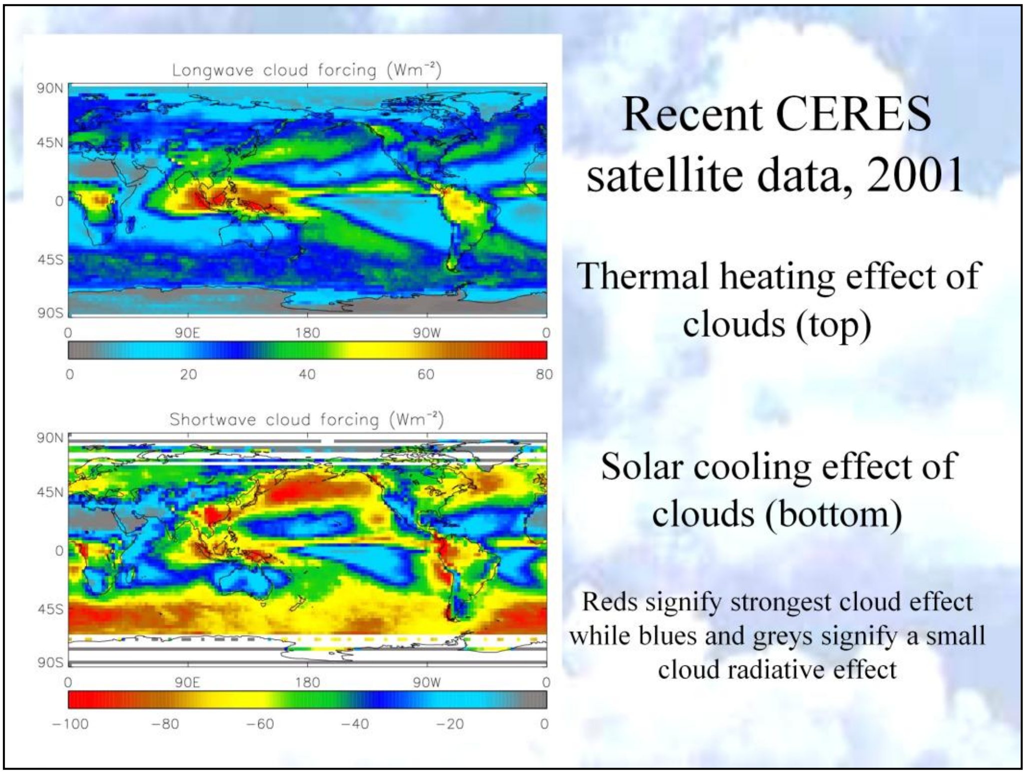
As air temperature increases the amount of water vapour the air can hold before saturation and condensation occurs rises rapidly. Therefore, if air is cooled and water vapour stays constant, the relative humidity will rise and eventually saturation will take place causing condensation and the formation of water or ice droplets depending on the temperature.

Since the amount of water the air can hold rises non-linearly, when you mix warm and cold air masses close to saturation, the average and average temperature of the two air masses may result in saturation (see above).

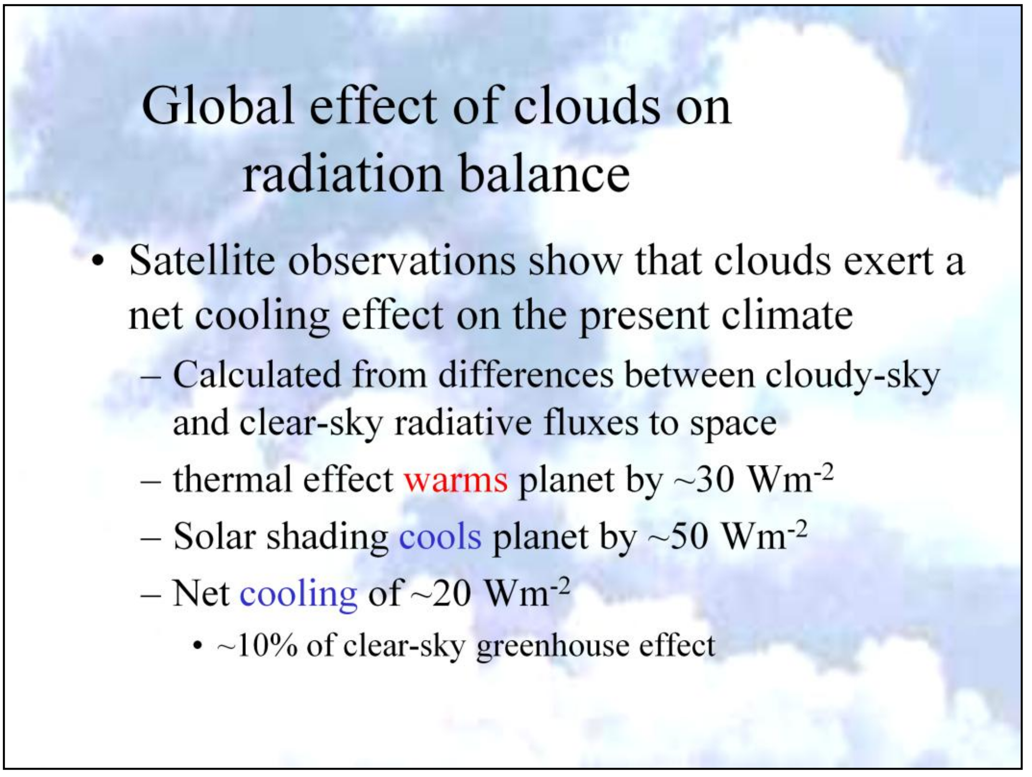
A similar process occurs when you can see your breath on a cold day.



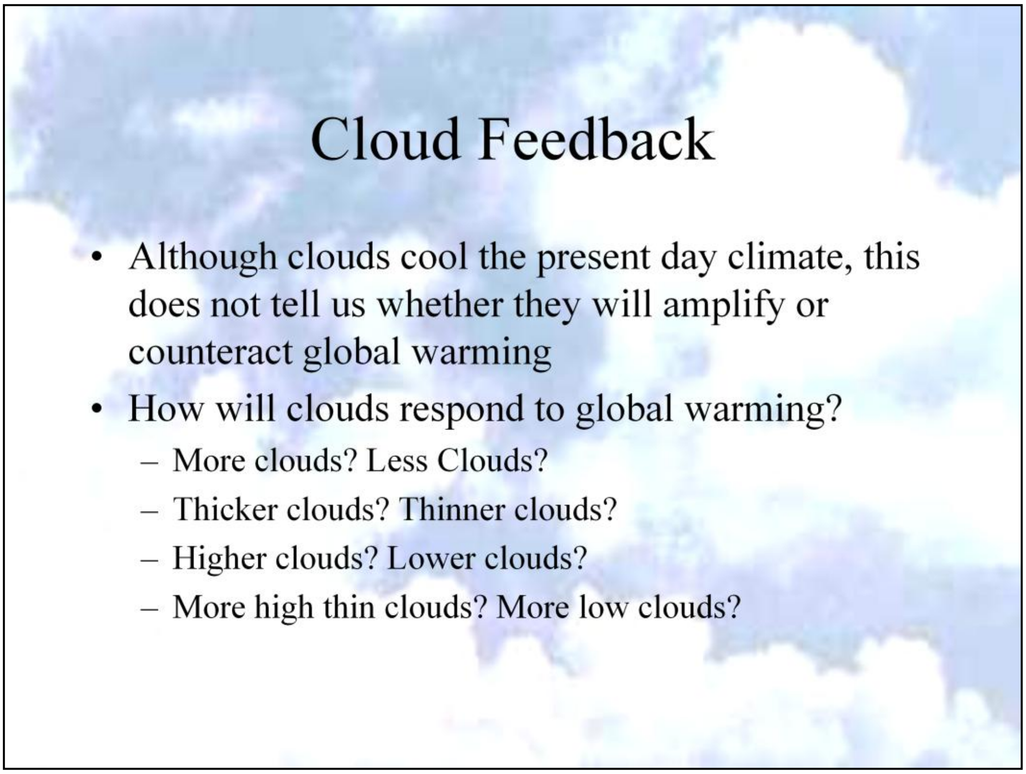
It is obvious to the surface observer that during the day, clouds cool the surface by shading us from the direct sunlight. At night, they impede the thermal cooling to space; on clear nights, the temperature drops more than on cloudy nights. The relative importance of the cooling and warming effects depends on whether the sun is up and how high in the sky the sun is. Additionally, cloud and atmospheric properties are important.



Clouds cool the planet, especially over the tropical rainy belt (ITCZ) and for mid-latitude wet regions such as experienced over the UK. Their greenhouse effect is also particularly strong over the tropical rainy belt and so here the net effect of clouds is small since the solar shading effect is counteracted by the greenhouse warming effect. Over mid-latitude regions and in particular for sub tropical regions of low-level, thick cloud (e.g. Peruvian stratocumulus belt) the solar shading effect dominates.



Averaged globally and over day and night, the cooling effect of clouds dominates over the greenhouse effect. This net cooling effect is approximately 10% of the strength of the clear-sky greenhouse effect from water vapour and other greenhouse gases including CO_2.



The fact the clouds exert a net cooling effect on the current climate does not tell us much about whether clouds will amplify global warming (positive feedback) or counteract global warming (negative feedback). To know what sign and magnitude feedback clouds may provide, we need to know how clouds will respond to climate change. For example, if cloud properties stay the same but coverage increases, clouds will likely counteract global warming (since clouds have a net cooling effect on present day climate). Alternatively, if low cloud cover diminishes with warming, the reduced cloud albedo effect will heat the surface, amplifying the initial warming.

Conclusions

- Clouds crucial to weather and climate
  - Global water cycle
  - Radiative Energy Balance
- Clouds currently exert a cooling effect
  - Cooling by day, especially thick, low clouds
  - Warming by night, especially for high altitude clouds
- Complex cloud processes
  - Difficult to represent in computer models
  - How will clouds respond to global warming?
  - Uncertainty in cloud feedback leads to large uncertainty in climate prediction; more observations required…