Lecture 5.

Are there trends in cirrus and contrail clouds?

Outline:

1. Background materials.

2. *Papers for class discussion*:

Minnis, P., et al., Contrails, cirrus trends, and climate, J. of Climate 17 (8):1671-1685, 2004.

Stordal F. et al., Is there a trend in cirrus cloud cover due to aircraft traffic? Atmos.Chem.Phys., 5, 2155-2162, 2005.

Additional reading (focus on sections 3 and 4):

Lohmann, U., and J. Fletcher, Global indirect aerosol effects: A review, Atmos.Chem.Phys., 5, 715-737, 2005.

Background materials.

Direct radiative forcing of aerosols (or clouds) is defined as a difference between the **net fluxes** in 'clean' and perturbed atmospheric conditions.

$$\Delta F = F_{aer}(TOA) - F_{clean}(TOA) \quad [5.1]$$

where

$F_{aer}(TOA)$ is **the net total flux** at the top of the atmosphere in the presence of aerosols (or clouds);

$F_{clean}(TOA)$ is the net total flux at the top of the 'clean' atmosphere.

Direct radiative forcing of aerosols (or clouds) can be expressed as

$$\Delta F = SWF + LWF \quad [5.2]$$

where ***SWF*** is the shortwave (solar) component of radiative forcing;

LWF is the longwave (thermal IR) component of radiative forcing;

$$SWF = F^{\uparrow}_{SW,clean}(TOA) - F^{\uparrow}_{SW,aer}(TOA) \quad [5.3]$$

$$LWF = F^{\uparrow}_{LW,clean}(TOA) - F^{\uparrow}_{LW,aer}(TOA) \quad [5.4]$$

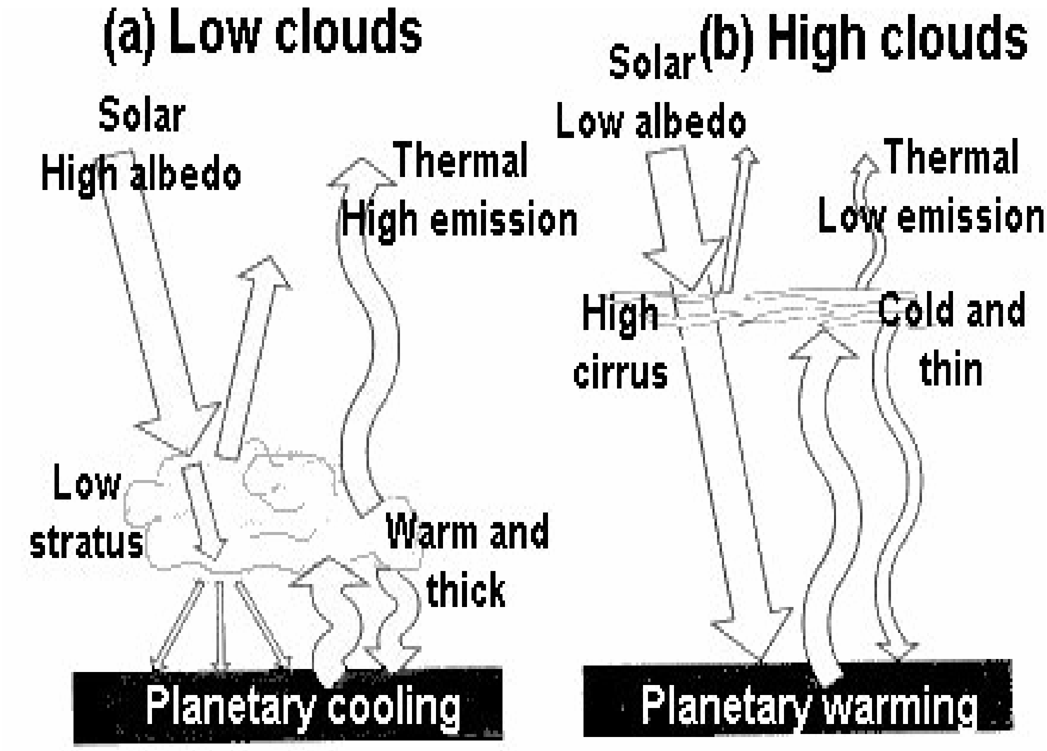


Figure 5.1 Radiative effects of water and cirrus clouds

Basics of cold clouds:

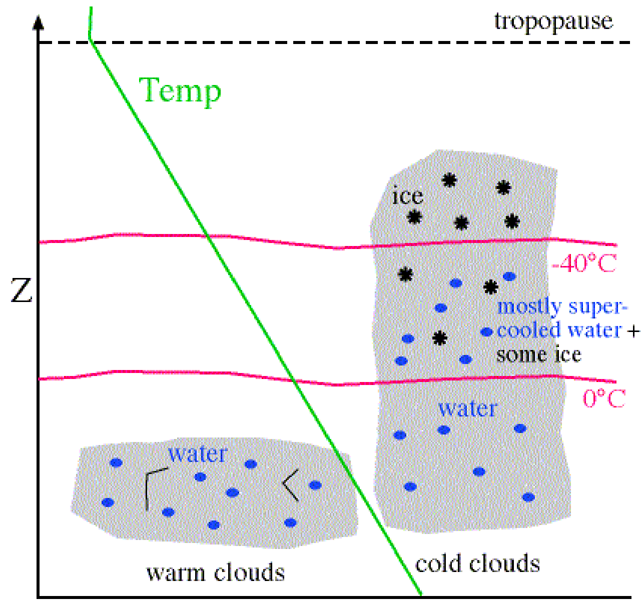
Cold clouds are defined as those clouds with tops colder than 0°C.

Can be comprised of:

- water
- super-cooled water - liquid droplets observed at temps less than 0°C
- ice

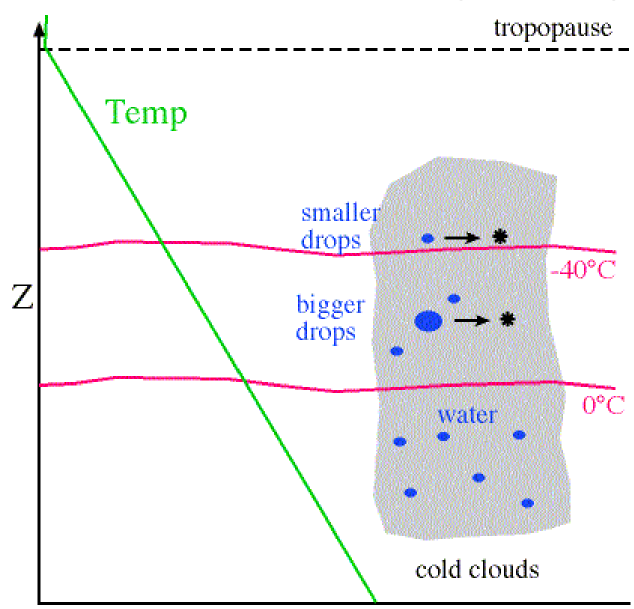
NOTE: Super cooled water is found at altitudes where: -40°C < Temp < 0°C

only ice is found at altitudes above -40°C



<u>Ice crystal formation by homogeneous freezing</u>

- Pure water drops do NOT freeze at 0°C
    - it needs to be colder
- bigger water drops will freeze at warmer temperatures than smaller drops
- smaller water drops require colder temperatures to freeze
- hence, you will find more smaller drops than larger drops higher in the cloud



Ice crystal growth through deposition:

- Vapor can deposit onto ice nuclei (IN) in a cloud
- There tends to be more cloud condensation nuclei (CCN) than ice nuclei (IN):
    - therefore, there tends to be more super cooled water droplets formed by condensation than ice particles formed by deposition at altitudes where -40°C < Temp < 0°C

Ice crystal growth through contact freezing:

- Occurs when a supercooled drop comes in "contact" with an ice nuclei
- causes the supercooled drop to freeze

Accretion/Riming:

- Occurs when super cooled drops freeze onto ice particle
- the resultant particle is often referred to as graupel

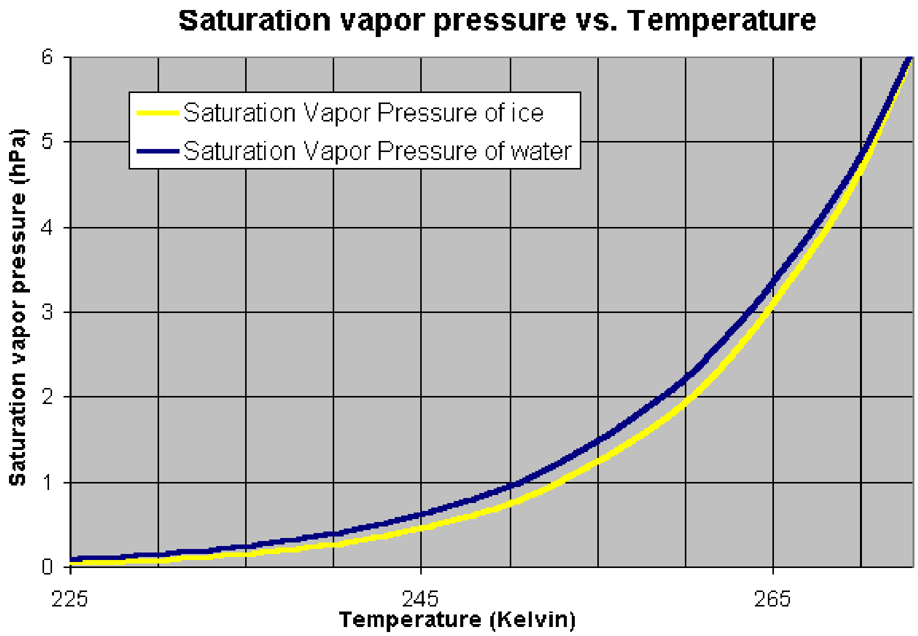
Aggregation

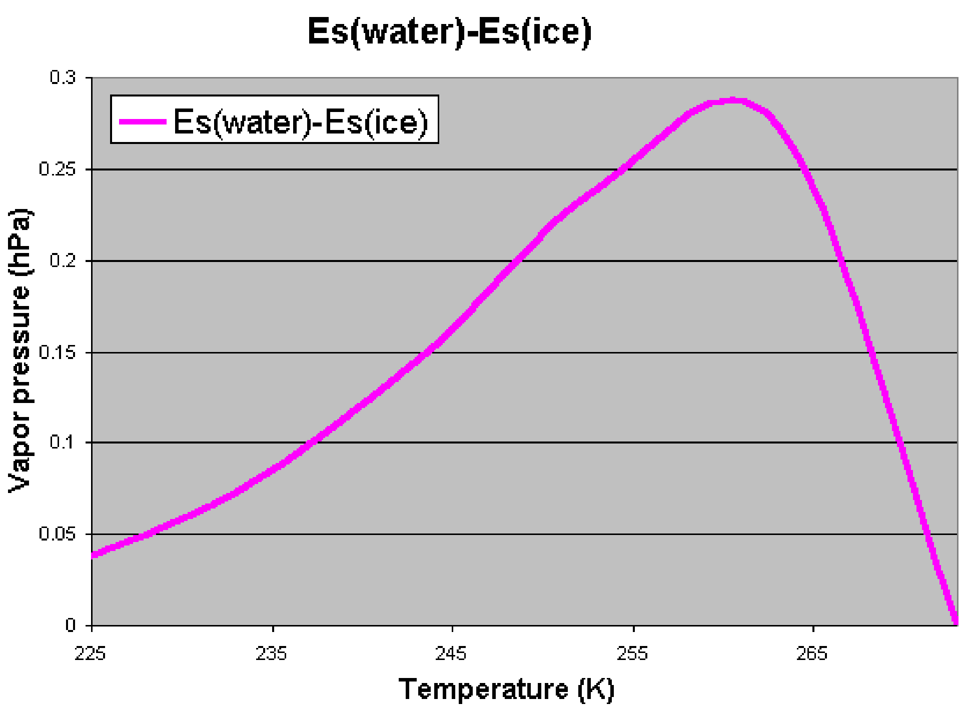
- Occurs when two ice particles stick together, forming one larger particle

<u>All of the aforementioned processes</u> are occurring in a cold cloud to form ice particles

- homogeneous freezing
- deposition
- contact freezing
- accretion
- aggregation

Saturation water vapor e_s(water) > e_s (ice)





- The largest differences e_s(water) - e_s (ice) is a maximum at -15°C
- Hence, it is near this temperature in a cold cloud that ice particles will grow more readily than water particles

***Aerosol and contrail formation processes in an aircraft plume and wake as a function of plume age and temperature*.**

http://www.grida.no/climate/ipcc/aviation/index.htm

Reactive sulfur gases, water vapor, chemi-ions (charged molecules), soot aerosol, and metal particles are emitted from the nozzle exit planes at high temperatures. H_2SO_4 increases as a result of gas-phase oxidation processes. Soot particles become chemically activated by adsorption and binary heterogeneous nucleation of SO_3 and H_2SO_4 in the presence of H_2O, leading to the formation of a partial liquid H_2SO_4/H_2O coating. Upon further cooling, volatile liquid H_2SO_4/H_2O droplets are formed by binary homogeneous nucleation, whereby chemi-ions act as preferred nucleation centers. These particles grow in size by condensation and coagulation processes. Coagulation between volatile particles and soot enhances the coating and forms a mixed H_2SO_4/H_2O-soot aerosol, which is eventually scavenged by background aerosol particles at longer times. If liquid H_2O saturation is reached in the plume, a contrail forms. Ice particles are created in the contrail mainly by freezing of exhaust particles. Scavenging of exhaust particles and further deposition of H_2O leads to an increase of the ice mass. The contrail persists in ice-supersaturated air and may develop into a cirrus cloud. Short-lived and persistent contrails return residual particles into the atmosphere upon evaporation. Scavenging time scales are highly variable and depend on exhaust and background aerosol size distributions and abundances, as well as on wake mixing rates.