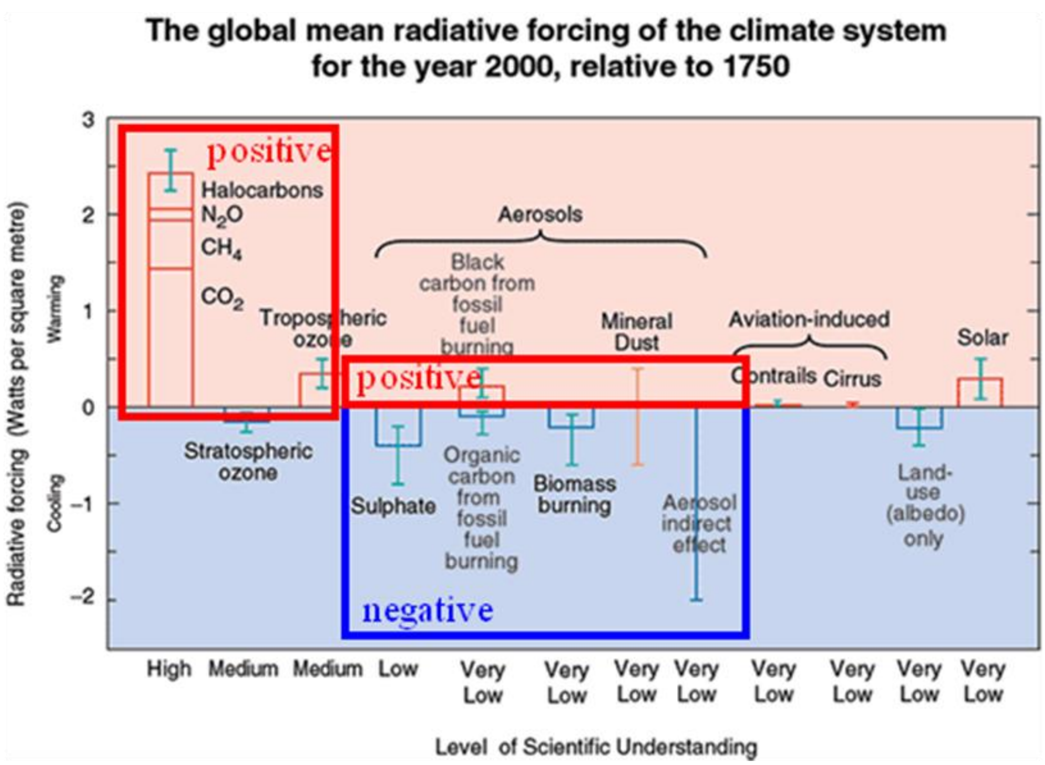
Lecture 8.

Hot topic:
Aerosol-cloud-climate interactions: Aerosol indirect effects

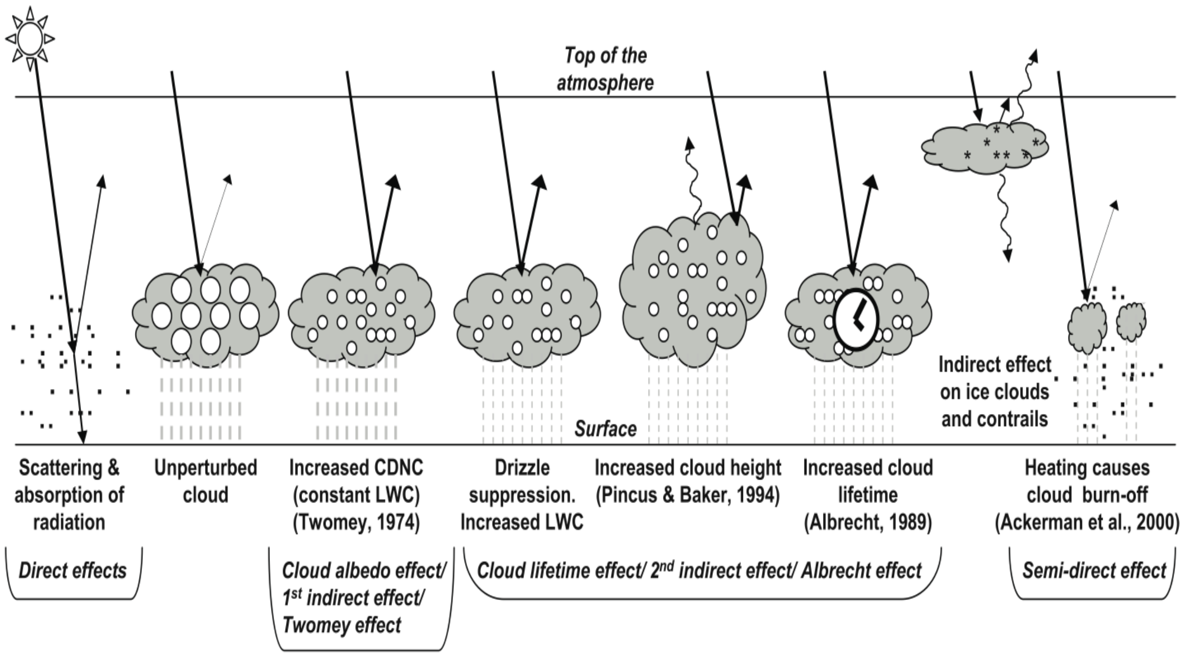
<u>Required reading:</u>

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

IPCC(29007): Aerosol indirect effect causes the largest negative forcing but remains poorly quantified



Mechanisms of the first and second indirect aerosol effects.



Mechanism of First indirect effect:

more aerosol particles -> more CCN->more CDNC but smaller sizes if LWC is constant -> more reflectivity from clouds (i.e. higher albedo) -> more negative radiative forcing

Mechanism of Second indirect effect (Albrecht effect):

more aerosol particles -> more CCN->more CDNC but smaller sizes -> suppression of precipitation (slowed down collision-coalescence) -> more negative radiative forcing

Emerging questions:

1) Do first and second indirect effects act in all types of clouds and for all types of aerosols?
2) How well are mechanists involved in second indirect effects understood?
3) What are implications for aerosol impacts on precipitations?

<u>First indirect effect</u>. Figure 1 below summarizes some measurements of number concentrations of cloud drop (CDNC) and aerosols in differing environments.

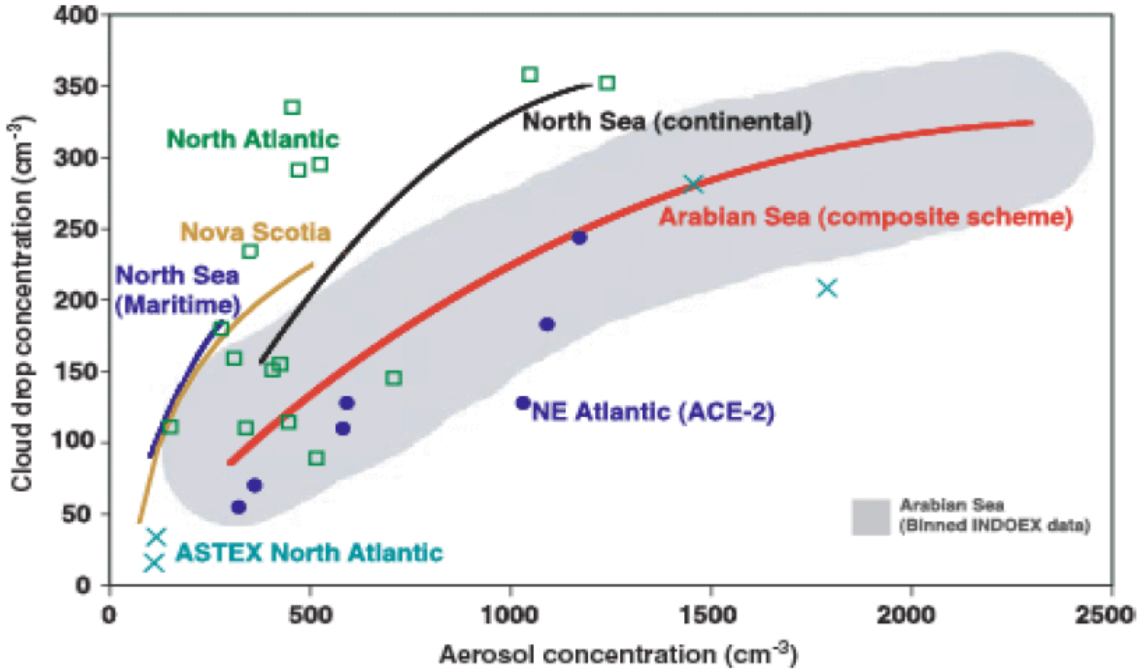


Figure 1. Aircraft measurements of CDNC aerosol number concentration. The thick red line is a theoretical parameterization based on INDOEX aircraft data for the Arabian Sea (Ramanathan et al., 2001).

Conclusions:

1) Measurements show that CDNC increases with increasing aerosol concentration. However, this relationship is not simple (linear) because of several possible reasons.
2) One reason is that CCN are only a fraction of the aerosol population and that this fraction varies significantly with the size distribution and chemical composition of the aerosol.
3) Another reason is that the fraction of available CCN that are actually activated in a cloud increases with the intensity of the updraft velocity at cloud base, and hence differences between activation in stratus (stratocumulus) and deep convective clouds (compare stratocumulus observed in ASTEX and some in ACE-2 versus deep convective clouds observed in North Atlantic).

4) Furthermore, the total aerosol concentration can vary from measurement to measurement depending on which instrument is used (sizes bigger than 2.5, 10, 20 nm) because, during nucleation events, the relative concentration of the smallest particles can be very high, while such particles can hardly be activated in clouds. This may introduce additional biases in establishing the linkages between CDNC and aerosol concentration.

Summary of different indirect aerosol effects associated with clouds

Effect	Cloud Type	Description	Sign of TOA Radiative Forcing
First indirect aerosol effect (cloud albedo or Twomey effect)	All clouds	For the same cloud water or ice content, more but smaller cloud particles reflect more solar radiation	Negative
Second indirect aerosol effect (cloud lifetime or Albrecht effect)	All clouds	Smaller cloud particles decrease the precipitation efficiency, thereby prolonging cloud lifetime	Negative
Semidirect effect	All clouds	Absorption of solar radiation by soot leads to evaporation of cloud particles	Positive
Glaciation indirect effect	Mixed-phase clouds	An increase in ice nuclei increases the precipitation efficiency	Positive
Thermodynamic effect	Mixed-phase clouds	Smaller cloud droplets inhibit freezing, causing supercooled droplets to extend to colder temperatures	Unknown
Surface energy budget effect	All clouds	The aerosol-induced increase in cloud optical thickness decreases the amount of solar radiation reaching the surface, changing the surface energy budget	Negative

Why is the indirect effect poorly characterized?

- Aerosol-cloud interactions take place at smaller spatial scales than global climate models can resolve, and must be parameterized.
- Aerosol-cloud interactions are complex; many aspects are unknown or poorly understood.
- Climate models provide limited information about clouds and aerosols.

Research needs:

- A variety of aerosol activation effects need to be included (chemical composition) in parameterizations of aerosol-cloud interactions.
- Laboratory and *in-situ experiments are necessary for constraining* parameterizations.
- Organic compounds are a major source of predictive uncertainty.
- Parameterizations are being developed that address key aerosol-cloud interactions at their appropriate scale. A major problem is inferring subgrid properties (particularly dynamics) from resolved GCM quantities.
- Sources of CCN precursors need to be carefully characterized.