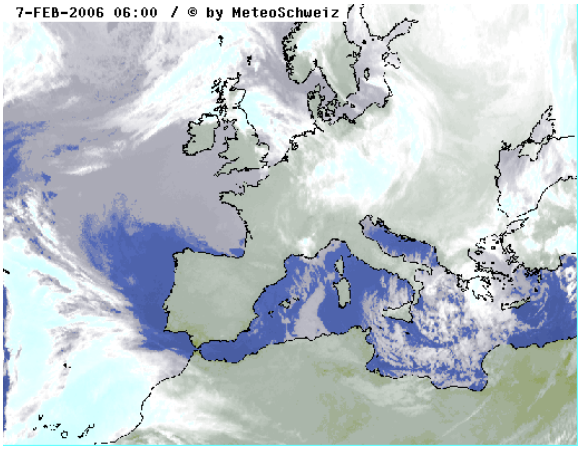
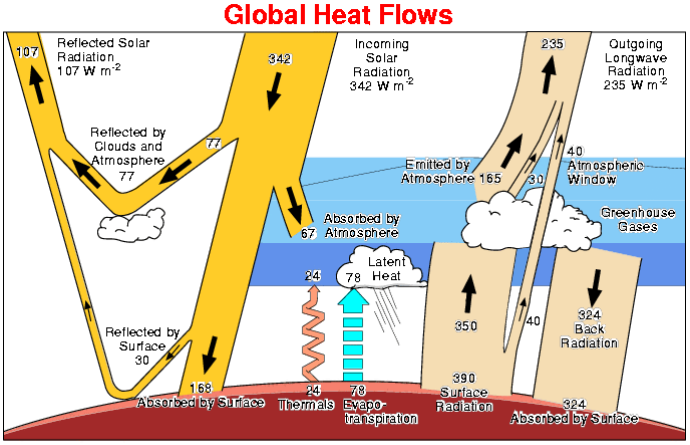
Radiative effects of clouds and aerosols



Importance of clouds for the energy budget

- Clouds are a major factor in the Earth's radiation budget, reflecting sunlight back to space and trapping infrared radiation emitted by the Earth's surface.
- The largest variations of albedo and outgoing longwave radiation are associated with clouds.
- Convection also supports large transfers of sensible and latent heat from the Earth's surface, which represents an important heat source for the atmosphere

Global Heat Flows



Kiehl and Trenberth 1997

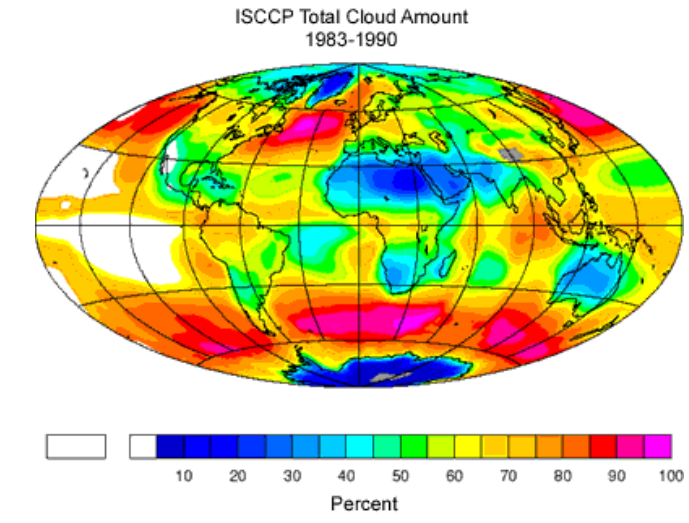
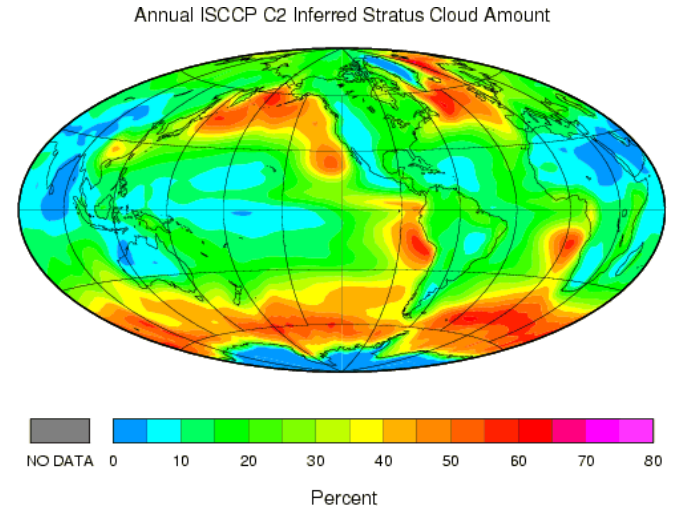
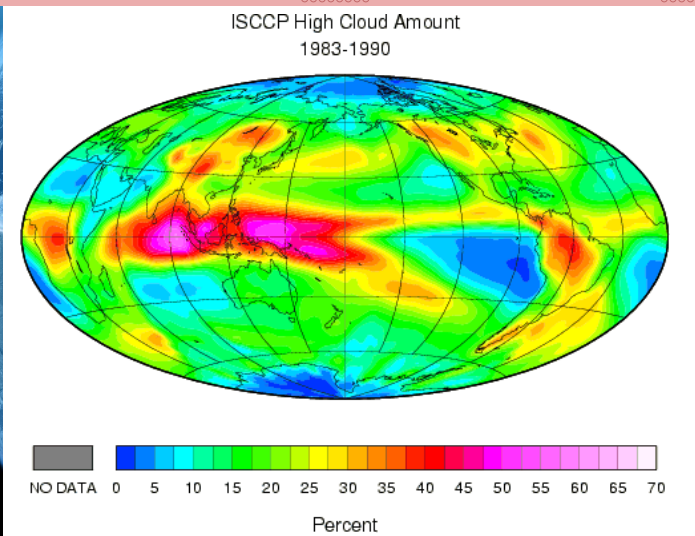


Figure: Annual mean cloud cover 60-65%





Cloud forcing

- Interpret influence of clouds on the radiation balance as "forcing".
- In the longwave, the colder and higher the cloud, the more longwave radiation is trapped and re-emitted to the surface (increases surface temperature).
- In the shortwave, the high reflectivity of clouds (which is independent of cloud height) decreases the incoming solar flux, reducing surface temperature. → clouds cool in the shortwave.
- Clouds also introduce heating by absorbing SW radiation.
- Obtain cloud forcing (CF)as the difference between cloudy conditions and cloud-free conditions:

$$CF_{SW} = F_{SW} - F_{SW}^{CS} \quad (1)$$

$$CF_{LW} = F_{LW}^{CS} - F_{LW} \quad (2)$$

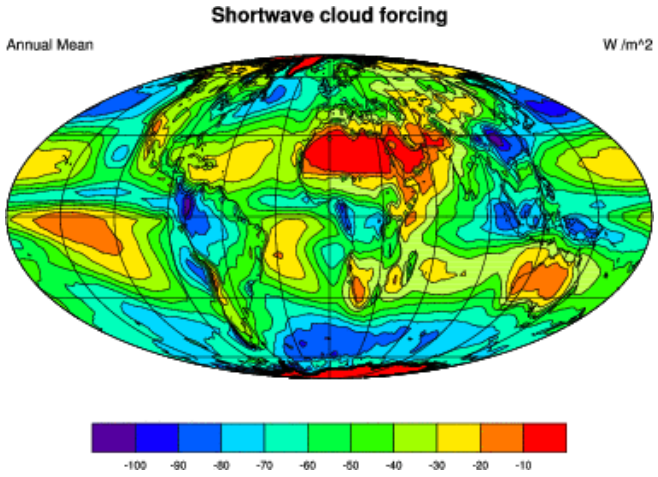


Figure: Global annual mean shortwave cloud forcing: -50 W m^{-2}

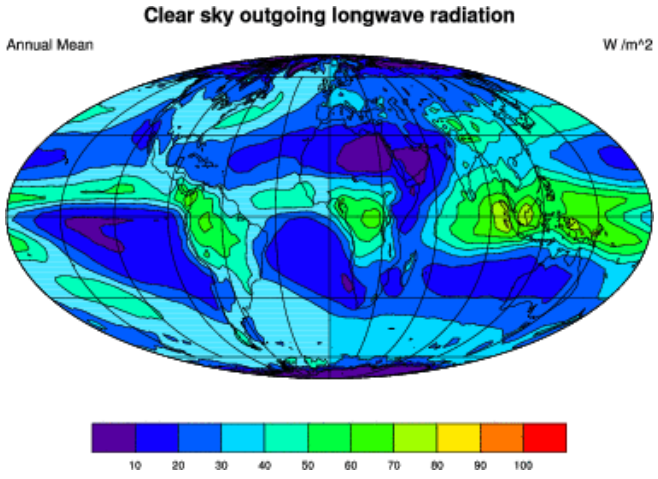


Figure: Global annual mean longwave cloud forcing: 30 W m^{-2}

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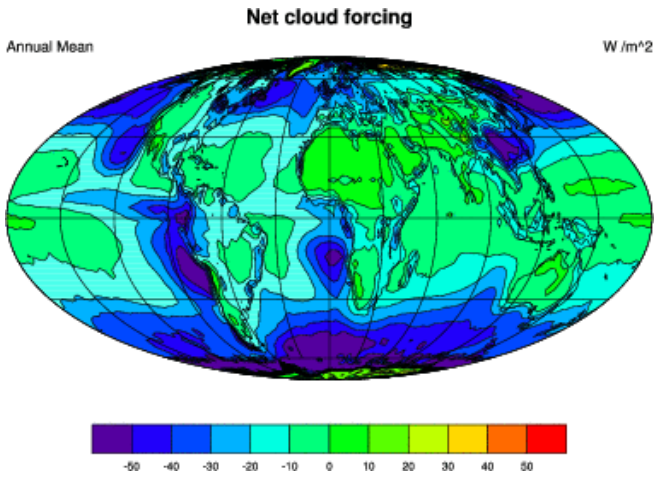

Figure: Global annual mean net CF: -20 W m^{-2} ($\hat{=}$ 5 times 2 x CO_2)

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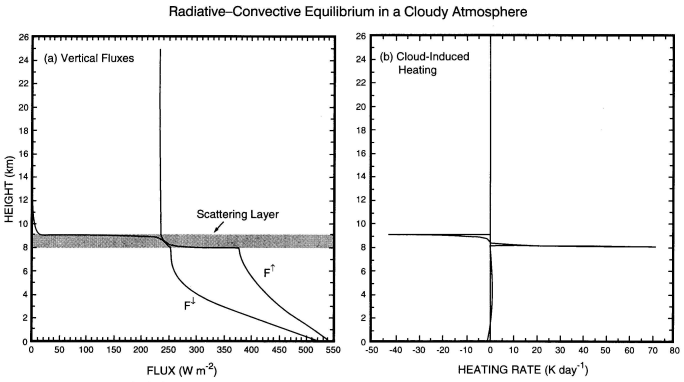

Figure 9.33 Energetics inside a cloudy atmosphere that is in radiative–convective equilibrium and contains a 1-km-thick scattering layer with microphysical properties of cumulus in Fig. 9.23. The fractional cloud cover is adjusted to give an albedo of 0.30. (a) Upwelling and downwelling LW fluxes. (b) Cloud-induced heating: $\frac{q}{c_p} - \left(\frac{q}{c_p}\right)^{CS}$, where the superscript refers to radiative–convective equilibrium under clear-sky conditions (Fig. 8.22).

Figure: Source: Salby (1996)

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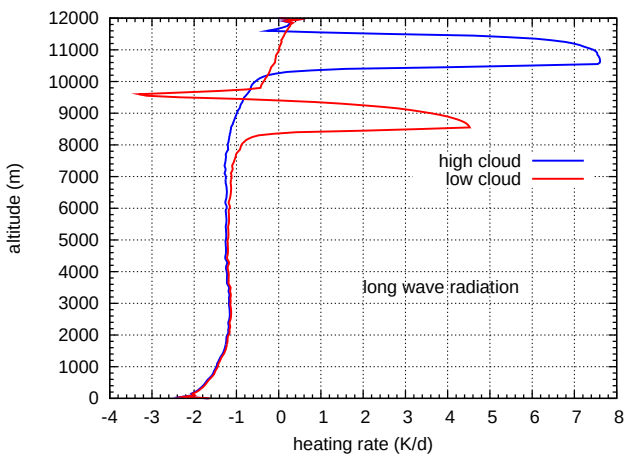
Cirrus longwave heating rates



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Cirrus cloud forcing Ackerman (1988)

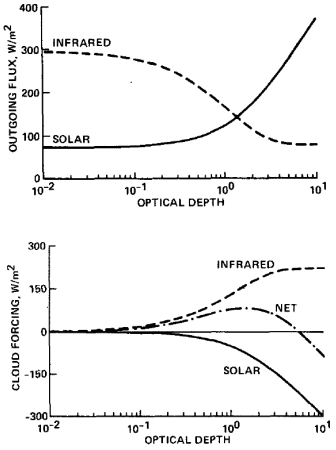

FIG. 13. (a) Emitted infrared and reflected solar flux and (b) infrared, net, and solar cloud forcing in W m^{-2} as a function of cirrus 0.55 μm optical depth. The cloud is assumed to be plane-parallel and located between 15 and 17 km altitude. The solar zenith angle is 53°.

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Tropical cloud forcing (Lohmann&Roeckner, 1995)

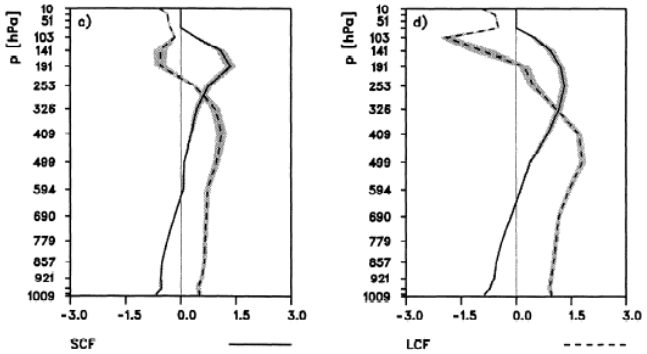

Figure 12. Vertical profiles of SCF and LCF averaged between 0°–30°N and 60°E–150°E for the experiments (a) 1M2, (b) SM2, (c) SP2, and (d) BM2. Units, K/d. Shading indicates standard deviations of monthly means.

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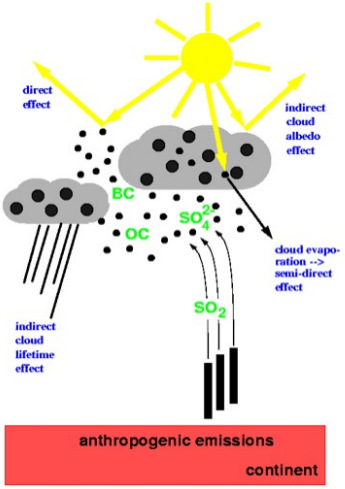
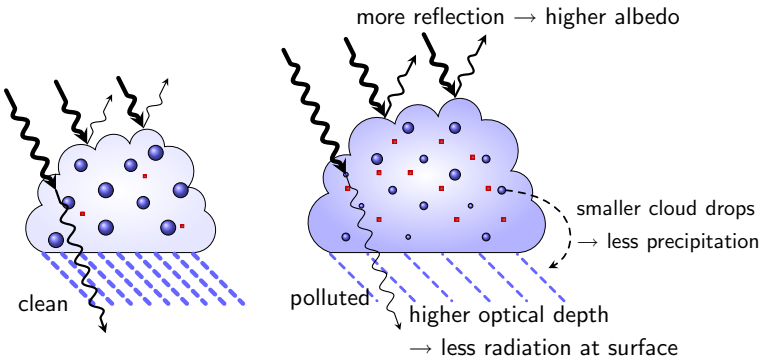
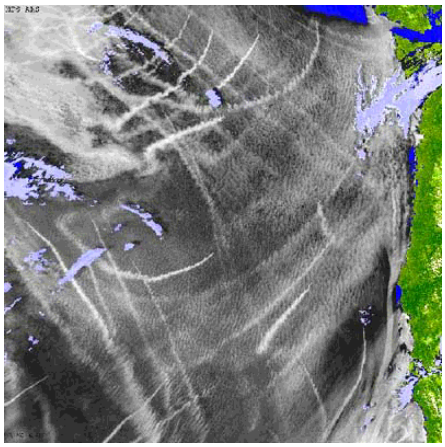
Aerosol radiative effects



Cloud albedo and lifetime effect (negative radiative effect for warm clouds at TOA, less precipitation); solar dimming (less radiation at the surface)



Shiptracks off the coast of Washington



Evidence of the cloud albedo effect

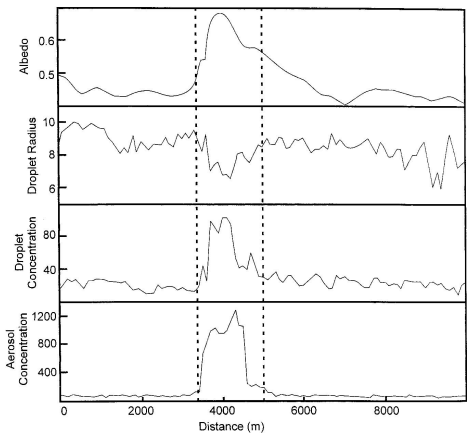


Figure: Durkee et al., JAS, 2000

Evidence of the cloud lifetime effect

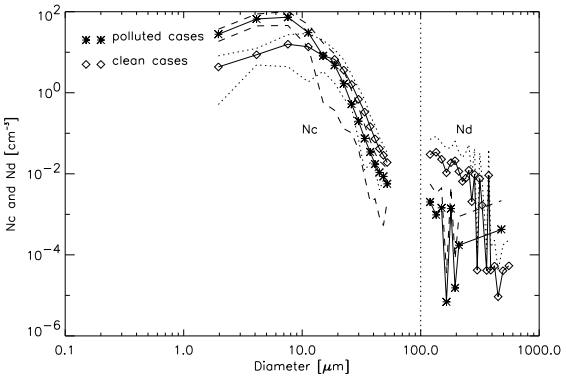


Figure: Peng et al., JGR, 2002

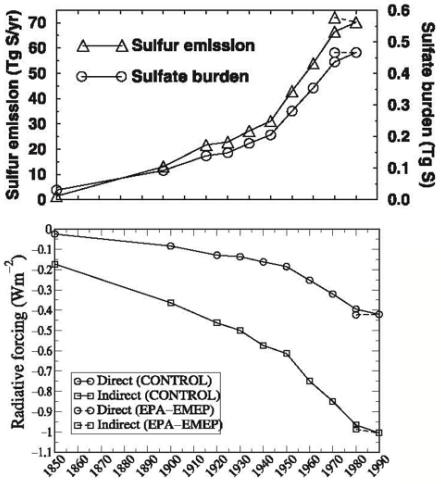


Figure: Boucher and Pham, GRL, 2002

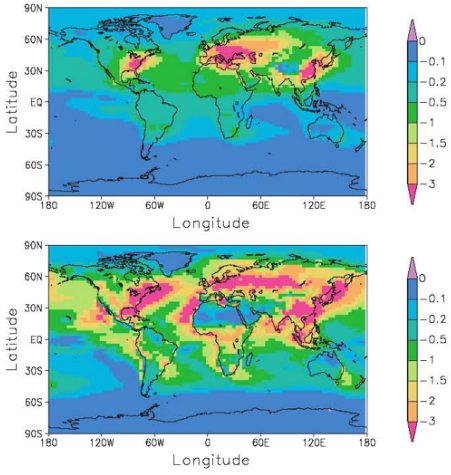


Figure: Boucher and Pham, GRL, 2002

Global mean radiative forcing from 1750-2000

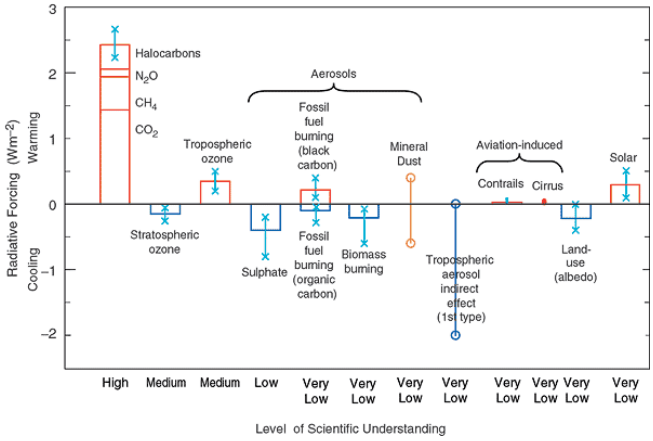
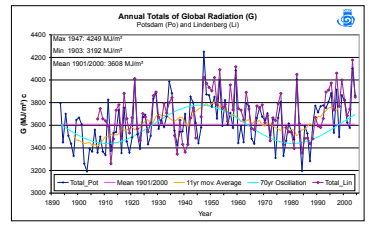


Figure: IPCC, 2001

Shortwave surface radiation in Germany



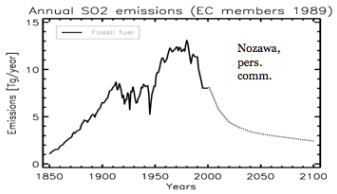


Figure: Wild et al., Science [2005] and Behrens [2003]