Monday 11 September, 2017
10:30-11:30
Class#06

Topics for the hour
Announcements

- Review
- Longwave Radiation
- Radiative Model of Atmosphere
- Albedo and what it is sensitive to
- Clouds and how they impact earths surface

http://www2.gi.alaska.edu/~bhatt/Teaching/ATM694.fall2017/ATMGEO694.htm

Review

- shortwave radiation
- longwave radiation
- Solar radiation at the TOA, at surface of earth?
- albedo, earth's albedo
- Emission temperature

What are these?

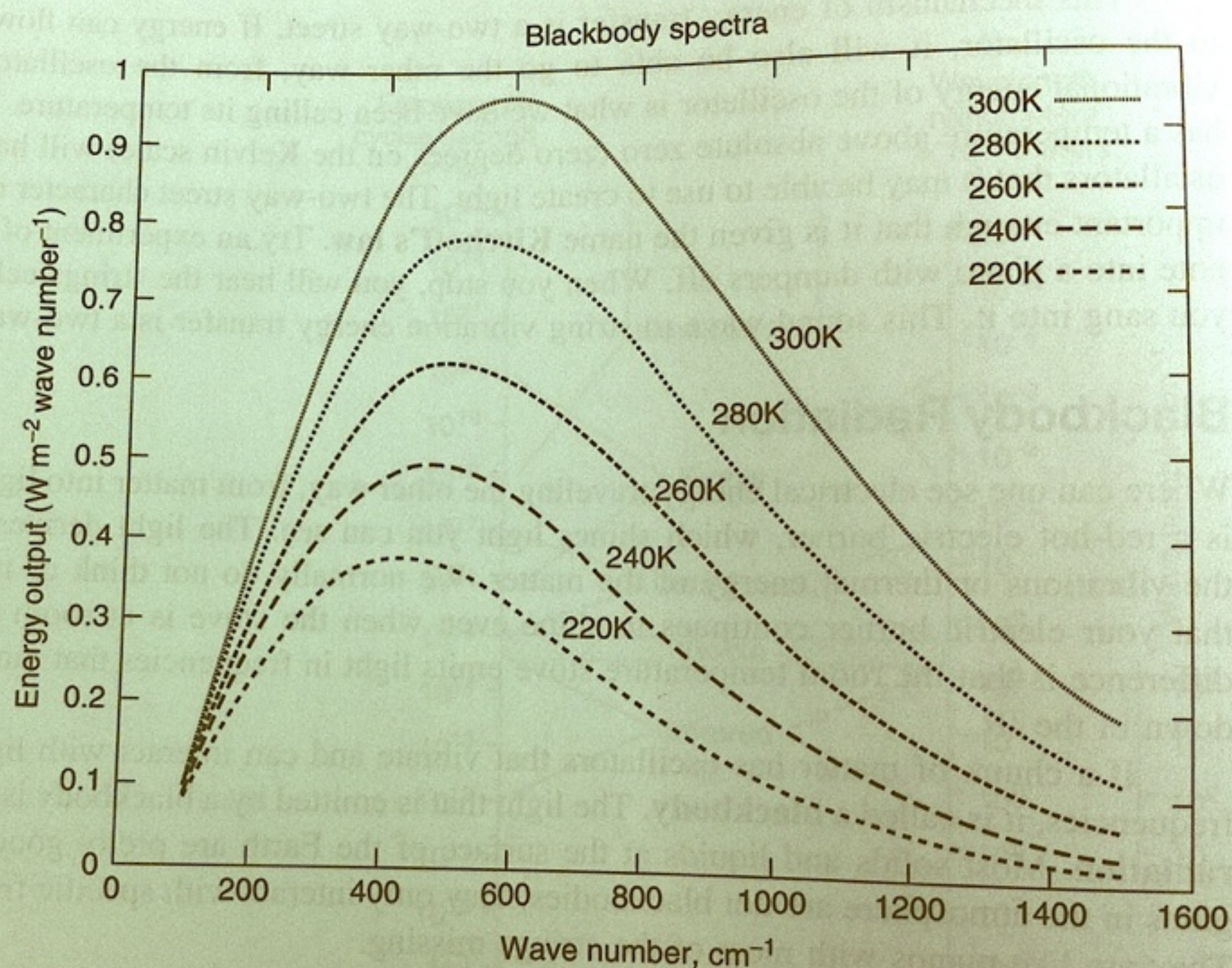

Figure 2-4 The intensity of light emitted from a blackbody as a function of the wave number (cycles per centimeter) of the light. There are several spectra shown for different blackbody objects at different temperatures. A warmer object emits more radiation than a cooler one.

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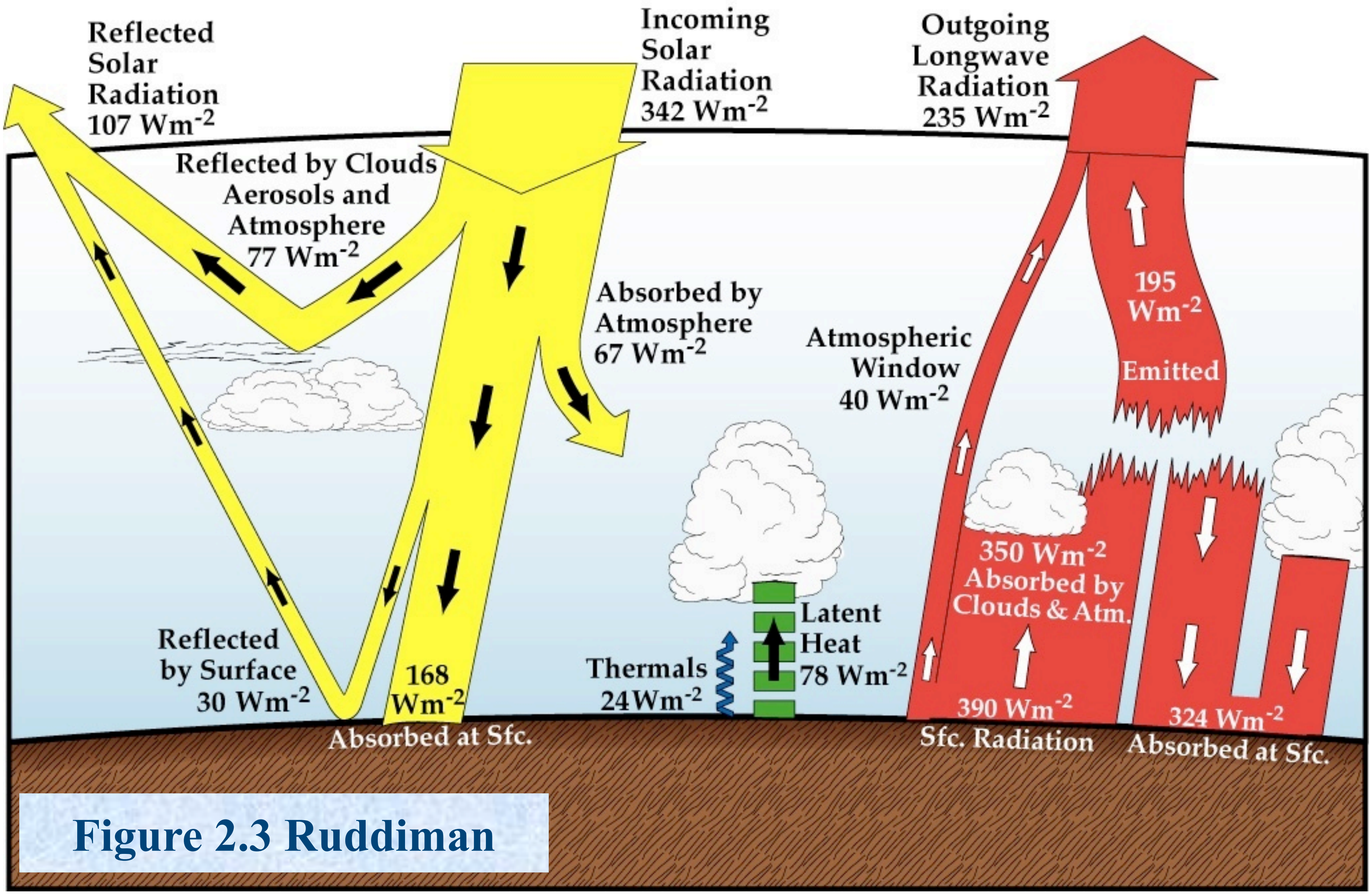
Global Energy Balance

Pathways of energy transfer in a global average



Slide from Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

After Kiehl and Trenberth, 1997, *Bull. Amer. Meteor. Soc.*

Emission Temperature

Temperature at which a planet needs to emit in order to achieve energy balance.

Solar radiation absorbed = planetary radiation emitted

$$E_R = \varepsilon \sigma T^4$$

$$\sigma = 5.67 \times 10^{-8} W m^{-2} K^{-4}$$

- E_R is the total rate of energy emission from the object at all frequencies in Watts/m^2.
- ε is emissivity, a number between 0 & 1 telling us how good a blackbody we have (1=best)
- σ is the Stefan-Boltzman constant
- T is emission temperature

- Compare spectra of Sun and Earth

Emission Temperature of Earth

Set Solar in equal to Terrestrial out!

$$\frac{S_0}{4}(1-\alpha_p) = \sigma T_e^4$$

242 W/m^2

$$T_e = \sqrt[4]{\frac{(1367/4)(1-0.3)}{\sigma}} \approx 255K = -18C$$

Factor of 1/4 comes from the ratio of shadow area of sphere to the surface area of a sphere ($\pi R_E^2 / 4 \pi R_E^2$)

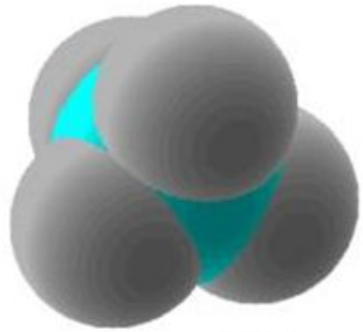
Hmmm… Emission Temperature is much less than observed Surface temperature of Earth (~288K)??? WHY??

Physical way in which molecules interact with radiation

How molecules interact with radiation - Briefly

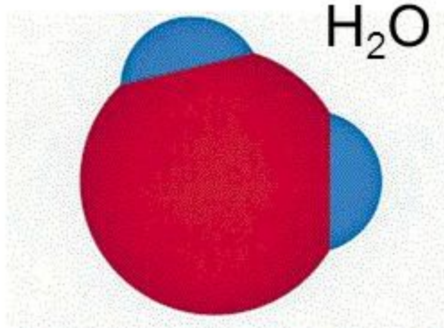
Why do certain gases interact with radiation?

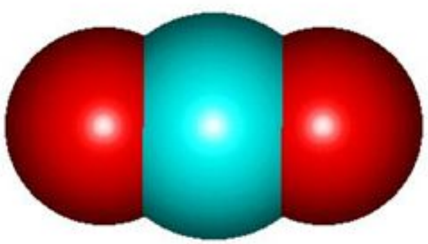
When radiation impinges on a molecule, it can excite the molecule, either by vibrating or rotating it. Molecules of a particular kind of gas have a different shape from molecules of another type of gas, and so are excited by radiation in different ways.



CH_4

H_2O

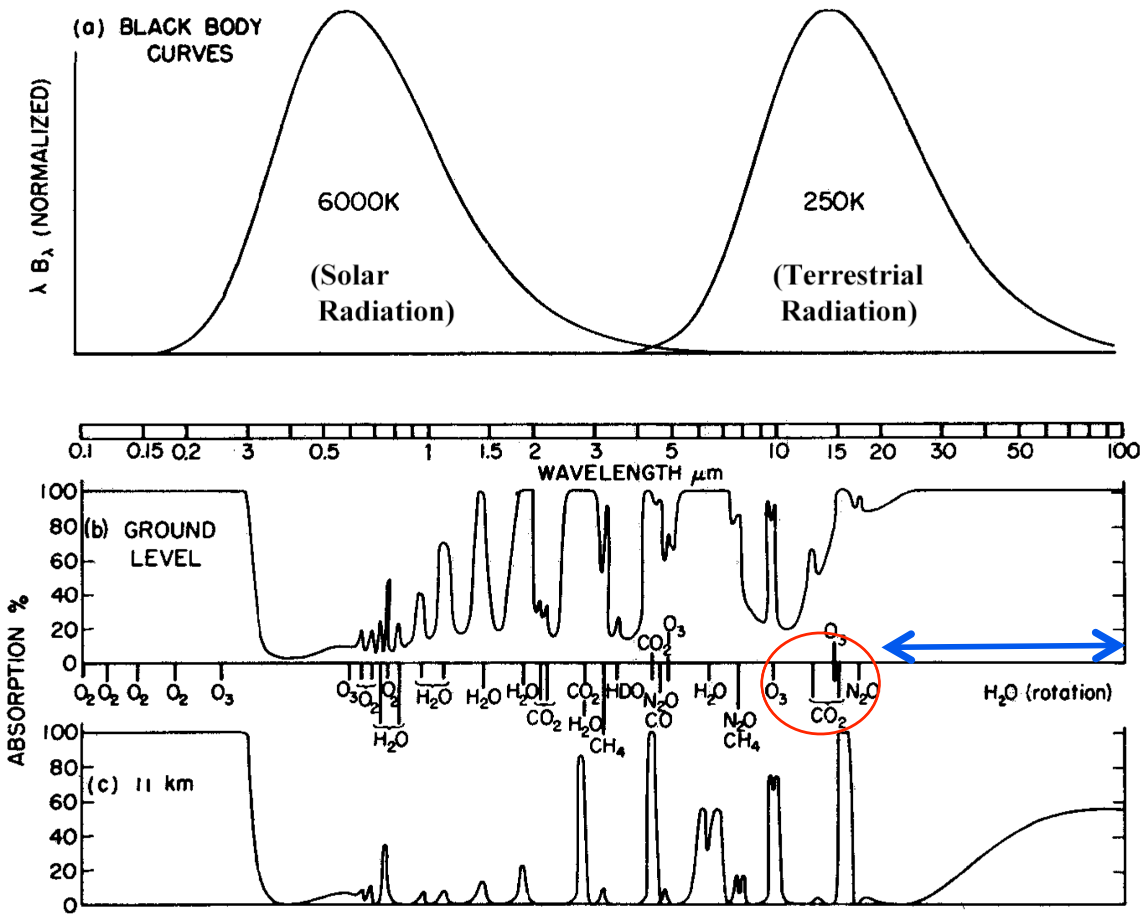




CO_2

Depends on the frequency - which molecules get excited.

Normalized Spectra of Sun and Earth (same heights)



Atmospheric absorptions. (a) Blackbody curves for 6000 K and 250 K. (b) Atmospheric absorption spectrum for a solar beam reaching ground level. (c) The same for a beam reaching the temperate tropopause. The axes are chosen so that areas in (a) are proportional to radiant energy. Integrated over the earth's surface and over all solid angles, the solar and terrestrial fluxes are equal to each other; consequently, the two blackbody curves are drawn with equal areas. Conditions are typical of mid-latitudes and for a solar elevation of 40° or for a diffuse stream of terrestrial radiation.

- **Visible not absorbed**
- **Ozone absorbs most incoming solar radiation**
- **4 micron break**
- **CO_2 vibration-rotation absorption key wavelength**
- **Water vapor absorption between 12-100 microns**

You can imagine that radiation is NOT easy to model!

Layer Model of the Atmosphere

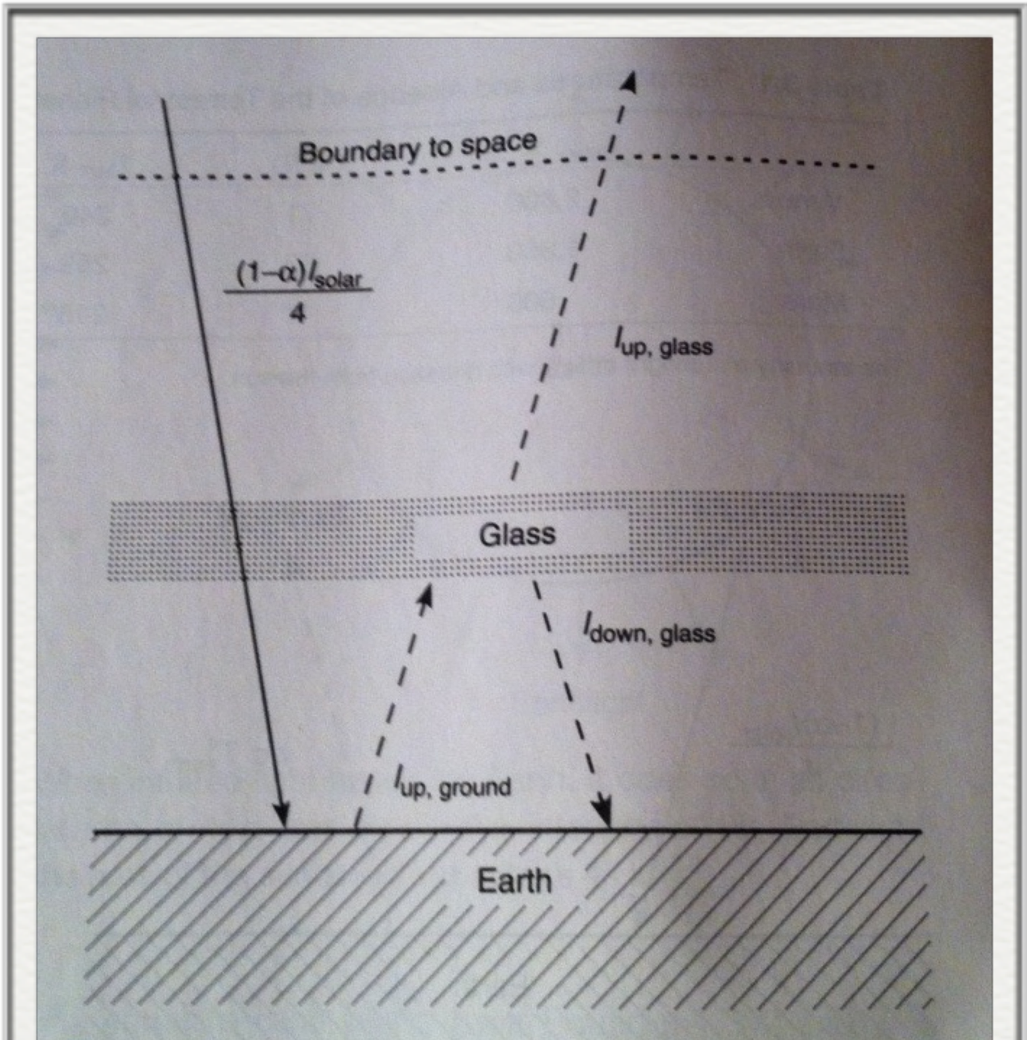


Figure 3-4 An energy diagram for a planet with a single pane of glass for an atmosphere. The glass is transparent to incoming visible light but a blackbody to infrared light.

- **Recall bare rock model had an emission temperature of 255 K , much cooler than real temperature of 288 K.**
- **Atmosphere is transparent to visible light (solar)**
- **Solar energy all reaches the surface and converts into Terrestrial radiation and emits upward.**
- **Terrestrial radiation (LW) is absorbed in atmosphere and emitted upwards and downwards**

Band Saturation Effect

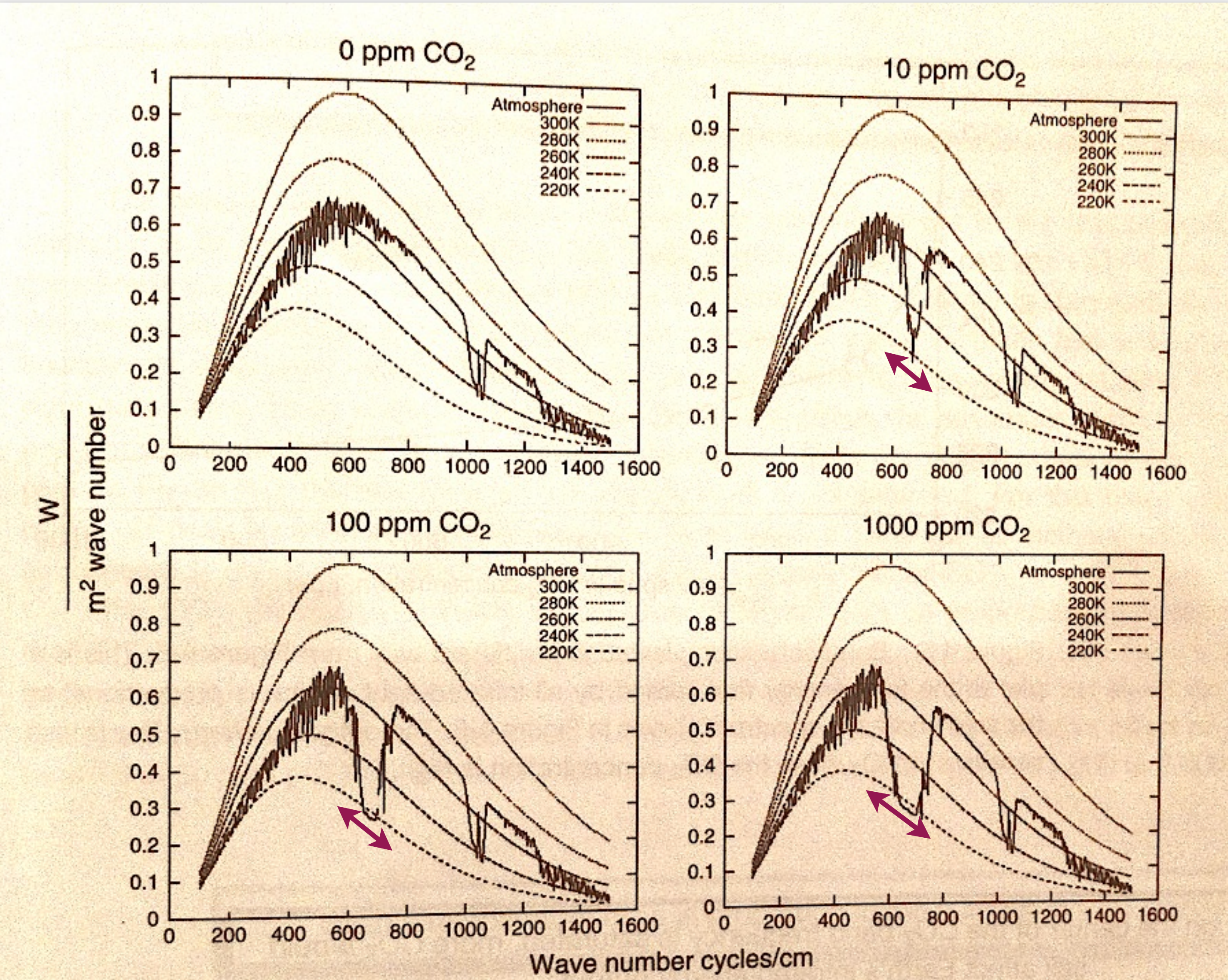


Figure 4-5 A demonstration of band saturation by CO_2. The addition of 10 ppm CO_2 (*upper right*) makes a huge difference to the outgoing infrared light spectrum relative to an atmosphere that has no CO_2 (*upper left*). Increasing CO_2 to 100 and 1,000 ppm (*lower panels*) continues to affect the spectrum, but you get less bang for your CO_2 buck as CO_2 concentration gets higher.

[Archer 2011, based on model]

- **Outgoing IR spectrum**
- **Band saturates (murky pond analogy)**
- **Often used as an argument why we don't have to control CO_2.**
- **10 ppm has significant impact and then as it is increased the absorption area becomes wider.**
- **More CO_2 always makes it warmer, since dip gets fatter.**
- **Go play with this model!**

http://forecast.uchicago.edu/models.html

Radiative Equilibrium Model

Each layer of atmosphere that is almost opaque for longwave radiation can be approximated as a blackbody so it absorbs all the incident terrestrial radiation and emits at its own temperature.

Layers of blackbodies

Transparent to solar

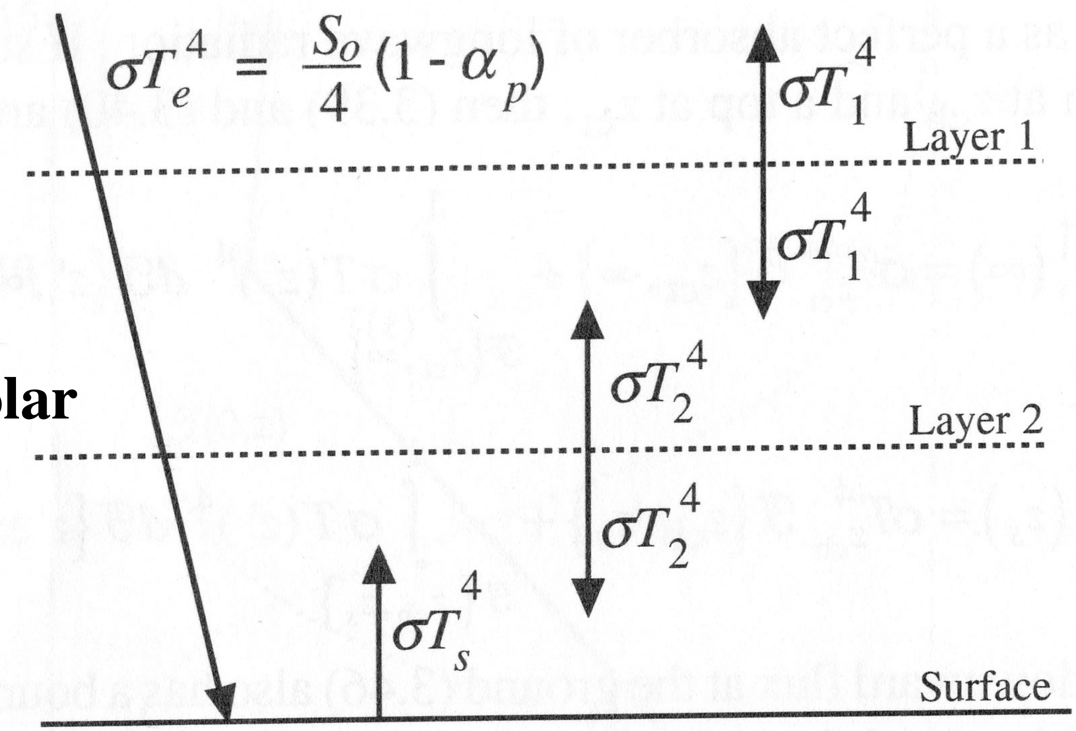


Fig. 3.10 Diagram of simple two-layer radiative equilibrium model for the atmosphere–Earth system, showing the fluxes of radiant energy.

Hartmann, 1994

Develop Radiative Model

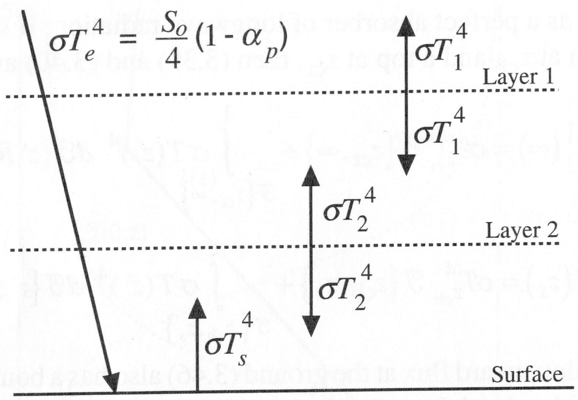


Fig. 3.10 Diagram of simple two-layer radiative equilibrium model for the atmosphere–Earth system, showing the fluxes of radiant energy.

At TOA:

$$\frac{S_0}{4}(1-\alpha_p) = \sigma T_e^4 = \sigma T_1^4$$

Key to developing equations: Absorbed = Emitted

Energy Balance in Layer 1:

$$\sigma T_2^4 = 2\sigma T_1^4$$

Energy Balance in Layer 2:

$$\sigma T_1^4 + \sigma T_s^4 = 2\sigma T_2^4$$

Energy Balance at Surface:

$$\frac{S_0}{4}(1-\alpha_p) + \sigma T_2^4 = \sigma T_s^4$$

Solar augmented by atmospheric radiation

Simple Radiative Equilibrium Model Analysis

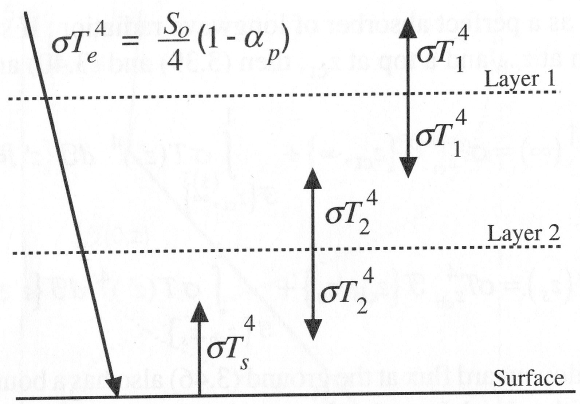


Fig. 3.10 Diagram of simple two-layer radiative equilibrium model for the atmosphere–Earth system, showing the fluxes of radiant energy.

Solve for surface temperature, work out the math yourselves

$$T_s^4 = 3\left(\frac{\frac{S_0}{4}(1-\alpha_p)}{\sigma}\right) = 3T_e^4$$

A model of n layers has this relationship:

$$T_s = \sqrt[4]{n+1}\,T_e$$

n=0, T_e=255K then T_s=255K

n=1, T_e=255K then T_s=303K

n=2, T_e=255K then T_s=335K

Surface too hot… Radiative equilibrium not great approximation for surface temperature since heat removed by sensible and latent fluxes are ignored here.

Shortcomings of the *Radiative Equilibrium Model*

Pg 62-63 Hartmann

Add a thin upper layer to model at stratosphere and a thin layer next to surface. Solve our model for T at each level getting:

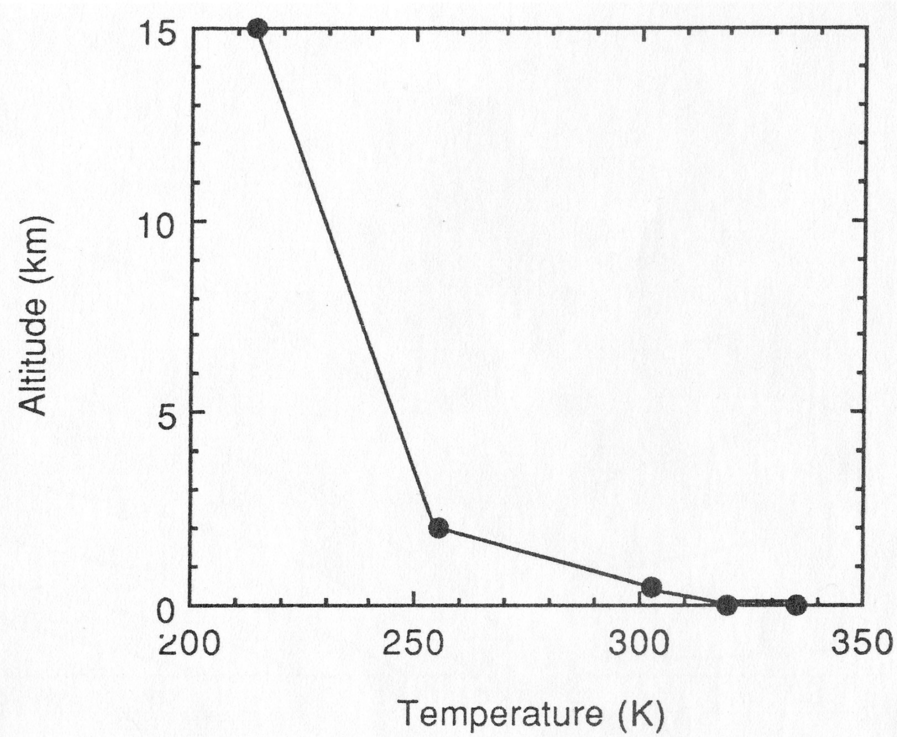


Fig. 3.11 Plot of temperature profile obtained from the simple two-level atmosphere radiative equilibrium model.

R-E model gives large temperature difference between surface and the thin layer of atmosphere above it. Need to add heat transport due to conductive and convective heat transport.

Hartmann, 1994

Albedo and zenith angle

8% accurate for solar zenith angles less than 40

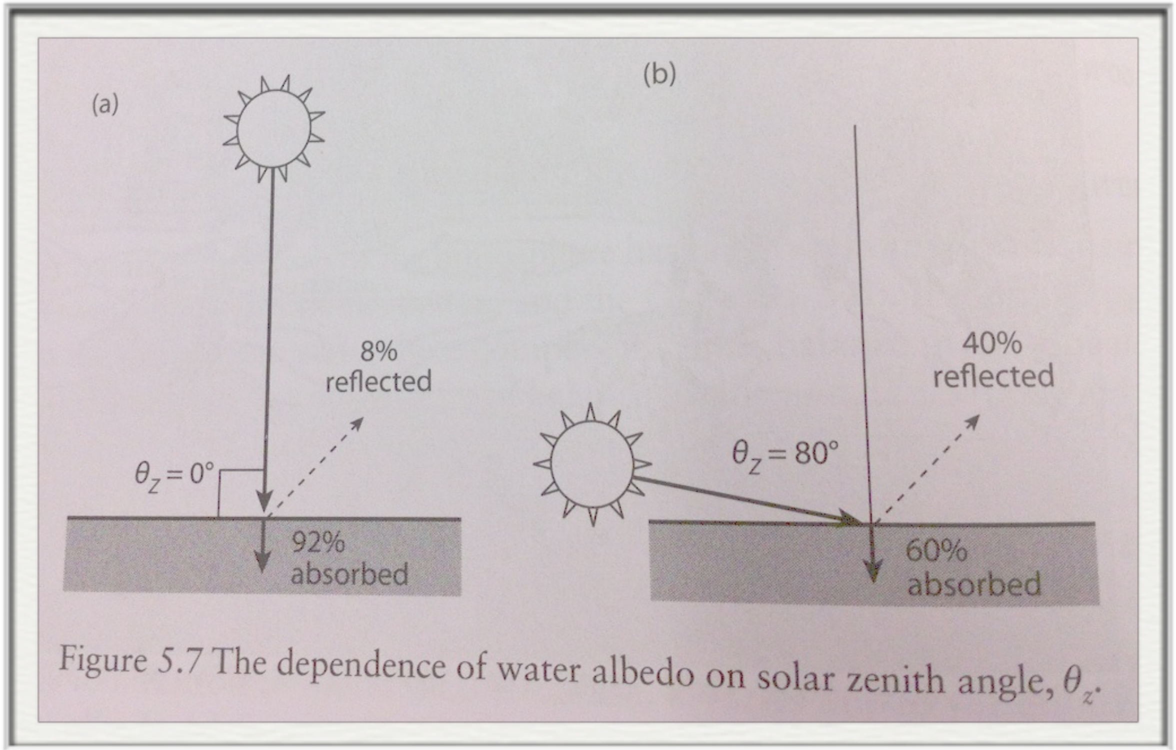


Figure 5.7 The dependence of water albedo on solar zenith angle, θ_z.

late in the day, clear sky, glare effect most evident in clear sky!

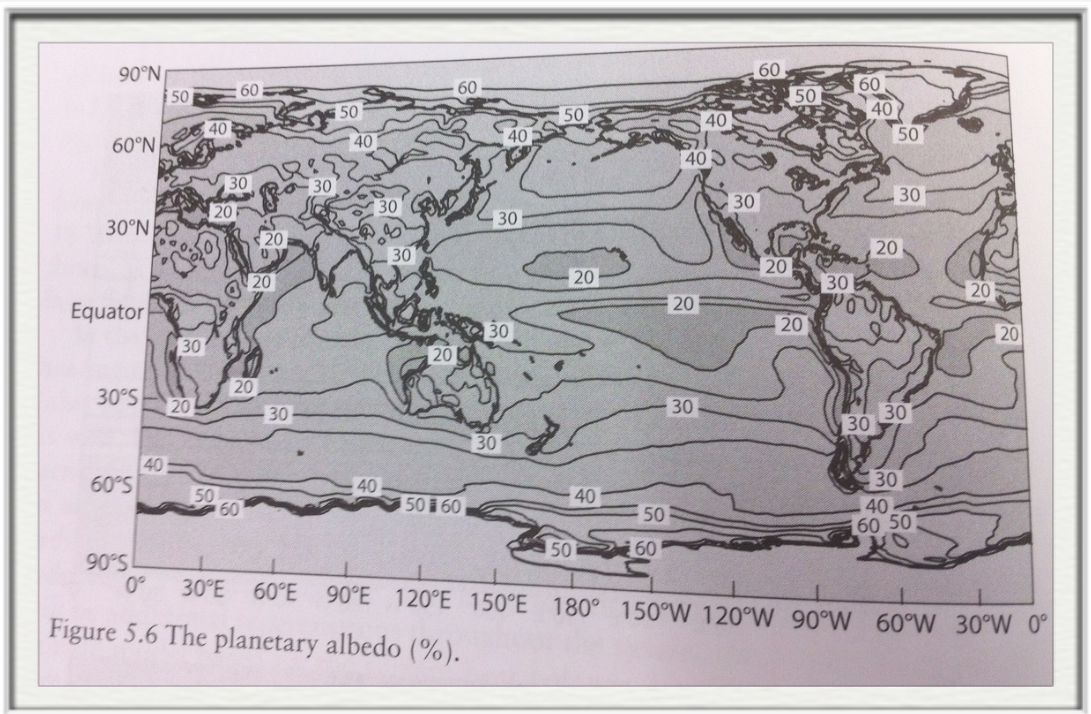


Figure 5.6 The planetary albedo (%).

[Cook 2013]

Albedo over water depends angle of incidence & cloud cover: Surface albedo insensitive to zenith angle if cloudy

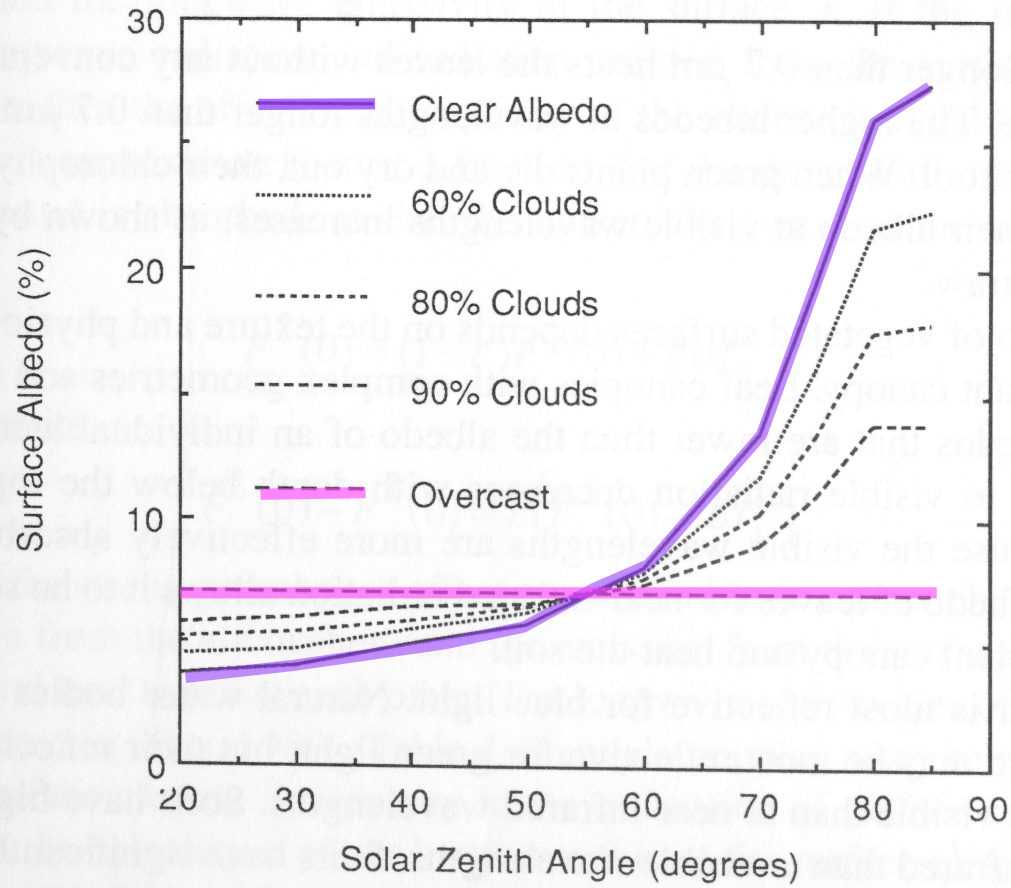


Fig. 4.4 Dependence of the albedo of a water surface on solar zenith angle and cloud cover. [Data from Mirinova (1973).]

Hartmann, 1994

- **Under clear skies albedo increases as Θ increases**
- **Clouds scatter incident solar so it is no longer a parallel beam, so albedo changes with Θ are smaller as clouds cover increases.**

Clouds and Climate, Key question for climate change…

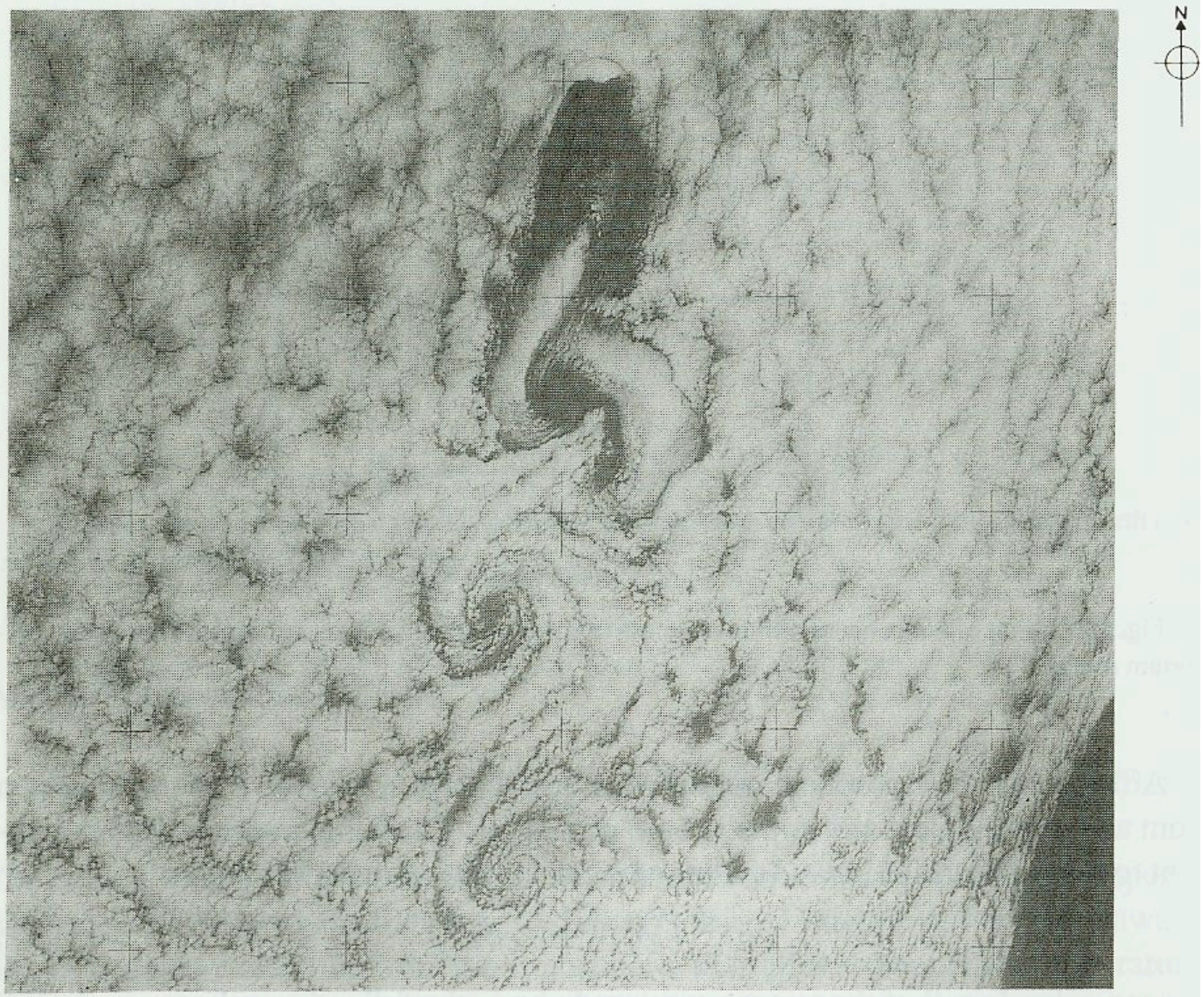


Fig. 3.12 Stratocumulus clouds moving past Guadalupe Island off the west coast of Mexico. Note the vortex rings shed downstream of the island. Stratocumulus clouds have a large negative effect on the radiative energy budget of Earth because they are good reflectors of solar radiation, but are confined near the surface and so do not provide strong trapping of outgoing longwave emission. The vortex centers are about 60 km apart. (Skylab 3, NASA, August 1973.)

Liquid droplets or Ice particles

- **water amount**
- **droplet size/shape**

All impact how clouds interact with solar and terrestrial radiation.

Cloud liquid water content **- total mass of cloud water in vertical column of unit surface area**

Hartmann, 1994

Model Calculations of cloud albedo and absorption

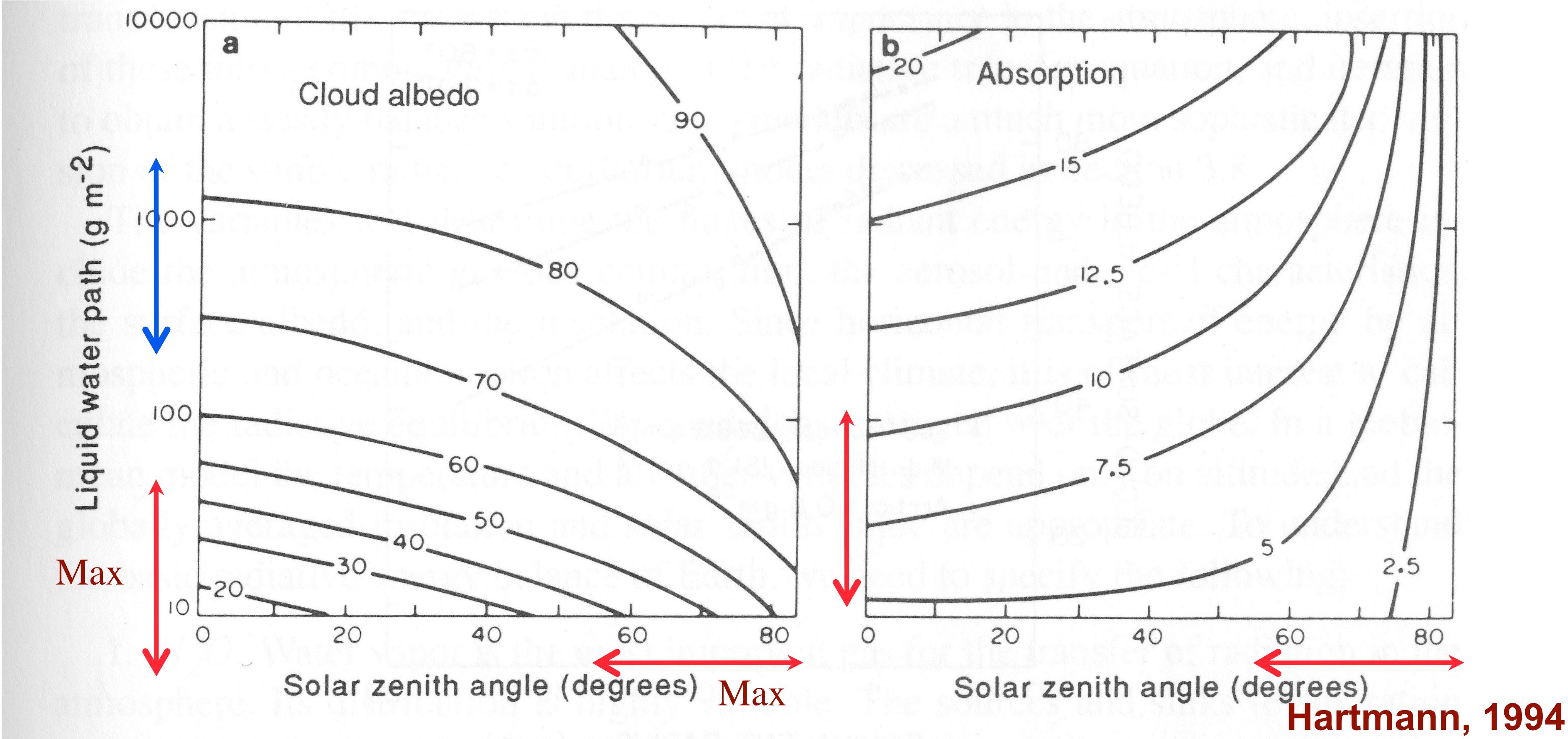


Fig. 3.13 The dependence of (a) cloud albedo and (b) cloud absorption on cloud liquid water path and solar zenith angle. Values are given in percent. [From Stephens (1978). Reprinted with permission from the American Meteorological Society.]

Model calculations

1. **albedo increases**
   clouds thicken and increase in albedo slows down
2. **Absorption decreases at high zenith angles-more reflected so less can be absorbed**

Albedo influenced by Droplet Size: as droplet size decreases the albedo increases

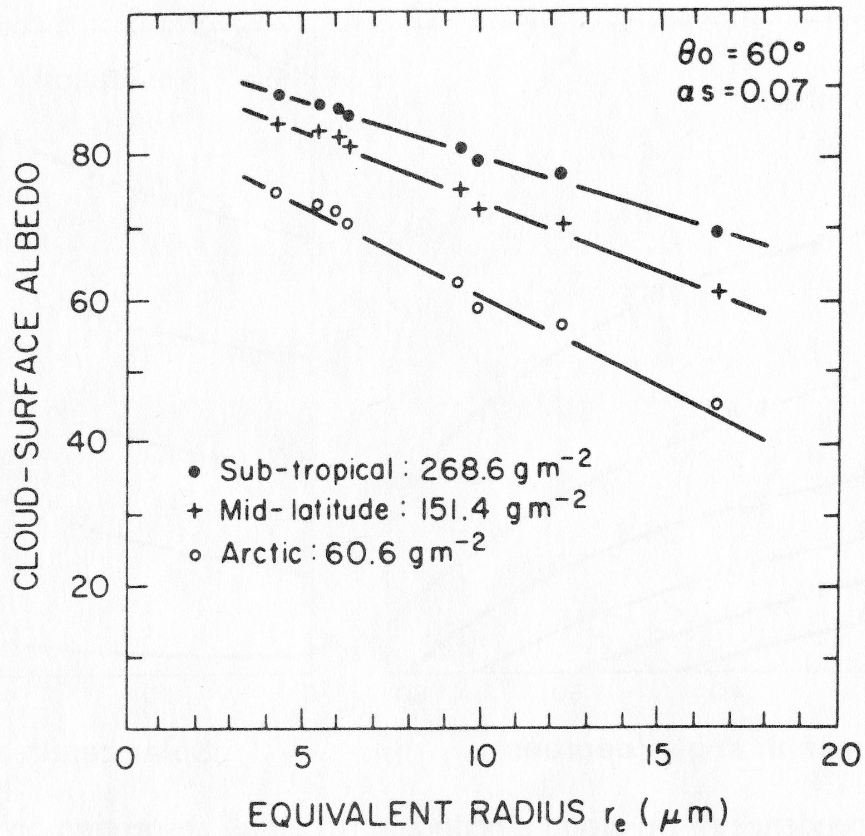


Fig. 3.14 The dependence of planetary albedo on the size of cloud droplets. [From Slingo and Schrecker (1982). Reprinted with permission from the Royal Meteorological Society.]

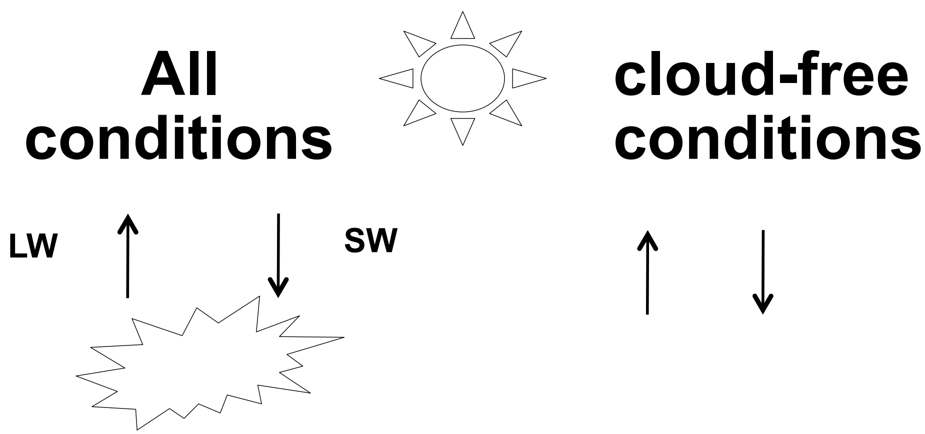
albedo increases as droplet size decreases for 3 different cases where liquid water levels kept fixed

Why should this be the case? **(larger surface area for the same mass!)**

Hartmann, 1994

Role of Clouds in Energy Balance

• **Measure radiative fluxes from satellites, both solar and terrestrial.**



Difference of averages is cloud radiative forcing - effect of clouds on the radiative budget

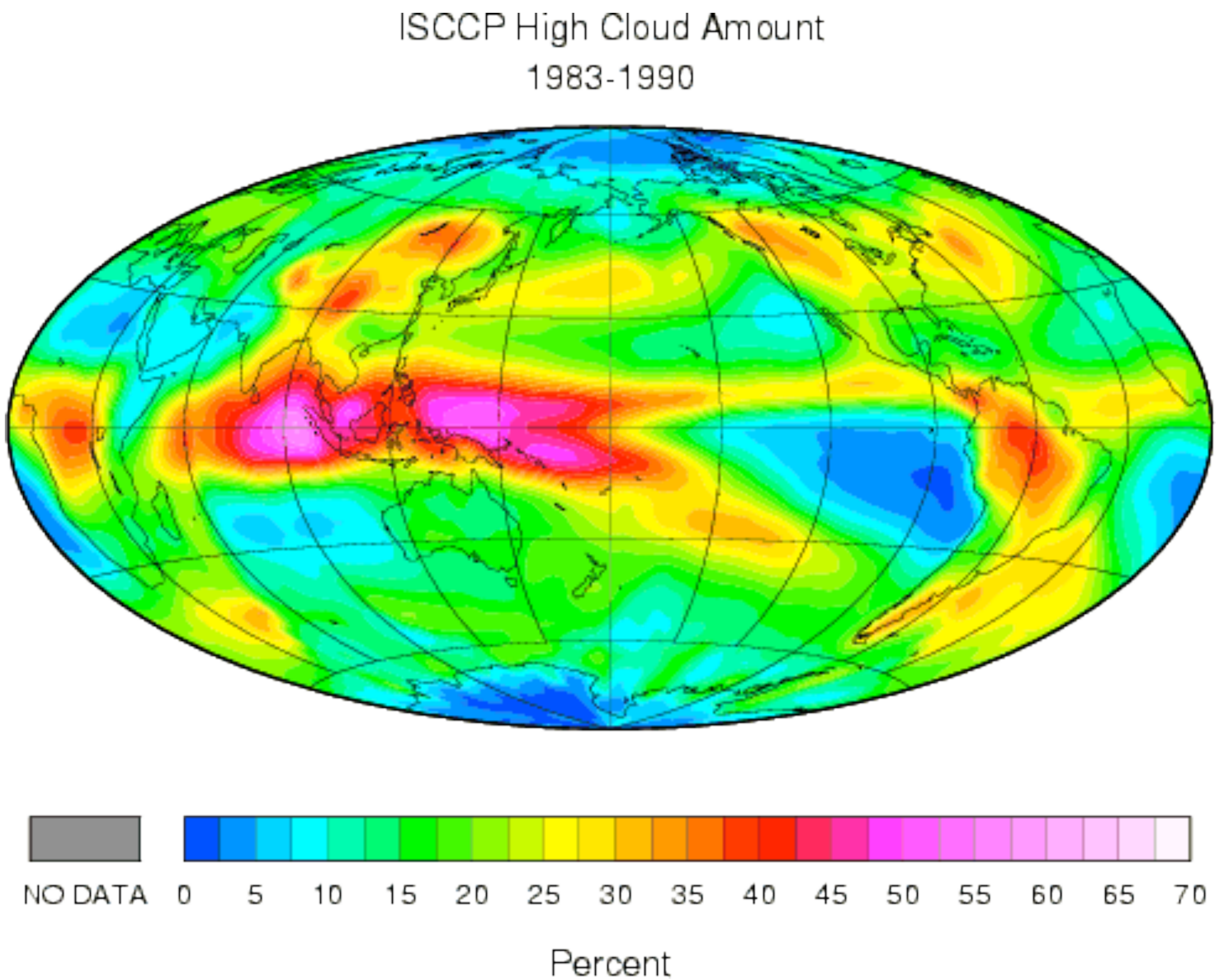
Clouds act to cool the Earth's Energy Budget

Table 3.3

W/m^2	Average	Cloud Free	Cloud Forcing
OLR	234	266	+31
Absorbed Solar Radiation	239	288	-48
Net Radiation	+5 (uncertainty)	+22	-17
Albedo	30%	15%	15%

- Clouds increase albedo (15->30) which decreases absorbed by 48.
- OLR held in by clouds increases by 31
- Net is a cooling of atmosphere by 17 W/m^2 , which means...

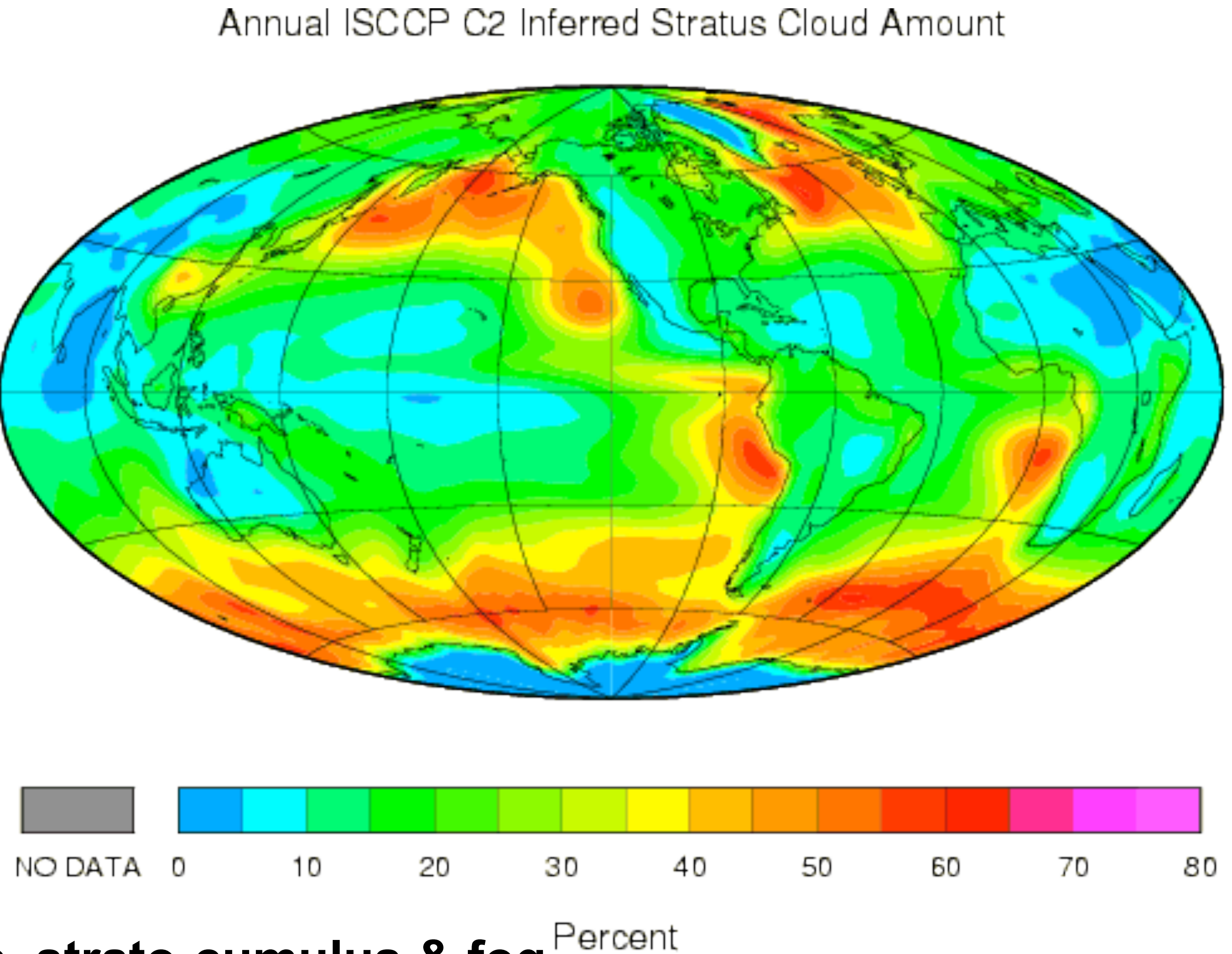
High Clouds (%), tops above 400hPa



- **Largest values in 3 tropical convection centers & ITCZ.**
- **Midlatitude regions**

http://depts.washington.edu/uwpcc/remote_sensing/cloud_sst.html
Close to **Fig 3.21a, Hartmann, 1994**

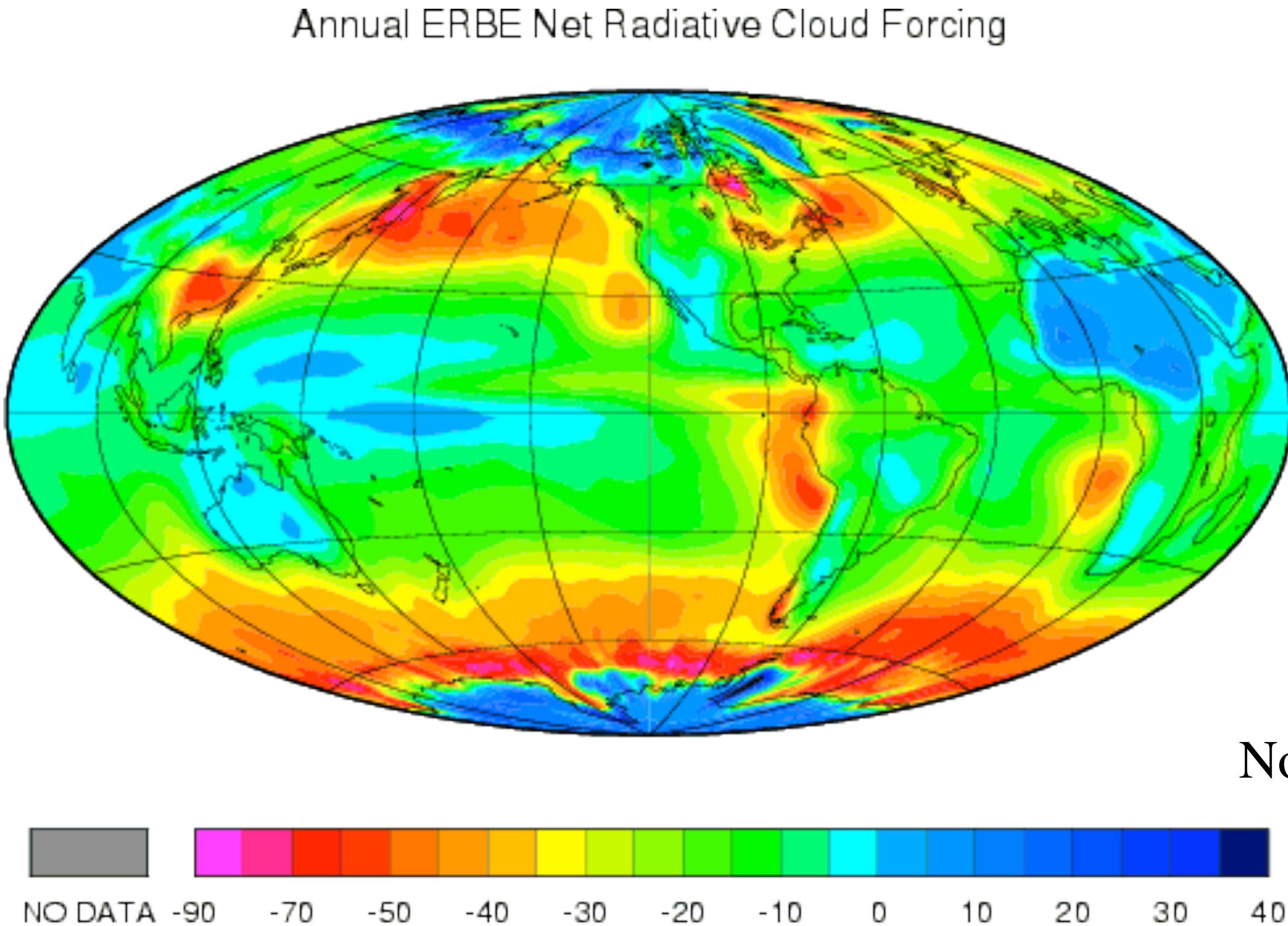
Low Cloud Areas (%), tops lower than 680hPa



- **Stratus, strato-cumulus & fog.**
- **Midlatitude regions**

http://depts.washington.edu/uwpcc/remote_sensing/cloud_sst.html
Similar to **Fig 3.21b, Hartmann, 1994**

Net Cloud Radiative Forcing, depends on type of cloud!



Note scale

- **Negative forcing of marine boundary layer clouds, block solar radiation and cool surface**
- **LW cloud forcing reduces OLR, so clouds warm surface**

http://depts.washington.edu/uwpcc/remote_sensing/cloud_sst.html
Similar to **Fig 3.22c, Hartmann, 1994**