Wednesday 4 October 2017, Class #15

Concepts for Today (Basics for Thermodynamics)

- Adiabatic Processes
- Potential Temperature
- Hydrostatic Law
- Scale Height

https://www.youtube.com/watch?v=3vGfWoPIstk

Ideal gas versus real gas, assume zero volume of a molecule, no attraction between molecules, and no impact of gravity.

Review

- What is Global Dimming?
- What is Black Carbon and what is its relevance for climate?
- What is potential temperature and what is it useful for?

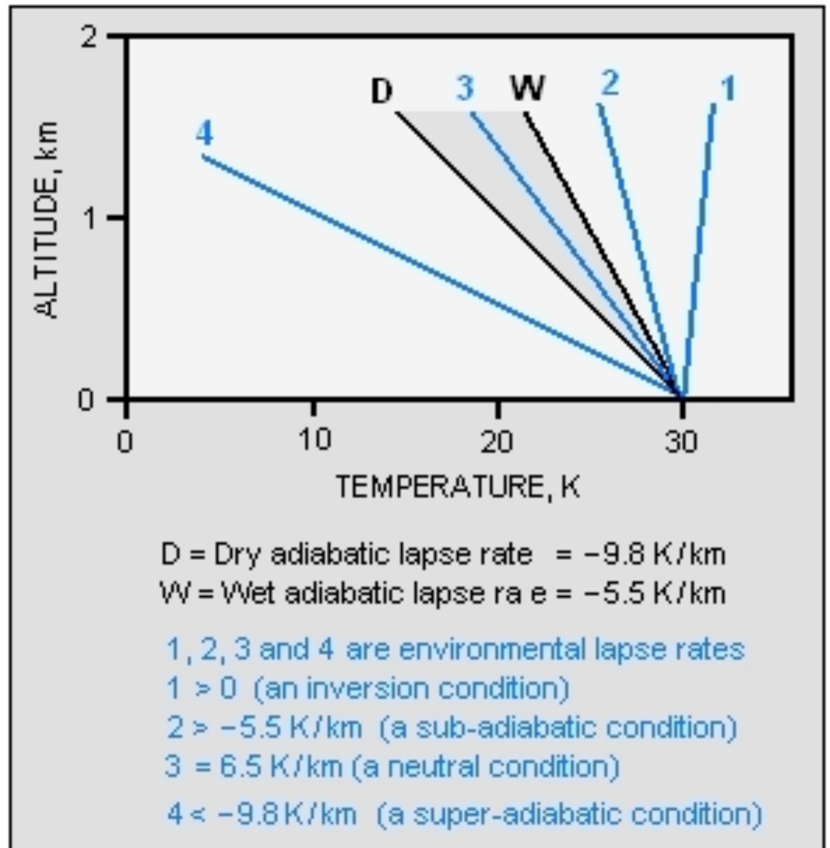
Dry Adiabatic Lapse Rate

$$\Gamma = -\frac{dT}{dz} = \frac{g}{c_p} \quad = 9.8\ \mathrm{K/km}$$

6.5 K/km is the average global lapse rate

Moisture is ignored above and if there was moist adiabatic processes included then this decrease with height would be smaller.

atmospheric stability



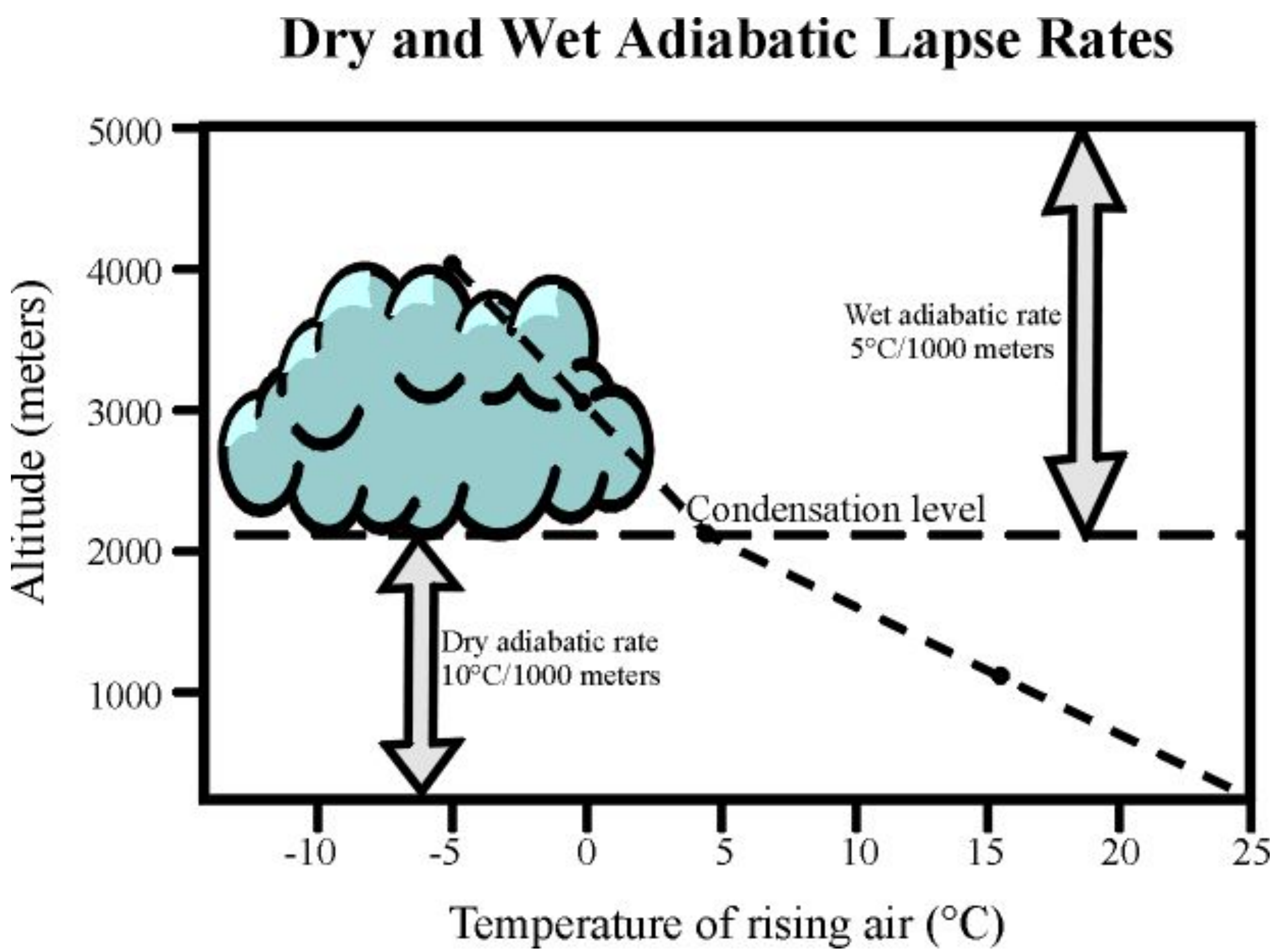
Source: Milton Beychok

Various lapse rates defining the change of atmospheric temperature with altitude.

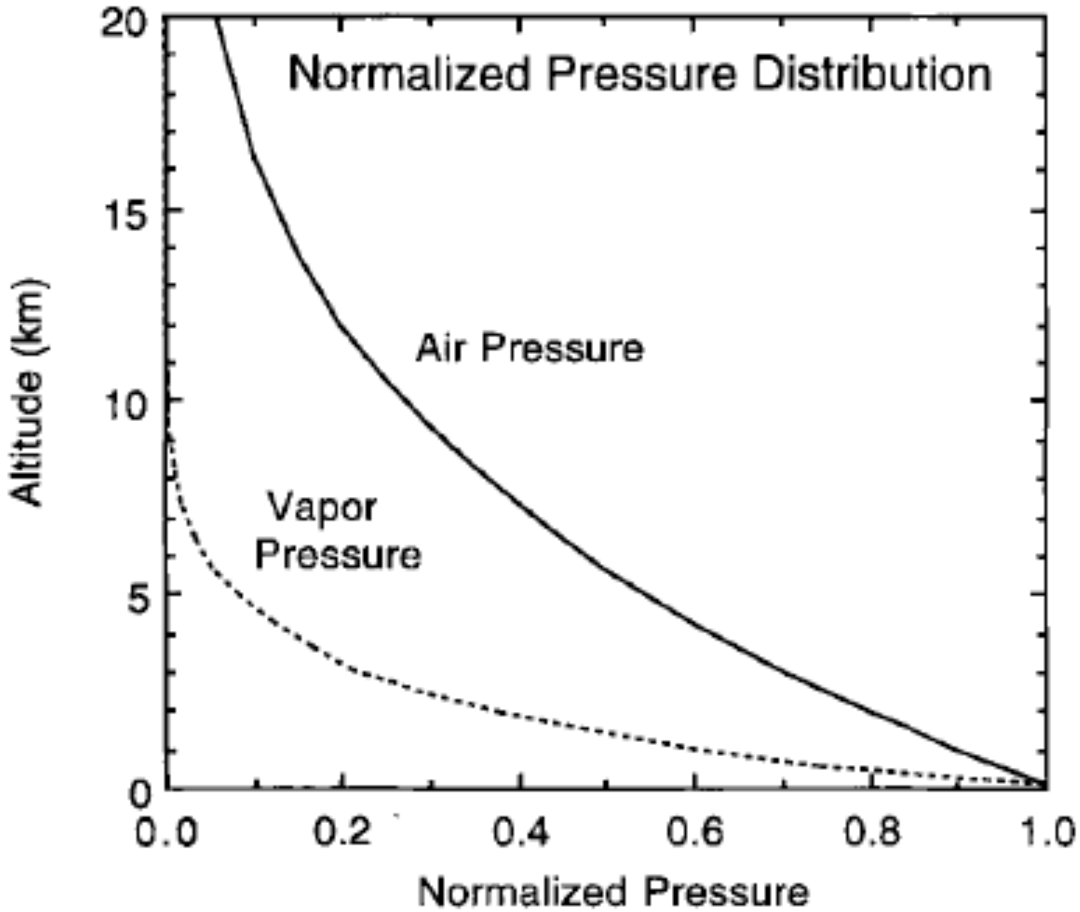
http://www.eoearth.org/view/article/170859/

Moist Adiabatic Lapse Rate is lower than Dry Adiabatic Lapse Rate

Moist Adiabatic implies air is saturated As this parcel rises, the parcel cools and the water condenses. This releases heat so the moist adiabatic parcel of air does not cool as fast as the one which is dry and does not undergo any phase change.



Hydrostatic Balance in Atmosphere, Pressure balances Gravity



Pressure profile in the atmosphere

Fig. 1.8 Vertical distributions of air pressure and partial pressure of water vapor as functions of altitude for globally and annually averaged conditions. Values have been normalized by dividing by the surface values of 1013.25 and 17.5 mb (millibars), respectively.

Hartmann, 1994

Hydrostatic & Scale Height

$$g = -\frac{1}{\rho}\frac{dp}{dz}$$

Force = mass times acceleration

Atmosphere at rest has downward force due to gravity at all times.

replace density using ideal gas law $p = \rho RT$

$$\frac{dp}{p} = -g\frac{dz}{RT} = -\frac{dz}{H}$$

$$H = \frac{RT}{g}$$

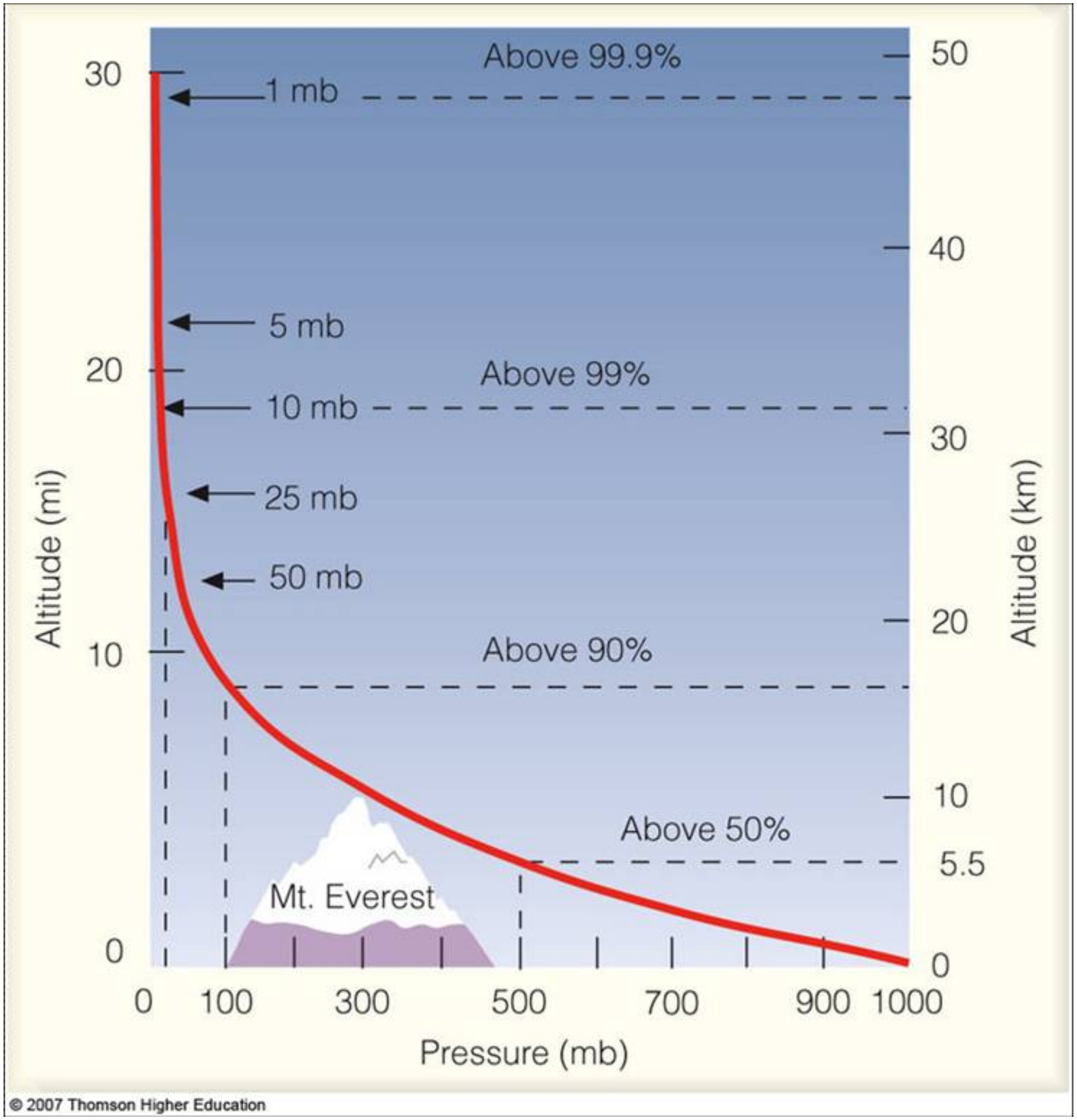
Scale height is the height at which pressure drops off by factor 1/e.

Assume isothermal T=constant then H=constant, get pressure distribution by integrating.

$$\boxed{p = p_s e^{-\frac{z}{H}}}$$

H is scale height about 7.6 km

Pressure Decrease with Height



Atmospheric Humidity: Rapidly decreases upward & poleward

Humidity is amount of water vapor in air.

- **mixing ratio, w (g/kg), mass vapor over mass dry air (w)**
- **specific humidity, q (g/kg), mass vapor over total mass air**
- **relative humidity %=100*w/w_s**

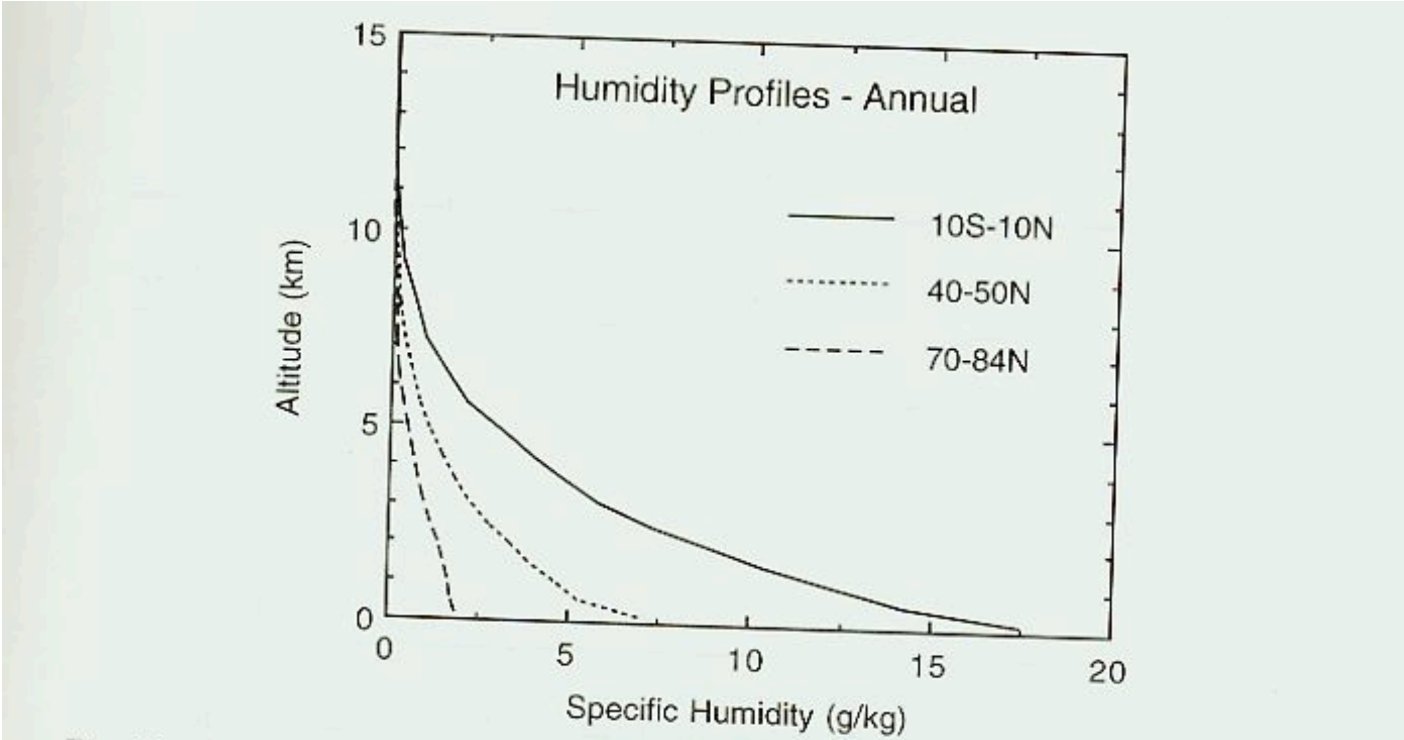


Fig. 1.9 Specific humidity or mass mixing ratio of water vapor for annual-mean conditions at latitude belts centered on the equator, 45°N and 75°N. [Data from Oort (1983).]

Hartmann, 1994

Mean Annual Specific Humidity

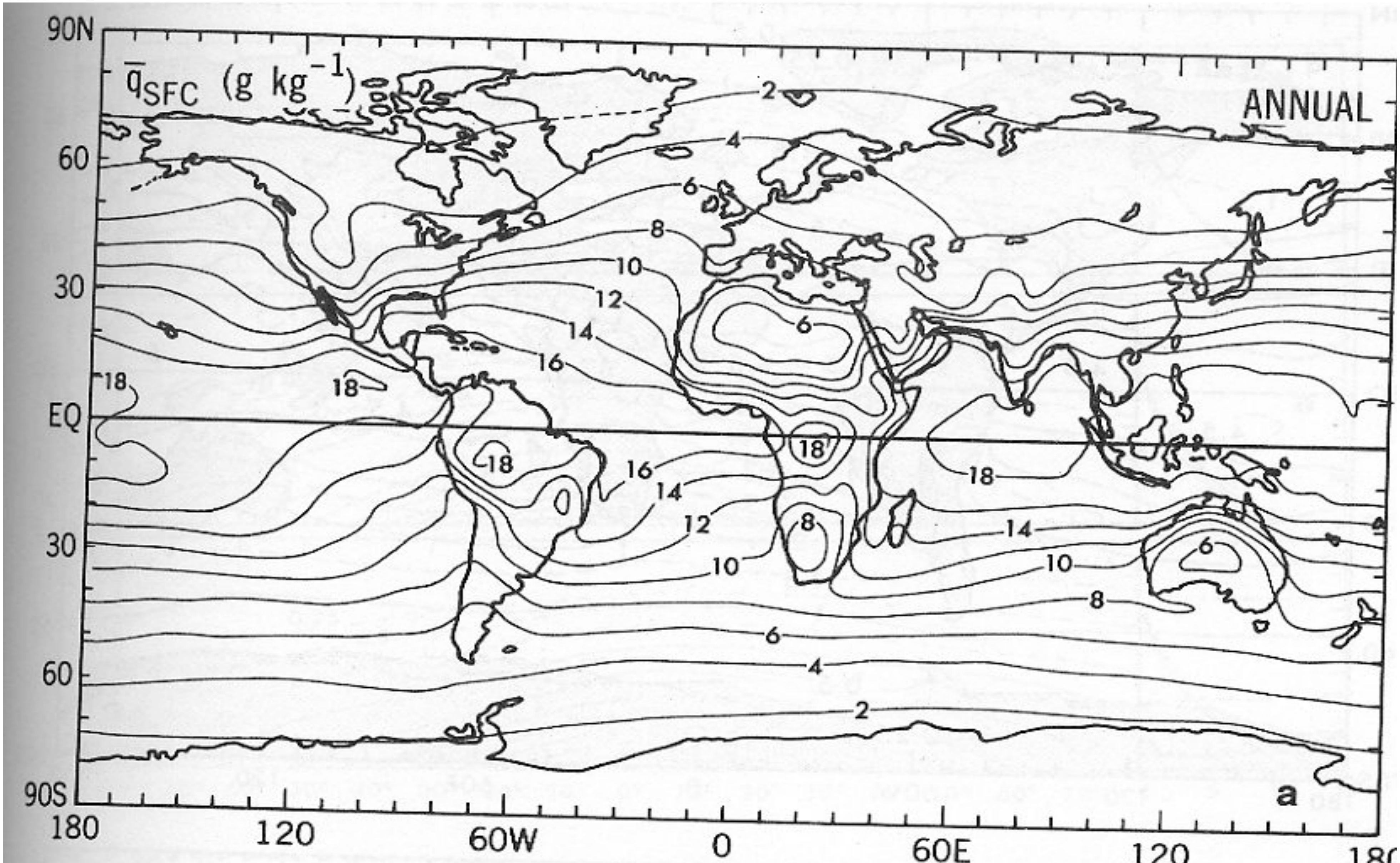


FIGURE 12.3a

Peixoto & Oort, 1992

Seasonal Amplitude of Specific Humidity

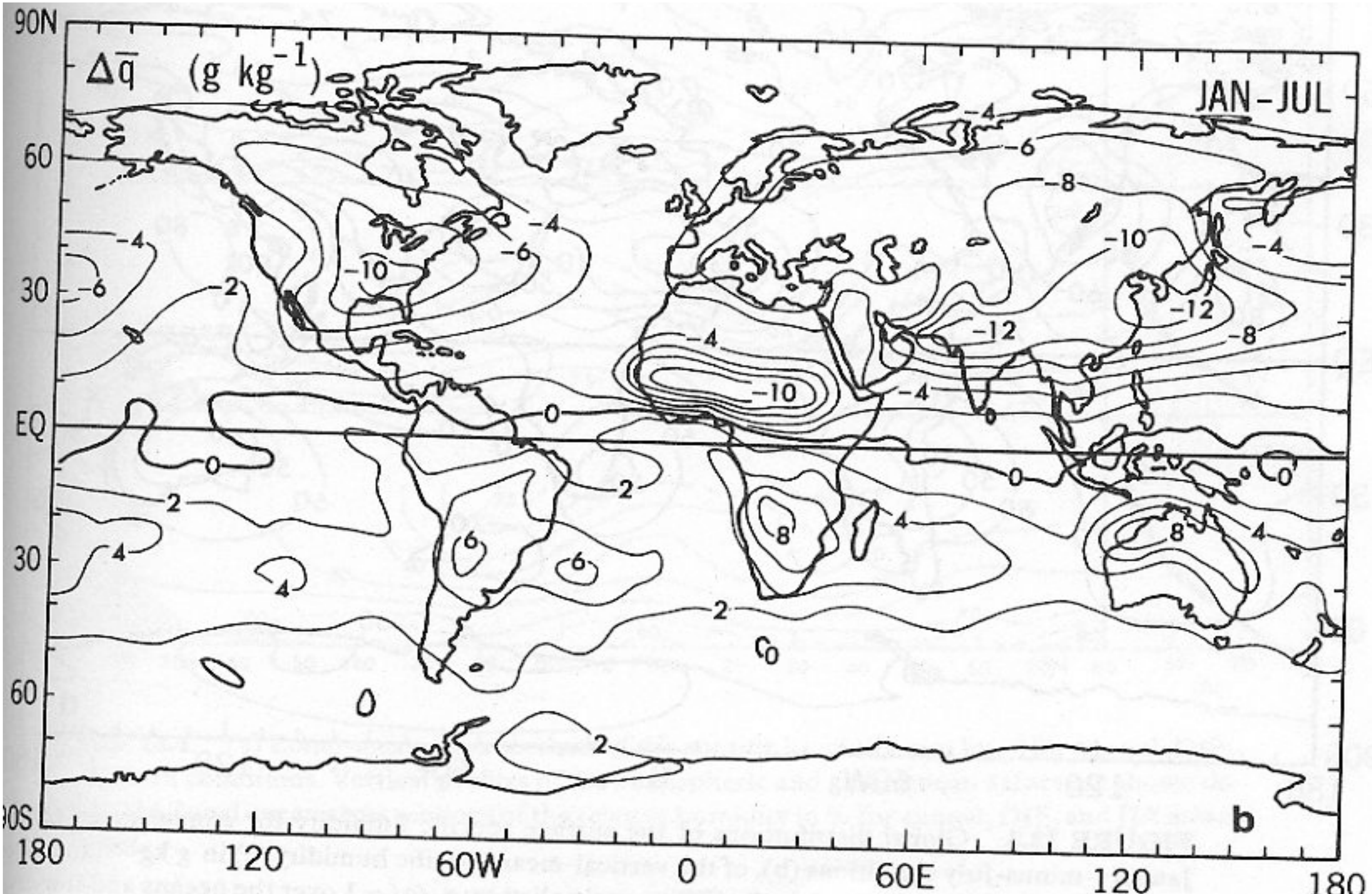


FIGURE 12.3b

Peixoto & Oort, 1992

Relative Humidity at 850 mb %

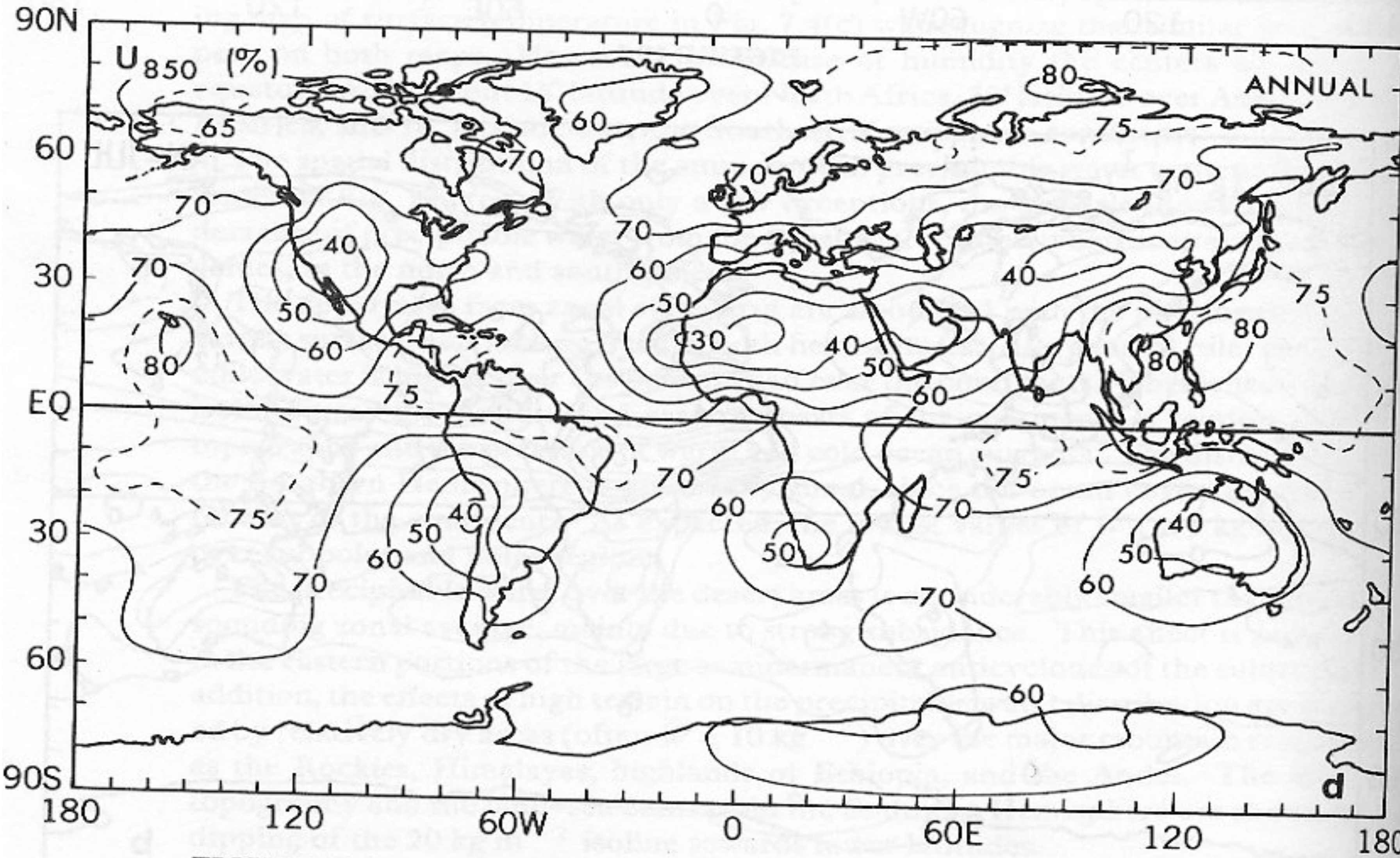


FIGURE 12.3. Global distributions of the surface specific humidity for annual-mean (a) and January-minus-July conditions (b), of the vertical-mean specific humidity (c) in g kg^{-1}, and of the relative humidity (d) at 850 mb in %. [When multiplied by p_0/g (≈ 1 over the oceans and low-level land areas) the third field gives the precipitable water in the atmosphere in units of 10 kg m^{-2}.]

Peixoto & Oort, 1992

Summary & Homework

- Introduction to terminology for Thermodynamics.
- Exposure to the basic equations

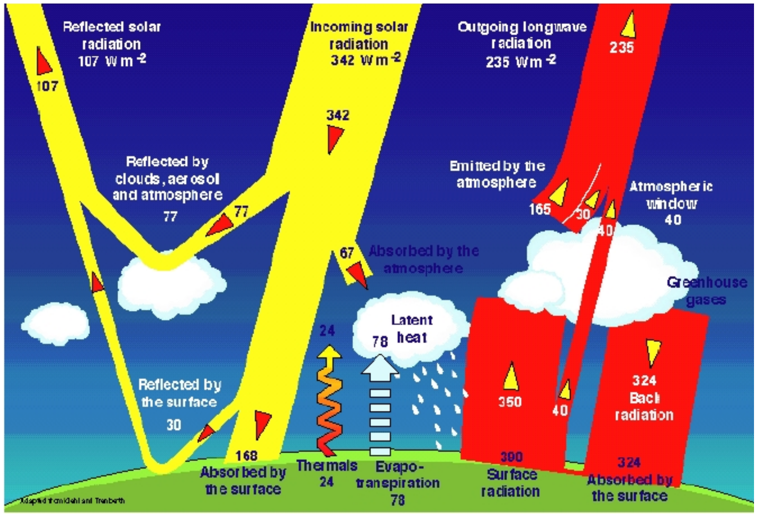
Homework: Due Monday October 16

1. If the atmosphere warmed up by 5˚C, would the atmospheric pressure at 5 km above sea level increase or decrease and by about how much?

2. Explain why the North Polar temperature inversion is present in winter but not in summer.

3. Explain why the environmental (actual observed one) lapse rate is less than the adiabatic one.

Equilibrium Surface Heat Balance



Global Energy Balance

Surface Energy Balance
Energy coming in = Energy leaving

$$Q_{sw} = Q_{LW} + Q_L + Q_S$$

Shortwave Radiation = Net Longwave Radiation + Latent Heat + Sensible Heat

Non-equilibruim Surface Heat Balance

- **Addition or removal of heat is non-zero so temperature will change**

$$C\frac{\partial T_S}{\partial t} = (1-\alpha_S)S_{\mathrm{INC}} + F_{\mathrm{BACK}} - \varepsilon\sigma T_S^4 - H_S - H_L - F_H - F_V$$

C= heat capacity

Land or ocean

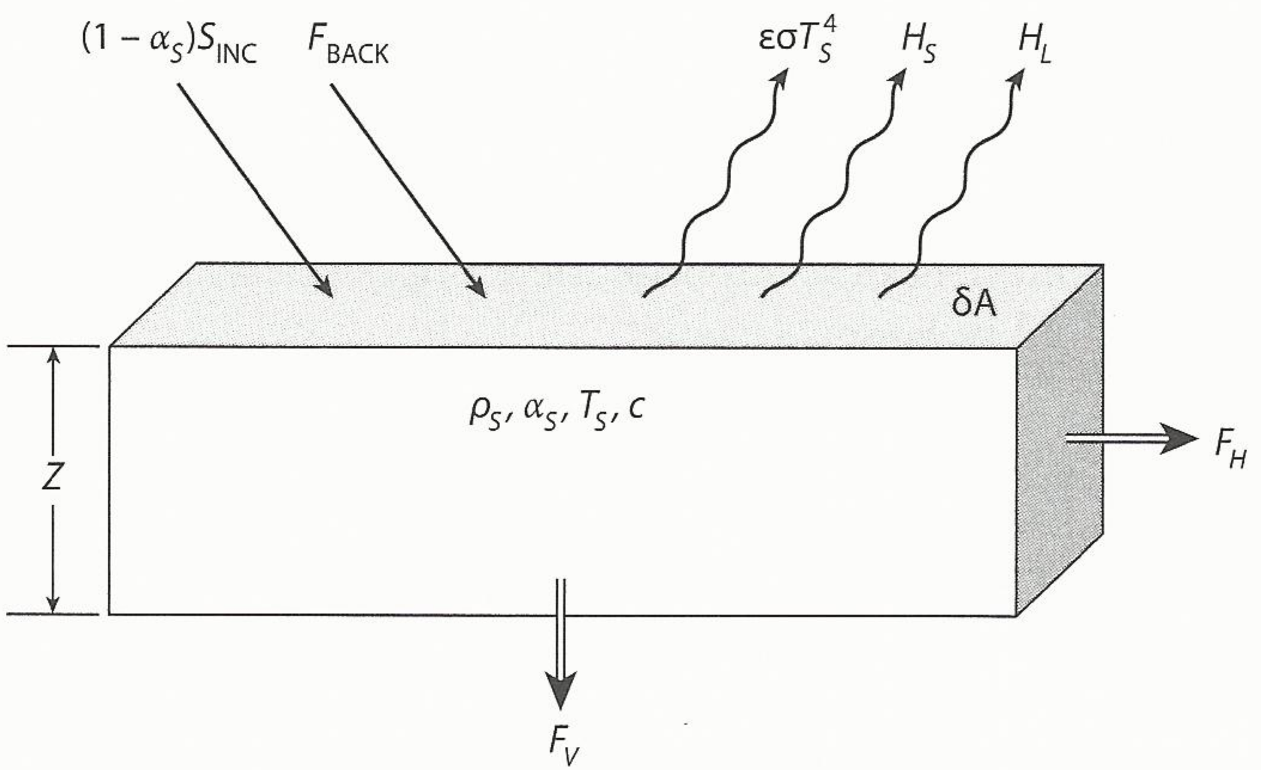


Figure 5.3 A volume, *V*, of surface material exchanging heat with the atmosphere as well as with adjacent surface material.

[Cook, 2012]

Nonequilibruim Surface Heat Balance

- **Specific Heat and Mass impact how much body will warm (Heat Capacity)**

mass of material associated with surface area in kg/m2

$$M_A = \frac{\text{mass of the volume}}{\text{surface area of the volume}} = \frac{\rho_S V}{\delta A} = \rho_S Z.$$

heat capacity

$$C = cM_A = c\rho_S Z.$$

- **Suppose the surface heating is 20 W/m2**

$$C\frac{\partial T_S}{\partial t} = 20\ \text{W/m}^2.$$

- **If the top 100m of the ocean is warming then:**

$$C = c_W \rho_W Z = [4218\ \text{J/(kg}\cdot\text{K)}](10^3\ \text{kg/m}^3)(100\ \text{m}) = 4.2\times 10^8 \text{J/(m}^2\cdot\text{K)}.$$

specific heat water

density water

depth

[Cook, 2012]

Nonequilibruim Surface Heat Balance

- **How long with it take to heat an ocean mixed layer by 2C?**

$$\boxed{C\frac{\partial T}{\partial t} \rightarrow C\frac{\Delta T}{\Delta t}}$$

$$\Delta t = \frac{C\Delta T_S}{20\ \mathrm{W/m^2}} \approx 1167\ \mathrm{hr} = 48\ \mathrm{days.}$$

- **How long will it take to heat 2 cm of dry sand soil the 2C?**

$$C = c_S\rho_S Z = [840\ \mathrm{J/(kg\cdot K)}](2.65\times10^3\,\mathrm{kg/m^3})(2\times10^{-2}\mathrm{m}) = 4.5\times10^4\mathrm{J/(m^2\cdot K)},$$

specific heat soil　　density soil　　depth

$$\Delta t = \frac{C\Delta T_S}{20\ \mathrm{W/m^2}} \approx 1.25\ \mathrm{hr.}$$

- **The soil layer responds on a diurnal time scale while the ocean responds on a seasonal time scale. What is not consistent about this comparison?**

[Cook, 2012]

Global Energy Balance with details

outgoing balances incoming at top of atmosphere

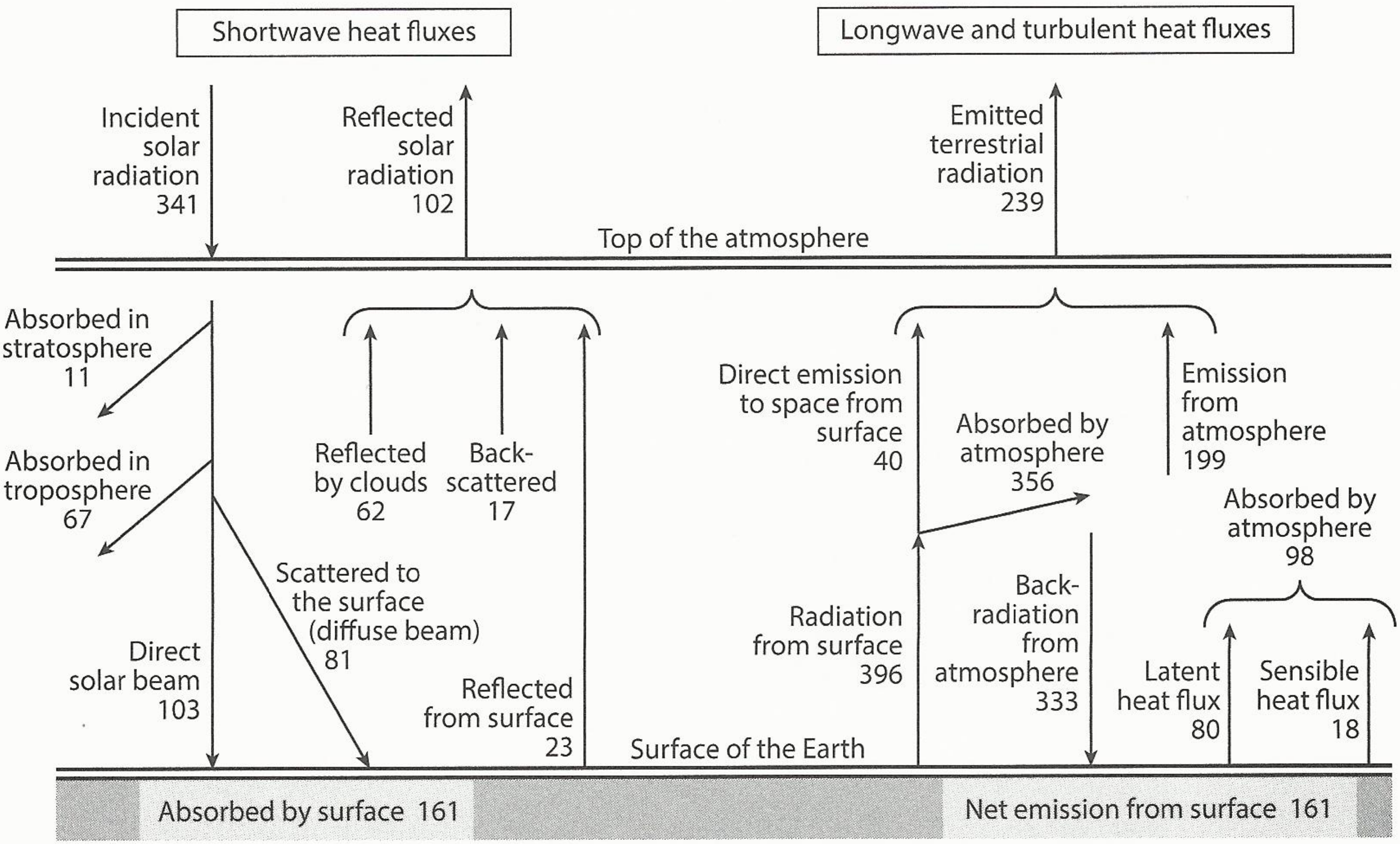
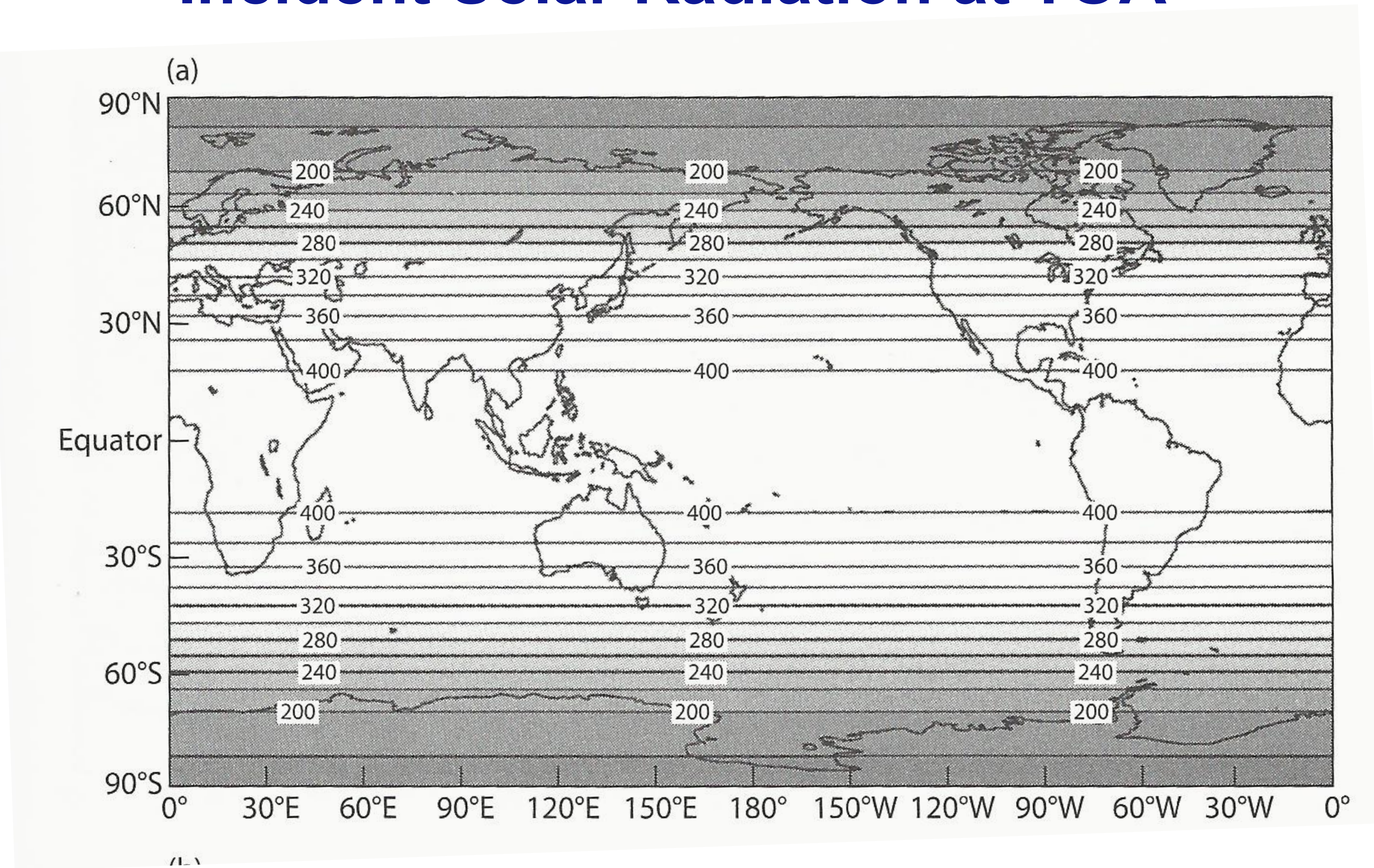


Figure 5.4 The estimated global heat balance (W/m^2). Based on Trenberth, Fasullo, and Kiehl (2009).

net heating by solar balances loss at surface

[Cook, 2012]

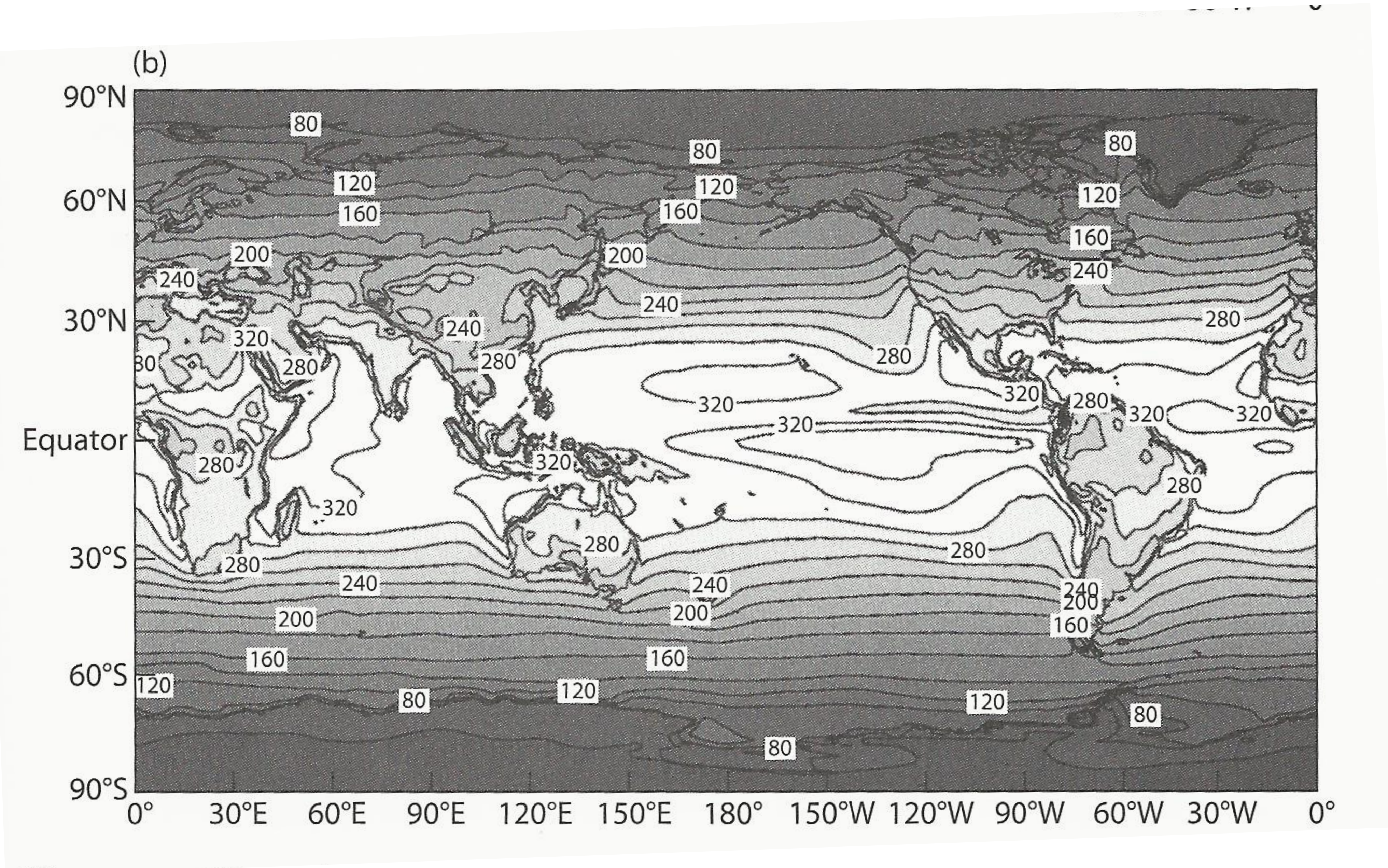
Incident Solar Radiation at TOA



CI 20 W/m²

[Cook, 2012]

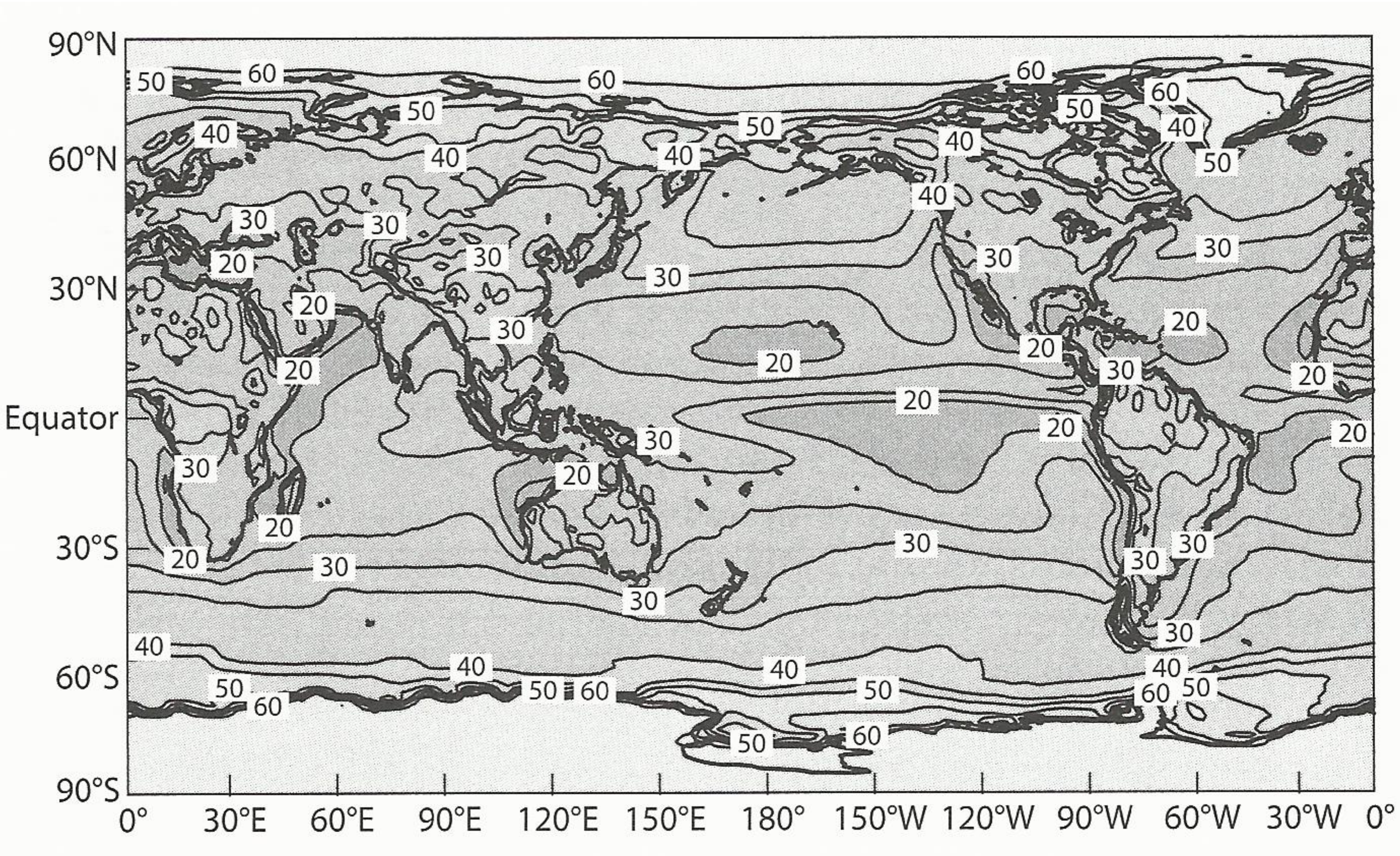
Solar Radiation at absorbed at TOA



[Cook, 2012]

CI 20 W/m²

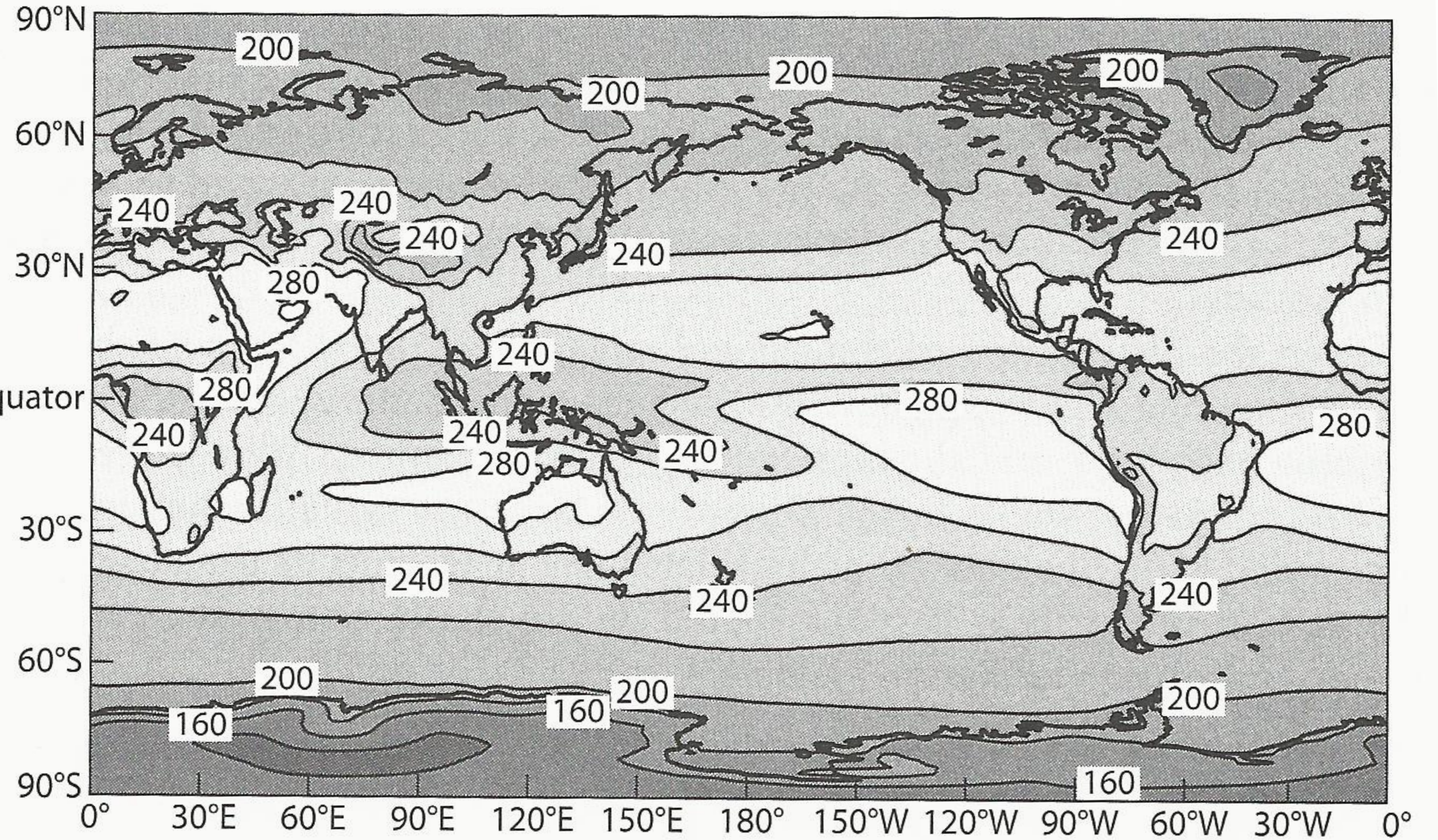
Planetary Albedo



CI = 10 %

[Cook, 2012]

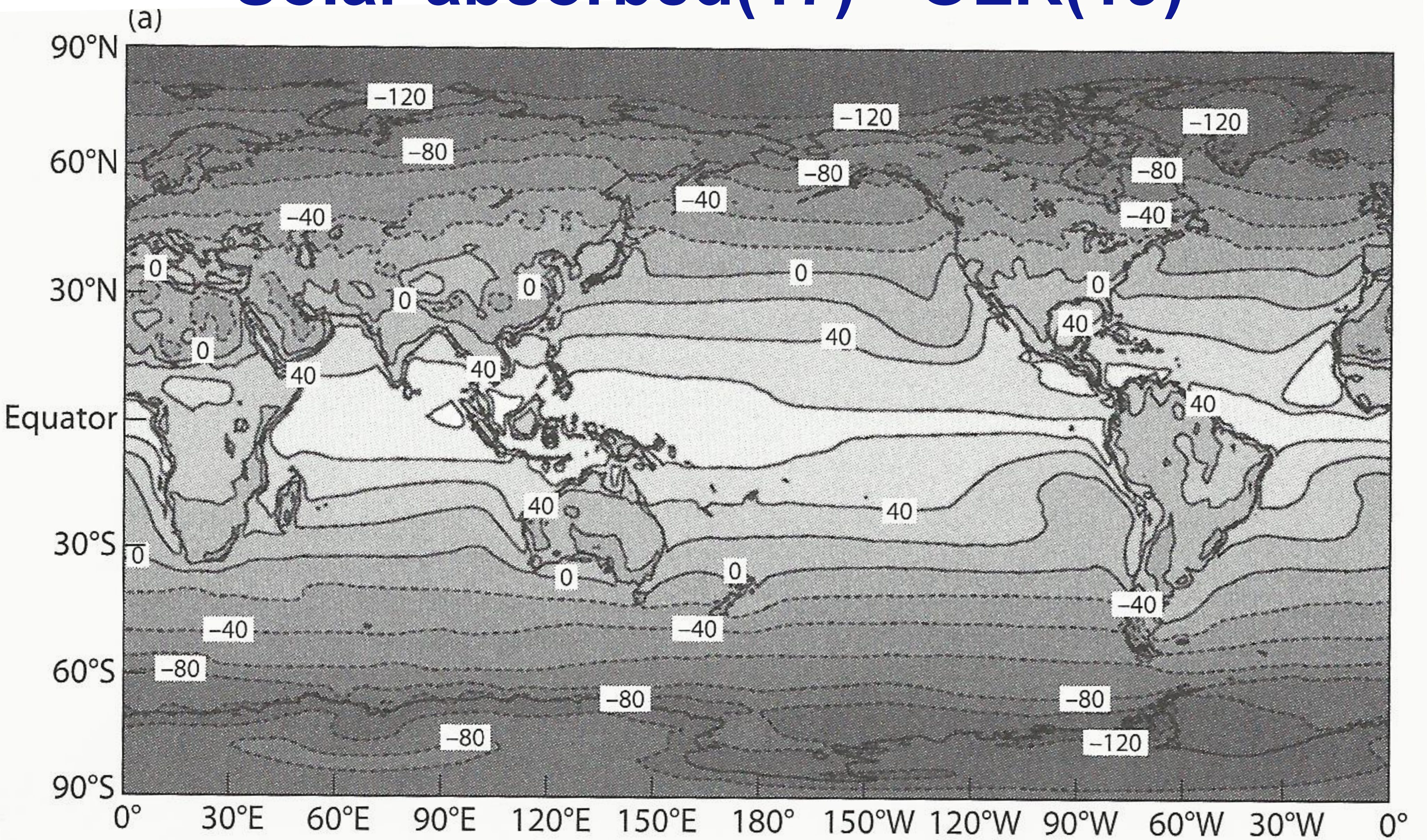
Annual Mean Outgoing Longwave Radiation



[Cook, 2012]

CI 20 W/m²

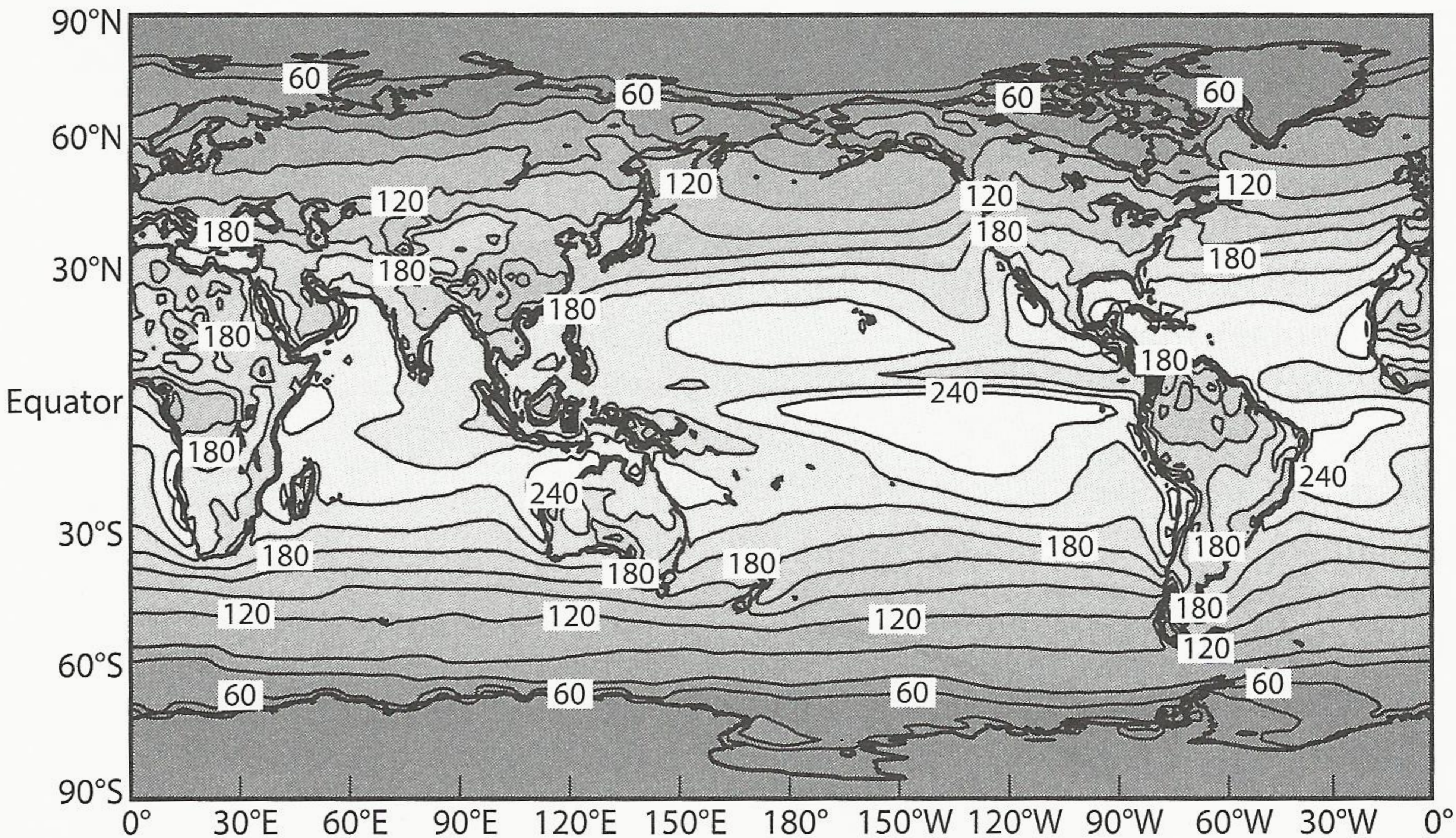
Net Radiation at the Top of Atmosphere
Solar absorbed(17) - OLR(19)



[Cook, 2012]

CI 20 W/m²

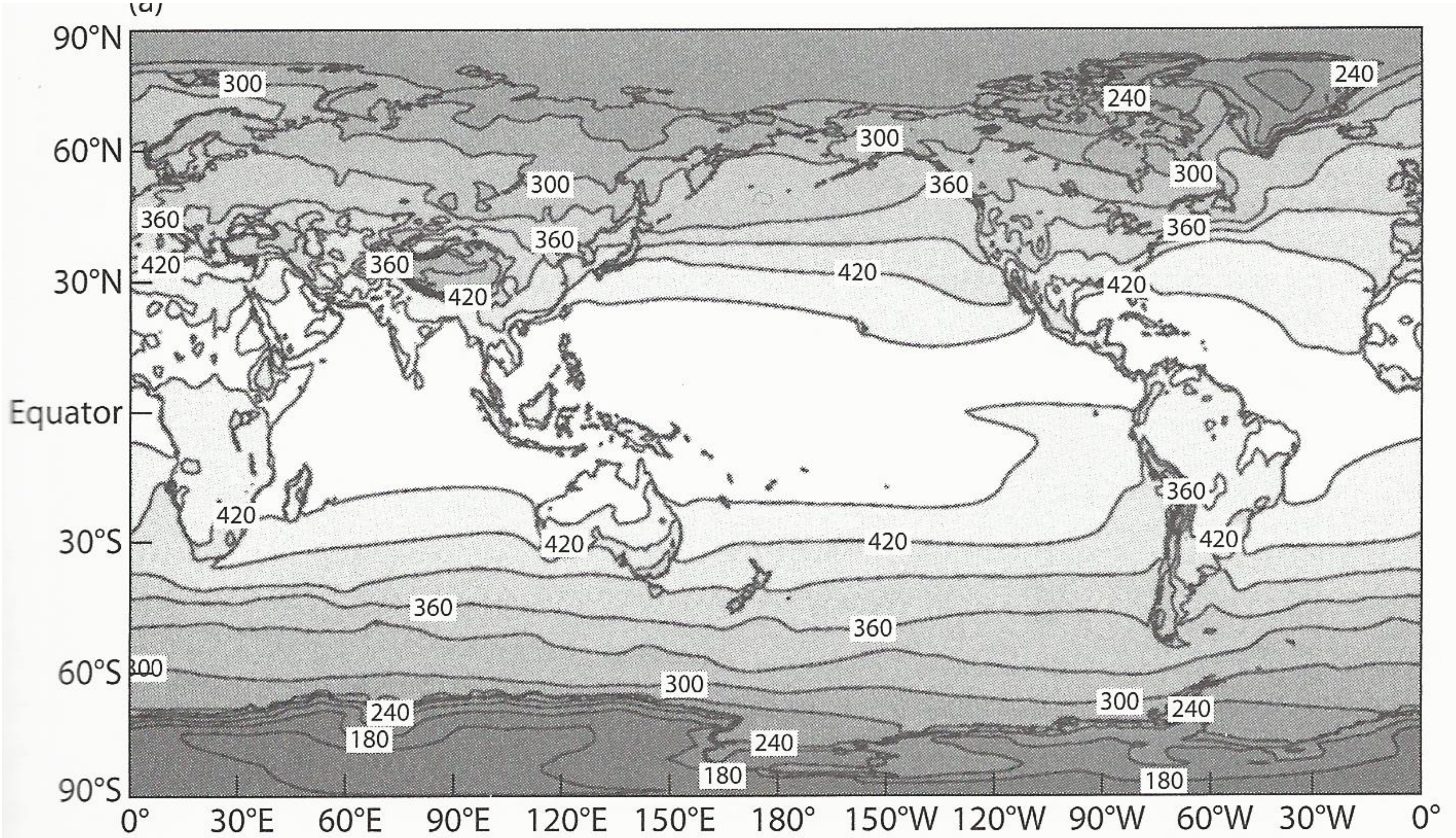
Solar Radiation Absorbed at Surface



[Cook, 2012]

CI 20 W/m²

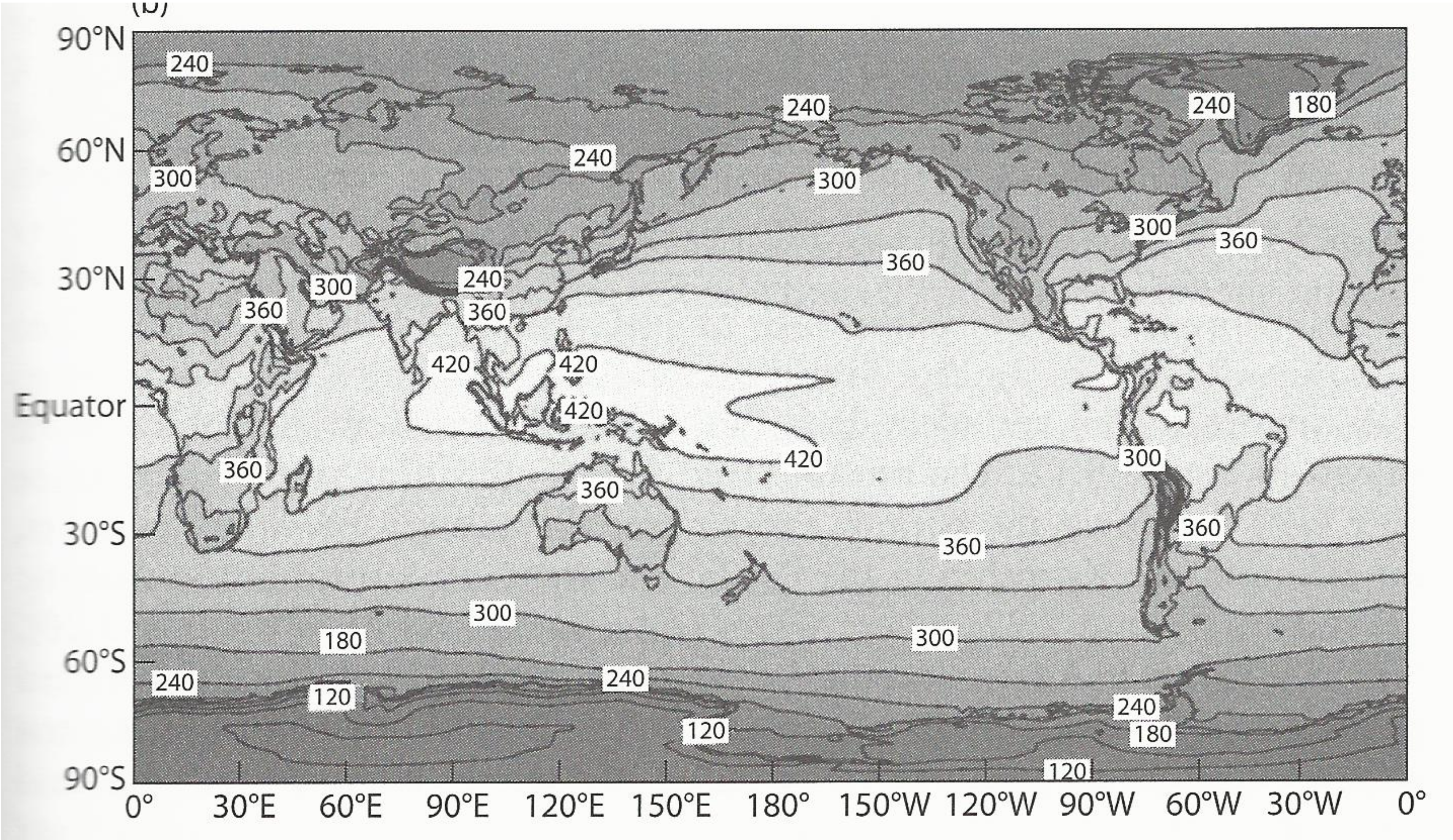
Longwave emission from surface



CI 30 W/m²

[Cook, 2012]

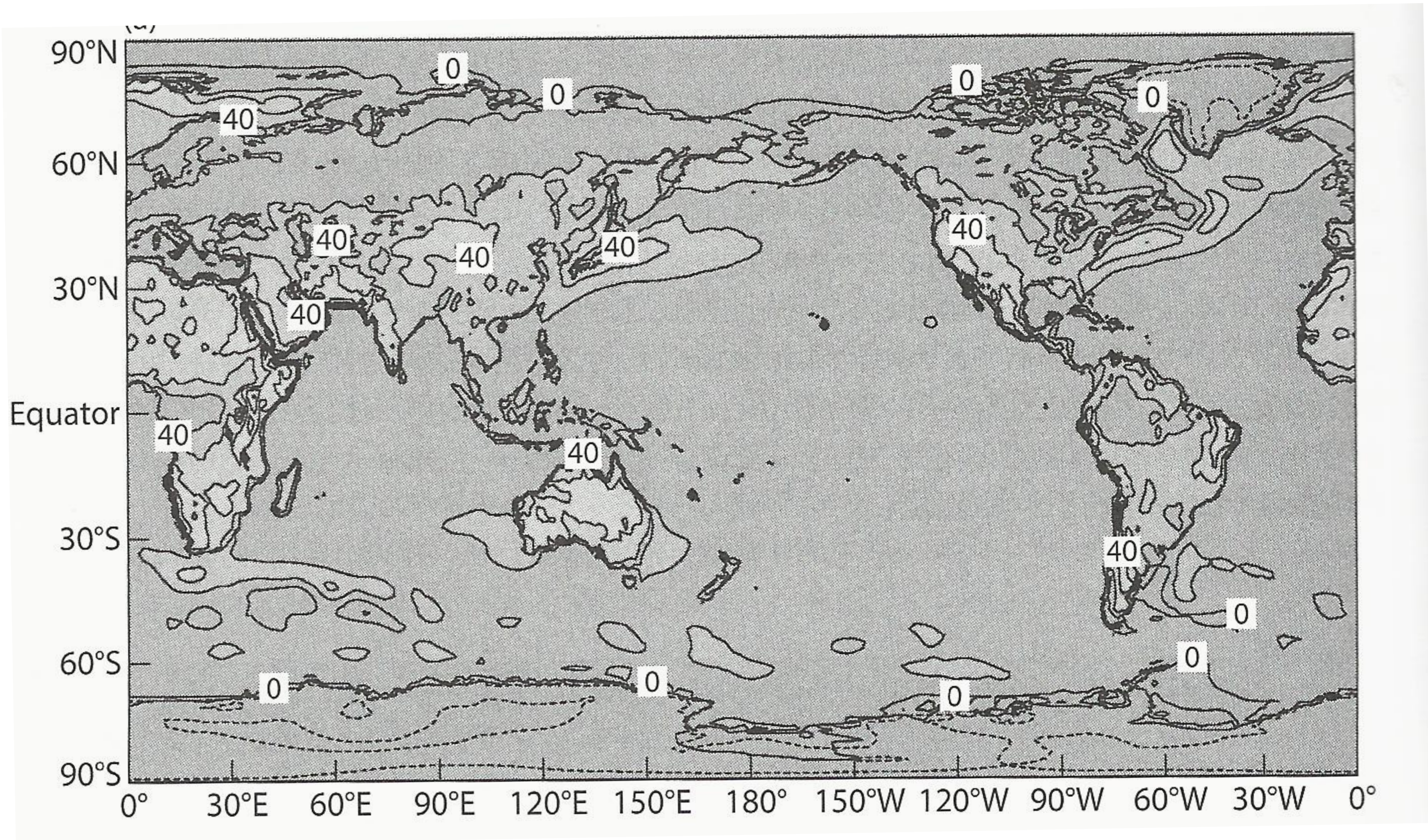
Longwave back radiation from the atmosphere to the surface



CI 30 W/m²

[Cook, 2012]

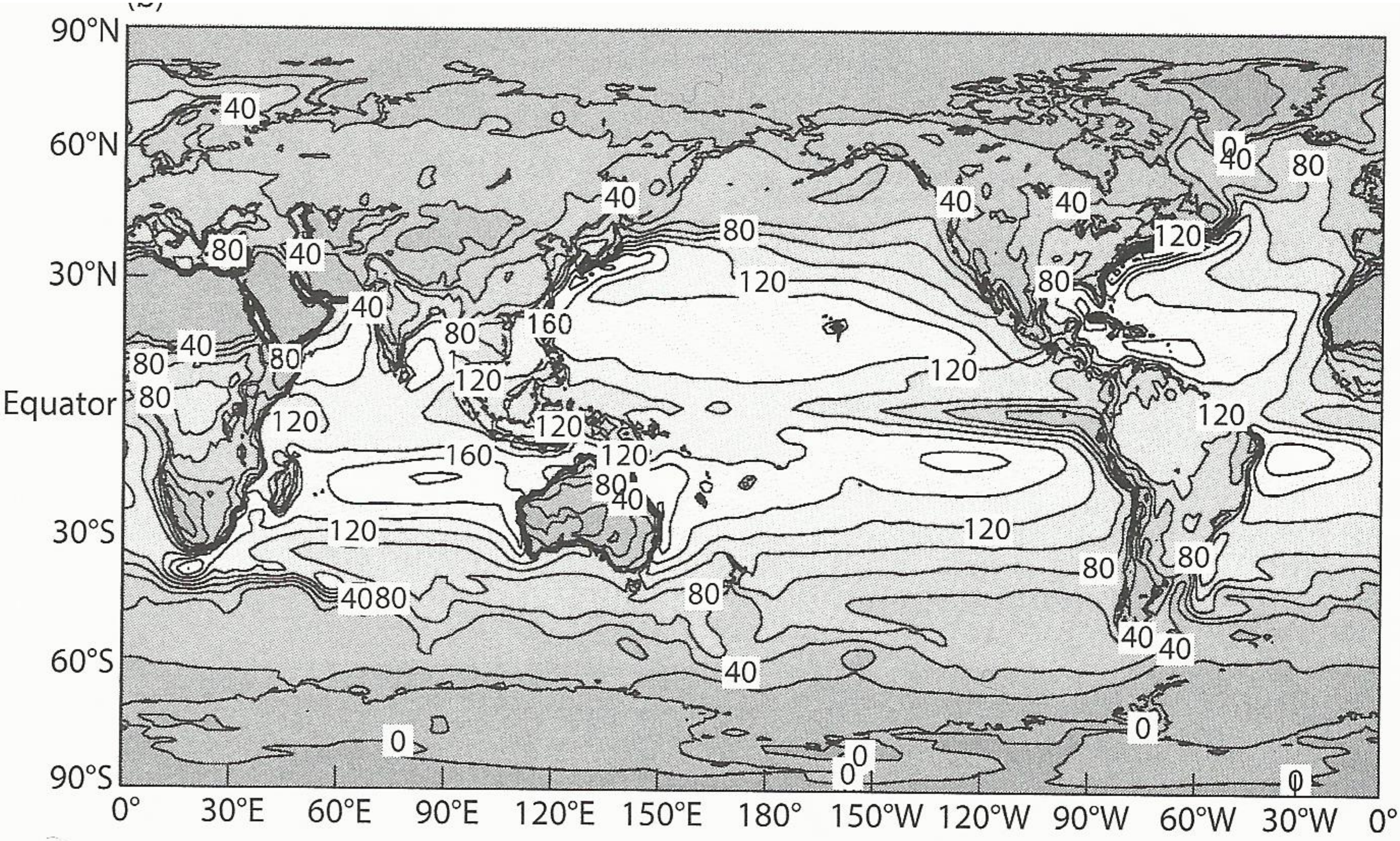
Sensible Heat Flux



CI 20 W/m²

[Cook, 2012]

Latent Heat Flux



CI 20 W/m²

[Cook, 2012]

Summary

- Energy Balance - If the net energy is non-zero then the land, ocean, or air cool or warm.
- Moist versus Dry Lapse Rate: Think of non-condensed moisture in air as energy in air, because when the air parcel cools and water vapor condenses (goes through a phase change) energy is released.
- Most of the atmospheric mass is close to the surface. The pressure decreases exponentially with height.
- Review key features of climatological maps.