

Thermal Physics of the Atmosphere

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Thermodynamics is a funny subject. The first time you go through it, you don't understand it at all. The second time you go through it, you think you understand it, except for one or two small points. The third time you go through it, you know you don't understand it, but by that time you are so used to it, it doesn't bother you any more.

Arnold Sommerfeld



A theory is the more impressive the greater the simplicity of its premises, the more different kinds of things it relates, and the more extended its area of applicability. Therefore the deep impression that classical thermodynamics made upon me. It is the only physical theory of universal content which I am convinced will never be overthrown, within the framework of applicability of its basic concepts.

Albert Einstein



In this house we obey the laws of thermodynamics!

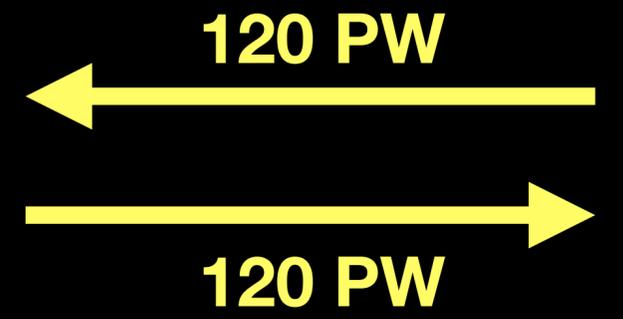
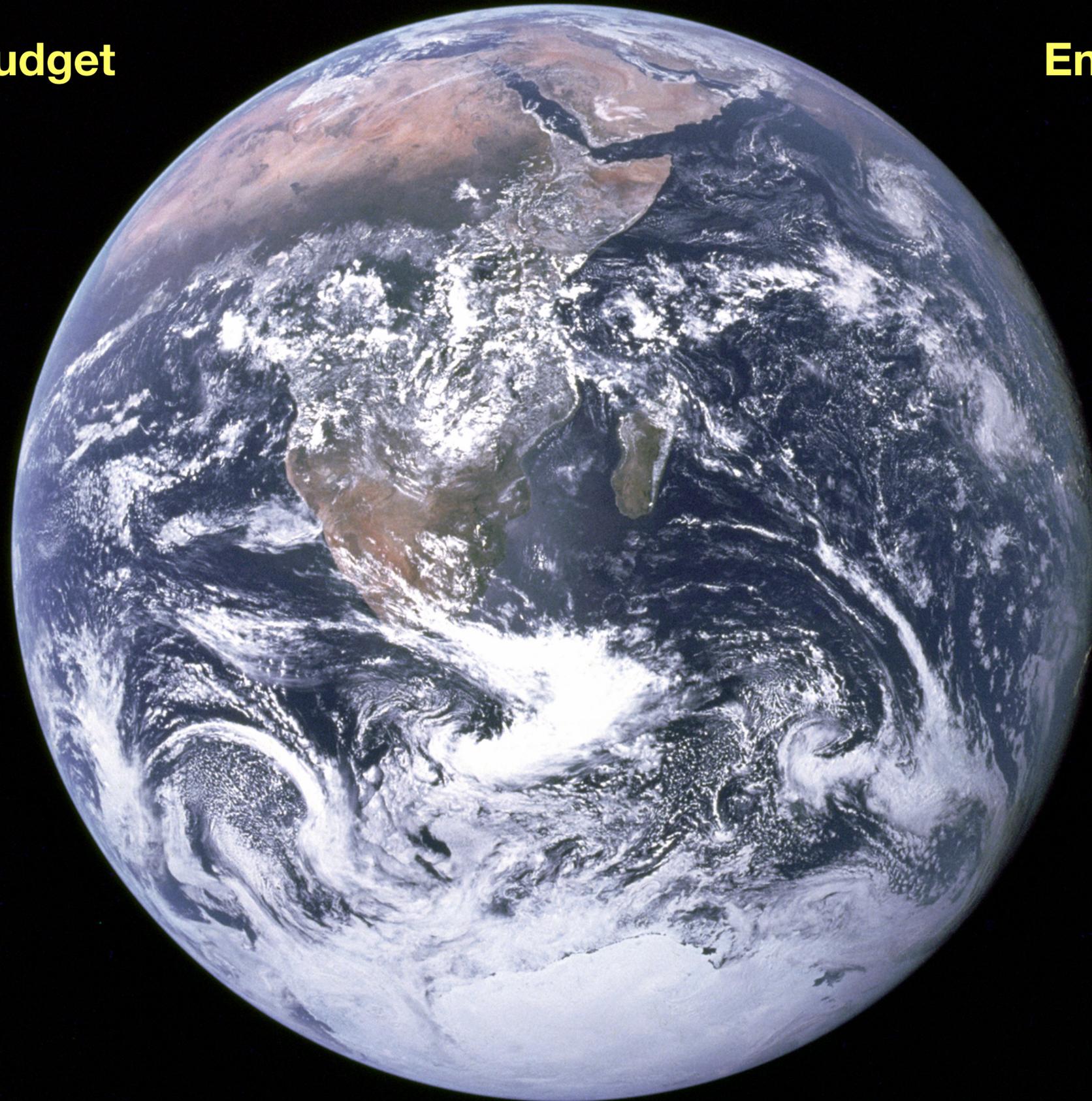
Homer Simpson





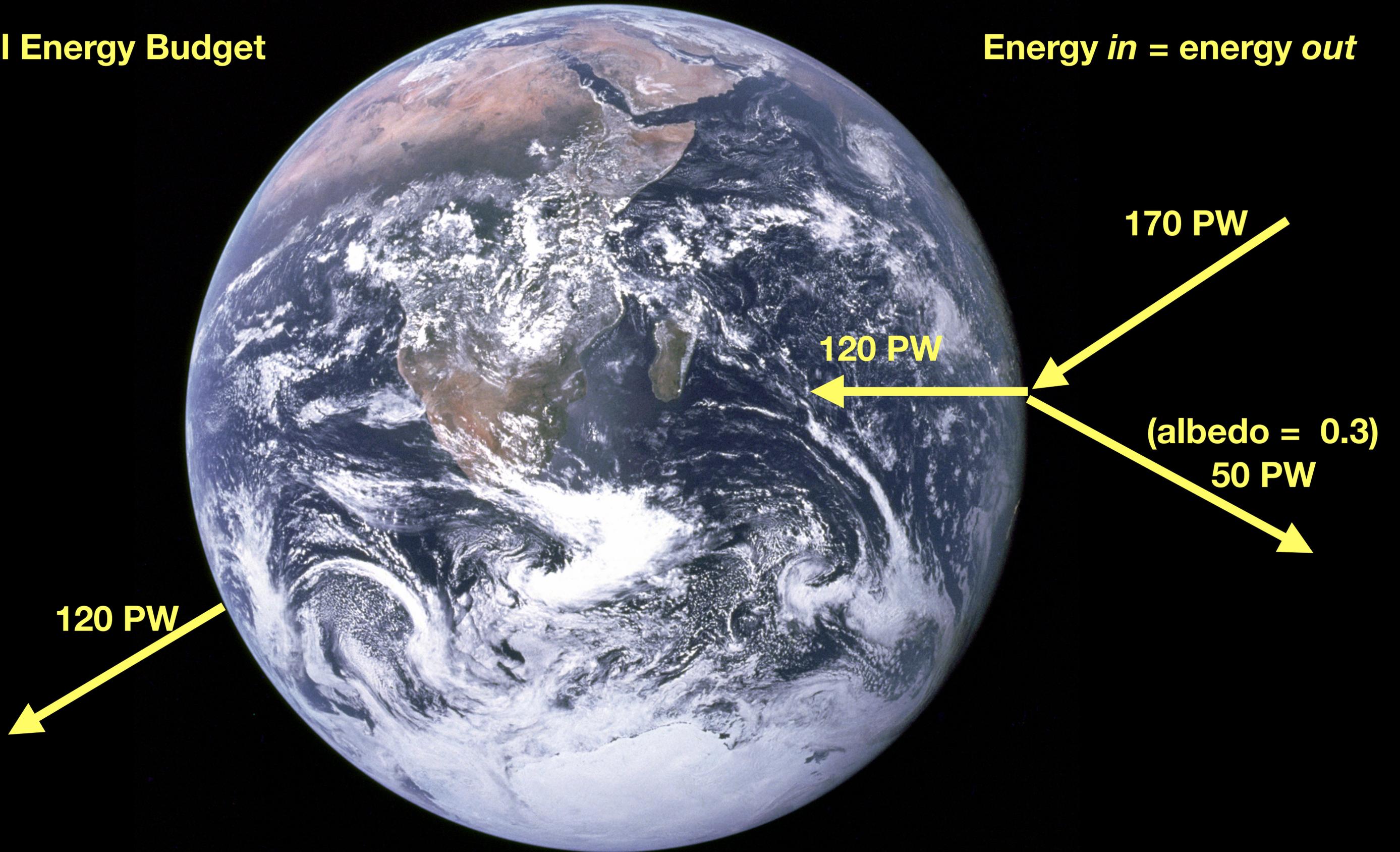
The Global Energy Budget

Energy *in* = energy *out*



The Global Energy Budget

Energy in = energy out

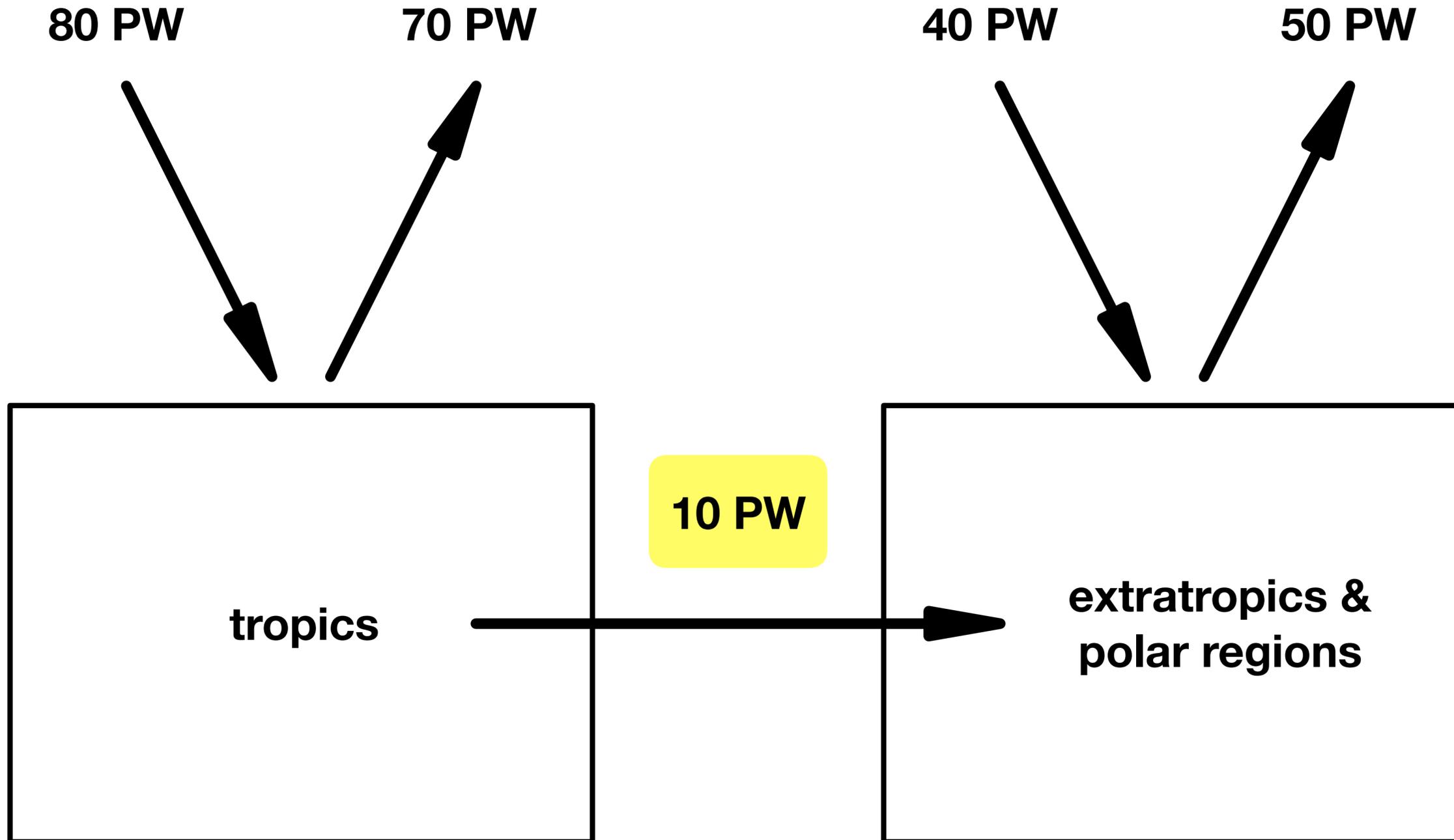


120PW corresponds to 240 W/m²

= enough to satisfy *total* UK energy demand 225 times over

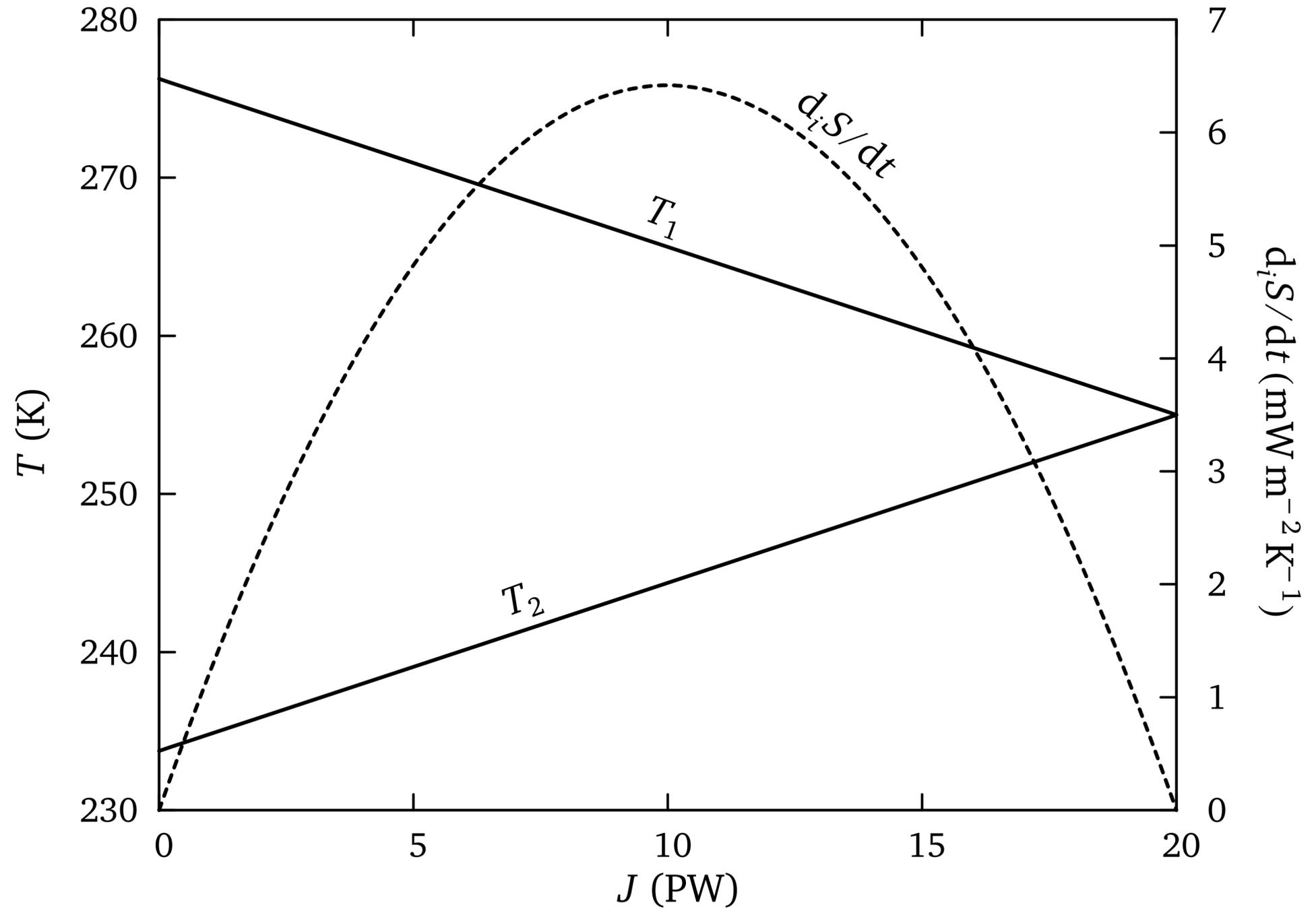


The Global Circulation

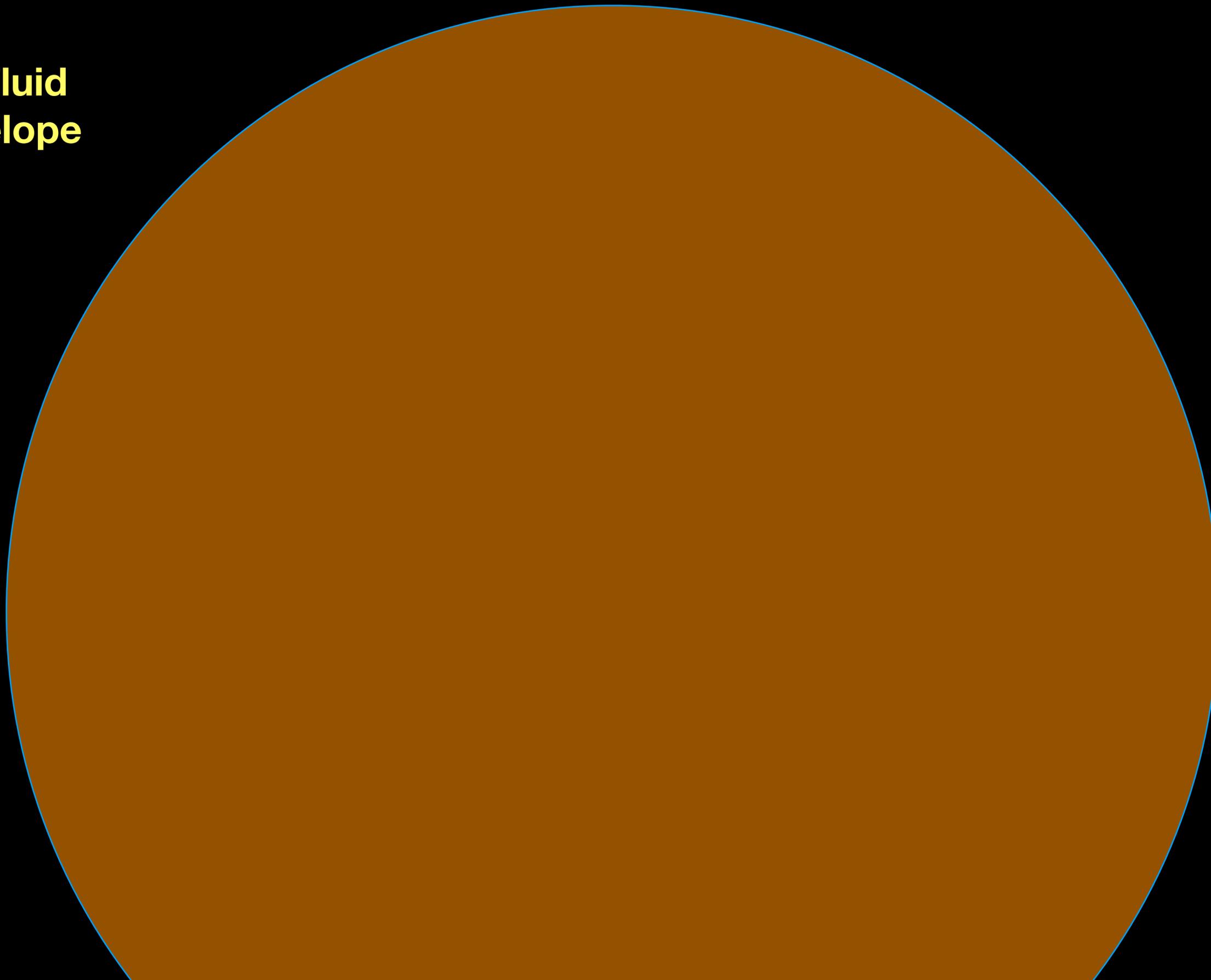


Predictive thermodynamics: maximum entropy production

$$\frac{d_i S}{dt} = J \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$



**the fluid
envelope**

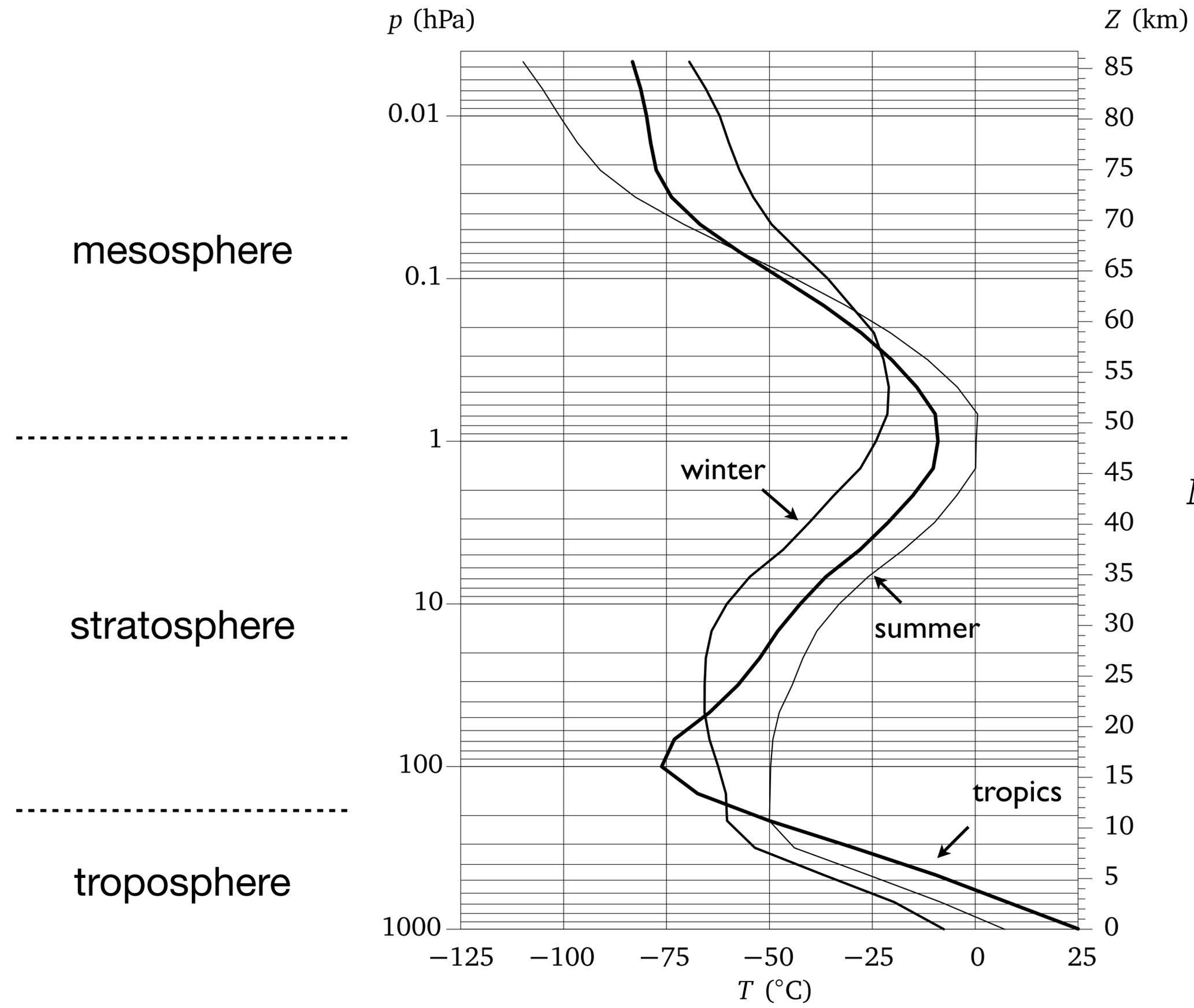


120 PW



120 PW





**Hydrostatic Balance:
mass = pressure drop**

$$M = \int_{z_0}^{z_1} \rho \, dz = \int_{p_1}^{p_0} \frac{dp}{g} \approx \frac{p_0 - p_1}{g}$$

mean surface temperature – Earth's radiation temperature = greenhouse effect
288 K – 255 K = 33 K

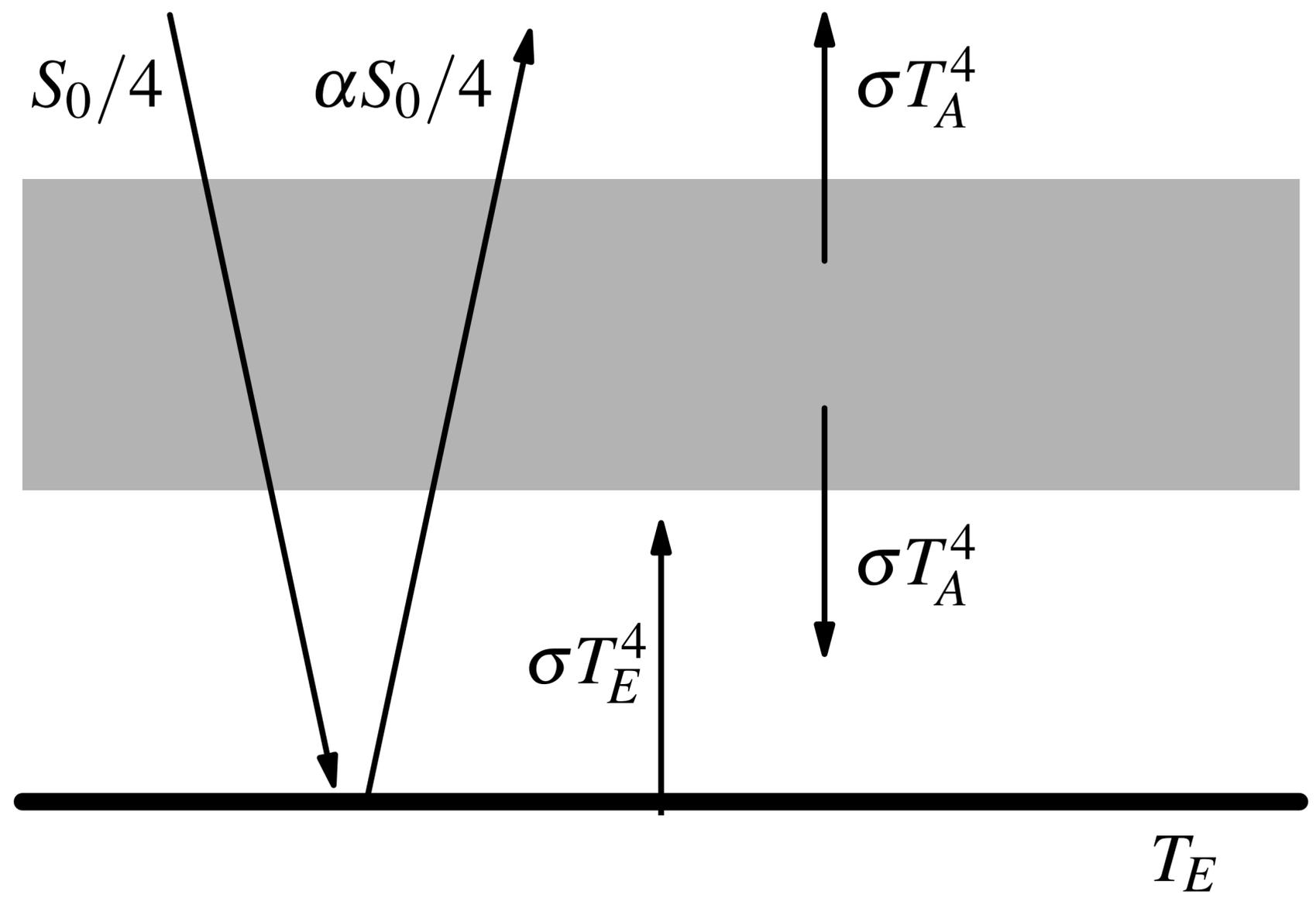
Stefan-Boltzmann:

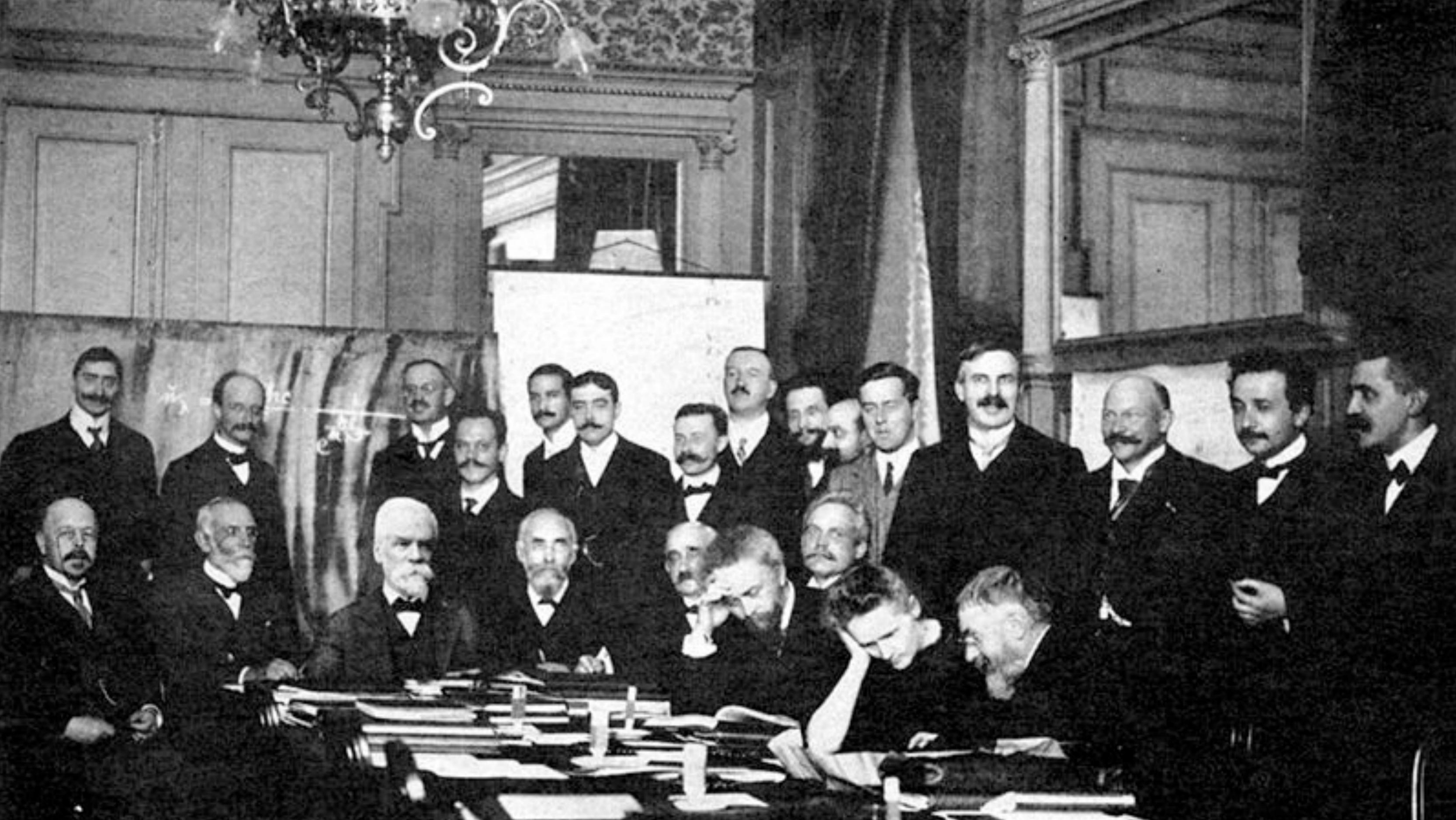
$$B = \sigma T^4$$

$$240 \text{ W m}^{-2} = \sigma (255 \text{ K})^4$$

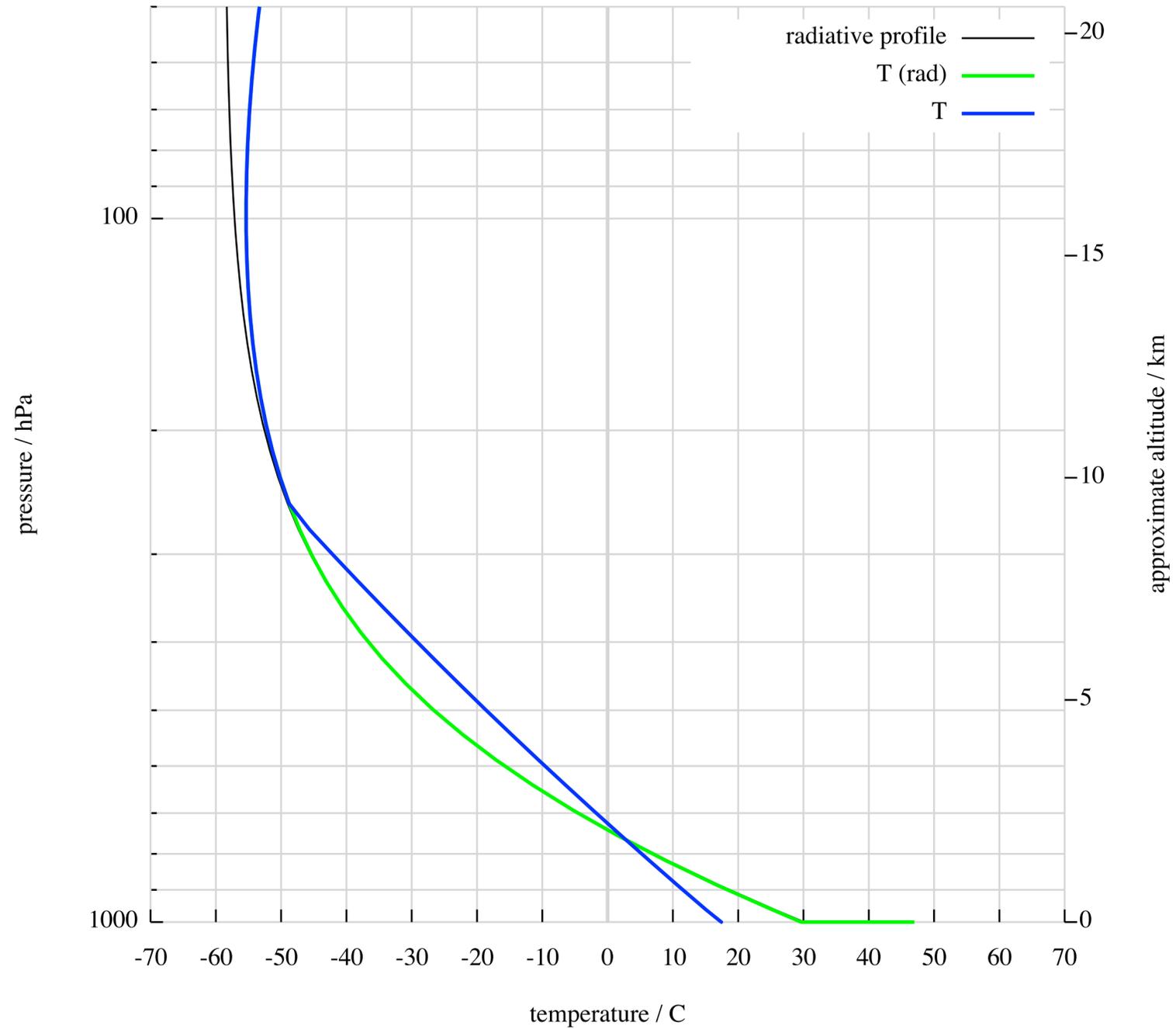
Solar constant:

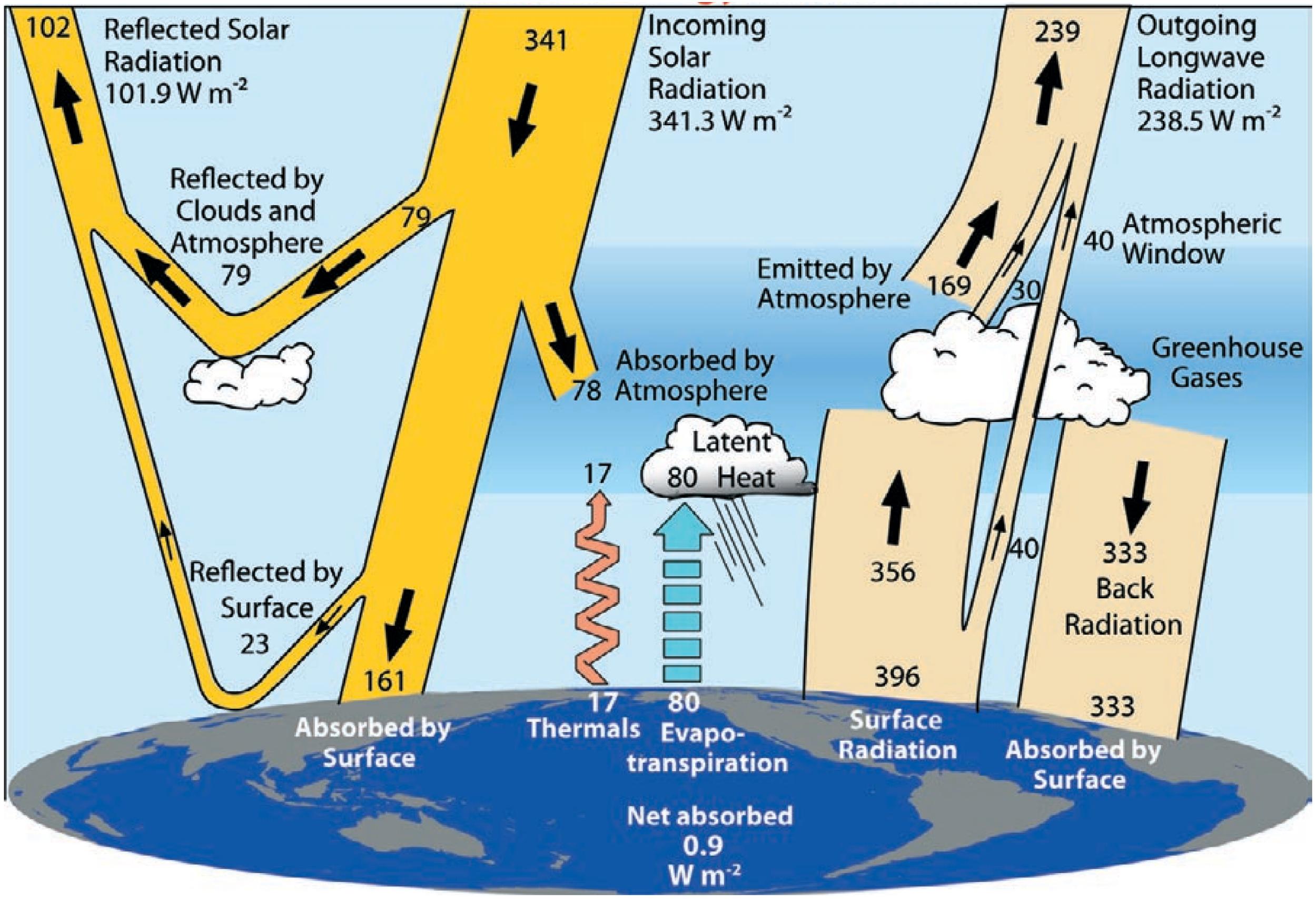
$$S_0 \approx 1366 \text{ W m}^{-2}$$





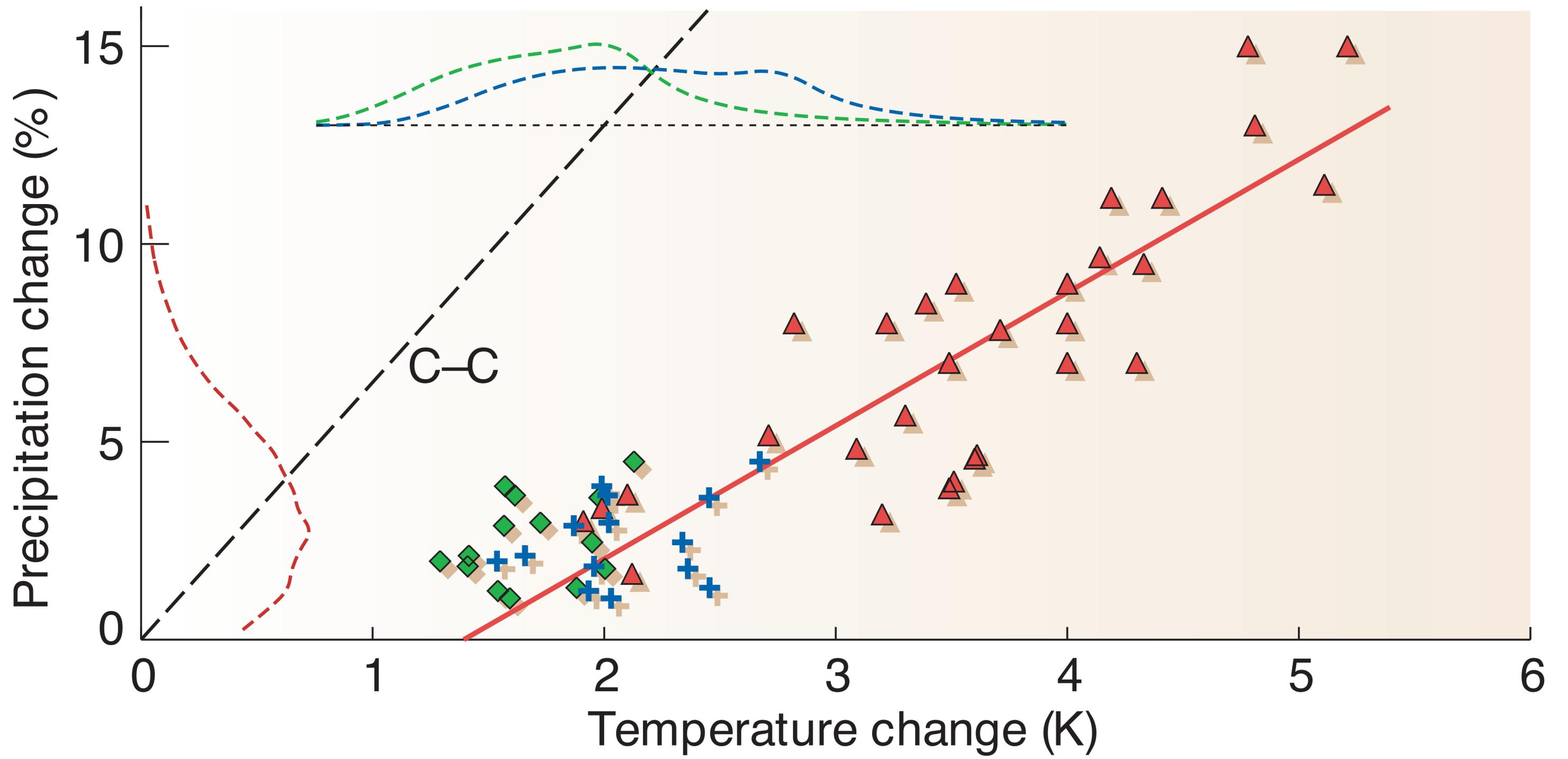
Radiative Transfer (a pen-and-paper example)



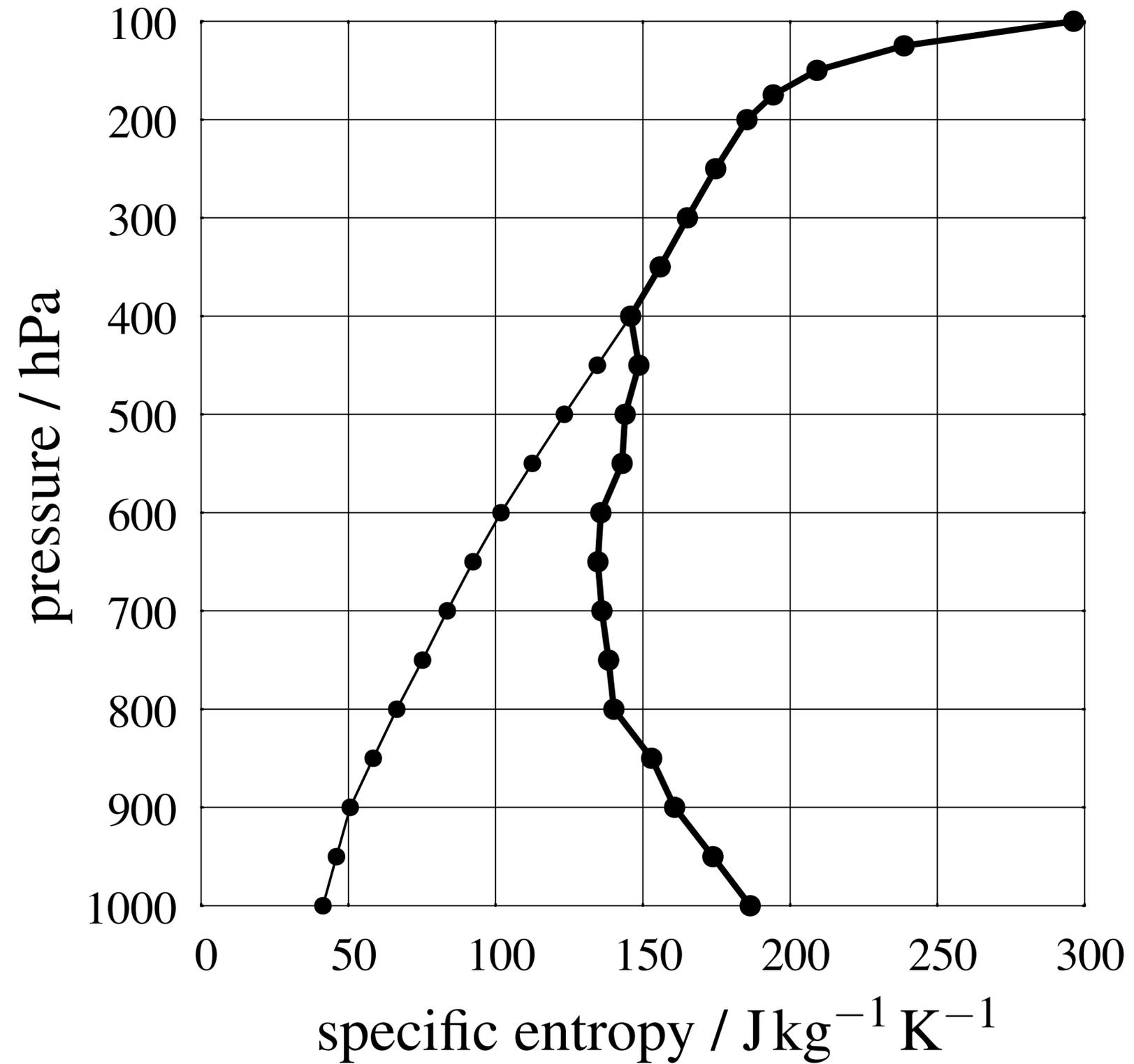


from Trenberth, Fasullo & Kiehl, *Bull. Am. Met. Soc.*, 2009

Global Hydrological Cycle: constrained by "basic" thermodynamics



Entropy for dry and moist air (constraint on structure of tropical convection)

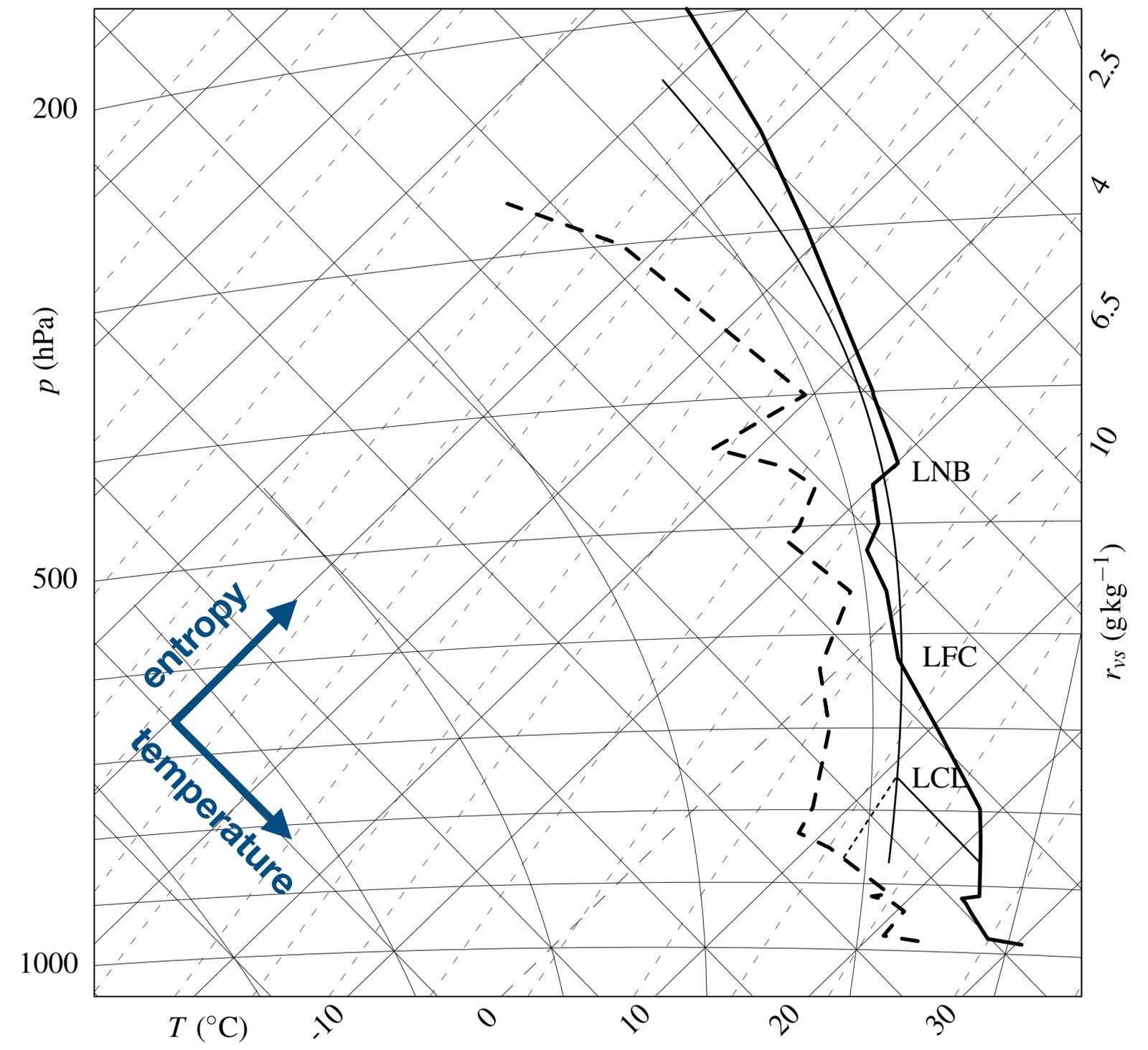


**(tropical mean
during storm season)**

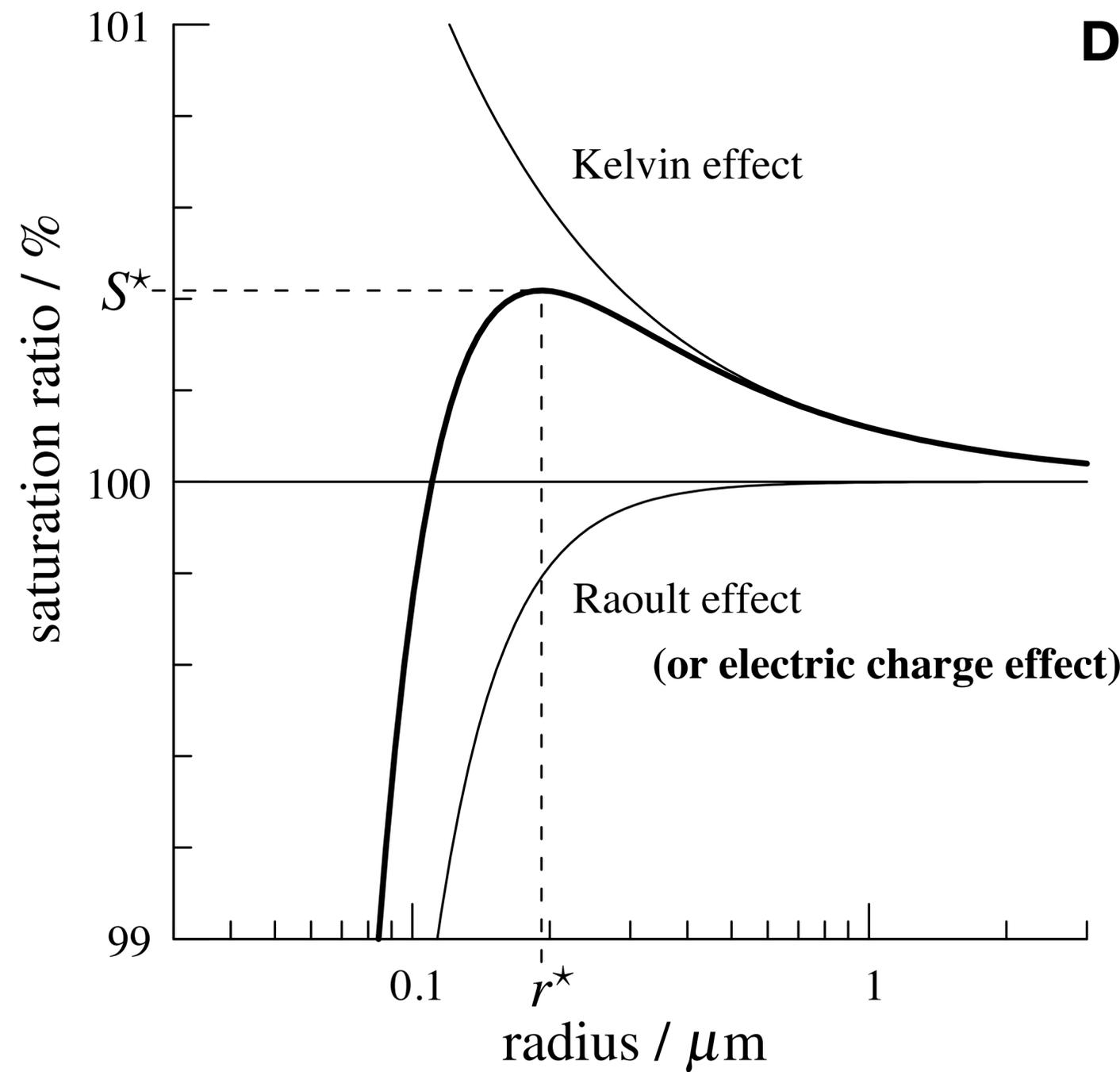


Tephigrams (T- ϕ)

(an example of graphical jargon)



**Down to the smallest scales:
cloud drop formation**



- Wilson cloud chamber (see IOP lobby)
- Cosmic ray effect on climate?
- Cloud seeding with ions

Apollo 11 moonrise
20 July 1969

Philippe Lopez, ECMWF

