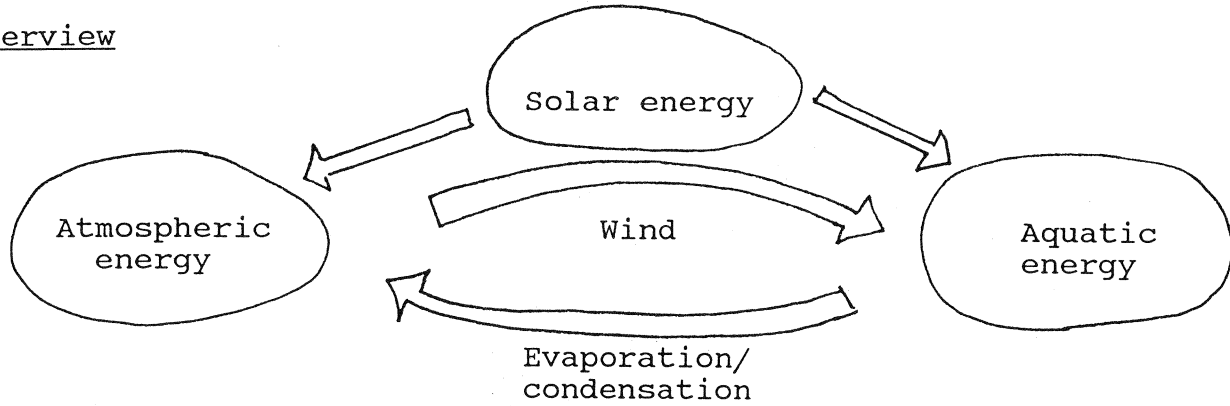


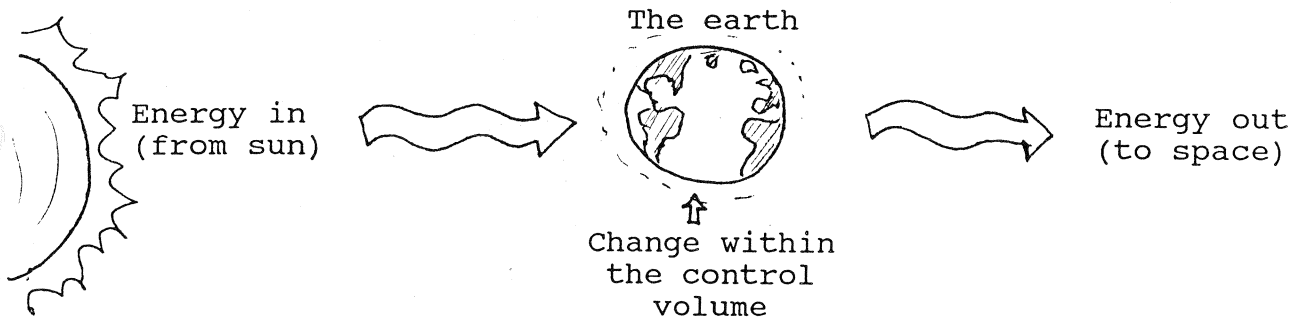
1.2. Overview of Thermal Energy Transfers and Radiation Physics

Overview

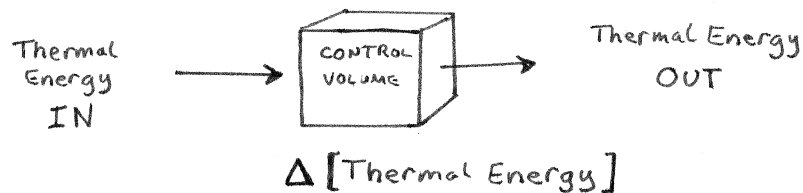
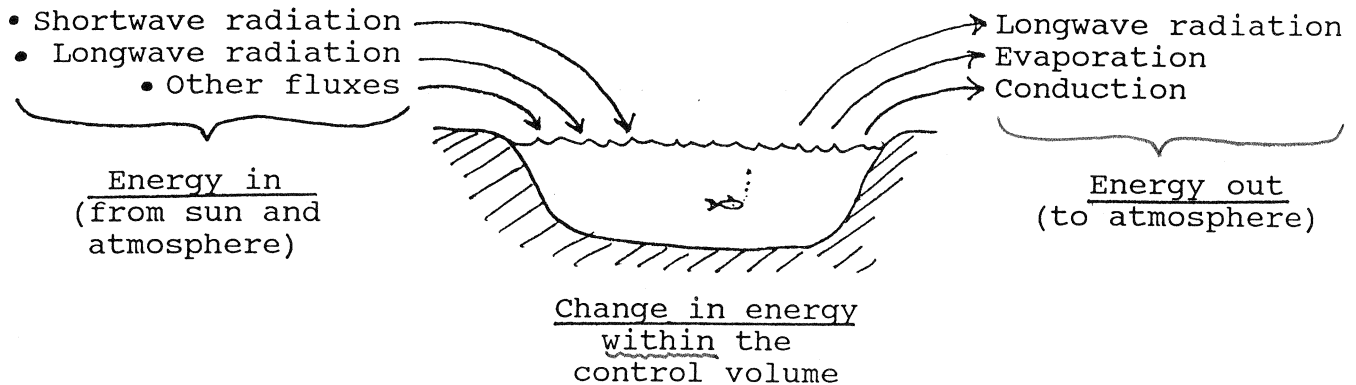


Think about control volumes:

Heat conservation for the earth:



Heat conservation for a pond:



Transfers of thermal energy:

Basic Energy Transfers	Related physical or meteorological variables
<ul style="list-style-type: none"> • Radiation 	<ul style="list-style-type: none"> • Radiation (solar input, etc.)
<ul style="list-style-type: none"> • Conduction 	<ul style="list-style-type: none"> • Air temperature/ H₂O temperature
<ul style="list-style-type: none"> • Latent heat (evaporation & condensation) 	<ul style="list-style-type: none"> • Relative humidity • Wind velocity

Think about the nature of the connections (arrows) between the basic physical phenomena on the left-hand side and the meteorological variable on the right-hand side. For example, do you see why radiation at a pond surface is connected to both solar radiation and air temperature, but not to wind? (Answer: Air temperature influences the amount of radiation from the atmosphere, solar radiation is a form of radiation, but wind speed has no effect on any radiation process. However, wind does affect conduction, etc.)

Central Idea:

There are three ways heat can be transferred to the environment: radiation, conduction, and as latent heat conversion (evaporation/condensation). But a whole suite of natural processes affects and controls the flow of heat via these three mechanisms. E.g., if we want to understand radiative heat flow, we must learn about radiation physics, and then consider the natural processes on earth that create or mediate radiation.

So we must know about solar radiation, atmospheric absorption of light, atmospheric radiation of light, light scattering, light reflection, absorption and radiation by clouds, absorption and radiation by liquid water, etc.

Radiation Physics: A few basic elements, mostly identified by Germanic surnames.

1. Kirchoff's Law: Develops the notion of a black body radiator

→ Any body above 0 K (zero Kelvin) radiates heat

→ The degree to which a body radiates is exactly proportional to the degree to which it absorbs radiation.

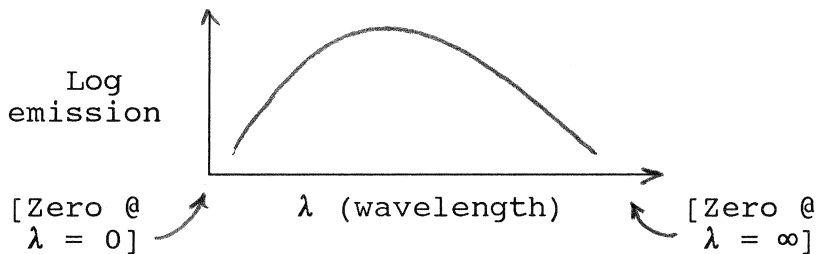
$$\frac{W_1}{a_1} = \frac{W_2}{a_2} = W_B$$

W_i \equiv intensity of radiation
 = power density (power/area)
 = energy flux (energy/time/area)
 a_i \equiv specific absorptivity ($0 < a_i < 1$)

That is, a perfectly "black" body absorbs any energy that hits it and perfectly radiates any energy it contains. So, a black Cadillac in the sun heats up faster than a white Cadillac, but at night, the black Caddy cools off faster than the white Caddy.

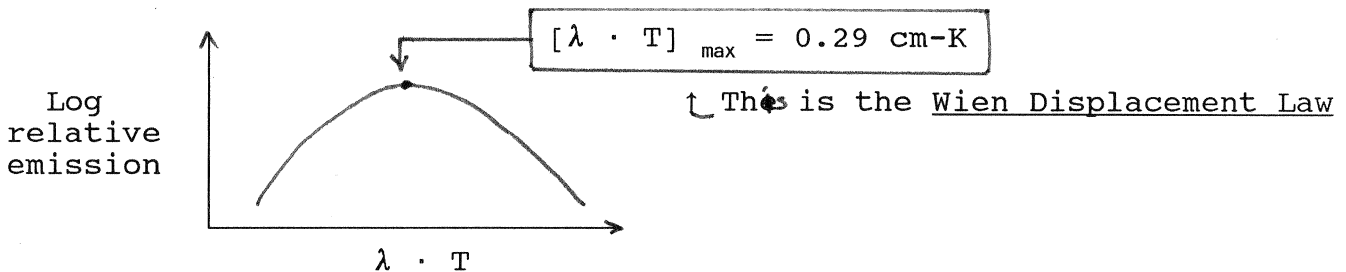
Nothing on earth is truly a black body. A body's "blackness" is indicated by a_i . As $a_i \rightarrow 1.0$, the body's blackness approaches the theoretical limit. You can see this from $W_1 = a_i W_B$.

2. Planck's Law: Black body radiation is distributed w/r/t wavelength.



$$\int_0^{\infty} W_B^{\lambda} d\lambda = W_B$$

And that this distribution is positioned by the absolute temperature of the body.



3. Stefan-Boltzmann Law: Simplifies the overall problem and states the relationship between the total black-body radiation and the absolute temperature of the radiator.

$$W_B = \sigma T^4$$

$$\sigma = 8.3 \times 10^{-9} \text{ cal} \cdot \text{cm}^{-2} \text{ min}^{-1} \text{ K}^{-4}$$

(cont'd)

or

$$W = \epsilon \sigma T^4$$

$$\sigma = 5.8 \times 10^{-8} \text{ J} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{K}^{-4}$$

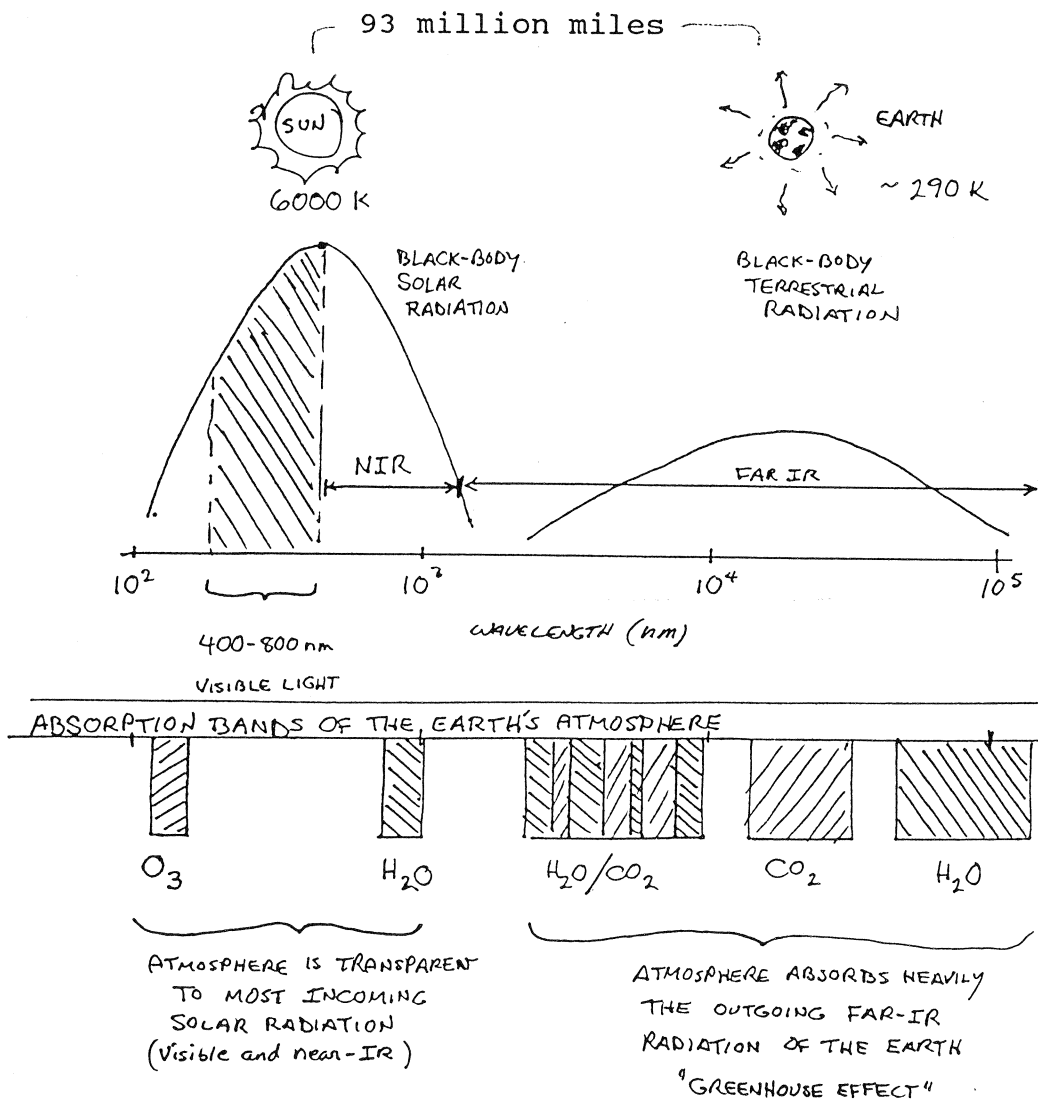
$\epsilon \equiv$ emissivity factor = a at thermal equilibrium

Units of σ , of course, depend on the units you wish to use for W_B or W .

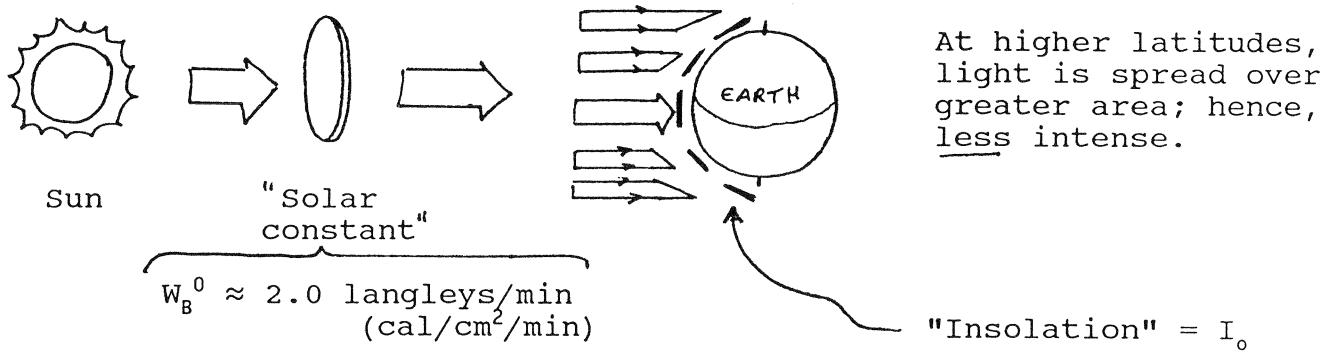
Meteorologists and ecologists traditionally have used the unit $\text{cal} \cdot \text{cm}^{-2} \cdot \text{min}^{-1}$ and called a cal/cm^2 a "Langley" (Ly). Hence, radiation flux is expressed in Ly/min (Langleys per min).

The modern SI (Système Internationale) units for radiation flux are $\text{Joules} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ which has no special name I am aware of.

We can apply this set of equations to the earth/sun system to understand the essentials of radiative fluxes reaching the earth.



The spherical shape of the earth also is very important:

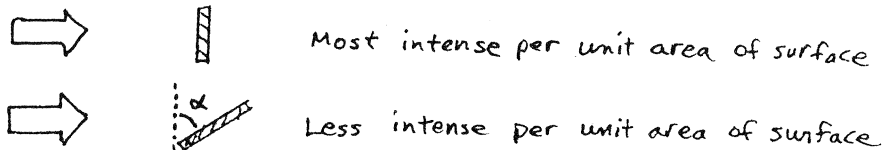


$$I_0 = W_{B_0} \sin \alpha$$

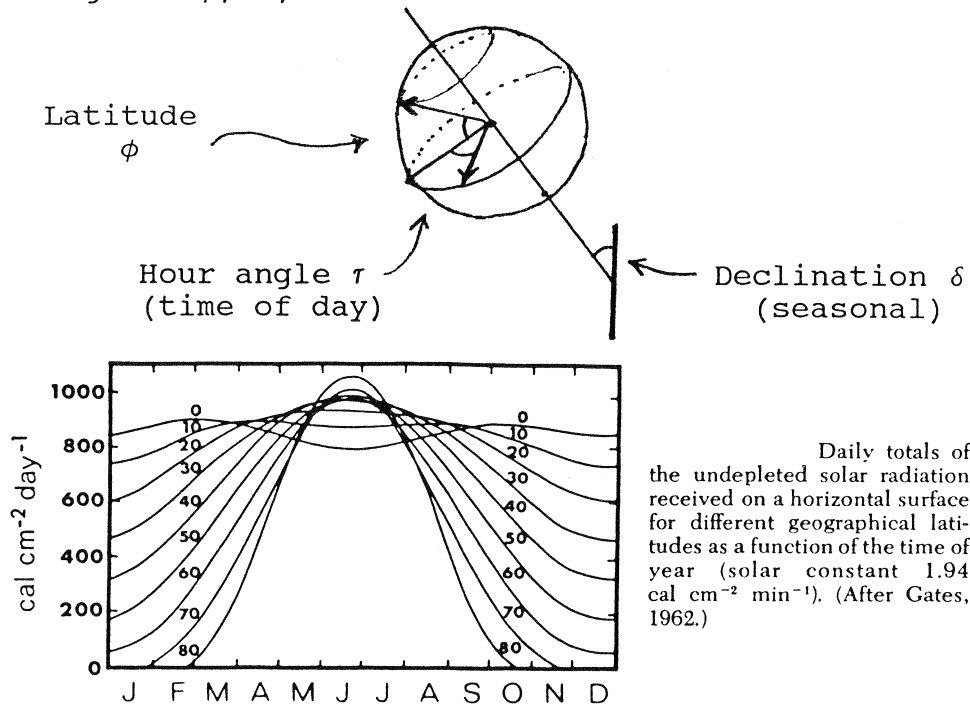
$$= W_{B_0} \cos \phi$$

$\alpha = [90^\circ - (\text{latitude})]$ ← for noon at the equinox

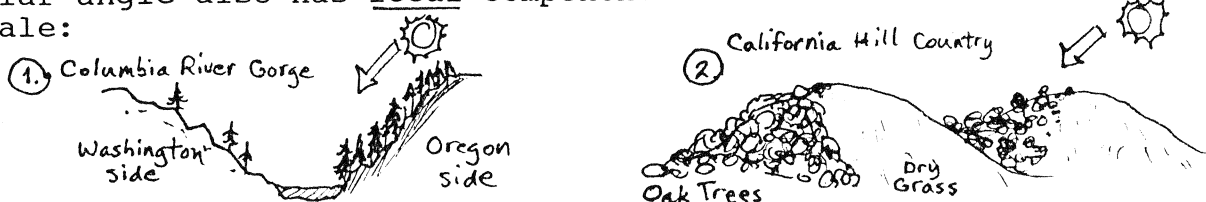
$\alpha \equiv$ solar angle (See Eagleson's chapter)



A. Solar angle for a flat surface can be calculated using the three component angles: ϕ , τ , δ .



B. Solar angle also has local components on the meso-scale or micro-scale:



Absorbance and especially molecular and particulate scattering also affect insolation: smoke, haze, clouds, pollution, etc. So what hits the surface is significantly less than ($W_{B_0} \sin \alpha$).

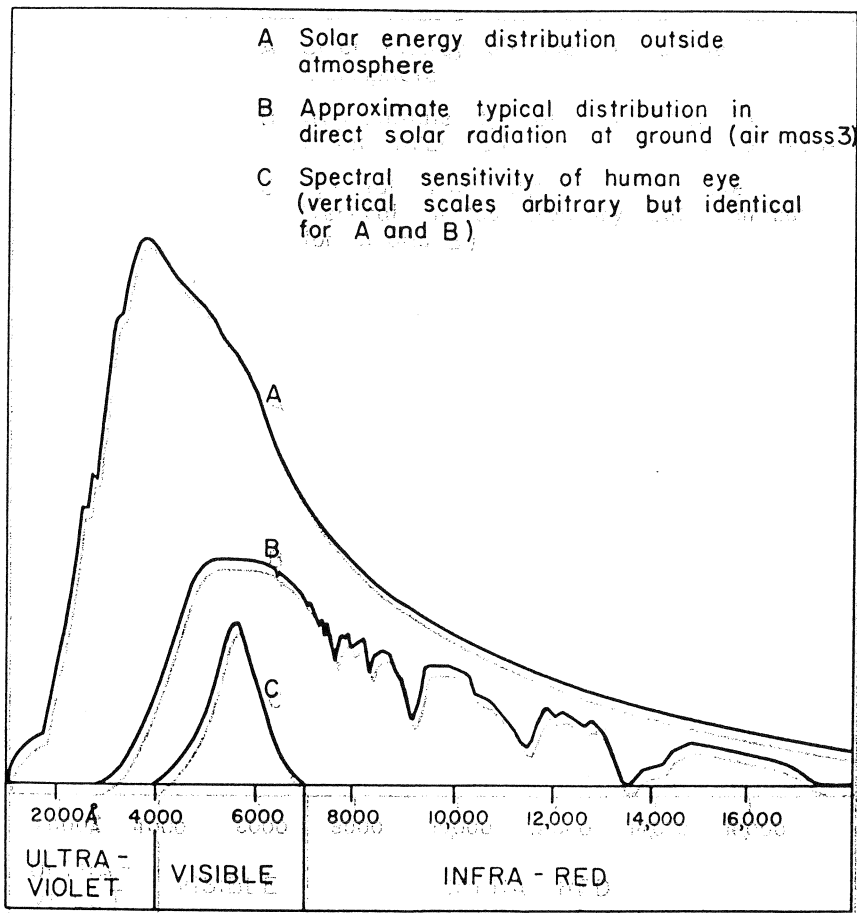


FIGURE 109. Spectral distribution of radiant energy outside the atmosphere and at the earth's surface (air mass 3), with the spectral sensitivity of the human eye.

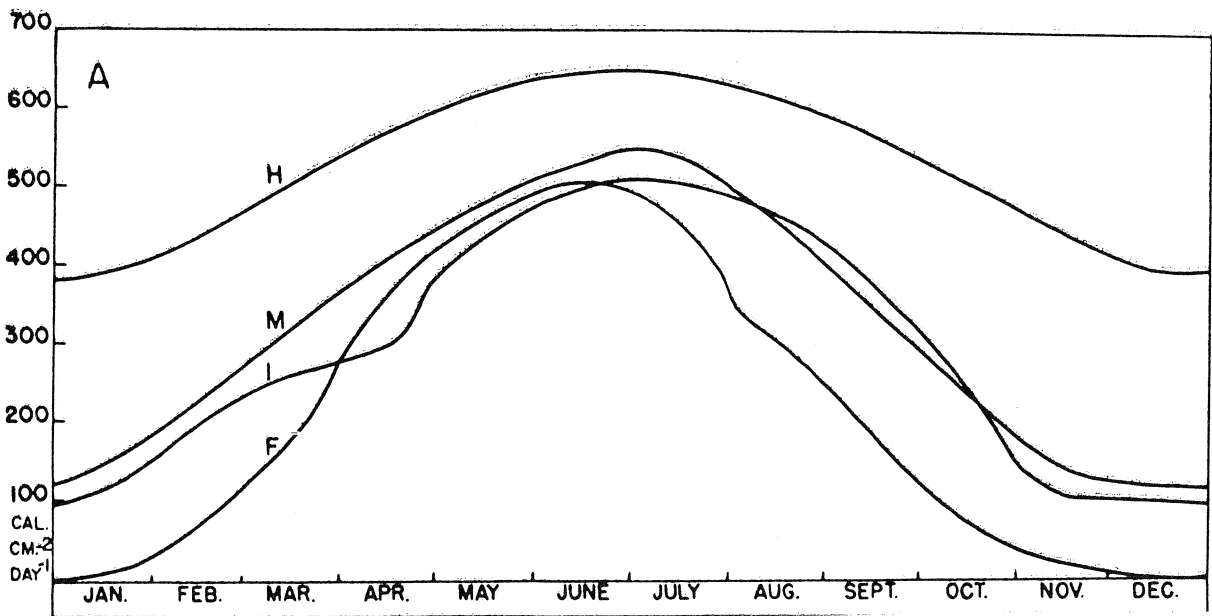
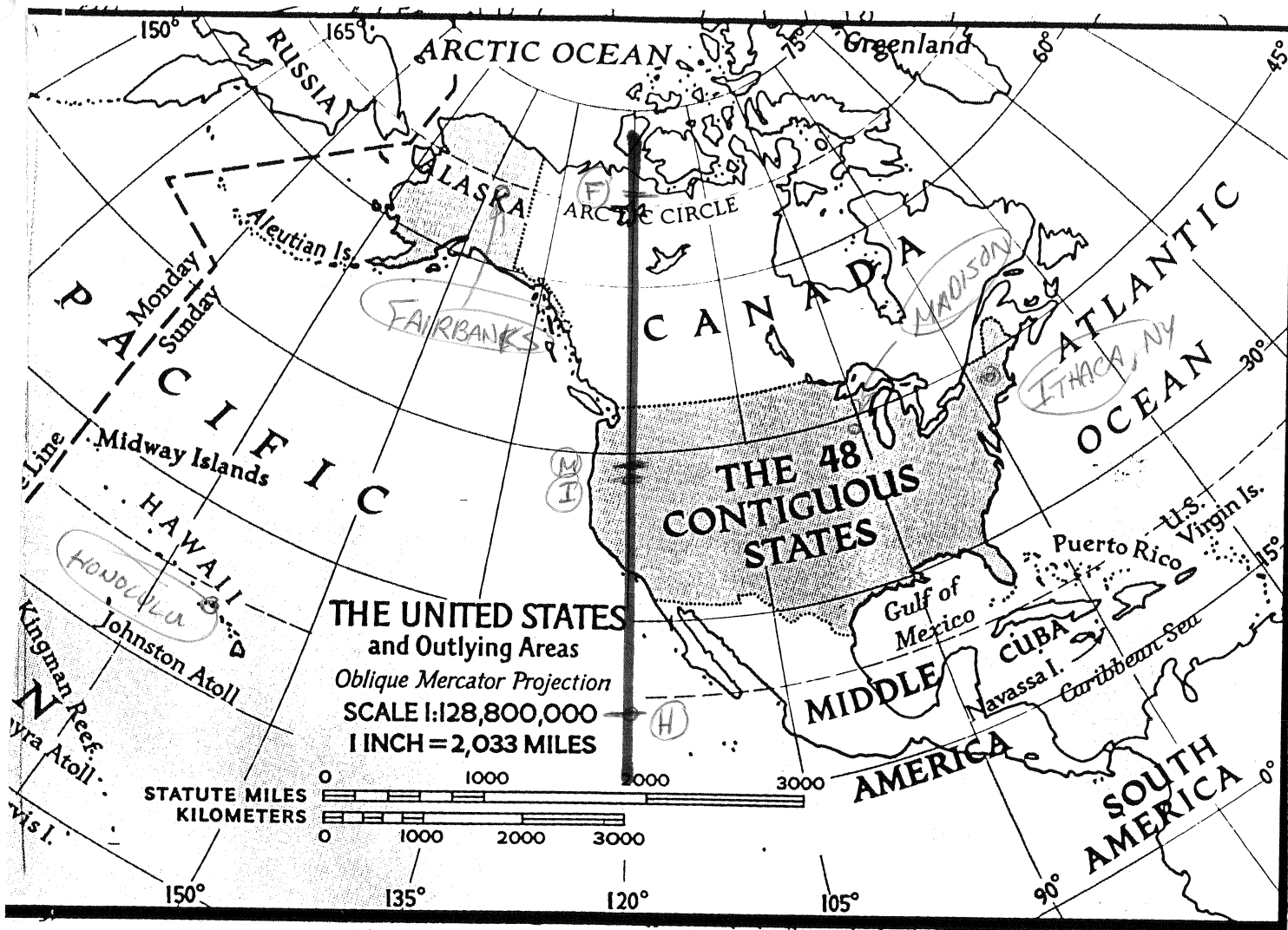


FIGURE 111. A, mean radiation (cal. cm.⁻² day⁻¹) received at various times of year at H, Honolulu, Hawaii, lat. 21°18' N.; M, Madison, Wisconsin, lat. 43°05' N.; I, Ithaca, New York, lat. 42°27' N.; F, Fairbanks, Alaska, lat. 64°52' N. (after Hand). Note the slightly lower radiation received at nearly all seasons at Ithaca (Lake Cayuga) as compared with Madison (Lake Mendota).



COMPARATIVE LATITUDES
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