Radiation

Summary of 3/10/09 lecture given by Trudy.

Recall the energy balance of an organism...

\[ R_n = \text{net radiation} = \text{radiation absorbed} \]

or “kept” by control volume

= incoming radiation – outgoing radiation

(but, atmosphere) (reflected, emitted)

Net radiation is the most important component of the energy balance!

Solar radiation supplies virtually all of the energy that drive Earth processes!

Radiation Basics

- Radiant energy transferred by photons (can think of either)

- Radiant energy transfer does not require an intervening medium.

- Photons/waves are emitted by a source, and are then either absorbed, transmitted, or scattered (reflected) by a receiving source.

- Radiation is characterized by its wavelength, or equivalently, frequency.

- The electromagnetic spectrum is the infinite range of all wavelengths of radiation. The spectrum is grouped into bands of similar wavelengths.

\[ u_p = \text{phase velocity (or speed of radiation) } = v \lambda \]

\[ u_p = \frac{E}{m} \text{ m/s} \]

\[ v = \text{frequency, Hz} \]

\[ \lambda = \text{wavelength, m} \]

\[ u_p | \text{free space} = c = \text{speed of light} = 3 \times 10^8 \text{ m/s} \]

\[ E = \text{photon energy} = \frac{hc}{\lambda} = h \nu \]

\[ h = \text{Planck constant} = 6.63 \times 10^{-34} \text{ J.s} \]

What is the source of radiation?

Because all matter above 0 K. (absolute zero) contains accelerating electric charges, all matter emits electromagnetic radiation.
Planck Law for Blackbody Radiation

A blackbody is a perfect radiator and a perfect absorber. A blackbody absorbs all incident radiation and emits at all wavelengths.

Do blackbodies exist in nature? NO. Do some materials behave like blackbodies in certain bands? YES. A blackbody is a good conceptual model.

Emission of radiation by a blackbody is described by the Planck law.

\[ B_\lambda (\lambda, T) = \frac{\text{spectral brightness}}{\text{spectral radiance}} = \frac{2h\nu^2}{\lambda^5} \frac{1}{e^{h\nu/kT} - 1} \]

\[ B_\nu (\nu, T) = \frac{\text{spectral radiance in terms of frequency}}{\text{frequency}} = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT} - 1} \quad T = \text{temperature, K} \]

**Note**
- Spectral radiance increases with temperature.
- At each temperature, there is a wavelength/frequency of maximum radiation:

\[ \frac{dB_\lambda (\lambda, T)}{d\lambda} = 0 \Rightarrow \lambda_{\text{max}} T = 2.897 \times 10^{-3} \tag{1} \]

\[ \lambda_{\text{max}} = \text{m}, \quad T = \text{K} \]

Approximation to Planck law

When \( \frac{hc}{kT} \gg 1 \) (short wavelengths at typical Earth temperatures),

then \( e^{h\nu/kT} - 1 = e^{h\nu/kT} - 1 \Rightarrow \frac{1}{e^{h\nu/kT} - 1} = \frac{1}{e^{h\nu/kT}} = e^{-h\nu/kT} \) and

\[ B_\lambda (\lambda, T) = \frac{2hc^2}{\lambda^5} e^{-\frac{hc}{kT}} \]

Wien law for short wavelengths

When \( \frac{hc}{kT} \ll 1 \) (long wavelengths at typical Earth temperatures),

then \( e^{h\nu/kT} - 1 = \frac{h\nu}{kT} \) and

\[ B_\nu (\nu, T) = \frac{2k\nu^2}{c^2} T \]

Rayleigh-Jeans law for long wavelengths

\[ [B_\lambda (\lambda, T)] = \text{W} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{m}^{-1} \]

\[ [B_\nu (\nu, T)] = \text{W} \cdot \text{m}^{-2} \cdot \text{s}^{-1} \cdot \text{Hz}^{-1} \]

\text{power \text{ per} frequency \text{ per} area \cdot \text{solid angle} \cdot \text{wavelength} \quad \text{What is a solid angle?}}
Figure 10.1. Part of the electromagnetic spectrum showing names of some of the wavebands and some of the biologically significant interactions with plants and animals.
Planck law, $B_\lambda(\lambda, T) = B_\nu(\nu, T)$

- Wavelength, m
- Frequency, Hz
- $B_\lambda$
- Spectral brightness $B_\nu$, W m$^{-2}$ Hz$^{-1}$ sr$^{-1}$
- Brightness $B_\lambda$, W m$^{-2}$ m$^{-1}$ sr$^{-1}$
- Radio, Infrared, Optical, X-ray and Ultraviolet

$\lambda$ = wavelength, $\nu$ = frequency, $T$ = temperature