2.4.2. Longwave (IR)

Upward emission of IR radiation from the Earth's surface can be found from the Stefan-Boltzmann relationship:

$$I\uparrow = e_{IR} \cdot \sigma_{SB} \cdot T^4 \qquad (2.37)$$

where e_{IR} is the surface emissivity in the IR portion of the spectrum (e_{IR} = 0.9 to 0.99 for most surfaces), and σ_{SB} is the Stefan-Boltzmann constant (= 5.67×10^{-8} W·m^{-2}·K^{-4}).

However, downward IR radiation from the atmosphere is much more difficult to calculate. As an alternative, sometimes a **net longwave flux** is defined by

$$I^* = I\downarrow + I\uparrow \qquad (2.38)$$

One approximation for this flux is

$$I^* = b \cdot (1 - 0.1\sigma_H - 0.3\sigma_M - 0.6\sigma_L) \qquad (2.39)$$

where parameter $b = 98.5$ W·m^{-2}, or $b = 0.08$ K·m·s^{-1} in kinematic units.

2.4.3. Net Radiation

Combining eqs. (2.33), (2.34), (2.35), (2.36) and (2.39) gives the **net radiation** ($\mathbb{F}^*$, defined positive upward):

$$\mathbb{F}^* = -(1-A) \cdot S \cdot T_r \cdot \sin(\Psi) + I^* \quad \text{daytime} \quad \bullet(2.40a)$$

$$= I^* \quad \text{nighttime} \quad \bullet(2.40b)$$

2.5. ACTINOMETERS

Sensors designed to measure electromagnetic radiative flux are generically called **actinometers** or **radiometers**. In meteorology, actinometers are usually oriented to measure downwelling or upwelling radiation. Sensors that measure the difference between down- and up-welling radiation are called **net actinometers**.

Special categories of actinometers are designed to measure different wavelength bands:

- **pyranometer** – broadband solar (short-wave) irradiance, viewing a hemisphere of solid angle, with the radiation striking a flat, horizontal plate (Fig. 2.15).
- **net pyranometer** – difference between top and bottom hemispheres for short-wave radiation.

Sample Application

Find the net radiation at the surface in Vancouver, Canada, at noon (standard time) on 22 Jun. Low clouds are present with 30% coverage.

Find the Answer

Assume: Grass lawns with albedo A = 0.2 .
No other clouds.

Given: σ_L = 0.3

Find: $\mathbb{F}^*$ = ? W·m^{-2}

Use ψ = 64.1° from an earlier Sample Application.
Use eq. (2.35) to find the transmissivity:

T_r = [0.6+0.2·sinψ]·(1–0.4·σ_L)
= [0.6 + 0.2·sin(64.1°)]·[1–(0.4·0.3)]
= [0.80]·(0.88) = 0.686

Use eq. (2.39) to find net IR contribution:

I^* = b·(1 – 0.6·σ_L)
= (98.5 W·m^{-2})·[1–(0.6·0.3)] = 80.77 W·m^{-2}

Use eq. (2.40a):

$\mathbb{F}^*$ = –(1–A) · S · T_r · sin(ψ) + I^*
= –(1–0.2) · (1361 W·m^{-2}) · 0.686 · sin(64.1°)
+ 80.77 W·m^{-2}
=(–671.89 + 80.77) W·m^{-2} = **–591. W·m^{-2}**

Check: Units OK. Physics OK.

Exposition: The surface flux is only about 43% of that at the top of the atmosphere, for this case. The negative sign indicates a net inflow of radiation to the surface, such as can cause warming during daytime.

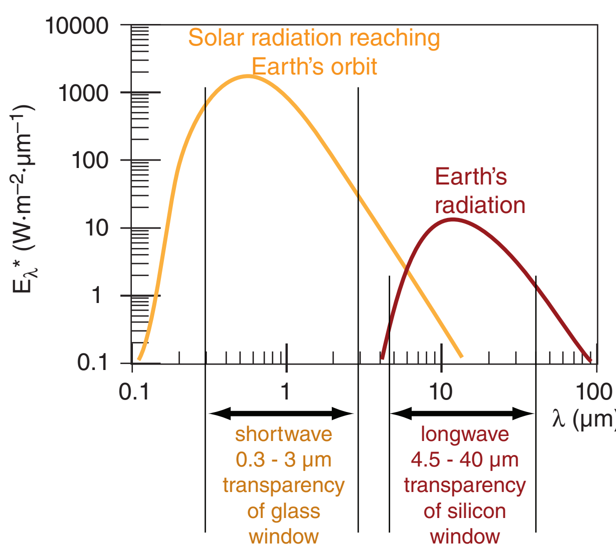

Figure 2.15
The wavelength bands observed by pyranometers (shortwave radiation) and pyrgeometers (longwave radiation) depends on the transparency of the windows used in those instruments.

A SCI. PERSPECTIVE • Seek Solutions

Most differential equations describing meteorological phenomena cannot be solved analytically. They cannot be integrated; they do not appear in a table of integrals; and they are not covered by the handful of mathematical tricks that you learned in math class.

But there is nothing magical about an analytical solution. **Any reasonable solution is better than no solution.** Be creative.

While thinking of creative solutions, also **think of ways to check your answer**. Is it the right order of magnitude, right sign, right units, does it approach a known answer in some limit, must it satisfy some other physical constraint or law or budget?

Example

Find the irradiance that can pass through an atmospheric "window" between wavelengths λ_1 and λ_2.

Find the Answer:

Approach: Integrate Planck's law between the specified wavelengths. This is the area under a portion of the Planck curve.

Check: The area under the whole spectral curve should yield the Stefan-Boltzmann (SB) law. Namely, the answer should be smaller than the SB answer, but should increase and converge to the SB answer as the lower and upper λ limits approach 0 and ∞, respectively.

Methods:

- Pay someone else to get the answer (Don't do this in school!), but be sure to check it yourself.
- Look up the answer in a Table of Integrals.
- Integrate it using the tricks you learned in math class.
- Integrate it using a symbolic equation solver on a computer, such as Mathematica or Maple.
- Find an approximate solution to the full equation. For example, integrate it numerically on a computer. (Trapezoid method, Gaussian integration, finite difference iteration, etc.)
- Find an exact solution for an approximation to the eq., such as a model or idealization of the physics. Most eqs. in this textbook have used this approach.
- Draw the Planck curve on graph paper. Count the squares under the curve between the wavelength bands, and compare to the value of each square, or to the area under the whole curve. (We will use this approach extensively in the Thunderstorm chapter.)
- Draw the curve, and measure area with a planimeter.
- Draw the Planck curve on cardboard or thick paper. Cut out the whole area under the curve. Weigh it. Then cut the portion between wavelengths, & weigh again.
- ...and there are probably many more methods.

- **pyrheliometer** – solar (short wave) direct-beam radiation normal to a flat surface (and shielded from diffuse radiation).
- **diffusometer** – a pyranometer that measures only diffuse solar radiation scattered from air, particles, and clouds in the sky, by using a device that shades the sensor from direct sunlight.
- **pyrgeometer** – infrared (long-wave) radiation from a hemisphere that strikes a flat, horizontal surface (Fig. 2.15).
- **net pyrgeometer** – difference between top and bottom hemispheres for infrared (long-wave) radiation.
- **radiometer** – measure all wavelengths of radiation (short, long, and other bands).
- **net radiometer** – difference between top and bottom hemispheres of radiation at all wavelengths.
- **spectrometers** – measures radiation as a function of wavelength, to determine the spectrum of radiation.

Inside many radiation sensors is a **bolometer**, which works as follows. Radiation strikes an object such as a metal plate, the surface of which has a coating that absorbs radiation mostly in the wavelength band to be measured. By measuring the temperature of the radiatively heated plate relative to a non-irradiated reference, the radiation intensity can be inferred for that wavelength band. The metal plate is usually enclosed in a glass or plastic hemispheric chamber to reduce error caused by heat conduction with the surrounding air.

Inside other radiation sensors are **photometers**. Some photometers use the **photoelectric effect**, where certain materials release electrons when struck by electromagnetic radiation. One type of photometer uses **photovoltaic cells** (also called **solar cells**), where the amount of electrical energy generated can be related to the incident radiation. Another photometric method uses **photoresistor,** which is a high-resistance semiconductor that becomes more conductive when irradiated by light.

Other photometers use **charge-coupled devices** (**CCD**s) similar to the image sensors in digital cameras. These are semiconductor integrated circuits with an array of tiny capacitors that can gain their initial charge by the photoelectric effect, and can then transfer their charge to neighboring capacitors to eventually be "read" by the surrounding circuits.

Simple spectrometers use different filters in front of bolometers or photometers to measure narrow wavelength bands. Higher spectral-resolution spectrometers use **interferometry** (similar to the Michelson interferometer described in physics books), where the fringes of an interference pattern can be measured and related to the spectral intensities. These are also sometimes called **Fourier-transform spectrometers**, because of the mathematics used to extract the spectral information from the spacing of the fringes.

You can learn more about radiation, including the radiative transfer equation, in the weather-satellite section of the Satellites & Radar chapter. Satellites use radiometers and spectrometers to remotely observe the Earth-atmosphere system. Other satellite-borne radiometers are used to measure the global radiation budget (see the Climate chapter).

2.6. REVIEW

The variations of temperature and humidity that you feel near the ground are driven by the diurnal cycle of solar heating during the day and infrared cooling at night. Both diurnal and seasonal heating cycles can be determined from the geometry of the Earth's rotation and orbit around the sun. The same orbital mechanics describes weather-satellite orbits, as is discussed in the Satellites & Radar chapter.

Short-wave radiation is emitted from the sun and propagates through space. It illuminates a hemisphere of Earth. The portion of this radiation that is absorbed is the heat input to the Earth-atmosphere system that drives Earth's weather.

IR radiation from the atmosphere is absorbed at the ground, and IR radiation is also emitted from the ground. The IR and short-wave radiative fluxes do not balance, leaving a net radiation term acting on the surface at any one location. But when averaged over the whole globe, the earth-atmosphere system is approximately in radiative equilibrium.

Instruments to measure radiation are called actinometers or radiometers. Radiometers and spectrometers can be used in remote sensors such as weather satellites.

2.7. HOMEWORK EXERCISES

2.7.1. Broaden Knowledge & Comprehension

(Don't forget to cite each web address you use.)

B1. Access a full-disk visible satellite photo image of Earth from the web. What visible clues can you use to determine the current solar declination angle? How does your answer compare with that expected for your latitude and time of year.

B2. Access "web cam" camera images from a city, town, ski area, mountain pass, or highway near you. Use visible shadows on sunny days, along with your knowledge of solar azimuth angles, to determine the direction that the camera is looking.

B3. Access from the web the exact time from military (US Navy) or civilian (National Institute of Standards and Technology) atomic clocks. Synchronize your clocks at home or school, utilizing the proper time zone for your location. What is the time difference between local solar noon (the time when the sun is directly overhead) and the official noon according to your time zone. Use this time difference to determine the number of degrees of longitude that you are away from the center of your time zone.

B4. Access orbital information about one planet (other than Earth) that most interests you (or a planet assigned by the instructor). How elliptical is the orbit of the planet? Also, enjoy imagery of the planet if available.

B5. Access runway visual range reports from surface weather observations (METARs) from the web. Compare two different locations (or times) having different visibilities, and calculate the appropriate volume extinction coefficients and optical thickness. Also search the web to learn how runway visual range (RVR) is measured.

B6. Access both visible and infrared satellite photos from the web, and discuss why they look different. If you can access water-vapor satellite photos, include them in your comparison.

B7. Search the web for information about the sun. Examine satellite-based observations of the sun made at different wavelengths. Discuss the structure of the sun. Do any of the web pages give the current value of the solar irradiance (i.e., the solar constant)? If so, how has it varied recently?

B8. Access from the web daytime visible photos of the whole disk of the Earth, taken from geostationary weather satellites. Discuss how variations in the apparent brightness at different locations (different latitudes; land vs. ocean, etc.) might be related to reflectivity and other factors.

B9. Some weather stations and research stations report hourly observations on the web. Some of these stations include radiative fluxes near the surface. Use this information to create surface net radiation graphs.