1. 10.1 in Campbell and Norman. There is a mistake in the textbook: $c$, the speed of light in a vacuum, is $2.9979 \times 10^8$ m s$^{-1}$.

2. Download and play with the PhET simulation (http://phet.colorado.edu/) “Blackbody Spectrum.”

(a) According to the simulation, at what temperature does it appear that the peak wavelength of radiation is no longer in the visible spectrum, i.e., the peak wavelength is too long for our eyes to see? Check this with Wien’s law.

(b) Write and answer your own question.

3. Reproduce Figure 10.4 in Campbell and Norman with two figures, one containing emittance spectra for a 6000 K source, and the other containing emittance spectra for a 288 K source. If using MATLAB, use the function “semilogx” to produce a log scale on the x-axis and consider using the function “logspace” to produce an array of numbers for wavelengths. Be careful with units: there is a mistake/omission in Figure 10.4. What is the mistake?

4. 10.4 in Campbell and Norman.

5. 10.5 in Campbell and Norman.

6. 10.6 in Campbell and Norman.

7. This question outlines a problem I had to solve when conducting my Ph.D. research. It was eventually included in a paper, Hornbuckle and England (2005). I include it as an example of when it is sometimes necessary to think very carefully about what is actually being measured. It is a little challenging, but you can do it! I’ll try to walk you through it.

Consider an infrared thermometer (IRT) viewing a vegetation canopy at nadir (normal to the surface) as described in Section II of Hornbuckle and England (2005) and as pictured in Figure 1. Since emission from the sky at infrared wavelengths is considerably different than emission from the canopy (since the temperature of the sky is normally much colder), sky brightness reflected by the canopy into the field of view of the IRT and its effect on the temperature reported by the IRT should be considered. The radiant emittance just above the top of the canopy, $I$, is:

$$ I = \epsilon I_B(T_{can}) + [1 - \epsilon] I_{sky} $$  \hspace{1cm} (1)
where $\epsilon$ is the emissivity of the canopy, $I_B$ is blackbody radiant emittance, $T_{can}$ is the radiometric temperature of the canopy, and $I_{sky}$ is sky irradiance. $I$, $I_B$, $I_{sky}$, and $\epsilon$ are specific to the finite wavelength band of the IRT, which is 6.5 to 14 $\mu$m. Recall that $1 - \epsilon = \rho$, where $\rho$ is the reflectivity of a surface (Kirchoff’s law). According to Campbell and Norman (1998) a vegetation canopy can be modeled as a Lambertian or perfectly rough (diffuse) surface with an emissivity of 0.98 to 0.99.

(a) What are the units of radiant emittance, emissivity, and irradiance?

(b) An IRT reports a brightness temperature that corresponds to the radiance, $R$, in its field of view. What are the units of radiance?

(c) If the radiant emittance just above the canopy was measured to be 150 W m$^{-2}$, what would $R$ be?

(d) Clear–sky spectral emittance is shown in Figure 10.6 of Campbell and Norman (1998). If $I_{sky}$ estimated (by hand) from Figure 10.6 is 65.4 W m$^{-2}$ and $I_B(T = 288$ K) is 171 W m$^{-2}$ (where 288 K is the effective radiating temperature of the atmosphere), what is $\epsilon_{sky}$? Remember, $I_{sky}$, $I_B(T = 288$ K), and $\epsilon_{sky}$ are for the finite wavelength band of the IRT, 6.5 to 14 $\mu$m. And don’t be surprised if you find that $\epsilon_{sky}$ is lower than what you would expect.

(e) Total sky irradiance (over all wavelengths) can be related to a representative air temperature, $T_a$. An equation for the emittance of the sky over all wavelengths, $\epsilon_{sky,\infty}$, can be written

$$\epsilon_{sky,\infty} = \frac{I_{sky,\infty}}{\sigma T_a^4}$$  \hspace{1cm} (2)

where $I_{sky,\infty}$ is sky irradiance over all wavelengths and $\sigma$ is the Stefan–Boltzmann constant. For a clear sky,

$$\epsilon_{sky,\infty} = 1.72 \left[ \frac{e_a}{T_a} \right]^{1/7}$$  \hspace{1cm} (3)

where $e_a$ is the water vapor pressure near the surface in kPa and $T_a$ is in kelvin (Brutsaert, 1984). If $e_a = 1.3392$ kPa and $T_a = 288.0$ K, find $\epsilon_{sky,\infty}$ and calculate $I_{sky,\infty}$. Compare this to $I_{sky}$ in 7d.

(f) If clear sky irradiance within the IRT waveband is 65 W m$^{-2}$ and the radiometric temperature of a vegetation canopy is actually 295 K, what brightness temperature would an IRT pointed at the canopy report? Use (1), $\epsilon = 0.98$, and Figure 2 which plots the brightness temperature reported by the IRT as a function of incident radiance.

(g) Normally $\epsilon = 1$ is assumed when using an IRT. When will the difference between the brightness temperature reported by the IRT and the true radiometric temperature of the canopy ($T_{can}$) be greatest, on clear or cloudy days, if $\epsilon = 1$ is assumed? Recall that you found in Problem 6 that more radiation is emitted from a cloudy sky than from a clear sky. It may also help if you think about what the radiant emittance from the canopy would be if $I_{sky} = I_B(T_{can})$.

8. Read “Where is the Hottest Place on Earth?” on the syllabus. The MODIS sensor on NASA’s Aqua satellite consists of several radiometers that operate between 0.4 and 14.4 $\mu$m. Note that this band of wavelengths is similar to the band of the IRT in Problem 7.

(a) At the time this article was written, what was the current world record air temperature, and where was it recorded?
Figure 1: Micro–meteorological tower in Southeastern Michigan, July, 2001. The IRT is on a small arm pointing out of the paper, just to the left of the white pyranometer and pyrgeometer on the end of the long arms.

(b) What is an advantage of using remotely–sensed measurements of land surface temperature (LST)?

(c) What is a disadvantage of using remotely–sensed measurements of LST?

(d) According to MODIS, what is the hottest Earth LST, and where did it occur?

(e) How does vegetation influence LST?

References


Figure 2: Brightness temperature reported by the IRT as a function of incident radiance. By definition, this is also the relationship between blackbody radiance and radiometric temperature in the IRT wavelength band.