Agronomy 405/505
Spring 2011
Problem Set 9
Due Tuesday, March 29, 2011.

Assigned March 22, 2011. Updated March 24, 2011.

1. 10.1 in Campbell and Norman.

2. 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 in Figure 10.4. What is the mistake?

3. 10.4 in Campbell and Norman.

4. 10.5 in Campbell and Norman.

5. 10.6 in Campbell and Norman.

6. 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] (available on the course website) 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 should be considered. The radiant emittance just above the top of the canopy, I, is:

$$I = \epsilon \, I_B(T_{can}) \; + \; [1 - \epsilon] \, I_{sky} \tag{1}$$

where ϵ 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 ϵ are specific to the finite wavelength band of the IRT, which is 6.5 to 14 μm. Recall that $1 - \epsilon = \rho$, where ρ 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 $I_B(T = 288\text{ K})$ is 171 W m^{-2} (where 288 K is the effective radiating temperature of the atmosphere), what is ϵ_{sky}? Remember, I_{sky}, $I_B(T = 288\text{ K})$, and ϵ_{sky} are for the finite wavelength band of the IRT, 6.5 to 14 μm. And don't be surprised if you find that ϵ_{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

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

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

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

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 6d.

(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 5 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 $I_{sky} = I_B(T_{can})$.

7. Read "Starfish 'Pump Up' to Cool Down" at `http://tinyurl.com/yzxaa6n`.

(a) What does a starfish do to lower its body temperature?

(b) How did scientists find this out?

(c) Why does this behavior lower a starfish's body temperature? Explain the physics.

(d) About how much water would a typical human have to drink (in gallons) in order to replicate the starfish behavior?

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.

(e) How much can this behavior decrease starfish body temperature?

(f) Explain the scientist's worries in terms of climate change and starfish.

References

Brutsaert, W., *Evaporation in the Atmosphere: Theory, History, and Applications*, D. Reidel, Boston, 1984.

Campbell, G. S., and J. M. Norman, *An Introduction to Environmental Biophysics*, Springer–Verlag, New York, 1998.

Hornbuckle, B. K., and A. W. England, Diurnal variation of vertical temperature gradients within a field of maize: Implications for satellite microwave radiometry, *IEEE Geosci. Remote Sens. Lett.*, *2*, 74–77, 2005.

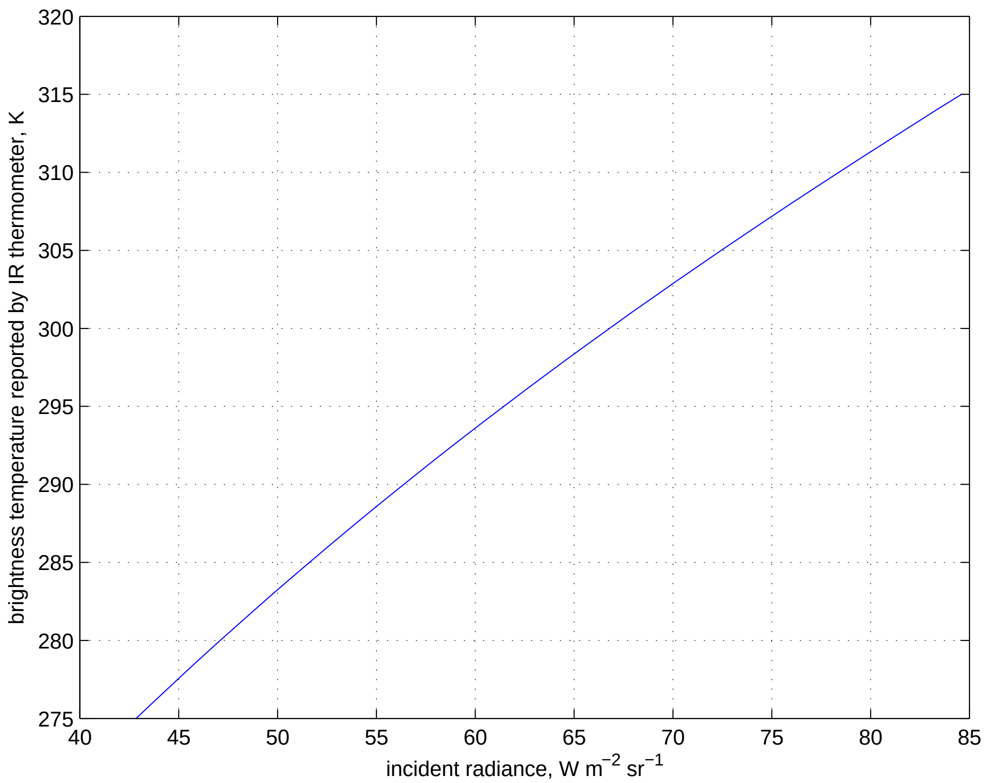

Figure 2: Brightness temperature reported by the IRT as a function of incident radiance. By definition, this is also the relationship between blackbody radiance and radiometric temperature in the IRT wavelength band.