Radiance, Irradiance and Reflectance

When making field optical measurements we are primarily interested in reflectance, a relative measurement. At a minimum, measurements of reflectance require observations of the downwelling irradiance and the upwelling radiance. While neither observation has to be in absolute units (e.g., $W/m^2$), calibration is still required. This lab (and the associated problem set) is intended to provide some insight into the requirements and procedures for making reflectance measurements in the lab and in the field. We will also consider the further requirements for making absolute measurements of radiance and irradiance.

REFLECTANCE

There are several type of reflectance measurement. The most common for remote sensing purposes is Remote sensing reflectance, $R_{RS}$.

Remote Sensing Reflectance: The simplest reflectance measurement that is commonly used in remote sensing applications is a ratio of upwelling radiance to the downwelling irradiance. This is defined as the remote sensing reflectance, $R_{RS}$:

$$ R_{RS} = \frac{L_u(\lambda, \theta_d)}{E_d(\lambda)} $$

There are several issues to consider when deciding how to go about making a reflectance measurement. The main considerations are the stability of the illumination and the availability of radiometers. Stability of the light field is always an issue in field measurements because sun and skylight can, and do, vary rapidly. Since reflectance requires a pair of measurements ($L_U$ & $E_D$), if a single spectrometer is used to measure both $L_U$ & $E_D$, and the light field changes between measurements, then one cannot compute a reliable reflectance. On the other hand, if a pair of spectrometers is used to make the two measurements simultaneously, they must be cross-calibrated. While it is more efficient in the field to have the two calibrated spectrometers, it is less expensive and usually sufficient to use a single spectrometer and move fast. In the laboratory it is less of a problem to use one radiometer since the illumination can be controlled.

1) Procedure using a single spectrometer:

Using a single spectrometer, sequentially measure

1) the upwelling radiance from a target, $L_t$ and
2) the upwelling radiance from a reflectance standard, $L_s$

Measurements must be made close enough in time to ensure that the atmospheric conditions have not changed. $R_{RS}$ can then be retrieved from the

![Figure 1: Measuring reflectance with a single radiance meter. The measurements cannot be made simultaneously.](image)
relative reflectance if the absolute reflectance ($\rho_s$) of the standard is known:

$$ R_{RS}(\lambda) = \frac{L_u(\lambda)}{E_d(\lambda)} = \left( \frac{L_t(\lambda)}{\pi L_s(\lambda)} \right) \rho_s(\lambda) \quad (2) $$

Note that the standard is assumed to be Lambertian. If the radiance measured from a perfectly reflective Lambertian standard is $L_d$, then $E_d = \pi L_d$, and the radiance from a real reflectance standard is then, $\rho_s L_d = L_s$. This procedure will produce consistent results ONLY if the light field has not changed between measurements. We will use this procedure in today's lab. It is probably the most commonly used field procedure.

2) Procedure using two radiance meters:

An alternative to sequential measurement is to use two cross-calibrated instruments. The measurements of radiance from the object and radiance from the standard can thus be made simultaneously with the instrument pair (Figure 2). This approach requires that the two instruments be cross-calibrated and that the two measurements be, in fact, made simultaneously, and in close proximity.

The second radiometer can be configured to measure irradiance directly, or to measure radiance using a reflectance standard similar to the procedure 1). It is helpful if the instruments are as similar as possible, but it is critical that they be calibrated spectrally and cross-calibrated in their response (Bachmann et al., 2012).

This method also uses the reflectance standard, and requires that the reflectance standard be calibrated as well.

![Figure 2: Measuring reflectance with a radiance meter for $L_u$ and either a cosine irradiance meter or a radiance meter viewing a diffuse reflectance standard for $E_d$](image)

REFERENCES

Reflection Measurements

The tasks for this lab are to:

A. Evaluate the assumption of Lambertian reflectance from a reflectance standard using a fixed illumination and varying the observation angle. (Use the Ocean Optics spectrometer and goniometer).

B. Using the Lambertian Assumption, make spectral reflectance measurements of several targets using Procedure 1. (Use the ASD HandHeld radiometer)

We will use procedure 1) described on the previous page. Reflection is expressed as a percentage relative to the reflection from a reflectance standard:

$$\% R = \left( \frac{V_t(\lambda, \theta) - V_{dark}(\lambda, \theta)}{V_s(\lambda, \theta) - V_{dark}(\lambda, \theta)} \right) \times 100\%$$

where $V_s$ is the sample value (voltage, current, digital counts) at wavelength $\lambda$ observed when viewing the reflectance standard, and $V_{dark}$ and $V_t$ are the corresponding values for dark current and the target. This should be exactly equivalent to a radiance reflectance: $R_{rad} = L_v / L_i$, where $L_i$ is the radiance incident on the target and $L_v$ is the radiance viewed at the detector. Note: If the reflected radiance is the same in ALL directions then we may compute the Remote Sensing Reflectance by dividing the radiance reflectance by $\pi$, i.e., $R_{RS} = \% R / \pi$

**TASK A: Evaluate the assumption of Lambertian Reflectance from the reflectance standard.**

**Equipment:**


b. **Goniometer**: This is the peculiar-looking metal structure on the table. It is designed to allow precise observations at specific viewing & illumination angles.

c. **Fiber optic probe**: The metal-clad, cable is the fiber optic. One end is connected to a lens mounted on the goniometer, the other end bifurcates with one arm attaching to the spectrometer and the other covered with a light-blocking cap.

d. **Reflectance standards**: There are two reflectance standards available for use: 98% Spectralon (in the cardboard box), and 18% (gray plastic material on a plexiglass base).

e. **Light sources**: A full spectrum lamp provides radiation over the VNIR spectral range.

**Setting up the spectrometer:**

1. On the computer, if the OceanView software is not already running:

   a. Double click on the OceanView icon in the upper right corner of the screen.

   b. Select OK or simply close the Welcome Screen.
There are 3 spectrometers. We will only need one. Select *Schematic Window* on the left sidebar. Right Click on ADUDO181_1 and select *Delete*. Repeat the action for ADUDO181_2. *Only the third spectrometer ADUDO181_3 should remain.*

2. Check the set up
   a. Turn on the LS-1 lamp. (To provide stable illumination, a lamp should be on for several minutes at least. We will be using this lamp for alignment, not measurements, so the short warm-up time should be sufficient.)
   b. Adjust the probe in the goniometer until you see a ring of 6 circles in clear focus.
   c. **Position the Spectralon 98% reflectance standard on the jack stand and adjust the position.** For the directional measurements to work properly, the target must be at the origin of the arc. To check this we use a light source passing through the fiber optic. If the target is at the correct height, the illuminated spot will change shape, but not shift position as the angle of the goniometer changes. In this case, when the goniometer viewing position is at 0° you should see six circles at the focal point of the lens. As the goniometer arm is moved to larger angles, the shape of the spots should become ellipses but the center point of the array should not shift. That is the observation point. If the center of the pattern shifts, then the standard panel is either too high or too low.
   d. Push the probe into the mount (a lens) as far as it will go. Take note of the size of the illuminated area at various angles. You will need to have a sense of this later.
   e. Turn off the LS-1 lamp.

3. **Turn on the full spectrum lamp.** It should warm up for a few minutes in order for its output to stabilize. The lamp should be far enough away to provide an effectively uniform illumination over a large area of the reflectance standard.

4. **Adjust the room lights.** Close the blinds, turn off the room lights and make sure the door is closed. We cannot eliminate all the extraneous light, but we can at least minimize it.

5. **Position the reference reflectance panel.** Place the Spectralon 98% reflectance panel in the center of the goniometer viewing area.

6. **Manually set the integration time.** The integration time is the length of time the detector is active. The idea is to maximize the S/N without saturating the detectors.
   a. Select *Acquisition Group Window* on the left sidebar.
   b. Manually set the integration time (near the top of the window) so that the peak intensity of the signal is between 3500-4000 counts. The optimal integration time will probably be in the range of 5-25 ms. The spectral curve should respond immediately.
   c. Insure that there is no saturation. If there is reduce the integration time.
7. **Set the number of scans averaged.** The spectrum is still quite noisy. The S/N can be improved by averaging a number of scans. In the Control Console, increase the number of scans averaged to 10 or more. (I like ~30). Observe the improvement in S/N.

8. **Set the boxcar width.** This is the number of adjacent detectors that will be averaged for each observation. It is a spectral average.

9. Close the *Acquisition Group Window* window. (Click on the side tab.)

**Set up for Reflectance measurements**

1. Select the OceanView symbol at the upper left of the window.

2. In the *Spectroscopy and Application Window*, select *Reflectance*, check the radio button for *Active Acquisition*, and then select *Next*.

3. Check the integration time, scan average and boxcar average and adjust as needed in order to produce a reference spectrum that is on scale and relatively noise free. Then click on *Next*.

4. **Collect a reference spectrum.** This is the spectrum of the reflectance standard.
   a. Position the reference panel on the goniometer.
   b. With the full-spectrum lamp providing reasonably uniform illumination of the reflectance panel, click on the store reference spectrum icon. Then click *Next*.

5. **Collect a dark current**
   a. Cover the input optics with the felt pad.
   b. With the input optics blocked, click on the store dark current icon. Then click *Finish*.
   c. Remove the felt pad.
   d. You should see a flat line at 100% reflectance from 400-1000 nm with noise at either end.

6. **Adjust the spectral range to 400-1000 nm.**
   a. Select the icon to manually adjust the display range
   b. Set the minimum and maximum of the x-axis to 400 and 1000, respectively.

**Experiment A:** Evaluate the assumption of Lambertian reflectance from a *reflectance standard* with a fixed illumination but with varying observation angles.
1. Begin with the detector observing reflectance at nadir. The spectrum should be spectrally flat at 1.0. There will be some noise, especially at the extremes of the wavelength range, but there should be no spectral features.

2. Click on the graph. This will bring up useful annotation at the bottom, including the wavelength of the vertical green line and the reflectance at that marker.

3. Pick a reference wavelength near the center of the plot (~700 nm). Insert 700 in the Wavelength box at the bottom of the graph and hit Return. The vertical green (reference) line should move to the nearest wavelength observed by the spectrometer (the center of the waveband of a single detector). The magnitude of the function at that point will appear in red toward the center of the bottom of the graph.

4. Record the value on the graph below at the angle of zero (x-axis).

5. Repeat the observations by positioning the detector at multiple angles both toward and away from the light source. Collect and plot enough points on the graph below. A 100% reflectance line at all viewing angles (the ideal), and a cosine falloff pattern are plotted for reference.

How well does this material meet the assumption of Lambertian (perfectly diffuse) reflectance?
Experiment B: Observe the spectral reflectance of a selection of color targets.

Equipment:

a. **Spectrometer**: ASAD HandHeld II (HHII) fitted with an 8-degree foreoptic.

b. **Reflectance standard**: There is a small disk of 98% Spectralon (in a plastic sleeve), and

c. **Light sources**: An incandescent floodlamp provides radiation over the VNIR.

Setting up the spectrometer:

a. Turn on the HHII by pressing the On/Off button.

b. Wait 30 seconds for the "Starting Standalone Mode…” message to appear (Figure 3a).

c. Wait a bit longer for the spectrum display to appear (Figure 3b).

d. Optimize – this sets the integration time for the HHII
   i. Position the spectralon disc in the Field of View (FOV) of the HHII.
   ii. Check by pressing the laser button. Center the disk in the FOV of the laser.
   iii. Press the "OPT" button and then press the red trigger on the right. This will take about 30-60 seconds. When it is done you should see a raw (uncorrected) spectrum of the white panel (Figure 4).

e. With the Spectralon disc still in the FOV, press the DC/WR button. The instrument then measures the dark current (DC) and white reference (WR) signal and switches to reflectance mode. You should see a flat line representing 100% reflectance across the spectrum.

Figure 3: a) standalone mode display; b) spectrum display

Figure 4: a) Raw (uncorrected) spectrum of the white panel; b) WR reflectance.
Observe spectral reflectance:

a. Move the Spectralon disc, put it back in the plastic cover. Please take care to handle it at the edges. **Don't touch the flat surface!**

b. Observe the reflectance of the various colored folders and pamphlets.
   i. Note where there are maxima and minima for the different materials. Does this make sense in terms of what you see visually?
   ii. Get a sense of where the boundary between visible and infrared is.
   iii. Get a sense of where Red, Green & Blue are along the x-axis.
   iv. Look at the spectra of other objects: cloth, skin, leaves, soil, rock, …
   v. Look at the transmission of the filters (please handle the filters by the edges, and avoid touching the glass.)