Making Accurate Field Spectral Reflectance Measurements

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Introduction

Accurate field spectral reflectance measurements are important in the calibration and validation of airborne and space-borne hyperspectral and multispectral imaging data. The ASD FieldSpec® 4 instrument was designed with these requirements in mind. However, even the best instrument can deliver inaccurate data if the measurements are not properly carried out. This document discusses techniques for making quality field-spectral measurements.

Spectral Irradiance Field

Outdoors, the primary source of spectral irradiance is the sun, but there are others as well shown below. The diffuse radiation from the sky is found primarily in the visible and UV portions of the spectrum. The Rayleigh scattering is proportional to $\lambda^{-4}$and affects the shortest wavelengths while the aerosol component may vary from $\lambda^{0}\ to\ \lambda^{-3}$ in its wavelength behavior (Figure 1).

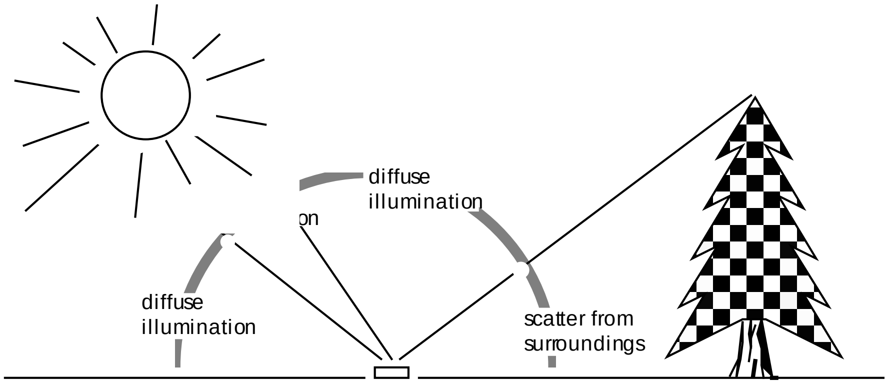

Figure 1. Spectral irradiance sources

The scatter from surroundings may be from buildings, vehicles, trees or perhaps from the person operating the spectrometer. In all cases, there are time-varying components to the spectral irradiance that must be accounted for. This is accomplished by measuring a reflectance standard close to the area in which the reflectance measurements are taken. This measurement integrates the irradiance from all the components of the radiation field. The most important variable is the solar elevation angle and the intervening atmosphere and they dictate how often a measurement of the standard should be made (Figure 2).

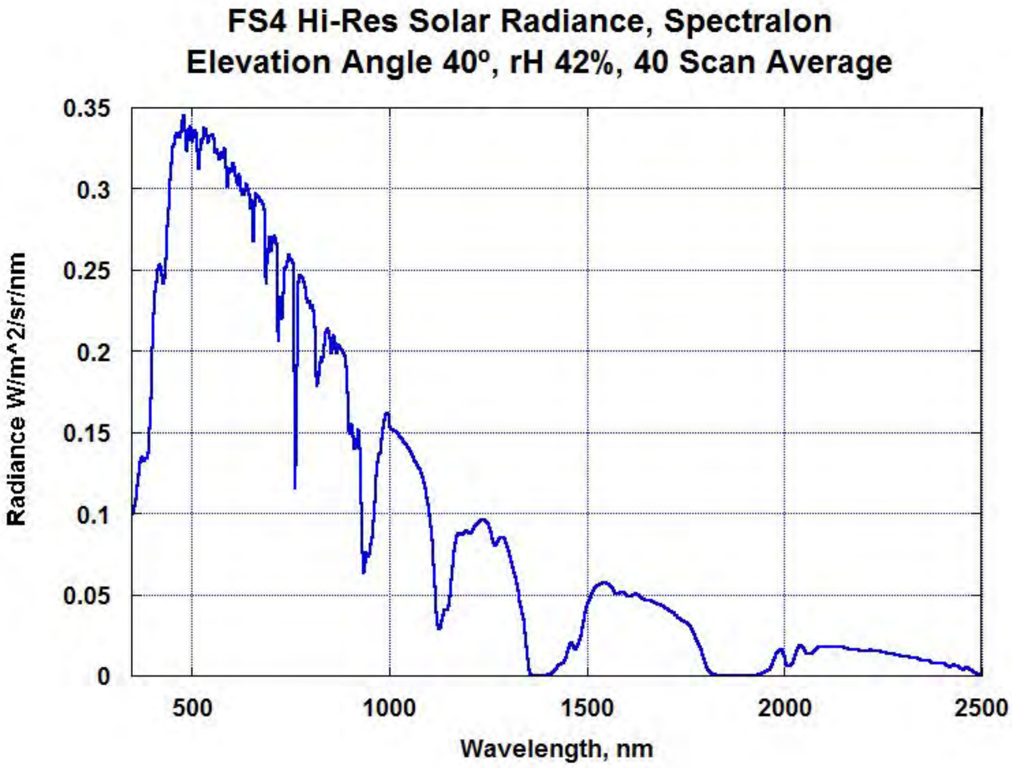

Figure 2. Solar radiance measured from the reference panel used in the following demonstration

Scatter from the Surroundings

The irradiance at any location is affected by the scattering off of nearby objects and is proportional to the solid angle subtended by the object at the measurement location. Not only do the objects scatter, but they also obscure the sky, which contributes to the radiation field. These effects are demonstrated in the following plots of measurements from a white reference standard taken outdoors.

The reference panel was positioned on a tripod approximately one meter above the ground. A pistol grip was mounted to view the panel from the northeast corner at an angle of approximately 45 degrees. The solar azimuth was approximately 140 degrees True. The solar elevation angle was 40 degrees (Figure 3).

Figure 3. Radiance measurement set-up

The effects of operator scattering are shown in the following sequence. Wearing dark clothes does not mitigate the effects of proximity to the sample measured as much as one might think. An operator wearing a black shirt has a low reflectance of around 3 percent in the visible region but just beyond, at 800 nm, the actual reflectance is 57 percent. The black shirt analyzed in Figure 4 is made of polyester fabric identified by the triplet absorption near 2100 nm. The blue shirt, worn by the operator in the following sequence, is made of cotton. Looks are deceiving in the spectral world.

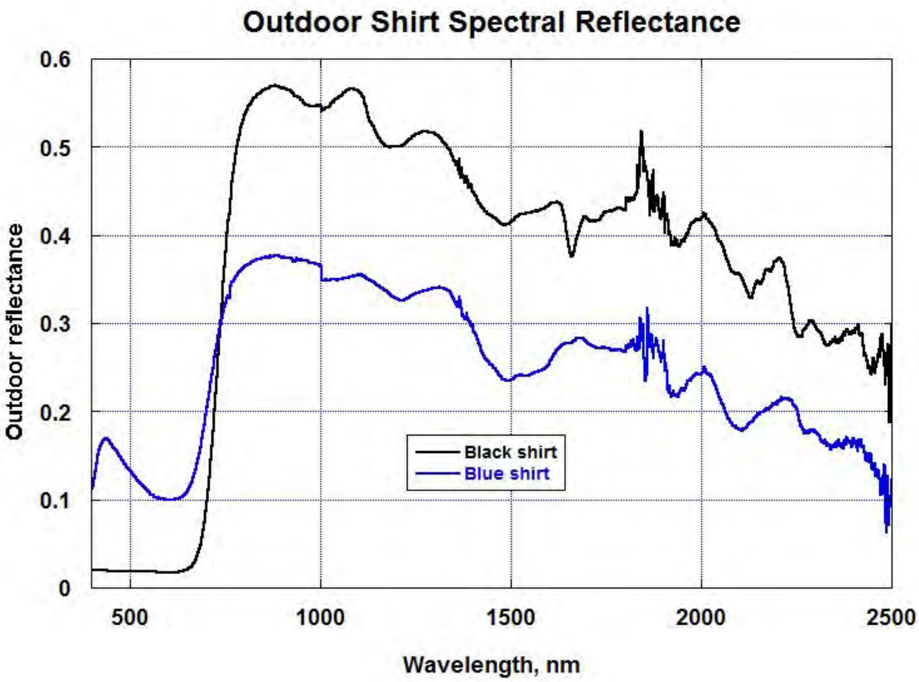

Figure 4. Spectral variances between a black polyester and blue cotton shirt

Next, the operator moves in close to the panel and will take up the four cardinal positions. Each shows a different effect, depending primarily on the relationship to the solar azimuth. Figure 5 shows the effects of the operator standing one meter away and to the west of the reference panel. The scattering and sky obstruction are minimal, less than one percent.

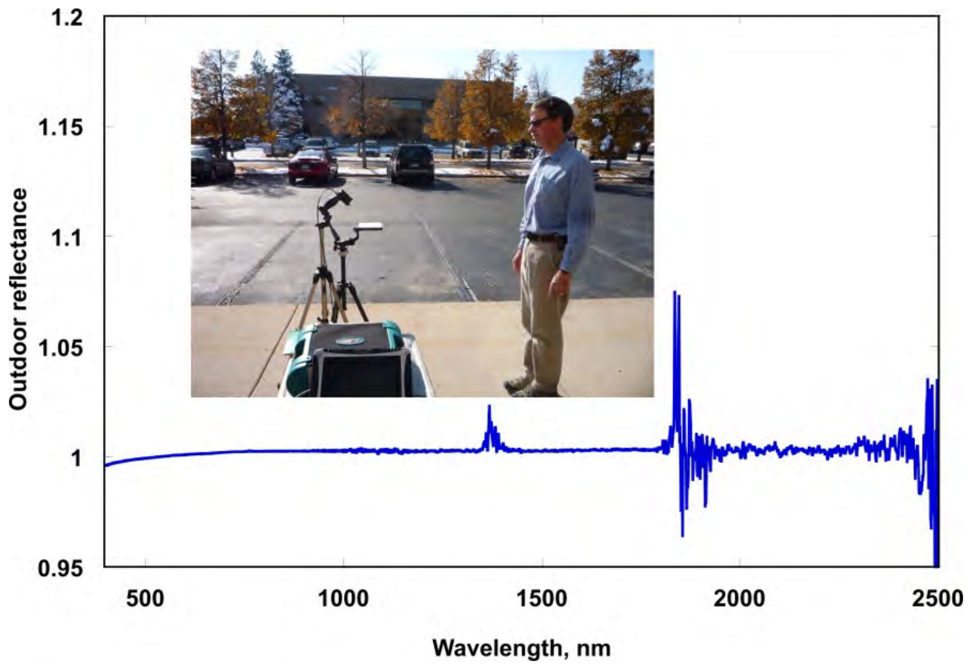

Figure 5. Effects of the operator standing one meter from the reference panel

In Figure 6, the operator is standing west of the panel but within inches of the panel. The effects of the blue shirt are significant, as much as 14 percent of the measured reflectance.

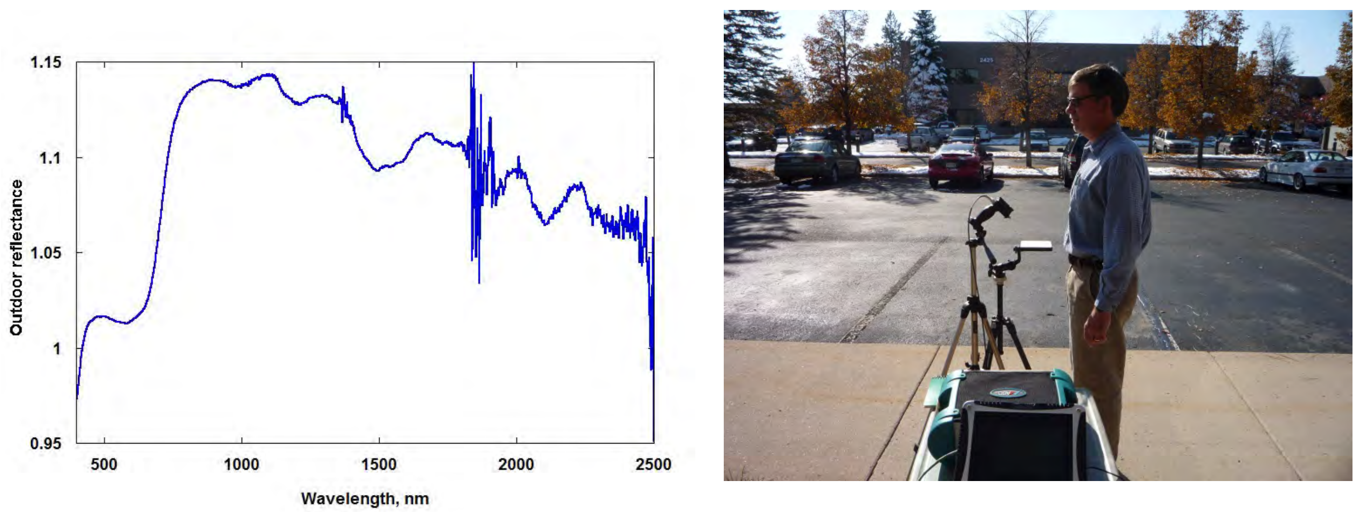

Figure 6. Close proximity reflectance effects of a blue shirt

With the operator standing south of the panel in Figure 7, sunlight is obstructed and a marked drop off in the shorter wavelengths is observed.

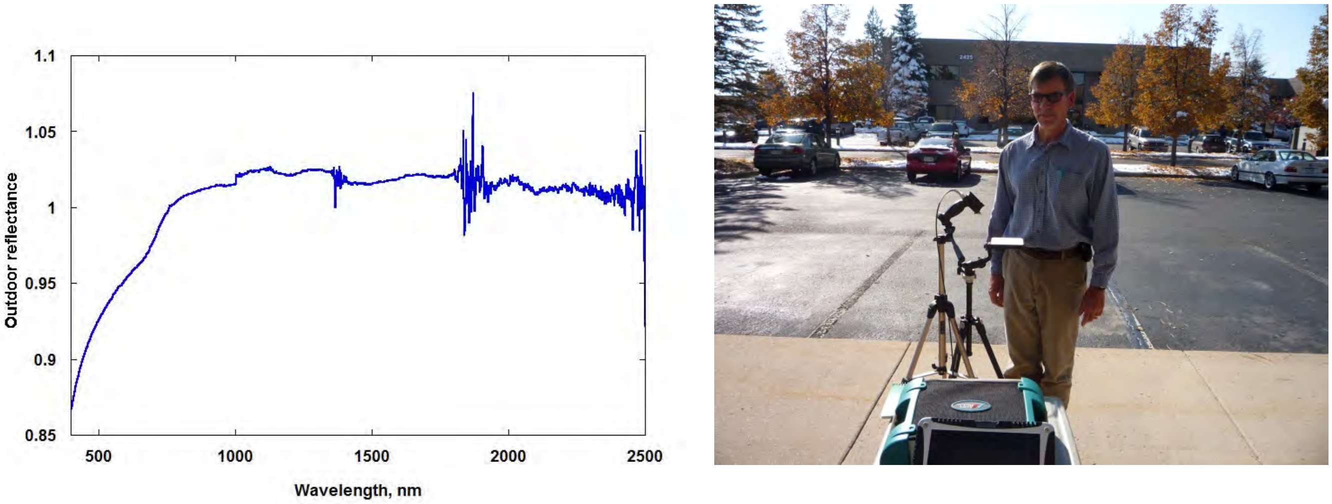

Figure 7. Obstructed sunlight produces a drop off in the shorter wavelengths

In the next figure, the operator has moved to the east of the panel. The scattering effects in the longer wavelengths are one to two percent, but in the blue-UV region skylight obstruction is the main contributor to the reflectance drop (Figure 8).

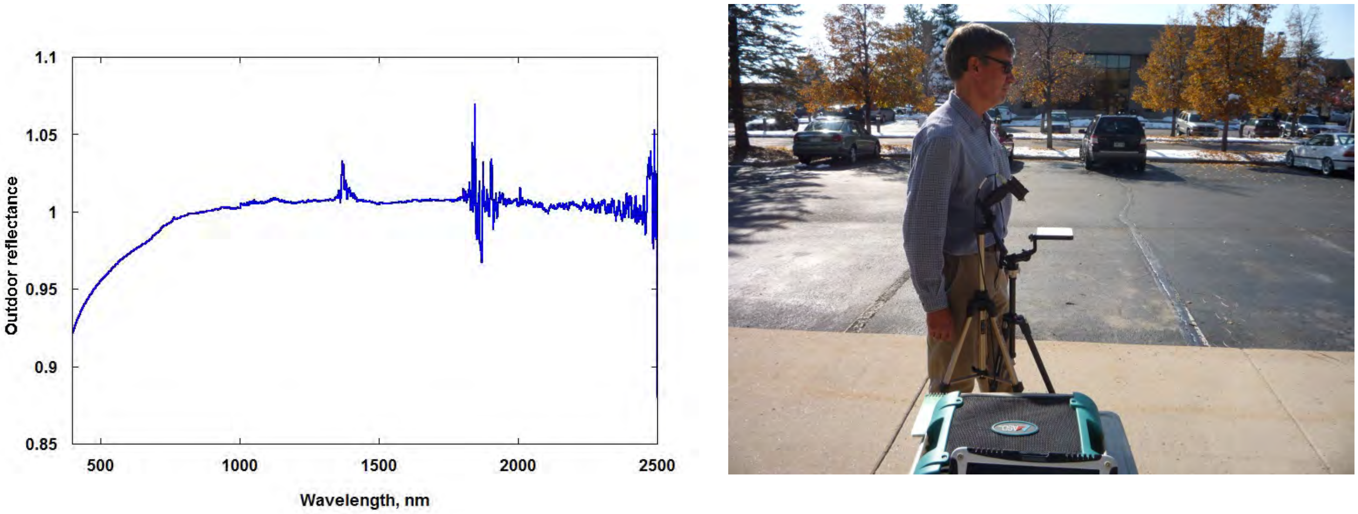

Figure 8. Effects of obstructed sunlight are amplified with the operator standing east of the panel

Scattering from the shirt is maximized in the north position because of the solar azimuth. The building behind him is occulting the sky, hence no obscuration contribution from the operator (Figure 9).

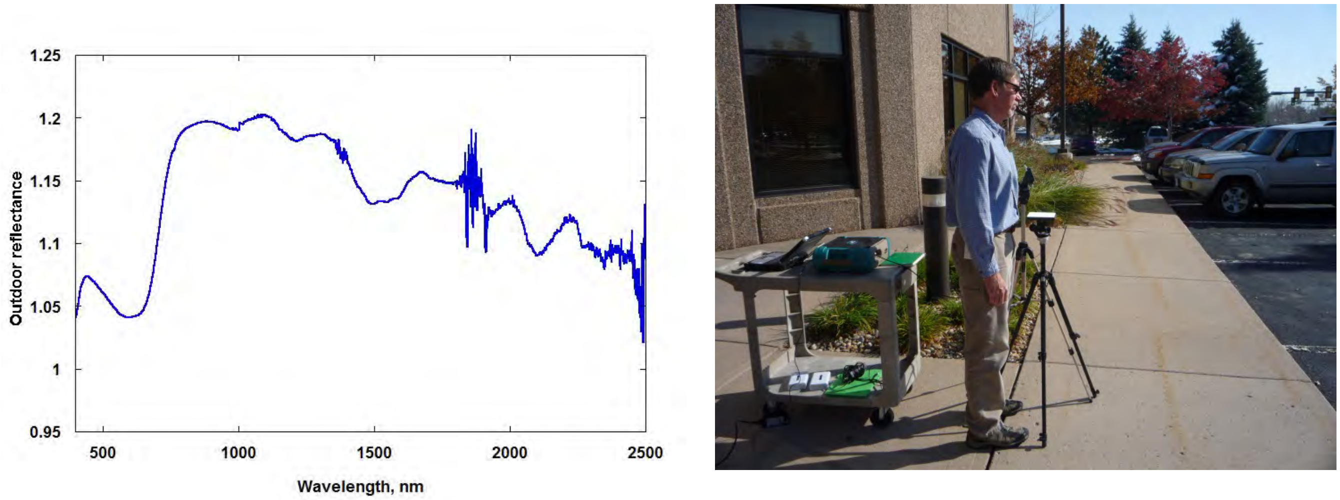

Figure 9. The effects of the operator standing north of the panel

Findings

As has been shown, standing at least a meter away from the measurement point minimizes the contribution from scattered light off of clothing and reduces the solid angle subtended at the measurement point sufficiently to make the skylight obscuration negligible. The least effect of the operator comes when measurements are made perpendicular to the solar azimuth. Therefore, for profiles, the pistol grip should be held at arm's length to the side, or suspended on a pole away from the body, while walking toward or away from the sun. Figure 10 demonstrates how the fiber optic bundle can be mounted on a pole on the shoulder. The pistol grip is mounted on a bamboo stick approximately one meter away from the shoulder. For profiling, the author would turn 90 degrees to walk either up or down sun.

Figure 10. The author using a FieldSpec spectroradiometer with a pistol grip on a remote mount

How often should a reference measurement be taken?

Reference measurements need to be made often because of the number of variables in the spectral irradiance such as:

- Solar elevation angle changes
- Changes in atmospheric absorption
- Changes in water vapor
- Changes in aerosol loading
- Changes in cirrus cloud cover

The instrument itself is far more stable than the atmosphere and if it has been running for an hour or so, nominally will be stable to 0.1 percent.

In general, if the atmosphere is unstable, causing intermittent cloud formation, or there is cirrus cover, in both cases it is possible to make reasonably good spectral reflectance measurements as long as a reference measurement is taken just before the reflectance measurement. A more involved question concerns the frequency requirement for a reference measurement on a clear day.

On a clear day, the interval between reference measurements is a function of the rate of change in the solar elevation angle. The rule of thumb is to take data within ± two hours of local noon and make reference measurements at least every ten minutes. Another consideration is the expected accuracy of the reflectance measurement: the more modest the requirement, the longer the interval available between reference measurements.

Figure 11 shows some examples of measurements taken from three hours before noon until noon. The instrument was normalized by taking the ratio of successive one minute scans at three hours before noon with a solar elevation of 45.9 degrees.

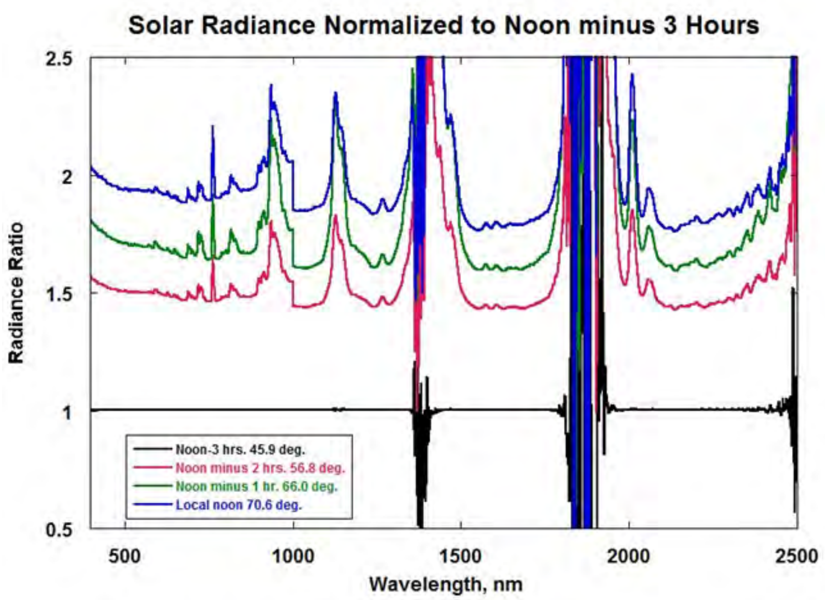

Figure 11. Solar radiance normalized to noon minus three hours

Over the three-hour period the irradiance changed on average by a factor of two with more significant changes in the regions of the atmospheric gases such as oxygen, water vapor and CO_2. Figure 12 displays the changes seen over five and ten minute intervals at each hour before noon.

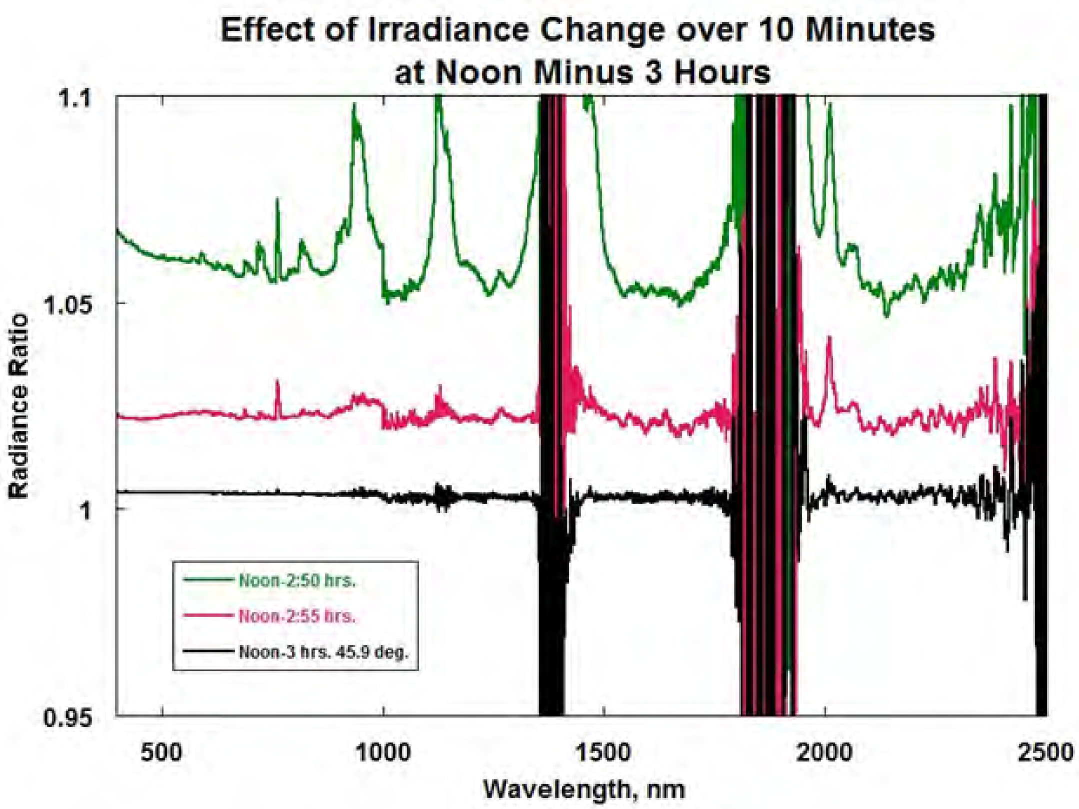

Figure 12. Effects of irradiance change over 10 minutes at noon minus three hours

The major changes in apparent reflectance are approximately two percent at five minutes and six percent at ten minutes from the baseline measurement at three hours before local noon.

The effects of "invisible" water vapor changes between five and ten minutes are highlighted in Figure 13. This is a problem in the field because the "clouds" of water vapor are invisible to the eye and may give one a false sense of security that the measurements are not tainted. The effects of the changing sun elevation angle can be seen at the 762 nm O_2 feature and the 2050 nm CO_2 bands from these well-mixed gases.

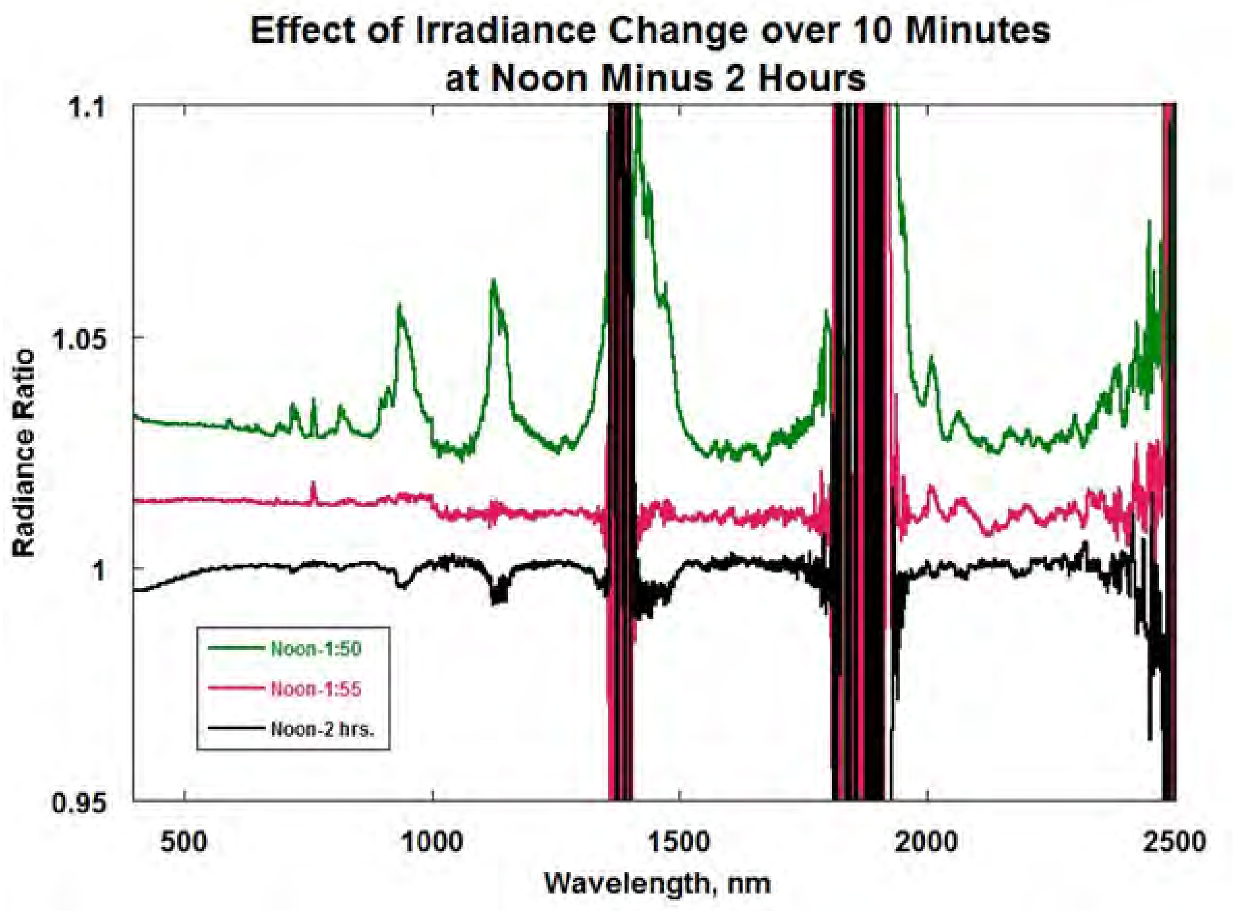

Figure 13. Effects of five and 10 minute waits before measurement of the white reference

In Figure 14, the ten-minute wait is not shown because clouds moved in front of the sun. The oncoming cloud is heralded by an increase in water vapor evidenced by the width of the water vapor feature at 1400 nm shown in red.

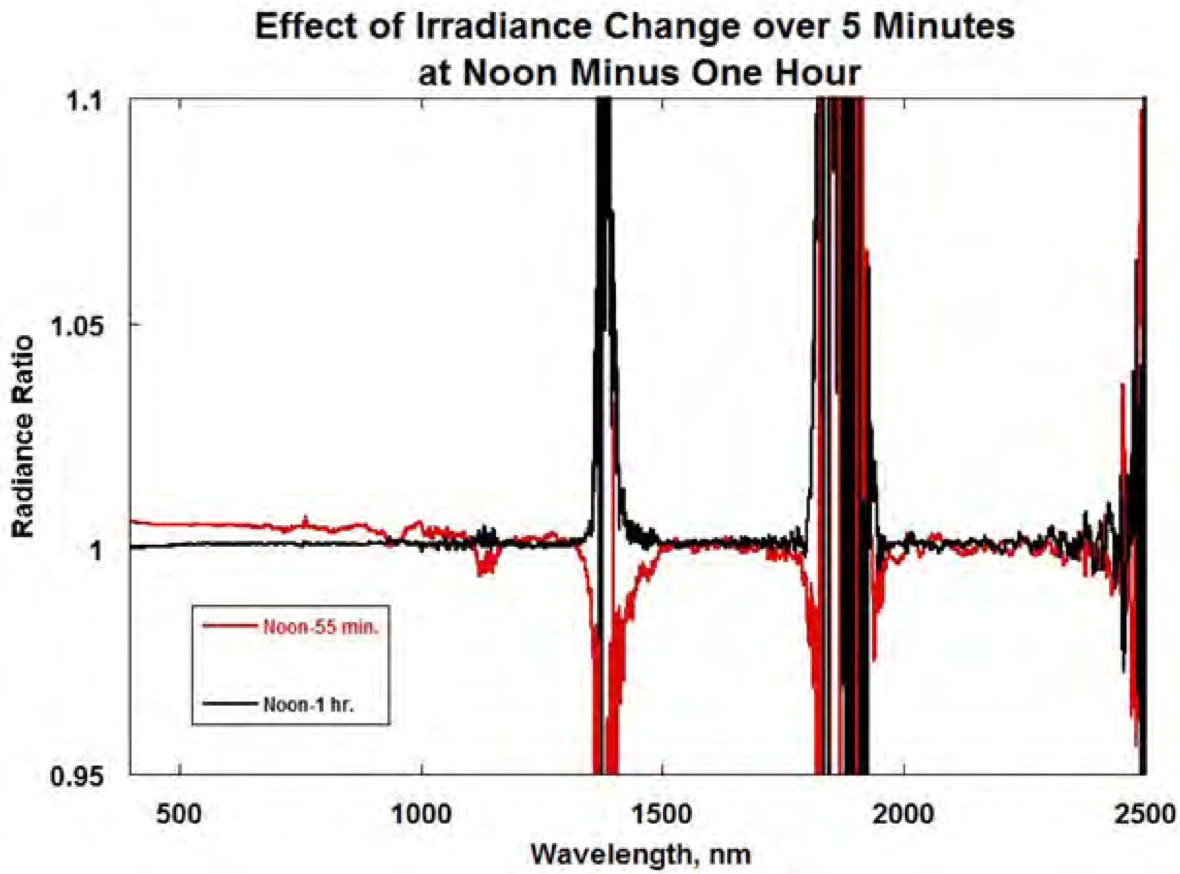

Figure 14. Effects of irradiance change over five minutes at noon minus one hour

The frequency of the reference measurements needed depends on the accuracy of the measurement required. If errors on the order of one percent are required, then within one hour of noon on a clear and stable day it is possible to wait ten minutes between white reference measurements. For the same error requirement, at two hours from local noon, three to four minutes between measurements would be necessary. At three hours, reference measurements would need to be made every one to two minutes.

Validation of Remote Spectral Imaging Data

Ground Truthing 30 Meter Imagery

A question often asked is how many spectra must be taken to create an average for a 30 meter pixel that can be used for normalizing image radiance data to spectral reflectance? Figures 16 through 21 illustrate the results from profiling the area of one pixel from a Hyperion overpass of Table Mountain north of Boulder, Colorado. The black dot in Figure 15 represents the location of a 30 x 30 m pixel measured with two FieldSpec Pro instruments.

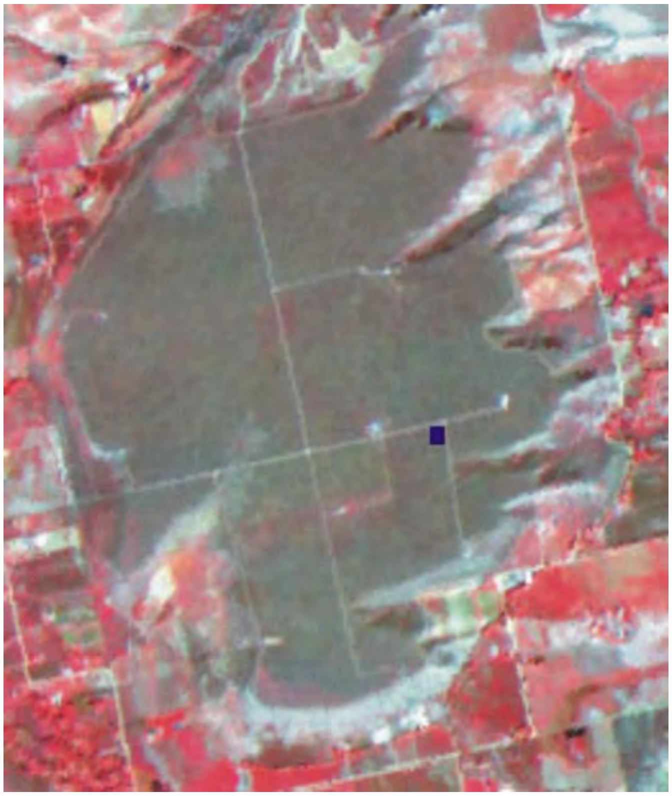

Figure 15. A Hyperion false color infrared image of Table Mountain, Boulder, Colorado

Figure 16 shows ground views of Table Mountain. The flat terrain covered with scrub vegetation and grasses at the end of the growing season causes significant shadowing, which can cause great variability in single measurements.

Figure 16. Ground view of Table Mountain

An approximately 20 x 30 meter area within Table Mountain was traversed with spectral reflectance measurements taken (Figure 17).

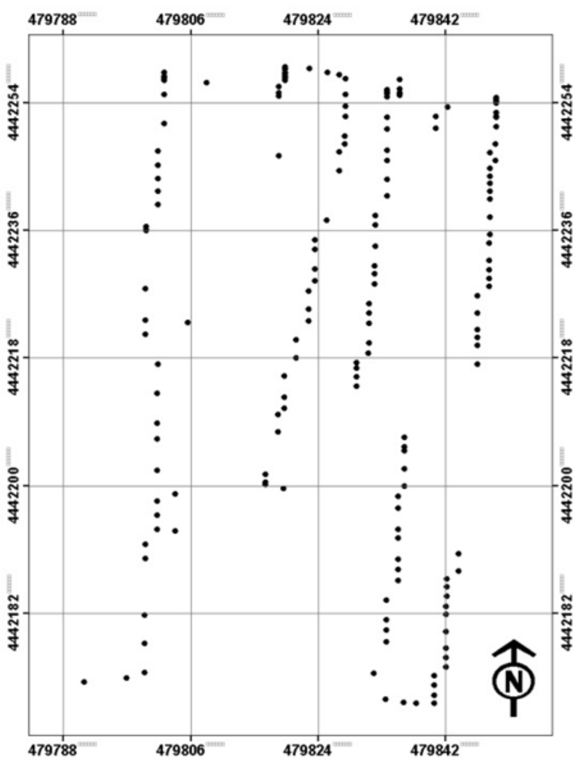

Figure 17. GPS positions of recorded spectral reflectance measurements at Table Mountain

Two FieldSpec spectroradiometers were carried by two operators. The first operator (Figure 18) took more than twice the number of spectra as the second operator (Figure 19) as seen in the following figures. The average is shown in white.

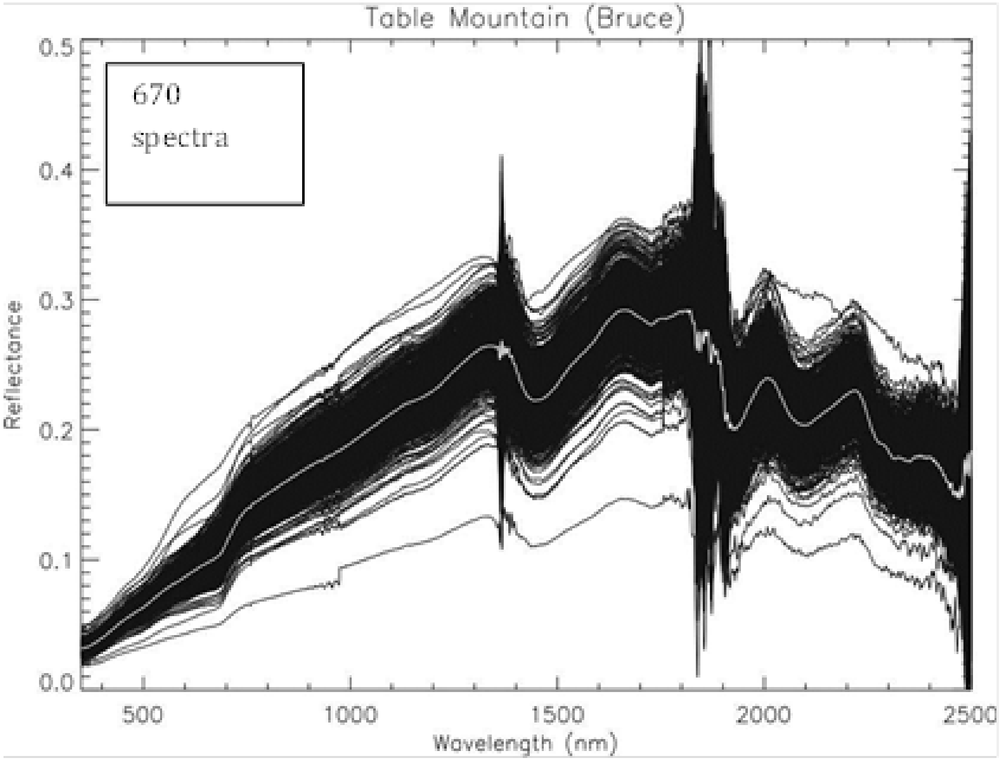

Figure 18. Table Mountain spectra recorded by operator one

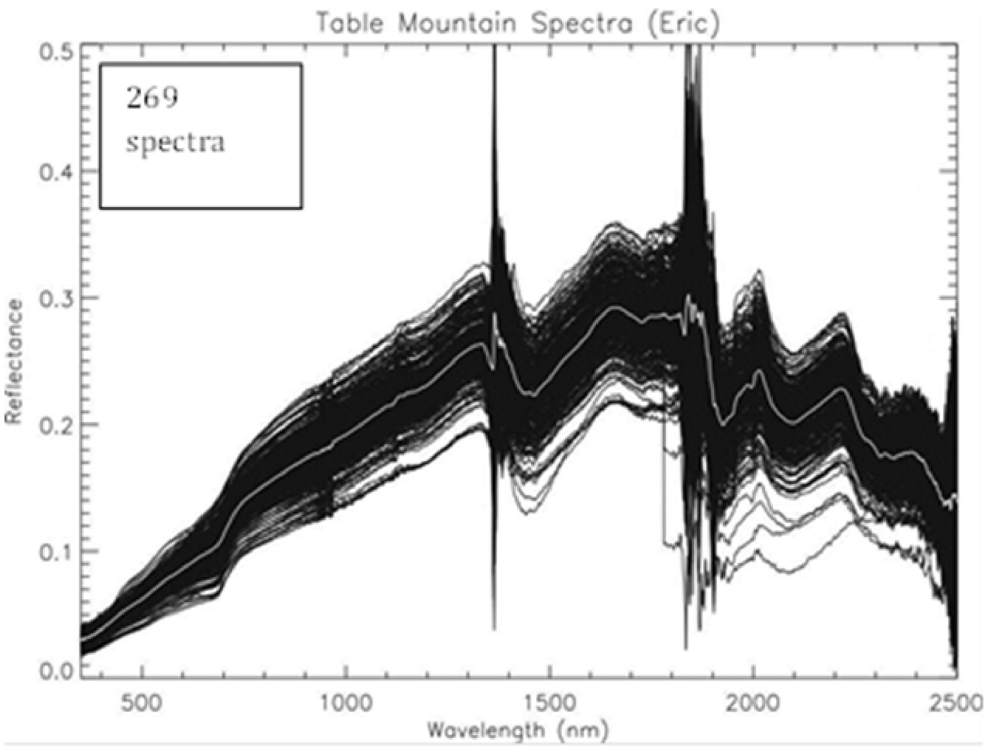

Figure 19. Table Mountain spectra recorded by operator two

The two averages are over-plotted in Figure 20 showing the remarkable coincidence of the two independent measurement sets.

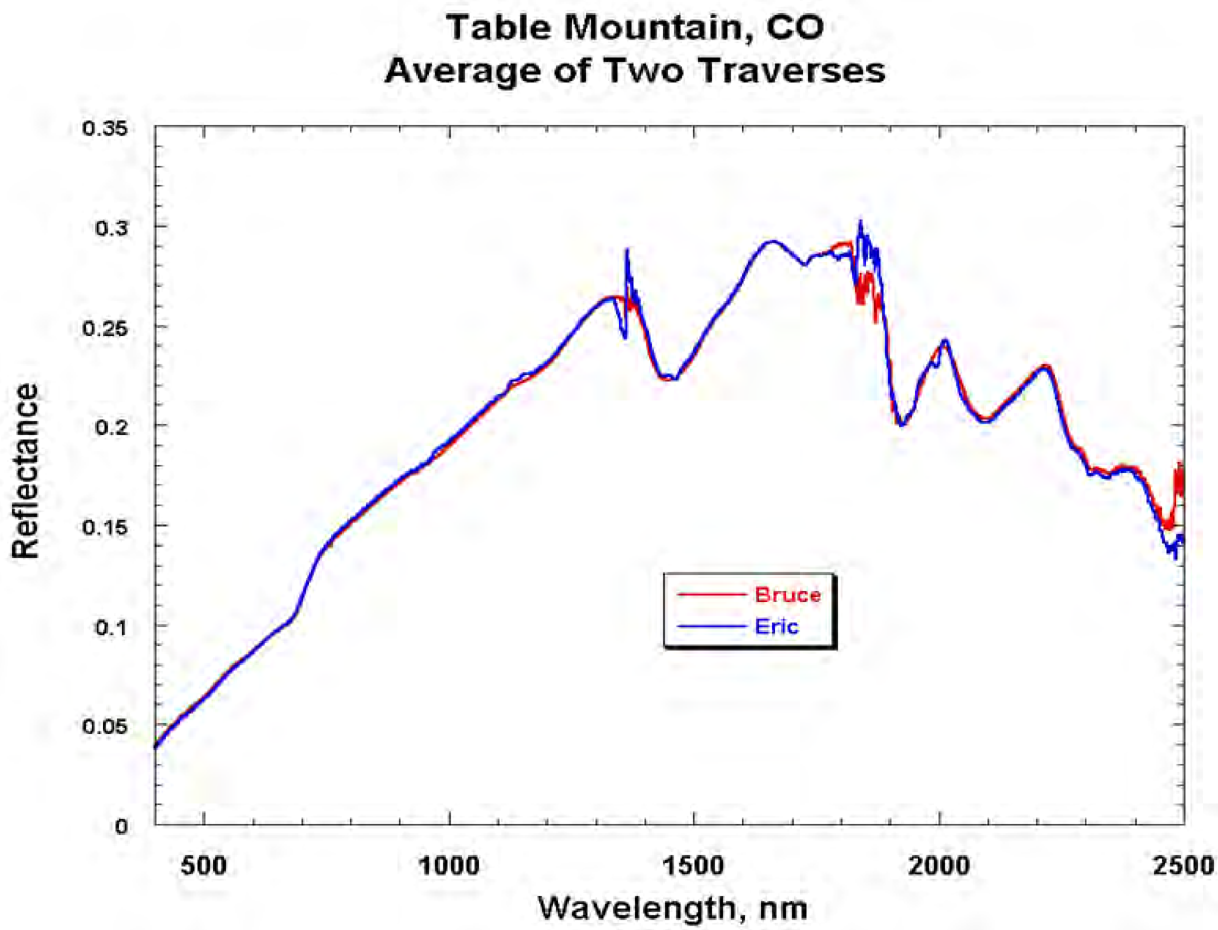

Figure 20. Average of reflectances for the two traverses

Figure 21 shows the average reflectances in the 2000-2400 nm region and coincidence of the two sets of measurements to within 0.2 percent absolute or approximately one percent relative reflectance.

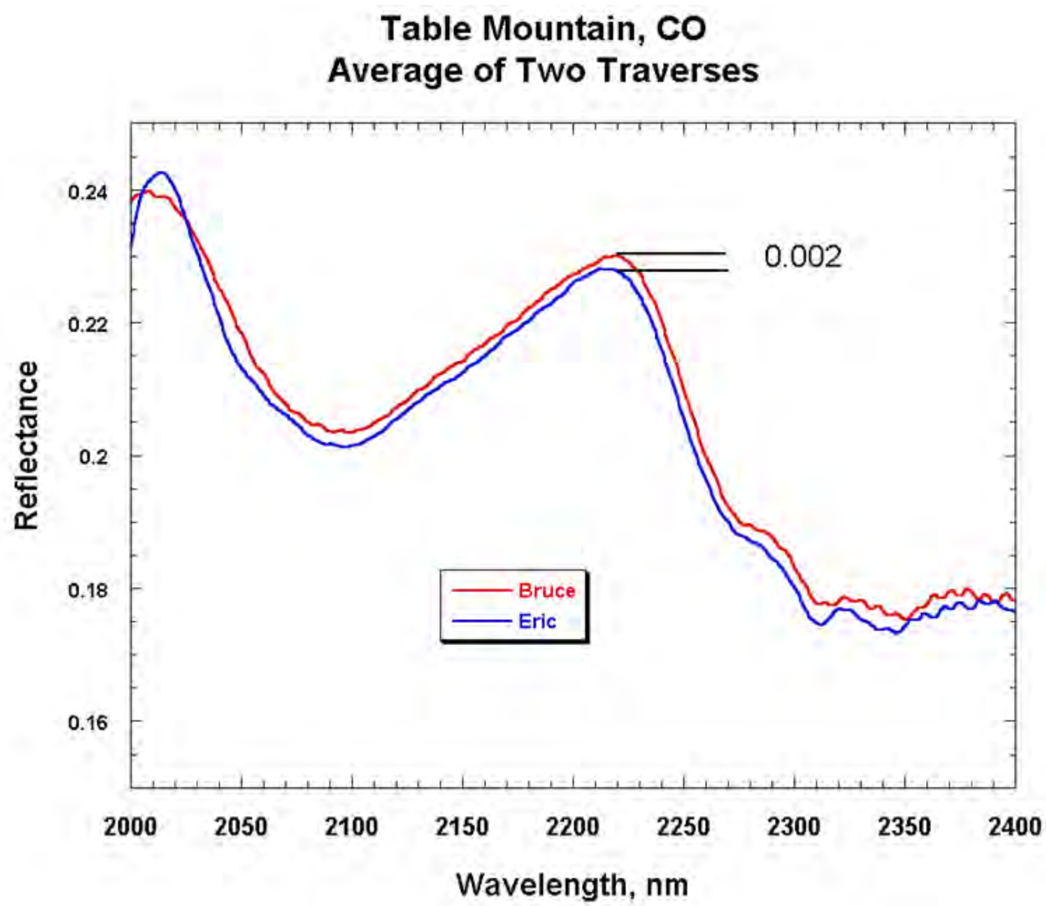

Figure 21. Expanded view of Figure 20 showing correlation between the averages of the two traverses

Summary

Consistent, average spectra for pixels within a hyperspectral or multispectral image can be acquired even in heavily shadowed terrain. The number of measurements required will depend on the accuracy desired. Nominally, a 30 x 30 m pixel can be covered in about ten minutes with an ASD spectroradiometer, collecting spectra every five seconds and making traverses 1m apart. The instrument should be set to average forty scans so that data collection is accomplished during almost the entire traverse. This technique compensates for the fact that in the SWIR each wavelength is acquired from a slightly different area on the ground. As demonstrated in Figure 20, no artifacts are introduced by wavelength scanning.

The protocol is the following:

- Place or hold the pistol grip at arm's length to one side or farther if possible
- In ASD's RS^3 spectroscopy software, set scan average to 40
- Set spectrum interval to five seconds, spectrum number to 120 for a 30 x 30 m pixel
- Take a white reference measurement

- Start data collection
- Walk up- or down-sun at a moderate pace, approximately 1.5 m/sec.
- Do not stop walking until all the spectra have been collected
- As a general rule, acquire data within two hours of local noon
- Each spectrum acquired will have a different irradiance. Take white reference measurements as often as necessary based on the accuracy required
- Alternatively, the spectrum acquisition can be done manually if it is necessary to stop for some reason during data acquisition

This review of techniques for the proper acquisition of spectral measurements outdoors with the sun as the source of radiation is based on more than thirty five years of field measurement experience. Major advancements in instrument technology and data storage incorporated in the latest ASD product offerings, such as the FieldSpec 4 spectroradiometer, have made it much easier to collect large quantities of precise, spectral radiance and reflectance data in the field to better understand our world.

Contact us at (303) 444-6522 or NIR.sales@panalytical.com for further details regarding taking proper reflectance measurements and FieldSpec instrumentation for remote sensing applications.

About ASD Inc., a PANalytical company

Established in 1990 in Boulder, ASD Inc., a PANalytical company is the global leader in high-performance analytical instrumentation solutions, solving some of the most challenging real-world materials measurement problems. ASD spectrometers — unparalleled in providing laboratory-grade results in the field or on-site — are the instruments of choice for remote sensing, environmental sciences, agricultural, mining, pharmaceutical, and pulp and paper industry applications, where results drive paradigm-changing insights, efficiency and profit. ASD's collaborative culture and world-class customer service put the best, fastest and most accurate spectroscopic instruments to work for industry and science in more than 70 countries around the world. For more information, please visit www.asdi.com.