SVC
Spectra Vista Corporation

Field Spectroscopy Guide
with
SVC *i-series* Spectroradiometers

Contents

1 Introduction

Scientists have, for hundreds of years, used the transmission, reflectance, scattering and absorption of light to measure and identify the physical properties of a solid, liquid or gas substance. Nicodemus et al, [6] introduced the concept of a reflectance factor based on the ratio of two measurements of reflected light from the surface of a test to that of a perfect, diffuse standard surface. This concept has been widely adopted and finessed for field spectroscopy measurements, where the reflectance factors of vegetation, mineral or liquid surfaces are measured, analyzed and matched to the physical properties of that surface.

Likewise, Airborne and Satellite Earth Observation studies, use reflected light from the surface, together with modelled or derived incident light onto that surface, to calculate the reflectance factors for the surface. Field Spectroscopy provides an independent means to validate this data and as a means of scaling-up from the fine scale of individual measurement elements such as the leaf, to coarser, canopy-scale or field-size representative values.

The scope of this field guide is to provide the scientist with a detailed step-by-step guide for acquiring spectral reflectance measurements from a surface, using the latest field spectroradiometers. The guide will include measurement definitions, an explanation of instrument specifications and details for a variety of methods and hints in order to attain the highest quality data.

2 Reflectance, Radiance & Irradiance

In field spectroscopy the principal goal is to use light to obtain an accurate measurement of the reflectance values of a surface and from this derive physical properties for that surface. In the process it will be necessary to measure the total light incident on the surface from all points in the hemisphere above it. In radiometric terms this is called irradiance. Most surfaces will reflect a proportion of the incident light back into the hemisphere above it. The radiometric term for the total reflected (or emitted) light from a surface is called the exitance. In field spectroscopy it is not practical to measure exitance, instead we make assumptions about the type of reflectance and measure just a small proportion of the reflected light into the hemisphere. In radiometric terms we call this radiance.

This chapter will discuss the different types of surface reflectance and the relationship between measurements of irradiance, radiance and reflectance.

2.1 Reflectance – Specular, Diffuse & Lambertian

The reflectance properties of a surface are derived from the ratio of the incident light onto the surface to the light reflected from the surface. This requires two separate measurements to quantify the *intensities* of the light incident onto the surface and emitted from the surface. In Figure 1 the smooth surface reflects 50% of the incident laser light (640nm) and absorbs 50%, generating local heat, some of which will be re-emitted from the surface as the thermal infra-red light or, with some materials, the absorbed light can induce fluorescence. In either case, it is important that the reflectance detector is isolated from these secondary emissions.
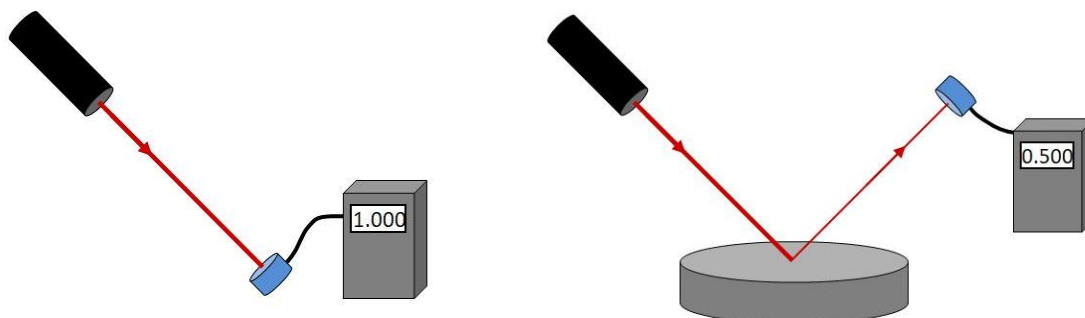
Figure 1 Specular Reflectance

A smooth surface that only reflects light into a single angle (specular reflectance) is rare in nature.

Most surfaces will reflect light into a range of forward and backward scattering angles as shown in Figure 2. To quantify the total reflected light from diffuse surface will require multiple measurements over a range of angles. This will be discussed later in this chapter.

Figure 2 Diffuse Reflectance
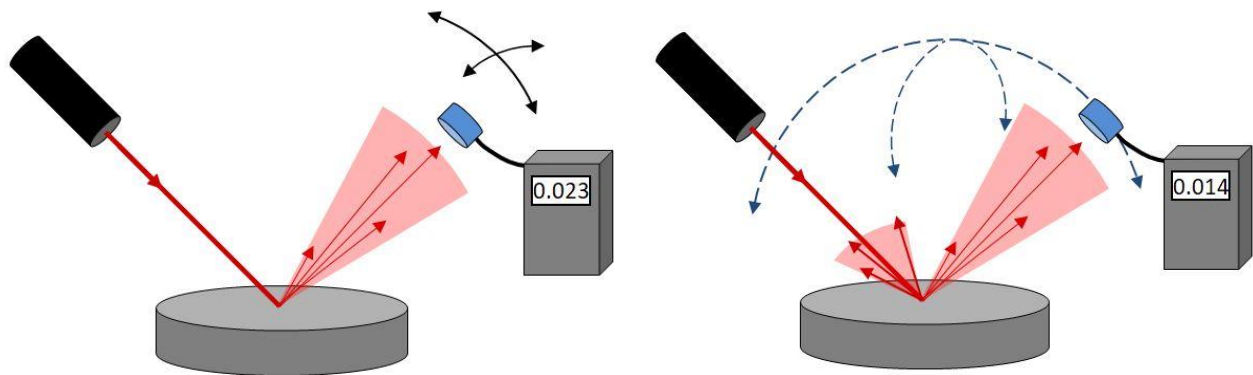
Some surfaces reflect light equally into all forward and backward scattering angles of the hemisphere – ref Figure 3. These surfaces, known as Lambertian surfaces, allow for a single measurement to be scaled to accurately quantify a reflectance value for the surface for all illumination and measurement geometries.
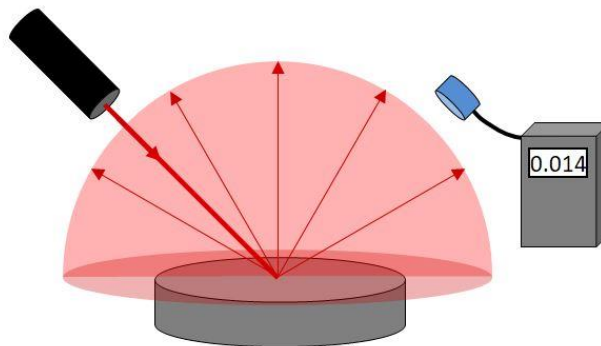
Figure 3 Lambertian Reflectance

A value of reflectance measured with a laser is only valid at the wavelength of the laser light. For spectral information on the reflectance of a surface it is necessary to illuminate with a broad band source.

2.2 Solar Spectrum

In field spectroscopy direct sun & skylight are the predominant illumination sources for non-contact reflectance measurements. This is far more complex than the single laser beam at a fixed angle shown in the illustrations above. Some understanding of the solar

spectrum and light distribution across the sky is useful when interpreting the data and evaluating measurement uncertainty.

Listed below are some of the key **pros** and *cons* when sunlight (& skylight) are used to illuminate a natural surface for reflectance measurements in the field:

- *High intensity*
- *High (correlated) color temperature rich in visible and blue light – ref Figure 4*
- *Matched to Earth Observation (EO) measurement data*
- *Highly uniform across a surface (assuming no clouds and shadows)*
- *Short term stability with "DC output" as opposed to "AC" from mains powered lamps*
- *Perfect weather for field spectroscopy (blue sky days) can restrict opportunities for field spectroscopy in many parts of the world*
- *Atmospheric variability and direct solar illumination geometry (azimuth & zenith) mean no two days will have the identical lighting conditions. This is especially true when measuring plant canopy reflectance throughout a season*
- *Wind, temperature and humidity may need to be factored into your data analysis*

The sun can be considered as a point source illuminating the Earth's surface. For a clear atmosphere the irradiance levels at the surface are dependent on the solar zenith and azimuth angles. In addition, skylight will add to the surface irradiance; however, the spectrum of skylight is strongly biased to the shorter wavelength region, where it can exceed 30% of the surface irradiance at 400nm, for example, and less than 3% at 1500nm.

GPS Coordinates:
Lat.   41° 40.7' N
Lon.   73° 51.3' W
Alt.   70m

Date: July 7th 2019
GPS Time: 18:03:30
Local Time: 14:03:30
Solar Zenith Angle: 64.3°
~61 mins after solar noon
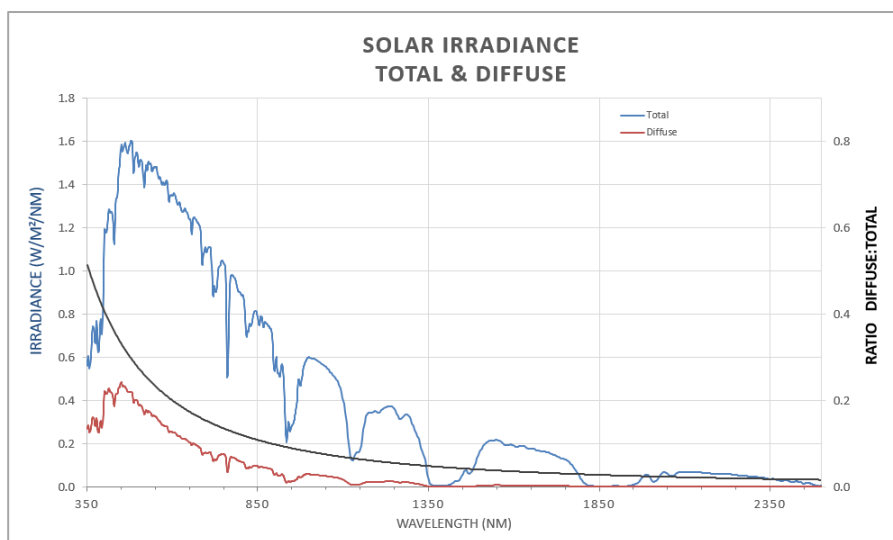
Figure 4 Solar Irradiance (at ground level)

2.3 Irradiance, Radiance & Exitance

Irradiance:

In field spectroscopy it is necessary to measure both the direct solar and sky light contributions to the total irradiance, E_e incident onto a surface – ref Figure 5. This is expressed as the integral of the radiant flux, Φ per unit area over all angles in the hemisphere above the surface – ref Equation 1

$$E_e = \int\!\!\!\int_{-90°}^{90°} \frac{d\Phi}{dS} d\theta d\phi \qquad (W/m^2)$$
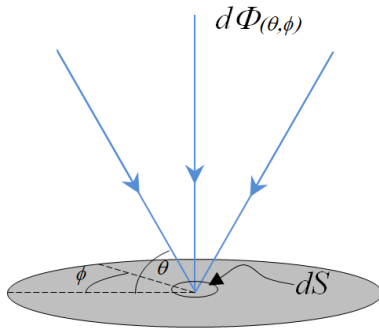
Equation 1

Figure 5 Irradiance

Where, θ and ϕ are the zenith and azimuth angles for the hemisphere above the surface. Note the units for spectral irradiance are $W/m^2/nm$.

Radiant Exitance:

The total light emitted by (or reflected from) a surface into all angles within a hemisphere above the surface is expressed as the radiant exitance, M_e, ref Figure 6 & Equation 2

$$M_e = \int\!\!\!\int_{-90°}^{90°} \frac{d\Phi}{dS} d\theta d\phi \qquad (W/m^2)$$
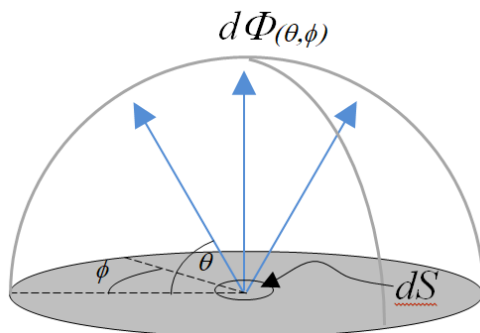
Equation 2

Figure 6 Radiant Exitance

Radiance:

Radiant exitance measurements are rarely possible in field spectroscopy due to their complexity, risk from shading the surface by the instrument, and time constraints.

Radiance, L_e, on the other hand, is a more convenient measurement and often substituted for exitance in reflectance measurements in field spectroscopy, when certain assumptions are applied.

Radiance is a measurement of the radiant flux, Φ into a unit of solid angle, ω (steradian) from a surface of unit area – ref Figure 7 Radiance and Equation 3.
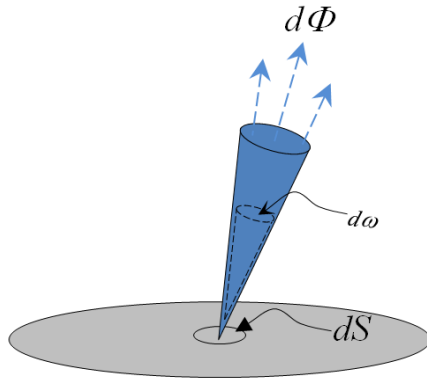
$$Le = \frac{d^2\Phi}{d\omega dS} \quad (W/sr/m^2)$$

Equation 3

Figure 7 Radiance

When light is reflected from a Lambertian surface the relationship between the radiant exitance and radiance can be expressed as:

$$M_e = \pi \cdot L_e$$

Equation 4

(Radiant Exitance $= \pi$ x Radiance - for Lambertian sources/surfaces only)

2.4 Reflectance via Radiometry

In its most general expression the reflectance of a surface, ρ is a ratio of the reflected flux, Φ_R to the incident flux, Φ_I. In field spectroscopy this equates to the ratio of the radiant exitance, M_e to the irradiance, E_e. Note reflectance values are dimensionless.

$$\text{Reflectance} = \frac{\text{Exitance}}{\text{Irradiance}} \qquad \rho = \frac{M_e}{E_e}$$

Equation 5

If we assume the surface has a Lambertian reflectance property then combining Equation 4 and Equation 5 we get:

$$\text{Reflectance} = \pi \cdot \frac{\text{Radiance}}{\text{Irradiance}} \qquad \rho = \pi \cdot \frac{L_e}{E_e}$$

Equation 6

Equation 6 outlines the method for measuring the reflectance of a surface with irradiance and radiance calibrated spectroradiometers.

2.5 Reflectance via a Calibrated Reference Panel

A spectroradiometer calibrated for radiance measurements from a surface – ref Figure 8a can also be configured to measure the irradiance incident on the surface with the use of a calibrated Lambertian reflectance panel - ref Figure 8b.

Equation 6 can be re-arranged to show:

$$\text{Irradiance, } E_e = \pi \cdot \frac{L_{e(Panel)}}{\beta} \quad (W/m^2) \qquad \text{Equation 7}$$

Where β is the calibrated (spectral) reflectance/radiance factor(s) for the reference panel.
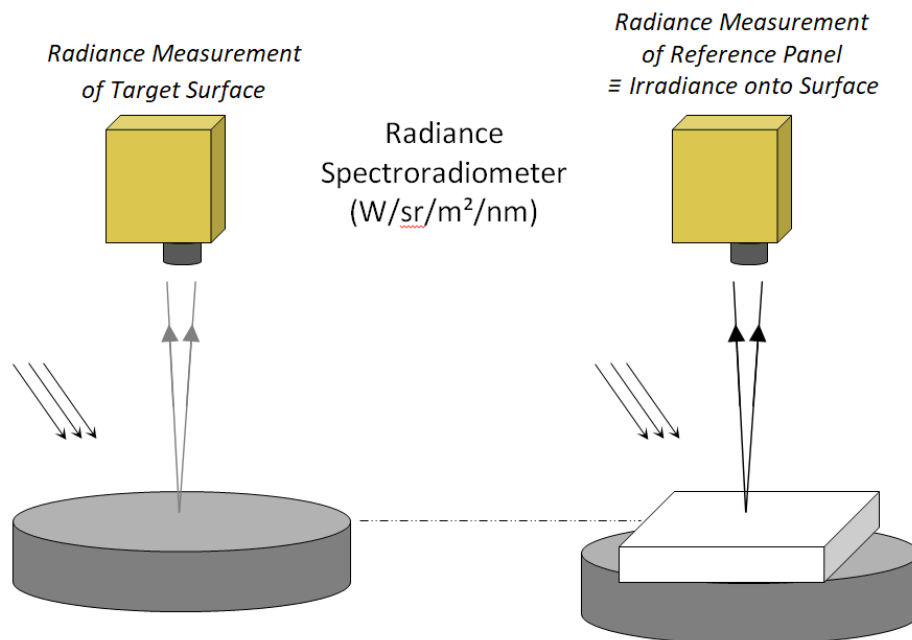
Figure 8 Irradiance measurements using a Radiance spectroradiometer & reference panel.

Figure 8 shows a method for measuring radiance and irradiance with one spectroradiometer and a calibrated reflectance panel. Using Equation 6 this can be extended to reflectance measurements (of Lambertian surfaces). Replacing the irradiance term in Equation 6 with Equation 7 expresses reflectance as a ratio of two radiance measurements:

$$\text{Spectral Reflectance, } \rho_\lambda = \frac{L_{e\lambda\,(Target)}}{L_{e\lambda\,(Ref\,Panel)}} \cdot \beta_\lambda \qquad \text{Equation 8}$$

Note:

The ratio of the Target & Ref Panel radiance values are defined as Relative Reflectance data, and ρ_λ as Calibrated or Absolute Reflectance data.

A radiance measurement with a spectroradiometer requires a calibration factor C_λ (at each wavelength) to scale the raw detector signal (digital number – DN) to radiance values.

$$\text{Spectral Radiance, } L_{e\lambda} = DN_\lambda \cdot C_\lambda \qquad \text{Equation 9}$$

The radiance terms in Equation 8 can be replaced with the raw detector signal and calibration terms from Equation 9:

$$\text{Spectral Reflectance, } \rho_\lambda = \frac{DN_{\lambda(Target)} \cdot C_\lambda}{DN_{\lambda(Ref\,Panel)} \cdot C_\lambda} \cdot \beta_\lambda$$

The radiance calibration factors are the same for a single spectroradiometer and cancel out leaving a simple expression for a reflectance measurement based on the calibration of the reflectance panel:

$$\text{Spectral Reflectance, } \rho_\lambda = \frac{DN_{\lambda(Target)}}{DN_{\lambda(Ref\,Panel)}} \cdot \beta_\lambda \qquad \text{Equation 10}$$

Note:

As with Equation 8 the ratio of the DN_λ Target & Ref Panel values in Equation 10 are defined as Relative Reflectance data and ρ_λ as Calibrated or Absolute Reflectance data.

It should be emphasized that although the radiance calibration is not required for this method of reflectance measurement, the wavelength (spectral) calibration of the spectroradiometer is critical.

Reflectance measurements based on a calibrated reference panel have become widely adopted as the preferred method in field spectroscopy. In addition, the introduction of high performance reference reflectance panels with near Lambertian reflectance has reduced measurement uncertainty. However, the simplicity of the method has led to some abuse and poor practices, resulting in low quality data without quantified uncertainties. Examples of poor practice include:

- Assuming the radiance/reflectance factors for the reference panel (β_λ) have a value of 1 across the spectrum.
- Assuming the reflectance panel has perfect Lambertian reflectance. The best reflectance panels available today still have some anisotropy with a small bias to forward scattering at low angle of incidence.
- Ignoring the differences between hemispherical and bi-directional reference panel calibration factors and how this might be factored into the measurement uncertainty.
- Assuming the target surface canopy has Lambertian reflectance.

These assumptions need to be tested and quantified in order to build a complete uncertainty budget. However, some short-cuts are permissible if controls are applied to restrict data capture within tight geometrical or spectral limits.

2.6 The Geometric Terminology for Reflectance Measurements

The terminology to describe the possible measurement configurations for reflectance measurements is detailed in the NIST publication by F. Nicodemus [6]. Field spectroscopy and the remote sensing communities have applied these terms to more precisely define the geometric conditions applicable for the reflectance data. Figure 9 and Figure 10 show some of the more commonly used reflectance nomenclature.
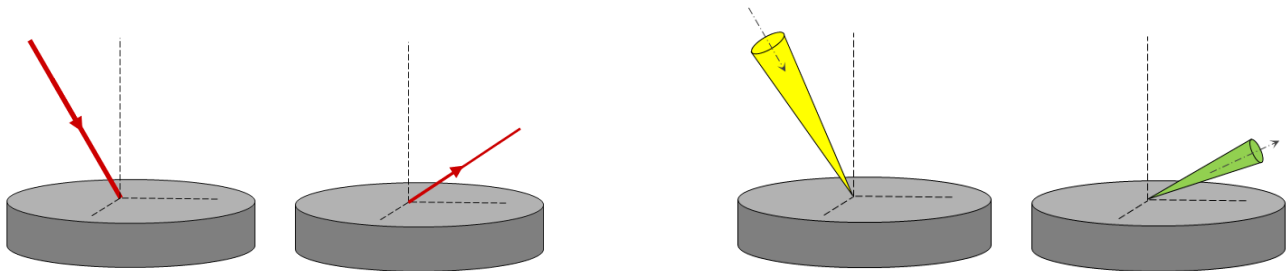
Figure 9 Bi-Directional (left) and Bi-Conical Reflectance (right)

The term Bi-Directional Reflectance relates to a beam of light from an infinitely small solid angle incident onto a surface and subsequently measured by an instrument with an infinitely small field of view. This is generally seen as an unmeasurable configuration. Bi-Conical Reflectance on the other hand, is a more representative of real world measurement. However, Bi-Directional Reflectance is often used where in reality the measurement is Bi-Conical Reflectance albeit with a small solid angle and field of view.

Most natural surfaces do not have Lambertian reflectance properties and often demonstrate a strong bias to forward reflectance. It would therefore be meaningless to quote the reflectance factors for a surface without including the illumination and observation angles:

$$Reflectance,\ \rho\ (\theta_i\phi_i\ \theta_r\phi_r)\quad or\quad \rho\ (\theta_i\phi_i\ \omega_i\ \theta_r\phi_r\omega_r)$$

Where θ and ϕ are the zenith and azimuth angles for incident and reflected beams of Bi-Directional Reflectance with ω the solid angles included for Bi-Conical reflectance.

In field spectroscopy the irradiance of the canopy surface may originate from any part of the hemisphere above the surface. The angular distribution of the irradiance is a complex combination of direct light from the sun and diffuse or scattered light from the sky and adjacent objects, all of which are spectrally dependent. Figure 10 shows the hemispherical irradiance of a surface, with the reflected radiance measured at nadir;

this is referred to a Hemispherical Conical Reflectance Factors (HCRF) or Hemispherical Directional Reflectance Factors (HDRF).
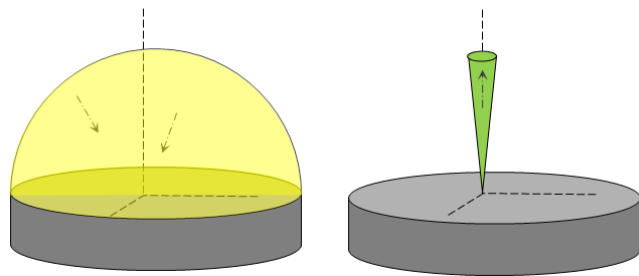
Figure 10 Hemispherical – Conical (Directional) Reflectance

Further information on the terminology of reflectance measurements is available through the bibliography references [3], [6] and [7].

The level of detail required to fully specify the irradiance field and measurement conditions is quite daunting. However, in practice the range of illumination conditions and viewing geometry should be restricted to limit options and allow for better inter-comparisons. For example:

- Strict adherence to blue sky conditions
- Solar noon ± ½ hour
- Nadir viewing
- Off nadir viewing limited to range of a satellite's swath for example
- Methods to quantify variability of canopy reflectance relating to changes in illumination and measurement geometries.

3 Instrumentation & Specifications

3.1 SVC i-Series Field Spectroradiometers

Spectra Vista Corporation has supplied instrumentation and supported the remote sensing and field spectroscopy communities for more than 30 years. The latest range of i-Series field portable spectroradiometers is the culmination of intense research with users, the latest sensor technology and optical design, with manufacturing, calibration protocols and experience second to none.

Key features of the i-Series include:

- Low noise, high sensitivity, detector arrays
- Excellent signal linearity
- High quality optical design with concentric and symmetric fields of view
- Integrated target image camera
- Integrated GPS
- Bluetooth interface to laptop or PDA
- External detector interface (WEDI) to monitor ambient light
- Can be easily configured for Dual Field of View operation
- Wide range of input optics and accessories
- Compact & lightweight
- Stand-alone model with touchscreen graphic control

A tried and tested methodology is the first step to attaining good measurement data. However, an intimate knowledge of the spectroradiometer's specification and its accessories are essential in order to get the very best performance from your instrument in the field, assist in data analysis including statistical outliers and build uncertainty budget.

3.2 Spectral Properties

As the name suggests, a spectroradiometer will measure and analyze the spectral content of light beam. However, the data it produces will in some part depend on the specification of the instrument. For example the width and depth of a spectral absorption feature may differ from the *true* value if the spectroradiometer has a lower resolution than the absorption feature.

Procuring a field spectroradiometer requires the scientist to set out a list of performance and specifications that are necessary to meet their requirements, bearing

in mind that some compromise may be necessary. For example improved resolution (FWHM) often comes at the cost of lower sensitivity.

SVC has six models of i-Series field spectroradiometers. The principal spectral specification features for these models are detailed below:

Spectral Range:

The electro-magnetic spectrum can be divided into regions with ranges which may vary according to the science application. In field spectroscopy these regions also include subdivisions based around detector technologies.

Figure 11 Electro-magnetic & Solar Spectrum 300 – 2500nm

The spectral regions listed below are not set in stone but will used as a short-hand description within this guide.

Spectral Range	Wavelengths	Detector Technologies
Ultra-Violet (UV):	200 – 400nm	UV enhanced silicon photo-diode detectors
Visible (Vis):	400 – 700nm	Silicon photo-diode and CCD detector arrays
Near Infrared (NIR):	700 – 1000nm	Silicon photo-diode and CCD detector arrays
Visible NIR (V-NIR):	400 – 1000nm	Typical range of silicon photo-diode array detector
Shortwave Infrared (SWIR):	1000 – 2500nm	Typical range of PbS detector array
SWIR-1	1000 – 1890nm	Typical range of InGaAs detector array
SWIR-2	1890 – 2500nm	Typical range of Extended InGaAs detector array
Full Solar Spectral Range	300 – 2500nm	Thermopile pyranometer

Table 1

Multiple Grating & Detector Arrays:

The first step in choosing a field spectroradiometer is to ensure the spectral range of interest to your research is within the instrument's specification. For example the SVC HR-512i spectroradiometer is ideal for measurements covering the visible and near infra-red spectral range, ref Table 1. This instrument includes a single diffraction grating and silicon photo-diode array detector. Figure 12 shows a simplified Vis-NIR

spectroradiometer. Note the entrance slit, shutter, electronics, user interface and battery are not shown.
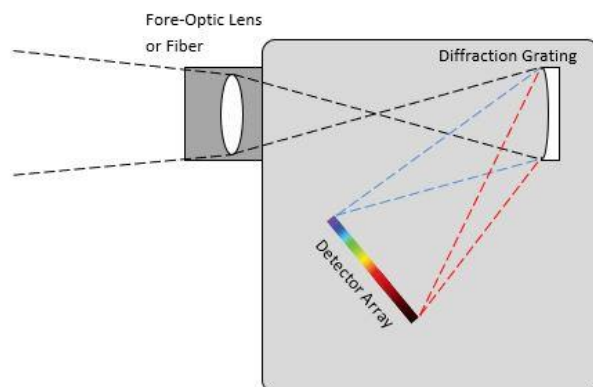
Figure 12 Optical layout for a simple spectroradiometer

Diffraction gratings are matched to give their optimal performance over the spectral range and physical size of the detector array. In general this is limited to one or two octaves of the spectrum, for example 350 to 700nm or 350 to 1050nm. It would not be possible to cover the full solar spectral range (300- 2500nm) using a single diffraction grating and detector array.

However, many applications in a field spectroradiometer require a spectral range beyond that available from a single detector array and diffraction grating. To overcome this design restriction, the SVC i-series spectroradiometers incorporate two or three gratings and detector arrays within a single instrument housing. In addition, all the grating/ detector combinations share a common input optic with aligned and matched field of view, thus ensuring accurate spectral data from a target surface. Table 1 lists the spectral range and multiple detector array technologies used in the Spectra Vista series of field spectroradiometers.

Examples of SVC i-Series Spectroradiometers:

Field Spectroradiometer	Spectral Range	Detector Technologies	No.
SVC HR-512i	350 – 1050nm	Silicon photo-diode detector array	(1)
SVC HR-640i	350 – 2500nm	Silicon, InGaAs & Ext InGaAs photo-diode arrays	(3)
SVC HR-768si	350 – 1890nm	Silicon & InGaAs photo-diode arrays	(2)
SVC HR-768i	350 – 2500nm	Silicon, InGaAs & Ext InGaAs photo-diode arrays	(3)
SVC HR-1024i	350 – 2500nm	Silicon, InGaAs & Ext InGaAs photo-diode arrays	(3)
SVC XHR-1024i	350 – 2500nm	Silicon, InGaAs & Ext InGaAs photo-diode arrays	(3)

Table 2

Bandwidth (Sampling Interval):

The spectral distance between the center of each spectral band in the detector array is referred to as the Bandwidth or spectral sampling interval. The bandwidth will vary slightly across the spectral range of each detector array. Table 3 shows the specified values for the SVC spectroradiometers.

Spectroradiometer	V-NIR Bandwidth	SWIR-1 Bandwidth	SWIR-2 Bandwidth
SVC HR-512i	$\leq$ 1.5 nm		
SVC HR-640i	$\leq$ 1.5 nm	$\leq$ 14 nm	$\leq$ 10 nm
SVC HR-768si	$\leq$ 1.5 nm	$\leq$ 3.8 nm	
SVC HR-768i	$\leq$ 1.5 nm	$\leq$ 7.6 nm	$\leq$ 5.0 nm
SVC HR-1024i	$\leq$ 1.5 nm	$\leq$ 3.8 nm	$\leq$ 2.5 nm
SVC XHR-1024i	$\leq$ 1.5 nm	$\leq$ 3.8 nm	$\leq$ 2.5 nm

Table 3 Bandwidth of field spectroradiometers

Spectral Resolution (Full Width at Half Maximum, FWHM):

The photodiode detector array(s) within the spectroradiometer comprise of hundreds of pixels each measuring a small part of the spectrum. Figure 13 highlights two pixels (blue & grey) within a detector array with overlapping Gaussian shape response functions for these pixels which extend on either side beyond the bandwidth.
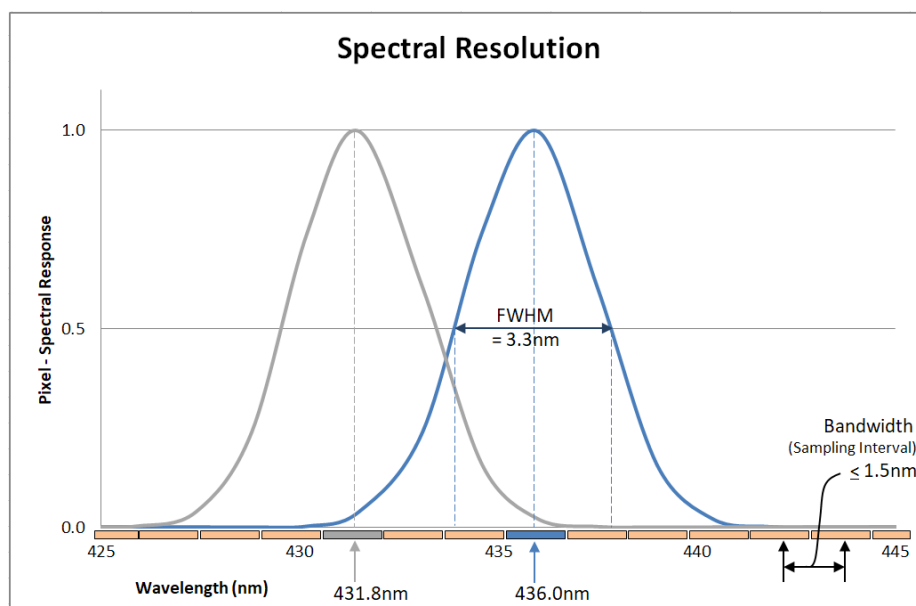
Figure 13

The spectral resolution of an instrument is an important indicator as to its ability to identify and resolve reflectance or absorption features in a spectrum. For example the

twin kaolinite absorption features around 1400nm require a FWHM value of < 15nm to resolve them. Table 4 lists the FWHM values for the SVC instruments across each spectral region. Note, unlike many field spectroradiometers, these values generally hold true across each of the spectral regions.

Spectroradiometer	Spectral Resolution, FWHM		
	V-NIR @ 700 nm	SWIR-1 @ 1500nm	SWIR-2 @ 2100nm
SVC HR-512i	< 3.2 nm		
SVC HR-640i	< 3.3 nm	< 30 nm	< 28 nm
SVC HR-768si	< 3.3 nm	< 9.5 nm	
SVC HR-768i	< 3.3 nm	< 16 nm	< 14 nm
SVC HR-1024i	< 3.3 nm	< 9.5 nm	< 6.5 nm
SVC XHR-1024i	< 2.8 nm	< 8.0 nm	< 6.0 nm

Table 4 Spectral resolution of SVC Field Spectroradiometers

The spectra data in all SVC field spectroradiometer is over sampled to meet Nyquist Theorem – sampling interval < 0.5 x FWHM.

3.3 Field of View

The scientist will always need to know exactly what the instrument is measuring. The field of view and distance from the input optics (fore-optics) provide a first order approximation of the measurement area of the target canopy or reference panel.

The SVC *i-Series* of field spectroradiometers use a unique design of fore-optics which creates a well-defined field of view[§]. The interchangeable fore-optic accessories for non-contact reflectance measurements include 4 °, 8° & 14° lenses and a fiber optic light guide. A built in laser aligned to the fore-optics is included to assist in alignment of the spectroradiometer to the target or reference panel.

Each FOV lens is supplied with a unique template which specifies the size and shape of the field of view together with the distance between the alignment laser and the fore-optic optical axis. Ref Appendix 1 for sample template.

Figure 14 Field of View
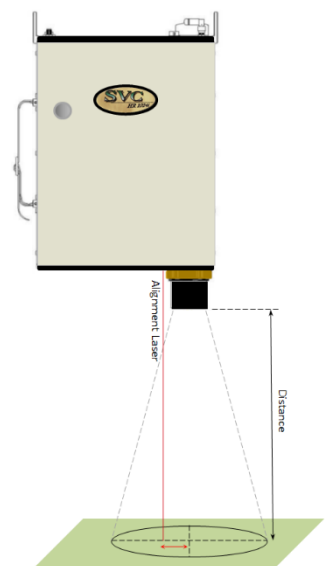
§ Note the SVC i-series spectroradiometers with multiple grating/detector arrays are aligned to ensure the optical axis for each grating/detector combination is centered and

matched to the common fore optics. Thus ensuring a concentric and equal sized field of view for the target surface across the full spectral range of the instrument.

3.4 Reflectance Panels

In field spectroscopy the vast majority of reflectance measurements will use a reference reflectance panel with the most common being a 12mm thick, low density, sintered PTFE tile such as the 5"or 10" Spectralon® panels housed in a wooden box from Spectra Vista. These panels offer diffuse, near flat spectral reflectance over a wide range, 250 – 2500nm.

The calibration of the panels is typically based on an 8° directional illumination, total hemispherical detection, 8°/T configuration. As the panel does not have true Lambertian reflectance due to small anisotropies[§], the bi-directional and hemispherical reflectance values are not equal. However, a comparison between 8°/T and 0°/45° bi-directional calibration values has yielded a simple conversion factor which can be applied across the spectral range 350-2500nm – ref [8].
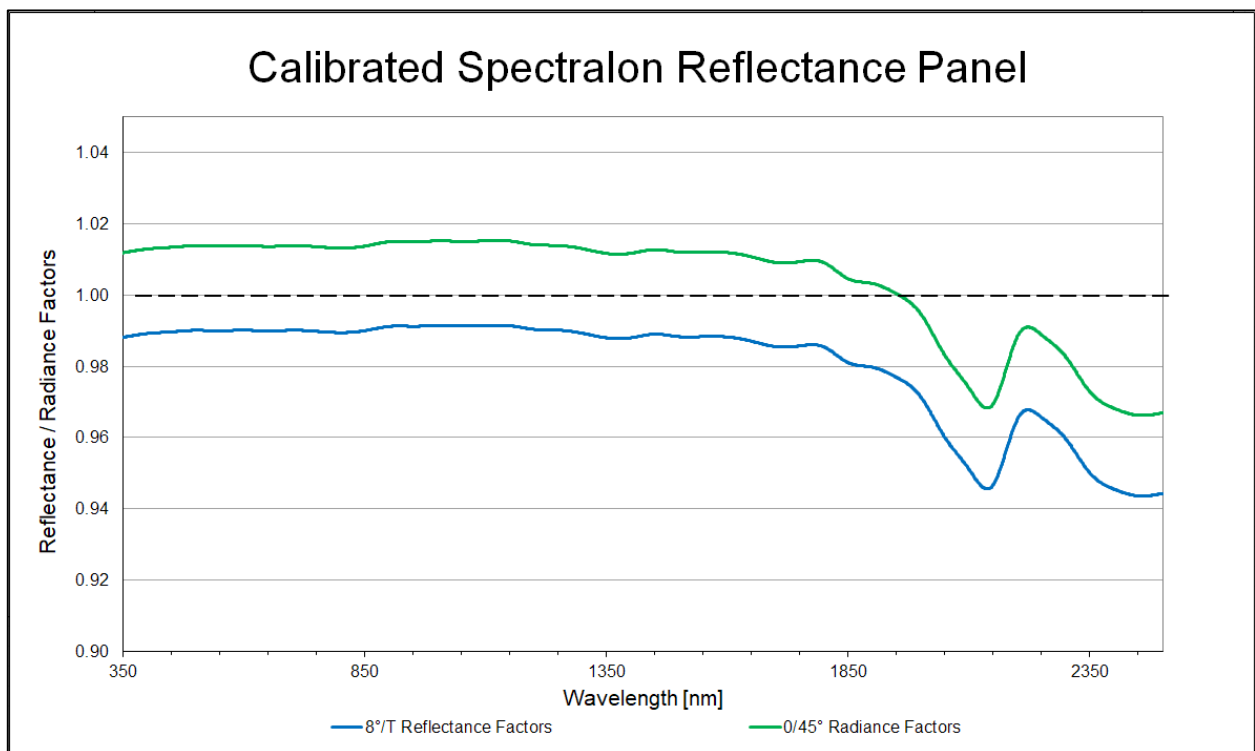
Figure 15 Hemispherical-Directional & Bi-Directional Factors for Spectralon® Reference Panels

[§]Anisotropy – the surface has directional dependencies with different reflectance values at different angles of incidence and viewing. Opposite to isotropy - uniformity in all orientations.

The SVC spectroradiometer software will display a combined radiance and reflectance graph after completing a reference and target set of measurements – ref Figure 16.

It should be noted that at this stage the graph is displaying *relative reflectance* values, the ratio of the two radiance measurements.
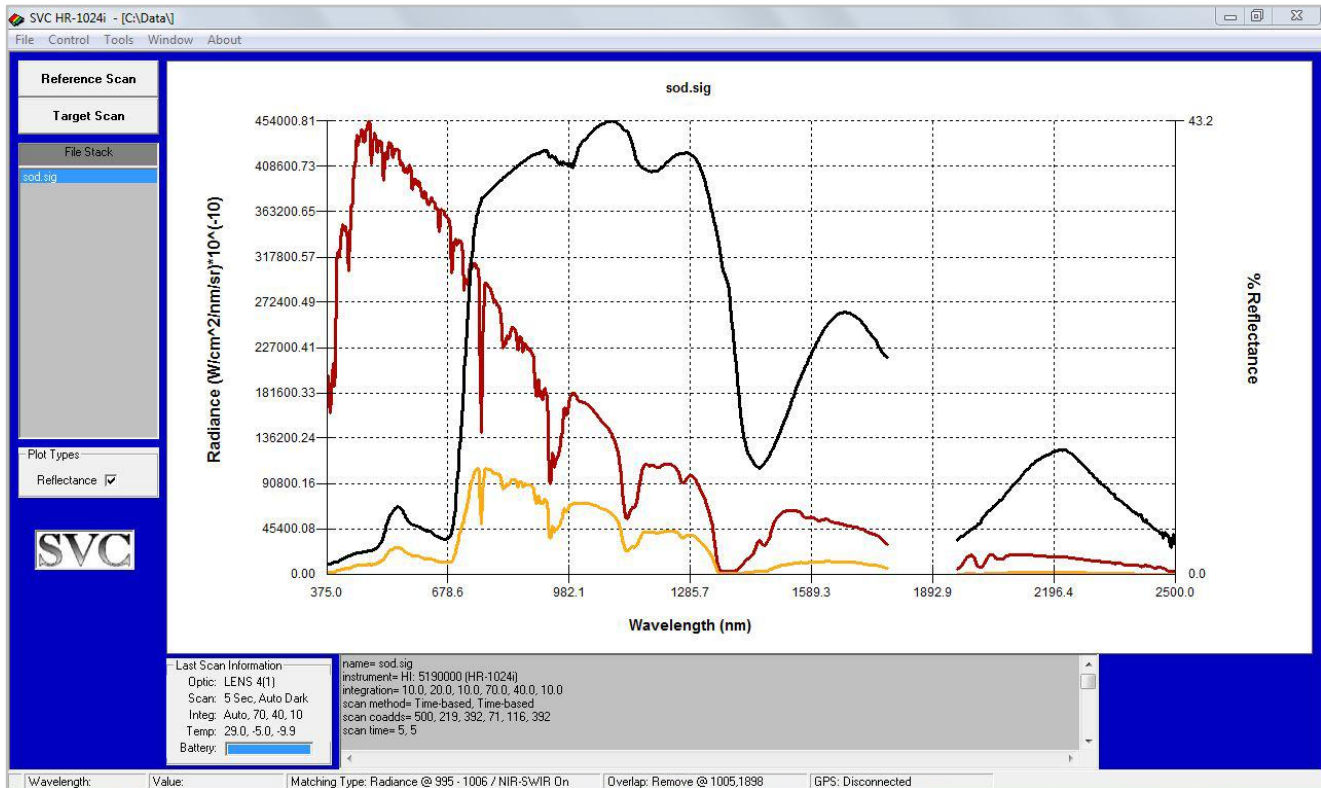
Figure 16, Spectral reflectance measurement of plant canopy surface

The next step is to scale these *relative reflectance* values to calibrated *Absolute Reflectance.* Equation 8 and Equation 10 require that the reference panel calibration factors (β_λ) be applied to the relative reflectance data to attain absolute reflectance values for the surface. The dilemma facing the field scientist is whether to use the widely available 8°/T calibration factors which are similar to sky illumination and near nadir measurement (HDRF) or 0°/45° bi-directional, sun illumination @ 45°, nadir observation. The former is convenient and closer to reality in the blue part of the spectrum; the latter is more representative at most wavelengths above 1000nm. What should you use when the sun has a solar zenith angle of say 30°? The practical option used by most field scientists is to choose the 8°/Total hemispherical calibration typically supplied with the panel. The caveat here is that this information should be declared in the Meta data and accounted for in the uncertainty budget.

Reference Panel Care

All the reflectance measurement data acquired using your calibrated reference panel will rely on maintaining a pristine front surface equal to that when it was last calibrated. The polytetrafluoroethylene (PTFE) material is soft and easily marked and the surface has a rough finish into which dust can easily penetrate. However the panel can be cleaned a soft brush or de-ionized water. Listed below are the "Dos & Don'ts" when handling or cleaning a panel.

DON'T	DO
Do not touch the panel with your fingers	_Keep in protective box when not in use_
Do not place it on ground or dirt	_Mount on tripod_
Do not clean with alcohol or solvents	_Keep level_
Do not clean with detergent	_Clean before each field campaign_
Do not clean with compressed air can which uses a chemical propellant	_Build a collection of reference reflectance panels for comparison measurements_
Never use a dirty panels for reference reflectance measurements	_Set aside a "gold standard" reference panel for calibration measurements_

Table 5 Reference Panel Care

Cleaning a panel by _exfoliating_ the front surface will rejuvenate its reflectance properties close to the original calibration values. Panel cleaning instructions are detailed in Appendix 1.

Reference Panel Use

During a canopy reflectance measurement sequence it will be necessary to repeat the panel radiance /reference scan many tens of times per hour either to refresh the reference measurement or to confirm ambient light stability. It is therefore necessary that the panel be located at a convenient point near the center of the study area to minimize the distance and times between the Reference and Targets measurements.

It is high recommended that the panel be mounted on a tripod. This will reduce the risk of surface dirt contaminating the surface of the panel. The new SVC range of boxed, calibrated reflectance panels includes a tripod mounting screw thread in the base and a removable lid.

Ensure the box lid remains closed before mounting on the tripod. Find a suitable location in your field site and mount the panel at a height above the canopy or between 3 and 4 feet above the ground. Ensure the tripod is stable and unlikely to be blown over with a gust of wind or accidently knocked over. In extreme conditions attach a sandbag to center column or around the feet.

Use the spirit level in the tripod head or place a spirit level on the lid of the box and adjust to ensure the panel is mounted horizontally. Figure 17 shows the importance of leveling the panel at various solar zenith angles.

In exceptional circumstances such as short vegetation on a hill side gradient the panel should be mounted parallel to ground.
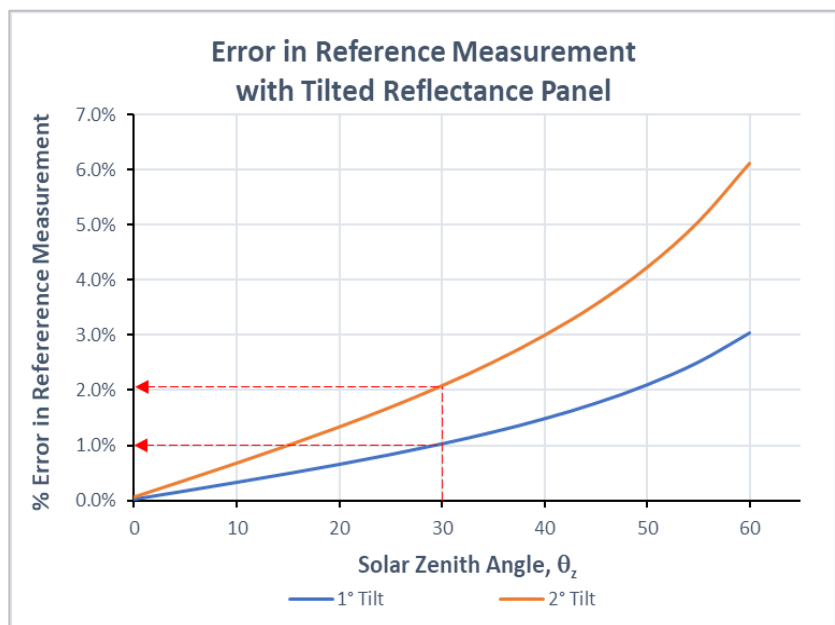
Figure 17 Examples of Reference Measurement Error from a Tilted Reflectance Panel [11]

3.5 SVC Field Spectroradiometer Accessories

Fore-Optic Lenses:

The SVC i-Series of field spectroradiometers have a choice of interchangeable fore-optic lenses with 4°, 8° or 14° Fields of View giving a nominal measurement scene diameter of approximately 7, 14 and 25cm respectively at a height of 1 meter above the surface.

Fiber Optic Light Guide:

Alternatively the fore-optic lens can be replaced with a flexible fiber optic light guide with a nominal field of view of 25° giving a measurement scene diameter of 47cm at 1 meter. Note: great care is required when aligning the fiber to the reference panel to ensure it's FOV is within the area of the panel. For example, at tip of the probe must be perfectly centered and a maximum height of 0.5m above a 25 x 25cm panel. The recommended maximum height is 30cm, to allow for some misalignment.

Reflectance Probe with Leaf Clip:

The model LC-RP Pro allows for rapid reflectance measurements of leaves. It can also be configured for contact measurements of solid surfaces .
The LC-RP Pro is fiber coupled to the i-Series spectroradiometer and includes an internal lamp, white reference, black surface and trigger switch. The lamp power level can be adjusted to minimize leaf damage during measurement scans.

Reflectance – Transmittance Integrating Sphere:

The direct connect reflectance/ transmittance integrating sphere, model DC-R/T is the ideal accessory to perform precision diffuse spectral reflectance and transmittance measurements on leaves. From this the leaf absorbance can be calculated.

3.6 SVC Applications

The SVC User Manual [9] and Tech Guide [10] provide comprehensive instructions and guidance to set up the wireless communication and operate the i-Series field spectroradiometer. Listed below are some of features when acquiring reflectance data.

3.6.1 PC or Laptop Windows Application:

This Windows version of the application provides the most comprehensive control of the instrument, file saving and data analysis. For the field guide we will feature a number of key settings and the main acquisition display.

Control / Setup dialog:

- Ensure the correct Optic and therefore its calibration file is selected.
- The Scan Timing can be a personal preference or judgment call between acquiring more scans for post processing analysis or fewer longer scans with higher signal to noise values. However, with less stable ambient light a shorter Scan Time is always beneficial.
- The Target Photo Acquisition can be of significant benefit when reviewing data files and identifying targets or false targets. Switch from Hi to Low Resolution photos to minimize any delays during unstable ambient light conditions. The Photo Acquisition can be turned off when the fiber-optic light guide is fitted.
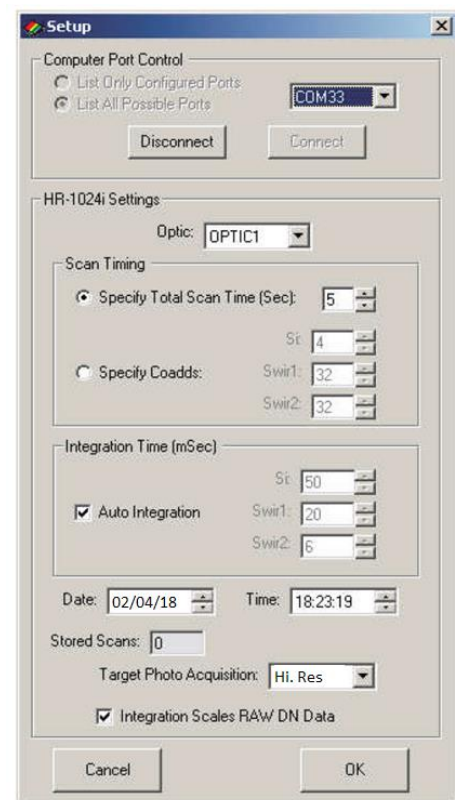
Main Acquisition and Graph Display:

This screen features five key areas:

- The Reference & Target Scan buttons
- The File Stack listing file names for Single & Multi graphs
- Single graph with Reference & Target spectral radiance and reflectance plots.
- Multi- graph with either Reference or Target spectral radiance or reflectance plot
- Instrument settings
- File header information including GPS, scan times, settings, WEDI values.

Scan Acquisition Controls (PC Mode):

- The Reference & Target Scan buttons can be activated with a mouse click or via the keyboard short-cut keys R or T.
- Right click on the Target Scan button to acquire multiple target scans.
- In Single Graph mode the Reflectance plot can also be included. Use the check box below the File Stack.
- Multi-Graph mode allows for either Reference or Target Radiance or Reflectance plots.
- Double click on a file name in the stack to revert back to a Single plot with the reference, target and reflectance data.

A typical single graph spectral reflectance plot is shown in Figure 18. In this example the red plot shows the reference panel radiance, the orange plot the vegetation canopy radiance and the black plot the vegetation reflectance. Data in the strong atmospheric water aborption band 1790 to 1960nm has been supressed - ref Window/Plot Settings dialog.
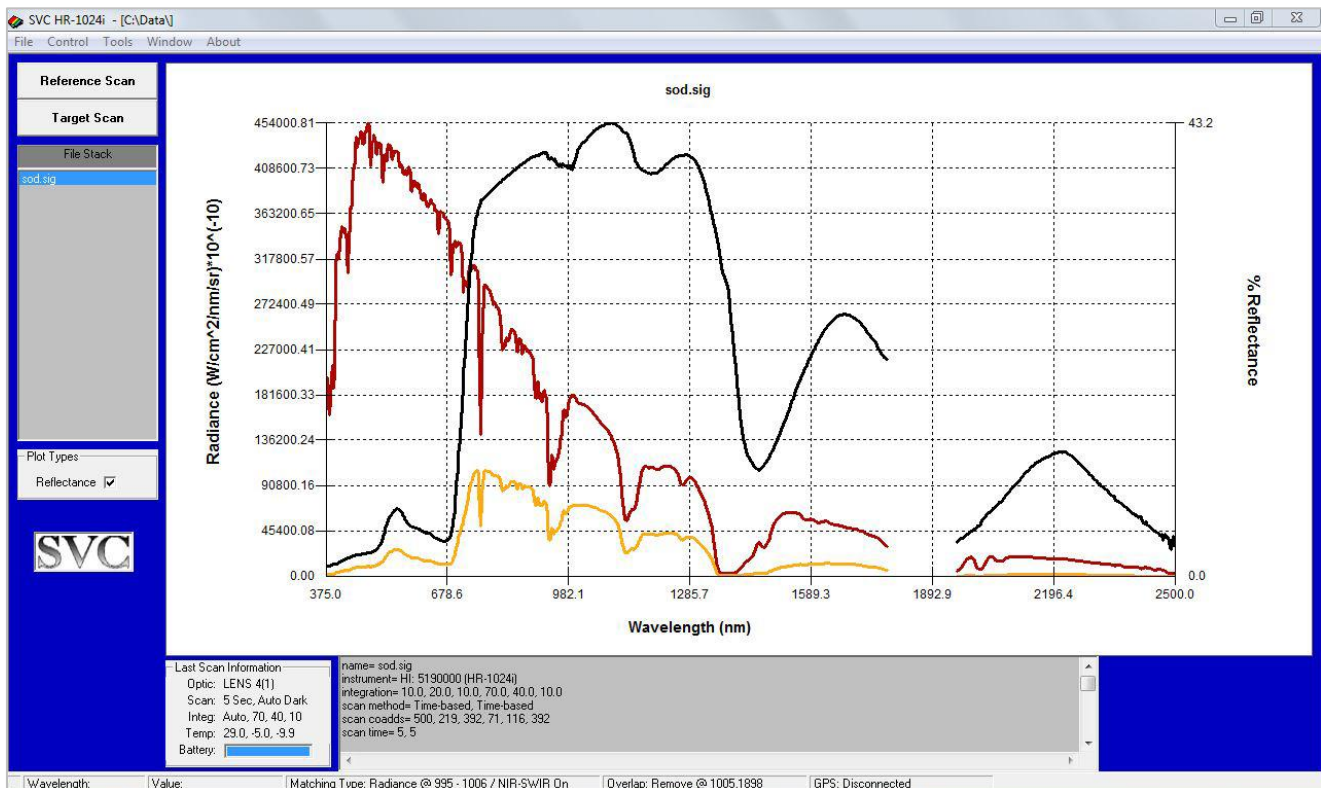
Figure 18

3.6.2 Windows Mobile or Android Applications for Compact Handheld Computers:

The SVCscan application for handheld computers offers a simpler graphic interface for controlling the i-Series spectroradiometers through a small touch-screen interface.

Instrument / Setup dialog

- Use the Instrument/Connect dialog to establish a Bluetooth interface to the spectroradiometer.
- Change to Instrument/Settings and select the correct Optic.
- Change the Scan Timing to your preference. However, with less stable ambient light a shorter Scan Time is always beneficial.
- The Photo Mode menu provides for Hi or Low resolution images to be captured together with the spectral data. Switch from High to Low Resolution photos to minimize any delays during unstable ambient light conditions. The Photo Acquisition can be turned off when the fiber-optic light guide is fitted.
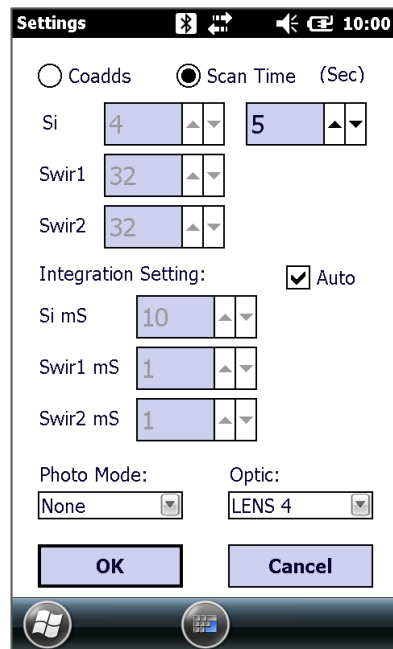
Acquisition and Graph Display:

This screen features:

- Large Reference & Target scan buttons
- Spectral Radiance or Reflectance graph. Use the Graph menu to switch between radiance & reflectance.
- File header/metadata information including GPS, scan times, settings..
- Menu bar

28
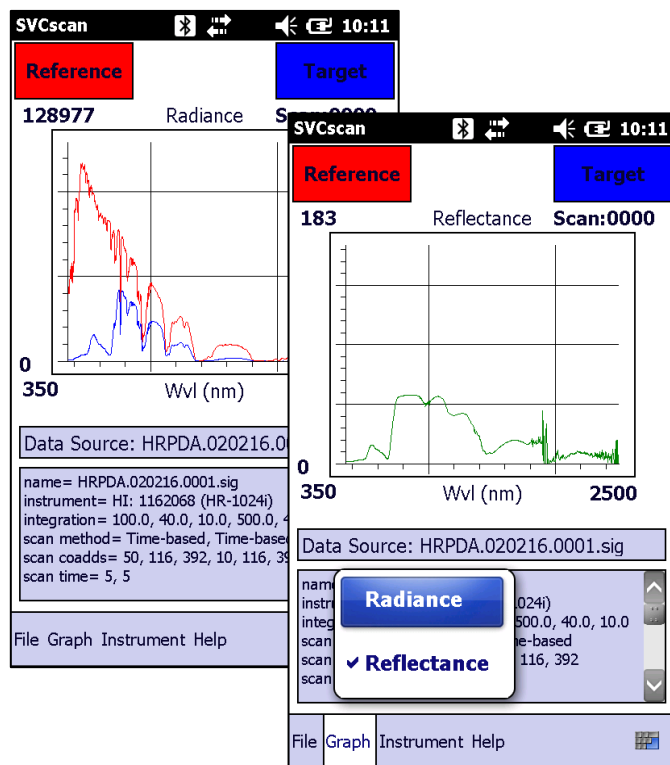
3.6.3 Stand-Alone Mode:

The SVC i-Series spectroradiometers have a large graphic display which provides visual prompts, system information and spectral data graphs. The touch screen can also be used to configure the instrument's communication and calibration settings, including the internal GPS, camera, trigger button with laser, Aux control and the WEDI, external detector interface.

Stand-Alone mode allow the user to take reflectance measurements without a computer or PDA. Full control is through the graphic touch screen display with the Reference and Target spectral files saved to the internal memory. The graphic display show full spectral information for each scan. Refer to the user manual and the Post Processing section in this guide for detail instructions when uploading spectral data files to a computer.

Instrument Settings:

Use the touch screen graphic display to control and adjust the spectroradiometer settings.
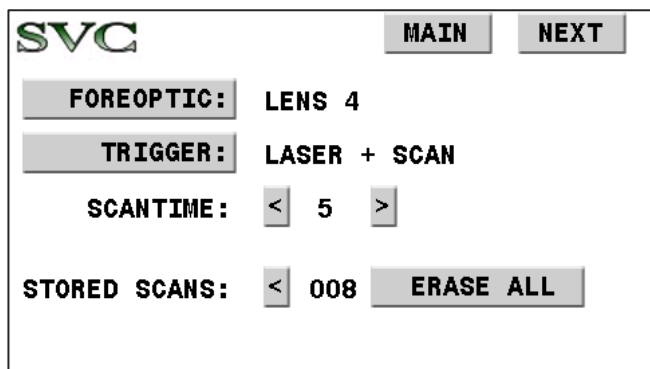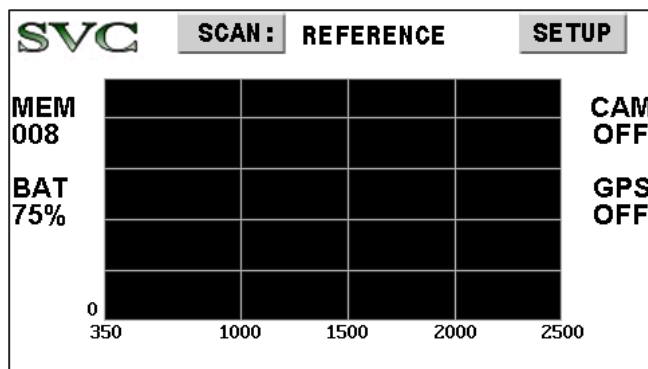
- From the main display touch the SETUP button and confirm or change the FOREOPTIC to match the lens or fiber fitted.
- The TRIGGER option relates to the function of the push button. The internal laser provides a useful marker to align the spectroradiometer to the reference panel or target surface when a fore-optic lens is fitted. The laser will switch on as the button is pushed down and remain on till the button is released, when the measurement scan will start. Change the TRIGGER option to SCAN ONLY when the fiber optic light guide is fitted.
- Set the SCANTIME to suit your preferences and ambient lighting conditions.
- Use the SETUP button to scan through the other settings screens:
    - CAMERA   HI, LOW (resolution) or OFF
    - GPS   ON, OFF and status
    - EXTERNAL DATA   WEDI
    - AUX FUNCTION
    - TILT UNIT   Internal tilt sensor settings, sound and calibration

Full details of all the Stand-Alone Settings are provided in the SVC User Manual [9].

Data Acquisition in Stand-Alone Mode:

The benefits and success of using the field spectroradiometer in "Stand-Alone" mode will require practice and experience. Users should familiarize themselves with PC or PDA modes before attempting to acquire data in Stand-Alone mode during a complex field campaign.

In stand-alone mode the spectroradiometer can be hand held, although it is recommended that a monopod is used to provide a stable platform and still allow quick movement between the reference panel and target surfaces. Use the audio tone for the internal Tilt sensor to ensure nadir viewing during reference and target scans.

The trigger button has multiple actions:
- Enable alignment laser
- Initiate a Reference scan
- Initiate a Target scan
- Acquire an image of the Target scene

The Settings menus are used to configure the laser and camera settings. However, the control for a Reference / Target scan option is through the main menu graphic SCAN button. After initially switching on the unit, the SCAN button will display REFERENCE.

This will change to TARGET on completion of the reference scan. However, it can be reset to REFERENCE to repeat the reference scan if necessary.

Use the same methodologies described in section 4.1 and 4.2 to acquire a sequence of Reference and Target scans including the final Target scan of the panel.

If the WEDI external detector interface is used it will be possible to monitor the ambient light on the graphic display for each target scan. This immediate feedback should be used to ensure high quality data sets or to determine when to abandon a sequence due to unstable lighting.
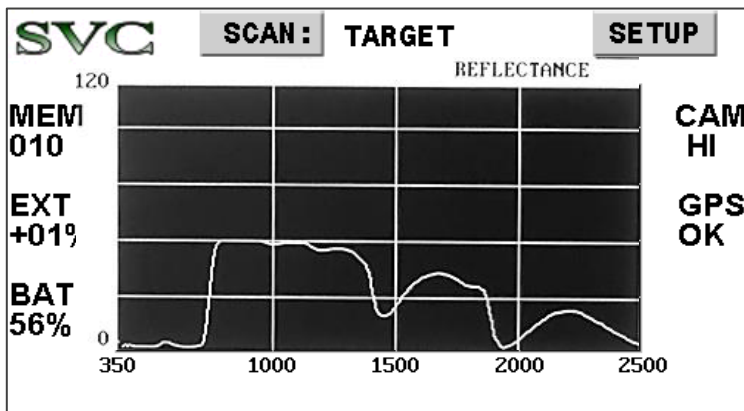
Stand-alone mode does allow for fewer members in a field campaign team. However, it may be difficult to complete a Log Sheet and also look after the reference reflectance panel without at least two team members. The Log Sheet template in the appendix should be adapted to replace the base filename with MEM (memory) location, Reference/Target type scan and external data values.

4 Methods & Configurations

The challenge in field spectroscopy is to record a pair of measurements (reference & target) in potentially variable or unstable ambient lighting conditions. Even under ideal blue sky conditions the scientist may be unaware of small changes in the light levels. In this section four methods are outlined where by it is possible to assess the stability of the ambient lighting between the reference and target scans. A data quality threshold can be applied to filter out compromised or invalid measurements.

Based on the SVC i-Series field spectroradiometers and accessories, the four methods, configured as either a single or dual FOV configurations are listed below:

- A spectroradiometer with for- optic lens or fiber optic acquiring bi-conical (bi-directional) sequential reference and target scans. One calibrated reference panel.
- A spectroradiometer with external irradiance detector (WEDI) acquiring bi-conical sequential reference and target scans and simultaneous irradiance measurements. One calibrated reference panel.
- Two spectroradiometers configured with fore-optic lenses or fiber optics acquiring simultaneous reference and target scans. Two calibrated reference reflectance panels. Dual Field of View (Bi-Conical).
- Two spectroradiometers, one configured with an irradiance diffuser or integrating sphere, the second with a fore-optic lens or fiber optic, acquiring simultaneous reference and target scans. One calibrated reference panel. Dual Field of View (Cos-Conical).

4.1 Method I - Single Field of View, Bi-Conical

By far the most common configuration for field measurements includes just a single spectroradiometer configured with a fore-optic lens (or fiber optic light guide) and a reference panel to acquire sequential reference and target scans. In normal practice, this method would have to rely on very stable ambient lighting or minimize the time between the reference (panel) scan and the target (canopy) scan. This can be realized by minimizing the 'Scan Time' settings in the SVC application and acquiring a single target scan for each reference scan often referred to as RT,RT, etc. Unfortunately this protocol does not give any feedback on any changes in the ambient light.

However, by adding a 'target' measurement of the reference panel at the end of the sequence, it is possible to record the any change in the ambient lighting relative to the

initial reference scan, with each target scan bracketed by a before and after measurement of the panel. A shorthand expression for this could be:

$$REF_{Panel} \rightarrow TAR_{Canopy} \rightarrow TAR_{Panel}, \text{ or } R_P\text{-}T_C\text{-}T_P, \text{ or } R\text{-}T\text{-}P$$

The reflectance values for the Target/Panel measurement will indicate any change in the ambient light. This would show as a 100% horizontal line with stable lighting. At this point a simple quality threshold level could be implemented where by data can be rejected if the ambient light levels changed by more than ±2%, for example. This could be applied across the spectrum or perhaps just in the region of interest. Note however, there is more variation in ambient light levels within atmospheric vapor bands.

With more stable ambient lighting conditions, it would be possible to extend the measurement series with sequential target measurements of the canopy before a final target measurement of the panel as shown in Figure 19.
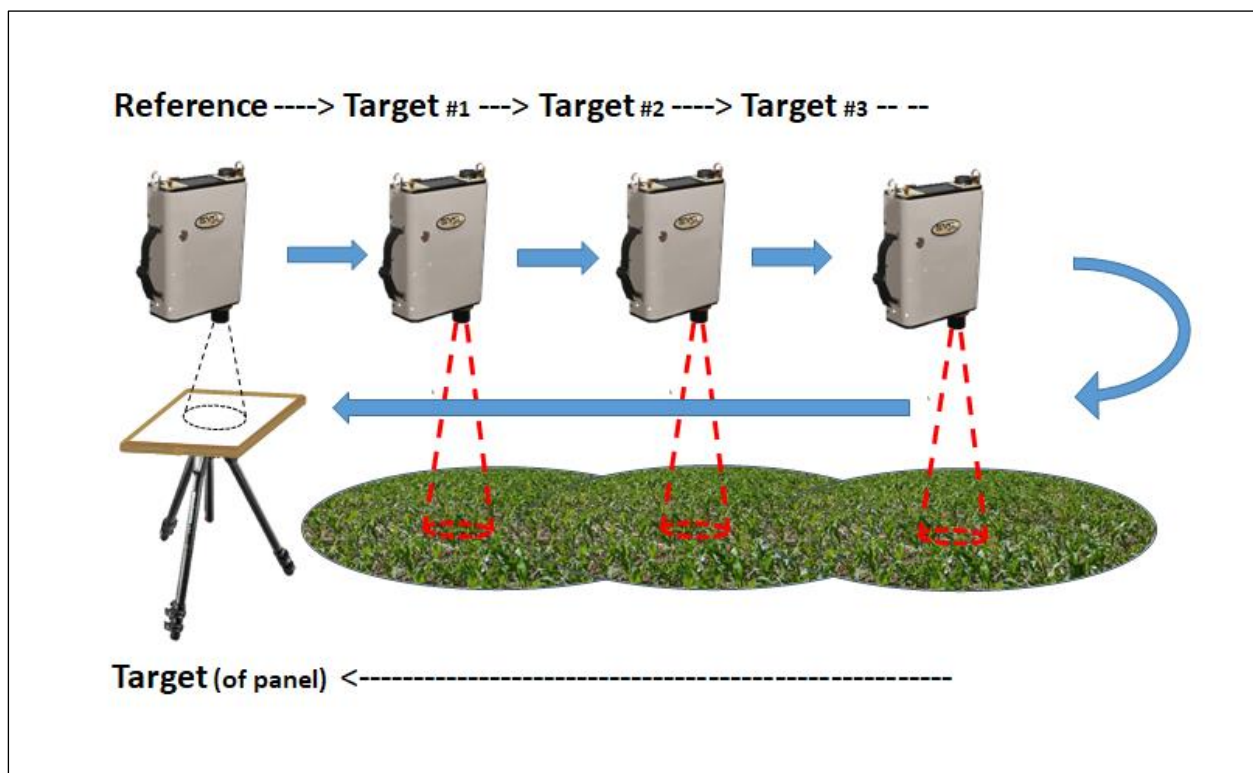
Figure 19 Spectroradiometer with single fore-optic lens or fiber acquiring sequential measurements.

All the spectra are automatically saved within the SVC application and can be graphed to show radiance or reflectance values. The latter can be used to give a quick visual check on the ambient light stability with the final panel measurement – ref Figure 20.
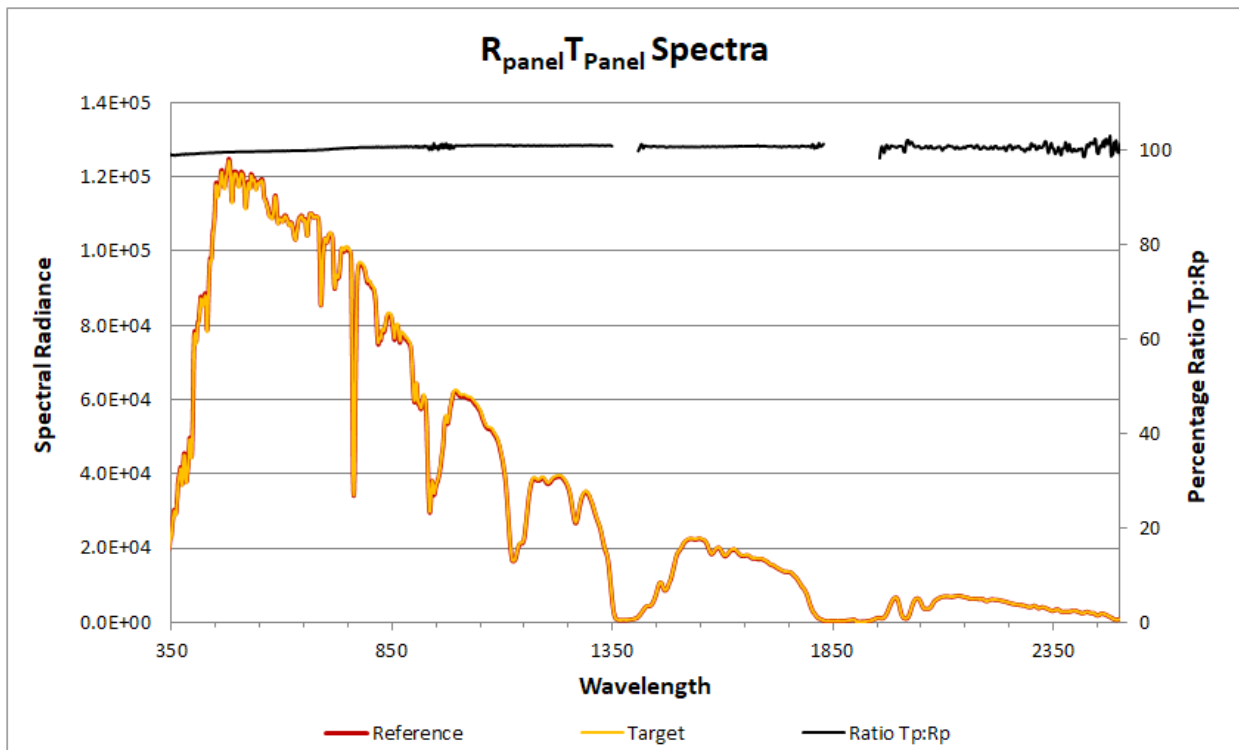
Figure 20 Graph showing the Ratio of Reference & Target Panel scans (water band data removed)

It is essential to include notes in the Log Sheet detailing the sequence in short hand, for example R-T-T-T-P (99%), with the percentage a quick indicator of the light stability.

Repeated (Target) measurements of the reference panel can also be used to quantify the ambient light stability and tailor the method prior to the field trial.

4.2 Method II - Single Field of View with External Sensors (WEDI)

The single FOV spectroradiometer acquiring bi-conical measurements detailed above gives a measure of the ambient light levels at the start and end of a sequence, but lacks any information regarding the stability of the light between the first and last panel scans. Good practice requires that this method be restricted to a limited number of target scans with the total sequence time under a minute or two.

The SVC Wireless External Detector Interface (WEDI) accessory allows for a record of the ambient light levels immediately prior to and after each spectral scan throughout a sequence with the data displayed on the computer and recorded into the file header for each measurement. This gives an immediate indicator of changes in light level without the need for any guess work. The WEDI can be configured with up to sixteen narrow band detectors, providing multi-spectral information across the full spectral range. Alternatively, a single broad-band detector such as the Licor quantum (PAR) &

silicon pyranometer detectors or CropScan multi-spectral radiometer can be coupled to WEDI with their signals integrated into the SVC application and spectral data files, ref Figure 21.
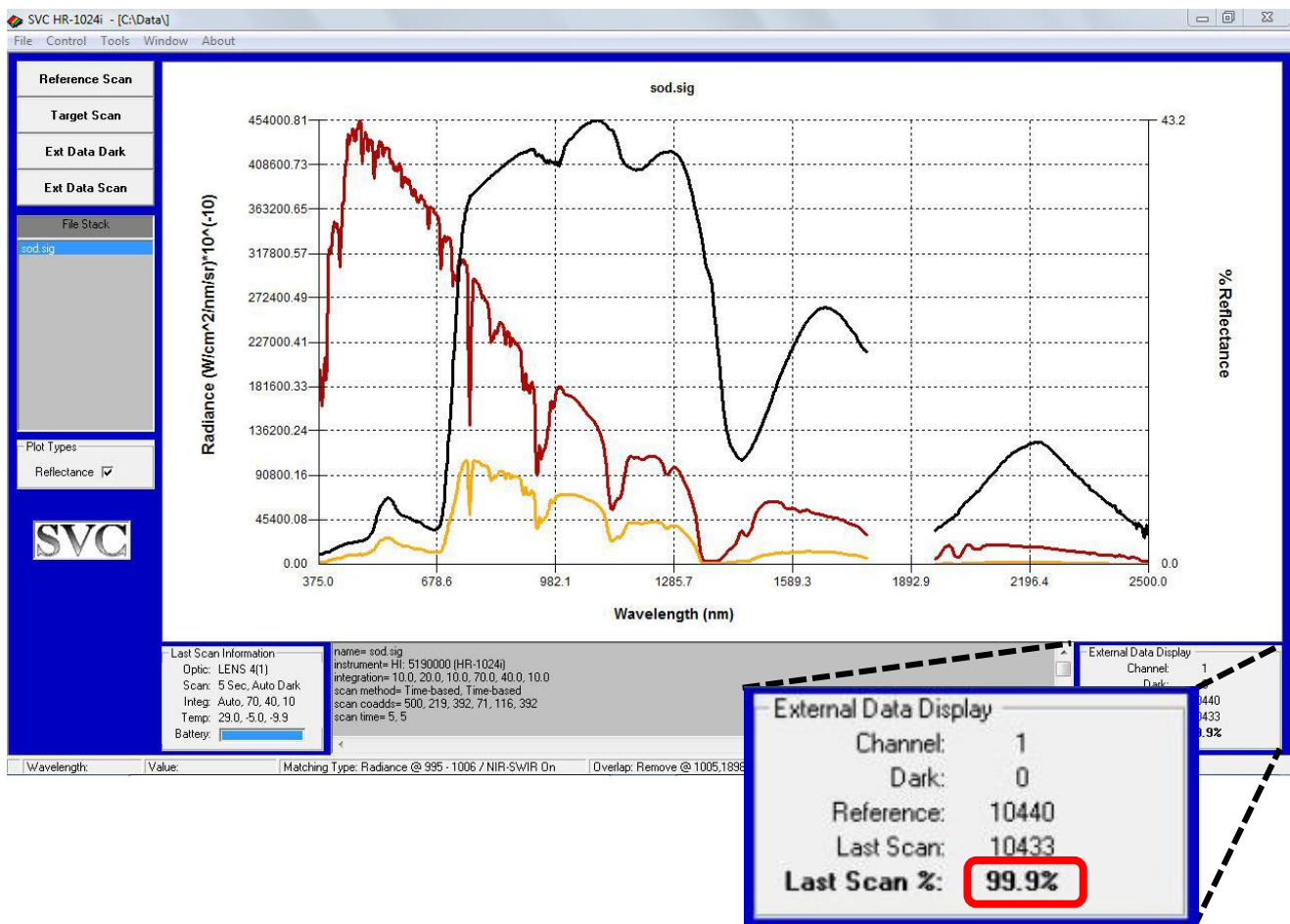
Figure 21 SVC application showing External Data (WEDI) acquired with each spectral measurement.

The sequence of measurements when acquiring data with WEDI support is similar to Method 1 with the option of extended the sequence to include more Target measurements as shown in Figure 22.

An initial reaction may be to cancel a sequence due to a dramatic change in the ambient light as observed with the External Data values. However, there is still value in returning to the reference panel and recording a final "Target" scan and thus provide a bracketed data set. Milton E. R., [4] postulated that the spectral irradiance spectrum could be calculated from multi-spectral data. The WEDI data could then be used to re-calculate the Reference scan for a modified reference which in turn is used to recalculate the

Target reflectance values. The final Target measurement of the reference panel provides a check for the WEDI data adjusted reflectance calculations.
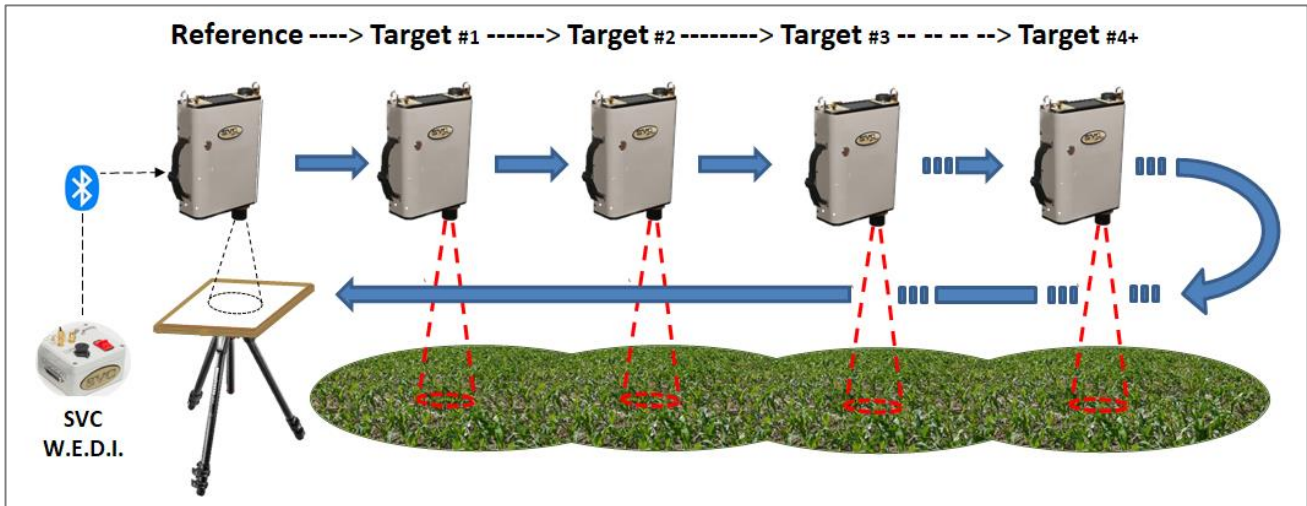
Figure 22 Method II, Spectroradiometer with External Ambient Light Detector(s)

The short hand sequence for Method II shown in Figure 22 would be:

$$REF_{Panel} - TAR - TAR - TAR - TAR - TAR_{Panel} \text{ or } R_p\text{-}T\text{-}T\text{-}T\text{-}T\text{-}T_p$$

From the WEDI data stored in each file header, it would be possible to track the ambient light during the measurement sequence, for example:

Scan	REF$_{Panel}$	TAR #1	TAR #2	TAR #3	TAR #4	TAR$_{Panel}$
WEDI (Ref)	100%	-	-	-	-	-
WEDI (Tar)	-	99.8%	99.7%	99.8%	99.9%	100.2%

The WEDI data can also be used to filter out data files where the change in ambient light is above the quality threshold or requires a scaling correction.

4.3 Method III - Dual Field of View, Bi - Conical

Methods I and II require sequential scans of a reference panel and then target canopy to measure the reflectance properties of a surface. However, when two spectroradiometers are configured in a Bi-Conical (or Cos-Conical) Dual Field of View, the reference and target scans can be simultaneous and thus the reflectance data is independent of variations in ambient light levels. Following the NERC, Field Spectroscopy Facility protocol [5] changes in ambient light levels are simultaneously recorded on the "Reference" spectroradiometer (S1) while acquiring multiple target scans (S2) – ref Figure 23.
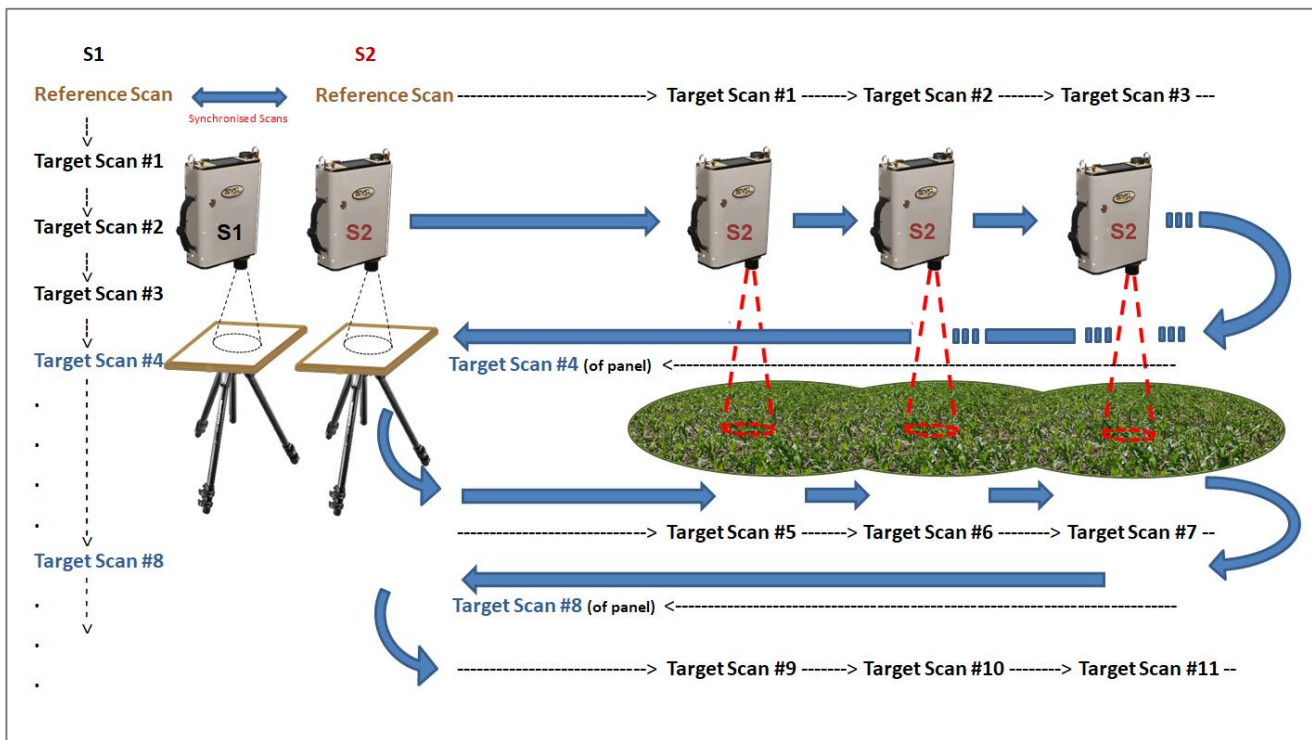
Figure 23 Method III, Two Spectroradiometers, Bi-Conical Dual Field of View

The short-hand sequence for Method III shown in **Figure 23** would be:

Synchronized Scans	Ref Scan	Target Scans										
		#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**
Spectro. S1	R_p	T_p	T_p	T_p	T_p	T_p	T_p	T_p	T_p	T_p	T_p	T_p
Spectro. S2	R_p	T	T	T	T_p	T	T	T	T_p	T	T	T
Time	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}

Table 6 Example Bi-Conical DFOV Measurement Sequence

Under variable ambient lighting conditions, the reflectance data from the Target scans of the reflectance panels (#4 & #8) may show deviation from the 100% reference.

After processing the DFOV reflectance data according to the NERC FSF protocol, the Target Scans of the reference panel are rescaled back to 100%, ref Figure 24. This data set was taken under variable ambient lighting conditions. The near perfect correction of the Target panel data (outside the atmospheric water bands) provides strong visual evidence for the success of the correction method. This confidence can then be transferred to the quality of the Target canopy reflectance data.
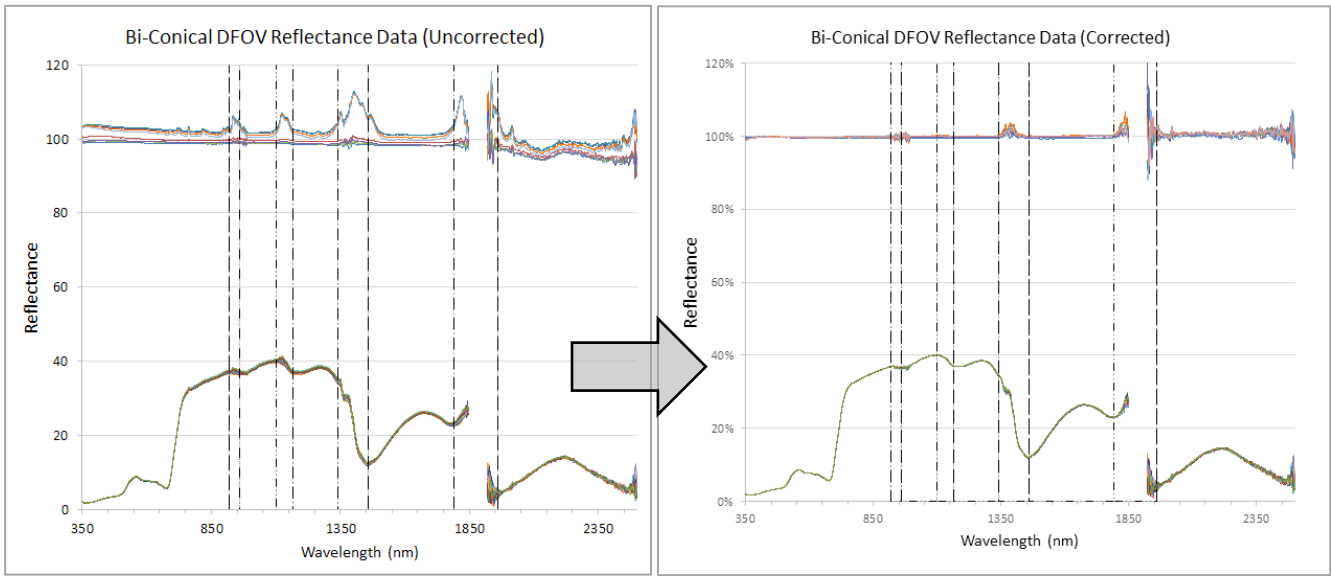
Figure 24 Uncorrected and Corrected DFOV Vegetation Canopy and Reference Panel Data
(atmospheric water band data removed 1850 – 1930nm)

Under most conditions, it is possible to increase the number of DFOV Target scans of a canopy to ,say, 10 before returning to the reference panel for a TAR$_{Panel}$ scan. In principal it would be possible to continue to acquire say 50 or more simultaneous scans with S1 & S2 spectroradiometers without requiring a new Reference scan, ref Table 7.

	Ref	Target Scans																				Ref
	Scan	1	2	3	4	5	6	7	8	9	10	11	12	13	14					48	49	50	Scan
S1	R$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	T$_p$	..	..	..	..	T$_p$	T$_p$	T$_p$	R$_p$
S2	R$_p$	T	T	T	T	T	T	T	T	T	T$_p$	T	T	T	T	..	..	..	..	T	T	T$_p$	R$_p$

Table 7 Example of Extended Bi-Conical DFOV Measurement Sequence

However, the risk of signal saturation or sub-optimal settings could reduce data quality and it is recommended that the Reference scans be reacquired after 10 minutes of data capture.

4.4 Method IV - Dual Field of View, Cos - Conical

Methods III and IV are very similar with the exception that the Reference spectroradiometer (S1) is reconfigured to measure the down welling irradiance using an integrating sphere optical accessory. Note as the NERC Field Spectroscopy Facility protocol uses the relative change in ambient light levels recorded by S1 to correct the reflectance data measured by spectroradiometer S2, it is not a requirement that both S1 and S2 spectroradiometers have identical input optics. However, the integrating sphere fore-optic of S1 must have a cosine angular response.
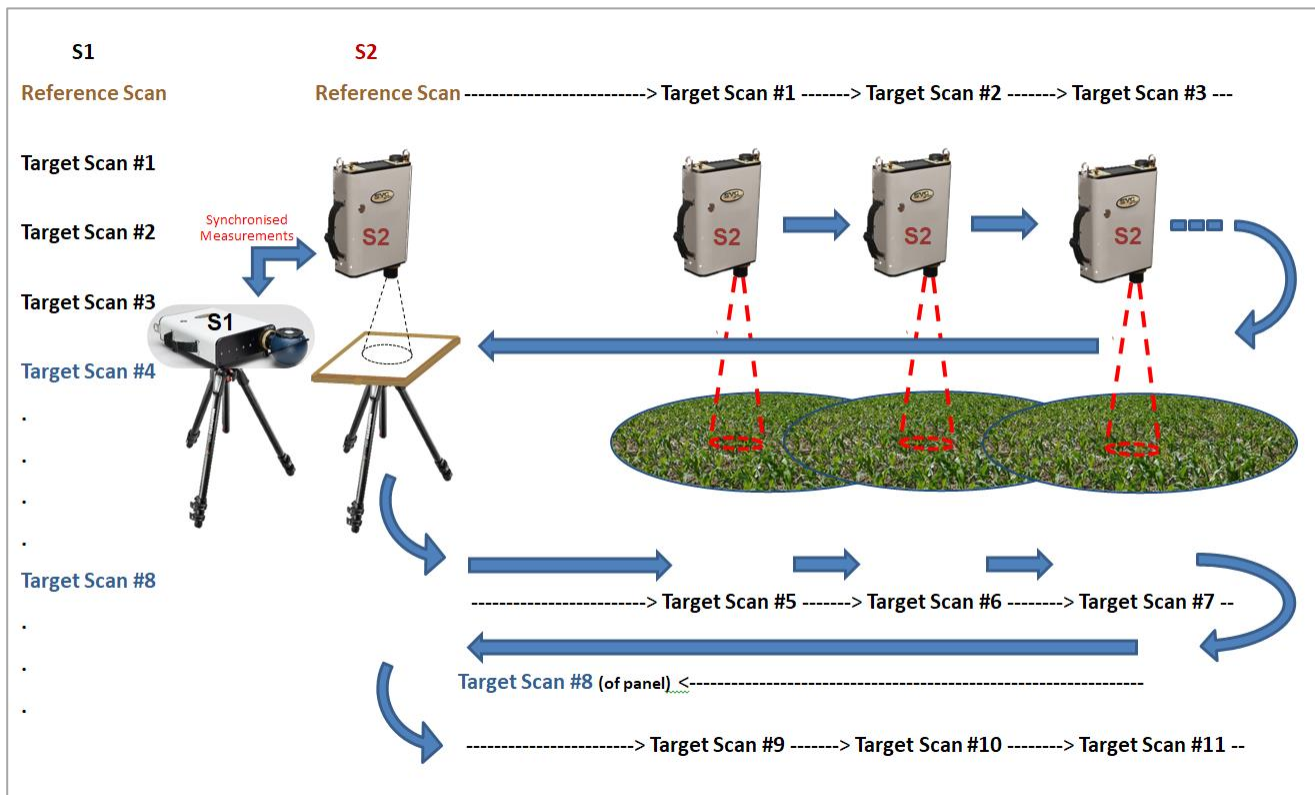
Figure 25 Method IV, Simultaneous Measurements with Two Spectroradiometers - Cos-Conical

The short-hand sequence for Method IV shown in Figure 25 would be:

Synchronized Scans	Ref Scan	Target Scans										
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Spectro. S1	R_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}	T_{cos}
Spectro. S2	R_p	T	T	T	T_p	T	T	T	T_p	T	T	T
Time	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}

Table 8 Example Bi-Conical DFOV Measurement Sequence

5 Field Measurements

The design and methodology for the field study will first be dependent on the research objectives for the study. For example, is the data collection intended to create or build spectral libraries, or to establish or test a hypothesis? The field work may also be in support of airborne or satellite image data and used with empirical line method in atmospheric correction.

Prior research of the field test site will allow advanced planning for a robust measurement strategy with consideration for uniformity/heterogeneity, size/scale, personnel requirements, jigs and fixtures, public access to the site, security and risk assessment.

5.1 Sampling Strategy

The sampling strategy for each site will be guided by a combination of factors including the site scale, ranging for example from the reflectance of an individual leaf or plant to representative reflectance values for a satellite sensor pixel 10 meters in size or larger. Uniformity or heterogeneity of a site will also have strong bearing on the sampling strategy. For example, with heterogeneous sites a deliberate target selection of high and low reflectance surfaces may be required to quantify the range of reflectance values within the site. This list below describes some of the sampling methods deployed in field spectroscopy.

- Point Sampling: The strategy may be to visit a test site and identify different areas of interest. This may not be representative of the site as a whole but perhaps the diversity of reflectance values for the site. Note also that sample size should be larger for variable site.

  Random Sampling: each point is randomly selected across the tests site.

  Stratified Random Sampling: divide the test site into equal areas and randomly select 'n' sampling points within each area (strata).

  Systematic: the test site has a virtual grid pattern across it with a sample measurement taken at each intersect of the virtual grid. Care should be taken to avoid intentional or unintentional deviation from the grid pattern which may introduce a bias to the data.

- Plots: Experiments are often carried out on controlled plots within a research station for example. In this case it may be important to

get a representative reflectance value or range of reflectance values for each plot on a regular basis. This may also require careful measurement for location and height at each sample point to track changes in spectral reflectance throughout the trial period. Careful planning may be required to accommodate large changes in canopy height and spread, for example.

- Transects & Smear:

Transect measurements can be conducted on foot, in a vehicle, along a rail track or even from a boat. In general the measurement(s) will follow a straight line but it can also be a contour or path. It should however be replicable rather than random. The transect can be a series of point measurements, for example move – stop – record etc. Alternatively, the spectroradiometer can be configured to record continuous measurements as the instrument moves across the landscape on a vehicle. Figure 26 shows optional settings for the scan time/co-adds, auto-integration and movement. The optional WEDI provides valuable information on ambient light stability. GPS data is recorded prior to saving each spectral data file.

During a walking or moving transect scan the field of view of the spectroradiometer moves across the target canopy / scene while a measurement is taken (shutter open). This smearing of the target scene creates a reflectance spectra that is equivalent to the average target reflectance across the smeared scene.

Note: for certain scenes in moving smear measurements it is possible to have temporary signal saturation, for example when the integration time is set for low reflectance soil and subsequently used on a high reflectance canopy.
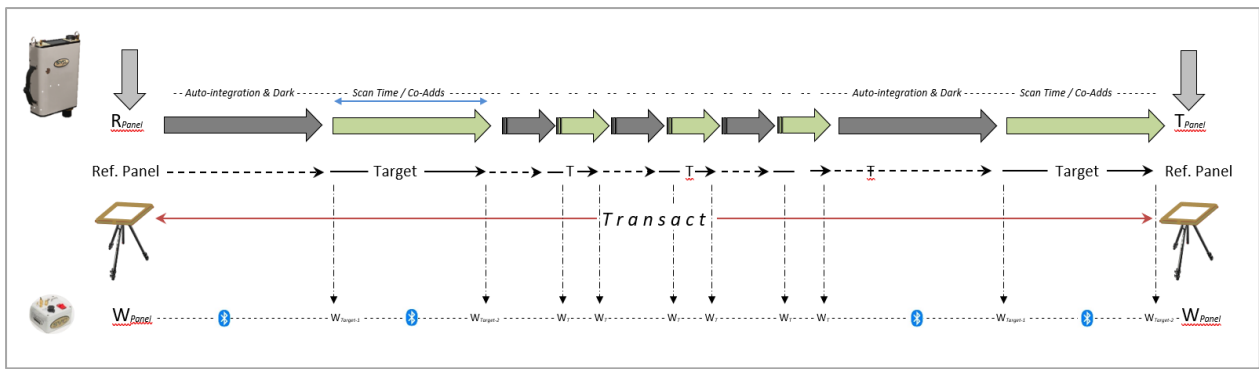
Figure 26 Timing sequence during a Smearing Transect scan

5.2 Replication and Statistics:

A single spectral reflectance measurement on its own is of limited use and this will require additional information to quantify data uncertainty. From the series of measurements listed below it will be possible to extract information that should be factored into the measurement uncertainty budget:

- Signal to noise ratio:

    The s:n ratio of measurement data provides a simple test for maintaining data quality. For example 10 spectral scans of the same target are acquired and analyzed to give a standard deviation in the measurement value for each spectral point. This can then be ratioed with the mean value at each wavelength. Regions where the s:n ratio is below say 100 can be identified and excluded from the analysis.

- Measurement repeatability & pseudo replication:

    Statistical analysis of a large number measurements of the same target sample can be used to assess for training and method robustness. For example, a test can be devised to compare reflectance data of a specific canopy sample acquired by a number of students. In each case the measurement sequence will require the spectroradiometer to be moved alternatively from the reference panel to the target canopy and back – REF_{Panel} -> TAR_{Canopy} -> TAR_{Panel}. This will ensure the instrument has to be re-aligned three times in each sequence – a critical operation in any measurement. The sequence can be extended to include two or more different target canopies ($TAR_{\#1}$ -> $TAR_{\#2}$) between the REF_{Panel} and TAR_{Panel} measurements.

    Students should be aware of pseudo replication where repeated measurements of the same sample are taken without re-aligning the tripod and spectroradiometer between measurements. Pseudo replication would only be valid when assessing ambient light stability.

    Measurement repeatability provides valuable feedback when assessing, developing or improving your method. Note it may be necessary for training or

method testing to use a homogeneous target prior to field tests with a complex heterogeneous canopy.

- Sample variability: It may be necessary to quantify the variability of the spectral reflectance values across the test site. This analysis may require dozens of targets and replicates of those same targets. It is thus important to ensure the detail in your method gives the best measurement repeatability and includes provision to monitor ambient light stability and data quality control.

5.3 Planning & Preparation

Planning and preparation are essential steps towards a successful field campaign. The list below can be used as a guide which should be adapted to your requirements and experience.

- Research goals: The research questions and goals should be documented and articulated to your team members.

- Field site survey: Where possible, visit the site, take photographic records, GPS co-ordinates, landmarks etc. Satellite and airborne surveys may not show all the details or obstacles which can hinder your campaign. Investigate any recent changes to your site caused by farming, deforestation, fires and other natural events.

- Support team: A minimum support team can comprise of Team Leader and an assistant. However, with additional team members it should be possible to acquire more measurement data and record important meta data. Be aware that with a large support team there are risks of inadvertent damage to the field site. For example, trampling over the vegetation canopy.

- Health & Safety: Conduct a risk assessment for your field campaign and disseminate the information with the team. A first aid kit should be included with the equipment.

- Method details: The method[§] deployed will depend on the equipment available for your field campaign, but other factors may need to be considered, such as transportation

limitations, support team, public access, security and difficulties of moving around the field site.

§ Reference Section 4 for suggested methods and system configurations.

- Sampling strategy:

  Detail the sampling strategy onto the log-sheet templates. This will improve efficiency and accuracy of data record collection.

- Training:

  Training will greatly improve the success of your field campaign. An outline training program for a field spectroscopy measurements is listed in Appendix 1.

  Bring the team together for a day's training at your institute or if this is not possible, add an extra day to the field campaign for training.

- Equipment QA tests:

  It is essential to run a series of Quality Assurance (QA) and functional tests with the spectroradiometer and its accessories well in advance of the start of your field campaign. This will allow some time for adjustments and reduce the risk of cancelling the field campaign due to equipment or computer§ failure or damage to the reference panel, for example. Details for recommended QA tests are shown in Appendix 1.

  §Some difficulties can arise when switching to a new computer for the field spectroradiometer. In particular some operating systems may require *Administrator permission* to allow the Bluetooth interface to be re-configured. Refer to the SVC User Manual or Tech Guide #1 – iSeries Communications.

- Equipment list:

  The field spectroradiometer with its accessories is typically supplied in an equipment case. However, there are additional items, such as tripods, jigs & booms, reference reflectance panels, DGPS, cameras, light meter etc, which may be desired. It is highly recommended that a list of all required items is generated before packing or shipping. A field campaign may be repeated throughout a season or over several years. Review and update your equipment

list at the start and end of each field campaign. An example list is included in Appendix 1.

- Batteries & Power:

  Charging the batteries of the spectroradiometer, computer and other accessories can be challenging for some field campaigns. There are many options available including multiple batteries per device, solar panel chargers, laptop car adapters and battery eliminator option – ref SVC accessory.

- Weather:

  It is almost impossible to take field measurements when the weather is wet or at risk of raining. The exception to this may be when samples are collected and measured indoors, or in a tent with a LC-RP Pro or Reflectance/Transmittance integrating sphere accessories.

  Outdoor field spectroscopy can be totally reliant on weather conditions, with the reflectance data dependent on the illumination and factored into the measurement uncertainty budget. The reflectance spectra with its accompanying meta data includes a description or measurement§ of ambient sun and sky lighting conditions.

  The Principal Investigator should always review the weather including ambient light and wind conditions before proceeding or continuing with field measurements.

  §The global/diffuse ratio of sky and illumination is calculated from two radiance measurements of the reference panel with and without sun shading or from a sunshine pyranometer. Ambient light stability can also be monitored using an external detector or repetitive measurements of the reference panel.

5.4 Records/Log Sheets/Images

During the course of a field campaign you are likely to capture hundreds of spectral scans, perhaps even hundreds per day. Most vegetation reflectance spectra, for example will at first glance seem similar and it is therefore quite possible to lose track of which spectral relate to the different samples. Listed below are some options to facilitate record keeping:

- Log sheets:

  Log sheets will provide a valuable record of the field campaign and should be digitized (imaged or scanned) and saved with the spectral data files. Pre-printed log sheets should reflect the method, sampling strategy, replication statistics , file naming and meta data plan. In order to maintain order in the sequence the computer operator or assistant should complete the log-sheets in real time.

  Incorrect measurements or anomalies should be immediately recorded in the log sheet for review and quarantine at a later time.

  The log sheet should clearly indicate when a new reference measurement is taken and the final target measurement of the reference panel. This will allow for verification of ambient light stability during a sequence.

  Periodically include the computer time on the log sheet beside a filename. It should not be necessary to include the computer time with each measurement.

- Custom log sheets:

  The generic log sheet can also be tailored to suit different methods, sequences or applications. For example, a separate log sheet can be created when recording ambient light stability, or when measuring the global/diffuse ratio for sun and skylight. A customized log sheet should improve measurement protocols and simplify record keeping.

- Team co-ordination:

  The PI (Principal Investigator) should co-ordinate the measurement sequences to ensure accurate records, compliance with methods, ambient lighting conditions etc. The PI should also pause the data capture after the first sequence to perform an in-situ review of the radiance & reflectance graphical data to confirm the correct processes and records. In-situ reviews should be repeated at frequent intervals.

- File naming / directories:

  In general the application software for a field spectroradiometer will automatically add a numerical suffix to the file name. However, great care has to be

- Computer clock: Ensure the computer/laptop clock is set to local GPS time.

- Image capture: Whatever the strategy deployed, it is highly recommended that an image of each measurement scene is recorded with the internal camera (SVC iSeries) or a phone camera when the fiber optic accessory is used. Note the former is automatically linked to the spectral data file, while he latter will require a note in the log sheet to identify the image to the data file.

- GPS co-ordinates: GPS points of the field site boundary, sample points or transacts provide a useful record. Spectroradiometer systems with built in GPS systems will automatically record the Lat/Lon/Alt/Time to each data file header. The GPS system within the SVC iSeries spectroradiometers can also be configured to work with a local base station for higher positional accuracy.

- Measurement sequences: Use your own short-hand script to record sequences or as shown in section 4: REF_{Panel} -> TAR_{Canopy} -> TAR_{Panel} *or* R_P-T_C-T_P *or* R-T-P …

5.5 Equipment Setup

Weather and time permitting, arrive on the field site at least 3 hours before solar noon. More time may be required if addition equipment and systems are to be deployed.

Before removing the equipment from their cases, it is prudent to remind the team that care should be taken when handling optical instruments which need to be protected from rain, water and dust. In particular, the surface of the calibrated reference panel should never to touched and should be covered when not in use.

Find a suitable base to lay out the equipment. In bright sun it may be necessary to shade the instruments when not in use to reduce heating from direct sunlight. Note the spectroradiometer detector arrays are cooled to well below ambient. If the spectroradiometer housing is heated by sunlight the battery life will be reduced as the

detector coolers are required to dissipate more heat. An optional fan module [9] is available for high temperature environments.

The spectroradiometers should be switched on and allowed to stabilize for 10 - 15 minutes prior to start measurements. Select the fore-optic as per your preferred method and note the required height between the surface (top of canopy) and the entrance to the fore optic.

A YouTube demonstration for field measurements is also available.

Field Spectroscopy - YouTube Video

5.5.1 Field Site

Set up the GPS base station if available.

Following the design method and sampling strategy, mark out the field site and sampling points or transects with flags or cord. GPS co-ordinates for various markers should be recorded in the site plan and log sheets. At this point, it is important to inform the team members, the land owner or public which areas to avoid and minimize unnecessary disturbance.

A portable weather station with anemometer will also provide valuable meta data.

5.5.2 Reference Panel

Set up the reference reflectance panel on a tripod. The panel should be positioned close to the sampling plots or transect and above the height of the vegetation canopy or in a clearing. In general the panel is to be mounted horizontal.

Table 9 lists the recommended distance between the fore-optic lens or fiber and the surface of a 10” x 10” (25 x 25cm) reference reflectance panel.

The size of the measurement scene is derived from simple trigonometry with the diameter of the lens also factored in.

SVC Fore Optic	Height	Scene Dia. (ϕ)
4° Lens	30 cm, 12"	5 cm
8° Lens	30 cm, 12"	7 cm
14° Lens	30 cm, 12"	9 cm
Fiber Optic Light Guide	30 cm, 12"	15 cm

Table 9 – Panel to spectroradiometer height

With the recommended distance of 30cm above the panel, the spectroradiometer will shade only 3% of skylight, typically < 0.2% of the total illumination at 700nm.

Smaller size reference reflectance panels are not recommended when the spectroradiometer or fiber optic light guide is hand held.

Shade: Note that the spectroradiometer should never shade the reference panel. Team members should stand well back from the panel to avoid shading or reflecting sunlight onto it.

When the sun is directly overhead, it may be necessary to re-orientate the spectroradiometer to view the center of the panel and target canopy at a small angle off nadir. This should not affect the measurement accuracy, as the panel has excellent Lambertian reflectance properties close to nadir.

Stance: Whether the spectroradiometer is hand held, monopod, tripod or jib mounted, it should always be presented to the reference panel with a method that minimizes sunlight reflected from the person or equipment onto the top surface of the panel. For example, with the sun illuminating from the front, stand to the left or right, minimize your height and increase the separation between the panel and you. Note, monopod, tripod, jib or jigs should have blackened surfaces when in proximity to the panel.

Clothing: Dark clothing is recommended for the spectroradiometer team members but care should be taken when selecting the correct clothing. Many black dyes are highly reflective in the NIR and SWIR regions. Use the field spectroradiometer to quickly assess the suitability of available materials.

5.5.3 Field Spectroradiometer

The setup for the field spectroradiometer is detailed in the User Manual [9]. Listed below are a number of settings and features which will aid data collection, records and analysis.
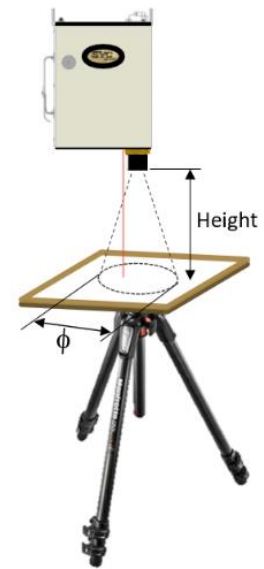
- **File Name & Directory:** From the file menu select New and create a base filename & directory. This should match the log sheet nomenclature.

  From the File/Data Options menu choose Autosave to collect a sequence of measurement files with a numerical suffix, or Prompt to save for unique filenames for each measurement.

  From the File/Data Options/Format menu select Sig File. This provides a complete set of data comprising of the file header and four columns of data – Wavelength, Reference Radiance scan, Target Radiance scan and Spectral Reflectance.

- **Instrument Settings:** Ensure the correct Optic is selected from the drop down menu.

  Note after connection to the spectroradiometer the Date & Time should match GPS time.

  Auto Integration should be checked for most applications, although Transect /Smears may require the integration time to match the reference panel settings.

  Scan Timing – the default is 5 seconds Total Scan Time but this may be reduced with perfect sunlight illumination.

  The Scan Time refers to the accumulation of multiple auto exposures for each detector array. A second set of multiple exposure are also acquired with the shutter closed. Thus a default scan time of 5 seconds takes 5 + 5 seconds + data transfer to complete.

- **Target Photo Acquisition:** Whatever the strategy employed, it is highly recommended that an image of each measurement scene is recorded with the internal camera. However if the fiber optic option is used, the internal camera should be disabled and an external camera or phone camera used to capture scenes. Note high resolution images take longer to upload to the computer or PDA.

For transect measurements change the Photo Acquisition to low resolution.

Note, when using the Android application with a fiber, the Android's internal camera can be used to capture and simultaneously link the photo with its SIG data files.

- GPS:

  The SVC i-Series spectroradiometers have a GPS module built in with data saved to each file's header. This is factory set but can adjusted to link to a GPS Base Station for even higher precision measurements.

- Matching/Overlap:
  (Does not apply to the SVC HR-512i)

  The recommended settings for the SVC i-Series are:
  Remove Overlapped Data
  Reflectance Matching
  Region 960 – 1000nm
  Factors Min 0.90, Max 1.10
  Use the NIR/SWIR Overlap Algorithm

  Experienced users may have alternative preferences.

- Single / Multiple Graphs:

  Single graph option displays the initial Reference radiance scan (of the panel), the Target radiance scan and relative Reflectance. The captured image file can also be viewed with a Single Graph.

  Multiple graph can display up to 50 Reference or Target or Reflectance scans.

  Select the graphic options which provides you with the greatest feedback.

  Atmospheric water will strongly attenuate parts of the SWIR region. This is most evident in the reflectance data where noise can dominate the graph and result in large re-scaling of the Y axis. Use the Window/Plot Settings menu to 'blank' selected regions. For example remove atmospheric water bands data @1350-1460nm and @ 1790-1960nm.

- External Data option:

  Mount the external detector module (WEDI) on a tripod above the canopy. The Bluetooth interface has a range of up to 50m and can be placed near to the

center of the field site or close to the edge for small sites.

Follow the User Manual [9] to set up SVC PC or Mobile data applications for the wireless external detector interface (WEDI). Note this should be tested, using the External Data Dark & Scan buttons, prior to taking measurements.

5.5.4 Field Accessories

There are numerous options for holding or mounting the field spectroradiometer when acquiring spectral data. For example, the instrument can be hand held over the reference panel and target canopy. It can be mounted on a monopod and quickly moved around between the panel and target or a tripod over the target with the panel inserted below on a swing boom. Alternatively the SVC i-series can be fitted with a fiber optic light guide and mounted in a back pack.

The best option depends on the terrain, sampling strategy and/or method. Transects may require a mobile stand with large boom. Plot sampling may also require a large reach with a rotating or extending jib. Custom frames or jigs can be constructed to reach high above a tree canopy or to increase the scene size when measuring crop rows, for example.

Henk Pieter Sterk, ERI, Thurso

Monopod, Tripod, Jib & Boom Mounting Options

A little time invested here to create or purchase a suitable mounting accessory should dramatically improve efficiency and measurement repeatability.

5.6 Ambient Lighting Conditions

5.6.1 Solar Arc Progression @ Noon & 2 Hours Before Noon

An analysis of the rate of change of the solar zenith angle throughout the day indicates a significant benefit to ambient light stability around local solar noon. **Table 10** is derived from calculations of the SZA, θ and the cosine of the SZA, $\cos(\theta)$. The latter is indicative of the direct irradiance from the sun on a horizonal surface.

Date	Latitude	θ_{12} (12:00)	$\theta_{\pm0.5}$ (12:00 ±½ Hr)	$\cos(\theta_{12})$	$\cos(\theta_{\pm0.5})$	%Δ
21st March	0	0°	7.5°	1.000	0.9914	0.9%
21st June	30°	6.6°	9.4°	0.9933	0.9866	0.7%
21st June	45°	21.6°	22.4°	0.9300	0.9245	0.6%
21st June	50°	26.6°	27.2°	0.8942	0.8894	0.5%

Table 10 Percentage change[§] in direct solar irradiance around solar noon

In general on a perfect blue sky day the direct illumination will vary by less than 1% during the period ± ½ hour of solar noon. **Table 10** can be extended to show similar values for dates between the Spring and Autumn equinox.

However, at 2 hours before/after solar noon the rate of change of the <u>direct</u> illumination is closer to 15% over an hour interval. This rate if change is depend on latitude. In general the rate is around 15% during the spring and autumn equinox reducing to 10-12% in high summer.

Date	Latitude	$\theta_{09:30}$	θ_{10}	$\theta_{10:30}$	$\cos(\theta_{09:30})$	$\cos(\theta_{10})$	$\cos(\theta_{10:30})$	%Δ
21st March	0	37.3°	29.8°	22.3°	0.7955	0.8678	0.9252	15.0%
21st June	30°	33.9°	27.4°	21.0°	0.8300	0.8878	0.9336	11.7%
21st June	45°	37.2°	32.5°	28.2°	0.7965	0.8434	0.8813	10.1%
21st June	50°	39.4°	35.3°	31.8°	0.7727	0.8161	0.8499	9.5%

Table 11 Percentage change[§] in direct solar irradiance 2 ± ½ hours before solar noon

As an indication of the benefits of taking measurements around local solar noon, the time allowed for a 1% change is only 4 minutes at 10am versus the hour around noon.

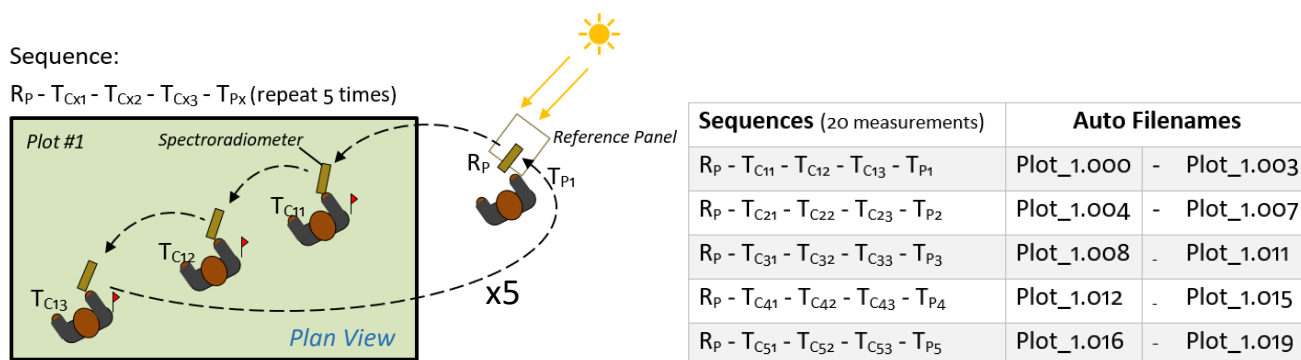§ Does not account for changes in atmospheric absorption.

5.6.2 Ambient Light Stability

With the exception of the dual field of view method detailed in section 4 of the guide, the two step measurement process requires that the ambient light is stable between the reference and target measurement sequence, for example over a 30 or 60 second

period. An inspection or hemispherical photograph of the sky can give a reasonable prediction of the ambient light stability. Evidence for this prediction can be gathered by recording a series (say 10 scans) of Target reflectance or radiance scans of the reference panel, preferably with the spectroradiometer mounted on a tripod. Viewing the reference panel under bright sunlight should provide some of the highest signal to noise levels attainable with a field spectroradiometer, outside the atmospheric water absolution bands. An analysis of a number of spectral points in this data set over time should indicate ambient light stability or quantify the drift.

5.7 Visualizing the Measurement Sequences

It is easy for team members to get out of sequence or lost with complex or extensive field campaigns. The log sheet with shorthand notes (eg. R_P-T_C-T_P , or R-T-P) will provide a record of the measurements but this can also be aided with a simple chart for the sequence and the field site.

Sequence:

R_P - T_{Cx1} - T_{Cx2} - T_{Cx3} - T_{Px} (repeat 5 times)

Sequences (20 measurements)	Auto Filenames		
R_P - T_{C11} - T_{C12} - T_{C13} - T_{P1}	Plot_1.000	-	Plot_1.003
R_P - T_{C21} - T_{C22} - T_{C23} - T_{P2}	Plot_1.004	-	Plot_1.007
R_P - T_{C31} - T_{C32} - T_{C33} - T_{P3}	Plot_1.008	-	Plot_1.011
R_P - T_{C41} - T_{C42} - T_{C43} - T_{P4}	Plot_1.012	-	Plot_1.015
R_P - T_{C51} - T_{C52} - T_{C53} - T_{P5}	Plot_1.016	-	Plot_1.019

Five replicates of three sample points within a plot with a "Target" measurement of the reference panel at the end of each sequence.

5.8 BRF Measurements

There is extensive research and literature relating to BRF and BRDF measurements of surfaces and plant canopies. This guide provides only a brief mention of one instance of off-nadir measurements for bi-directional reflectance factors.

Field measurements are typically taken with the spectroradiometer positioned above the target or reference panel with the optical axis aligned to nadir. This would be equivalent to the center of the swath in an airborne or satellite spectral imager. However, it is often valuable to acquire spectral reflectance measurements off nadir, for example at the imager's swath angles. This will help quantify the variation in a surface's reflectance with observation angle - Bi-Directional Reflectance Factors, BRF.

- The target surface should be uniform/homogeneous across the field of view of the spectroradiometer. For example, nadir viewing with a 8° FOV lens @ 1 meter from the target, the diameter of the measurement scene is 14 cm and at ± 30° the scene diameter extends to 16 cm and ~20 cm at ±45°.

- Use the alignment laser (SVC iSeries) to ensure the spectroradiometer is aligned to the center of the same target scene for all BRF measurements.

- Take care to align the BRF measurements perpendicular to the direction of travel as shown in Figure 27.
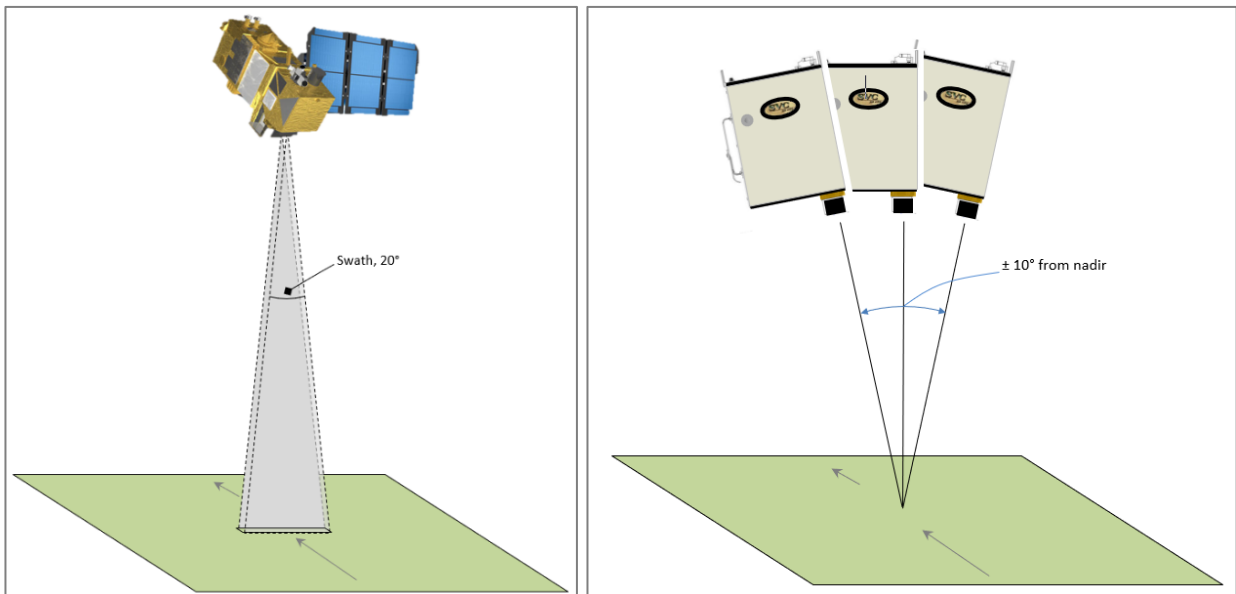
- Figure 27 Satellite swath & BRF measurements

5.9 Data Quality – In Field Analysis

It is always necessary to demonstrate the quality of your data through a careful analysis of each step in the measurement process, with particular attention paid to the areas where there is greatest potential for error or uncertainty. As discussed above, the method, training, equipment, calibration, reference panel and environmental conditions each play an important part in the analysis.

There are a number of tests & measurements that can provide immediate in-field analysis and feedback which hopefully will give confidence to proceed with the measurements, prevent poor data collection or tag bad data for quarantine.

5.9.1 Verify Spectral / Wavelength Calibration

Spectral reflectance data relies on a valid wavelength calibration. The SVC i-Series of field spectroradiometers have been designed with <u>fixed</u> gratings and detector arrays. This gives accuracy, stability and reliability. However, the wavelength calibration can be quickly verified in the field by viewing the reference radiance scan (reflectance panel) and confirming the position of the atmospheric oxygen absorption line at 762nm. From a simple transmission measurement[§] of mylar it is possible to verify the location of the two mylar absorption features in the SWIR region.
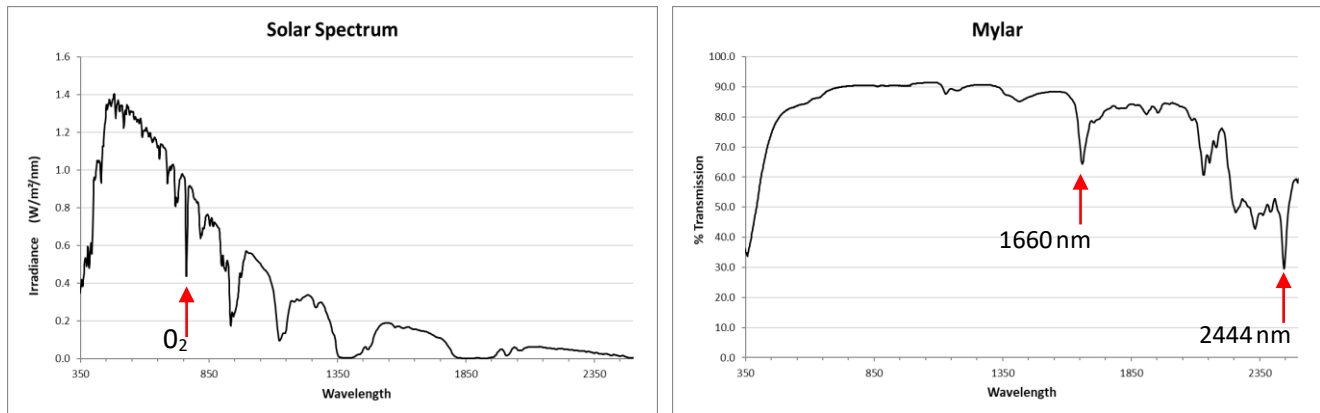

Figure 28 Verification of Wavelength Calibration in the Field

§ After collecting the Reference measurement, continue to view the reference panel and collect a Target spectrum with the mylar sheet placed in front of the fore-optic lens.

5.9.2 Monitoring Ambient Light Stability

On its own, a single field spectroradiometer will rely on ambient light stability. On a perfect cloudless sky the ambient light will change by only <1%, in the half hour either side of solar noon – ref

Date	Latitude	θ_{12} (12:00)	$\theta_{\pm 0.5}$ (12:00 ±½ Hr)	$Cos(\theta_{12})$	$Cos(\theta_{\pm 0.5})$	%Δ
21st March	0	0°	7.5°	1.000	0.9914	0.9%
21st June	30°	6.6°	9.4°	0.9933	0.9866	0.7%
21st June	45°	21.6°	22.4°	0.9300	0.9245	0.6%
21st June	50°	26.6°	27.2°	0.8942	0.8894	0.5%

Table 10. This would seem at first to be very acceptable, given that a typical measurement sequence might only last 2 – 5 minutes. However, this is assuming ideal conditions. Any atmospheric instability will only added to the 1% base level. Measurements to quantify atmospheric stability can be attained at the start (repetitive scans of the reference panel) or as part of a measurement sequence (Target measurements of the reference panel at the end of each sequence).

Multiple Graph (Reflectance) view: During and after acquiring a series of target measurements of the reflectance panel, it will be possible to quickly gauge any change in the ambient light levels and asses if it passes your own QA test, for example < 1 or 2% over 5 minutes[§]. To aid visual assessment, remove the atmospheric water bands data and zoom the Y axis reflectance scale to say 90 – 110%. If the light stability is poor, it may be necessary to reduce the time duration of the field measurement sequences or to abandon field measurements altogether.

Single Graph (Reference Target & Reflectance) view: Each spectral data file contains the reference panel and the target measurements (R_p & T_C). At the end of a sequence, this would therefore be the original reference and target measurements of the same reference panel in a single data file (R_p & T_p). In single graph, it is very easy to verify the ambient light stability by noting any deviation from 100% in the reflectance data. Again, it may be necessary to remove the atmospheric water bands data from the graph view. An on-site decision can thus be made to continue, repeat or pause the measurements. Add a note to the log sheet to tag the file for quarantine when data which fails to pass the threshold. Do not spend time resetting filenames or deleting files as this could add confusion.

§ The Dual Field of View and WEDI methods can sustain data collection during periods of higher levels of atmospheric instability if post processing correction is applied.

External Data The change in the ambient light signal measured by the external sensor can be viewed immediately after <u>each</u> target scan in the External Data dialog. This continuous feedback aids the on-site decision to continue, repeat or pause the measurements. Note: external data from the SVC WEDI is saved to each data file.

5.9.3 Signal Saturation
At the start of each measurement scan (Reference & Target), the spectroradiometer samples the ambient light and automatically sets the integration (exposure) times for each detector array, to optimize the signal amplitude. Typically, this process takes less than half a second. These settings are then used for the duration of the 'Scan Time' and its twin 'Dark Scan'. Signal saturation may result when there is a dramatic rise in the ambient light during the Scan Time. This can occur with a dynamic surfaces such as waves on water when specular reflected sun light can flash through the measurement scene. Signal saturation will generally result in the data being rendered useless with the file tagged for quarantine in the Log Sheet. Saturated data can typically be identified as high intensity, spectrally flat regions within the radiance plots. It is possible when

viewing only the reflectance spectrum to miss saturation that may be more obvious when also viewing the radiance plots. The risk of saturation can be minimized by reducing the 'Scan Time' from say 5 to 1 second when measuring dynamic surfaces.

5.9.4 Sample Data Plots

The field scientist will have good knowledge of what should be expected when taking reflectance measurements and may have a number of library or sample files available on hand. It is therefore possible to Multi-Graph a sample reflectance data file before taking measurements and use it to provide a real-time comparison to newly collected data. In Figure 29 a sample vegetation canopy is used as a quick reference for the field data.
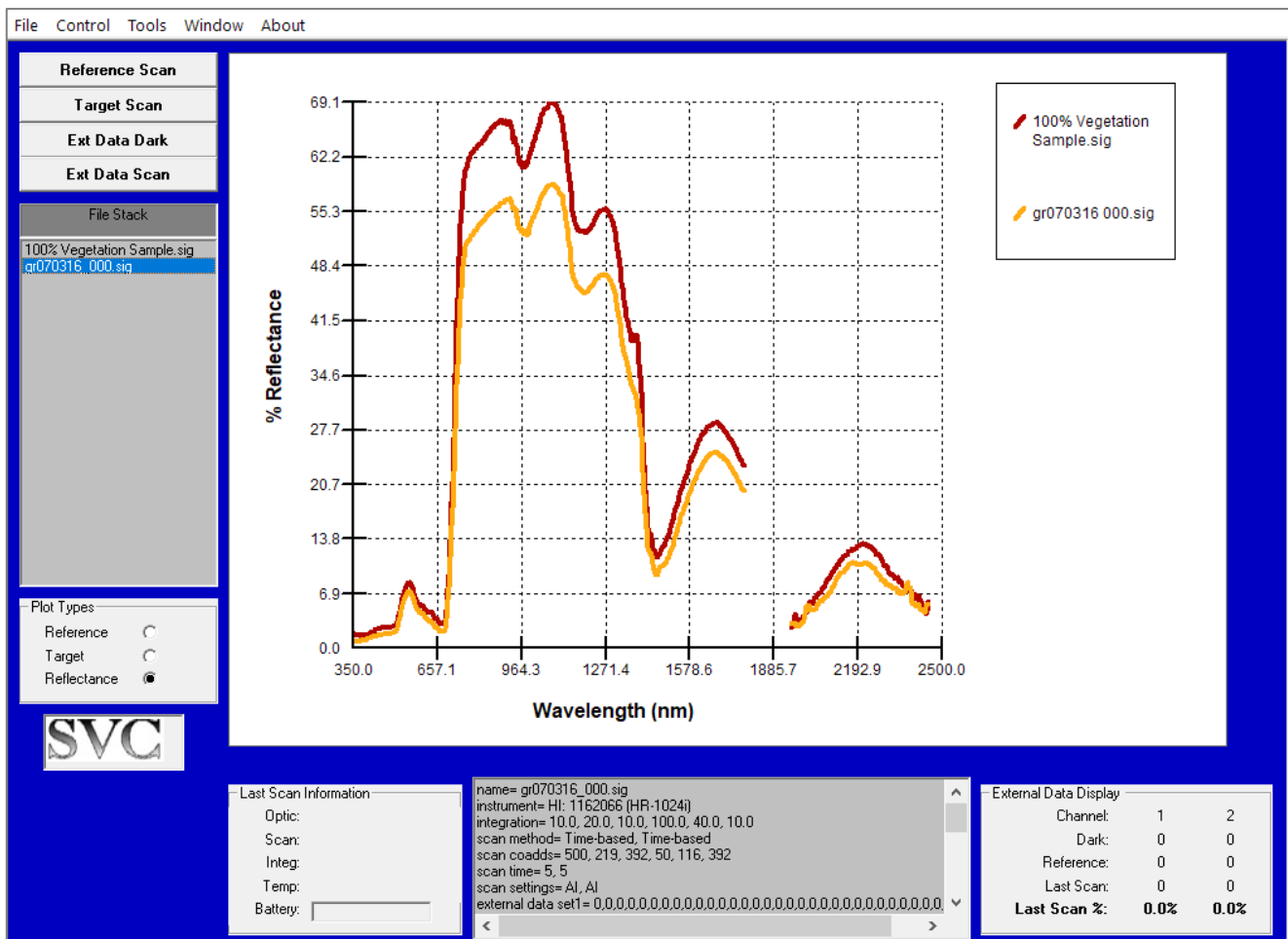

Figure 29 Multi-Graph Plot - Canopy Reflectance Measurement with Library Sample Data File

Note: a second sample file can also be graphed to show a vegetation canopy with lower reflectance limits. Unexpected deviations from the sample spectra may be a result of poor alignment with the reference panel, a proportion of ground soil in the scene or a

higher diffuse/direct ratio for the ambient light. On-site analysis of the data allows for additional measurements to verify the validity of the data.

5.9.5 Signal Noise

Field reflectance data is calculated from a ratio of two measurement scans with the same instrument. However, if the spectroradiometer has been knowingly or unknowingly damaged, resulting in a sub optimal performance, it will still give the same expected reflectance values for the surface, but it may include unexplained signal noise across parts of the spectrum (excluding atmospheric water regions) when compared to a Sample Data Plot – ref section 5.9.4 above.

While it is possible to continue with measurements, the data set will be compromised and perhaps less valuable. It is certainly worthwhile to examine the instrument as it may reveal incorrectly attached fore-optics, a damaged light guide or incorrect instrument settings in the application.

6 Post Processing

Processing the spectral reflectance data files into valuable products or scientific evidence begins with a few steps within the SVC PC Data Acquisition Software and a review of the log sheets and file headers to collate and filter in preparation for analysis.

6.1 SVC PDA & Android Data Files

Spectral data acquired with SVC Windows Mobile PDA or Android applications can be viewed within their apps for analysis and feedback in the field. However, there are a number of additional features and post processing tools available within the SVC PC Data Acquisition Software, such as matching and removal of the overlap data. It is recommended all data files and their images are transferred to a Windows computer for post processing.

6.2 SVC Stand-Alone Mode Data

The SVC i-Series of field spectroradiometers can also be operated in the "Stand -Alone" mode, without a PC. The spectral data is saved within the internal memory as a series of individual Reference and Target scans. During the transfer process to a Windows computer, the files are matched up into the standard SIG format with each file containing header information, wavelength, reference and target spectral data and the calculated reflectance data.

Connect the SVC i-Series spectroradiometer to the computer. Open the SVC PC Data Acquisition Software. From the Control/Setup menu, connect to the instrument.

Open the Control / Read Memory dialog. Confirm number of scans in the instrument memory. Adjust settings and create a File Base Name or use the optional format *yyMMdd_HHmm_RxxxTxxx* to tack the matching of the Reference & Target scans. Further information on the settings and steps for this process is provided in the SVC i-Series User Manual [9].

During the download process, it may be necessary to check with the Log Sheets to ensure the correct match of Reference & Target scans and to add the new SIG file names.
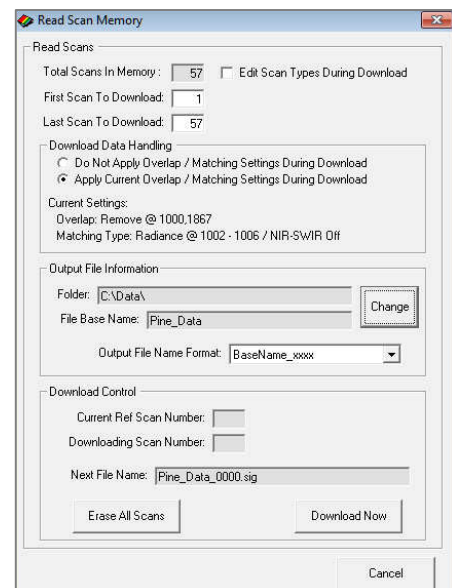
6.3 QA & Data Files Quarantine

Before proceeding to post process the data, it is essential to remove and quarantine any measurements that fail to meet your quality threshold based on ambient light stability or operator error.

- Refer to the Log Files and identify data files that have been tagged for quarantine during "In Field Analysis".

Single Field of View, Bi-Conical (Method 1. Section 4.1)

- Start the SVC PC Data Acquisition Software. From the Log Sheets, identify and Open all the Target scan of the reference reflectance panel (TAR$_{panel}$, T$_p$ or P) data files (one per sequence). Graph each file in turn and identify the files/sequences that fail to meet the quality threshold for ambient light stability, e.g. 100 ± 2% between the initial Reference scan and final Target scan of the reflectance panel. Assuming post processing adjustment is not feasible, all the data files in each failing sequence should be quarantined.

Dual Field of View (Method 3 & 4. Section 4.3 & 4.4)

- Open the data files for the reference spectroradiometer S1, one sequence (e.g. 10 files) at a time, for example (R$_p$, T$_p$, T$_p$, T$_p$, T$_p$, T$_p$, T$_p$, T$_p$, T$_p$, T$_p$). Select each file in turn in the single graph view by double clicking on the filename in the File Stack. Plot the reflectance data and note the approximate reflectance value outside the atmospheric water bands. Assuming a threshold limit of, say, 100 ± 5%, note in the Log Sheet any 'S1' data file and its corresponding 'S2' data file that is unsuitable for post processing correction. Confirm both files have the same (±2 seconds) time stamp and quarantine them.

6.4 SVC Application Tools

The SVC PC Data Acquisition Software has a range of data processing tools to format, combine and re-sample multiple SIG data files. In addition, the calibration data for the reference reflectance file can be used to scale the relative reflectance values to absolute reflectance data – ref Section 3.4.

Please refer to the User Manual for information on the Instrument Calibration, SIG File Wavelengths, ENVI Spectral Library and Remote Access Server tools.

It is important to note that certain tools will only operate on standard SIG format data files and it is therefore necessary to use the tools in a preferred order. For example:

✓ Overlap/Matching Tool -> White Plate Reflectance Tool -> Resample Spectral Data Tool

✓ Overlap/Matching Tool -> White Plate Reflectance Tool -> Merge Tool

<u>Always</u> remove the Overlap data <u>before</u> running White Plate Reflectance and Resample Spectral Data tools.
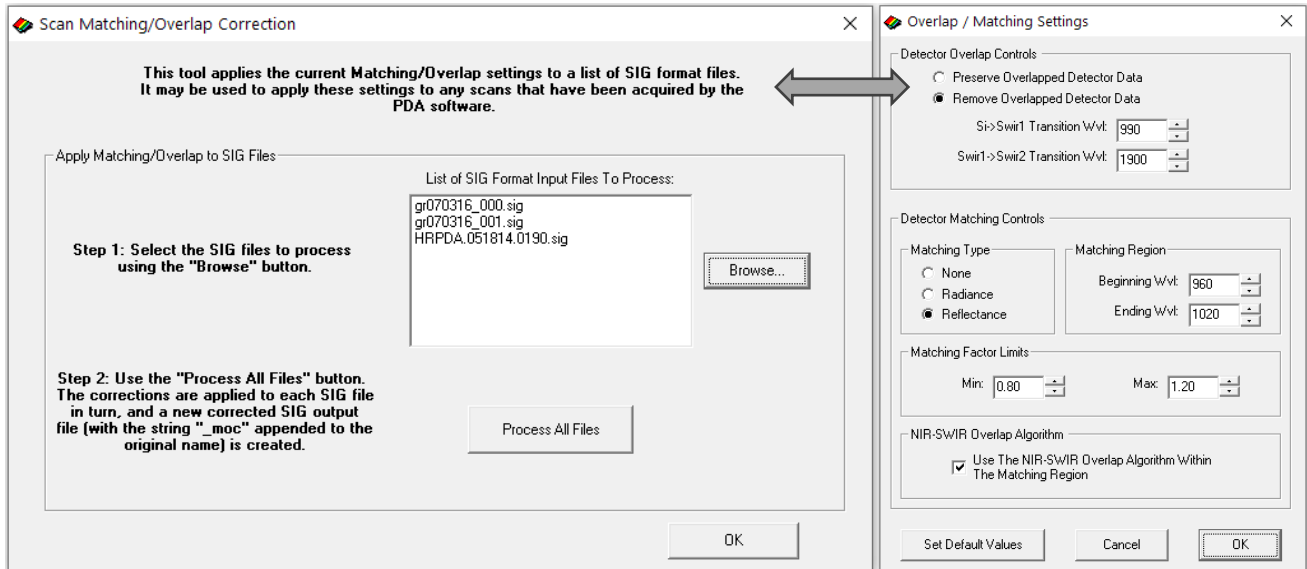
Figure 30 SIG File Overlap/Matching Tool

It is not possible to use the Tools when the file size has more than 1024 data points. This might occur when resampling a SIG file to a 1nm interval over the spectral range 350 – 2500nm (2151 data points).

✖ Overlap/Matching Tool -> Resample Spectral Data Tool -> Sig File Merge Tool

✖ Resample Spectral Data Tool -> White Plate Reflectance Tool

✖ Merged (CSV) data files cannot be further processed with the Tools

6.4.1 SIG File Overlap/Matching Tool

The SVC spectroradiometers have the option of preserving the overlap data straddling the spectral region from overlapping detector arrays (excluding HR-512i). Spectral measurements collected using the PDA/Android application or in Stand-Alone mode[§] will always preserve the overlapped data. The SIG File Overlap/Matching Tool can be used to reprocess data files, according to the Overlap Matching Settings dialog.

§ Note: it is also possible to apply Overlap / Matching Settings when importing Stand Alone files from the instrument – Control / Read Memory dialog.

SIG files that are processed with the Overlap/Matching tool are not over written but re-created, using the original filename with the "_moc.sig" suffix.

6.4.2 White Plate Reflectance Tool

It may be necessary to create a White Plate Reflectance Data file (*.dat) for your specific reflectance panel. Appendix B of the User Manual details the two column file format for the calibration data of this file. The typical calibration data from the reference panel manufacturer may contain a small level of signal noise. It is recommended this noise is carefully smoothed out while creating the "White Plate" Reference Data File. This will then avoid factoring calibration noise onto the SIG files when applying the reference panel calibration.

Equation 8 & Equation 10 in section 2.5 explain the importance of applying a reference panel calibration to the relative reflectance values of the SIG files. This is most pronounced in the SWIR2 region where the panel reflectance is at its lowest ref Figure 15.

6.4.3 SIG File Merge Tool

The SIG File Merge tool is the quickest method for importing large numbers of files into an Excel spreadsheet while still retaining all the meta data for each file. Figure 31 shows the result of Merging two SIG files into a CSV format file.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
4	scan method= Time-based Time-based					scan method= Time-based Time-based											
5	scan coadds= 500 219 392 50 116 392					scan coadds= 500 219 392 50 116 392											
6	scan time= 5 5					scan time= 5 5											
7	scan settings= AI AI					scan settings= AI AI											
8	external data set1= 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					external data set1= 1213 1104 1109 1108 868 867 865 863 0 0 0 0 0 0 0 0 1213 1104 1109 1108 868 867 865 863 0 0 0 0 0 0 0 0											
9	external data set2= 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					external data set2= 1213 1104 1109 1108 868 867 865 863 0 0 0 0 0 0 0 0 1213 1104 1109 1108 868 867 865 863 0 0 0 0 0 0 0 0											
10	external data dark= 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					external data dark= 113 104 109 108 68 67 65 63 0 0 0 0 0 0 0 0											
11	external data mask= 0					external data mask= 255											
12	optic= LENS 4(1) LENS 4(1)					optic= LENS 4(1) LENS 4(1)											
13	temp= 21.2 -5.1 -9.8 21.3 -5.1 -9.8					temp= 21.2 -5.1 -9.8 21.3 -5.1 -9.8											
14	battery= 8.12 8.13					battery= 8.12 8.13											
15	error= 3 3					error= 3 3											
16	units= Radiance Radiance					units= Radiance Radiance											
17	time= 03/07/2016 10:17:50 03/07/2016 10:18:11					time= 03/07/2016 10:17:50 03/07/2016 10:18:11											
18	longitude= 00315.5162W		00315.5162W			longitude= 00315.5162W		00315.5162W									
19	latitude= 5557.7038N		5557.7038N			latitude= 5557.7038N		5557.7038N									
20	gpstime= 091746.000		091807.000			gpstime= 091746.000		091807.000									
21	comm=					comm=											
22	memory slot= 0 0					memory slot= 0 0											
23	factors= 0.943 0.933 1.000 [Overlap: Remove @ 990 1					factors= 0.943 0.933 1.000 [Overlap: Remove @ 990 1900 Matching Type: None]											
24											AVERAGE OF INPUT FILES: gr070316_000.sig:gr070316_001.sig						
25	Wavlen	Refer	Target	Reflect		Wavlen	Refer	Target	Reflect		Wavlen	Avg Refer	Avg Target	Avg Reflect			
26	339.8	103377.6	1005.06	0.97		339.8	103377.6	1005.06	0.97		339.8	103377.6	1005.06	0.97			
27	341.2	106408.7	1037.86	0.98		341.2	106408.7	1037.86	0.98		341.2	106408.7	1037.86	0.98			
28	342.7	105819.6	1017.08	0.96		342.7	105819.6	1017.08	0.96		342.7	105819.6	1017.08	0.96			
29	344.1	105625.2	1013.27	0.96		344.1	105625.2	1013.27	0.96		344.1	105625.2	1013.27	0.96			
30	345.6	107088.2	1014.83	0.95		345.6	107088.2	1014.83	0.95		345.6	107088.2	1014.83	0.95			
31	347.1	108720	1014.72	0.93		347.1	108720	1014.72	0.93		347.1	108720	1014.72	0.93			
32	348.5	111886	1040.6	0.93		348.5	111886	1040.6	0.93		348.5	111886	1040.6	0.93			
33	350	115137.6	1068.96	0.93		350	115137.6	1068.96	0.93		350	115137.6	1068.96	0.93			
34	351.5	121867.6	1122.36	0.92		351.5	121867.6	1122.36	0.92		351.5	121867.6	1122.36	0.92			
35	352.9	128924.5	1160.71	0.9		352.9	128924.5	1160.71	0.9		352.9	128924.5	1160.71	0.9			
36	354.4	132109.6	1187.16	0.9		354.4	132109.6	1187.16	0.9		354.4	132109.6	1187.16	0.9			
37	355.8	126799	1147.3	0.9		355.8	126799	1147.3	0.9		355.8	126799	1147.3	0.9			

Figure 31 Spreadsheet view of Merged Data with Averaged Data Columns

The benefit of bringing the SIG files into a spreadsheet or other data analysis tool can be seen when a template is used to set up a range of bespoke calculations including file averaging with standard deviation and variance and signal to noise calculations. All of which can be used to assess the quality of the data before scientific analysis and indices calculations.

6.4.4 Resample Spectral Data Tool

The SVC range of i-Series spectroradiometer have up to 1024 individual pixels in their multiple photodiode detector arrays - ref Figure 13. Each pixel (or channel) has a unique wavelength calibration assigned to it. This represents the center wavelength for the channel. The first column after the header information in the SIG file includes the center wavelength for each channel. The bandwidth (ref Figure 13) between the pixels will vary throughout the spectral range of the instrument.

It is often desirable to resample the spectral wavelength scale to an even interval (say 1nm) for better comparison with other data sets. The Resample Spectral Data Tool will interpolate the data points in the SIG file to a specified interval over a specified spectral range.

```
/*** Spectra Vista SIG Data ***/        /*** Spectra Vista SIG Data ***/
name= gr070316_001.sig                  name= gr070316_001_resamp.sig
.....                                   .....

units= Radiance, Radiance               units= Radiance, Radiance
time= 03/07/2016 10:17:50, 03/07/2016 10:18:11   time= 03/07/2016 10:17:50, 03/07/2016 10:18:11
longitude= 00315.5162W      , 00315.5162W        longitude= 00315.5162W      , 00315.5162W
latitude= 5557.7038N        , 5557.7038N         latitude= 5557.7038N        , 5557.7038N
gpstime= 091746.000       , 091807.000           gpstime= 091746.000       , 091807.000
comm=                                   comm= Resampled spectral data
memory slot= 0, 0                       memory slot= 0, 0
factors= 0.943, 0.933, 1.000 [Overlap: Remove @ 990,1900,   factors= 0.943, 0.933, 1.000 [Overlap: Remove @ 990,1900,
data=                                   data=
339.8  103377.60  1005.06  0.97         350.0  115137.60  1068.96  0.93
341.2  106408.65  1037.86  0.98         351.0  119624.27  1104.56  0.92
342.7  105819.60  1017.08  0.96         352.0  124387.93  1136.06  0.91
344.1  105625.20  1013.27  0.96         353.0  129136.85  1162.47  0.90
345.6  107088.20  1014.83  0.95         354.0  131260.25  1180.11  0.90
347.1  108720.00  1014.72  0.93         355.0  129833.60  1170.08  0.90


.....                                   .....

2504.2  1208.30  73.06  6.05            2495.0  951.34  95.40  10.03
2506.3  1098.24  74.36  6.77            2496.0  969.83  91.06  9.39
2508.4  936.80  81.97  8.75             2497.0  999.40  88.61  8.87
2510.5  834.70  72.06  8.63             2498.0  1030.06  85.38  8.29
2512.6  772.38  55.17  7.14   1024 Data Points   2499.0  1070.58  75.21  7.03   2151 Data Points
2514.7  658.35  100.32  15.24           2500.0  1111.10  65.04  5.85
```

Figure 32 Original & Resampled SIG data file

Note: resampled spectral files with more than 1024 data points cannot be plotted within the SVC PC Data Acquisition Software.
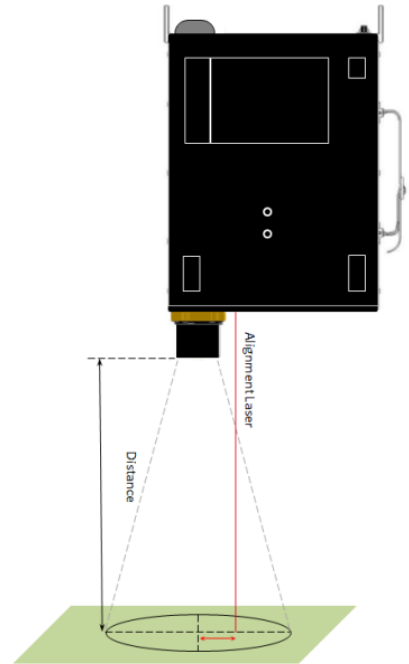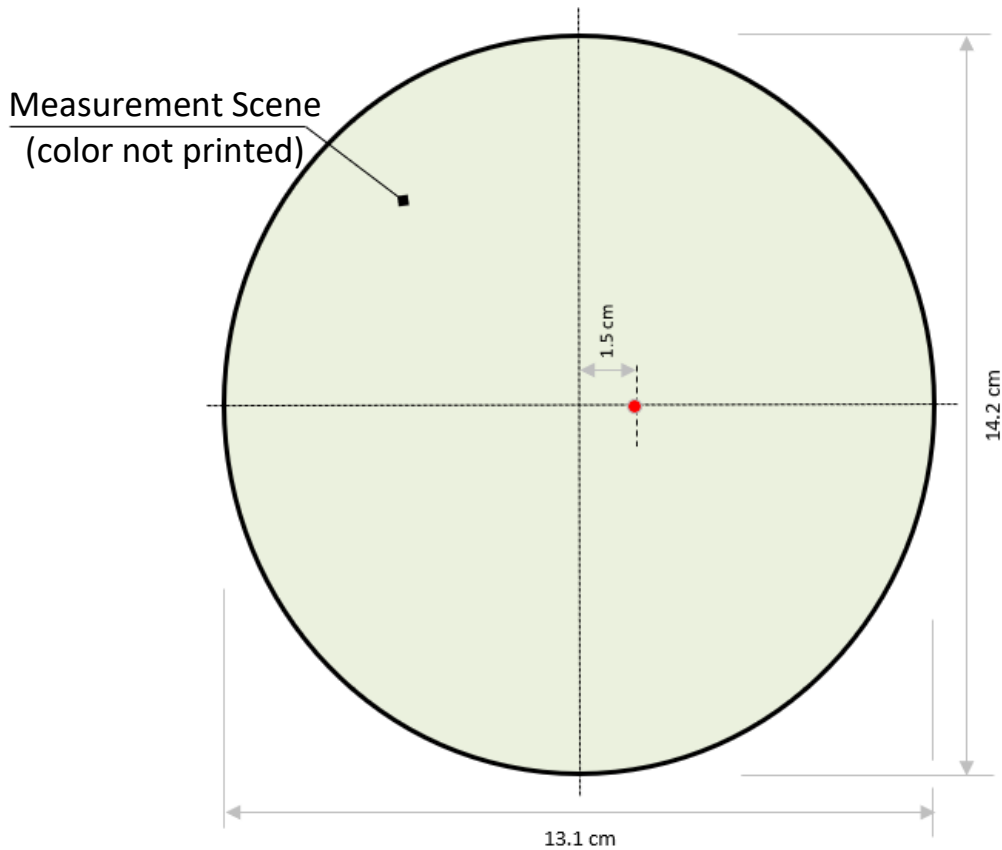
Appendix 1

A1.1 Fore-Optic Template

Create a 1:1 scale drawing for the fore-optic from SVC alignment chart.

Print on clear acetate and confirm dimensions are to scale.

The acetate can be placed on the sample surface and aligned with the laser to indicate the fore optic's measurement scene (area).

8° FOV @ 1m

Measurement Scene
(color not printed)

1.5 cm

14.2 cm

13.1 cm

A1.2 Outline Training Program for a Field Campaign

Roles & Responsibilities:

It is very difficult to collect field spectral measurements on your own. In this guide, we have listed the roles and responsibilities for a team of four people. With smaller teams it will be necessary to combine roles, prioritize and perhaps reduce or remove some of the tasks. During the training program, it will be necessary to explain these roles in detail, practice the data collection method and analyze the data. The table below is a guide and should be adapted as necessary.

Team Leader:	The team leader should understand in detail, the vision and goals for the field campaign. *Responsibilities include:* o Site selection. o Sampling protocol. o Method. o Co-ordinating the team. o Timing & sequences. o Recording information into the Log Sheets. o In-field data analysis for feedback and quality control. o Setting up reference panel (when assistant #3 unavailable)
Assistant #1:	Assistant #1 looks after the field spectroradiometer and its accessories. *Responsibilities include:* o Care for the instrument at all times including transportation to the site. o Charging all the batteries <u>including</u> PDA or laptop computer batteries. o Switch on and warming up prior to start of measurements. o Setting up the fore-optic or fiber. o Setting up the mounting fixture or backpack. o Positioning the spectroradiometer over the reference panel and each sample point as directed by the Team Leader and in co-ordination with computer/PDA operator (Assistant #2).

Assistant #2:	The second assistant operates the computer or PDA. This requires careful co-ordination and communication between the instrument handler and the team leader.
	Responsibilities include:
	
	   o Clear communication.
	   o File naming & storage.
	   o Initiate Reference & Target scans.
	   o Monitoring data from external ambient lighting detectors (WEDI).
	   o Adding comments & notes for entry into log sheets.
	   o Assisting team leader with in-field data analysis at the end of each sequence.

Assistant #3:	The third assistant will set up and move the reference reflectance panel about the site. Great care has to be taken when handling and using the reference reflectance panel. A clean panel provides the reference to which all measurements are taken and as such requires a specific role within the team. The team leader should deputize if the third assistant is unavailable.
	Responsibilities include:
	
	   o Keeping the panel clean.
	   o Setting up the panel and ensuring it is level.
	   o Protect the panel from being knocked or blown over.
	   o Moving the panel to a new or alternate locations to reduce the distance to the spectroradiometer during transects, for example.
	   o Sky and field site cameras
	   o In exceptional circumstances, cleaning and cross calibrating the panel with the backup panel.

Equipment Training

Training and familiarization of the equipment should be conducted in the days or weeks before starting a field campaign. The training programming should cover:

- The field spectroradiometer and its accessories
- The software applications for the field spectroradiometer
- SIG data files and their headers

- Care and use of the reference reflectance panel
- The method / sequence
- In-field data analysis
- Log sheets
- Health and safety on field sites
- Assessing or monitoring ambient lighting

Site Etiquette

The first rule of field work is to seek out permission from the land owner or custodian and always to respect their property and the natural environment. Avoid lighting fires.

It is important to restrict movement of the team over the test site in order to protect and maintain the vegetation canopy or surfaces for subsequent field visits. The team leader should mark out routes to the various plots and clearly identify exclusion areas.

Set up your base-camp off any public paths.

Shading & Clothing

Everyone within the team should be aware of their own shadow and avoid shading the reflectance panel or target canopy during a measurement scan. It should also be noted that a person standing next to the reference panel (or target surface) will influence the measurement by either reflecting sunlight from their clothing onto the target surface or to a lesser extent reduce the sky irradiance onto the surface. There are a number of options for minimizing these effects including dark clothing, crouching, reaching out to increase the distance between yourself and the surface or using a mounting accessory such as monopod or jib.

A1.3 Spectroradiometer QA Tests

It is important to inspect and test your field equipment well in advance of the field campaign. Listed below are a series of functional and performance tests which can be used to confirm the status of your equipment and its readiness for field use.

- PC Laptop, PDA & Android tests.
  - o Battery test: Fully charge the batteries and confirm the number of hours until the battery life displays, say, 20% with the display continuously on at full brightness. Log this time and monitor its reduction over time. The same exercise should be repeated on spare battery packs. Included notes in the test log to indicate typical charge times from, say, 20%, to 100%.

- A performance reduction may be noticed if the computer is used for other applications and its operating system or anti-virus data are routinely updated. At some point, it may be necessary to install the application on a new or backup computer/laptop or device. It is highly recommended that any new installation be conducted in your office and not in the field. After installation, run the application, connect to the field spectroradiometer and acquire a test spectrum.
- The calibration files for each fore-optic and the wavelength scale are saved to the internal memory of the field spectroradiometer. The calibration information is displayed in a dialog after connecting to the instrument. Confirm the instrument calibration date and files are up to date.
- The SVC i-Series of field spectroradiometers have three options for communicating with a laptop computer: wireless Bluetooth, USB cable and RS232 COM cable. It is a wise precaution to ensure the USB cable interface works in addition to the Bluetooth interface. Note COM port numbers for these interface options.

- **Spectroradiometer Batteries:**
  As describe above it is also necessary to routinely monitor the performance of battery packs and their chargers for your field spectroradiometers. Set up the instrument and connect to its computer via Bluetooth interface. With the lens cap fitted and Scan Time set to, say, 5 seconds, set up a continuous timed scan, 1 second interval, within the PC application. Note the number of scans recorded before the battery is exhausted. Compare this to the previous year's performance to identify any reduction in charge.

- **Verify Wavelength Calibration:**
  The calibration of the wavelength scale can be readily checked and verified both in the laboratory or in the field. These tests should be conducted on a regular basis with the spectra saved for future reference. For example, a scan of a fluorescent (not LED) lamp will contain emission lines from the mercury vapor in the lamp. These lines can be used as references within the visible part of the spectrum. Likewise a measurement of the solar spectrum has distinctive spectral absorption features. A measurement of the transmission of a sheet of mylar will yield spectral features in the SWIR region.

  Regular measurements as listed above can be compared over time to indicate any change in the wavelength calibration, perhaps as a result of shock during transportation. Note the recalibration of the wavelength scale will also impact the radiance calibration. It is highly recommended that the instrument be returned to

SVC for a full calibration. However, should the instrument receive a shock on route to a field site, it may be possible to continue with Reflectance measurements and rescale the wavelength calibration retrospectively, after a factor calibration. Contact SVC to ensure a pre-calibration inspection and correction.

- Dark Noise DN Test:

This test provides some basic confirmation of the detector and readout electronic performance. This guide does not set pass/fail limits for this test, instead, it provides a means for the user to build up a performance log and identify any changes in the instrument performance.

Instrument Settings:

- Fit lens cap to the fore-optic.
- Set the Optic to "RawDN" (Digital Number)
- Set the Total Scan Time to 1 second
- Auto-Integration and check box "Integration Scales RAW DN Data"

Collect 30 scans in quick succession using the Timed Scans dialog. Use the Tools/SIG Files Merge dialog to create a CSV file. Import file into a spreadsheet. Copy the Wavelength data into column A of a new worksheet and Target data from each SIG file into the same new worksheet.
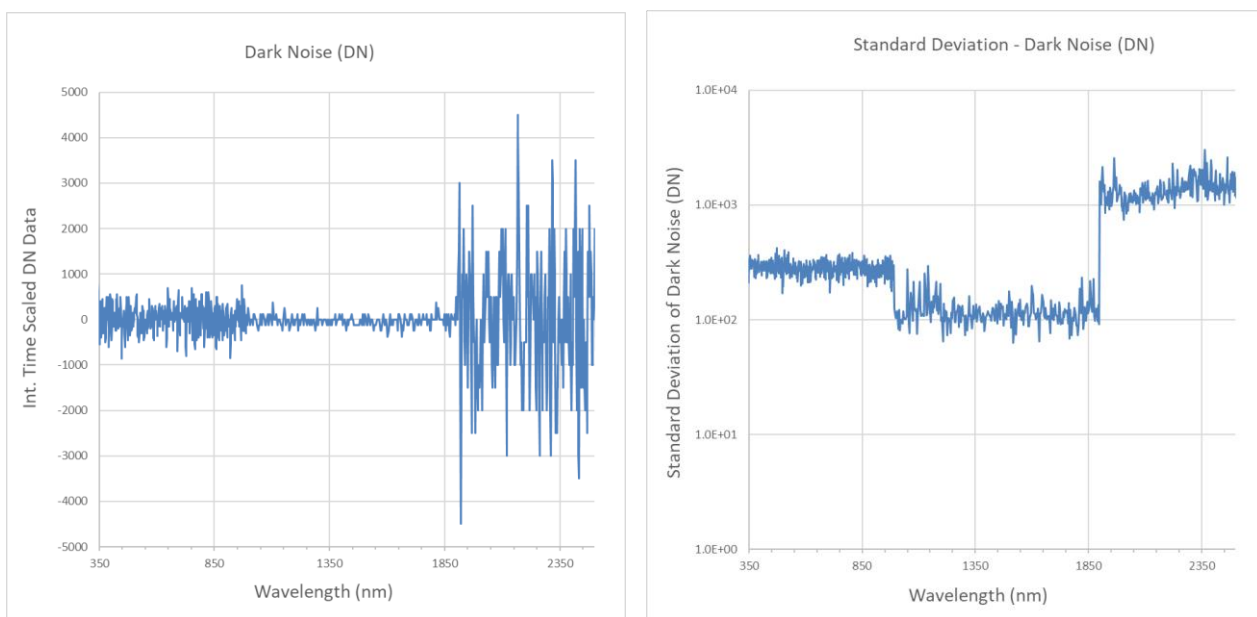

Figure 33 A & B Dark Noise (DN) Tests

Figure 33A shows a Raw DN spectral scan with the lens cap fitted. Note the Raw DN values are lowest for the SWIR1 cooled InGaAs detector. Calculate the standard deviation for the 30 scans at each wavelength. Figure 33 B shows a graph of the

standard deviation of the Raw DN signal for the 30 scans. The spreadsheet and these plots can be saved and compared to earlier test data.

It should also be noted that this test will not confirm the system's radiometric (radiance / irradiance) calibration.

- Reference Reflectance Panels:

The reference reflectance panel must remain in pristine condition to allow for calibrated measurements of spectral reflectance. Figure 34 shows the reflectance factors for a well-used, "dirty" reference panel and the same panel after cleaning. In this extreme case, the difference was only clear to the eye when compare side by side to a new reflectance panel. After careful cleaning, the visual difference between the cleaned and new panel was hard to see.
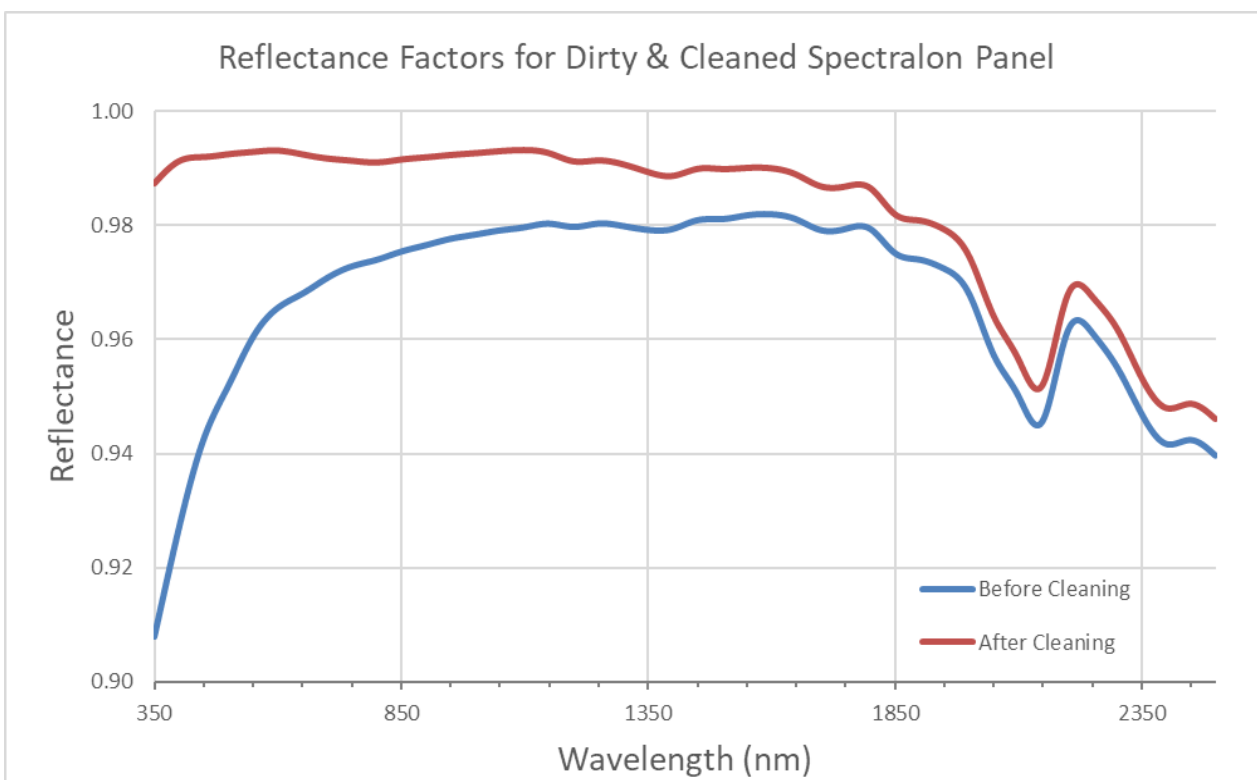
Figure 34 Dirty & Cleaned Reflectance Panel

The re-calibration of reflectance panels will require a well equipped laboratory. However, it is possible to create a simple setup using the field spectroradiometer and a strong tungsten halogen source to compare a field used panel with a pristine in-house reference panel of the same size and reflectance (99%). Figure 34 should also demonstrate the need to procure a new calibrated panel on a very regular basis or at least clean your panel rather than allow it to slowly degrade.

A1.4 Log Sheet Template

This sample log sheet has been created in a spreadsheet and is for illustration purposes. A customized log sheet matched to your equipment, accessories, method and sequencing will help ensure accurate recording of each measurement.

SVC HR-1024i Log Sheets

Sheet #		1	of	4		
Date:	12th Aug 2019		Instrument s/n:	2039		
Team Leader:	J W Smith		Ref. Panel s/n:	1023-1598		
Assistant #1	I Bell		Fore Optics:	8° FOV Lens		
Assistant #2	D Bach		Assistant #3	T Curtis		
Location:	Railroad Valley Playa, Nv. 38.504° N latitude, 115.692° W longitude					
Notes:	Clear sky					

Time	Filename Base	No.	Scan	Target Details	Notes
11:37			R	Ref. Panel	
11:37	P-1A	000	T	Plot 1A location #1	WEDI #1 = 99.5
11:38	P-1A	001	T	Plot 1A location #2	WEDI #1 = 99.6
11:38	P-1A	002	T	Plot 1A location #3	WEDI #1 = 99.8
11:39	P-1A	003	T	Plot 1A location #4	WEDI #1 = 100.0
11:39		004	P	Ref. Panel	WEDI #1 = 99.9
11:40			R	Ref. Panel	
11:40	P-1A	005	T	Plot 1A location #1	WEDI #1 = 100.0
11:40	P-1A	006	T	Plot 1A location #2	WEDI #1 = 100.1
11:41	P-1A	007	T	Plot 1A location #3	WEDI #1 = 99.8
11:41	P-1A	008	T	Plot 1A location #4	WEDI #1 = 99.9
11:42		09	P	Ref. Panel	WEDI #1 = 100.1

SVC Spectra Vista Corporation

A1.5 Equipment List

The equipment list includes all the items that should be checked and packed before the field trip.

Field Spectroradiometer:

- Spectroradiometer & case
- Fore-optic lenses with their FOV templates
- Fiber optic light guide
- Laptop computer
- PDA (optional)
- Interface & battery power cables

Field Spectroradiometer Optional Accessories:

- WEDI external detector interface
- LC-RP Pro with fiber optic light guide
- DC-RT Integrating sphere
- Batteries & chargers for optional accessories

Batteries, Chargers & Adapters:

- Spare spectroradiometer batteries
- Spectroradiometer battery charger
- Spare laptop battery
- Car adapter for laptop
- Travel adapter(s)
- Alternative power cables

Reference Reflectance Panels

- Reference reflectance panel
- Backup reference reflectance panel
- Air duster or soft brush
- Spirit level
- Tripod for mounting panel

Accessories

- Medical first aid kit
- Sun protection – creams, hats and loose clothing of an acceptable color
- Large shade umbrella or gazebo at base-camp.

- Tripod, monopod, jib, boom or custom mounting jig
- Log sheets, notebook & pen
- Global/diffuse sunshine monitor
- Digital camera
- Sky camera
- GPS to plot site boundaries and optional DGPS base station
- Tape measure
- String/cord for grid/ wire flag markers, pegs & hammer

A1.6 Cleaning the Spectralon Reference Reflectance Panel

A dirty panel has lost its calibration.

Cleaning without re-calibration has some merits where calibration options are limited.

Do <u>not</u> use chemical such as a compressed air can with propellants to clean the panel!

A visual inspection can indicate a dirty panel, however a simple water test will show any hidden contamination. Pour clean (distilled) water onto the surface of the panel. The surface of a clean panel is hydrophobic, resulting in large water droplets form which can easily flow off the panel as shown in Figure 35. Where there is contamination or dirt the water will generally stick to the surface.

Figure 35 Water Test on Clean Reflectance Panel

Panel Cleaning Requirements:

- Clean distilled water
- 220 – 240 grit waterproof emery cloth (wet/dry sanding paper)
- Sanding block

Wrap the sanding paper round the sanding block. Wet the surface of the panel and the sand paper. Gently rub the wet surface of the panel in circular or a figure of eight

movement to "exfoliate" the dirt or contamination. Note: to maintain a flat surface the sanding block should be moved evenly across the whole surface. It should not be necessary to remove more than 0.1 mm (2-3 thou) of the panel surface. Periodically run water over the surface of the panel to clean off the loose particles and to test if the surface it hydrophobic.

After cleaning the panel should be left to air dry.

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