



EnMAP Field Guides

Technical Report

Spectral Sampling with the ASD FIELDSPEC 4

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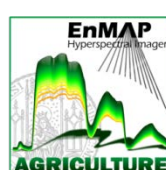
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Technical Report

Spectral Sampling with the ASD FIELDSPEC 4

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1 Introduction

1.1 Definitions

Hyperspectral remote sensing is the measurement of reflected radiance in narrow contiguous spectral bands over the full visible and solar reflective infrared spectrum (Goetz et al., 1985). Outside the laboratories, the main source of energy is solar radiation. As an approximate black body, the sun absorbs all incident light and emits energy corresponding to Planck's law with a surface temperature of around 5800K. The reaction of molecules on energy fluxes as transmission, absorption and reflectance, is dependent on the wavelength λ . Numerous natural processes can be observed by analyzing the amount of energy transferred in the principle domain of solar radiance between roughly 350nm and 2500nm. Amongst others, sunlight represents the main factor for plant photosynthesis, thus explaining why the majority of science in this field is geared to spectral characteristics of leafs and canopies (Turner et al., 2004). Measurements of the share of reflected, transmitted and/or emitted energy account for plant conditions and further biophysical parameters.

This field guide intends to give an overview of background knowledge, measurement practices and related information for the retrieval of spectra with the ASD FieldSpec 4.

1.1.1 Definition of spectrum

In the field of physics, the term *spectrum* is defined as

“The distribution of a characteristic of a physical system or phenomenon, especially:

- a. The distribution of energy emitted by a radiant source, as by an incandescent body, arranged in order of wavelengths.

[...]”

(The American Heritage Dictionary, 2009)

Thus, a spectral measurement is always a wavelength-dependent measurement of radiance emitted or reflected by the examined target. The higher the spectral resolution of the device, the more individual radiance measurements are carried out by the product for each electromagnetic frequency. The graph of a function assigning the amount of reflected or emitted energy for each wavelength is called the *spectral signature* of a target. In theory, these signatures reveal detailed information about the physical, bio-chemical and structural composition of a surface and parts of their interior.

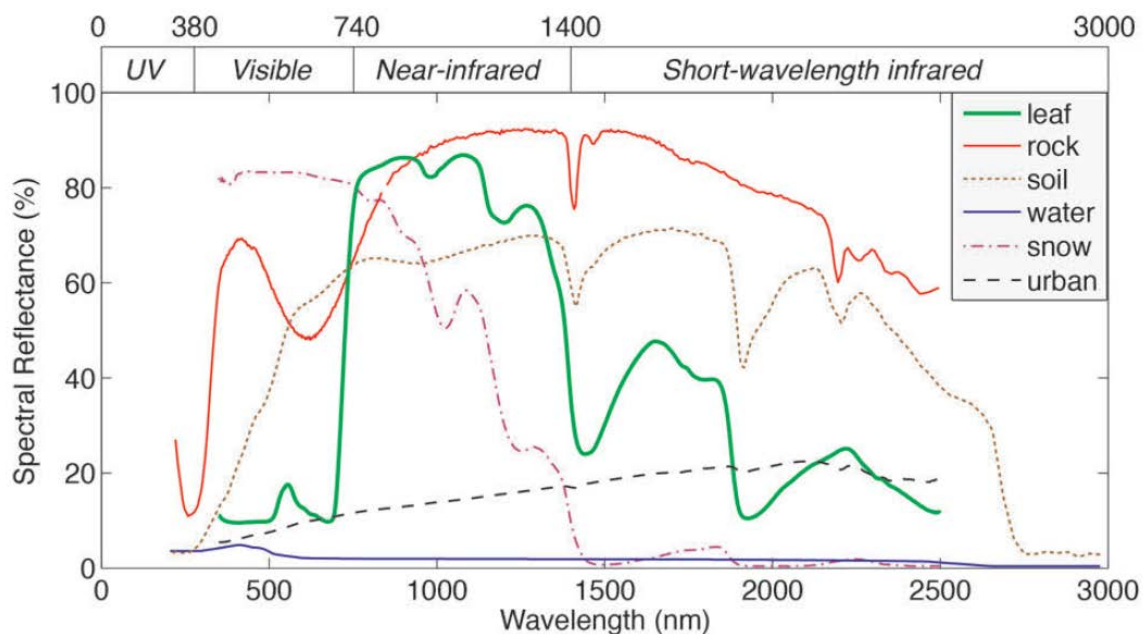


Figure 1-1: Reflectance spectra of selected Earth's surface components (Kaufmann et al., 2012; based on data derived from the USGS Digital Spectral Library). The laboratory measurements represent samples of an oak leaf from Colorado (leaf), Aventurine quartz from India (rock), Montmorillonite and Illite from Virginia (soil), seawater from the Pacific Ocean (water), fresh snow from Colorado (snow), and black road asphalt from Colorado (urban).

1.1.2 Definition of Field Spectrometry

Field Spectrometry is “The quantitative measurement of reflectance, reflected radiance, or irradiance using [...] Field portable spectrometers and spectroradiometers that acquire a continuous spectrum” (ASD Inc., 2007). Consequently, field spectroscopy serves to upscale processes of interaction between energy and mass from single individuals up to large-scale alignments (Gamon et al., 2006)

1.2 Areas of Application

The hyperspectral technology is often used where spectral information in continuous narrowbands is needed. Aside from resource management and monitoring of terrestrial and aquatic ecosystems, there are also applications in the field of risk management and atmospheric science (Kaufmann et al., 2012). This guide, however, puts emphasis on the use of field spectrometers mainly for agronomic concerns. An improvement of spectral and spatial resolution in the past decades has also paved the way for precision farming (Rao et al., 2007). The exact observation of pigments, water content and variables of leaf structure offers valuable information about plant stress and biomass productivity. By choosing suitable band combinations, more and more parameter-specific indices are developed.

The development of hyperspectral airborne sensors, like *AIS* or *AVIRIS*, has started in the early years of 1980. The installation of this technology on satellite platforms, however, finally proved successful with NASA's *Hyperion*, ESA's *CHRIS* or China's *HJ-1A* sensors beyond the turn of the millennium (Schaepman et al., 2009). Once in orbit, the *EnMAP HSI* will continue this trend, providing spectra of earth's surface with a ground resolution of 30x30 meters (Storch et al., 2013). Until then, airborne

flights and field measurements serve as main sources for spectral data. Being closest to the target, field spectrometers are considered to provide the most reliable information about the spectral behavior of all different kinds of surfaces. Hence, these devices are often used in the course of calibration/validation campaigns as well as in the examination of geological and vegetative features (ASDInc., 2007).

1.3 Measurement and Devices

Probably the most famous producer of non-imaging spectrometers is the Analytical Spectral Devices, Inc.: ASD. With their three different series TerraSpec, LabSpec and FieldSpec they cover a wide range of possible application. Having created the world's first portable spectroradiometer in 1990, the first version of the ASD FieldSpec was on the market in 1993 (ASDInc., 2013). Since then, new generations of field spectrometers have been developed by this company – the latest of which has been used for this field campaign. The Geophysical and Environmental Research Corporation (GER) is another manufacturer of spectroradiometers used for scientific purpose. For a comprehensive list of instruments available see Milton (1987).

2 Data Collection

2.1 Theory: Measurement Principle

The *ASD FieldSpec 4 standard res. (FS4)* is a transportable battery powered spectrometer. It is designed for measurements either in the course of field campaigns or in the laboratory. The spectral range of this highly resolving device covers wavelengths between 350 and 2500nm, the sampling rate is 0.2 seconds per spectrum. Three different detectors facilitate the recording of the spectra: a silicon-photodiode-array composed of 512 elements for the VNIR (350-1000nm) and thermoelectrically cooled InGaAs-photodiodes (Indium, Gallium, Arsenid) for each the SWIR1 (1000-1800nm) and the SWIR2 (1800-2500nm). With a spectral resolution varying from 3nm in the very short and 10nm in the farer wavelengths, the device records spectra based on the information of 2151 bands. For a complete overview of the specifications, see Table 2-1.

Table 2-1: Technical specifications of the ASD FieldSpec 4 Standard Resolution (ASD Inc. 2007).

Spectral Range	350-2500 nm
Spectral Resolution	3 nm @ 700 nm 10 nm @ 1400/2100 nm
Sampling Interval	1.4 nm @ 350-1050 nm 2 nm @ 1000-2500 nm
Scanning Time	100 milliseconds
Stray light specification	VNIR 0.02%, SWIR 1 & 2 0.01%
Wavelength reproducibility	0.1 nm
Wavelength accuracy	0.5 nm
Maximum radiance	VNIR 2X Solar, SWIR 10X Solar
Bands	2151
Detectors	VNIR detector (350-1000 nm): 512 element silicon array SWIR 1 detector (1000-1800 nm): Graded Index InGaAs Photodiode, TE Cooled SWIR 2 detector (1800-2500 nm): Graded Index InGaAs Photodiode, TE Cooled
Input	1.5 m fiber optic (25° field of view). Optional narrower field of view fiber optics available.
Noise Equivalent Radiance (NE_{DL})	VNIR 1.0 X10 ⁻⁹ W/cm ² /nm/sr @700 nm SWIR 1 1.2 X10 ⁻⁹ W/cm ² /nm/sr @ 1400 nm SWIR 2 1.9 X10 ⁻⁹ W/cm ² /nm/sr @ 2100 nm
Weight	5.44 kg (12 lbs)
Calibrations	Wavelength, absolute reflectance, radiance*, irradiance*. All calibrations are NIST traceable. (*radiometric calibrations are optional)
Computer	Windows® 7 64-bit laptop (instrument controller)

2.2 Technical Accomplishment

2.2.1 Preparation (Handling the Device)

Safe Handling of the Cables	
<ul style="list-style-type: none"> Always be careful when positioning, using and curling the fiber optic cable! 	<ul style="list-style-type: none"> Do not place the device onto the ports when the respective cables (power / LAN) are plugged in!
<ul style="list-style-type: none"> The cable must not be bent nor be curled up with a diameter of less than 12cm! 	<ul style="list-style-type: none"> Make sure to safely curl up the fiber optic cable and place it beneath the net on top of the device (Figure 2-1)!
<ul style="list-style-type: none"> Avoid any kind of pressure onto the cable (e.g. a cable jam at the cover of the transport bag)! 	<ul style="list-style-type: none"> A single disruption of even only one of the 57 glass fibers inside the cable causes degradation of the signal-to-noise-ratio up to 5%!



Figure 2-1: ASD FieldSpec 4 in an open backpack with the fiber optic cable curled and safely stored.

Safe Handling of the Device and its further Utilities

- The FS4 produces waste heat, so do not cover the ventilation slots on the bottom and the top of the device (e.g. clothes which are stored inside the backpack)!
- The backpack's rain cover is not suitable for use during continual rainfall → store the FS4 in a dry and cool place!
- The device is to be switched on at least 20 minutes before any kind of measurements (a warm up phase of one hour is recommended for measurements of absolute radiance)!
- SWIR modules are being chilled down to -20°C, so the FS4 is not to be left in a hot car during warm up phase. When exposed to direct sun radiation the device will not be able to keep up the low temperature and therefore generate imprecise measurements or simply overheat and turn off!
- Put the Spectralon Panel back into its isolated case whenever it is not in use!
- A rechargeable battery will provide electrical power to the FS4 for approx. 4 hours. It is placed in another pocket of the backpack (Figure 2-2). When changing the battery, the FS4 is to be turned off first!
- There are two notebook-batteries. Each of them has an operating time of approx. 1.5h, so this is the most common limiting time factor of measurements in the field!
- Under no circumstances must the surface of the Spectralon Panel be touched or messed!
- The FS4 is an expensive and precisely calibrated measurement device which is not insured by the state. Treat it carefully and responsibly at all time! Never leave it out of site, in the car or in a hotel room!

Correct Placement of all Components

- For the use in the field, put the plastic board at your belly and place the belt around your shoulder and your neck. When safely attached and adjusted, put the notebook onto the plate
- Before putting on the loaded backpack, make sure all fasteners are correctly plugged and stable (ask others for help!)
- The notebook has a reflective display which is usually easily legible. Make sure that brightness is adjusted to the maximum as long as there is enough battery capacity left.
- The pistol grip is an auxiliary tool to keep the fiber optic cable in place. Carefully run it into the hole at the metallic back of the grip until you notice it click into place
- When not in use, the pistol grip can be stored in the little pocket of the back pack which should be found at one's right side of the hip when carried on the back (do not bend or squeeze the fiber optical cable!)



Figure 2-2: ASD FieldSpec 4 kept in the backpack; equipped with several storage pockets, a battery and a pistol grip for accurate fixation of the fiber optic cable.

2.2.2 Measurement

Measurement Procedure

- (1) Connect the FS4 with the battery power unit or, if available, with an electrical socket via power supply unit.
- (2) Start the FS4 by flipping the On/Off switch which is located at the back of the device (see Figure 2-3)
- (3) When the FS4 is ready to measure, carefully take the optic fiber cable out of the upper storage net. Remove the black rubber cap and run the cable end into the pistol (carefully overcome the slight resistance) – do absolutely not bench or squeeze the cable! Mind the minimum curvature radius of ~12cm!
- (4) Put the FS4 into the open ASD backpack, safely place all components and fasten the upper and the two lateral latches as shown in Figure 2-5
- (5) Let others help you shoulder the backpack and fasten the last latch around your waist
- (6) Put on the plastic board and place the notebook on top of it
- (7) Boot the notebook and start the RS³ software. The FS4 should automatically connect to the notebook via WiFi which is indicated by a Windows message and the instant display of measured spectra (raw data). If this is not the case, see the information box below (Figure 2-4) or the trouble shooting part for an explanation of correct network setup



Figure 2-3: Console for technical controls and connections at the back of the FS4.

Network Name: 18017
IP Address (wireless): 10.1.1.77
IP Address (Ethernet): 10.1.1.11
Network Mask: 255.255.255.0

Figure 2-4: Network settings.



Figure 2-5: ASD FieldSpec 4 kept in the backpack; equipped with several storage pockets, a battery and a pistol grip for accurate fixation of the fiber optic cable.

2.3 Sampling Strategy

The field of view (FOV) of the fiber optic cable is $\alpha = 25^\circ$. This geometrically results (see Figure 2-6) in a sampling area (A) depending on the distance (d) between the cable-end and the target:

$$A = \pi \cdot \left(\tan \frac{\alpha}{2} \cdot d \right)^2 \quad (\text{Equation 2-1})$$



Figure 2-6: Schematic illustration of the technical arrangement of a hyperspectral field- or laboratory measurement.

With a recommended distance to the target of 100cm the recorded spectrum will be an average over the ground area of 15dm² which equals a circle of 44cm in diameter.

Table 2-2: Correlation between distance to target and area / diameter of the field of view.

Distance [cm]	Area [dm ²]	Ø [cm]
10	0.2	4
20	0.6	9
30	1.4	13
40	2.5	18
50	3.9	22
60	5.6	27
70	7.6	31
80	9.9	35
90	12.5	40
100	15.4	44
110	18.7	49
120	22.2	53
130	26.1	58
140	30.3	62
150	34.7	67

Sampling Strategy

- Make sure that no other obstacles obstruct the area of measurement. Most important: the user of the FS4 is suggested to spread his legs and hold the pistol grip directly in front of him with a distance to his body of at least 40cm.
- During calibration or spectrum save notice any kind of environmental changes, such as clouds covering or revealing the sun, direct reflection by surrounding obstacles etc. Repeat the measurement if necessary, and/or write down source and magnitude of the disturbance.
- For the same reason as above, preferable surfaces to measure are those with a maximum of homogeneity.
- Don't forget to update your measurement report (coordinates, target, file-names, picture number, time and abnormalities: s. chapter 9).
- The spectrum can be recorded as soon as the user points directly and vertically at the target. A bubble level on the backside of the pistol grip indicates when the deviation angle from vertical becomes zero.
- Take at least two pictures with your camera: one of the surface condition and one of the location.
- While RS³ saves the spectrum, hold the pistol grip as steady as possible.

2.4 Sources of Errors and Uncertainties

Problem	RS³ error “Spectrometer isn’t ready“
Reason	Low battery power (< 9.7 Volt)
Solution	<ul style="list-style-type: none"> ▪ Switch off the device and recharge the battery or replace it by a charged one

Problem	After white reference measurement, spectralon spectrum does not equal a 1.0 flat line
Reason	Wrong adjusted or dirty spectralon panel
Solution	<ul style="list-style-type: none"> ▪ Check: <ul style="list-style-type: none"> ○ Adjustment (horizontal? Correct distance? Completely sun exposed?) ○ Surface (dirt spots, water droplets) ○ Lighting stability (changing cloud cover? Additional sources of radiation?) ▪ Repeat the white reference calibration <p>! Note, however, that the natural variability of the atmospheric water vapor concentration causes interferences of high amplitude at ~1850nm and of low amplitude at ~1400nm for any kind of <i>outdoor</i> application. These errors might seem severe to the user but in fact have neither notable effect on the measurement nor can they be eliminated!</p>

Problem	Spectrum (partially) exceeds a reflectance of 1.0
Reason	<ul style="list-style-type: none"> ▪ Lighting intensity is likely to have increased (appearing of the sun, includes former coverage by invisible cirrus clouds) ▪ Last white reference too long ago, notable change in the zenith angle of the sun ▪ Target is closer to the sensor than the spectralon panel used to be (indoor use only)
Solution	<ul style="list-style-type: none"> ▪ Take another white reference measurement (consider correct distance!) and repeat / continue with the next measurement

Problem	RS³ does not connect to the FieldSpec device
Reason	various
Solution	<ul style="list-style-type: none"> ▪ Check <ul style="list-style-type: none"> ○ power (cable or battery) and status (noticeable ventilation sound if running) ○ connection of the fiber optic cable to the device ○ distance between FS4 and notebook (low/no signal) ○ notebook switch for WiFi connections ▪ Network Settings: <ul style="list-style-type: none"> ○ Check if the wireless connection has been changed ○ If so: re-connect or add a new wireless connection <p><i>Windows 7 → Control Panel → Network and Internet → Manage Wireless Networks → Add</i></p> <ul style="list-style-type: none"> ▪ Network Name: 18017 ▪ Security Type: WEP ▪ Security Key: 0123456789 <div style="background-color: #e0e0e0; padding: 5px; margin-top: 10px;"> <p>Network Setting:</p> <p>IP address (wireless): 10.1.1.77</p> <p>IP address (Ethernet): 10.1.1.11</p> <p>Network mask: 255.255.255.0</p> <p>Gateway, DNS, DHCP: 0.0.0.0</p> </div>

Problem	RS³ does not show any spectra (though connected to the FS4)
Reason	The FS4 does not receive enough radiation
Solution	<ul style="list-style-type: none"> ▪ Remove rubber sealing cap from the optic fiber cable ▪ Check illumination (shadowing, clouds, possibly electric lighting)
Reason	Inappropriate display configuration in RS ³
Solution	<ul style="list-style-type: none"> ▪ First zoom out completely (right click on chart, “undo zoom”) ▪ Then zoom into the bottom of the chart by drawing a rectangle around it
Problem	Spectrum disappears between 350 – 1000nm after dark current measurement
Reason	Malfunctioning shutter
Solution	<ul style="list-style-type: none"> ▪ Move or gently shake the FS4 and repeat the measurement

3 Data Elaboration

3.1 Required Software

3.1.1 Using the RS³-Software

First Adjustments

- As soon as RS³ is connected to the FS4 it will display current measurements in the main window
- These spectra are results of an average of single measurements. You can manually enter the number of samples to be taken for each measurement procedure
 - *Control* → *Instrument configuration* → *Number of samples* → *Spectrum: ##*
 - Choosing a low value (eg. 2 – 5) for this variable will make short term differences visible for the user, but might catch/save outliers (extreme spectra) by chance.
 - A high value (15 – 25) leads to slower reaction and takes more time to save, but will generate relatively smooth spectra
 - A good compromise of these both advantages could be a number of samples of 10

Optimize

- Just like any other optical sensor the FS4 needs to adjust its integration time, i.e. its sensitivity to the amount of energy available for the photodiode array (CCD sensor)
 - *Button "OPT"* → *wait until optimization is complete*
 - The appearing spectrum should now look like shown in Figure 3-1 - it represents sensitivity of the detectors in each wavelength
 - Note that there are four dominant minima of sensitivity, located at the lower and upper end of the spectral range, as well as at $\lambda=1000\text{nm}$ and $\lambda=1800\text{nm}$
- As an alternative you can also manually adjust the integration time
 - *Control* → *Adjust Configuration* → *choose integration time* → *hit set* → *"OK"*
 - The more intense ambient light is, the shorter the integration time is to be set
 - ! Under no circumstances change offset and gain of the InGaAs-detectors (1000nm – 2500nm) !

These values are pre-calibrated for this particular appliance and any modification will cause degradation of measurement precision.

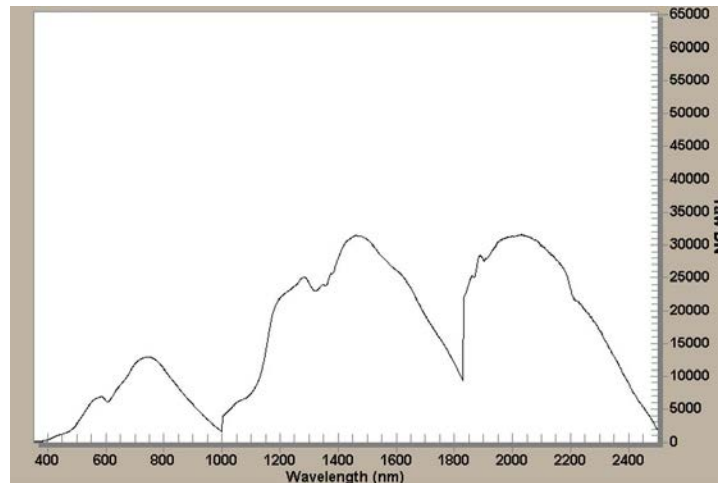


Figure 3-1: Optimized spectrum, equals wavelength-related sensitivity

Measurement of Radiance

- By now the y-axis of any shown spectrum is a dimensionless *raw digital number* (Raw DN)
 - In order to generate a spectrum of radiance, execute the following step:
 - Button “RAD” → wait until black current is measured and the new spectrum appears → zoom in if necessary by drawing a rectangle around the graph - right within the spectrum diagram
- ! Notice that there is a more or less visible detector step at $\lambda=1000\text{nm}$ which is caused by the changeover between the silicon- and the InGaAs-detectors which later has to be edited manually!

Measurement of Reflectance

- The spectrum of reflectance (Ref) is the share of radiance a target reflects from the luminous source in each wavelength
- Values of the reflectance can only vary between 0 (total absorption or transmission) and 1 (total reflection by the target)
- Maximum reflection needs to be calibrated by a *Spectralon Panel* which combines two elementary attributes:
 - “perfect” diffuse surface
 - “perfect” reflection within the span of examined wavelengths (350nm – 2500nm)
- these two characteristics make the Spectralon Panel a (nearly) perfect white body
- Any target-related reflectance has to be referred to the maximum reflection of the Spectralon Panel
- If not yet done, adjust the number of spectra to be taken for white reference
 - Control → Instrument configuration → Number of samples → White Reference: ##
 - Under constant lighting conditions a greater value will smooth the WR-line by auto-compensation of outliers

- It is suggested to set this variable to 25
- Put the Spectralon Panel into the FS4's field of view
 - Button "WR" → wait until a horizontal line at 1.0 reflection appears (Figure 3-2).
- If the spectrum of reflectance shows excessive disturbances, repeat the white reference calibration

Note, however, that the natural variability of the atmospheric water vapor concentration causes interferences of high amplitude at ~1850nm and of low amplitude at ~1400nm for any kind of *outdoor* application. These errors might seem severe to the user but in fact have neither notable effect on the measurement nor can they be eliminated

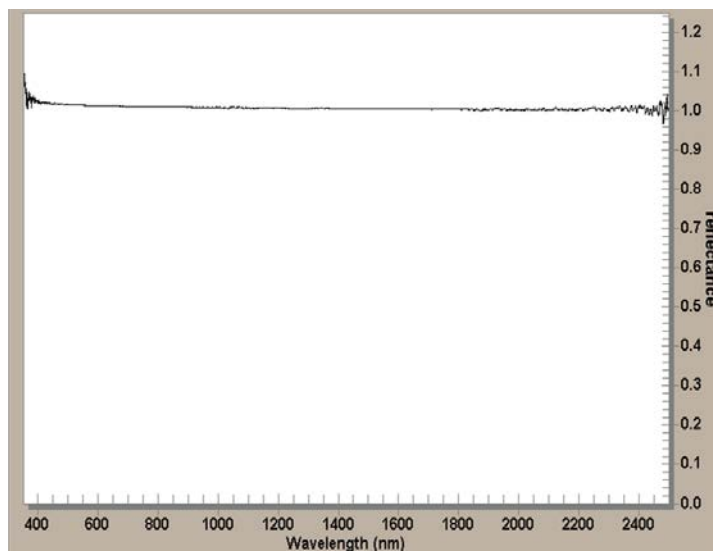


Figure 3-2: White reference spectrum of a Spectralon Panel (indoor use)

Figure 3-3: Example for a completion of the 'Spectrum Save' template

Spectrum Save

→ *Control* → *Spectrum Save* → ...

In order to save the displayed spectrum, RS³ needs the following input:

- *Path Name*: Path where you want to store the spectra
- *Base Name*: Name of the file you are about to generate (should include whether this is a radiation or reflectance measurement)
- *Starting Spectrum Num*: Extension of the Base Name. If several files are being created, this parameter sets the first number to be remitted
- *Number of Files to save*: Indicates how many files of the same spectrum (and the same base name) are to be generated
- *Interval between saves*: setting a period of time between the saving of each spectrum
- *Comment*: optional notes. This input is often carelessly neglected, although it will help reconstruct problems or limitations of each measurements (such as: try-and-error spectra, unsure circumstances, interpretation ideas, completion or explanation of the file-name, user name ...)

... → *"Begin Save"*

- Hitting "Begin Save" will make RS³ immediately carrying out the saving procedure as specified above

... → *"OK"* → *Hit space bar when ready*

- Choosing the option "OK" will not have any effect until the user hits *space bar*
- As soon as he does so, RS³ starts saving the spectrum as specified above
- Without having to re-open the "spectrum save" window, another hit on space bar will save the next spectrum with the consecutive file number(s)

Saving GPS coordinates

The RS³ software allows contemporaneous saving of positioning data. Connect the GPS unit via USB-cable to the notebook and turn them on both.

1. Activate software „Spanner“

- converts the USB signal into Serial-Port signal for RS³
- take the exterior USB port. If the GPS unit is not instantly recognized, unplug it and repeat the procedure

2. Optionally check the signal by executing C:\VisualGPS.exe

→ *Connect to GPS* → *Connect Using Serial Port*

3. Re-open RS³ (VisualGPS has to be closed!)

→ *GPS* → check "Enabled"

→ *Settings: Keep settings* → *OK*

The connection ought to be established after about 10 seconds. Coordinates are continuously being displayed in the status bar.

Please note: GPS data will be stored in the log-file (if GPS → Settings: „Write to log file“ is checked)

3.1.2 Viewing / Exporting Spectral Data with ViewSpec Pro

Loading Files

- RS³ saves the recorded spectra with the spectrum number as file extension (e.g. vegetation.000, vegetation.001, ...)
- In order to view, edit or export the spectral data, these files have to be opened in another software – the free tool ViewSpec Pro

Start ViewSpec Pro → File → Open → mark all relevant spectra → hit Open

- The spectrum files appear in the main window, ready for examination

Viewing Spectra

Select relevant spectra (single or multiple) → View → Graph Data

- The diagrams allow zooming just like RS³ does
- Right click on the plot for further visual adjustments (grids, font size, plotting options...)

Exporting Data

- ViewSpec Pro can convert any data gathered by the RS³ software into editable format

“Setup” menu → Output directory → choose your path → if INPUT- and OUTPUT-directory differ, ViewSpecPro will ask you if you like to unify them → select relevant spectra (single or multiple) → Process → ASCII Export...

- ...in the box Data Format for .asd-files only: select either “reflectance” or “Radiance/Irradiance” (depending on the respective spectrum)
- ...optionally select 1st or 2nd derivate (relevant for some analysis procedures)
- ...select a field separator (important for the import of ASCII data into other software)

... → hit “OK”

- The spectra will be saved in .txt format in the chosen output directory
- You can import the data into calculation software like MS Excel for further investigation and editing

3.2 Correction Methods

As indicated above, the recorded spectra are at first saved as raw data which contain all desired information. Irrespective of the sensor geometry in the field, these spectra need to be corrected for atmospheric and sensory errors. With ViewSpec Pro, the provisional .asd-files in binary form first have to be screened for anomalies occurring at slight or obvious changes in the lighting conditions or impending movements of the sensor. Multiple spectra of the same target, which have been recorded consecutively, then need to be merged to single ASCII text-files.

3.2.1 Splice correction

The so-called splice correction eliminates the gaps in the signal between the domains of the different detector arrays. Critical transitions are located at $\lambda=1000\text{nm}$ and $\lambda=1800\text{nm}$. The objective of the splice correction is to compensate the difference between the reflectance $R_{1000\text{nm}}$ and $R_{1001\text{nm}}$ by adapting all values from 1001nm upwards to the level of those to 1000nm. Expressed mathematically, this implies that

$$R_{i,\text{splice}} = \begin{cases} R_i, & i \in [1; 1000] \\ R_i - f_{1000}, & i \in [1001; 1800] \\ R_i - f_{1800}, & i \in [1801; 2500] \end{cases} \quad (\text{Equation 3-1})$$

with

$$f_{1000} = R_{1001} - (2 \cdot R_{1000} - R_{999}) \quad (\text{Equation 3-2})$$

$$f_{1800} = R_{1801} - (2 \cdot R_{1800} - R_{1799}) \quad (\text{Equation 3-3})$$

f_{1000} and f_{1800} represent biases which are added to the original values and – depending on their algebraic sign – either increase or decrease all further reflectances. $R_{i,\text{splice}}$ are the corrected new values with smooth splices at the critical transition wavelengths. When new values are corrected into negative, they need to be set to zero.

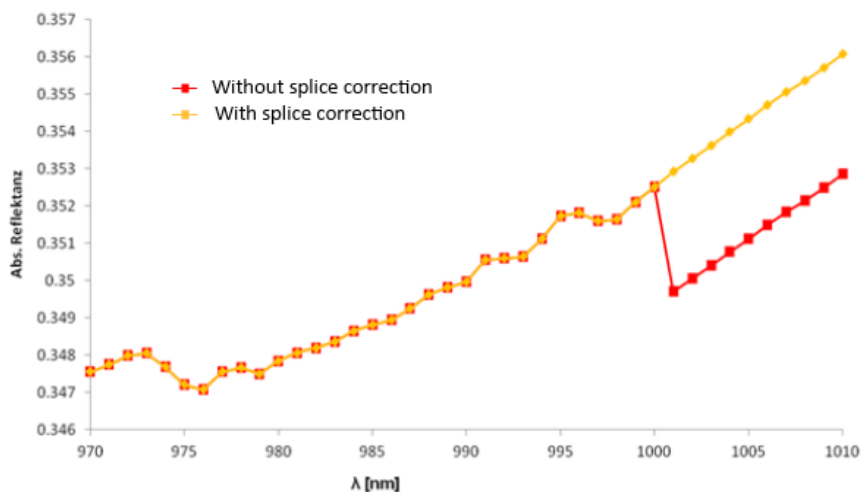


Figure 3-4: Demonstration of the effect of a splice correction on the spectral signature

3.2.2 Absolute reflectance

To this moment, spectral data are all relative reflectances, i.e. calibrated on the white reference panel. Its relative sensitivities for each wavelength is provided by the respective producer (e.g. LapSphere Spectralon) allowing a conversion into absolute reflectances by multiplication of the original data with the correction factors.

3.2.3 Signature Smoothing

A smoothing of the spectra is carried out by a quadratic polynomial with filter coefficients. This method is known as the Savitzky-Golay-Filter.

$$R_{i,SG} = \frac{1}{f_{norm}} \cdot \sum_{j=-m}^{j=m} C_j \cdot R_{i+j} \quad (\text{Equation 3-4})$$

In this algorithm, $R_{i,SG}$ are the smoothed and R_i the original reflectance values. C_j are the filter coefficients from Savitzky & Golay (1964). C_j -values for a smoothing of 14 points are listed in Table 3-1. f_{norm} is the normalization coefficient as a sum over all C_j .

Table 3-1: Coefficients of the Savitzky-Golay-Filter for m=13. Extension of Savitzky & Golay (1964)

C ₀	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	C ₈	C ₉	C ₁₀	C ₁₁	C ₁₂	C ₁₃	f _{norm}
517	46	46	44	42	38	34	28	22	14	62	-	13	-	1081
5	7	2	7	2	7	3	7	2	7	33	8	25	3	9

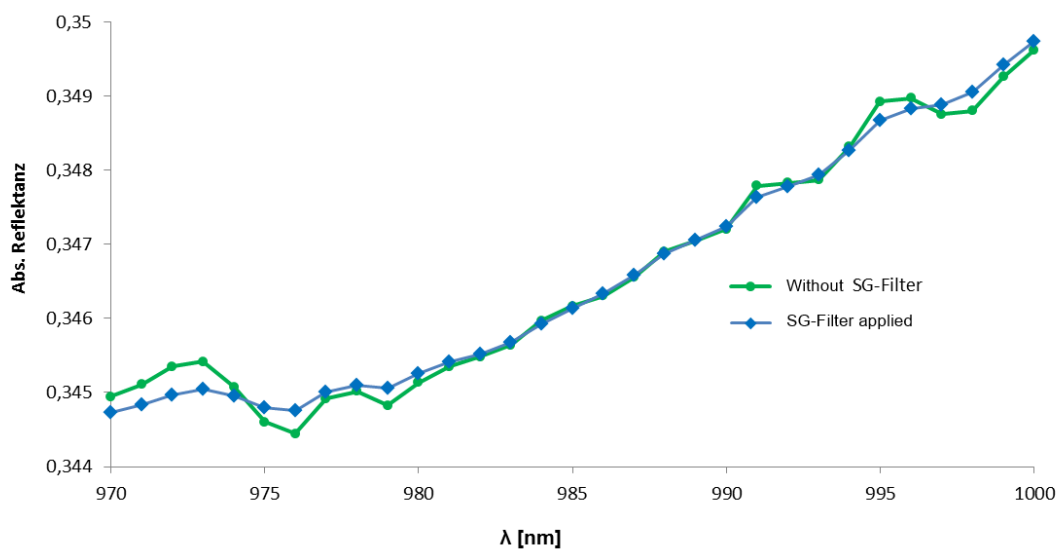


Figure 3-5: Demonstration of the smoothing effect of the Savitzky-Golay-Filter for m=13.

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4.1 Further Reading:

Continuative help for the FS4 and the RS³-Software can be found in different ASD manuals as well as on their webpage (www.asdi.com). For us the following manuals were available:

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|---|------------------------------|---|
| 1 | <i>RS3.pdf</i> | RS ³ Software guide - explanation for the RS ³ Software |
| 2 | <i>InstallationGuide.pdf</i> | Installation guide |
| 3 | <i>FieldSpec.pdf</i> | User manual for the FS4 - composition, settings, usage, maintenance, setup etc. |
| 4 | <i>Tech_guide.pdf</i> | Technical guide. Technical details for the FS4, as well as various useful hints for usage |
| 5 | <i>Accessories.pdf</i> | ASD accessories handbook |