Guidelines for user calibration of multispectral sensors

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Contents

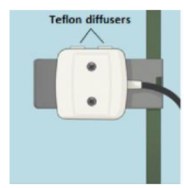
1. Objective

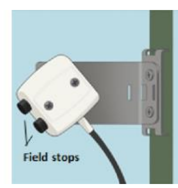
This document describes user calibration of a pair of multispectral sensors using daylight, and a standardized reflective panel. The obtained relative calibration factor is used for accurate estimation of vegetation reflectance. The documentation follows the principles outlined in Jin and Eklundh (2015).

2. Instruments and Tools

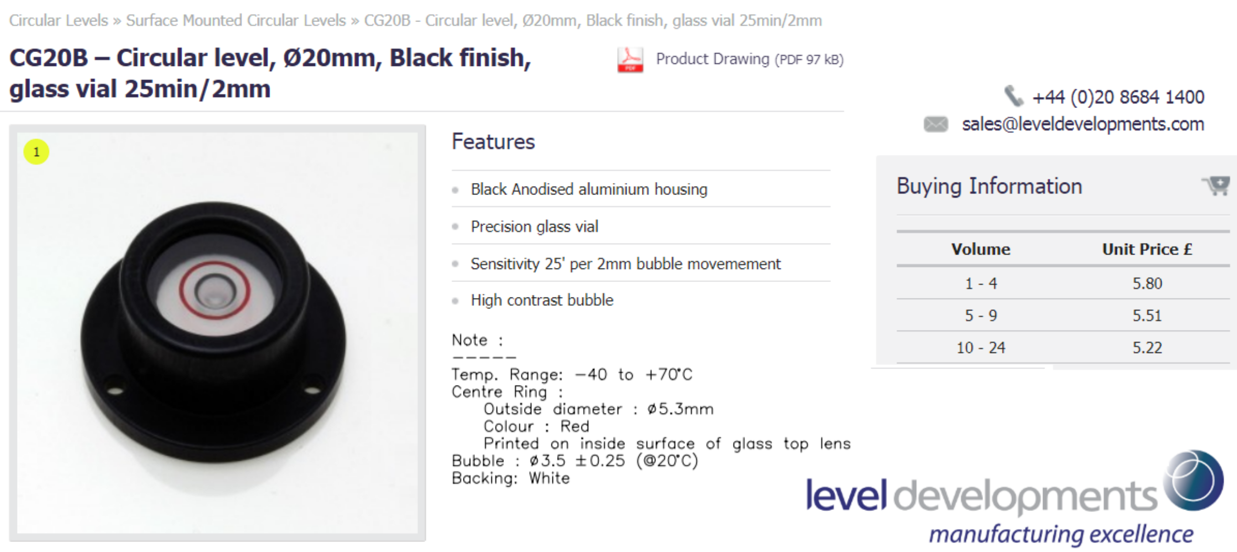
The following equipment is needed: An accurate data logger with the smallest sampling interval <= 5 Seconds (e.g. Campbell CR-1000), a Labsphere Spectralon™ 99% white reference panel, a high-precision circular bubble level (precision better than 0.5 degree), battery for data logger, two tripods, ruler, screw-driver and other basic tools.

Decagon EM50 data logger has a minimum sample interval of 1 minute and is not recommended to be used for sensor calibration. It is suggested to use CR1000 or other data loggers that both have SDI12 protocol and sample interval <= 5 Seconds to calibrate Decagon RSR spectral sensor





Here is an example of the circular bubble level


Circular Levels » Surface Mounted Circular Levels » CG20B - Circular level, Ø20mm, Black finish, glass vial 25min/2mm

CG20B – Circular level, Ø20mm, Black finish, glass vial 25min/2mm

Product Drawing (PDF 97 kB)

+44 (0)20 8684 1400
sales@leveldevelopments.com

Features

- Black Anodised aluminium housing
- Precision glass vial
- Sensitivity 25' per 2mm bubble movemement
- High contrast bubble

Note :

Temp. Range: −40 to +70°C
Centre Ring :
Outside diameter : ø5.3mm
Colour : Red
Printed on inside surface of glass top lens
Bubble : ø3.5 ±0.25 (@20°C)
Backing: White

Buying Information

Volume	Unit Price £
1 - 4	5.80
5 - 9	5.51
10 - 24	5.22

level developments
manufacturing excellence

Web page: https://www.leveldevelopments.com/products/circular-levels/surface-mounted-circular-levels/cp40b-circular-level-40mm-black-anodised-finish-plastic-vial/

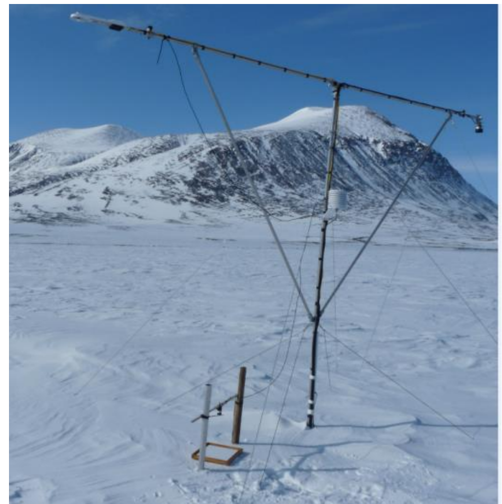
Tip!

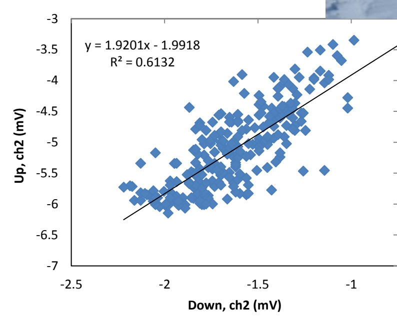
Estimate tilt angle from bubble ring position:
Bubble center movement (mm) × sensitivity per mm
Example of the above CG20B level with a sensitivity of 25′ per 2mm, when the bubble touches the red mark ring, the tilt angle is
$(5.3 - 3.5(\pm 0.25))/2 \times (25'/2) = 0.19° \pm 0.03°$

3. Location and weather conditions

The calibration is carried out outdoors in a large open space without obstacles blocking the sky view from the upward-looking sensor. It is preferably carried out in overcast sky for more than 2 hours, in which situation the calibration accuracy can be easily reached. If the calibration measurement is carried out in a sunny day, it should be done during a period lasting from more than one hour before local solar noon to more than one hour after local solar noon. The situation with rainy weather or ground covered by snow should be avoided.

Snow is very bright and generates too high proportion of diffuse light on the white reference panel, while the upward-looking senor only receives weak diffuse light from the sky. Such a situation is not ideal for sensor calibration.
Non-optimal calibration condition at this photo (Photo credit: M. Lund) in Greenland produces strongly scattered calibration data. We suggest not to use data from such conditions to calibrate sensor pairs.





4. Time and manpower

A rough calculation of time consumption for calibration is as follows:

Calibration preparation, programming, wiring, mounting	2 hours
Calibration timespan:	2.5 hours
Dismount tripods and collect/pack all items:	0.5 hour
Calibration data process and reporting:	3 hours

The work needs one main operator and is simplified with an assistant for the set-up before calibration and packing up after calibration.

5. Cautions

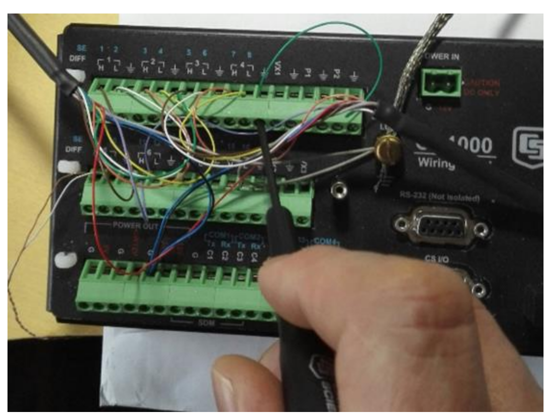
1. NO touching of the sensor light-sensing surface! NO touching of the white reference panel surfaces. For further information about how to care and handle the white

reference panel; see Appendix 12.1 Guidelines for care and handling of the Spectralon white reference panel by Labsphere Inc., 2017.

2. Do NOT expose the sensor sensing surfaces without any protective covers or wrappings before data logging, to avoid accidentally touching/spoiling the sensor sensing surfaces.
3. Do NOT put the white reference panel in place before the sensors are mounted onto the tripod tightly and are ready for measurement. Any accidental dropping of sensors or tools onto the white panel will irreversibly damage the panel surface.
4. When dismounting the sensor from spectral tower for calibration, put the sensor immediately and safely in a protective bag. Do NOT touch the sensor light sensing surface. If you find there is any old dirt on the sensor, do NOT clean the sensor light-sensing surface. The sensor should be calibrated twice, once before sensor cleaning, the other time after sensor cleaning. The calibration before cleaning is used to rectify the old measurement data together with last time calibration factors. The calibration after cleaning is for the new measurement data. When cleaning the light sensing surface, suggest using camera lens cleaning paper, or deionized water. Use neutral detergent when necessary.
5. Do NOT direct the without-diffuser sensor (the downward-looking sensor) toward the Sun, to avoid accidental damage the light sensing detector.
6. Always hold the sensor by its body instead of lifting it in the sensor cable. Frequent grabbing/pulling of sensor cable will irreversibly damage the connection between cable and sensor.

6. Calibration procedure

1. Charge the battery for the data logger. The voltage of the battery should preferably be above 12V. It is suggested to check the voltage 5~10 min after the charging clip has been unplugged. Immediate voltage measurement after charging will give a superficially high voltage reading.
2. Figure out the data logger and sensor (extension) cable connections.
3. Prepare the logger data sampling program (see below).



Connect the sensor wires to a CR1000 data logger

Here we use an example of Skye SWIR sensor (4 spectral channels plus 1 temperature channel) and a Campbell CR1000 data logger. For such a sensor pair, 10 channels are needed for the data logger. We therefore use single-end connection of the CR1000 data logger. CR1000 can be used in 16 SE mode or 8 DIFF mode.

To make things simple, it is suggested to always use the first 4 channels for the upward-looking sensor measuring incoming light, and the next 4 channels for the downward-looking sensor measuring the reflected signal. After fastening each cable wire to the logger pin-hole with a screwdriver, it is suggest to gently pull the wire to check if it is connected firmly enough. Loose connections or short-cut connections among bare wires must be avoided.

For sensors without SWIR band, there is no temperature channel. The extension cable only has 8 wires.

Amplified Voltage Output Sensor with Extension cable EXT/4

Wire Colour	Function
Brown	Cable screen / sensor body
Red	Power supply ground
Orange	Sensor signal ground
Yellow	Power supply positive
Green	Channel 1 positive voltage output
Blue	Channel 2 positive voltage output
Violet	Channel 3 positive voltage output
White	Channel 4 positive voltage output

Amplified Voltage Output Sensor with channels incorporating wavelengths over 1000nm and Extension cable EXT/5

Wire Colour	Function
Grey	Cable screen / sensor body
Blue + black	Power supply **negative**
Green	Sensor signal ground
Violet	Temperature positive voltage output
Red	Power supply positive
Brown	Channel 1 positive voltage output
White	Channel 2 positive voltage output
Orange	Channel 3 positive voltage output
Yellow	Channel 4 positive voltage output

Skye 1860 sensor, extension cable wire color code for sensors without (8-wire) and with (10-wire) temperature channel. Refer to *Guidelines for multispectral data collection* by SITES & NordSpec for details about sensor wire color code and connections to CR1000.

The details of connection of each sensor channel to the logger channels can be seen from the CR1000 CRBasic logger program in Appendix 12.2.

4. Program the data logger and do indoor test

The examples of calibrating Skye sensor and Decagon SRS sensor using CR1000 data logger are shown in Appendix 12.2.

Check the real-time monitoring data; all the readings should be within reasonable ranges: a small mV value (about 0~5 mV) for 8 spectral channels (Up_Ch1_Avg, Up_Ch2_Avg, Up_Ch3_Avg, Up_Ch4_Avg, Dw_Ch1_Avg, Dw_Ch2_Avg, Dw_Ch3_Avg, and Dw_Ch4_Avg). Check the wire connections if there are large negative values. Negative values could indicate no power supply for the sensor amplifier and that the op-amp amplifier does not work. The indoor ambient temperature Temp_Avg should show a reasonable value and this value divided by 10 should be roughly the value of two sensor temperature readings: Up_Temp_Avg and Dw_Temp_Avg.

If the checked readings are at reasonable values it is now ready to go out to set up the calibration tripods.

If the test is perfect, put all the stuff in a plastic box, ready to go out for sensor calibration.

7. Calibration setup

It is convenient to use two tripods for sensor calibration: one for sensor mounting, and the other for holding the white reference panel.

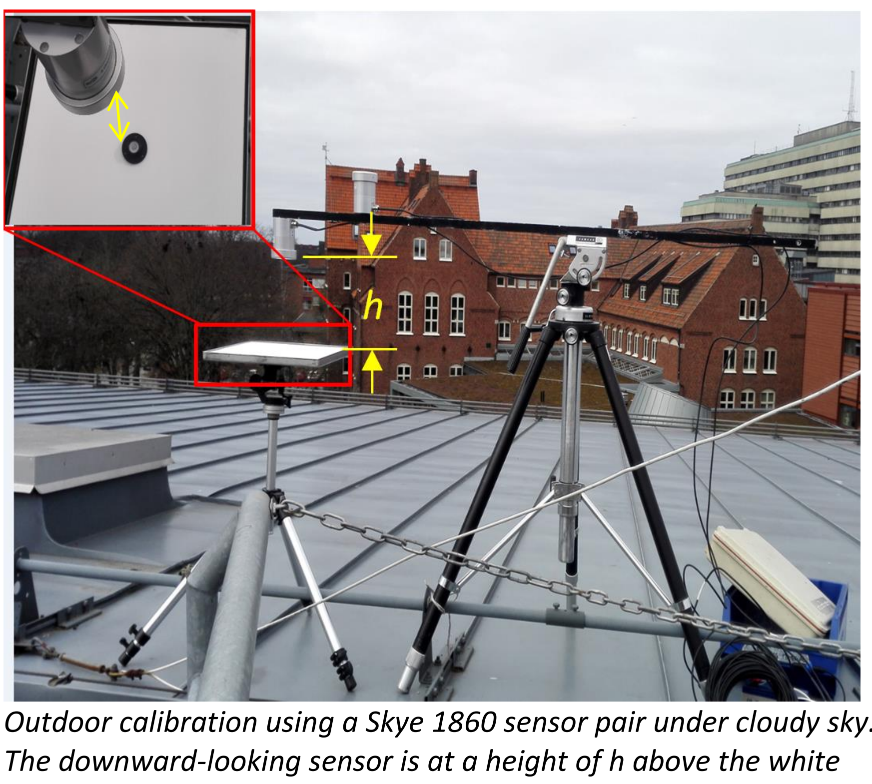
Set up the calibration tripods on a flat rooftop. Mount the sensor first and adjust the level using an accurate circular bubble level.

The calibration should be carried out in open air at a high place. Any nearby object with a height of H meters above the calibration level should be >10H meters away from the calibration tripods, so as to reduce the portion of hemispheric viewing blocked by nearby objects. There should not be any shining or white object above the level of the calibration. It is suggested to paint everything used in calibration, like tripod, metal boom, bolts and etc. in matte black color.

Adjust the relative place of the two tripods so as to make sure the mounting hole on the boom for the downward-looking sensor is centered above the middle of the tripod holder for placing the white reference panel. The two tripods should be firmly fixed/tied to the place, so as to avoid moving or falling due to wind. Mount the two sensors on to the boom that has been fastened onto the tripod. Adjust the level of the upward-looking sensor with a high-precision circular bubble level. There is no need to adjust the downward looking sensor given the boom with the two parallel surfaces above and below. The height h of the sensor above the reference panel is determined by the sensor Field-of-View (FOV) and the size of the white panel (Table 1). The basic requirement is that the sensor should not view outside of the panel. Considering the actual sensor viewing region is usually a little larger than the nominal FOV, we limit the sensor view within 2/3 of the panel dimension when calculating the height above the panel. For the 10 inch X 10 inch squared panel, the sensor should view a circular area with a diameter of 17 cm.

Table 1. Position height *h* (cm) of the sensor above white panel

Panel size / Sensor FOV (°)	25 cm (10 inch)	30 cm (12 inch)
25 (Skye sensor)	35~38	40~45
36 (Decagon sensor)	25~26	25~31
60 (the sensor with an extra view stop)	Too small to be used	15~17



Outdoor calibration using a Skye 1860 sensor pair under cloudy sky. The downward-looking sensor is at a height of h above the white reference panel.

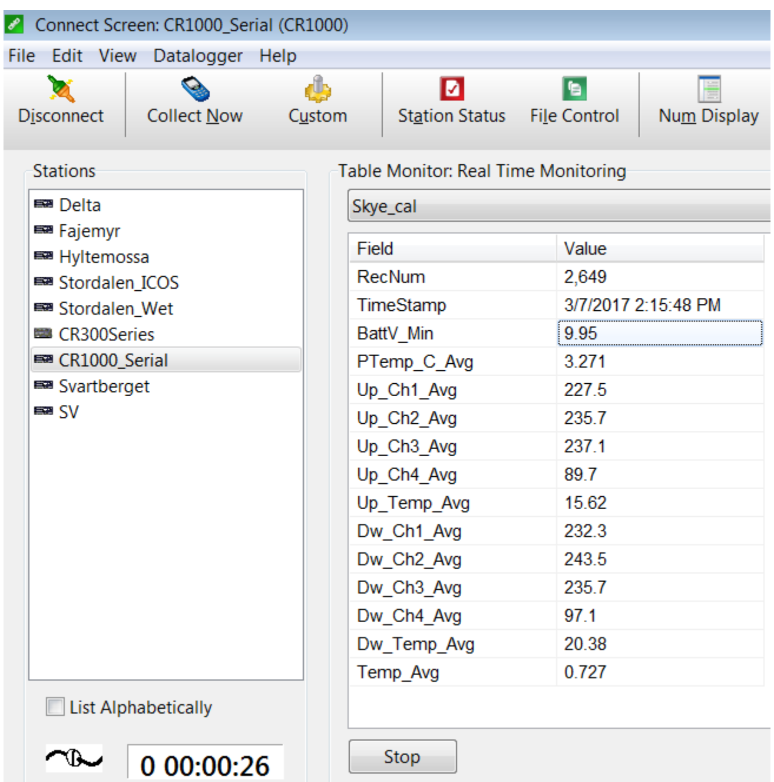
After the sensor level has been adjusted as perfectly horizontal as possible, and fixed tightly, place the white reference panel onto the panel holder that has been fixed on the other firmly-standing tripod. Now level the plate as perfectly horizontal as possible.

Put the data logger at least 1.5 m lower than the white reference panel, or about 10 m away from the tripod. The reason for doing so is, when checking the calibration data during calibration process, the operator should not introduce disturbances to the calibration measurement. Now it is ready to start data logging!

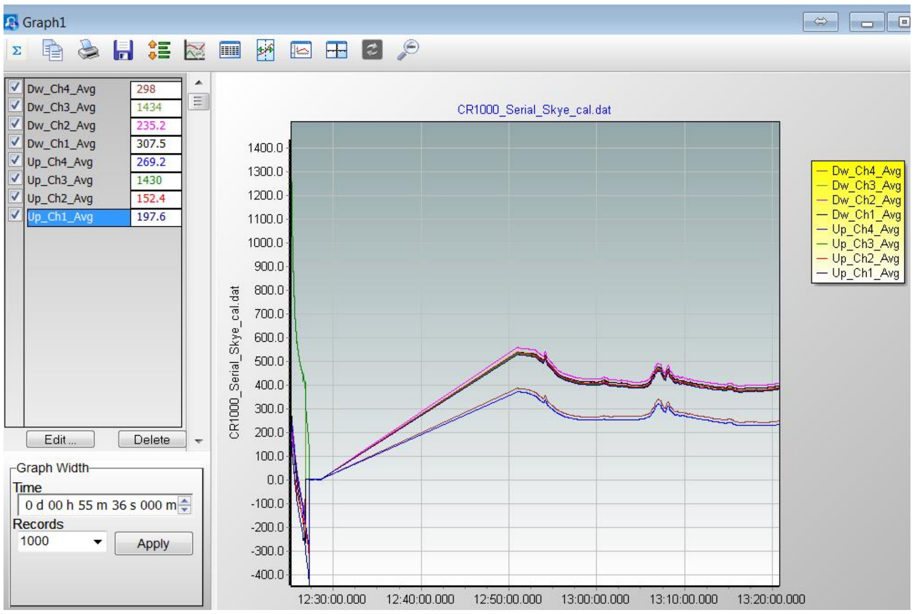
8. Calibration

Check the sensor reading to see if everything is working in the same way as indoor test, except that the sensor reading numbers should be larger than the in-door readings.

During the whole calibration process, it is suggested to keep other persons at least 10 meter away from the calibration set up. Any calibration data recorded when people are close to the sensor should be removed from the further processing.



Check the data again after about 30 min. Download data and plot the time series. All the spectral channel should follow the same temporal pattern during the calibration.



Carefully approach the calibration data logger if it is near the tripod. Keep your head lower than the white reference panel.

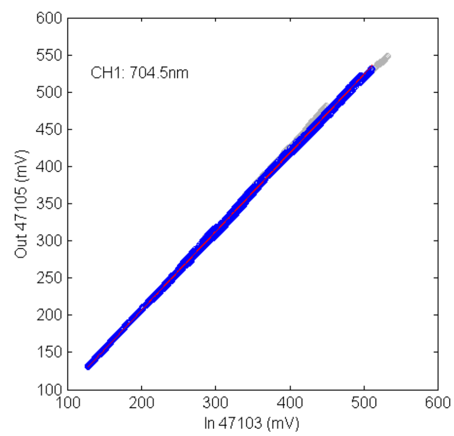
During the 2.5 hours' calibration, the measurement condition should be occasionally checked. Wind gusts may move the tripod or sensor boom. The white panel may be blown away. There may also be some unexpected spider or bird disturbance.

When calibration is finished, download and check the data for the last time. If everything is OK, dismount and tidy up all the equipment carefully. First, dismount the white reference panel and pack it up. Secondly, dismount sensors, and put them in protective bags. Finally, pack up all the other stuff.

9. Processing calibration data and document results

The data processing is to estimate the regression slope *k* between the incoming signal and the outgoing (reflected) signal. Excel can do the job simply to get an overview of the data noise and quality. The more advanced way is to use the Matlab script (calibration.m) in Appendix 12.3. In the Matlab function, the actual reflectance factor of the white reference panel (usually 0.99 for visible band and 0.98 for NIR band for the Spectralon panel) is also considered. The outliers due to unknown reasons in the calibration process are automatically and recursively removed by the Matlab function using a predefined tolerance threshold, default 2% (remove points with error above 2% between measurement and the regression line).

Example of the output from calibration.m




```
>> calibration(A(:,1),A(:,5),.99,0.02)
Iteration 1, Wait...
Iteration 2, Wait...
Iteration 3, Wait...
...
Iteration 9, Wait...
Samples left 5360.
fun =
     Linear model Poly1:
     fun(x) = p1*x + p2
     Coefficients (with 95% confidence bounds):
       p1 =       1.055  (1.054, 1.056)
       p2 =      -3.777  (-3.944, -3.611)
```

From the output we report the calibration factor as

CH1 of No. 47103 (Upward-looking sensor)	CH1 of No. 47105 (Downward-looking sensor)
1	1.055

For the calibration in clear day, the calibration process spans before and after the local noon. The calibration factor *k* should be computed for the two periods: before solar noon, and after solar noon. If the before-noon and after-noon measurements have different calibration factors above 10%, the calibration should be repeated again with perfectly leveled calibration plate and sensors.

A calibration document should be compiled using the calibration data. An example of such a document is shown in Appendix 12.4.

It is suggested to also compare the calibration results with those of the previous year or from the manufacturer, as well as before and after sensor cleaning, if there is before-cleaning calibration.

Note: from the manfaturer		Own_ca	% error
k_CH1 =	1.092	1.055	-3.5%
k_CH2 =	1.047	1.070	2.2%
k_CH3 =	0.995	1.027	3.1%
k_CH4 =	1.067	1.074	0.7%

10. Calculate vegetation reflectance and relevant indices

The calibration factor k is used to calculate vegetation reflectance in multiple spectral bands. An example of CH1 from the previous test is given here:

$$\boldsymbol{r\_CH1} = \frac{\boldsymbol{CH1_{47105}/1.055}}{\boldsymbol{CH1_{47103}}}$$

NDVI and other vegetation indices can be calculated accordingly.

11. Reference

Jin, H.X.; Eklundh, L. **2015** In Situ Calibration of Light Sensors for Long-Term Monitoring of Vegetation. *IEEE Transactions on Geoscience and Remote Sensing*, *53*, 3405-3416.

12. Appendix

12.1 Guidelines for care and handling Spectralon white reference panel

Labsphere

Spectralon® Reflectance Standards Care and Handling Guidelines

Spectralon Reflectance Standards (SRS) and Reflectance Targets (SRT) are optical standards and should be handled in much the same way as other optical standards. Although the material is very durable, care should be taken to prevent contaminants such as finger oils from contacting the material's surface. Always wear clean gloves with handling Spectralon.

1. Cleaning Instructions

If the material is lightly soiled, it may be air brushed with a jet of clean dry air or nitrogen. DO NOT use Freon. For heavier soil, the material can be cleaned by sanding under running water[1] with a 220-240 grit waterproof emery cloth until the surface is totally hydrophobic (water beads and runs off immediately).
Blow dry with clean air or nitrogen or allow material to air dry.

If the material requires high resistance to deep UV radiation, prepare the piece as above, and then perform either of the following two treatments:

1. Flush Spectralon piece with >18 MΩ.com distilled, deionized water for 24 hours.
2. Vacuum bake the Spectralon piece at 75°C for a 12 hour period at a vacuum of 1 Torr or less, then purge the vacuum oven with clean dry air or nitrogen.

[1]Low reflectance Spectralon (<10% reflectance) should be dry sanded.

2. Storage and Transportation

Spectralon standards should be stored in a clean laboratory environment. It is recommended to always keep the standards in a plastic bag or covered box except for during use. After exposure to extreme temperature and humidity conditions, e.g. during transportation, the standard should be allowed to adapt to the laboratory environment for a period of 2 hours.

Temperate Range: -80°C to 350°C
Humidity Range: 5% to 95%

3. Recommended Recalibration

Spectralon standards are stable over a long period of time when they are stored and maintained properly. When standards are not in use and kept in their original package under proper storage conditions, the recommended calibration period can start from the date of first use.

4. Disposal Recommendations

If Spectralon reflectance standards do not show the specified optical parameters after extensive use or after recalibration, they are to be disposed of according to the government regulations for non-hazardous, non-biodegradable materials.

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advancing the technology of light

12.2 CRBasic scripts for sensor calibration using CR1000 data logger

1. Calibrate a pair of 5 channel Skye sensor (4 spectral channels, 1 temperature channel)
Filename: Skye_cal1860A.CR1

```
'CR1000 logger program for calibrating Skye 4 channel sensors with inbuilt amplifier

'Declare Variables and Units
Public BattV
Public PTemp_C                                           'logger connection
Public Up_Ch1   'incoming 47103 red-edge 704 connect to SE 1 of logger
Public Up_Ch2   'incoming 47103 red-edge 740 connect to SE 2 of logger
Public Up_Ch3   'incoming 47103 NIR 860      connect to SE 3 of logger
Public Up_Ch4   'incoming 47103 SWIR 1636    connect to SE 4 of logger

Public Dw_Ch1   'outgoing 47105 red-edge 704 connect to SE 5 of logger
Public Dw_Ch2   'outgoing 47105 red-edge 740 connect to SE 6 of logger
Public Dw_Ch3   'outgoing 47105 NIR 860      connect to SE 7 of logger
Public Dw_Ch4   'outgoing 47105 SWIR 1636    connect to SE 8 of logger

Public Up_Temp ' Upward-looking sensor temp connect to SE 11 of logger
Public Dw_Temp ' Dwward-looking sensor temp connect to SE 12 of logger

Public Temp    ' air temperature             connect to Diff 5 (SE9 SE 10)


Units BattV=Volts
Units PTemp_C=Deg C
Units Up_Ch1=mV
Units Up_Ch2=mV
Units Up_Ch3=mV
Units Up_Ch4=mV
Units Dw_Ch1=mV
Units Dw_Ch2=mV
Units Dw_Ch3=mV
Units Dw_Ch4=mV
Units Up_Temp=mV 'divided by 10 to get temperature in Deg C
Units Dw_Temp=mV 'divided by 10 to get temperature in Deg C

Units Temp=Deg C
'Define Data Tables
DataTable(Skye_cal,True,-1)
      DataInterval(0,2,sec,10)
      Minimum(1,BattV,FP2,False,False)
      Average(1,PTemp_C,FP2,False)
      Average(1,Up_Ch1,FP2,False)
      Average(1,Up_Ch2,FP2,False)
      Average(1,Up_Ch3,FP2,False)
      Average(1,Up_Ch4,FP2,False)
      Average(1,Up_Temp,FP2,False)
      Average(1,Dw_Ch1,FP2,False)
      Average(1,Dw_Ch2,FP2,False)
      Average(1,Dw_Ch3,FP2,False)
```

```
      Average(1,Dw_Ch4,FP2,False)
      Average(1,Dw_Temp,FP2,False)

      Average(1,Temp,FP2,False)
EndTable

'Main Program
BeginProg
      'Main Scan
      Scan(2,Sec,1,0)
      'Default Datalogger Battery Voltage measurement 'BattV'
      Battery(BattV)
      'Default Wiring Panel Temperature measurement 'PTemp_C'
      PanelTemp(PTemp_C,_50Hz)
      'The Skye sensor with inbuilt op-amp need 5-15V power up for at least
0.5 Sec
      SW12(1)
      Delay(0,500,mSec)
      'Generic Single-Ended Voltage measurements 'Up_Ch1'
      VoltSe(Up_Ch1,1,mV2500,1,True,0,_50Hz,1,0)
      'Generic Single-Ended Voltage measurements 'Up_Ch2'
      VoltSe(Up_Ch2,1,mV2500,2,True,0,_50Hz,1,0)
      'Generic Single-Ended Voltage measurements 'Up_Ch3'
      VoltSe(Up_Ch3,1,mV2500,3,True,0,_50Hz,1,0)
      'Generic Single-Ended Voltage measurements 'Up_Ch4'
      VoltSe(Up_Ch4,1,mV2500,4,True,0,_50Hz,1,0)
      'Generic Single-Ended Voltage measurements 'Dw_Ch1'
      VoltSe(Dw_Ch1,1,mV2500,5,True,0,_50Hz,1,0)
      'Generic Single-Ended Voltage measurements 'Dw_Ch2'
      VoltSe(Dw_Ch2,1,mV2500,6,True,0,_50Hz,1,0)
      'Generic Single-Ended Voltage measurements 'Dw_Ch3'
      VoltSe(Dw_Ch3,1,mV2500,7,True,0,_50Hz,1,0)
      'Generic Single-Ended Voltage measurements 'Dw_Ch4'
      VoltSe(Dw_Ch4,1,mV2500,8,True,0,_50Hz,1,0)

      VoltSe(Up_Temp,1,mV2500,11,True,0,_50Hz,1,0)
      VoltSe(Dw_Temp,1,mV2500,12,True,0,_50Hz,1,0)
      SW12(0)

      'Type T (copper-constantan) Thermocouple measurements 'Temp'
      TCDiff(Temp,1,mV2_5C,5,TypeT,PTemp_C,True,0,_50Hz,1,0)

      'Call Data Tables and Store Data
      CallTable Skye_cal
      NextScan
EndProg
```

2. Calibrate two pairs of Decagon SRS sensors using CR1000 data logger

Filename: Decagon_cal.CR1

```
'Program to read 2 set of Decagon SRS-NDVI (1 up and 1 down-facing) using a
CR1000 datalogger port C1, C3, C5, and C7.

'Wiring:
'Upward-facing, hemispherical SRS-NDVI
'White wire (power) -> SW12V
'Red wire (data) ->    C1
'Bare wire (ground) -> G

'Downward-facing, 36 degree field-stop SRS-NDVI
'White wire (power) -> SW12V
'Red wire (data) ->    C3
'Bare wire (ground) -> G

'The other pair of sensors red wire connecting to C5 and C7, white and bare
share the same connection as the previous pair.

'Declare Public Variables
Public PTemp, Temp, BattV
Public UpN20(3)
Public DwN20(3)
Public UpN21(3)
Public DwN21(3)

Alias UpN20(1) = Up20Red ' NDVI Ni19
Alias DwN20(1) = Dw20Red 'Nr18a
Alias UpN20(2) = Up20NIR   'NDVI Ni19
Alias DwN20(2) = Dw20NIR 'Nr18a
Alias UpN20(3) = Up20ind
Alias DwN20(3) = Dw20ind

Units Up20Red = W/m^2 nm
Units Dw20Red = W/m^2 nm sr
Units Up20NIR = W/m^2 nm
Units Dw20NIR = W/m^2 nm sr

' Public NDVI
Alias UpN21(1) = Up21Red
Alias DwN21(1) = Dw21Red
Alias UpN21(2) = Up21NIR
Alias DwN21(2) = Dw21NIR
Alias UpN21(3) = Up21ind
Alias DwN21(3) = Dw21ind

Units Up21Red = W/m^2 nm
Units Dw21Red = W/m^2 nm sr
Units Up21NIR = W/m^2 nm
Units Dw21NIR = W/m^2 nm sr

'Define Data Tables
```

```
DataTable (DecagonCal,1,-1)
	DataInterval (0,5,Sec,10)
	Minimum (1,BattV,FP2,0,False)
	Sample (1,PTemp,FP2)
	Sample (1,Temp,FP2)
	'save NDVI data
	Sample (1,Up20Red,IEEE4  )
	Sample (1,Up20NIR,IEEE4  )
	Sample (1,Up20ind,IEEE4  )
	Sample (1,Dw20Red,IEEE4  )
	Sample (1,Dw20NIR,IEEE4  )
	Sample (1,Dw20ind,IEEE4  )
	Sample (1,Up21Red,IEEE4  )
	Sample (1,Up21NIR,IEEE4  )
	Sample (1,Up21ind,IEEE4  )
	Sample (1,Dw21Red,IEEE4  )
	Sample (1,Dw21NIR,IEEE4  )
	Sample (1,Dw21ind,IEEE4  )
EndTable

'Main Program
sequential mode
BeginProg
	Scan (5,Sec,0,0)
		PanelTemp (PTemp,250)
		Battery (BattV)
		TCDiff(Temp,1,mV2_5C,5,TypeT,PTemp,True,0,_50Hz,1,0)
		'Apply power to white wire of both sensors through SW-12
		PortSet (9,1)  ' or use SW12(1) command
		'Delay for at least 250 mSec for sensors to enter SDI-12 mode.
		Delay (0,250,msec)
		'Query sensor for 3 SDI-12 outputs.  Default address for all
Decagon Digital sensors is 0.
		Move (UpN20(),3,NAN,1)
		Move (DwN20(),3,NAN,1)
		Move (UpN21(),3,NAN,1)
		Move (DwN21(),3,NAN,1)
		SDI12Recorder (UpN20(),  1,0,"M!",1.0,0)
		SDI12Recorder (DwN20(),3,0,"M!",1.0,0)
		SDI12Recorder (UpN21(),  5,0,"M!",1.0,0)
		SDI12Recorder (DwN21(),7,0,"M!",1.0,0)
		'Turn SW12V off
		PortSet (9,0)  'or use SW12(0) command
		'calculate NDVI from individual outputs of both sensors.  See
equation 1 of the SRS manual
		'Enter other measurement instructions
		'Call Output Tables
		CallTable DecagonCal
	NextScan
EndProg
```

12.3 Matlab scripts for calculating calibration factors

```
% White panel reflectance factor 0.99 for red band and other visible bands,
refer to the Document for the panel;
% Example usage calibration(A(:,1),A(:,5),.99,0.02);% A is the calibration
data, 8 columns, copied from CR1000 output .csv file.
%calibration(A(:,4),A(:,8),.98,0.02)
% White panel reflectance factor 0.98 for NIR band

function calibration(IN, OUT,standard,Threshold, Iter, speed)
if (nargin <6), speed=6; end
if (nargin <5), Iter=100; end
if (nargin <4), Threshold=0.03; end
if (nargin <3), standard=1; end
if (size(IN,2)~=1 & size(OUT,2)~=1) disp('NOT work on matrix data!'); return;
end
if (size(IN,1) ~= size(OUT,1)) disp('Must be two equal length arrays');
return; end
OUT=OUT/standard;
XX=IN;YY=OUT;
fun = fit( IN, OUT, 'poly1');
yfit=fun(IN);
ME=abs((yfit-OUT)./yfit);
MaxME=max(ME);
counter=0;
while MaxME>Threshold
    figure(1);plot(IN,OUT,'o','markersize',4)
    drawnow
    pause(0.5)
    Ind=find(ME>speed*Threshold);
    IN(Ind)=[]; OUT(Ind)=[];
    fun = fit( IN, OUT, 'poly1');
    yfit=fun(IN);
    ME=abs(yfit-OUT)./mean(yfit); % abs((yfit-OUT)./OUT);
    MaxME=max(ME);
    speed=speed-1;
    if (speed<1), speed=1; end
    counter=counter+1;
    fprintf('Iteration %d, Wait...\n',counter);
    if (counter>100); disp('Reach maximum iteration!');return; end
end
fprintf('Samples left %d.\n',size(IN,1));
figure(1);
plot(XX,YY,'o','color',[0.7 0.7 0.7],'markersize',4)
hold on;
plot(IN,OUT,'o','markersize',4)

plot(IN, yfit,'r-'); hold off
% xlabel('Sensor 1 (mV)'); %need to change
% ylabel('Sensor 2 (mV)');
fun
```

12.4 User calibration document

Department of Physical Geography and Ecosystem Science, Lund University
Sölvegatan 12, S-223 62 Lund, Sweden

Reference No. 20170307

LUNDS UNIVERSITET

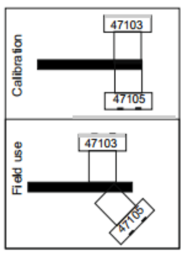
Certificate of Calibration

Multi-Spectral Sensor No 47103 (cosine) vs. No 47105(25° FOV)

For: Sites project

Discription: Multi-spectral sensor No. 47103 and No. 47105 are 4-channel (CH1: red edge 704nm, CH2: 740nm , CH3: NIR 858nm, and CH4: SWIR 1640nm) sensors for measuring reflectances used in pair for Sweden SITES project. No. 47103 is mounted with a cosine diffuser and the nominal FOV of 180°. No. 47105 is of 25° FOV, viewing downward e.g. 45° off nadir (Figure). Both sensors have in-built op-amp amplifier and the SWIR band comes with a temperature sensor with 10mV/°C.
Outliers are recursively removed when computing normalization factors.

Date and time of Calibrtion: 2017-03-07 13:00-16:00



Location of Calibration: INES roof

Conditions: cloudy sky and weak incoming ligh

Temperature: 0 to 2.5 ° C

Data reading Instrument: CR1000 datalogger (2500 mV range)
White spectalon standard reflector

Uncertainties: This relative calibration is done for 3 hours under cloudy sky.
The relative error <2.0%
There might be non-linear response for some light intensity, e.g. extremely weak or extremely strong lights.

Results: Normalization factors of No 47103(cosine) relevant to No 47105 (25° FOV)

CH1 47103	CH1 47105
1	1.055
CH3 47103	**CH3 47105**
1	1.027

CH2 47103	CH2 47105
1	1.070
CH43 47103	**CH4 47105**
1	1.074

Limitation: The calibration accuracy depends on the standard white panel, using reflectance factor 0.986 for SWIR, and 0.99 for others.

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Page 1 of 2

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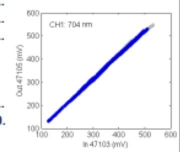
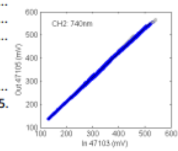
Appendix 1 : Results of recursive outlier removal

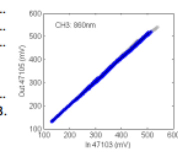
```
>> calibration(A(:,1),A(:,5),.99,0.02)
Iteration 1, Wait...
Iteration 2, Wait...
Iteration 3, Wait...
...
Iteration 9, Wait...
Samples left 5360.

fun =

   Linear model Poly1:
   fun(x) = p1*x + p2
   Coefficients (with 95% confidence bounds):
     p1 =      1.055  (1.054, 1.056)
     p2 =     -3.777  (-3.944, -3.611)
```



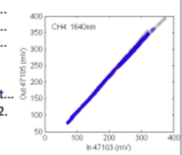

```
>> calibration(A(:,2),A(:,6),.99,0.02)
Iteration 1, Wait...
Iteration 2, Wait...
Iteration 3, Wait...
...
Iteration 9, Wait...
Samples left 5365.

fun =

   Linear model Poly1:
   fun(x) = p1*x + p2
   Coefficients (with 95% confidence bounds):
     p1 =       1.07  (1.069, 1.07)
     p2 =     -4.353  (-4.532, -4.174)
```




```
>> calibration(A(:,3),A(:,7),.99,0.02)
Iteration 1, Wait...
Iteration 2, Wait...
Iteration 3, Wait...
...
Iteration 7, Wait...
Samples left 5343.

fun =

   Linear model Poly1:
   fun(x) = p1*x + p2
   Coefficients (with 95% confidence bounds):
     p1 =      1.027  (1.026, 1.027)
     p2 =      -3.42  (-3.596, -3.244)
```




```
>> calibration(A(:,4),A(:,8),.986,0.02)
Iteration 1, Wait...
Iteration 2, Wait...
Iteration 3, Wait...
...
Iteration 11, Wait...
Samples left 4832.

fun =

   Linear model Poly1:
   fun(x) = p1*x + p2
   Coefficients (with 95% confidence bounds):
     p1 =      1.074  (1.073, 1.074)
     p2 =     0.9493  (0.8567, 1.042)
```



Following the manfaturer's document
CH1: red edge 704nm, CH2: 740nm , CH3: NIR 858nm, and CH4: SWIR 1640nm

$$r\_CH1=\frac{CH1_{47105}/1.055}{CH1_{47103}} \quad r\_CH2=\frac{CH2_{47105}/1.07}{CH2_{47103}} \quad r\_CH3=\frac{CH3_{47105}/1.027}{CH3_{47103}} \quad r\_CH4=\frac{CH4_{47105}/1.074}{CH4_{47103}}$$

Page 2 of 2