Measuring spectral reflectance and transmittance (350-2500 nm) of small and/or narrow leaves using an integrating sphere

Etienne Laliberté

Abstract

Here we describe the standardised protocol used by the Canadian Airborne Biodiversity Observatory (CABO) to measure leaf spectral reflectance and transmittance, using an integrating sphere fitted to a portable full-range field spectroradiometer, for the special case where an individual **leaf is too small and/or too narrow** to entirely cover the reflectance or transmission port of the integrating sphere. Briefly, three arrays of mature, healthy and sunlit leaves from a canopy plant are arranged on a custom sample mount, and are then used for measurements of adaxial reflectance and transmittance. Leaf array scans are referenced to a calibrated Spectralon® disk and corrected for stray light to yield NIST-traceable, leaf spectral reflectance and transmittance measurements. Our leaf spectroscopy protocol builds from that of Noda et al. (2013), as well as Carnegie Airborne Observatory's protocol and integrating sphere user manuals from two companies (SVC, ASD Inc.).

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Guidelines

Handling Spectralon®

- **Do not touch Spectralon®** (e.g. sphere interior, reference disks, plugs) with your fingers.
- **Do not use canned air** to remove dust on the Spectralon® disk; canned air contains chemicals that can alter Spectralon®'s optical properties.
- **Do not attempt to clean Spectralon®** in the field, other than **blowing surface dust only on the Spectralon® reference disk or sphere plugs** using the Canless Air Duster System; cleaning Spectralon® requires a special procedure that should only done in the lab.
- **Never blow air inside of the integrating sphere, especially not when it is attached to the spectroradiometer**, as this will blow dust inside the instrument.

Equipment

- Spectra Vista Corporation HR-1024i full-range (350-2500 nm) field spectroradiometer
- Spectra Vista Corporation 3-inch Spectralon® DC-R/T Sphere
- Semi-rugged laptop or PDA running the SVC Scan software

- Canless Air Duster System O_2 Hurricane (**never use canned air**) to remove dust from the surface of the Spectralon® reference disk

- Plastic containers with lids to temporarily store leaf arrays during measurements (optional)

Consumables

- Nitrile gloves for handling leaves
- Whatman No. 2 filter paper (110 mm diameter)
- Acetate sheets (to make thin plastic sample mounts)
- Manila file folders (to make thin cardbboard sample platforms)
- Scotch™ Magic Tape

Before start

1. Consult the user manual of the spectroradiometer and the integrating sphere to set up the instrument.
2. The instrument should be set up in the shade, sheltered as much as possible from the elements.
3. All canopy plants selected for measurements should have already been tagged, identified, and georeferenced before spectroscopy measurements start.
4. The spectroscopist should be positionned as close as possible to the sampled plants to minimise time from collection to measurement.
5. The spectroscopist should be in a confortable position and have enough room around the instrument to spread leaf samples around without the risk of mixing up individual leaves during handling.
6. **Mature, fully-developped, healthy-looking leaves from the sunlit (>3 h per day of direct sunlight) portion of the canopy are selected** for spectral measurements from the bulk leaf sample (often one of a few branches). Leaves should be collected from the uppermost surface of the branch (i.e. receiving the most direct sunlight).

Materials

Manila File Folders 116723 by Staples

Write-On Transparency Film 954144 by Staples

Whatman™ Qualitative Filter Paper: Grade 2 Circles (110 mm diameter) 09-810E by Fisher Scientific

Scotch™ Magic Tape 14172 by Staples

Protocol

Instrument set-up

Step 1.

Install the integrating sphere onto the spectroradiometer.

NOTES
Etienne Laliberté 24 Apr 2018

Follow the SVC integrating sphere manual p. 9-14.

Instrument set-up

Step 2.

Power the spectroradiometer and integrating sphere lamp on and **warm up for >15 min**.

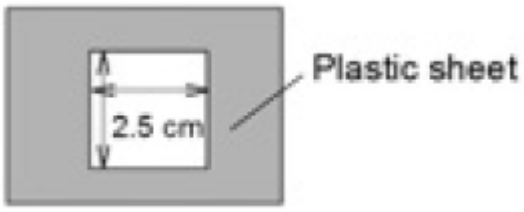
ANNOTATIONS
Raymond Soffer 30 May 2018

See comments for Step two in Large leaf protocol

Prepare sample mounts and sample holders

Step 3.

Build a few sample mounts from thin plastic (e.g. acetate sheets).



NOTES
Etienne Laliberté 25 Apr 2018

The sample mount is made of a thin plastic sheet with a square window that is larger than the edge of the sample port lip (e.g. 2.5 cm × 2.5 cm).

Etienne Laliberté 25 Apr 2018

Fig. 3a from Noda et al. (2013). https://doi.org/10.1111/pce.12100

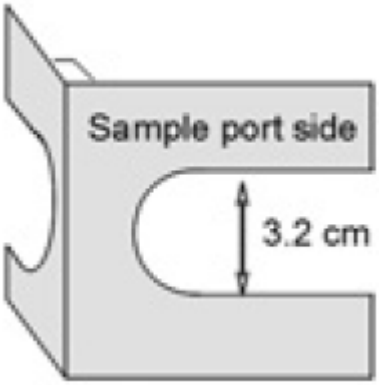
ANNOTATIONS
Raymond Soffer 30 May 2018

This step may be difficult/time consuming to perform properly in a consistent manner. This is why Harron developed his neddle carrier. Also with a 2.5 cm port, you will need leaves 3.5 cm long to ensure there is enough material to tape over meaning that you may need to use seperate leaves taped at either end for short leaves. Perhaps having an alternate mount with a smaller aperture would be worth testing for this situation.

Prepare sample mounts and sample holders

Step 4.

Build a few sample platforms from thin cardboard (e.g. file folders).



NOTES

Etienne Laliberté 25 Apr 2018

The sample platform is made of cardboard and will eventually attach to the integrating sphere to create a flat surface.

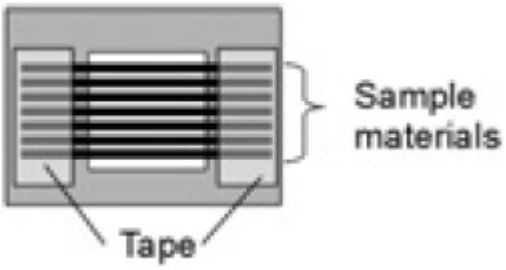
Etienne Laliberté 25 Apr 2018

Fig. 3c from Noda et al. (2013). https://doi.org/10.1111/pce.12100

Prepare leaf arrays

Step 5.

Fix leaves onto the sample mount with tape to make leaf array #1.



NOTES

Etienne Laliberté 25 Apr 2018

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <2.5 cm long), fix leaves by their petiole with tape in or two rows.

Etienne Laliberté 25 Apr 2018

Fig. 3b from Noda et al. (2013). https://doi.org/10.1111/pce.12100

ANNOTATIONS

Paul Hacker 30 Apr 2018

If leaves are shorter than the sample mount hole (i.e. <2.5 cm long), fix leaves by their petiole with tape in (one) or two rows

OR

If leaves are shorter than the sample mount hole (i.e. <2.5 cm long), fix leaves by their petiole with tape in two rows

Etienne Laliberté 18 May 2018

Should probably move those steps as close as possible to the actual leaf measurement to avoid water stress etc

Prepare leaf arrays

Step 6.

Fix leaves onto the sample mount with tape to make leaf array #2.

NOTES

Etienne Laliberté 25 Apr 2018

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <2.5 cm long), fix leaves by their petiole with tape in or two rows.

Prepare leaf arrays

Step 7.

Fix leaves onto the sample mount with tape to make leaf array #3.

NOTES

Etienne Laliberté 25 Apr 2018

Leaves should be separated by about 1 mm to avoid multiple scattering among them.

If leaves are shorter than the sample mount hole (i.e. <2.5 cm long), fix leaves by their petiole with tape in or two rows.

Prepare leaf arrays

Step 8.

Fix sample mount holding leaf array #1 onto the sample platform with tape.

NOTES

Etienne Laliberté 25 Apr 2018

The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

Prepare leaf arrays

Step 9.

Fix sample mount holding leaf array #2 onto the sample platform with tape.

NOTES

Etienne Laliberté 25 Apr 2018

The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

Prepare leaf arrays

Step 10.

Fix sample mount holding leaf array #3 onto the sample platform with tape.

NOTES

Etienne Laliberté 25 Apr 2018

The sample mount holding the leaf array should be sandwiched between the two sides of the cardboard sample platform.

Reflectance: Reference scan set-up

Step 11.

Position the lamp over the sphere **primary light entrance port**.

SAFETY INFORMATION

The lamp can get very hot. Grab it by the slotted heat shield.

NOTES

Etienne Laliberté 24 Apr 2018

Make sure lamp is secured in locked position.

Reflectance: Reference scan set-up

Step 12.

Check lamp alignment.

NOTES

Etienne Laliberté 24 Apr 2018

Use a thin piece of paper at the exit of the reflectance sample port (empty port) the to ensure the light beam under-fills and is centered in the reflectance port. **If it is not, then proceed to lamp alignment** as described in the SVC integrating sphere user manual, p. 23-24.

Reflectance: Reference scan set-up

Step 13.

Screw the tethered light trap on the **reflectance port** sample holder.

NOTES

Etienne Laliberté 24 Apr 2018

The light trap can stay on the sample holder for the entire measurement session.

Reflectance: Reference scan set-up

Step 14.

Screw the tethered light trap on the **transmission port** sample holder.

NOTES

Etienne Laliberté 24 Apr 2018

The light trap can stay on the sample holder for the entire measurement session.

Reflectance: Reference scan set-up

Step 15.

Place the tethered calibrated Spectralon® reflectance standard over the **reflectance port**.

NOTES

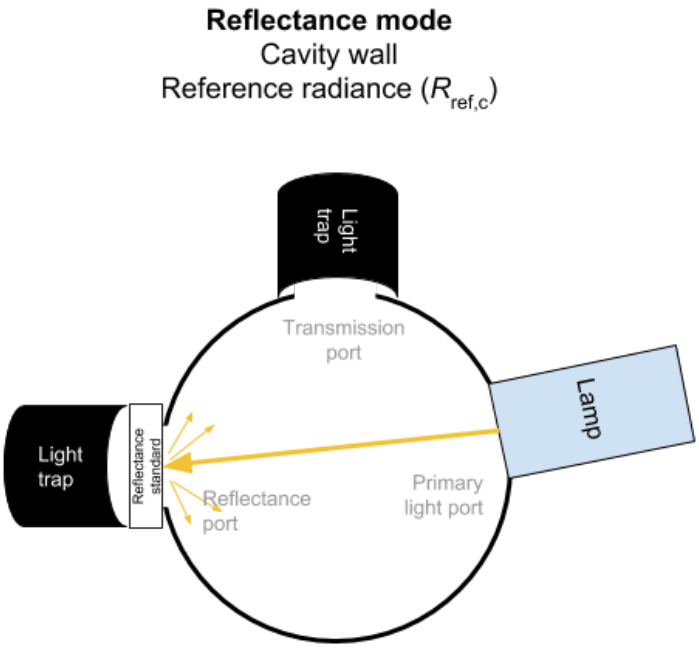
Etienne Laliberté 24 Apr 2018

Place the standard over the reflectance port so that the light beam shines directly on its reflective surface (= facing inside of the sphere).

Reflectance (cavity wall): Reference scan

Step 16.

Collect a '**Reference Scan**' in this configuration.



NOTES

Etienne Laliberté 25 Apr 2018

The **transmission port** should be **empty** (but with the **light trap on**).

Etienne Laliberté 25 Apr 2018

This corresponds the the **reference radiance** of the **cavity wall** (i.e. sphere wall) in reflectance mode ($R_{ref,c}$). It will be used in the transmittance calculation.

ANNOTATIONS

Raymond Soffer 30 May 2018

This is Rref,w, radiance of the reference panel. Rref,c would be acquired with the lamp in the transmission port and trap in the primary port (step 53). Since it is a Labsphere IS where the walls are Spectralon and the refernece is spectralon, this should be a very small distinction. However if the reference sample degrades, recognizing this distinction might allow one to track the degradation and use the new values in the equation for Rref,w.

Etienne Laliberté 26 Apr 2018

if we measure refl_cavity ourselves (everytime we calibrate the field disks), then we wouldn't need this step as we'd have it directly.

Etienne Laliberté 18 May 2018
Remove empty notes

Etienne Laliberté 18 May 2018
Remove empty notes

Reflectance (cavity wall): Reference scan

Step 17.

Collect a '**Target Scan**' in the same configuration and **save the file**.

Reflectance (leaf array, abaxial): Reference scan

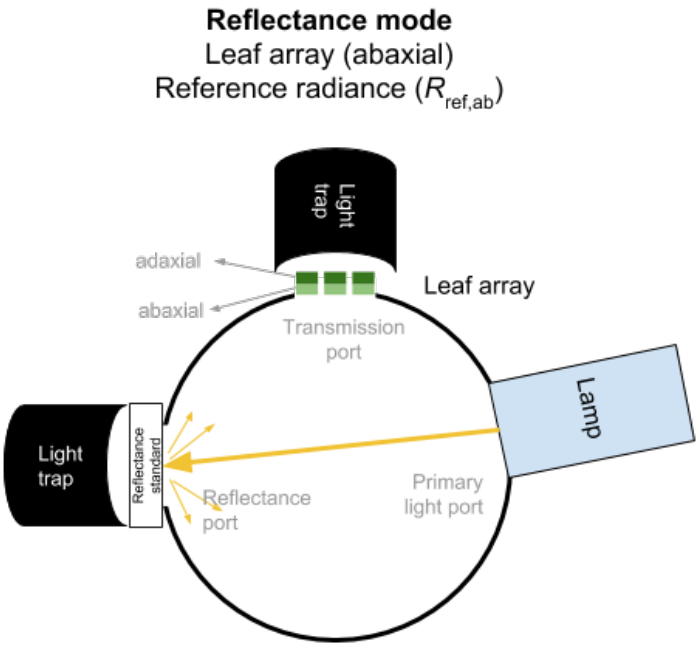
Step 18.

Position the sample platform containing leaf array #1 over the **transmission port** with the **abaxial** (lower) surface of the leaves facing the inside of the sphere.

Reflectance (leaf array, abaxial): Reference scan

Step 19.

Collect a '**Reference Scan**' in this configuration.



NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **reference radiance** for the **leaf array** (**adaxial**) in reflectance mode ($R_{ref,ad}$).

ANNOTATIONS

Etienne Laliberté 26 Apr 2018
Correct note: abaxial not adaxial
Etienne Laliberté 26 Apr 2018
Correct note: abaxial not adaxial
Etienne Laliberté 30 May 2018

Why this scan? Can’t remember why référence of leaf à axial is needed - for transmittance I believe?

Reflectance (leaf array, abaxial): Reference scan

Step 20.

Collect a '**Target Scan**' in the same configuration and **save the file**.

Reflectance (leaf array, adaxial): Reference scan

Step 21.

Flip leaf array #1 around the transmission port so that the **adaxial** (upper) surface of the leaves is now facing the inside of the sphere.

ANNOTATIONS

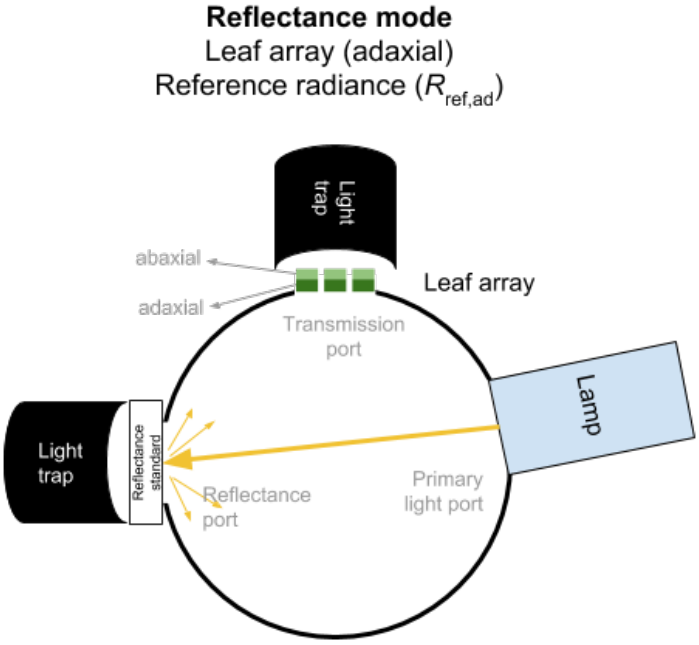
Etienne Laliberté 26 Apr 2018

... faces into the sphere

Reflectance (leaf array, adaxial): Reference scan

Step 22.

Collect a '**Reference Scan**' in this configuration.



NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **reference radiance** for the **leaf array** (**adaxial**) in reflectance mode ($R_{ref,ad}$).

Reflectance (leaf array, adaxial): Reference scan

Step 23.

Collect a '**Target Scan**' in the same configuration and **save the file**.

Reflectance (leaf array, adaxial + filter paper): Reference scan

Step 24.

Place a filter paper directly behind the sample platform holding leaf array #1.

NOTES

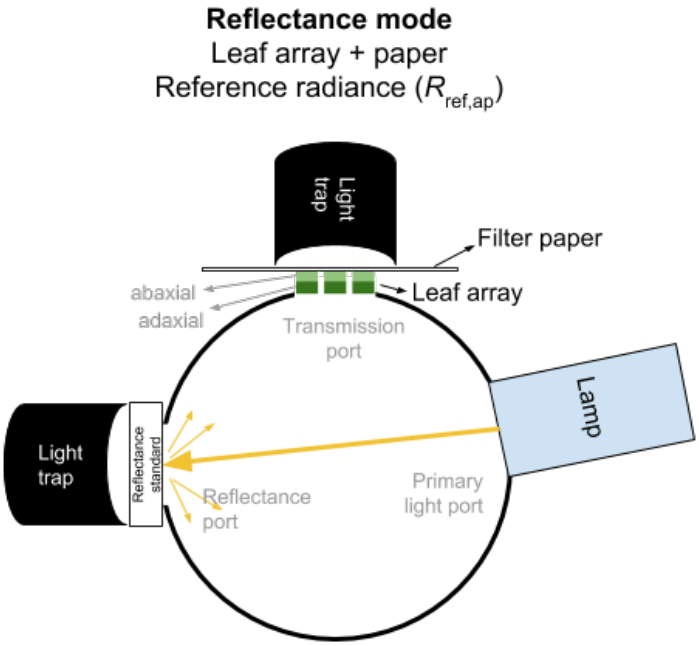
Etienne Laliberté 25 Apr 2018

The leaf array #1 should remain in the same position.

Reflectance (leaf array, adaxial + filter paper): Reference scan

Step 25.

Collect a '**Reference Scan**' in this configuration.



NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **reference radiance** for the **leaf array** (**adaxial**) **+ paper** in reflectance mode ($R_{ref,ap}$).

Reflectance (leaf array, adaxial + filter paper): Reference scan

Step 26.

Collect a '**Target Scan**' in the same configuration and **save the file**.

Reflectance (filter paper): Reference scan

Step 27.

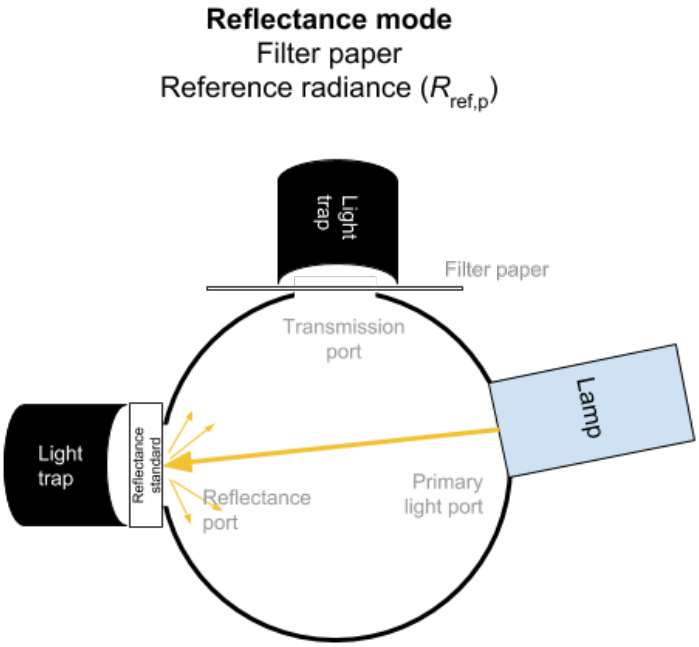
Carefully remove the sample platform holding leaf array #1 from the transmission port.

NOTES
Etienne Laliberté 25 Apr 2018

The filter paper should remain in the same position.

Reflectance (filter paper): Reference scan
Step 28.

Collect a '**Reference Scan**' in this configuration.



NOTES
Etienne Laliberté 25 Apr 2018

This corresponds to the **reference radiance** for the **filter paper** in reflectance mode ($R_{ref,p}$).

Reflectance (filter paper): Reference scan
Step 29.

Collect a '**Target Scan**' in the same configuration and **save the file**.

Reflectance: Stray light
Step 30.
Remove the filter paper from the transmission port sample holder.

Reflectance: Stray light
Step 31.

Remove the tethered calibrated Spectralon® reflectance standard from the reflectance port.

Reflectance: Stray light

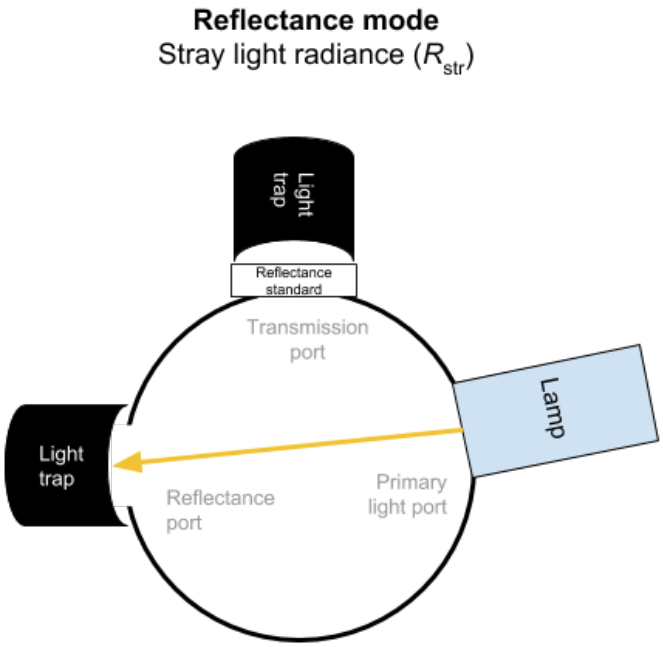
Step 32.

Place the tethered calibrated Spectralon® reflectance standard over the **transmission port**.

Reflectance: Stray light

Step 33.

Collect a '**Target Scan**' in this configuration and **save the file**.



NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **stray light radiance** in reflectance mode (R_{str}).

Reflectance (filter paper): Target scan

Step 34.

Place the filter paper over the **reflectance port**.

NOTES

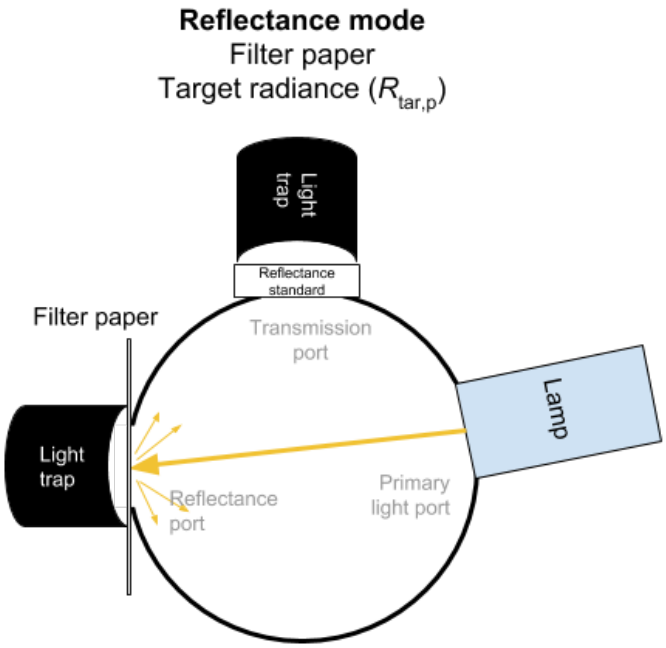
Etienne Laliberté 25 Apr 2018

Focus the measurements on the same area of the paper used in previous measurements.

Reflectance (filter paper): Target scan

Step 35.

Collect a '**Target Scan**' in this configuration and **save the file**.



NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **target radiance** of **leaf array** #1 (**adaxial**) in reflectance mode ($R_{tar,a,1}$).

Reflectance (leaf array, adaxial +/- filter paper): Target scans

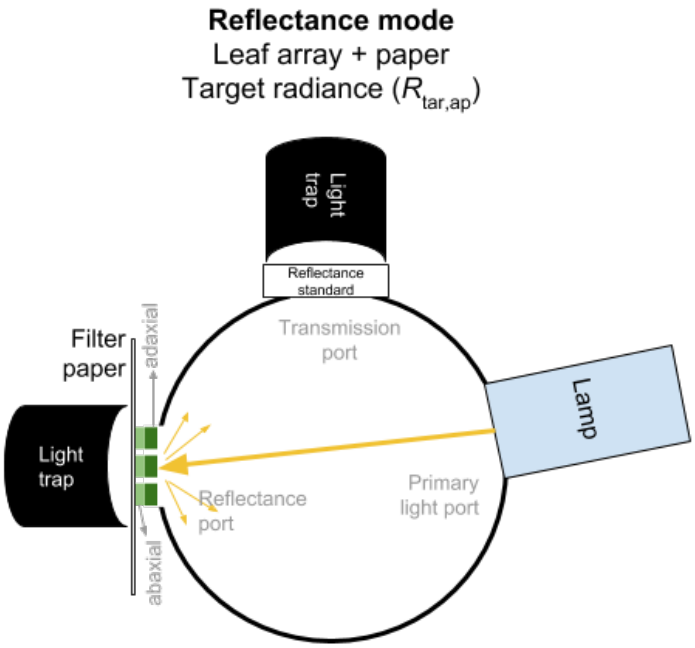
Step 36.

Position the sample platform containing leaf array #1 in front the filter paper over the **reflectance port** with the adaxial (upper) surface of the leaves facing the inside of the sphere.

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 37.

Collect a '**Target Scan**' in this configuration and **save the file**.



NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **target radiance** of **leaf array** #1 (**adaxial**) in reflectance mode ($R_{tar,a,1}$).

ANNOTATIONS

Etienne Laliberté 26 Apr 2018

+ paper...

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 38.

Remove the filter paper from the reflectance port.

NOTES

Etienne Laliberté 25 Apr 2018

The sample platform holding leaf array #3 should remain in the same position.

ANNOTATIONS

Raymond Soffer 30 May 2018

How difficult is it to keep the same position?

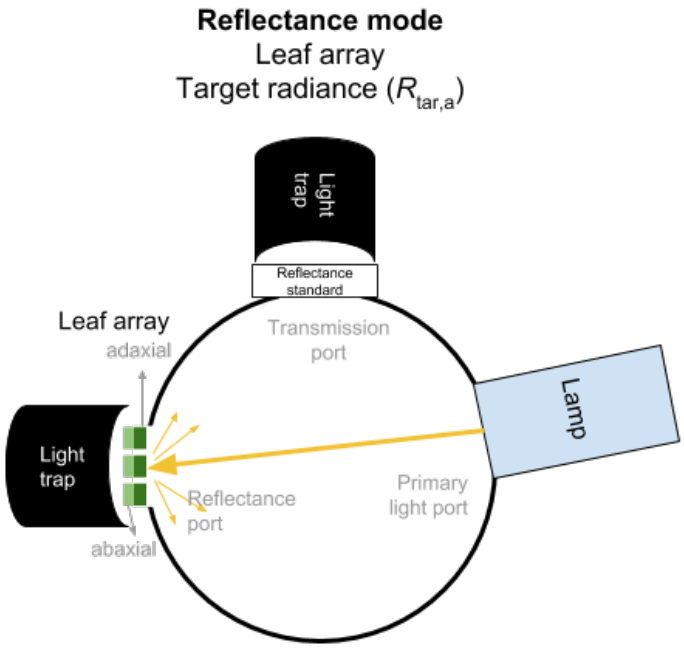
Raymond Soffer 30 May 2018

Should this not refer to leaf array #1?

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 39.

Collect a '**Target Scan**' in this configuration and **save the file**.



NOTES
Etienne Laliberté 25 Apr 2018

This corresponds to the **target radiance** of **leaf array** #1 (**adaxial**) in reflectance mode ($R_{tar,a,1}$).

Reflectance (leaf array, adaxial +/- filter paper): Target scans
Step 40.

Carefully replace leaf array #1 by leaf array #2.

ANNOTATIONS
Raymond Soffer 30 May 2018

Missing note as in Step 44.

Reflectance (leaf array, adaxial +/- filter paper): Target scans
Step 41.

Collect a '**Target Scan**' for leaf #array 2 in this configuration ($R_{tar,a,2}$) and **save the file**.

Reflectance (leaf array, adaxial +/- filter paper): Target scans
Step 42.

Place the filter paper directly behind leaf array #2 over the **reflectance port**.

NOTES
Etienne Laliberté 25 Apr 2018

The sample platform holding leaf array #2 should remain in the same position.

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 43.

Collect a '**Target Scan**' for leaf array #2 + filter paper in this configuration ($R_{tar,ap,2}$) and **save the file**.

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 44.

Carefully replace leaf array #2 by leaf array #3.

NOTES

Etienne Laliberté 25 Apr 2018

The filter paper should remain in the same position.

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 45.

Collect a '**Target Scan**' for leaf array #3 + filter paper in this configuration ($R_{tar,ap,3}$) and **save the file**.

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 46.

Remove the filter paper from the reflectance port.

NOTES

Etienne Laliberté 25 Apr 2018

The sample platform holding leaf array #3 should remain in the same position.

Reflectance (leaf array, adaxial +/- filter paper): Target scans

Step 47.

Collect a '**Target Scan**' for leaf array #3 in this configuration ($R_{tar,a,3}$) and **save the file**.

Transmittance (cavity wall): Target scan

Step 48.

Carefully remove leaf array #3 from the **reflectance port**.

NOTES

Etienne Laliberté 25 Apr 2018

The **reflectance port** should now be **empty** (but with the **light trap on**).

Transmittance (cavity wall): Target scan

Step 49.

Remove the tethered calibrated Spectralon® reflectance standard from the sphere transmission port.

Transmittance (cavity wall): Target scan

Step 50.

Remove the light trap from the transmission port sample holder.

Transmittance (cavity wall): Target scan

Step 51.

Position the lamp over the sphere **transmission port**.

SAFETY INFORMATION

The lamp can get very hot. Grab it by the slotted heat shield.

NOTES

Etienne Laliberté 24 Apr 2018

Make sure lamp is secured in locked position.

Transmittance (cavity wall): Target scan

Step 52.

Install the Spectralon® plug over the **primary light port**.

NOTES

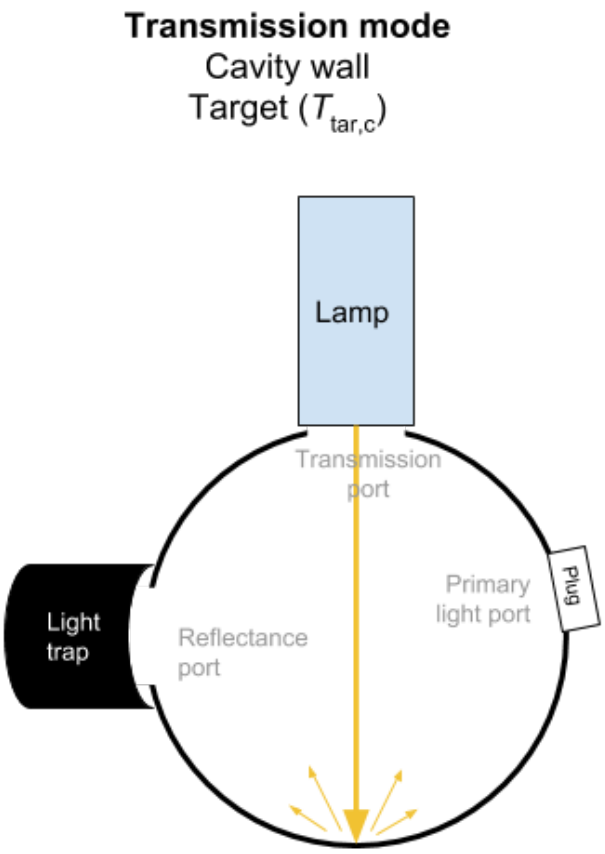
Etienne Laliberté 24 Apr 2018

Ensure that the curved plug is placed the correct way to match the curvature of the sphere.

Transmittance (cavity wall): Target scan

Step 53.

Collect a '**Target Scan**' in this configuration and **save the file**.



NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **target radiance** of the cavity wall in transmission mode ($T_{tar,c}$).

Transmittance (leaf array, adaxial): Target scans

Step 54.

Gently pull lamp away from the sphere.

SAFETY INFORMATION

The lamp can get very hot. Grab it by the slotted heat shield.

Transmittance (leaf array, adaxial): Target scans

Step 55.

Place the sample platform holding leaf array #1 over the **transmission port** with the abaxial (lower) surface of the leaves facing the inside of the sphere.

Transmittance (leaf array, adaxial): Target scans

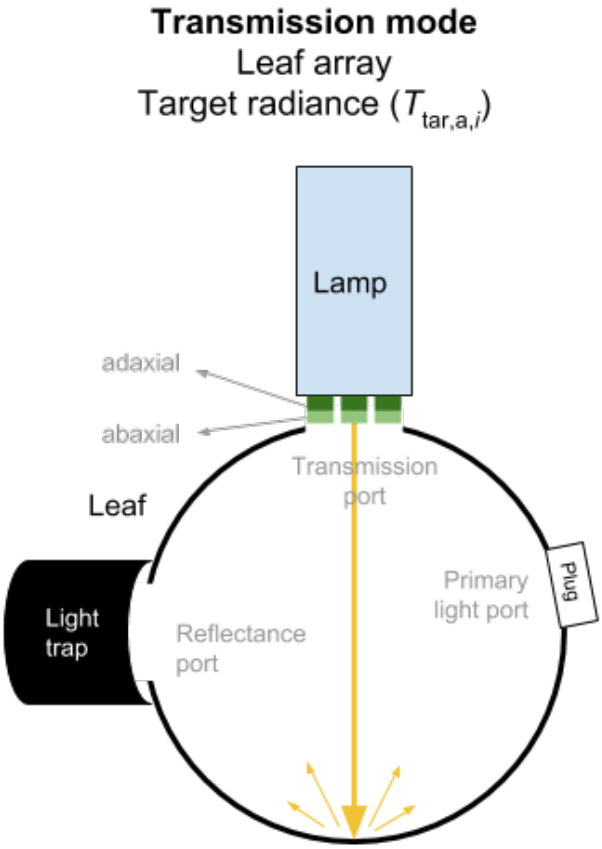
Step 56.

Release the transmission sample holder and move lamp back to its locked position.

Transmittance (leaf array, adaxial): Target scans

Step 57.

Collect a '**Target Scan**' for leaf array #1 in this configuration and **save the file**.



NOTES
Etienne Laliberté 25 Apr 2018

This corresponds to the **target radiance** in transmittance mode (adaxial side) for leaf array #1 ($T_{tar,a,1}$).

Transmittance (leaf array, adaxial): Target scans

Step 58.

Carefully replace leaf array #1 by leaf array #2.

Transmittance (leaf array, adaxial): Target scans

Step 59.

Collect a '**Target Scan**' for leaf array #2 in this configuration and **save the file**.

NOTES
Etienne Laliberté 25 Apr 2018

This corresponds to the **target radiance** in transmittance mode (adaxial side) for leaf array #2 ($T_{tar,a,2}$).

Transmittance (leaf array, adaxial): Target scans

Step 60.

Carefully replace leaf array #2 by leaf array #3.

Transmittance (leaf array, adaxial): Target scans

Step 61.

Collect a '**Target Scan**' for leaf array #3 in this configuration and **save the file**.

NOTES

Etienne Laliberté 25 Apr 2018

This corresponds to the **target radiance** in transmittance mode (adaxial side) for leaf array #3 ($T_{tar,a,3}$).

Transmittance (leaf array, adaxial): Target scans

Step 62.

Remove leaf array #3 from the transmission sample port holder.

Calculating absolute reflectance of leaf array (adaxial side)

Step 63.

The equation (Noda et al. 2013; eqn. 9) for **adaxial reflectance** of leaf array i, $\rho_{a,i}$ is

$$\rho_{a,i} = [(R_{tar,a,i} - R_{str}) \div (R_{ref,ad} - R_{str})] \times \rho_{ref} \times [1 \div (1 - G_{r,i})]$$

where

$R_{tar,a,i}$ is the target radiance of leaf array i (adaxial side) in reflectance mode,

$R_{ref,ad}$ is the reference radiance used for all leaf arrays (**adaxial** side) in reflectance mode,

R_{str} is the stray light radiance in reflectance mode,

ρ_{ref} is the absolute reflectance of the calibrated Spectralon® reflectance standard, and

$G_{r,i}$ is the gap fraction in reflectance mode for leaf array i, which is calculated **at 400 nm** (Noda et al. 2013; eqn. 13) by

$$G_{r,i} = [\ (\ (R_{tar,ap,i} - R_{str}) \div (R_{ref,ap} - R_{str})\ ) - (\ (R_{tar,a,i} - R_{str}) \div (R_{ref,ad} - R_{str})\ )\ ] \times (\ \rho_{ref} \div \rho_{p})$$

where

$R_{tar,ap,i}$ is the target radiance of leaf array *i* (adaxial side) + filter paper in reflectance mode,

$R_{ref,ap}$ is the reference radiance used for all leaf arrays (adaxial side) + filter paper in reflectance mode, and

ρ_p is the absolute reflectance of the filter paper, which is calculated (Noda et al. 2013; eqn. 3) by

$$\rho_p = [(R_{tar,p} - R_{str}) \div (R_{ref,p} - R_{str})] \times \rho_{ref}$$

where

$R_{tar,p}$ is the target radiance of the filter paper in reflectance mode, and

$R_{ref,p}$ is the reference radiance of the filter paper in reflectance mode.

ANNOTATIONS

Raymond Soffer 30 May 2018

Should this not be repeated for the Abaxial refelctance? I believe the measurements were made.

Raymond Soffer 30 May 2018

Given my earlier note about the distinction between Rref,c and Rref,w, the following clarifications should be made:

- ρ_{ref} should be $\rho_{ref,w}$ or ρ_w

- $R_{ref,ad}$ should be $R_{ref,w,ad}$

Calculating absolute transmittance of leaf array (adaxial side)

Step 64.

The equation (Noda et al. 2013; eqn. 15) for **adaxial transmittance** of leaf array *i*, $\tau_{a,i}$ is

$$\tau_{a,i} = [\ (\ (T_{tar,a,i} \times \rho_{ref}) \div (\ R_{ref,ab} - R_{str})\ ) - G_{t,i} \times \rho_c\ ] \times [\ 1 \div (1 - G_{t,i})\ ]$$

where

$T_{tar,a,i}$ is the target radiance of leaf array *i* in transmission mode,

ρ_{ref} is the absolute reflectance of the calibrated Spectralon® reflectance standard,

$R_{ref,ab}$ is the reference radiance used for all leaf arrays (**abaxial** side) in reflectance mode,

R_{str} is the stray light radiance in reflectance mode,

ρ_c is the absolute reflectance of the cavity wall (i.e. sphere wall interior), calculated as (Noda et al. 2013; eqn. 5)

$$\rho_c = [\ T_{tar,c} \div (R_{ref,c} - R_{str})] \times \rho_{ref},$$

$G_{t,i}$ is the gap fraction in transmission mode for leaf array *i*, which is calculated **at 400 nm** (Noda et al. 2013; eqn. 16) by

$$G_{t,i} = [\ T_{tar,a,i} \div (R_{ref,ab} - R_{str})\ ] \times (\rho_{ref} \div \rho_c).$$

ANNOTATIONS

Raymond Soffer 30 May 2018

Should this not be repeated for the Abaxial transmittance? I believe the measurements were made.

Raymond Soffer 30 May 2018

Eqn 1) In this case R_{ref} should be R_w as it is associated with the reflectance mode measurments in the denominator. $R_{ref,ab}$ − should be

Etienne Laliberté 26 Apr 2018

include description for T_tar,c and R_ref,c

if we decide to measure reflecntace of cavity wall in lab (same time as when we calibrate our field standards against lab standard), then we could remove the R_ref,abaxial step in protocol.

Warnings

The lamp of the integrating sphere can get **very hot** and should handled from its slotted base to avoid burns.