Hovi A., Mõttus M., Juola J., Manoocheri F., Ikonen E., Rautiainen M. (2020). Evaluating the performance of a double integrating sphere in measurement of reflectance, transmittance, and albedo of coniferous needles. Silva Fennica vol. 54 no. 2 article 10270. https://doi.org/10.14214/sf.10270.

Supplementary file S1

This supplementary text provides details of the measurement setups and protocols (Section 1), preprocessing of the raw spectrometer data (Section 2), and preparation of light masks for computation of gap fractions in needle samples (Section 3).

1 Measurement setups and protocols

The double and single integrating spheres (DIS and SIS) were connected to an ASD FieldSpec4 Standard-Res spectrometer (Serial nr 18641). Due to transmission losses in the optical fibers, the signal level in DIS was lower than in SIS. To obtain comparable signal levels, we used 8.7 s and 1.09 s integration times in DIS and SIS, respectively. Five measurements (i.e., five integration times) were always averaged into one spectrometer reading (digital numbers, [DN]). Table S1.1 illustrates the readings taken per each measurement with DIS, and Table S1.2 illustrates the same for SIS. The design of the spheres as well as the carrier configurations in the measurements are illustrated in Fig. S1.1. An uncalibrated 1.25-inch Spectralon panel with 99% nominal reflectance was used as a white reference in the measurements. Its reflectance was determined by measuring against a calibrated Spectralon. The SIS setup was used in this measurement.

Table S1.1. Measurement protocol for the double integrating sphere (DIS). The protocol for measurements with needle carriers is presented. The protocol for measurements without carriers is the same: the carriers are only removed. Independent of whether carriers were used or not, white reference was always measured once without carrier. This measurement was used in determining the amount of stray light in the reflectance sphere (stray light is proportional to the white reference measurement without carrier).

Spectrometer reading	Abbreviation	What's in sample port?
White reference for reflectance sphere (no carrier)	P(SPC)	99% uncalibrated Spectralon (surface upwards)
White reference for reflectance sphere	P(SPC)	99% uncalibrated Spectralon (surface upwards) + carrier
Measurement of empty reflectance sphere	P(0)	Empty port + 2×carrier
Measurement for empty transmittance sphere	P'(0)	Empty port + 2×carrier
Sample transmittance, side A	P'	Sample (side A upwards) + 2×carrier
Sample reflectance, side A	P	Sample (side A upwards) + 2×carrier
Sample reflectance, side A, dark background	P_{DBG}	Sample (side A upwards) + 2×carrier + 1% Acktar coating
Sample reflectance, side B	P	Sample (side B upwards) + 2×carrier
Sample reflectance, side B, dark background	P_{DBG}	Sample (side B upwards) + 2×carrier + 1% Acktar coating
Sample transmittance, side B	P'	Sample (side B upwards) + 2×carrier

Table S1.2. Measurement protocol for the single integrating sphere (SIS). The protocol for measurements with needle carriers is presented. The protocol for measurements without carriers is the same: the carriers are only removed.

Reading	Abbreviation	Port A[a]	Port B[a]	Port C[a]	Port D[a]	Port E[a]
White reference for reflectance	P(SPC)	L	$S_F + 2{\times}C$ + PT	$W + C$	P	P
Sample reflectance, side A	P	L	$W + C$	$S + 2{\times}C$ + PT	P	P
Sample reflectance, side B	P	L	$W + C$	$S + 2{\times}C$ + PT	P	P
Stray light for reflectance	STR_R	L	$W + C$	PT	P	P
White reference for transmittance	$P'(0)$	P	$W + C$	$S + 2{\times}C$ + PT	L	P
Sample transmittance, side A	P'	P	$W + C$	PT	$L + S + 2{\times}C$	P
Sample transmittance, side B	P'	P	$W + C$	PT	$L + S + 2{\times}C$	P
Stray light for transmittance	STR_T	P	PT	$W + C$	L	P

[a] Abbreviations for configurations in ports A–E: W = white reference, L = lamp, S = sample, S_F = false sample (=sample prepared from the same material as the actual sample), PT = photon trap, P = plug, C = carrier.

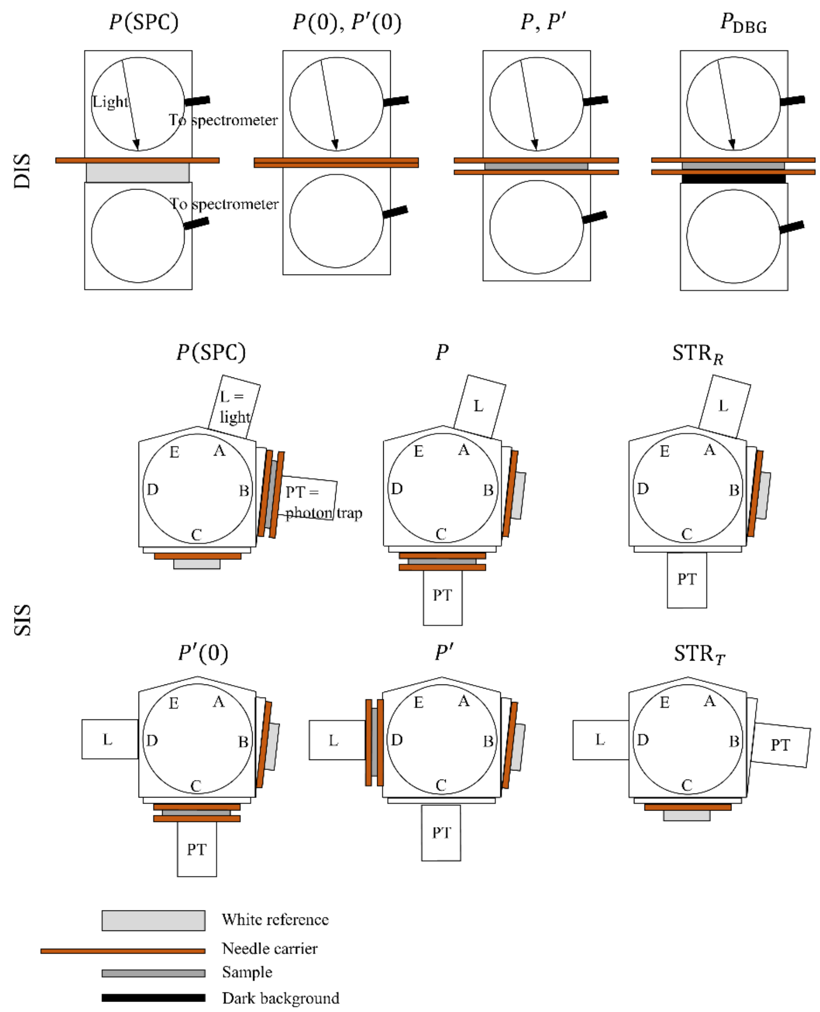

Fig. S1.1. Carrier and sample configurations in the measurements with single and double integrating spheres (SIS, DIS). The measurements with carriers are presented. Measurements without carriers are similar, but the carriers are ignored. The inner diameters of the DIS spheres are 20 mm, and the inner diameter of SIS is 75 mm. For visual clarity, the relative dimensions of the spheres, as well as different components in each sphere, may differ from reality. For explanation of abbreviations, see Tables S1.1 and S1.2.

2 Data preprocessing

Dark current was measured for each sample, and subtracted from all measurements before the computations. Stray light in DIS was measured once by measuring the empty sample port when the system was covered with a black box, i.e. it was in complete darkness. As in Mõttus et al. (2017), the stray light was expressed as fraction of signal from the white reference measured without needle carriers (*P*(SPC)) and could therefore be predicted for each sample. In SIS, the stray light was measured for each sample separately (see the measurement protocol in Table S1.2). Before computations, stray light was subtracted from the measurements made in the reflectance sphere of DIS, and from the measurements made in reflectance mode in SIS. Finally, it was noticed that there was a small discontinuity in the ratio of *P*(SPC) to *P'*(0) in the DIS (Fig. S1.2). Examining the data from an earlier publication by Mõttus et al. (2017), in which the same setup was used, similar but slightly smaller discontinuity was detected. The discontinuity is likely caused by small differences in optical pathways from the sphere to the spectrometer, e.g. small defects in the ends of optical fibers. The discontinuity was empirically corrected by adjusting the measurements made in the transmittance sphere. The adjustment was less than 2% in all wavelengths, and it ensured that there were no discontinuities in the reflectance and transmittance spectra derived from the measurements.

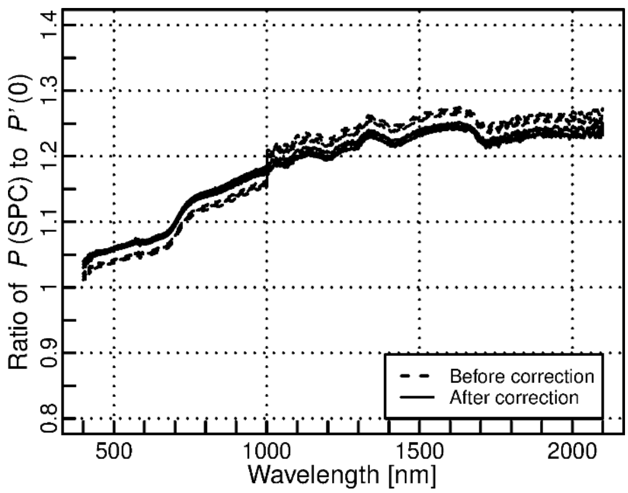

Fig. S1.2. Ratio of *P*(SPC) to *P'*(0) in the measurements with DIS. The dashed line shows the original measurements (n = 4) after stray light and dark current corrections, and the solid line shows the measurements after a correction for the difference in optical pathways between the two spheres.

3 Preparation of light masks for determining gap fractions in needle samples

The light masks for direct illumination beams were prepared by measuring the light beam's irradiance distribution, using a digital camera (Nikon D5000), and assuming that the digital numbers in the images taken in raw format in the blue channel were in linear relation to the observed power. The images were photogrammetrically orientated using targets with known coordinates (yellow points painted on the background) to allow measurements of position and dimensions of the light beam. Two types of images were taken. First, the light beam was imaged when projected onto a Spectralon panel at the same distance as the sample in the reflectance and transmittance measurements. Because the Spectralon panel is assumed spatially homogeneous in reflectance, this image gave the dimensions and irradiance distribution of the light beam. For DIS the same distance as in the actual measurements was not possible to obtain, because the light is not detachable from the system. Therefore, images from several distances (longer than the actual measurement distance) were taken, and a linear model was developed to scale the image of the light beam. Second, image of the light beam was taken when a carrier with dark paper placed in its opening was attached to the sample port in the measurement system. The light beam was projected on the dark paper and its position relative to the carrier could be measured. The two images, giving the irradiance distribution and position, were manually aligned. The positions of the light masks were further refined by repeating the reflectance and transmittance computations for a separate set of measurements (a needle-like paper sample measured 12 times by rotating the sample 30 degrees between measurements) so that the position of the light mask was moved in a regular 0.1×0.1 mm grid. The optimal positions were found when the standard deviation of the reflectance and transmittance spectra reached their minimum. The original resolutions of the images were 0.07–0.1 mm/pixel. The obtained light masks were interpolated into 0.02 mm grid to approximately correspond the resolution of the scanned grayscale images of the carriers.