Hukseflux
Thermal Sensors

Measuring albedo of finite samples

Tips and tricks to get the most out of your albedometer measurement

The measurement of the albedo, or reflectance, of surfaces is gaining popularity. Bifacial PV modules aim to use both the global solar radiation and the reflected solar radiation to provide electricity. As these modules are often mounted close to the surface, the albedo of smaller samples becomes relevant. Downfacing pyranometers are suitable to make this measurement, but you must carefully consider the installation height. This note delves into the theory of the albedometer measurement, to help you get the most out of your albedometer.

Introduction

Albedometers are instruments that measure global and reflected solar radiation and the solar albedo, or solar reflectance, of surfaces. It is composed of two pyranometers, the downfacing one measuring reflected solar radiation.
The classic application is in energy balance studies, studying albedo variations of large fields over several years.
With the rise in popularity of bifacial PV modules, there is an increased demand to measure the albedo of finite samples. This is certainly possible with pyranometers, but there are a few things to keep in mind.

Figure 1 *SRA20 albedometer*

Standard recommendations

ISO/TR 9901[1] states that the ground beneath the downfacing pyranometer should have a covering which is typical of the desired measurement conditions. For general energy balance studies, ISO/TR 9901 states that the height above the ground should be between 1.5 and 2 m. The Baseline Surface Radiation Network uses installation heights of 30 m to get a field of view that is comparable to a satellite pixel[2].

Mounting structure

ISO/TR 9901 states that the mounting device should be designed to minimize reflections or shadows in the field of view of the albedometers. WMO[3] says that mounting devices should be designed to cause less than 2 % error in the measurement.
To avoid reflections, masts are painted with non-reflective paint. To minimize shading, albedometers are mounted on booms extending towards the equator.

Figure 2 *NR01, including a downfacing pyranometer, installed on meteorological station. The boom on which the NR01 is mounted should extend towards the equator*

Detailed considerations

To make sure that the field of view of the downfacing pyranometer is largely filled by the sample of interest, an installation height of less than 2 m is required for smaller samples.
Ease of maintenance is also a reason to consider a low installation height.

This section develops theory to show that the installation height is a trade off between representativeness and errors due to self-shading.

Field of view

Pyranometers have a full hemispherical field of view, and measure according to cosine response. The measured irradiance is the integrated radiation *E* from the entire field of view.

$$\mathrm{E} = \int_0^{2\pi} \int_0^{\pi/2} E(\theta, \varphi) \cos\theta \, d\theta \, d\varphi$$

with θ the zenith angle, ϕ the azimuthal angle.

Consider a downfacing pyranometer mounted at a height of *h* m above a sample with a radius x_{sample}. The sample subtends an angle $\theta_{\text{sample}} = \tan^{-1}\left(\frac{x_{\text{sample}}}{h}\right)$ from nadir.

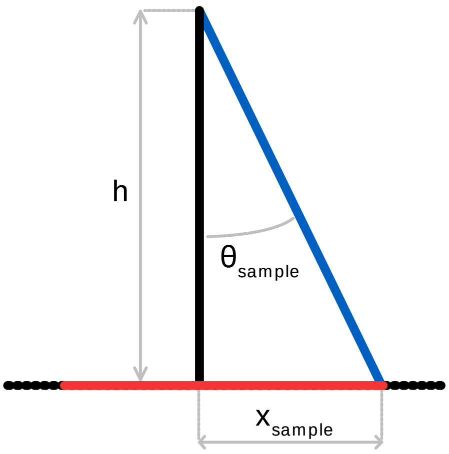

Figure 3 *schematic drawing of an albedometer mounted at a height h above a finite sample with radius* x_{sample}*. The sample extends an angle* θ_{sample}

A part of the measured reflected irradiance is reflected global irradiance from the sample; the rest is reflected from the surroundings.

Assuming spherical symmetry, the measured reflected irradiance E_r is

$$E_{l,\downarrow}\left(A_{\text{sample}} \int_0^{\theta_{\text{sample}}} \cos\theta \, d\theta + A_{\text{surroundings}} \int_{\theta_{\text{sample}}}^{\pi/2} \cos\theta \, d\theta\right)$$

or

$$E_{l,\downarrow}\left(A_{\text{sample}} \sin\theta_{\text{sample}} + A_{\text{surroundings}}\left(1 - \sin\theta_{\text{sample}}\right)\right)$$

with A_{sample} the albedo of the sample, $A_{\text{surroundings}}$ the albedo of the surroundings.

The relative contribution of the sample to the total signal is $\sin(\theta_{\text{sample}})$. See Figure 4 for a plot of this contribution as a function of h/x_{sample}. The lower you mount the albedometer, the larger this contribution becomes.

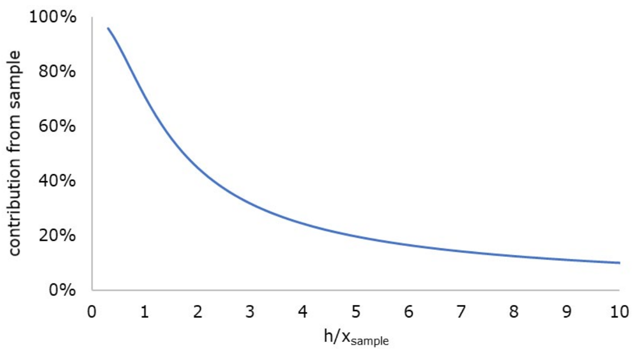

Figure 4 *relative contribution of the surroundings to the total measure albedo when measuring the albedo of a finite sample as a function of h/*x_{sample}

The actual measurement error depends on the difference between the albedo of the sample and the surroundings.

$$\Delta_{\text{field of view}} = \frac{\text{measured albedo}}{\text{actual albedo}} - 1$$

$$= \frac{A_{\text{sample}} \sin\theta_{\text{sample}} + A_{\text{surroundings}}\left(1 - \sin\theta_{\text{sample}}\right)}{A_{\text{sample}}} - 1$$

Self-shading

A problem with mounting an albedometer close to the surface is the shading of direct solar radiation on the sample by the albedometer itself.

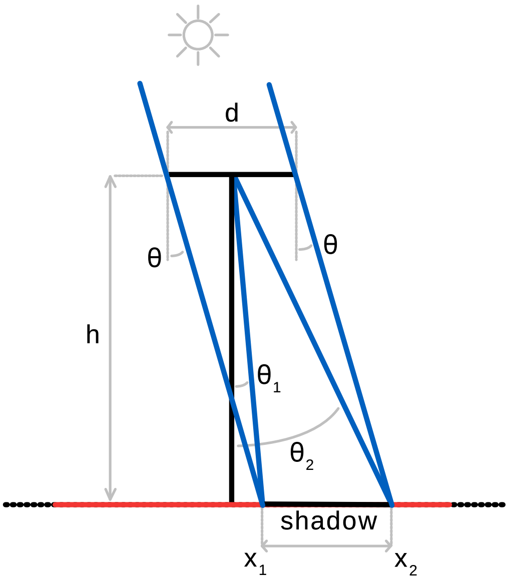

Figure 5 *schematic drawing of the shadow cast by an albedometer with a diameter d for a certain solar zenith angle θ*

Hukseflux
Thermal Sensors

The position of the shadow depends on the solar zenith angle and the installation height *h*. The size of the shadow depends on the diameter of the pyranometer *d*.

From the centre of pyranometer, the shadow subtends between angles θ_1 and θ_2, between a distance x_1 and x_2 from the middle of the sample.

$$x_{1,2} = h \tan\theta \mp \frac{d}{2}$$
$$\theta_{1,2} = \tan^{-1}\left(\frac{x_{1,2}}{h}\right)$$

The reflected irradiance from the band in which the shadow lies is

$$EA\int_{\theta_1}^{\theta_2} \cos\theta \, d\theta = EA(\sin\theta_2 - \sin\theta_1)$$

with *E* the direct solar radiation, *A* the albedo of the sample.
The 'missed' irradiance is $f \cdot \mathrm{E_{band}}$ with

$$f = \frac{\text{area of the shadow}}{\text{area of the band}} = \frac{\frac{1}{4}\pi(x_2 - x_1)}{\pi({x_2}^2 - {x_1}^2)} = \frac{d}{8h\tan\theta}$$

The measured albedo is

$$\frac{EA - f\mathrm{E}_{band}}{E}$$

and the measurement error is

$$\Delta_{\text{shadow}} = \frac{\text{measured albedo}}{\text{actual albedo}} - 1$$
$$= -\frac{d}{8h\tan\theta}(\sin\theta_2 - \sin\theta_1)$$

See Figures 6 and 7 for plots of this error as a function of pyranometer height. The error becomes significant at heights below 1 m, at low zenith angles. The larger your pyranometer, the greater the error. Table 1 gives diameters for Hukseflux albedometers.

Table 1 *diameters of Hukseflux albedometers*

ALBEDOMETER	d [m]
SRA20	0.15
SRA20 without sunscreen	0.078
SRA01	0.066

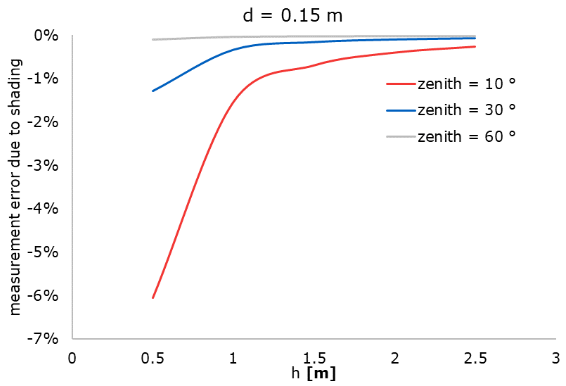

Figure 6 *measurement error due to shading for different zenith angles, at a pyranometer diameter of 0.15 m*

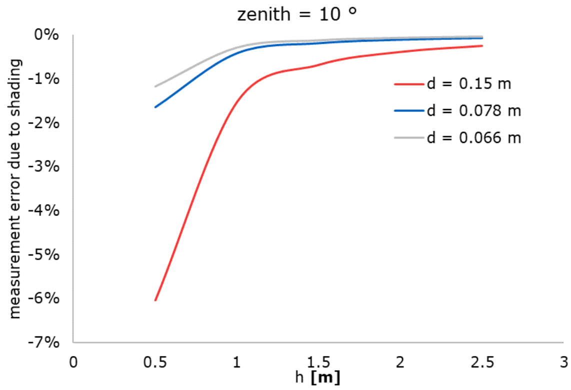

Figure 7 *measurement error due to shading for the different pyranometer diameters given in Table 1, at a zenith angle of 10 °*

Summary

When measuring small samples a low installation height makes the measured albedo more representative for the sample. At the same time, the shadow cast by the pyranometer can lead to significant errors if you mount it too close to the surface.

Worked example

Let's say you want to measure the albedo of a sample with a radius of 2 m, using a SRA20 albedometer.

To achieve a situation where 97 % of the measurement signal is coming from the sample, install the downfacing pyranometer at a height of 0.5 m. This can cause significant self-shading errors, up to 6 % for low zenith angles. A solution is to use the SRA20 without its sunscreen. This reduces the measurement error due to self-shading by a factor 3.

Conclusion

Albedometers are suitable to measure the reflectance of finite samples.
All the normal recommendations for performing an albedometer measurement apply.
To improve the measurement, carefully consider the installation height. This is a trade off between representativeness and errors due to self-shading.

References

1. ISO (1990) ISO/TR 9901:1990 Solar energy -- Field pyranometers -- Recommended practice for use
2. McArthur L.J.B. (2005) WMO/TD-No. 1274 Baseline Surface Radiation Network (BSRN). Operations Manual. Version 2.1
3. WMO (2017) WMO-No. 8 WMO Guide To Meteorological Instruments And Methods Of Observation

Figure 8 *SRA01 second class albedometer*

See also

- SRA01 second class albedometer
- SRA20 secondary standard albedometer
- NR01 net radiometer

About Hukseflux

Hukseflux Thermal Sensors offers measurement solutions for the most challenging applications. We design and supply sensors as well as test & measuring systems, and offer related services such as engineering and consultancy. With our laboratory facilities, we provide testing services including material characterisation and calibration. Our main area of expertise is measurement of heat transfer and thermal quantities such as solar radiation, heat flux and thermal conductivity. Hukseflux is ISO 9001:2015 certified. Hukseflux sensors, systems and services are offered worldwide via our office in Delft, the Netherlands and local distributors.

Would you like more information?
E-mail us at: info@hukseflux.com