Introduction

Albedometers are instruments that measure global and reflected solar radiation and the solar albedo, or solar reflectance, of surfaces. An albedometer 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 small areas of ground surface; in scientific terms: finite samples. This is certainly possible with pyranometers, but there are a few things to keep in mind.

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.
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 / inspection 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.

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

with \(\theta\) the zenith angle, \(\varphi\) the azimuthal angle.

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

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

\[
E_{\text{\overline{L}}\text{\overline{\downarrow}}} = \left( A_{\text{sample}} \int_0^{\theta_{\text{sample}}} \cos \theta \, d\theta + A_{\text{surroundings}} \int_{\theta_{\text{sample}}}^{\pi/2} \cos \theta \, d\theta \right)
\]
or

\[
E_{\text{\overline{L}}\text{\overline{\downarrow}}} = \left( A_{\text{sample}} \sin \theta_{\text{sample}} + A_{\text{surroundings}} \left(1 - \sin \theta_{\text{sample}}\right)\right)
\]

with \(A_{\text{sample}}\) 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 \(h/x_{\text{sample}}\). The lower you mount the albedometer, the larger this contribution becomes. In other words: if you have a small representative sample, and the area beyond the sample is not representative of what you want to measure, the first impression is that you would want to measure as close as possible to this sample.

![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}](image)

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.
The measured albedo is
\[ \frac{EA - f E_{\text{band}}}{E} \]
and the measurement error is
\[ \Delta_{\text{shadow}} = \frac{\text{measured albedo} - 1}{\text{actual albedo}} = -\frac{d}{8h \tan \theta} (\sin \theta_2 - \sin \theta_1) \]

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.

![Figure 6](image-url) measurement error due to shading for different zenith angles, at a pyranometer diameter of 0.15 m

![Figure 7](image-url) 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.
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. An installation height of 1.5 m is a good compromise, allowing a high-accuracy measurement, as well as inspection and cleaning. This height also allows people to walk around the instrument without shading it as long as they keep their distance, and is sufficient to keep above most snow covers.

See also
- NR01 net radiometer
- SRA01, SRA20-D2, SRA30-D1 albedometers
- AMF and ALF mounting and levelling kits

About Hukseflux

Hukseflux Thermal Sensors makes sensors and measuring systems. Our aim is to let our customers work with the best possible data. Many of our products are used in support of energy transition and efficient use of energy. We also provide services: calibration and material characterisation. 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 certified. Hukseflux products and services are offered worldwide via our office in Delft, the Netherlands and local distributors.

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.

References

3. WMO (2017) WMO-No. 8 WMO Guide To Meteorological Instruments And Methods Of Observation

Figure 8 AMF03 albedometer mounting kit for 2 x SR30 / SR15 pyranometers