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A new simplified method for measuring the albedo of limited extent targets

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ABSTRACT

Albedo is important in the research fields of atmospheric sciences, forestry, urban climatology, building energy sciences, and several others. Here we establish a new simplified method for measuring the albedo of limited extent targets in field. Back-to-back pyranometers are centered and leveled over the target to measure the incident radiation and the reflected radiation. A circular baffle with an aperture at the bottom is assembled around the lower pyranometer's detector to make the detector receiving the reflected radiation from the target only. Measurement is calibrated by covering the target with a spectrally non-selective diffuse mask. We use the proposed method to measure the albedo of typical land covers; the measured results were then compared against the measured albedo attained using the ASTM E1918-06 standard. The comparison shows close agreements, indicating that the proposed method is reliable to measure the albedo of a limited extent target and can serve as a simplified alternative to ASTM E1918-06.

1. Introduction

Albedo is defined as the fraction of solar radiation reflected by a surface. The albedo is an important parameter in climatology (He et al., 2014), forestry (Betts, 2000), urban climatatology (Aida and Gotoh, 1982; Aida, 1982; Sievers and Zdunkowski, 1985), photovoltaic devices (Brennan et al., 2014; Andrews and Pearce, 2013), global climatatology (Akbari and Matthews, 2012; Menon et al., 2010; Dev and Surabi, 2011), agriculture (Kaleita et al., 2005; Matthias et al., 2000; Salvucci, 1997), building energy efficiency (Levinson, 1997; Christen and Vogt, 2004; Erell et al., 2012), and several other fields. Measuring the albedo of a surface is critical to understand the thermal balance at the earth surface and to regulate the albedo of surfaces for favorable thermal environments.

The albedo varies with the incident solar radiation spectrum, the solar angle, the surface's texture, the surface roughness, and others. The albedo, ρ, of a homogeneous flat surface can be calculated using Eq. (1):

$$\rho = \int_S i(\lambda) \times R(\lambda)\mathrm{d}\lambda / \int_S i(\lambda)\mathrm{d}\lambda \quad (1)$$

where i(W/m^2/nm) represents the incident solar spectrum; λ(nm) is the wavelength; R is the spectral reflectance of the homogeneous surface; S is the radiation wavelength range, usually $S = 250$–2500 nm.

2. Existing methods for measuring albedo

Laboratory, remote-sensed, and field methods are available for measuring the albedo of a surface at diverse scales. In the laboratory, the albedo of a homogeneous flat surface can be measured using several testing tools with varied mechanisms. In method ASTM E903, a solar spectrophotometer is used to illuminate a surface of with monochromatic light at a near-normal incident angle to measure the light reflected into an integrating sphere (ASTM-E903-12, 2012). A series of such measurements in the wavelength ranging from 250 nm to 2500 nm obtains the surface's near-normal solar spectral reflectance (Levinson et al., 2010a). The specimen must be large enough to cover the aperture of the integrating sphere, which is about 2–3 cm in diameter. The albedo of such a specimen can be calculated by integrating the spectral reflectance over the wavelength range weighting with a specific solar spectral irradiance (ASTM-E903-12, 2012). Alternatively, the albedo of a laboratory sample with a diameter of 2.5 cm, such as a concrete sample, can be found by using a commercial portable solar reflectometer (Levinson et al., 2010b; ASTM-C1549-09, 2014), which is specified in the ASTM standard C 1549-16 (ASTM-C1549-09, 2014) (Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer).

The albedo of larger surfaces, such as a 1 km^2, can be determined by remote sensing. Aircraft or satellite-based tools are applied to observe high-resolution narrowband satellite information (Liang, 2001). The

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Nomenclature

Symbols

ρ	albedo
I	downwelling solar radiation (W/m^2)
J	upwelling reflected radiation (W/m^2)
F	view factor (-)
k	the fraction of global horizontal irradiance that is diffuse (-)
λ	the wavelength, (nm)
i	the solar spectral irradiance (W/m^2/nm)
R	spectral reflectance (-)
r	radius (m)
H	the sensor-to-target height (m)
h	the height of the baffle (m)

Subscript

d	the detector of the lower pyranometer
w	the baffle's interior wall
t	the target
tu	un-shaded area on the target
ts	shadow on the target
m	the reference mask
b	background (target and surrounding)
bs	shadow on the background
s	the area surrounding the target
su	the un-shaded area on the surrounding
ss	the shadow on the surroundings
1	measurement performed with target uncovered
2	measurement performed with target masked

albedo of the target area is obtained by integrating the narrowband reflectance (Song and Gao, 1999; Lucht et al., 2000; Cierniewski et al., 2015; Ban-Weiss et al., 2015a, 2015b). The estimated broadband albedo can be validated and calibrated by the ground-based albedometer measurements (Lucht et al., 2000; Kaufman et al., 2001; Williamson et al., 2016). While remote sensing may be suitable for field measurements of reflectivity at a larger scale (in scale of square kilometers), this approach has a limited accuracy for targets at a small scale (such as several square meters) in heterogeneous field environments. Testing the albedo of a limited extent target at small scale is important for characterizing the solar absorption for soil surfaces, natural ground surfaces, roof tiles, pavements, and other applications.

The measurement of solar reflectance of various horizontal and low-sloped surfaces in the field is available. The ASTM E1918-06 (Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field; hereafter, noted simply as "E1918") measures the albedo of a target by centering and leveling a pyranometer over the target to record the reflected radiation and by minimizing the shadow of the instrument on the target. The albedo of such a surface is the ratio of the reflected radiation to the incident radiation. The errors of E1918 depend on the shadows prevalent on the target (Appendix A). The shadows of the pyranometer and of the supporting rod can underestimate the true albedo of the target in many instances. This underestimation is of its greatest value when the albedo is measured at the solar noon (Appendix A). The E1918 is designed for measuring the albedo of existing large surfaces (such as roofs and pavements), which must fill the view field of the down-facing pyranometer. For a pyranometer installed at a 0.5 m height, the target must be at least 4 m in diameter, which fills approximately 95% of the view field of the down-facing pyranometer (ASTM-E1918-06, 2015). The E1918 is not suitable to measure the albedo of a limited extent target, such as 1 m × 1 m.

An alternative of the E1918 method is the ASTM E1918A (non-ASTM standard, hereafter, simply as "1918A"), which is a white-black control method to measure the albedo of a limited extent target. In the 1918A, two pyranometers are assembled back to back to read the incident radiation and the reflected radiation simultaneously. The measured procedures are to sequentially cover the target with a white spectrally-nonselective mask and then a black spectrally-nonselective mask and to finally leave the target uncovered (Akbari et al., 2008). Details of the method can be referred in Appendix B. Qin et al. (2016a) extends this method by considering the variations of the incident solar radiation during the measurement. One concern is that the shadow of the instrument setup causes errors to the measurement. The1918A method, however, can eliminate the effect of shadow on the albedo of the target (Appendix B). The albedo measured by using the1918A method might be subject to the variation of the albedo of the background. Recently, Mei et al. (2017) measured the albedo of a limited extent target by stapling a retro-reflective tape on the inner side of the baffle (assembled around the down-facing pyranometer) to returning the stray reflected radiation from the area surrounding the target. Alternatively, Sailor et al. (2006) proposed a novel method for measuring the albedo of a limited extent target by placing a cylindrical shade ring around the target to shield the reflectance from the surrounding area. In this method, the down-facing pyranometer receives the reflected radiation from the target only. The measurement does not need any mask,

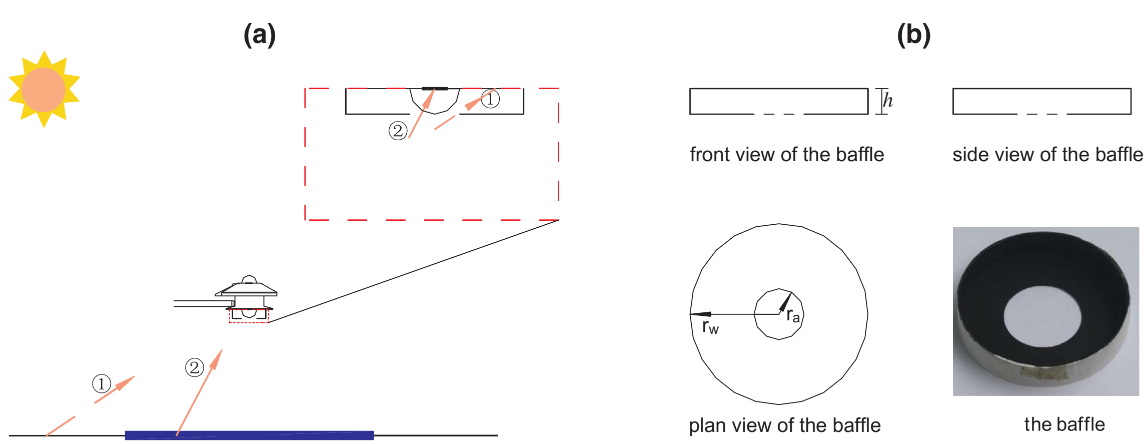

Fig. 1. The measurement setup. (a) A baffle with an aperture at the bottom is assembled to force the lower detector receiving reflected radiation from the target only, (b) front, side and plan views of the baffle.