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Simulated impact of sensor field of view and distance on field measurements of bidirectional reflectance factors for row crops

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ABSTRACT

It is well established that a natural surface exhibits anisotropic reflectance properties that depend on the characteristics of the surface. Spectral measurements of the bidirectional reflectance factor (BRF) at ground level provide us a method to capture the directional characteristics of the observed surface. Various spectroradiometers with different field of views (FOVs) were used under different mounting conditions to measure crop reflectance. The impact and uncertainty of sensor FOV and distance from the target have rarely been considered. The issue can be compounded with the characteristic reflectance of heterogeneous row crops. Because of the difficulty of accurately obtaining field measurements of crop reflectance under natural environments, a method of computer simulation was proposed to study the impact of sensor FOV and distance on field measured BRFs. A Monte Carlo model was built to combine the photon spread method and the weight reduction concept to develop the weighted photon spread (WPS) model to simulate radiation transfer in architecturally realistic canopies. Comparisons of the Monte Carlo model with both field BRF measurements and the RAMI Online Model Checker (ROMC) showed good agreement. BRFs were then simulated for a range of sensor FOV and distance combinations and compared with the reference values (distance at infinity) for two typical row canopy scenes. Sensors with a finite FOV and distance from the target approximate the reflectance anisotropy and yield average values over FOV. Moreover, the perspective projection of the sensor causes a proportional distortion in the sensor FOV from the ideal directional observations. Though such factors inducing the measurement error exist, it was found that the BRF can be obtained with a tolerable bias on ground level with a proper combination of sensor FOV and distance, except for the hotspot direction and the directions around it. Recommendations for the choice of sensor FOV and distance are also made to reduce the bias from the real angular signatures in field BRF measurement for row crops.

1. Introduction

The earth's surface scatters radiation anisotropically, especially at the shorter wavelengths that characterize solar irradiance (Strahler, 1997; Walthall, Roujean, & Morisette, 2000). The anisotropy of surface scattering can be described by the bidirectional reflectance distribution function (BRDF) (Nicodemus, Richmond, Hsia, Ginsberg, & Limperis, 1977; Schaepman-Strub, Schaepman, Painter, Dangel, & Martonchik, 2006). Spectral measurements of the directional reflectance at ground level enable us to gain an understanding of the directional reflectance characteristics of the observed surface and energy–matter interactions (Milton, Schaepman, Anderson, Kneubühler, & Fox, 2009). Field measurement of the bidirectional reflectance factor (BRF) is further motivated by the development of surface reflectance models (Goel, 1988), applications of ground-based remote sensing sensors to aid farm management (El-Shikha, Waller, Hunsaker, Clarke, & Barnes, 2007), the normalization of multiple view angle remote sensing data acquired by satellite sensors with wide swaths (Zhao et al., 2013), vicarious calibration of airborne and space-borne remote sensing devices (Secker, Staenz, Gauthier, & Budkewitsch, 2001; Wang, Czapla-Myers, Lyapustin, Thome, & Dutton, 2011), and the validation of satellite-derived products, e.g. albedo (Huang et al., 2013).

Field measurements of the directional reflectance characteristics of vegetation have received widespread attention to better monitor

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and measure the structure and state of ecosystems. The application of vegetation monitoring was almost concurrent with the early development of field spectroscopy (Milton et al., 2009). Because of the absence of consistent protocols and procedures for such measurements, spectroradiometers with various specifications were used under different mounting conditions to make directional reflectance measurements. Daughtry, Vanderbilt, and Pollara (1982) summarized these experiments for crops in the early 1980s, and showed that sensors with a field of view (FOV) from 15° to 28° were positioned from less than 2 m to 9 m or so above the ground. Since then, a series of field measurements of BRFs for crops and other short canopies were conducted with various types of sensor configurations (Table 1). We can see that sensors with different FOVs ranging from 3° to 25° were adopted and mounted on the support structures from less than 1 m to 6 m or so above the ground. The choice of sensor FOV and altitude (see notation a under Table 1) partly depends on the available instrument and mounting system in a given circumstance. However, measurement uncertainties can arise from the difference of spatial resolution and the variations of the target for the non-imaging spectroradiometer. The issue can be further compounded with the difficulty to accurately determine the actual measurement area of the sensor and the spatial non-uniform responsivity across the sensor FOV (Mac Arthur, MacLellan, & Malthus, 2012).

Few researchers have studied the impact of the choice of sensor FOV and distance to the target on the field measurement of BRFs of vegetation canopies. With the reflectance factors measured from nadir across the row direction, Daughtry et al. (1982) studied the variability of reflectance with sensor altitude for three different row crops and showed that the variance of reflectance factor measurements from nadir at low altitudes was attributable to row effects which disappeared at higher altitudes. In a previous study, we used the reverse ray tracing software POV-Ray (Persistence of Vision Ray-tracer, POV-team, 2009) to evaluate the influence of sensor FOV and distance on the field directional measurements for typical row canopies (Shang, Zhao, & Zhao, 2012). However, only the impact on four components' fractions (i.e. sunlit leaves, shaded leaves, sunlit soil and shaded soil) was studied, which should be more appropriate for the modeling of brightness temperature in the thermal infrared bands, as shown in the study by Ren et al. (2013).

This paper investigates how different sensor FOVs and distances affect the field measurements of BRFs for row canopies. Because of the difficulty to conduct the repeatable experiments under controlled conditions as in the laboratory, a Monte Carlo model to study the impact was developed and briefly described in Section 2. The evaluation of the model with field BRF measurements is provided. More comparison results with other state-of-the-art 3-D Monte Carlo models via the RAMI Online Model Checker (ROMC) (Widlowski et al., 2008) are in the companioning Supplement Data. In Section 4 the application of the model to study the impact of sensor FOV–distance combinations

Table 1
Examples of sensor FOV and altitude.

Investigator	Surface type	Canopy height (cm)	LAI (or %cover)	Sensor altitude above the ground (cm)[a]	Sensor FOV (°)
Kimes (1983)	Corn	33	0.65 (25%)	150	12
	Lawn	14	9.9 (97%)	150	
	Soybeans	77	4.6 (90%)	150	
	Orchard grass	22	1.1 (50%)	350	
Kimes et al. (1985)	Plowed field	NA	NA	200	12
	Annual grassland	3	<5%		
	Steppe grass	38	18%		
	Hard wheat	46	14%		
	Salt plain	9	20%		
	Irrigated wheat	76	70%		
Deering and Eck (1987)	Uniform grass	16	1.16 (90%)	606[b]	15
	Tufted grass	14	1.81 (79%)		
	Soya bean	85	5.68 (98%)		
Pinter, Jackson, and Moran (1990)	Cotton	31	0.42	160	15
	Cotton	21	0.18		
	Cotton	34	0.51		
	Wet wheat	97	4.86		
	Dry wheat	96	3.87		
	Furrowed soil	–	–		
Ranson, Irons, and Daughtry (1991)	Bluegrass sod	5	NA	200	15
	Bare soil	–	–		
Deering, Eck, and Grier (1992)	Shinnery oak	43.1	0.7 (60.2%)	606[b]	15
Eck and Deering (1992)	Steppe grassland	NA	3.59	500	15
			4.06		
Sandmeier and Itten (1999)	Grass lawn	3–3.5	NA	200	3
Vierling, Deering, and Eck (1997)	Wet sedge tundra	NA	<2	400	15
	Tussock tundra			NA	18
Abdou et al. (2001)	Dry lake surface	–	–	200	5
Giardino and Brivio (2003)	Colza field	NA	NA	120	25
	Herbaceous species	NA	NA	110	25
	Grass	NA	NA	110	8
	Snow	–	–	110	8
Strub, Schaepman, Knyazikhin, and Itten (2003)	Alfalfa	50	3–5.5	198.6[c]	3
Gamon, Cheng, Claudio, MacKinney, and Sims (2006)	Shrub	NA	NA	< 500	20
Gianelle and Guastella (2007)	Forbs grasses and legumes	NA	NA	150	10
Anderson et al. (2013)	Meadow	NA	3.41	23.6	21–25
Buchhorn, Petereit, and Heim (2013)	Moist non-acidic tundra	2–35	NA	200	8.5

[a] Researchers use sensor 'altitude', 'height', and 'distance' differently. In this paper, we also used them interchangeably. By 'altitude' or 'height', we mean the distance from the sensor to the ground at nadir. For 'distance', it is the distance from the sensor to the ground for any viewing angle. See Fig. 2 for an illustration.
[b] Values were estimated according to the circular area at nadir.
[c] Value was estimated according to the radius of the circular footprint at nadir.