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A note on suitable viewing configuration for retrieval of forest understory reflectance from multi-angle remote sensing data

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ABSTRACT

The contribution of understory vegetation especially to the reflectance of boreal forest landscapes cannot be ignored. In this letter, we identify the most suitable angular configuration for accurate retrieval of the understory signal. We use a new high angular resolution bidirectional reflectance factor data set with accompanying in situ measurements of understory reflectance in two RAdiation transfer Model Intercomparison (RAMI) mature stands in Järvselja, Estonia. Our results are pertinent towards the ultimate goal of achieving more reliable estimates of biophysical properties of the tree layer through separating the effect of understory on forest reflectance.

1. Introduction

Since ground vegetation (understory) has an essential contribution to the whole-stand reflectance signal in many boreal, sub-boreal and temperate forests, its reflectance spectra are urgently needed in various forest reflectance modelling efforts (Eriksson, Eklundh, Kuusk, & Nilson, 2006; Kobayashi, Suzuki, & Kobayashi, 2007; Rautiainen & Stenberg, 2005; Suzuki, Kobayashi, Delbart, Asanuma, & Hiyama, 2011). However, systematic reflectance data covering different site types are almost missing.

The measurement of understory reflectance is a real challenge because of the extremely high variability of irradiance at the forest floor, weak signal in some parts of the spectrum and its variable nature (Miller et al., 1997). Understory consists of several sub-layers (tree regeneration, shrub, grasses or dwarf shrub, mosses or lichens, litter, bare soil) and has spatially temporally variable species composition and ground coverage (Rautiainen et al., 2011). Additional problems are introduced by patchiness of ground vegetation, ground surface roughness and understory–overstory relations (Peltoniemi et al., 2005; Rautiainen & Heiskanen, 2013). Due to this variability, remote sensing might be the only technology to provide consistent data at the required spatially extensive scales.

Several previous studies examined the feasibility of determining the background information given two viewing geometries with an inversion approach at different spatial scales using different sensors (MISR, Canisius & Chen, 2007; airborne CASI, Pisek et al., 2010; MODIS, Pisek, Rautiainen, Heiskanen, & Mõttus, 2012). Despite their relative success, the unavailability of bidirectional reflectance factor (BRF) profiles of forests in the wide range of view angles with high angular resolution and accompanying in situ measurements had so far prevented determining the most suitable viewing configuration for the understory signal retrieval. Recently, Kuusk, Kuusk, and Lang (2014a) presented high resolution BRF data for several forest stands included in the RAdiation transfer Model Intercomparison (RAMI) exercise (Widlowski et al., 2007) with very different 3D structure supported by the extensive description of stand structure and their optical properties including ground vegetation. In this short communication paper, we use this data set to identify the most suitable viewing configuration for the retrieval of understory signal from remote sensing data.

2. Materials

BRF measurements were carried out over two mature RAMI stands (Table 1) at Järvselja, Estonia (58.3°N, 27.3°E). The first RAMI site was a 124-year-old Scots Pine (*Pinus sylvestris L.*) stand, growing on a transitional bog. Average tree height was 15.6 m; the forest understory consisted of various *Sphagnum* moss species and marsh tea (*Ledum palustre*). The second RAMI site, a 49-year-old Silver birch (*Betula pendula Roth*) dominated stand, grows on a typical brown gley-soil. Average height of the upper tree layer was 25.0 m with a ~ 2 m high hazelnut (*Corylus avellana*) and lime (*Tilia cordata)* shrubs and a mixture of several grass species in understory. More detailed information may be found in Kuusk, Kuusk, and Lang (2009); Kuusk, Lang, and Kuusk (2013).

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Table 1
Stand parameters.

Stand	Birch	Pine
Stand density (trees/ha)	992	1122
Mean tree height (m)	25	15.6
Mean length of live crown (m)	9.2	4.2
Mean radius of crown projection (m)	1.87	1.5
Canopy closure	0.8	0.74
Lef area index	3.14	2.55

The angular distribution of hemispherical–directional reflectance over the two RAMI sites was measured in flight campaigns in July–August of 2008–2011. The BRF-sensor of UAVSpec instrument (Kuusk, 2011) measures the angular distribution of reflectance along the flight path up to view zenith angles (VZA) of 70°. The azimuth angle of the recorded BRF relative to the sun azimuth is determined by the flight direction. Spectral band is selected with a band-pass filter. BRF profiles (29 in total) in red (660 nm, full width at half maximum (FWHM) = 11 nm) or near infrared (NIR) bands (850 nm, FWHM = 25 nm) sampling the full range of azimuths were collected over the two RAMI sites. The range of solar zenith angles was 37–54°. Kuusk et al. (2014a) provides more detailed information on the sensor setup and acquisition of the BRF profiles.

The airborne BRF observations (averaged over the whole stand area for the given angular configuration) were fitted with a hybrid type forest reflectance model FRT (Kuusk, Kuusk, & Lang, 2014b) to reproduce the fine angular structure of forest BRF (Fig. 1). The reported model parameters by Kuusk et al. (2014b) were used to obtain off-nadir BRF values at desired angles over the two stands for testing the various viewing configurations for the understory signal retrieval (Fig. 2). Kuusk et al. (2014b) provide details on the fitting procedure.

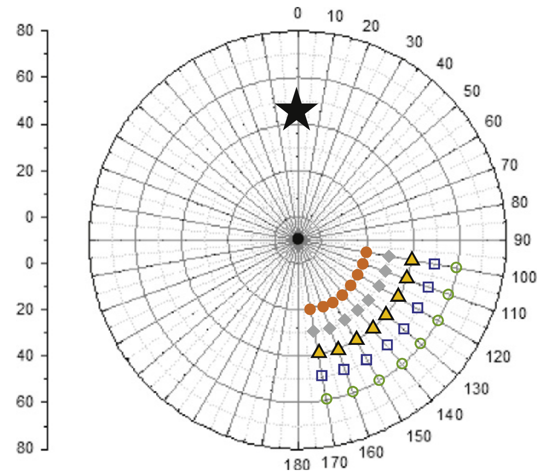

Fig. 2. Layout of all the tested positions for off-nadir viewing direction. Solar position SZA = 45°; PHI = 0°) is marked by a black star.

Reflectance spectra of ground vegetation were measured with the UAVSpec spectrometer at nine points in cloudless conditions with solar zenith angles close to 45° on 22 July (RAMI birch stand) and 5 August (RAMI pine stand) 2007. At every point, the radiance spectra of ground vegetation were measured vertically downward from a height of about 1 m using a field restrictor of 8° and walking along a

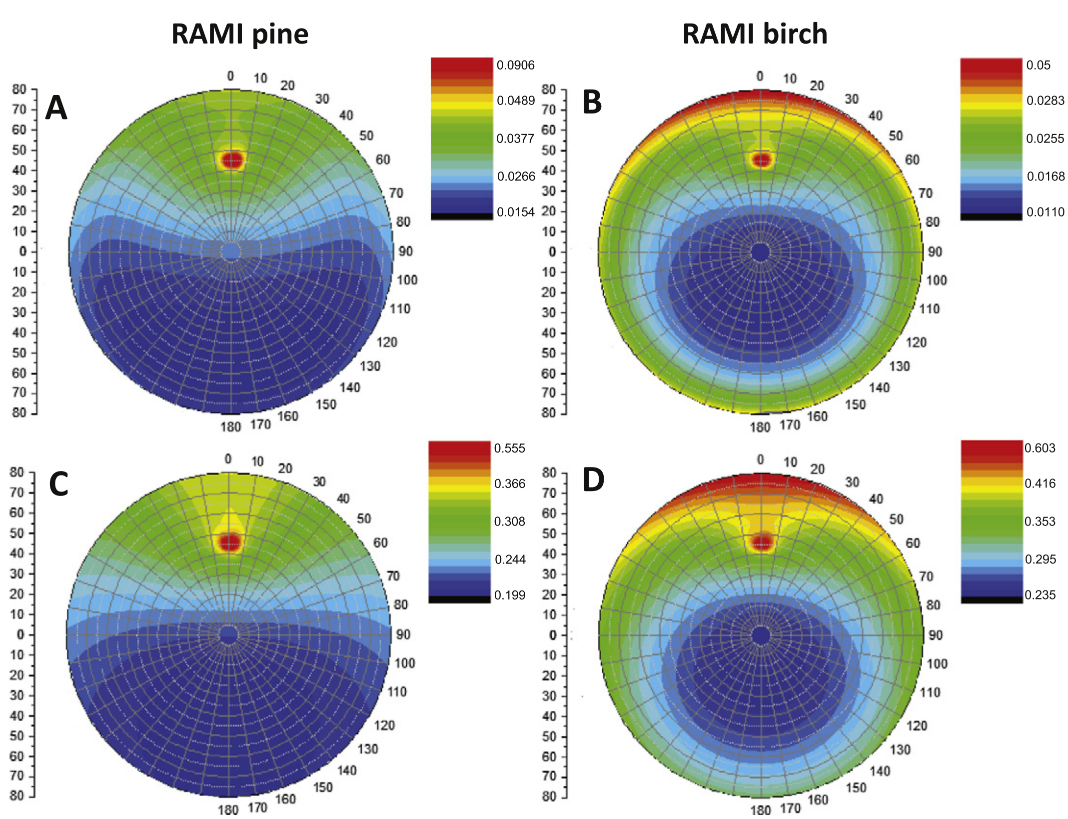

Fig. 1. BRF of the two RAMI stands at two wavelengths with solar zenith angle (SZA) = 45°. A and B—660 nm; C and D—850 nm.