Measurements of spectral and polarised bidirectional reflectance factor of various natural and artificial land surfaces

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Methodology and instrumentation to measure multiple scattering of light from particulate media such as snow, gravel, and sand are discussed. Some results are shown.

INTRODUCTION

Many land surfaces on Earth and other celestial bodies are covered by a particulate medium, i.e., a medium, that is formed by individual particles. Understanding scattering from such surfaces is important for remote sensing, as a boundary condition for Earth radiation and climate models, and for many research purposes.

Models for scattering from the single particles and particulate media are discussed in other presentations of this meeting. All models need validation and stimulation by experimental research. Here, a short discussion of various measurement methods and instruments are given, with special emphasis on field and laboratory gonio-polari-spectro-photometry. Some illustrative sample results are shown.

MEASURABLES AND DEFINITIONS

If the medium is illuminated by a directional beam F_0 from direction (ι, ϕ_0), and observed from direction (ϵ, ϕ) (Fig. 1), the observed intensity $I(\epsilon, \phi) \propto R(\epsilon, \phi, \iota, \phi_0) F_0(\iota, \phi_0)$, where R is the bidirectional reflectance factor (BRF), defined as a ratio against ideal diffuse (Lambertian) reflector. If the incident light is polarized, or if the sensor is sensitive to polarisation, or if the results are used in multiple-scattering calculations, polarisation must be taken into account. Optically complete description of polarisation is given by defining the observables using the Stokes vectors $\mathbf{I} = [I, Q, U, V]$, where I is the intensity (radiance), Q is the 0°–90°linearly polarised component, U is the 45°–135°linearly polarised component, and V is the circularly polarised component. BRF is then defined as a 4×4 matrix. Further define degrees of linear polarisation, $P = -Q/I$ or $P_{\mathrm{lin}} = \sqrt{Q^2 + U^2}/I$.

In field measurements, the situation is further complicated by diffuse light coming from the sky and environment. To recover the BRF matrix from the measurements, the incoming direct and diffuse light must be measured separately.

MEASUREMENT INSTRUMENTS

The BRF for a medium can be measured by several systems. If the medium is homogeneous over large enough area, one can scan over the area from one point [1, 2]. Also a wide-angle-lens camera can be used. Small surface areas are better measured by moving the sensor head around the target using a goniometer. Typically such instruments consist of a moving arm

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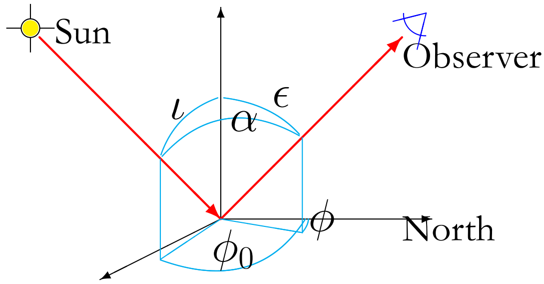

Figure 1. Definition of the angles used in surface reflectance work: ϵ and ι are the zenith angles of the emergent (Observer) and incident (solar) radiation respectively, ϕ and ϕ_0 are the corresponding azimuths.

or rail holding the sensor or optical head[3, 4, 5, 6]. Alternatively all directions are measured simultaneously using light cable construction. To measure large heterogeneous surfaces, one option is to fly the camera over the surface using satellite or air plane. Until recently, this has been an expensive technique for research purposes only, but now new advanced unmanned aerial vehicles (UAV) can carry light cameras economically and accurately, making many new opportunities possible. Spectral properties are measured either using selected filters in the camera, or more completely with a spectrometer. Polarisation can be measured using polarising filters or prisms.

An important issue is to calibrate the measurement system. Most uncertainties and errors are related to deficient calibration. To overcome uncertainties in absolute calibration, most measurements are taken relative to a known reference standard, usually Spectralon. For field use, also larger white or grey sheets are used.

Figure 2. Left: FIGIFIGO measuring snow, foreground left the Spectralon reference panel, right the sky monitoring pyranometer. Right: Microdrone md4-200.

Finnish Geodetic Institute field gonio-spectro-polari-photo-meter (FIGIFIGO) is a light-weight portable instrument to measure the BRF of land surfaces inside and outside (see Fig. 2). It has one moving arm holding the fore optics and fine-pointing system. The main sensor is an ASD FieldSpec Pro FR spectrometer. Footprint is about 10 cm in diameter. Optionally, polarisation can be measured using wide band calcite polariser in four positions to give the Stokes I, Q, and U parameters[7]. Two small UAVs, Microdrone md4-200 and md4-1000, have been equipped with calibrated cameras to measure BRF of larger land surfaces. These are flown in preprogrammed tracks over and around selected target areas, and BRF map is then produced[8].

SAMPLE RESULTS

Over 200 samples have been measured using FIGIFIGO, its predecessors, and the UAV system[9, 10]. Here, two cases are shown: moist snow measured in Sodankylä spring 2009, and grey gravel from Sjökulla aerial image test site, measured summer 2008. A 3-D BRF plot shows how different the cases are: snow is a strong forward scatterer and gravel a backward scatterer (Fig. 3). The reflection spectra taken in four directions in the principal plane show that the spectral shape varies as a function of the observation angle, but all characteristic features remain. The steepness of the spectral features depends on grain size. The degree of linear polarisation is depicted in the principal plane as a function of the observation zenith angle in three wavelengths, indicating how the polarisation depends on the scattering angle (Fig. 4) with maximum in far forward. The polarisation spectrum gives a small surprise with the increase between 600 and 900 nm where BRF is flat.

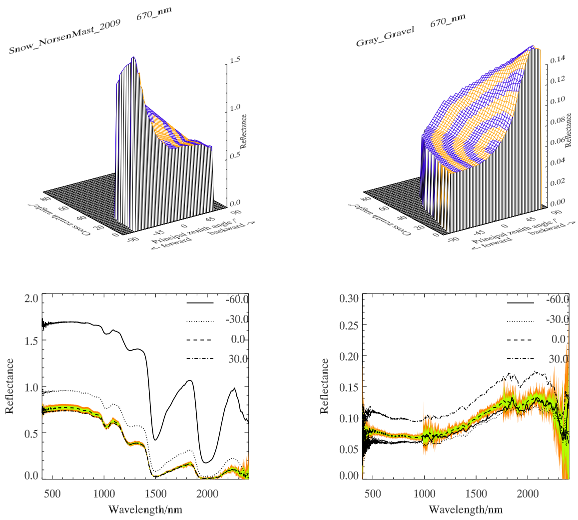

Figure 3. Top: BRF plot of the sample. Bottom: the reflection spectra of the samples in four zenith angles (ϵ) in the principal plane. The targets are snow (left) and grey gravel (right). The zenith angle of incidence (ι) were about 55°.

CONCLUSIONS

Reflectances of many particulate, solid and vegetated surfaces have been measured. Differences between targets are large. Most information is available from the spectrum. Many features are so strong that basic identification is possible even from poor data, but for accurate quantitative analysis careful measurements must be taken, and directional effects taken into account. The directional effects (BRF shape) in general are rather difficult to exploit, because they depend on so many things, and often the angular range remains too narrow. The polarisation poses still many challenges and has unexplained features. New research is needed before full utilisation. Polarisation is a very strong function of the scattering angles, and must be measured angularily.

One must notice that in real nature, every sample is individual, and one cannot generalise results so easily. The surfaces are very heterogeneous, and all parameters, topography, composition, flora and fauna vary in all possible scales. Also, the temporal variations are large, as no target exposed to weather can be assumed to be invariant over any significant

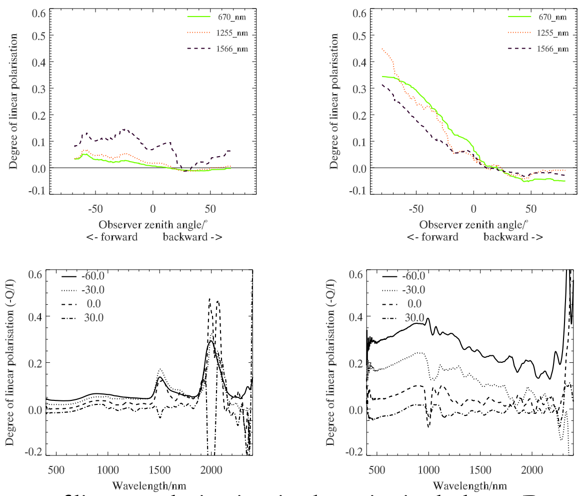

Figure 4. Top: Degree of linear polarisation in the principal plane. Bottom: the polarisation spectra of the samples in four directions in the principal plane.

time scale. The measurements presented here and in the database, are all from carefully selected or artificially made targets, to make interpretation easier. Results have been valuable for modelling, aerial observations, and developing remote-sensing processes. Measurements continue with new targets and improving techniques.

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