Intercomparison of field and laboratory goniometer measurements

Schopfer, Jürg ; Dangel, Stefan ; Verstraete, Michael M ; Kneubühler, Mathias ; Schaepman, Michael E ; Itten, Klaus I

Intercomparison of Field and Laboratory Goniometer Measurements

Jürg Schopfer[1], Stefan Dangel[1], Michel M. Verstraete[2], Mathias Kneubühler[1], Michael E. Schaepman[3] and Klaus I. Itten[1]

[1]Remote Sensing Laboratories (RSL), Department of Geography, University of Zurich, Switzerland
[2]Institute for Environment and Sustainability (IES), EC Joint Research Centre, Italy
[3]Wageningen UR, Wageningen University, Department of Environmental Sciences, Centre for Geo-Information, The Netherlands

Field and laboratory goniometers are widely used in the remote sensing community to assess spectrodirectional reflectance properties of selected targets. Even when the same target and goniometer system are used, field and laboratory results cannot directly be compared due to inherent differences, mainly in the illumination conditions: typically goniometers measure a hemispherical-conical reflectance in the field and a biconical reflectance in the laboratory. Yet, the ability to compare and combine measurements from different instrumental designs is critical to ensure sensor cross-calibration. It is also critical for all applications that rely on measurements obtained with both types of instruments. One solution is to retrieve the BRDF of the targets of interest for each experimental setup individually and to compare those, since theoretically they are independent from the particular conditions of illumination and observation. This involves a correction for diffuse incoming radiation in the case of field measurements, and a correction for the conicality and inhomogeneity of illumination in the case of laboratory measurements. We present a BRDF retrieval scheme for typical laboratory goniometers as well as results of measurements and BRDF retrievals using the field and laboratory goniometer systems (FIGOS/LAGOS) of the University of Zurich and the same artificial target for both goniometer setups.

1. Introduction

Ground based spectrodirectional measurements can be performed using goniometers either in the field or in a laboratory environment. The goniometer system of the Remote Sensing Laboratories (RSL) can be used in both configurations, either as FIGOS (Field Goniometer System) (Sandmeier et al. 1995) or as LAGOS (Laboratory Goniometer System) (Dangel et al. 2003). However, there are obvious differences between the two measurement cases - even when using the same goniometers/spectroradiometer combination -, which have to be considered:

- In field experiments the target is left in its natural environment and is exposed to direct and diffuse illumination. Diffuse illumination is present in the field also under clear sky conditions, but can usually be neglected in the laboratory.
- The direct solar illumination can be treated as being parallel (within 0.5°) and homogeneous over the area and height profile of the target, while laboratory illumination is usually non-parallel, non-homogeneous and not constant as a function of the target height.
- The illuminated area in the laboratory is limited; adjacency and multiple scattering effects are expected to be different from field experiments (Demarez et al., 2000).
- The spectrum of artificial light sources differs from that of the sun, which is additionally attenuated by the atmosphere. This is usually neglected since reflectance measurements are normalized using a reference target.
- The polarization of the natural and artificial light sources, as well as the scattering medium can be different.
- Living plants behave differently under field and laboratory conditions.

The advantage of laboratory measurements lies in the independence of weather conditions, time of day or seasonal conditions. The illumination intensity and angles can be held constant over time and freely chosen. Despite these differences, it is important to ensure the effective comparability of spectrodirectional field and laboratory measurements by permitting the cross-calibration of these experimental devices.

The directional surface reflectance properties are by definition characterized by the bidirectional reflectance distribution function (BRDF) and depend on the surface properties only (Nicodemus et al., 1977, Martonchik et al., 2000). However, spectrodirectional field experiments with goniometer systems are only able to observe approximations of the bidirectional reflectance factor (BRF). The directly observed quantity in field experiments is called hemispherical conical reflectance factor (HCRF), corresponding to hemispherical illumination, which depends on the atmospheric conditions, and conical observation. Laboratory experiments suffer from imperfect illumination resulting in a rather biconical (BCRF) than bidirectional reflectance factor. Due to these differences, field and laboratory spectrodirectional measurements cannot be directly compared and the intrinsic BRDF of the target must be retrieved separately from each set of measurements.

In this study, we summarize a novel BRDF retrieval scheme (Dangel et al. 2004) for typical laboratory goniometers by considering the conical geometry of the illumination source and the inhomogeneity of the illuminated area in the laboratory as well as the direct/diffuse illumination component in the field, since they reportedly are of prime importance for BRDF retrieval in the field and laboratory cases. The other influencing factors are minimized by using the same goniometer system, spectroradiometer and invariant target.

2. BRDF retrieval for field and laboratory goniometers

The FIGOS instrument at the RSL is used extensively for the validation of spectrodirectional data, the acquisition of a priori information and for estimating biophysical variables (c.f. Beisl 2001, Strub 2003). Measurements are performed with a GER3700 spectroradiometer at steps of 30° azimuth and 15° zenith angle over the whole hemisphere. The BRDF for field measurements is retrieved following the procedures proposed by Martonchik (1994) and Lyapustin (1999). These methods correct the measurements for the diffuse illumination components but not for any other imperfections as mentioned above. Ideally, the diffuse illumination has to be known at the same angular resolution as the reflectance. First studies have been performed using a simplified approach (Schopfer et al. 2004), since irradiance measurements using RSL's sunphotometer (MFR-7, Yankee Environmental Systems, USA) have so far been limited to hemispherical diffuse illumination. FIGOS is currently being upgraded to observe the incoming diffuse radiation at high angular and spectral resolution. This will be achieved by mounting a dual FOV combination of spectroradiometers, each pointing in opposite directions, onto the goniometer.

In the laboratory, the same goniometer system (LAGOS), measurement setup and sensor is used, as described for FIGOS, with the addition of a 1000W quartz tungsten halogen lamp as illumination source. The above mentioned BRDF retrieval procedures for field measurements cannot be used in the laboratory, since the illumination in the laboratory cannot be separated into a direct and diffuse part. The proposed BRDF retrieval scheme for laboratory goniometers consists of two major parts: a forward modeling (1) of the measurement resulting from a given lamp setup and target BRDF and the inversion (2) of the forward case.

(1) Forward modeling: The forward model is based on accurate knowledge of the BRDF of the target, the heterogeneity of the illuminated area on the reference plane and the conical illumination and observation geometries. The actual heterogeneity of the illuminated area can be directly observed using a power meter (LM-2 semiconductor Coherent Inc., California, USA). The heterogeneity measurements have to be repeated for every desired illumination zenith angle. The forward model allows for the simulation of the detector signal for any given lamp setup and target BRDF. It can also estimate the error of the LAGOS facility for a certain target, or simulate the additional error introduced by a heterogeneous target by varying the BRDF as a function of the location in the reference plane.

(2) The inversion method can be described as follows: in a first step, the experimentally observed BRF R_0, which is already close to the true BRF R_{true}, is inserted into a forward simulation with the actual LAGOS parameters. In the second step, the information about how R_0 has been transformed by the forward simulation is used to approximate R_{true}. Since R_0 is usually not measured for many illumination angles, we can either use interpolation and extrapolation or fit a BRDF model to the available values of R_0 and then use the model to supply all missing values.

3. Artificial target

The ultimate goal is to compare spectrodirectional field and laboratory measurements of natural targets. However, such comparisons and a validation of the described retrieval methods can be more easily controlled using artificial targets. As target the so called JRC panel (Govaerts et al. 1997) has been used. It consists of a matrix of cubes, carved out of a thick plate of sanded duralumin. It is well qualified for BRDF investigations, since it shows a high angular anisotropy and is inert. Fig. 1 shows its BRF at 496 nm for an illumination direction of 40° zenith.

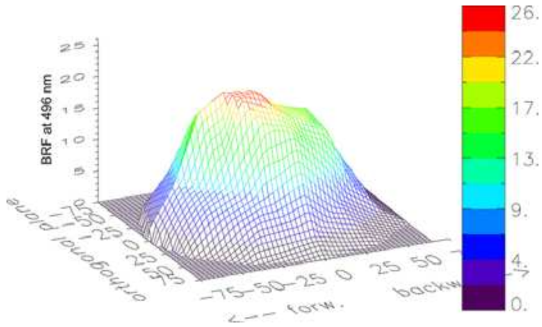

Figure 1. BRF of JRC panel at 496 nm, illumination from top right at 40°.

Since the size of the used JRC panel is rather small (25cm x 25cm) and the GIFOV of the spectroradiometer is increasing for larger observation zenith angles, spectrodirectional measurements of the JRC panel with FIGOS/LAGOS are only reasonable for observation directions up to 45° zenith. Therefore a new and larger artificial target with similar characteristics (highly anisotropic and non rotationally symmetric BRDF) as the JRC panel was recently built at RSL (Fig. 2).

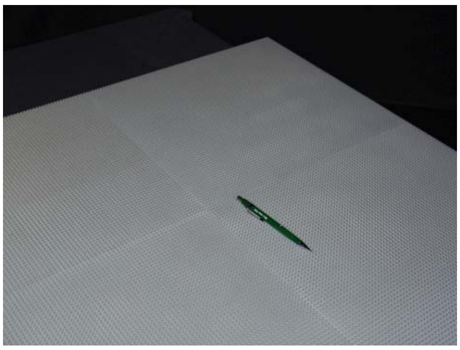

Figure 2. New artificial and highly anisotropic target of RSL.

4. Results

A comparison of raw and corrected FIGOS and LAGOS data from measurements of the JRC panel (illumination zenith 40°, azimuth 29.5° off-parallel) is shown in Fig. 3. Fig 3a) and c) show the uncorrected data. Fig. 3b) visualizes the FIGOS data with a correction applied for the hemispherical diffuse irradiance $L^{inc,diff}$ (measured with the sunphotometer) corresponding to the simplified method as discussed in Schopfer et al. (2004). Fig. 3d) reports the LAGOS data corrected with the presented laboratory BRDF retrieval method. While the correction of the laboratory data results in a change of a few percent only, the correction of the field data is immediately apparent. The remaining differences between the corrected FIGOS and LAGOS data can mostly be attributed to the aforementioned assumption where $L^{inc,diff}$ = constant.

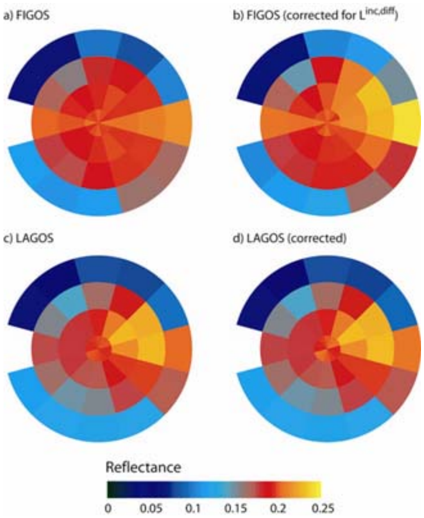

Figure 3. Comparison of FIGOS and LAGOS results at 496 nm.

5. Outlook and discussion

Our results show that the new retrieval scheme for laboratory goniometers can improve the accurate characterization of the BRDF and therefore support comparisons of field and laboratory goniometer measurements effectively. By comparing measurements of FIGOS and LAGOS relative to each other, we have not yet conducted an absolute validation of the retrieval scheme. This requires an absolute BRDF characterization of a highly anisotropic target, such as the newly constructed panel of RSL and is planned for the near future.

Furthermore, the BRDF retrieval for LAGOS will be improved by the added capability to observe the incoming radiation at high angular and spectral resolution. Additional accuracy might be obtained by keeping the GIFOV of the detector independent of the observation angles while conserving a high enough signal to noise ratio. Finally, it will be a challenge to extend field and laboratory comparison measurements to natural targets and to develop field-laboratory transfer functions for more complex targets such as vegetation or other materials.

References

[1] Beisl, U. (2001). Correction of Bidirectional Effects in Imaging Spectrometer Data. RSL Remote Sensing Series 37.

[2] Dangel, S., M. Kneubühler, R. Kohler, M.E. Schaepman, J. Schopfer, G. Strub and K.I. Itten (2003). Combined field and laboratory goniometer system – FIGOS and LAGOS. In: International Geoscience and Remote Sensing Symposium IGARSS, Toulouse, 2003.

[3] Dangel, S. M.M. Verstraete, J. Schopfer, M. Kneubühler, M.E. Schaepman and K.I. Itten (2005). Towards a direct comparison of field and laboratory goniometer measurements. IEEE TGRS, in print.

[4] Demarez, V., J.-P. Gastellu-Etchegorry, P. Mordelet, C. Tosca, G. Marty and P. Guillevic (2000). Modeling of the radiation regime and photosynthesis of a finite canopy using the DART model. Influence of canopy architecture assumptions and border effects. Agronomie, 20, 259-270.

[5] Govaerts, Y., M.M. Verstraete and B. Hosgood (1997). Evaluation of a 3-d radiative transfer model against goniometer measurements on an artificial target. Journal of Remote Sensing, 1, 131-136.

[6] Lyapustin, A. and J. Privette (1999). A new method of retrieving surface bidirectional reflectance from ground measurements: atmospheric sensitivity study. Journal of Gephysical Research, 104(D6), 6257-68.

[7] Nicodemus, F., J. Richmond, J. Hsia, I. Ginsberg and T. Limperis (1977). Geometrical considerations and nomenclature for reflectance. National Bureau of Standards, Monograph 160.

[8] Martonchik, J. (1994). Retrieval of surface directional reflectance properties using ground level multiangle measurements. Remote Sensing of Environment, 50, 303-316.

[9] Martonchik, J., C. Bruegge and A. Strahler (2000). A review of reflectance nomenclature used in remote sensing. Remote Sensing Reviews, 19, 9-20.

[10] Sandmeier, S. und W., K.I. Itten, M.E. Schaepman and T. Kellenberger (1995). The Swiss Field-Goniometer System (FIGOS). In: Proceedings of IGARSS.

[11] Schopfer, J., S. Dangel, J.W. Kaiser, M. Kneubühler, J. Nieke, G. Schaepman-Strub, M.E. Schaepman and K.I. Itten (2004). Comparison of field and laboratory spectrodirectional measurements using a standard artificial target. In: Proceedings SPIE, 5570, 626-633.

[12] Strub, G., M.E. Schaepman, Y. Knyazikhin and K.I. Itten (2003). Evaluation of spectrodirectional alfalfa canopy data acquired during DAISEX'99. IEEE TGRS, 41(5), 1034-42.

Address:

Winterthurerstr. 190, 8057 Zurich, (jschopfer@geo.unizh.ch)