ABSTRACT - A diurnal directional reflectance data set of alfalfa acquired using a field goniometer during the DAISEX'99 campaign is compared to simulated bidirectional reflectances using PROSPECT and SAILH model. Differences are computed and discussed in terms of measured data and simulation quality.

1 - INTRODUCTION

The comparison of multiangular data sets with field goniometer measurements is a method to validate bidirectional effects present in data acquired by air- and spaceborne sensors. For this reason, goniometer measurements were performed during DAISEX'99 (ESA Contract No. 13390/NL/GD), an airborne imaging spectrometer campaign to substantiate the retrieval of geobiophysical variables [Berg 00].

The diurnal directional measurements performed with the RSL Field Goniometer System (FIGOS) exhibit the effect of changing view and sun angles on the reflectance of a dense alfalfa canopy. The high spectral resolution of the measurement equipment allows to consider wavelength dependent anisotropy effects. Recent work has shown good agreement of the angular behavior of goniometer measurements for three selected targets with the angular behavior modeled from imaging spectrometer data of the same area [Beis 00].

The objective of this work is to compare measured and simulated bidirectional reflectance factors (BRFs) of a dense alfalfa canopy. This procedure is part of linking measured directional reflectance data to canopy BRDF models for the derivation of biophysical parameters.

The description of the measurement setup at the Barrax test site (Spain) and preprocessing of the field goniometer data is followed by a discussion of performed model simulations. Reflectances are simulated using PROSPECT/SAILH, with input parameters either estimated or derived from the extensive field characterization of the alfalfa canopy performed during DAISEX'99. The PROSPECT model [Jacq 90 ] allows to simulate leaf reflectance and transmittance, whereas SAILH [Verh 98] calculates the reflectances of a vegetation canopy with respect to sun and view angles. Differences of measured and simulated bidirectional reflectance factors are determined and discussed with respect to measurement and simulation uncertainties.
2 - METHODS

2.1 - Goniometer measurement setup

FIGOS is a transportable goniometer for measuring BRF under natural illumination conditions [Sand 99]. The goniometer is operated with a GER3700 spectroradiometer with a FOV of approximately 3° and a spectral range from 0.4 to 2.5 µm [Scha 98]. Mounted on the zenith arc of the goniometer, the footprint of the radiometer at ground level has a radius of 5.2 cm at nadir position.

To retrieve reflectances of the target surface and to determine irradiance conditions, a Spectralon reference panel is measured from nadir position once for each zenith arc. In increments of 15° in zenith and 30° in azimuth direction, 66 target and seven panel measurements covering a full hemisphere are recorded in about 23 minutes.

Nine hemispheres of directional reflectances of alfalfa were measured at the Barrax test site, covering sun zenith angles in the range of 17° to 53°.

2.2 - Preprocessing of goniometer data

During the preprocessing, spectral regions with atmospheric transmittance lower than 20% are removed from the BRFs. FIGOS measurements do not represent adequately the hot spot feature, because a sector of approximately 10° in the solar principle plane is shaded by the sensor. Therefore, measurements around the hot spot direction are excluded.

In a qualitative analysis, reflectance measurements with instrumental artefacts are determined and excluded from further analysis. The deviation of the Spectralon reference panel from an ideal Lambertian reflector is corrected with a calibration coefficient determined in the laboratory [Sand 98].

The nadir reflectances of a single hemisphere show deviations mainly due to the changing sun angle and instrument related uncertainties. To assess the effect of angular variations of the sun, the standard deviation for all six nadir target reflectances of each hemisphere is computed (cf., Fig. 1). The deviations at 560 nm are significantly larger than the reported measurement uncertainty for field reflectance calibration of +/- 2.9% for the GER3700 spectroradiometer [Scha 98]. It can therefore be concluded that a strong directional variation of the reflectance is present in the data.

![Fig. 1](image_url)

**Fig. 1** Standard deviations of the nadir alfalfa reflectances of hemispheres A to I (one to nine).

After the quality control and preprocessing, the following data is selected for comparison with simulated canopy reflectance data (Tab. 1):
The comparison of measured and simulated BRF data requires model input parameters which characterize the measured vegetation canopy and atmospheric conditions as appropriate as possible. Despite of the extensive field work at the Barrax test site, most input required for the PROSPECT/SAILH simulations is not reliable or missing at all. Therefore, some parameters (e.g., leaf area index (LAI), structure parameter, chlorophyll content) are adapted or determined by experience.

A single run is performed by PROSPECT (N = 1.8, Cab = 41.4 \( \mu \)g/cm\(^2\), Cw = 0.022 cm, Cm = 0.004 g/cm\(^2\), brown pigment content = 0.1). The resulting leaf reflectance and transmittance serve as input for SAILH. Using optical depth derived from sun photometer data, the ratio of the diffuse and total irradiance on a horizontal plane is modeled for each hemisphere using MODTRAN4. This ratio is wavelength and time dependent. For example, it varies between 0.26 and 0.36 for 400 nm and decreases to about 0.05 at 800 nm. The minimum fraction of diffuse irradiance occurs around noon.

For the geometry (illumination and view angle) of each goniometer measurement, a run of SAILH is performed (cf., Tab. 2).

<table>
<thead>
<tr>
<th>Hemisphere</th>
<th>sa [°]</th>
<th>sz [°]</th>
<th>no. m.</th>
<th>Hemisphere</th>
<th>sa [°]</th>
<th>sz [°]</th>
<th>no. m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Gonio_A</td>
<td>90</td>
<td>53</td>
<td>59</td>
<td>6 Gonio_F</td>
<td>224.5</td>
<td>22</td>
<td>63</td>
</tr>
<tr>
<td>3 Gonio_C</td>
<td>107</td>
<td>35.8</td>
<td>64</td>
<td>7 Gonio_G</td>
<td>246.5</td>
<td>31.3</td>
<td>66</td>
</tr>
<tr>
<td>4 Gonio_D</td>
<td>140.8</td>
<td>20.5</td>
<td>64</td>
<td>8 Gonio_H</td>
<td>254.8</td>
<td>37.3</td>
<td>66</td>
</tr>
<tr>
<td>5 Gonio_E</td>
<td>181.5</td>
<td>17</td>
<td>66</td>
<td>9 Gonio_I</td>
<td>262.5</td>
<td>44.8</td>
<td>66</td>
</tr>
</tbody>
</table>

Tab. 1 Bidirectional reflectance hemispheres of an alfalfa canopy selected after quality control. (sa = average sun azimuth, sz = average sun zenith, no. m. = remaining number of reflectance measurements after quality control).

### 2.3 - PROSPECT/ SAILH simulations

The comparison of measured and simulated BRF data requires model input parameters which characterize the measured vegetation canopy and atmospheric conditions as appropriate as possible. Despite of the extensive field work at the Barrax test site, most input required for the PROSPECT/SAILH simulations is not reliable or missing at all. Therefore, some parameters (e.g., leaf area index (LAI), structure parameter, chlorophyll content) are adapted or determined by experience.

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For the geometry (illumination and view angle) of each goniometer measurement, a run of SAILH is performed (cf., Tab. 2).

<table>
<thead>
<tr>
<th>SAILH parameter</th>
<th>input value</th>
<th>SAILH parameter</th>
<th>input value</th>
</tr>
</thead>
<tbody>
<tr>
<td>leaf area index</td>
<td>5.5</td>
<td>soil reflectance</td>
<td>measured at test site</td>
</tr>
<tr>
<td>average leaf angle</td>
<td>50</td>
<td>view zenith angle</td>
<td>angular resolution of goniometer</td>
</tr>
<tr>
<td>hot spot parameter</td>
<td>0.057</td>
<td>sun zenith angle</td>
<td>for each hemisphere</td>
</tr>
<tr>
<td>leaf reflectance</td>
<td>from PROSPECT</td>
<td>rel. azimuth sun-sensor</td>
<td>angular resolution of goniometer</td>
</tr>
<tr>
<td>leaf transmittance</td>
<td>from PROSPECT</td>
<td>diffuse fraction</td>
<td>from MODTRAN4</td>
</tr>
</tbody>
</table>

Tab. 2 SAILH input parameters used for simulation runs.

### 2.4 - Normalization

For deriving a relative deviation from a perfect lambertian object, the measured BRF is divided by a target standard spectrum (e.g., nadir or hemispherical reflectance). The anisotropy factor generated by ratioing directional reflectance values by the nadir reflectance is called ANIF [Sand 99]. In analogy to this definition, ANIF\(_h\) is used here for the directional reflectance normalized by the hemispherical reflectance. This normalization is a method to separate the spectral variability of directional remote sensing data from the spectral signature of the target [Stru 00].

The hemispherical reflectance is the ratio of the reflected flux integrated over the hemisphere to the incident radiant flux and is also referred to as ‘spectral albedo’. This quantity is calculated by integrating the measured BRFs over the hemisphere [Sand 99].
For this study, the spectral albedo is derived from each measured and simulated hemisphere (cf., Fig. 2). It is expected to be lower than the real albedo, because the reflectance values in the hot spot region are interpolated from surrounding values in the goniometer and simulation data. ANIF$_h$ is derived from the whole set of measured and simulated alfalfa BRF data.

**Fig. 2** Spectral albedos of measured (left) and simulated (right) hemispheres.

### 3 - RESULTS

#### 3.1 - Preprocessing procedure

The effect of changing sun position during the measurements has been validated by the consistency test of nadir reflectances of a single hemisphere (cf., Fig. 1). Differences are higher than the expected instrument uncertainties. Thus, the exact sun position for each single measurement has to be derived and accounted for in future analysis.

Spectral albedos derived from measured data exhibit a larger variation than hemispherical reflectances of the simulated data set. The relative position of the view angle net in relation to the hot spot position is supposed to lead to variations between different spectral albedos of the simulated data.

#### 3.2 - Wavelength dependent effects of anisotropy

Wavelength dependent effects of the alfalfa canopy anisotropy can be analyzed by comparing the ANIF for different sun zenith angles (cf., Fig. 3). Where anisotropy factors for the simulated data mainly show an offset for nadir measurements at different sun zenith angles, measured anisotropy factors indicate a more complex wavelength dependent behavior.

**Fig. 3** Anisotropy factors derived from measured (left) and simulated (right) BRF data for different sun zenith angles (view zenith = 0°, view azimuth = 0°).
3.3 - Comparison of resulting anisotropy factor hemispheres

Anisotropy factors derived from measured and simulated reflectance data show similar surface shapes. Highest reflectances occur in the direction towards the sun, i.e., in the backscattering direction, and therefore follow the sun zenith angle (cf., Fig. 4).

![Diagram of anisotropy factors](image)

Fig. 4  Comparison of measured (left) and simulated (right) anisotropy factors (ANIF<sub>h</sub>) of an alfalfa canopy for three sun zenith angles at 560 nm.

A major difference is embedded in the symmetrical behavior of modeled data with respect to the solar principle plane. In measured directional data, the symmetry is less strict. This discrepancy probably originates in the missing rotational symmetry of the measured alfalfa target. Measured data show lower anisotropy factors in the forward scattering direction than SAILH simulated data.

4 - DISCUSSION AND CONCLUSIONS

Deriving biophysical parameters from imaging spectrometer data by inversion of canopy reflectance models are limited to the angular range of airborne sensors. The capability of acquiring bidirectional data is limited by the FOV of present airborne sensors (e.g., DAIS 7915 +/- 26°, HyMap +/- 30°). Field goniometer instruments have the potential to cover the missing angular information. The study shows that measured and simulated BRF hemispheres of the selected alfalfa canopy have similar
shapes. The differences have to be further analyzed to determine the uncertainties for the inversion of vegetation canopy models with goniometer data for deriving biophysical parameters.

Main uncertainties of the measurements include instrumental variations, changing atmospheric conditions and spatial inhomogeneity of the target with respect to the sensor’s footprint. Instrument uncertainties have been quantified in detail [Scha 98] and therefore can be included in error estimations.

Most input parameters for the simulations had to be estimated. A better characterization of the vegetation canopy is essential especially for model driving parameters like LAI. In this study, the inclination of leaves was only parametrized by the mean leaf angle. For more sophisticated studies, the leaf angle distribution function is to be calculated. Future goniometer field work has to be accompanied by an exact characterization of the vegetation canopy for a greater reliability of the simulated bidirectional reflectance data.

Further improvements can be achieved by measuring the diffuse fraction of irradiance. The change in solar angles during the acquisition of a hemisphere has to be accounted for in future analysis. With the exact time of each reflectance measurement, its corresponding sun angle can be determined.

A major drawback of the data set is the lack of hot spot reflectance measurements. The resolution of the viewing angle has to be adapted, especially in the solar principle plane.

Further work has to be done in the determination of target homogeneity and the selection of appropriate target structure size for goniometer measurements.

5 - ACKNOWLEDGMENTS

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6 - REFERENCES


