EVALUATION OF DIURNAL HYPERSPECTRAL BRF DATA ACQUIRED WITH THE RSL FIELD GONIOMETER DURING THE DAISEX'99 CAMPAIGN

G. Strub (1,2), U. Beisl (3), M. Schaepman (1), D. Schläpfer (1), C. Dickerhof (1), K. Itten (1)

(1) Remote Sensing Laboratories, RSL, University of Zurich, Winterthurerstr. 190, CH-8057 Zurich, phone +41 1 635 52 51, fax +41 1 635 68 46, mail gstrub@geo.unizh.ch

(2) Laboratory of Atmospheric Chemistry, LAC, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

(3) German Aerospace Center, German Remote Sensing Data Center, D-82230 Wessling, Germany

KEYWORDS: BRDF, Hyperspectral, Vegetation, Soil

ABSTRACT

A directional data set of bare soil and alfalfa acquired using the Swiss Field Goniometer during the DAIS Experiment 1999 (DAISEX'99) campaign is preprocessed and analyzed for its quality. Two different normalization methods to derive anisotropy factors are tested and discussed. The possible effect of varying reflectances on the retrieval of vegetation parameters due to changing sun and viewing geometries is shown by the derivation of the weighted difference vegetation index (WDVI) for the available alfalfa multiangular data.

1 INTRODUCTION

The comparison of multiangular data sets with field goniometer measurements is a method to validate the bidirectional effects present in data acquired by ground-, air- and spaceborne sensors. For this reason, goniometer measurements are performed during DAISEX'99 (ESA Contract No. 13390/NL/GD), an airborne imaging spectrometer campaign in the framework of ESA's Earth Observation Preparatory Programme .

The main scientific objective of the campaign is to demonstrate the retrieval of geobiophysical variables, such as surface temperature, LAI, canopy biomass, leaf water content and canopy height from imaging spectrometer data [4]. The agricultural test site Barrax (Spain) included a variety of crops such as wheat, barley, maize and alfalfa. Remote sensing data were acquired using the imaging spectrometers DAIS 7915 and HyMap, as well as the multispectral instrument POLDER in combination with Leandre atmospheric measurements. Simultaneous intensive ground truth measurements were carried out, including the measurement of biophysical and –chemical quantities, soil characteristics, emissivity and spectro-directional reflectance signatures. the latter was measured by the RSL field goniometer [2].

The concept of the goniometer allows to measure the reflectance of targets under changing view angles. For the study of the effect of different sun angles, BRF (bidirectional reflectance factor) data of bare soil, a dense alfalfa canopy and non-irrigated ripe barley are acquired over the day. The selected fields are located in the crossing area of different flight lines, thus the reference fields acquired by the DAIS, HyMap and POLDER sensors are represented under different illumination and viewing geometries.

After the description of the measurement setup and some results of the quality assessment, two different methods for the normalization of spectroscopic directional data are tested and discussed. The resulting anisotropy indices are a means to determine the spectro-directional variability of the data.

2 METHODS

2.1 Measurement setup

FIGOS is a transportable goniometer which is designed to measure BRF under natural illumination conditions [10]. The goniometer is operated with a GER3700 spectroradiometer with a FOV of 3° and a spectral range from 0.4 to 2.5 µm [11]. 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.

At the beginning of the measurements, the azimuth arc is directed to magnetic north, and the zenith arc is adjusted to the solar principal plane. The azimuth angle refers to the solar principle plane and is defined as zero on the position opposite to the sun whereas the zenith angle is defined as zero at nadir position. Negative zenith angles indicate a direction opposite to the sun (forward scattering), positive zenith angles indicate a direction towards the sun (backward scattering).

To retrieve reflectances of the target surface and to determine irradiance conditions, a Spectralon reference panel [6] is measured from the nadir position once for each zenith arc. In increments of 15° in the zenith and 30° in the azimuth direction, 66 target and seven panel measurements covering a full hemisphere are taken in about 23 minutes.

The goniometer is placed directly onto the soil, whereas on the alfalfa and barley field, boxes are put underneath the azimuth arc. By this means plant height and azimuth arc are situated on the same level (cf., Figure 1).

Figure 1: FIGOS on the alfalfa field at the Barrax test site.

The following data resulted from the goniometer deployment at the Barrax test site (cf.,Table 1):

Table 1. Overview of BRF data acquired at the Barrax test site from June, 2nd to June, 5th 1999

Target	Number of measured hemispheres at different solar zenith angles	Range of solar zenith angle
Bare soil	13	17.5° - 79.0°
Alfalfa	8	17.0° - 55.0°
Barley	5	17.3° - 52.8°

According to Nicodemus et al. [7] the quantity measured by the goniometer can be described as 'hemispherical conical reflectances'. Due to the clear sky and the small sensor FOV of 3°, the measurements come close to

biconical reflectances measurements. The latter can directly be related to the bidirectional reflectance distribution function.

2.2 Data quality assessment

2.2.1 Preprocessing. In the preprocessing of the directional reflectance data, the deviation of the Spectralon reference panel from an ideal Lambertian reflector is corrected according to a calibration coefficient determined in the laboratory [8].

Spectral regions with atmospheric transmittance values lower than 20% are determined in a MODTRAN 4 [1] run for standard atmospheric conditions and excluded from further analysis. FIGOS measurements do not include an adequate representation of the hot spot feature, because a segment of approximately 10° is shaded by the sensor. The shaded target measurements have to be excluded from the analysis. The hot spot is not interpolated for the following analysis.

2.2.2 Atmospheric stability. A ground based, sun-looking Reagan 10 channel sun photometer is set up next to the goniometer, measuring direct solar irradiance for the determination of atmospheric conditions during the measurement of each hemisphere [12]. Ten channels between 382 and 1033 nm are measured at a sampling interval of 30 seconds.

Panel radiance measurements of any time are approximated as a function of the transmittance derived from sun photometer direct irradiance data. The atmospheric conditions during the measurements at Barrax with clear sky and low diffuse scattering allow to neglect the diffuse component. Thus the relation between transmittance and radiance can be expressed as follows:

$$L(\lambda,t) = L(\lambda,t_0) \cdot \frac{\rho(\lambda, t)}{\rho(\lambda, t_0)} \cdot \frac{\cos\theta(t)}{\cos\theta(t_0)} \cdot \frac{\tau(\lambda,t)}{\tau(\lambda,t_0)}, \tag{1}$$

where L denotes the radiance reflected by the Spectralon panel, ρ the reflectance of the panel, θ the incident angle, τ the transmittance derived from direct solar irradiance measurements of the sun photometer, λ is the wavelength, t the time and t_0 starting time. For the flat test site at Barrax, the incident angle refers to the solar zenith angle.

Change in irradiance conditions during the time between two reference panel measurements are present in the directional data. If sun photometer transmittance data indicate unstable atmospheric conditions, the relation between transmittance and Spectralon panel reflected radiance (Eq. 1) can be used for the correction of the changed irradiance conditions.

In order to test the accuracy of this method, the first GER3700 panel radiances of each hemisphere acquired from nadir position are spectrally resampled to the 10 channels of the sun photometer. These radiances are already corrected for the non-lambertian behavior of the Spectralon panel, i.e. for the reflectance changes of the panel due to changing illumination angles (see section 2.2.1 on page 3). According to Equation (1), the first panel radiance is multiplied with the ratio of the transmittance at a specific time divided by the transmittance of the starting time and cosine-corrected for the specific sun angles. The resulting extrapolated panel radiance is compared to the actually measured panel radiance. The comparison of the measured radiance values and the extrapolated radiances in two wavelength regions (0.50 μm, 0.81 μm) over the day shows deviations lower than +/-2% of the radiance. In the late evening, at sun zenith angles higher than 70°, measured panel radiances are higher than the radiances extrapolated with the sun photometer transmittance data. Thus, the above approximation is useful for radiometric normalization of BRF data.

2.2.3 Consistency of nadir reflectances. During the 66 target measurements, the sun angles are changing due to the non zero time frame required for the hemispherical measurements. The range of the deviations further depends on the actual time of the day, the date of year and the geographical location. For the available goniometer data from Barrax, maximum values for the change of the azimuth angle are reached around noon (up to 20°) in combination with relatively low change (1°) of the zenith angle, whereas in the morning and evening the deviations of the azimuth decrease to a minimum of 4° and the zenith angle changes can reach up to 6°.

To assess the effect of the angular variations of the sun, the standard deviation for all nadir target reflectances of each hemisphere is computed, which should be zero in case of invariant sun geometry. The deviation of the nadir target reflectances is computed for all hemispheres over the whole spectral range (cf., Figure 2). For soil nadir measurements and alfalfa, the mean standard deviations are related to the solar zenith angle change (cf., Figure 3). The higher the zenith angle change, the higher the standard deviation of the nadir measurements. The computed mean relative standard deviations for alfalfa are obviously higher than for bare soil.
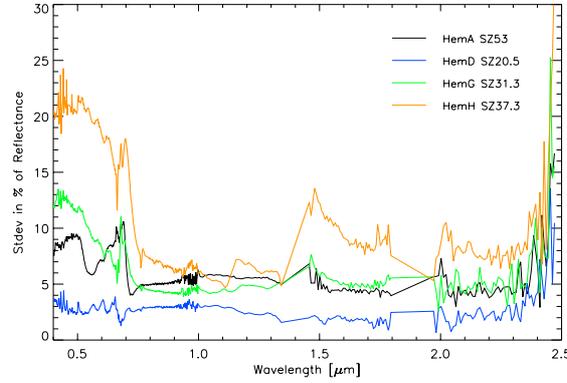

Figure 2: Relative standard deviations in percent of reflectances of different alfalfa hemispheres for four solar zenith angles.
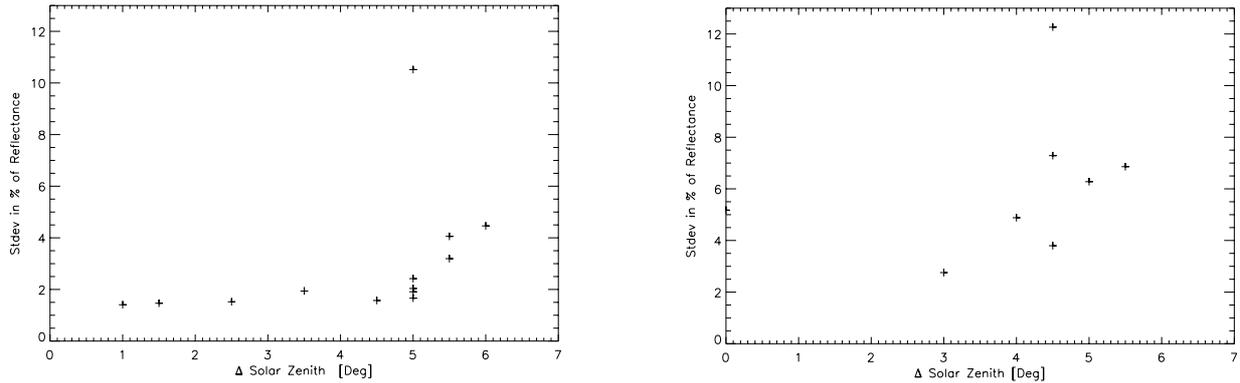

Figure 3: Mean relative standard deviations of nadir measurements during one hemisphere related to the deviation of the solar zenith for the targets bare soil (left) and alfalfa (right).

2.3 Normalization methods

In order to derive a relative deviation from a perfect lambertian object, the measured BRF is compared to a target standard spectrum. This normalization is a means to separate the spectral variability of directional remote sensing data from the spectral signature of the target. Two main methods for field goniometer data are proposed: the normalization by nadir reflectance and by 'mean hemispherical reflectance' [5] [10].
For the comparison of the two approaches only the solar principle plane is considered, where the anisotropy is most pronounced.

2.3.1 Normalization by nadir target reflectance. The anisotropy factor (ANIF) describes the portion of reflectance into a specific view direction in relation to the nadir reflectance. It can be used to analyze the spectral variability of BRF data and is defined as follows [10]:

$$ANIF(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) = \frac{\rho(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda)}{\rho_0(\theta_i, \varphi_i, \lambda)} \,, \qquad (2)$$

where ρ denotes the reflectance and ρ_0 the nadir reflectance, θ_i and φ_i are the zenith and azimuth angles of the incident direction, θ_r ad φ_r refer to the zenith and azimuth angles of the reflection direction.

All reflectance data of bare soil and alfalfa are divided by the nadir target reflectance with the same view azimuth angle.

2.3.2 Normalization by hemispherical reflectance. The hemispherical reflectance ρ_A is the ratio of total hemispherical reflected to incident radiant flux and is also referred to as 'spectral albedo'. It can be derived by the integration of the measured BRF's over the hemisphere [10]:

$$\rho_A(\theta_i, \varphi_i, \lambda) = \frac{1}{\pi} \int_{\varphi_r = 0}^{\varphi_r = 2\pi} \int_{\theta_r = 0}^{\theta_r = \pi/2} \rho(\theta_i, \varphi_i, \theta_r, \varphi_r, \lambda) \cdot \cos(\theta_r) \sin(\theta_r) d\theta_r d\varphi_r, \tag{3}$$

The actual spectral albedo is derived from each hemisphere measured with the goniometer. The computed hemispherical reflectance is expected to be lower than the real albedo, because the reflectance values of the hot spot region are not included in the goniometer data.

The quotient of the directional reflectance values and the spectral albedo refers to the deviation of the reflection behavior in a specific view direction from a mean hemispherical reflectance for the actual irradiance conditions.

For all hemispheres of bare soil and alfalfa, the spectral albedo and their statistics were computed. The albedo is nearly constant for solar zenith angles lower than 60°. For hemispheres with higher solar zenith angles, higher hemispherical reflectance values are obtained (cf., Figure 4).
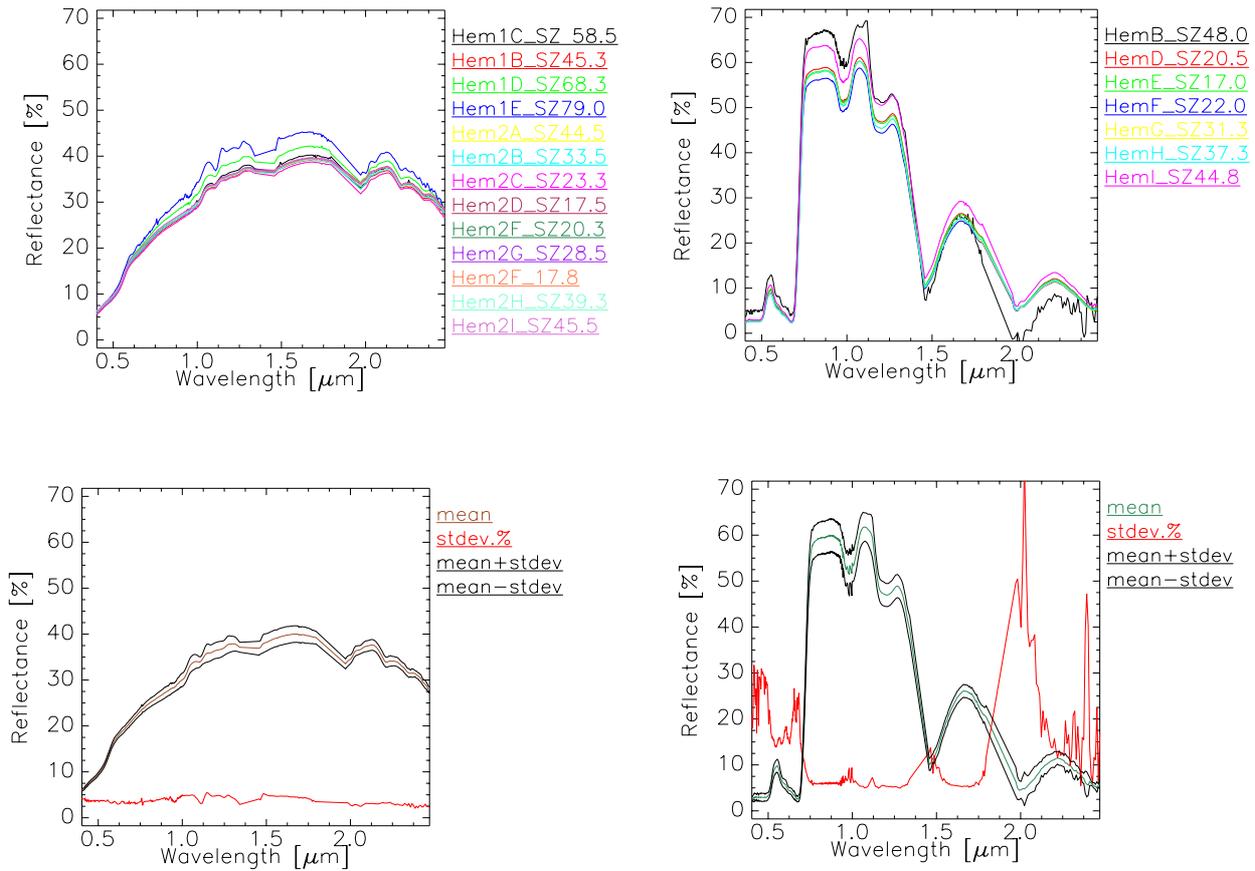

Figure 4: For all hemispheres of bare soil (left) and alfalfa (right) the spectral albedo (top) is computed. Statistical analysis show the standard deviation in percent of the reflectance over the measured wavelength range (bottom).

3 RESULTS

3.1 Comparison of Normalization Methods

Both methods, normalization by nadir reflectance and by hemispherical reflectance can be used to analyse the spectral variability of BRDF effects.

More obvious are the differences in range of the two anisotropy factors for different sun zenith angles. As an example, the reflectance of soil at 0.8 µm is normalized with nadir reflectance and spectral albedo. It can be demonstrated, that for reflectances acquired at low sun zenith angles, thus with a hot spot lying close to the nadir (e.g. 17.5°), the derived ANIF for view zenith angles in the region of the hot spot is lower than the reflectances normalized by the spectral albedo (cf., Figure 5).
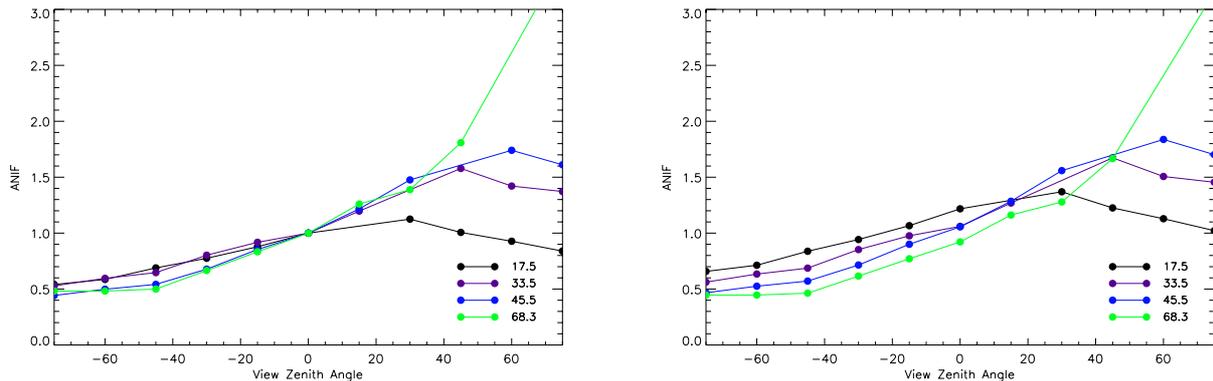

Figure 5: Comparison of normalized reflectance factors (0.8µm) of bare soil in the solar principle plane. Normalization by nadir reflectances (left) and spectral albedo (right).

The concept of normalizing directional reflectance data by nadir reflectance is applicable if a low angular resolution of directional data is available which does not allow the derivation of the spectral albedo. Further it is the most convenient projection center. Nevertheless, the normalization with hemispherical reflectance has the advantage that it does not depend on the actual sun zenith angle and therefore allows to compare different hemispheres (cf., Figure 4). Uncertainties are expected for the normalization by hemispherical reflectance due to the lack of reflectance values in the region of the hot spot. For the following analysis only anisotropy factors derived with hemispherical reflectances will be considered.

3.2 Results from Normalization by Hemispherical Reflectance

The reflectance factors normalized by hemispherical reflectance are a means to demonstrate wavelength dependant effects caused by the variation of sun and viewing geometry. Deviations that are not caused by the changing geometry, such as variations of the biochemicals over the day, should be eliminated, because they are represented in the spectral albedo derived for each hemisphere and thus divided out.

The measured soil and dense alfalfa canopy show a clearly distinct spectral behavior for various sun zenith angles (cf., Figure 6). Soil anisotropy factors mainly show an offset for different solar zenith angles, with the exception of the highest zenith angle of 79°, whereas alfalfa shows a distinct spectral behavior for different solar zenith angles.

This reveals the different mechanisms which cause the BRDF [13]. The bare soil anisotropy is dominated by geometric-optical surface scattering, which is driven by shadow-casting and mutual obscuration of three-dimensional surface elements, i.e. furrows in the harrowed field. This is independent of the wavelength and gives a constant offset in the ANIF. Dense Vegetation, instead, is dominated by spectrally dependent volume scattering by finite scatterers (leaves of plant canopies) that are uniformly distributed, potentially nonuniformly inclined and themselves have anisotropic reflectance. Variation in canopy structure leads to a varying spectral behaviour of the ANIF. For a discussion of the spectral behaviour of grass and watercress see [9].
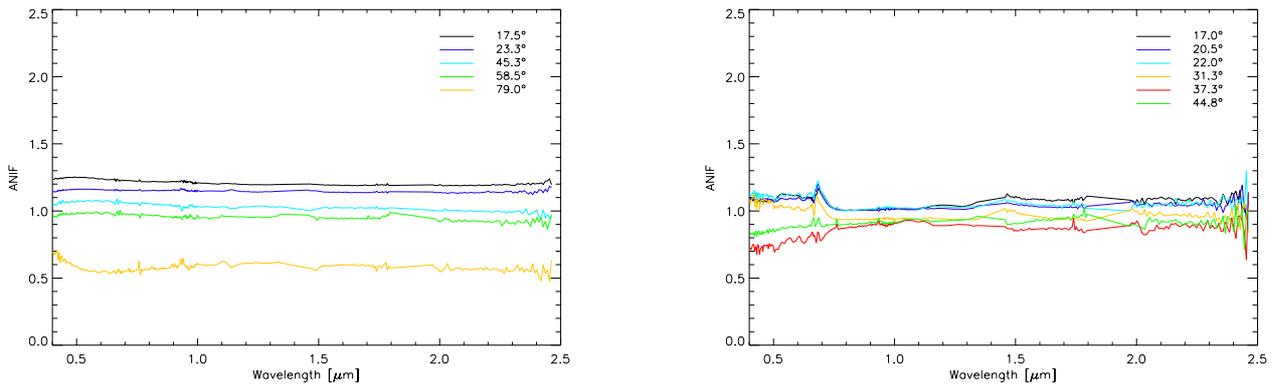
.

Figure 6: Comparison of the reflectances of soil (left) and alfalfa (right) normalized by the spectral albedo for different sun zenith angles. (View zenith angle = 0°, view azimuth angle = 0°).

Anisotropy factors of alfalfa observed for different view angles show a similar shape for different wavelength but clearly other ranges (cf., Figure 7).
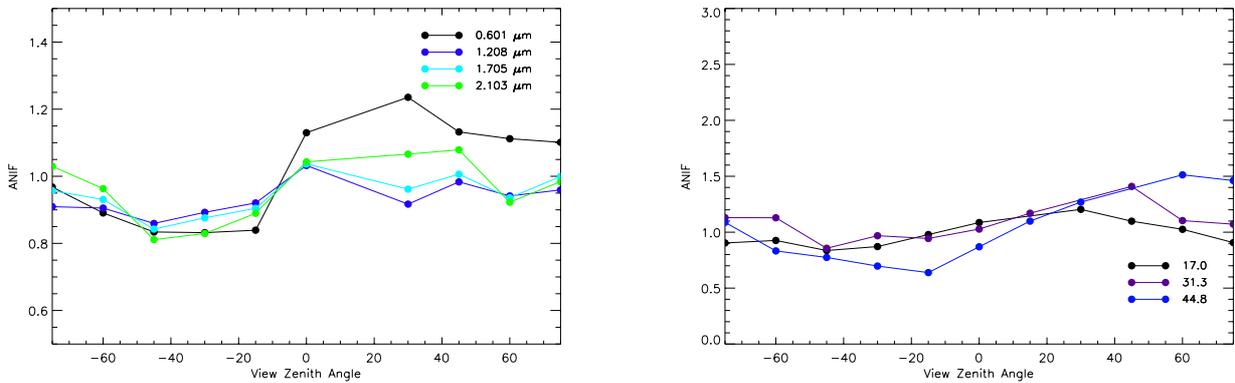

Figure 7: Comparison of normalized reflectances of alfalfa in different wavelength ranges for a sun zenith angle of 22° and a view azimuth angle of 0° (left) and at the wavelength of 0.55 μm for different sun zenith angles (right).

3.3 Directional Effects present in the Weighted Difference Vegetation Index

To test the potential influence of directional data for vegetation parameter retrieval methods, the behavior of the reflectance in two spectral bands (0.67 μm and 0.78 μm) which can be used for the derivation of the weighted difference vegetation index (WDVI) [3] is observed over the day. All reflectance measurements acquired of alfalfa from nadir position for different sun zenith angles are compared as well as the anisotropy factors normalized by spectral albedo (cf., Figure 8). Reflectance values at 0.78 μm vary between 58% and 50%. The WDVI is determined as follows:

$$\mathrm{WDVI} = \rho(0.78\mu m) - 1.5\rho(0.67\mu m). \tag{4}$$

where ρ is the reflectance. The resulting relation between the derived WDVI and the directional reflectance reveals the following conclusions:

The derived WDVI follows the directional behavior of the reflectance at 0.78 μm, with a maximum value of 54 and a minimum of 47. Because of the low reflected signal, the absolute differences of the reflectance at 0.67 μm caused by different view angles are low as well. For the presented case, the directional effects at 0.67 μm can be ignored. Thus, directional effects are represented in reflectance as well as in WDVI data at

about the same dimension and cannot be overlooked, if the reflectance measurements are performed at different sun zenith angles during the day. Special attention has to be paid to the deviation introduced by directional effects if vegetation parameters are derived from the WDVI. Depending on the actual range of the WDVI, due to the proposed exponential relation of the WDVI to the leaf area index (LAI) [3], the variation of the LAI can even be higher than in the original reflectance data.
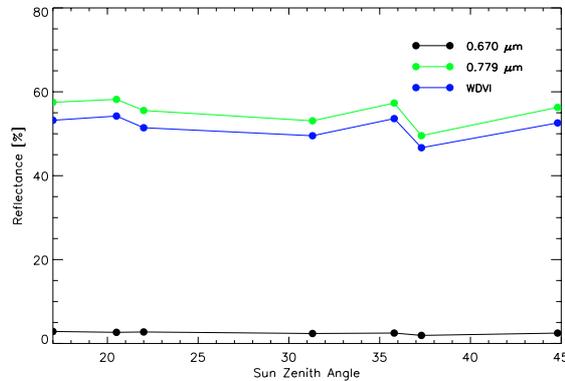

Figure 8: Comparison of reflectances of a dense alfalfa canopy used for the derivation of the WDVI over a day.

4   CONCLUSIONS

The diurnal directional reflectance data acquired with the Swiss Field Goniometer at the test site of Barrax enables to study the influences of sun and viewing geometry on the anisotropy of a bare soil and a dense alfalfa canopy.

Comparing transmittance data derived by the sun photometer with nadir panel reflectances, the latter represent the actual atmospheric conditions very well. Sun photometer data are essential to determine the quality of the acquired directional data. The proposed relation between panel radiance and transmittance (Eq. 1) allows a satisfying approximation of lacking panel radiance measurements for clear sky conditions and low sun zenith angles. However, the effect of the diffuse component on the radiance measurements for zenith angles higher than 70° needs further investigation.

The - especially at high sun zenith angles - high standard deviation of nadir reflectances during a single hemisphere shows that the effect of changing sun geometry has to be addressed and taken into account for further work, if such BRF measurements are exploited.

Normalization methods allow to generate anisotropy factors which point out the spectral variation of BRDF effects. Two different methods, namely the normalization by nadir reflectances and by hemispherical reflectance (i.e., spectral albedo), are tested. For a high resolution of directional measurements, the normalization by hemispherical reflectance is highly preferred because it is independent of the position of the hot spot for a specific sun zenith angle. The normalization with spectral albedo allows to compare different hemispheres over the day, due to the elimination of effects which are not caused by the changes of the sun geometry.

Future work has to address the quantification of the above described effects and the improvement of the measurement setup covering the hot spot region more precisely. Diurnal hemispherical reflectance data for varying canopy types and phenological stages have to prove the presented results. This will allow to compare and transfer the knowledge of the anisotropy of vegetation canopies to imaging spectrometer data.

Variability of vegetation canopy reflectances can have a strong effect on the range of derived quantities, such as the LAI. Therefore directional effects have to be addressed and their influence on secondary variables has to be determined in order to improve vegetation parameter retrieval methods.

5 ACKNOWLEDGEMENTS

REFERENCES

[1]   Berk, A., L.S. Bernsten, D.C. Robertson,1989: MODTRAN: A Moderate Resolution Model for LOWTRAN7. AFGL Technical Report, GL-TR-89-0122, Hanscom AFB, MA, 38 pp.

[2]   Berger, M., J. Moreno, A. Müller, M. Schaepman, P. Wursteisen, M. Rast, E. Attema, 2000: The Digital Imaging Spectrometer Experiment - DAISEX'99. In: Proc. IGARSS, Hawaii, in Press.

[3]   Clevers, J., 1989: The Application of a Weighted Infrared-Red Vegetation Index for Estimating Leaf Area Index by Correcting for Soil Moisture. In: Remote Sensing of Environment, Vol. 29, pp 25-37.

[4]   ESA, 1999: DAISEX-99 Experimenters Handbook. Draft 3, 27 May 1999, ESA Scientific Campaign Unit, ESTEC.

[5]   Jackson, R. D., P. M. Teillet, P. N. Slater, G. Fedosejevs, M. F. Jasinski, J. K. Aase and M. S. Moran, 1990: Bidirectional Measurements of Surface Reflectance for View Angle Corrections of Oblique Imagery. In: Remote Sensing of Environment, Vol. 32, pp 189-202.

[6]   Labsphere, 1997: Diffuse Reflectance Coating and Materials. Catalogue 1, North Sutton, N.H.

[7]   Nicodemus, F.E., J.C. Richmond, J.J. Hsia, I. W. Ginsberg and T. Limperis, 1977: Geometrical Considerations and Nomenclature for Reflectance. NBS Monograph, 160, U.S. Department of Commerce/ National Bureau of Standards.

[8]   Sandmeier, S., C. Müller, B. Hosgood and G. Andreoli, 1998: Sensitivity Analysis and Quality Assessment of Laboratory BRDF Data. In: Remote Sensing of Environment, Vol. 64, No. 2, pp 176-191.

[9]   Sandmeier, St., Mueller, Ch., Hosgood, B., Andreoli, G., 1998: Physical Mechanisms in Hyperspectral BRDF Data of Grass and Watercress. In: Remote Sensing of Environment, Vol. 66, pp 222-233.

[10] Sandmeier, S. R., and K. I. Itten, 1999: A Field Goniometer System (FIGOS) for Acquisition of Hyperspectral BRDF Data. In: IEEE Transactions on Geoscience and Remote Sensing, Vol. 37, No. 2, pp 978-986.

[11] Schaepman, M. E., 1998: Calibration of a Field Spectrometer. Remote Sensing Series, Vol. 31, Dept. of Geography, University of Zurich, 146 pp.

[12] Schlaepfer, D., 1998: Differential Absorption Methodology for Imaging Spectroscopy of Atmospheric Water Vapor. Remote Sensing Series Vol. 32, Dept. of Geography, University of Zurich, 131 pp.

[13] Strahler, A.H., Muller, J.-P. et al, 1999: MODIS BRDF/Albedo Product: Algorithm Theoretical Basis Document Version 5.0. MODIS Product ID: MOD43. NASA EOS MODIS.