

# FIELD GONIOMETER SYSTEM FOR ACCOMPANYING DIRECTIONAL MEASUREMENTS

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## ABSTRACT

Field measurements with the “Mobile Unit for Field Spectroradiometric Measurements” (MUFSPM) accompanying the CHRIS/Proba data have been planned for 2002 at the core test site Gilching. The experiment was cancelled as while the instability of parameter extraction in the daily cycle by applying ProSail inversion algorithms did not satisfy our expectations. To eliminate as much error sources as possible a new system was designed and constructed in 2003, working according to the goniometer principle, but allowing the measurements from 10m above the canopy in the 400 – 2200 nm range. Mounted on the top of a 4WD vehicle the change of position is very fast. Delays in construction progress but component delivery prohibited the introduction of the system during the 2003 vegetation period. The system will be finished and free for application during the 2004 measurement season. Existing angular measurement systems are briefly reviewed, the developed new mobile field goniometer construction is presented and moot under discussion.

**Keywords:** field spectroscopy, field goniometer, BRDF, physical modeling, ProSail inversion.

## 1. BACKGROUND AND MOTIVATION

At the time, we handed in our proposals we have been involved in precision farming research activities [1]. The general research concept matches very well the flow chart showed by the ESA AO 1-3381 in 1998 [2] (Fig. 1). Light blue lines mark areas and relations under present investigation. For the specific PF needs we are speaking about the integration of growth-, physical backscatter as well as inverted physical backscatter models.

There is a general consent about the necessity of radiometric calibration of airborne scanner data to normalize for sensor, atmospheric, topographic and cross track effects. Less investigated are diurnal effects due to changing illumination to stand structure

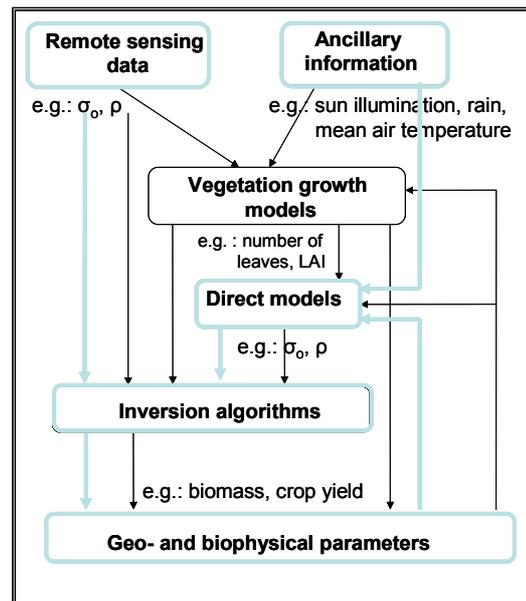


Fig. 1. Data flow for the evaluation of RS data by the help of models as proposed by ESA AO /1-3381 from 1998. Light blue lines mark areas and relations under present investigation

geometries which are superimposing the before mentioned alterations. The presentation reports from a study conducted to quantify reflection changes for predefined view directions over the day and over the vegetation period of maize by the help of multidirectional field spectroscopic measurements. Morning, midday and afternoon measurement series are used to approximate the BRDF at different phenologic stages during the vegetation period 2000 and 2001 [3]. By the help of ProSail canopy parameters are calculated for five particular times of the day. The results show significant differences in parameter retrieval leading to the conclusion that both complexes, the phase angle related correction approaches as well as the adaptation of physical models to the specific crop structure should further be improved.

The modern agriculture allows the application of knowledge based interpretation rules. Grouped in

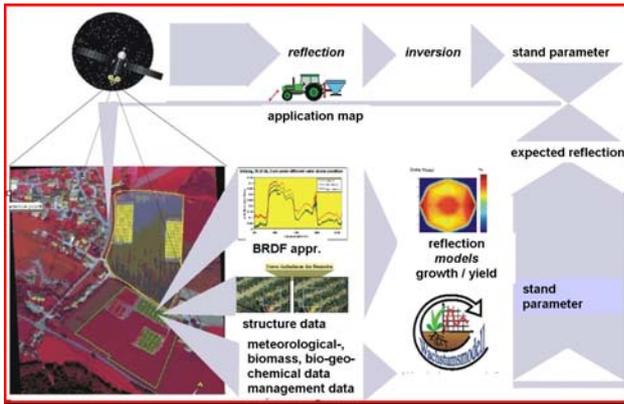


Figure 2: development chain for an operational “precision farming” management system. Spectral measurements and stand parameter on sample plots with different varieties and management schemes are used to optimize and relate reflection- and growth models (“experimental loop”, below). Remote sensing data are inverted, the calculated stand parameters are compared with the predictions of the growth models, application maps are delivered. “Real time” sensors are performing the “fine tuning” during application (“operational loop”, top of flow chart).

growing regions, which are defined by soil condition, microclimate, topographic units, seeding is distributed by regional seed centers (in Bavaria for example the BayWa or Raiffeisen companies). Sort variety for market production is restricted on some few for each crop type and growing region. The specific properties of these sorts are well known. About plots, managed with precision farming methods, a comprehensive database is established with information about the topographic parameters slope and aspect, soil parameter, yield of the last few years, calamity and management history, microclimate parameter, etc. (database of the mapping approach).

For the combined approach this information base needs to be extended by incorporating additional data layers. Two groups of unknown variables can be distinguished:

- (i) the precipitation, temperature and fPAR history of the respective vegetation period, defined by parameters which are easy to sample by permanent meteorological ground stations, and
- (ii) the distribution, magnitude and reason of growth differences on subplots. The second group of variables is not as easy to be parameterized, especially when fast and cost effective methods are demanded. It is a general consent that only remote sensing is appropriate to provide such information.

The problem to be solved at this point is that at least optical remote sensing data takes are dependent on cloud conditions. In Central Europe this is a sever restriction especially during the vegetative stage of crop development, from April to June, the most important period for fertilization. It can not been foreseen at which growth stage remotely sensed data are available. This

situation leads to the need to introduce vegetation growth models into the evaluation chain. The precondition is that the basic variables and parameters for running the growth models are available in the plot related databases. Implemented in crop and variety adopted growth models, the expectations on the phenologic stage and physiologic status needed for the detailed management plan can be calculated taking into account growth differences on subplots. The requirements on a specific data take period are now less strict. Each remote sensing data set registered during the ongoing vegetation period can be used to calibrate the growth models.

### *So far the theory!*

For developing the operational chain first the adapted growth models have to be related to “physical models of canopy reflectance” of the respective crop. For the envisaged precision farming application especially the inversion of the physical models is of relevance. On behalf of the inversion results, bio-geo-physical parameters of the crop under investigation can be derived from remote sensing data for each observation to illumination situation at any time of the growing period. In the final step, the retrieved parameters are used to calibrate the growth models according to the present growth situation. This is the key step for the elaboration of the application maps needed for fertilizer distribution or irrigation control.

Implemented on the bulldog mounted field computer this “a priori” information can directly be used for fertilization or irrigation (improving the “mapping approach”). Further developed to the “real-time approach with map overlay” the application maps should be fine tuned by the signal received by the real-time sensors, taking into account the recent progresses in canopy development and the site specific conditions. The abusive application of fertilizer on subplots with a limited field capacity and a reduced growth potential is expected to be avoided, preventing the environment and especially the ground water from pollution by fertilizers or pesticides. In case of irrigation application the control loop should identify areas with drought stress and restrict the irrigation on these areas. The combined approach is expected to gain essential improvements in front of the traditional precision farming practices.

The general evaluation chain of the combined approach is very close to the scheme proposed by ESA [2]. At the present nearby each of the described steps needs to be improved before an operational evaluation becomes possible. The approach is especially dependent on the accurate evaluation of remotely sensed data. To be successful, the evaluation chain must be able to detect small growth differences, compare them with the site specific stand conditions, and relate them with the phenologic and/or physiologic status of the crop or, in general with each other vegetated surface.

A basic need in the frame of this concept is the adaptation of backscatter models to the specific crops under investigation. For this purpose a spectral database should be established and based on high resolution field spectroradiometric data. In order to be prepared for all possible sun and observer positions, a calibration database should ideally be based on bidirectional reflection distribution functions (BRDFs) [4][5] covering all phenologic and physiologic stages of a crop.

There are two basic principles for angular measurements for BRDF approximation:

- (i) the “goniometer” principle, where always the same section of a surface is observed by moving the measuring unit (European GOniometer facility (EGO) in Ispra at the Joint Research Center (JRC) [6] and the FIeld GOniometer System (FIGOS) of the Remote Sensing Laboratories (RSL) of the University of Zurich, Swiss [7]) and
- (ii) a principle which is based on the assumption that the observed surface is homogeneous and it is sufficient to change the look angle observing different sections of the surface while the instrument is at the same place (PARABOLA (Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere [8]), operated from NASA, GSFC, WAAC instrument (Wide Angle Airborne Camera), DLR Berlin [9]).

Evaluating these systems we came to the following conclusions:

- FIGOS is the perfect system for physical measurements but with restricted mobility and with an insufficient distance between instrument and surface so there are doubts whether the surface section is representative in case of high growing crops
- Parabola system is working very fast, the measurement height is sufficient but the instrument is restricted on some few spectral bands (650-670nm, 810-840nm, 1620-1690nm) [8]
- WAAC very fast, narrow spectral bands, measurement height sufficient but restricted on VIS/NIR [9]

To accomplish our objectives we decided to develop a platform according to our requirements: the Mobile Unit for Field Spectroradiometric Measurements (MUFSPeM) [10] was constructed and a special measurement strategy was developed.

The results presented in this paper focus on a detail of the evaluation chain: diurnal effects due to changing illumination to stand structure geometries which are superimposing the before

mentioned alterations. A data set of maize at the phenologic stadium EC 67 is used to demonstrate the MUFSPeM data collection capability, to discuss the limitations of BRDF approximation from morning, midday and afternoon measurements and finally the retrieval of canopy parameter by the help of the ProSail physical model [11].

The evaluation of the results finally led to the decision to skip the CHRIS/Proba measurement campaign with MUFSPeM and to start the development of a new system.

For understanding the limitations of the solution a detailed description of MUFSPeM and the measurement strategy is given in the next chapter.

## 2. MATERIAL AND METHODS

### 6.1 Testsite

The core testsite covers the area of the research farm „Dürnast“ of the Agricultural Faculty of the TU of Munich in Freising /Weihenstephan at an average altitude of about 450 m above sea level. It lies between 11°37'30.4''E and 11°43'55.4''E longitude and 48°22'39.4''N and 48°25'58.9''N latitude. The main part of the test and surrounding area belongs to tertiary aged hills, formed from clastic sediments of the upper molassic series. Common soils in this area are sandy loams and loam with soilpoints from 34 to 67 on a scale from 0 (for an unproductive soil) to 100 (excellent productive soil).

### 6.2 Mobile Unit for Field Spectroradiometric Measurements (MUFSPeM)

The Mobile Unit for Field Spectroscopy Measurements (MUFSPeM)(Fig. 3), presented during the outdoor exhibition session of the IWMMM-2 workshop in Ispra, 1999, has been used over the last three years to create a data base for BRDF approximation throughout the

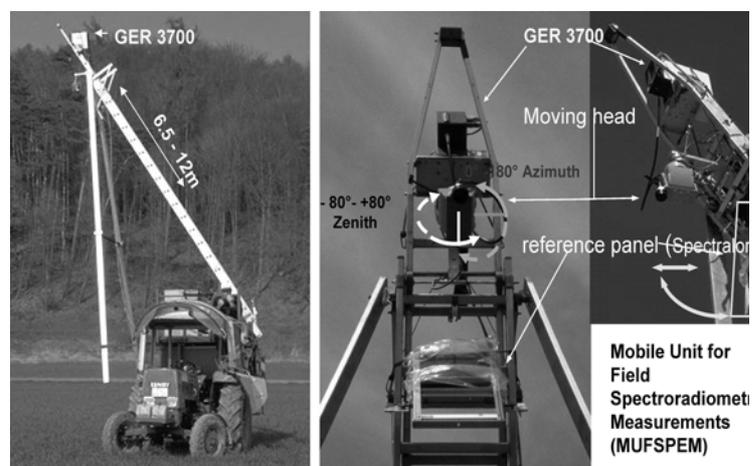


Fig 3: The Mobile Unit for Field Spectroscopy Measurements (MUFSPeM) for BRDF approximation

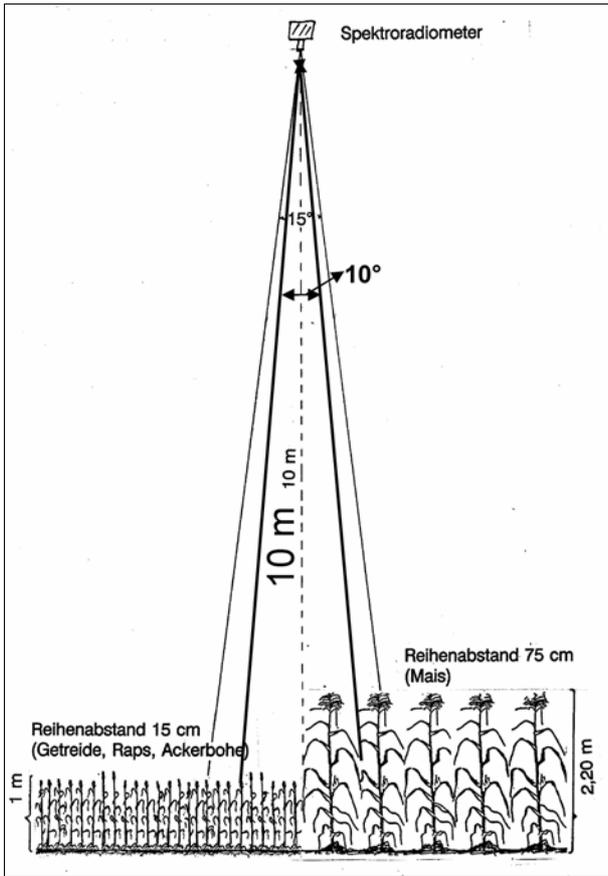


Fig. 3: Scheme of min. measurement height required for a measurement section representative for the surface at an aperture of 10°

vegetation period of winter wheat, winter barley and maize (74, 51 & 67 available BRDF-hemispheres respectively).

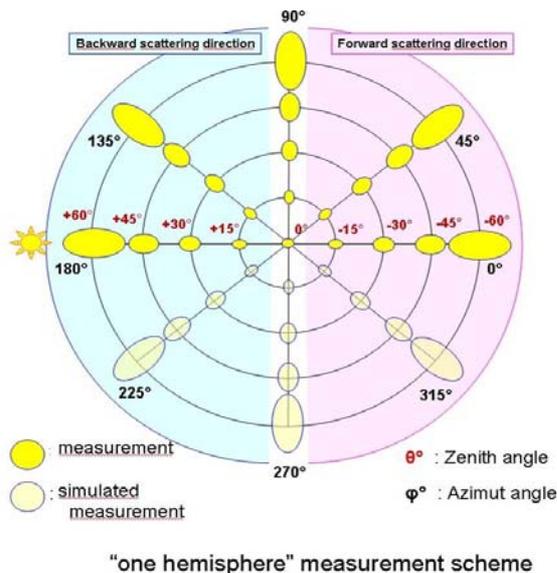


Fig 4: Measurement sequence for BRDF approximation. Starting from the nadir looking position (reference and object measurement) the five azimuth directions for each of the four zenith angles are measured. The series is finished by a second nadir measurement pair.

The concept for the measurement arrangement was to be **high, mobile** and **fast**. The MUFSPeM allows registering in situ the **multispectral** and **multiangular** radiation from the vegetation canopy from a height of about 10 meters above the surface. The fibre optic of a GER 3700 instrument with 10° field of view is mounted on a computer controlled motor driven tripod head performing the measurements following the predefined sequence of look directions from an ASCII file. [11]

The set up of the whole construction lasts about 20 minutes for the two men team.

### Measurement strategy

Angular backscattered reflectance measurements are time sensitive and time consuming. The measurement sequence suggested and adopted for the multiangular mode is described by the Fig. 4 and 5. One measurement cycle consists of about 25 measurements including the reference measurements and lasts about 17 minutes. The measurement sequence begins by placing MUFSPeM's vehicle long axis parallel to the sun principal plane. Measurements take place every 45° in the azimuth direction (0°, 45°, 90°, 135° and 180°) and 15° in the zenith one (0°, 15°, 30°, 45° and 60 °). For time saving reasons reference measurements are registered at the beginning and the end of a measurement sequence. The draw back of this measurement concept is that at every registration position the measurement covered a different section in the selected sub area (Fig. 4).

High and low useful water storage capacity (UWSC) sites were depicted in order to compare differing canopy vitality situations. Sub areas of these sites are considered to be homogeneous and are taken into account as a unity. Each of them was covered by a semi-hemisphere of measurements (including the sun principal plane). The two different UWSC sites in a plot

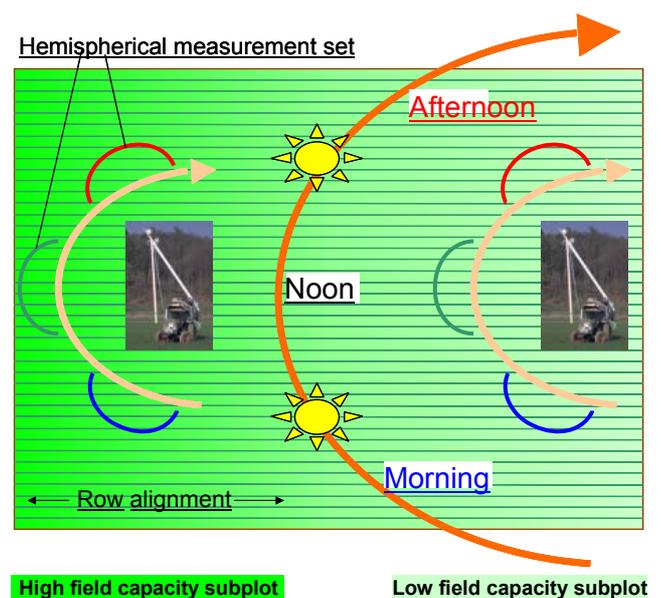


Fig 5: measurement scheme for BRDF approximation showing the measurement positions over the daytime which are controlled by the principal plane

are measured within a hour, so the comparability of the registered data is assured at an acceptable degree of reliability

Due to the BRDF database requirements [12] the reflectance of the same plot site was registered at three different times in a day. The first measurement series was taken as early in the morning as sun position allows (<65° zenith angle) the second one as close to the highest sun position at noon as possible and the last one late in the afternoon.

Ancillary data, such as direct and diffuse light flux, and temperature are simultaneously registered by two neighboring meteorological stations. Soil and plant water potential data and samples for wet and dry biomass laboratory estimation are acquired at selected dates during the vegetative period. Furthermore, target pictures of the field of view are taken for laboratory evaluation of stereo stand parameters by photogrammetric methods. All this information should be used together with soil, crop yield, height, and topographic maps for the final evaluations.

The growth stage of crops are determined on behalf of the eucarpia scale (EC) used by the German Biological State Foundation for Agriculture and Forestry (Biologische Bundesanstalt fuer Land- und Forstwirtschaft, [13]). In this case a data set of maize at EC stage 67 is evaluated. During the measurements the sky was clear (direct to diffuse irradiation ratio: 2 - 3.5), and the visibility was extended up to 25km, the air temperature between 21.2°C and 23.8°C, and the wind velocity at the canopy height was low (< 1 m/sec).

### Software

GER 3700 original software is used for the guidance of

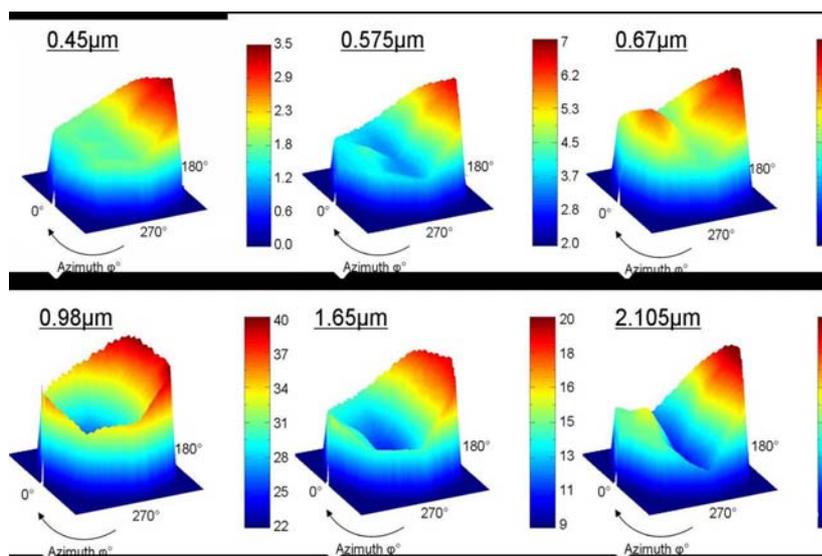


Fig 6: Changes of the reflection (scale is given in the bar near each 3D plot) with the observation direction in six selected wavelength as measured with MUFSPM

the spectroradiometer. The pan-tilt head is being driven by the prototype developer's software [14]. Further data assessment is being carried out with a specific series of program routines (Hemispheric Reflectance Viewer, Parametric Goniometric Viewer), written for IDL5.0, by S. Sandmeier (NASA), U. Beisl (DLR) and Martin Habermayer(DLR). Statistic and logistic platforms, such as SPSS and Ms Excel, are also involved in the data assessment procedure.

### Data processing

Registered data are sorted out in conjunction with the field protocol in a database. Calibration of the data is carried out using the Spectralon white panel reference measurements and interpolating between the beginning and end references of the hemispherical measurement sequence according to the registration times of each measurement file. Diagrams and plots, as well as statistics are used to establish the fluctuation of the reflectance over the day according to the sun versus registration geometry. The whole spectrum is assessed. However, preference and priority is given to wavelengths that are related better to canopy characteristics.

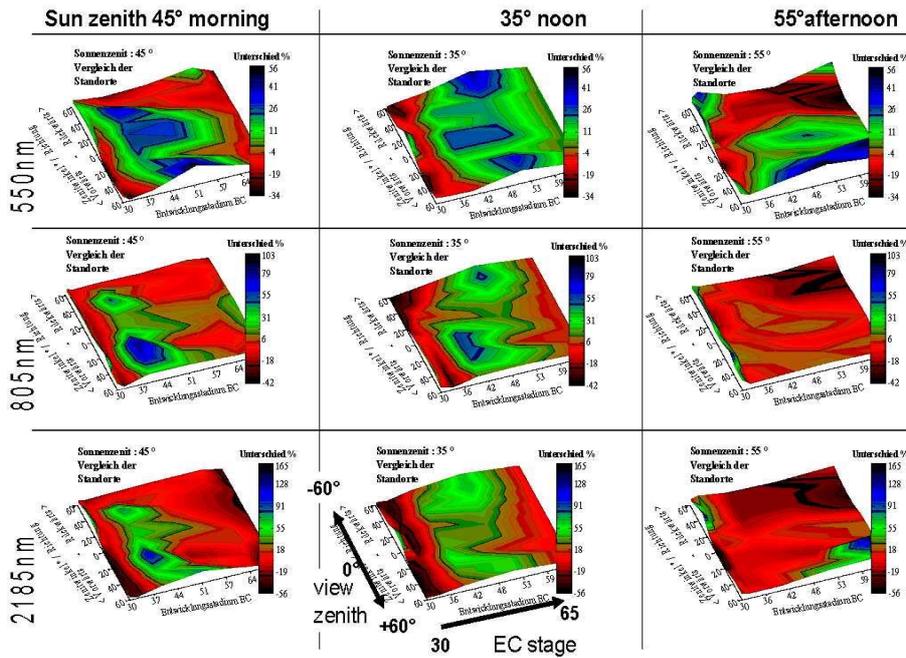
From the three measurement series taken over the daytime an approximation function is calculated for each look direction [15][16]. On base of this function each other look direction at sun positions between the morning and the afternoon measurement series can be simulated. For ProSail adaptation and inversion simulated data sets for five daytimes have been calculated (see Fig. .

### 3. RESULTS

The measurement arrangement proofed to be high, mobile and fast enough to measure from 10 m above the maize canopy and to change position as fast that the two different UWSC subplots could be measured within one hour.

The GER 3700 worked well in the VIS, NIR and SWIR 1 wavelength region. In the SWIR 2 region from about 2200nm to 2500 nm the SNR of the GER 3700 instrument was not satisfying, so we cannot thrust this data. The reflectance differences with changing azimuth and zenith angle are in the range of 100 to 150%, the distribution show a strong wavelength (Fig. 6) and development stage dependency. All over this results confirm the results reported from other investigations [17][18][19] [20].

The new aspects investigated in the frame of the IKB Dürnast project are



**Fig. 7:** Reflection differences of high and low UWSC subplots at 550, 805 and 2185nm, calculated for morning, noon and afternoon series and displayed for the principal plane from +60° to -60° view angle (y-axis) across the vegetation period (EC 30 to 70, x-axis)

the differences between high and low UWSC sub plots over the vegetation period and the diurnal changes due to changing illumination conditions. In both cases the data analysis indicated significant differences. For demonstration the diagrams in Fig. 7 are restricted on three wavelengths, at 550, 805 and 2185 nm in the NIR, and the principal plane, where the highest differences can be observed (y-axis). The values are calculated as difference of the nadir reference normalized reflection of the corresponding view direction from high and low UWSC sub plots. Changes over the day are shown in the three 3D diagrams of the morning, midday and afternoon series, the development due to phenologic changes from EC 30 to EC 70 is displayed along the x-axis. Green to dark blue colors indicate the reflectance of high UWSC sub plot to be higher, brown to dark red the reflectance of the low UWSC. The smallest differences occur during the midday measurements. With increasing sun zenith angle the differences become more and more pronounced. Furthermore it is to be pointed out that at each daytime and throughout the vegetation period there are view directions where the lower UWSC and other where the higher UWSC subplot show higher reflectance values!

The next step was to run ProSail with these data sets. As described above five distinct sun zenith angle situations have been simulated dependent on the daytime of the first and last registered measurement series. In case of the maize example discussed in this paper the high

UWSC subplot was first measured at a sun zenith angle of more than 57° and the last series was measured at around 48°, the low UWSC started at 46° and the last series was taken at a sun zenith angle of around 58°. The approximated BRDF from this measurement series allowed to deliver data for 55°, 45°, 35°, 35° and 45° for the high UWSC sub plot and for 45°, 35°, 35°, 45° and 55° for the low UWSC site. The two data sets at 35° sun zenith angle represent the situation before and after the highest sun position at midday. Soil, leaf mesophyll and leaf area to canopy height variables are assumed to be constant.

Fig. 8 is displaying the results of ProSail inversions. The Root Mean Square Error (RMSE) is giving an estimate about the reliability of the inversion process from the statistical/mathematical point of view. Values between 0.017 and 0.04 are good, between 0.04 and 0.07 still acceptable. As lower the sun elevation as higher the RMSE. Best results are retrieved for the midday measurement series at the highest sun elevation. According to the RMSE indicator the calculation for sun zenith angles higher 45° should not be used for parameter retrieval. Despite this fact the retrieved parameter show a clear trend which is similar for subplots with high and low UWSC. This let us decide to present and discuss these results as well.

Leaf area inclination (LAD) meaning the mean inclination angle of all leaves is calculated with values from 64° to 69° for the high UWSC site and from 43° to 77° for the low UWSC site. For the leaf area index (LAI) values from 1 to 6 (high UWSC) and 2 to 4 (low UWSC) are retrieved. LAD and LAI values increase from the morning to the afternoon. The parameter Chlorophyll (a+b) content (Cab), Canopy dry matter (Cm), Canopy water content (Cw) decrease from the morning to the afternoon calculations. At the low UWSC site Chlorophyll (a+b) content (Cab) from 97 to 23 [ $\mu\text{g}/\text{cm}^2$ ], Canopy dry matter (Cm) from 0,012 to 0,002 [ $\text{g}/\text{cm}^2$ ] and Canopy water content (Cw) from 0,037 to 0,008 [ $\text{g}/\text{cm}^2$ ] and at the high UWSC site Chlorophyll (a+b) content (Cab) from 101 to 47 [ $\mu\text{g}/\text{cm}^2$ ], Canopy dry matter (Cm) from 0,03 to 0,003 [ $\text{g}/\text{cm}^2$ ] and Canopy water content (Cw) from 0,045 to 0,017 [ $\text{g}/\text{cm}^2$ ].

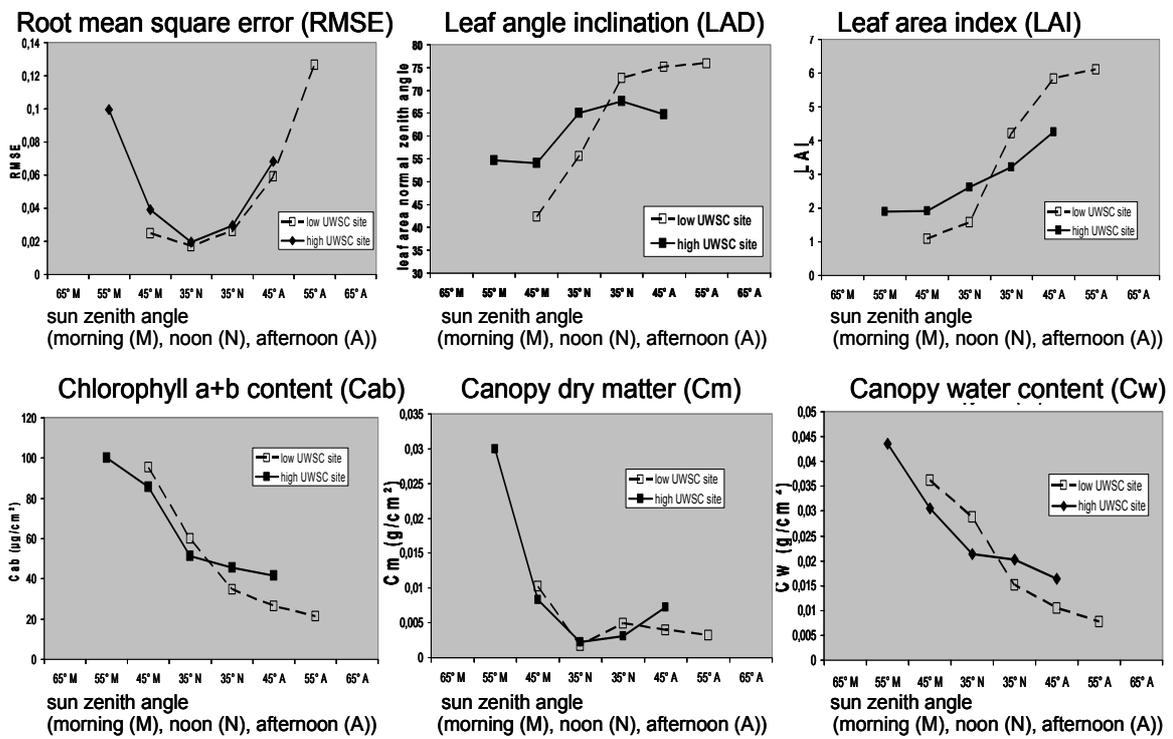


Fig. 8: results of ProSail inversion of the measurement series of maize, EC 32. The parameter settings for soil, leaf mesophyll and leaf area to canopy height variables are set to be constant.

#### 4. INTERIM DISCUSSION

The results proofed:

- the well known fact, that directional reflection is dependent on wavelength, illumination and observation direction (Fig. 6, 7)
- the highest differences occur in the wavelength region of absorbing pigments in the VIS (fig. 6)
- field capacity differences are displayed in the data and change over the vegetation period (fig. 7)
- that ProSail inversion results do not accurately retrieve the B-G-C-P parameter in case data are registered under different illumination and observation conditions ! (fig.8)

Especially the last result has drawbacks on our general concept of growth and physical backscatter model driven vegetation assessments. All measurements representing one development stage are expected to deliver the same or nearly the same parameter values. One may concede some slight differences in some of the parameters which are explained by diurnal physiological cycles of the canopy, e.g. Cw or LAD, but these differences should not exceed the 5% limit. The reason for the observed differences of up to the factor 10 (Cm for the high UWSC site) have to be of other origin. Under discussion is the measurement strategy but the ProSail model as well.

**Measurement strategy:** The applied measurement strategy was developed to unravel the anisotropy behaviour of crops using field spectroradiometric measurements. Time saving reasons, the mobility requirement, hardware, and budget limitations force to compromises which led inevitably to simplify the measurement scheme taking some assumptions:

- **The Helmholtz reciprocity theorem is supposed to be valid for the undertaken measurements, since neither fluorescence nor the light polarisation plane is under investigation [21].** → The arrangement is delivering measurements which are acceptable from the physical point of view, but the assumption is not absolutely true. Compared to the other error sources the errors due to this assumption are small.
- **The backscatter characteristic right and left of the principal plane is treated as symmetrical.** → Measurements can be restricted on one part of the hemisphere which is a time saving assumption and allowed to simplify the ladder construction. In reality such a situation is only exceptionally to be found and may lead to significant errors, especially in case special conditions occur, like wind aligned ears [23], with heliotrope vegetation, etc.
- **The whole measurement area is homogeneous.** In such case not the observation position (FIGOS measurement strategy [7]), but the measured spot of the sub area is changed (Parabola, WAAC concept [8][9]). → Taking into account that the area, which is supposed to be homogeneous has a magnitude of 240-485m<sup>2</sup> (crop and observation height depended), it could be criticised that this area is most possibly including heterogeneities due to differences in plant physiology or the local geomorphology. On the other hand, taking into consideration that the fertiliser application raster cell has a minimum of 225m<sup>2</sup> at the present or that the average spatial satellite image resolution of the Landsat generation (Landsat TM and ETM+, Spot, IRS, etc.) lies at about 400m<sup>2</sup>, it could be conceded that the error

potential is kept under acceptable proportions. Nevertheless the occurring errors may be of a magnitude, which do not allow deriving general valuable rules as required for optimizing physical models.

Another often asked question is why we decided to measure first the different azimuth directions at constant zenith angles and not one azimuth plane at the established zenith angles like it is done from systems like Chris/Proba or MISR. The reason was that stereo data sets of satellite systems like MOMS-02, Spot 6 or ALOS, of airborne systems like the HRSC camera but of the Hydro-N [23] sensor as well are operating with predefined zenith angles. For normalizing such data sets it was considered more important in a disturbed measurement sequence to have at least complete hemispherical values for one zenith angle than to have a complete zenith sequence for an azimuth angle.

A next weak point of the measurement arrangement was that it was not possible to measure the different sort, variety and management type sample plots installed by the partners of the IKB Dürnast project for phenologic/physiologic experiments [1]. These plots have been systematically measured by traditional laboratory methods. The sample plots, being of a size of 5 \* 2,5m can only be measured by a goniometer like measurement arrangement.

On the other hand, the measurement series performed and the inversion results retrieved show a logical trend. The values for the low UWSC sub plot are indicating a reduced vitality compared to the high UWSC test site, the trend is constant increasing or decreasing and similar for both subplots. This results are similar to the results of [3] obtained by analyzing the behaviors of two wheat subplots of high and low UWSC over the vegetation periods 2000 and 2001.

**ProSail** inversion requires a set of additional external information and is based on functions, which relate the measured reflection to the canopy parameters to be retrieved. Error sources may be the accuracy of the input variables, e.g. the BRDF of the soil which is dependent on the micro surface, the mineral composition but on the wetness stage and under story vegetation as well, changing atmospheric conditions, etc.. The other, and regarding the magnitude of the observed errors in the diurnal comparison probably most sever, error source is the insufficient adaptation of the functions and look up tables needed to relate the registered signal and the canopy parameters. A major problem in this case is the accuracy of traditional sampling methods. Experiences in the frame of the IKB Dürnast project with state of the art sampling methods proofed, that the variability is in the range of 20%!! The variability of the same parameter retrieved from field spectroscopy was in the range of less than 10% [24].

## 5. RESULTING CONCLUSIONS

The working hypothesis is basically verified:

- There exist differences in the anisotropy behaviour of the canopy reflectance at different UWSC sites in a plot.
- The fluctuation of this behaviour between the high and low UWSC sites in a plot for the investigated crops and growth stages can be registered and sampled in BRDF databases.
- Variables that influence the registered reflectance, such as the sun zenith and azimuth angle, the registration geometry, the row alignment, the topography, as well as the atmosphere interference need to be further investigated and the degree of their contribution to the angular spectral response of the canopy to be estimated. Correlations should be established.

The major conclusion from the four year research work are that it is inevitably to continue, more, to increase the efforts for adaptation of physical models by field measurements. For this task it is necessary to improve ground sampling techniques and the measurement arrangement as well. The development of more precise ground sampling techniques (measurement accuracy, sampling design, etc.) is in the duty of the respective specialists. Our contribution to advances in field spectroscopy for BRDF approximation and physical model adaptation is the development of an improved measurement arrangement which is taking into account the experiences made in the IKB Dürnast project.

The drawback for the planned CHRIS/Proba supporting campaign was that it makes no sense to work with a system which we can not explain.

***That fore the campaign was cancelled and we started to construct a new system working according the goniometer principle.***

## 6. THE “NEW” GONIOMETER SYSTEM

### 6.1 Goniometer like unit

The scheme of the “goniometer like” solution proposed to be developed is shown in Fig. 9. The same section of the surface is observed. Changes in area at increasing view zenith angle, which occur with “pure” goniometer systems, are partially compensated by the rotating arm with the entrance object optic and are of less than 20%. At the same time the distance from the optic to the surface is changing and is around 50% closer than in the nadir looking position.

The ASD Field Spec Pro FR instrument purchased proofed to be too heavy for the already developed system so the construction had to be changed.

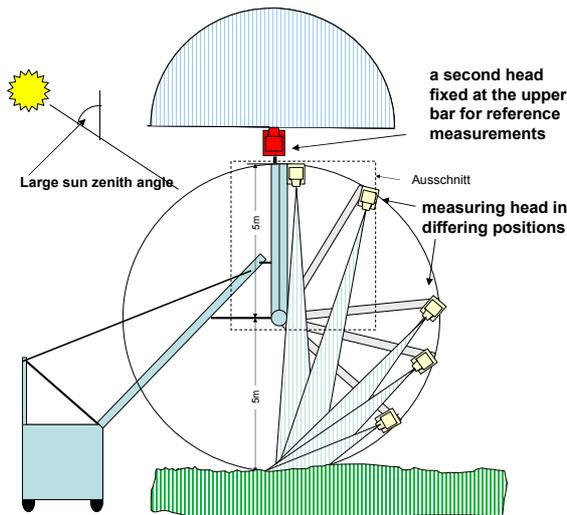


Fig 9: scheme of the measurement construction allowing registering multidirectional measurements following the goniometer principle. Changing the azimuth angle is possible by rotating around the vertical axis. Object and reference measurements are taken quasi simultaneously

Different from this scheme the realized solution is using bifurcated fiber optic cables attached to the ASD Field Spec Pro FR instrument to take the measurements. The negative consequence of this compromise is the reduction of transmissivity for about 50% and the complete loss of signal at wavelength higher 2200nm. The positive one is the fact that both, the reference and the object are measured with the same detector set, facilitating the radiometric calibration of the system.

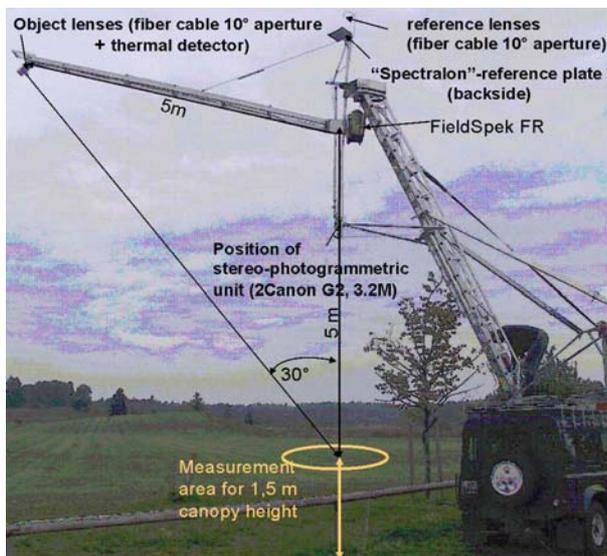


Fig. 10: New system for BRDF approximation by field spectroscopic measurements with a ASD Field Spec FR instrument an a bifurcated fiber cable with 10° aperture for nearby simultaneous object and Spectralon™ reference measurements

In the frame of the ongoing projects this system shall be used for BRDF approximations of grasslands (pasture and meadows), reed and different crops of the Waging Tachinger lake catchment, for supporting CHRIS/Proba sensor calibration by simultaneous measurements.

Fig. 10 shows the system at the 2nd assembly test in Iffeldorf, on the 1th of October 2003. The Goniometer system works with a Field Spec FR field spectroradiometer from ASD company covering the wavelength region from 400 to 2500 nm combined with a broadband (8 – 12,5 μm) thermal sensor (KT 15D) of the Heitronics company. The goniometer unit will be used to approximate the BRDF from an altitude of about 10m above the top of the canopy. In Tab. 1 the technical details are specified.

Tab. 1: Technical specifications of the device

goniometer <sup>cc</sup> device:	height above canopy: 10m (ground: 10-12,5m)
	azimuth/zenith positioning accuracy +/- 3° resp. +/- 2° (worst case)
	azimuth angle range: 270°
	zenith angle range: 0° to 70°
	rotating assembly on the roof rack: 360°
Photogrammetric stereo device:	mounting time 2 persons: appr. 1h
	2 Canon G2 digital cameras
	base distance: 1m
Detectors:	height above canopy: 5m
	software by Wilfried Linder based on BLUH and LISA
	ASD Field Spec FR (350 – 2500nm)
	bifurcated fiber cable for alternate object/ reference measurement
	Heitronics KT 15D 8-14μm

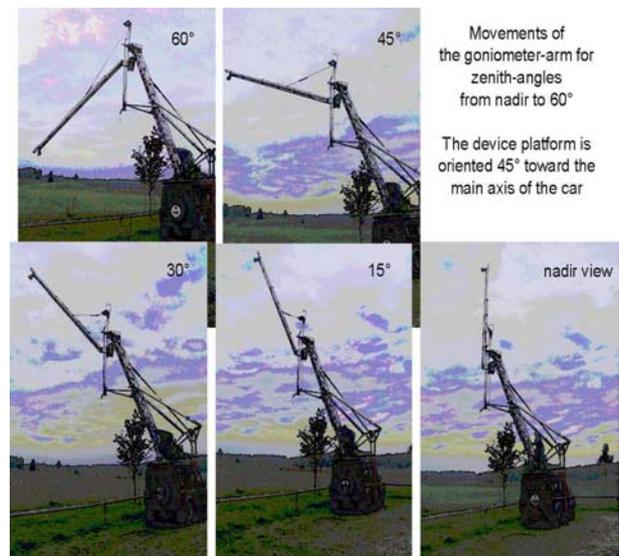


Fig. 11: Movements of the object measurement positioning arm of the goniometer-like field device for BRDF approximation. The slides show five positions from nadir view to 60° view zenith angle. The subsection of the canopy to be measured can be additional changed by rotating the device on the roof.

Not finally solved is the problem of the shutter, needed to alternatively close the object or the reference optic end of the fiber cable. A mechanical solution is under development and will hopefully be operational end of May.

Other changes compared to the MUFSPeM measurement system is concerning the sequence of measurements and the positions to be measured. The change of view zenith angle being faster than of azimuth angle, the measurement sequence will now start with positioning the azimuth angle than performing the zenith angle measurements for half a hemisphere and than changing to the next azimuth position. The discussion on the establishment of the positions to be measured is still not finished. The points are whether it make sense to measure with a higher density around the hot spot position and to reduce or not at other positions as the results of [27][28] indicate and which is the best mesh for optimizing the BRDF approximation.

Due to the uncertainty with the shutter solution and until the final measurement sequence is not fixed the time period for one measurement series can not be given exactly at the present. A period of less than 20 minutes is envisaged and should be possible.

## 6.2 Field survey

The necessity to improve the accompanying measurements for the quantitative and qualitative description and parameter determination is a point which is recognized as a severe bottleneck for modelling but for interpreting results as well. We do not know any report addressing this special topic. During our work on divers projects [1][3][21][25][28][29] we learned that the parameter estimation by field surveying methods, the so called “ground truth”, is gaining errors of around 20%. In vegetation related disciplines like agriculture, forestry, biology, such errors are accepted as common for ground sampling methods. For remote sensing based assessments of parameter, which should be further used for decision making, e.g. in precision agriculture, forestry, environmental sciences, etc., or in our case for developing and improving models, such an error is not acceptable. It is practically not possible to control the whole chain of a ground sampling process, which covers the steps from sample design, sample collection, sample transport, sample measurement in the laboratory (analysis) or in the field (number, position, etc.). We tried at least to improve the assessment of parameter, which are required from backscatter physical models and are illumination and view geometry dependent. Of special interest was the assessment of the Leaf Angle Distribution (LAD), a parameter which is of high significance in crop status determination in precision farming and is influencing directly the angular signature of vegetation. State of the art determination is the rough estimate in three categories, from plano- to erectophile.

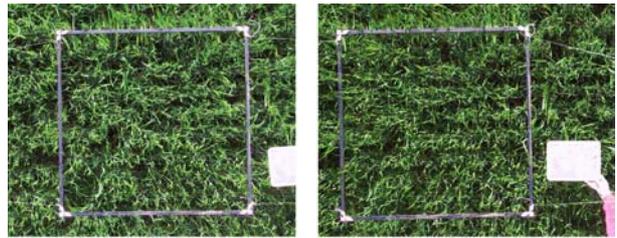


Fig. 12: Stereo pair imaged with two Canon G2 digital cameras from about 5 m above the canopy. The frame includes an area of 1m<sup>2</sup>, is fixed in horizontal position and marks approx. the same area as measured by the goniometer system.

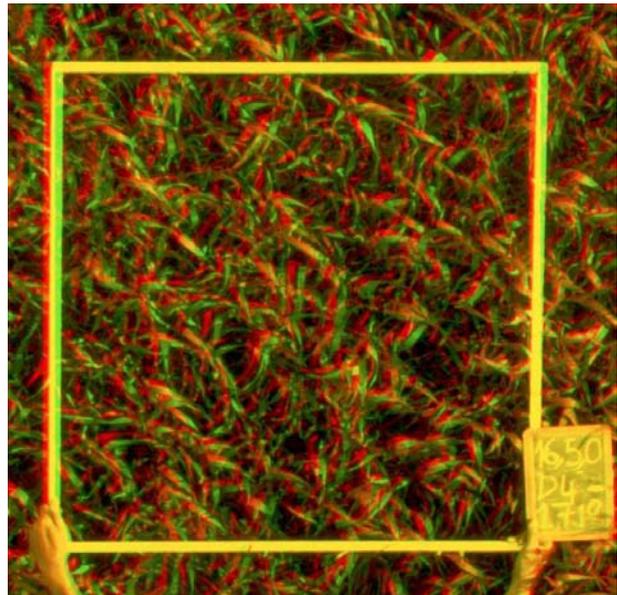


Fig. 13: Anaglyph image of two stereo pairs analysed for canopy parameter calculation

The solution under development is based on stereo photo pairs taken with two digital cameras (Canon G2) from a unit integrated in the goniometer device. Additionally to the well known nadir view photographs used to derive parameter like shaded, sunlit, mirrorlike fractions, ground coverage, soil fraction, etc. [3][29] for stereoscopic analysis, the stereo pairs should deliver the LAD. An automatic extraction process was initially envisaged. Being a “multiple stories” problem standard photogrammetric packages, developed for digital surface model derivation, failed. Dr. Dr. Ing. W. Linder, from the IPI in Hannover, is developing a semiautomatic solution integrated in the software environment of the LISA and BLUH. The prototype proved to be able to deliver the parameter LAD, LAI (or better leaf total projected area) as well as fraction of sunlit, shaded, mirror like backscatter fraction, stand height, etc.. Fig. 12 shows a stereo pair as imaged with the two Canon G2 digital cameras from about 5 m above the canopy. Fig. 13 is showing an “anaglyph” image of a stereo pair of a wheat canopy. With a

red/green eyeglass the 3D effect is visible. The parameter estimation is restricted on the 1m<sup>2</sup> area inside the horizontal adjusted frame which marks approximately the same area as measured by the goniometer system.

## 7. OUTLOOK

The described system will be operated to take systematic measurements for adapting backscatter models for specific vegetation surfaces, to relate growth with the corresponding physical backscatter models and so to contribute improving the reliability of remote sensing data evaluations. Our present interests are in nature close vegetation surfaces, - especially wetlands,- in agriculture and forestry.

Introducing and establishing remote sensing methods in operational application chains is the overall goal of our research activities.

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