ANALYSES OF HYPERSPECTRAL AND DIRECTIONAL DATA FOR AGRICULTURAL MONITORING USING THE CANOPY REFLECTANCE MODEL SLC PROGRESS IN THE UPPER RHINE VALLEY AND BAASDORF TEST-SITES

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ABSTRACT

CHRIS data of the years 2003 and 2004 of two agricultural test-sites in Germany were analyzed with the goal to evaluate the potential of hyperspectral and directional remote sensing data to deliver input information for precision agriculture. Multitemporal observations are available for the Upper Rhine Valley test-site along the German/French border for the year 2003.

After geometric correction of the multiangular data set and atmospheric correction, the obtained reflectance spectra were compared to optical radiative transfer simulations with SLC. SLC is an extended version of the canopy reflectance model GeoSAIL.

Directional reflectance spectra were extracted and the angular variations compared to the model results. BRDF analyses illustrate the spectral properties of the BRDF for different land uses. As results from the optical modeling, crop parameters like LAI and chlorophyll content are retrieved from the CHRIS data and provided as spatial maps. The directional measurements additionally contain information on the canopy structure that is crop specific, but also changes with phenological development and sometimes even with cultivars. These crop parameters will serve as input parameters for plant production and management models.

1. INTRODUCTION

Remote sensed data allows the spatial mapping of crop status that serve as an important input to precision agriculture. The application of fertilizer can be varied according to the observed distribution of nitrogen uptake. Fungicides and pesticides applications should consider the spatial variation of leaf area in order to optimise its effect.

Optical hyperspectral data obtained from imaging spectrometers with up to 256 spectral bands provide highest potential for the provision of crop parameters, but they have only been available from airborne sensors recently. Therefore spaceborne multispectral sensors (e.g. SPOT, LANDSAT-TM and IKONOS) are mostly used, while hyperspectral sensors are currently subject to research activities. Nevertheless, the prospect of more detailed crop information due to more and narrower spectral bands is promising. Spectrometers may allow the retrieval of information on leaf area, biomass, canopy structure, water, chlorophyll and nitrogen content of the canopy using radiative transfer models and dedicated software tools. These presently still require additional research and development activities.

CHRIS data provide the first opportunity to analyse hyperspectral and directional data acquired by a sensor in space.

Figure 1. Overview on the overlap of georeferenced CHRIS nadir acquisitions along the Rhine in 2003. The heavily clouded Sep 11 image is excluded (from left to right: Mar 25, Jun 02, Jul 18, Aug 03, bgr: 669 nm, 709 nm, 776 nm)

Proc. of the 3rd ESA CHRIS/Proba Workshop, 21–23 March, ESRIN, Frascati, Italy, (ESA SP-593, June 2005)

2. MATERIALS AND METHODS

2.1. Test-site and CHRIS acquisitions

For multitemporal analyses CHRIS acquisitions of an agricultural region in the Upper Rhine Valley along the German/French border were selected. The dominant crop in the area is maize. Other crops grown are wheat and barley, as well as special cultures, such as tobacco and miscanthus. Alluvial forests spread along the river sides.

Five CHRIS acquisitions for the test-site were successful in 2003. They span over the time period from March to September and thus give a good opportunity to observe the crop development. Three of the acquisitions were completely cloud free. Three consisted of all observation angles. Usually the spatial overlap of the angular observations was better for ±36° than for ± 55°, but it is always at least half of the covered ground area. An overview on the test-site illustrating the overlapping area is given in Fig. 1.

Intensive processing of the raw CHRIS images was conducted. A statistical destriping approach was developed in order to enhance the signal-to-noise ratio. Atmospheric correction was carried out using the radiative transfer model MODTRAN 4 (Berk et al, 2000) to compensate for the scattering and absorption effects of the atmosphere. The procedure includes a correction of the adjacency effect (Bach & Mauser 1997). This is necessary as the contribution of radiation from adjacent surfaces influences the reflectances of the target pixel and the BRDF. As a last step the images were georectified using ground control points and standard image processing tools. The result of the correction is a series of geo-referenced images containing the spectral and angular reflectance properties and their change with time.

2.2. Canopy Reflectance Model SLC

SLC is a surface reflectance model that evolved from the GeoSAIL model (Verhoef & Bach, 2003). It was extended through a non-lambertian soil BRDF model (Hapke, 1981) and the consideration of vegetation with ground or crown coverage below 100%. This allows a more realistic simulation of directional acquisitions and forests. SLC follows a 4-stream concept, so that modeled fluxes are divided in their direct and diffuse, upward and downward contributions. The input parameters to SLC describe structural and physiological information on the vegetation, soil properties and the observation geometry. A submodel for the soil reflectance and its variation with moisture is incorporated (Bach, 1995). The canopy is modeled in a two-layer version of the model SAILH (Verhoef, 1985). The two layers emulate a vertical leaf color gradient. Though the structural properties (i.e. leaf angle distribution and leaf size) are assumed to be identical in the two layers, LAIs (leaf area indices), chlorophyll, water and dry matter content may differ between the two layers. The structural information about the leaf angle distribution is approximated by two parameters, ‘a’ and ‘b’. The first of those parameters, ‘a’, describes the average leaf slope, while the second, ‘b’, determines the so-called bimodality of the distribution (Verhoef, 1998). The distribution of total LAI is governed by the two parameters fraction of brown leaves fB and the dissociation factor D, which can vary between D = 0 (homogeneous mixture of brown and green leaves) and D = 1 (complete dissociation). Calculation of the spectral reflectance and transmittance of green and brown leaves is done by the PROSPECT model (Jaquemoud & Baret, 1990) using improved water and chlorophyll absorption coefficients.

The application of SLC considering the spectral and geometrical configuration of the CHRIS sensor allows the simulation of surface reflectances as seen with CHRIS from the PROBA satellite.

3. RESULTS

3.1. Comparison of CHRIS measurements with forward modelling with SLC

After completion of the processing, qualitative and quantitative analyses of different features were started. BRDF functions of different land uses were analyzed visually and a comparison between measured reflectances of CHRIS data and simulated reflectances of the canopy reflectance model SLC have been performed. For bare soil and maize examples are illustrated in Fig. 2 and 3, respectively.

Qualitative interpretation of the bottom of atmosphere reflectance of all 5 observation angles of CHRIS (Fig. 2, left) showed that for bare soil, the nadir spectrum lies in the middle between the forward and backward (negative) looking angles. - 55° and - 36° are close to the ”hot spot”, which is characterized by an increase of reflectance since shadows disappear if the sun is situated behind and in-line with the viewing orientation, and therefore are brighter than the nadir spectrum. + 55° and + 36° look towards the sun and thus are darker. For the simulated spectra (Fig. 2, right), a soil-moisture of 5 Vol% was assumed, as there was no precipitation during the days before the acquisition and the summer 2003 had been very dry. The agreement between the measured and simulated spectra is very good for the nadir and the 36° spectra. The -55° spectrum is not represented quite as well. The measured -36° spectrum has higher reflectance values than the -55% spectrum, while the opposite is observable for the simulated spectrum.

The same comparison between measured and simulated spectra was conducted for maize for the same acquisition date, Aug 03, and is illustrated in Fig. 3.

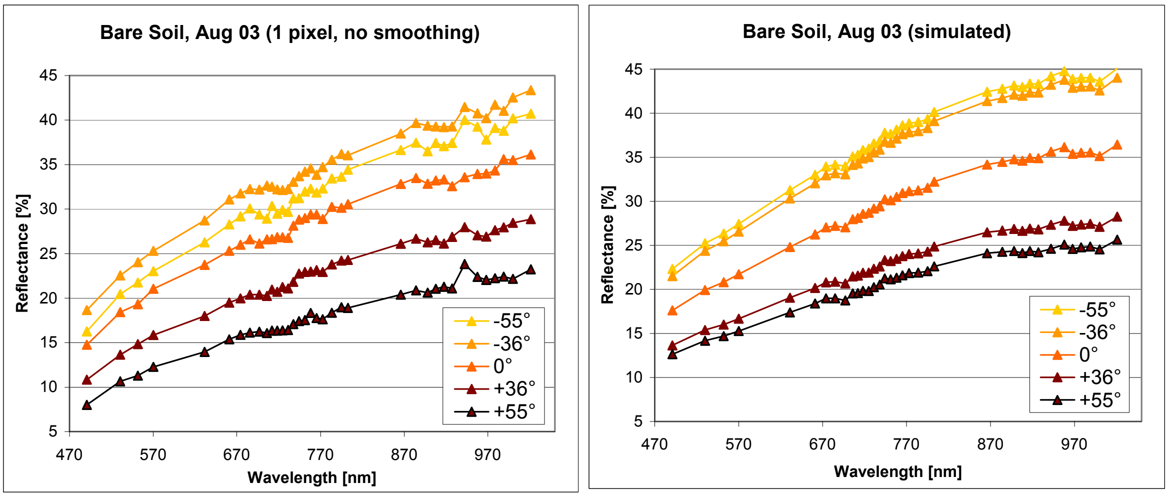


Figure 2. Measured (left) and simulated (right) reflectance spectra for bare soil obtained by CHRIS for 5 observation angles (Aug 03, solar zenith: 32°, relative azimuth: 146.31° (forward looking), 33.70° (backward looking))

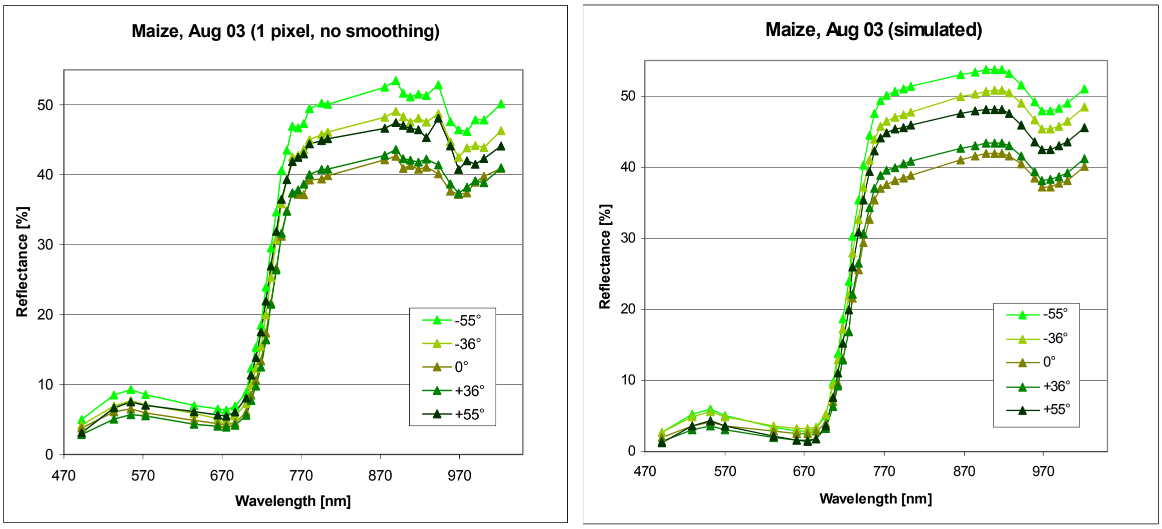


Figure 3. Measured (left) and simulated (right) reflectance spectra for maize obtained by CHRIS for 5 observation angles (Aug 03, solar zenith: 32°, relative azimuth: 146.31° (forward looking), 33.70° (backward looking))

For the simulation, canopy parameters were optimized from the nadir spectrum. This resulted in a LAI of 4.0, a chlorophyll content of 40µg/cm², a fraction of brown leaves of 25% and a leaf water content of 0.02 g/cm². There is a good agreement between CHRIS measurements and SLC simulations, though the simulated values seem to be too low in the visible spectral range (450 – 680 nm). This might be due to the blossoming of maize at the time of observation, which is not considered in the SLC model in a sufficient way yet. Especially at the +-55° observation angles the blossom on top of the maize canopy dominate visually. This can also be discerned in the CHRIS measurements in an increase of reflectances especially in the visible spectral range.

Fig. 4 shows the same spectral reflectances, retrieved from the Aug 03 CHRIS acquisitions and simulated with the parameters mentioned before, but this time at a fixed wavelength (780 nm) and with varying observation angle. The reflectance values are normalised to the nadir observations in order to illustrate better the BRDF. Also for the angular features, the SLC model agrees well with the measurements. For bare-soil (Fig. 4, left) the most notable difference is again the decrease in reflectance for -55° in the measured values. For maize (Fig. 4, right) the shape of both BRDF functions (measured and simulated) is very similar with a slight overestimation of the BRDF especially in the backward direction.

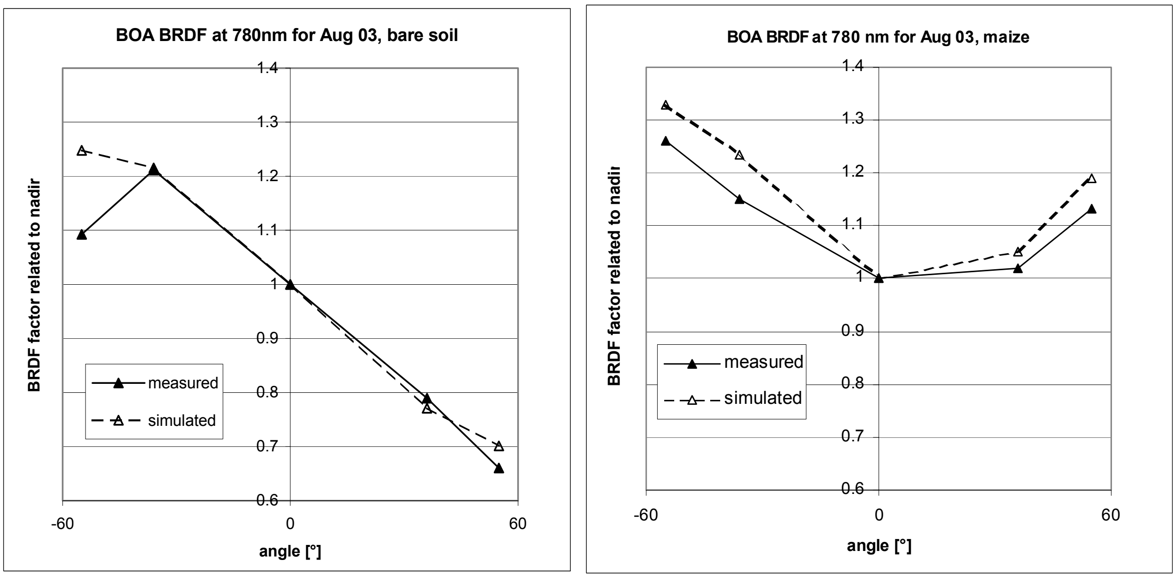


Figure 4. Relative change of the reflectance at 780 nm with observation angle (Bottom of Atmosphere BRDF), measured with CHRIS and simulated with SLC for bare soil (left) and maize (right) on Aug 03.

The whole shape of the BRDF function for maize differs clearly from the bare soil function. Nevertheless the reflectance model can reproduce both well. While the soil shows a almost linear decrease of BRDF factor from backward to forward looking, the maize BRDF in August 03 forms a bowl shape. This observation of a bowl shape of the BRDF for a canopy with dense vegetation cover is however not a general rule. Similar analyses of different crop types showed that the BRDF function varies a lot. For example, dense rape seed observed in September shows a BRDF shape similar to soil, however with higher gradients of the BRDF factor (decreasing from 1.5 to 0.7). Tobacco observed in August showed that the BRDF factors have extremes for the +-36° observation angles in the red spectral bands. Miscanthus however, a more than 2m tall crop that is used for bio-fuel production and subsidized by the EC, behaves close to a Lambertian reflector in the near infrared, since almost no angular effect could be observed in this wavelength region.

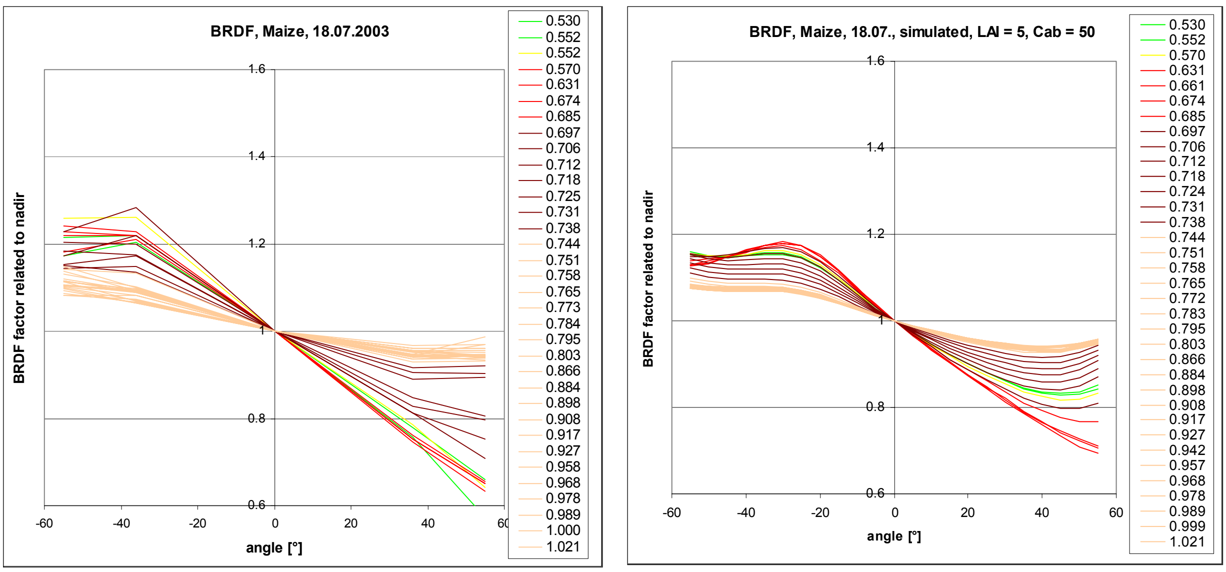


Figure 5. Relative change of the reflectance with observation angle (Bottom of Atmosphere BRDF), measured with CHRIS (left) and simulated with SLC (right) for maize on July 18. The simulation was conducted for steps of 1°. Thus the simulated curves appear smoother than the linearly interpolated 5 CHRIS acquisitions.

More investigations on a larger set of test-sites and for different phonological states are required to identify whether these observations are reproducable. If so, these specific features of the BRDF would be an excellent information source for more physically based crop classifications.
This will however not be an easy topic, since also the phenological development of the respective crop needs to be considered. This shall be illustrated for maize. The BRDF factor function of maize changes significantly already within 2 weeks. The BRDF illustration in Fig. 5 shows the same maize field used in Fig. 4, but 2 weeks earlier. In this plot all spectral bands are displayed at the same time in order to additionally show the spectral properties of the BRDF. The bowl shape of the BRDF was not observable on July 18. Nevertheless the SLC-model allows well to simulate also this BRDF shape. The good agreement between measured and modeled BRDF was obtained by adapting the canopy structure parameters 'a' and 'b' used in SLC. For July 18 an 'a' - parameter of –0.1 was applied to simulate maize canopies. For August 03 the 'a' - parameter was set to –0.4. This corresponds well with the observable change of canopy structure during crop development. Maize leaves become more vertical oriented with maturity. This reflects in a increase of the average leaf angle (assuming an angle of 90° for vertical leaves) and thus a reduced value for 'a'.

3.2. Crop parameter retrieval using CHRIS data through model inversion of SLC

After the performance of the SLC model was validated, a retrieval of LAI and chlorophyll content was targeted. The crop parameter retrieval requires an inversion of the SLC model. The inversion procedure minimizes the deviation between simulated and measured reflectance spectra through changing the model input parameters. The parameter combination with the best fit (lowest RMS error between simulation and measurement) then provides the crop parameter.
The inversion procedure should be tested on the maize fields in the test-site. Therefore it was necessary to obtain a mask for all maize fields. The classification of the maize crops used a specific hyperspectral feature, that we had observed in a large set of spectrometer data. The red edge of maize shows a wavelength shift to longer wavelength compared to other crops. Therefore the inflection point of the red edge of the CHRIS measurements were calculated and a simple criterion: "red edge position lies between 727 and 735 nm" was sufficient to identify maize in vegetated pixels. This example shows how much benefits hyperspectral data can bring also for classification purposes.
The image that was used as input to the inversion procedure is illustrated in Fig. 6. Maize shows up in all tones of red. A subset of an area of approx. 4 km by 3 km is chosen here that corresponds with the spatial availability of all five angular observations.

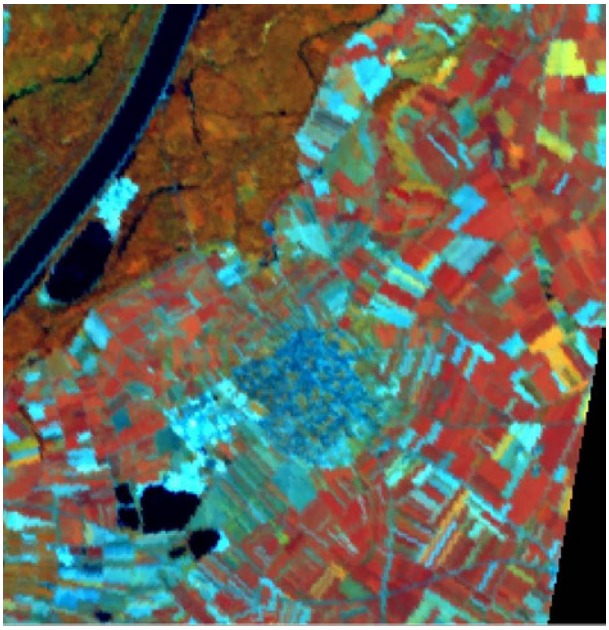
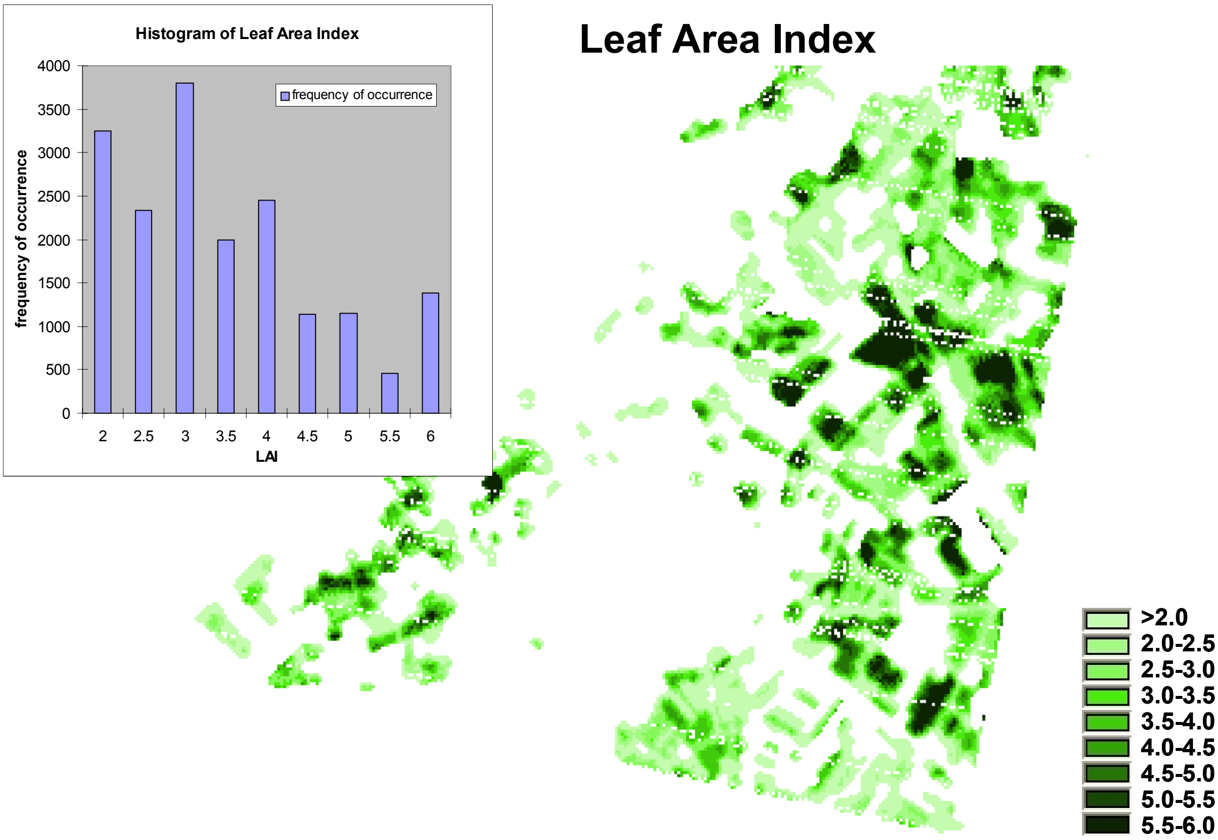


Figure 6. CHRIS image subset of July 18 for testing parameter retrieval. Maize fields show up in red. (bgr: 669 nm, 709 nm, 776 nm)

The result of the retrieved LAI distribution is shown in Fig. 7 (top) for the masked maize pixels. The map of LAI illustrates a large variability of leaf area that span from values of 2 to 6. At this time of the year maize crops usually have LAI values between 3 and 5. In 2003 relative lower LAI values were measured in the Upper Rhine Valley due to a very dry summer. This might explain the higher occurrence of lower LAI values in the histogram.
The inversion provides not only the LAI distribution. At the same time the chlorophyll content of the maize crops was calculated from the CHRIS scenes. The resulting map reveals different patterns compared to the LAI maps. The histogram shows an almost Gaussian distribution of chlorophyll values with maximum occurrence of 45 to 50 μg/cm².
It should be noted that both the retrieved LAI and chlorophyll distributions are spatially not scattered. Instead their patterns delinate the forms of single fields. This illustrates that management practice of the farmers led to these spatial variations. E.g. the high LAI values of a few fields might be caused by irrigation that is only rarely applied by some farmers in this area. Whereas the high chlorophyll values of certain fields might be a result of increased fertilization of the farmer. In this analysis the impact of management seems to be more relevant than soil differences, that would follow a different pattern.



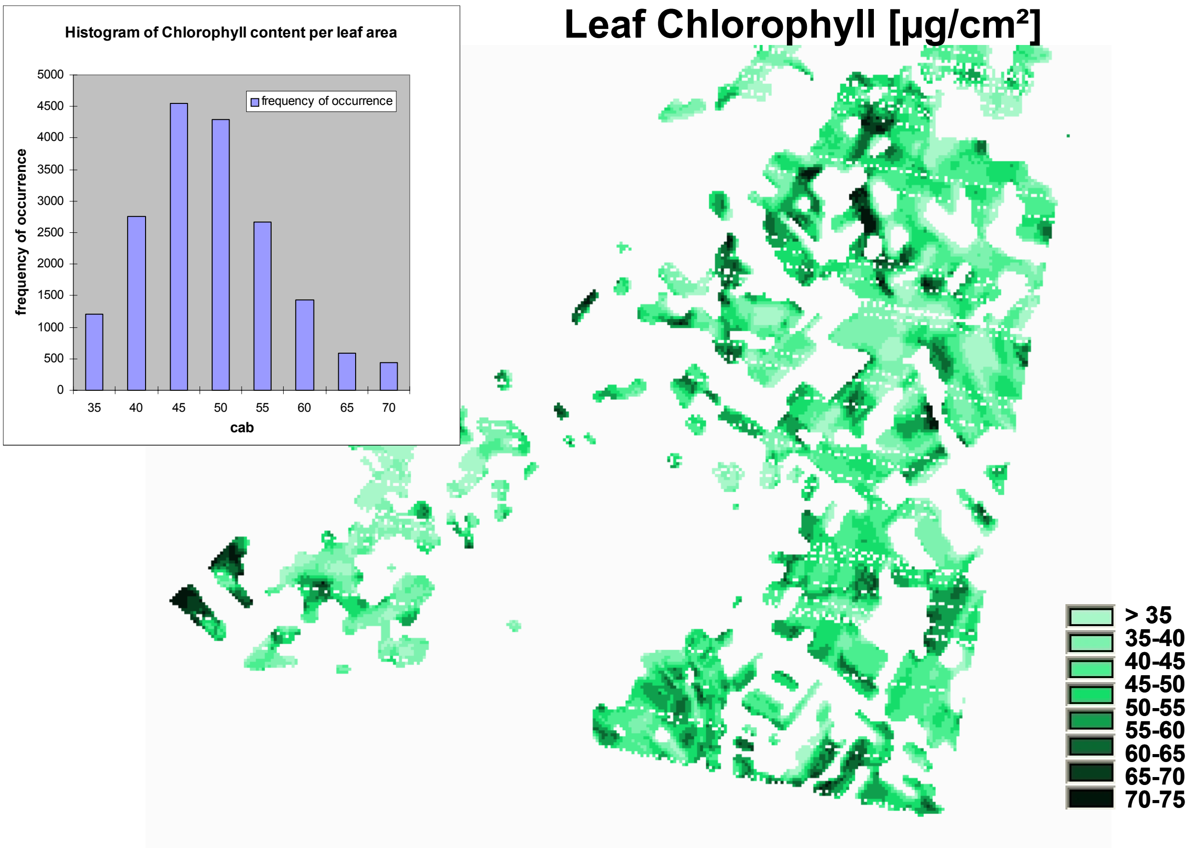


Figure 7. Retrieval result for leaf area index (top) and leaf chlorophyll (bottom) for maize on July 18.

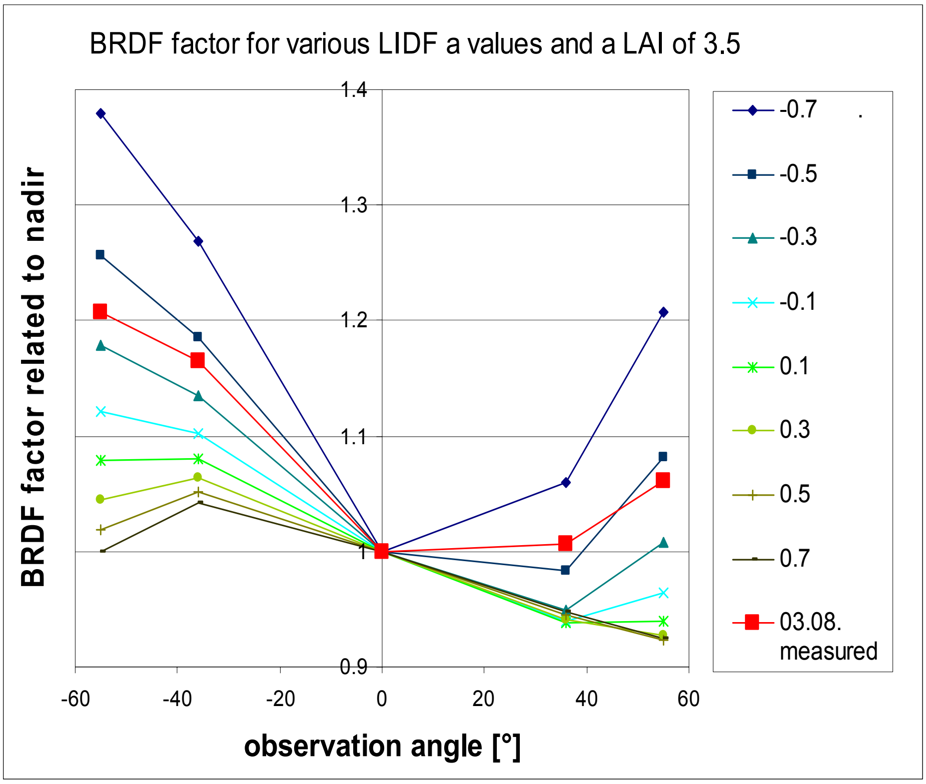


Figure 8. Sensitivity of BRDF factor related to nadir with the canopy structure parameter a and illustration of potential retrieval of the canopy structure based on CHRIS measurements of July 18.

Already other imaging spectrometers have demonstrated that the LAI and chlorophyll content can be retrieved from hyperspectral observations (e.g. Haboudane et al., 2003). The additional information content of the multiangular observations of CHRIS is still a new field of research. Some first results could be obtained in our study. The idea is that the multiangular observations provide information on the canopy structure that is in turn required for a more accurate retrieval of other crop parameters like LAI.

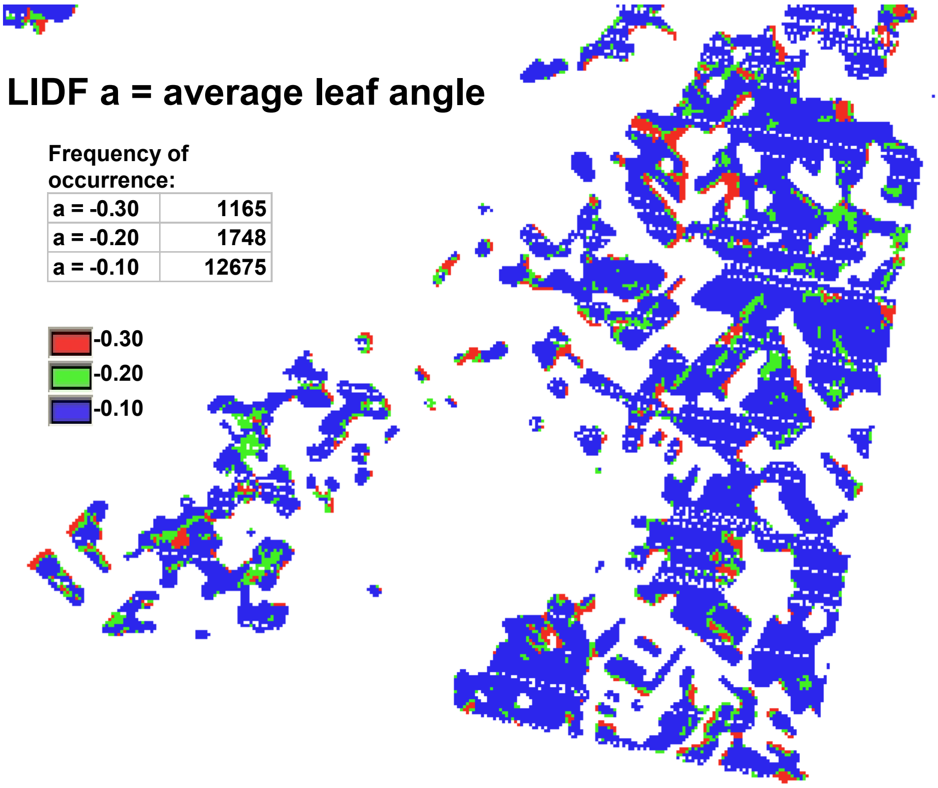
First it shall to be demonstrated that the canopy structure has a strong influence on the BRDF and then that the BRDF function derived from multiangular observations have unique features that can be assigned to structural parameters. Fig. 8 shows a sensitivity analyses of the BRDF function for various average leaf angles represented in the parameter ‘a’ of SLC. The BRDF function changes from a bowl shape in case of very vertical leaves (small ‘a’ values) to a more bell shape with maximum in the hot spot direction in case of almost horizontal leaves (large ‘a’ values). The measured BRDF function from CHRIS fits in very well. The shape of the measurements for the maize field on July 18 can be interpreted that this field is simulated best by using an a-parameter of approx. –0.4.

This illustrates that it should be possible to retrieve canopy structure when inverting multiangular observations. The parameter retrieval of the maize fields of July 18 therefore also allowed the variation and thus retrieval of the structural parameters ‘a’ and ‘b’ in SLC. The resulting distributions are shown in Fig. 9.

The retrieved average leaf angle parameter ‘a’ shows a very homogenous distribution. For all maize fields a ‘a’ value of –0.1 fits best. Different ‘a’ parameters are retrieved mostly at the boundaries of the fields. They can be explained in mixed pixels, which are more pronounced for larger observations angles with pixel sizes of twice of the nadir observation.

For the ‘b’-parameter, describing the bimodality of the distribution function, the situation looks different (Fig. 9 bottom). Two different sets of fields can be observed. For most fields a ‘b’-parameter of –0.4 fits best, but specific fields show up with a ‘b’-parameter of –0.2. This might be caused by different varieties of maize crops.

The white pixels within the maize fields in figures 7 and 9 are caused by sensor errors in the raw data that mostly follow a scanline. Thus they form oblique patterns in the georectified images. These pixels with sensor errors are identified in an automatic procedure and not used in the inversion. Since the retrieval algorithms uses all 5 observation angles at the same time, an error in one angular observation is sufficient to mask this pixel out. Therefore the number of “white” pixels is relatively high.



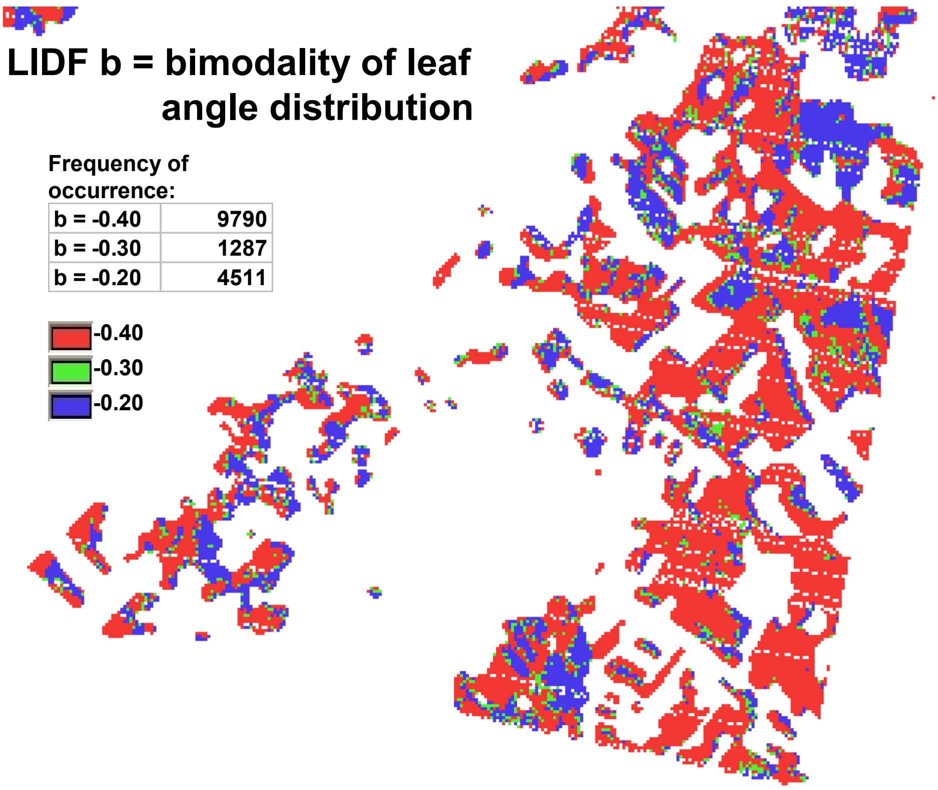


Figure 9. Retrieval result for canopy structure a (top) and b (bottom) for maize on July 18.

The detailed comparison of CHRIS measurements and SLC inversion results with ground truth must be postponed to the future. Ground truth on LAI or chlorophyll content was not available for 2003, since prediction of overflight and data acquisition for the Upper Rhine Valley test-sites was usually too late and no field measurements could be conducted continuously during the vegetation period. In order to improve the availability of in-situ data, for 2004 the CHRIS test-site was therefore translocated to Baasdorf, a village in eastern Germany. A further special advantage of this test-site is the larger field sizes that will allow the study of infield variations using CHRIS data.

Baasdorf is a test farm of the *preagro* project (www.preagro.de), the largest precision farming project in Germany. A set of crop parameters are measured by the *preagro* team during the vegetation period and additional hyperspectral data will be obtained from airborne AVIS (Mauser, 2003) acquisitions. Within *preagro*, VISTA is in charge of the analyses of hyperspectral remote sensing data of the test farms.

First results from CHRIS data of the Baasdorf test-site from September 2004 provided the BRDF characteristic sof the soil in the area. Vegetation studies were yet not possible, because the fields under investigation were already harvested during the data take. They will continued in 2005.

4. DISCUSSION

Today commercial airborne hyperspectral sensors exist and are in use, yet spaceborne sensors are still in a research and development state. CHRIS is the only high resolution imaging spectrometer in space that additionally provides directional measurements. This makes it an unique instrument. The first analyses of CHRIS data demonstrated that it is possible to extract valuable crop and soil information from spaceborne hyperspectral and directional measurements. Further analyses of such data will most possibly grant us new insights into the characteristics of different crops. Especially the potential of CHRIS to measure the canopy reflectance at different observation angles provides information on the canopy structure. With this information on canopy structure we can expect that the retrieval of plant physiological (LAI), phenological and biochemical (water, chlorophyll and nitrogen content) parameters will be improved.

The CHRIS test-sites distributed almost over the complete globe would provide an excellent source of information to study the hyperspectral BRDF properties of the land surface. However, this source has not been systematically explored so far. A closer collaboration of the Principal Investigators of CHRIS, providing information on land use and their phenological development during the CHRIS acquisitions, together with state-of-the-art atmospheric correction tools, would be a basis for collecting a kind of BRDF catalogue of the land surface of the Earth.

Canopy reflectance model like SLC have achieved a status that they allow the extraction of plant parameters such as LAI, chlorophyll or water content. Improvements of the model performance are still desirable especially in case the crops are flowering. This optical effect has been neglected in SLC so far. This is mostly acceptable for nadir observations. The angular CHRIS acquisition made it however obvious, that for oblique view, where the flowers appear more dominant, flowering needs to be considered in the model.

Crop parameters retrieved from CHRIS data using inversion techniques of canopy reflectance models, can serve as essential input parameters for plant production and management models like crop growth models. Through assimilation of the remotely sensed information these models can better represent the heterogeneity of the land surface. However still research and development activities are required to allow the combined use of remote sensing measurements, canopy reflectance models and crop growth models for operational applications, like improved precision farming measures.

ACKNOWLEDGMENTS

The authors would like to thank ESA and SIRA for the provision of CHRIS data and technical support. CHRIS acquisition planning by P. Fletcher (RSAC) is acknowledged. Many thanks also to W. Verhoef (NLR) for his support in surface reflectance modeling and SLC applications. This work was supported by ESA within the SPECTRA preparatory studies (17179/03/NL/GS) and within the BMBF project *preagro* (FK 0330679).

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