Analyses of Spaceborne Hyperspectral and Directional CHRIS Data to Deliver Crop Status for Precision Agriculture

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Abstract

CHRIS is the first spaceborne multiangular imaging spectrometer with high spatial resolution. CHRIS data was analyzed to deliver input information for precision agriculture. The reflectance spectra obtained were compared with optical radiative transfer simulation results of SLC, an extended version of the canopy reflectance model GeoSAIL. Directional reflectance spectra are extracted and the directional variations compared to the model results. As results from the optical modelling approach, crop parameters such as LAI and chlorophyll content are retrieved from the CHRIS data and provided as spatial maps. These can be further used for plant production simulations.

Keywords: remote sensing, spectroscopic analyses, measurements of crop status

Introduction

Remote sensed data allows the spatial mapping of crop status that can serve as an important input to precision agriculture. Optical hyperspectral data obtained from imaging spectrometers with up to 256 spectral bands provide highest potential but have only been available from airborne sensors recently. So spaceborne multispectral sensors (e.g. SPOT, LANDSAT-TM and IKONOS) are already widely used, while hyperspectral sensors are currently mostly subject to research activities. However 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 sophisticated models and software tools. These are presently at a research and development stage.

CHRIS data provide the first opportunity to analyse hyperspectral and directional data acquired by a sensor in space. The test-site for this study was situated in the Upper Rhine Valley in Germany and focuses on the potential of spaceborne spectroscopic analyses for agricultural investigations.

Materials and Methods

Sensor

CHRIS (Compact High Resolution Imaging Spectrometer) is a multiangular imaging spectrometer in space, carried on board a platform called PROBA (Project for On Board Autonomy). CHRIS, as a scientific instrument on PROBA, serves as a technology demonstration mission of ESA (Teston, 2004). Therefore the mission provides images of only a limited number of test-sites throughout the globe that are selected by a scientific board of ESA. The specific feature of CHRIS is that it allows the acquisition at five observation angles (± 55°, ± 36° and nadir viewing) with high spatial resolution during one data take. This is important for the observation of the bi-directional reflectance distribution function (BRDF) of different crops, which describes the change of reflectance with observation geometry and sun position. This information can be used for a better interpretation of any optical acquisition (also of field spectrometers).

CHRIS measures the reflected radiances over the visible and near infrared spectral range (400 to 1050 nm) with up to 63 spectral bands with approximately 10nm width. Several bands in the red edge (about 680 - 780 nm) allow the characterisation of the shape of the most important region of the spectrum for vegetation analysis that is sensitive to chlorophyll content, leaf area and biomass. The water absorption bands in the near infrared are further covered by CHRIS, allowing analysis of the water content and detection of water stress.

With a ground resolution of 18m at nadir view, CHRIS cannot determine as many small field variations as some airborne sensors (e.g. AVIS with a spatial resolution of 2 – 8m (Mauser, 2003)), yet the resolution is still high enough for extraction of field variations due to, for example, differences in soil type or soil moisture.

For the analyses presented in this paper an acquisition mode of CHRIS was selected that allows at the same time highest possible spectral, directional and spatial resolution. This means 18m spatial resolution at half swath width (approximately 7 km image width), 37 spectral bands and along track BRDF (5 angles).

Test-Site

The test-site for this study was located in the Upper Rhine Valley near the village Weisweil at 7.68° East and 48.19° North along the German/French border. Its average height above sea level is 150m. Land use and especially field size vary between the German and the French sides of the Rhine. One of the most important crops in the area is maize. Other crops grown are wheat and barley, as well as special cultures, such as tobacco. Close to the riverside there are alluvial forests.

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 overlap of the angular observations is 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.

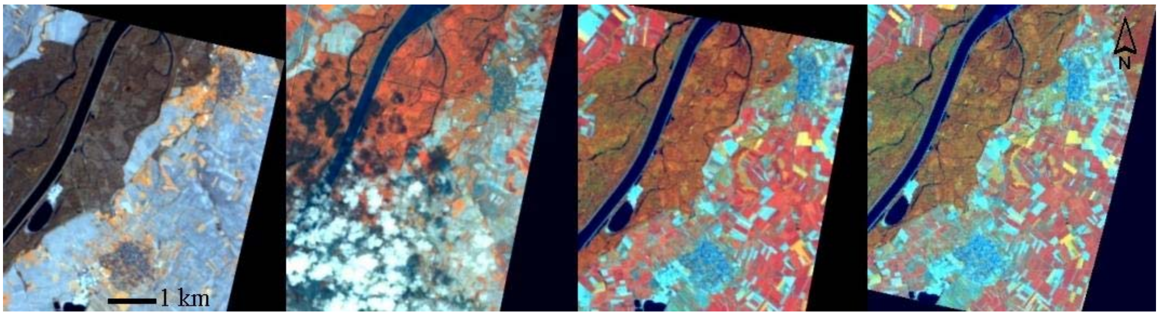


Figure 1: Overview on the overlap of georeferenced CHRIS nadir acquisitions along the Rhine in 2003. The heavily clouded Sep 11 image is excluded (from left to right: Mar 25, Jun 02, Jul 18, Aug 03, bgr: 674 nm, 712 nm, 784 nm)

Extensive processing of the raw CHRIS images was conducted. A statistical destriping approach was developed in order to enhance the signal-to-noise ratio. An atmospheric correction using the radiative transfer model MODTRAN 4 (Berk et al, 2000) was carried out to compensate for the scattering and absorption effects of the atmosphere. It included a correction of the adjacency effect (Bach & Mauser 1997). This is necessary as the contribution of radiation from adjacent surfaces influences the reflectances 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.

Canopy Reflectance Model SLC

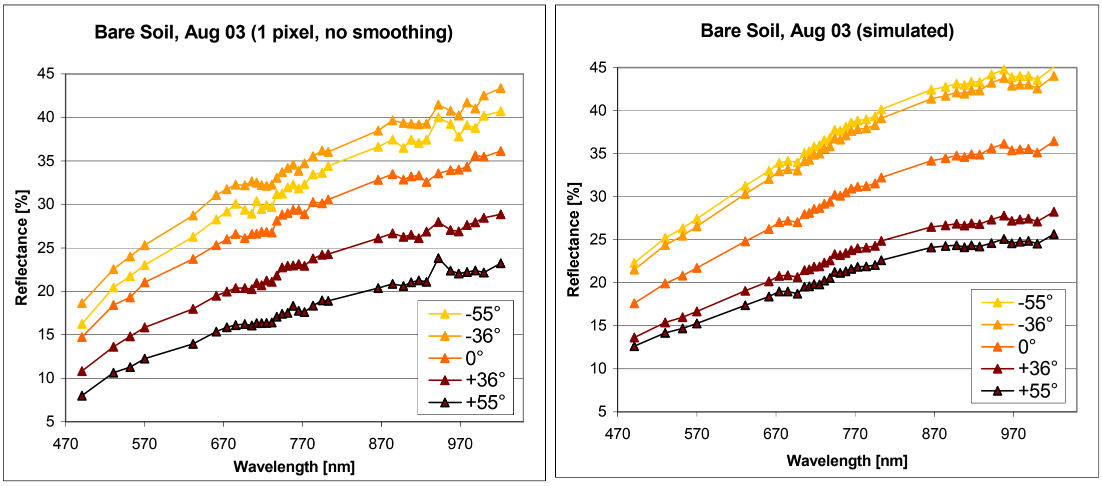
SLC is a surface reflectance model that evolved from the GeoSAIL model (Verhoef & Bach, 2003). Its extension through a non-lambertian soil BRDF model and the consideration of vegetation with ground or crown coverage below 100% allows a more realistic simulation of directional acquisitions and forests. 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 the vertical leaf color gradient which is often seen in agricultural canopies. Though the structural properties (i.e. leaf angle distribution and leaf size) are assumed to be identical, LAIs (leaf area indices) and chlorophyll 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 improved PROSPECT model (Jaquemoud & Baret, 1990).

The application of SLC considering the spectral configuration of the CHRIS sensor allows the simulation of surface reflectances as seen with CHRIS from the PROBA satellite and the deduction of canopy parameters like LAI and chlorophyll content.

Results and Discussion

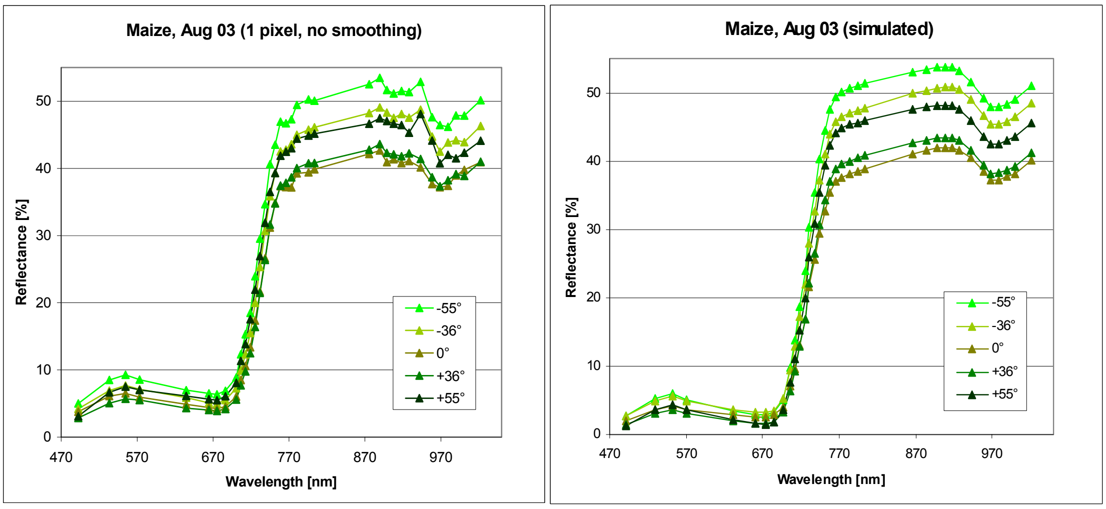
After completion of the preprocessing, qualitative and quantitative analyses of different features were started. BRDF functions of different land uses were analyzed visually and a comparison between measured reflectances of CHRIS data and simulated reflectances of the canopy reflectance model SLC have been performed.

Qualitative interpretation of the bottom of atmosphere reflectance of all 5 observation angles of CHRIS showed that for bare soil, the nadir spectrum lies in the middle between the forward and backward (negative) looking angles (Fig. 2, left). - 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


Bare Soil, Aug 03 (1 pixel, no smoothing)

Bare Soil, Aug 03 (simulated)

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))


Maize, Aug 03 (1 pixel, no smoothing)

Maize, Aug 03 (simulated)

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))

orientation, and therefore are brighter than the nadir spectrum. + 55° and + 36° look towards the sun and thus are darker. Fig. 2 shows spectra for bare soil, measured and simulated, for Aug 03. The brightest measured spectrum is the –36° acquisition, closely followed by the –55° acquisition. For the simulated spectra, a soil-moisture of 5 % volume 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 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 (Fig. 2, right).

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

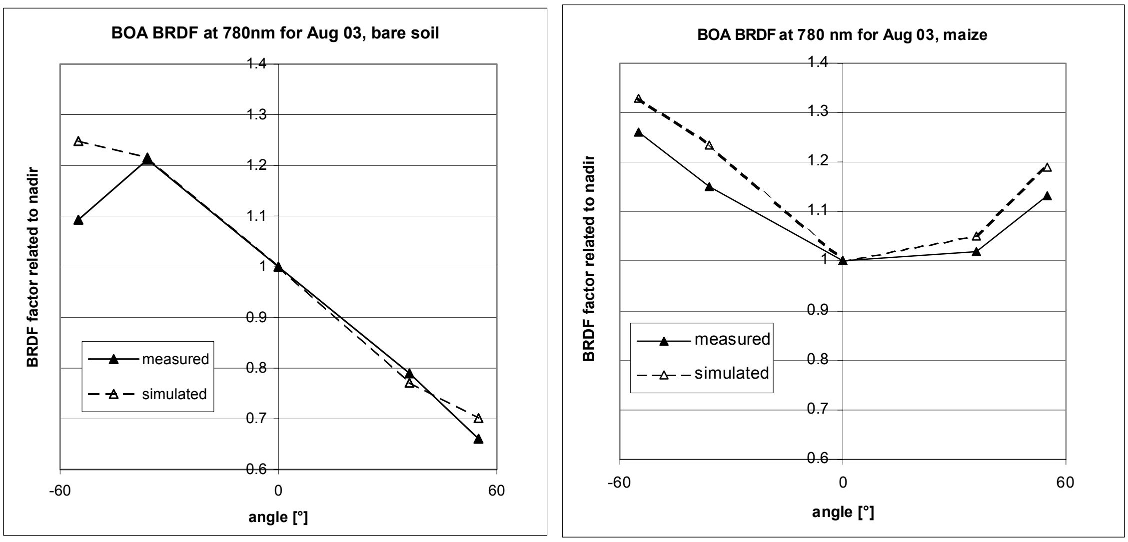


Figure 4: Relative change of the reflectance at 780 nm with observation angle (Bottom of Atmosphere BRDF), measured with CHRIS and simulated with SLC for bare soil (left) and maize (right) on Aug 03.

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, which cannot be simulated in the model.

Fig. 4 shows the same 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. The whole shape of the BRDF function for maize differs clearly from the bare soil function.

After the performance of the SLC model was validated with these single spectra, 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

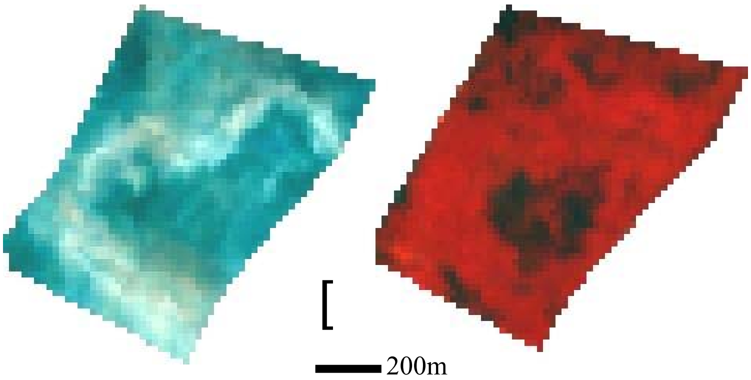


Figure 5: Maize field on the French Rhine side, CHRIS nadir acquisitions, left: Jun 02, right: Aug 03 (bgr: 674 nm, 712 nm, 784 nm)

deviation between simulated and measured reflectance spectra and provides the crop parameters with the best fit (lowest RMS error).

The first test application of this inversion was conducted for a maize-field in France. The area of the maize field was approximately 60ha. This field was selected because it showed a high spatial variability caused by a dried up bayou of the river Rhine. This can be seen in Fig. 5. Shades of Blue indicate no or minimal vegetation, shades of Red and Yellow indicate dense vegetation. On Jun 02, the field was almost free of vegetation, the differences in the underlying soil caused by the bayou are clearly visible. On Aug 03, the meander is still visible, yet now it is defined by differences in vegetation cover. The goal for the classification with SLC was to quantify those variations through the retrieval of the crop parameters LAI and chlorophyll.

The results of model inversion for the nadir acquisition of Jun 02 can be seen in Fig. 6. As there was only sparse vegetation cover, the chlorophyll value was kept constant to 60 µg/cm². Soil moisture and LAI variation were small, yet the influence of soil differences can be seen. Soil moisture was lower in the meander and so was the LAI.

Crop parameter retrieval using the SLC model inversion provides a quite different picture for the LAI on Aug 03 (Fig. 7). The LAI had increased to an average value of 3.85. Though soil variations cannot be observed directly due to the dense vegetation, the bayou is again clearly visible. Highest values > 4.0 are reached where the alluvial soils of the Rhine's meander seemed to provide best growing conditions. Fig. 8 and 9 show the chlorophyll content per leaf area and per ground area, respectively.

For the chlorophyll content per leaf area, a slight inverse relation to the LAI can be seen. It is not very strong (correlation coefficient approx. 0.3), yet visible. This might be

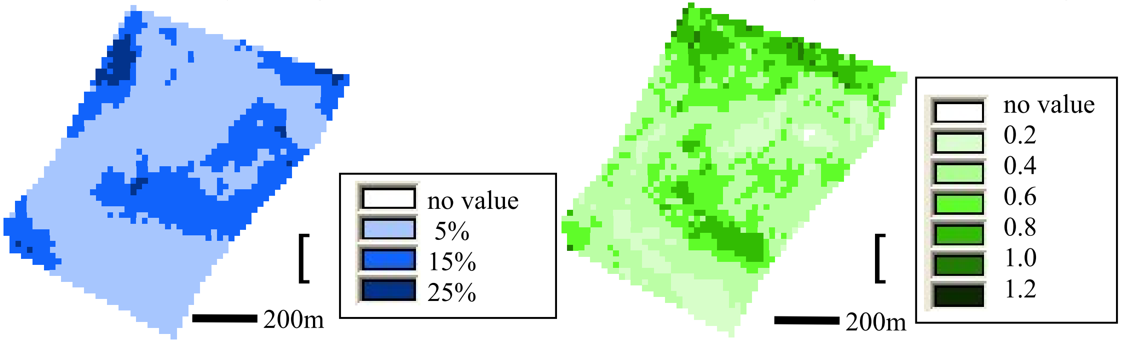


Figure 6: Soil moisture (left) and leaf area index (right) retrieved from the CHRIS nadir acquisition data of Jun 02 using the SLC model inversion.

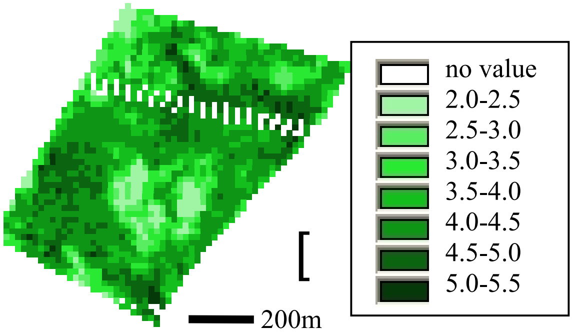


Figure 7: Leaf Area Index retrieved with SLC model inversion from CHRIS nadir acquisition (Aug 03)

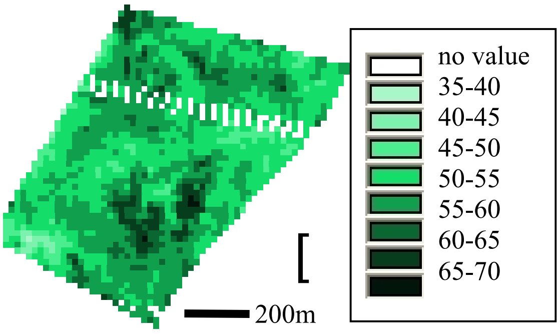


Figure 8: Chlorophyll content per cm² leaf area [µg/cm²], retrieved with SLC model inversion from CHRIS nadir acquisition (Aug 03)

due to the simple fact that the same soil nitrogen content has to be divided through more biomass where LAI is higher. Consequently, the resulting chlorophyll content per leaf area is lower. If the chlorophyll content per leaf area is multiplied with the observed leaf area, the result is the chlorophyll content per ground area (Fig. 9). As expected, the aggregated chlorophyll content is higher in the regions with higher LAI – and the meander can still be seen.

For the angular acquisitions differences in the retrieval results compared with the results obtained from the nadir acquisition are small. Table 1 shows the average and standard deviation at Aug 03 for LAI and chlorophyll for the forward looking angles. For the LAI, the average of nadir and +55° acquisitions are almost the same, 3.85 to 3.83. The +36° estimates slightly higher LAI values of 4.03. Sigmas range from 0.69 to 0.75. For chlorophyll, the retrieved average values get higher with larger incident angles, yet variances get smaller.

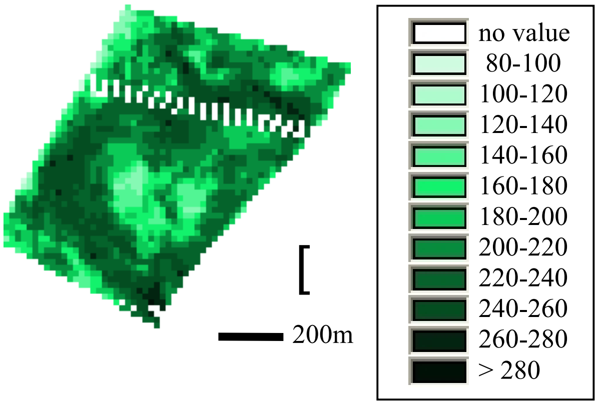


Figure 9: Chlorophyll content per m² ground [µg/m²] derived from chlorophyll per cm² leaf times LAI, CHRIS nadir acquisition (Aug 03)

Table1: Average and standard deviation (sigma) of LAI and chlorophyll retrieval of directional CHRIS acquisitions for the maize field (Aug 03)

	Nadir		+36°		+55°	
	average	sigma	average	sigma	average	sigma
LAI	3.85	0.75	4.03	0.70	3.83	0.69
Chlorophyll	55.45	4.88	56.05	4.71	60.43	4.34

The comparison of CHRIS measurements and SLC inversion results with ground truth will be targeted in future. For the next year ground measurements will be timed to satellite acquisitions. This was unfortunately not possible for 2003 as prediction of over-flight and data acquisition for the Upper Rhine Valley test-sites was usually too late. Since 2004 this CHRIS-test site is translocated to Baasdorf, a village in eastern Germany. In this region a test farm of the PreAgro project (www.preagro.de) is situated. Here a large amount of ground truth will be available. A further advantage of this region is the larger field sizes that will allow the study of infield variations using CHRIS data to a wide extend.

Conclusions

Today commercial airborne hyperspectral sensors exist and are in use, yet spaceborne sensors are in a research and development state; CHRIS is the only sensor already in space that additionally provides directional measurements. The first analyses of CHRIS data demonstrated that it is possible to extract valuable crop and soil information from spaceborne hyperspectral and directional data. 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 will provide information on the canopy structure. With this improved information on canopy structure the retrieval of plant physiological (LAI), phenological and biochemical (water, chlorophyll and nitrogen content) parameters can be expected.
Canopy reflectance model like SLC have achieved a status that they allow the extraction of plant parameters such as LAI, chlorophyll and water content. Those parameters can in turn serve as input parameters for plant production and management models like crop growth models. The combined use of remote sensing measurement, canopy reflectance models and crop growth models will be a baseline for improved precision farming measures.

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