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A LUT APPROACH FOR BIOPHYSICAL PARAMETER RETRIEVAL BY RT MODEL INVERSION APPLIED TO WIDE FIELD OF VIEW DATA

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ABSTRACT

Since many years scientists have been working on techniques for retrieving biophysical and biochemical canopy parameters from remote sensing data. Recently the inversion of canopy reflectance models has been well established as a reliable alternative to the classical empirical approaches. However, still a few obstacles have to be taken for making this technique fully operational. In this context a lookup table approach was developed for the inversion of the combined leaf and canopy reflectance model PROSPECT+SAILH. The approach contains some elements that enable the use of scene specific information, such as the option of performing the inversion per user-defined land cover class. This may lead both to a more reliable parameter estimation as well as to a reduced calculation time since the algorithm does not have to take into account all possible reflectance cases within a scene. An important aspect of the inversion algorithm is the possibility to incorporate pixel based information on view geometry thus using the information contained in BRDF signatures instead of correcting for it.

The model was tested on HyMap hyperspectral imagery of summer 2003 taken of the area surrounding Lake Waging-Taching in Southeast Germany. Scan angle and azimuth information contained in a file resulting from parametric geocoding was used to assess the spatial variation of view geometry to the separate pixels. Compared to the case in which only nadir view information is used, the model performed significantly better in the sense that it eliminated biased parameter estimations induced by BRDF effects. A comparison of parameter values estimated from data of the same area, but with different flight and sun configurations, shows that the results are much more consistent when view geometry is taken into account, even though measurements were not taken in the principal plane, and were supposed to be little affected by directional influences. A validation with measured field parameters is yet to be performed.

INTRODUCTION

With regard to precision farming and crop growth modelling, there is an ever increasing interest in remote sensing products describing canopy biophysical variables at pixel scale. Knowledge of vegetation state variables such as leaf area index (LAI) or canopy water content can help to improve predictive performance of agro-hydrological models which in turn may contribute to a more appropriate use of pesticides, fertilizers and water.

For the retrieval of biophysical parameters radiative transfer model inversion is more and more regarded as a promising alternative to the classical (semi-)empirical methods (i, ii). Even if radiative transfer model inversion has a lot advantages compared to the classical approaches, such as a broader applicability and the possibility to use all spectral information and incorporate sun and view geometry, it also has to deal with several drawbacks as for instance the fact that there is not always a unique solution of the inverse problem and that large computational expenses are requested. Last mentioned becomes critical if one wishes to transfer the model from the research level to an operational environment where large data sets and many spectral bands have to be processed. Additionally, particularly when the inversion model is applied to imagery originating from sensors with a wide field of view, for a single image the algorithm has to deal with differences in reflectance resulting from a changing view zenith and azimuth.

For the inversion of radiative transfer models, three techniques are commonly used: iterative optimization (i, ii), artificial neural networks (iii, iv) and look-up table approaches (i, v, vi) which all have their advantages and disadvantages (for a comparison see: (vii)). For this study an approach based on a lookup table (LUT) inversion was chosen which has the advantage that once the LUTs have been generated, inversion is relatively fast. Besides, the LUTs can be adapted according to the view/sun geometry and the variation of the scene elements at the time of data recording. For the moment the model runs only for the for agricultural combined leaf and canopy reflectance model PROSPECT+SAILH (viii, ix) and therefore is suited only for land cover types that fulfil the assumption of a turbid medium. SAILH is based on the so-called four-stream approximation that takes into account both directional and hemispherical incoming and outgoing radiation. For a detailed description of both models and the required inputs, see (viii, ix).

METHODOLOGY

General approach

The inversion algorithm proposed in this paper follows a methodology similar to the one used for the generation of FPAR and LAI products from MODIS/EOS data (x). A schematic layout of the inversion procedure is given in figure 1. The LUT based inversion algorithm consists of two principle modules: a module in which the LUTs are generated using PROSPECT and SAILH in the direct mode to simulate a large range of possible spectra, and a module in which the generated LUTs are used in an inverse way to retrieve the biophysical parameters from the top of canopy reflectance data in the scene.

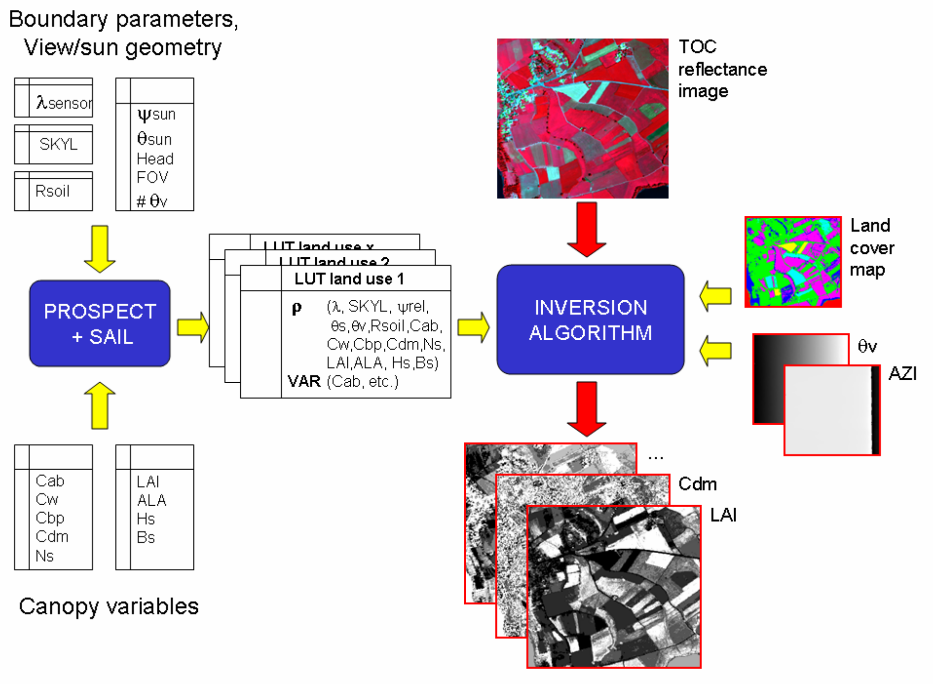


Figure 1: Schematic overview of lookup table based inversion.

Inversion can be performed for different land cover classes separately. This option has the advantage that the user, taking into consideration the crop type, its phenological stage, and the background signal, can confine the parameter values to plausible ranges prevailing at the time of recording. This a priori knowledge may lead to more reliable estimations and has the welcoming side effect of a reduced calculation time since the LUTs do not have to comprise all possible reflectance cases that can be found within the scene. The LUTs that were generated for the different land cover units are linked to the relevant image by a land cover map. This land cover map may be the result of a classification, a ground truth campaign in the field, or other.

Core of the inversion procedure is the incorporation of view and sun geometry. As canopy reflectance varies with relative azimuth and relative zenith angle between view and sun direction, this information implicitly has to be taken into account during the generation of the LUT. Although solar elevation and sun and view azimuth can be considered constant for one airborne scene, the scan angle for every pixel changes with a regular increment between the extreme view angles delineated by the field of view (FOV) of the sensor. Obviously, not for every scan angle in the image a different LUT can be created. (xi) proposed a method based on a polynomial fit for suiting a single LUT to any view/sun geometry. We followed a different approach consisting in automatically creating different LUTs for a limited, user defined, number of scan angle intervals and azimuth directions while other parameters remain unchanged. During model inversion the algorithm for the pixel under inversion picks out the right LUT using an image containing the scan angle and scan azimuth information of each pixel. For most data this file is automatically generated during preprocessing, e.g. (xii).

The study area

The performance of the algorithm was tested on site close to Lake Waging-Taching in the foreland of the Bavarian Alps, close to Salzburg. It is characterized by an undulating landscape whose elevation oscillates between 450 to 700 meters above sea level. Land use at the test site is dominated by agriculture, of which around two third is constituted by grassland. Grassland use is predominantly intensive, which is represented by up to seven cuts a year and additional manuring for meadows and frequently grazing (and the resulting constant dung input) for pastures.

Hyperspectral data

Remote sensing data were recorded from an airborne platform at June 30th 2003 with the HyMap sensor (xiii). The instrument contains 126 spectral bands throughout the optical domain and has a FOV of approximately 61°. The flight altitude of roughly 2400 meter above ground level resulted in an average pixel size of 5 meters for the selected scenes. Properties of the flight lines, the solar elevation and the solar azimuth for the different (sub)scenes used in this study are found in table 1. Flight configuration was chosen such that the study area of interest was recorded under different view and illumination directions. Due to a flight schedule that was changed on the run, unfortunately no recordings in the principal (plane) were recorded.

Table 1: Configuration of the flight lines used in this study.

Flight line	Heading	Solar azimuth	Solar zenith
waging07	180.04°	118.96°	37.43°
waging13	89.98°	136.2°	30.57°

Ground based reflectance measurements during the overflight have been obtained with a handheld ASD Fieldspec Pro FR (Analytical Spectral Devices, Inc, Boulder, Colorado, USA). Reference spectra were taken of homogeneous highly reflective surfaces in order to validate sensor calibration and atmospheric correction.

For the direct georeferencing of the radiometrically calibrated HyMap images a parametric approach was carried out. For the geocoding of the image the software program PARGE (xii) uses the flight attitude and DGPS position of the sensor recorded during the overflight, together with a digital elevation model of the area. Additionally a small number of ground control points (GCPs) was used, based on a 1:25000 topographical map of the area. As an ancillary product of geocoding, a file is created that contains view azimuth and view angle information of each pixel in the scene. The software tool ATCOR4 (xiv), based on the MODTRAN radiative transfer code was used for the combined correction of atmospheric and topographic effects of the wide field-of-view HyMap imagery. Calibrated radiance data were converted to top of canopy reflectance using a few reference ASD ground spectra for in-flight calibration.

Radiative transfer model inversion

The inversion was tested for several grasslands in the area. As it appeared to be difficult to characterize grass land use solely by its spectral properties (xv), we decided to apply a supervised maximum likelihood classifier and divide the grasslands into two classes: fields that recently had been cut, characterized by a low LAI and leaf chlorophyll content, and fields that were in a more mature stage. As a result of the chosen classifier both classes contained a lot of intermediate growth stages as well. Other land cover types were masked during analysis.

For the two grassland types LUTs were generated with a combination of PROSPECT and SAILH according to the input parameters described in table 2. For the purposes of calculation speed, variables that have little influence on the reflectance spectrum or vary little per land use class were kept fixed at a typical value (for both classes leaf dry matter content was fixed to a value of 0.0105 g cm^{-2}, leaf brown pigment content is 0.001, leaf structure parameter N is set to 1.7, soil brightness equals 1 and the hotspot is set to 0.015 cm cm^{-1}), which resulted in a LUT with 2500 entries in total. The fraction of diffuse radiation was estimated with ATCOR (xiv), and a soil spectrum measured in the field was used as background spectrum. No noise or bias was added to the simulated spectra in the LUT. LUTs were generated for the two different relative azimuth angles, pertaining to the left/right part of each scene (with respect to nadir), at view angle intervals of one degree.

Table 2: Parameter distributions used for the generation of the lookup table for the classes grass-cut (l)and grass-mature(r). Parameter distribution functions are taken from (i).

Inputs (units)	Minimum	Maximum	Nr. of values	Transformed variable
SAILH				
LAI (unitless)	0.5 / 0.5	3 / 8	20	$e^{-LAI/2}$
ALA (°)	60 / 50	85 / 85	5	cos(ALA)
PROSPECT				
Cab (µg cm^{-2})	5 / 10	50 / 100	5	$e^{-Cab/100}$
Cw (g cm^{-2})	0.004 / 0.005	0.03 / 0.03	5	e^{-50Cw}

The solution of the inverse problem is found by sorting the LUT according to a cost function which is a simple root mean square error between the measured spectrum and the simulated reflectance found in the LUT:

$$RMSE = \sqrt{\frac{1}{n_\lambda}\sum_{i=1}^{n_\lambda}\left(R^i_{meas} - R^i_{LUT}\right)^2}$$

where n_λ is the number of wavelengths used in the calculation, R^i_{meas} the measured image reflectance, and R^i_{LUT} the simulated reflectance of the spectrum in the lookup table at wavelength *i*. The solution is considered as the mean of the set of simulated canopy reflectances providing the 50 smallest RMSE values with the measured spectrum (vi). In our case the RMSE was calculated based on the centre wavelengths of the 6 broadband channels of the LANDSAT ETM+ sensor, since others had achieved good results using this configuration (iii). Inversion concentrated on the retrieval of LAI and leaf chlorophyll content.

RESULTS AND DISCUSSION

Figure 2 shows the estimated chlorophyll a+b content for class "meadow-long" applying a LUT inversion on waging07(a), for the cases that only one LUT created for nadir looking direction is used (b) and for the case that view angle dependent LUTs are used (c). It can be clearly seen that the BRDF effects present in the TOC reflectance scene are reflected in the estimated parameter values if no correction for scan angle is applied.

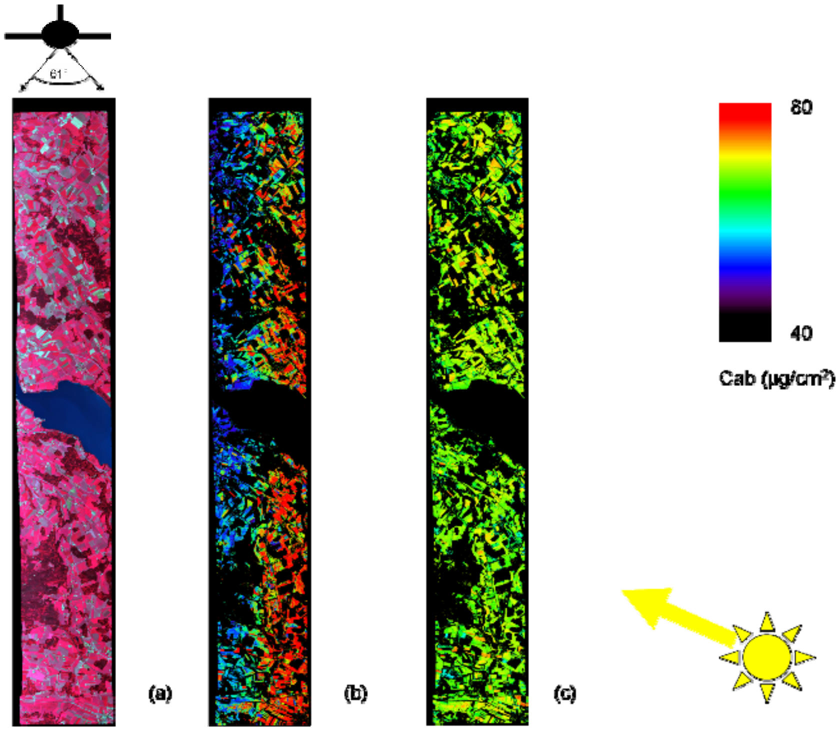


Figure 2: PROSPECT+SAILH inversion of HyMap scene of Waging Taching catchment from June 30th 2003 for the class "meadow – long" (heading = 180°, ψs = 118°, θs = 38°)(a). Chlorophyll a+b content (µg/cm2) retrieved without (b) and with (c) the view angle correction described in this paper.

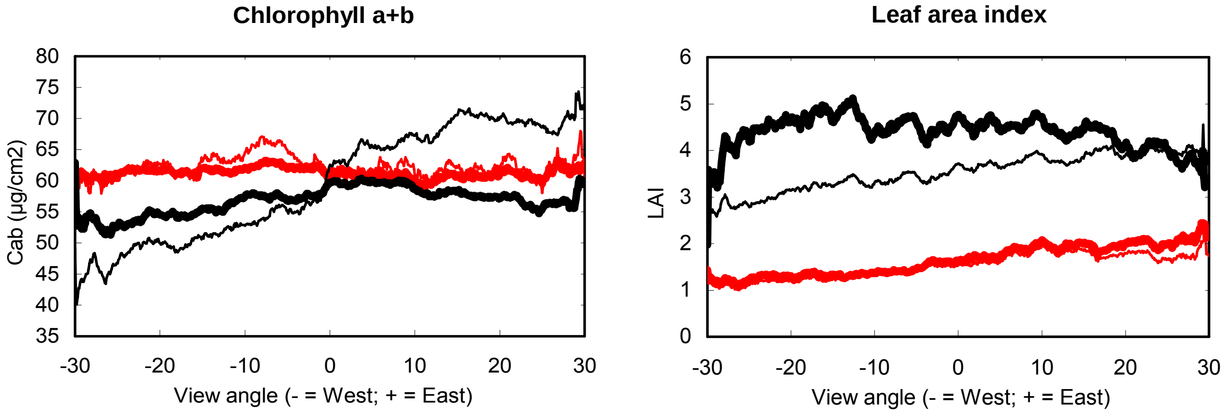


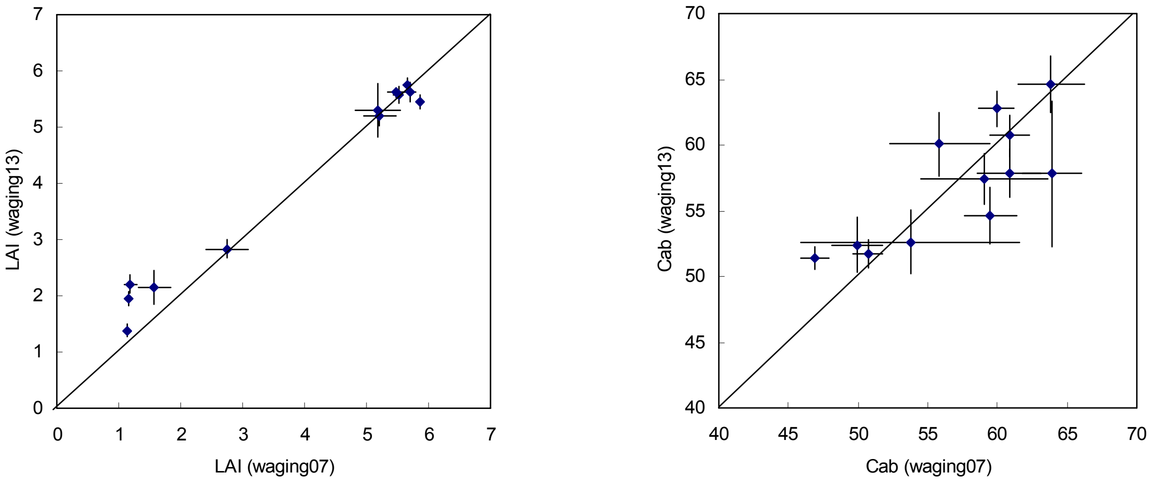
Figure 3: Scan angle dependence of the average estimated chlorophyll a+b content and LAI for class "meadow – long" (black) and "meadow - cut" (red). Thick lines correspond to values estimated with view angle correction, thin lines to data without view angle correction.

In order to better visualize the trends in the retrieved parameters, the average chlorophyll content per view angle was calculated for class meadow-long and meadow-cut for the whole scene (figure 3). Trends resulting from BRDF effects now can be clearly distinguished. However, for LAI the improvements due to the incorporation of view angle information is not so convincing as for the chlorophyll content. This might have to do with the fact that changes in LAI are partially compensated by changes in other parameters such as average leaf angle (not shown). This is a well known phenomenon which is also called the ill-posed problem (i). Further constraining the parameter ranges for each land cover class during the generation of the LUTs may possibly reduce errors of this nature.

It would be interesting to see how consistent the parameter retrieval is for the cases with and without scan angle correction when sun and view configuration are changed. For this purpose, for 12 fairly homogeneous fields where the two flight lines given in table 1 overlap, retrieved LAI and chlorophyll content were compared. If the inversion algorithm is consistent, the algorithm should provide the same parameter values for both view/sun configurations. The results of the comparison is given in figure 4.

LAI – no view angle correction

LAI – with view angle correction



Ca+b (µg cm-2) - no view angle correction

Ca+b (µg cm-2) - with view angle correction

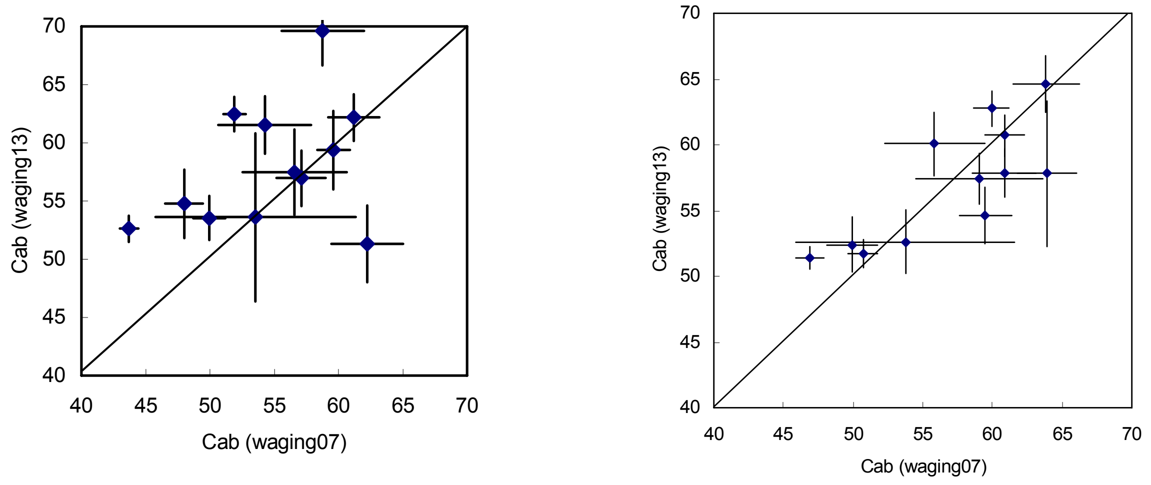


Figure 4. LAI and Chorophyll a+b values retrieved from two images with different view/sun geometry without (left) and with(right) the view angle correction presented in this paper. Error bars show the standard deviation within one field.

In the two upper plots presented in figure 4 the retrieved LAI from both view/sun configurations is compared for the LUT inversion without (left) and with (right) view angle correction. For both cases predicted values for the two view/sun geometries are very similar and show a correlation coefficient of 0.98 (RMSE = 0.24) and 0.99 (RMSE = 0.21) respectively. The scan angle based inversion performs slightly better for lower LAI values. These results confirm the findings illustrated in figure 3 where there is not a very strong difference for LAI either. The two clusters of data points that can be distinguished in the plots correspond to the two grassland classes with low and high LAI values.

A clearly distinct result is found for the estimated chlorophyll content (figure 4b). The values retrieved from both images show much less dispersion when view angle correction is taken into account (R^2 = 0.63; RMSE = 2.86 µg cm^{-2}) compared to the ones that were retrieved without taking into account differences in reflectance due to BRDF effects (R^2 = 0.13; RMSE = 5.19 µg cm^{-2}). Although the results are not 100% consistent between the two flight/sun configurations, the correction for view angle dramatically improves the parameter retrieval in this case. This finding becomes even more remarkable if one realizes that flight configuration was far out of the principal plane. A future validation with field measurements should further test the validity of the results.

CONCLUSIONS AND OUTLOOK

A LUT approach was presented for the retrieval of biophysical parameters by radiative transfer model inversion on a regional scale. Spectral differences resulting from BRDF effects are directly incorporated in the inversion algorithm while using information on view/sun geometry. The algorithm showed promising results in terms of eliminating aberrant trends in retrieved parameter values resulting from BRDF effects in the TOC reflectance scene. However, improvements were not uniform for all parameters, which could be attributed to the ill-posedness of the inverse problem. Further constriction of parameter ranges for each land cover class might bring a solution to this problem.

In the case where view/sun geometry for specific targets were altered, the parameters retrieved by model inversion appeared significantly more consistent if view angles were taken into consideration.

The retrieval performance of the model has yet to be validated with field based measurements of biophysical properties. Moreover, it would be interesting to look how the model reacts on data taken in the principal plane. This would be an important issue since view configurations including the principal plane deliver most information on structural canopy parameters and might reduce the number of multiple solutions of the inverse problem. A comparison with an inversion performed on data that have been corrected ex ante for BRDF effects would spell out the actual gain of the approach described in this study.

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