ESTIMATION OF FOREST BIOPHYSICAL CHARACTERISTICS THROUGH COUPLED ATMOSPHERE-REFLECTANCE MODEL INVERSION USING HYPERSPECTRAL MULTI-DIRECTIONAL REMOTE SENSING DATA – A CONTRIBUTION TO FUTURE FOREST INVENTORY STRATEGIES

Martin Schlerf & Joachim Hill

University of Trier, Remote Sensing Department, D-54286 Trier, Germany
E-mails: schlerf@uni-trier.de – hillj@uni-trier.de

ABSTRACT

Our planned research activities for 2005 are embedded in ongoing activities concerning advanced forest inventory strategies with remotely sensed data which are conducted in cooperation between the Remote Sensing Department and the Ministry of Environment and Forestry of the federal state of the Rhineland-Palatinate. The scope of these activities is the development of a remote sensing based support segment to the conventional forest inventory system which is increasingly affected by the limitations of public finances. It is to be expected that hyperspectral multi-directional sensor systems may provide substantial progress in comparison to the operational earth observation systems (such as Landsat, Spot, Quickbird and Ikonos), and that they may become an important component in future earth observation strategies. The analysis of CHRIS data will thus be substantially supported by staff and financial resources being available under the research umbrella outlined above.

1. INTRODUCTION

Remote Sensing of forest biophysical variables has become increasingly important for a wide range of applications such as forest inventory and management, forest fire assessment and environmental change analysis (Cihlar et al., 2003). In contrast to vegetation index and spectral mixture analysis, forest reflectance models can take into account effects of shadowing and multiple scattering and are general applicable to all sites and sampling conditions (Asner et al., 2003). For the retrieval of canopy variables from measured signals it is necessary to invert the model. Most of the research on model inversion either used synthetic data (Iaquinta et al., 1997; Kimes et al., 2002) or multi-/hyperspectral nadir images (Fernandes et al., 2004; Kötz et al., 2004). However, it was shown that the use of multi-angle data further improved estimates of forest canopy variables compared to nadir data (Bicheron & Leroy, 1999; Gemmell, 2000; Meroni et al., 2004); additionally, narrowband hyperspectral imaging systems are able to capture more information relevant to the characterisation of forests than broadband multispectral systems (Lee et al., 2004; Schlerf et al., 2005). Consequently, the utilisation of hyperspectral multi-directional angle data is considered a prime option for advanced quantitative analysis.

Yet, studies that used model inversion on hyperspectral multi-angle satellite remote sensing data for the estimation of forest characteristics including a validation with ground truth data are still rare. Therefore, the main objective of the intended project is to estimate forest biophysical characteristics, such as leaf area index (LAI), crown cover and standing biomass from CHRIS data through inversion of an approved forest reflectance model thereby providing an in-depth validation of the estimates by ground truth sampled during the satellite overpass.

2. MODELLING OF RADIATIVE TRANSFER IN THE ATMOSPHERE

A successful inversion of a reflectance model requires three factors: a set of calibrated reflectances, a well-adapted model and an appropriate inversion procedure (Jacquemoud et al., 2000). Calibrated and atmospherically corrected reflectances will be obtained using an in-house developed software package AtCPro 3.01 (Hill & Sturm, 1991; Hill et al. 1995) that is based on the formulation of radiative transfer in 5S and 6S (e.g., Tanré et al., 1990). The software has recently been refined to cope with specific requirements of airborne hyperspectral image data (Hill & Mehl, 2003) and will be further adapted to accomplish multi-view angle data.

A successful sensor calibration and atmospheric correction of hyperspectral remote sensing imagery has been already achieved with data from the HyMap sensor that was acquired over the intended test site during on July 17, 1999 (Figure 1). On this day nearby Idarwald, measurements of atmospheric beam transmittance were conducted with a CIMEL photometer between 6:00 and 12:00 GMT. Their evaluation yielded an aerosol optical depth of $\tau_a = 0.33$ at $\lambda = 0.550$ µm (i.e., a horizontal visibility of approximately 15 km). Contemporarily, bi-directional reflectance measurements from 11 carefully selected ground targets with different surface characteristics (gravel, asphalt, dense lawn and water) were collected with an ASD FieldSpec II instrument to reconstruct, in combination with the derived aerosol

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

optical depth and a water vapour concentration of 3.8 g/cm^2 (iterative approximation based on several MODTRAN runs), a set of updated HyMap in-flight calibration coefficients. It turned out that, except for single noisy bands with limited radiometric performance (e.g. band 1 = 0.403 µm, all bands > 2.410 µm) the resulting adjustments remained within ± 15 % of the HyMap pre-flight calibration values. Using these updated calibration coefficients with our extended implementation of 5S (AtCPro 3.01) it was possible to reconstruct a spatially differentiated water vapour map for the HyMap scene acquired over Idarwald which, in a final run, was integrated into the atmospheric correction processing of this image. This correction also included a correction for terrain induced illumination effects, for which specific DEM-derivates (slope, aspect, and the proportion of the visible hemispherical sky at each pixel) had been transferred to the geometry of the original HyMap image using the parametric image processing software PARGE developed by Schläpfer et al.(1998). The visual impression of relief present in the raw data was removed after applying the topographic correction. The obtained reflectance spectra indicated a good data quality, ensuring a sound basis for quantitative data exploration.

3. MODELLING FOREST REFLECTANCE

A prime candidate model to simulate forest reflectance is the Invertible Forest Reflectance Model (INFORM; Atzberger, 2000) which simulates the bi-directional reflectance of forest stands between 400 and 2500 nm. It is essentially a combination of FLIM (Rosema et al., 1992), SAIL (Verhoef, 1984), and LIBERTY (Dawson et al., 1998). The model was successfully inverted by a neural network approach (Gong et al., 1999; Udelhoven et al., 2000; Kimes et al., 2002) using the radiometrically corrected HyMap data. The inversion procedure, developed by Schlerf & Atzberger (2002, 2005) consisted of four major steps (Figure 2): (a) forward modelling to generate synthetic canopy spectra, (b) training of the neural network using the modelled data, (c) application of the trained ANN to measured HyMap spectra to estimate forest canopy variables and for eventually modifying the network architecture, and (d) the application of the final ANN to the image for generation of bio-physical parameter maps.

A fundamental prerequisite to reflectance model inversion is a valid model that is capable of accurately representing radiative transfer within the complex forest structure. To make sure that the model outputs were realistic, INFORM was parameterised using ground truth information. This allowed comparing modelled and measured HyMap reflectances. In 1999, 40 relatively homogenous spruce stands were identified at the study area and within these stands quadratic plots of 30 m side length were established. The central location of each ground plot was determined with an accuracy of about ±5 m using a differential GPS device. At each plot, measurements of forest biophysical variables were carried out during summer and autumn of 2000. Measured biophysical variables included leaf area index (LAI), stem density, canopy closure and stand height. LAI was estimated using a Li-Cor LAI-2000 Plant Canopy Analyser (PCA). The instrument estimates effective LAI using measurements of diffuse solar radiation above and below the forest canopy.

After correct parameterisation, the INFOR model simulated forest reflectance spectra comparable to those measured by the HyMap sensor. There was a good agreement between modelled and measured spectral reflectance in the near-IR wavebands and an acceptable agreement in the mid-IR. In the visible, however, model outputs and HyMap reflectances disagreed and the model has to be further improved. The results further showed that INFORM can be inverted with a neural network approach to give estimates of important structural forest characteristics. Relatively simple network architecture with just one neuron in the hidden layer proofed to be suitable to solve the inversion problem. Estimates of forest LAI and percent coverage showed good agreement with ground truth data that had been obtained from 39 forest plots whereas stem density could only be estimated with fair quality. Using two HyMap wavebands at 837 nm and 1148 nm the obtained accuracy of the LAI map amounts to an rmse of 0.58, e.g. relative rmse 18 % of mean (Schlerf & Atzberger, 2005).

In opposition to empirically derived prediction functions that are generally limited to the local conditions at a certain point in time and to a specified sensor type, the calibrated reflectance model could be applied more easily to different optical remote sensing data acquired over central European spruce forests.

4. RESEARCH PROGRAMME FOR 2005

In the preparation phase, the software package AtCPro 3.01 will be adapted to cope with multi-view angle data and the forest reflectance model will be modified to meet specifications of the CHRIS sensor. Parallel to the overpass of the CHRIS sensor in summer 2005, ground data of two types will be sampled: i) ground reflectance of targets that are used to validate the radiometric correction of the image data will be measured with a Field-Spec II spectroradiometer; ii) field measurements of forest stand attributes will be used to validate the results of the reflectance model inversion. About 40 plots of *Picea abies* were already probed in 1999 at the test site at the Idarwald forest in south western Germany; these measurements will be repeated during summer 2005 to obtain up to date stand values of leaf area index (LAI), stem density, diameter at breast height, canopy height and crown cover. After geometric and radiometric correction of CHRIS image data, the fine-tuning of the reflectance model with respect to

CHRIS data has to be performed. The inversion results obtained on CHRIS data are going to be validated with the ground truth data collected in the field. In particular, results obtained with nadir data alone will be compared to the multi-angle product. At the end of the planned research map layout and end production finalisation will take place.

Deliverables of the project will be image data corrected to ground reflectance and maps of forest biophysical variables (e.g., LAI map). Once the forest reflectance model is calibrated using the ground truth data, repetitive acquisition of CHRIS imagery in the future can be used to retrieve the actual forest condition and to document changes in forest structure over space and time.

5. REFERENCES

Asner, G. P., Hicke, J. A., Lobell, D. B. 2003: Per-pixel analysis of forest structure: Vegetation indices, spectral mixture analysis and canopy reflectance modeling. In: Wulder, M. A. & Franklin, S. E. (Eds.): Remote sensing of forest environments. Concepts and case studies. Boston, Dordrecht, London (Kluwer Academic Publishers): 209-254.

Atzberger, C. 2000: Development of an invertible forest reflectance model: The INFOR-Model. In: Buchroithner (Ed.): A decade of trans-European remote sensing cooperation. Proceedings of the 20th EARSeL Symposium Dresden, Germany, 14.-16. June 2000: 39-44.

Bicheron, P. & Leroy, M. 1999: A method of biophysical parameter retrieval at global scale by inversion of a vegetation reflectance model. Remote Sensing of Environment, 67: 251-266.

Cihlar, J.; Latifovic, R.; Beaubien, J.; Trishchenko, A.; Chen, J.; Fedosejevs, G., 2003: National scale forest information extraction from coarse resolution satellite data, Part 1. In: Wulder, M. A. & Franklin, S. E. (Eds.): Remote sensing of forest environments. Concepts and case studies. Boston, Dordrecht, London (Kluwer Academic Publishers): 337-358.

Dawson, T. P., Curran, P. J., Plummer, S. E. 1998: LIBERTY - Modeling the effects of leaf biochemical concentration on reflectance spectra. Remote Sensing of Environment, 65: 50-60.

Fernandes, R., Miller, J. R., Chen, J. M. & Rubinstein, I. G. 2004: Evaluating image-based estimates of leaf area index in boreal conifer stands over a range of scales using high-resolution CASI imagery. Remote Sensing of Environment, 89: 200-216.

Gemmell, F. 2000: Testing the utility of multi-angle spectral data for reducing the effects of background spectral variations in forest reflectance model inversion. Remote Sensing of Environment, 72: 46-63.

Gong, P., Wang, D. & X., Liang, S. 1999: Inverting a canopy reflectance model using a neural network. International Journal of Remote Sensing, 20(20): 111-122.

Hill, J. & Mehl, W. 2003: Georadiometrische Aufbereitung multi- und hyperspektraler Daten zur Erzeugung langjähriger kalibrierter Zeitreihen. Photogrammetrie-Fernerkundung-Geoinformation, 1/2003: 7-14.

Hill, J.; Mehl, W.; Radeloff, V. 1995: Improved forest mapping by combining corrections of atmospheric and topographic effects in Landsat TM imagery. In: Askne, J.: Sensors and environmental applications of remote sensing. Proc. 14th EARSeL Symposium, Göteborg, Sweden, 6-8 June 1994 Rotterdam (Balkema): 143-151.

Hill, J.; Sturm, B. 1991: Radiometric correction of multi-temporal Thematic Mapper data for use in agricultural land-cover classification and vegetation monitoring. International Journal of Remote Sensing, 12: 1471-1491.

Iaquinta, J., Pinty, B., Privette, J. L. 1997: Inversion of a physically based bidirectional reflectance model of vegetation. IEEE Transactions on Geoscience and Remote Sensing, 35(3): 687-698.

Jacquemoud, S., Bacour, C., Poilve, H. & Frangi, J.-P. 2000: Comparison of four radiative transfer models to simulate plant canopies reflectance: Direct and inverse mode. Remote Sensing of Environment, 74: 471-481.

Kimes, D., Gastellu-Etchegorry, J, Estève, P. 2002: Recovery of forest canopy characteristics through inversion of a complex 3D model. Remote Sensing of Environment, 79: 320-328.

Kötz, B., Schaepman, M., Morsdorf, F., Bowyer, P., Itten, K. & Allgöwer, B. 2004: Radiative transfer modeling within a heterogenous canopy for estimation of forest fire fuel properties. Remote Sensing of Environment, 92: 332-344.

Lee, K.-S., Cohen, W. B., Kennedy, R. E., Maiersperger, T. K. & Gower, S. T. 2004: Hyperspectral versus multispectral data for estimating leaf area index in four different biomes. Remote Sensing of Environment, 91: 508-520.

Meroni, M., Colombo, R. & Panigada, C. 2004: Inversion of a radiative transfer model with hyperspectral observations for LAI mapping in poplar plantations. Remote Sensing of Environment, 92: 195-206.

Rosema, A., Verhoef, W., Noorbergen, H. 1992: A new forest light interaction model in support of forest monitoring. Remote Sensing of Environment, 42: 23-41.

Schlerf, M. & Atzberger, C. 2002: Use of a forest reflectance model for empirical estimation of Norway spruce characteristics from hyperspectral remote sensing imagery. In: Sobrino, J. (Ed.):

Recent advances in quantitative remote sensing, Proc. of the 1st International Symposium, Valencia: 121-128.
Schlerf, M. & Atzberger, C. 2005: Inversion of a forest reflectance model to estimate leaf area index from hyperspectral remote sensing data. Submitted to Remote Sensing of Environment.
Schlerf, M., Atzberger, C. & Hill, J. 2005: Remote sensing of forest biophysical variables using HyMap imaging spectrometer data. Remote Sensing of Environment, 95: 177-194.
Schläpfer D.; Schaepman M. E. & Itten K. I. 1998: PARGE: Parametric Geocoding Based on GCP-Calibrated Auxiliary Data. In: SPIE Int. Symp. on Opt. Sc., Eng. and Instr. San Diego, CA: 334-344.
Tanré, D.; Duhaut, P.; Herman, M. 1990: Description of a computer code to simulate the signal in the solar spectrum: the 5S code. International Journal of Remote Sensing, 11: 659-668.
Udelhoven, T., Atzberger, C. & Hill, J. 2000: Retrieving stuctural and biochemical forest characteristics using artificial neural networks and physically based reflectance models. In: Buchroithner (Ed.): A decade of trans-european remote sensing cooperation. Proceedings of the 20th EARSeL Symposium Dresden, Germany, 14.-16. June 2000: 205-211.
Verhoef, W. 1984: Light scattering by leaf layers with application to canopy reflectance modeling: The SAIL model. Remote Sensing of Environment, 16: 125-141.

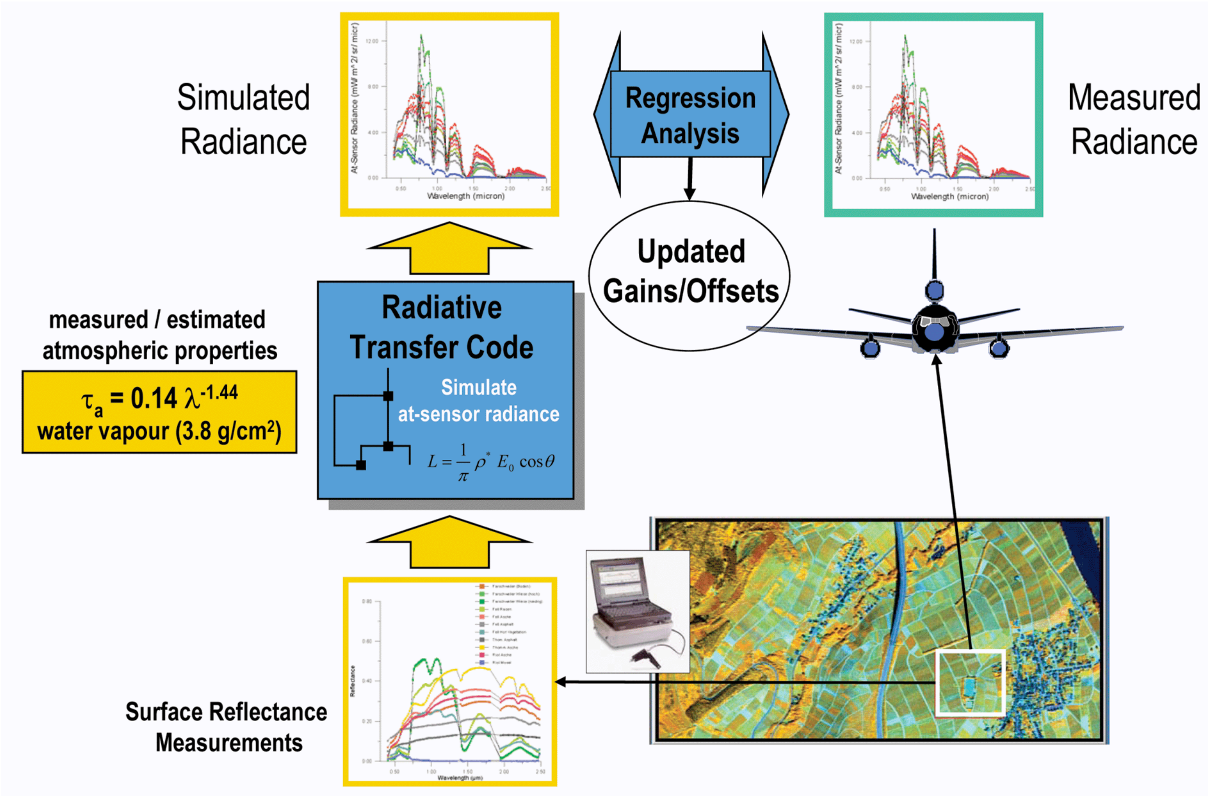

Fig.1. Sensor calibration setup with AtCPro 3.01

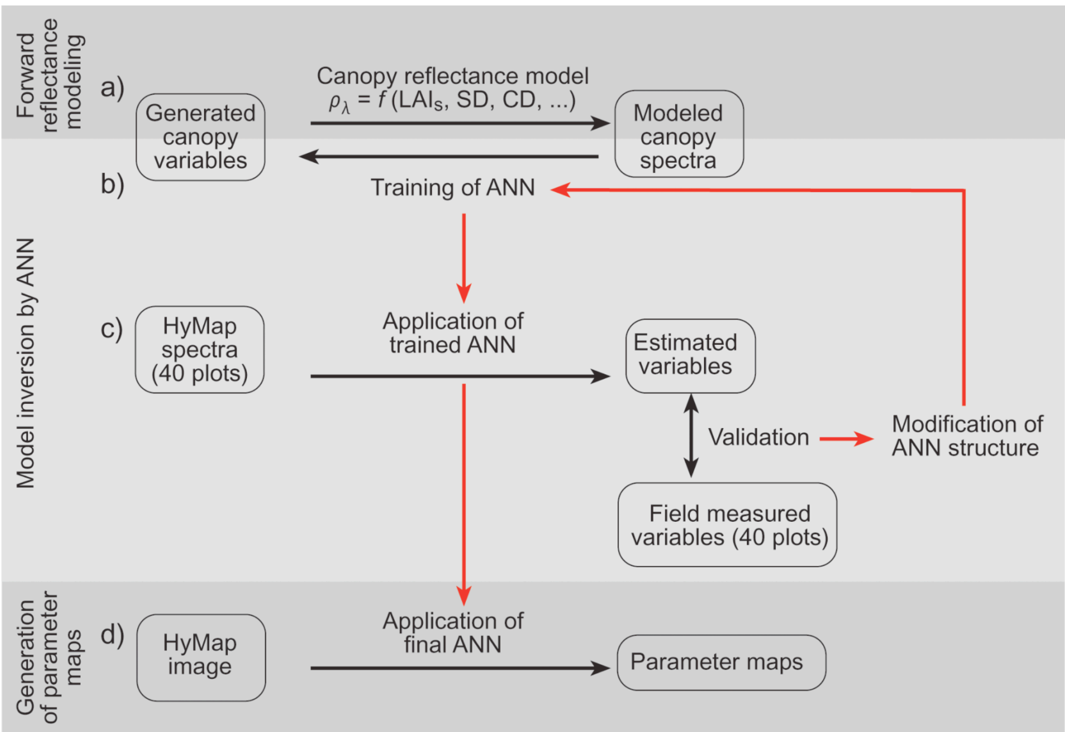

Fig. 2. General procedure for estimating canopy attributes from remote sensing data through inversion of a forest reflectance model. From Schlerf & Atzberger (2005).