

COMPARISON OF A HYPERSPECTRAL CLASSIFICATION METHOD IMPLEMENTED IN TWO REMOTE SENSING SOFTWARE PACKAGES

Benedicte Odden, Mathias Kneubühler and Klaus I. Itten

University of Zurich, Department of Geography, Remote Sensing Laboratories,
Winterthurerstrasse 190, 8057 Zürich, Switzerland, bodden [kneub, itten] @geo.uzh.ch

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ABSTRACT:

This paper presents a study that aims at applying, comparing and characterizing a proven method for hyperspectral land use classification that is currently integrated in two different remote sensing software packages. Recently a great deal of advances in the Geomatica Hyperspectral Analysis Package (HAP) has been made. The Spectral Angle Mapper (SAM) algorithm was used in both Geomatica and ENVI for this study and a hyperspectral dataset from the European sensor CHRIS onboard the platform PROBA-1 served as a test case. The study showed that, despite of many differences in the workflow of the two software packages, the two land use classification results of SAM turned out to be identical.

1. Introduction

The objective of this paper lies in a comparison of the Spectral Angle Mapper (SAM) classification method which is currently implemented in both the Geomatica [Geomatica, 2005] and the Environment for Visualizing Images (ENVI) [ENVI, 2006] software packages. The SAM algorithm permits rapid classification and mapping of the spectral similarity of image spectra to reference spectra [Kruse et al., 1993], however, its functionality is not the main focus of this paper. We concentrate on a) the assessment of the data processing environment (classification workflow tools) offered to the user by the two software packages in order to perform spectral angle mapping and b) the subsequent investigation of the classification result.

2. Datasets and Methods

2.1 Study area

An intensively used agricultural area (Vordemwald, 7°53'E, 47°16'N) located on the Swiss Plateau in central Switzerland is used as a testsite in this study. The lower parts of the testsite are dominated by agricultural fields and the hilltops mainly consist of mixed forests (elevations up to 700 m a.s.l.). Agriculture concentrates on barley, wheat, maize, sugar beet and pasture land. The Vordemwald testsite has been widely used in various studies that deal with an improved estimation of ecosystem

variables from imaging spectroscopy data [Huber et al., 2008, Kneubühler et al, 2008].

2.2 Data

Several multiangular CHRIS/PROBA datasets were acquired over the testsite Vordemwald on eight different dates between 26 May 2005 and 22 September 2005 [Kneubühler et al., 2006]. Out of these datasets, the nadir image of a dataset acquired on 17 August 2005 was chosen to be used in this study. Geometric and atmospheric correction of the dataset were performed following an approach described by Kneubühler et al. [2005].

During the 2005 growing season, extensive ground truth data collections in support of the CHRIS data takes were performed. In addition, a *Leica Geosystems Airborne Digital Scanner (ADS40)* [Sandau, 2005] dataset of the test area, acquired on 17 August 2005 in parallel to the CHRIS data takes was available as an additional source of ground truth. ADS40 datasets offer very high spatial resolution (25cm) and can therefore be used to visually locate individual fields belonging to different land use classes. As a consequence, a sufficient amount of training samples could be defined in order to make the subsequent classification as accurate as possible.

2.3 Endmember Selection and Classification

The SAM algorithm, being implemented in both Geomatica and ENVI, was applied, compared and characterized in the respective software

packages using the CHRIS/PROBA nadir image dataset of 17 August 2005. SAM is designed to classify hyperspectral image data using a set of reference spectra that define the classes [ENVI Help, 2006]. The land use classes were defined on the basis of the collected ground truth data (see Tab. 1).

Land Use Class	Ascertainment Abbreviation
Maize	M
Stubble Field (harvested, stramineous)	S2
Stubble Field (harvested, bare)	S3
Stubble Field (seeded, partly green)	S4
Harvested Field	A1
Seeded Field	A2
Ploughed Field	A3
Pasture Land	We
Grassland with trefoil	Wi
Alfalfa	L
Grassland without trefoil	GS
Sugar Beet	Z

Table 1: Land use classes as available from ground truth data.

The choice of adequate endmembers (reference spectra) is of major importance to obtain accurate classification results. Since the CHRIS/PROBA dataset has a spatial resolution of 18 meters, some of the sampled fields were not large enough to be taken into consideration because they mainly consist of mixed pixels.

In addition, several land use classes defined from ground truth data turned out to be spectrally not separable (e.g., the three Stubble Field classes (S2, S3 and S3) and the Harvested Field class (A1)). They had to be merged into one single class named Bare Fields. The respective classes all consist of very sparse vegetation due to harvesting and ploughing, which made their spectra unseparable from each other. For three other classes (Alfalfa (L), Seeded Field (A2) and Ploughed Field (A3)) the samples identified in the CHRIS/PROBA image contained mainly mixed pixels. Therefore, these land use classes had to be excluded from the following classification step. The quality of the training samples of the remaining classes was satisfactory to be used as endmembers for the classification. Additional classes (e.g., clouds, water, urban areas, forest and shadow) were defined by visual means and by using the ADS40 dataset (verification samples). Tab. 2

summarises the endmember classes used for SAM classification.

The same endmembers that were first defined for the classification in ENVI were also used in Geomatica. Thereby, possible differences in the implementation of the two programs could be found easier.

Endmembers classes for SAM classification
Maize
Bare Fields
Pasture Land
Grassland with trefoil
Grassland without trefoil
Sugar Beet
Clouds
Water
Urban area
Forest
Shadow

Table 2: Visually defined endmember classes for subsequent SAM classification.

2.3.1 SAM Classification ENVI

ENVI contains an application called the *Spectral Hourglass Wizard* (SHW) which guides the user step-by-step through the ENVI hourglass processing flow to find and map image spectral endmembers from hyperspectral data (see Fig. 1).

The SHW displays detailed instructions and useful information for each processing step.

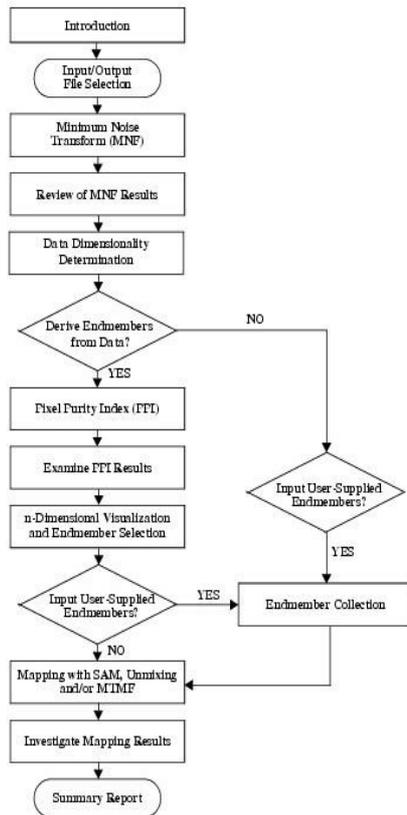


Figure 1: The ENVI Spectral Hourglass Wizard (SHW) [ENVI Help, 2006].

The first step in the hourglass processing flow deals with the *Minimum Noise Fraction* (MNF) determination. The MNF is used to describe the inherent dimensionality of imaging data, to segregate and equalize the noise in the data, and to reduce the computational requirements for subsequent processing [ENVI Help, 2006]. This processing step of the SHW is designed to provide a default calculation of the data dimensionality, but it is critical and scene dependent. It is therefore recommended to slightly overestimate the data dimensionality and add a few extra bands in order not to lose important information. Since the CHRIS/PROBA dataset used in this study consists of only 37 bands and the main objective of this work is to compare two software packages rather than to optimize the classification result, none of the 37 bands were left out for further processing.

The second step of the hourglass processing flow contains functionalities to derive endmembers directly from the input data. The *Spectral Analyst* is explicitly designed to do so. However, it is also possible to enter the endmembers from another source such as a spectral library, an ASCII file, a statistics file or

regions of interest (ROI). It is crucial that these files have the same data units and the same spectral scaling as the image data. For the classification of the CHRIS/PROBA image file the endmembers were derived from existing ground truth and imported from a regions of interest (ROI) file. Individual fields for the respective land use classes endmember determination were selected by considering whether their size was large enough to be identified and sampled in the CHRIS/PROBA dataset. By selecting such samples with the ROI tool, the problem of mixed pixels could be reduced.

In a next step, the *Pixel Purity Index* (PPI) was calculated on the CHRIS/PROBA dataset. This was done in order to identify additional endmembers beside the ones already identified from the ground truth. To calculate the PPI, the user needs to specify the number of iterations. The SHW recommends 5000 iterations for a useful result. The resulting PPI plot shows the number of iterations and the cumulative number of pixels that have been found to be spectrally extreme. When the iterations are completed, a PPI image is created in which the value of each pixel corresponds to the number of times that pixel was recorded as spectrally extreme. The bright pixels in the PPI image denote potential endmembers. In this study, however, the PPI identified no new potential endmembers. It was therefore left out of the classification workflow.

The *SAM classification* is the last step in the SHW. The SAM output consists of a classification image and a set of rule images which correspond to the spectral angle calculated between each image pixel and each endmember. One rule image is delivered for each endmember. The rule images are helpful if the SAM classification image does not show spatially coherent classes. They can then be examined individually by loading each rule image into a display window. The SHW automatically reverses the colour table and estimates a linear stretch of the image. The best matches are the small angles. To change the stretch maximum of the displayed rule image, the desired value can be entered in the *Default Stretch Max* text box. The *ENVI Cursor Location Tool* can be used to look at the SAM spectral angles for each pixel and identify a new SAM threshold if necessary [ENVI Help, 2006]. In this study, the threshold was set to 0.5 radian. The final panel of the ENVI SHW workflow is the *Spectral Mapping Wizard Summary Report*. This report contains a summary of each

processing step made using the SHW and it also contains a list of the output files created.

2.3.2 SAM Classification Geomatica

Geomatica's *Hyperspectral Analysis Package* (HAP) can be found under *Technical References* in the *Geomatica Help*. The HAP is designed for processing and analysing images acquired with airborne and satellite imaging spectrometers. However, in contrary to the SHW in ENVI, each processing step within the HAP is only described, rather than being implemented in a workflow. The HAP consists of individual PACE application programs, a set of visualization operations accessible through FOCUS and spectral library files. A possible workflow scheme of these individual parts is presented in Fig. 2.

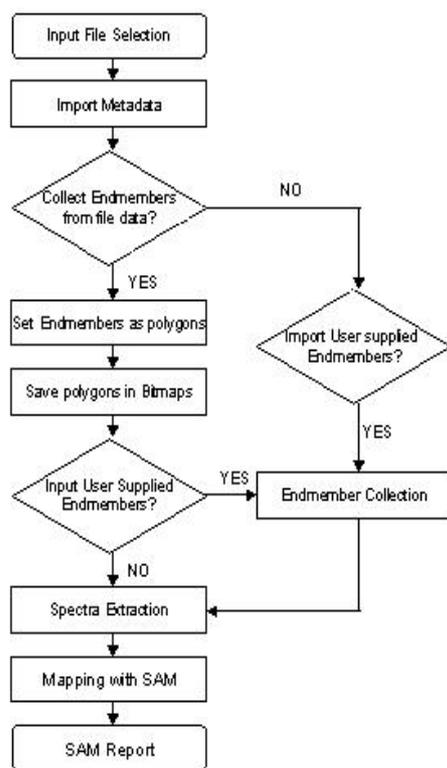


Figure 2: The Geomatica Hyperspectral Analysis Package (HAP) workflow for a SAM classification.

The PACE application programs consist of different functionalities like *Preprocessing*, *Atmospheric Correction*, *Local Analysis*, *Spectral Handling* and *Metadata I/O*. The functionalities used in this study were *Preprocessing*, *Local Analysis* and *Metadata I/O*.

Under the functionality *Preprocessing*, the tasks *Sensor-related Calibration*, *Geometric*

Correction, and *Noise Removal* can be found. However, before applying any of these functions, the ENVI image file (BSQ) was converted into Geomatica/PCI format (PIX) using an integrated functionality of ENVI.

In support of the image data, various metadata concerning the mission and the sensor need to be related to the image file. Importing metadata is important when working with Geomatica's *Hyperspectral Analysis Package* because of the additional information about the dataset and the sensor that acquired the data. Such metadata needs to be attached to the image data to make the subsequent processing and analyzing more efficient or even possible. By using the functionality *Metadata I/O* (In/Out), mission and sensor data can be imported or exported. The metadata has to be formatted as an *Extensible Mark-up Language* (XML) document in a text file. The XML document file must be in the same directory and have the same base name as the image file (PIX). The metadata is then read into the PIX file using the *METAIN* task.

Since the CHRIS dataset was already geometrically and atmospherically corrected [Kneubühler et al., 2005], noise removal was the only task which may be further applied. Geomatica PACE offers several programs that can be used for noise removal. Thereof, two of them are of interest: *Maximum Noise Fraction Noise Removal* (MNFNR) and *Maximum Noise Fraction Linear Transformation* (MNFLT). These steps were, however, left out for the same reasons as in the previous ENVI classification workflow.

The subsequent *Local Analysis* functionality consists of the three different programs *ENDMEMB*, *SAM*, and *SPUNMIX* (Spectral Unmixing).

The *ENDMEMB* program supports the localisation of endmembers in the dataset and was not needed in this study since the endmembers were previously defined in ENVI with the help of ground truth data. The ROI classes from ENVI were imported into Geomatica to make sure the classifications performed in both programs were based on exactly the same sampled regions. Each ROI class was converted into a shapefile with an integrated function provided by the ENVI ROI tool. These shapefiles were then converted into bitmaps by the program *POLY2BIT* in Geomatica. *POLY2BIT* converts polygons into bitmaps, which are storage spaces for masks. To be able to use these endmembers (bitmaps) for a SAM classification, one must first extract the

spectra of each endmember into a spectra file. This can be done by configuring the endmember data with the *Spectra Extraction Configuration* dialog box, which is found in Geomatica FOCUS under *Analysis*. Here, the input image file and the channels to work with must be specified. One can either select an existing channel or create a new one. In our case, a new channel was created. For such a channel, a *Spectra Extraction* dialog box appears, in which all the spectra from the bitmaps can be imported. When starting a *Spectra Extraction Configuration* with no open data in the FOCUS view, the dialog box will automatically create a new map area for this work. If the FOCUS view already contains data and the input data in the *Spectra Extraction* channel has the same georeferencing as the view data, a new hyperspectral metalayer is added to the existing FOCUS view data. In case the georeferencing between the FOCUS view data and the channel input data is incompatible, which was not the case here, a new area is added to the existing FOCUS view data. When the hyperspectral metalayer is configured, a *Spectra Plot* dialog box can be accessed, where the spectra from the *Spectra Extraction* dialog box mentioned above can be imported. These spectra can then be saved as a spectra file (.spl) which is needed for the SAM classification. During the *Spectra Extraction Configuration*, a hyperspectral metalayer is created in the files tree in FOCUS. A sub-menu can be accessed by right-clicking this meta-layer. In this sub-menu, commands like *Spectra Extraction* and the *Spectra Plot* are found. After running these two tasks, a sub-layer called *Regions of Interest*, which is attached to the hyperspectral meta-layer, appears. The *Regions of Interest* layer (ROI) contains the masks which were imported from the bitmaps. One can link the analysis between the image and the ROI layer and work with scatter plots or spectra plots.

The two programs *SAM* and *SPUNMIX* are based on different algorithms which classify hyperspectral image data. For this study, the SAM classification method was chosen. SAM computes the spectral angle between each band-vector in a specified region of the input image (in this case the whole image) and each of the spectrum read from the spectra file. This angle is the amount of *spectral similarity* between the band-vector and the reference spectrum; the smaller the angle the greater the similarity [Geomatica Software, 2005]. All 37 bands of the CHRIS/PROBA dataset were used for the

classification. The CHRIS spectral values are treated as band-vectors for the purpose of the angle computation. A classification channel indicates the input reference spectrum with which it has the smallest angle for each image pixel. The pixels are assigned to the NULL (0) class if the minimum spectral angle is greater than the threshold value. This threshold is optional and specifies the spectral angle in degrees (between 0 and 180). If this field is left open all pixels are assigned to the class corresponding to the smallest spectral angle, no matter how large that angle is. This method was not appropriate for the CHRIS/PROBA dataset, because many pixels were assigned to classes they do not belong to. In the end, the threshold value was empirically set to 30 degrees.

2.3.3 Accuracy Assessment

In order to statistically differentiate between the two classification results, accuracy assessments have to be performed. In Geomatica, an *Accuracy Assessment* task can be found in FOCUS in the *Post Classification Analysis* dialog box.

The accuracy assessments determine the correctness of classified images. The measure of accuracy is the correlation between a standard that is assumed to be correct and an image classification of unknown quality.

In this work, the ground truth data consist of 39 verification samples which were set as vector layers in the image file. The verification samples are used as a standard for the accuracy assessments of the classifications performed in both ENVI and Geomatica.

The training classes which were added to the classification by visual means (clouds, forest, shadow, water, and urban area) were excluded from the classified images prior to the accuracy assessments. This was done using the Geomatica *Class Labelling*, and *Class Editing* dialog boxes. These classes were excluded because they all contained samples which were set over large areas, which made it impossible to locate verification samples without overlapping the classification samples. The classification samples of these classes were set without the use of ground truth data and could therefore not be assumed to be correct with absolute certainty.

The Geomatica *Accuracy Assessment* task produces an *Accuracy Report* which contains a *Random Sample Listing*, a *Confusion Matrix* and *Accuracy Statistics*.

3. Results and Discussion

The classification result images in both ENVI and Geomatica show some overlapping between the different land use classes due to mixed pixels. These classes are mainly the ones with spectra very similar to each other. The overlapping is particularly obvious along the borders of the land use fields. Another reason for these overlapping effects is the choice of the threshold value for the spectral angle between each pixel and endmembers in the SAM classification. This angle was set to 0.5 radian in the SAM classification in ENVI and to 30 degrees in Geomatica. The overlapping effects in both classification results are, however, identical. The classified images of ENVI and Geomatica are given in Fig. 3 and Fig. 4, respectively.

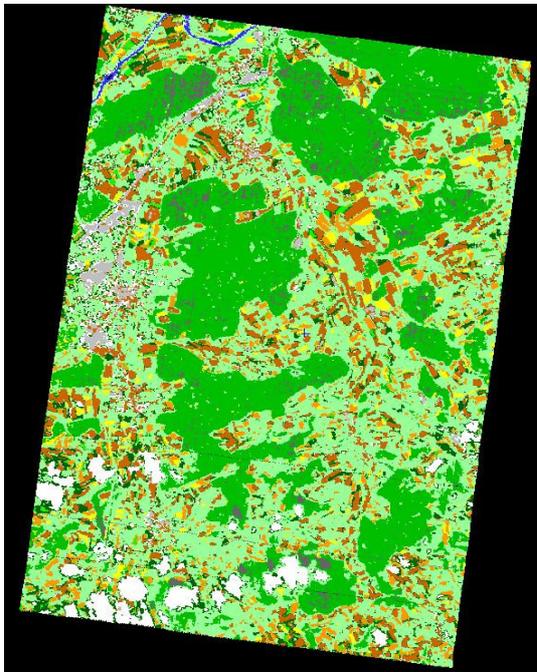


Figure 3: ENVI SAM classification result.

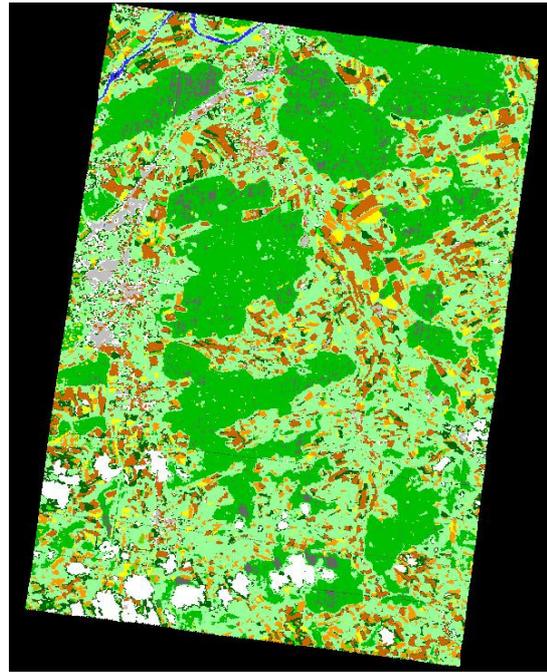


Figure 4: Geomatica SAM classification result.

The accuracy assessment results confirm the observations from the classification result images. The overlapping effects can be observed in the *Users's* and *Producer's Accuracy* listings of the *Accuracy Report* in Tab. 3. All the statistical listings, however, are identical for both classification images (see Tab. 3).

Class	Producer's Accuracy	User's Accuracy	Cappa Statistic
Maize	60.00%	100.00%	1.00
Bare Fields	80.00%	100.00%	1.00
Pasture Land	100.00%	50.00%	0.41
Grassland with Trefoil	57.14%	57.14%	0.48
Grassland without Trefoil	40.00%	100.00%	1.00
Sugar Beet	100.00%	50.00%	0.49

Table 3: ENVI and Geomatica Accuracy Statistics, Overall Accuracy: 71.80%.

The statistical measure *Overall Accuracy* is the percentage of correctly classified pixels in the classification images [Congalton and Green, 1998]. The classifications made in ENVI and Geomatica both have an Overall Accuracy of 71.80%. These results are satisfying, considering the difficulties of endmember selection due to

CHRIS/PROBA's spatial resolution and the heterogeneity of the dataset.

The *Producer's Accuracy* shows what percentage of a particular reference class was correctly classified [Congalton and Green, 1998]. The accuracy for all of the reference classes in the two SAM classifications (ENVI and Geomatica) is identical. The accuracy values range between 40% and 100% in both classifications. In the case of Sugar Beet and Pasture Land, both classes have a Producers's Accuracy of 100%. Bare Fields (80%) and Maize (60%) also have a relatively high accuracy, while Grassland with Trefoil (57.14%) and Grassland without Trefoil (40%) show low accuracy values. The accuracy values of these classes are low because they contain pixels which belong to other classes (errors of commission).

The *User's Accuracy* is calculated by dividing the number of correct pixels in a class by the total number of classified pixels in that class [Congalton and Green, 1998]. The Users's Accuracy is also identical for all of the classified classes in the ENVI and Geomatica classifications in this study. The accuracy values are ranging from 50% to 100%. The values show what percentage of a certain class was correctly classified. Maize, Bare Fields and Grassland without Trefoil have an accuracy value of 100%. Pasture Land (50%), Grassland with Trefoil (57.14%) and Sugar Beet (50%) all show lower accuracy values. The pixels which are not identified by these classes are not taken into consideration by the process of User's Accuracy determination.

The *Kappa Coefficient* is a statistical measure of the agreement, beyond chance, between two maps [Congalton and Green, 1998]. The classes Maize, Bare Fields and Grassland without Trefoil all show a Kappa value of 1. Pasture Land (0.41), Grassland with Trefoil (0.48) and Sugar Beet (0.49) all show lower Kappa values, which indicates that these classes are not as accurate in the classification result as the other classes.

5. Conclusions

The SAM classification in ENVI and Geomatica showed identical results despite differences in the classification workflow tools. While the ENVI *Spectral Hourglass Wizard* (SHW) workflow is fully implemented into the software package, the Geomatica *Hyperspectral Analysis Package* workflow is only listed in a Help function. Both classification tools contain all the

work steps required to perform a SAM classification, however, the ENVI *Spectral Hourglass Wizard* lies a step ahead because of the integrated workflow, which makes the classification procedure much easier and clearly arranged.

The main difference in the two work flows was the missing functionality in Geomatica's HAP to calculate a *Pixel Purity Index* (PPI). This step only exists in the ENVI SHW workflow. Since PPI was not applied to this study's dataset, its absence from the HAP workflow was not a problem. If the PPI process is necessary, the function can be found in the *Algorithm Library* in Geomatica FOCUS. Another difference is Geomatica's necessity to import metadata into the image file. This process is performed automatically in ENVI, and is therefore not found in the SHW. The *Spectra Extraction* dialog box in Geomatica denotes another difference among the two software package workflows. Using this box, the training area samples are imported and a new file with the spectra and regions of interest (ROI) is configured. In ENVI the training area samples can be defined as ROIs from the beginning on, which makes this step redundant. Finally, a major difference between the two workflows concerns the SAM spectral angle between each image pixel and endmembers, which has to be defined for the classification. In ENVI, this angle is defined in radian and in Geomatica in degree. In this study, the angles were chosen empirically. Although the used angles slightly differed from each other (0.5 radian ($\approx 28.7^\circ$) in ENVI and 30 degrees in Geomatica) the resulting SAM classification images are identical.

Concerning endmembers, their selection was performed in ENVI using the ROI tool. These endmembers were then imported into Geomatica. The possibility to do this work step in Geomatica is, however, also available. Once the endmembers are defined, one has to decide whether their spectra are of sufficient quality for classification. To find out if this is the case the user has to run a test classification, observe the result image and decide if the spectra represent their mixed components well. To be able to do this, some pre-knowledge of the composition of mixed materials in the picture elements are useful. Due to CHRIS/PROBA's spatial resolution, the image pixels were often heterogeneous. This fact made the endmember selection difficult, since clear spectral separation of land use classes was challenging. Especially

vegetation spectra were rather similar. Land use classes of very small areas in the CHRIS/PROBA had to be excluded from the classification.

The classification results from both ENVI and Geomatica were compared to each other, both visually and by applying an accuracy assessment. Visual comparison revealed no differences between the two classification results. The images showed similar overlapping effects along field boundaries at the same locations and the areas not affected by mixed pixels were also identical in both images. To be sure that these visual observations were correct, an accuracy assessment in Geomatica FOCUS was performed to statistically differentiate between the two classification results. These accuracy results confirmed the previous findings that the two classification results obtained by the ENVI and Geomatica workflows are identical.

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7. References

- Congalton, R.G. and Green, K., 1998: Assessing the Accuracy of Remotely Sensed Data: Principles and Practices (Mapping Science Series). Lewis Publishers, USA.
- ENVI Help, 2006: ENVI 4.3 Help. ITT Industries Inc., Boulder, CO, USA.
- Geomatica Software, 2005: Geomatica Version 10.0, Software Solutions. PCI Geomatics Enterprises Inc., Ontario, Canada.
- Huber, S., Kneubühler, M., Psomas, A., Itten, K. and Zimmermann, N.E., 2008: Estimating Foliar Biochemistry from Hyperspectral Data in Mixed Forest Canopy. *Forest Ecology and Management*, 256, 491-501.
- Kneubühler, M., Koetz, B., Huber, S., Schopfer, J., Richter, R. and Itten, K.I., 2006: "Monitoring Vegetation Growth using Multitemporal CHRIS/PROBA Data", in *IEEE Geoscience and Remote Sensing Symposium (IGARSS 2006)*, pp: 2677-2680, IEEE Denver (USA).
- Kneubühler, M., Koetz, B., Huber, S., Zimmermann N.E. and Schaepman, M.E.,

2008: Space-Based Spectro-directional Measurements for the Improved Estimation of Ecosystem Variables. *Can. J. Remote Sensing*, Vol. 34, No. 3, pp. 192-205.

- Kneubühler, M., Koetz, B., Richter, R., Schaepman, M. and Itten, K., 2005: Geometric and Radiometric Pre-processing of CHRIS/PROBA Data over Mountainous Terrain. *Proc. 3rd CHRIS/PROBA Workshop, Frascati (I)*, 21-23 March 2005, ESA Publications Division, Noordwijk (NL), SP-593, CD-ROM.
- Kruse, F., Lefkoff, A.B., Boardman, J.W., Heidebrecht, K.B., Shapiro, A.T., Barloon, P.J., and Goetz, A.F.H., 1993: The Spectral Image Processing System (SIPS) – Interactive Visualization and Analysis of Imaging Spectrometer Data. *Rem. Sens. Environ.*, Vol. 44, pp. 145-163.
- Sandau, R., 2005: *Digitale Luftbildkamera, Einführung und Grundlagen*. Wichmann Verlag, Heidelberg, p. 342.