DEVELOPMENT AND IMPLEMENTATION OF REMOTE SENSING TECHNIQUES FOR LONG-TERM MONITORING OF BIOLOGICAL SOIL CRUSTS (BSCs) - UTILIZATION OF CHRIS PROBA DATA FOR UPSCALING AND CLASSIFICATION

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ABSTRACT/RESUME

Within the scope of a biodiversity monitoring project in Africa (BIOTA), a methodology for identification, mapping and quantification of Biological Soil Crusts (BSCs) using both field spectroradiometers and hyperspectral remote sensing data is being developed. The spectral signal of BSCs (an association between soil particles and different proportions of cyanobacteria, algae, microfungi, lichens and bryophytes) represents a complex mixture of various reflectance characteristics, depending on the species dominance and distribution as well as on the soil characteristics. We assume that characteristic pigments, such as phycocyanin in cyanobacteria, will allow the spectral discrimination of BSCs from the surrounding vegetation (phanerogamous plants).

The planned investigations should cover three different vegetation zones with varying crust type composition in southern Africa: Nama Karoo (Soebatsfontein, South Africa), Thornbush Savanna (Rehoboth, central Namibia) and Central Namib Desert (Namibia). Spectroradiometer measurements were already started in 2004, resulting in a spectral library, that will aid in calibration and characterization of the different BSC types within hyperspectral remote sensing images. CHRIS-Proba datasets would further enable us to refine the results of a recent PhD thesis using Landsat 7 ETM+ images in the Namib Desert and to upscale from airborne CASI and SASI data recorded in the Nama Karoo from the meso- to the macro-scale. Overall we hope to establish a methodology for the classification and mapping of spatio-temporal dynamics of BSCs in southern Africa.

1. INTRODUCTION

In the course of the project “BIOTA” (www.biota-africa.org), which is financed by the Federal Ministry of Education and Research, Germany, the distribution and diversity of Biological Soil Crusts (BSCs) along a transect in southern Africa is studied (Fig.1). Biological soil crusts, composed of cyanobacteria, algae, lichens, microfungi, and bryophytes in varying proportions and associated between soil particles [1] are well known from southern Africa [2]. However, most reports on BSCs either restrict themselves to isolated spots and do not consider the total area covered by BSCs, or they are restricted to a certain taxonomical group [3]. BSCs mainly occur in soils of arid and semi-arid regions, which cover 30% of the earth surface and they are assumed to play a major role as primary producers, as C- and N- sink [4] and as soil stabilizers [5].

Fig. 1. BIOTA-South study area and observatories along the transect through Namibia and South Africa
Remote sensing techniques allow to map the distribution of BSCs on a larger scale [6, 7]. With the help of both field spectra and hyperspectral data, a methodology for identification, mapping and quantification of BSCs is being developed. With the help of CHRIS-Proba datasets we hope to establish a methodology for upscaling from the meso- to the macroscale and for the classification and monitoring of spatio-temporal dynamics of BSCs in three different vegetation zones in southern Africa.

2. FUNDAMENTALS FOR BSC SPECTRAL ANALYSIS

2.1. BSC Classification into major Crust Types

Depending on the species dominance and distribution in the soil crust, the spectral signal of BSCs represents a complex mixture of various reflectance characteristics. For classification purposes, remote sensing analysis will be based on three main crust types. Regarding their major components, BSCs can be classified into cyanobacteria-, lichen- and moss-dominated crusts [8].

Cyanobacterial crusts are usually visible as a darker tinge of the soil (Fig.2) and often form a dense cover and a surface layer up to several millimeters. The presence of filamentous cyanobacterial species contributes to the cohesive character of the soil crust [5]. Cyanobacterial crusts are widely distributed in arid and semiarid microhabitats along the BIOTA transect and form well established crusts for instance in the Nama Karoo.

Moss-dominated crusts mainly consist of foliose mosses or liverworths. They occupy microhabitats with higher humidity as under shrubs in the Thornbush Savanna or in the Nama Karoo (Fig.3). Crustose, foliose and fruticose lichens together with green algae form the predominant components of lichen dominated crusts in the coastal fog zone of the Central Namib Desert. These extraordinary vast lichen communities, described as “lichen-fields”, depend on frequent fog events and extend along the Atlantic coast up to 60 km inland with considerable variations within and amongst the communities (Fig.4a) [9, 10, 11]. Furthermore, well established soil lichen crusts are found in the Thornbush Savanna and in the Nama Karoo (Fig.4b).
2.2. Chlorophyll Content of BSCs and their Contribution to Biomass

Chlorophyll analysis (chlorophyll$_a$ and chlorophyll$_{a+b}$ content per square meter) of samples along the BIOTA transect revealed, that BSCs considerably contribute to the ecosystem biomass. In several cases, biomass even equals values of phytoplankton densities in the Atlantic ocean [12]. It also became clear, that BSCs and their biomass contribution are not an occasional phenomenon but a regular part of almost all ecosystems along the BIOTA transect (Fig. 5). Combined with the remote sensing data and analysis, those field results can be applied in order to estimate the biomass contribution of BSCs at the meso- and macro-scale.

Phycocyanin causes a relatively higher absorption in the spectral region between 550 and 650 nm, which could be used as a spectral “fingerprint” of cyanobacteria in general, since there are no other photosynthetic pigments, which cover this range [13]. Chlorophyll$_b$, which is not present in cyanobacteria, absorbs in a much narrower area between 630 and 660 nm and could therefore easily be distinguished from phycocyanin. Another characteristic pigment is Scytonemin, located in the extracellular polysaccaride sheath of some cyanobacteria, like Calothrix, Microcoleus and Scytonema, which also occur as characteristic genera in the examined soil crusts of southern Africa. The pigment has two main absorption peaks, one at 252 and one at 386 nm [14], which should make it easily detectable within hyperspectral images. An example spectrum of the genus Microcoleus is shown in Fig.6.

3. REMOTE SENSING OF BSCs - ANALYSIS AND FIRST RESULTS

3.1. Monitoring of Lichen Communities in the Namib Desert with Landsat data

In the Central Namib Desert (Namibia), the extraordinary vast lichen communities were recently mapped and classified in the framework of the PhD thesis by Christoph Schultz conjoined with the German Remote Sensing Data Center (DFD). Multispectral LANDSAT 7 ETM+ satellite imagery was utilized for an untemporal supervised classification as well as for the establishment of a monitoring based on a combined retrospective classification approach.

Initial results comprise a map showing the distribution of lichen communities for the Central Namib Desert between Kuiseb- and Huab-River (Fig.7). Based on the framework of morphological groups for monitoring microphytic crusts in arid lands, six different lichen communities for the Central Namib Desert were separated [15].
Due to the fact that phanerogameous vegetation in the hyperarid gravel plains of the Central Namib Desert is very low, as well as variation in terrain, the Central Namib serves as a perfect site for further testing of the transferability of the applied methodology to hyperspectral datasets such as CHRIS-Proba [16]. Therefore, field spectrometer measurements of various species, communities and soils, using an ASD FieldSpec-Pro-Full-Range, were recorded in March 2005 in order to support future hyperspectral analysis.

At the same time, field spectroradiometer measurements for the spectral reflectances of various soil crusts in vivo as well as of uncolonized soil at different sites were taken in order to be able to calibrate the hyperspectral data and to establish a spectral library (Fig.9). In addition, spectra of the prominent higher plant species in the area were taken in order to be able to differentiate between soil crusts and phanerogameous vegetation.

Fig. 7. Distribution map of lichen communities of the Central Namib Desert. Based on a supervised classification approach of six morphological classes utilizing Landsat 7 ETM+ data of April / May 2003.

3.2. Hyperspectral Remote Sensing of BSCs at the Meso-scale in the Nama Karoo

In order to map the distribution of different soil crust types at the meso-scale, hyperspectral remote sensing techniques have been applied at a site in northern South Africa in the Nama Karoo (near Soebatsfontein). In October 2004 airborne CASI and SASI data with a spatial resolution of 1 meter were recorded. The flight area comprises an area of 4 x 6 km (Fig.8).

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Fig. 8. Flight area for the acquisition of hyperspectral data and observed ground control points in the Nama Karoo (observatory Soebatsfontein)

Fig. 9. Example spectrum of a lichen-dominated soil crust in the Nama Karoo (Soebatsfontein area)
4. PLANNED UTILIZATION OF CHRIS-PROBA DATASETS

4.1. Lichen Communities in the Namib Desert

Further testing of the recently classified lichen communities in the Central Namib Desert (Namibia) shall verify the transferability of the applied methodology (based on Landsat 7 ETM+ data) to hyperspectral datasets as CHRIS-Proba and furthermore examine the future potential for refining the existing results.

4.2. Upscaling from the meso- to the macro-scale in the Nama Karoo

By the additional utilization of CHRIS-Proba data for this area, upscaling from the meso- to the macro-scale could be accomplished. After classifying the BSCs within the high-resolution airborne CASI and SASI images we plan an upscaling to a spatial resolution of 17m, obtained by the CHRIS PROBA data.

4.3. Monitoring of Soil Crusts in the Thornbush Savanna

The third area located in Central Namibia (near Rehoboth) comprises two adjacent observatories of the BIOTA project characterized by different grazing intensities. The northern observatory (Nareis) is extensively grazed by sheep, whereas the southern observatory (Duruchaus) is intensively grazed by cattle and sheep. It is known that different grazing and trampling intensities have a large impact on the development and vitality of BSCs. By comparing the two adjoining observatories along the fence line (Fig.10) and in the Landsat ETM7 scene (Fig.11), the contrast between both observatories is clearly visible but was not further analysed up to now. The detection of this so-called fence line effect and a classification based on the different grazing intensities is expected to be possible using hyperspectral CHRIS-Proba imagery.

Fig. 10. Fenceline effect resulting from different grazing intensities at the observatories Nareis and Duruchaus (Rehoboth area, Thornbush Savanna)

Fig. 11. Fenceline effect in the Rehobot area visible in a Landsat ETM 7 scene: less intense grazing NW of the red line (Nareis) and intense grazing SE (Duruchaus)

4.4. Planned Hyperspectral Data Analysis

By relating detailed ground truth data from the developed spectral library to the airborne hyperspectral images, the spectral reflectance of different crust types will be characterized and calibrated against other signals. After preprocessing of the data, the first step in image interpretation will be to identify the training sites, where field spectra were recorded simultaneously to the flight. The computer can then be instructed to highlight other regions characterized by the same spectral response. The training areas could be classified and used for a supervised classification. In a second step, a spectral mixing analysis could be applied in order to dissolve the effect of mixed pixels. Since it is not possible to conduct the spectral mixing analysis on the basis of all spectral bands, a principal components analysis (PCA) has to be applied for identification of the most characteristic spectral bands used for further analyses. Then the values of all pixels within a specific image or subimage are presented as an n-dimensional data swarm (dimensions are represented by the spectral bands). Within this data swarm, few data points at the extreme limits of the swarm, approximating the shape of the data swarm if connected to each other, are defined as endmembers. The interior pixels are then defined as linear combinations of the pure endmembers. The objective will then be to match the endmembers to spectra within the spectral libraries and to prepare maps that reveal the varied mixtures of surfaces within the images.

5. REFERENCES


