EXTRACTION OF KARST ROCKY DESERTIFICATION INFORMATION FROM EO-1 HYPERION DATA

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ABSTRACT:

Karst rocky desertification is a special kind of land desertification developed under violent human impacts on the vulnerable eco-geo-environment in karst ecosystem. The process of karst rocky desertification results in simultaneous and complex variations of many interrelated soil, rock and vegetation biophysical parameters, rendering it difficult to develop simple and robust remote sensing mapping and monitoring approaches. In this study, we aimed to use Earth Observing 1 (EO-1) Hyperion hyperspectral data to extract the karst rocky desertification information. A spectral unmixing model based on Monte Carlo approach, AutoSWIR, was used to quantify the fractional cover of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and bare bedrock. The results showed that SWIR2 (2.1-2.4μm) region of the spectrum were significantly different in PV, NPV and bare rock spectral properties. It has limitations in using full optical range (0.4-2.5μm) or only SWIR2 region of Hyperion to decompose image into PV, NPV and bare bedrock covers. However, when use the tied-SWIR2, the sub-pixel fractional covers of PV, NPV and bare bedrock constituents were accurately estimated. It was due to the tied-SWIR2 minimized the contribution of intra-canopy structural variation to nonlinear photon-tissue interactions. Our study indicated that AutoSWIR unmixing spectral model is a useful tool to accurately extract mixed ground objects in karst ecosystem. Karst rocky desertification information can be accurately extracted from EO-1 Hyperion. Hyperspectral data can provide a powerful methodology toward understanding the extent and spatial pattern of karst rocky desertification in Southwest China.

1. INTRODUCTION

Karst region is a typical ecological fragile zone, with small environmental and anti-interference capability (LeGrand, 1973). Southwest China is one of the largest karst regions in the world (Yuan, 1993). It is estimated that the karst geomorphology covers about 540,000km^2 in this region (Wang and Liu, 2004). Karst rocky desertification there has expanded at an overwhelming rate during the past few decades. Karst rocky desertification is a special kind of land degradation process that soil was eroded seriously or thoroughly, bedrock was exposed widespread, carrying capability of land declined seriously, and ultimately, landscape appeared similar to desert under violent human impacts on the vulnerable eco-geo-environment (Wang, 2002).

Vegetation cover and bare bedrock rate are key evaluation indexes of the extent and degree of karst rocky desertification. However, the process of karst rocky desertification results in simultaneous and complex variations of many interrelated soil, rock and vegetation biophysical parameters, rendering it difficult to develop simple and robust remote sensing mapping and monitoring approaches. Using multispectral remote sensing has proven to be difficult to specific quantification of non-photosynthetic (NPV) and bare substrates cover with existing vegetation indexes (Huete *et al*., 2003). Imaging spectrometry provides near-contiguous, narrowband spectral analysis of the land surface that has proven useful for studying a wide variety of biophysical and geological processes (Green *et al.*, 1998; Asner and Lobell, 2000). However, to our konwledge, there was no research on karst rocky desertification through application of hyperspectral remote sensing, which has the potential ability to resolve the problems above.

Spectral mixture analysis (SMA) has proven useful for estimating image subpixel land cover fraction from remotely sensed data (Roberts *et al*., 1993), and was also ever be used in karst region (Wan and Cai, 2003). However, there are two major assumptions of traditional SMA approaches: (1) the total pixel reflectance is a linear combination of the endmember reflectance; (2) the reflectance of each endmember does not vary across an image (Lobell and Asner, 2001). While the first assumption has proven reasonable in many ecosystems at the landscape scale, variability of endmember reflectance is a major obstacle to accurately using SMA approach (Roberts *et al*., 1998). This variability ultimately impedes regional-scale analyses of vegetation cover and associated processes.

An automated spectral unmixing method, AutoSWIR, which was successfully reduced the variability of endmember reflectance, was used to decompose images pixels into subpixel

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surface constituents (Asner and Lobell, 2000). While this model was developed for arid and semiarid ecosystems, the biogeophysical properties of the cover types that the method involved were general and could potentially work in other ecosystem types. In an effort to generalize the AutoSWIR approach to new ecosystems, it is important to understand the potential variability of endmember spectra from other environments, like karst ecosystem.

The main goal of this research was to investigate the potential of extracting karst rocky desertification from EO-1 Hyperion data. Specific objectives included: (1) analyzing the canopy spectral characteristics of green vegetation (PV), non-photosynthetic vegetation (NPV), and bare bedrock in karst region; (2) evaluating the effectiveness of using AutoSWIR model to decompose the fractional cover of PV, NPV, and bare bedrock; (3) comparing the performance of spectral signatures for dominant land-cover types and S/N in extraction of karst rocky desertification from EO-1 Hyperion.

2. METHODS

2.1. Study area

The study area, Hujiang experimental station of karst ecosystem, Chinese Academy of Sciences, is located in the northwest of Guangxi province, China. It is an typical karst rocky degradation region with area 25 km^2 and belongs to Chinese Ecosystem Research Network (CERN).

2.2. Field Measurements

A stratified random sampling scheme was employed by establishing three 100-m transects in the study area. The fractional cover of PV, NPV, and bare bedrock was recorded along each transect in 50-cm intervals using the point-intercept method. Canopy and bare bedrock spectral data were collected using an ASD FieldSpec radiometer with a spectral range from 350-2,500 nm. The spectral radiance measurements were collected at 5m intervals along the each 100m transects and were converted to reflectance using a Spectralon.

2.3. Hyperion Data

The Hyperion hyperspectral imager is a pushbroom sensor that covers a ground width of approximately 7.5 km at 30-m resolution and in 220, 10-nm bands covering the spectrum from 400-2,500 nm. The EO-1 Hyperion sensor imaged the study area on March, 3, 2008. Some of the vegetation especially grasses were senesced during this time, making it easily to identify the major land-cover types. Apparent surface reflectance was estimated from the radiance data using the Atmospheric Correction Now (ACRON) algorithm.

2.4. Spectral Mixture Model

We used a general, probabilistic model for decomposing optical reflectance measurements into subpixel estimates of PV, NPV and bare bedrock covers for karst ecosystem. This model is fully automated and uses a Monte Carlo approach to derive uncertainty estimates of the sub-pixel cover fraction values (Asner and Lobell, 2000) (Figure1). The model, *AutoSWIR*, is based on a code first developed only for the shortwave-IR spectral region, but it is more general in that any combination of optical wavelengths can be used in the unmixing process. *AutoSWIR* uses three spectral endmember bundles, derived from field measurements, to decompose each image pixel using equation (1):

$$\rho(\lambda)_{pixel} = \sum_{e=1}^{n}[C_e \bullet \rho_e(\lambda)] = [C_{pv} \bullet \rho_{pv}(\lambda) + C_{npv} \bullet \rho_{npv}(\lambda) + C_{rock} \bullet \rho_{rock}(\lambda)] + \varepsilon \quad (1)$$

where $\rho_e(\lambda)$ is the reflectance of each land-cover endmember e at wavelength λ; C is the fraction of the pixel composed of e; and ε is the error of the fit.

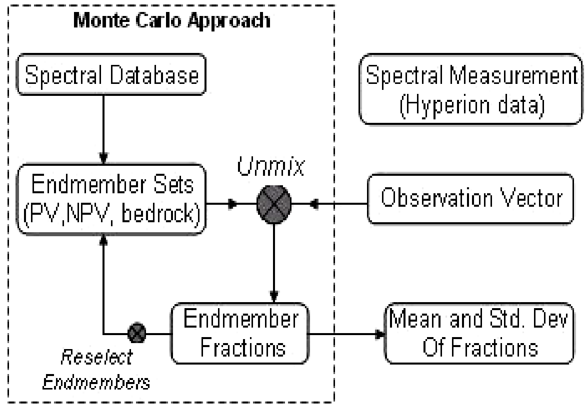

Figure1. Schematic diagram of AutoSWIR algorithm

The three spectral endmember bundles (PV, NPV, bedrock) were collected from the field. Then they were resampled to Hyperion wavelength channels using the spectral response functions. In addition, we tested the accuracy of spectrally decomposing image pixels using the full range of 0.4-2.5μm, only the SWIR2 (2.1-2.4μm), and only the “tied” SWIR2 spectrum from Hyperion. The “tied” spectrum, or subtracting the reflectance at the first band from all bands, is performed to eliminate major albedo differences between otherwise similar spectra. Based on both field and radiative transfer studies, tied-SWIR2 spectra of PV and NPV should be less susceptible to variation in canopy biomass, architecture and leaf biochemistry (Asner and Lobell, 2000). Tied-SWIR2 spectral bundles of bare bedrock (mainly carbonate) accommodate variation in geochemistry properties that cause the distinct 2340nm carbonate (CO_3) absorption feature to shift in width, shape, and depth (Chabrillat *et al*, 2004). Therefore by developing bundles of these tied-SWIR2 spectra for use in the Monte Carlo unmixing model, *in situ* variations in biochemical and geochemical properties are propagated to the subpixel cover fraction estimates.

3. RESULTS AND DISCUSSION

3.1. Spectral characteristics of dominant land-cover types

Field spectral data of three dominant land-cover types (PV, NPV and bare bedrock) collections from the three transects were shown distinct spectra characteristics (Figure2). The PV spectra showed typical value ranges for the visible, NIR, and

SWIR wavelength regions as found in other ecosystems. The strong NIR spectral variation is indicative of highly varying leaf index (LAI) at the scale of individual plant canopies (Asner *et al*., 2000). While the SWIR2 (2.1-2.4μm) region did show some variability in the magnitude of reflectance, but the whole spectral shapes were highly consistent.

The NPV spectra show almost constant monotonic-increasing reflectance in the visible-NIR region. Several spectral absorption features in the SWIR2 (2.1-2.4μm) region are clearly apparent. The features near 2.1μm and 2.4μm are associated with the presence of cellulose and lignin.

The spectral characteristics of bare bedrock are also apparent, especially the CO_3 absorption feature near 2.3μm. This is due to that the most components of bare bedrock in karst ecosystem are carbonate, which is mainly composed of limestone (Yuan, 1993).

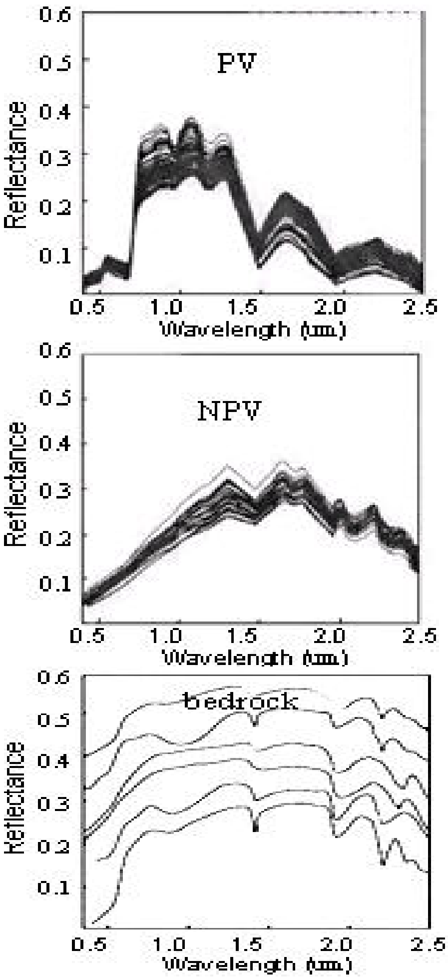

Figure2. Field spectral from the three transects: photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV), bare bedrock (bedrock).

3.2. AutoSWIR spectral mixture analysis

The Monte Carlo spectral unmixing method, AutoSWIR, incorporated both spectral endmember variability and uncertainty in the unmixing process. It involved generating a large number of endmember (PV, NPV, bedrock) combinations for each pixel by randomly selecting spectra from the database of field spectra. The performance was evaluated using full range (0.4-2.5μm), only SWIR2 (2.1-2.4μm), and only tied-SWIR2 endmember spectra. Table1 showed the spectral decomposition results for the study area using the four different wavelength permutations.

Wavelength permutation	Land-cover types	Study area	Std. Dev.
Field measurements	PV	0.436	0.010
	NPV	0.272	0.010
	bedrock	0.302	0.020
	SUM	1.01	-
Hyperion full-range	PV	0.392	0.050
	NPV	0.291	0.063
	bedrock	0.377	0.046
	SUM	1.06	-
Hyperion SWIR2	PV	0.157	0.102
	NPV	0.312	0.041
	bedrock	0.341	0.053
	SUM	0.81	-
Hyperion tied-SWIR2	PV	0.412	0.060
	NPV	0.269	0.033
	bedrock	0.319	0.046
	SUM	1.0	-

Table1. PV, NPV, and bare bedrock cover fractions from 4 different wavelength permutations using AutoSWIR.

Spectral unmixing with the full-range (0.4-2.5μm) of Hyperion unmixing yielded very close NPV cover fraction to the field NPV values. It indicate that full spectral range may provide some measure of NPV presence, but it grossly under-estimated PV and over-estimate bare bedrock rate. This is likely duo to the presence of very bright bare bedrock, which saturates this wavelength region and leads to over-estimates of bedrock cover.

Spectral unmixing with the only SWIR2 (2.1-2.4μm) region of the Hyperion data also yielded poor results (Table1). In karst rocky severely degradation region, especially during the vegetation senesced period, SWIR2 spectra are dominated by bright bare bedrock and NPV, this can lead to a substantial under-estimate of PV cover.

Spectral unmixing with the tied-SWIR region of the Hyperion yielded accurate estimates of all three land-cover types (Table1). The field measurements of PV, NPV and bare bedrock fractions were well within the statistical uncertainty rang of the AutoSWIR results. It was due to the tied-SWIR2 minimized the contribution of intra-canopy structural variation to nonlinear photon-tissue interactions. These results were consistent with the work did by Asner and Lobell (2000), and indicate that the tied-SWIR2 (2.1-2.4μm) spectra are a means for estimating the dominant land-cover types (PV, NPV and bare bedrock) in karst degradation ecosystem. Karst rocky desertification information can be accurately extracted from EO-1 Hyperion data.

4. CONCLUSION

The research presented here indicates that SWIR2 (2.1-2.4μm) spectral region are the main distinctive spectral characteristics of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and bare bedrock in karst degradation regions. It has limitations in using full optical range (0.4-2.5μm) or only SWIR2 region of Hyperion to decompose image into PV, NPV and bare bedrock covers, but the tied-SWIR2 region provides verifiably accurate estimates of PV, NPV and bare bedrock. AutoSWIR is a useful model to resolving spatial heterogeneity of vegetated landscapes in karst ecosystem. Hyperspectral data can provide a powerful methodology toward understanding the extent and spatial pattern of karst rocky desertification in Southwest China.

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REFERENCES

Asner, G. P., and Heidebrecht, K. B., 2002. Spectral unmixing of vegetation, soil and dry carbon cover in arid regions: comparing multispectral and hyperspectral observations. *International Journal of Remote Sensing*, 23(19), pp. 3939-3958.

Asner, G. P., and Lobell, D. B., 2000. A biogeophysical approach for automated SWIR unmixing of soils and vegetation. *Remote Sensing of Environment*, 64, pp. 234-253.

Asner, G. P., Wessman, C. A., Bateson, C. A., and Privette, J. L., 2000. Impact of tissue, canopy and landscape factors on reflectance variability of arid exosystems. *Remote Sensing of Environment*, 66, pp. 69-84.

Chabrillat, S., Kaufmann, H., Palacios-Orueta, A., Escribano, P., and Mueller, A., 2004. Development of land degradation spectral indices in a semiarid Mediterranean ecosystem, *Proceedings of the SPIE*, 5574, pp. 235-243.

Green, R. O., Eastwood, M. L., and Williams, O., 1998. Imaging spectroscopy and the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). *Remote Sensing of Environment*, 65, pp. 227-240.

Huete, A. R., Miura, T., and Gao, X., 2003. Land cover conversion and degradation analyses through coupled soil-plant biophysical parameters derived from hyperspectral EO-1 Hyperion. *IEEE Transactions on Geoscience and Remote Sensing*, 41(6), pp. 1268-1276.

LeGrand, H. E., 1973. Hydrological and ecological problems of karst regions. *Science*, 179, pp. 859-864.

Lobell, D. B., and Asner, G. P., 2001. Subpixel canopy cover estimation of coniferous forests in Oregon using SWIR imaging spectrometry. *Journal of Geophysical Research*, 106(D6), pp. 5151-5160.

Roberts, D. A., Smith, M. O., and Adams, J. B., 1993. Green vegetation, non-photosynthetic vegetation, and soils in AVIRIS data. *Remote Sensing of Environment*, 44, pp. 441-450.

Roberts, D. A., Gardner, M., Church, R., Ustin, S., Scheer, G., and Green, R. O., 1998. Mapping chaparral in the Santa Monica Mountains using multiple endmember spectral mixture models. *Remote Sensing of Environment*, 65, pp. 267-279.

Wan, J., and Cai, Y. L., 2003. Applying linear spectral unmixing approach to the research of land cover change in karst area: a case in Guanling county of Guizhou province. *Geographical Research*, 22(4), pp. 439-446.

Wang, S. J., 2002. Concept deduction and its connotation of karst rocky desertification. *Carsologica Sinica*, 21(2), pp. 101-105.

Wang, S. J., Liu, Q. M., and Zhang, D. F., 2004. Karst rocky desertification in southwestern China: geomorphology, landuse, impact and rehabilitation. *Land Degradation & Development*, 15, pp. 115-121.

Yuan, D. X., 1993. ***The Karst study of China.*** Geology Press, Beijing.