Detection of Amazonian black earth sites using hyperspectral satellite imagery on regional and landscape levels

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Introduction

The pre-Columbian indigenous population estimates of the Amazon Basin lowlands are highly uncertain and the subject of considerable controversy. Proponents of the low population density suggest that the forest is pristine, delicate, and sensitive to human disturbance. If populations were high, it is likely that Amazonian forest vegetation had been significantly altered and may be thought of as a cultural artifact, resilient to human disturbance and not an undisturbed forest. One of the archaeological sources used in reconstruction of Amazonian societies are Amazonian black earths (ABE) or in Portuguese, *terra preta* soils. The immense size of Amazonia, remoteness of many areas, forest vegetation, and lack of archaeological field surveys, make remote sensing beneficial to archaeological studies in this region. Remote sensing allows for comparison and analysis of vegetation across vast areas. Previous research has shown that hyperspectral image data can detect vegetation canopy chemistry differences, associated with soil nutrients and chemistry. This literature suggests that the high nutrient content of ABE soils will cause detectable changes in vegetation structure, phenology, and/or foliar chemistry. Hyperspectral remote sensing with dense coverage of the spectral reflectance of vegetation canopies will provide a key to detection of high nutrient ABE sites. The broad spatial coverage afforded by the proposed research allows for the unique opportunity to begin to quantify the Pre-Columbian human impact in Amazonia through the analysis of the distribution of ABE sites across the region.

Archaeological excavation of terra preta sites in Brazil. Courtesy of Eduardo Neves

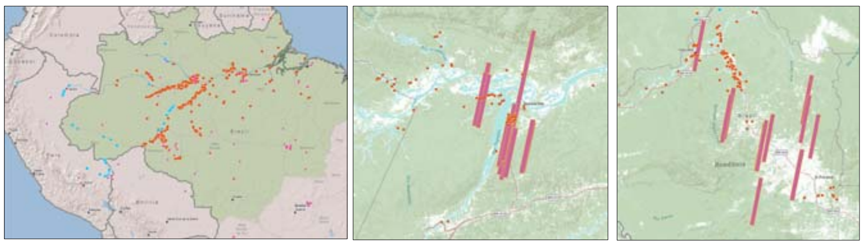

Figure 1. (A) Locations for the LBA archive of HYPERION data (pink polygons) and known ABE sites (orange circles) for the Amazon region. (B) Close-up of area near Santarem and the Tapajos National Forest. (C) Close-up of Rhodonia. Locations for over 700 ABE sites from Eduaro Neves, Johannes Lehmann (pers. Comm.), and Gerhard Becktold (MS Thesis 1982). Blue squares are test sites that indicate no ABE. These sites are vital for our statistical analysis.

As part of LBA, NASA acquired 108 Hyperion images of LBA field research sites (Figure 1). Satellite image acquisition was determined based on the location of LBA eddy flux tower sites and field sites, and interviews with investigators (Hurtt et al. 2003). As such, these images do not represent a random sampling of the Amazon region and any conclusions that we draw from this project will need to take potential biases into account. However, we must point out that there are over 100,000 km^2 of Hyperion images acquired as part of LBA, covering 1.1% of the Amazon basin. These represent a broad range of climatic, geological, topographical, and pedological conditions. We are currently acquiring more images.

Site	Type	Depth	Color	Age	Sand	Silt	Clay	pH		Organic C	Total N	C/N	Total P	Total Ca
		cm	dry soil	yr		%		1:2.5 H_2O	1:2.5 KCl	mg g^{-1}			mg kg^{-1}	
HAT	Anthrosol	43–69	10YR 4/1	600–1000	51.3	21.7	27.0	6.4	5.5	22.0	1.0	23	9064	17545
	Adjacent soil	0–10	10YR 5/4		60.4	3.8	35.9	4.6	3.8	21.8	1.6	14	273	115
LG	Anthrosol	0–16	10YR 3/1	900–1100	47.9	29.6	22.6	5.9	4.9	31.5	1.8	18	5026	6354
	Adjacent soil	0–8	7.5YR 5/4		69.4	3.9	26.7	4.2	3.5	17.5	1.3	14	251	119
ACU	Anthrosol	48–83	10YR 4/1	2000–2300	81.9	7.7	10.4	5.6	4.2	15.7	1.0	16	777	332
	Adjacent soil	0–30	7.5YR 4/2		87.9	3.6	8.5	4.7	3.9	15.4	0.8	20	198	50
DS	Anthrosol	190–210	5YR 3/1	6700–8700	96.8	2.9	0.3	5.0	4.1	16.5	1.1	15	139	40
	Adjacent soil	0–12	5YR 2/2		91.1	8.6	0.3	3.9	2.6	10.2	0.4	27	51	165

Table 1. Chemical properties of ABE soils and adjacent soils in the central Amazon (from Liang, B., Lehmann, J., Solomon, D., Kinyangi, J., Grossman, J., O'Neill, B., Skjemstad, J.O., Thies, J., Luizão, F.J., Petersen, J., Neves, E.G., (2006) Black carbon increases cation exchange capacity in soils. Soil Science Society of America Journal, 70: 1719-1730).

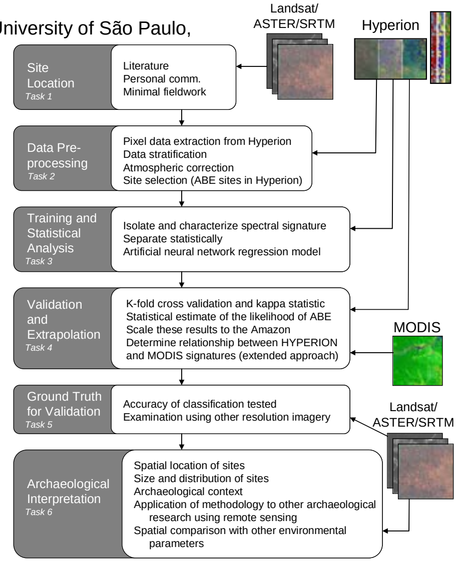

Figure 5. A schematic diagram of the strategy for the use of hyperspectral satellite imagery from Hyperion in the detection of Amazonian black earth (ABE) sites.

The Hyperion instrument is a hyperspectral imager on board the USGS/NASA EO-1 satellite platform. It is a high spatial resolution (30 m) pushbroom scanner with a swath width of approximately 7.5 km and a typical image length of 140 km. This hyperspectral sensor images the Earth in 242 separate spectral bands.

False Color Composite
R-SWIR (1650 nm)
G-NIR (850 nm)
B-R (660 nm)

Acquired 2003 AUGUST 21

Analysis

Our preliminary analysis was accomplished by first selecting a Hyperion scene near Santarem. We selected scene (EO1H2270622003233110PN) acquired on August 21, 2003, because of its limited cloud cover and the fact that multiple coordinates for ABE site were available in this area. A false color composite image is presented in Figure 2, using R-SWIR (1650 nm), G-NIR (850 nm), and B-R (660 nm).

We next converted the Hyperion digital numbers to reflectances. Eight ground control points (primarily road intersections) visible in both the Hyperion scene and in previously geo-registered data were used to geo- register the Hyperion scene. We warped the scene using 1st order polynomial, nearest neighbor into UTM projection.

Next, we overlayed an ABE vector file that we have compiled from literature sources (Figure 1) over the georegistered Hyperion image and identified three ABE sites in forested areas (Figure 3). We also selected three forested non-ABE sites, each approximately 200 m away from an ABE site. It is possible that these chosen non-ABE sites are actually ABE sites; but they are not known to be ABE sites. We extracted the Hyperion reflectance data of the 4 nearest pixels (60 m x 60m) for the ABE/non-ABE site.

Using this reflectance data we calculated the mean spectral response of the ABE pixels and non-ABE pixels, and examined the difference of the two mean spectral responses (Figure 4).

When viewed across the entire visible to SWIR spectrum, the forested areas (both ABE and non-ABE) all appear to have similar spectral responses, likely because they share broad tropical forest structural and chemical properties. Closer examination reveals portions of the spectrum at which differences between ABE and non-ABE sites emerge. Specifically, there are nine portions of the spectrum where the three ABE sites are completely separable from the three non-ABE sites. These wavelengths include the portion near the well-documented red-edge inflection point (753 nm), which is know to vary with biomass and chlorophyll content.

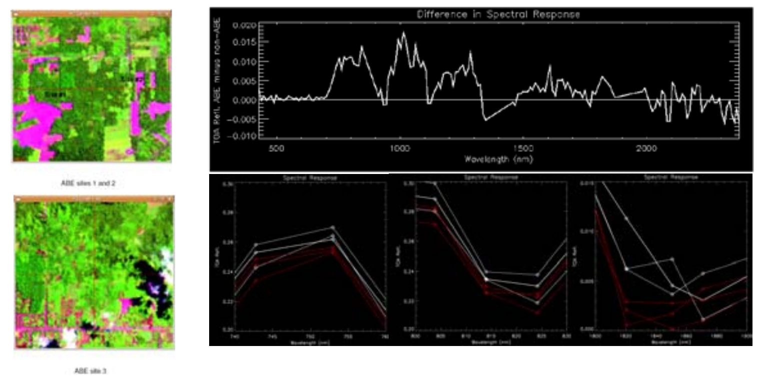

Figure 4. A preliminary analysis of spectral differences between ABE and non-ABE sites. The top panel shows the difference in spectral response (ABE minus non-ABE) across the full HYPERION spectrum. The three lower panels show specific spectra that are indicative of differences between three replicated ABE and non-ABE sites from near Belterra, Para. Panels show specific spectra that are indicative of differences between ABE (white lines) and non-ABE sites (red lines).

Summary

We conducted a preliminary analysis to demonstrate our conceptual plan and identify potential spectral differences between ABE sites and non-ABE sites using hyperspectral data from the Hyperion satellite. Our preliminary analysis indicates that, at three pairs of sites near Santarem, there are spectral differences between ABE and non-ABE sites. There are nine portions of the spectrum where the three ABE sites are completely separable from the three non-ABE sites.

This limited demonstration analysis highlights the important opportunity that Hyperion data provide for identifying and mapping ABE sites. As much as our current knowledge of this forest expands, it is still limited by ignorance of past disturbance and dynamics as well as the populations and agricultural practices of previous human societies.

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