Final Technical Report:

Simple and Multiple Endmember Mixture Analysis in the Boreal Forest

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a joint proposal with the California State Los Angeles proposal

Integrating models with narrow-band, multi-scale remotely sensed data for improved assessment of photosynthetic fluxes

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$20,000/yr ($40,000 total)

Note: See related report will be sent by collaborators Gamon and Qiu

Summary

A key scientific objective of the original BOREAS field campaign (1993-1996) was to obtain the baseline data required for modeling and predicting fluxes of energy, mass and trace gases in the boreal forest biome. These data sets are necessary to determine the sensitivity of the boreal forest biome to potential climatic changes and potential biophysical feedbacks on climate. A considerable volume of remotely sensed and supporting field data were acquired by numerous researchers to meet this objective. By design, remote sensing and modeling were considered critical components for scaling efforts, extending point measurements from flux towers and field sites over larger spatial and longer temporal scales. A major focus of the BOREAS Follow-on program was concerned with integrating the diverse remotely sensed and ground-based data sets to address specific questions such as carbon dynamics at local to regional scales.

Through a joint proposal with Cal State Los Angeles, UCSB directly addressed questions of spatial and temporal scaling at the BOREAS sites through advanced analysis of hyperspectral data and AIRSAR. UCSB contributed to this joint research effort by processing select AVIRIS scenes acquired over BOREAS sites to reflectance, mapping canopy moisture and water vapor, initial development of spectral libraries from AVIRIS and initial simple and multiple endmember spectral mixture analysis. Additional analysis performed at UCSB included analysis of multitemporal AIRSAR in combination with AVIRIS.

The UCSB effort focused on two aspects of the problem: 1) Reflectance retrieval, thereby converting AVIRIS data from a non-useable form, to a form that can be readily used by a large number of researchers and 2) Mapping efforts to develop accurate maps of land-cover through a combination AVIRIS and AIRSAR data and sophisticated mixture models. High quality reflectance was retrieved for a total of 239 AVIRIS scenes, primarily located over flux sites in April, July and September. A supporting document, describing AVIRIS processing was developed to be included as metadata in BORIS (Roberts and Prentiss, 2000: Appendix I). Mapping efforts at UCSB focused on a combination of species-level mapping using multiple endmember spectral mixture analysis (MESMA, Roberts et al., 1998a; 1999) and sensor fusion using binary decision tree classifiers (Roberts et al., 1998b) with input parameters derived from simple mixture models, AVIRIS liquid water and C, L and P band radar backscatter (Roberts et al., 1999; Reith et al., 1999). Maps were developed from AVIRIS and AIRSAR for three seasons, winter, early summer and fall in an effort to determine which combination of wavelengths and dates were optimal for map generation. Accuracy was assessed using

the Saskatchewan Environment and Resource Management Forestry Branch – Inventory Unit (SERM-FBIU) as a reference. Map accuracies ranged from a low of 33.5% for Tamarack mapped by AIRSAR in September 1994 to a high of 81.1% for Jack Pine mapped by AVIRIS in July, 1994. Overall accuracy ranged from 55% in September 1994 to 69.8% in July 1994, with the highest accuracies achieved using AVIRIS.

A key component of the UCSB effort was in providing high quality reflectance products to collaborators at Cal State LA. All AVIRIS reflectance products developed at UCSB were transferred to Cal State LA for subsequent analysis. At Cal State LA AVIRIS reflectance was used to develop biochemical based classified maps (Fuentes et al., 2000a/b) and an empirical model relating the product of NDVI and PRI to CO2 uptake from flux towers (Rahman et al., 2000a/b). See the associated final report from Cal State LA for more details on this research.

Results

Reflectance Retrieval

In order to compare data acquired by multiple sensors across time and space it is often necessary to convert the data from sensor-specific units, to radiometric units (radiance) and ultimately reflectance. Radiometrically calibrated AVIRIS data, acquired from the Jet Propulsion Laboratory, were processed to apparent surface reflectance using Modtran 3.5 and a technique developed by Robert Green (Green et al., 1993; Roberts et al., 1997). The technique entails the use of four programs and is summarized in Roberts et al., (1999) and described in detail in Appending I.

Approximately 1000 AVIRIS scenes were acquired during the BOREAS campaign. One of our first steps was to prioritize scenes for ordering and processing. Scenes were prioritized starting with calibration targets as the highest priority (SSA-Cal-W for 940419, 940721 and 940916) followed by a selection of scenes selected by collaborators at Cal State Los Angeles. Our general strategy was to use ground spectral reflectance measurements acquired by Robert Green over a target in SSA-Cal-W to improved reflectance retrievals, then port the correction to all other scenes acquired within the same campaign. At times when no ground reflectance data exist, we used temporally invariant targets as a means of correcting data. Initial results presented at JPL suggest that this approach is valid (Roberts et al., 1999). Ground corrections were also ported to scenes acquired in the northern BOREAS study sites (NSA) when data were acquired within a similar time frame as the southern sites.

A significant factor complicating reflectance retrieval was difficulties encountered in acquiring high quality radiometrically calibrated data from JPL. Difficulties were encountered due to a combination of poor radiometric calibration, poor transfer media and problems in data delivery. Radiometric calibration was complicated by the fact that most of the data ordered were acquired in 1994 and the software needed to process the data to radiance had become obsolete due to changes in equipment. New software developed at JPL by Robert Green initially failed to adequately compensate for problems in dark current files specific to 1994 data, resulting in all initial orders having errors. Transfer errors resulted due to a combination of hardware problems at JPL and UCSB (tape drive problems), and the potential damaging effects of increased x-ray doses used by the US Postal service. A major component of the first 9 months of our study focused on developing a protocol for identifying problem data sets, identifying sources of errors and devising ways to correct them. Working in combination with JPL, all error sources were corrected and high quality data sets were shipped in 1999.

Currently, a total of 873 radiometrically calibrated AVIRIS scenes have been shipped to UCSB out of the 923 acquired during BOREAS (Section VII, Appendix I). Although the possibility of poor data quality remain in some scenes, a majority are likely to be good based on measures taken to improve data quality. A total of 239 scenes, concentrating primarily in the southern BOREAS sites have been processed to reflectance and made available to Cal State LA. A significant problem that remains is devising a method whereby these data sets can be transferred to BORIS with adequate metadata. A document, describing AVIRIS processing followed by a table of meta-data was developed by UCSB to provide the necessary information for users to interpret the reflectance products (Appendix I). Additional AVIRIS scenes have been processed to reflectance by special request.

Mapping and Mixture Models

One primary focus at UCSB has been on acquiring radiometrically calibrated AVIRIS data from JPL and processing them to retrieve surface reflectance. As a further step, we have focussed on developing maps of vegetation dominants using Multiple Endmember Spectral Mixture Analysis (MESMA) and fraction images of green vegetation, soils, non-photosynthetic vegetation (NPV) and shade using a simple mixture model (Roberts et al., 1993; 1998a). We explored the potential application of retrieved liquid water as a measure of canopy structure (LAI; Roberts et al., 1997; 1998c). Through an unfunded PhD student from the National Image and Mapping Agency (NIMA: Ernie

Reith), we explored potential applications of sensor fusion (AVIRIS and SAR) for mapping forest biophysical properties and species. Preliminary research results were presented at the Seventh Airborne Earth Science Workshop (Roberts et al., 1999; Gamon et al., 1999; Reith and Roberts, 1999).

One of our initial objectives in the proposal was to develop a regionally specific spectral library for BOREAS. Unfortunately, we have found a remarkable lack of representative reflectance spectra that cover the entire spectral region covered by AVIRIS. For this reason, much of our focus has been on developing spectral libraries from AVIRIS scenes acquired over well described targets over a growth season. Initial findings were reported in Roberts et al., (1999). A subset of spectra were also used by Fuentes et al. (2000) to map vegetation. A full manuscript describing land-cover reflectance and radar backscatter is under developed by Ernie Reith, with an objective of submitting it as part of a BOREAS special issue in Remote Sensing of Environment under development. Copies of Roberts et al. (1999) and all other BOREAS publications from UCSB are included in Appendix II.

Simple and multiple endmember spectral mixture models were implimented at UCSB and used to map land-cover types in several of the flux sites. Initial results were described by Roberts et al., (1999). These results have been expanded by Ernie Reith as part of his PhD research. Mr Reith is interested in evaluating sensor requirements for producing optimal map accuracies and selected BOREAS flux sites as his test sites. For his PhD he is attempting to determine which combination of seasonal information and wavelengths produce the highest map accuracies, using the SERM-FBIU as a reference map. Data sets he is using include full seasonal AIRSAR and AVIRIS acquired over the Old Jack Pine and Black Spruce sites. Initial findings suggest that no single sensor or date is optimal for mapping land-cover. In general, AIRSAR performed best in flooded sites and open water, while AVIRIS performance was best in upland sites. Producers accuracies ranged from 33.5% in Tamarack to 81.1% for Jack Pine (Table 1). A significant factor limiting accuracies involved errors in the reference data set. For example, analysis of airphotos acquired near the time of the flights demonstrated that a number of sites, mapped as Aspen, were in error in SERM-FBIU due to either the scale of the map (the patches were small and assimilated into other land-cover types) or recent changes.

Table 1. Individual land cover type producer's accuracy (Reith et al., 2000).

Landcover	Accuracy	Date	Sensor
Aspen	65.1%	940916	AVIRIS
Black Spruce	73.2%	940428	AIRSAR
Fen	70.8%	940721	AVIRIS
Jack Pine	81.1%	940721	AVIRIS
Muskeg	73.2%	940920	AIRSAR
Open	80.1%	940916	AVIRIS
Tamarack	33.5%	940920	AIRSAR
Water	77.5%	940721	AIRSAR

Personnel:

At UCSB PI Roberts took primary responsibility for organizing research activities. AVIRIS reflectance processing and data transfer between UCSB and Cal State Los Angeles was performed primarily by two research assistants who were funded in part by this grant. The research assistants included Keir Keightley, who was funded at 25% over a period of one year starting in July, 1998, and Dylan Prentiss who was funded at a variable rate over the entire funding period. In addition to reflectance retrieval, data archiving and copying Dylan Prentiss contributed significantly to materials shown in Appendix I.

Major contributions were made by a UCSB PhD student, Ernie Reith, who was on temporary leave from the National Imaging and Mapping Agency (NIMA). Mr Reith's primary research interest is in the selection of optimal spectral, temporal and spatial sensor properties for land-cover mapping. Upon the advice of PI Roberts, he selected BOREAS sites as his primary test sites, where he integrated multitemporal AVIRIS and AIRSAR to map land-cover. Two non-refereed publications have resulted (Reith et al., 1999; 2000). At least two more refereed publications are anticipated as a part of his final dissertation research. No BOREAS funds were used to support Mr. Reith. However, participation in BOREAS gave Mr. Reith access to aerial photographs, land-cover maps, AIRSAR and AVIRIS data that would be otherwise difficult to obtain, and is thus considered a major contribution to his PhD research.

Close collaborators at Cal State Los Angeles included Dr. John Gamon, a student named David Fuentes and a post-doctoral researcher Dr. Abdullah F. Rahman.

Publications & Presentations:

Attended First Boreas Follow-on workshop, March 25-27, 1998, Oregon.

Fuentes D, Gamon JA, Qiu H-L, Roberts D, Sims D (1999) Mapping functional vegetation types using hyperspectral remote sensing in chaparral and boreal ecosystems. (abstract accepted for presentation at the August 1999 Annual Meeting of the Ecological Society of America, Spokane, Washington).

Fuentes, D.A., Gamon, J.A., Qiu, H., L., Sims, D., and Roberts D., (2000), Mapping vegetation cover types in the Canadian boreal forest using pigment and water absorption features derived from AVIRIS, Proc. 9th AVIRIS Earth Science Workshop, JPL, Pasadena, CA, Feb 23-25, 2000, 14 pp.

Fuentes, D.A., Gamon, J.A., Qiu, H., L., Sims, D., and Roberts D., (2000), Mapping Canadian boreal forest vegetation using pigment and water absorption features derived from AVIRIS sensor, submitted *J. Geophys. Res. Atmospheres* BOREAS special issue.

Gamon JA, Qiu H-L, Roberts DA, Ustin SL, Fuentes DA, Rahman A, Sims D, Stylinski C (1999) Water expression from hyperspectral reflectance: Implications for ecosystem flux modeling, Presented at the Seventh Airborne Earth Science Workshop, February 1999, JPL, Pasadena CA, pp. 117-126.

Gamon JA, Fuentes D, Qiu H-L, Roberts DA (1999) Initial AVIRIS results from BOREAS (poster presented at the Feb 1999 BOREAS follow-on workshop, Tallahassee, Florida).

Rahman, A.F., Gamon, J.A., Fuentes, D.A., Roberts, D.A., Prentiss, D., and Qiu, H., (2000), Modeling CO2 flux of boreal forests using narrow band indices from AVIRIS imagery, Proc. 9th AVIRIS Earth Science Workshop, JPL, Pasadena, CA, Feb 23-25, 2000, 14 pp.

Rahman, A.F., Gamon, J.A., Fuentes, D.A., Roberts, D.A, and Prentiss, D. (2000), Modeling spatial distributed ecosystem flux of boreal forests using hyperspectral indices from AVIRIS imagery, submitted *J. Geophys. Res. Atmospheres* BOREAS special issue.

Reith, E., and Roberts, D., (1999), Land-cover characterization of the Boreal Forest: A SAR Approach, Presented at the Seventh Airborne Earth Science Workshop, February 1999, JPL, Pasadena CA, 10 pp.

Reith, E., Roberts, D., and Prentiss, D., (2000), Multi-sensor characterization of the boreal forest: initial findings, Proceedings of the 2000, International Symposium on Spectral Sensing Research, 7 pp.

Roberts DA, Gamon J, Keightley K, Prentiss D, Reith E, Green RO (1999) AVIRIS land-surface mapping in support of the BOReal Ecosystem-Atmosphere Study (BOREAS), Presented at the Seventh Airborne Earth Science Workshop, February 1999, JPL, Pasadena CA, pp. 355-364.

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Fuentes, D.A., Gamon, J.A., Qiu, H., L., Sims, D., and Roberts D., 2000a, Mapping vegetation cover types in the Canadian boreal forest using pigment and water absorption features derived from AVIRIS, Proc. 9th AVIRIS Earth Science Workshop, JPL, Pasadena, CA, Feb 23-25, 2000, 14 pp.

Fuentes, D.A., Gamon, J.A., Qiu, H., L., Sims, D., and Roberts D., 2000b, Mapping Canadian boreal forest vegetation using pigment and water absorption features derived from AVIRIS sensor, ubmitted *J. Geophys. Res. Atmospheres* BOREAS special issue.

Green, R.O., Conel, J.E. and Roberts, D.A., 1993, Estimation of Aerosol Optical Depth, Pressure Elevation, Water Vapor and Calculation of Apparent Surface Reflectance from Radiance Measured by the Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) Using MODTRAN2, *SPIE Conf. 1937, Imaging Spectrometry of the Terrestrial Environment*, 2-5.

Rahman, A.F., Gamon, J.A., Fuentes, D.A., Roberts, D.A., Prentiss, D., and Qiu, H., 2000a, Modeling CO2 flux of boreal forests using narrow band indices from AVIRIS imagery, Proc. 9th AVIRIS Earth Science Workshop, JPL, Pasadena, CA, Feb 23-25, 2000, 14 pp.

Rahman, A.F., Gamon, J.A., Fuentes, D.A., Roberts, D.A, and Prentiss, D.,2000b, Modeling spatial distributed ecosystem flux of boreal forests using hyperspectral indices from AVIRIS imagery, submitted *J. Geophys. Res. Atmospheres* BOREAS special issue.

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Roberts, D.A., Smith, M.O., and Adams, J.B. 1993, Green vegetation, nonphotosynthetic vegetation, and soils in AVIRIS data. *Remote Sens. Environ.* 44:255-269.

Roberts DA, Gamon J, Keightley K, Prentiss D, Reith E, Green RO 1999, AVIRIS land-surface mapping in support of the BOReal Ecosystem-Atmosphere Study (BOREAS), Presented at the Seventh Airborne Earth Science Workshop, February 1999, JPL, Pasadena CA, pp. 355-364.

Roberts, D.A., Green, R.O., and Adams, J.B., 1997,Temporal and Spatial Patterns in Vegetation and Atmospheric Properties from AVIRIS, *Remote Sens. Environ* 62: 223-240.

Roberts, D.A., Gardner, M., Church, R., Ustin, S., Scheer, G.,and Green, R.O., 1998a, Mapping Chaparral in the Santa Monica Mountains using Multiple Endmember Spectral Mixture Models, *Rem. Sens. Environ.* 65: 267-279.

Roberts, D.A., Batista, G., Pereira, J., Waller, E., and Nelson, B. 1998b, Change Identification using Multitemporal Spectral Mixture Analysis: Applications in Eastern Amazonia, Chapter 9 in Remote Sensing Change Detection: Environmental Monitoring Applications and Methods, (Elvidge, C. and Lunetta R., Eds.), Ann Arbor Press, Ann Arbor, MI, pp. 137-161.

Roberts, D.A., Brown, K.J., Green, R., Ustin, S., and Hinckley, T., 1998c, Investigating the relationship between liquid water and leaf area in clonal Populus, Proc. 7th AVIRIS Earth Science Workshop JPL 97-21, Pasadena, CA 91109, 335-344.

Appendix II: Select BOREAS Publications

Reith, E., and Roberts, D., (1999), Land-cover characterization of the Boreal Forest: A SAR Approach, Presented at the Seventh Airborne Earth Science Workshop, February 1999, JPL, Pasadena CA, 10 pp.

Reith, E., Roberts, D., and Prentiss, D., (2000), Multi-sensor characterization of the boreal forest: initial findings, Proceedings of the 2000, International Symposium on Spectral Sensing Research, 7 pp.

Roberts DA, Gamon J, Keightley K, Prentiss D, Reith E, Green RO (1999) AVIRIS land-surface mapping in support of the BOReal Ecosystem-Atmosphere Study (BOREAS), Presented at the Seventh Airborne Earth Science Workshop, February 1999, JPL, Pasadena CA, pp. 355-364.