Final Report
Contract No. NAG5-4447
Understanding Variability in the AVIRIS-Derived Parameters from Vegetation Cover

Alexander F.H. Goetz

Introduction

This project was carried out in two phases, the first was an investigation of the possible sources of variability in the canopy leaf chemistry parameters derived from AVIRIS data on a year-to-year basis, and the second was a follow-on effort to improve the atmospheric correction program ATREM as well as to provide support to the community on the use of ATREM. This final report embodies a general review of the results obtained over the life of the contract as well as detailed interim reports and copies of the six papers published in AVIRIS Workshop Proceedings over the last 3 years.

Scope of Work

The overall goal of this research was to understand how variables such as atmospheric modeling for correction of spectral transmission and path radiance, BRDF, instrument spectral and radiometric calibration, and information extraction algorithms affect the quality and precision of derived parameters such as lignin and nitrogen concentration in forest canopies measured over a period of years. The second phase concentrated on the most likely cause of inter-year discrepancies in canopy chemistry results, atmospheric correction. The Atmospheric Removal (ATREM) program was upgraded to include platforms at intermediate altitudes and support for the software for users in other research groups. The latter group numbers over 300 worldwide. Given the age of ATREM and the difficulties with burdening the original author of the software with questions from the community, in March 2000 ATREM was removed from the FTP site. In February 1999, work was started on HATCH (**H**igh-accuracy **AT**mospheric **C**orrection for **H**yperspectral data) that resulted in a paper at the February 2000 AVIRIS conference (Qu et al, 2000). The development work is continuing as part of the author's work on the EO-1 Science Validation Team.

Results

Canopy Chemistry

The data analyzed were AVIRIS scenes of Black Hawk Island, WI (BHI) and Harvard Forest (HF) for 1992 and 1993. The reason for this study came from the fact that the values for nitrogen and lignin calculated from a statistically-derived, multiple linear regression (MLR) regression of the laboratory analysis of green foliage from field sites and AVIRIS spectral data from the same sites in 1992 did not agree with the 1993 data within a factor of 2. Similar results were obtained with curve fitting (CV) methods (Gao et al, 1994)

A sand pit with known spectral reflectance characteristics was used to normalize the data to remove atmospheric and illumination effects in the BHI data. The results for BHI showed that before normalization was performed on the 1993 BHI scene, the lignin values predicted by the curve fit algorithm were nearly double the laboratory values, and the MLR predicted values were within range. When the normalization was performed on the 1993 BHI scene, then both algorithms predicted lignin values in the same range as laboratory values, and the correlation with the laboratory values improved for the MLR technique (R=. 77). However, the correlation of the CF predicted values and the laboratory values were fairly low (R=. 30).

The results for HF showed that when ATREM-only was applied to the 1993 HF scene, the predicted lignin values for both the MLR and CF techniques was more than 50% higher than the laboratory values. Also, the correlations with the laboratory data were low (R=. 25 for MLR, R=. 56 for CF). For the 1996 HF scene, the MLR predicted lignin values were within a reasonable range to the laboratory, even without a normalization of the data. The CF predicted lignin values, which were about 50% higher than the laboratory values in the ATREM-only scene, moved into close range with the laboratory values after the normalization was applied. However, the predicted lignin values from both techniques did not correlate well with the laboratory values (R= -0.40 for MLR, R=0.52 for CF). These results were published in Goetz et al (1997).

Conclusions (Canopy Chemistry)

1. The atmosphere correction does affect the results of both the MLR and CF techniques. After the normalization was applied to the ATREM only data, the CF values fell within range of the laboratory values.
2. Neither the MLR nor the CF techniques predicted lignin with a high correlation to the laboratory data in the years subsequent to 1992.

There are several possible sources of error:

1. Systematic errors in the lignin prediction algorithms
2. Errors in registering the images
3. BRDF effect of the different sun elevation and azimuth angles
4. Year to year differences in the canopy architecture (LAI, LAD, gaps)
5. For the normalization technique, differences in the AVIRIS pixel coverage and the surface reflectance measurements at the calibration sites
6. Changes in the lignin concentration of the canopy

Although there are many factors that could render a MLR calibration of a live canopy inaccurate, the most visible factor was the atmospheric correction that showed major departures from ground-acquired spectra, particularly in the 1.0 μm and 2.3-2.5 μm regions.

Atmospheric Corrections

As it became clear that the program ATREM by itself was not capable of yielding an atmospheric correction of AVIRIS data without additional ground calibration targets, we pursued another avenue of atmospheric correction using MODTRAN 3 to develop a database to be used as a lookup table. The technique relies on determining atmospheric parameters from the spectral irradiance measurements made at the surface, which in turn drive the MODTRAN model to provide an at-sensor modeled radiance.

The initial attempts to find a MODTRAN model that would match the irradiance spectrum demonstrated that, for practical application, a method for rapid searching was required. For this purpose, we developed two databases, the first a set of measured irradiance spectra that includes over 8000 spectra acquired in the summer of 1997 in Boulder, Colorado under a variety of atmospheric conditions. The second data base consisted of a series of 13,200 MODTRAN models incorporating combinations of variations in six parameters; zenith angle, water vapor, aerosol, cloud model, visibility and atmospheric profile.

The measured and modeled databases were resampled to AVIRIS resolution. A principal components transformation of each database revealed similarity in the dimensionality. Plots of individual eigenvectors showed that beyond the first principal component the eigenvectors differed significantly. Mapping the intersection of subspaces revealed that the two data sets shared a 10-dimensional spectral space and that one could be transformed into the other. This property made it possible to search for a model equivalent to an irradiance measurement rapidly, and subsequently use the model parameters to calculate the surface-sensor atmospheric path corrections. Principal components transformation of the intersecting database shows that the eigenvectors up to the 8th component are nearly identical.

The results were encouraging in that the values matched well in the atmospheric windows. However, the intervals in solar zenith angle and atmospheric water vapor in the MODTRAN database were very coarse and that led to compensation in other parameters chosen, such as cirrus cover. The MODTRAN modeled transmission in the wings of the water vapor absorption features did not agree with the irradiance measurements and the departures were similar to those seen in model-corrected AVIRIS data.

Conclusions (Atmospheric Correction)

The conclusion reached was that a much larger model database is required to recover the atmospheric parameters accurately enough for correction to the level provided currently with ATREM. Therefore, it was agreed that during the contract extension an attempt would be made to create a more accurate form of ATREM that had as input ground irradiance measurements to anchor the model.

New Atmospheric model

The development of an atmospheric model to replace ATREM followed two paths; one was to rewrite ATREM to produce a program called HATCH (High-accuracy ATmospheric Correction for Hyperspectral data) and the second was to develop a technique to obtain atmospheric transmission at all wavelengths for the sun-surface path at the time of overflight that could be used in the new model.

Kindel et al (1999) developed a method by which the instantaneous atmospheric transmission could be retrieved along the sun-surface path with an ASD-FR portable spectroradiometer. The instrument was extensively calibrated in the laboratory radiometrically with a NIST-traceable lamp over a 6-month period. Precisions of +/- 1% were achieved for most wavelengths.

For the solar measurement, the instrument fiber-optic cable was inserted into an integrating sphere attached to a lensless telescope with a 2 deg. FOV. In the atmospheric windows, Langley plots were made in Colorado and Hawaii to determine the stability and reproducibility of the measurements and extrapolate to the solar irradiance above the atmosphere. Only 20% of the wavelength region 0.4-2.5 μm can be used for Langley measurements to determine the optical depth. The other 80% of the region lies within absorption features from water, carbon dioxide, oxygen, ozone and methane. The technique for calibrating the non-Langley channels rests upon the fact that the spectral shape of NIST-traceable 1000 W bulbs is very well known. A scaling factor is determined from the ratio of the Langley-determined coefficients to the bulb coefficients in the valid Langley channels. This scaling factor is then applied to the bulb calibration to fill in where Langley is not valid and should closely agree with the coefficients where Langley is valid.

The agreement between the bulb-scaled and Langley-derived coefficients were generally very good, with 69% of the channels within +/- 1% of each other and 96% of the channels within +/- 2%. The results were used to drive a MODTRAN model for surface reflectance retrieval and the results achieved over vegetated terrain showed that the instrument was making accurate transmission measurements, but that more care was necessary in spectral calibration and defining the spectrometer point spread function at each wavelength.

The successor to ATREM (Gao et al, 1993) has been completed to the point of preliminary testing on AVIRIS data. It is a completely new set of code that does not rely on ATREM (Zheng et al, 2000). Changes made reduce the errors in ATREM created by use of the Malkmus band model based on the HITRAN 92 database. HITRAN 99 is now available. The correlated-k method is used instead of the Malkmus band model. This method for gaseous absorption calculation transforms the line-by-line integration over a narrow spectral band of a radiative quantity such as transmittance to integration over the cumulative probability distribution function of the gas absorption coefficient. The transformed integration can therefore be computed using a few quadrature points without compromising accuracy, since the function to be integrated is a smooth one. HATCH does not employ the multiplication rule to handle transmittance in spectral regions where multiple gas absorption is present. Previously, this resulted in less accurate transmission in the 2 μm region where both H2O and CO2 strongly absorb.

HATCH does not separate the multiple scattering processes from the absorption in the atmosphere, which causes less accurate path radiance calculation for short wavelengths and for turbid atmospheric conditions. HATCH makes use of a smoothness test to aid in water vapor retrieval rather than the 3-band ratio in ATREM. This test avoids the linearity assumption for the surface reflectance. The best water vapor estimation yields the smoothest retrieved surface reflectance in the water vapor absorbing regions.

The preliminary results show significant improvement in the retrieved surface reflectance having fewer artifacts than the spectra derived using ATREM. The development is being continued with support from the EO-1 program.

Summary

This research effort over three years resulted in 5 AVIRIS Workshop Proceedings papers and two journal papers in preparation for Applied Optics and Remote Sensing of Environment. The question of what caused a factor of two difference between foliar chemistry values for lignin and nitrogen is still not completely resolved. The atmospheric correction uncertainty certainly was a large factor. However, other factors such as canopy structure differences, water status and trunk and branch exposure cannot be ruled out. The multivariate statistical analysis used to produce unknown values based on known calibrations only is valid if the spectra being analyzed fall with in the calibration set. Outliers caused by different atmospheric conditions or structural differences not accounted for in the calibration model would certainly lead to inaccurate regression values.

The major difference between the two years has to do with atmospheric correction. We undertook to strengthen ATREM and eventually to rewrite it to take adantage of new HITRAN line strength values and to make it more capable and accurate. The new software is called HATCH and is being further developed under the EO-1 program.

A more detailed list of conclusions can be found in the attachments containing all papers written under this contract.

References

Gao, B.-C., K. B. Heidebrecht and A.F.H. Goetz, Derivation of scaled surface reflectance from AVIRIS data, *Remote Sens. Environ. 44*, 165-178, 1993

Gao, B.-C. and A.F.H. Goetz, Extraction of Dry Leaf Spectral Features from Reflectance Spectra of Green Vegetation, *Remote Sens. of Env.,47*, 369-374, 1994.

Goetz, A.F.H., K.B. Heidebrecht, and B. Kindel, The effect of atmospheric correction on AVIRIS data to obtain consistent multiyear foliage chemistry results, *Presented at the IEEE IGARSS'97 Conference in Singapore,* August 3-8, 1997

Goetz, A. F. H., K. B. Heidebrecht, B. Kindel and J. W. Boardman, Using ground spectral irradiance for model correction of AVIRIS data, *Summaries of the 7th AVIRIS Earth Science and Applications Workshop,* Vol 1, 159-169,1998

Goetz A. F. H. and B. Kindel, Comparison of unmixing results derived from AVIRIS, high and low resolution and HYDICE at Cuprite, NV, *Summaries of the 8th AVIRIS Earth Science and Applications workshop,* Vol 1, 1-10, 2000

Kindel,B, Z. Qu and A.F.H. Goetz, Hyperspectral solar radiometry for surface reflectance retrieval, presented at the 9th AVIRIS Earth Science and Applications Workshop, JPL, CA, February 23-25, 2000

Qu, Z., A.F.H. Goetz and K.B. Heidebrecht, High-accuracy atmospheric correction for hyperspectral data (HATCH), presented at the 9th AVIRIS Earth Science and Applications Workshop, JPL, CA, February 23-25, 2000