AVIRIS Observation of Forest Ecosystems
Along the Oregon Transect

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Abstract. AVIRIS data have been acquired over several diverse forest sites in support of the Oregon Transect Ecosystem Research project. Overflights have occurred at key times during the growing season to assess the temporal and spatial sensitivity of AVIRIS spectra to foliar biochemical concentration. Preliminary analysis includes an image-based estimation of signal-to-noise, comparison with other imaging spectrometers, and stepwise regression against laboratory-determined nitrogen concentration.

I. Introduction

The Oregon Transect Ecosystem Research (OTTER) project is studying biogeochemical cycling along a climatic and fertility gradient in western Oregon. The transect extends from the Pacific coast inland approximately 200 km. Six study sites (Figure 1) represent a broad range in ecosystem structure and function. Two sites are subdivided into control and fertilizer amended plots, while a third site contains coniferous and broadleaf plots.

A variety of remotely-sensed and in-situ measurements are being used to characterize forest physiological and structural parameters, nutrient cycling, and biochemistry. These measurements will be transformed into ecosystem process rates and fluxes by use of the FOREST-BGC model (Running and Coughlan, 1988). The overall OTTER goal is to test and validate FOREST-BGC, which will be driven with remotely-derived measurements to the extent possible.

Within the OTTER project, the sensitivity of AVIRIS to the quantity of plant biochemical constituents is being examined. Such sensitivity would provide insight into ecosystem carbon and nitrogen cycles. For instance, starch, sugars and carbohydrates are related to rates of carbon assimilation, above and below ground carbon allocation, carbon turnover, growth, maintenance, and respiration. Nitrogen and lignin affect the rate of litter decomposition, which in turn regulates the amount of nitrogen available for uptake, volatilization (of N_2O), and leaching (of NO_3^-).

The ability to reliably measure foliar biochemical components from first principles is hampered by incomplete knowledge concerning internal

leaf scattering and absorption properties arising from the presence of biochemical compounds. The various co-occurring constituents are composed of similar molecular bonds (eg: C-H, N-H, O-H) and thus have overlapping absorption features, forming functional groups which cluster at several locations in the near-infrared (NIR) region. Atmospheric water vapor, foliar water, and soil moisture pose another complicating factor. O-H bonds of free or bound water absorb strongly, and co-vary with biochemicals to differing degrees. Other factors which influence the remotely sensed spectra, yet are not directly related to biochemical optical properties, include plant morphology, leaf angle and leaf area distribution, and canopy architecture.

Over the past several decades, researchers in the agricultural sciences have met with considerable success in drawing statistical relationships between forage biochemical constituency and laboratory-derived NIR spectra (Marten *et al.*, 1989). Recent studies have built upon these methods to develop statistical relationships between forest biochemical concentration and canopy upwelling radiance as measured by imaging spectrometers (Peterson *et al.*, 1988; Wessman *et al.*, 1989; Swanberg and Matson, 1989). The availability of laboratory biochemical assay (nitrogen, lignin, starch, chlorophyll, cellulose, amino acids, sugar) in conjunction with the OTTER AVIRIS observations establishes a basis for a comparison of statistical results with these previous studies. In addition, lab spectra performed on samples collected at fertilized and control plots will be of use in identifying overt indications of biochemical content variation, particularly nitrogen, in the AVIRIS spectra.

II. Data Analysis

AVIRIS data were acquired across the transect in March, August, and October of 1990. These data, along with an acquisition in late May 1991, provide observations which coincide with distinct forest developmental stages: budbreak, full leaf-out, maximum water stress, and dormancy. Each mission was supported by two sunphotometers to provide atmospheric optical depth readings at or near the time of overflight for each site. Also during each mission, foliage samples were collected from five trees at each plot and assayed for several biochemical constituents. Spectral measurements were made at spectrally flat fields near each site with a field spectroradiometer (Spectron Engineering, Inc., 1990) during two overflights. A discussion of preliminary evaluation and analysis of these datasets follows.

A. Signal-to-Noise

The signal-to-noise ratio (SNR) was estimated in five channels as the ratio of the mean to the standard deviation of AVIRIS at-sensor radiance within a 3x3 pixel matrix over an apparently homogeneous sandspit approximately 5x5 pixels in size (Figure 2). Each SNR was calculated as the mean SNR of three neighboring channels. The sandspit reflectance was estimated as the quotient of the surface radiance (*π) divided by the incoming irradiance, modeled by an atmospheric correction algorithm (Fraser *et al.*, 1989). Estimated reflectance trended from ~20% at 635nm up to ~40% at 2119nm. Observation dates 8/90 and 10/90 were compared with pre-OTTER data flown in 6/89 and 9/89. The target was obscured by cloud cover in the 3/90 dataset.

The limited target size and uncertainty about atmospheric conditions during the 1989 flights reduce confidence in the absolute values presented. Nonetheless, an interesting trend is apparent. SNR in the 1989 data, particularly the June dataset, diminished markedly in the longer wavelengths with respect to the visible channel (635nm). The 1990 data, particularly the August dataset, were more constant across the spectral regions. Presumably this is due at least in part to noise-reduction modifications made to AVIRIS during 1990.

B. Inter-Sensor Comparison

During the August 1990 campaign, nearly simultaneous observations were made at several sites by AVIRIS, the Advanced Solid-State Array Spectroradiometer (ASAS) (Irons *et al.*, 1991), and the Compact Airborne Spectrographic Imager (CASI) (Borstad and Hill, 1989). ASAS was flown at 15000 feet above-ground-level (AGL) aboard the NASA C-130; CASI was flown at 5000 feet AGL aboard a light aircraft. ASAS is a pointable instrument which measures the 462-865 spectral region in 29 channels; the nadir view is used for the present comparison. CASI samples the 425-950nm spectral region in 288 channels.

Figure 3a shows a comparison of raw data for the alder (*Alnus rubra*) plot at site #1 from the three spectrometers. AVIRIS and CASI data were acquired about 90 minutes after solar noon on 14-August-1990, while ASAS were acquired about 60 minutes before solar noon. The spectra show the additive influence of atmospheric path radiance, most obvious in the visible channels, as a function of flight altitude. The green peak, chlorophyll trough, and major atmospheric absorption features appear well aligned.

An atmospheric correction procedure (Fraser *et al.*, 1989), using optical depth readings made at the site approximately 90 minutes after the AVIRIS flight, was used to convert at-sensor radiance into surface radiance (Figure 3b). The correction included all AVIRIS and ASAS channels in the 500-900nm region, along with a subset of the 288 CASI channels. The correction removed the path radiance from the visible channels. The ASAS measurement is greater than that of the other sensors in the NIR, primarily because these data were measured with a higher solar elevation (56.5° vs. 51°). The AVIRIS and CASI measurements agree to within 1 $\mu W/cm^2/sr/nm$ in the NIR region.

All datasets were converted into reflectance by dividing the estimated surface radiance ($*\pi$) by the downward irradiance estimated by the algorithm (Figure 3c). All datasets agree to within about 1-2% absolute reflectance except at the longer wavelengths, where AVIRIS and CASI differ by about 4%.

C   Statistical Analysis

The OTTER sites represent a gradient in major variables which affect plant chemical and physical characteristics: species, seasonal growth stage, stand maturity, availability of water, nutrients and light, and climatic conditions, among others. The sites are representative of a broad cross-section of mid-latitude forest ecosystems. Reflectance spectra from these sites may be regressed against laboratory chemical assay to develop predictive equations for biochemical concentration.

Nitrogen (N) concentration (mg/g) was estimated for each plot as the mean of laboratory assays performed on five foliage samples collected throughout the plot. Stepwise multilinear regression was used to calculate the correlation of the AVIRIS (3x3 pixel average) NIR spectra for two overflights with plot N concentration. AVIRIS data taken over all conifer sites during the 8/90 and 10/90 flights were converted to 1st-difference spectra representing the slope between each neighboring channel pair. Conversion to 1st-difference emphasizes structure due to the relatively weak biochemical absorptions which are superimposed upon dominating water absorption features.

Results presented herein are based on a small sample size and should be considered preliminary at this time. Regressions with small sample size, though insufficient for development of analytical equations, may

however indicate measurement potential for a given constituent (Barton and Cavanagh, 1988). If the selected wavelengths make physical sense, this would be a good indication as well.

A total of 58 channels per date were used as candidate independent variables, occupying the region 1122-1350nm and 1500-1787nm. These regions are known to contain biochemical absorption features (Williams and Norris, 1987), with relatively low interference from water absorption. Three-term stepwise results are shown in Tables 1a and 1b. Essentially the same wavelengths were chosen in the first and second positions for each date, albeit in different order. The stepwise procedure was re-run on 30 channels between 1500-1787nm for both dates (Tables 1c and 1d). The 1540/1550nm selections correspond with a selection at 1555nm found in an earlier N-concentration study using the JPL Airborne Imaging Spectrometer (AIS) data over Oregon conifers (Swanberg and Peterson, 1988). The 1658nm selection in both of the 8/90 datasets is close to a selection of 1655nm made in a previous AIS study of N-concentration in Douglas-fir in New Mexico (Swanberg and Matson, 1989).

For reference, Table 1 shows the center wavelength of the established protein absorption feature (after Williams and Norris, 1987) which is nearest to each wavelength selected in the stepwise procedure. Features centered at the reference locations are typically 10-20nm or more at full-width-half-maximum. As most organic nitrogen is held by proteins, it might be expected that waveband selections for N-concentration would occur in the vicinity of these absorption feature. An absorption peak, due to saturation, may be insensitive to biochemical concentration. Information regarding biochemical concentration is often found instead along the wings of the absorption feature, and is convolved with other absorption features occurring in the same functional group. Most of the wavelength selections appear to be associated with a reference protein feature. Some selections occur near the reference absorption peak, while others differ by up to ~30nm.

III. Future Work

The OTTER design presents an opportunity to explore the effect of biochemistry upon AVIRIS spectra with a statistical approach. Development of prediction equations for several biochemicals will proceed at such time as a full set of AVIRIS data has been collected, and the wet chemistry is completed. Appropriately corrected multi-season AVIRIS data will be pooled, and relationships with plot biochemical concentration

will be established by stepwise regression and partial least squares (Sjostrom *et al.*, 1983) techniques.

Fertilizer amendment at Scio provides the opportunity to examine laboratory and AVIRIS spectra for overt biochemical influence, while controlling for complicating differential factors such as species, topography, atmosphere, and canopy architecture. Initial assay results show that fertilizer amendment at the Scio site has created a (60m x 60m) plot with elevated N-concentration (~.5% absolute) above that found at a neighboring control plot. The 5/91 AVIRIS overflight will be supported by comprehensive harvest of fertilized and control foliage at Scio, to include acquisition of laboratory spectra and assay for N-concentration.

Acknowledgements

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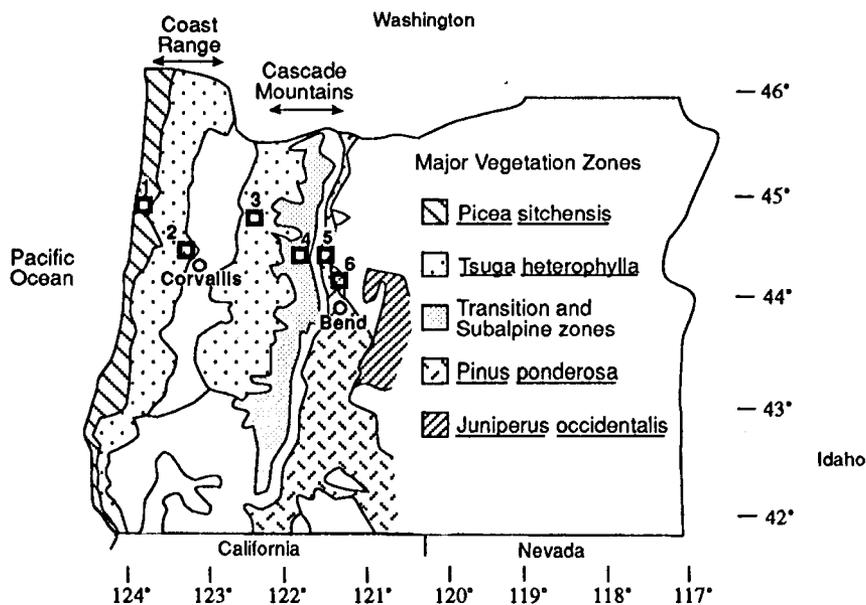
Figure 1. Study site map. 1 = CH-A (alder) and CH-H (hemlock); 2 = WW; 3 = SC-C (control) and SC-F (fertilized); 4 = SA; 5 = ME-C (control) and ME-F (fertilized); 6 = JU. (vegetation zones after Franklin and Dyrness, 1973)

ESTIMATED S:N, 4 DATES
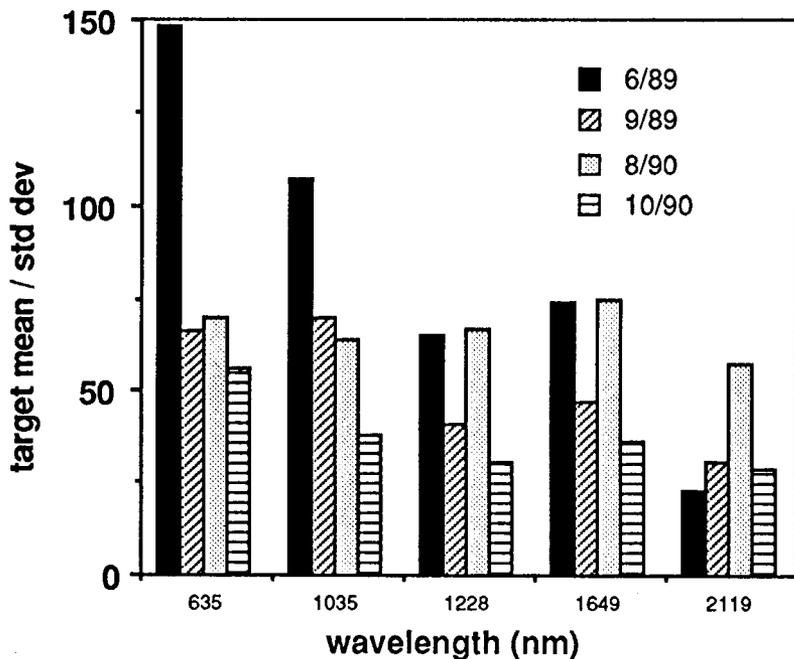
Figure 2. Estimated signal-to-noise in four datasets. S:N estimated as the mean / standard deviation of 3x3 pixels above a uniform target.

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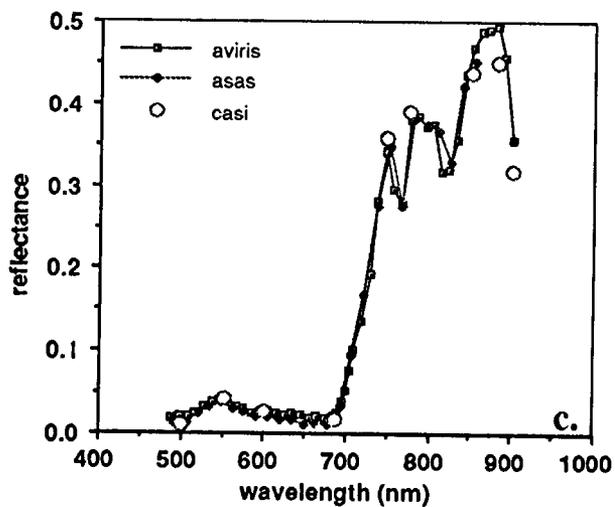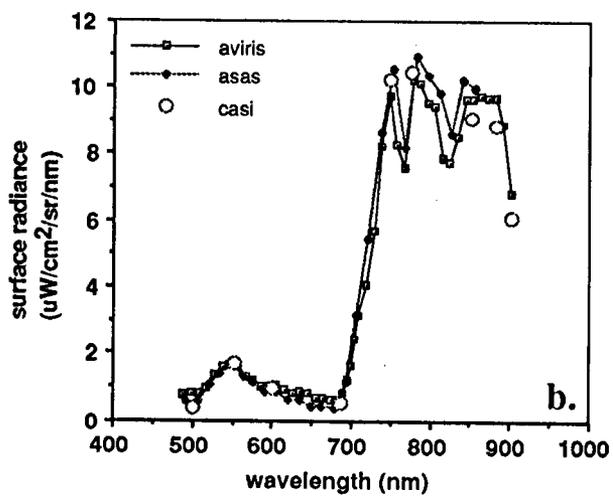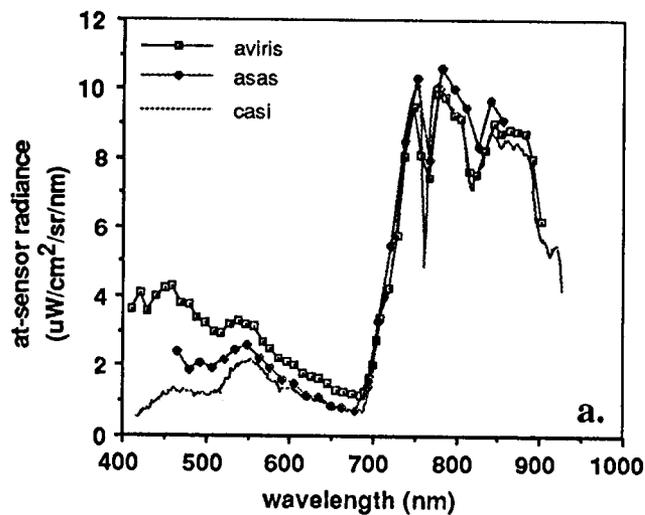
Figure 3. Inter-sensor comparison above alder plot (CH-A) on 8/14/90. a) at-sensor radiance b) surface radiance c) reflectance. Flight altitudes above ground were: AVIRIS, 65000'; ASAS, 15000'; CASI, 5000'. Optical depth at the time of overflight was ~0.5.

	Wavelength Selection (in order)	Nearest Protein Feature	R^2 (per step)	SEE (per step)	n	date
a.	1322	(1357^2)	0.76	0.95		
	1209	(1187^4)	0.91	0.65	8	8/90
	1658	(1690^4)	0.98	0.35		
b.	1199	(1187^4)	0.56	0.84		
	1332	(1357^2)	0.86	0.52	8	10/90
	1276	(1276^2)	0.94	0.38		
c.	1658	(1690^4)	0.30	1.61		
	1550	(1570^2)	0.42	1.61	8	8/90
	1757	(1757^1)	0.85	0.92		
d.	1718	(1735^2)	0.76	0.87		
	1738	(1735^2)	0.88	0.48	8	10/90
	1540	(1570^2)	0.99	0.10		

Table 1. Results of 3-term stepwise regression against nitrogen concentration, NIR region, for the 8/90 and 10/90 flights. Included for reference are the nearest established protien absorbtion features. Superscripts represent relative strength of feature, 4 being the strongest (Williams and Norris, 1987).