N95- 33768

VALIDATING SPATIAL STRUCTURE IN CANOPY WATER CONTENT USING GEOSTATISTICS

E. W. Sanderson[1], M.H. Zhang[1], S.L. Ustin[1], E. Rejmankova[2], and R.S. Haxo[1],
[1]Dept. Land, Air, and Water Resources, University of California, Davis, CA 95616
[2]Division of Environmental Studies, University of California, Davis, CA 95616

Introduction

Heterogeneity in ecological phenomena are scale dependent and affect the hierarchical structure of image data (cf. Levin, 1992). AVIRIS pixels average reflectance produced by complex absorption and scattering interactions between biogeochemical composition, canopy architecture, view and illumination angles, species distributions, and plant cover as well as other factors. These scales affect validation of pixel reflectance, typically performed by relating pixel spectra to ground measurements acquired at scales of $1m^2$ or less (e.g., field spectra, foliage and soil samples, etc.). As image analysis becomes more sophisticated, such as those for detection of canopy chemistry, better validation becomes a critical problem. This paper presents a methodology for bridging between point measurements and pixels using geostatistics. Geostatistics have been extensively used in geological or hydrogeological studies but have received little application in ecological studies (Rossi et al, 1992). The key criteria for kriging estimation is that the phenomena varies in space and that an underlying controlling process produces spatial correlation between the measured data points. Ecological variation meets this requirement because communities vary along environmental gradients like soil moisture, nutrient availability, or topography.

Project Description: The overall goal of our AVIRIS project is to develop strategies for monitoring salt marsh conditions (species distributions, biomass, leaf area, water content, etc.) and identifying spectral signatures that can be used as diagnostic indicators of wetland functioning (chlorophyll, nitrogen, carbon, evapotranspiration and photosynthetic rates, etc.). The study site is located along the northern shore of San Pablo Bay, CA (northern extension of San Francisco Bay) and includes the Petaluma and Napa River estuaries and the Mare Island Naval Base. These systems experience large naturally occurring spatial and temporal gradients in salinity, nitrogen, redox potential and are subject to regional pollution and point sources of soil and groundwater contamination (toxics, heavy metals, and others). Mare Island, scheduled for decommissioning and transfer to the University of California, Davis, has multiple contaminated sites.

Methods

Study Area and Sampling Design: Three sites were studied along the Petaluma River estuary that are considered to be "healthy" but differ in species distributions, biomass, and in the magnitude and structure of their environmental gradients. This paper focuses on one site located approximately 8 km upriver. Sampling was coincident with AVIRIS overflights on May 21 and May 23, 1994. This site is threaded with a network of fine channels that bring nutrients and leach accumulated salts. Three salt tolerant species dominate. In the lower intertidal, *Spartina foliosa*, a grass is dominant. *Scirpus robustus*, a bulrush grows near mean high tide (10-20m above the low tide) and forms a patchy distribution at sites with low spring salinities. The most halophytic species and a succulent shrub, *Salicornia viriginica*, dominates the high marsh. Canopy and soil reflectance measurements, plant cover and height were measured at 196 locations on an evenly spaced 15m grid (see Figure 1, the schematic map in AVIRIS Workshop Slide 8) with the location determined by GPS. At 42 sites within the 200 point grid, aboveground biomass, soil salinity, redox potential, and soil nitrogen content, canopy carbon, nitrogen, and pigments' samples were obtained. Geostatistics were used to spatially interpolate these data to provide a basis for interpreting patterns in AVIRIS data.

Sample Collection and Water Content Analysis: Canopy spectra were measured using an ASD PSII for the 345-1072nm interval, with an 18° view restrictor on foreoptics suspended 1m above the canopy; spectra were calibrated to reflectance using a Spectralon panel. Spectra were averaged to 10nm wavebands and normalized (defined as the $\sqrt{\Sigma(\text{reflectance}^2)}$) for comparison to AVIRIS spectra. Following Clark and Roush (1984), the continuum removal method was applied to a feature centered at 980nm to determine canopy equivalent water thickness. In this technique, a line is extended across an absorption feature and the depth is determined for each AVIRIS waveband, depths are summed over the 10nm intervals to estimate the area. Water depth features were calculated for all spectra and from the 40 spectra having corresponding biomass. Regression relationships were developed to predict water content (Figure 2). Aboveground biomass was harvested in 42 circular quadrats (0.126 m^2), the area corresponding to the FOV. Biomass was sorted by species into woody and green components (*Salicornia* and *Scirpus*) and green for *Spartina*. Fresh and dry weights were measured after drying for 2-3 days at 70°C. Water contents were determined by subtraction and relative water content as (fresh - dry weights)/(fresh weight). All water contents were normalized to an area of $1m^2$ (kg water/ m^2). Descriptive statistics and histograms were compared among the datasets as described in the results section.

Geostatistical Methods: A contour map was prepared using the inverse distance squared method based on 196 site water contents predicted from the continuum removal (see Figure 3, AVIRIS Workshop Slide 8). Observed variograms were calculated and modeled and applied in kriging estimation using GEO-EAS (Englund and Sparks, 1988) and GEOPACK (Yates and Yates, 1989). A variety of lag distances and search neighborhoods were attempted to bring the best structure to the variogram. It was found that a lag of 15m, corresponding to the approximate spacing of the sample grid with an elliptical search neighborhood oriented roughly along the N-S axis gave the best results. The observed variogram was calculated from 0-100m in the E-W direction and 0-200m in the N-S direction. An exponential variogram model was fit for cokriging. Canopy water content was interpolated using cokriging estimation to a 5m by 5m grid of points over the sampling area. This denser network of interpolated points was combined with observed data for comparison to georeferenced AVIRIS pixels.

Results

Measured and Predicted Water Content : Water content varies between and within species. *Salicornia* dominated sites have the greatest water content, more than 86% water by weight. Preliminary evidence suggests that canopy water content increases closer to the channel network. *Spartina* foliage has less water content than *Salicornia*, and *Scirpus* has less still. Histograms of the predicted and measured water content show approximately normal distributions.

	Salicornia virginica		*Spartina foliosa*	*Scirpus robustus*		*Frankenia grandifolia*
	Green	Woody		Green	Woody	
Mean Water Content (kg/m^2)	1.034	0.750	0.718	0.145	0.057	0.061
Standard Deviation	0.854	0.561	0.415	0.260	0.039	0.041
Mean Relative Water Content (%)	86.5	52.5	78.3	65.4	32.7	60.9

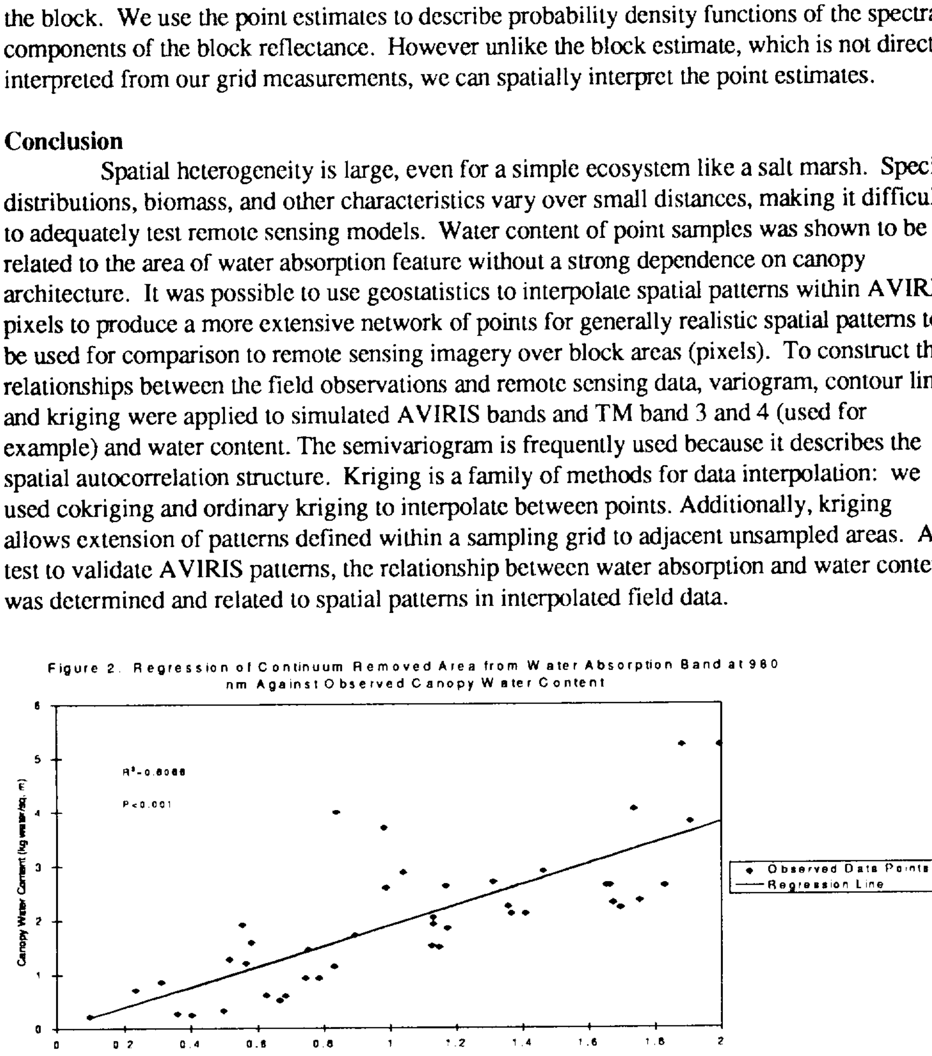
Spatial Pattern of Water Content: Two distinct and important spatial structures are seen in the contour map. First, the patch size are differences between species distributions (~50m). In May, most of the *Scirpus* biomass was standing litter with little green biomass. In the northeast corner a large patch of *Scirpus* corresponds to the area of lower water content; similar patches occur along the eastern edge. The second spatial structure occurs near the center where the area is dissected by a network of fine drainage channels (~150m). As a result, conditions are apparently better for *Salicornia*, (indicated by the higher biomass and water content). Several elongated patches of high water content correspond to the channels. This interpretation will be further examined by more detailed comparison in the GIS currently under construction. We expect other spatial features related to ecosystem functioning (e.g., biomass, chlorophyll and nitrogen) to be preserved in interpolation results.

Kriging Estimation of Spatial Pattern: Using the variogram model developed from the sampling points, kriging was used to estimate the water content at unsampled locations and over block areas (e.g., pixels). Interpolation techniques, like kriging, allow single measurements to be extended to area estimates and to make multiple point estimates within the block. We use the point estimates to describe probability density functions of the spectral components of the block reflectance. However unlike the block estimate, which is not directly interpreted from our grid measurements, we can spatially interpret the point estimates.

Conclusion

Spatial heterogeneity is large, even for a simple ecosystem like a salt marsh. Species distributions, biomass, and other characteristics vary over small distances, making it difficult to adequately test remote sensing models. Water content of point samples was shown to be related to the area of water absorption feature without a strong dependence on canopy architecture. It was possible to use geostatistics to interpolate spatial patterns within AVIRIS pixels to produce a more extensive network of points for generally realistic spatial patterns to be used for comparison to remote sensing imagery over block areas (pixels). To construct the relationships between the field observations and remote sensing data, variogram, contour line, and kriging were applied to simulated AVIRIS bands and TM band 3 and 4 (used for example) and water content. The semivariogram is frequently used because it describes the spatial autocorrelation structure. Kriging is a family of methods for data interpolation: we used cokriging and ordinary kriging to interpolate between points. Additionally, kriging allows extension of patterns defined within a sampling grid to adjacent unsampled areas. As a test to validate AVIRIS patterns, the relationship between water absorption and water content was determined and related to spatial patterns in interpolated field data.

Figure 2. Regression of Continuum Removed Area from Water Absorption Band at 980 nm Against Observed Canopy Water Content



References

Clark, R.N. and T.L. Roush 1984, Reflectance spectroscopy: Quantitative analysis techniques for remote sensing applications. J. Geophys. Res. 89: 6329-6340.

Englund, E., and Sparks, A. 1988, GEO-EAS (Geostatistical Environmental Assessment Software) User's Guide. Environmental Monitoring Systems Laboratory, Las Vegas, NC. EPA600/4-88/033.

Levin, S. 1992, The Problem of Pattern and Scale in Ecology. Ecology 73:1943-1967.

Rossi, R., Mulla, D., Journel, A., and Franz, E. 1992, Geostatistical tools for modelling and interpreting ecological spatial dependence. Ecology 62: 277-314.

Yates, S.R., and Yates, M.V. 1989, Geostatistics for waste management: A User's manual for the GOEPACK Geostatistical Software System. USDA Salinity Lab, Riverside, CA.