HIGH RESOLUTION DIGITAL IMAGERY APPLIED TO VEGETATION STUDIES

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ABSTRACT

With the advent of new sensor systems which allow digital multispectral images to be acquired on demand with spatial resolution in the .5 to 3 meter per pixel range, applications for remotely sensed data are expanding. The high resolution and rapid availability of these data provide opportunities for studying new types and scales of spatial phenomena which may not have been possible using satellite images, multispectral scanner data, videography, or aerial photography. Several project examples are described.

One of the projects involved analysis of four-band images of conifer forests acquired in Oregon and Washington at .5 and 2 meter per pixel resolution. The data were used to characterize proportions of various scene components in forest inventory plots and Long Term Ecological Research (LTER) sites, and thus to facilitate more accurate modeling of forest canopy reflectance. The high resolution imagery was also used to characterize riparian vegetation conditions, locate streamside forest gaps, and map patterns of riparian canopy disturbance.

In another project, high spatial resolution, digital multispectral data were acquired to resolve the low reflectance signal of the characteristically sparse vegetation cover of semiarid regions. Vegetation properties such as percentage vegetation cover and above ground green and woody biomass are being quantified from ADAR System image data collected at an LTER site in New Mexico.

The last project involves the detection and analysis of conifer dieback in southern California caused by bark beetle infestation. Dead and stressed trees are identified by variations in spectral signatures and spatial statistical patterns.

KEY WORDS: GIS, Remote Sensing, Spatial, Multispectral, High Resolution, Vegetation.

In those studies, the spatial properties of SPOT 10m panchromatic High Resolution Visible (HRV) imagery were found to be highly correlated with a variety of stand-level structural attributes, whereas similar properties of LANDSAT 30m Thematic Mapper (TM) imagery were not. However, a spectral feature of the TM Tasseled Cap was found to be highly correlated with stand structure.

Table 1.
Spectral bands used for ADAR System 5000 flight in Oregon and Washington (9/23/91)

Band	Bandwidth (nm)	Band Center (nm)	Spectral Region
Band 2	80	450	Blue
Band 1	80	550	Green
Band 4	80	650	Red
Band 3	80	850	Near Infrared

The next step in this analysis is to determine the optimum ground resolution cell size for characterizations of stand structure using image spatial properties. To accomplish this objective, the ADAR data have been spatially degraded to 5m, 10m, 15m, and 20m prior to analyses. Results of this study will have implications relative to the type of satellite imagery chosen for similar analyses at a regional scale. The next LANDSAT satellite will carry a 15m panchromatic channel registered to the 30m multispectral channels. If 15m data are useful for spatial analyses in the forest conditions of interest, then LANDSAT 6 TM data will be a powerful tool permitting both the spectral and spatial domains of image data to be used in unison to extract forest structure information. If the spatial properties of 20m data are useful, then HRV multispectral imagery may provide this opportunity. The value of using high spatial resolution ADAR data for this study is that we have the ability to determine the change in spatial information content of image data as it is spatially degraded from very fine to relatively coarse pixel sizes.

An additional direction for research of forest structure with satellite imagery is to use canopy reflectance models (Li and Strahler 1985; Smith et al. 1990). For this study ADAR data are being used to characterize the proportions of various scene components (e.g., sunlit and shaded tree canopy and sunlit and shaded background) typically found under a variety of stand structural conditions. This information will help us to calibrate our models for use with 30m TM imagery, where these individual scene components are not resolvable. With the multispectral properties of the ADAR System 5000 we can determine the spectral properties of the individual scene components relative to the TM bands 1 through 4.

For retrospective studies using LANDSAT Multispectral Scanner (MSS) data, ADAR System spectral channels can be matched to MSS channels. Again, knowing the proportions of scene components and the spectral properties of those components can be very useful when relating satellite image spectral properties to stand structure properties. ADAR imagery is being used in this way for a study of land use effects on carbon storage by forests of the Pacific Northwest from 1972 to 1992 (Cohen et al. 1992).

2.2 Mapping of Stream Channel Disturbances

The RAPID (riparian aerial photographic inventory of disturbance) technique was developed as a method for using measurements made from aerial photos of patterns of riparian canopy disturbance to evaluate changes in channel conditions through time, and to link those changes to their upstream causes (Grant 1988). The ADAR data provide an opportunity to extend this technique to digital image data and thus make the technique amenable to computerization. As a pilot study we are using ADAR data for this purpose along the Lookout Creek drainage in the H.J. Andrews Experimental forests where recurring flood-related disturbances are common.

In a related study, ADAR data are being used to characterize riparian vegetation conditions and to locate streamside forest gaps. The objective is to determine how dissimilar forest fragmentation along stream corridors is from fragmentation up slope. Results of this study have significant implications on issues related to global and regional biodiversity.

DISTRIBUTION AND DYNAMICS OF VEGETATION IN THE JORNADA BASIN

3.0 Introduction.

Desertification of the Jornada Basin in New Mexico and some other desert areas that were formerly productive semi-arid grasslands has occurred because of grazing disturbances. Grazing disturbance has apparently caused a relatively homogeneous distribution of soil resources to become more patchy, which lead to the invasion of woody shrubs that now dominate the landscape (Buffington and Herbel, 1965). Plant biomass and net primary production patterns seem to be more patchy following the development of "islands of fertility," which develop under positive feedbacks that further increase the heterogeneity of soil resources (Schlesinger et al., 1990).

Procedures are needed for quantifying the spatial distribution of above ground plant biomass and net primary production of grassland, shrubland and playa (high runoff accumulation) sites, as spatial and temporal scales that are appropriate for testing the relationships described above (Musick 1984, Warren and Hutchinson, 1983).

INTRODUCTION

A new four-band multispectral imaging system was used to collect digital images of several research sites at pixel resolutions ranging from .5 meter to 2 meters. This paper provides a brief description of the imaging system and a progress report on three projects.

THE ADAR SYSTEM 5000

1.0 System Overview.
The Airborne Data Acquisition and Registration (ADAR) System 5000 is a multispectral imaging system developed for commercial use (Benkelman et al. 1990). The System 5000 was designed to serve resource managers, earth scientists, and planners who use GIS/image processing systems with a source of rapidly available multispectral image data with high spatial resolution.

Development of the System 5000 began in September of 1990, with the first flight test of the system completed in July of 1991. A beta testing program was conducted through early October of 1991, providing image data for numerous applications, including agriculture, forestry (Benkelman et al. 1992), aquatic biology, and others.

The ADAR System 5000 is an integrated remote sensing/data collection system, incorporating four full-frame CCD sensors with a global positioning system (GPS) receiver in a lightweight package. The System 5000 provides a source of raster image data with several key features:

1.1 Digital image data is provided in formats compatible with common GIS/image processing systems.

1.2 Image data may be collected at the time and place required by the project, and is available for processing immediately upon completion of the flight.

1.3 The spectral range of the System 5000 sensors is from 400 nanometers (nm) to 1.0 micron, covering the visible bands and near infrared. Spectral bandwidths range from 12 to 300 nm. Bandwidth and band center of the four spectral bands may be configured to meet the specific needs of the project.

1.4 Spatial resolution of images collected by the System 5000 ranges from 1/2 to 3 meters per pixel if the System 5000 is carried on a single engine, fixed wing aircraft. Area covered by a single scene may be increased by flying at higher altitudes with a twin engine aircraft. Resolution higher than 50 cm per pixel requires use of a helicopter.

1.5 A Global Positioning System (GPS) receiver records the approximate location of the host aircraft at the time each image is acquired. Images from the System 5000 are thus referenced to latitude and longitude but not registered; image registration must be finalized through post processing.

1.6 Overlapping stereo images may be collected in a single flightline.

1.7 The ADAR System 5000 is based on a modular design concept, incorporating commercially available components and industry standards whenever possible. Different image sensors, covering shortwave (3-5 micron) and longwave (8-14 micron) thermal infrared, the middle infrared (1 - 3 micron), and ultraviolet (wavelength < 400 nm) spectral regions can be added with relative ease. Other sensors, such as a laser rangefinder and aircraft orientation sensor (recording pitch, roll, and yaw) can also be added to provide additional data about the imaging geometry. With knowledge of the sensor's location, orientation, and distance from the image subject, it may be possible to automatically register each image to the ground. The modular design of the System 5000 also simplifies operation and maintenance of the system.

FORESTRY APPLICATIONS: OREGON AND WASHINGTON

2.0 Introduction.
This project is a continuation of work begun in Fall, 1991 (Benkelman et. al. 1991). The high resolution imagery, collected in conifer forests in Oregon and Washington, are being used to characterize proportions of various scene components, and thus facilitate more accurate modeling of forest canopy reflectance using satellite data. In addition, the data are being used to observe patterns of riparian canopy disturbance to evaluate changes in stream channel conditions.

On the western slopes of the Cascade Mountains in Oregon and Washington, ADAR data are being used to characterize forest structure and map small-scale disturbances in stream channels. ADAR System 5000 imagery was obtained over the H.J. Andrews Experimental Forest in Oregon and the Wind River Experimental Forest in Washington. For this project, the System 5000 was installed and flown in a single engine, fixed wing aircraft (Cessna 206). All ADAR imagery for this project was collected on September 23, 1991, at spatial resolutions of .5 and 2 meters per pixel. Spectral bands were matched as closely as possible to the first four bands of the Landsat Thematic Mapper (TM), as indicated in Table 1.

2.1 Characterizations of Forest Structure
This usage of ADAR data is an extension of previous work (Cohen et al. 1990, Cohen and Spies 1992), for which the objective is to characterize forest structural attributes with satellite imagery in Douglas-fir/western hemlock forests.

The high spatial resolution, multispectral imaging capabilities of the ADAR System 5000 may allow such procedures to be implemented.

Researchers at San Diego State University (SDSU) and New Mexico State University collaborating on the Jornada LTER project (Franklin et al., 1990) are examining the utility of high resolution digital multispectral data for quantifying above ground biomass (green and total), percent vegetation cover (shrub and grass/annuals) and above ground green biomass production. It should be feasible to derive spatial patterns of these properties at high spatial frequency and temporal patterns at seasonal and interannual time scales, due to the ability to achieve high spatial and temporal resolution with the ADAR System 5000. A further advantage of such a high spatial resolution sensing system is the potential to detect the generally low vegetation abundance signal of a desert landscape (ie., a greater proportion of each pixel contains greater vegetation cover, therefore achieving a higher signal-to-noise ratio). Also, the characteristic spatial scales of desertification processes being studied by Jornada LTER scientists are 10^{-1} 10^{2} meters, which means that satellite image data are not adequate and should be limited to regional-scale extrapolations.

ADAR System 5000 image data were acquired from a Cessna 206 over existing study plots and transects established at the Jornada LTER site near Las Cruces, New Mexico. Fifteen 70 x 70 meter plots were established as permanent plots within five different desert shrub and grassland vegetation communities. These plots provide a limited set of ground reference data for testing vegetation abundance relationships. The corners of the square plots were marked with highly reflective materials prior to the overflight, and were easily referenced on the ADAR imagery.

Digital image frames covering the fifteen permanent plots have been selected from numerous frames captured over the Jornada LTER site. Because of band-to-band misregistration, individual bands within each image frame were registered by simple linear translations relative to a single reference band. Spectral vegetation indices were computed and index values have been extracted for pixels falling within the permanent plot boundaries. Correlation analyses between above ground biomass and ADAR-derived NDVI values are underway.

DETECTING PINE BARK BEETLE INFESTATION IN SOUTHERN CALIFORNIA

4.0 Introduction.
For the third study, the potential utility of high spatial resolution remotely sensed data was examined by SDSU researchers for assessing vegetation condition within a climatic change context. The drought in southern California that started in 1987 and the associated increase in tree mortality due to bark beetle infestations provided the application scenario for the study. Most readily available remotely sensed data tend to have ground resolutions substantially greater than the size of individual plants so pixels may contain a mixture of vegetation types, background cover, illumination intensity and shadow. These mixtures make it difficult to evaluate fine-scale vegetation dynamics. High spatial resolution (0.5m) reflected spectral radiances were collected with the ADAR System 5000 over the Cuyamaca State Park in southern California and related to levels of bark beetle infestations that increased during the drought years.

Two specific test were conducted as part of this demonstration project. The first test was to determine whether there was a relationship between levels of bark beetle infestation in Jeffries Pine (*Pinus jeffreyi*) and their spectral response. In the second test, semi-variograms of uninfested and infested trees were compared since Murtha and Wiart (1989) demonstrated that intra-tree spectral variability decreases when trees are under attack by bark beetles. The semi-variogram provides a comprehensive means of examining the overall variance of the data (sill) and the nature of the spatial autocorrelation.

High spatial resolutions spectral radiance data were collected over target areas of the Cuyamaca State Park in October, 1991 using the ADAR System. Spectral radiances were measured at a ground resolution of approximately 0.5 m. The data were resampled to 1.0 m resolution as part of a rubbersheeting registration routine to remove misalignment caused by slight errors in the bore-sighting of the four sensors.

Ten ADAR images were collected over the Cuyamaca State Park, targeting areas where the trees showed visible bark beetle damage. Data from a single ADAR image were used for these exploratory analyses. The scene was dominated by Jeffries Pine and bark beetle infestation of individual trees and stands of this species was quantified in the field using six categories.

The spectral radiances for the blue, green, red and near infrared bands were extracted for each tree/stand. Spectral vegetation indices have been shown to be sensitive to vegetation quantities such as leaf area index and biomass (Perry and Lautenschlager, 1984). Thus, the near infrared and red radiances were combined to calculate the simple ratio index, which is obtained by dividing the near infrared radiance by the red radiance. The high spatial resolution ADAR data allowed spectral radiances to be extracted for the tree crowns that were isolated from the background and shadows in the imagery. These two classes constituted a substantial proportion of the scene (approximately 25%). These image components would be averaged in pixels from systems such as the TM and MSS sensors, and could pose significant problems in analyses of vegetation condition.

The mean radiances for the blue and green bands and the spectral ratio were plotted against corresponding infestation classes. The results indicated that differences in the reflected spectral radiances were correlated with the level of infestation. The blue and green radiances increased with the infestation level while the ratio showed a corresponding decrease. The increase in the blue and green radiances may have been associated with the physical changes in the canopy or greater reflectance from the soil/understory background, as these components became more exposed. As may be expected, the decrease in the ratio values indicated that the trees were losing green foliage as the degree of infestation progressed.

In order to demonstrate the potential utility of high resolution data for geostatistical analyses, semivariograms were constructed using the near infrared data for an area of approximately 300 m^2 in the uninfested and the recently infested areas. Changes in the canopy variance characteristics may be indicative of stress (Murtha and Wiart, 1989) so the sill of the semi-variograms of infested trees could be expected to be lower than that of infested trees. The sill of the semivariogram of the infested trees was found to be lower than that of the healthy trees.

The results from this demonstration project indicated that high spatial resolution remotely sensed data allow investigators to isolate individual plants from the scene background and are likely to provide valuable information for assessing vegetation condition. The characteristics of the reflected spectral radiances and their geostatistical properties may be potential indicators of differences in vegetation condition. These data are also likely to be valuable for determining biophysical quantities required in models of ecosystem function and for monitoring key species that may be particularly sensitive to climatic change (indicator species). The problems associates with shadows, background and mixed pixels can be minimized and the high resolution data provide for new analytical approaches.

SUMMARY

Three separate projects are described which utilize high resolution multispectral image data. The studies focus on analysis of vegetation properties with spatial extent too small for effective study using commercially available satellite data. Digital image data for these studies were collected in four spectral bands at spatial resolutions ranging from .5 to 2 meters per pixel. Spectral band selections were chosen to match the first four bands of Landsat TM. Preliminary results indicate high resolution multispectral imagery can be effectively used to study small scale phenomena.

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