Remote sensing inputs and a GIS interface for distributed hydrologic modeling[1]

GREG S. CROSBY, CHRISTOPHER M. U. NEALE

Department of Biological and Irrigation Engineering, Utah State University, 4105 University Blvd., Logan, Utah 84322-4105

Email: gscrosby@indigo.ecob.usu.edu, cneale@cc.usu.edu

MARK SEYFRIED

USDA-ARS, Northwest Watershed Research Center, Boise, Idaho

mseyfrie@nwrc.ars.pn.usbr.gov

DAVID TARBOTON

Department of Civil and Environmental Engineering, Utah State University, 4110 University Blvd., Logan, Utah 84322-4110

Abstract The Reynolds Creek Experimental Watershed in southwest Idaho, has been used for various hydrologic process studies over the last 30 years. To support an ongoing hydrologic modeling and scaling study, high resolution aerial (0.3 meters to 3.0 meters) multispectral imagery was acquired over the various sub-basins of the watershed in 1996 to provide various spatial resolution imagery for the development of vegetation related GIS layers (leaf area index (LAI), percent cover, vegetation type, canopy height, root depth, etc.). Thematic mapper imagery (30m) was also collected for the entire Reynolds Creek Experimental Watershed, coinciding with the date of one of the flights. The different

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scales of imagery will be evaluated for their effects in modeling different size watersheds, providing inputs to a remotely sensed input driven hydrologic model that will be developed with this research. This paper will concentrate on the development of the GIS layers in the ARCVIEW environment to be used with the distributed hydrologic model. The interface will assist in analyzing the various GIS layers that will be developed for input and verification of the hydrologic model.

INTRODUCTION

Reynolds Creek is a semi-arid watershed where the hydrologic processes are highly variable and dependent on precipitation (primarily snow) and evapotranspiration. Many of the conventional hydrological modeling methods are limited for application to multiple spatial scales encountered in nature. Data collection over large areas has not been possible, making it difficult to apply models over large watersheds. Remotely sensed imagery offers a method of collecting data across various spatial scales to parameterize inputs to a distributed model and provide verification of model outputs (Artan, 1996).

The objective of this paper is twofold: (1) to develop a relationship between high spatial resolution (0.3m) airborne multispectral digital video imagery and ground based canopy LAI and percent cover measurements that will provide spatial distribution of these important parameters for various modeling scales and (2) to demonstrate the creation of model input data in a GIS environment that may be accessed by a distributed hydrologic model through an interface.

BACKGROUND

Site Description

The research was conducted at the Reynolds Creek Experimental Watershed located in the Owayhee Mountains of southwestern Idaho. A wide array of instrumentation is permanently installed for supporting hydrologic studies. The watershed has an area of 23400 hectares and is primarily used for grazing. There are areas of Junipers, Douglas fir and Aspen in the upper elevations and rangeland species are found throughout. Reynolds Creek Experimental Watershed has an average of 10 inches of annual precipitation at its lower elevations and over 40 inches at the highest elevations with 75% falling as snow (Agricultural Research Service, 1973).

One of the advantages of this research watershed are the monitored sub-basins of varying sizes that are located within the watershed at various elevations (1098 m – 2254 m). Nancy's Gulch is the most northern sub-basin being studied and has the lowest elevation and the least topograghical change. The basin consists primarily of small sagebrush, perennial grasses and other forbes. Lower Sheep Creek sub-basin is a 13.25 ha sub-basin located at 1622 m. The watershed is comprised entirely of sagebrush rangeland that is primarily used for grazing. Whiskey Hill is located in the higher elevations and consists of a big mountain sagebrush community with mixed shrubs and perennial grasses, however some junipers and dry meadow site areas are present. Reynolds Mountain (40.47

hectares) is located at an average elevation of 2073 m predominantly covered with rangeland vegetation but scrub aspen, willow, and Douglas fir are also present. Tollgate is a 5444 hectare watershed that encompasses the southern end of the Reynolds Creek experimental watershed.

Methodology

Multispectral videography The second generation USU airborne multispectral videography system (Neale, 1991, Neale and Crowther, 1994, Neale et al., 1997) was used to acquire high resolution imagery (0.3, 0.6, 0.9m) over the vegetation transects within each sub-basin throughout the season. Due to the varying topography, the flight altitudes were planned based on the average elevation of the sub-basin being flown. The resolutions were then verified with white panel targets that were located at the ground data collection sites at known distances.

Due to the interaction of light on the curvature of the lens and filters, the methodology described by Crowther (1992) and Neale and Crowther (1994) for the first generation USU system was used to reduce brightness errors. An Exotech radiometer was calibrated against the video cameras for radiometric correction as described by Neale and Crowther, 1994. Aircraft motion effects were removed using programs developed at the USU Remote Sensing Services Laboratory, described by Neale, et al., 1994 for band interlacing.

During each remote sensing flight, an EXOTECH radiometer with Thematic Mapper bands TM1-4 was set up at the Nancy's Gulch sub-basin to acquire incoming irradiance over a calibrated barium sulfate panel with known bi-directional properties. Sampling occurred at every 10 seconds and one-minute averages were stored.

Ground data The ARS in Boise, Idaho collected the vegetation cover and LAI field data using the point frame method (Canfield, 1933). Vegetation plots set up within each sub-basin were considered representative of the surrounding watershed. The plots consisted of five transects 1.2 m apart and 30 m long. The white panels were set up at the four corners of this plot so that it could be readily observed in the multispectral imagery. The point frame (consisting of 20 rods with points) was moved along each transect. At each point frame measurement location, the rods were slowly moved down through the canopy and a note was taken of any green vegetation hit. The locations were 1 meter from the end of the transects, 4 meters, 12 meters, 16 meters, 24 meters and 28 meters coinciding with frame numbers 2,4,5,7,8 respectively along a transect. See Figure 1.

The vegetation data were always collected close to the date of the image acquisition flights. Table 1 summarizes the dates for each flight and the vegetation data collected. There were no field data collected at the Reynolds Mountain site during the first flight.

ANALYSIS

Ground Data

The LAI was calculated by dividing by the total number of points within a frame (20) by the total number of green hits at a frame location. Percent cover was evaluated at each point (20 within a frame) to verify whether at least one green hit occurred or not. The number of hits were divided by 20 to estimate the area of land that was covered by green vegetation. These data were averaged across the transects by frame numbers resulting in six data points at each sub-basin and on each date (See Figure 1).

Multispectral imagery

Images were selected for analysis by observing which image had the vegetation plot located within the center of the image. A registered 3-band image was produced using the red band as the base image and rectifying the green and NIR images to it using a second order transformation and at least 30 control points spread across the image. ERDAS Imagine was used for all image processing. The resulting 3-band image was then calibrated to reflectance using the following equation:

$$R_{pixel} = \frac{(DN_{g,r,NIR} * calibration_{3629}) / (voltageconv_{3629})) * panelref}{panel_{3630}} * \frac{v_{3630}}{v_{3629}}$$

R	=	reflectance of an individual pixel in an image
DN	=	digital number of the green, red or NIR pixel
calibration	=	linear relationship between DN and radiometer radiances (#3629) (Watts/m^2)
voltageconv	=	voltage conversion for aircraft radiometer #3629 (Watts/m^2/Volt)
panelref	=	bi-directional reflectance for the barium sulfate panel based on the sun's zenith angle
$\frac{v_{3630}}{v_{3629}}$	=	cross-calibration of the radiometers over the panel
panel	=	panel radiometer voltage readings

In order to calibrate the imagery in terms of reflectance it was necessary to have a GPS time stamp on each image to correlate with the panel irradiance readings that were continuously being taken in the field. Panel measurements were averaged every minute so an interpolation was done between the two time measurements closest to the image. Each 3-band image selected was converted to reflectance in this manner using the Model Maker program in ERDAS Imagine. A normalized difference vegetation index (NDVI =(NIR+red)/(NIR-red)) image was calculated.

The 3-band reflectance imagery was rectified to an imaginary grid that was based on the orientation of the ground vegetation transects and frame locations that were used in the field. Plot #1 therefore contained the average ground data for the five *Frame #1* sites for each transect 1-5. A vector polygon cut out was made for plots 1-6 with dimensions of 3 x 22 pixels. The means were then collected from this plot for comparison with the corresponding ground data.

The lower resolution imagery was rectified to digital orthophotquads and the higher resolution imagery was rectified sequentially in turn down to the .3m meter resolution imagery to match the data geographically. Contour and soil maps of the watersheds were digitized for creating the layers for the GIS. Vegetation type data were verified in the field with imagery in hand to aid in the supervised classification of the imagery and obtaining a vegetation type layer. Figure 3 presents a sample of some of the layers that are present in the GIS.

RESULTS

Table 2 shows NDVI data obtained from the calibrated imagery and ground data. A second order polynomial was used to fit a curve since increasing orders only provided a small change in the RMS and did not follow the trend of the data but rather attempted more to follow the individual points.

There was a strong relationship between the NDVI and ground biophysical data (percent cover and LAI) that were collected as indicated by the high R^2 (Figures 2 and 3). It would have been helpful to have more heavily vegetated areas to improve the relationships. Unfortunately, the Reynolds Mountain site did not yield expected higher LAI and percent cover data. July imagery was not included in the relationship as the presence of clouds on that flight date has posed some problems that are still unresolved. Some of the vegetation species would be reaching their peak growth stages in early July. A simple model was written in ERDAS Imagine to convert the NDVI to percent cover and LAI using the developed relationships. This data was then brought into ARCVIEW as a grid file, for further analysis and interaction with the hydrological model under development. Imagery acquired at different spatial resolutions will be used along with this high-resolution layer, to study the effects of scaling-up some of the parameters to larger sub-basins. The ArcView GIS database and interface allows for the quick preparation of hydrologic model input data and visualization of model results.

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Table 1. Data collection dates, 1996.

	Ground	Airborne	Ground	Airborne	Ground	Airborne
Nancy's Gulch	May 31	June 6	August 2	August 2	September 3	August 29
Lower Sheep	June 3	June 6	August 2	August 2	September 3	August 29
Whiskey Hill	May 30 - 31	June 6	August 5	August 2	September 3	August 29
Reynolds Mountain		June 6	August 5	August 2	September 3	August 29

Table 2. Field data and imagery statistics for Whiskey Hill - June and August. Ground data day (Multispectral)

JDOY	**151**					**247**				
Frame	**Hits**	**Total Hits**	**Percent Cover**	**LAI**	**NDVI**	**Hits**	**Total Hits**	**Percent Cover**	**LAI**	**NDVI**
1	69	117	0.69	1.17	0.341	28	44	0.28	0.44	0.201
2	78	160	0.78	1.6	0.39	32	44	0.32	0.44	0.259
4	83	170	0.83	1.7	0.406	43	64	0.43	0.64	0.197
5	65	130	0.65	1.3	0.362	22	34	0.22	0.34	0.143
7	75	152	0.75	1.52	0.369	40	69	0.4	0.69	0.235
8	67	119	0.67	1.19	0.348	16	20	0.16	0.2	0.136
Total	437	848				181	275			

Figure 2. NDVI vs. LAI relationship.

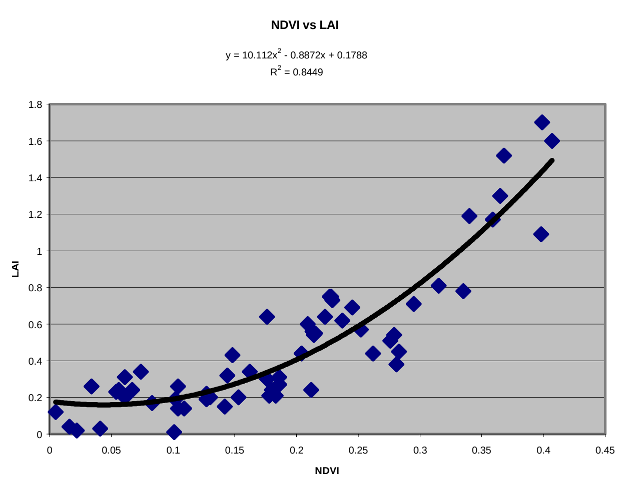

Figure 3. NDVI vs. Percent Cover relationship.

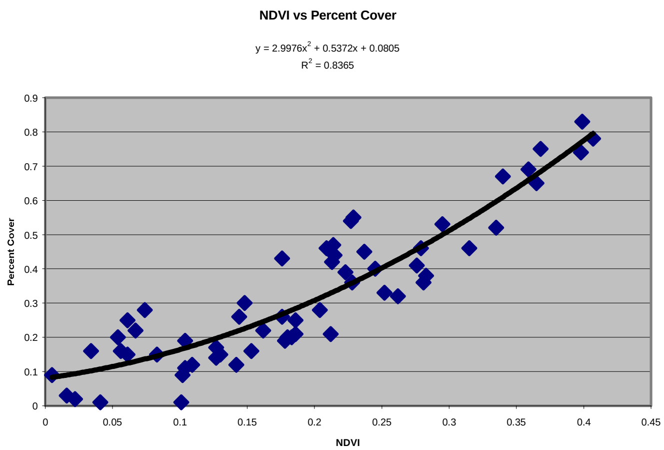

Figure 1. Whiskey Hill ground data transects

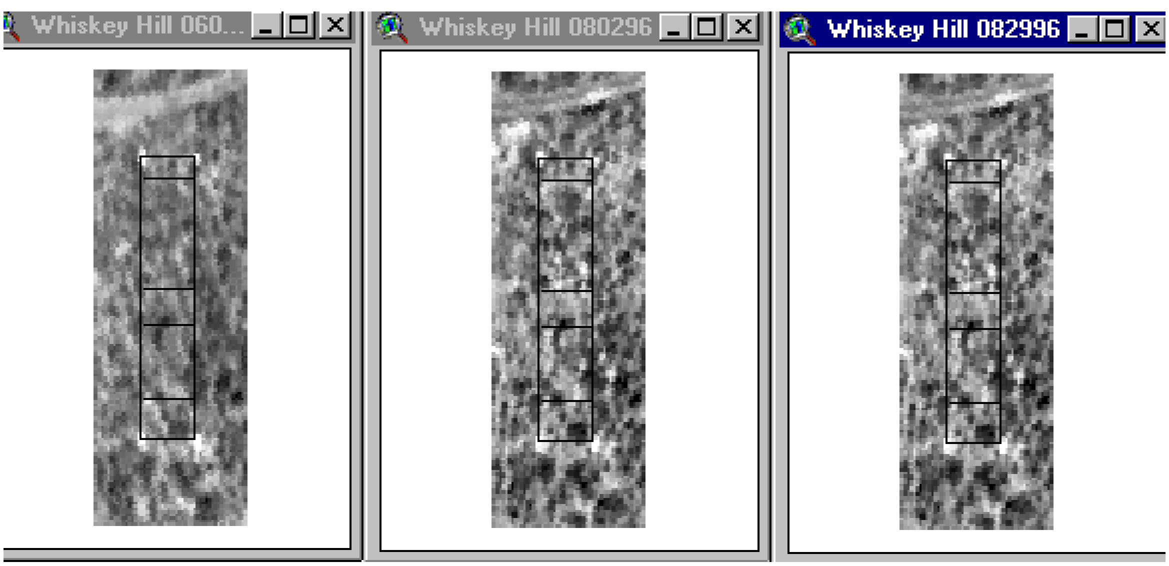

Figure 4. GIS layers for Reynolds Creek Experiment Station