Vegetation Parameter Scaling On A Semi-Arid Watershed[1]

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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 different spatial resolution imagery for the development of vegetation related GIS layers (leaf area index (LAI), vegetation type and cover, canopy height, root depth etc.). Thematic mapper imagery was also acquired for the entire Reynolds Creek Experimental Watershed, coinciding with the date of one of the flights. The higher resolution imagery (0.3 meters) was used for the development of preliminary relationships between remotely sensed vegetation indices with ground-based LAI (point-frame method) and vegetation samples. Upon developing the relationships in the semi-arid landscape in different ecosystems, the coarser resolution imagery (up to 3 meters and then 30 meters) was calibrated against the high resolution imagery. The different 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 is being developed. This paper will concentrate on the development of distributed LAI and plant cover relationships obtained from the high resolution multispectral imagery.

INTRODUCTION

This research is part of a NSF-EPA supported project – Scaling up Spatially Distributed Hydrologic Models of Semi-Arid Watersheds (EPA Grant R824784). Hydrologic processes can be viewed at various scales and many of the conventional modeling methods are spatially limited to explore various levels of scale. Data collection over large areas has not been possible making it difficult to apply models over large watersheds. In Reynolds Creek, a semi-arid watershed, the hydrologic processes are highly variable and dependent on precipitation (primarily snow) and evapotranspiration. Remotely sensed imagery therefore provides a method of collecting data across various spatial regimes to parameterize inputs to a distributed model and provide verification of model outputs (Artan, 1996).

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The objective of this paper is to develop a relationship between high spatial resolution (0.3m) airborne multispectral video imagery and ground based data that will serve to provide important parameters for various modeling scales. The different spectral band images will be converted to a vegetation index in terms of surface reflectance using system calibration curves developed in the lab as well as calibration data collected in the field during the flight season. The vegetation index images will be related to ground measured (point frame) LAI and percent cover.

BACKGROUND

Site Description

The research was conducted at the Reynolds Creek Experimental Watershed located in the Owayhee Mountains (See Figure 1). This experimental watershed has served as a site for numerous hydrologic studies and a wide array of instrumentation is permanently installed for this purpose. The watershed has an area of 23400 hectares and is primarily used for grazing, though irrigated land exists in the valley bottom. Rangeland plant communities may be observed throughout the watershed including sagebrush, bitterbrush, rabbitbrush , greasewood and various perennial grasses. There are areas with encroaching junipers, and douglas fir and aspen may be found in the upper elevations. 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 benefits of this watershed are the sub-basins (watersheds) of varying sizes that are located within the watershed at various elevations (1098 m – 2254 m). The relationships developed in the smaller sub-basins will serve as a control for expansion of the methodology to the larger watershed.

Nancy's Gulch is the most northern sub-basin being studied and has the lowest elevation with least topograghical change. The basin consists primarily of small sagebrush and perennial grasses. This site provides some of the earliest perennial growth and much of the vegetation becomes senescent by mid-summer.

Lower Sheep Creek sub-basin is a 13.25 ha sub-basin located at 1622 m. The topsoil is primarily residuals of rhyolitic volcanics with a general slope between 10 and 20 %. The watershed is comprised entirely of sagebrush rangeland that is primarily used for grazing. Vegetation types are bluebunch wheat grass, Sandberg bluegrass, cheatgrass, yarrow and little sagebrush.

Whiskey Hill is located on a northern aspect in the higher elevations and consists of a big mountain sagebrush community with mixed shrubs and perennial grasses. Junipers are interspersed within this higher elevation site. The watershed has some dry meadows in some of the flat areas though the basin is characterized by more sloping topography.

Reynolds Mountain (40.47 hectares) is the fourth sub-basin in the study and is located at an average elevation of 2073 m. The vegetation in this basin is the most diverse of all sub-basins in the hydrologic study. Reynolds Mountain is predominantly covered with rangeland vegetation but scrub aspen, willow, and douglas fir are also present.

These various sub-basins were critical for developing a complete vegetation index vs. LAI relationship. The lower elevation sub-basins with their sparse shrubs and perennial grasses provided the lower values and the higher elevation sites, which are more densely vegetated, provided for the high end of the curve. Any one sub-basin taken by itself would likely have led to a more linear relationship since only part of the curve would be observed.

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 over the vegetation transects. Flights were scheduled four times during the field season to collect imagery with a nominal pixel resolution of 0.3 m and 0.6 m. These flights were conducted in 1996 on Julian Days 158 (June 6), 185 (July 3), 215 (August 2) and 242 (August 29) at different times during the day. Due to the varying topography, the flight altitudes were planned based on the average elevation of the sub-basin.

The resolutions were then verified based on white panel targets that were located at the ground vegetation data collection sites. Based on the known distances between panels and the number of image pixels between each panel, the pixel resolution of the imagery was derived from the ratio.

In order to reduce errors 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. The image acquisition was all conducted using 16mm lenses at an f-stop of f8. Calibration imagery was acquired at the Remote Sensing Services Laboratory at Utah State University with the same video camera set-up (16mm, f-stop 8) on a barium-sulfate standard reflectance panel. This imagery was calibrated radiometrically based on a developed relationship between image digital number and Exotech radiometer radiances as described by Neale and Crowther, 1994. Due to the scan interlaced format of the high resolution video imagery, aircraft motion effects were removed using programs developed at the USU Remote Sensing Services Laboratory, described by Neale, et al., 1994.

During each remote sensing flight, an EXOTECH radiometer with Thematic Mapper bands TM1-4 was set up at ground level to acquire incoming irradiance over a barium sulfate panel located within the watershed. Sampling occurred at every 10 seconds and one-minute averages were stored. The EXOTECH radiometer on the aircraft and the one placed over the panel were cross-calibrated over the panel on the day of each flight. The use of this data will be demonstrated in the analysis part of the paper.

<u>Ground data</u> The ARS in Boise, Idaho collected the vegetation cover and LAI field data using the point frame method (Canfield, 1933). This method was used in the past in the watershed and served as a way of continuing to increase the database for the watershed. Vegetation plots were set up within the sub-basin considered representative of the surrounding watershed. The plots consisted of five transects 1.2 m apart and 30 m long. 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 hits as well as the class of vegetation (grass, forb, shrub).

The ground data at Nancy's Gulch, Lower Sheep and Whiskey Hill were all collected in the same manner. The first frame collection point was located on transect one in the southeast corner, one meter in from the southern pole identifying the transect. The next locations were at 4 meters from the pole, 12 meters, 16 meters, 24 meters and 28 meters coinciding with frame numbers 2,4,5,7,8 respectively along a transect. Each transect sampling began in the south and continued north for each point frame collection site. At Reynolds Mountain, the transects were aligned from west to east (as opposed to south to north like the other sites) and the first frame began in the southern most transect. The data collector then moved west to east along the transect. See Figure 2.

The vegetation data were primarily collected by two ARS field technicians, on or around the date of the image acquisition flights. Table 1 summarizes the dates for each flight and the vegetation data that were collected. There was not any field data collected at the Reynolds Mountain Site during the first flight.

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

ANALYSIS

Ground data The ground data were summarized by adding the total number of green hits at a frame location and dividing by the total number of points within a frame (20) to determine the LAI. Percent cover was evaluated at each point (20 within a frame) to verify whether at least one green hit occurred or not.   This number of hits was then divided by 20 to determine the area of land that was covered by green vegetation. In order to better correlate the ground data to the airborne imagery, data from the same frame number in each of the transects were added together and divided by 100. This resulted in six data points for comparison with imagery at each sub-basin and on each date (See Figure 2).

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:

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

where:

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) described by Neale and Crowther (1994) for each camera and filter combination (Watts/cm^2) green => radiance = 0.1070*DN + 0.607 red => radiance = 0.0962*DN + 0.269 NIR => radiance = 0.2276*DN+ 1.362
voltageconv	=	voltage conversion for radiometer #3629 (Watts/cm^2/Volt) x 10^-3 green => 4.99 red => 5.05 NIR => 51.7
panelref	=	bi-directional calibration coefficients for the barium sulfate panel based on the sun's zenith angle green => 1.206355-5.912489E-3x+7.260363E-5x^2-1.418622E-6x^3+7.776987E-9x^4 red => 1.194632-5.531206E-3x+5.04034E-5x^2-8.964636E-7x^3+4.172883E-9x^4 NIR => 1.17483-5.010488E-3x+4.097914E-5X^2-7.916402E-7x^3+3.764162E-9x^4
$\frac{v_{3630}}{v_{3629}}$	=	cross-calibration of the radiometer used in the field (#3630) and the one used during lab camera calibration (#3629) over the same standard reflectance panel
panelrad	=	panel voltage readings

In order to calibrate the imagery in terms of reflectance, as described above, it was necessary to note the time the image was taken in order to correlate it with the panel readings that were continuously being taken in the field to obtain the incoming radiation at that time. The GPS time stamp on the image was used for this purpose. Since panel measurements were averaged every minute the value in the equation is an interpolation between the two measurements taken closest to the time of the image. Each 3-band image selected was calibrated in this manner using the Model Maker program in ERDAS Imagine.

Once the 3-band imagery was calibrated in terms of reflectance, a normalized difference vegetation index (NDVI) image was calculated using the individual spectral bands and following formula:

$$NDVI = \frac{(NIR - \mathrm{Re}\,d)}{(NIR + \mathrm{Re}\,d)}$$

where: NIR = reflectance value of a pixel in the near-infrared (0.840-0.860 :m)
Red = reflectance value of a pixel in the red band (0.645-0.655 :m)

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. This method was used to eliminate any bias when extracting pixel data from the imagery and to provide a systematic way of computing the average NDVI for pixels which fell within the frames across each transect. (See Figure 3). Plot #1 therefore contained the ground data for the five *Frame #1* sites for each transect 1-5. A cut out was made for plots 1-6 with dimensions of 3 x 22 pixels. The mean and standard deviation statistics were then collected from this plot for comparison with the ground data.

RESULTS

The following table is a summary of the field data that were collected and the statistics that were obtained from the NDVI calibrated imagery. The Nancy's Gulch data was not used on July 3, 1996 since no imagery was available at 0.3 meter resolution.

Table 1. Field data and imagery statistics

Site and Date	Frame	Hits at pin	Total hits	Percent Cover	LAI	NDVI
Whiskey Hill, site #2, Bowen Ratio Point Frame data, May 30 to May 31, 1996						
1to5	1	69	117	0.69	1.17	0.341
1to5	2	78	160	0.78	1.6	0.39
1to5	4	83	170	0.83	1.7	0.406
1to5	5	65	130	0.65	1.3	0.362
1to5	7	75	152	0.75	1.52	0.369
1to5	8	67	119	0.67	1.19	0.348
		437	848			
Lower Sheep, site #3, Bowen Ratio Point Frame data, June 3, 1996						
1to5	1	55	73	0.55	0.73	0.233
1to5	2	44	55	0.44	0.55	0.209
1to5	4	46	60	0.46	0.6	0.219
1to5	5	47	54	0.47	0.54	0.207
1to5	7	45	62	0.45	0.62	0.233
1to5	8	54	75	0.54	0.75	0.231
Nancy Gulch, site #1, Bowen Ratio Point Frame data, August 2, 1996						
1to5	1	12	14	0.12	0.14	0.104
1to5	2	11	14	0.11	0.14	0.101
1to5	4	14	19	0.14	0.19	0.112
1to5	5	1	1	0.01	0.01	0.095
1to5	7	9	19	0.09	0.19	0.095
1to5	8	19	26	0.19	0.26	0.096
		66	93			
Lower Sheep, site #3, Bowen Ratio Point Frame data, August 2, 1996						
1to5	1	19	21	0.19	0.21	0.174
1to5	2	20	24	0.2	0.24	0.171
1to5	4	26	30	0.26	0.3	0.174
1to5	5	25	27	0.25	0.27	0.188
1to5	7	21	24	0.21	0.24	0.209
1to5	8	20	21	0.2	0.21	0.183
		131	147			

Site and Date	Frame	Hits at pin	Total hits	Percent Cover	LAI	NDVI
Reynolds Mt., site #4, Bowen Ratio Point Frame data, August 5, 1996						
1to5	1	36	38	0.36	0.38	0.273
1to5	2	74	109	0.74	1.09	0.383
1to5	4	46	54	0.46	0.54	0.283
1to5	5	53	71	0.53	0.71	0.277
1to5	7	41	51	0.41	0.51	0.272
1to5	8	38	45	0.38	0.45	0.287
		288	368			
Nancy Gulch, site #1, Bowen Ratio Point Frame data, September 3, 1996						
1to5	1	9	12	0.09	0.12	0.011
1to5	2	3	4	0.03	0.04	0.014
1to5	4	16	24	0.16	0.24	0.057
1to5	5	1	3	0.01	0.03	0.037
1to5	7	2	2	0.02	0.02	0.022
1to5	8	16	26	0.16	0.26	0.033
		47	71			
Whiskey, site #2, Bowen Ratio Point Frame data, September 3, 1996						
1to5	1	28	44	0.28	0.44	0.201
1to5	2	32	44	0.32	0.44	0.259
1to5	4	43	64	0.43	0.64	0.197
1to5	5	22	34	0.22	0.34	0.143
1to5	7	40	69	0.4	0.69	0.235
1to5	8	16	20	0.16	0.2	0.136
		181	275			
Lower Sheep, site #3, Bowen Ratio Point Frame data, September 3, 1996						
1to5	1	20	23	0.2	0.23	0.058
1to5	2	15	20	0.15	0.2	0.064
1to5	4	22	24	0.22	0.24	0.071
1to5	5	28	34	0.28	0.34	0.076
1to5	7	25	31	0.25	0.31	0.06
1to5	8	15	17	0.15	0.17	0.088
		125	149			
Reynolds Mt., site #4, Bowen Ratio Point Frame data, September 3, 1996						
1to5	1	12	15	0.12	0.15	0.139
1to5	2	42	56	0.42	0.56	0.205
1to5	4	26	32	0.26	0.32	0.146
1to5	5	30	43	0.3	0.43	0.135
1to5	7	15	20	0.15	0.2	0.132
1to5	8	17	22	0.17	0.22	0.125
		142	188			

The data were placed in a spreadsheet and graphed with the NDVI as the independent variable since the relationships that were developed will be used for the creation of distributed LAI and percent cover maps for the entire watersheds. The data collected demonstrated a high correlation visually and it was important to find a curve that best fit this relationship (See Figures 3 and 4). The NDVI vs. Percent Cover developed a 2nd order polynomial relationship (y=2.92x^2+0.669x+0.707) with a root mean square (RMS) error of 0.8563. The NDVI vs. LAI developed a 2nd order polynomial relationship (y=11.342x^2-1.2037x+0.1933) with a RMS of 0.872. A second order polynomial was used 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.

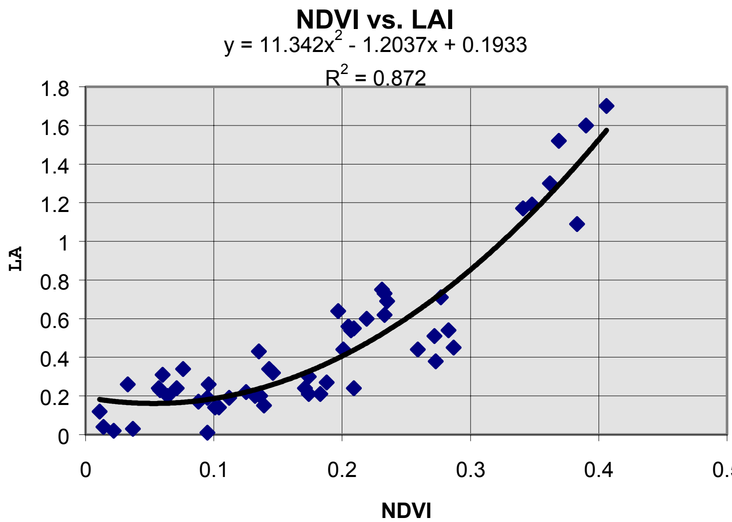

Figure 3. NDVI vs. LAI relationship.

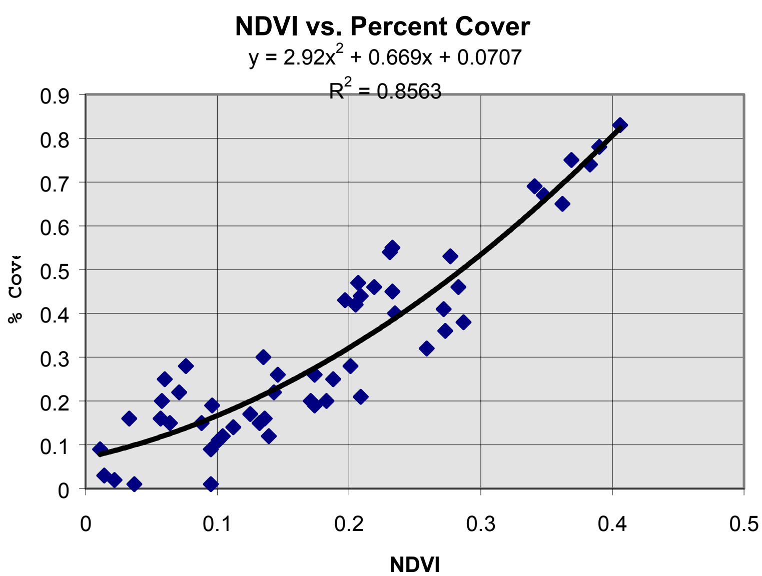

Figure 4. NDVI vs. Percent Cover relationship.

COMMENTS AND CONCLUSIONS

The 2nd order polynomials that were used to fit the data points demonstrate a strong relationship between the airborne (NDVI) and ground (percent cover and LAI) data that were collected as indicated by the high R. It would have been helpful to have more heavily vegetated areas to improve the relationships. The Reynolds Mountain site did not result in higher LAI and percent cover data that was expected. There were additional data collected in the 1997 field season in a different area of the Reynolds Mountain sub-basin with denser vegetation, which will help to assess the seasonal growth pattern of the vegetation and will be used as a check of the 1996 relationship in the future. Additional imagery from July 1996 still needs to be processed and may provide some greater control for the curve. Some of the vegetation species would be reaching their peak growth stages in early July.

A small mosaic of the Lower Sheep sub-basin is included in Figure 5 showing the application of the LAI relationship and the resulting distribution of LAI in the sub-basin. In order to apply the developed relationships across the entire watershed it will be necessary to use lower resolution imagery and therefore it will be important to investigate the effects of using the 0.6m resolution imagery as well as understanding and correcting for atmospheric affects.

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