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GPS- vs. DEM-Derived Elevation Estimates from a Hardwood Dominated Forest Watershed

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Abstract

Topographic attributes are often used as explanatory variables when providing spatial estimates of various environmental attribute response variables. Elevation of sampling locations can be derived from global positioning systems (GPS) or digital elevation models (DEM). Given the potential for differences in elevation among these two data sources, especially in response to forest canopy cover, our objective was to compare GPS and DEM-derived elevation values during the dormant season. A non-parametric Wilcoxon test indicated GPS elevation was higher than DEM elevation with a mean difference of 6 m. Linear regression analysis indicated that GPS and DEM elevation were well correlated ($R^2 = 0.71$, $r = 0.84$, $p < 0.0001$). Although elevation among the two data sources differed, the strong linear relationship allows for correction of elevation values in a predictable manner.

Keywords: Forest Canopy Cover, Linear Regression, Spatial Estimates

1. Introduction

Global positioning systems (GPS) are widely used in environmental research to identify locations of permanent sampling locations. Horizontal accuracy is suggested to be influenced primarily by GPS grade and canopy cover [1-4]. Spatial estimates of various environmental attribute response variables are widely developed using digital elevation model (DEM) derived topographic attributes as explanatory variables. Elevation derived from a DEM is an attribute typically used in this methodology. Alternatively, elevation determined by GPS may also be used in this type of analysis. Given the potential for differences in elevation among these two data sources, our objective was to compare GPS and DEM-derived elevation in a statistically rigorous manner on a typical hardwood forest site. GPS data for this analysis were collected in part in support of a recently published study on forest soil C and N [5] and are reanalyzed here. The utility of this analysis results from a lack of studies that compare elevation derived from these two data sources.

2. Methods

2.1. Site Description

The Camp Branch Experimental Watershed is located in Fall Creek Falls State Park on the Cumberland Plateau in Central Tennessee ($35^{0}38^{'}$ N lat.; $85^{0}18^{'}$ W long.). The watershed is a 94 ha mixed hardwood forest. Permanent data points (**Figure 1**) were marked with steel posts as part of an earlier study [6]. GPS data were collected after leaf fall in November 2006 and canopy coverage was

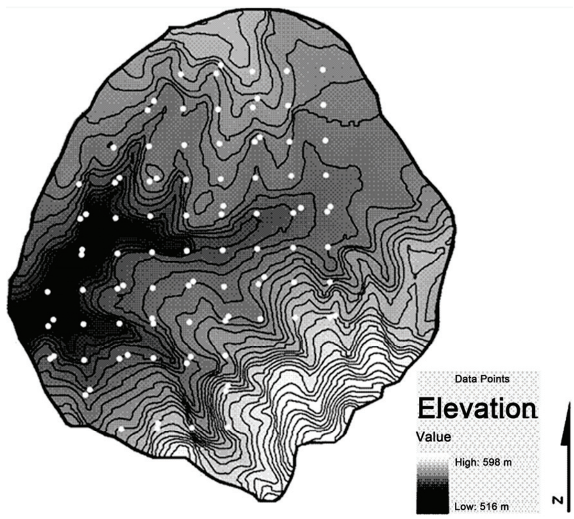

Figure 1. Elevation map of the 94 ha Camp Branch Experimental Watershed. Also shown are the 95 data points for which coordinates and elevation were determined.

estimated to range from 15% to 25% during the GPS data collection period. Mean GPS elevation is 554 m and ranges from 532 m to 584 m. Mean DEM-derived elevation is 548 m and ranges from 528 m to 567 m.

2.2. GPS Data

Coordinates (UTM zone 16N; horizontal datum NAD83) and elevation of the 95 data points were collected in November 2006 with a mapping-grade Trimble GeoXT receiver (Trimble Navigation Ltd., Sunnyvale, CA, USA). Elevation of the data points was recorded as height above mean sea level (MSL) using the EGM96 geoid model. Data were post-processed with TerraSync v.2.52 (Trimble Navigation Ltd., Sunnyvale, CA, USA) using a continuously operating reference station (CORS) in Hartsville, TN located approximately 68 miles from the study area. After post-processing, a shapefile of the 95 data points was generated. Mean and standard deviation of the number of positional fixes was 15.0 and 9.8, respectively. Mean and standard deviation of maximum positional dilution of precision (PDOP) was 4.4 and 0.65, respectively. Mean and standard deviation of horizontal precision was 1.3 m and 0.2 m, respectively.

2.3. Digital Elevation Model

A level 2, 10-m resolution DEM of the watershed taken from the 7.5 minute Sampson, TN quadrangle was obtained from the U.S. Geological Survey's National Elevation Dataset (EROS, Sioux Falls, SD, USA). The horizontal datum of the DEM is NAD27 and the vertical datum is NAVD88.

2.4. ArcGIS

Both the GPS data point shapefile and the DEM were imported into ArcGIS v.9.2 (ESRI Inc., Redlands, CA, USA) and projected in UTM zone 16N and NAD83 (**Figure 1**). Elevations of the 95 data points derived from the DEM were extracted for comparison with GPS elevations. The spatial analyst function was used to generate 10 m contour lines to aid in visualizing topographic features.

2.5. Statistical Analysis

Due to a non-normal mean difference, a non-parametric Wilcoxon procedure was used to test for differences among GPS and DEM-derived elevation (PROC NPAR-1WAY, SAS v.9.1, SAS Institute Inc., Cary, NC, USA). The relationship of GPS to DEM-derived elevation was examined using simple linear regression (PROC REG, SAS v.9.1, SAS Institute Inc., Cary, NC, USA).

3. Results and Discussion

The Wilcoxon test indicated GPS elevations were larger than DEM-derived elevations ($Z = 4.18$, $p < 0.0001$). Mean and standard deviation of the difference in elevation was 6 m and 5 m, respectively. The difference in elevation ranged from 21 m to –5 m (**Table 1**) and was not related to maximum PDOP, the number of positional fixes, and horizontal precision. Regression analysis indicated that GPS and DEM-derived elevation were well correlated ($y = 123.74 + 0.7665x$, $F = 226.2$, $R^2 = 0.71$, $r = 0.84$, $p < 0.0001$) (**Figure 2**). Out of 95 data points, 4 fell outside the 95% prediction interval for the regression (**Figure 2**). Results indicate DEM-derived elevation of other data points within the study area can be adjusted with confidence when GPS-derived elevation is considered more representative of actual elevation thereby minimizing error propagation effects on accuracy of spatial estimates of environmental attribute response variables.

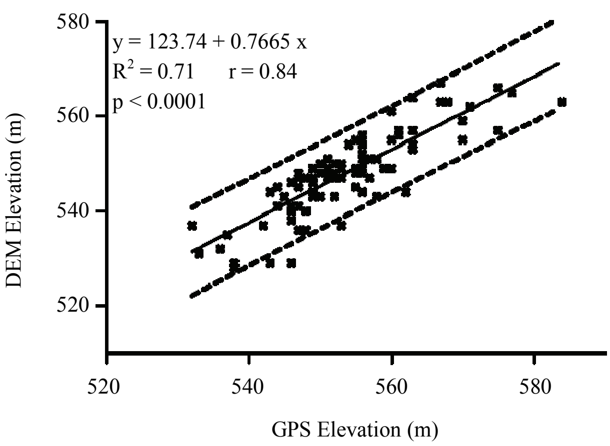

Figure 2. Scatterplot depicting DEM elevation as a function of GPS elevation. Linear regression equation, R^2, r, p-value, and 95% prediction interval are also shown.

Table 1. GPS data collection parameters, GPS elevation, DEM elevation, and elevation difference for each of the 95 permanent data points on the Camp Branch Experimental Watershed.

Maximum PDOP	Positional Fixes	Horizontal Precision	GPS Elevation	DEM Elevation	Elevation Difference
4.8	17	1.1	584	563	21
3.3	14	1.2	575	557	18
3.9	6	1.7	562	544	18
4.3	10	1.3	546	529	17
5.2	15	1.2	553	537	16
5.8	28	1.1	570	555	15
4.9	12	1.3	558	543	15
3.3	13	1.0	543	529	14
4.6	11	1.3	548	536	12
4.7	6	1.3	577	565	12
4.4	15	1.4	556	544	12
5.1	10	1.5	560	549	11
5.0	11	1.4	547	536	11
5.7	14	1.3	570	559	11
3.9	7	1.5	555	545	10
4.4	15	1.4	538	528	10
4.4	19	1.4	557	547	10
4.6	17	1.0	559	549	10
3.9	64	1.0	563	553	10
5.1	11	1.6	563	554	9
4.9	10	1.2	575	566	9
4.5	4	1.8	571	562	9
4.8	10	1.3	552	543	9
3.3	6	1.3	538	529	9
4.9	15	1.1	548	540	8
4.9	10	1.2	556	548	8
4.1	32	1.4	546	538	8
4.3	18	1.5	550	543	7
5.4	16	1.2	555	548	7
4.2	10	1.6	555	548	7
4.6	11	1.1	558	551	7
5.0	16	1.4	556	549	7
4.1	12	1.3	553	547	7
4.7	10	1.6	563	557	6
3.3	12	1.1	549	543	6
4.9	15	1.1	547	541	6
4.5	17	1.0	557	551	6
4.2	15	1.3	555	549	6
3.1	17	1.1	546	540	6
3.8	8	1.0	549	543	6
3.3	16	1.5	552	547	5
2.5	11	0.9	560	555	5
5.2	13	1.1	546	541	5
4.8	12	1.2	556	551	5
3.9	4	1.1	561	556	5
4.0	10	1.1	552	547	5
4.8	66	1.1	549	544	5
3.9	10	1.2	568	563	5
4.7	26	1.3	542	537	5
3.4	10	1.3	551	547	4
4.7	12	1.3	556	552	4

Table 1 continued

Maximum PDOP	Positional Fixes	Horizontal Precision	GPS Elevation	DEM Elevation	Elevation Difference
4.9	12	0.9	561	557	4
3.2	10	1.2	552	548	4
2.5	12	1.1	553	549	4
4.1	12	1.1	536	532	4
4.9	11	1.3	553	549	4
4.7	10	1.2	567	563	4
4.0	14	1.1	553	549	4
5.4	12	1.4	553	550	3
5.0	19	1.6	553	550	3
4.6	11	1.2	549	546	3
4.4	7	1.4	544	541	3
4.7	12	1.1	551	548	3
3.8	12	1.3	551	548	3
4.2	10	1.6	553	550	3
4.2	13	1.2	550	548	2
4.8	22	1.0	545	543	2
4.6	43	1.2	547	545	2
4.4	20	1.2	551	549	2
4.0	13	1.4	549	547	2
5.2	7	1.4	537	535	2
4.7	13	1.6	552	550	2
4.1	12	1.4	550	548	2
4.9	13	1.4	552	550	2
4.8	10	1.0	556	554	2
3.3	15	1.2	533	531	2
4.7	10	1.1	548	547	1
4.1	15	1.4	548	547	1
4.7	16	1.2	556	555	1
4.2	21	1.4	551	551	0
4.9	12	1.7	549	549	0
3.4	14	1.2	554	554	0
4.2	14	0.9	555	555	0
5.3	10	1.8	547	547	0
4.9	12	1.2	551	551	0
4.8	14	1.4	546	546	0
4.8	22	1.4	567	567	0
3.8	9	1.4	550	550	0
4.5	23	1.4	556	556	0
4.1	10	1.3	543	544	-1
3.6	10	1.3	544	545	-1
4.4	46	1.8	563	564	-1
4.9	15	1.4	547	548	-1
5.5	12	1.0	560	561	-1
4.8	23	1.3	532	537	-5

In a study that compared elevations from five mapping-grade Trimble GPS receivers with surveyed benchmark elevations [7], average absolute vertical errors of post-processed data among the receivers ranged from 0.8 m to 1.9 m. The greatest effect on vertical error was canopy coverage. Vertical error of post-processed data was 0.2 m under open sky, 0.4 m under 50% canopy, and 3.3 m under 100% canopy. While the vertical error in our study was larger at 6 m, the two studies are not directly comparable.

4. Conclusions

Results indicate that, under conditions specific to this study, although GPS elevation was overestimated compared to DEM-derived elevation, the relationship among these data sources was predictable and followed a well defined linear relationship. While the magnitude of the elevation difference among the two data sources was large for some of the data points, the strong linear relationship allows for correction of elevation values in a predictable manner. More generically, the results of this analysis indicate that potential differences in GPS and DEM derived elevation estimates will need to be considered when elevation related environmental attributes are analyzed and extrapolated spatially.

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