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Conifer Tree Influence on Digital Terrain Elevation Data (DTED): A Case Study at Dulles International Airport

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13. ABSTRACT *(Maximum 200 words)*

Conifer tree influence on the collection and portrayal of Digital Terrain Elevation Data (DTED) is presented. Study sites are investigated which had dense conifer canopy closure. Two separate DTED collection techniques are examined in the context of studying conifer tree influence: (1) photo source auto-correlated, and (2) photo source operator assisted (floating dot). Field surveying is the mechanis[illegible]d for collecting accurate, verifiable ground elevation data subsequently compared against the elevations of corresponding DTED positions. Estimated conifer tree stand heights (at the time of DTED photo source) are compared against the difference in value between DTED and field surveyed elevations. A close relationship between stand height and difference values demonstrates the potential for conifer tree height inclusion within DTED "ground" elevations. Terrain modelling impacts caused by the addition of tree heights within the DTED are addressed.

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PREFACE

This work was funded under DA Project 4A162784A855, Task CO, Work Unit 066, "Terrain Analysis Product Evaluation and Development."

This work was performed during the period of March 1991 to August 1991 under the supervision of Homer Babcock, Chief, Geographic Information Systems Branch, and Douglas Caldwell, Chief, Terrain Analysis and Data Generation Division. Directly contributing in survey data collection and post-processing were Mike Collins, Brad Conver, and John Viletto. Aerial photography expertise was provided by Mark Burnell.

Walter E. Boge was Director of the U.S. Army Topographic Engineering Center at the time of publication of this report.

CONIFER TREE INFLUENCE ON DIGITAL TERRAIN ELEVATION DATA (DTED): A CASE STUDY AT DULLES INTERNATIONAL AIRPORT

INTRODUCTION

Background

An issue of concern for users of Digital Terrain Elevation Data (DTED) is the impact of tree cover on the accuracy of raw elevation values and its effect on products derived from digital terrain models using DTED. Most terrain model users assume that DTED reflects accurate elevation on the ground and accounts for all adjustments for vegetation. However, past and present contributing compilers and reviewers of the data admit that on occasion vegetation heights are inevitably incorporated into DTED because the ground is simply invisible to the source photography from which DTED is compiled. This conjecture regarding the inclusion of vegetation into DTED, albeit responsible and based on years of professional experience, has never, to my knowledge, been confirmed through exacting field research. Evidence of the inclusion of vegetation into DTED would provide an empirical starting point for the evaluation of research solutions for correcting DTED elevation inaccuracies.

Line-of-Sight (LOS) modelling is especially vulnerable to generating products of questionable reliability if vegetation, such as a tall tree stand, is included within DTED. For example, it is important to know whether the observing point of origin for a LOS model lies within a stand of trees or outside the trees. LOS models typically ask if vegetation heights should be included at the observation point. If these values were added at the compilation stage, including them as a response to a vegetation modelling query would be tantamount to adding vegetation heights for a second time. Accurate LOS products could never be achieved in areas with heavily canopied cover if the observation point happened to fall within the canopy. Such inaccuracy could be a serious problem in the terrain models which use LOS, such as Radial Terrain Masking, Aerial Detection, Flight Line Masking, Concealment, and Perspective Views models.

Likewise, slope modelling is vulnerable to exaggerated DTED elevations. Slope is an integral component of many terrain models, including mobility, bivouac siting, helicopter landing zones, watershed delineation, slope contour area, elevation contour intervals area, and color shaded contour elevation modelling. If the slope data is incorrect, the error propagates through these other models.

This research examines conifer tree stand influence on DTED values representing ground elevation at Washington Dulles International Airport. DTED values will be compared with actual ground truthed values. Association between conifer tree cover and DTED will be established.

Gridded Digital Elevation Data Collection Process. Gridded digital elevation data may be better known by two product specific names: 1) DTED, generated by the Defense Mapping Agency (DMA), and 2) Digital Elevation Models (DEM), generated by the United States Geological Survey (USGS). DTED is collected on either 1 arc second (or approximately 30 meter interval posts) or 3 arc second (or approximately 100 meter interval posts) spaced in grid-like alignment to one another. Level 1 DTED is spaced every 100 meters and has a greater degree of interpolation and generalization of detail than does Level 2 DTED which is spaced every 30 meters. Level 1 DTED is more prevalent worldwide and accordingly was selected in this study for examination and comparison against ground truthed elevation values. Three different technologies were used for collection of DTED: 1) photo source operator assisted, semi-automated, 2) photo source auto-correlated, and 3) carto source interpolated.

1) In **operator-assisted collection**, the accuracy of the ground level determination depends on the skills, abilities, knowledge, state of mind, interest, and time constraints of the individual collecting the DTED posts. The operator uses a stereo plotter to manually profile, or float a dot along, what is perceived to be the ground.

2) **Auto-correlated collection** of DTED relies on little to no human intervention to determine ground elevation values. The instrument automatically profiles the photographs for elevation values at a predetermined spacing. Human intervention occurs only at the operator's discretion. Auto-correlated collection appears to be the desired way of the future for DMA per unrecorded discussions held with several DMA staff members in the winter of 1991. Like the operator-assisted method, this collection technique also uses stereo photography for its modelling.

3) **Carto source interpolated collection** uses original hard copy map products converted to digital products to determine post values for DTED. This collection technique results in degraded accuracy due to considerable interpolation in converting topographic contour values and/or spot elevations to specific grid post values, inevitable digitizing errors in the conversion process, and the generalized nature of source maps.

DEMs are generated by the USGS in five formats, two of which are mentioned here because of their application to this research: 7.5 minute DEM at 30 x 30 meter data spacings and 1 degree DEM at 100 x 100 meter posts (or 3 x 3 arc-second spacing) (USGS, 1990, p. 2). The 7.5 minute DEMs are consolidated by the USGS to make 1 degree DEMs. When post spacings for these two formats are compared, there are no equivalent locations so a 4-neighbor weighted interpolation must occur during the transformation from 30-meter posting to 100-meter posting (Caruso, August 1991). One degree DEMs are then submitted to the DMA and, through cooperative agreement, converted directly into DTED format.

HYPOTHESIS

It was hypothesized that differences in value between Field Surveyed elevations and the corresponding DTED elevation posts would be closely associated with the heights of vegetation occupying the area. Therefore, DTED heights over vegetated areas were expected to show up as greater than actual ground elevations. An unknown combination of percentage canopy closure and vegetation type was thought to adversely impact the accurate portrayal of true ground elevations. Canopy closure was considered the primary culprit in restricting the 'seeing of the ground' on aerial photography.

For this research, vegetation type was limited to trees; they were categorized as either evergreen (conifers in this instance) or deciduous. Evergreen stands were thought to have a greater impact on visualizing true ground elevations because of their perennial leaf-on characteristics. Aerial photography is preferably flown during the winter months to accommodate leafless vegetation and improve ground visibility, but conifers will obstruct visibility regardless of season. Noteworthy are comments by Mr. Caruso (March 1991), a USGS digital elevation data technical expert, indicating that even photography flown during the leaf-off season for deciduous trees may not be showing the true ground because the branches of mature hardwoods are likely to restrict visibility. This implies a 'ground' elevation collected at some unknown branch level between ground and treetop. This last point really complicates the effort to accurately represent DTED elevations in areas of deciduous tree cover.

METHODOLOGY

Research Formula. Differences in elevation between DTED and corresponding Field Surveyed points were stored as a new variable and evaluated against vegetation heights. It was anticipated that differences between Field Surveyed elevations and DTED reported elevations would be close to the estimated tree heights (see Figure 1).

DTED	=	DTED elevation value
FIELD	=	Field Surveyed elevation value
TREEHT	=	Height of tree stand at time of photo source
ASSOC	=	Measure of association of elevation difference with actual tree height

Solution: (DTED - FIELD) / TREEHT = ASSOC

Sample data points in meters:

Point	DTED	FIELD	TREEHT
1	323	315	8
2	350	325	23
3	220	217	15

Point 1: (323 - 315) / 8 = 1.0

Sample point 1 shows perfect association between DIFF and TREEHT.

Point 2: (350 - 325) / 23 = 1.0869

Sample point 2 shows a strong positive association between DIFF and TREEHT.

Point 3: (220 - 217) / 15 = 0.20

Sample point 3 shows a weak positive association between DIFF and TREEHT.

Figure 1. Evaluating Association of Elevation Difference with Tree Stand Height: Calculation Examples

Matching DTED Posts to Field Surveyed Points. Determining identical DTED and Field Surveyed locations presented immediate problems. Should DTED attempt to match the ground control X,Y location or, conversely, should the Field Survey attempt to match the 100-meter grid posts of DTED? Surveying to match DTED could be done using a roving Global Positioning Satellite receiver but only in areas without tree cover, because GPS does not receive adequate satellite reception through the trees. Replacing under canopy surveying with more conventional surveying techniques still did not allow for easy real-time location of position. Consequently it was decided that DTED posts should match to the field surveyed points via a nearest neighbor post interpolation routine. The AirLand Battlefield Environment (ALBE) Geographic Information System (GIS) was available as a system capable of importing and analyzing DTED data. ALBE GIS software permits an operator to receive DTED elevations at interactive cursor controlled positions or from keyboard entered Universal Transverse Mercator (UTM) coordinates. Elevations returned by the GIS were to the elevation of the nearest 100-meter DTED post selected by user-defined keyboard position.

Site Selection. Dulles Airport was selected as the best site at which to ground truth DTED data for several reasons:

1) The airport contained areas with large, tall conifer stands with dense canopy closure.

2) Auto-correlated digital elevations were available for the study site. Per a USATEC request, computer-generated listings were provided by USGS which identified Dulles Airport as an auto-correlated area within the Herndon 7.5 minute DEM. The year of the DEM photo source material was 1981 and the collection instrument was the Gestalt Photo Mapper II. The extreme western portion of Dulles Airport is located on the Arcola 7.5 minute DEM which had been compiled using 1977 stereo photography on a C-8 manual profiling instrument (i.e. one which uses the floating dot principle). Gestalt Photo Mapper II used an operator assisted stereo plotter collection method.

3) Dulles Airport provided proximity to USATEC for anticipated support and the elimination of per diem costs for the project.

4) It was important to select a basically flat site to eliminate potential terrain variations under the tree canopy. Dulles Airport fulfills this requirement.

5) Airport operations managers granted relatively unconditional access to the research site. This allowed the researchers to avoid problems with access to secured areas, wetlands, and private property.

6) An accurate geodetic control network had recently been established in the area from which to initiate the surveying mission.[1]

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[1]The Virginia Department of Transportation (VDOT) had just worked in the area outside the airport one week prior to our contact with them. Numerous Global Positioning Satellite (GPS) stations of high quality accuracy (1 decimeter vertical and 1 centimeter horizontal) had been established all around the airport. These monuments were easily recovered by the USATEC survey team.

7) Very recent DTED data covering the Dulles Airport area was available for USATEC research purposes.[2]

Tree Stand Selection. After Dulles International Airport was selected as the optimal research site, investigation began on-site to determine the best tree stands under which to conduct field surveying. Two tall coniferous stands within the airport grounds appeared adequate (Sites A and B). Both stands were approximately 450 by 600 meters wide as measured from 1979 1:12,000 scale aerial photography. Open, cleared land stood near (within 1 mile) and/or adjacent to the conifer stands. These clearings were crucial for showing that DTED elevations matched, or came close to matching, the Field Surveyed elevations in these non-tree-covered areas. Site A was located in the Arcola DEM, which was photo compiled by an operator from 1977 source photography. Site B was located in the Herndon DEM, which was auto-correlated from 1981 source photography.

Exact heights and canopy closures of these two conifer stands at the time of the DTED collection were unknown and needed to be determined. Ideally, photography coinciding with the DEM source years for Arcola-March 1977 and Herndon-1981 would have been evaluated. However, no photography was available for those years, so tree height and canopy closures needed to be estimated. A baseline for tree growth in the Arcola area was established by evaluating tree heights/closures for the years in which aerial photography was available. The rate of computed annual growth was applied to both tree stands. Historic 1:12,000 black and white panchromatic aerial photography was evaluated by a USATEC photo analyst trained as a forester. The Loudoun County Department of Natural Resources graciously made April 1982 and March 1979 photography available for review. Best estimates (plus or minus 20%) of overall tree stand heights were made using a parallax bar. Canopy closure was estimated to be within 10% of the actual closure (see Table 1).

Table 1. USATEC Aerial Photo Interpretation Estimates

	Site A: Route 606	Site B: Runway
	1982 Photography	
Tree stand height (meters)	12-15	19-22
Canopy closure	85%	100%
	1979 Photography	
Tree stand height (meters)	10-12	not available
Canopy closure	100%	not available

[2]The 7.5 minute DEMs which covered the Dulles Airport area were Herndon and Arcola. Each was re-sampled and incorporated into the USGS 1 degree Washington West DEM. Washington West DEM had been released to DMA for conversion to DTED around 1989. DMA had converted this DEM into a DTED cell but had not officially released it. DMA permitted USATEC to utilize the unreleased DTED cell for research purposes only.

A difference of 24 months, or two growing seasons, existed between the Site A-Arcola DEM photo source (March 1977) and the March 1979 photography interpreted to estimate tree canopy and heights. To correctly estimate tree heights and canopy closures for the DEM photo source, the change in tree stand growth measured between the years 1979 and 1982 was first computed. This difference was divided by 3 (i.e. 3 years of growth) for an annual growth rate. Two years of annual growth were subtracted from the 1979 estimates to compute the 1977 Site A corrected tree stand height and canopy closure (see Figure 2). A difference of 12 months or one growing season existed between the actual month and year of the auto-correlated Site B-Herndon DEM photo source (April 1981) and the April 1982 photography reviewed to determine tree canopy and heights. Unfortunately, 1979 photography was unavailable over Site B. A rate of tree growth could not be accurately established. Judging from Site A's tree growth of approximately 0.7 meters per year, it was reasoned that one year of tree growth for Site B would not have been of significance.

Site A Tree Stand Height (in meters):

12-15 (in 1982)
- 10-12 (in 1979)
~2 meters change between 1979 and 1982

2 meters / 3 years = 0.6666 meter change per year

2 years * 0.6666 meters = 1.3333 meters change during 2-year period

10-12m (in 1979)
- 1.3333
~8.5-10.5 meters tree stand height in 1977

Site A Canopy Closure:

85% (in 1982)
- 75% (in 1979)
10% change between 1979 and 1982

10% / 3 years = 3.3333% change per year
2 * 3.3333% = 6.6666% change during 2-year period
75% (1979) - 6.6666% = ~70% canopy closure in 1977

Figure 2. Corrected Tree Stand Heights and Closures

The final corrected 1977 tree stand height for Site A was 8.5 to 10.5 meters with a canopy closure of 70%. Site B values were retained as originally computed from the 1982 photography (19-22 meters in height and 100% canopy).

Black and white photography flown over Dulles Airport in 1990 at scale 1:12,000 was also reviewed to make sure that the tree stands, as visible to the researchers on the ground in 1991, were in fact in the same place in the 1982 and 1979 photography. This effort ensured that the research survey points destined for collection in 1991 did not fall into an area of new forest cover that was not in existence in either 1981 or 1977, the years of the respective DEM photo source. Overlays were made of the two tree stand study sites for the years 1982 and 1990; these were placed one atop the other and compared for discrepancies. There was little to no growth outward at any juncture along the tree stand's periphery from either 1979 or 1981 to the 1990 photography. Therefore, any survey traverse point collected at least 10 meters inside the present tree canopy was considered to be legitimate for this research.

Field Surveying. Ashtech Global Positioning Satellite (GPS) equipment was selected due to its in-house availability, speed in data collection, ease of use, and decimeter level post-processing solutions in the vertical (elevations) direction. GPS was used for surveying in control from the VDOT control monuments outside the airport onto the airport grounds. Static GPS surveying, using one known control position relative to one or more unknown positions, was selected because of its decimeter accuracy capability in both horizontal and vertical ranges, and its not requiring line of sight between control points. Clearings around the two airport study sites were to receive GPS controlled elevations. After completion of these newly controlled 'open field' survey points, surveying into and underneath the tree canopy required different equipment. GPS does not function under dense canopy. A Wild T-2000 Total Station capable of measuring X, Y, and Z parameters for any newly established control point was selected. This sophisticated digital theodolite permitted rapid advance along a desired traverse line due in part to its stored recall of previous station positional data from which it computed new survey station parameters.

The minimum number of GPS orbiting satellites in view required to adequately adjust for both horizontal and vertical ground control positioning is 4. The longest continuous block of time in which a minimum of 4 satellites were visible in the Dulles Airport area was early afternoon to early evening. A 3-man, and later a 4-man, USATEC survey crew was responsible for collecting all GPS field data. Differential GPS was used to establish new control points for Sites A and B. One receiver was placed over a known location (established control point) while all other receivers were simultaneously placed over unknown, new points to be established. Two receivers were utilized for the majority of the survey but there were 2 days on which 5 receivers were utilized. Accuracy of the GPS data collection was in the 5-meter horizontal range and decimeter vertical range following office post processing of the data. Satellite reception was always of high quality with little to no noise interference.[3]

Post-processing of the collected GPS data presented infrequent minor difficulties which stemmed from in-the-field GPS receiver operator errors (i.e. forgetting to include antennae slant height, forgetting to change a session number, and forgetting to change a station number) and from in-the-office processing errors (i.e. forgetting to eliminate the use of a satellite reported as 'unhealthy' during data collection time and forgetting to add antennae radii to the program parameters). GPS data were downloaded and processed through several in-house computer programs designed to compute the accuracy and location of each new control station. VDOT stations were established as fixed points

[3]Loss of satellite lock was very infrequent and when it did occur was usually the result of positioning too close to tall trees which temporarily obstructed satellite visibility.

from which all new station values were computed. Thirteen GPS stations were attempted and 12 were successfully solved for. The sole failure was a long shot, at best, due to its close proximity to tall trees on almost all sides. The GPS stations established provided an acceptable geodetic framework from which to begin more conventional ground surveying using the T-2000.

The T-2000 is dependent on the existence of one known control point and an azimuth from which to begin a survey line. An additional point acts as a backsight and the known point is the starting location. Previously established GPS stations served as the starting point. Closed traverse loops utilizing GPS stations for the starting and ending points were the chosen method of surveying as they provided an in-the-field rough evaluation of accuracy. Numerous side shots were taken using the T-2000 to collect both open field and canopy-covered control points. Side shots were rapidly computed. All data was adjusted in the office for horizontal and vertical corrections.

RESULTS

Once all Field Surveyed points were adjusted to the correct ground elevation and horizontal position it was possible to compare Field Surveyed elevations to the closest identical DTED post elevations. Field Surveyed points were grouped by study site as either tree-covered or open field. Accordingly, a total of four data sets (two per study site) were eventually evaluated. Several open field control points were duplicated and used for the data sets of both study sites. All open field control points originated from the geographic areas on the Herndon auto-correlated DEM. Control points established below tree canopy were differentiated as unique to each site and were not shared between data sets (see Table 2 and Table 3).

ANALYSIS

Statistical Analysis

Generalized statistical data such as average, range, standard deviation, variance, and standard error were computed. Spearman Rank correlation coefficients and significance levels were computed. One-sample and two-sample analyses were computed. Refer to Table 4 and Table 5 for summary tables of the statistical findings.

A Spearman Rank Correlation was also run on the variables Site A-open field DTED and Site A-tree-covered DTED. A weak negative relationship existed indicating that if open field elevations dropped so would the tree-covered elevations. Two sample analyses were run for Sites A and B to validate the hypothesis that differences in value between Field Surveyed and DTED elevations under canopied areas would be closely associated with the heights of the vegetation occupying the area. The variables 'open field DTED elevations minus open field Field Surveyed elevations' were evaluated against 'tree-covered DTED elevations minus tree-covered Field Surveyed elevations'. Only at Site A where tree heights were apparently incorporated into the DTED was the null hypothesis rejected and a lack of significance between variables identified.

Table 2: Comparison of Field Surveyed Elevations to Nearest DTED Post Elevations
Site A: Route 606 (70% canopy, 8.5 - 10.5 meters)

#	Station	Field	DTED	DIFF	Open/Tree
1	G1	105.60	105.00	-0.60	O
2	G2	99.50	109.00	9.50	**
3	G9	96.60	111.00	14.40	**
4	G10	99.50	109.00	9.50	**
5	RNWY	95.50	99.00	3.50	O
6	PT_A	96.10	96.00	-0.10	O
7	PT_B	97.60	96.00	-1.70	O
8	C3	108.60	109.00	0.40	O
9	G4	94.10	94.00	0.10	O
10	G5	93.20	96.00	2.80	O
11	G8	91.00	89.00	-2.00	**
12	OPEN1	93.10	93.00	-0.10	O
13	OPEN2	91.90	95.00	4.10	O
14	OPEN3	92.30	95.00	2.70	O
15	SS12	91.10	91.00	-0.10	O
16	SS14	90.30	91.00	0.70	O
17	SS16	89.70	90.00	0.30	O
18	TP50	99.60	110.00	10.40	T
19	SS50	98.30	110.00	11.70	T
20	SS51	100.10	110.00	9.90	T
21	TP51	100.60	109.00	8.40	T
22	SS52	98.80	109.00	10.20	T
23	TP52	101.20	109.00	7.80	T
24	SS53	100.90	110.00	9.10	T
25	TP53	100.10	109.00	8.90	T
26	SS54	101.20	108.00	6.80	T
27	SS55	100.30	109.00	8.70	T
28	SS56	101.80	108.00	6.20	T
29	TP54	101.10	109.00	7.90	T
30	SS57	101.50	109.00	7.50	T
31	TP55	101.20	109.00	7.80	T
32	SS58	99.80	109.00	9.20	T
33	TP56	100.80	109.00	8.20	T
34	TP57	99.90	109.00	9.10	T
35	SS59	100.40	109.00	8.60	T
36	SS60	100.00	109.00	9.00	T
37	TP58	99.00	109.00	10.00	T
38	SS61	99.10	109.00	9.90	T
39	TP59	100.10	109.00	8.90	T
40	SS62	100.80	109.00	9.20	T
41	SS63	99.20	110.00	10.80	T
42	TP60	99.50	109.00	9.50	T
43	SS19	91.60	89.00	-2.60	O
44	SS18	91.60	89.00	-2.60	O

** <100 meter radius around point with DTED post presumed to be within tree canopy

Table 3. Comparison of Field Surveyed Elevations to Nearest DTED Post Elevations Site B: Runway (100% canopy, 19-22 meters)					
#	Station	Field	DTED	DIFF	Open/Tree
1	G1	105.6	105	-0.6	O
2	G2	99.6	109	+9.4	**
3	G4	94.1	94	-0.1	O
4	G5	93.2	96	+2.8	O
5	G7	93.5	92	-1.5	O
6	G8	91.0	89	-2.0	O
7	C1	88.6	84	-4.6	O
8	C2	96.3	100	+3.7	O
9	RNWY	95.6	99	+3.4	O
10	PT_A	96.1	96	-0.1	O
11	PT_B	97.6	96	-1.6	O
12	SS13	90.5	91	+0.5	O
13	SS15	89.2	90	+0.8	O
14	SS17	91.2	89	-2.2	O
15	OPEN1	93.1	93	-0.1	O
16	OPEN2	91.9	95	+4.1	O
17	G10	99.5	109	+9.5	**
18	GPCUT	91.9	95	+4.1	T
19	TP1	92.7	93	+0.3	T
20	SS1	90.8	95	+4.2	T
21	TP2	91.6	92	+0.4	T
22	SS2	94.1	92	-2.1	T
23	SS3	90.2	93	-2.8	T
24	TP3	93.4	92	-1.4	T
25	SS4	91.3	93	+1.7	T
26	TP4	94.3	92	-2.3	T
27	SS5	---	92	---	T
28	TP5	93.9	93	-0.9	T
29	TP6	93.6	93	-0.6	T
30	G6	92.0	91	-1.0	O

** <100 meter radius around the point with DTED post presumed to be located within the tree canopy.

Table 4. Summary of Statistical Findings. Site A: Route 606				
	A TREE (DTED)	A TREE (SURVEY)	A OPEN (DTED)	A OPEN (SURVEY)
SAMPLE PTS	27	27	16	16
AVG ELEV m	109.148	100.2	94.8125	94.6312
SKEW	0.1694	-0.0925	1.3174	1.8777
STD DEV	0.5337	0.8945	5.6829	5.3263
VARIATION	0.2849	0.8002	32.2958	28.3703
STD ERROR	0.1027	0.1722	1.4207	1.3315
SPEARMAN	Coefficient -0.323		Coefficient 0.8873	
	Significance 0.0996		Significance 0.0006	
ONE SAMPLE	Significance 0 REJECTED		Significance 0.7156 ACCEPTED	

Table 5. Summary of Statistical Findings. Site B: Runway.				
	B TREE (DTED)	B TREE (SURVEY)	B OPEN (DTED)	B OPEN (SURVEY)
SAMPLE PTS	12	12	15	15
AVG ELEV m	92.7	92.4	94.1	93.9
SKEW	-0.7193	-0.057	0.2369	1.5526
STD DEV	1.557	1.4378	5.0634	17.2886
VARIATION	2.4242	2.0672	25.6381	4.1579
STD ERROR	0.4494	0.415	1.3074	1.0735
SPEARMAN	Coefficient -0.2286		Coefficient 0.8879	
	Significance 0.3409		Significance 0.0009	
ONE SAMPLE	Significance 0.9373 ACCEPTED		Significance 0.8714 ACCEPTED	

Greatest weight was placed on the statistical interpretation of the rank correlation coefficients due to the "soft" nature of the data accuracy (i.e. DTED horizontal accuracy 90% circular error, DTED vertical accuracy 90% linear error, and corrected tree stand height estimates). More rigorous statistical analyses on indefinite data of this type could have misrepresented the results. Rank correlation coefficients and significance levels were heavily relied upon.

Spearman's Rank Correlation exhibited very highly significant associations between DTED and Field Surveyed points for the open field control points of both study Site A and B. The tree-covered areas of Site A and B were another story. Rather unexplainably, Site-B tree-covered DTED values approximately matched the Field Surveyed values. This association appeared as difficult for Spearman's Correlation to interpret as it was for the researchers to rationalize. An inconclusive positive significance level of 0.3409 indicated that DTED and Field Surveyed elevations were really close in value but there was no systematic match to the data (i.e. DTED was not consistently higher in value than the Field Surveyed). The -0.2286 coefficient value weakly indicated that a decrease in the DTED value resulted in a decrease in the Field Surveyed value (a value of 0.0000 would have indicated no correlation between DTED and Field Surveyed values). In a nutshell, Site B results cannot be adequately explained.

As anticipated, Site A tree-covered showed a moderately significant (0.0996) association between DTED and Field Surveyed elevations. DTED values were systematically higher than the Field Surveyed values, attributable to DTED's inclusion of vegetation heights. A highly significant (0.0006) level of association between Site A open field DTED and Field Surveyed elevations validated the open field data accuracy. With the accuracy of the open field data confirmed, a rank correlations comparison of the open field Site A DTED data to the tree-covered Site A DTED was initiated. Tree heights must have been added to the DTED data, because an inconclusive significance of 0.3314 (not graphed) indicates that the data sets were indeed quite different. Why? The addition of the trees.

One-sample and two-sample analyses with 95 percent confidence intervals were established to further evaluate DTED and Field Surveyed values over open field and tree-covered areas of Site A and B. For one-sample analyses, the null hypothesis was designed to reject a data set if tree heights were an apparent factor in the DTED values. The variable evaluated from each of the four data sets was the difference of DTED minus Field Surveyed values. The Site A tree-covered data set was the only data set rejected. This rejection tells us that the tree-covered areas are capable of including tree heights within the DTED. For two-sample analyses, DTED minus Field Surveyed values for open field control points were compared against DTED minus Field Surveyed values for tree-covered control points. Sites A and B were both evaluated. Similar to the one-sample analysis, only Site A resulted in a rejection of the null hypothesis. The two-sample analysis isolated the impact of tree heights upon the Site A conifer tree-covered DTED data. Wherever open field DTED and Field Surveyed control points existed, their values were acceptably close.

Possible Scenarios for Differences in Elevation

In the analysis, several individual control points showed curious differences between DTED and Field Survey values, but the differences in elevation are explainable. There are two possible scenarios in which differences in elevation could occur. In one, the control point lies in cleared land less than 50 meters from vegetation in any direction. In the other, the control point lies in cleared land more than 100 meters from vegetation in any direction.

Confined Clearings. In the first scenario, control points G2 and G10 were established using GPS receivers in small, confined clearings within 50 meters of tree cover. They seem to duplicate the findings of the points under the canopy because, in all probability, the nearest DTED post to the GPS field position was located within the trees. If a Field Surveyed point did not fall directly onto a DTED post, elevation was selected using two ALBE GIS nearest neighbor search routines. Neither G2 nor G10 had greater than a 50-meter radius of cleared land around it, implying at least one or potentially all surrounding DTED posts may fall within the vegetation.

Another instance of this scenario would be Control point G9 which was also established by GPS in a very confined clearing. Like G2 and G10, this point appears to have incorporated vegetation heights into the DTED. However, because the tree heights in the area of this point were never determined, a further analysis is not possible.

Open Field. In the second scenario, the control point RNWY (Runway) was an open field point easily lying outside any influence of vegetation (> 100 meter radius). The DTED value for RNWY was 3.5 meters higher than the comparable GPS Field Surveyed value. Three explanations come to mind. First, RNWY is farther than 100 meters from a large dense tree stand. A general smoothing of the DTED data may be occurring from the incorrectly portrayed DTED over the nearby trees and onto the open field. This first possibility is supported by the knowledge that the profiling direction of 7.5 minute DEMs (original source) is designed to go from west to east (USGS, 1990, p. 3) and the geographic relationship between the nearby tree stand and open field is west to east. A second explanation may lie in the subtle micro-terrain evident in this open field. DTED may have found a subtle rise in the terrain and the GPS receiver may have been located in a slight depression. G5 and G8 were additional open field GPS surveyed points which were not a close match to the DTED (2.8 and 2.0 meters difference respectively). These points were also in an area of subtle micro-terrain, which was believed to be the cause of their difference. A third, albeit unlikely, explanation regarding the minor differences in value between DTED and Field Surveyed positions is that there was some internal geodetic control problems with the source photography used in the DTED collection process.

T-2000 Open Field. OPEN2 and OPEN3 were open field T-2000 side shots. The points were well outside the range of tree heights influencing the DTED values. Micro-terrain again is evident. One member of the survey team would almost disappear when walking a straight line across this terrain so this would certainly account for about 2 meters of discrepancy. 'Smoothing' from DTED post values atop trees down to lower open field values was not possible in this instance because these particular points are nearest to Study Site B which showed no inclusion of tree heights in the DTED.

C1 and C2 had questionable DTED values. Both were VDOT GPS control stations. C1 was in the middle of a perennially maintained grass field on the grounds of the National Weather Service. The land was flat and without trees. The -4.6 meter discrepancy between DTED and GPS was not readily explainable. The negative value was especially confusing and unlike the remainder of the research data. Other DTED posts immediately around our GPS Field Surveyed location were checked on the ALBE GIS using both cursor and keyboard query to see if there was a DTED post resembling our 88.6 meter field finding. One out of eight additional posts checked did show a DTED value of 86 meters which closed the difference a little. Point C2 was in the middle of a grassy meridian strip at the intersection of Route 28 and 606. The DTED value was 3.7 meters higher than the field elevation. This was plausible as there was an embankment leading to higher ground on one side of the field location. The embankment was no more than 30 meters from the ground control point.

Summary of Analysis

Site A Discussion. Site A readily validated the hypothesis that tree-covered areas may incorrectly alter the DTED accuracy by adding in the heights of the vegetation within the area. Site B did not. Figures 3 and 4 attempt to spatially illustrate the relationship between DTED and Field Surveyed points at the Site A tree-covered location. Figure 3 displays the elevations of the Field Surveyed points and the corresponding DTED posts, and Figure 4 displays the differences in value between DTED elevations and Field Surveyed elevations. In Figure 4, the control points float above the ground (0 meters) in the z plane at about the estimated 8.5 - 10.5 meter tree stand height. (Figure 4 also symbolizes the conifer tree stand within study Site A.)

Continued empirical support for the belief that Site A incorporates tree heights comes from the original research formula: (DTED - Field) / Tree Height. A proportion was used as a constant from which to compare all study sites. Any sum close to 1.0 showed excellent association of DTED to Tree Height. Site A- tree-covered had numerous control points which came close to the proportion 1.0. The mean value for DTED in this area was 109.148 and the mean value for Field Surveying under the trees was 100.159. Plugging these values into the research formula along with the estimated tree stand height range of 8.5 to 10.5 meters gives the calculation shown in Figure 5.

Only Site A- tree-covered showed proportions coming even close to 1.0. Site A-open had an average 'DTED minus Field Surveyed' difference of only 0.1813 meters. This value computed to a proportion of 0.0213 (8.5-meters divisor) or 0.0172 (10.5-meter divisor). The difference between means for Site B- tree-covered DTED and Field Surveyed elevations was only 0.2227 meters. This value computed to a proportion of 0.0117 (19-meter divisor) or 0.0101 (22-meter divisor). The difference between means for Site B-open DTED and Field Surveyed elevations was 0.1667 meters. This value computed to a proportion of 0.0087 (19-meter divisor) or 0.0075 (22-meter divisor).

A uniform difference was evident at Site A- tree-covered between estimated tree heights and the DTED minus Field Surveyed elevation difference. DTED values were always between 6.2 and 11.7 meters taller than the actual Field Survey data. The data set had a very slight skew to the left of the mean indicating more elevations were less than the mean elevation of 109.148. The reason for this skew, and the subsequent 5-meter range, was interpreted to be the shape of the conifer tree--triangular at the top. Tree heights were calculated by the USATEC photo analyst based on tree tops. When floating a dot across the tree stand during photo source operator assisted elevation collection, an operator is not likely to place the dot directly onto the very crown, or pinnacle, of conifers. It is much more likely that the posts fall somewhere between the crown and the falling branches of the trees (this is similar to the deciduous trees scenario mentioned previously but without the penetration into the smaller, leafless tree branches). When the operator-derived contour intervals were interpolated to the Arcola 7.5 minute DEM with 30 meter grid posts, the digital elevations did not reflect the maximum heights of the trees but instead a point somewhere below the tree crowns (see Figure 5). Two of the 27 tree-covered Field Surveyed points had corresponding DTED elevations that were at least 10.5 meters taller. The elevation *difference* of these points--10.8 meters and 11.7 meters--cannot be accounted for based on conifer tree shape. Perhaps these two points were recorded by the operator of the DTED collection instrument as floating above the tree tops.

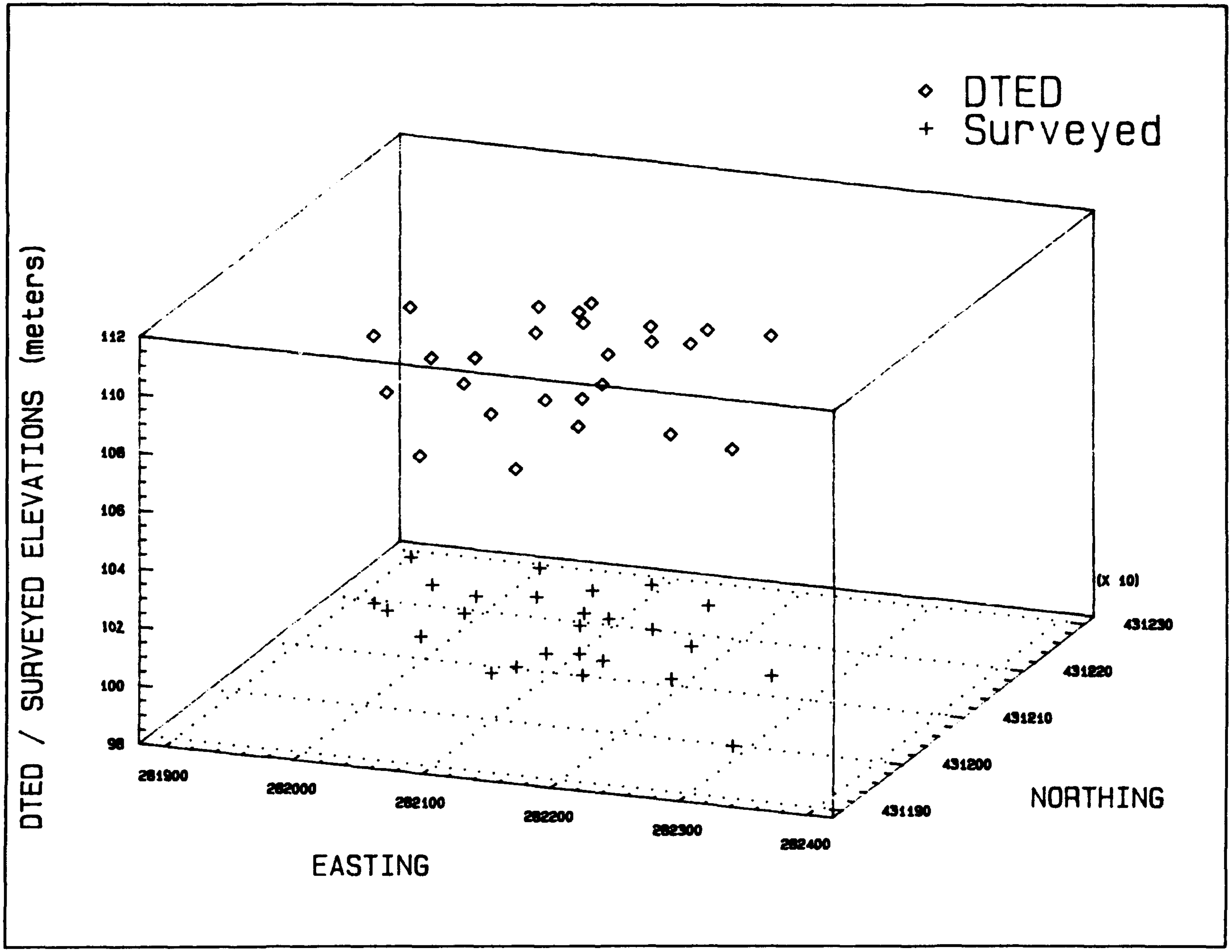

Figure 3. DTED Elevations and Corresponding Field Surveyed Points under a Dense Conifer Tree Stand

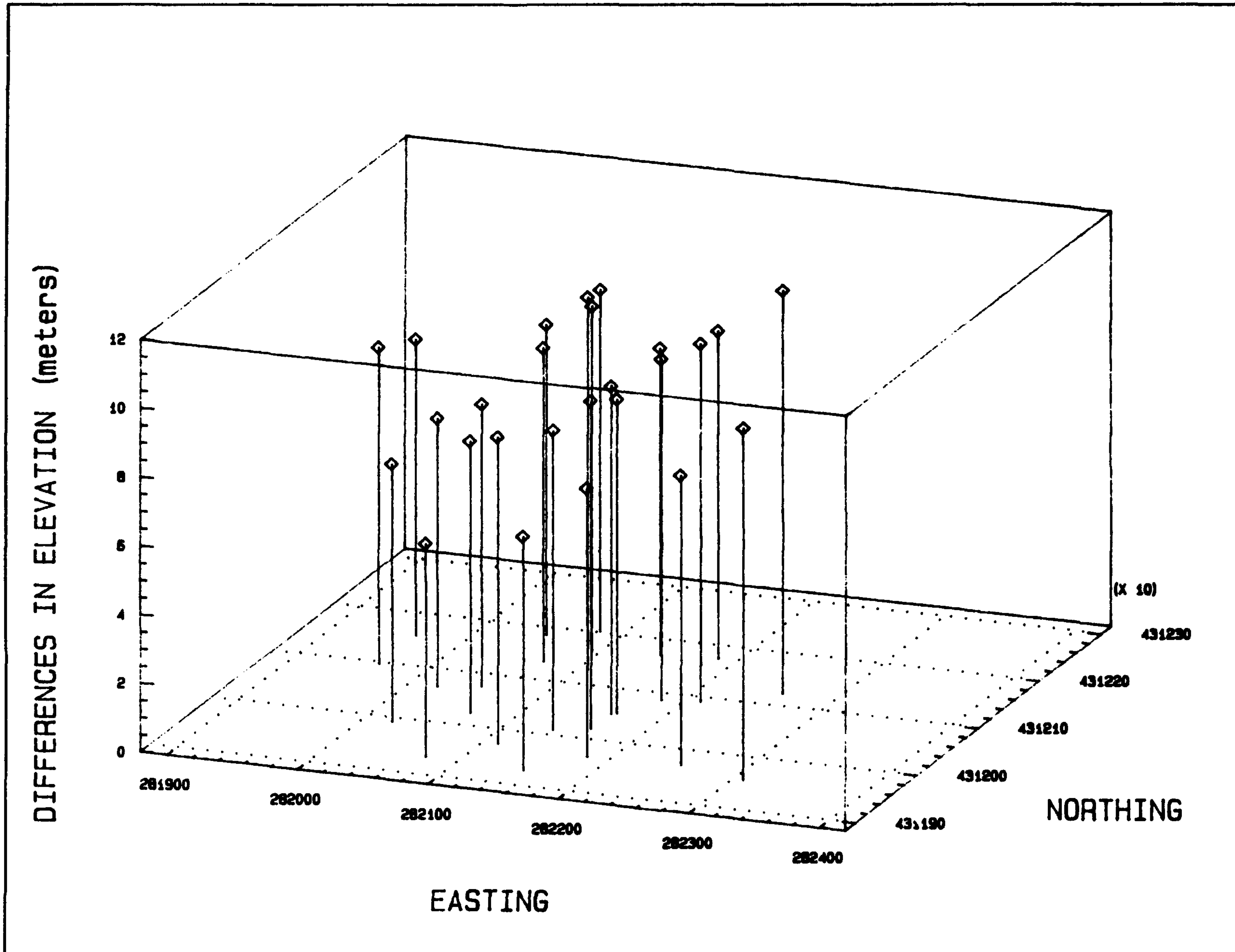

Figure 4. Differences in Value Between DTED Elevations and Corresponding Field Surveyed Elevations under a Dense Conifer Tree Stand

(DTED - FIELD) / TREEHT = ASSOC

DTED elevation = 109.148
Field Surveyed elevation = 100.159
Low end of the estimated tree stand height range = 8.5 meters
High end of the estimated tree stand height range = 10.5 meters

(109.148 - 100.159) = 8.989 meters difference in elevation

Measure of association for low end of tree stand
(109.148 - 100.159) / 8.5 = 8.989 / 8.5 = 1.0575

Measure of association for high end of tree stand
(109.148 - 100.159) / 10.5 = 8.989 / 10.5 = 0.8561

Figure 5. Evaluating Association of Elevation Difference with Tree Stand Height for Site A: Calculation

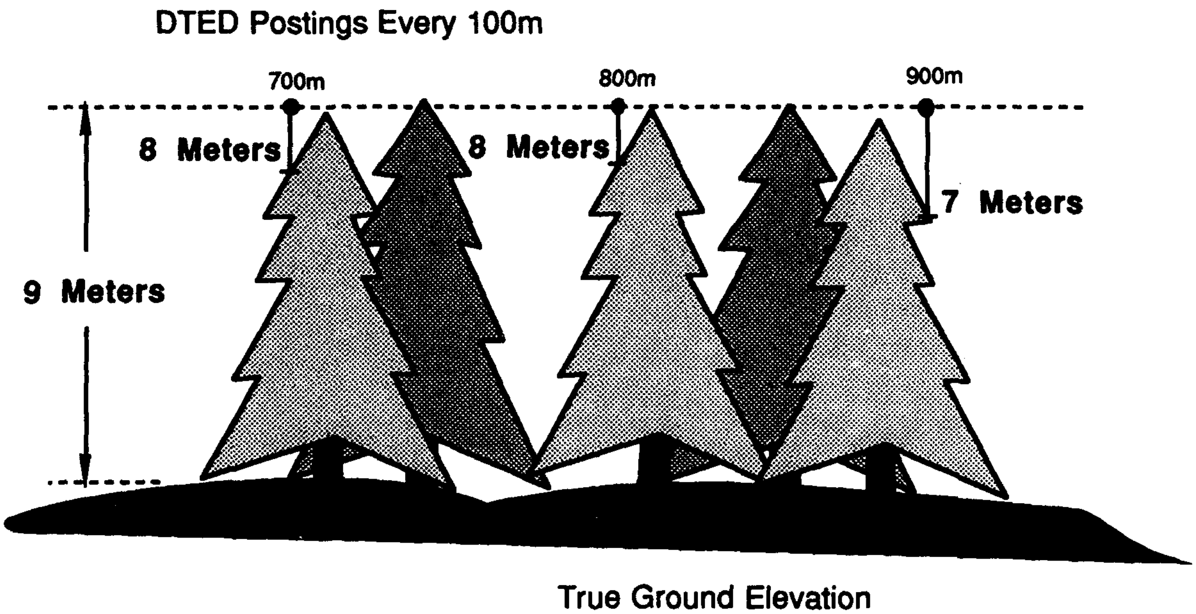

Figure 6. Effect of Conifer Tree Shape on DTED Collection Values

Site B Discussion. Site B did not evoke the kind of results hypothesized. There was no relationship between the tree stand and the minor differences between DTED and Field Surveyed elevation values. How did the DTED almost match the Field Surveyed data at Site B, while 1 mile away at Site A, with identical tree species and lower canopy closure (70%), the DTED incorporated vegetation heights?

The initial idea to explain Site B's unusual results was that the auto-correlator used to collect the DTED values from photo source had either not been able to interpret the area and had skipped right over it, or more likely, an operator had recognized the area of the tree stand as incapable of correlation and had overridden the profiling of the auto-correlator. Both scenarios inferred that the elevations under the tree stand had to be interpolated. When an area is skipped over, an auto-correlator looks for the nearest recognizable elevation values around the area in question and interpolates in all the missing elevations. Elevations for the T-2000 Field Surveyed points under the tree stand at Site B were plotted as were the elevations of all open field survey points surrounding the tree stand. A general dip of the land was evident from a field south of the tree stand to a field north of the tree stand. The range of elevation difference was about 5 meters. This 5-meter difference was subdivided (interpolated) evenly across the tree stand. The DTED values assigned to the traverse stations mirrored these interpolated values but the side shots did not follow any pattern of continuity. There was not a continuous agreement between the interpolated values and the DTED values. Interpolation was essentially discounted. An explanation for the matching of elevations from Site B DTED to Field Surveyed elevations could not be reached.

CONCLUSIONS

Accuracy of DTED for Vegetation

DTED cannot be counted on to reflect accurate ground elevation in areas of vegetation, especially tall tree stands. Until DTED can be corrected to account for vegetation it should be used with caution. Simply knowing that a data cell may or may not contain higher elevations than are actually occurring will confuse the user.

Selection of DTED Observation Points. A user of DTED data for modelling should consider these questions when selecting observation points:

1) <u>Does the user-defined observation point in an LOS model lie in an open field area and look out over DTED which may incorporate forest heights</u>? If the answer is yes, then the DTED containing the vegetation is actually beneficial to portraying real-world visibility viewsheds.

2) <u>Does the user-defined observation point lie in a forested area and attempt to look out over the remainder of the DTED covered area (forested or not)</u>? If the answer to this question is yes, then the DTED containing the vegetation heights is actually detrimental to portraying real-world viewsheds. Visibility would in fact be about zero but the elevated stature of the observation point might provide a vantage point which erroneously provides a far sweeping viewshed.

3) Even more confusing to the user is this scenario: <u>Does the user-defined observation point for a LOS model lie in an open field area with the viewshed looking out over DTED which incorporated tree heights of some forest stands but not others</u>? Needless to say, this could really create difficulty

in accurately showing real-world viewsheds. The Dulles Airport research shows that this could occur. Within 1 mile of each other, two tree stands of the same species and similar canopy closures imposed different impacts on DTED values--Site A incorporated an average of 8.9 meters of tree height into the DTED and Site B did not incorporate any recognizable tree heights.

Effect of Vegetation on Accuracy of LOS Models. The essence of these research findings is that LOS model predictions can be very untrustworthy if the geographic area being modelled is covered with evergreen trees. The user of DTED needs to be aware of the possibility of tree heights being included within the DTED and the implications it can have. Accurate LOS data is critical given the role it plays as an integral component to the larger, more detailed models such as Aerial Detection and Radial Terrain Masking.

It follows that the DTED cells with 25-75% vegetation cover would represent the greatest possibility for unreliable modelling predictions because DTED over these areas could conceivably look like a patchwork quilt of more highly elevated areas attributable to the trees. Areas without trees would not present this problem (i.e. DTED performed beautifully in the Middle East), nor would areas with 100% tree cover. Complete canopy closure would result in DTED which was either uniformly higher than it should be (i.e. if tree heights were added at the time of data collection) or uniformly at true ground elevation.

Effect of Vegetation on Slope Modeling. Slope modelling is equally critical as a component of other models. Inclusion of treetops within the DTED could have dramatic effects upon slope generation. If the DTED were exaggerated to be higher than it really is--as it was across the treetops in Site A of this research--the slope coming off the artificially created tree stand 'mesa' would be steeper than naturally occurring. The actual pitch of a slope has been undetermined pending further investigation. It is anticipated that the boundary at which open field DTED meets tree-covered DTED will not appear as a 'wall' of sorts with very steep dimension but rather as a gradual transition between the two surfaces induced by computer smoothing algorithms. Rise (computed as the elevation *difference* between a Field Surveyed point just inside the canopy and a corresponding DTED post elevation) over run (computed as the *distance* away from the open field/tree cover edge *measured in either 30 or 100 meter* posts to the location at which Field Surveyed points and DTED elevation values agree) would give the slope.

The critical question will be how gradual or how steep the resulting slope will be. Artificially steeper slopes would certainly be detrimental to the generation of accurate slope map products. In turn, steeper slopes might 1) restrict a mobility model from considering certain types of traffic across an area, 2) change the results derived about a watershed area, and 3) modify the results of site emplacement project considerations.

Need for Further Research

Vegetation is not a trivial problem within DTED and further work is needed to clarify and improve its impact on DTED accuracy. It is difficult to find a terrain model that does not utilize either Line of Sight or Slope as a key component. Vegetation affects both of these components in unpredictable ways. At study site A, an operator compiling DTED elevations using a "floating dot" C-8 manual profiling instrument collected elevations which incorporated the tree stand height. At study site B, an auto-correlator represented DTED elevations approximating the actual Field Surveyed elevations. Intuitively, this seems opposite to what would have been expected. The original research hypothesis was validated only for Site A which incorporated the tree heights of the conifer stand while Site B provided no basis for validation. Additional DTED cells in areas of conifer tree stands collected by means of both operator-assisted and auto-correlated techniques need to be further investigated before generalizations can be made regarding the capabilities specific to each collection system.

It would be ideal to import the digital polygon outlining the vegetation and overlay it onto the DTED. Anywhere that the vegetation polygon is located would be recognized as areas of questionable predictability for models incorporating either LOS or slope factors. This last suggestion is achievable. Digitizing polygons of the 1979 and 1982 conifer boundaries and adding these polygons as overlay layers to the DTED data would be a first step. The vegetation boundary would be overlaid atop a slope map generated from DTED and checked to see if an anticipated association exists between steeper slopes and tree cover boundaries.

Any refinement which atones for the inclusion of vegetation within DTED would greatly improve the model output. Modelling accuracy is critically dependent on data accuracy.

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