USING UPWARD OPENNESS FOR VIEWSHED PREDICTION

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ABSTRACT

Yokoyama and others (2002) described openness as a new geomorphic parameter. Openness incorporates the terrain line-of-sight or viewshed, but they viewed openness as a tool for interpreting landforms. We computed a number of geomorphometric terrain parameters to compare with exhaustive viewshed computations, assuming that better locations should be located atop ridges and hills, and geomorphic parameters could predict these locations. We computed slope, 5 curvature measures, and upward and downward openness. Because openness uses a larger region around the point, it is more expensive to compute, but much faster than exhaustive viewshed computations when dealing with millions of potential sensor locations. Viewsheds depend on range, observer, and target heights and can be ranked by the percentage of visible points within the specified range. Over the range of viewshed parameters considered, good locations correlate highly and a single set of exhaustive viewshed computations can make reliable predictions about good or bad locations. None of the relationships between geomorphic parameters and viewshed coverage is linear, but upward openness provides the best predictions and predicts viewshed coverage well. The best viewshed locations will have near zero values of curvature and convexity, but not all points with zero values of these parameters will have good viewsheds. In many cases when a number of sensors will be deployed, total coverage and not individual sensor locations matters most. Upward openness may not find the absolute best sensor locations, but finds most of the very good locations, and is likely to lead to excellent network coverage solutions.

INTRODUCTION

Viewshed computations represent one of the most useful computations performed with digital elevations models (DEMs), and one of the most expensive in terms of computational effort. When the user wants simply to compute the viewshed for one or a small number of locations, the time required may not appear significant, but if a user wants to computer optimal locations over a large area using a high resolution DEM, the computing effort may be prohibitive.

This work started with an initial assumption that better locations should be located atop ridges and hills (Franklin and Ray, 1994), and worse locations would be in valleys. Kim and others (2004) reported on strategies for using terrain features to optimize viewsheds starting with a simple morphometric classification, but considered only a very small area. More sophisticated geomorphic parameters (Hengl and Reuter, 2008) might help predict optimal locations more effectively.

GEOMORPHOMETRY

Hengl and Reuter (2008 and papers within that book) summarized the state of geomorphometery, the science of quantitative land-surface analysis. A DEM consists of point measurements of elevation, but the immediate neighbors can be used to compute first derivatives (slope and aspect) and second derivatives (curvature), and larger regions can be used to compute a host of other parameters. Elevation alone will not greatly help in picking good viewsheds, but other parameters might. The MICRODEM program (Guth, 2008) can compute over 30 regional geomorphometric parameters, can easily be extended, and integrates with a sophisticated viewshed algorithm (Guth, 2004).

Yokoyama and others (2002) proposed openness for its visual properties in image analysis and geomorphometry, Openness must be computed over a region of defined size. Within the region, eight radials extend in each of the principal compass directions. For upward openness, the angle from the vertical down to the tangent line-of-sight is computed, and the eight values averaged to get the final openness value. Figure 1 shows a ridge with a high value of upward openness, and a valley with a very low value. Figure 1 suggests that viewsheds will correlate with upward openness, and that numerical values might differentiate different hilltops or locations along ridges.

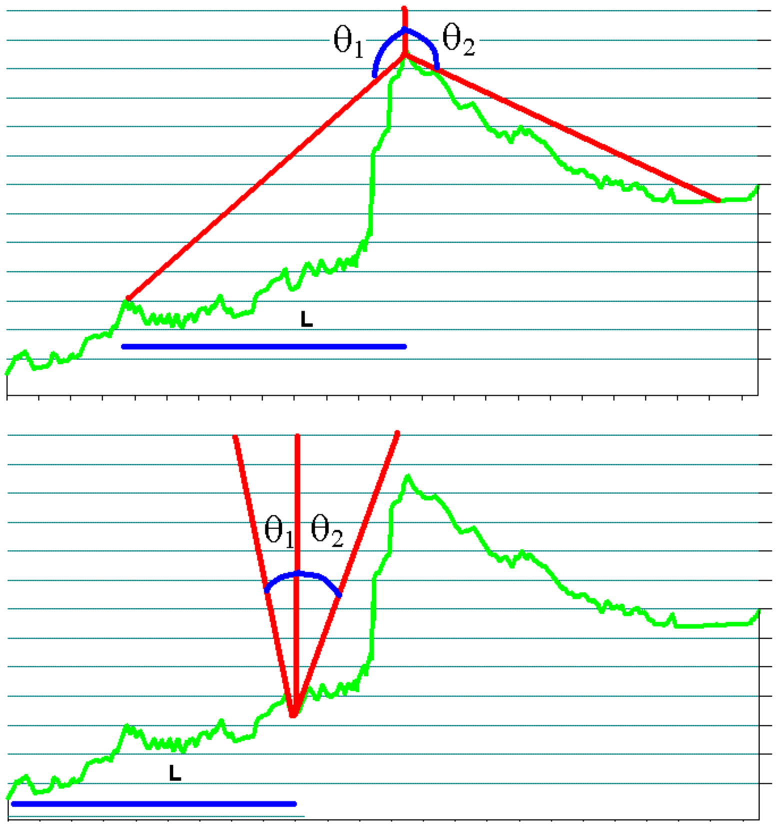

Figure 1. Openness computation. The point in the top diagram has a high value of upward openness, while the point on the bottom has a low value. The computation uses 6 additional angles oriented at 45º to these.

METHODS

From the geomorphometric parameters available in MICRODEM, 10 will be compared with exhaustive viewshed computations. In part we used a grid of computers in a college lab to break down the viewshed computations, since the task represents an ideal job for parallel computing.

The geomorphic parameters included slope computed in percent with an unweighted eight neighbors algorithm; previous research indicates that the slope algorithm or measurement in degrees or percentage would have little impact on the results (Guth, 1995; Hodgson, 1998; Jones, 1998). In addition to slope, we computed 5 curvature measures (Schmidt and others, 2003; Olaya, 2007). The slope and curvature measures are computed at each point in the DEM using its eight nearest neighbors. Finally, we computed upward and downward openness (Yokoyama and others, 2002) over two region sizes, 200 and 1000 m. We included openness because openness correlates strongly with both maximum and minimum curvature. Because openness uses a region around the point in question, it is much more expensive to compute than the slope and curvature measures, but much faster than exhaustive viewshed computations (Table 1). These basic viewshed computations use a 2500 m range and a 3" DEM; the time would increase if the range increased or the resolution of the DEM improved. Additional tests to explored the sensitivity of the results to these viewshed parameters.

Table 1. Computation time for geomorphic parameter maps. Experiment performed on a Pentium IV 3.2/4Gb memory computer, 1.44 million points, SRTM DTED1.

Calculated map	Computation Time
Curvature measures	5-6 seconds
Slope	3 seconds
Upward and downward openness (1000m)	108 seconds
Exhaustive Viewsheds	180,000 seconds (50 hours)

This analysis used 6 DEMs, covering a range of scales from 3" (about 100 m) to 1/9" (about 3 m) spacing. This spans the range of scales readily available and commonly used for viewshed analysis. These included 4 SRTM DEMs from France with a variety of landforms, a merge of nine 10 m USGS DEMs in SDTS format for an area in the Teton Range of Wyoming, and a 1/9" NED DEM of Mount Saint Helens in Washington.

In their simplest form the viewshed from a point depend on three parameters: the range, or distance over which intervisibility is computed, and the height of the observer and the target. Changing any one of the three parameters changes the viewshed. We measure the viewshed coverage by the percentage of points within the specified range that are visible. A point with perfect intervisibility will have a viewshed score of 100%, and a point that can see nothing will have a score of 0%. In rugged terrain the best locations may have scores less than 50%. This metric uses omnidirectional viewsheds, covering 360º horizontally, for a sensor with an unlimited vertical field of view.

RESULTS

Figure 2 shows exhaustive viewsheds computed at every grid posting for four SRTM DEMs in France. Neglecting the water, each DEM contains 1.44 million viewshed computations. The patterns clearly reflect the underlying topography. These computations used a 2500 m range for the sensors, with both the sensor and target 2 m above the ground. The largest regions with high viewshed scores are flat regions; narrow valleys consistently have low viewshed scores.

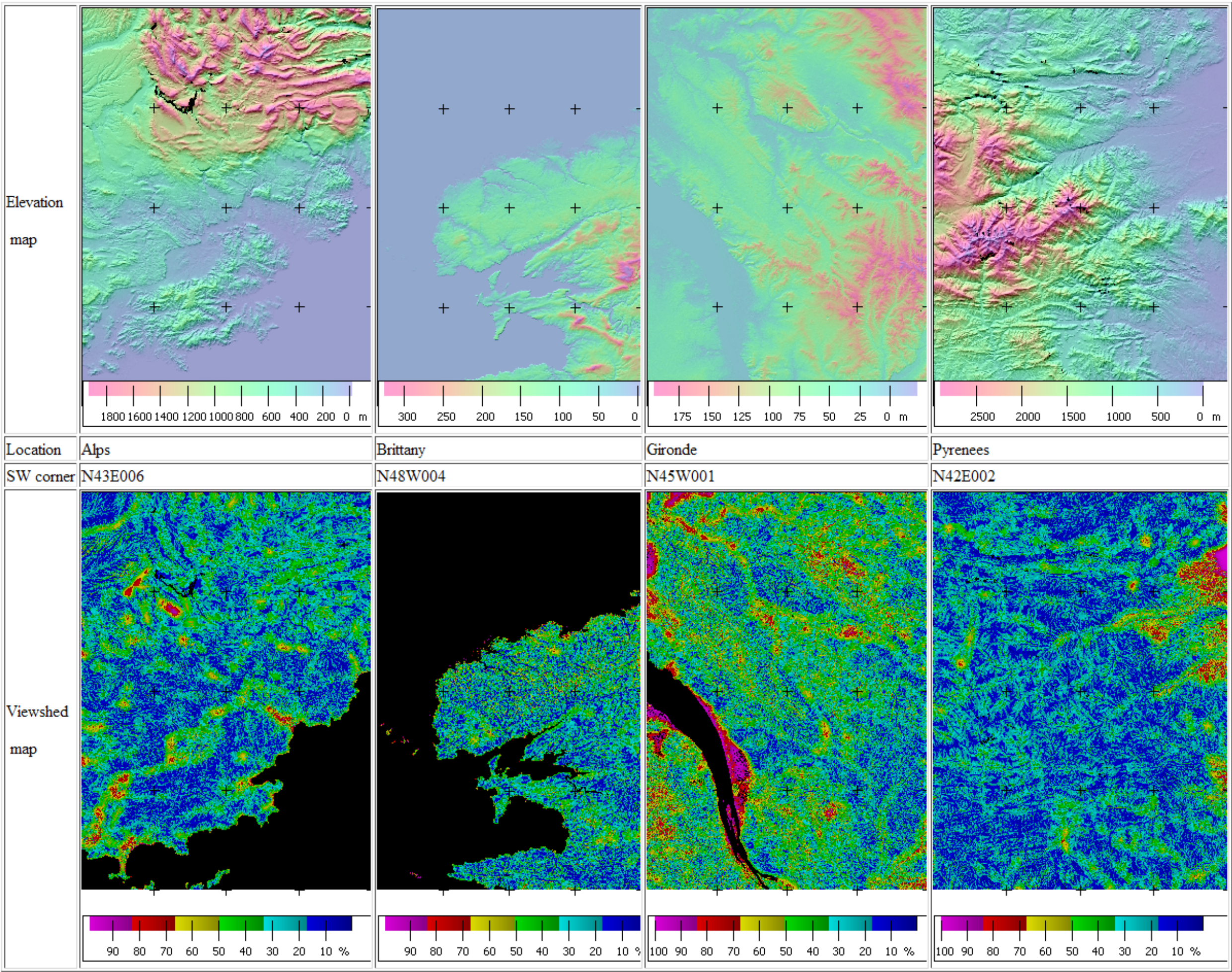

Figure 2. Four SRTM DEMs in France, with exhaustive viewsheds computed at every point.

At each point in the Tetons DEM, exhaustive viewsheds were computed for six combinations of range, observer height, and target height. Figure 3 show the DEM and five of the resulting maps. The maps and the histogram in Figure 4 show several patterns: (1) as the sensor range increases, the viewshed scores go down; (2) as the sensor height increases, the viewshed scores go up; and (3) as the target height increases, the viewshed scores go up. While peaks and ridges have good relative scores in their local region, overall the flatter terrain has better scores. The large number of 100% scored viewsheds occur around a large lake in the southeastern corner of the DEM. Table 2 shows correlation coefficients for the six different viewshed configurations. The lowest correlation coefficient in the table is 0.80, and for the 2500 m ranges, the lowest coefficient is 0.90. This suggests that over the range of parameters considered, good locations correlate highly and that we can use a single set of exhaustive viewshed computations to make reliable predictions about good or bad locations, regardless of the exact sensor parameters.

Table 2. Correlation matrix for exhaustive viewsheds computed with the Tetons DEM. Viewsheds identified by range, observer height, and target height.

	2500_2_2	2500_2_10	2500_10_2	2500_10_10	5000_2_2	7500_2_2
2500_2_2	1.0000	0.9798	0.9591	0.9034	0.9296	0.8695
2500_2_10	0.9798	1.0000	0.9757	0.9529	0.8969	0.8368
2500_10_2	0.9591	0.9757	1.0000	0.9812	0.9082	0.8561
2500_10_10	0.9034	0.9529	0.9812	1.0000	0.8488	0.8017
5000_2_2	0.9296	0.8969	0.9082	0.8488	1.0000	0.9774
7500_2_2	0.8695	0.8368	0.8561	0.8017	0.9774	1.0000

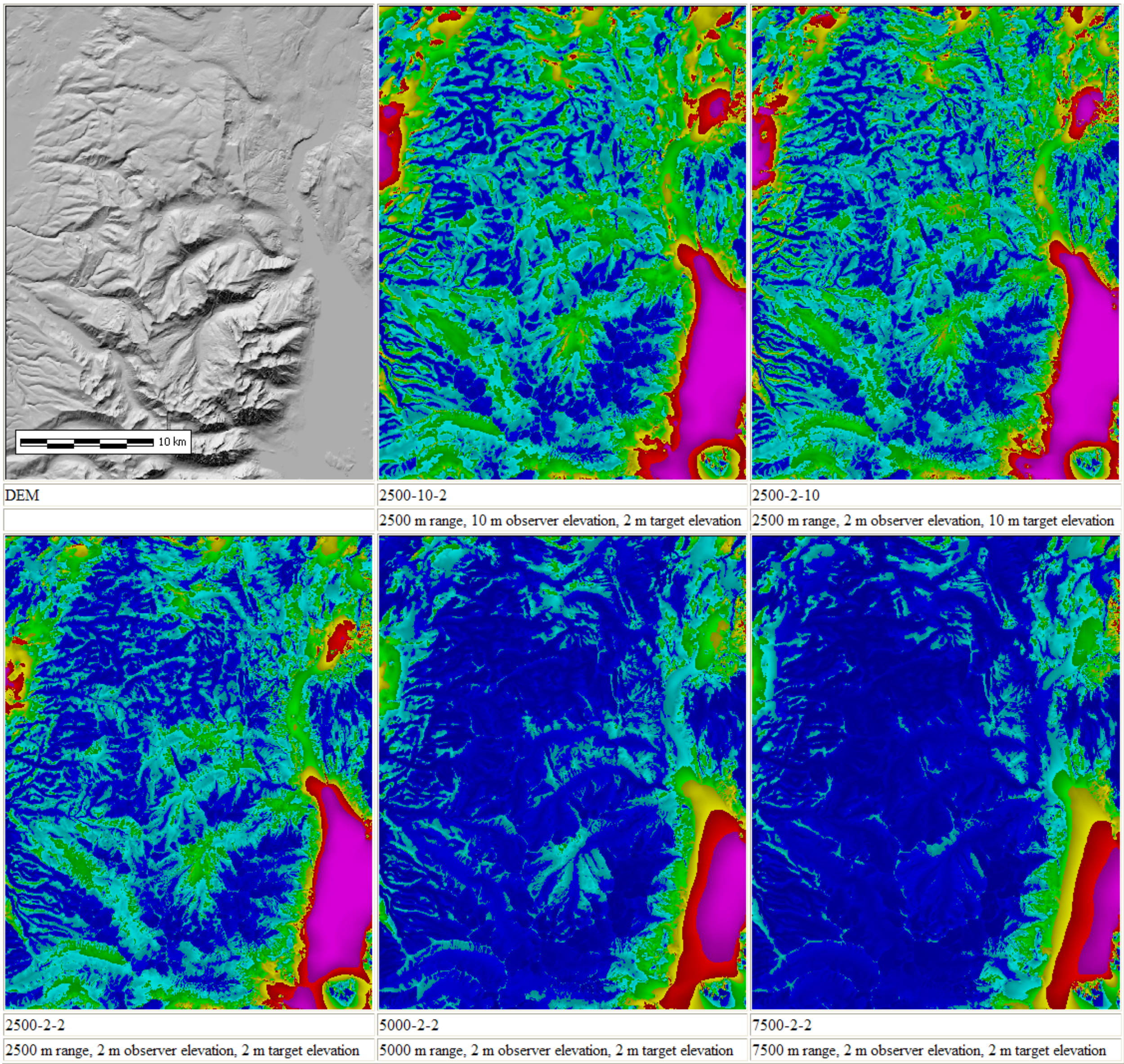

Figure 3. Tetons DEM and exhaustive viewshed maps for 5 combinations of sensor characteristics. The best viewshed scores are in purple, and the lowest in blue.

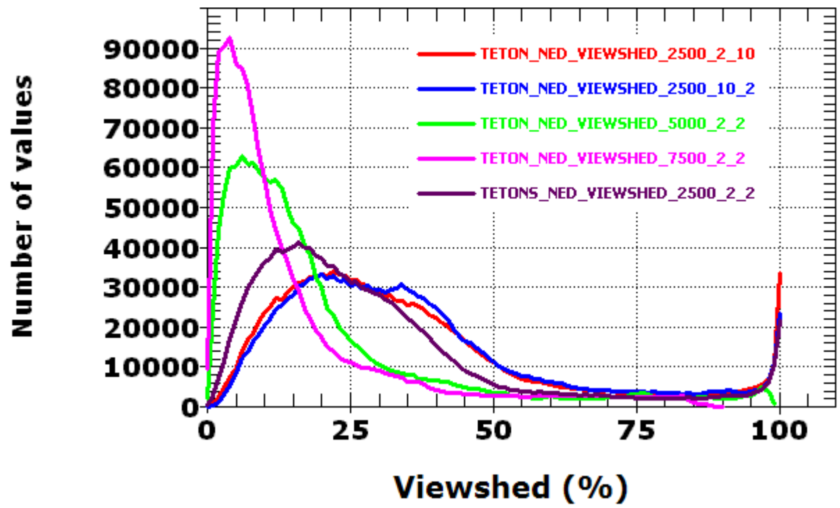

Figure 4. Histogram of viewshed scores for Tetons DEM.

Table 3 shows the correlation coefficients between viewshed coverage and the terrain parameters for the 6 DEMs. Figure 5 shows scatter plots for one DEM, the Tetons. It is clear that none of the relationships is linear, and that the correlation coefficients show only general trends. Nonetheless, upward openness clearly provides the best parameter for prediction. For all 6 DEMs, both openness parameters have the largest correlation coefficients. Of the other parameters, only two have the same sign for all 6 DEMs: minimum curvature and slope. For the 4 SRTM DEMs, minimum curvature has a correlation only slightly less than upward openness, but minimum curvature has a much smaller correlation for the other two DEMs. With the 3" SRTM spacing, openness does not consider that much larger a region than curvature, and thus does not show that much improvement. For SRTM resolution DEMs, curvature considers a fairly large region and becomes less of a single point parameter. Slope has a negative correlation with viewshed coverage, probably because steep slopes will be on the sides of hills and ridges, which will block a significant portion of the 360º viewshed.

Upward openness provides the best prediction of the parameters considered because it uses a large area to find terrain that is not blocked by nearby terrain. While it uses only eight rays, this allows rapid computations while still considering a larger region than the other point parameters. These results suggest that the 200 m region produces very similar results to the 1000 m region, and the 200 m region requires one fifth of the computing time.

Downward openness might initially be assumed, as the opposite of upward openness, to have a negative correlation with viewshed coverage. However, for these DEMs the downward openness has negative correlation coefficients, near zero correlation coefficients, and some high coefficients.

The graphs in Figure 5 suggest that for 360º viewsheds, the best locations will have near zero values of curvature and convexity. However, the best locations in this DEM are all on the lake the SE corner of the DEM, and it's not hard to find good locations in that region. Not all points with zero values of these parameters will have good viewsheds, as is clear in the figure, because curvature and convexity consider only the immediate neighborhood.

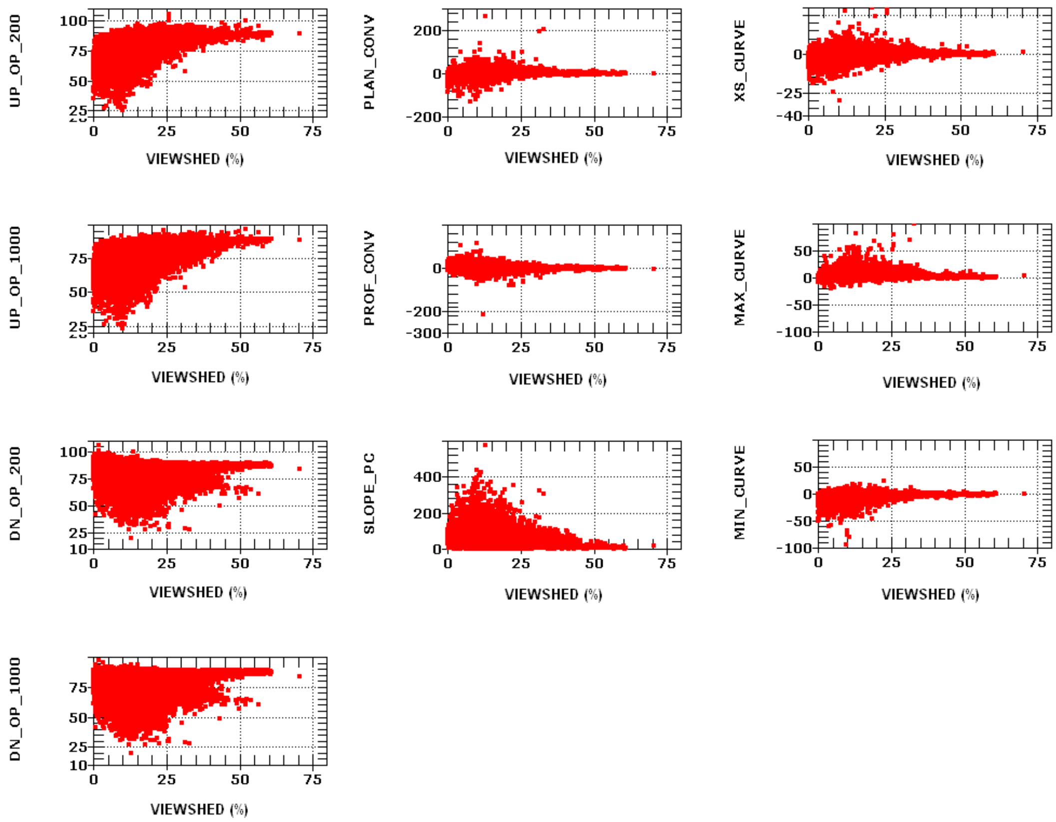

Figure 5. Scatterplot of 10 geomorphic parameters plotted against exhaustive viewsheds for the 10 m Tetons DEM.

Table 3. Correlation coefficients relating viewshed with geomorphic parameters

	Alps	Brittany	Gironde	Pyrenees	Teton	Mount Saint Helens
DEM Resolution	3” (~90 m)	3” (~90 m)	3” (~90 m)	3” (~90 m)	10 m	1/9” (~3m)
+ Openness (upward, L=200)	0.4750	0.5469	0.5830	0.4902	0.4067	0.6040
+ Openness (upward, L=1000)	0.4330	0.5227	0.6605	0.4906	0.5293	0.5999
- Openness (down, L=200)	-0.2988	-0.4301	-0.4088	-0.2998	0.3662	0.0928
- Openness (down, L=1000)	-0.0547	-0.2424	-0.1486	-0.0385	0.5074	0.1859
Cross sectional curvature	0.3250	0.3763	0.3615	0.3266	-0.0115	0.1160
Maximum curvature	0.1985	0.2870	0.2638	0.1926	-0.1976	-0.0252
Minimum curvature	0.4257	0.4309	0.4868	0.4426	0.2000	0.2458
Plan convexity	-0.1597	0.3682	0.3952	0.3244	0.0013	0.1070
Profile convexity	0.2904	-0.3746	-0.3892	-0.3301	0.0107	-0.1016
Slope (%)	-0.1215	-0.1093	-0.3026	-0.2165	-0.4883	-0.3334

Figure 6 shows an example using openness to correlate with viewshed scores. This shows a small region around Jenny Lake in the Tetons, with the parameters calculated at a subsample of the points in the DEM. Note the highest values of openness on the lake, and along the crest of the moraine ridge on the east side of the lake. On more interest, note that the highest values of openness along the range front correspond with the largest values of viewshed score. Figure 7 shows a scattergram showing the relationship between viewshed score and upward openness for these points.

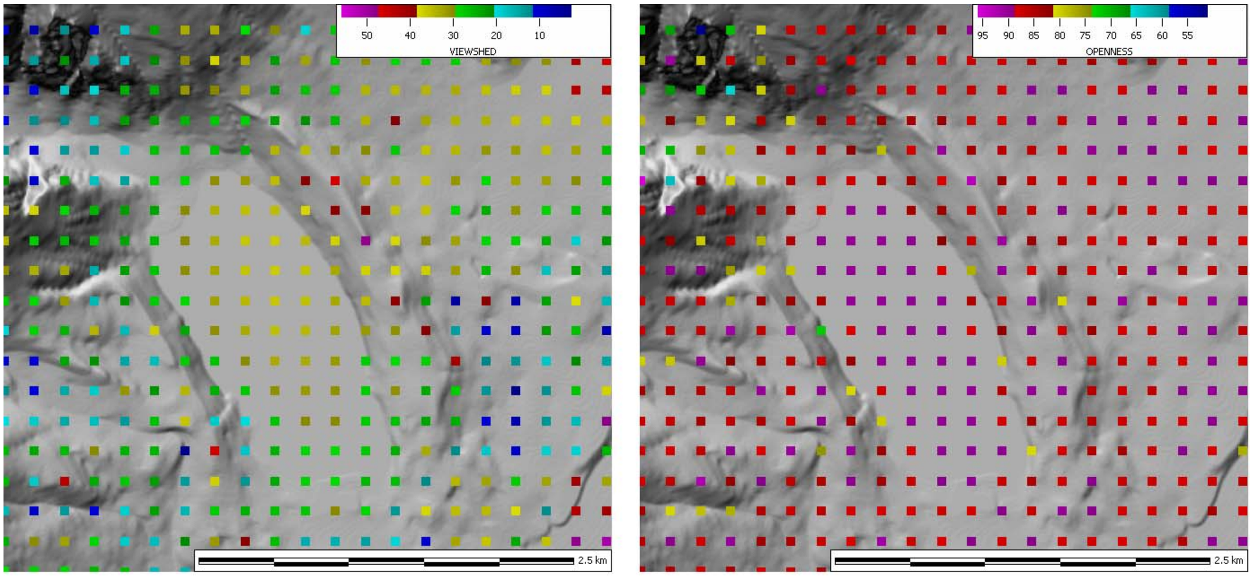

Figure 6. Viewshed scores and upward openness for a small region in the Tetons.

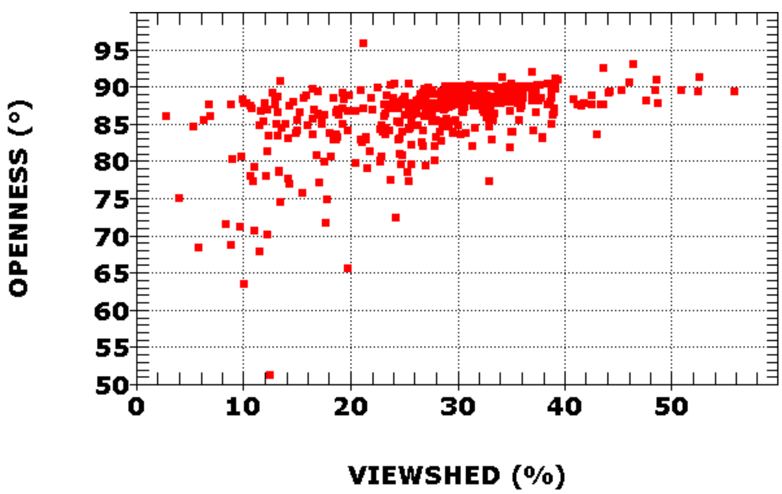

Figure 7. Scattergram of openness versus viewshed score for the points shown in Figure 6.

Figures 8 and 9 show a second example, with a smaller, more homogenous region. In this mountainous terrain, the best viewsheds see only 25% of the potential areaNone of the large openness values corresponds to a low viewshed score. This suggests that comparisons of openness scores must be done in small regions, and that a search strategy for sensor placement should seek points within small search regions, and then attempt to optimize networks.

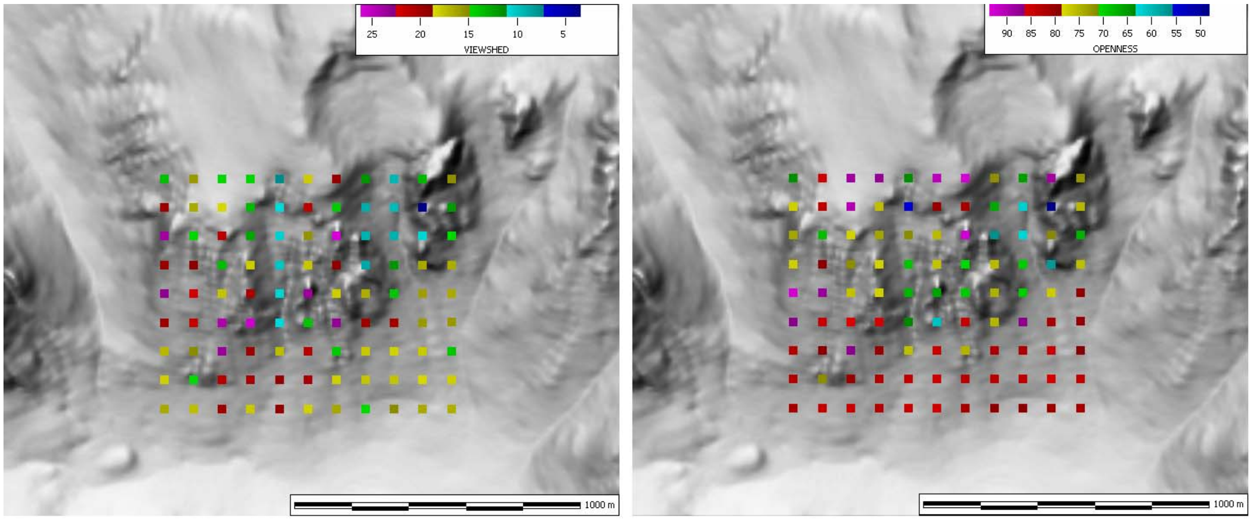

Figure 8. Viewshed scores and upward openness for a smaller region, more homogeneous region in the Tetons.

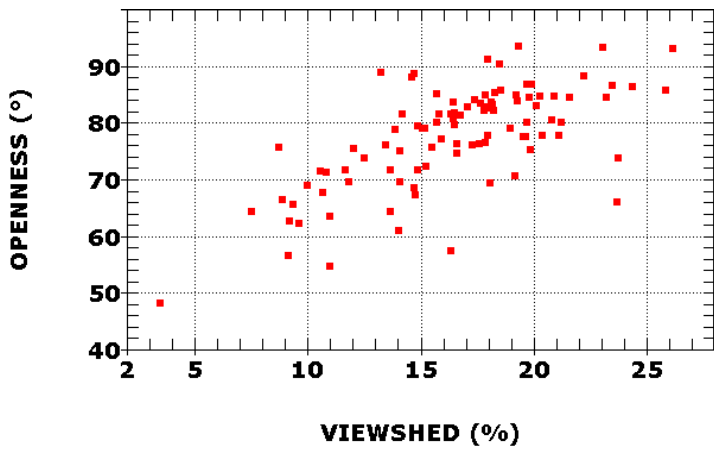

Figure 9. Scattergram of openness versus viewshed score for the points shown in Figure 8.

CONCLUSIONS

The best viewshed locations will be in flat terrain, but this trivial result is not important. The key task finds local optimal locations in steep terrain. With the range of DEMs (3" to 1/3"), topography, and sensor characteristics (ranges from 2.5 to 10 km, observer and target 2-10 m above the ground) considered, a single characteristic--upward openness-- can effectively score and rank potential viewshed locations. Upward openness for a 1000 m region is about 4 times more expensive to compute than a 200 m range. For three of the six DEMs the 200 m values actually correlate better with viewshed scores, so the openness does not have to extend out very far to greatly improve on point characteristics like curvature. This might depend on DEM resolution and quality, and the type of terrain. LIDAR DEMs have significantly more information ("noise") for geomorphometric parameters, and computation of openness with them might require some filtering to be useful.

When a group of sensors will be employed, combined coverage becomes the important metric. The best individual locations will not be as important as finding good locations that work together. High viewshed scores, and upward openness, tend to cluster, and search for potential locations needs to look for optimal locations within small regions and then consider the effects of combined coverage. Sensor locations can also require additional constraints such as slope, road access, land cover types, or land ownership, which will complicate the optimal solution (or, perversely, simplify it by severely restricting the number of points that must be considered).

For many operations, a 360˚ viewshed may not be appropriate. In that case the openness computation could be modified to only consider values within a specified angular range. A sensor height for openness computations might also improve results.

ACKNOWLEDGMENTS

This work used the freeware MICRODEM program, available at http://www.usna.edu/Users/oceano/pguth/website/microdemdown.htm

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