

GIS and Satellite Visibility: Viewsheds from Space

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ABSTRACT

The Global Positioning System (GPS) has recently become the significant mapping tool for millions of customers worldwide, providing its users with accurate terrestrial positions almost instantaneously. The functionality of a GPS receiver depends on the number of satellites to which it can establish an unobstructed line of sight. Current tools perform satellite visibility predictions without considering terrain or structures that block GPS signals, a major issue in mountainous and urban areas. This paper will describe a new tool for ArcGIS that predicts satellite visibility considering line of sight obstructions. The tool requires a raster surface model, the test date and time, and the orbital properties of the GPS satellites. It produces grids depicting the number of visible satellites and optimal viewing time in each cell. The new tool allows users to avoid areas of signal loss and choose the best time to map using their GPS receiver.

This paper presents a new GIS tool that predicts GPS satellite visibility for an entire test area for a given day and time period. The tool is named *Satellite Viewsheds* and is unique in its ability to consider line of sight obstructions between a GPS receiver and the satellites; obstructions that may cause loss of or reduced service. No such tool currently exists. The objectives of the project in which the tool was created were to:

- 1) Research the current availability and capabilities of existing GPS satellite visibility prediction tools and determine if there is an existing method of performing predictions considering features of a local environment
- 2) Address the anticipated incapability of existing tools by creating a new GIS tool to perform GPS satellite visibility predictions for any place and time while considering possible signal obstructions
- 3) Assess the performance of the new tool with a field test

A full discussion of the research can be found in Germroth, 2005, in which the contents of this paper are further elaborated.

Geographic Information Systems and the Global Positioning System

A Geographic Information System (GIS) is a complex computer software system that is used for the management, storage, display, and analysis of spatial data. GIS developed along with the evolution of mapping from manual data entry and management into the digital world. Perhaps the most prolific period of enhancement to computer mapping technologies has occurred over the past two decades and is arguably continuing today with the advent and growth of present-day GIS. GIS has become an immeasurably powerful tool for the display, management, and analysis of geospatial data and is now used extensively by the intelligence community, local and federal governments, environmental agencies, planners, developers, recreational users and researchers worldwide. The GIS software used in this research was ArcGIS version 9.0, produced by Environmental Systems Research Institute, Inc., or ESRI, a well-known heavyweight of GIS software. More specifically, the computer program written for this research runs in ArcMap, one of ESRI's window-oriented display and analysis GIS products.

In recent years, the Global Positioning System (GPS) has developed into the primary navigational and geospatial data collection tool for millions of consumers worldwide. Originally developed in the 1970's by the United States Military and declared open to civilians with "final operational capability" in 1995, GPS uses satellites to provide accurate and rapid positioning information to terrestrial users (Kennedy, 1996). A GPS receiver accepts time-stamped radio signals transmitted by a constellation of 24 operational earth-orbiting satellites to triangulate its position. Depending on the accuracy of the receiver and the method of data collection, positional accuracies of 1 cm or less can be achieved by GPS.

Purpose of Satellite Viewsheds

In order for a GPS receiver to triangulate its three-dimensional (3-D) position, it must establish radio contact with at least four satellites. To establish radio contact, an unobstructed direct line of sight (LOS) path must exist between the receiver and each satellite. Although only four visible satellites are required for a GPS receiver's operation, the accuracy of the position triangulation generally increases with an increased number of visible satellites. For a given receiver, the number of satellites used in the triangulation algorithm is a primary factor in the receiver's performance. It is typically recommended that a receiver use at least six satellites for triangulation, and there are many cases in which this requirement is attained. However, there are also times and locations in which a GPS user's satellite visibility requirement is not met. If the receiver cannot establish LOS with enough satellites, its accuracy diminishes to a two-dimensional point with an assumed elevation, or it may not function at all. This research focuses on predicting areas and times in which the number of visible GPS satellites is insufficient for a user's objectives.

Due to the dynamic positions of GPS satellites relative to the earth's surface, a GPS receiver's performance varies at different locations and at different times. In many cases, it is important for a GPS user to predict if or how well his or her receiver will perform during a designated usage time. Current GPS satellite visibility prediction tools perform the analysis under the assumption that the sky above the receiver's position is

completely unobstructed. In other words, these tools perform their visibility prediction algorithms without considering LOS obstructions between the receiver and the satellites that may block the signal. The predictions are performed as if the receiver was on “bare earth” or on the open sea. This assumption may be inadequate if the receiver is to be used in any environment in which there are objects that may block the LOS paths, which is often the case on land. Tools working under this assumption may predict that an acceptable number of satellites is visible, but in actuality some of those satellites may be hidden from the receiver by terrain or buildings. Receiver performance is especially an issue in mountainous or urban areas, commonly referred to as “urban canyons”, where large portions of the sky can be blocked by buildings or terrain (Figure 1). Currently, there are no tools available that predict GPS satellite visibility while considering such LOS obstructions for an area of the earth’s surface. This paper presents *Satellite Viewsheds*: a new GIS tool that predicts GPS satellite visibility while considering surface features in the receiver’s environment that may influence its performance. The tool can be used to predict performance for a receiver at any location on the earth’s surface and for any time. The tool can also be used to determine the best time at which to use GPS for a given test day and location, and only requires a raster surface model grid and a text file describing the satellite’s orbits. The new tool runs as a customization of widely available

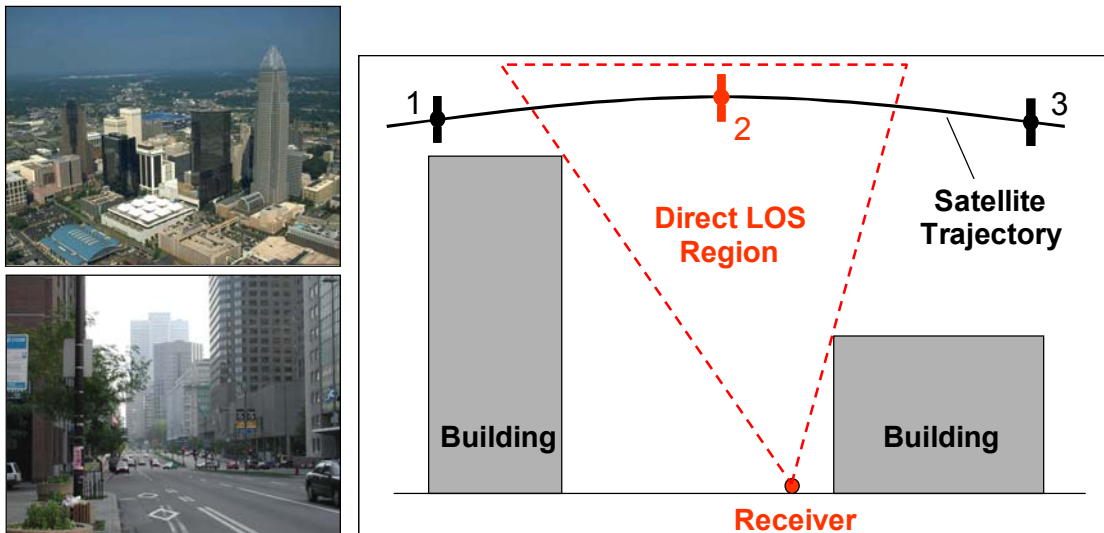


Figure 1. Examples of “urban canyons” in Charlotte, North Carolina (top left, photo credit: UNC Charlotte) and Montreal, Quebec (bottom left, photo credit: Jim Campbell), where large buildings can obstruct GPS signals and cause problematic reception. At right is a greatly simplified two-dimensional illustration of the urban canyon concept. Current satellite visibility tools predict reception from the satellite at positions 1, 2 and 3; but reception is actually possible only when the satellite is at position 2.

conventional GIS software and will allow a GPS user to determine: a) whether he or she will be able to use his or her receiver at all in a given area at a desired time, and b) if so, the time at which the maximum number of satellites will be visible during a specified day. The tool is easy to use, requires minimal user input, and is fully automated. Using the tool allows GPS users, including researchers, surveyors, and sportspersons, to save time and money by pinpointing the time at which their receiver will produce the highest accuracy and the times at which GPS data collection should not be performed.

Current Satellite Visibility Prediction

There are many tools currently available that perform GPS satellite visibility prediction. Some may be included with a GPS package, others may be purchased separately, and still others may reside on the Internet as freeware. However, each of these tools falls short, in one way or another, of the objective of *Satellite Viewsheds*. As a representative example, one tool studied in the investigation of current software was the *Satellite Availability Program*, offered by Leica Geosystems. The tool is available online at no charge at www.leica-geosystems.com. *Satellite Availability Program* requires the observer's latitude and longitude, as well as an almanac file describing the orbits of the GPS satellites. Leica Geosystems' website provides almanac files updated daily for users to download. The program produces comprehensive charts and reports of GPS satellite visibility for a 24-hour period (Figure 2). *Satellite Availability Program* also allows the user the option of sketching or providing points for a model of the horizon surrounding the observer's point on a circular sky plot (Figure 3). Using this option does allow the user to incorporate local LOS obstructions into his or her GPS satellite visibility predictions, which is a primary objective of the new tool created for ArcGIS. However, in order to use the horizon masking option, a user must

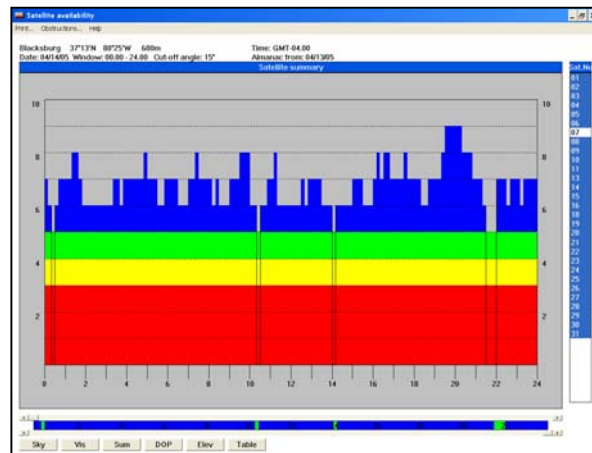


Figure 2. Example of GPS satellite visibility prediction using Leica's *Satellite Availability Program*, with time on the horizontal axis and number of satellites on the vertical axis

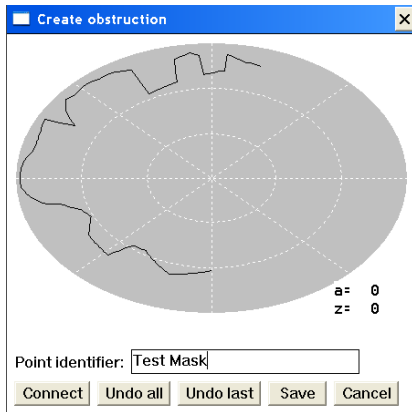


Figure 3. Example of a horizon mask input for the *Satellite Availability Program*

travel to the location at which he plans to use his GPS receiver and record the elevations and azimuths of all features on the local horizon before running the visibility program. For surveyors, this extra step may result in the expenditure of extra time and travel money while only improving the prediction at a single point. While the *Satellite Availability Program* and similar tools provide powerful prediction capabilities and useful data display, they do not

perform predictions across an entire area while considering LOS obstructions.

Relevance of Hillshades and Viewsheds

There are two existing GIS surface analysis concepts that are relevant to the objective of the new tool: hillshades and viewsheds. ArcGIS offers functions that perform both of these operations on a valid raster surface model through both its Spatial Analyst and 3D Analyst extensions. To reiterate the objectives of *Satellite Viewsheds*, the tool must use multiple satellites (or view sources) that are located outside of the boundaries of the surface model grid to predict satellite visibility for a test area and time while considering local signal obstructions. The existing Hillshade and Viewshed functions each offer pieces of this objective, but neither fully performs the desired task

In ArcGIS, the Viewshed function requires an input surface grid and the location of the viewshed source point, points, area or areas. The viewshed algorithm then investigates each cell in the grid and determines whether or not the source(s) can be seen from that point. At every cell, the height or elevation of all cells between the current cell and the source is compared with the elevation of the line of sight at that location. If the terrain is higher than the line of sight at any point, then the cell under consideration is assigned a value of 0, meaning that the cell is hidden from view of the source. Viewsheds are typically used for applications such as optimizing forest fire tower locations for the largest possible viewsheds; or perhaps placing an unattractive feature at a low-visibility site. According to ArcGIS Desktop Help, the Viewshed function creates a raster

recording the number of times each cell can be seen from the input point observer locations. Relating ArcGIS's Viewshed function to the goals of this research, there are several useful features that deserve mention. The Viewshed function does have the ability to handle more than one view source, and it does perform visibility analyses based on local LOS obstructions. However, one primary restriction of ArcGIS's Viewshed function prevents it from being used for GPS satellite visibility prediction. The routine is only designed to handle view source points that are located within the boundaries of the surface model grid. This requirement is obviously insufficient for the accommodation of satellites that are thousands of kilometers from the test area. For this reason, the existing Viewshed function was not used in the creation of the new tool. However, the descriptive term "viewshed" will be used throughout this paper to describe the field of view for a given satellite and test time.

Like the Viewshed function, ArcGIS's Hillshade command requires an input surface grid, the azimuth and elevation angles of the imaginary light source, and the option of whether or not to model shadows. Hillshades are typically used to create 3-D visualizations of the terrain by shading the cells of the grid based on their illumination by the light source. The illumination is calculated based on the gradient and aspect of the cell. However, if the user chooses to "model shadows", the Hillshade function essentially creates a viewshed using the light source as the view source by indicating those areas that are in a shadow from the light source. Areas that are hidden from the light source, perhaps behind buildings or mountains, are assigned a value of 0. The rest of the cells are assigned a value between 1 and 255, depending on their degree of illumination. The restriction of the Hillshade function that prevents it from being fully capable of predicting GPS satellite visibility is its inability to handle more than one view source. Therefore, the existing Hillshade function cannot be used as a stand-alone tool to perform the task at hand, which is to create viewsheds from multiple celestial sources.

Look Angle Calculations

A major feature of the new ArcGIS satellite viewsheds tool is its ability to automatically determine the locations of GPS satellites in the sky based solely on the time and surface location of interest. The position of a satellite in the sky relative to a terrestrial point is described by the satellite's azimuth and elevation angle, which are collectively referred to as the "look angle". Most current tools require the user to provide an almanac file in order to calculate GPS satellite look angles. Almanac files can sometimes be downloaded online, but in many cases the user must acquire the file from an actual GPS unit prior to performing a visibility prediction. *Satellite Viewsheds* alleviates the need for an almanac file and only requires a user to download a pre-formatted Two-Line Element Set (TLES), which is readily available online.

There are three pieces of data needed to calculate a satellite's position relative to a location on the earth's surface. The first requirement is the latitude and longitude of the terrestrial target. This information is extracted from the surface model grid provided by the user. The second piece of data is the orbital properties of the satellite, which are provided by the TLES. All orbital properties of the satellite are drawn from the TLES file, input to the program in the form of a text (.txt) file. The third requirement for the calculation of a satellite's look angle is the exact time of interest, which is provided to *Satellite Viewsheds* by the user. Given these three pieces of information, *Satellite Viewsheds* calculates the positions of all GPS satellites given any user-specified time and location using the target-satellite geometry shown in Figure 4.

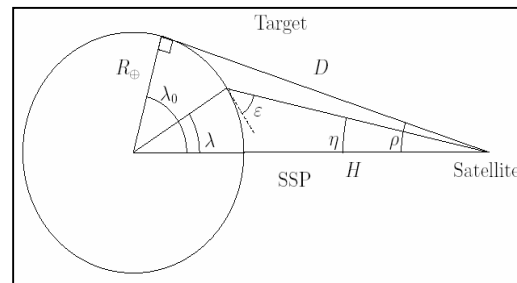


Figure 4. Target-satellite geometry (Wertz et al., 1999)

User-Inputs to Satellite Viewsheds

Figure 5 shows the user form that displays when *Satellite Viewsheds* is selected in the ArcMap window, with each letter corresponding to the item's description below:

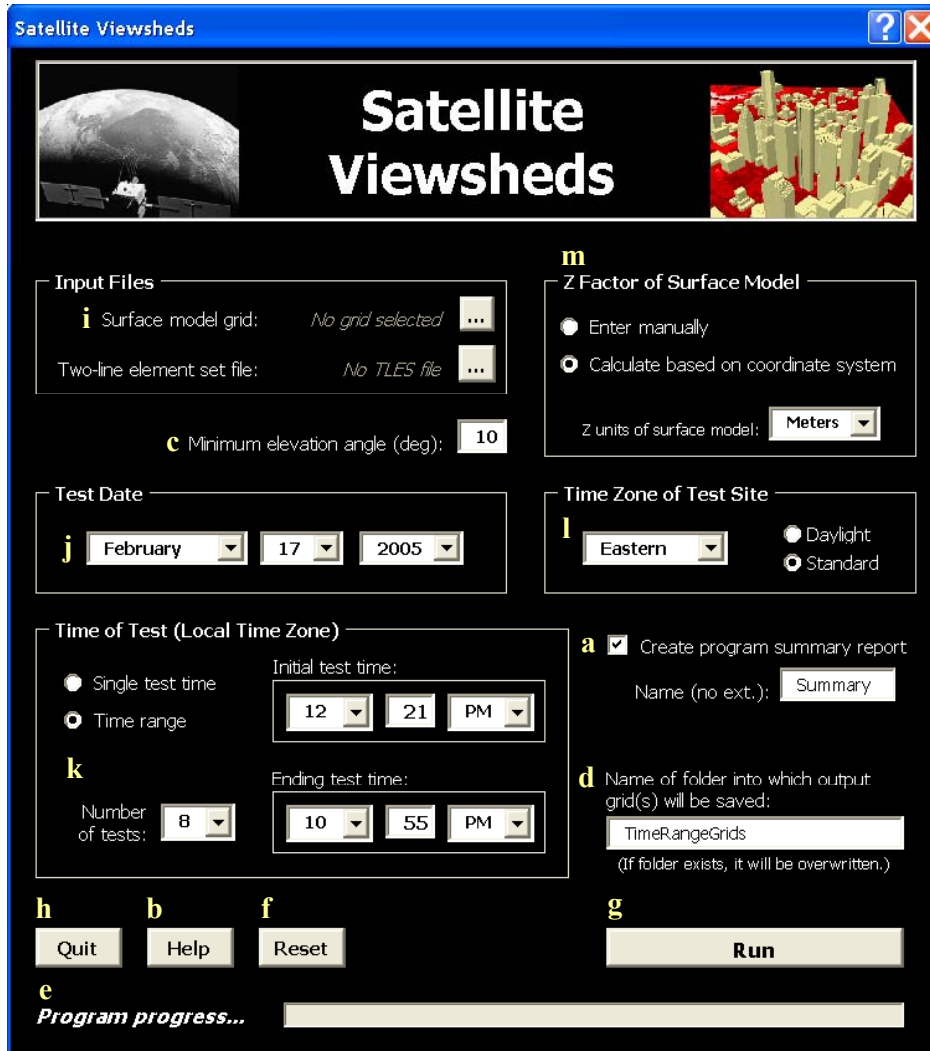


Figure 5. User interface for *Satellite Viewsheds* in ArcMap

a) *Create program summary report*: The program summary report provides details of the test, including the time, date, time zone, z factor (see item (m) below) and the look angle and percent coverage for each satellite at each test time. The report is saved as a text (.txt) file in the working directory, if the user opts to create one. If a report with the same name and path as the one specified by the user already exists, it will be overwritten.

b) *Help button*: Clicking this button displays a user form with additional information about each user input.

c) *Minimum elevation angle*: Satellites at elevation angles below this value, measured in degrees will not be considered to be visible. The standard horizon masking angle is 10 degrees, and the value entered is required by the program to be between 0 and 90. Signals transmitted by satellites at low elevation angles are more susceptible to atmospheric disturbance because they travel a longer distance through the earth's atmosphere.

- d) *Name of folder into which output grid(s) will be stored:* The user has the option to specify the name of a folder into which the output grid(s) will be saved within the working directory.
- e) *Program Progress:* A progress bar that automatically updates after the 'Run' button has been clicked. While the speed of the program varies with computer speed, surface model grid size, number of satellites in the TLES and the number of test times, the user should allow at least ten minutes of running time for a full GPS constellation and the maximum number of test times using a modern PC.
- f) *Reset button:* Clicking this button resets all form values to initial values. The initial values for the time and date options are the current time and date.
- g) *Run button:* The user clicks this button when he or she has completed data entry on the main user form. The button executes the program itself.
- h) *Quit button:* Clicking this button exits the program and returns the user to the ArcMap window.
- i) *Surface model grid:* The dialog box will prompt the user to select the auxiliary (.aux) file that represents the Digital Elevation Model (DEM), Light Detection and Ranging (LiDAR) or other surface model grid on which the viewsheds will be performed. The directory in which the selected grid resides will become the working directory for the program, into which the report and the output grid(s) will be saved.
- j) *Test date:* The date on which the satellite visibility analysis is to be performed, in the local time zone of the test site. If the user desires to perform the predictions for a range of times, the test date specified must be the date of the *first* test time.
- k) *Time of test:* The user selects whether to perform the satellite visibility analysis for a single time or across a range of times. The time(s) specified must be in the time zone of the test site. For the single test time option, one grid is created depicting the number of satellites visible at the specified time. For the time range option, two grids are created: one grid containing the maximum number of satellites visible at any of the test times across the time range and one grid depicting the time at which the maximum satellites are visible. These two grids may be combined after the program has finished by entering 'combine([MaxVisSats], [BestTime])' into the Raster Calculator. This will create a grid with unique classes based on both the best viewing time and the number of satellites visible at that time.
- l) *Time zone of test site:* The user specifies the time zone in which the surface model grid is located. The default time zone is 'Eastern', but any time zone in the world can be specified. On the initial user form, the user may select 'Eastern', 'Central', 'Mountain', 'Pacific', or 'Other'. If 'Other' is selected, a new user form displays allowing the user to select any time zone in the world, from Greenwich Mean Time (GMT) -12 to GMT +12.

m) *Z factor*: The z factor quantifies the relationship between the horizontal and vertical units of the surface model grid. For example, if the horizontal units are meters and the vertical units are in feet, the z factor is 0.3048. It is recommended that the user specify the vertical units and allow the program to calculate the z factor automatically. The program can calculate the z factor for vertical units of feet or meters. The program can automatically calculate the z factor for surface model grids with the following coordinate systems: Universal Transverse Mercator (UTM); State Plane Coordinate System (SPC); and Geographic (lat/long).

Virginia Tech Campus Test Data

To verify the results of the new satellite viewsheds program, its results were tested on the Virginia Tech campus in Blacksburg, Virginia. In order to test the area, a surface model grid of the campus, including buildings, was needed. The grid was created from polyline shapefiles containing 1-foot bare-earth elevation contours, building roof outlines and roof ridges with elevation, and spot elevations across campus. From the contours and building outlines, a Triangular Irregular Network (TIN) was created through the ArcGIS 3-D Analyst extension and then converted to a raster grid with 1-foot resolution. The building roofs were then digitized, converted to raster and overlaid with the bare-earth elevation model, creating the 1-foot resolution model of campus shown in Figure 6.

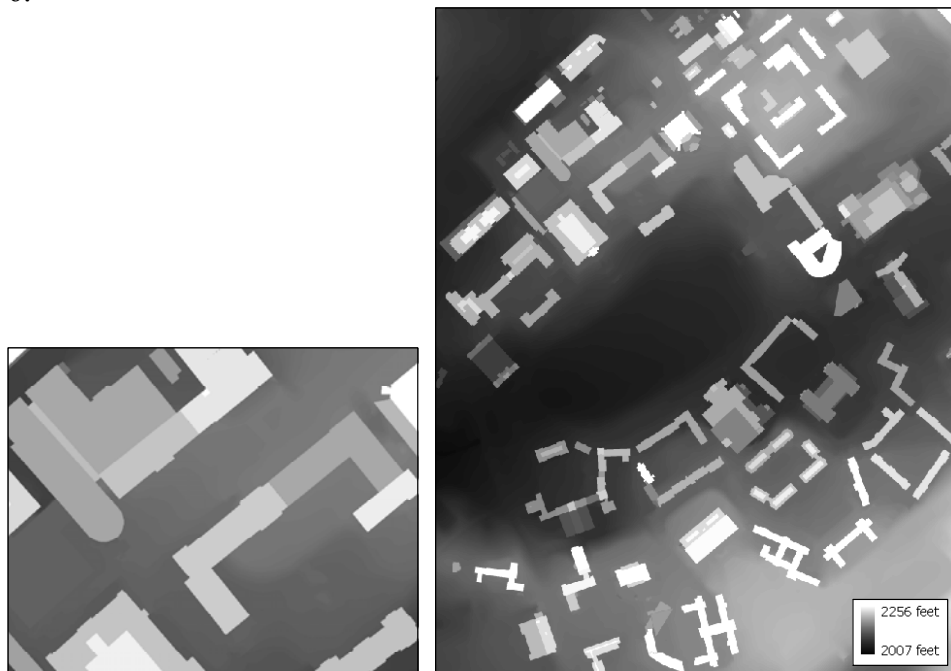


Figure 6. 1-foot surface model grid of the Virginia Tech campus used to test the satellite viewsheds tool. A close-up view is shown in the inset.

Algorithm Design

Satellite Viewsheds runs in ArcGIS version 9, in the standard ArcMap window. The tool was written in the Microsoft Visual Basic for Applications (VBA) version 6.3 editor, included with ArcGIS. The program also



Figure 7. ArcMap button that loads *Satellite Viewsheds*

references libraries of ArcObjects, the object-oriented programming language created by ESRI, recognized by ArcGIS and supported by the VBA editor. To run *Satellite Viewsheds*, the user simply clicks on the ‘Satellite Viewsheds’ button with the small satellite icon, shown in Figure 7. Clicking on the button loads and displays the Satellite Viewsheds user form shown above. The user form is the interface through which the user provides all input to the program. When the ‘Run’ button is clicked, the program opens the surface model grid, extracting and storing the grid’s properties. The algorithm then calculates the look angle of each satellite at each of the user-specified test times, given the location of the surface model grid. Next, ArcGIS’s Hillshade method is used to create individual satellite viewsheds for each visible satellite. The grids are then reclassified and combined according to the test time options specified by the user. Finally, the grids are symbolized, labeled, saved to disk and then displayed automatically in the ArcMap

display window. If the user has selected to perform the test at a single time, one grid is displayed depicting the number of visible satellites at each cell. Figure 8 shows an example of the single test time option of a DEM in northwestern Montana using ten randomly selected GPS satellites. If the user has selected to perform the satellite visibility prediction across a range of times, two grids are displayed: one containing the

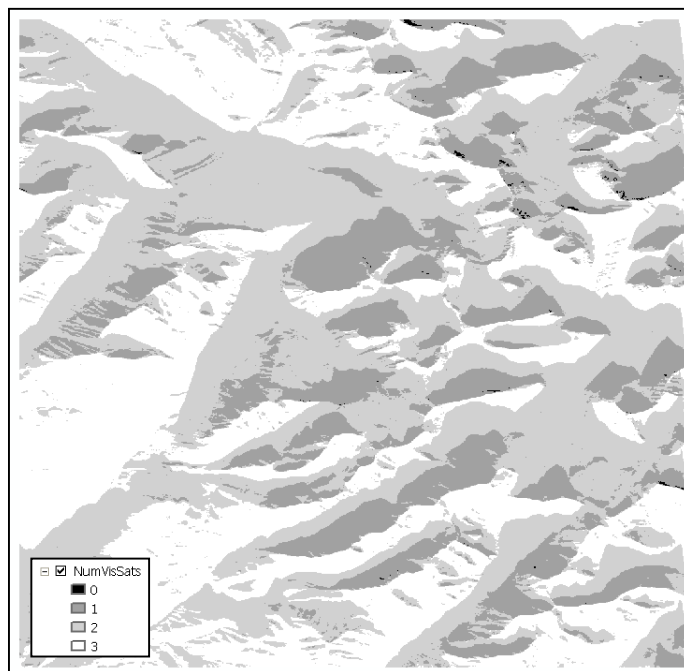


Figure 8. Sample *Satellite Viewsheds* visibility prediction for the Montana DEM for 3 visible satellites using the ‘Single test time’ option

maximum number of visible satellites at any of the times and another containing the time at which that occurs. Figure 9 shows an example of the time range option, again for northwestern Montana for ten GPS satellites. For both the single test time and time range options, *Satellite Viewsheds* also creates a program summary report that records the user inputs and the spatial properties of the original surface model grid. The report also provides the look angle and percent coverage of the grid of each GPS satellite at each test time.

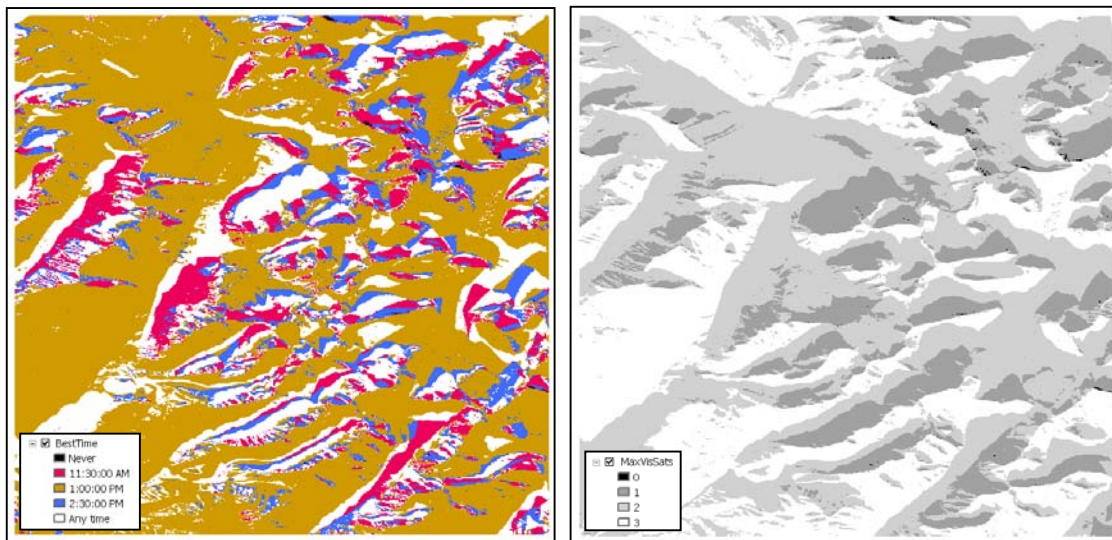


Figure 9. Sample ‘BestTime’ (left) and ‘MaxVisSats’ (right) grids of the Montana DEM created by *Satellite Viewsheds* for the ‘Time range’ option using three test times from 11:30 AM to 2:30 PM, for three visible satellites

Field Test Methodology

In order to assess *Satellite Viewsheds*’s performance in a real-world scenario, the program was field-tested on the Virginia Tech campus (Figure 10). The objective of the test was to quantify the tool’s performance in predicting the number of visible satellites. The first step in the testing process was the collection of the data. On two separate days, a Trimble GeoXT GPS receiver (Figure 11) was used to collect 44 points at stratified random locations across the Virginia Tech campus. On one



Figure 10. Aerial photograph of the Virginia Tech campus (photo by Rick Griffiths, courtesy of www.vt.edu)

day, the points were intentionally collected in the morning and on the other test day the points were collected in the afternoon. This staggering of the time of day for the tests was to ensure that different satellites would be visible for each test day due to the 12-hour orbits of GPS satellites. The points were collected in areas where the sky was largely unobstructed and also in locations adjacent to buildings (Figure 12). Each point saved to the unit was actually an average of at least ten positional recordings taken with the receiver in the same location at an interval of one second.

For each point, the time and visible satellites were recorded manually. After the points had been collected, they were imported from the receiver using Trimble's Pathfinder software. The points were then differentially corrected over the Internet using the Blacksburg base station located at the Virginia Tech Corporate Research Center. After the data points had been differentially corrected, they were exported from the Pathfinder software as an ArcGIS point shapefile. The locations of the points laid on top of the campus surface model grid can be seen in Figure 13.



Figure 11. Trimble GeoXT GPS receiver used for data collection during the field test

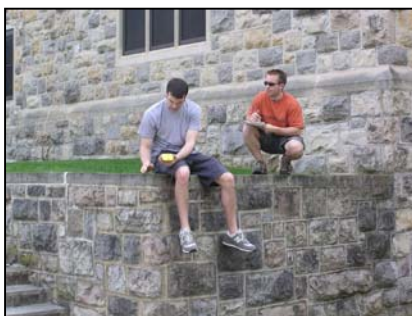


Figure 12. Field test GPS points were recorded in both open areas and adjacent to buildings.

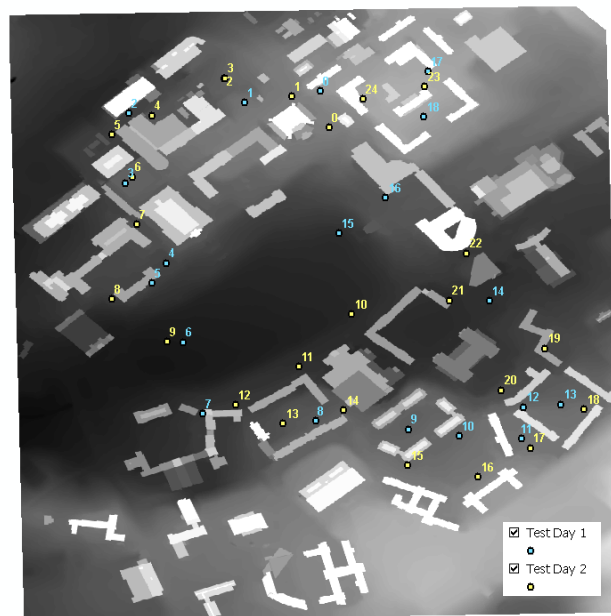


Figure 13. GPS points from both field test days laid on top of Virginia Tech surface model grid

The satellite visibility parameters observed at each test time were recorded for comparison with the predictions of *Satellite Viewsheds*. After the points were collected with the GPS unit, the tool was used to predict visibility at every time that a point was collected during the field test using the VT Campus 1-foot surface model. The tests were performed using the ‘Single test time’ option and the TLEs published the days of the field tests, which produced a grid depicting the predicted number of satellites visible from each cell in the grid at that time. After overlaying the field test points on to the satellite visibility prediction grid as shown in Figure 14, the total number of visible satellites as predicted by the program was visually determined and recorded. The process was repeated for all 44 field test points, allowing for comparison between the predicted and observed number of visible satellites at each. In addition, the discrepancy between the observations and predictions was calculated, allowing for a simple statistical analysis of the difference. The mean and maximum of the set of differences were determined, as well as a frequency table of the set.

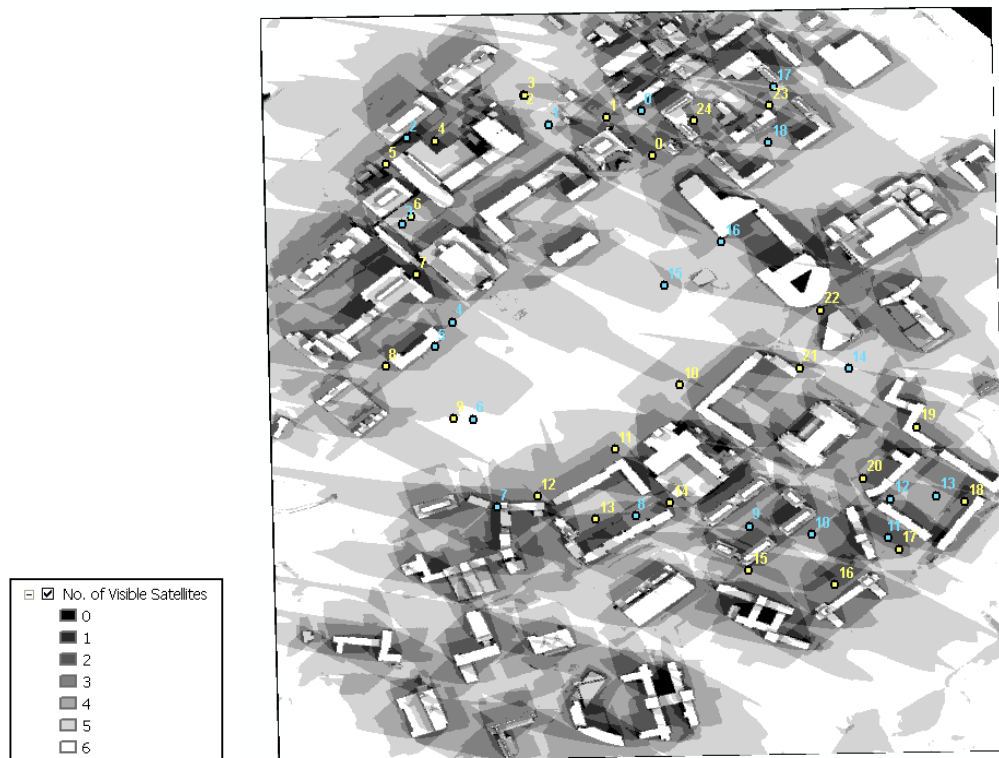


Figure 14. GPS test points laid on top of *Satellite Viewsheds*’ predicted ‘Number of visible satellites’ grid for the Virginia Tech campus at 2:29 PM on April 11, 2005. A grid like this one was created for every GPS point recording time, allowing the prediction of the number of visible satellites for each.

Field Test Results

The field test on the Virginia Tech campus revealed that the *Satellite Viewsheds* program is able to accurately and consistently

Mean discrepancy (satellites)	-0.023
Maximum difference (satellites)	1
Frequency of discrepancy = +1 satellite	3/44 (~6.8%)
Frequency of discrepancy = -1 satellite	4/44 (~9.9%)
Frequency of no discrepancy	37/44 (~84.1%)

Table 1. Statistics of data set containing discrepancy values between observed and predicted number of visible satellites

predict GPS satellite visibility. The number of visual satellites observed at the 44 field test points was compared with the predicted number of visible satellites for the same times and locations using the surface model grid of the campus. Table 1 shows the results of the comparison between the observed and predicted visible satellite counts. For just over 84% of the 44 test points, *Satellite Viewsheds* correctly predicted the number of visible satellites for the time of data collection. At no time were the program's predictions in error by more than one satellite. *Satellite Viewsheds* over-predicted by one satellite for four test points and under predicted by one satellite for three test points. For this sample data set, the program tends to slightly under predict the number of satellites that can be seen from a given point for a given test time. The slight under prediction is most likely a result of the occurrence of multipathing in the field. At the under predicted points, it is likely that the receiver collected data from a satellite whose signal had been reflected while the satellite was not considered visible by *Satellite Viewsheds* because direct LOS was not established. The over predictions are likely a result of possible signal obstructions in the field that were not included in the Virginia Tech campus surface model grid, such as trees.

In addition to the summary statistics, *Satellite Viewsheds*' ability to predict the number of visible satellites was examined through the creation of an error matrix. The error matrix, shown in Table 2, contains the number of correctly and incorrectly classified satellites (24 total satellites for each of the 44 test times). The diagonal of the error matrix contains the number of satellites predicted to be visible by *Satellite Viewsheds* and the number that were actually visible in the field; as well as the number of satellites that were predicted to be not visible and actually were not. The number of incorrectly predicted satellites is shown in the two cells off of the diagonals.

		<i>Observed</i>	
		Visible	Not Visible
<i>Predicted</i>	Visible	238	4
	Not Visible	3	811

Table 2. Error matrix comparing satellite visibility as predicted by *Satellite Viewsheds* and the field observations, with the diagonal containing correctly predicted satellites.

The k-hat, or kappa (κ), of the error matrix was then calculated. The kappa test provides a measure of the contribution of chance agreement to the success of the predictions (Campbell, 2002):

$$\kappa = \text{observed} - \text{expected} / (1 - \text{expected}) \quad \text{Eq. 5.1}$$

A kappa value of +1.0 means that a classification is perfectly effective, with no contribution from chance agreement. A kappa value of 0 indicates that the success of the classification is the same as it would be if the values were randomly classified. Using a Visual Basic script written by Dr. Bill Carstensen of the Virginia Tech Department of Geography, the kappa of the error matrix shown above was determined to be 0.981, with a significance level of 0.05. This means that the visibility predictions of *Satellite Viewsheds* were almost perfectly effective, with very little contribution from chance agreement. The kappa value of 0.981 means that the results of the prediction are 98.1% better than would be expected from chance predictions. The significance level indicates that one can be confident that less than one out of every 20 predictions is subject to chance error instead of systematic errors. Also, because the data set is statistically significant, the results of the comparison can be expected to represent any test performed under similar conditions.

Although the statistics discussed above are specific to the field test performed on the Virginia Tech campus, there is no reason to believe that their implications do not represent *Satellite Viewsheds's* performance under any conditions. The discrepancies between the predicted and observed look angles are relatively minor and are unavoidable considering the assumptions made by the program in the calculations. The errors that do exist in the predictions are most likely attributable to the assumptions made in the calculations as well as the time difference between the exact time of point recording and

the time entered into *Satellite Viewsheds* for the predictions. While the field test points were recorded in real time, *Satellite Viewsheds* accepts test times expressed in integer minutes. For GPS satellites that move more quickly across the sky (up to 30° per hour), the time difference may be sufficient to cause a small discrepancy between the predicted and observed look angles.

Satellite Viewsheds

A new, end-to-end GPS satellite visibility tool that considers LOS obstructions has been created for ArcGIS. Currently, no tools exist that predict GPS satellite availability based on local features in the receiver's environment that can block signals and cause problematic service. Of those that make some attempt to do so, no tools perform predictions for an entire area; instead they restrict their analyses to single points on the earth's surface. *Satellite Viewsheds* allows a user to predict the performance of his or her GPS receiver for an entire test area at any location and time with minimal user interaction. *Satellite Viewsheds* produces maps that show the user how many satellites will be visible at a test time and the time at which the most satellites will be visible across a time range. The program performs its predictions independently for each cell in the grid, providing the user with a visibility map at the resolution of his or her raster surface model grid. Because GPS receiver performance depends on the number of satellites with which it can establish an unobstructed LOS, the maps produced by the program allow a user to set-up data collection times and locations accordingly.

Satellite Viewsheds is unique in its ability to perform GPS satellite visibility predictions for an entire area while considering the effects of features in the local environment. The tool is user-friendly and includes many features that allow for its widespread use by GPS customers with varied objectives. Some of the key features of the program are listed below:

- The program accepts any valid raster surface model grid representing any portion of the earth's surface. The program accommodates grids with any units and any coordinate system.
- The main user form updates dynamically as the user enters input values. For example, if the user selects February for the test month, the program only

allows the selection of a value between one and 28 for the test day. In this manner, there is little chance for errors resulting from user entries. In addition, when the 'Run' button is clicked, the program extensively inspects the inputs to ensure that they are acceptable. For further assistance, the Help button on the form provides information about each of the user entries.

- Resulting satellite visibility maps are automatically displayed on the screen, complete with symbology and labeling. The grids are also saved permanently with a Value Attribute Table, which allows for any additional mathematical operations, such as manual reclassification or overlay, to be performed on the grid. The output grids also inherit all spatial reference properties of the user's surface model grid.
- The optional text report generated provides a summary of the test, including all inputs and parameters, as well as the look angles and percent coverage of the test area for every satellite in the TLES at each test time.
- The program accepts Two Line Element Sets (TLES) text files exactly as published by NORAD, meaning that the user does not need to manipulate the file in any way. For GPS satellites, the program extracts the name of the satellite, such as "PRN 01", for publishing in the program summary report.
- *Satellite Viewsheds* runs on any computer with a working copy of ArcGIS version 9, from any directory. The data supplied by the user may also reside in any location on the computer.

Conclusion

In recent years, both GPS and GIS have developed into predominant mapping tools with unlimited potential for future development. *Satellite Viewsheds* provides a powerful link between the two, using the powerful operations of GIS to optimize the capabilities of GPS. The ability to predict GPS satellite visibility provides a method of predicting GPS receiver performance because a receiver's functionality depends on the number of satellites from which it can acquire signals. Before the creation of *Satellite Viewsheds*, GPS users had no way of incorporating local signal obstructions into satellite visibility predictions for an entire test area. Current tools in the industry perform predictions for single points on the earth's surface only; and consideration of local features that may obstruct GPS signals, such as buildings and terrain, requires a preliminary survey of the test site. *Satellite Viewsheds* eliminates the need for preliminary observation of a test site by using a surface grid to model the local environment. The

program performs predictions for any location on earth for any test time or range of times. *Satellite Viewsheds* requires only the surface model grid and a TLES describing the orbits of the GPS satellites. If a user opts to perform a single test time analysis, the program produces a grid showing the number of satellites visible from each cell in the grid. If the user opts to perform the predictions for a range of times, two grids are produced: one showing the maximum number of satellites visible across the time range and another containing the time at which the maximum number of satellites is visible. A user can perform a full visibility prediction in a matter of minutes.

Satellite Viewsheds allows GPS users to predict and avoid times and locations at which their receiver will experience diminished service. Predicting receiver performance will maximize the efficiency of GPS data collection, saving time and money by allowing a GPS user to tailor his or her data collection routine to times and locations of optimal receiver performance.

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