RELATIVE ERRORS IDENTIFIED IN USGS GRIDDED DEMS

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ABSTRACT

The 1:250,000 series of gridded DEMs is now complete for the coterminous United States and thousands of 7 1/2 minute gridded DEMs have been released for purchase. As an ever increasing number of persons gain access to these models, it is important that users now of the possible problems, as well as the potential benefits, of using such models. Many of the errors that sneak into DEMs at creation will be removed in the editing stage before the models are released, but some are likely to escape detection. In working with a number of DEMs, the author has made efforts to evaluate how well the models capture the pattern of the land surface. In the larger-scale models, a variety of small, but sometimes significant relative errors have been detected. Relative errors are identified as those instances where one or a few elevations are obviously wrong relative to the neighboring elevations which as a group give an adequate definition of the form of the land surface.

One type of error is associated with the DEMs produced by the Gestalt Photomapper II using NHAP imagery. Working with a DLG-based DEMs produced by digitizing existing topographic maps, the author found three other types of error. In this paper, examples of the various types of errors are shown. Consideration is given to how such errors can be corrected.

INTRODUCTION

The U. S. Geological Survey has released thousands of gridded DEMs for distribution and the 1:250,000 series of DEMs is now complete for the coterminous United States. As an ever increasing number of persons gain access to these digital models, it is important that users know of the possible problems, as well as the potential benefits, of using such models. In the author's work with 7 1/2 minute DEMs and one 1:250,000 DEM, efforts have been made to evaluate how well the models capture the pattern of the land surface. This paper is built on the findings of occasional errors in the DEMs the author has worked with and the many hours of thought the author has given to the question of measuring the accuracy of DEMs.

THE NATURE OF GRIDDED DEMs

There is no standard terminology employed to refer to digital representations of the topographic surface (Carter, 1988), but in the parlance of the U. S. Geological Survey, the Digital Elevation Model, or DEM, is a gridded array of elevations. Such grids conform to either the graticule of latitude and longitude or to the UTM grid system. Those grids oriented to latitude and longitude are referred to as the arc-second data and are currently produced at either 3 arc-seconds or 1 arc-second. The arc-second grids are non-square reflecting the convergence of the meridians with increasing distance away from the equator. By contrast, the UTM grids are square and are normally referred to as being in the planar format. In the case of the USGS products, the 1:250,000 DEMs are constructed on a 3 arc-second grid and the 7 1/2 minute DEMs are built on a 30 meter square grid (U. S. Geological Survey, 1987).

For many years the only forms of digital elevation data released by the U. S. Geological Survey were the gridded arrays of elevation values as described above. In a new production program, called Mark II, the Survey will be producing representations of the topographic surface as digitized strings of contours in the DLG format (Rinehart and Coleman, 1988, 292). These DLG products will be used to produce gridded DEMs through processes of interpolation and editing.

ERROR AND ACCURACY IN GRIDDED DEMS

With the creation of the DEM product mix, USGS has created a terminology to refer to errors and classifies errors into three types: blunders, systematic errors, and randon errors. Blunders are those types of major errors that exceed reasonable limits and can be expected to be removed from DEMs when they are edited prior to release. Based on the source of the DEM and the tested quality of the particular model, a DEM will be classified into one of three accuracy levels. The testing is done by comparing spot elevations in the matrix with a known source and quantifying the fit with the RMSE statistic (Root Mean Square Error). Level-1 DEMs are of the lowest quality. This level of accuracy generally applies to all of those models derived from profiling high-altitude aerial photography, such as was done for many years with the Gestalt Photomapper II instruments. Models that do not meet the lowest level of accuracy are not released for distribution. DEMs designated as meeting Level 2 accuracy standards have been editied to be consistent with existing contour maps and water bodies. DEMs currently being derived from the DLGs will normally be designated as Level 2. Level-3 models are even more accurate and represent a goal to shoot for. DEMs so designated will ". . . have been vertically integrated to insure positional and hypsographic consistency with planimetric data categories such as hydrography and transportation. . . A RMSE of one-third of the contour interval, not to exceed 7 meters in elevation, is the maximum permitted. There are no errors greater than one contour interval in magnitude." (U. S. Geological Survey, 1986, 207).

The author has come to think of the errors in gridded DEMs of two basic types, relative and global, based on the extent of the error. Relative errors are defined as those instances where one or a few elevations are in obvious error relative to the neighboring elevations which as a group give an adequate definition of the form of the land surface. Global errors are thought of as those situations where the general form of the land surface is adequately defined by the digital data, but the total model departs significantly from the source map or the actual land surface. This treatment of errors is not consistent with the terminology employed by USGS, but it is complementary to their discussions of error and precision.

GLOBAL ERRORS

The focus of this paper is on relative errors, but brief consideration will be given to what the author calls global errors. For users with limited facilities, it is very difficult to identify and assess global errors unless they are very large and obvious. In all of this author's work, little effort has been made to identify global errors for it has generally been assumed that any global errors are insignificant and unimportant for the tasks at hand.

Conceptually, global errors may be thought of as displacements of the entire model along one or more axes. Such displacements may occur relative to the source map if digitized from a map or relative to the actual land surface if derived from field measurements or photos, or the displacements may occur relative to a neighboring map. Any corrections for global errors would involve standard graphics transformations applied to the entire model. These transformations include translation, rotation, and scaling and may need to be applied in a linear or non-linear form.

The only global error this author was able to identify was an error in matching neighboring 7 1/2 minute DEMs. An attempt was made to see how well models would fit together and a FORTRAN program was written to fit models together along their east and west sides. Because the sides of the UTM based DEMs do not consist of a single column of elevations but contain many offsets, the task is not trivial. The author did not continue this line of inquiry and the code was never developed to compare models with their neighbors to the north and south.

The test the author used to evaluate the fit of neighboring gridded DEMs is based on the idea that any distribution of differences between neighboring elevations should be consistent whether the neighbors are in the same DEM or form the boundaries of neighboring DEMs. In the very limited sample examined, some pairs showed no significant difference in the statistics of neighboring columns of elevations between models and within the same model. However, in one case, it appeared that the outer column of elevations of neighboring models was one and the same. In this case one or both models was displaced horizontally. The models so tested were older models of the GPM2 variety and were at the lowest level of accuracy. Presumably, DEMs of Level 2 or 3 accuracy will not display such global errors.

RELATIVE ERRORS

In the larger-scale models, a variety of small, but sometimes significant relative errors have been detected. The author has worked with three different types of DEMs and has encountered errors in each type of DEM. No attempt has been made to develop a typology of errors, but through experience different types of errors have manifest themselves. The author draws upon his experiences with the following DEMs: the W 1/2 Knoxville 1:250,000 in the 3 arc-second format; the Norris, Tennessee, and Thunderhead Mountain, North Carolina and Tennessee, 1:24,000 DEMs derived from NHAP imagery using the Gestalt Photomapper II (GPM2) and released without editing for water bodies; and the Thunderhead Mountain, North Carolina and Tennessee, 1:24,000 DEM based on interpolation from DLG contours.

The author carried out extensive analyses with the 1:250,000 DEM and deemed that the model was essentially error free (Carter, 1987). Subsequently, Houser (1988) examined the model for specific errors and found that there are a few small errors of a very local nature. All of the errors that Houser found show up on a contour plot as a crowding of contours in a small section. Comparing plots of these errors to the original topographic map from which the DEMs were derived, revealed that the errors occurred in sites of very steep terrain where the contours bled together on the original map. In many cases, an index contour label was also found at this site. It is apparent that these small errors are largely the product of too much detail in too small a space and a failure to refine the digital product to account for the finest details. No example of any of the errors in the 1:250,000 model are included in this paper.

GPM2-based DEMs

The author has had the greatest amount of experience with the 1:24,000 DEMs derived from profiling NHAP imagery through the Gestalt Photomapper II. The models the author purchased were some of the earliest released and predated the program of correcting the models to remove blunders in the areas of water bodies before release of the model. The inherent problem of creating proper profiling of DEMs over water bodies was brought home to the author early in his work with the models. The author wrote his own software to process DEMs (Carter, 1983) and because of the limitations of resources worked only with rectangular matrices pulled from the larger DEMs. The first area examined by the author was in the area of Norris Dam, where there is a high flood control dam, a deep valley below the dam, and a flat reservoir above the dam. It was assumed that this complex of topography would be readily identifiable in plots because of the dramatic differences in relief between the land surface and the water. In the first plots made, the dam and valley were readily distinquishable, but the reservoir was not the flat surface it should have been. This lead the author to purchase copies of the NHAP imagery used to create the DEMs. Areas of sun glint in the photos on the reservoir above the dam provided the reason why the model was in error, for the GPM2 creates a DEM by mechanically correlating stereo images and with the sun glint there was no way to objectively correlate the images on the two photos.

The nature of that specific error was not apparent until a larger matrix of elevations was pulled from the DEM and mapped with contours, Fig. 1. This map shows the edges between the patches created in the GPM2 that could not be correlated. To correct for such errors requires a large interactive workstation and appropriate software which most people will not have access to. The Technical Instructions issued by the Geological Survey (1986) describe the many editing and enhancement steps a DEM might be put through before it is to be declared of sufficient quality to be released for distribution. In fairness to the Geological Survey, it should be noted again that the GPM2-based models discussed in this paper were among the first releases of such models and predated many of the editing steps now applied to DEMs. However, this is not to imply that all DEMs being released now will be error free, for as noted in the Technical Instructions, although errors ". . . may be reduced in magnitude by refinements in technique and precision, they never can be completely eliminated." (U. S. Geological Survey, 1986, 2-1).

Fig. 2 displays a similar linear pattern of error but because it occurs along a fairly steep ridge, it is not so apparent. Obviously, the major error in this figure represents the inability to bring patches together in the GPM2. An examination of the NHAP imagery did not provide any clues as to why this error occurred. To the west of this error, another error is found where the contours between 1300 and 1400 meters are compressed in a local area. Again, an examination of the imagery did not reveal the cause of this error. These two errors are relatively minor and might be corrected by a user sketching contours from the published topo quad on a plot of this type and then using an editor to replace individual elevation values with better estimates. The complex error shown in Fig. 3 is even less obvious than those seen previously. This error was considered to be trivial for analyses being conducted by the author. However, in a correlation analysis of synthesized reflectivity values derived from a matrix containing this error with Thematic Mapper data, this error stood out as an extreme departure (Carter, 1989). This revelation pointed out that any error may be significant and all potential errors should be identified.

DLG-based DEM

Having spent many hours with the GPM2-based Thunderhead Mountain DEM, the author was pleased to find that one of the prototypes of the DLG-based DEMs was the same Thunderhead Mountain quadrangle (Berry, Moreland, and Doughty, 1988). The author got a copy of the new Thunderhead Mountain DEM which came from an entirely different source and began to work with it. At the time the model arrived, the author was experimenting with various indices of warp on a square cell formed by the elevations at each corner. These indices were applied to the new DEM and the frequency distributions of

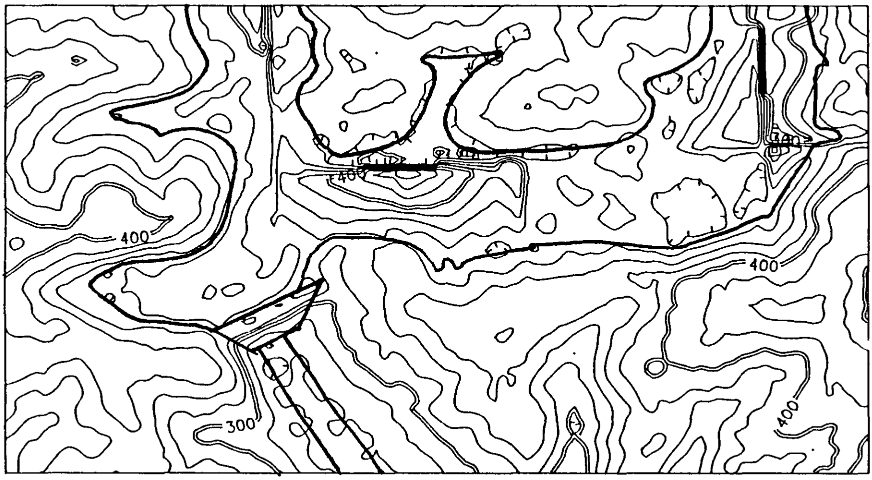

Fig. 1 - Surface II plot using a 20 m contour interval of a 60-Row by 110-Column matrix of elevations featuring Norris Dam and the areas immediately upstream and downstream. The bold lines sketched in by hand show the general form of the dam and reservoir. From the Norris, TN, 1:24,000 GPM2-based DEM before editing. The errors along the edges of some of the GPM2 correlation patches stand out due to their cardinal orientations and artificial nature.

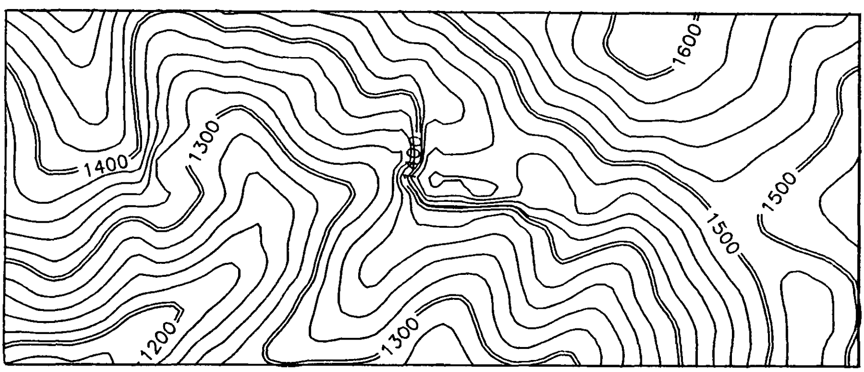

Fig. 2 - Surface II plot using a 20 m contour interval of a 22-Row by 52-Column matrix of elevations from the Thunderhead Mountain, NC and TN, 1:24,000 GPM2-based DEM before editing. The two errors displayed here are less obvious than those in Fig. 1.

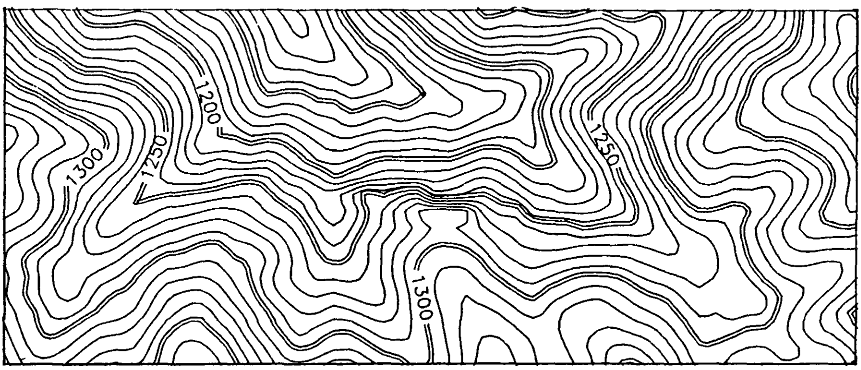

Fig. 3 - Surface II plot using a 20 m contour interval of a 22-Row by 52-Column matrix of elevations from the Thunderhead Mountain, NC and TN 1:24,000 GPM2-based DEM before editing. The complex error shown here is not immediately obvious but proved to be a problem in analyses undertaken by the author.

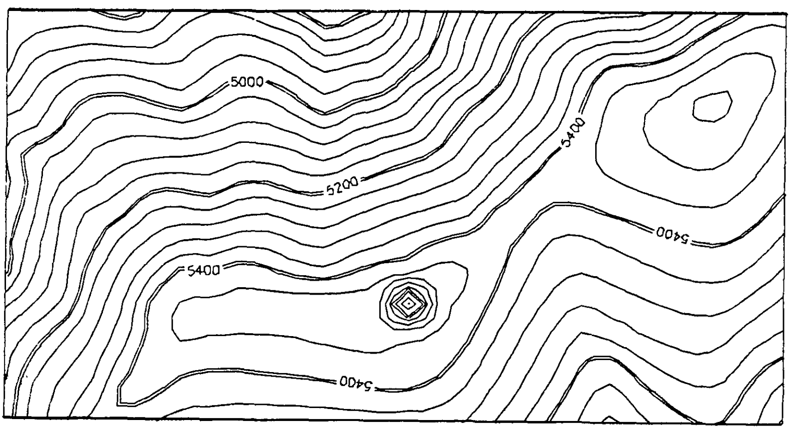

Fig. 4 - Surface II plot using a 40 foot contour interval of a 15-Row by 28-Column matrix of elevations from the Thunderhead Mountain, NC and TN 1:24,000 DLG-based DEM. The spike along the ridge was caused by a single elevation being too high by exactly 200 feet. The peak should be no different from the peak to the northeast.

index values were printed out. Most of the index values conformed to the distributions found in the other DEMs, but a few values were extremely large and well outside the normal distribution (Carter, 1989). The index program was modified to print out the row and column position of all index values above a give threshhold. Small rectangular matrices were then pulled at each place where a high index value occurred and contour maps were made of each matrix using Surface II. Each high index value revealed the existence of an error of the type shown in Figures 4 - 6. In total, NINE such errors were found in this DLG-based DEM. In subsequent work with this DEM no other errors or discrepencies have been found. It is assumed that this index departure revealed all of the errors in the DEM, but it would be presumptuous to state that there are no other errors in the DEM.

The most dominant type of error encountered in this DEM was a single peak extending 200 feet above the surrounding lands, Fig. 4. This type of error was found in six places. In all cases, the error occurred where a spot elevation was printed on the topographic map. Listing out the values revealed that in all cases the one elevation in the matrix was exactly 200 feet higher than the spot elevation shown on the map, while all of the neighboring elevations seemed to be correct. The obvious way to correct such errors is to use an editor and replace the value in the matrix, once the error is identified. The small area of the spike probably accounts for the failure to detect the error in the editing procedures.

In two other instances, the errors consisted of a block of elevations being too high by 200 feet. When plotted as contour maps, the erroneous blocks looked like buttes sitting atop a ridge. The errors only became obvious when the contours defining the ridge were compared with the original topographic map. Looking at a listing of the elevations it is fairly apparent that most of the elevations in the block are too high by the same amount. Figure 5 illustrates the erroneous butte that was found along the ridge extending east from Hornet Tree Top in the DLG-based Thunderhead Mountain 1:24,000 DEM.

The 200-foot discrepencies in all of the errors discussed above are obviously a relict to the contour interval on the original topographic quad, for the interval is 40 feet and thus the distance between index contours is 200 feet. One can surmise that such errors come about by tagging index contours, but it is interesting that all of the errors were occurrences where the features were too high by 200 feet. There were no occurrences where the featues were too low by 200 feet. It is possible that negative departures occurred in the original model, but were more easy to detect in the editing process and all occurrences were removed.

Another error was detected in the DEM and it was not a simple problem of being off by 200 feet. There is no easy way to describe this error. The map in the left half of Figure 6 shows the contour pattern that Surface II produced from the DEM values. Hand interpolating contours to these

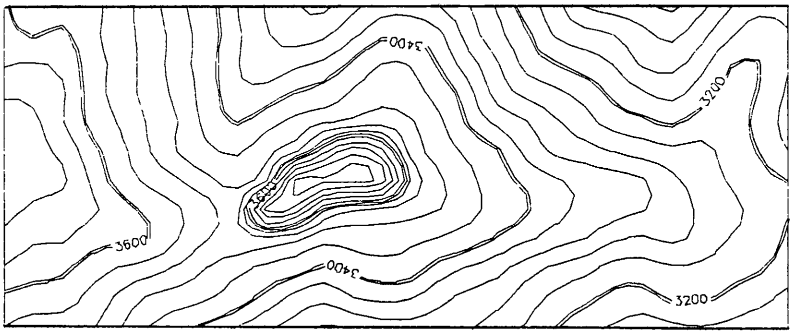

Fig. 5 - Surface II plot using a 40 foot contour interval of a 12-Row by 28-Column matrix of elevations from the Thunderhead Mountain, NC and TN 1:24,000 DLG-based DEM. The butte-like feature at the center of the plot does not exist on the original topographic map although features of this form can be found in nature. The problem appears to be that 7 elevations in the matrix are too high by 200 feet and 2 other values are too high by somewhat less.

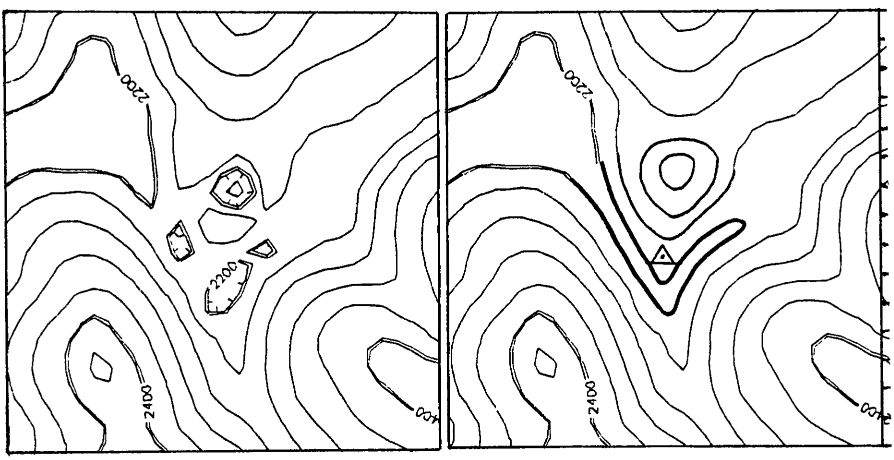

Fig. 6 - On the left a Surface II plot using a 40 foot contour interval of a 16-Row by 16-Column matrix of elevations from the Thunderhead Mountain, NC and TN 1:24,000 DLG-based DEM. On the right is the same plot with the problem area replaced by a sketch of the contour pattern and the BM symbol shown on the original topographic quadrangle map less BM 2215 and the stream name. The ticks on the right represent the spacing of the elevation values.

values produced a similar set of contours, so it is not a problem with Surface II. The map on the right half of Figure 6 shows the same area with the erroneous section cut out and replaced by a sketch of the contour pattern shown on the topographic map. While this is a detailed and complex topographic surface, it's definition is further complicated by having a benchmark and a placename occur in the same area. At the right side of this Figure, ticks have been drawn to show the spacing of the elevation values--30 meters on the ground. It is possible that part of the problem leading to this error is that the detail of the narrow channel is too fine for the spacing of the sample elevations. The author has no suggestions for correcting an error of this type. When the U. S. Geological Survey is able to integrate the hypsographic patterns of the contours with the planimetric detail of the hydrography as will be found in Level 3 models, such errors may become a thing of the past.

CONCLUSIONS

Errors of various types are always going to be with us, in whatever we do. As the digital production activities of the National Mapping program become refined with experience and overt actions, we can expect to see fewer and fewer errors occurring in the datasets entered in to the National Digital Cartographic Database. But it is presumptuous to assume that the Database will ever be error-free. Therefore, it behooves users to become aware of the nature of the types of errors that might exist in any digital database.

In this study, the author shows some of the errors he has encountered in the gridded DEMs he has had an opportunity to work with. Because the author has worked with only a limited sample of gridded DEMs, there may be many types of errors that exist in DEMs created by other processes or DEMs defining landscapes of differing relief and complexity. Colleagues who have worked with DEMs note that they have encountered errors, but no one seems to have shown the nature of the errors they have detected nor has anyone collected representative examples of errors known to occur in gridded DEMs. This paper is offered as perhaps the first of its kind to detail types of errors found in actual DEMs. If readers of this paper have encountered errors of other types, I hope they will make an effort to document those errors so that users can be better informed about the nature of the gridded DEMs.

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