Improving the positional and vertical accuracy of named summits above 13,000 feet in the United States

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Introduction

The National Map (TNM) portal provides public access to U.S. Geological Survey (USGS) high-resolution topographic datasets, and maps from the Historical Topographic Map Collection (HTMC). Elevation values shown on HTMC maps were obtained from ground spot elevation measurements, as compared to today's elevation measurements derived from more efficient methods, such as lidar, radar, or sonar. These spot elevations were collected either by levelling in the field or by photogrammetrists in the office, and are called mass points with post-spacings of two-arc seconds (arcsec), approximately 60 meters depending on latitude, in steep terrain and one-half arcsec, approximately 15 meters, in flat terrain (Federal Geographic Data Committee 1997). The vertical accuracy of spot elevations is ± 10 feet. Most spot elevations were used only in contour derivation to create a more spatially continuous representations of terrain, but some were also labelled on the maps to supply accurate elevations of culturally important features such as mountain peaks, gaps, and road junctions.

In contrast to the HTMC, the digital maps provided by the USGS today do not yet depict spot elevations for several reasons: 1) the focus for several decades has been on other themes such as hydrography and elevation, 2) to avoid conflict between elevations of automated contour generation and historical spot elevations, and 3) the lack of an official, published USGS database of spot elevations. Consequently, this research project was initiated to begin development of a national database of spot elevations. In the first phase, to maintain focus and efficiency, only spot elevations of summits are being evaluated. Accurate absolute and relative heights of summits are sought after by many user communities (such as cartographers, geoscientists, engineers, aviators, hikers, and mountain climbers).

Methodology for improving accuracy of named summits in the United States

Since the 1970s, the USGS has maintained the Geographic Names Information System (GNIS), which currently stores information about 2.28 million current and historical physical and cultural geographic features (excluding roads) located in the United States, associated areas, and Antarctica. There are approximately 70,000 named summits included in the GNIS database, all of which have a horizontal point location. Some points have an elevation value associated with the point's location. Because of the priorities of the GNIS program when collecting points from the HTMC, summit point location often fails to represent the highest point of its corresponding morphometric peak, particularly when compared to high-resolution digital elevation model (DEM) datasets. Thus, a workflow to find the most accurate location and spot elevation for GNIS summits was developed. Details about this process are described by Arundel and Sinha (*in press*). The method consists of two main stages: *summit stepping* and *summit snapping* (Figure 1). Summit stepping involves incrementally migrating the existing GNIS summit point uphill to the highest nearby point. Summit snapping involves comparison with higher resolution 3D Elevation Program (3DEP) DEM datasets to improve the location, thus ensuring that the summit 'snaps' to the point location determined from the highest precision dataset.

Summit stepping

The summit stepping procedure is the most important phase in the entire process and currently begins with the one-third arcsec (approximately 10 meters, depending on latitude) DEM, given that it is the highest resolution seamless elevation dataset covering the entire coterminous United States. Using the lower resolution one-third arcsec dataset initially reduces the number of pixels that need to be processed for the first 'move' of the summit point near the most accurate morphometric peak pixel. The first step – simple stepping - is to find the pixel containing the GNIS summit point location (Figure 1). Then, the eight surrounding pixels in a 3 x 3-pixel neighbourhood surrounding the original pixel are evaluated to determine if there is a higher neighbouring pixel. The search process with 3 x 3-pixel neighbourhood continues for all higher nearby pixels, until no higher neighbouring pixel can be found. Next, in complex stepping, the search is then expanded to 5x5 pixels, and the process repeats beginning at the last pixel, after which the highest pixel is used to complete a 7x7 pixel search. This size was found to be the most productive in test evaluation. The resulting pixel's centre coordinates and elevation value are assigned to the summit point, albeit as temporary values, since the values could change after the summit snapping method (see next section).

Summit snapping

In summit snapping, the new summit location is used to retrieve the corresponding one-meter elevation from TNM viewer via its application programming interface (https://viewer.nationalmap.gov/tnmaccess/api/index). Provided a one-meter (1-m) DEM is available for that location, summit stepping is reinitiated to find the highest pixel in the 1-m DEM. If the edge of the DEM is reached, the adjacent 1-m tile is retrieved. Finally, after the full summit stepping procedure completes, the new highest pixel in the 1-m DEM is used as a reference point to download the Lidar Point Cloud (LPC) dataset, if it exists there. The lidar ground return point within two meters of this point with the highest elevation value becomes the new summit point location and elevation.

The resulting new summit location must be compared visually with displays of elevation datasets and the HTMC to determine if the summit stepping process terminated at an insignificant local peak or the wrong peak altogether. Using a 7x7 pixel window point stepping truncated at insignificant peaks is greatly reduced. In the case of an original GNIS point location on the slope of a different morphometric peak, points must be manually moved to the correct slope, and then the automated stepping and snapping process is repeated.

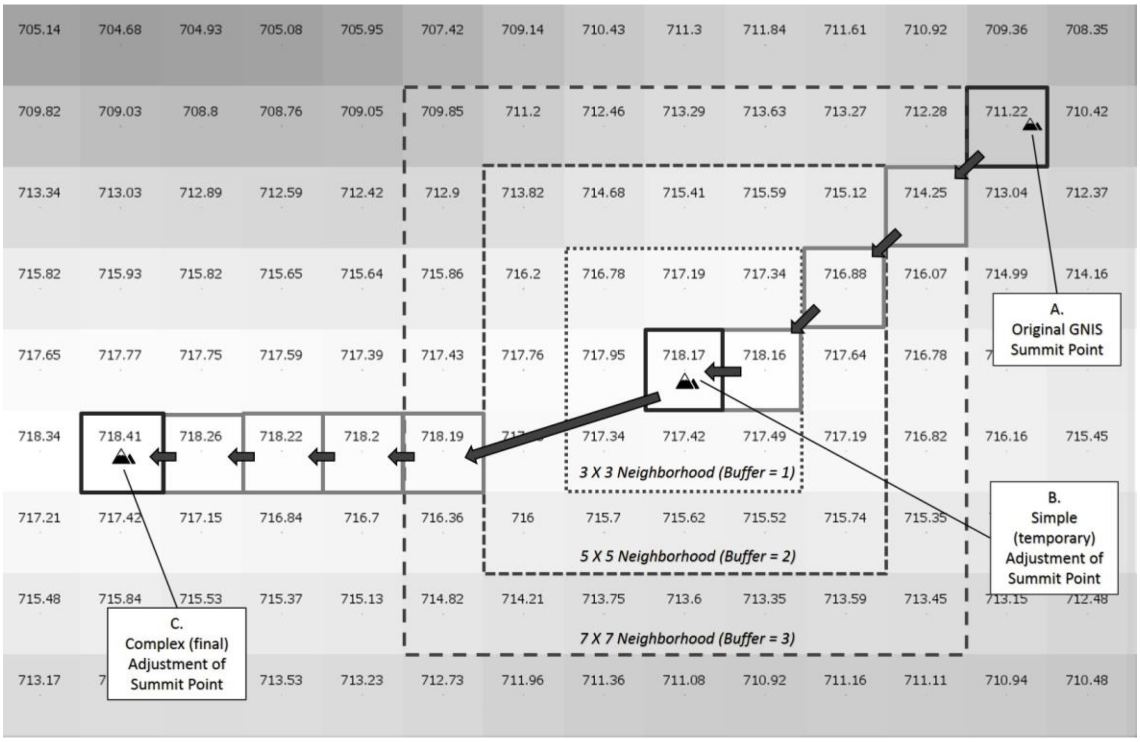

Figure 1. Complex summit stepping begins with simple summit stepping starting at the GNIS summit point A. Simple stepping stops at the adjacent pixel as it is the highest in the 9-pixel neighbourhood (point B), although it is clearly not the highest point of the local eminence (uplifted region). This point becomes a candidate for complex stepping, where the neighbourhood is increased by one in search for a higher point. In this case, a 7x7 neighbourhood is sufficient to find a higher pixel, which means simple stepping must be resumed from that cell to point C (from Arundel and Sinha, *in press*).

The workflow was applied to all 67 named summits above 14,000 feet (14ers) and a randomly chosen subset (132) of summits above 13,000 feet (13ers) in the United States. The summit stepping and snapping phases were implemented for the 199 summits based on available multiple elevation sources. The final spot elevations of summits were then compared first to corresponding historical topographic map spot elevations (if available), and then to peak elevations listed on the popular climbing website Peakbagger.com where spot elevations were not available (Table 1).

Results and Discussion

Of the 199 summits processed for this study, five points were manually relocated to force the stepping up the correct slope. Most (88.4%) of the values were extracted from the 3DEP one-third arcsec DEM, 4% from the 1-m DEM and 7.5% from the LPC. The general trend is an increase in elevation with increase in resolution (Table 1). Interestingly, all LPC points were higher than their value extracted from the 1-m DEM dataset. Values from the one-third arcsec dataset are 0.74 meters higher than the spot elevations labelled on the HTMC; whereas 1-m DEM values are more than twice that, and LPC values are almost twice that again. Horizontally, the highest point for 13ers was moved an average of 28.7 m and points on 14ers were moved 23.2 m.

Statistic	one-third arcsec	1-m	LPC
Count	176	8	15
Spot height (our method) > spot elevation (HTMC) (%)	64.8	87.5	86.7
Spot height < spot elevation (%)	35.2	12.5	13.3
Average height above (m)	3.23	2.00	3.96
Average height below (m)	-3.82	-0.97	-2.01
Average absolute difference (m)	0.57	0.06	3.71
Average difference (m)	0.74	1.63	3.17

Table 1. Differences between corrected spot heights and summit spot elevations labelled on historical topographic maps.

The original USGS one-third arcsec seamless DEM was created by digitizing map contours depicted on the HTMC, and then rasterizing the digitized contours using specially designed interpolation algorithms. The data smoothing that results from this process clearly reduced the recorded extreme values of summits. As higher resolution elevation data have become available to use as the source for the one-third arcsec dataset, interpolated values have become more accurate. However, the impact of interpolation still exists. The results from this study suggest the amount of smoothing of elevation values in the United States may reduce elevations, on average, by over three meters. Such reductions can impact models that rely on terrain as their foundation.

Conclusion

This study has improved the positional and vertical accuracy of 199 named summits over 13,000 feet. Higher resolution elevation data resulted in greater differences between values labelled on historical topographic maps and the corrected values. The corrected summit locations and elevations will lend greater accuracy to current United States topographic maps and provide insight into the impact of DEM interpolation on summit height estimates. The work led to automated production of spot height values nationwide for enhancing the display of cartographic maps. The practical insights from this pilot study will now be used to decide how to create a spot height database for almost 70,000 named summits in the United States.

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