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EVALUATION OF MEASUREMENT DATA ACROSS EIGHT GIS BASEMAPS USING DRUMLINS: COMBINING BASEMAPS IS OPTIMAL

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ABSTRACT

Choosing the best basemap for landform data collection and analysis is fundamental for accurate measurements and usability. Different types of basemaps may affect how we perceive relief through a map (Phillips et al., 1975); thereby, affecting the precision of data collected. This project collected length and azimuth data of 60 drumlins in Western, NY from four different, ArcGIS online (AGOL)-provided basemaps, as well as two parallel-to-strike and two perpendicular-to-strike hillshades (n=4). Testing the mean length (1,662m, ±529) and azimuth (171°, ±0.3) data for uniformity across basemaps determined if any basemap is more or less reliable for data collection. The Terrain map and 351° hillshade showed the lowest statistic values (t(59) = 1.84, p = .007, R^2 = 0.4116). This was due to a poor direction of shading that caused visual loss of the drumlin tails. The least number of difference occurred between the USGS Topographic map and the USA Topographic map (t(59) = -0.01, p = .992, R^2 = 0.9412), maps married in creation. The more traditional USGS/USA Topographic map is better for measurements of length and orientation due to the more established outline of landforms and less visual variability. Combining hillshade and topographic maps, however, can create an optimal representation of landforms for remote data collection. Choosing, or better yet, creating the correct basemap for an intended result can ensure readability and useability. It is essential that the creation of useful basemaps can keep up with the data being collected from advancing remote-sensing technologies.

KEY WORDS: GIS, Basemaps, Topographic Maps, Drumlins

INTRODUCTION

Traditional paper maps are being replaced by digital renderings representing every part of this globe and other terrestrial bodies (e.g., Mars). Geographic Information Systems (GIS) has provided the ability to layer and manipulate these maps, and even extract a wide variety of data including lengths and azimuths. GIS is used in many different fields, from geology to resource management to public health, and with the variety of uses comes a variety of basemaps and layers. This leads to the question of which basemaps are best for which purposes.

Students now report that they prefer visualizing specific areas on a map through mobile, map-based applications rather than a paper map (Sari et al., 2020). Digital maps are available for all types of users, workers, companies, and organizations and they are more accessible than paper maps because they include features to zoom in and out, move to new locations on the map, and sometimes access different basemaps. When improving the readability of a map, several factors can be considered: color scheme, speed of operation, number of features, and, possibly, interactive features (Sari et al., 2020). The ultimate purpose of the map must be considered as well; there are differences between a map meant for visualization and a map meant for accuracy/solution-based tasks (i.e., collecting data) (Herman et al., 2018).

Herman et al. (2018, p.20) examined the use of interactive versus static, virtual 3D maps. Several conclusions were made including that, "...various tasks in 3D maps were solved more accurately in the presence of interactivity...However, tasks were solved faster with static visualizations." The different types of map had different effects on readability, both positive and negative. It is possible, therefore, that a combination of the two map types could create the optimal user experience. This same concept, the need for a combination of maps, could be applied to the use of hillshade and topographic maps. Combining the hillshade for visualization with the topographic for accuracy, we have the abilities to make maps optimal for both visual understanding and accurate data collection.

Using ArcGIS Online (AGOL), this research focused on collecting length and azimuth data of 60 drumlins across multiple GIS basemaps to determine if any basemap is more, or less, reliable for data collection and analysis. In Western New York, just south of Lake Ontario (Fig. 1), there are three areas of glacial drumlins (Miller, 1972). The section located southeast of Rochester, part of the central belt (Miller, 1972), was used for this project.

Four different, AGOL-provided basemaps were evaluated: a) USA Topographic, b) default hillshade, c) Terrain, and d) USGS National Topographic. In addition, we generated two parallel-to-strike hillshades and two perpendicular-to-strike hillshades (n=4) to evaluate shading effect on data collection.

Landforms, such as drumlins, can be viewed and analyzed remotely through a variety of GIS basemaps, but different types of basemaps may have a large effect on how we perceive relief (Phillips et al., 1975); thereby, affecting the precision of data collected. Choosing a basemap best for data collection and analysis is fundamental for studying landforms remotely, and the ability to improve upon these basemaps can provide better options for future remote data collection.

BACKGROUND

Topographic maps were used as the baseline map for choosing prototypical drumlins because the maps were generated from original paper maps. The topographic maps on AGOL are recreated from the United States Geological Survey (USGS) topographic maps produced from 1884-2006 (USTMUG, 2018).

USGS has been creating topographic maps since 1884 (Usery et al., 2009). The maps progressed from field measurements and contour sketches to pen-and-ink drawings, and then continued to grow through photogrammetry and orthophoto concepts (Usery et al., 2009), all the while developing larger scales for more detail. Electronic measurement technology was also embraced to improve the accuracy of the maps (Usery et al., 2009). In 1970, USGS began its digital journey by digitizing the paper topographic maps, and through a node data model, created digital line graphs; simultaneously, their photogrammetric technology was being used to developing digital elevation models (DEMs) (Usery et al., 2009). These digital topographic maps are updated every few years (Usery et al., 2009, Part 2). Coupled with computer coding, the map projections created by USGS are the basis of GIS programs, which debuted in the 1980s (Usery et al., 2009).

Today, there are two collections of USGS Topographic maps available for GIS databases: "US Topo" and "Historical Topographic Map Collection (HTMC)" (USTMUG, 2018). The US Topo maps are 7.5-minute quadrangle maps with a 1:24,000 scale and were derived from GIS data in 2009. These maps are widely published as digital documents. The USGS National topographic map used through AGOL comes from USGS and data gathered from The National Map (TNM). The USA Topographic map used through AGOL comes from USGS and data from the National Geographic Society.

Figure 1. Greater New York State region. Red square indicates the area of drumlins in Western New York (modified from ArcGIS Online); see Figure 2 for detail.

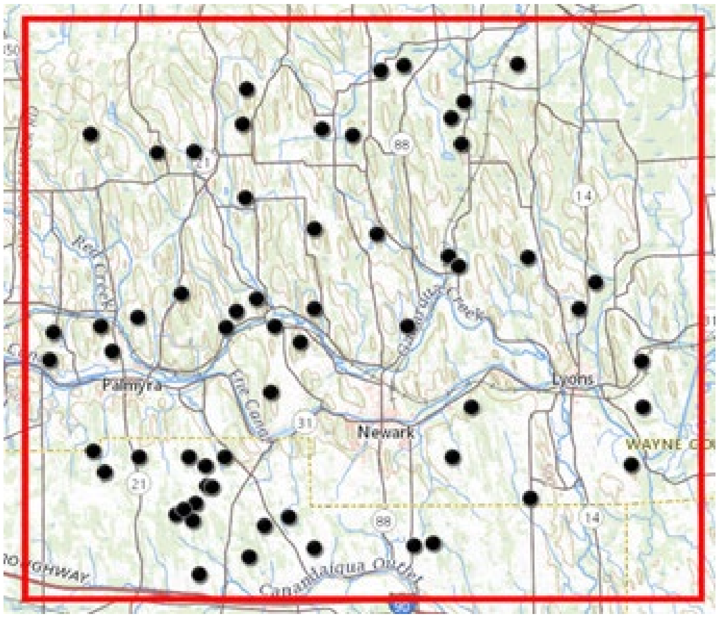


Figure 2. Inset from Figure 1 with black marks indicating 60 selected drumlins.

MATERIALS AND METHODS

Data Collection Process

Using AGOL, a high-density area of drumlins (792 km2) was isolated (Fig. 1) within Subregion 2 from work by Hess and Briner (2009). 60 prototypical drumlins were chosen (Fig. 2)—elliptical shape with a single tapered end and an asymmetrical long profile (Fig. 3). Map points were added to mark the highest elevation of each drumlin, based on the USA Topographic map.

Four preloaded, AGOL basemap options were used to collect measurement data initially: (A) USA Topographic, (B) USGS Topographic, (C) Multidirectional hillshade, (D) Terrain w/ labels (Fig. 4 A-D). Length and azimuth were measured using lines that connected the farthest two points of the drumlin, from blunt end to tapered end, while crossing through the center point (Fig. 5). For consistency, all lines were drawn from blunt end to tapered end. This process was repeated for the same 60 drumlins on all four AGOL provided basemaps.

Four hillshade maps (azimuth from which the light is projected): (E) 171°, (F) 261°, (G) 351°, (H) 081° (Fig. 4. E-H), were generated in ArcGIS Pro to evaluate the effects of shading on data collection. The azimuths used to generate the hillshade maps were determined by moving 90° from the mean azimuth of the drumlins (171°) (Fig. 6). The same process for measuring length and orientation data was repeated on the four generated hillshade maps. Length and orientation data (n=480) were extracted using ArcGIS Pro.

Figure 3. Long-axis cross-sectional profile of a prototypical drumlin.

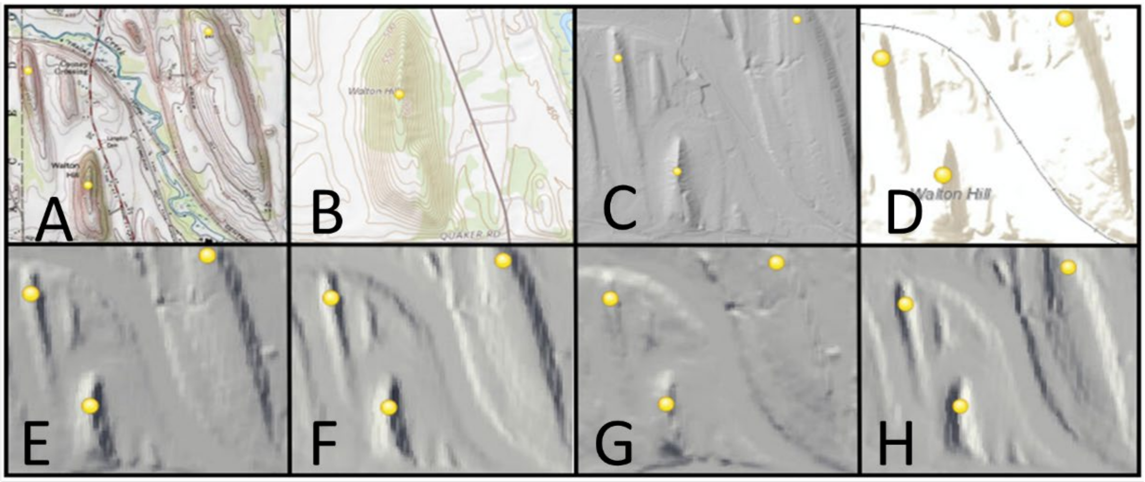


Figure 4. Basemaps evaluated. Top row (left to right)–AGOL provided basemaps: (A) USA Topographic, (B) USGS Topographic, (C) Multidirectional hillshade, (D) Terrain w/ Labels. Bottom row (left to right)–generated hillshades (light shining from azimuth): (E) 171°, (F) 261°, (G) 351°, (H) 081°.

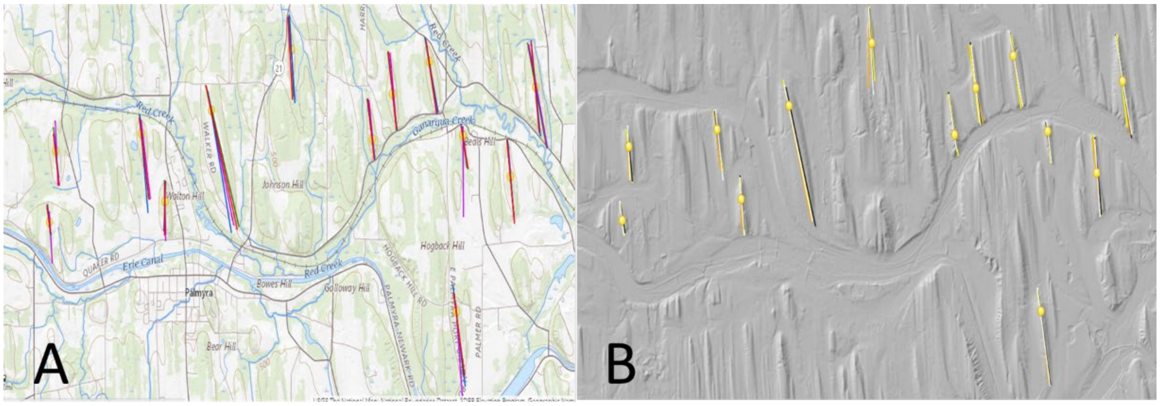


Figure 5. Drumlin length and orientation lines from (A) four ArcGIS basemaps and (B) four generated hillshades.

Data Organization

EZROSE (Baas, 2000) software was used to determine the mean azimuth of all 60 drumlins on each basemap. Rose diagrams were produced to visualize the distribution of the drumlin azimuths using Stereonet 11 (Allmendinger, 2020). Two rose diagrams were created, one diagram overlaying the AGOL basemaps (n=4), and one diagram overlaying the Hillshade maps (n=4) (Fig. 7). To compare mean length and azimuth data between the basemaps, two sample t-tests and linear regression tests were run through Minitab, and all results were recorded in tables.

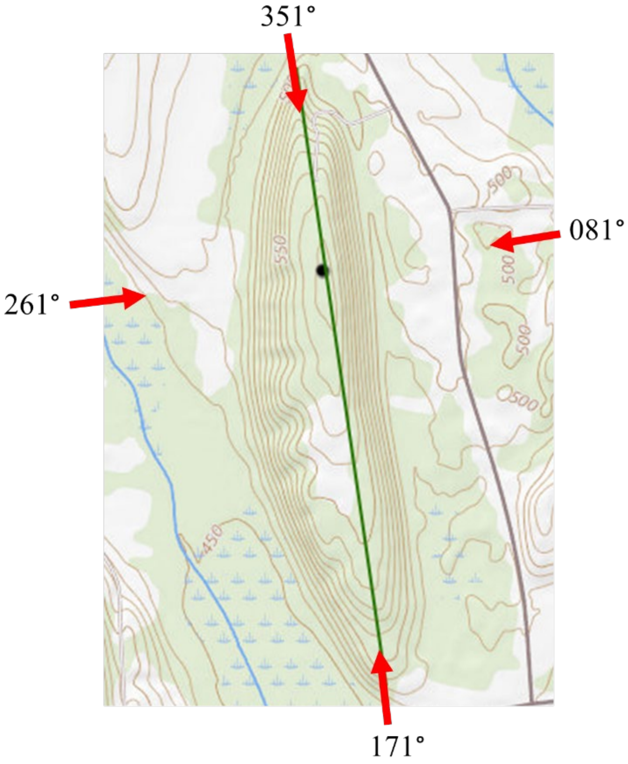


Figure 6. Prototypical drumlin from top view (drumlin #6) displaying angles of illumination for each hillshade map.

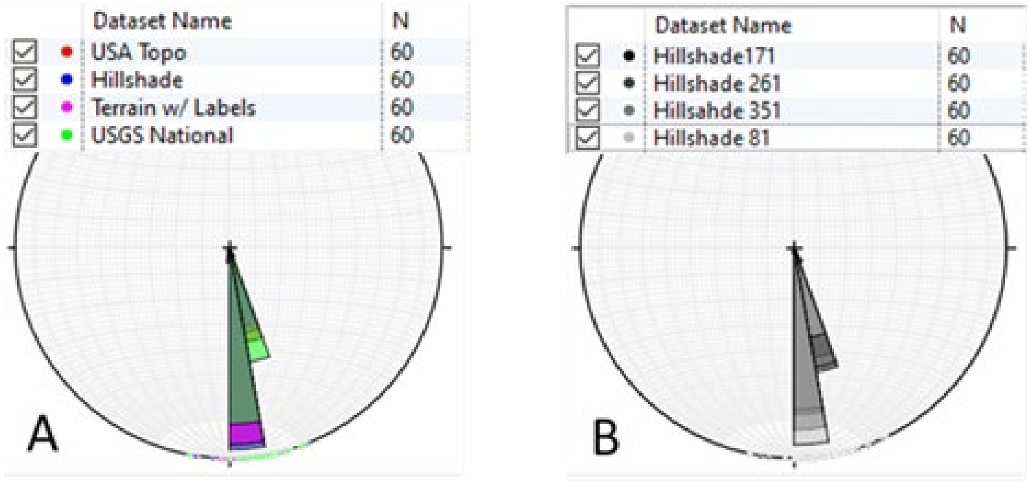


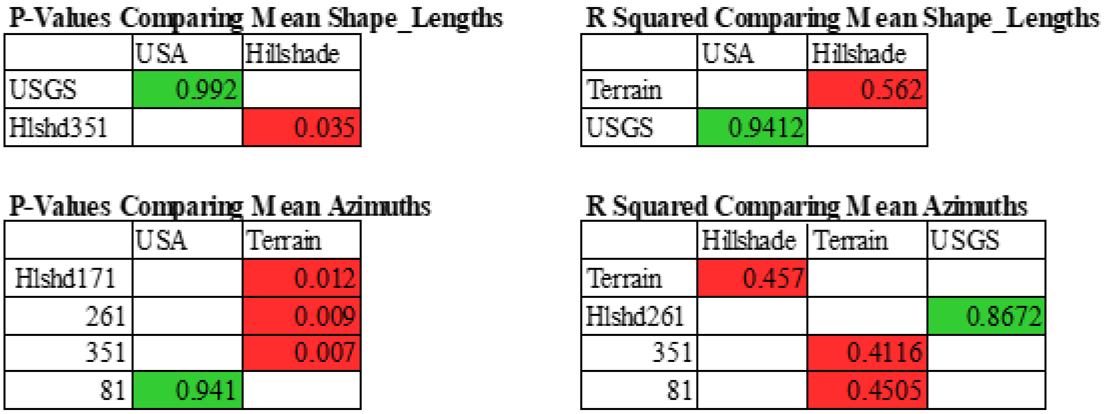
Figure 7. Rose diagrams displaying the drumlin azimuths on (A) the AGOL basemaps (n = 240) and (B) the generated hillshade maps (n = 240).

RESULTS AND INTERPRETATIONS

The mean drumlin length was 1,662m, ±529, and the mean azimuth was 171°, ±0.3. Compared across all eight basemaps, the results showed significant differences in the length and orientation data between the generated hillshade and terrain basemaps.

The p–value from the t-tests indicates how significant the results are in relation to the null hypothesis that there is no relationship between the type of map and the data collected. With a 99% confidence interval, a p-value above 0.01 indicates that the null hypothesis is accepted and there is no significant difference between data collected from different map types. A p-value below 0.01 indicates that the null hypothesis is rejected and there is a significant difference between data collected from different maps. The r-squared value is the coefficient of determination; it indicates the percent variation between two variables or data sets (Glen, 2021). R-squared values closer to 1 indicate a better relationship and less variation between data sets.

The Terrain map consistently got the lowest statistic values, particularly versus the hillshade from a direction of 351° (t(59) = 1.84, p = .007, R2 = 0.4116)(Fig. 8). It is difficult to place measurement lines on the hillshade drumlins because the tapered ends seem to disappear into the map and the reader is left to guess where the drumlin ends (Fig. 9). There is less zoom capacity on the terrain and hillshade maps, which causes lower resolution and makes it harder to determine if the measurement lines reach, or extend past, the actual edges of the drumlin (Fig. 9 B and C).



P-Values Comparing Mean Shape_Lengths

	USA	Hillshade
USGS	0.992	
Hlshd351		0.035

R Squared Comparing Mean Shape_Lengths

	USA	Hillshade
Terrain		0.562
USGS	0.9412	

P-Values Comparing Mean Azimuths

	USA	Terrain
Hlshd171		0.012
261		0.009
351		0.007
81	0.941	

R Squared Comparing Mean Azimuths

	Hillshade	Terrain	USGS
Terrain	0.457		
Hlshd261			0.8672
351		0.4116	
81		0.4505	

Figure 8. P-values and r-squared values comparing mean drumlin lengths and azimuths between all eight GIS maps (99% CI); green boxes are the highest values and least differences; red boxes are the lowest values and most differences.

The USGS Topographic map, which has a defined landform outline, had the least number of differences when compared to the USA Topographic map (t(59) = -0.01, p = .992, R2 = 0.9412)(Fig. 8) and was best for data collection. The defined outlines from the contours and high zoom capacity allowed clear placement of measurement lines (Fig. 9 A). The measurements were very closely related across the topographic basemaps, making them the more suitable options for collecting accurate measurement data. The USGS and USA Topographic maps are, additionally, both derived from USGS paper maps, which likely contributes to the lack of variability.

Hillshade maps rely on illumination and shading to create a more realistic, three-dimensional look, but certain angles and overexposure can lead to obscured edges and loss of landform structure (Nagi, 2014). On the 351° hillshade map, the sun is "shining" from the north at 351o, illuminating the drumlins parallel to the long axis and hitting the blunt/non-tapered end; causing the tapered tail to visually disappear into the shadow (Fig. 9 C). This effect makes it difficult to decide where the measurement lines should end. When using the AGOL-provided, or self-generated hillshade maps to analyze asymmetric landforms, a direction of shading parallel to the line of symmetry may be less accurate for analysis due to the visual loss of part of the landform. Seeing the entire landform outline is a critical detail on a basemap being used for measurement data. Topographic maps provide those outlines, making them a better basemap choice for landform measurements.

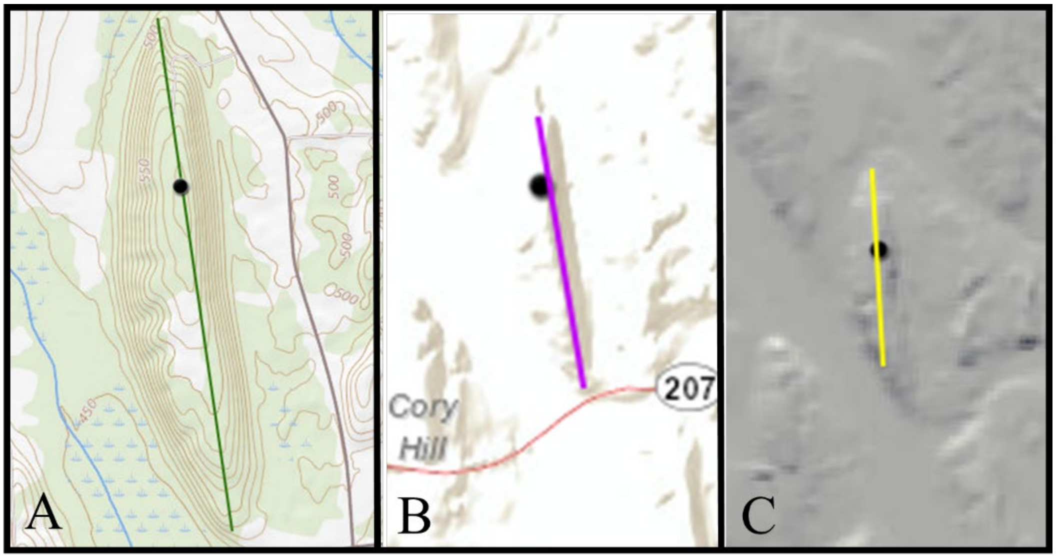


Figure 9. Drumlin #6 across three basemaps: (A) USGS Topo drumlin with visible outline, (B) terrain w/ labels drumlin with unclear outline, (C) hillshade 351° drumlin with disappearing tail.

DISCUSSION

Multiple factors make a map more or less readable; readability being measured as ease of use, ability to understand, and minimum time needed to interpret, subjectively (Sari et al., 2020). Those factors can include accessibility, speed, color scheme, interactive features, and labelling (Sari et al., 2020), and aid in creating the most suitable basemap. The type of basemap ultimately depends on the purpose of the map and what is being viewed (e.g., landforms, soil, water, vegetation). For drumlins, a topographic map was most suitable for collecting measurement data, but topographic and hillshade relief maps are both commonly used to view landforms. While topographic maps are better for measurements, hillshade maps are more visually appealing and help users understand the relief of the landform. As Herman et al. (2018) displayed, it is possible for one map type to be preferred by users, while another map type is more readable statistically. This being the case, map types should be combined to create an ideal map that is both pleasing to view and useable.

Optimal Map Design

In the case of mapping landforms for analysis and data collection, we can combine maps to create optimal visualization while also providing established landform outlines. For example, colors can be added to a 'bump' map to create an elevation color map (Nighbert, 2003), where a color scheme can simulate topographic lines (Fig. 10). Bump mapping is a technique that adds a Digital Elevation Model (DEM) onto an existing surface by assigning an elevation to each cell; using a grayscale, lighter pixels represent maximum relief and darker pixels represent minimal relief (Garrity, 2004). This eliminates the problematic angle of illumination. Then adding colors to the bump map visually creates a more definite outline of the landform leading to better measurement data.

Cammarano (2018) suggests that an ideal terrain map is one with simplified, or softened, ridge shading overlayed by image-based contour lines (Fig. 11). This map provides the accuracy from the contour lines. Shade softening can provide a more realistic appearance of landforms (Garrity, 2004), making the map easier to read as well. Both options suggest that an optimal map for surficial landforms can be created by combining 3D visualization with a form of topographic contour lines. Bump mapping may be a better visualization technique than regular hillshade and softening the shading will allow for a better combination with contour lines.

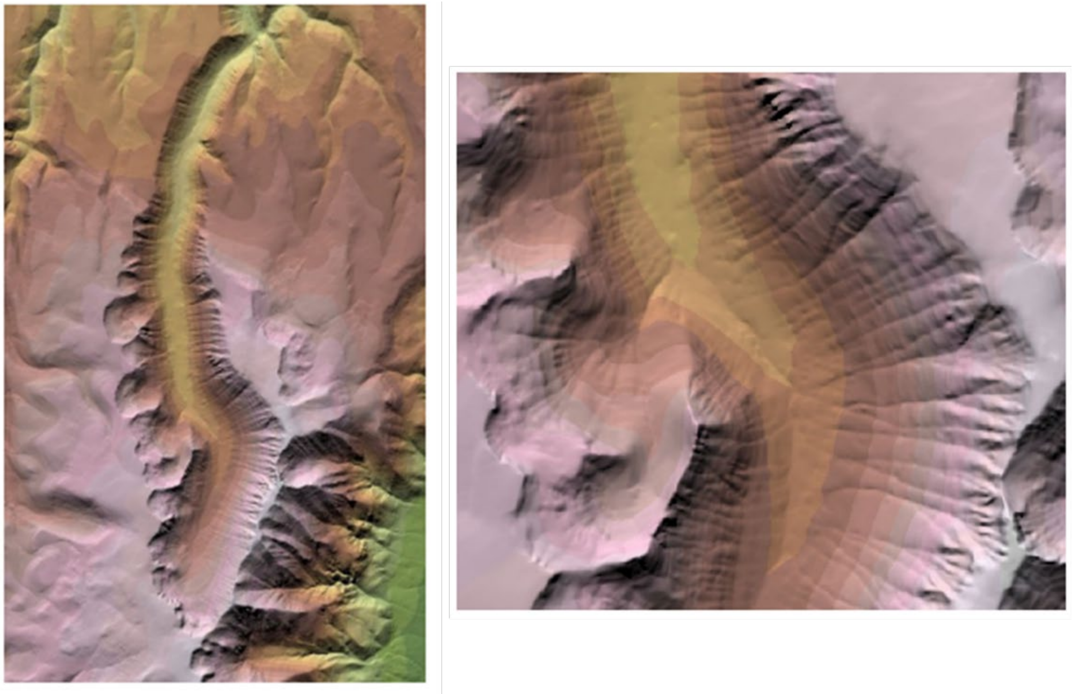


Figure 10. Hillshade bump map with elevation color ramp (modified from Nighbert, 2003).

Importance of Optimal Basemaps

Maps are a primary, and essential, form of interface between humans and spatial data (Gartner, 2014) because maps portray spatial data (e.g., physical, topographic, climatic, political) in a readable format. Continual advances in technology have created a surplus of collected data, all of which needs to be sorted, condensed, and displayed in useable forms (Gartner, 2014). Coupled with increasingly advanced remote-sensing technology, useable maps allow us to understand and analyze any place our technology can reach, including places like Mars, where humans have not yet stepped foot. All of the groundbreaking data collected must be conveyed in a readable and understandable format, and for spatial data that includes a map.

The ultimate use for a map should be considered when the map is created; this will ensure that the GIS technology can serve the use of the map and demands of the data (Gartner, 2014). When creating a map, we should focus on how the map will be used, whether for visualization, measurements, or another purpose, and if the map design will be practical for the purpose of the map. It is common to have generic maps and use them for multiple purposes, but they do not always allow for the best interpretation of data. This researched displayed that a better basemap improves the perception and useability of a map. Maps need to go beyond generic, standardized maps; they need to be reader-centric (Meier et al., 2019), and this means creating maps specifically for a certain use. Generic basemaps are a great start, but when there is a specific purpose for a map (e.g., collecting measurement data), we should optimize its primary use (e.g., readability, understanding, accuracy) by using a map type specifically designed for the purpose of the project.

Figure 11. Terrain map with ridge shading and contour lines (modified from Cammarano, 2018).

CONCLUSIONS

The ability to create new and better suited basemaps ensures that mapping can keep up with the enormous amounts of data collected through remote-sensing technology (Gartner, 2014). Viewing landforms on different basemaps causes variation in perception, readability, and useability, so it is vital to choose a basemap that works best for the outcome desired, such as remote landform measurements. Topographic maps are still a standard, dependable map because of the established outline of landforms and less visual variability, but they can be combined with other maps to create an optimal reader experience. Hillshade maps are very useful for landform visualization but lack accuracy for collecting remote measurements because of the varying angles of illumination and lack of definite landform outlines. Maps combining both hillshade relief and contour lines may be an optimal choice for collecting landform data (Fig. 10 and 11). Choosing an optimal basemap is an essential aspect of our mapping world, which acts as the primary interface between humans and spatial data (Gartner, 2014). Creating maps that serve the purpose for which they are needed is the best way to understand and accurately use the spatial data we have access to.

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