Advanced Techniques for Watershed Visualization

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Abstract

Analytical shaded relief is commonly used for visualization of Digital Elevation Models (DEMs). Sometimes, the quality of unaltered analytical shaded relief can be lacking for identification of streams and water divides. Hydroshading [1] is a technique that provides enhanced capabilities of visualization of hydrologically-meaningful topographical features. In this research, hydroshading algorithms are applied to NASA's Shuttle Radar Topography Mission (SRTM) DEM datasets. The visualization technique is applied to coastal and inland watersheds in Mississippi (Saint Louis Bay and Luxapallila, respectively). The testing of hydroshading in these two areas shows that the technique is more effective in areas with moderate topographical relief than in low relief terrain. Combining hydroshading with standard three-dimensional visualization of DEMs enhances identification of water divides and streams. Hydroshaded DEMs were used to manually delineate Luxapallila and Saint Louis Bay's Wolf River catchments. Delineation results are comparable to output of standard automated delineation produced by GIS software (BASINS).

1. Introduction

One of the initial steps on the process of modeling watershed hydrology is watershed delineation. Watershed delineation is the hydrologic division of a watershed into sub-watersheds that are relatively homogeneous in terms of topography, land use, and other criteria and information. Although land use and other factors play an important role within the process of delineating a watershed, topography is used as the primary reference [2]. Watershed delineation has been "automated" in many GIS/hydrologic software packages, needing the user only to provide (via interactive process) the database location and other information required by the delineation algorithm. Therefore, results of automatic delineation are strongly dependent on software-specific methodologies, quality of the topographic database (scale, resolution, etc), and user's requirements.

Several papers have examined the differences of watershed delineation results after swapping topographical databases or using different software packages. For example [2] used digital elevation data from Interferometric Synthetic Aperture Radar (IFSAR), Shuttle Radar Topography Mission (SRTM), National Elevation Dataset (NED), and the United States Geological Service' Digital Elevation Model (USGS-DEM), to delineate a portion of the Saint Louis Bay watershed (Mississippi). Although [2] used the same GIS software to perform the delineation (BASINS), final delineation results showed similar distribution of sub-basins but the demarcation of sub-basin boundaries was different in each case, producing differences in area and perimeter of sub-basins. Furthermore, [2] report that automatic delineation using IFSAR and SRTM data produced isolated inner areas generating defective final delineation of the watershed under study. [3] report automatic delineation results showing that using different-resolution Digital Elevation Models (DEM) and automatic delineation strategies affect total area of delineated watershed and sub-basin classification. [4] compared automatic delineation results using different DEMs for 50 locations (in the contiguous United States) and reported that using coarse DEMs causes a decrease in sub-basin catchment area. [5] showed that using automatic watershed delineation on three catchments in Mississippi, with two different topographic datasets, produced distinct watershed segmentations. Therefore, previous research has shown that automatic watershed delineation may produce ambiguous results in some cases. This opens the opportunity to novel techniques of fast watershed visualization that would enhance automatic delineation results by allowing watershed modelers visualize the watershed *a priori* or *a posteriori* of the automatic delineation process.

Shaded relief methods are commonly used for representing topography on maps in a natural, aesthetic, and intuitive manner. Analytical shaded relief is the name given to relief created from digital elevation models (DEMs) [6] [7] [8] [9]. However, sometimes the quality of unaltered analytical shaded relief can be lacking for making appealing and descriptive maps. For example, streams in flat areas tend to vanish if low illumination angles are not used, or water divides are not easily distinguishable. Graphical improvements to analytical relief are possible. Hydroshading [1] is a technique that provides enhanced capabilities of visualization of hydrologically-meaningful topographical features.

In this research, hydroshading algorithms [1] are applied to NASA's Shuttle Radar Topography Mission (SRTM) Digital Elevation datasets, for visualization of water divides and stream networks. The visualization of water divides is an important component of the process of watershed delineation. The visualization technique is applied to coastal and inland watersheds in Mississippi (Saint Louis Bay and Luxapallila, respectively).

2. Methods

2.1. Study area

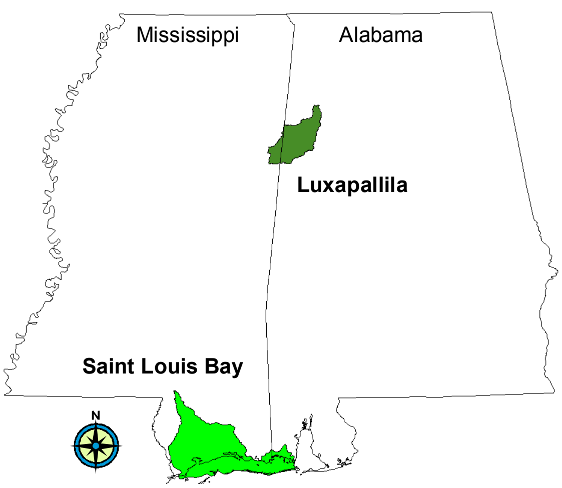

Figure 2.1. Study areas. Luxapallila and Saint Louis Bay watersheds.

Two watersheds in Mississippi were selected for this study (see Figure 2.1). Luxapallila watershed (USGS HUC 3160105) is located in northeastern Mississippi and northwestern Alabama (from 88° 40' W, 33° 17'; to 87° 41', 34° 5' N). The catchment's area is approximately 201227 ha; mostly covered by forest and agricultural lands according to the USGS GIRAS land use classification. Jourdan River and Wolf River catchments, located in Saint Louis Bay watershed (USGS HUC 03170009) draining approximately 202278 ha in the Mississippi gulf coast (from: 89° 44' W, 31° 7' N; to 87° 56' W, 30° 2' N). The region is mostly covered with forests with some agricultural lands in the western portions of the watershed. Urban development is concentrated along the Mississippi coast.

2.2. Topographical database

The Shuttle Radar Topography Mission (SRTM) was a collaborative work between the National Aeronautics and Space Administration (NASA) and the National Imagery and Mapping Agency (NIMA) [10]. SRTM collected interferometric radar data to generate a near-global topography data product for latitudes smaller than 60. As part of the SRTM mission, an extensive ground campaign was conducted by NIMA and NASA to collect ground-truth data which would allow for the global validation of the SRTM data set [11]. SRTM2 DTED are the finished DTED Level 2 (1 arc sec or nominal 30 meter post spacing, 0.01 m vertical) processed by NASA's Jet Propulsion Laboratory and edited by NIMA contractors. Spikes and wells over 100 m were eliminated. Small voids, 16 contiguous posts or less in extent, were filled by interpolation. Larger voids remain in the data. Water bodies were identified and delineated, and their elevations have been set. SRTM2 DTED over U.S. territory are public domain and unrestricted. All other SRTM2 DTED data are limited distribution [12].

This research used SRTM2 DTED data sets that were tailored according to the requirements of the hydroshading algorithm and the specific characteristics of the study areas.

2.2. Hydroshading technique

The hydroshading technique consists of enhancing the visualization of standard DEM datasets by providing better identification of concave areas on hill slopes and streams. This research uses the IDL scripts developed by [1] for the processing of the original DEMs. The hydroshading process (including pre-processing) is summarized in the flowchart below. Figure 2.2 shows details on the process steps for generating hydroshaded images from SRTM Digital Elevation Models (DEM).

Usually, the SRTM data cubes do not cover completely the geographical boundaries of the areas under study. A mosaic needs to be generated from several SRTM cubes and clipped to a manageable size for input into the hydroshading algorithm. This pre-processed DEM is also used to generate a shaded-relief version of the DEM.

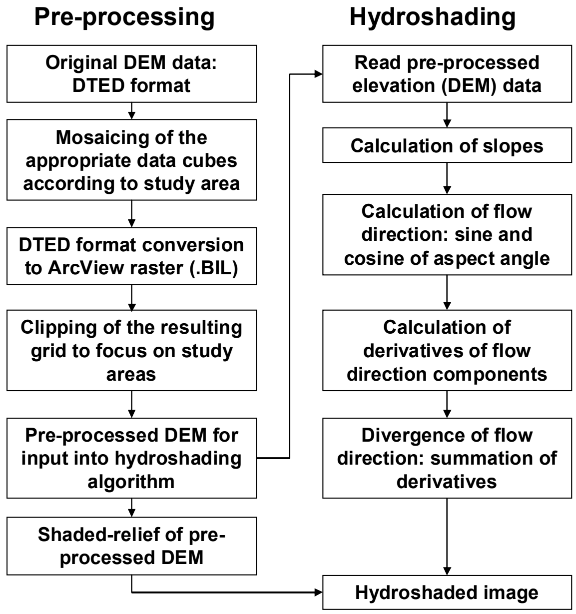

Figure 2.2 Hydroshading process.

The hydroshading algorithm consists, initially, on the calculation of slopes, from the pre-processed DEM. Slopes are considered to be vector entities with magnitude (gradient S) and direction (aspect angle Θ). Flow-direction unit vectors in the X and Y directions are calculated with Fx = sin Θ and Fy = cos Θ . The summation of the derivatives of these units vectors in the X and Y directions constitute the divergence of flow direction: $D = \frac{\partial Fx}{\partial x} + \frac{\partial Fy}{\partial y}$.

Having obtained the shaded-relief grid (SR) and the divergence grid (D) for the DEM, the hydroshaded image is generated by assigning red and green colors to the sum SR + D and blue color to the subtraction SR – D, through standard band-math imaging tools. Processing required the use of ArcGIS for mosaicing, and ENVI for all subsequent grid operations and visualization. ENVI scripts developed for [1] were used in this research, with permission and assistance from the author.

3. Results

Figure 3.1 shows initial, middle and final steps of the hydroshading process for the Luxapallila area. Figure 3.1A) shows the shaded-relief visualization of the Luxapallila area DEM, using typical lighting parameters (Azimuth: 315 deg; Elevation: 30 deg). Streams appear indistinguishable from water divides.

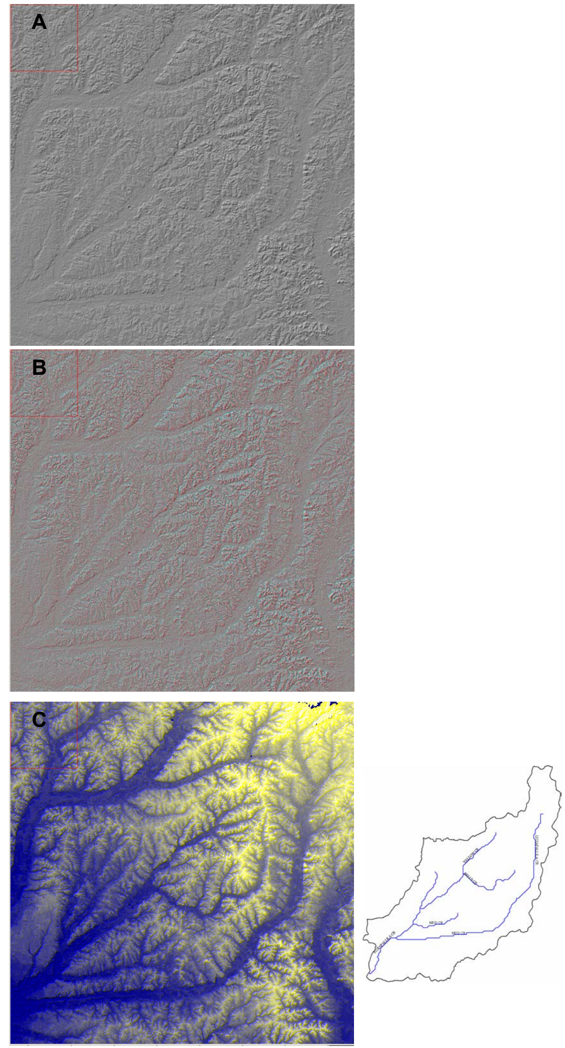

Figure 3.1 Hydroshaded DEM for Luxapallila watershed. A) shaded-relief, B) divergence of flow direction, C) hydroshaded image.

Figure 3.1A) illustrates how standard shaded relief methods may not be useful enough for visualization of low relief topography. Several combinations of azimuth and elevation values were tried without further success. Figure 3.1B) shows the divergence of flow direction for the same area. Divergence of flow direction is positive on ridges and negative in streams and hollows. However, by itself, divergence of flow direction does not provide further insight for DEM visualization. Nevertheless, the combination of both images (as described in the Methods section) produces optimum identification of ridges and streams, as seen in Figure 3.1C). Hydroshading allows clear identification of perennial and non-perennial streams, as well as water divides.

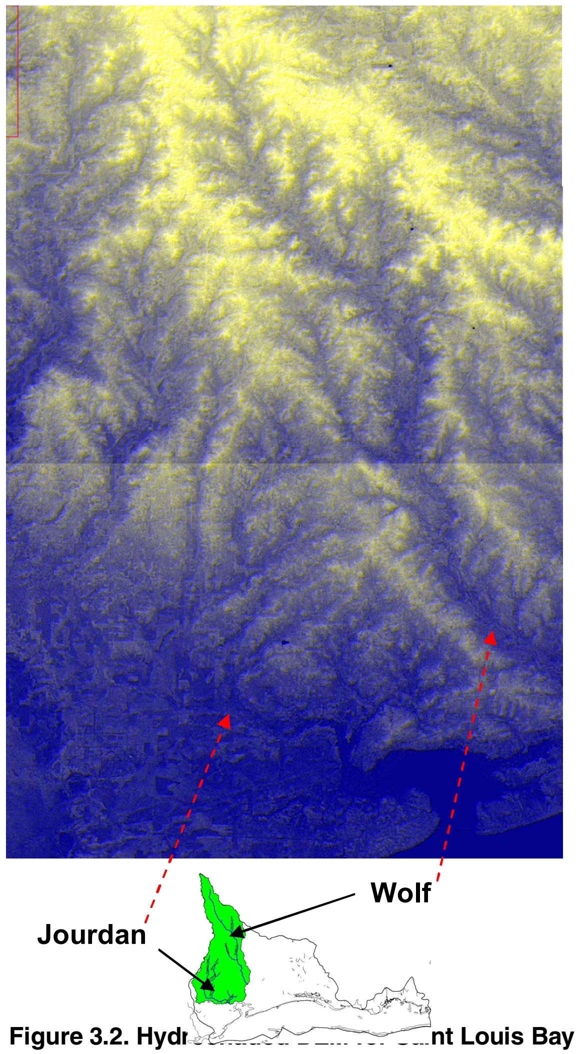

Figure 3.2. Hydroshaded DEM for Saint Louis Bay watershed (composite includes Jourdan and Wolf Rivers).

Saint Louis Bay watershed terrain is flatter than Luxapallila's [5]. This is shown by the hydroshading results for the region of Wolf and Jourdan rivers catchments (shown in green in Figure 3.2). Results for the Jourdan River surrounding area are less effective for visualization of ridges and streams because the area corresponds to the coastal plane of Saint Louis Bay with a total elevation difference of only 25 meters [5]. Therefore, hydroshading does not provide optimum visualization of areas with very low relief.

Combining the hydroshading results with three-dimensional visualization of DEMs seems to be the best option to visualize low-relief topography. Figure 3.3 shows 3-D visualization of the Saint Louis Bay areas under study.

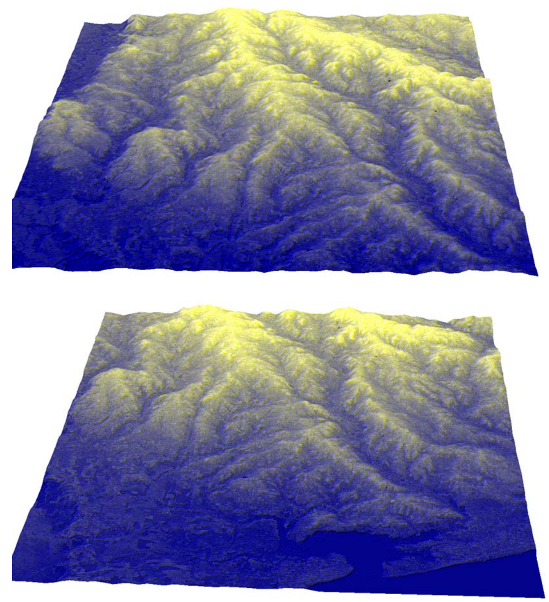

Figure 3.3 Three-dimensional visualization of upper and lower Wolf and Jourdan Rivers.

As seen in Figure 3.3, hydroshading and 3-D visualization provide a better characterization of water divides and streams, primordially in the Wolf River area.

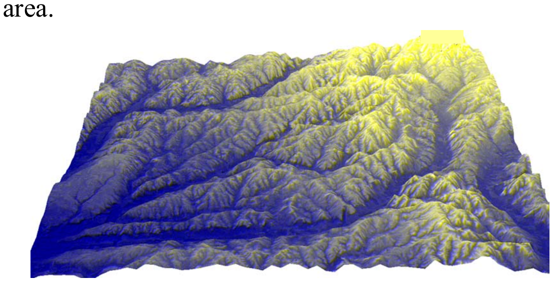

Figure 3.4. Three-dimensional visualization of hydroshaded Luxapallila area.

For an area with more topographical relief (such as Luxapallila), this combined visualization produces much better identification of ridges and areas of convergence (rivers), as seen in Figure 3.4. This enhanced visualization is applied for manual delineation of the Luxapallila watershed and the results are compared to a standard automatic delineation of the same area made through the BASINS software (Figure 3.5). Manual delineation of Luxapallila watershed is easily performed using the hydroshaded DEM for the Luxapallila area. The upper left corner of Figure 3.5 shows the results of a delineation made in BASINS (automatic delineation option). Areas in yellow (from the small image) should be compared to the manual delineation (red line) shown in the hydroshaded DEM for the area.

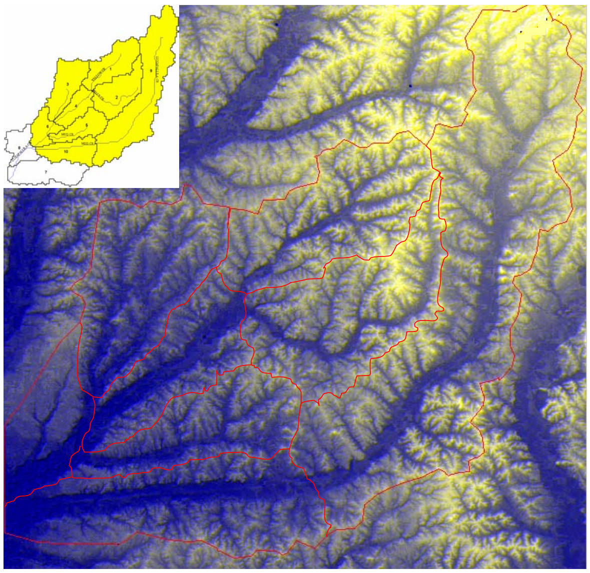

Figure 3.5 Manual delineation of Luxapallila watershed using hydroshading results.

Although minor differences are present, similarity in sub-basin distribution and areas is predominant. The resulting polygons from the manual delineation can be exported to Arcview shape files for use by other GIS/hydrological software.

Figure 3.6 compares results of manual delineation performed using the hydroshaded DEM for Wolf River, located in the Saint Louis Bay watershed. Although the manual segmentation of the catchment is not as straight-forward as in the Luxapallila case, the end-result compares optimally with the automated delineation shown in the upper left corner of the figure.

No attempt has been done to delineate Jourdan River catchment. Although hydroshading allows good identification of ridges and streams in the northern regions of the catchment (see Figures 3.2 and 3.3), lower regions are not well defined in terms of water divides and areas of water convergence.

Most of the time spent in the whole hydroshading process is invested in the pre-processing of the DEM. However, once that a good methodology is defined, a script for pre-processing speeds up the achievement of a final hydroshaded DEM. The actual application, processing, visualization and manual delineation of the hydroshaded DEM is comparatively much faster than automated delineation procedures. This is valid for either, a rough relief watershed terrain as Luxapallila's or a low relief watershed topography such as Wolf's.

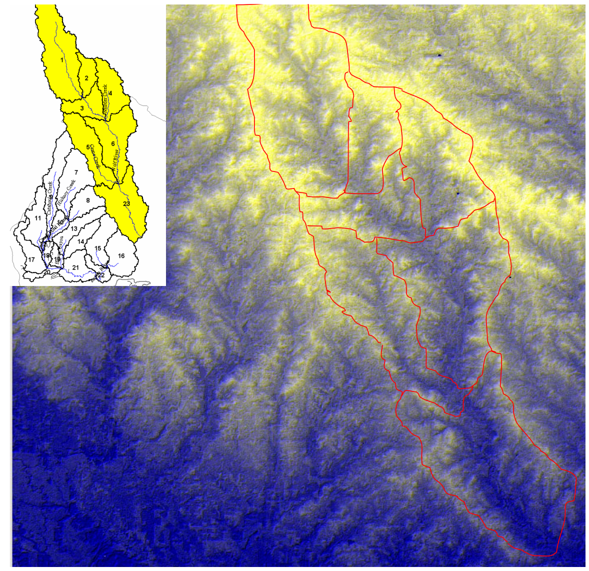

Figure 3.6 Manual delineation of Wolf River catchment in Saint Louis Bay watershed using hydroshading results.

4. Conclusions

Hydroshading is shown to be a good technique for visualization of topographical information contained in Digital Elevation Models (DEMs). The testing of hydroshading in two areas of study shows that the technique is more effective in areas with moderate topographical relief than in low relief terrain.

The combination of hydrohsading with standard three-dimensional visualization of DEMs provides an effective mean for representation and identification of areas of flow divergence (water divides) and flow convergence (streams). The ease and speed for producing hydroshaded DEMs makes hydroshading a good option for providing additional insight *a priori* or *a posteriori* of standard geoprocessing operations on DEM (e.g., watershed delineation).

Hydroshaded DEMs can be used to manually delineate a watershed into smaller hydrological units (sub-basins). Since the water divides and streams are easily viewed, watershed segmentation is fast. Manual delineation results for Luxapallila and Wolf River catchment (in Saint Louis Bay watershed) are comparable to output of standard automated delineation produced by a popular GIS software (BASINS), with the additional advantage that they are done very fast in comparison to the time-intensive automatic delineation process. Delineation for the low-relief Jourdan River catchment was not possible to perform due to the non-optimal identification of ridges and streams.

5. References

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