USING IFSAR AND SRTM ELEVATION DATA FOR WATERSHED DELINEATION OF A COASTAL WATERSHED

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ABSTRACT

In this research, Interferometric Synthetic Aperture Radar (IFSAR) and Shuttle Radar Topography Mission (SRTM) data are used to delineate a portion of the Saint Louis Bay watershed (Mississippi). In addition to these two digital elevation databases, the National Elevation Data (NED) and the United States Geological Service' Digital Elevation Model (USGS-DEM) are also used for delineation. Results show that, SRTM elevation data produce optimum delineation results comparable to delineation achieved using NED when areas and sub-basin perimeters are compared. Vertical topographical parameter values, however, differ substantially in flatter terrain. SRTM delineation provides overland plane slope values up to 35 times higher than those provided by the NED delineation. Flatter sub-basin's river slopes show up to 500 percent difference when comparing slopes provided by SRTM and NED. These results could be significant for hydrological simulation. Processing time and difficulty on getting final delineation results incur in limitations on the direct use of IFSAR data. Future improvements on BASINS may allow an efficient use of IFSAR data for watershed delineation. Conclusions are drawn from the comparison on the quality of the delineations and it's usefulness in hydrological modeling.

INTRODUCTION

Watershed delineation is the hydrologic division of a watershed into sub-watersheds that are relatively homogeneous. This homogeneity is determined taking into account land use, topography 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. With the widespread availability of digital elevation databases, watershed delineation has been automated in many GIS/hydrologic software. This automation, however, has made delineation very dependent on the quality of the digital elevation data.

The effects of Digital Elevation Models (DEMs) resolution in watershed delineation have been reviewed in several papers. Alarcon et al. (2006a and 2006b) explored the effects of DEM resolution in delineation and flow estimation for three catchments in Mississippi. Results showed that coarser DEM datasets produce further segmentation of the catchments' area. Chaubey et al. (2005) report results showing that DEM data resolution affects total area of delineated watershed, predicted stream network and sub-basin classification. Hancock (2005) explored the effect of different grid scales in the identification and characterization of catchments, finding that the area-slope relationship, cumulative area distribution, width function and Strahler statistics were sensitive to digital model grid scale. Wolock and McCabe (2000) compared DEMs for 50 locations (in the contiguous United States) for slope, specific catchment area and wetness index values. Their paper reports that using a coarse DEM causes a decrease in mean slope and increases in mean specific catchment area and wetness index, being terrain discretization (not terrain smoothing) the primary mechanism by which DEM resolution affects those catchment indicators. Wolock and McCabe (2000) also found that the terrain-discretization effect of DEM resolution is more pronounced on relatively flat terrain with long length-scale terrain features. Similar results are reported in Wolock and Price (1994). Zhang and Montgomery (1994) showed that grid size significantly affects topographic parameters and hydrographs by decreasing slope estimations and increasing contributing areas for larger grids, and, increasing peak discharges (in the estimated hydrograph) with increasing grid size.

The review above shows that DEM grid size, scale and resolution affects substantially watershed delineation. This is more evident in coastal areas where elevation differences are small and sub-basin areas tend to be large. In this research, Interferometric Synthetic Aperture Radar (IFSAR) and Shuttle Radar Topography Mission (SRTM) data are used to delineate selected regions of the Saint Louis Bay watershed (Mississippi). In addition to these two digital elevation databases, NED and USGS digital elevation models are also used for delineation.

METHODOLOGY

Study area

The study area is located in Southern Mississippi within the Saint Louis Bay watershed (Figure 1).

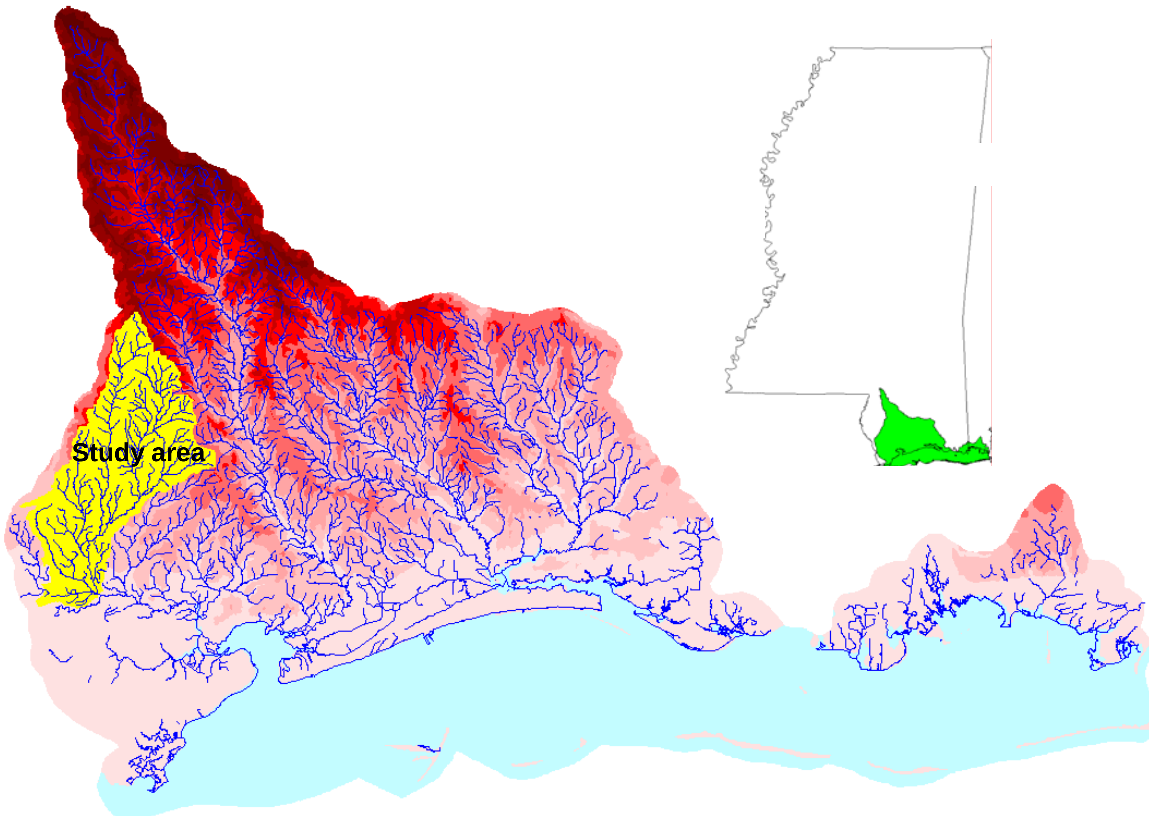

Figure 1. Study Area. Jourdan River catchment in Saint Louis Bay.

Digital elevation models

Interferometric Synthetic Aperture Radar (IfSAR or InSAR) is an aircraft-mounted sensor designed to measure surface elevation, which is used to produce topographic imagery. Radar pulses are aimed at targets on the Earth, and the return ground signals are received by two antennas that record elevations (z) at specific ground coordinates (x,y). The ground coordinates are determined by Global Positioning System (GPS) and inertial measurement unit (IMU) technology. Post-processing of these data produces topographic information in the form of orthorectified radar imagery (NOAA, 2006). IfSAR-Derived Products are: Digital Elevation Models (DEMs), Digital Terrain Models (DTMs) (bald-earth elevation data) and Digital Surface Models (DSMs). The Digital Surface Model (DSM) products represent the first reflective surface as illuminated by the radar. The DSM data for 7.5-minute by 7.5-minute units correspond to the USGS 1:24,000 scale topographic quadrangle map series was used for this research. Each 7.5-minute by 7.5-minute DSM is comprised of elevations at 5 meter postings. Each tile provides full coverage with overlap into adjacent tiles. Data was collected during November 2003 (Intermap Technologies Inc., 2005). The DEM grid cells are organized in 3001 rows by 3001columns, in geographic coordinates (0.0000416667 lat/long), decimal degrees (NAD83, GRS80), and 5 meter posting grid cell. The DEM is a 32 bit IEEE floating point value organized in a one-channel Band Interleaved by Line file (BIL) on a 7.5-minute by 7.5-minute geographic (lat/long) grid. The elevation values per grid cell have 0.01 m vertical resolution (Intermap Technologies Inc., 2005).

The Shuttle Radar Topography Mission (SRTM) was a collaboration between the National Aeronautics and Space Administration (NASA) and the National Imagery and Mapping Agency (NIMA) (USGS, 2006a). NIMA changed its name in November 2003 to the National Geospatial-Intelligence Agency (NGA). SRTM collected interferometric radar data which has been used by the Jet Propulsion Laboratory (JPL) 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 which would allow for the global validation of this unique data set (Rodriguez, 2005). 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 are limited distribution (USGS, 2006b).

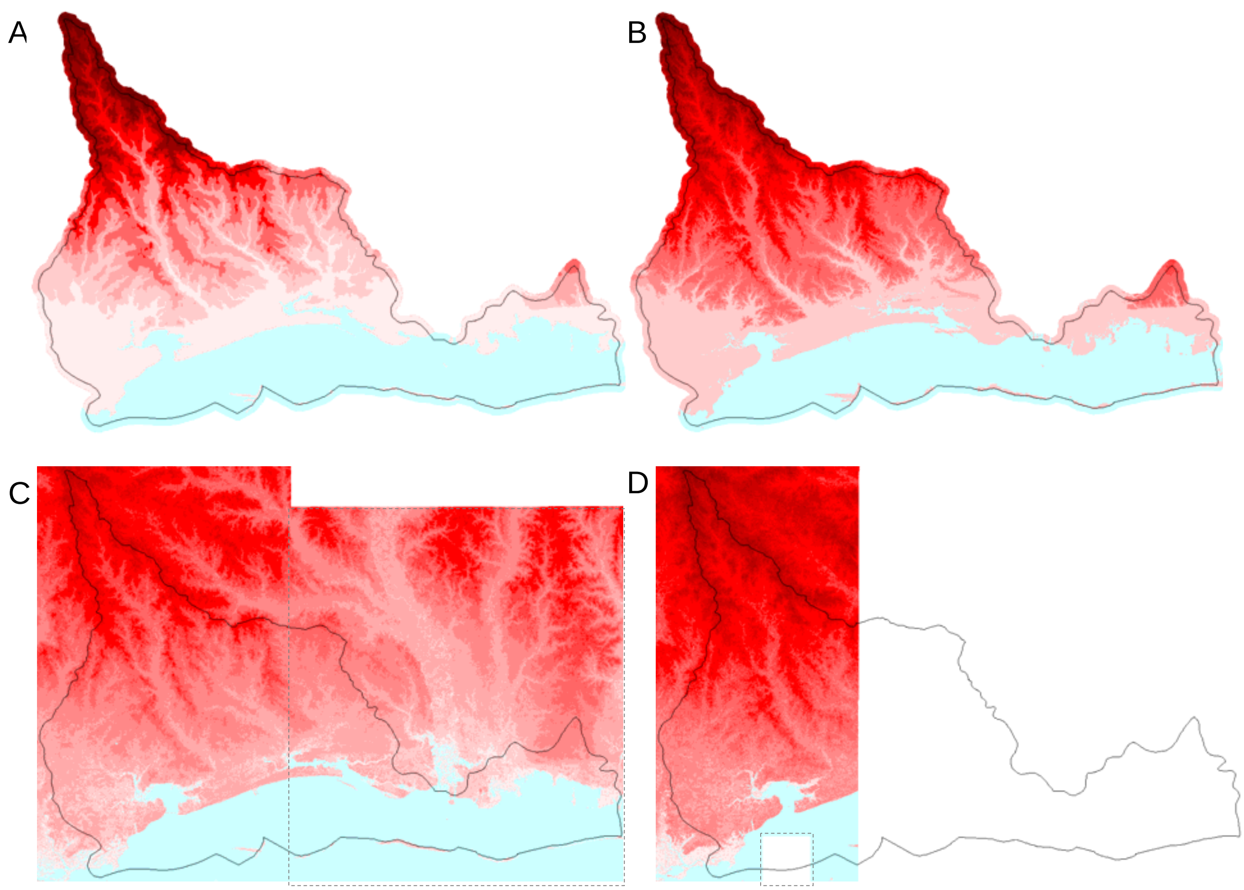

Figure 2. Effects of vertical and horizontal grid size on topography visualization for Saint Louis Bay watershed, Mississippi. A) USGS-DEM (horizontal 300m, vertical 1m), B) NED (horizontal 30 m , vertical 1 meter), C) SRTM (horizontal 30 m, vertical 1 cm), D) IFSAR (horizontal 5 m, vertical 1 cm). The empty quadrangle at the bottom of Figure 1 D) shows the size of 1 IFSAR data cube. To cover the area shown in Figure 1 D), 32 IFSAR data cubes are required. To cover the area shown in Figure 1 C), only 3 SRTM data cubes are required (the dotted quadrangle at the right of Figure 1C shows the size of 1 SRTM data cube).

The National Elevation Data (NED) is a seamless mosaic of best-available elevation data having as primary initial data source the 7.5-minute elevation data for the conterminous United States (EPA, 2004c). NED has a consistent projection (geographic), resolution (1 arc second, approximately 30 m), and elevation units (meters) (USGS, 2005b). The horizontal and vertical reference data are NAD83 and NAVD88, respectively. The USEPA used a "clipgrid" program to clip the GRID from each 8 digit HUC code boundary with a one mile buffer for the United States and its territories (EPA, 2004c). In this research, the clipped NED set for the Saint Louis Bay watershed was used.

The USGS produces five types of elevation data: 7.5-minute, 7.5-minute-Alaska, 15-minute-Alaska, 30-minute, and 1-degree DEMs. 1-Degree DEMs correspond to the 3 arc-second (or 1:250,000-scale) USGS topographic map series, and are available for all of the contiguous U.S. and most of Alaska (USGS, 2005a). The standard DEM consists of a regular array of elevations cast on a designated coordinate projection system and covers the contiguous United States and most of Alaska (EPA, 2004a). The data used in this research corresponded to the clipped EPA-USGS DEM: 300 Meter Resolution, 1-Degree Digital Elevation Models (DEM), 3 arc-second or 1:250,000-scale for the Saint Louis Bay watershed.

Delineation

The watersheds under study were delineated using the automatic delineation option available in BASINS. To compare results, all delineations were performed with no-flow towards inner cells. The National Hydrographic Dataset (NHD) for streams was used in all delineation procedures.

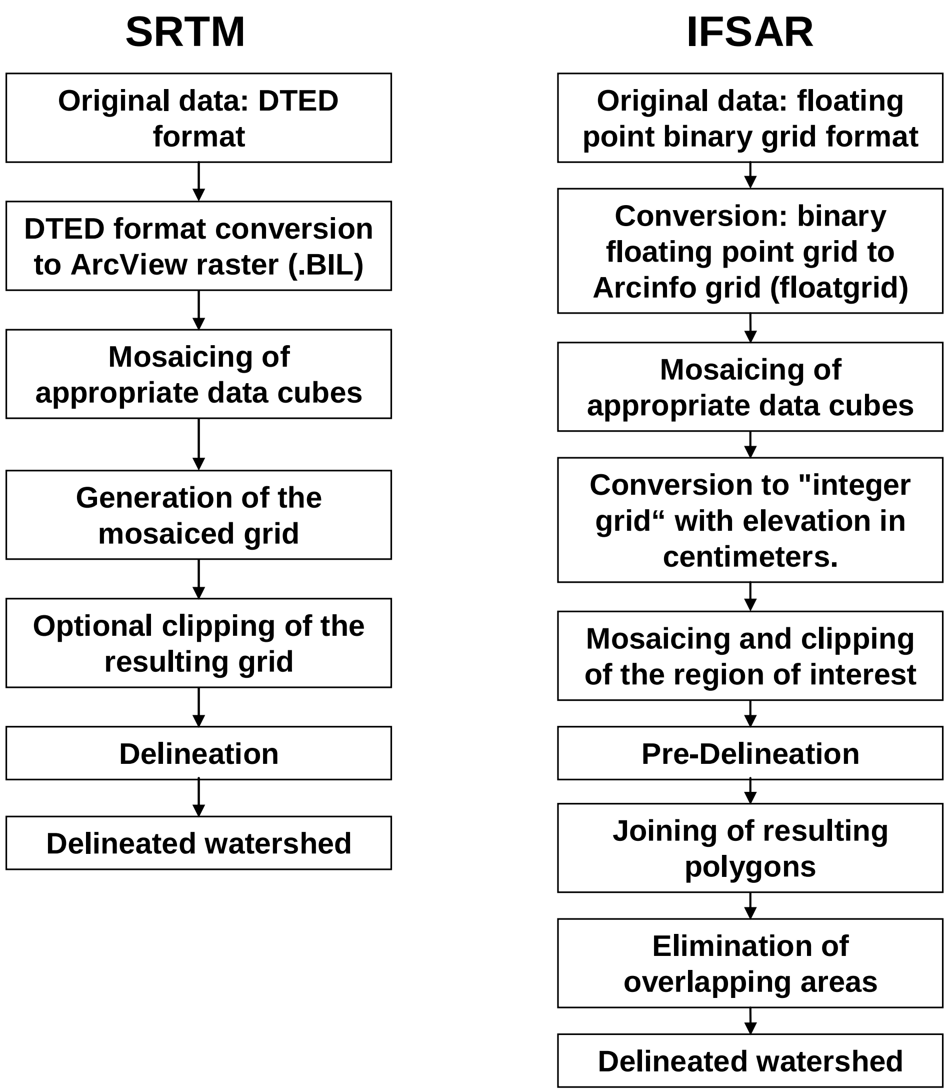

Figure 3. Methodology for watershed delineation using SRTM and IFSAR data.

During delineation, BASINS summarizes the topographic information per sub-basin and per stream in two tables: Attributes of Sub-Basins and Attributes of Streams. From the information contained by these tables the following topographic parameters were chosen for comparison of delineation results for their significance in hydrological modeling:

- Attributes of Sub-Basins: area, slope of the overland flow plane
- Attributes of Streams: stream length, stream slope, stream width, stream depth.

The technique for delineating the study area using USGS-DEM and NED data is well documented in Alarcon et al., 2005a and Alarcon, 2005b. However, the SRTM and IFSAR databases required specific strategies due to high resolution of the elevation data that produced increased file sizes to cover the study area. Figures 3 and 4 illustrate the steps followed for achieving the desired delineation. IFSAR data required clipping of the comprehensive grid shown in Figure 2D) to the reduced area shown in Figure 4A). After clipping, an attempt was done to delineate the area shown in Figure 4A, however, BASINS was unable to produce results due to the (still) big file that contained the clipped grid. To overcome this difficulty, the clipped grid was delineated in further reduced sections of the size shown at the bottom of figure 4A) (see the full red and green portion of the clipped area in 4A). Once that this pre-delineation step was performed for the whole study area, the resulting polygons (sub-basins and streams) were merged and dissolved to provide comparative results to delineations using the other three elevation databases. In summary, the delineation using IFSAR data was found to be time consuming and cumbersome as illustrated in Figure 3 (right hand side).

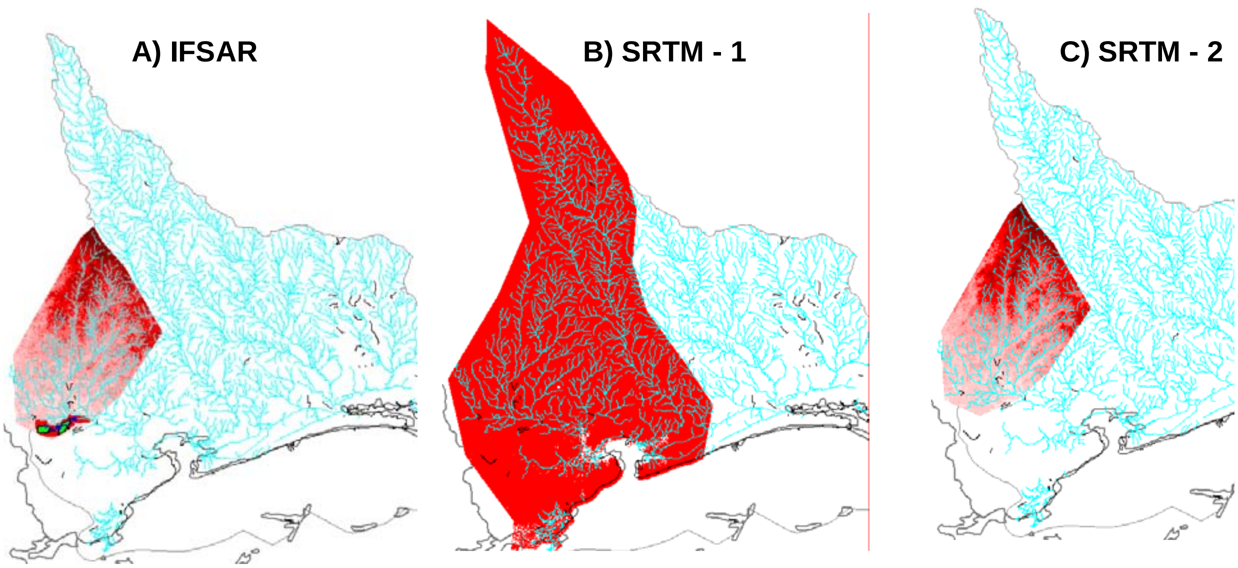

Figure 4 Strategy for delineation using IFSAR and SRTM data. Due to the size of the elevation data regions encompassing the study area were clipped.

Delineation using SRTM data proved to be almost as straight forward as when using the standard USGS-DEM or NED datasets. However, to avoid overloading the BASINS software with a grid of the size shown in Figure 2C), two clipping strategies were followed. Figures 4B) and 4C) show the two regions, encompassing the study area, that were clipped for use of the BASINS program. This alternative clipping produced interesting results as described in the next section.

RESULTS

Figure 5 shows final delineation results for each of the elevation databases used in this study. BASINS delineation algorithm provides similar distribution of sub-basins. However, the demarcation of sub-basin boundaries is different in each case. The most convoluted sub-basin perimeters correspond to IFSAR followed by SRTM-1 (Figures 5B and 5C respectively).

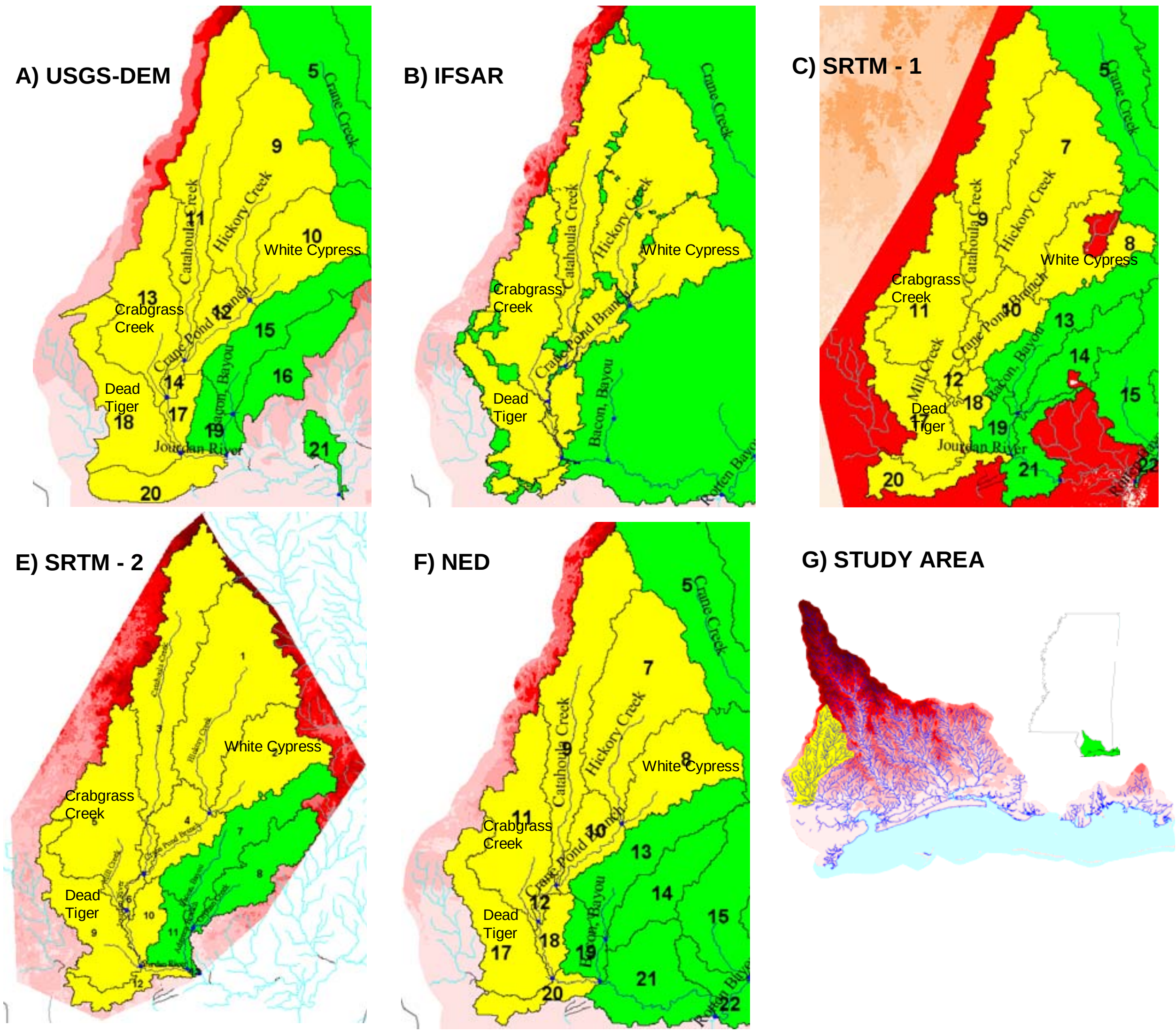

Figure 5. Watershed delineation using several elevation databases. Although the general distribution of sub-basins is similar, drainage areas for each sub-basin are different.

In addition to a more tortuous perimeter, IFSAR and SRTM-1 data produce isolated inner areas that do not belong to any sub-basin. Those two datasets also required more processing and memory requirements than the other three datasets, suggesting that the BASINS delineation capabilities were overloaded by such big data sets. On the other hand, SRTM-2, NED and USGS-DEM produce smooth and continuous demarcation of sub-basins.

Figure 6 shows a comparison of topographical-indicator values resulting from the delineation of the study area using the elevation datasets included in this study. As described in the previous section, the following topographical parameters were used for comparison: sub-basin area, slope of the overland flow plane, stream length, stream slope, stream width, and stream depth. The parameter values are compared in a per-sub-basin fashion. Sub-basins in the x-axis are arranged from the more roughed areas (Catahoula, Hickory, White Cypress) to the flatter sub-basins (Dead Tiger, Jourdan River).

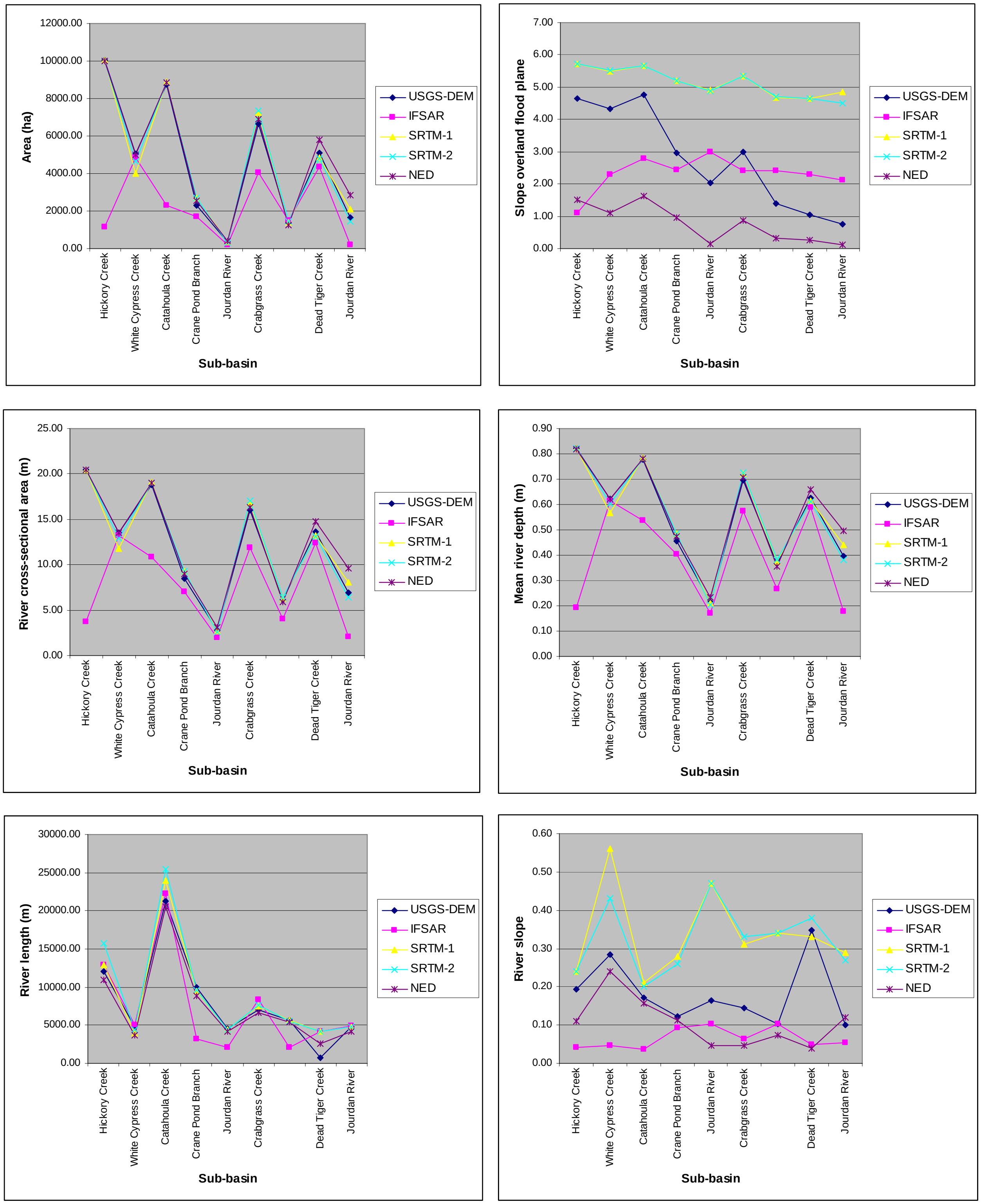

Figure 6. Comparison of delineation results for several topographical parameters. The charts provide values per sub-basin. Sub-basin area, slope of the overland flow plane, stream length, stream slope, stream width, and stream depth values are included.

In general, topographical indicators provided by the IFSAR delineation are dissimilar to the values provided by other delineation cases, including an inversely proportional trend in slope values to flatter terrain. This seems to suggest that the compulsory post-processing of pre-delineation results to achieve a final delineation (merging and dissolution of polygons) have affected the quality of final parameter values.

River length values provided by all of the delineations are relatively similar in absolute value and trend, meaning that this topographical indicator is the less affected by the use of different elevation databases. On the other end of the spectrum, the slope of the overland flood plane and the river slope seem to be the topographical parameters more affected by elevation database type. Area of sub-basins, river width, and river depth also appear to be within the same order of magnitude in all cases.

To further explore which is the magnitude of the effects of elevation data in river slope and slope of the overland flood plane parameter values, Figure 7 presents charts with of percent differences with respect to the NED database (that is considered to be the most reliable topographical elevation dataset).

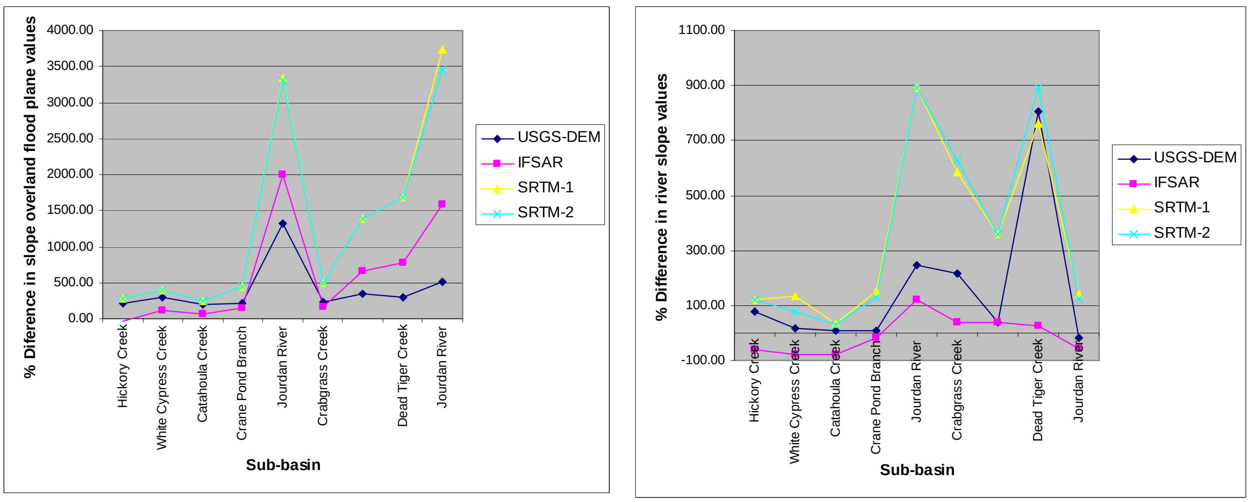

Figure 7. Percent differences for slope values (flood plane and river) with respect to NED-calculated values.

Figure 7 (right hand side) shows that overland plane slope values are substantially different to the values provided by the NED-delineated sub-basins. SRTM provides values substantially higher (up to 35 times) than those provided by NED delineation, especially in flatter areas. These results could be significant for hydrological simulation. Similar results are shown in Figure 7 (left hand side) for river slope. Flatter sub-basins show major percent differences in river slope values for SRTM. The effects on the calculated river slope reach up to 500% change in river slope values.

CONCLUSIONS

BASINS delineation algorithm provides similar distribution of sub-basins with somewhat different demarcation of sub-basin boundaries with the most tortuous perimeters corresponding to IFSAR and SRTM-1. In addition to this, both datasets provided delineations with isolated inner areas that do not belong to any sub-basin, due to the processing and memory requirements of these two datasets. Topographical indicators provided by the IFSAR delineation are the more dissimilar when compared to the parameter values provided by other delineation cases, including an inversely proportional trend in slope values to flatter terrain. Post-processing of pre-delineation results (merging and dissolution of polygons) affected the quality of final parameter values. This indicates that the current version of BASINS (v 3.1) have some limitations when dealing with high-resolution data.

Slope of the overland flood plane values and river slope are the topographical parameters more affected by elevation database type. SRTM delineation provides values up to 35 higher than those provided by NED delineation, especially in flatter areas. Flatter sub-basins show major percent differences in river slope values for SRTM. The effects on the calculated river slope reach up to 500%. These results could be significant for hydrological simulation.

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