Anthony Rodriguez
Due: May 6, 2010
GEO 327G Project

Mexican Gulf of Mexico Regional Introduction and Sea Level Rise Analysis of the Carmen Island, Campeche, Mexico Region

Problem formulation

For this project I have developed an overall regional introduction of my research area, the Mexican Gulf of Mexico (MGOM), with particular emphasis on tectonic setting, geology, and hydrocarbons. I also formulated a method to determine coastal effects of the Carmen Island, Campeche, Mexico region due to global sea-level rise associated with global climate change, assuming a maximum 60 cm sea-level rise by 2100 predicted by the 2007 IPCC AR4. Coastal inundation was determined using the Spatial Analyst tool within ArcGIS. This study shows that the total landmass area and surface area loss for the coastal regions of Carmen Island would be approximately 2,916 square meters and 695,142 square meters, respectively, by 2100 as a result of global climate change and a 60 cm sea-level rise.

Background

The Gulf of Mexico (GOM) is traditionally interpreted as a basin formed in a Mesozoic rift and passive margin setting that was subsequently modified by gravity-driven salt tectonics during Cenozoic time. The distribution of ultimate hydrocarbon reserves from Mann et al. (2006) shows that the Caribbean-Gulf of Mexico region contributes 5% of the world's ultimate giant oilfield reserves with 21% of these reserves being in the MGOM. There is still development to be done in the MGOM, and it is very likely that hydrocarbons will be found in foreland basins related to the Sierra Madre Oriental fold-and-thrust (SMOFTB) belt (Figures 1-4) related to Laramide-age tectonics (~66-40 Ma). The tectonics of the MGOM is related to the subduction of the Farallon remnants (Cocos and Rivera plates) below the Mexican portion of the North American plate (Figures 1 and 2). Regional earthquakes (Figure 2) greater than magnitude 5.0 are shown with the location, size (circle shapefiles based on magnitude) and depth (green – shallow, yellow – intermediate, red – deep) and approximate plate boundaries. The geologic map of Mexico (Figure 3) shows the convergence of several geologic trends along the southwestern GOM: 1) cuspate thrust front of the Sierra Madre Oriental in heavy blue line shortening mainly Cretaceous carbonate rocks shown by green colors; 2) onland Chicontepec foreland basin which ponded Late Cretaceous-Early Tertiary foreland basin sedimentary rocks; 3) forebulge separating foreland basin from southwestern GOM margin; forebulge (Tamaulipas Arch and Tuxpan Platform) exposed carbonate rocks along the bulge during thrusting period; 4) volcanic rocks of the Trans-Mexican volcanic belt (TMVB) in red colors comprising a late Cenozoic volcanic arc related to the shallow subduction of the Cocos plate; black triangles show active volcanoes; 5) pre-Mesozoic basements are shown in black; 6) dotted pink areas show down-slope-moving late Jurassic salt deposits; and 7) stable and undeformed carbonate rocks of the Yucatan peninsula is shown by burnt orange color (65 Ma Chicxulub crater is indicated by dotted purple circle). This supports the idea of a foreland basin existing in offshore MGOM. Distribution of giant oil and gas fields (Figure 4) are based on Mann et al. (2003) and show a lack of widespread deepwater drilling in the MGOM that has restricted Mexico's giant discoveries to onland, shelf, and slope areas.

Carmen Island is an island that stands above sea-level in the Laguna de Terminos which exists at the southernmost MGOM coast. Carmen Island is a part of the Mexican state of Campeche and is host to Ciudad del Carmen, a small city devoted to fishing, shrimping, and oil production. The population of Carmen Island was 199,988 according to the 2005 census. In the mid 1970s, Ciudad del Carmen was transformed from a fishing and shrimping city into a hub for oil when PEMEX discovered large amounts of petroleum off the coast. Ever since Carmen has become a home for Mexican and foreign oil workers alike, including many Texans, and now houses many foreign companies.

Data collection

In order to build a regional introduction to the MGOM, I incorporated Shuttle Radar Topography Mission (SRTM) DEM data, GEBCO bathymetry data, Sandwell gravity data, and USGS geologic, earthquake (NEIC), and hydrocarbon data from my research consortium (Caribbean Basins, Tectonics, and Hydrocarbons) CBTH at The University of Texas Institute for Geophysics (UTIG). Past study results of plate boundaries, GPS motion vectors, Benioff slab subduction zone, and geologic features were digitized to shapefiles and superimposed on the CBTH GIS data (Figures 1-4). The coastal effects due to sea-level rise were built using SRTM data from the University of Maryland Global Land Cover Facility (GLCF) website (glcf.umd.edu) using a 1degree latitude by 1 degree longitude coverage size for Carmen Island (Figures 7-11). The SRTM DEM resolution is 90 m, the GEBCO bathymetry uses a one minute global bathymetry grid, and the gravity resolution is 30 m. The spatial reference for the maps is WGS 1984 since most of the data is composed of data collected throughout the CBTH study region including North America, Central America, South America, Gulf of Mexico, and the Caribbean. For the Carmen Island data, I had to access the FTP server of GLCF and download a GeoTIFF file that contained the DEM for the area. I chose the *SRTM_f03_n018w092* file since Carmen Island falls entirely within this file range. The resolution of this GLCF DEM is 90 meters.

Data preprocessing

For preprocessing, the only method needed was to digitize past study maps of plate boundaries, GPS motion vectors, Benioff slab subduction zone, and geologic features such as the deep gulf provinces. Table 1 below shows the references used to digitize these regional maps (Figures 1-4).

Table 1: References of past study maps used for digitized regional introduction maps.

Past Study Map	Shapefiles Created	Reference
Plate Boundaries	polylines	Bird, 2003
GPS Motion Vectors	points, polylines	Marquez-Azua and DeMets, 2009
Benioff Zone	polylines	Pardo and Suarez, 1995
Deep Gulf Provinces	polygons	Guzman and Marquez-Dominguez, 2001

ArcGIS processing

To create the digitized maps, I would have to take initial TIFF files that I created from previous study maps and input the TIFF into ArcGIS (example shown in Figure 5A). The TIFF files were then georeferenced (Figures 5B and 6A) so that the maps were positioned accurately according to the spatial references (WGS 1984). This was done by using a country border shapefile that was available through the CBTH database. I would set the transparency of the TIFF map or the country border shapefile to 50% and align accordingly using the Georeferencing tool and selecting the TIFF map as the active layer file. After georeferencing the TIFF files, I would generate shapefiles that were necessary using ArcCatalog and right-clicking in the directory that I wanted to add a new shapefile. The shapefiles created depended on what I intended to generate for the particular past study map and are listed in Table 1. I then used the Editor tool, selected the shapefile that I wanted to edit, and created the shapefiles (Figure 5C). I would then make symbology edits to change the colors and sizes of the shapefiles until I had a final set of shapefiles (Figures 5D and 6B) that I would use to incorporate into my final regional maps (Figures 1-4). These final regional maps also include north arrows, scales, legends of important features shown, and reference grids showing latitude and longitude.

In order to determine the effects of a 60 cm sea-level rise, I began by adding the country boundaries and GLCF SRTM DEM files to ArcGIS. The STRM DEM symbology was edited in Layer Properties so that the color ramp was Elevation #1 and the transparency was set to 50% in the display settings (Figure 7). The stretch type within Symbology in Layer Properties was set to Minimum-Maximum to better distinguish topographic highs and lows for Carmen Island. I changed the options of Spatial Analyst so that all new files would be saved to a local directory that I would know where to access the files (working directory). I also selected the GLCF file to be the analysis mask so that only data within this file's extent would be used for spatial analysis. The next step was to create a new raster file based on the assumption of a 0.6 m (60 cm) sea-level rise. This was done by using the Raster Calculator within the Spatial Analyst tool and selecting the GLCF DEM file and subtracting it by 0.6 (since the DEM is in meters) to build a new calculated raster with elevations decreased by 0.6 meters (Figure 8). After making a calculated raster, I then made a binary raster in order to separate values below zero and values above zero to look at what areas were above water versus below water. In order to generate a binary raster, I needed to use a conditional statement in the Raster Calculator. The conditional statement that I used was ***con([Calculation] <= 0,1)*** so that values less than or equal to zero would output a value of 1 with all other values being outputted as "nodata". This will make only the 1 values show up in the new raster and the "nodata" values will not show up by default. This binary raster was treated as the new 60 cm sea-level rise and was superimposed on the DEM to show the coastal effects of Carmen Island (Figure 9). A new sea-level contour line was also generated using the Surface Analysis / Contour option within the Spatial Analyst tool and setting the calculated DEM as the input surface, the contour interval to 200 (since the highest value is 103.4), and the base contour to zero. This produced a contour line for the final topographic map of Carmen Island showing the coastal effects of a 60 cm sea-level rise (Figure 10).

For final calculations determining the loss of landmass for the Carmen Island region, I used the entire raster file (w92n18) and performed a 3D analysis. I used the Surface Analysis / Area and Volume option within the 3D Analyst tool and compared the original and calculated raster files. I selected each raster separately as the input surface, selected zero for the height of plane, and calculated statistics above this plane (since we wanted areas above sea-level). This gave me output statistics for 2D area, surface area, and volume shown below in Table 2. These values seemed quite small, but I recalled that I needed to multiply these values by 90 meters x 90 meters (area) to find realistic measurements of area since the cells have a particular resolution. The actual area measurements are shown in Table 3 (note that volume is not included in further calculations). The change in landmass was calculated by subtracting the areas of the calculated raster from the original raster (original – calculated). The landmass loss for the Carmen Island region is shown in Table 4.

Table 2: Output statistics determined for landmass above sea-level in Carmen Island region.

Raster file	2D area	Surface area	Volume
Original GLCF DEM	0.87	1991.92	8.27
Calculated DEM	0.51	1906.10	7.95

Table 3: Converted output statistics determined for actual landmass above sea-level in Carmen Island region.

Raster file	2D area	Surface area
Original GLCF DEM	7,047 sq. meters	16,134,552 sq. meters
Calculated DEM	4,131 sq. meters	15,439,410 sq. meters

Table 4: Total landmass loss in the Carmen Island, Campeche, Mexico region due to a 60 cm sea-level rise.

	2D area	Surface area
Landmass Loss	2,916 sq. meters	695,142 sq. meters

Discussions / Conclusions

The map generation portion of this study took past information and available GIS data to build a regional introduction for the Mexican Gulf of Mexico looking at tectonic setting, earthquakes, geology, and hydrocarbons. The analysis portion of this study took a look at MGOM and nearby coastal areas to determine how global climate changes would affect the regional coastlines of Carmen Island by 2100. With a dramatic change in local climate, the coastal communities are going to see many differences in the weather patterns; extreme differences that will cause human vulnerability within the region. These could possibly lead to the destruction of human coastal communities due to things such as sea level rises, flooding, sea storms, vegetation changes, amounts of precipitation, etc.

Continued climate change will bring increases in temperature, precipitation, and sea level for the MGOM. Human vulnerability in MGOM will come into play when events such as powerful storms, increased flooding, coastal erosion, vegetation change, and salinity in soils happen as a result of continued global climate change due to the burning of fossil fuels. For a predicted 60 centimeter maximum sea-level rise, the total landmass area loss was 2,916 square meters for the Carmen Island region. For the total landmass surface area loss due to the sea-level rise, it was determined to be 695,142 square meters. Carmen Island seemed to have less change in landmass loss compared to the mainland coast. The mainland MGOM in this region will be inundated significantly in the central and eastern portions. These topographic changes are very visible when looking at a side-by-side comparison of the original DEM with the 60 cm denudation raster (Figure 11). This will mean significant changes in ecology, environment, and human populations near the coastal areas by 2100 if sea-level rises 60 cm due to continued global climate change.

References

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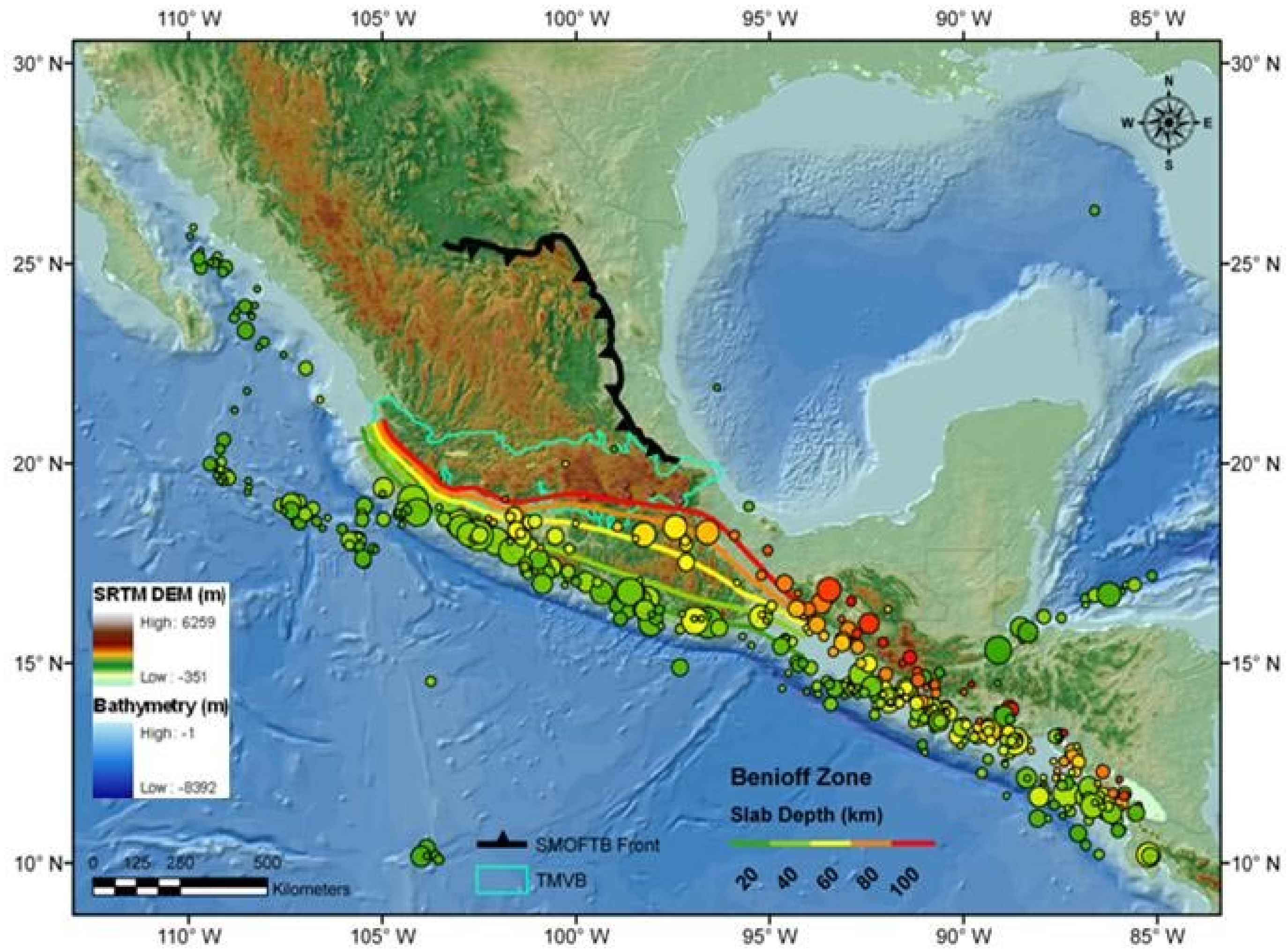


Figure 1: Because the Cocos plate is a very young oceanic plate, it is buoyant and subducts at a shallow angle beneath the Pacific margin of Mexico. This map shows the Benioff zone from Pardo and Suarez (1995) that extends at a shallow angle to a depth of about 100 km near the western margin of the GOM. The presence of this shallowly subducted slab is the likely cause for the narrowing of the GOM coastal plain of Mexico and the intersection of the thrust front of the Sierra Madre Occidental with the coastline. The Trans-Mexican volcanic belt (TMVB) is the young volcanic arc produced by shallow subduction and melting of the Cocos plate. The oblique trend of the TMVB across Mexico mimics the shape of the shallowly subducted slab of the Cocos plate that is melting to form it.

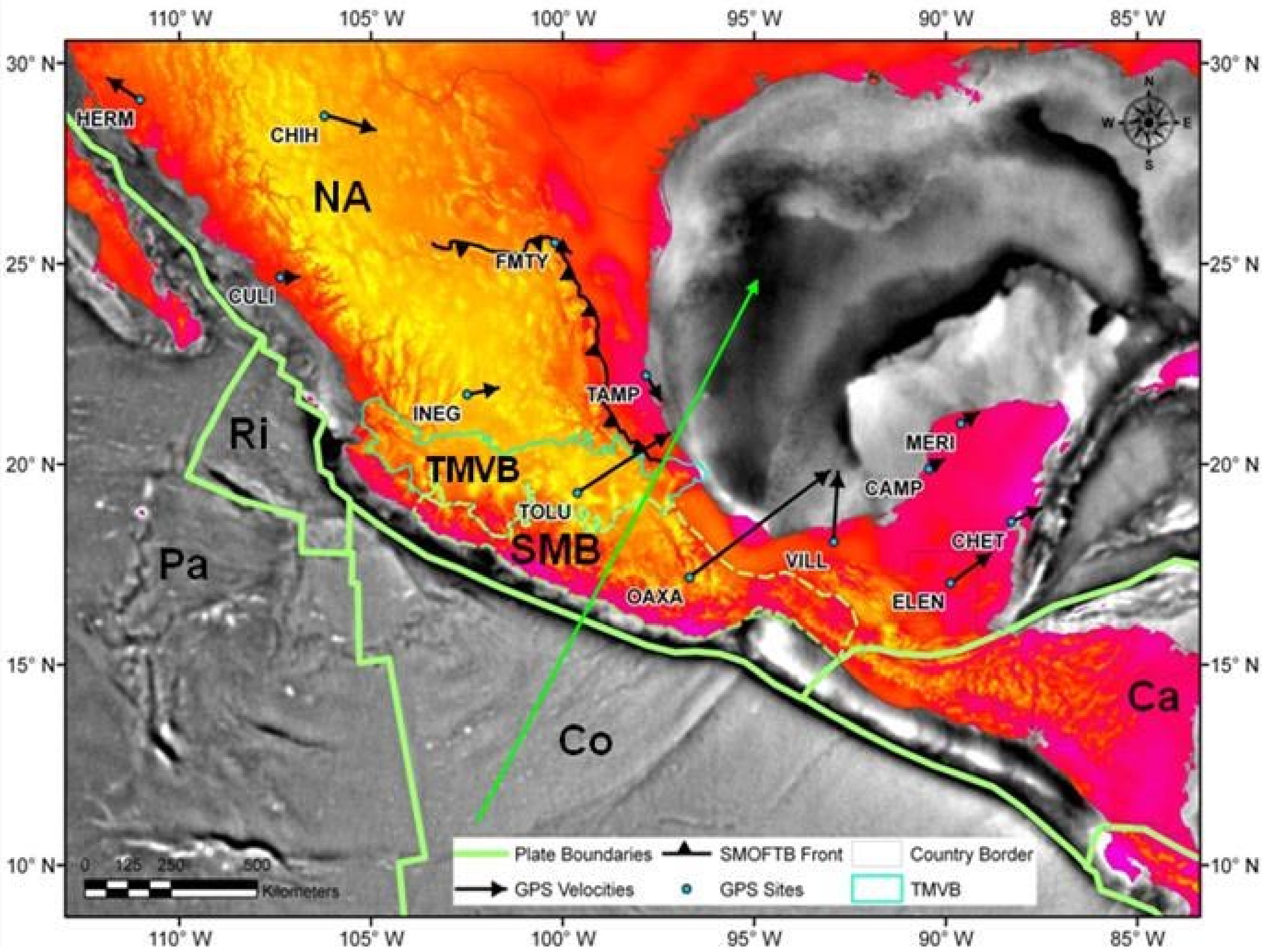


Figure 2: GPS data from Marquez-Azua and Demets (2009) show that Mexico is being pushed eastward relative to a fixed North America plate in the GOM probably as the result of shallow subduction of the Cocos plate beneath the trench along the Pacific margin of Mexico. This continued thrusting of Mexico relative to the GOM is a likely cause for the late Cenozoic elevation and erosion of Mexico into the GOM. The Sierra Madre Orientale is bounded on its eastern side by a major thrust fault that may accommodate the eastward motion of Mexico relative to the GOM. The green vector shows the ~60 mm/yr converge of the Cocos plate (Co) relative to North America (NA) estimated by NUVEL-1A (Demets, 1990).

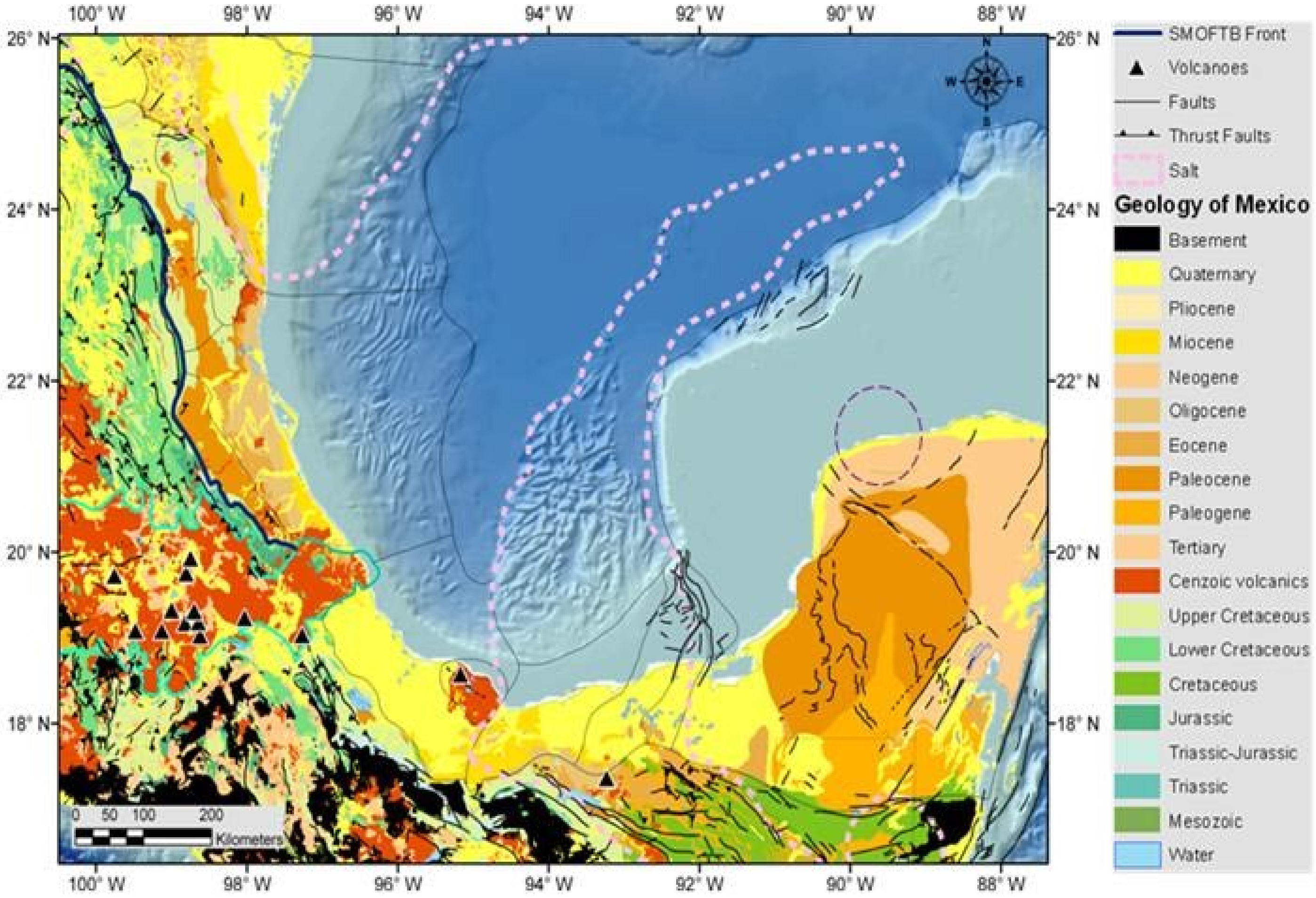


Figure 3: The geologic map of Mexico shows: 1) cuspate thrust front of the Sierra Madre Oriental in heavy blue line shortening mainly Cretaceous carbonate rocks shown by green colors; 2) onland Chicontepec foreland basin which ponded Late Cretaceous-Early Tertiary foreland basin sedimentary rocks; 3) forebulge separating foreland basin from southwestern GOM margin; forebulge (Tamaulipas Arch and Tuxpan Platform) exposed carbonate rocks along the bulge during thrusting period; 4) volcanic rocks of the Trans-Mexican volcanic belt (TMVB) in red colors comprising a late Cenozoic volcanic arc related to the shallow subduction of the Cocos plate; black triangles show active volcanoes; 5) pre-Mesozoic basements are shown in black; 6) dotted pink areas show down-slope-moving late Jurassic salt deposits; and 7) stable and undeformed carbonate rocks of the Yucatan peninsula is shown by burnt orange color (65 Ma Chicxulub crater is indicated by dotted purple circle).

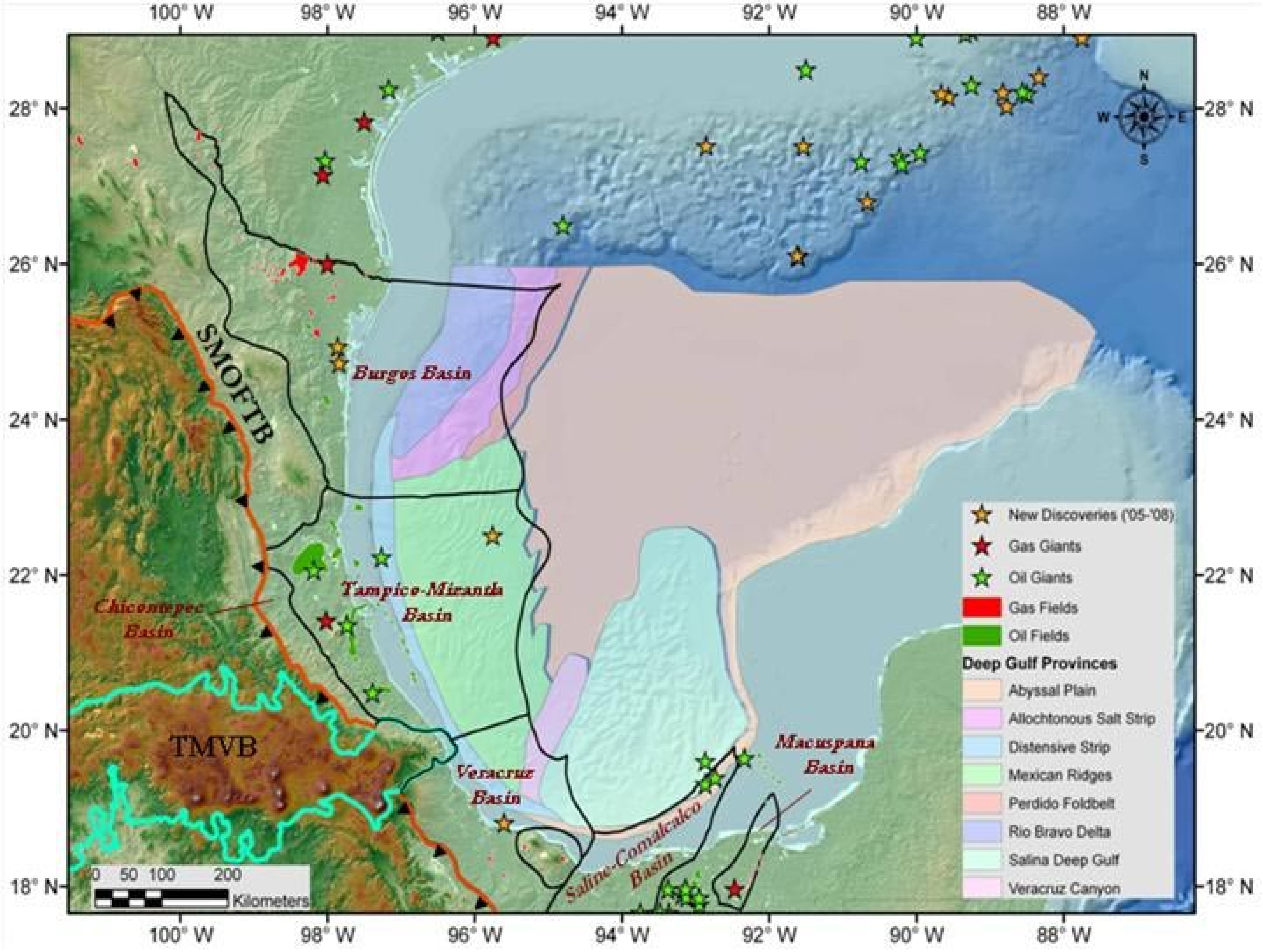


Figure 4: Distribution of giant oil and gas fields in the Mexican and US sectors of the GOM modified from Mann et al. (2003). In the US sector deepwater exploration has resulted in new giant discoveries in the deepwater area along the Sigsbee scarp. The lack of widespread deepwater drilling in Mexican has restricted their giant discoveries to onland, shelf and slope areas.

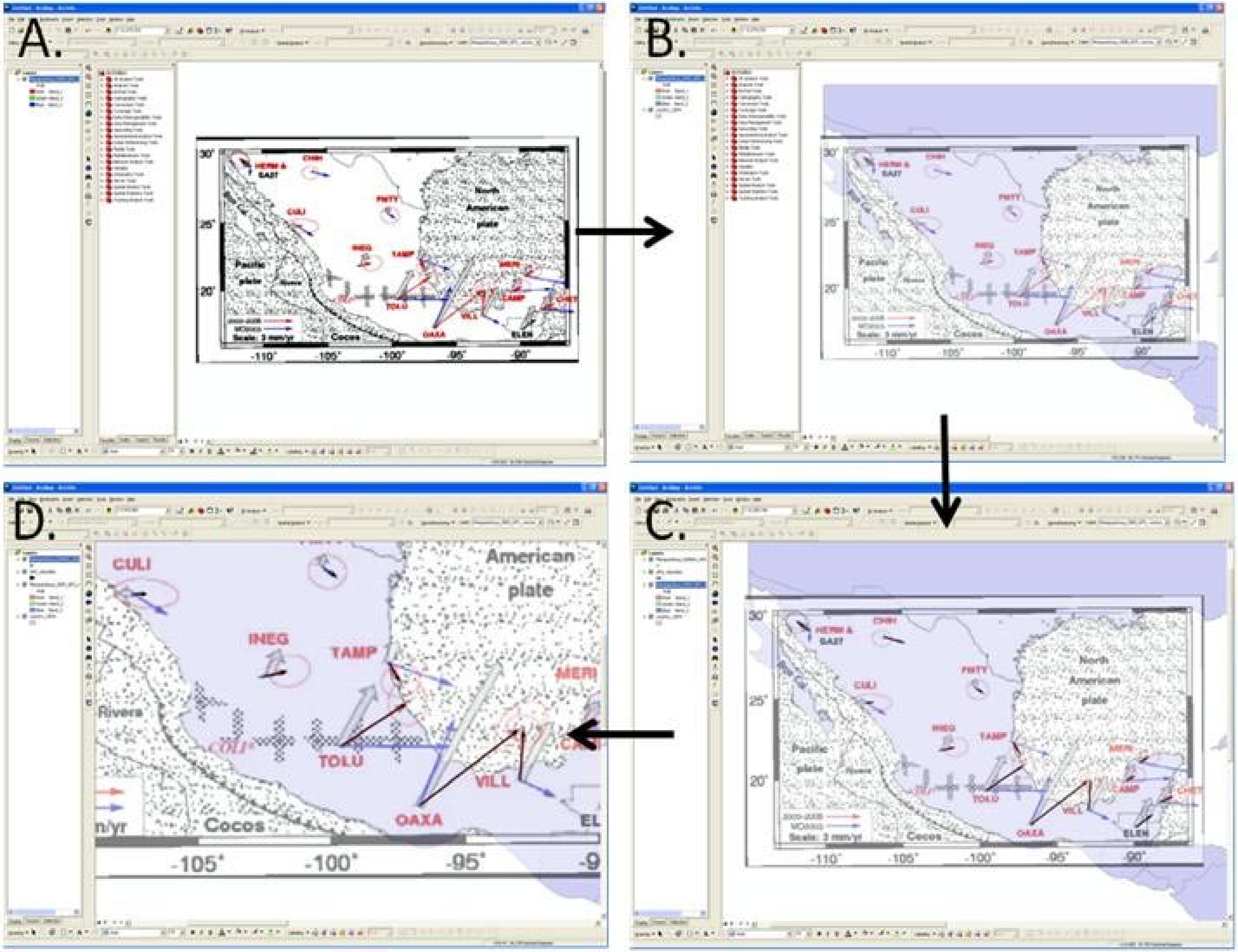


Figure 5: Flow map of screenshots showing example georeferencing, polyline and point shapefile generation, and shapefile editing for the Marquez-Azua and DeMets (2009) GPS motion vectors.

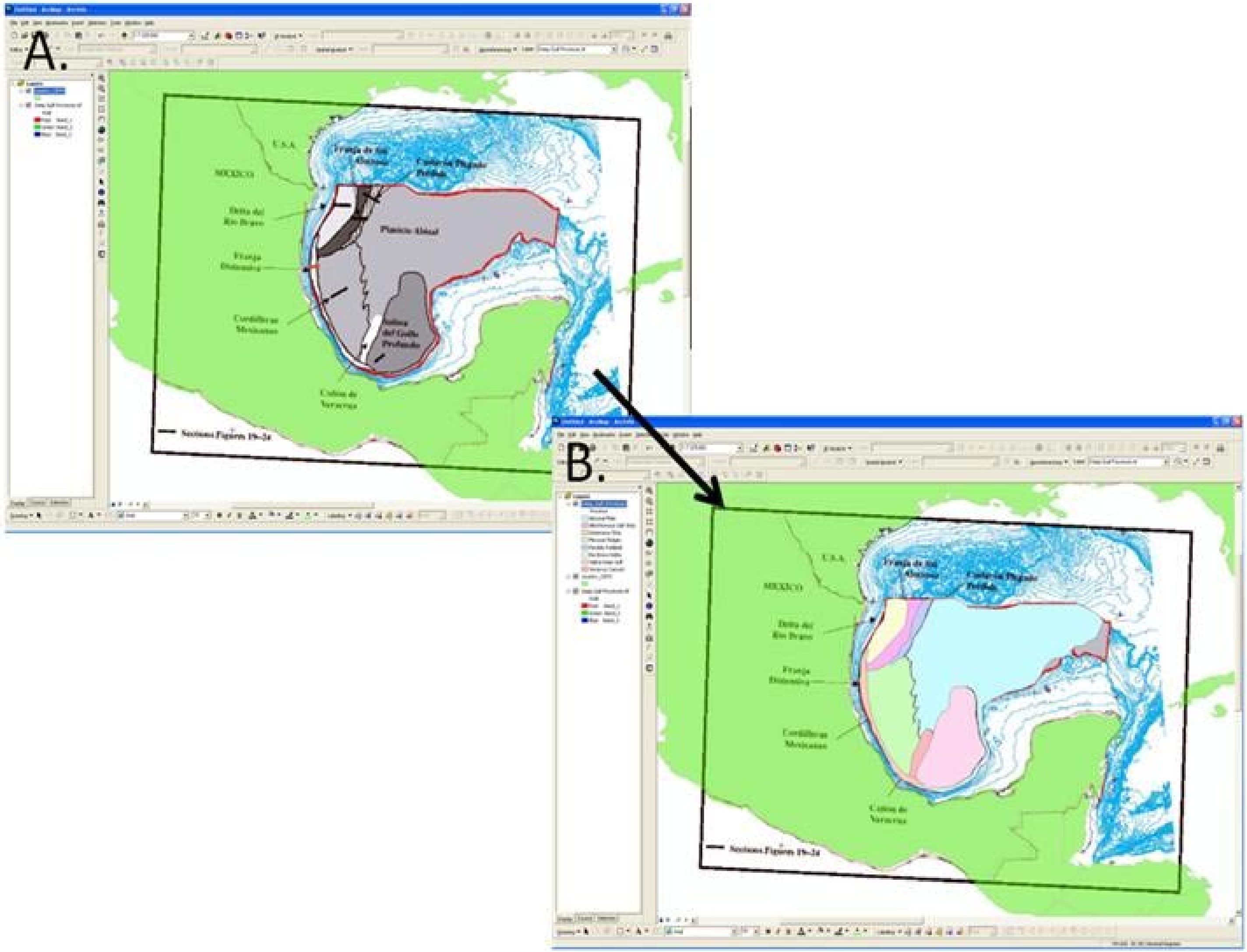
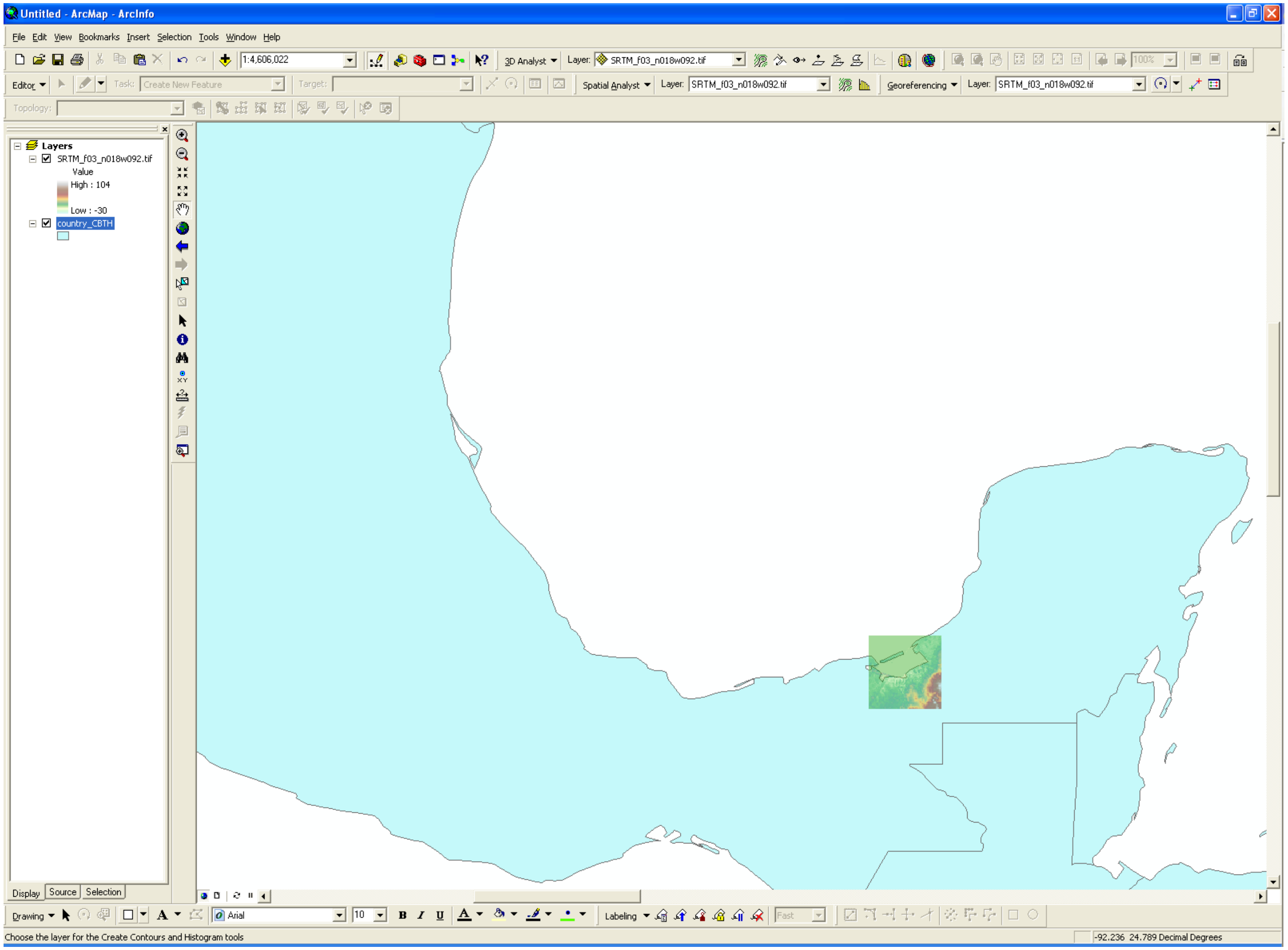


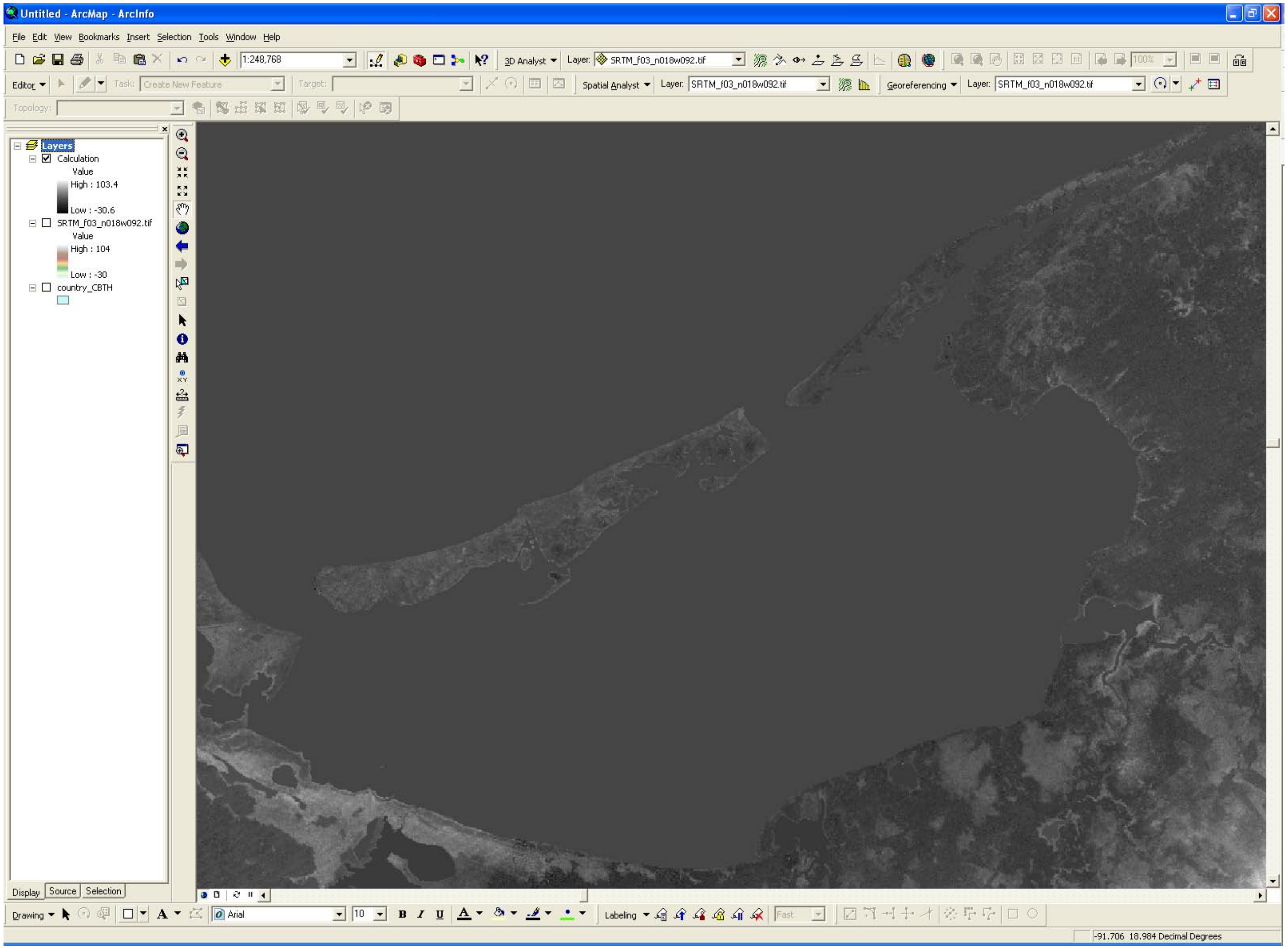
Figure 6: Flow map of screenshots showing example georeferencing, polygon shapefile generation, and shapefile editing for the Guzman and Marquez-Dominguez (2001) Deep Gulf provinces.



Choose the layer for the Create Contours and Histogram tools

-92.236 24.789 Decimal Degrees

Figure 7: Screenshot of the GLCF DEM raster file *SRTM_f03_n018w092* shown with the country boundary shapefile. The GLCF file has a 50% transparency to show the relative location of Carmen Island and compare it with the shapefile. This smaller size DEM file was used instead of the entire SRTM available from the CBTH database due to limited memory capability of the machines in the geology computer lab for processing and analysis.



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Task: Create New Feature

Layers
- ☑ Calculation
  - Value
  - High : 103.4
  - Low : -30.6
- ☐ SRTM_f03_n018w092.tif
  - Value
  - High : 104
  - Low : -30
- ☐ country_CBTH

-91.706 18.984 Decimal Degrees

Figure 8: Screenshot of the new calculated raster with elevations decreased by 0.6 meters (60 cm) used for assuming a 60 cm sea-level rise by 2100. This raster was then converted to a binary raster file to create predicted 2100 sea-level.

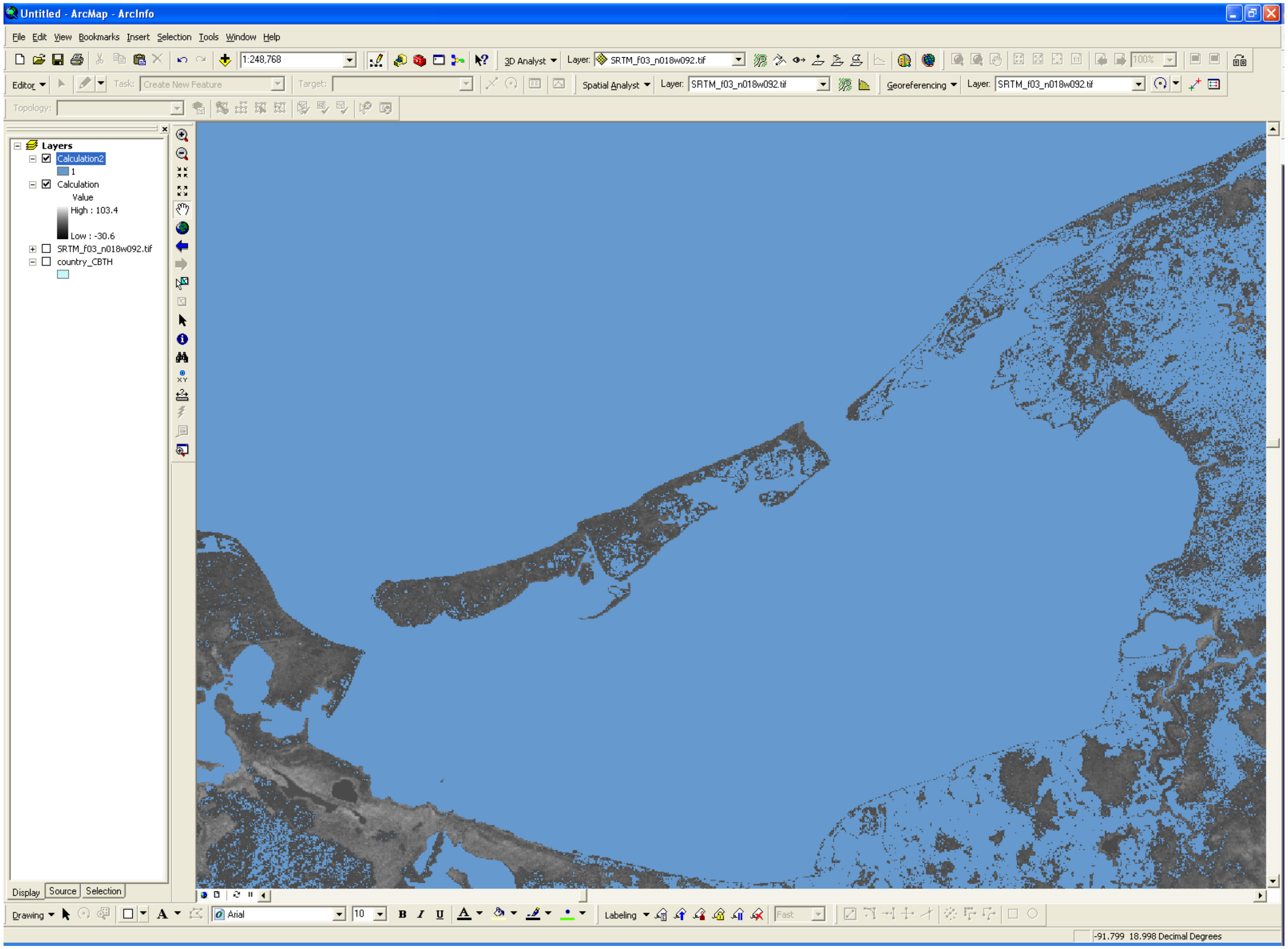

Figure 9: Screenshot of the predicted sea-level binary raster that allowed for water to be set as "nodata" and all other values to have values of 1. The blue areas are the 1 values and "nodata" values show up blank and allow for the calculated DEM to be superimposed on the sea-level binary raster.

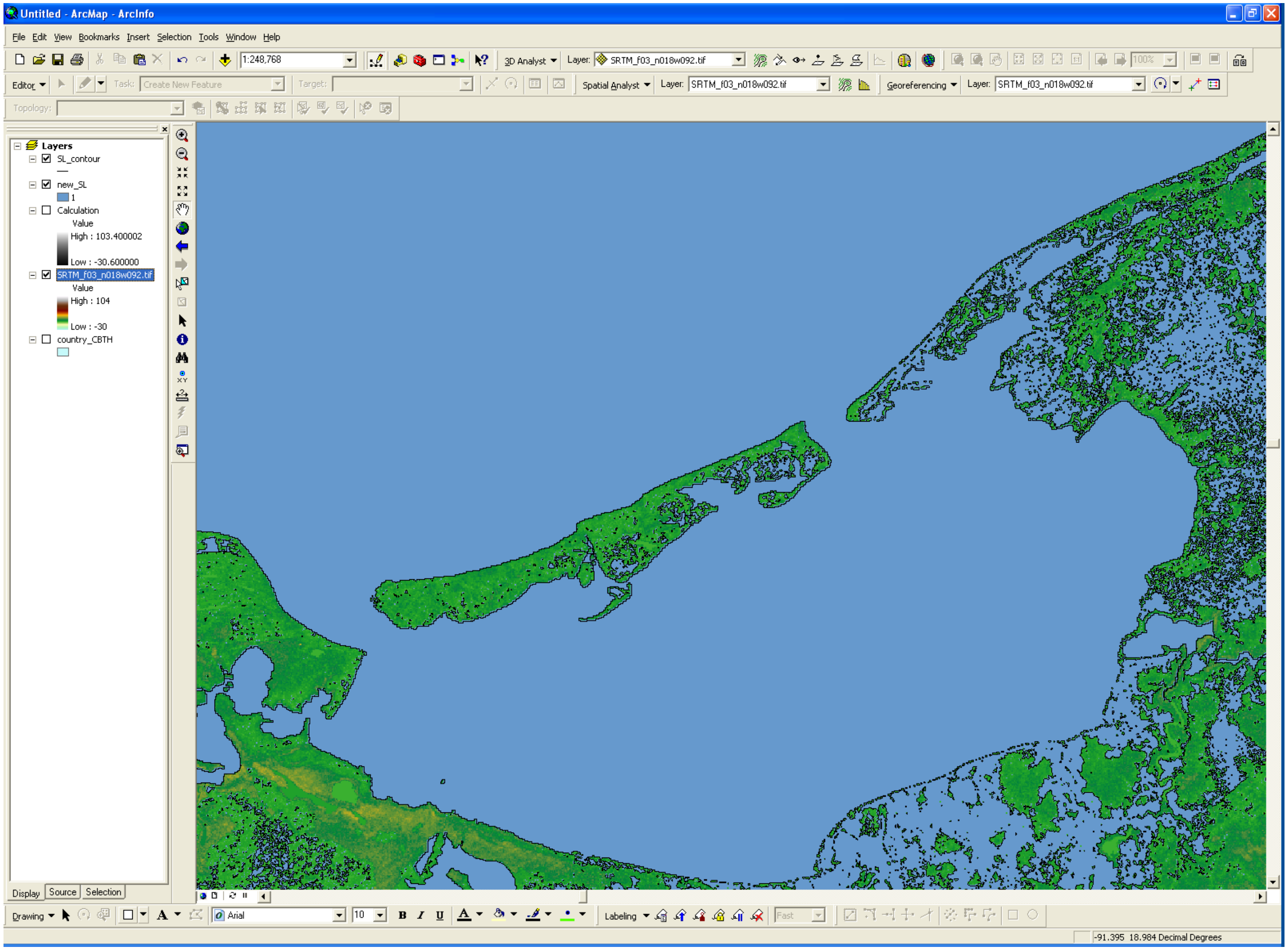

Figure 10: Screenshot of final raster showing the 60 cm sea-level rise and the denudation of Carmen Island coastal regions in Campeche, Mexico. A zero elevation contour line was generated to show predicted sea-level extent for 2100.

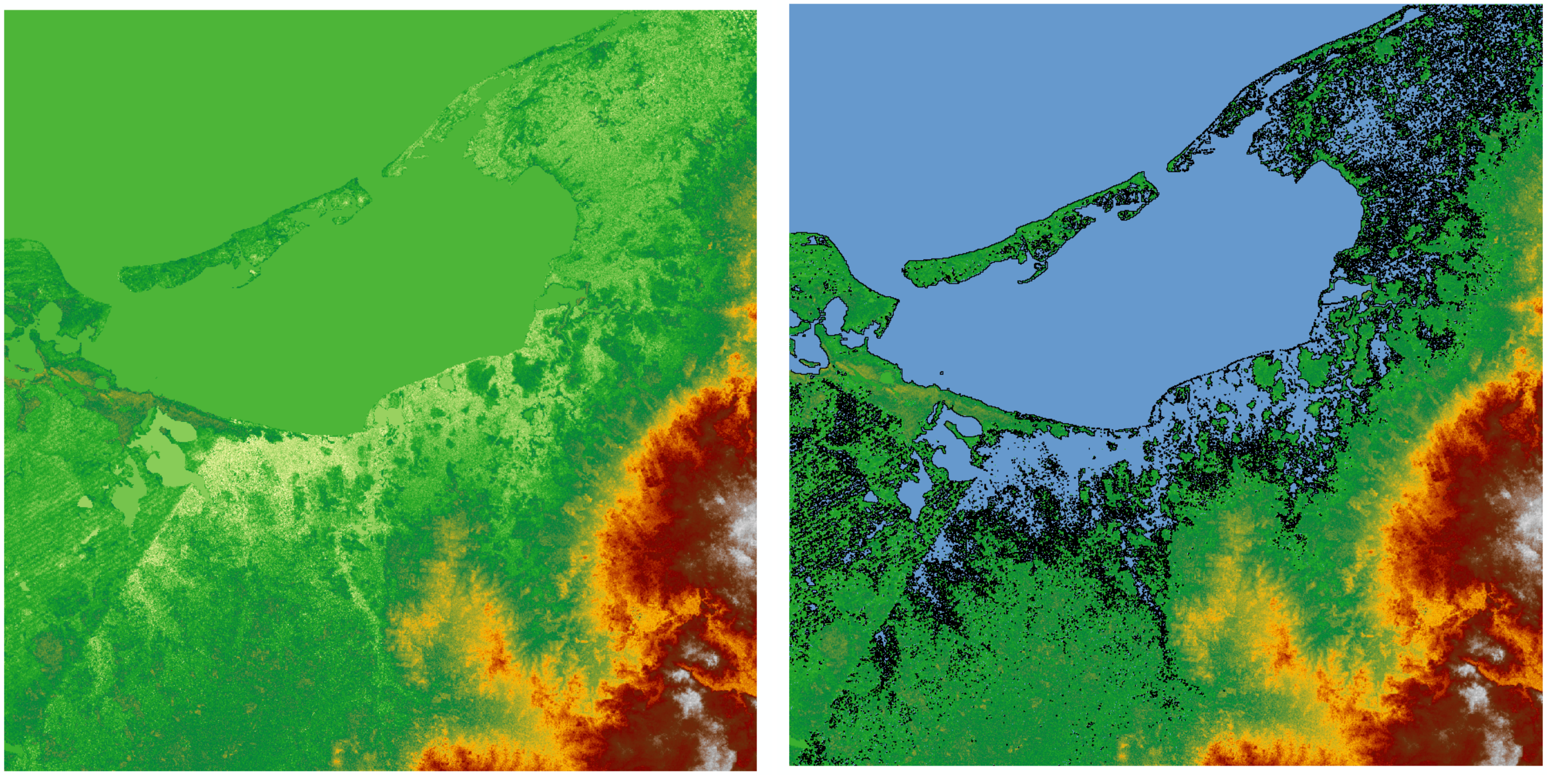

Figure 11: Side-by side screenshot comparison of the original DEM (left) with the 60 cm denudation raster file (right). Evident denudation would occur in the central and eastern portions of the Carmen Island coastal regions within the GLCF file extent.