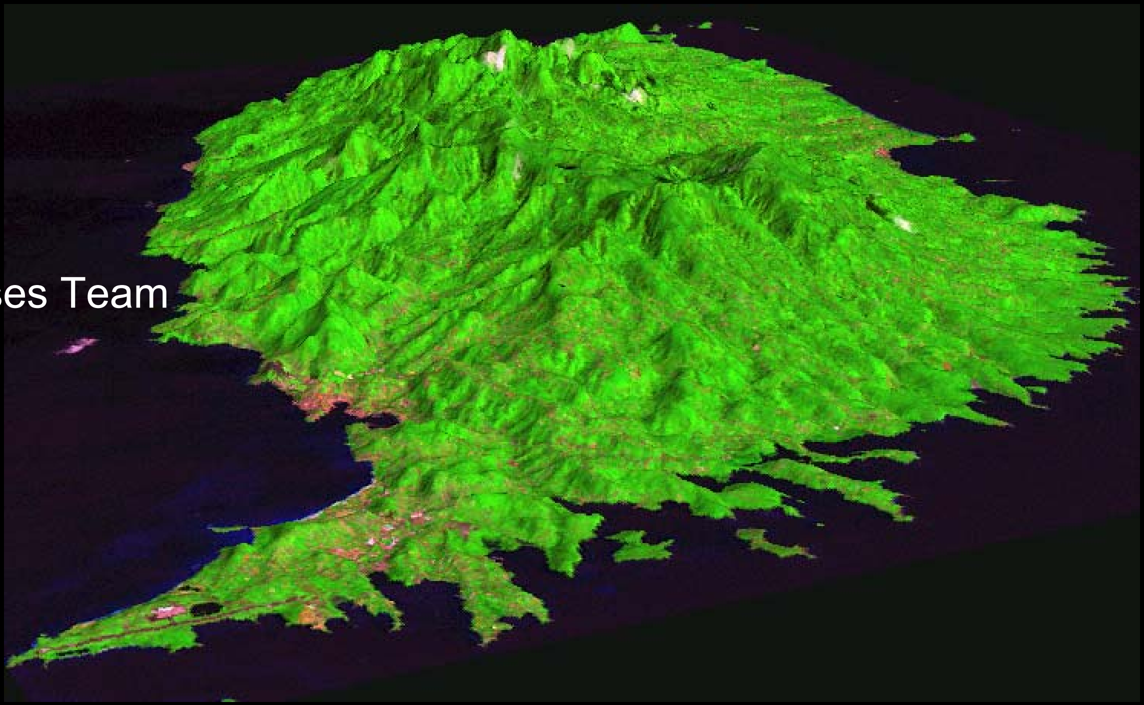
# AN EVALUATION OF SRTM, ASTER, AND CONTOUR-BASED DEMS IN THE CARIBBEAN REGION



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## INTRODUCTION

- This study evaluates digital elevation models (DEMs) derived from the Shuttle Radar Topography Mission (SRTM), the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite, and topographic contours for the island of Grenada in the southeastern Caribbean.

- Statistical measures of accuracy, developed through a comparison to high-resolution control points, demonstrate the vertical accuracy of the three sources of DEMs for the study area.

- The effect of terrain and vegetation on the accuracy of SRTM, ASTER, and contour-based DEMs is further demonstrated through an analysis of elevation, slope, and surface curvature measurements.

- Finally, selection of appropriate DEM data for natural hazard mapping, landform studies, and GIS applications in the Caribbean region is discussed.

## STUDY AREA

- Grenada is located in the Windward island chain at 12º 02’ N and 61º 15’ W. Grenada represents one of many islands in the Caribbean region with typical high central mountain topography and underlying volcanic geologic structure. Grenada’s topography includes narrow ravines and steep ridges, but also exhibits coastal plain topography along its eastern coast.


# METHODOLOGY

- Elevation models were acquired or produced from each source for the study area.

- Datum adjustment calculations were performed on the DEM data to adjust all source data to elevations based on the WGS84 EGM96 geoid in order to make comparisons between data that were collected in different vertical datums.

$H_w = (H_c + H_d) + (H_t + \varsigma)$

where:
$H_w$ = WGS84 EGM96 elevation
$H_c$ = Carib97 orthometric height
$H_d$ = Carib97/EGM96 calculated difference
$H_t$ = Tidal height
$\varsigma$ = +51cm PODT (local permanent ocean topography)

- Elevation control checkpoints were developed from the Grenada Ministry of Lands and Survey benchmarks and the U.S. National Geodetic Survey (NGS) high resolution global positioning system (GPS) measurements.

- A series of root mean squared error values were calculated for the elevation value (RMSEz) to quantify the vertical accuracy of the DEMs.

# METHODOLOGY: Contour-Derived DEM

- Contours for Grenada were digitized from Directorate of Overseas Surveys (DOS) 1:25,000 scale maps.

- A DEM with a 10m horizontal resolution was created using the TOPOGRID command in ArcGIS. Subsequently, the 10m DEM was resampled to 30m and 90m resolution for comparison to the ASTER and SRTM DEMs.

- The topographic maps of Grenada have a contour interval of 7.62m (25 ft) below 76.20m (250 ft) elevation and a 15.24m (50 ft) contour interval above 76.20m (250 ft) elevation. The vertical accuracy for a DEM developed from these contours is estimated to be ±3.81m to ±7.62m.

Example of DOS Topographic map sheet for Grenada


10m Contour-based DEM of Grenada

## METHODOLOGY: ASTER DEM

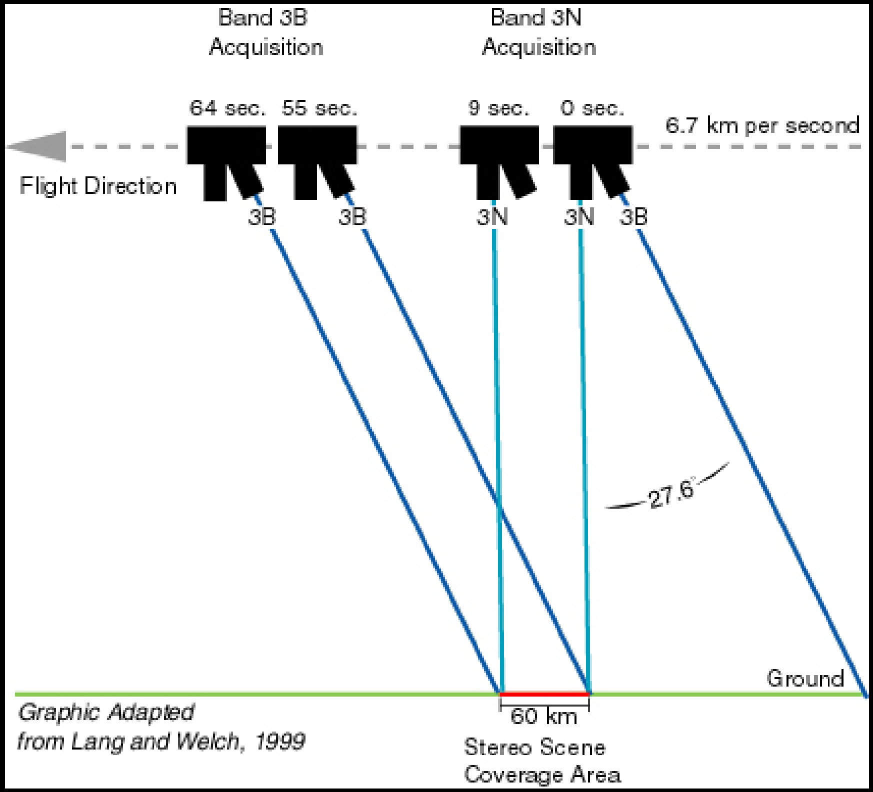
- The ASTER sensor is one of three instruments carried onboard NASA's Terra satellite platform in a near-polar orbit at 705km altitude. ASTER has 14 bans sampled from the visible and near infrared (VNIR), the shortwave infrared (SWIR), and the thermal infrared (TIR).

- Band 3, which samples from the 0.78 to 0.86µm range, is the only band to record through both a nadir (3N) and a back-looking (3B) telescope at 27.6º creating along track stereo scenes at 15m resolution.

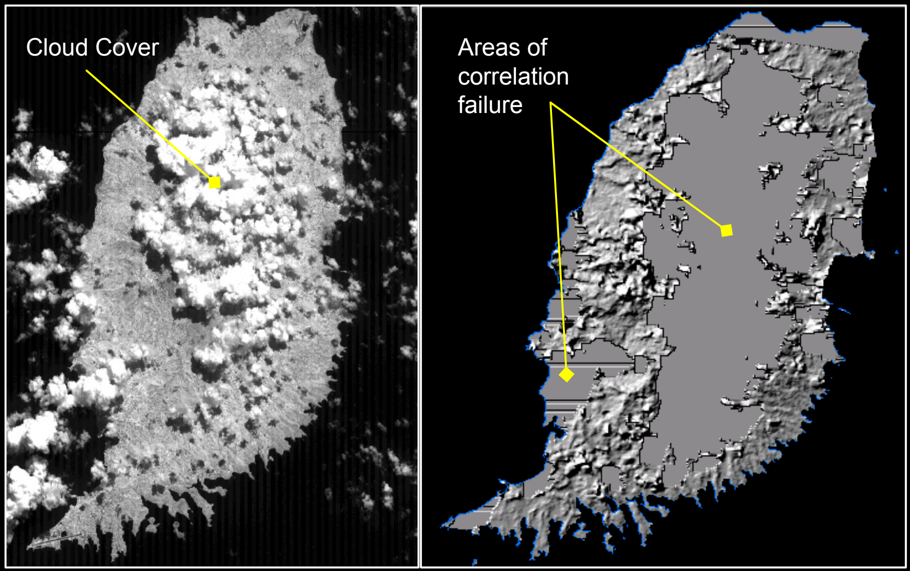
- Bands 3N and 3B (8-28-02) were individually imported into PCI Geomatica's Orthoengine® software (ver. 9.1.4) where triangulation and DEM extraction were performed.

- Original ASTER mission specifications called for DEMs to have a vertical resolution within the ±7m - ±50m RMSEz range depending on the number and quality of ground control points (GCPs) and tie points.

# METHODOLOGY: ASTER DEM




Schematic diagram showing ASTER stereo data collection process.




Example of ASTER Imagery (left) and DEM produced from ASTER (right) for Grenada.

## METHODOLOGY: SRTM DEM

- In February of 2000, NASA, the National Geospatial-Intelligence Agency (NGA), the German Aerospace Center (DLR), and the Italian Space Agency (ASI) flew X-band and C-band radar interferometry onboard the Endeavor Space Shuttle. The mission covered the Earth between 60ºN and 57ºS and will provide DEMs of approximately 80% of the Earth's land mass when processing is complete.

- Up to eight passes of data were merged to form the final processed SRTM DEMs which reduces but does not completely eliminate the amount of area with layover and terrain shadow effects.

- DEMs are processed to 1 and 3 Arc Seconds, which corresponds to approximately 30m and 90m resolution respectively. Currently, 30m SRTM DEM data are controlled by the NGA and use is restricted to certain government agencies under agreements with NGA. 90m SRTM data are publicly available and are distributed by the USGS.

- The vertical resolution of the 30m SRTM DEMs is stated as being ±16m for 90% of the data, while the remaining 10% may be greater than ±16m.

# METHODOLOGY: SRTM DEM

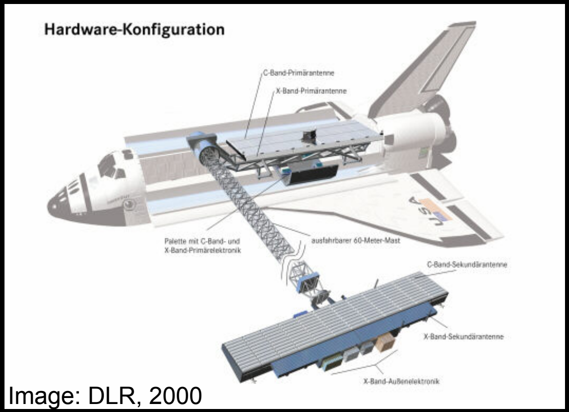



Image: DLR, 2000

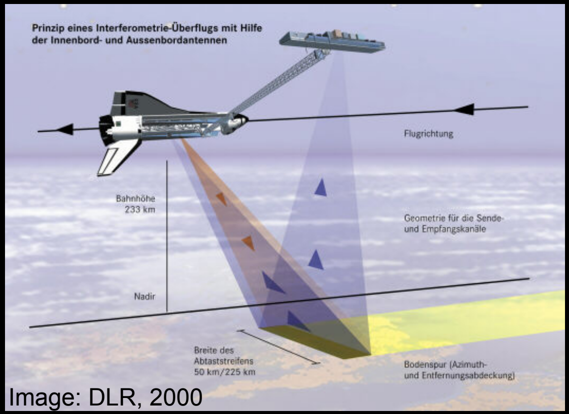
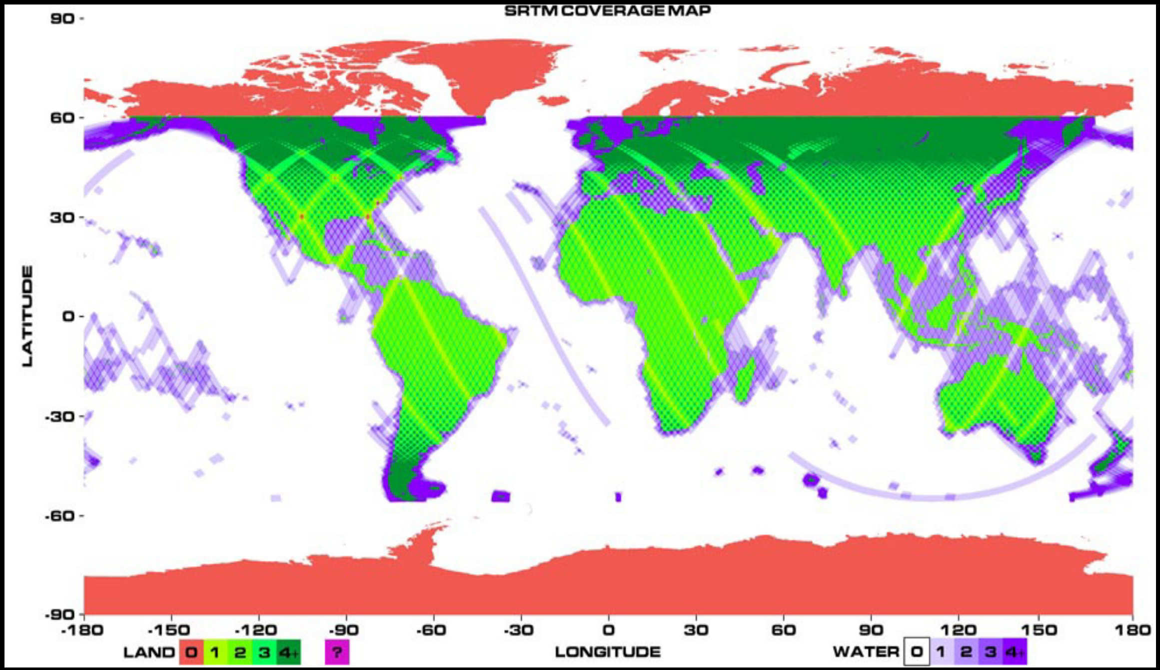



Image: DLR, 2000

90m SRTM DEM data acquired for Grenada

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## RESULTS

| Source | Total Number of Check Points | Expected RMSEz | RMSEz Below 75m | RMSEz Above 75m | Study Area RMSEz |
|---|---|---|---|---|---|
| 10m Contour DEM | 26 | ±3.81 - ±7.62 | ±5.97 | ±9.73 | ±8.48 |
| 30m Contour DEM | 26 | ±3.81 - ±7.64 | ±5.38 | ±10.16 | ±8.64 |
| 30m ASTER DEM | 6* | ±7 - ±50 | ±14.41 | ±28.30 | ±22.46 |
| 90m Contour DEM | 26 | ±3.81 - ±7.64 | ±16.80 | ±25.57 | ±23.30 |
| 90m SRTM | 26 | ±16 | ±14.64 | ±30.42 | ±25.53 |

- Elevation values for each DEM are compared to high resolution checkpoints, and root mean squared error values are calculated for the elevation value (RMSEz) to quantify the vertical accuracy of DEMs from each source. In addition to overall RMSEz values, values were compiled based on topographic elevations above and below 75m.

- 75 meters in elevation is a value designed to replicate the change in contour interval in the original topographic contour data for Grenada. This elevation value also serves as a topographic comparison of lower and generally flat elevations as compared to steeper, more mountainous topographic relief.

- Four major factors that contribute to DEM accuracy are the quality of the input data, the horizontal resolution of the DEM, the methodology of data collection, and the effects of terrain and vegetation.

# DISCUSSION: Data Quality/Data Sources

- The collection date of the source data is also a factor that affects vertical accuracy. Topographic changes over time, either due to physical factors or man-made changes in the environment, can render a DEM inaccurate. Topographic contour maps were developed from 1951 and 1978 aerial photography.

- RMSEz values for topography above 75m were nearly twice those for topography below 75m for all DEMs, with the exception of the 90m Contour DEM. This demonstrates that in areas of higher elevation the magnitude of error increases. Partially, this may be explained by inaccuracies due to horizontal resolution, but may also indicate that lower flatter topography is more simply modeled while higher elevation topography becomes more complex. Another factor may be related to land cover in lower elevation areas versus land cover in higher elevations.

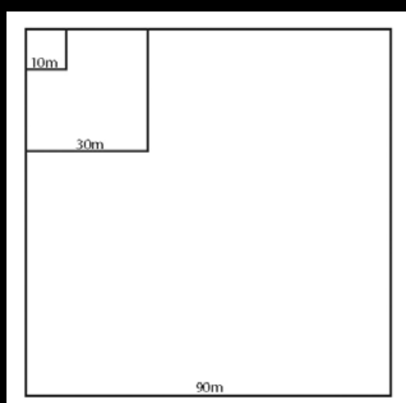
- C-Band Radar (SRTM) penetrates cloud cover and, in some cases, vegetation, whereas ASTER does not.

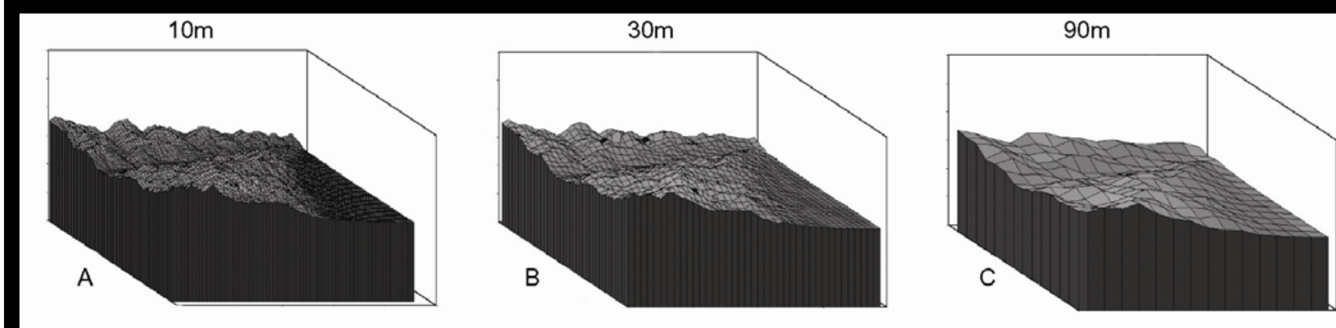
## DISCUSSION: Resolution

- Horizontal resolution affects the vertical accuracy of DEM data. As pixel size increases, a single DEM pixel value reflects more land area by averaging values within the pixel.

- For example, the 90m resolution SRTM and Contour DEM data have a single DEM elevation value for an area that is modeled by 9 elevation values in the ASTER and 30m Contour DEM and 81 values in the 10m Contour DEM (Figure 5).

- The effects of averaging elevation values for larger resolution models make them inherently less able to accurately model smaller variations found within the terrain. Thus, overall RMSEz values increase with resolution from ±8.48m for the 10m Contour DEM to ±25.53m for the 90m SRTM DEM.



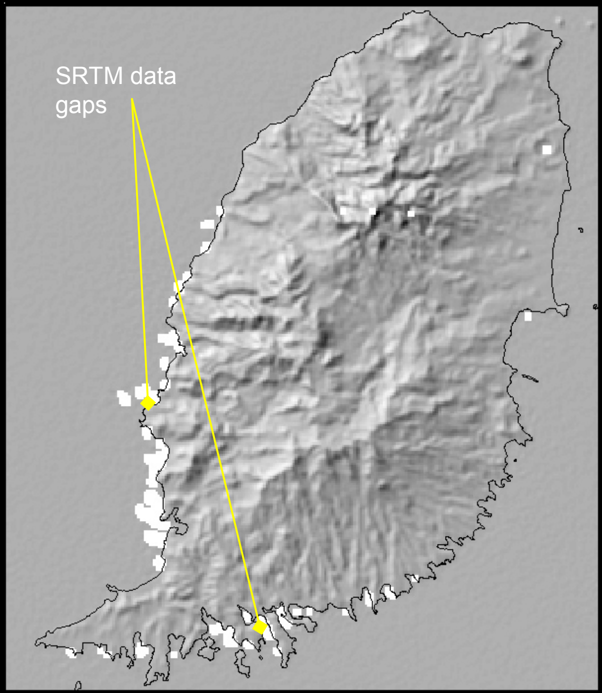



# DISCUSSION: Environmental Factors

- ASTER DEMs are likely to incorporate more features than simply the bare earth because pixel values in the imagery encompass all land cover within the pixel. Elevation values from ASTER reflect vegetation and manmade structure heights. In addition, cloud cover prevents elevation extraction.

- C-band SRTM penetrates clouds and is able to penetrate up to a few meters into vegetation cover but may be less effective in heavily forested areas and on steep terrain.

- In coastal areas and around lakes, ponds, and marshes, the SRTM data either drops elevation values or erroneous elevation values are reported from irregular surface reflections on top of the water or absorption of the RADAR signal.

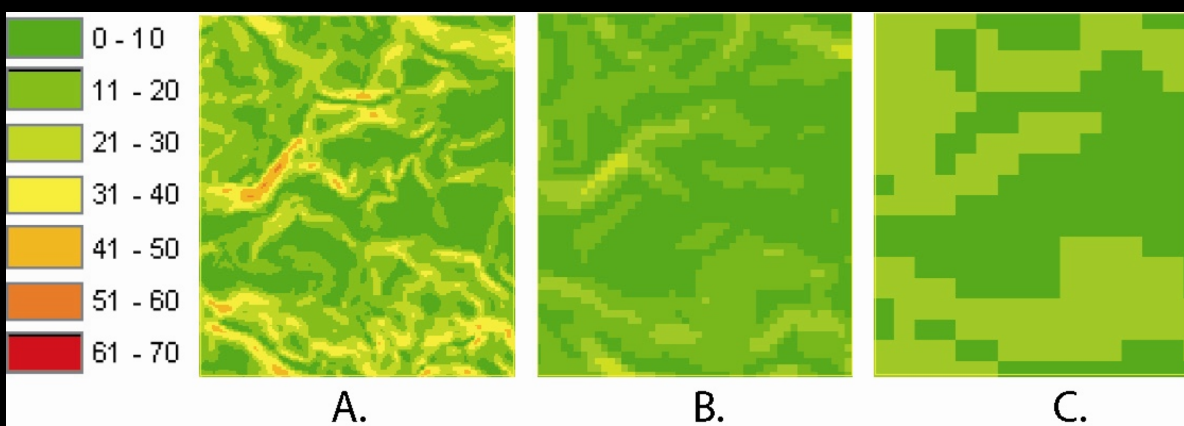


## DISCUSSION: Slope Comparison

- This example illustrates slope calculations for a small area in western Grenada from three sources of DEM data.

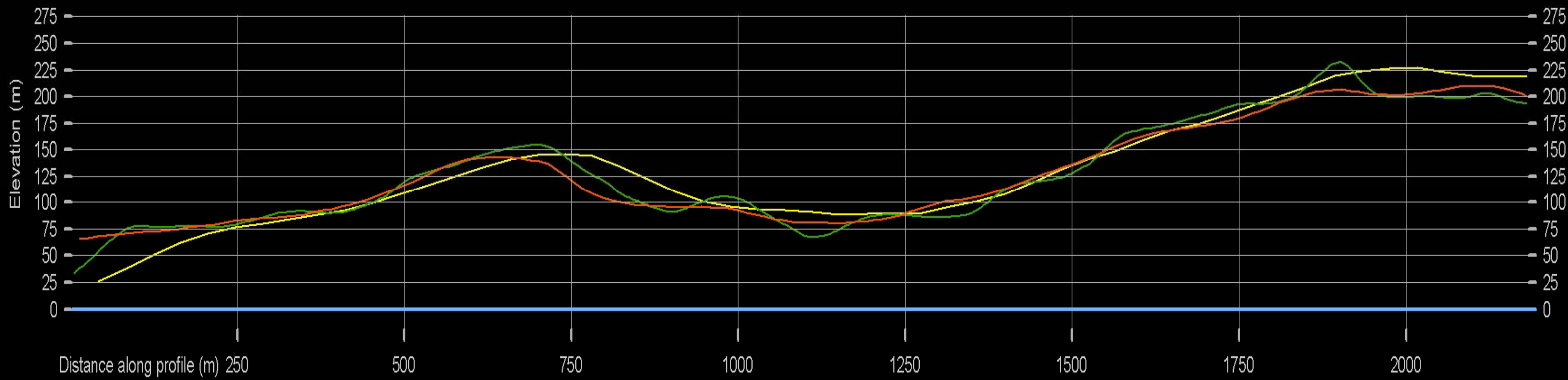
  The 10m Contour DEM (A) depicts slopes from 10º to areas of greater than 50º.  The 30m ASTER DEM's (B) highest slope, in this example, is greater than 30º, while the 90m SRTM DEM (C) shows slopes of no more than 20º.

- GIS models relying on accurate slope calculations would yield very different results using the three sources shown in this example.




Example of slope calculations (in degrees) from (A) 10m Contour DEM, (B) 30m ASTER DEM, and (C) 90m SRTM DEM.

# DISCUSSION: Topographic Profile Comparison





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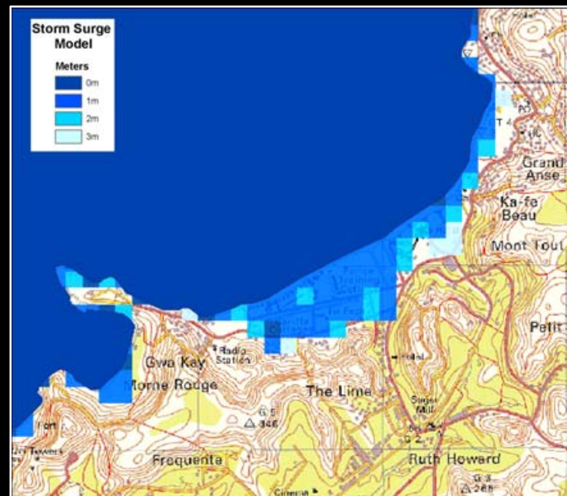
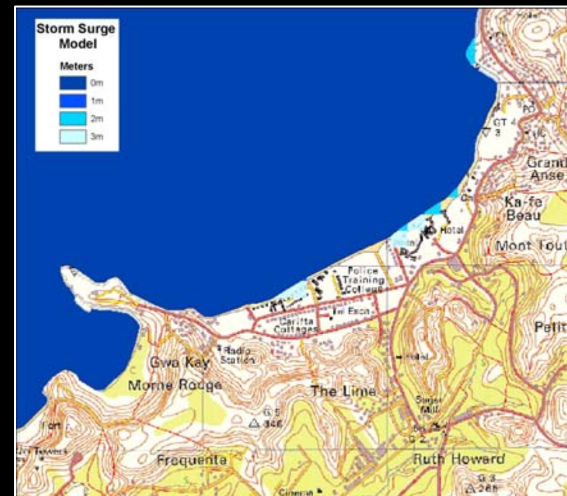
## DISCUSSION: Storm Surge Model Result Comparison


- 10m Contour Based DEM
- 90m Contour Based DEM
- 90m SRTM DEM

## CONCLUSION:

- Horizontal and vertical data resolution is a critical component to terrain modeling and represents the most important consideration in DEM source selection.

- The type of DEM needed for a particular application is an important consideration in selecting sources of DEMs. DSMs (ASTER, SRTM) may be more appropriate for terrain correcting imagery, air navigation routing, and wireless communication network modeling because DSMs that include man-made structures and vegetation are better suited for these applications. DTMs (Contours) are more appropriate for modeling erosion, hydrologic flow, and for use in landslide or storm surge models.

- DEMs developed from optical sources such as ASTER and aerial photography may be negatively impacted by the frequency of cloud cover. In contrast, SRTM data penetrates clouds but does not fully penetrate dense vegetation. In addition, SRTM data has significant voids in coastal areas, which must be masked or filled to produce a viable DEM.

- New technologies such as airborne InSAR and LIDAR are rapidly becoming the choice for GIS practitioners and land managers interested in very high resolution DEMs. These technologies have matured to become more than experimental, and future studies should be conducted to assess these systems for terrain modeling in the Caribbean region.