

Generation of Low-Cost Digital Elevation Models for Tsunami Inundation Modeling in Hambantota, Sri Lanka

1. Summary

Digital elevation models (DEMs) were generated from various data sources, such as survey data, map data, and satellite DEMs. In areas where different data sources overlap, priority is given to the higher accuracy or higher resolution dataset, such as survey data over map data, or SRTM (90m) over GEBCO_08 (900m) for land area.

Region 1, having the coarsest resolution, and Region 2 are composed of only GEBCO_08 data. Region 3 consists of a mixture of satellite DEMs: GEBCO_08 for sea and SRTM Level for land, map, and survey data. Region 4 mainly consists of survey and photogrammetry data.

The raster data were stored as xyz files containing a table of geographic coordinates in longitude, latitude and depth, which represent the center of each pixel. DEM development involved: i) format conversion (e.g. DGN to SHP), ii) projection transformation, iii) extraction, iv) data type conversion (e.g. raster to point or line to point), v) merging, and vi) interpolation.

2. Objective

Generate DEMs for 4 regions, required tsunami inundation modeling.

3. Project Site

DEM generation is focused on the project's pilot site in Hambantota, Sri Lanka. Figures 1 to 3 provide the location map and the extent of each region for simulation.

4. Data Requirements

Tables 1 and 2 show the metadata, resolution, and extent for each output DEM.

Table 1. Metadata of DEM

Reference System	Geographic coordinate system
Horizontal Datum	World Geodetic System 1984
Vertical Datum	Mean Sea Level (approximate)
Grid values	Height values in meter, positive for sea and negative for land
Data Format	xyz format (signed 32 bits)

Table 2. Resolution and extent for each DEM region

Region	Resolution (degrees)	Extent (x,y)	
		Upper Left	Lower Right
Region 1	0.033333	52.000000000, 29.308333300	101.999500000, -8.69128670000
Region 2	0.004167	80.500000000, 6.600000000	81.8584420000, 5.79993600000
Region 3	0.001389	80.952460180, 6.3681453989	81.3427691888, 5.98755939897
Region 4	0.000463	81.096004890, 6.1540823864	81.1537548901, 6.08755438642

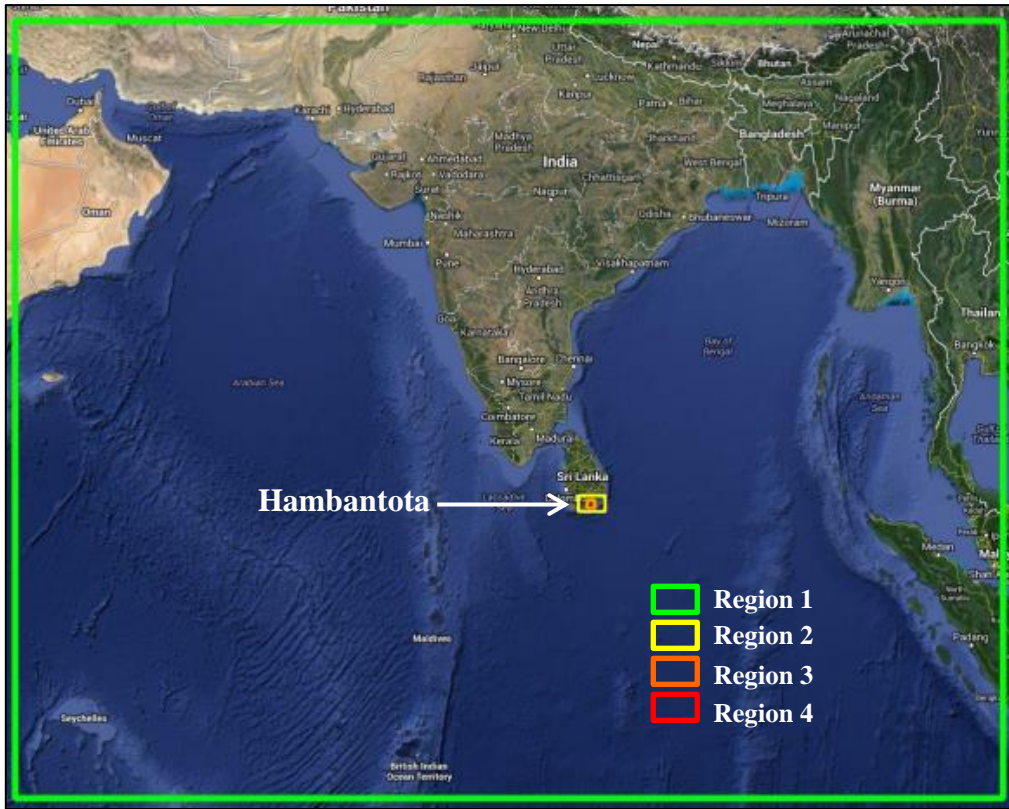


Figure 1. Map extents for Regions 1 to 4

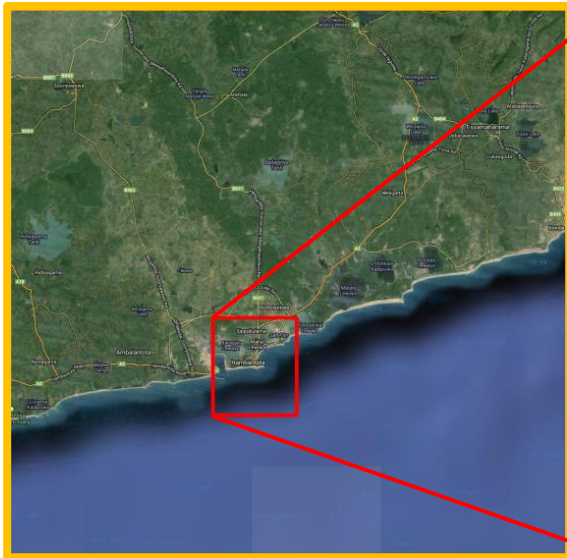


Figure 2. Region 3 extent



Figure 3. Region 4 extent

5. Data Sources

Various data sources were used to produce the DEMs. Table 3 shows the characteristics of each data source.

Table 3. Metadata of data sources

Region	Data	Resolution	Coordinate System	Horizontal Datum	Vertical Datum	Format
Region 1						
Bathymetry	GEBCO_08	30 arcsec	GCS	WGS84	*	Raster (ASCII)
Topography	GEBCO_08	30 arcsec	GCS	WGS84	*	Raster (ASCII)
Region 2						
Bathymetry	GEBCO_08	30 arcsec	GCS	WGS84	*	Raster (ASCII)
Topography	GEBCO_08	30 arcsec	GCS	WGS84	*	Raster (ASCII)
Region 3						
Bathymetry	<i>Same as Region 4; supplementary data outside Region 4 includes:</i>					
	Nautical chart	1:10,000	GCS	WGS84	LAT**	Raster (TIFF)
	Nautical chart	1:30,000	GCS	WGS84	LAT**	Raster (TIFF)
	GEBCO_08	30 arcsec	GCS	WGS84	*	Raster (ASCII)
Topography	<i>Same as Region 4; supplementary data outside Region 4 includes:</i>					
	Topographic map	1:10,000	SLD95		*	Raster (TIFF)
	SRTM 1	90 meters	GCS	WGS84	EGM96	Raster (TIFF)
Regions 4						
Bathymetry	Sounding points	200 meter interval	Lowrance	N/A	N/A	Table (CSV)
	Tidal data	1 minute	N/A	N/A	N/A	Table (CSV)
	Sounding points	1:1,100	SLD95		MSL	Raster(TIFF)
Topography	GPS data		GCS	WGS84		Table (CSV)
	Leveling survey data				MSL	Table (CSV)
	Aerial Photographs	Sub-meter				Raster (Panchromatic)

Notes:

* assumed to be referred to MSL, but vertical datum in some shallow areas may be different (Source: *GEBCO website*)

** Lowest Astronomical Tide (which is 0.6m below Mean Sea Level)

N/A not available

6. Methodology

The procedures in generating the DEMs for each region are as follows:

Regions 1 and 2: One data source

Procedure:

1. Verify the extent.
2. Resampling.

GEBCO_08 data were resampled from a resolution of 0.08333 degree to a resolution of 0.0333333 degree for Region 1, and 0.0041667 degree for Region 2, using the cubic convolution method.

Region 3: Multi-data sources

Region 3 consists of Region 4 survey data and supplementary data such as map and satellite data (Figure 4). Detailed procedures for processing survey data in Region 4 are explained in the next section.

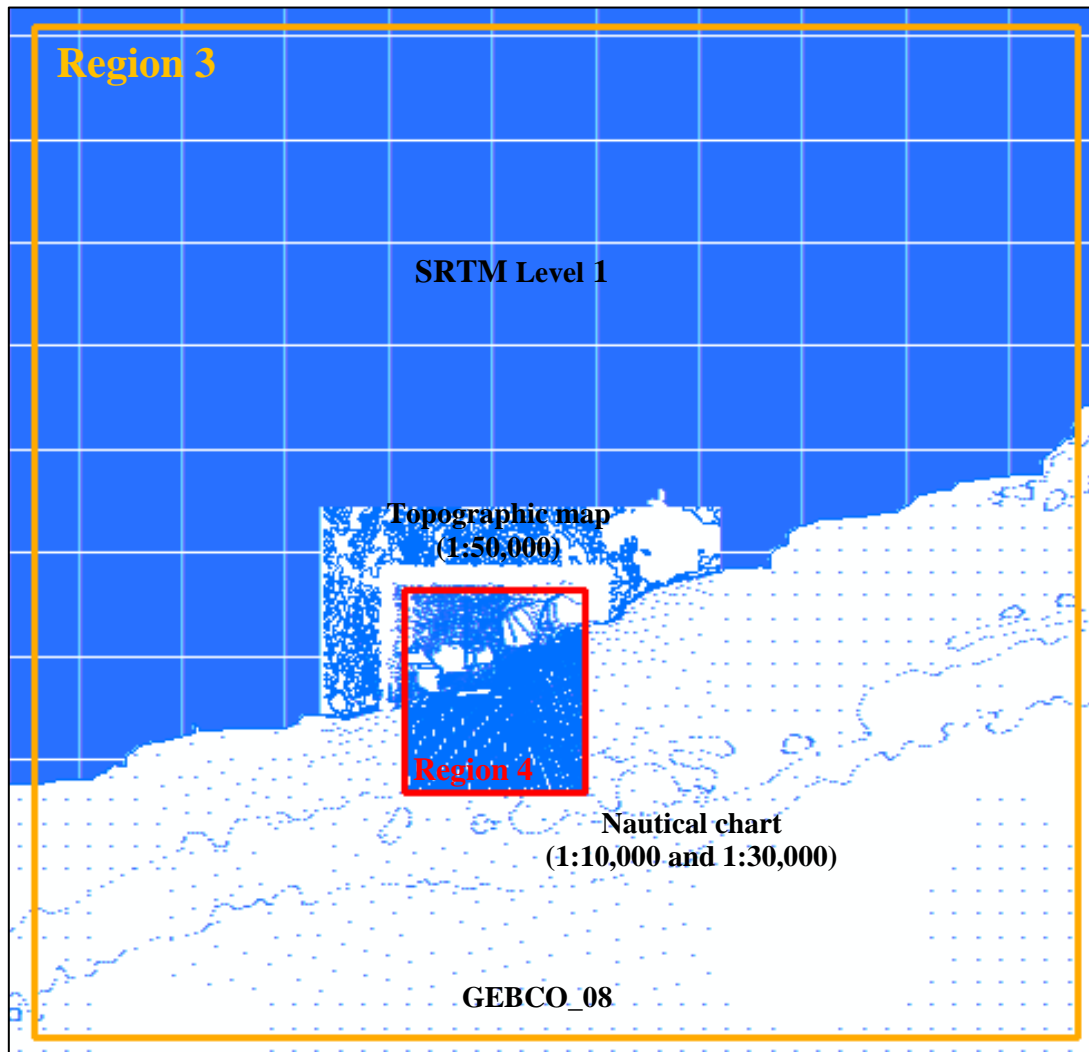


Figure 4. Data sources used for Region 3

Procedure:

1. Verify the extent.
2. Verify the shoreline.
3. Adjust the reference projection.
4. Clip various data sources using the verified shoreline.
5. Convert raster and vector data to points.
6. Merge all point data.
7. Interpolate point data.
8. Extract generated DEM.

Shoreline extraction

Various sources of shoreline data include the following: survey, map and satellite images, and DEMs such as SRTM and SPOT DEM. Extracting shoreline data by manual digitization may not be practical for a huge area, so a semi-automatic way by categorizing the positive and negative

elevations of a satellite DEM was done. However, not all satellite DEMs can be sources due to coarse resolution, such as GEBCO, and some DEMs do not account the shoreline, such as ASTER GDEM. In Sri Lanka, the RTK-DGPS survey data was used, along with the shoreline from Google Earth and topographic maps.

Data projection

All data were first projected to UTM 44N/WGS84, since the interpolation method used requires calculations to be done in meters. Also, it is necessary to use a single projection for all the datasets, to enable merging of data from different sources.

Data preparation

The shorelines, verified by Google Earth, were used to delineate the bathymetric and topographic areas. Higher accuracy and finer data were prioritized and, thus, included; while coarser data were removed in areas with more than one data source. The SRTM Level 1b (90 m) is finer than GEBCO_08 (900 m), so it was chosen for topographic areas. For the bathymetric area, which is not provided by SRTM, the GEBCO_08 was used.

All data were clipped and removed according to data quality and coverage and then converted to point data. Some gaps were created to reduce some inconsistencies and ensure smooth transitioning along the edges of different data sources.

Vertical Datum

Prior to merging, all data should be referred to a single datum to ensure seamless connection between data sources. Typically, tsunami inundation simulation requires all data to be converted to the MSL datum. However, it can vary, depending on the purpose. In this case, the MSL datum was used as the reference.

Topographic maps are usually referred to the MSL or Mean Higher High Water (MHHW), while the nautical charts to the LAT or Mean Lower Low Water (MLLW). For Sri Lanka, the topographic data was not be modified since it is already in MSL. However, since the nautical chart is referred to the LAT, the depth data was first be reduced to the MSL, which is 0.6m higher than the LAT.

Data merging

When merging all point data, a common field for elevation is created to ensure that elevations from different sources are rightly accounted prior to interpolation. In addition, the format of the shapefile dimension, whether 2D or 3D, should be consistent.

Data interpolation

Generally, certain conventions were followed when interpolating data. Cubic convolution is used when resampling rasters (converting to a different grid resolution), while Nearest Neighbor is used when converting raster data point data or re-projecting.

For generating the final DEM, interpolation of all merged point data to raster, the natural neighbor interpolation method was used, following the required resolution for region 3. After interpolation, output data were converted to GCS/WGS84 and extracted to the required extent.

Region 4: Multi-data sources

Region 4 mainly consists of survey data. For areas where survey cannot be conducted, supplementary data can be added (Figure 5).

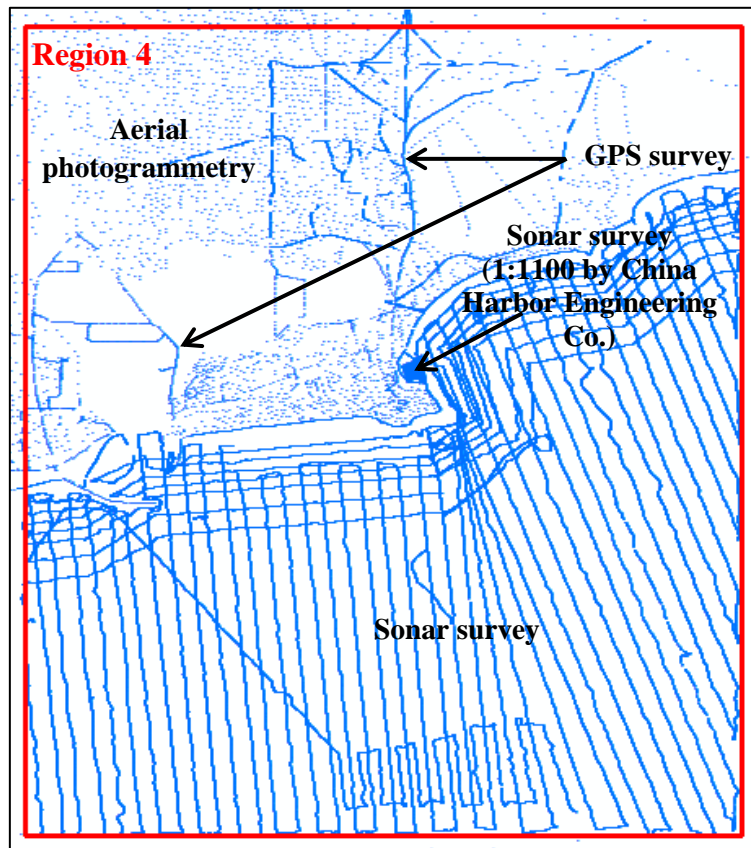


Figure 5. Data sources used for Region 4

Procedure:

1. Verify the extent.
2. Verify the shoreline.
3. Adjust the reference projection.
4. Process bathymetry data (tidal, sounding, etc.)
5. Process topography data (GPS, leveling, etc.)
6. Perform photogrammetry of ALOS stereo-pair images.
7. Clip various data sources using the verified shoreline.
8. Convert raster and vector data to points.
9. Merge all point data.
10. Interpolate point data.
11. Extract generated DEM.

Data projection and vertical datum

As mentioned earlier, it is necessary to use a single projection and vertical datum for all datasets, to enable seamless connection and merging of data from different sources. As in the supplementary data for region 3, all data were first converted to UTM44N/WGS84, and then projected to GCS/WGS84 after interpolation.

Data preparation

The shorelines used for region 3 were also used for region 4. In region 4, the finest data consists of the survey data (RTK, sonar), followed by map data, such as spot elevation / depth points, contour line, and then supplemented by the lower resolution SRTM level 1 and GEBCO_08.

Bathymetric survey data preparation

Two types of data were gathered for processing the bathymetry namely, tidal and sounding data. A Python script was customized by RIMES to facilitate fast and convenient conversions and corrections of these data.

Tidal data are the raw distances measured from the sensor to the water surface. These were first filtered by taking the average of each hour (30 minutes before and after each hour), and then reduced to the MSL using the elevation of a measured benchmark, measured by leveling survey. In this case, a temporary benchmark on the platform on top of the sensor was established to be 1.137m. The following equation was used to compute the elevation of the RIMES tide gauge sensor:

$$\begin{aligned} E_{RTG} &= E_{NTG} + D_{RTG} \\ &= 1.137 + (-1.360) \\ \mathbf{E_{RTG} &= -0.223 \text{ m}} \end{aligned}$$

Where:

E_{RTG} , is the elevation of the RIMES tide gauge with respect to the MSL

E_{NTG} , is the elevation of the NARA temporary benchmark with respect to the MSL

D_{RTG} , is the distance of the RIMES sensor to the NARA temporary benchmark

Sounding data are the raw distances measured from the sensor to the bottom of the sea. These are first converted to the GCS projection, since the equipment uses its own projection system, and converted to meters, since the default units are in feet. These are then corrected for draft, which is the distance from the sensor to the water surface (in Sri Lanka this draft was made constant every day), and the filtered hourly tidal data. On the other hand, since the river was surveyed using a calibrated pole, this was processed separately from the sounding data, but used the same tidal data for correction.

After importing the corrected sounding data to the 3D GIS software, these were then filtered for outliers, before merging with the other data (Figure 6).

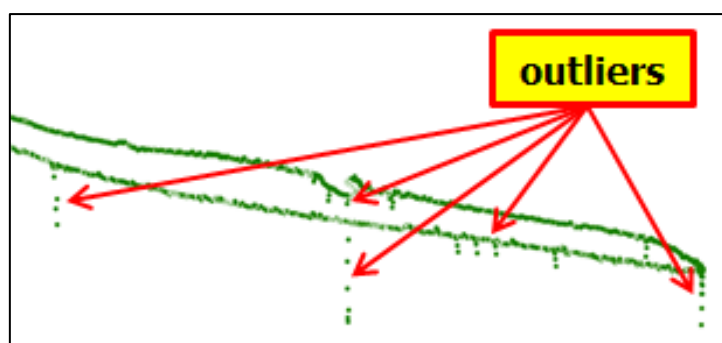


Figure 6. Removing outliers in sounding data

Topographic survey data preparation

For processing topographic data, two types of data were used, namely GPS survey data and photogrammetry data using ALOS PRISM stereo pair images.

GPS data, consisting of static (for GCPs and check points in photogrammetry) and kinematic data (elevation along the road network), were first processed and reduced to the MSL using a known tidal benchmark (NARA1-TBM). The following equation shows the how to compute the offset N , or undulation value needed to reduce the ellipsoidal height to MSL.

$$\begin{aligned}
 N &= \text{ellipsoid height} - \text{orthometric height (MSL)} \\
 &= 1.920 - 1.762 \\
 N &= \mathbf{0.158 \text{ m (undulation value)}}
 \end{aligned}$$

Photogrammetry was performed on scanned aerial photographs. After setting up the images, elevations were generated and corrected for outliers and irregularities in contours.

Data merging

When merging all point data, a common field for elevation is created to ensure that elevations from different sources are rightly accounted prior to interpolation. In addition, the format of the shapefile dimension, whether 2D or 3D, should be consistent.

Data interpolation

The same procedures were done for generating the final DEM. The natural neighbor interpolation method was used to interpolate the merged point data, following the required resolution for region 4. After interpolation, output data were converted to GCS/WGS84, and extracted to the required extent.

7. DEM Results

Figures 7 to 10 provide the DEMs generated for the pilot site.

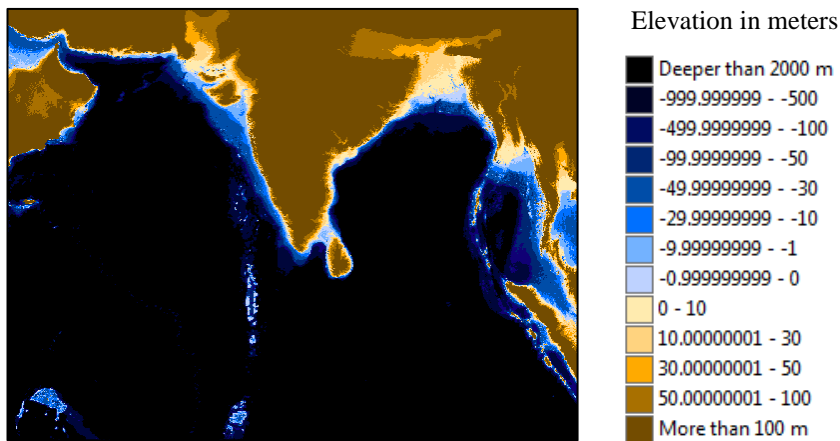


Figure 7. Region 1 DEM

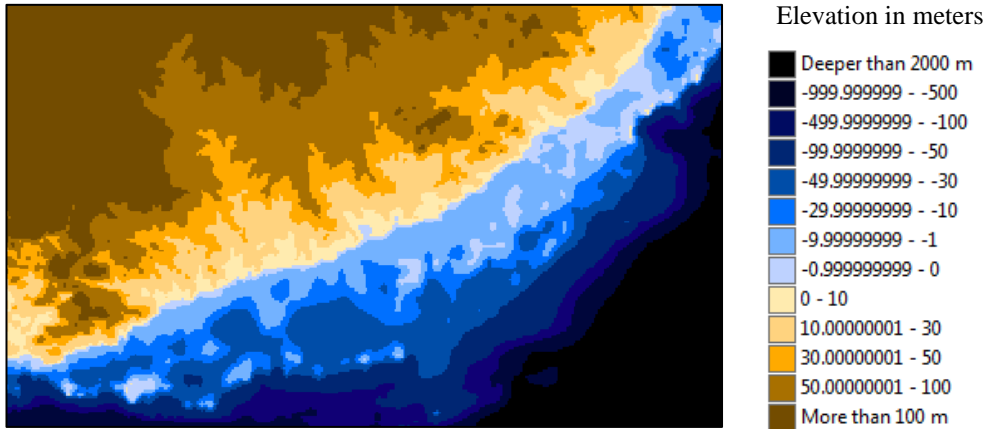


Figure 8. Region 2 DEM

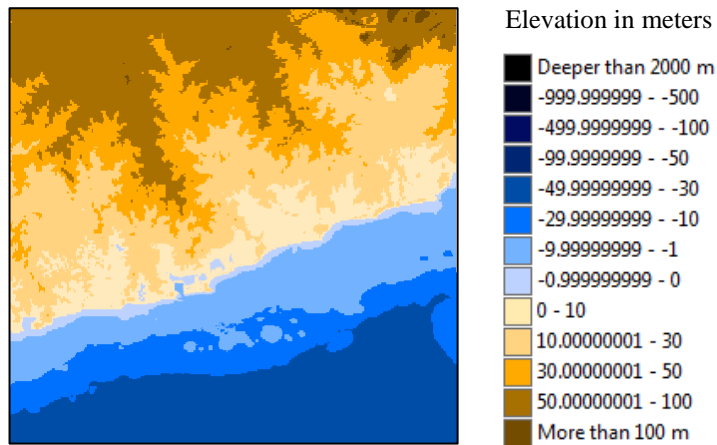


Figure 9. Region 3 DEM

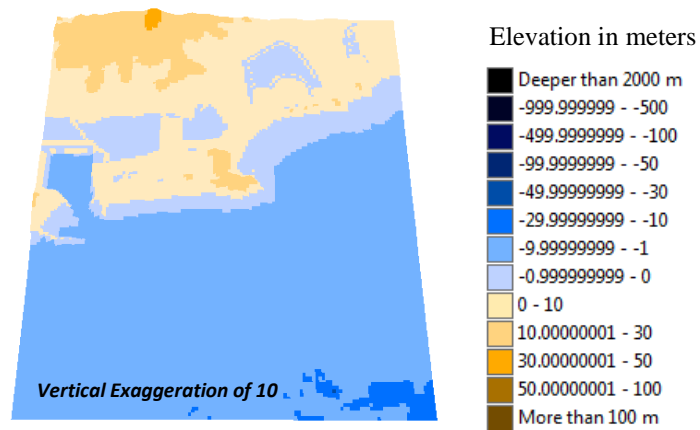


Figure 10. Region 4 DEM

8. Issues and Concerns

Noisy data

Bathymetric survey in Sri Lanka was conducted near the start of the monsoon season in April. Due to strong winds, the boat was quite unstable. This produced noise in the output data, so further filtering was necessary to smoothen the data (Figure 11). The filtering technique used was a simple moving average over 50 meters.

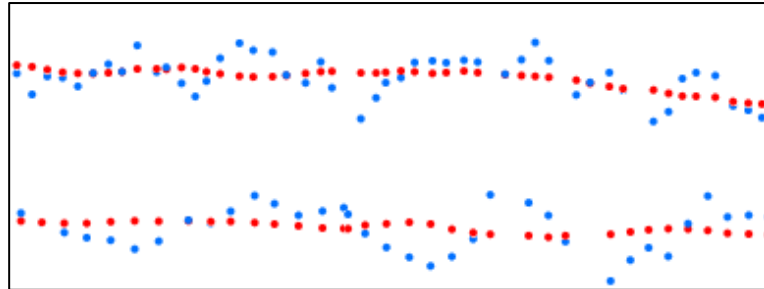


Figure 11 Noisy data (blue) vs. filtered data (red)

Outdated images

The existing aerial photographs used during the photogrammetry session were already outdated. A lot of major changes have already undergone since the date the aerial photographs were taken (Figures 12 and 13). The town of Hambantota, where the survey was conducted in April, is growing fast with the latest major constructions being undertaken within the harbor area. In this case, matching ground control points between the outdated aerial photographs with the current land use/ land cover of the area is quite difficult. More connections have to be established between the images during data processing to optimize the accuracy of the solution.



Figure 12. Recent harbor constructions

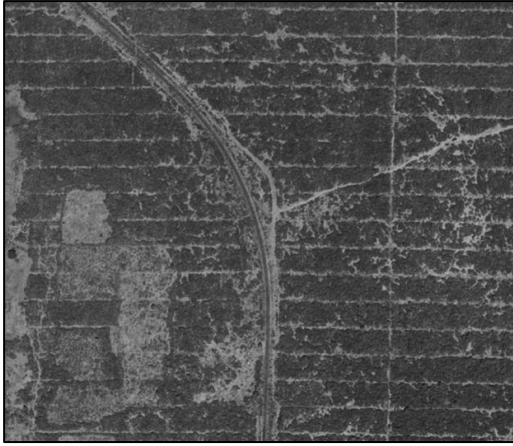


Figure 13. Land cover changes