Generation of Low-Cost Digital Elevation Models for Tsunami Inundation Modeling in Barrio Barretto, Olongapo, Philippines

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 was 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. Regions 3 and 4 consist of a mixture of satellite DEMs (SRTM Level) and 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 for tsunami inundation modeling

3. Project Site

DEM generation is focused on the project's pilot site in Barrio Barretto, Olongapo City, Philippines. 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	118.45000000, 23.241666667	126.24992200, 11.641782667
Region 2	0.004167	119.61666667, 15.100000000	121.03344667, 14.124922000
Region 3	0.001389	120.18397500, 14.890534670	120.30898500, 14.734966670
Region 4	0.000463	120.23400116, 14.875725794	120.28493116, 14.828499794

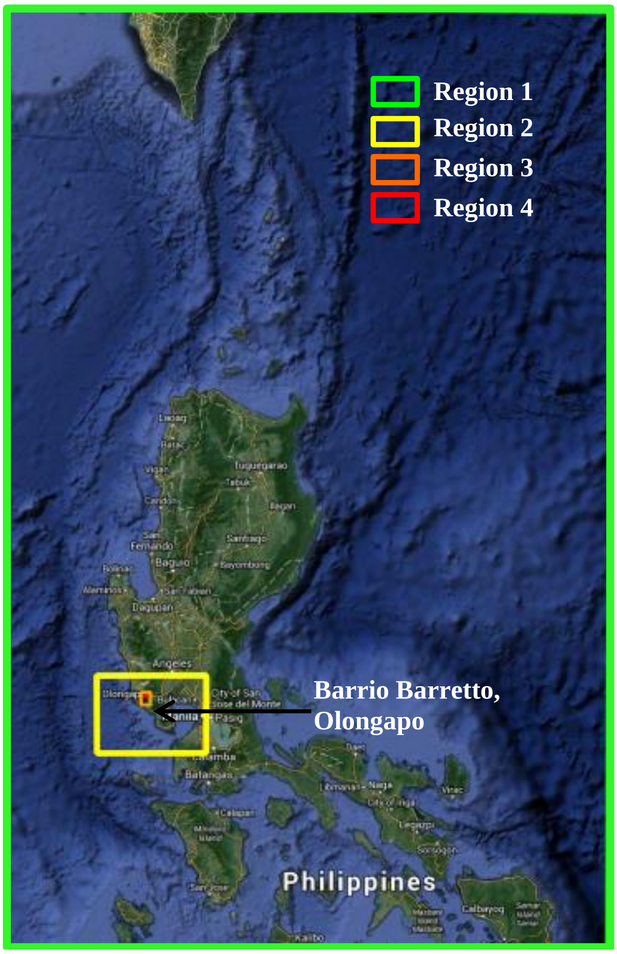

Figure 1. Map extents for Regions 1 to 4

Figure 2. Region 3 extent

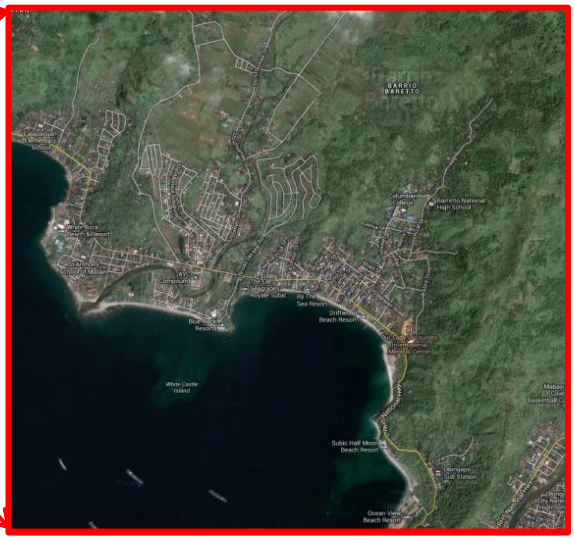

Figure 3. Region 4 extent

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	*Same as Region 4; supplementary data outside Region 4 includes:*					
	Nautical chart	1,10:000	GCS	WGS84	MLLW**	Raster (JPG)
	Nautical chart	1,30:000	GCS	WGS84	MLLW**	Raster (JPG)
Topography	*Same as Region 4; supplementary data outside Region 4 includes:*					
	Topographic map	1,50:000	GCS	Luzon	MSL ***	Raster (JPG)
Regions 4						
Bathymetry	Sounding points	200 meter interval	Lowrance	N/A	N/A	Table (CSV)
	River pole survey	100 meter interval	N/A	N/A	N/A	Table (CSV)
	Tidal data	1 minute	N/A	N/A	N/A	Table (CSV)
Topography	GPS data		GCS	WGS84	EGM96	Table (CSV)
	Leveling survey data				MSL	Table (CSV)
	ALOS PRISM	2.5 meters				Raster (DEM)
	SRTM 1	90 meters	GCS	WGS84	EGM96	Raster (TIFF)

Notes:

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

** Mean Lower Low Water (which is 0.46m below Mean Sea Level)

*** Mean Sea Level

N/A not available

6. Methodology

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

<u>Regions 1 and 2: One data source</u>

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.

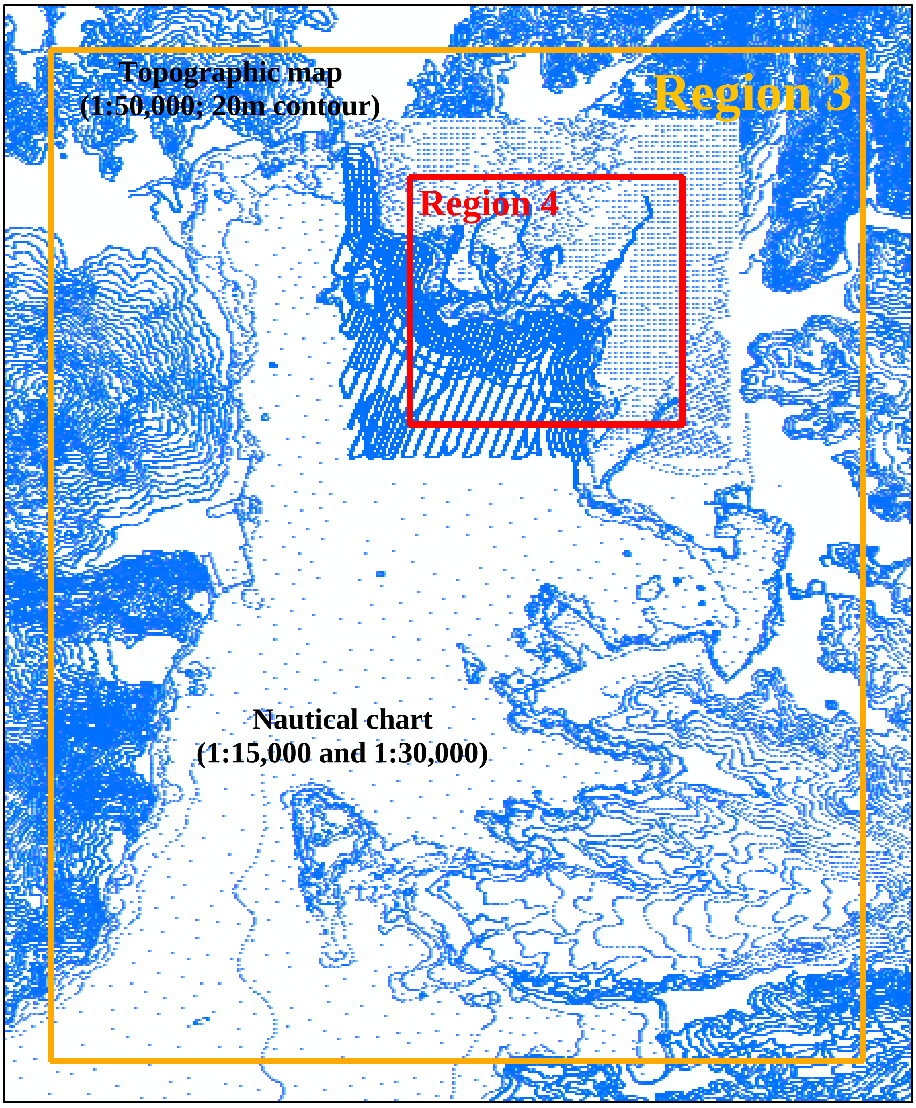

Figure 4. Data sources used for Region 3

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 data, map data, satellite images, and DEMs such as SRTM and SPOT DEM. Extracting shoreline data by manual digitizing 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 the Philippines, the RTK-DGPS survey data at estimated zero MSL was used, along with the shoreline from Google Earth and topographic maps.

Data projection
All data were first projected to UTM 51N/WGS84 since the interpolation method used requires calculations to be done in meters. Also, it is necessary to use a single projection for all 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.

Two types of data were used for this region: raster (SRTM 1) and vector (point and line) data. Data in different formats, such as tables and CAD files, were converted to shapefile format, excluding unnecessary CAD file data such as annotation and gridlines. All data were then clipped and removed, with priority given 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). However, since the nautical chart is referred to the MLLW, the depth data was first be reduced to the MSL, which is 0.46m higher than the MLLW.

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).

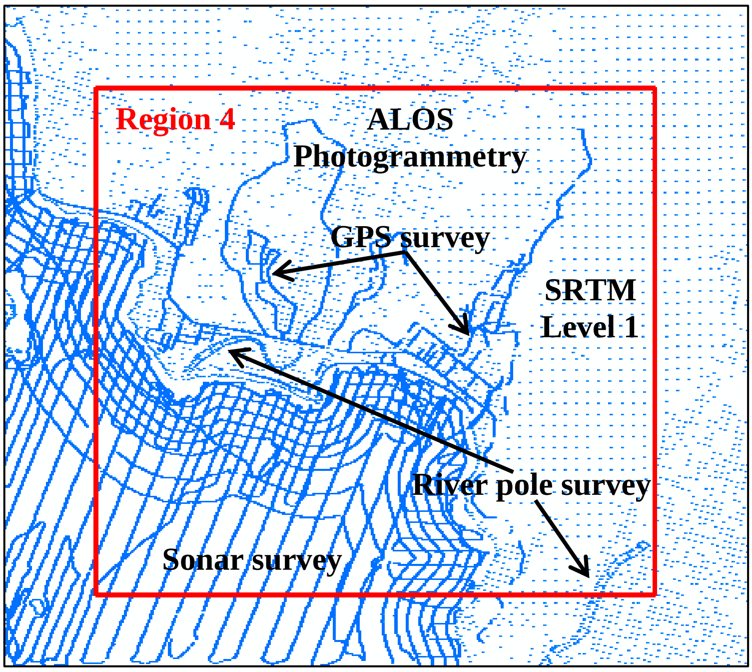

Figure 5. Data sources used for Region 4

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 UTM51N/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 and 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 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. The following equation was used to compute the elevation of the RIMES tide gauge sensor:

$$E_{RTG} = E_{NTG} + (D_{RTG} - D_{NTG})$$
$$= (-1.455) + ((-4.97530) - (-4.32722))$$
$$\mathbf{E_{RTG} = -2.10308\ m}$$

Where:
E_{RTG}, is the elevation of the RIMES tide gauge with respect to the MSL
E_{NTG}, is the elevation of the NAMRIA tide gauge with respect to the MSL
D_{RTG}, is the distance of the RIMES sensor to the tidal benchmark (TGBM-21A)
D_{NTG}, is the distance of the NAMRIA sensor to the tidal benchmark (TGBM-21A)

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 the Philippines this draft varies 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).

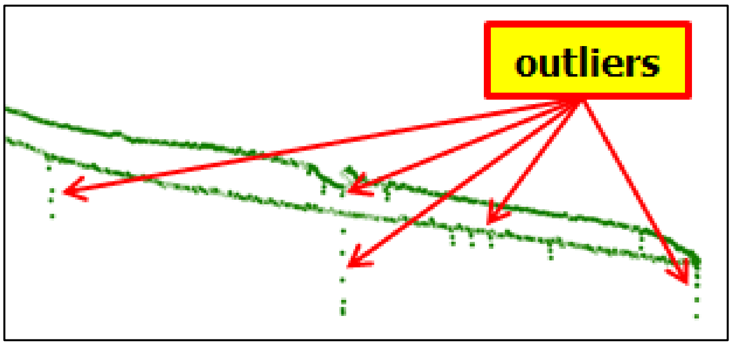

Figure 6. Removing outliers in sounding data

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 (BM ZA-17A). The following equation shows how to compute the offset N, or undulation value, needed to reduce the ellipsoidal height to MSL.

$$N = \text{ellipsoid height} - \text{orthometric height (MSL)}$$
$$= 49.684 - 2.530$$
$$\mathbf{N = 47.154\ m\ (undulation\ value)}$$

Photogrammetry was performed on ALOS PRISM images since the quality of the scanned aerial photographs is low (missing fiducial marks necessary for interior orientation). 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.

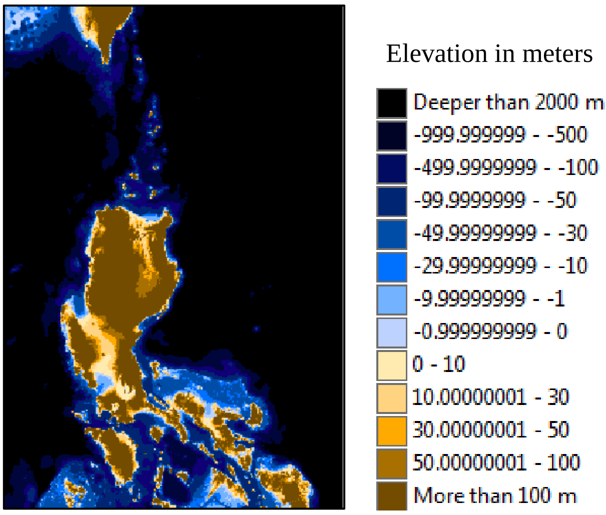

Figure 7. Region 1 DEM

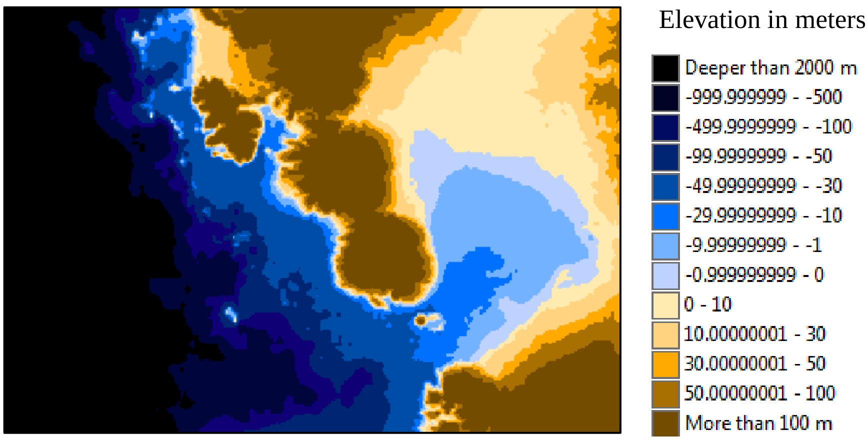

Figure 8. Region 2 DEM

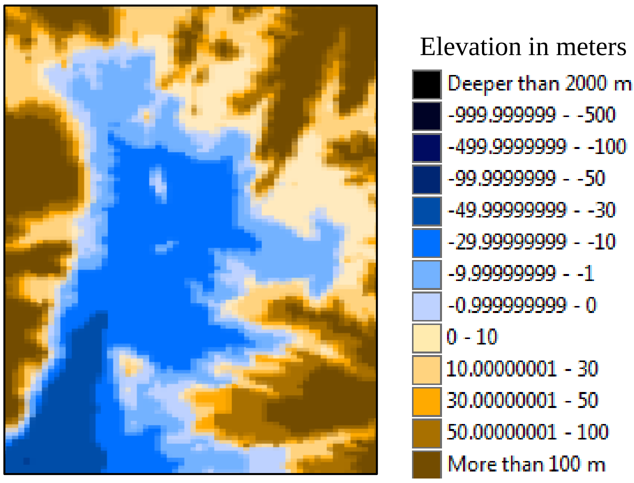

Figure 9. Region 3 DEM

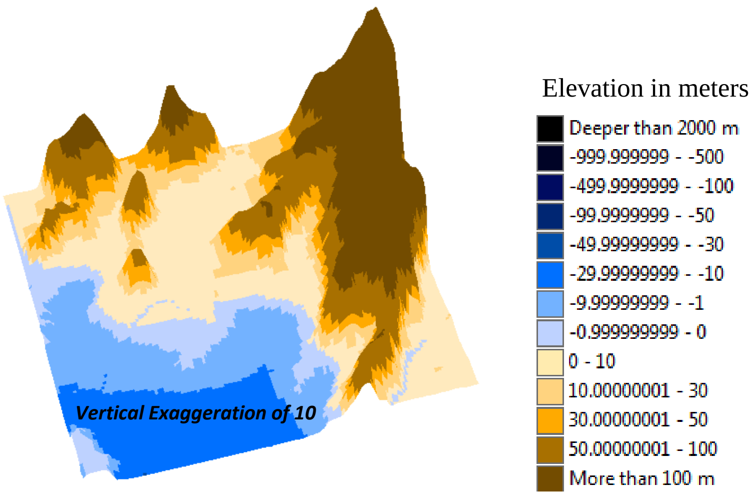

Figure 10. Region 4 DEM

8. Issues and Concerns

Poor quality images

One of the issues concerning the session on topography is about the quality of resource material to be used. Some fiducial marks, necessary for interior orientation, are missing on the aerial photographs, so photogrammetry cannot be performed. Although coarser at 2.5m resolution, the ALOS PRISM stereo pair images were used, instead of the existing aerial photographs with sub-meter resolution.

Coarse resolution

However, due to ALOS' coarser resolution, it was difficult to define the right shape of the mountain areas. So, the SRTM Level 1 was used, instead of ALOS, for elevations higher than 50 m (Figure 5).