REGION 8

Bohol River Flood Plain:

DREAM LiDAR Data Acquistion and Processing Report

TRAINING CENTER FOR APPLIED GEODESY AND PHOTOGRAMMETRY

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Abbreviations

ALTM	Airborne Laser Terrain Mapper
DAC	Data Acquisition Component
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVC	Data Validation Component
FOV	Field of View
FTP	File Transfer Protocol
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
POS	Position Orientation System
PRF	Pulse Repetition Frequency
NAMRIA	National Mapping and Resource Information Authority

Introduction

Introduction

1.1 About the DREAM Program

The UP Training Center for Applied Geodesy and Photogrammetry (UP TCAGP) conducts a research program entitled "Nationwide Disaster Risk and Exposure Assessment for Mitigation (DREAM) Program" funded by the Department of Science and Technology (DOST) Grants-in-Aid Program. The DREAM Program aims to produce detailed, up-to-date, national elevation dataset for 3D flood and hazard mapping to address disaster risk reduction and mitigation in the country.

The DREAM Program consists of four components that operationalize the various stages of implementation. The Data Acquisition Component (DAC) conducts aerial surveys to collect Light Detecting and Ranging (LiDAR) data and aerial images in major river basins and priority areas. The Data Validation Component (DVC) implements ground surveys to validate acquired LiDAR data, along with bathymetric measurements to gather river discharge data. The Data Processing Component (DPC) processes and compiles all data generated by the DAC and DVC. Finally, the Flood Modeling Component (FMC) utilizes compiled data for flood modeling and simulation.

Overall, the target output is a national elevation dataset suitable for 1:5000 scale mapping, with 50 centimeter horizontal and vertical accuracies. These accuracies are achieved through the use of state-of-the-art airborne Light Detection and Ranging (LiDAR) technology and appended with Synthetic-aperture radar (SAR) in some areas. It collects point cloud data at a rate of 100,000 to 500,000 points per second, and is capable of collecting elevation data at a rate of 300 to 400 square kilometers per day, per sensor.

1.2 Objectives and Target Outputs

The program aims to achieve the following objectives:

a) To acquire a national elevation and resource dataset at sufficient resolution to produce information necessary to support the different phases of disaster management;

b) To operationalize the development of flood hazard models that would produce updated and detailed flood hazard maps for the major river systems in the country;

c) To develop the capacity to process, produce and analyze various proven and potential thematic map layers from the 3D data useful for government agencies;

d) To transfer product development technologies to government agencies with geospatial information requirements, and;

e) To generate the following outputs:
   1) flood hazard map
   2) digital surface model
   3) digital terrain model and
   4) orthophotograph

1.3 General Methodological Framework

The methodology employed to accomplish the project's expected outputs are subdivided into four (4) major components, as shown in Figure 1. Each component is described in detail in the following sections.

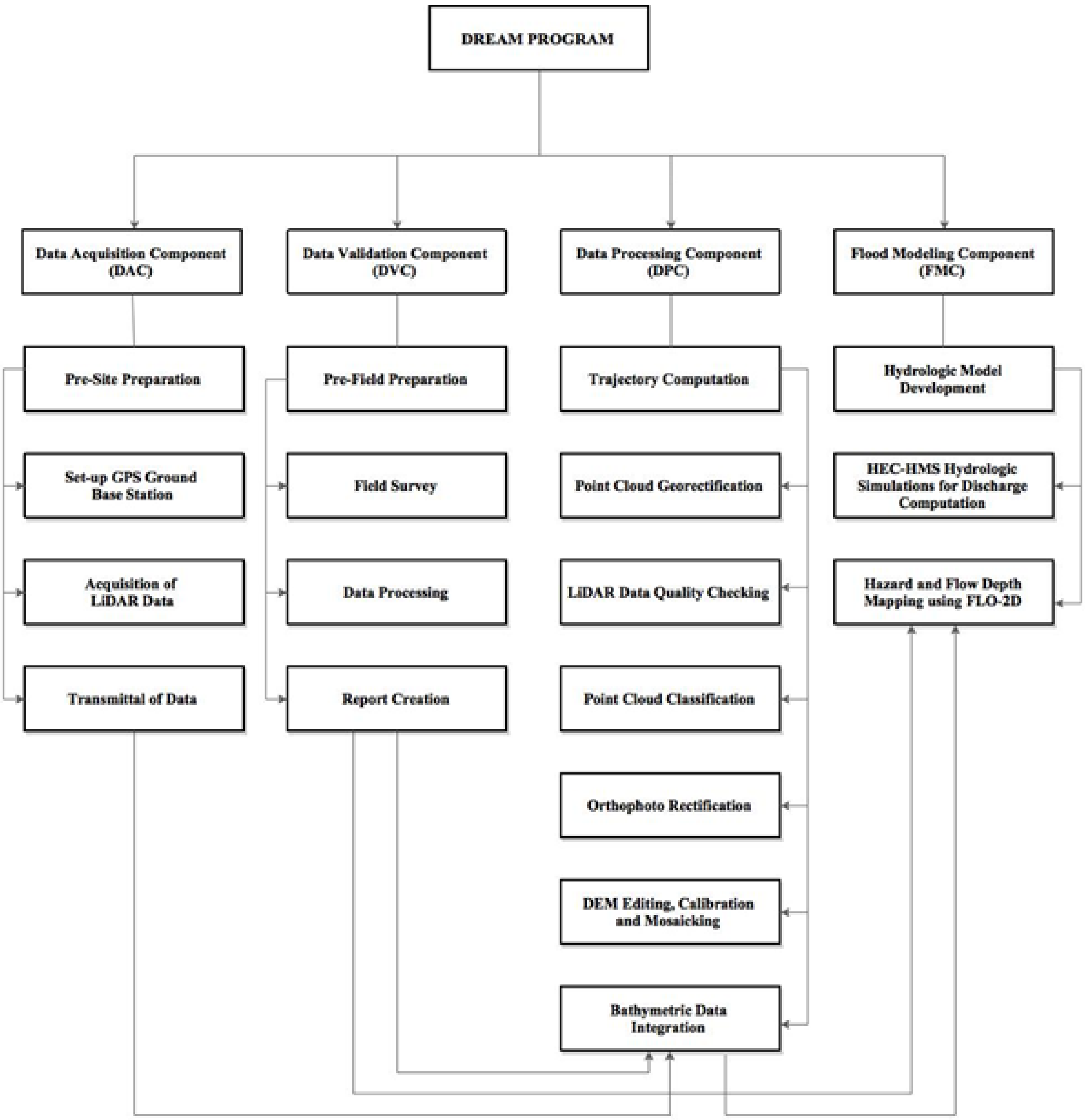

Figure 1. The General Methodological Framework of the Program

Study Area

Study Area

The Bohol River Basin is located in Central and Southern Mindanao. It traverses through Sarangani, South Cotabato, Davao del Sur, and General Santos City. It is the eighteenth largest river basin in the Philippines. It covers an area of 1,435 square kilometers and travels for 33 kilometers from its source to its mouth. The location of the Bohol-Malungon River Basin is shown in Figure 2.

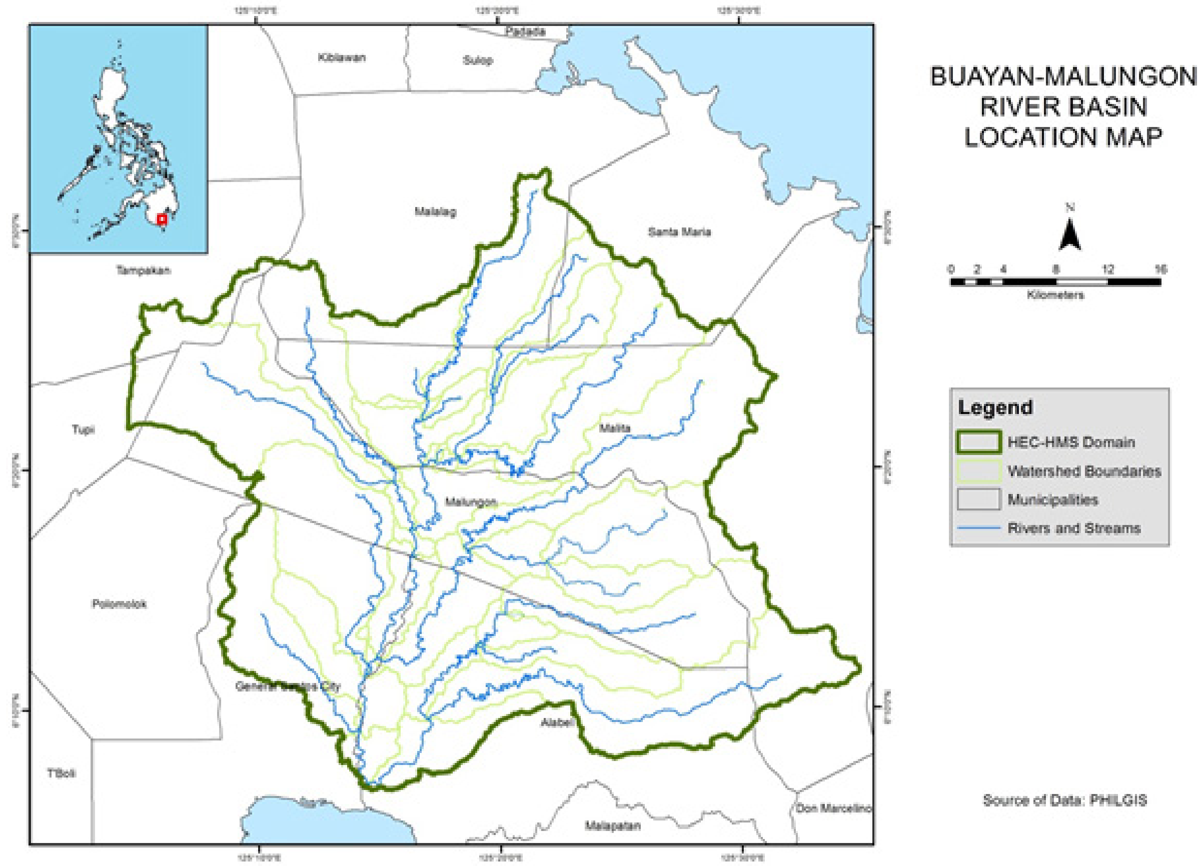

Figure 2. Bohol River Basin Location Map

The land and soil characteristics are important parameters used in assigning the roughness coefficient for different areas within the river basin. The roughness coefficient, also called Manning's coefficient, represents the variable flow of water in different land covers (i.e. rougher, restricted flow within vegetated areas, smoother flow within channels and fluvial environments).

The shape files of the soil and land cover were taken from the Bureau of Soils, which is under the Department of Environment and Natural Resources Management, and National Mapping and Resource Information Authority (NAMRIA). The soil and land cover of Agno River Basin are shown in Figures 3 and 4, respectively.

Study Area

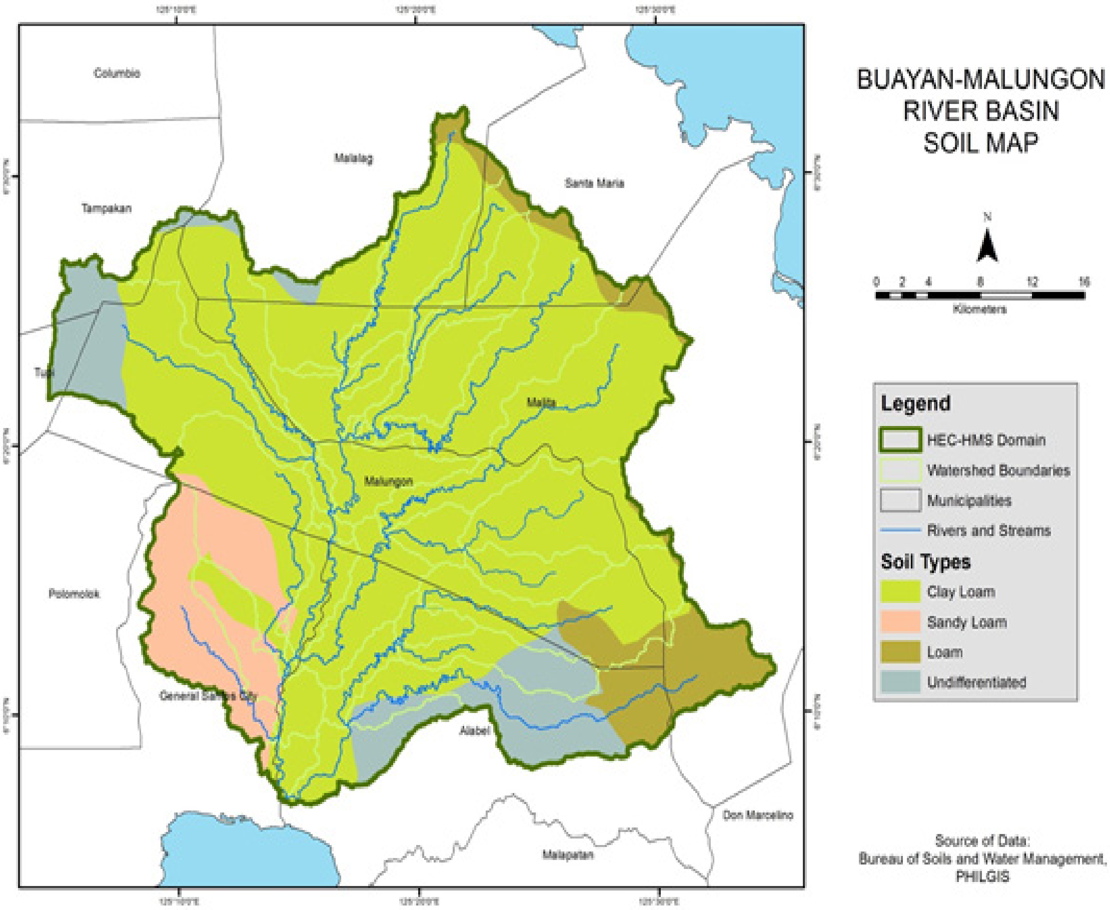

Figure 3. Bohol-Malungon River Basin Soil Map

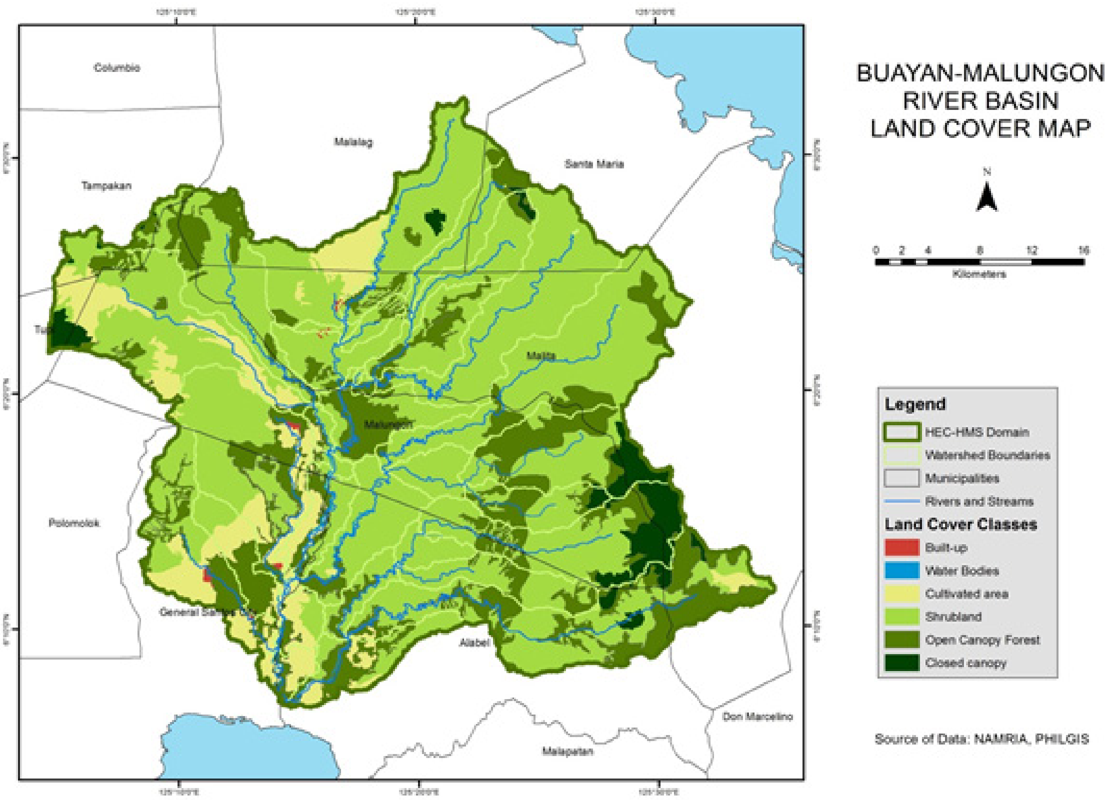

Figure 4. Bohol-Malungon River Basin Land Cover Map

Methodology

Methodology

3.1 Acquisition Methodology

The methodology employed to accomplish the project's expected outputs are subdivided into four (4) major components, as shown in Figure 5. Each component is described in detail in the following sections.

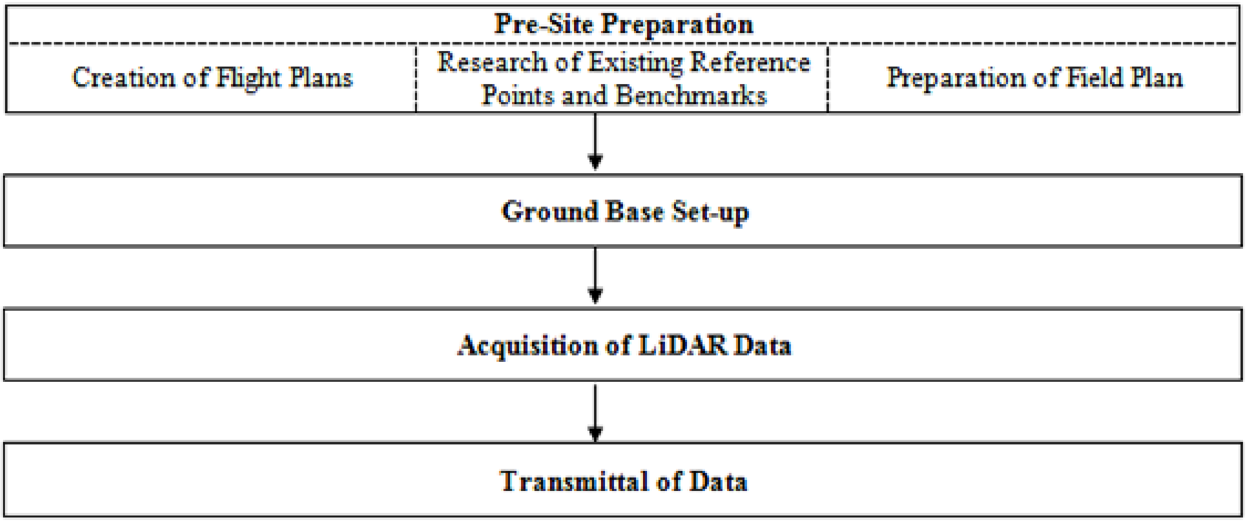

Figure 5. Flowchart of Project Methodology

3.1.1 Pre-site Preparations

3.1.1.1 Creation of Flight Plans

Flight planning is the process of configuring the parameters of the aircraft and LiDAR technology (i.e., altitude, angular field of view (FOV)), speed of the aircraft, scans frequency and pulse repetition frequency) to achieve a target of two points per square meter point density for the floodplain. This ensures that areas of the floodplain that are most susceptible to floods will be covered. LiDAR parameters and their computations are shown in Table 1.

The parameters set in the LiDAR sensor to optimize the area coverage following the objectives of the project and to ensure the aircraft's safe return to the airport (base of operations) are shown in Table 1. Each flight acquisition is designed for four operational hours. The maximum flying hours for Cessna 206H is five hours.

Table 1. Relevant LiDAR parameters

Parameter		Formula	Description
SW (Swath Width)		SW = 2 * H * tan (θ/2)	H – altitude Θ – angular FOV
Pointing Space	ΔXacross	ΔXacross = (Θ * H) / (Ncos2(Θ/2))	ΔXacross – point spacing across the flight line H – altitude Θ – angular FOV N – number of points in one scanning line
	ΔXalong	ΔXalong = v / fsc	ΔXalong- point spacing along the flight line v – forward speed (m/s) fsc – scanning rate or scan frequency
Point density, dmin		dmin = 1 / (ΔXacross * ΔXalong)	ΔXacross, ΔXalong point spacings
Flight line separation, e		e = SW * (1 – overlapping factor)	SW – swath width
# of flight lines, n		n = w / [(1 – overlap) * SW]	w-width of the map that will be produce in meters. The direction of flights will be perpendicular to the width.

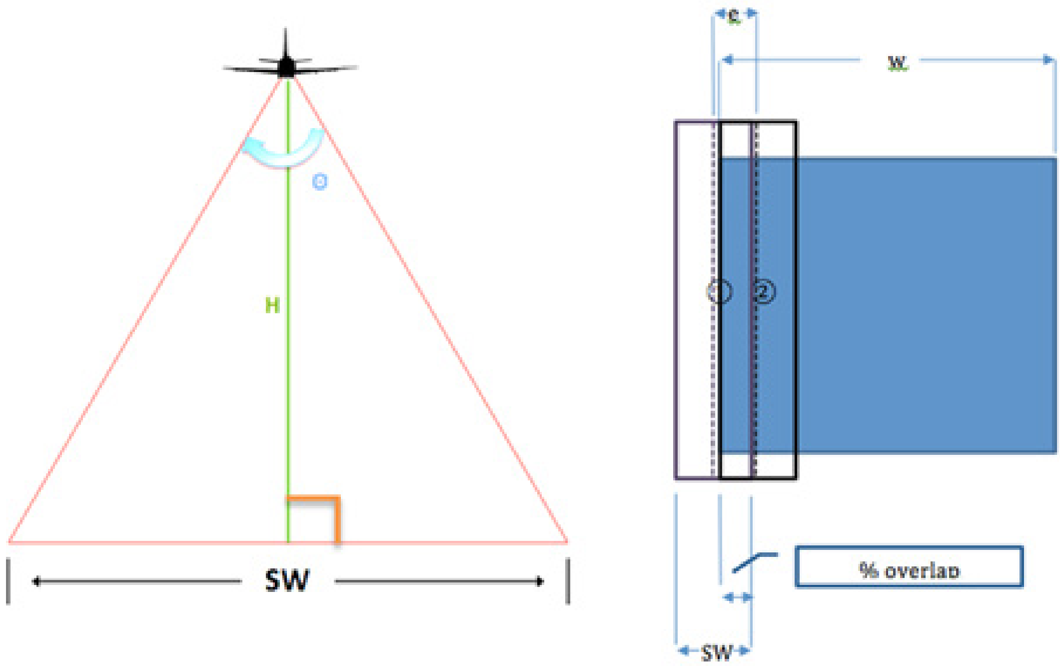

Figure 6. Concept of LiDAR data acquisition parameters

The relationship among altitude, swath, and FOV is show in Figure 6. Given the altitude of the survey (H) and the angular FOV, the survey coverage for each pass (swath) can be calculated by doubling the product of altitude and tangent of half the field of view.

3.1.1.2 Collection of Existing Reference Points and Benchmarks

Collection of pertinent technical data, available information, and coordination with the National Mapping and Resource Information Authority (NAMRIA) is conducted prior to the surveys. Reference data collected includes locations and descriptions of horizontal and vertical control (elevation benchmarks) points within or near the project area. These control points are used as base stations for the aerial survey operations. Base stations are observed simultaneously with the acquisition flights.

3.1.1.3 Preparation of Field Plan

In preparation for the field reconnaissance and actual LiDAR data acquisition, a field plan is prepared by the implementation team. The field plan serves as a guide for the actual fieldwork and included personnel, logistical, financial, and technical details. Three major factors are included in field plan preparation: priority areas for the major river basin system; budget; and accommodation and vehicle rental.

LiDAR data are acquired for the floodplain area of the river system as per order of priority based on history of flooding, loss of lives, and damages of property. The order of priority in which LiDAR data surveys are conducted by the team for the floodplain areas of the 18 major river systems and 3 additional systems is shown in Table 2.

Table 2. List of Target River Systems in the Philippines

	Target River System	Location	Area of the River System (km^2)	Area of the Flood Plain (km^2)	Area of the Watershed (km^2)
1	Cagayan de Oro	Mindanao	1,364	25	1,338.51
1.1	Iponan	Mindanao	438	33	404.65
2	Mandulog	Mindanao	714	7	707.41
2.1	Iligan	Mindanao	153	7	146.38
2.2	Agus	Mindanao	1,918	16	1,901.60
3	Pampanga	Luzon	11,160	4458	6702
4	Agno	Luzon	6,220	1725	4495
5	Bicol	Luzon	3,173	585	2,587.79
6	Panay	Visayas	2,442	619	1823
7	Jalaur	Visayas	2,105	713	1,392
8	Ilog Hilbangan	Visayas	2,146	179	1967
9	Magasawang Tubig	Luzon	1,960	483	1,477.08
10	Agusan	Mindanao	11,814	262	11,551.62
11	Tagoloan	Mindanao	1,753	30	1,722.90
12	Davao	Mindanao	1,609	54	1555
13	Tagum	Mindanao	2,504	595	1,909.23
14	Bohol	Mindanao	1,589	201	1,388.21
15	Mindanao	Mindanao	20,963	405	20,557.53
16	Lucena	Luzon	238	49	189.31
17	Infanta	Luzon	1,029	90	938.61
18	Boracay	Visayas	43.34	43.34	N/A
19	Cagayan	Luzon	28,221	10386	17,835.14

3.1.2 Ground Base Set-up

A reconnaissance is conducted one day before the actual LiDAR survey for purposes of recovering control point monuments on the ground and site visits of the survey area set in the flight plan for the floodplain. Coordination meetings with the Airport Manager, regional DOST office, local government units and other concerned line government agencies are also held.

Ground base stations are established within 30-kilometer radius of the corresponding survey area in the flight plan. This enables the system to establish its position in three-dimensional (3D) space so that the acquired topographic data will have an accurate 3D position since the survey required simultaneous observation with a base station on the ground using terrestrial Global Navigation Satellite System (GNSS) receivers.

3.1.3 Acquisition of Digital Elevation Data (LiDAR Survey)

Acquisition of LiDAR data is done by following the flight plans. The survey uses a LiDAR instrument mounted on the aircraft with its sensor positioned through a specially modified peep hole on the belly of the aircraft. The pilots are guided by the flight guidance software which uses the data out of the flight planning program with a mini-display at the pilot's cockpit showing the aircraft's real-time position relative to the current survey flight line. The reference points established by NAMRIA are also monitored and used to calibrate the data.

As the system collected LiDAR data, ranges and intensities are recorded on hard drives dedicated to the system while the images are stored on the camera hard drive. Position Orientation System (POS) data is recorded on the POS computer inside the control rack. It can only be accessed and downloaded via file transfer protocol (ftp) to the laptop computer. GPS observations were downloaded each day for efficient data management.

3.1.4 Transmittal of Acquired LiDAR Data

All data surrendered are monitored, inspected and re-checked by securing a data transfer checklist signed by the downloader (Data Acquisition Component) and the receiver (Data Processing Component). The data transfer checklist shall include the following: date of survey, mission name, flight number, disk size of the necessary data (LAS, LOGS, POS, Images, Mission Log File, Range, Digitizer and the Base Station), and the data directory within the server. Figure 7 shows the arrangement of folders inside the data server.

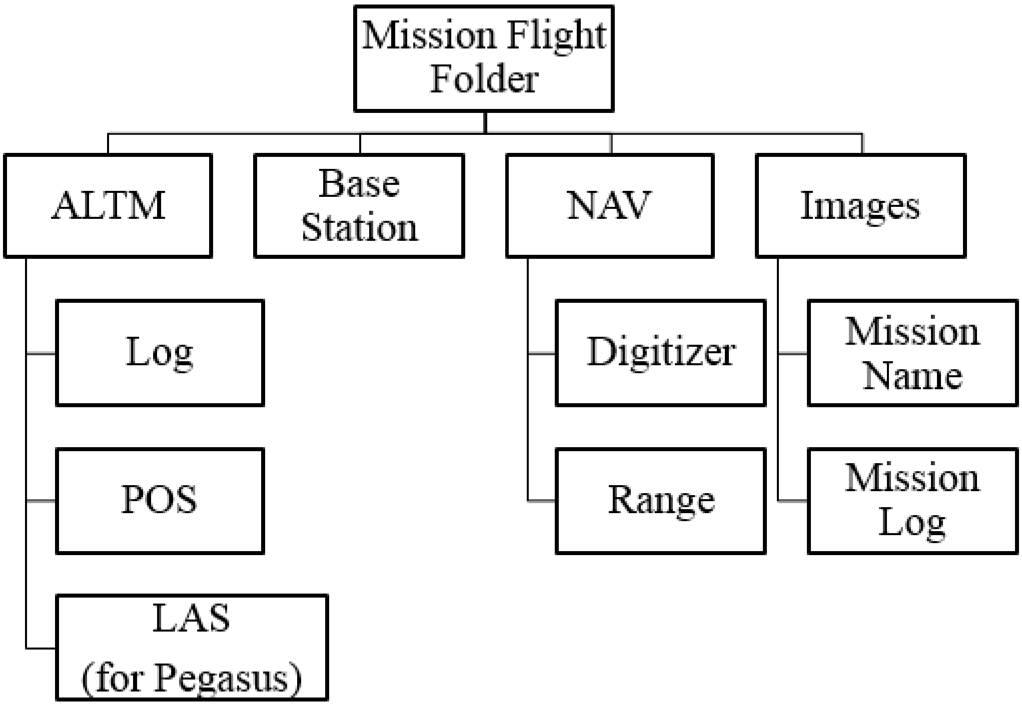

Figure 7. LiDAR Data Management for transmittal

3.1.5 Equipment (ALTM Pegasus)

The ALTM Pegasus (Optech, Inc) is a laser based system suitable for topographic survey (Figure 8). It has a dual output laser system for maximum density capability. The LiDAR system is equipped with an Inertial Measurement Unit (IMU) and GPS for geo-referencing of the acquired data (Annex A contains the technical specification of the system).

The camera of the Pegasus sensor is tightly integrated with the system. It has a foot-print of 8,900 pixels across by 6,700 pixels along the flight line (Annex B contains the technical specification of the D-8900 aerial digital camera).

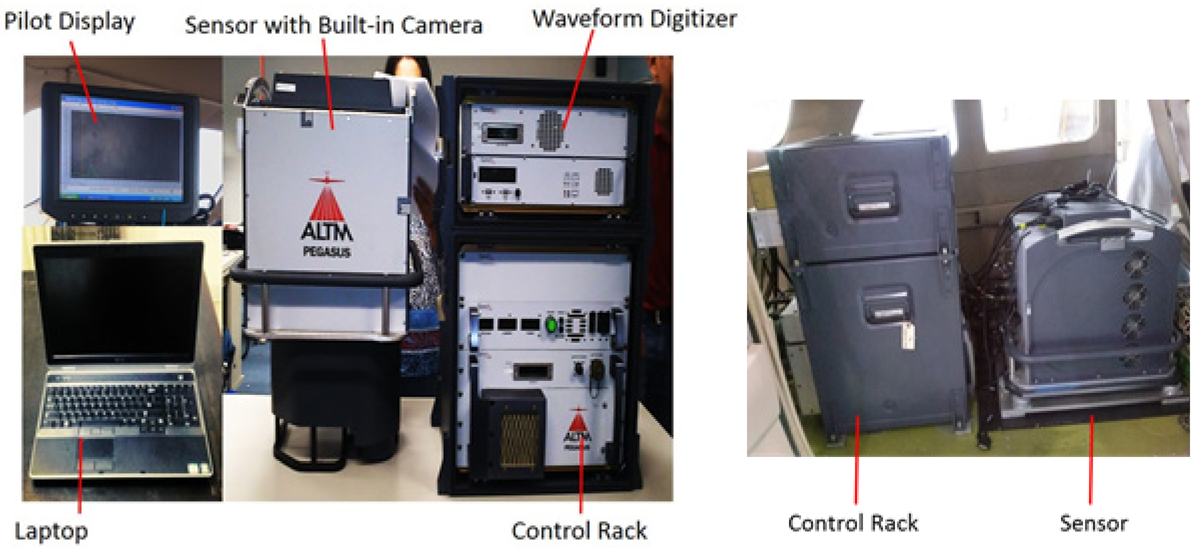

Figure 8. The ALTM Pegasus System: a) parts of the Pegasus system, b) the system as installed in Cessna T206H

3.2 Processing Methodology

The schematic diagram of the workflow implemented by the Data Processing Component (DPC) is shown in Figure 9. The raw data collected by the Data Acquisition Component (DAC) is transferred to DPC. Pre-processing of this data starts with the computation of trajectory and georectification of point cloud, in which the coordinates of the LiDAR point cloud data are adjusted and checked for gaps and shifts, using POSPac, LMS, LAStools and Quick Terrain (QT) Modeler software.

The unclassified LiDAR data then undergoes point cloud classification, which allows cleaning of noise data that are not necessary for further processing, using TerraScan software. The classified point cloud data in ASCII format is used to generate a data elevation model (DEM), which is edited and calibrated with the use of validation and bathymetric survey data collected from the field by the Data Validation and Bathymetry Component (DVBC). The final DEM is then used by the Flood Modeling Component (FMC) to generate the flood models for different flooding scenarios.

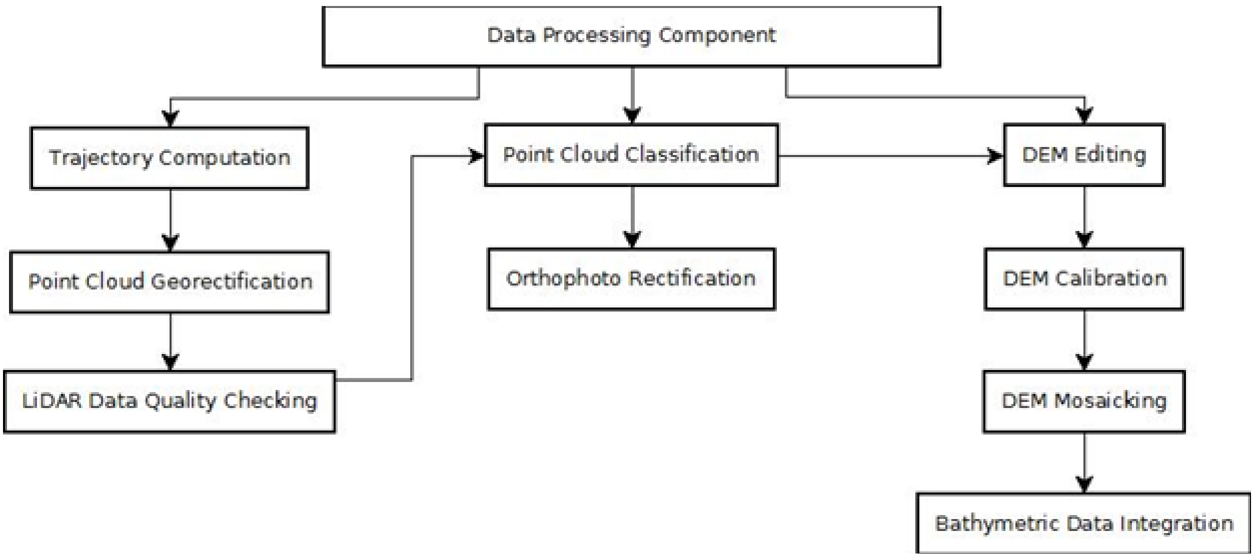

Figure 9. Schematic diagram of the data processing

3.2.1 Data Transfer

The Bohol mission, named 1TGB315A, was flown with the Airborne LiDAR Terrain Mapper (ALTM™ Optech Inc.) by Pegasus system on November 11, 2013. The Data Acquisition Component (DAC) transferred 12.9 Gigabytes of Range data, 115 Megabytes of POS data, 6.41 Megabytes of GPS base station data, and 17.6 Gigabytes of raw image data to the data server on December 3, 2013. DPC verified the completeness of the transferred data. The whole Bohol dataset was fully transferred on December 11, 2013.

3.2.2 Trajectory Computation

The trajectory of the aircraft is computed using the software POSPac MMS v6.2. It combines the POS data from the integrated GPS/INS system installed on the aircraft, and the Rinex data from the GPS base station located within 25 kilometers of the area. It then computes the Smoothed Best Estimated Trajectory (SBET) file, which contains the best estimated trajectory of the aircraft, and the Smoothed Root Mean Square Estimation error file (SMRMSG), which contains the corresponding standard deviations of the position parameters of the aircraft at every point on the computed trajectory.

The key parameters checked to evaluate the performance of the trajectory are the Solution Status parameters and the *Smoothed Performance Metrics* parameters. The *Solution Status* parameters characterize the GPS satellite geometry and baseline length at the time of acquisition, and the processing mode used by POSPac. The acceptable values for each Solution Status parameter are shown in Table 3.

The *Smoothed Performance Metrics* parameters describe the root mean square error (RMSE) for the north, east and down (vertical) position of the aircraft for each point in the computed trajectory. A RMSE value of less than 4 centimeters for the north and east position is acceptable, while a value of less than 8 centimeters is acceptable for the down position.

Table 3. Smoothed Solution Status parameters in POSPac MMS v6.2.

Parameter	Optimal Value
Number of satellites	More than 6 satellites
Position Dilution of Precision	Less than 3
Baseline Length	Less than 30 km2
Processing mode	Less than or equal to 1, however short burtsts of values greater than 1 are acceptable

3.2.3 LiDAR Point Cloud Rectification

The trajectory file (SBET) and its corresponding accuracy file (SMRMSG) generated in POSPac are merged with the Range file to compute the coordinates of each individual point. The coordinates of points within the overlap region of contiguous strips vary due to small deviations in the trajectory computation for each strip. These strip misalignments are corrected by matching points from overlapping laser strips. This is done by the LiDAR Mapping Suite (LMS) software developed by Optech.

LMS is a LiDAR software package used for automated LiDAR rectification. It has the capability to extract planar features per flight line and to form correspondence among the identical planes available in the overlapping areas (illustrated in Figure 10). In order to produce geometrically correct point cloud, the redundancy in the overlapping areas of flight lines is used to determine the necessary corrections for the observations.

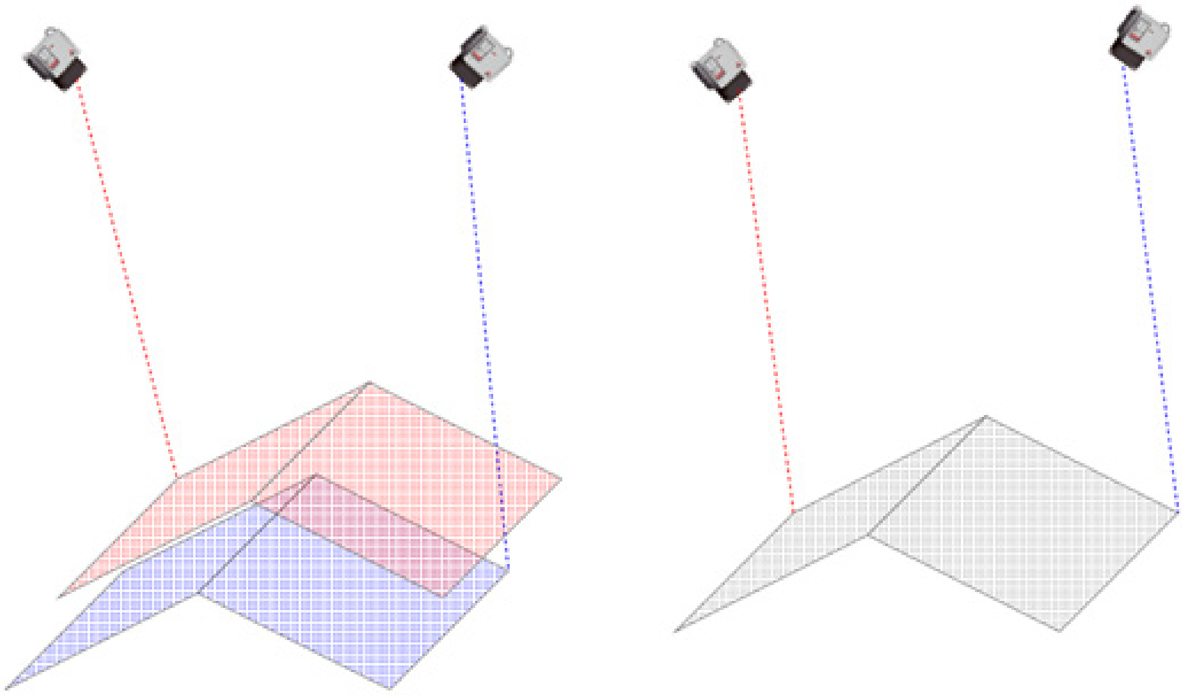

Figure 10. Misalignment of a single roof plane from two adjacent flight lines, before rectification (left). Least squares adjusted roof plane, after rectification (right).

The orientation parameters are corrected in LMS by using least squares adjustment to obtain the best-fit parameters and improve the accuracy of the LiDAR data. The primary indicators of the LiDAR rectification accuracy are the standard deviations of the corrections of the orientation parameters. These values are seen on the Boresight corrections, GPS position corrections, and IMU attitude corrections, all of which are located on the LMS processing summary report. Optimum accuracy is obtained if the Boresight and IMU attitude correction standard deviations are less than 0.001°, and if the GPS position standard deviations are below 0.01 meter.

3.2.4 LiDAR Data Quality Checking

After the orientation parameters are corrected and the point cloud coordinates are computed, the entire point cloud data undergoes quality checking, to see if: (a) there are remaining horizontal and vertical misalignments between contiguous strips, and; (b) to check if the density of the point cloud data reach the target density for the site. The LAStools software is used to compute for the elevation difference in the overlaps between strips and the point cloud density. It is a software package developed by Rapidlasso GmbH for filtering, tiling, classifying, rasterizing, triangulating and quality checking Terabytes of LiDAR data, using robust algorithms, efficient I/O tools and memory management. LAStools can quickly create raster representing the computed quantities, which provide guiding images in determining areas where further quality checks are necessary. The target requirements for floodplain acquisition, computed by LAStools, are shown in Table 4.

Table 4. Parameters investigated during quality checks.

Criteria	Requirement
Minimum per cent overlap	25%
Average point cloud density per square meter	2.0
Elevation difference between strips (on flat areas)	0.20 meters

LAStools can provide guides where elevation differences probably exceed the 20 cm limit. An example of LAStools output raster visualizing points in the flight line overlaps with a vertical difference of +/- 20 cm (displayed as dense red/blue areas) is shown in Figure 11.

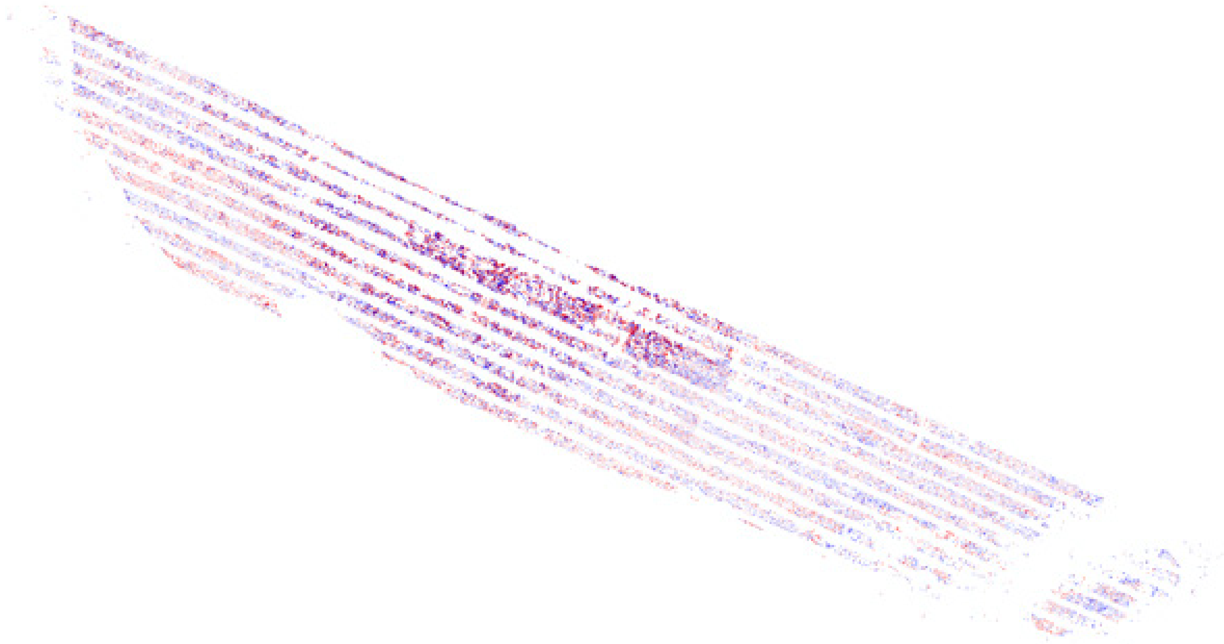

Figure 11. Elevation difference between flight lines generated from LAStools

To investigate the occurrences of elevation differences in finer detail, the profiling tool of Quick Terrain Modeler software is used. Quick Terrain Modeler (QT Modeler) is a 3D point cloud and terrain visualization software package developed by Applied Imagery, Inc. The profiling capability of QT Modeler is illustrated in Figure 12.

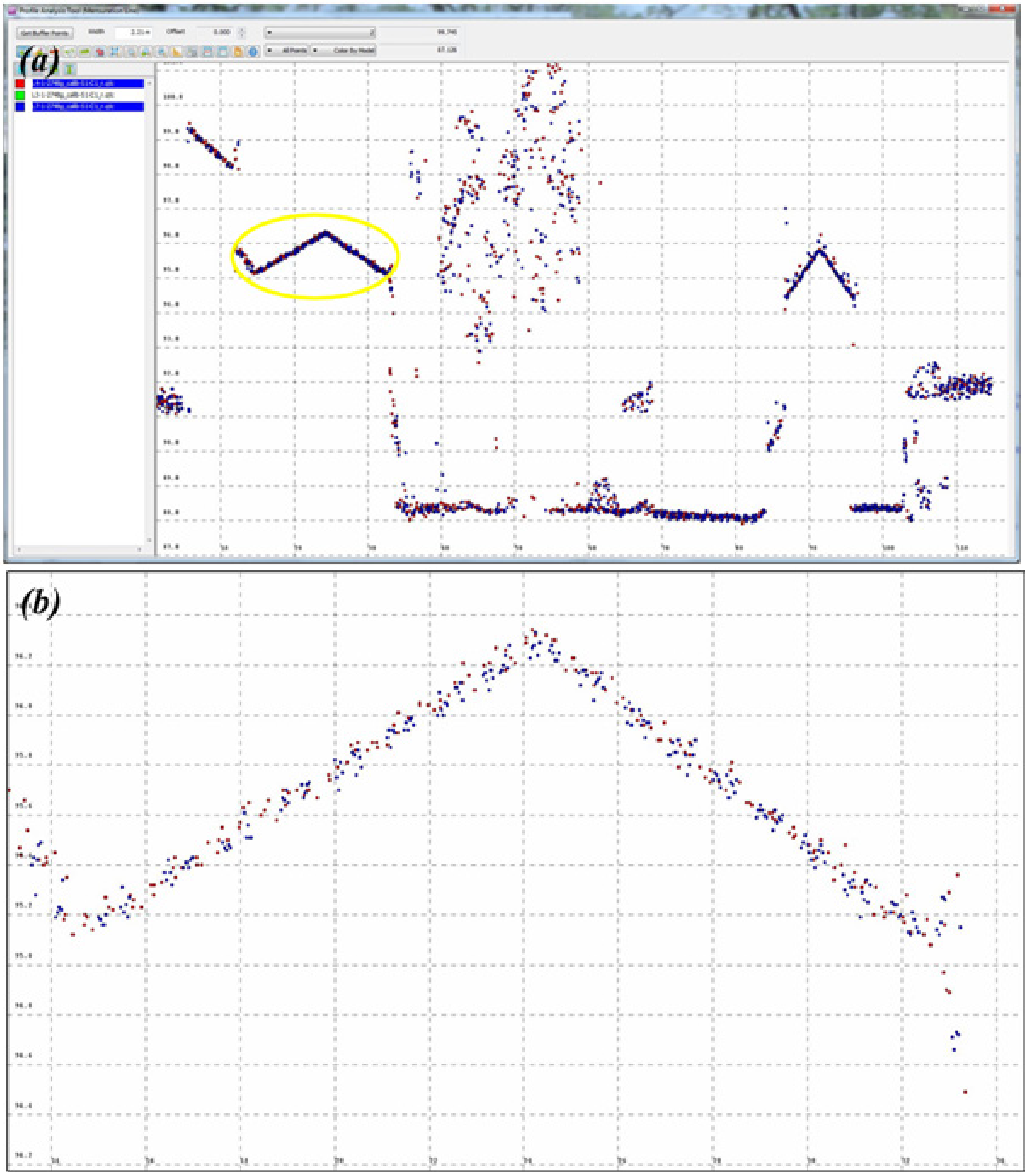

Figure 12. Profile over roof planes (a) and a zoomed-in profile on the area encircled in yellow (b)

The profile (e.g., over a roof plane) shows the overlapping points from different flight lines which serve as a good indicator that the correction applied by LMS for individual flight lines is good enough to attain the desired horizontal and vertical accuracy requirements. Flight lines that do not pass quality checking are subject for reprocessing in LMS until desired accuracies are obtained.

3.2.5 LiDAR Point Cloud Classification and Rasterization

Point cloud classification commences after the point cloud data has been rectified. TerraScan is a TerraSolid LiDAR software suite used for the classification of point clouds. It can read airborne and vehicle-based laser data in raw laser format, LAS, TerraScan binary or other ASCII-survey formats. Its classification and filtering routines are optimized by dividing the whole data into smaller geographical datasets called blocks, to automate the workflow and increase efficiency. In this study, the blocks were set to 1 km by 1 km with a 50 m buffer zone to prevent edge effects.

The process includes the classification of all points into Ground, Low Vegetation, Medium Vegetation, High Vegetation and Buildings. The classifier tool in TerraScan first filters air points and low points by finding points that are 5 standard deviations away from the median elevation of a search radius, which is 5 meters by default. It then divides the region into 60m by 60m search areas (the maximum area where at least one laser point hits the ground) and assigns the lowest points in these areas as the initial ground points from which a triangulated ground model is derived. The classifier then iterates through all the points and adds the points to the ground model by testing if it is (a) within the maximum iteration angle of 4˚ by default from a triangle plane, and (b) if it is within the maximum iteration distance (1.2 m by default) from a triangle plane. The ground plane is continuously updated from these iterations. The ground classification technique is illustrated in Figure 13. It is apparent that the smaller the iteration angle, the less eager the classifier is to follow changes in the point cloud (small undulations in terrain or hits on low vegetation). An angle close to 4˚ is used in flat terrain areas while an angle of 10˚ is used in mountainous or hilly terrains.

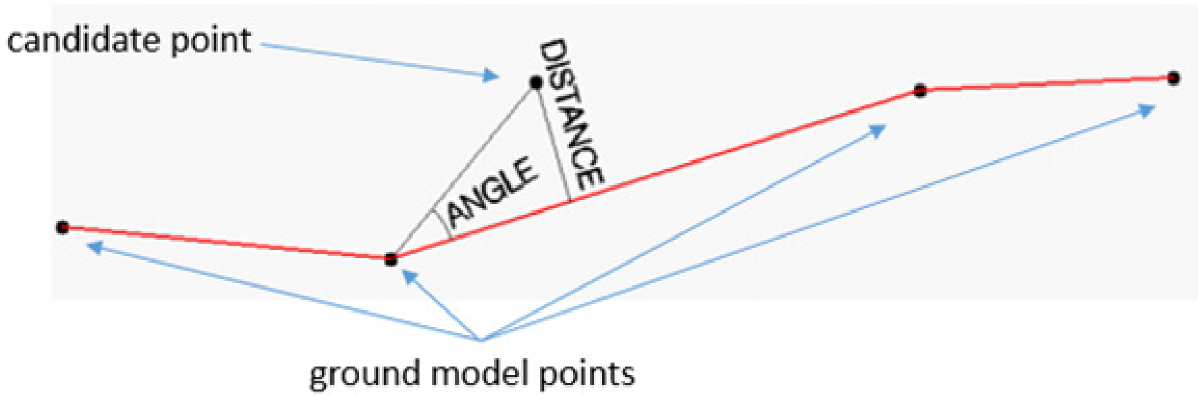

Figure 13. Ground classification technique employed in Terrascan

The parameters for ground classification routines used in floodplain and watershed areas are listed in Table 5.

Table 5. Ground classification parameters used in Terrascan for floodplain and watershed areas

Classification maximums	Floodplain (default)	Watershed (adjusted)
Iteration angle (degrees)	4	8
Iteration distance (meters)	1.20	1.50

The comparison between the produced DTM using the default parameters versus the adjusted is shown in Figure 14. The default parameters may fail to capture the sudden change in the terrain, resulting to less points being classified as ground that makes the DTM interpolated (Figure 14a). The adjusted parameters work better in these spatial conditions as shown in Figure 14b. Statistically, the number of ground points and model key points correctly classified can increase by as much as fifty percent (50%) when using the adjusted parameters.

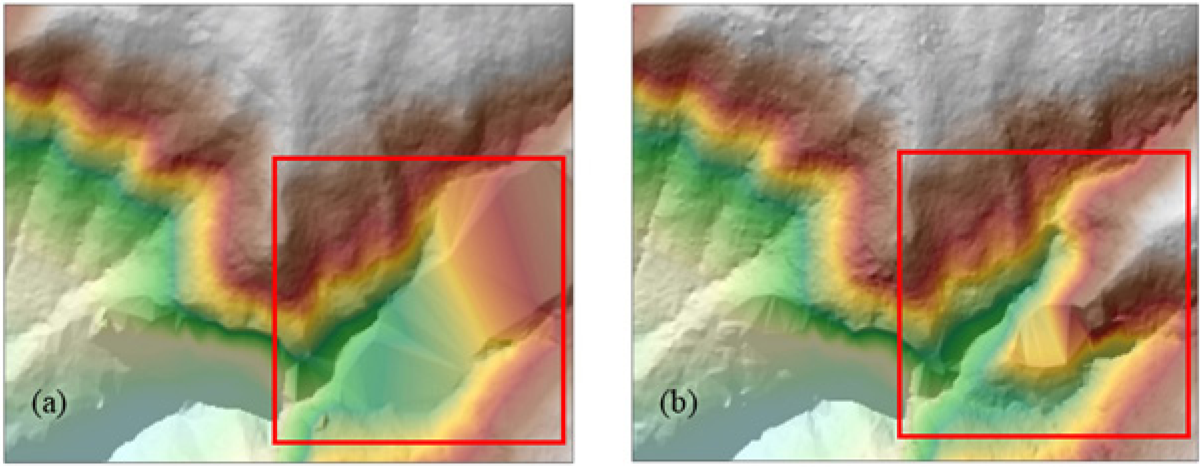

Figure 14. Resulting DTM of ground classification using the default parameters (a) and adjusted parameters (b)

The classification to Low, Medium and High vegetation is a straightforward testing of how high a point is from the ground model. The range of elevation values and its corresponding classification is shown in Table 6.

Table 6. Classification of Vegetation according to the elevation of points

Elevation of points (meters)	Classification
0.05 to 0.15	Low Vegetation
0.15 to 2.50	Medium Vegetation
2.50 to 50.0	High Vegetation

Methodology

The classification to Buildings routine tests points above two meters (2.0 m) if they only have one echo, and if they form a planar surface of at least 40 square meters with points adjacent to them. Minimum size and Z tolerance are the parameters used in the classify buildings routine as shown in Figure 15.

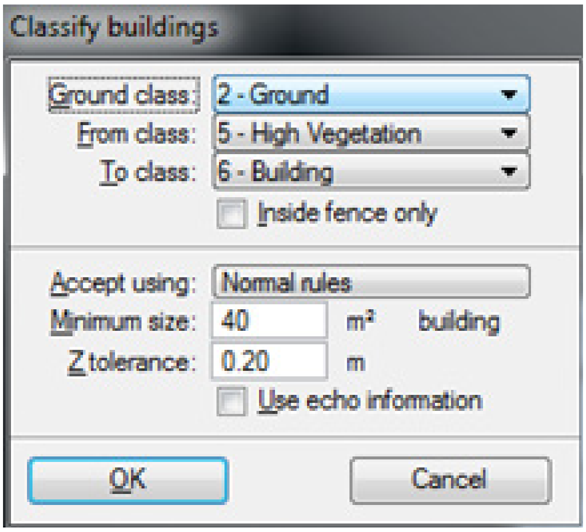

Figure 15. Default TerraScan building classification parameters

Minimum size is set to the smallest building footprint size of 40 m2 while the Z tolerance of 20cm is the approximate elevation accuracy of the laser points.

The point cloud data are examined for possible occurrences of air points which are to be deleted manually in the TerraScan window. Air points are defined as groups of points which are significantly higher or lower from the ground points. The different examples of air points are shown in Figure 16.

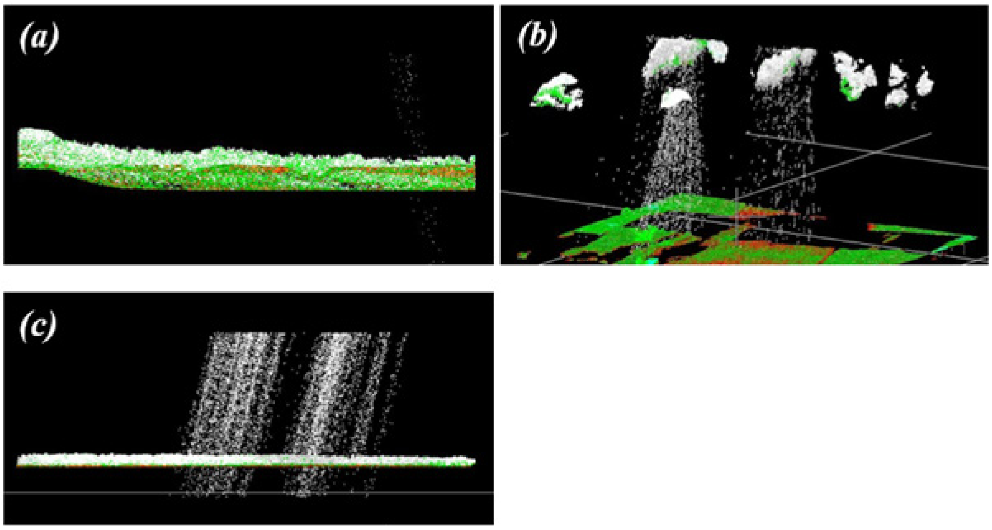

Figure 16. Different examples of air points manually deleted in the TerraScan window

The noise data can be as negligible as shown in Figure 16a or can be as severe as the one shown in Figure 16c. A combination of cloud points and shower of short ranges is displayed in Figure 16b. Shower of short ranges are caused by signal interference from the radio transmission of the tower and the aircraft. During every transmission on a specific frequency (around 120MHz), the signal is getting distorted due to the interference causing showers of short ranges in the output LAS.

Classified LiDAR point clouds that are free of air points, noise and unwanted data are processed in TerraScan to produce Digital Terrain Model (DTM) and the corresponding first and last return Digital Surface Models (DSM). These ground models are produced in the American Standard Code for Information Interchange format (ASCII) format. DTMs are produced by rasterizing all points classified to ground and model key points in a 1 m by 1 m grid. The last return DSMs are produced by rasterizing all last returns from all classifications (Ground, Model Key Points, Low, Medium, High Vegetation, Buildings and Default) in a 1 m by 1 m grid. The first return DSMs on the other hand are produced by rasterizing all first returns from all classifications. Power lines are usually included in this model. All of these ground models are used in the mosaicking, manual editing and hydro correction of the topographic dataset, in preparation for the floodplain hydraulic modelling.

3.2.6 DEM Editing and Hydro-correction

Even though the parameters of the classification routines are optimized, various digital elevation models (DTM, first and last return DSM) that are automatically produced may still display minor errors that still need manual correction to make the DEMs suitable for fine-scale flood modelling. This is true especially for features that are under heavy canopy. Natural embankments on the side of the river might be flattened or misrepresented because no point pierced the canopy on that area. The same difficulty might also occur on smaller streams that are under canopy. The DTM produced might have discontinuities on these channels that might affect the flood modelling negatively. Manual inspection and correction is still a very important part of quality checking the LiDAR DEMs produced.

To correctly portray the dynamics of the flow of water on the floodplain, the river geometry must also be taken into consideration. The LiDAR data must be made consistent to the topographic surveys done for the area, and the bathymetric data must be "burned", or integrated, into the DEM to make the dataset suitable for hydraulic analyses. However, no cross-sectional survey was performed for this area.

Results and Discussion

Results and Discussion

4.1 LiDAR Acquisition in Bohol Floodplain

4.1.1 Flight Plans

Plans were made to acquire LiDAR data within the Bohol floodplain. Each flight mission had an average of 10 flight lines and ran for at most 2 hours including take-off, landing and turning time. The parameter used in the LiDAR system for acquisition is found in Table 7.

Table 7. Parameters used in LiDAR System during Flight Acquisition.

Fixed Variables	Values		
Flying Height (AGL - Above Ground Level) (m)	750m	1000 m	1200 m
Overlap	30 %	30%	30 %
Max. field of View	50	50	50
Speed of Plane (kts)	130	130	130
Turn around minutes	5	5	5
Swath (m)	661.58 m	882 m	1058.53 m

The parameters that set in the LiDAR sensor to optimize the area coverage following the objectives of the project and to ensure the aircraft's safe return to the airport (base of operations) are shown in Table 7. Each flight acquisition is designed for four operational hours. The maximum flying hours for Cessna 206H is five hours.

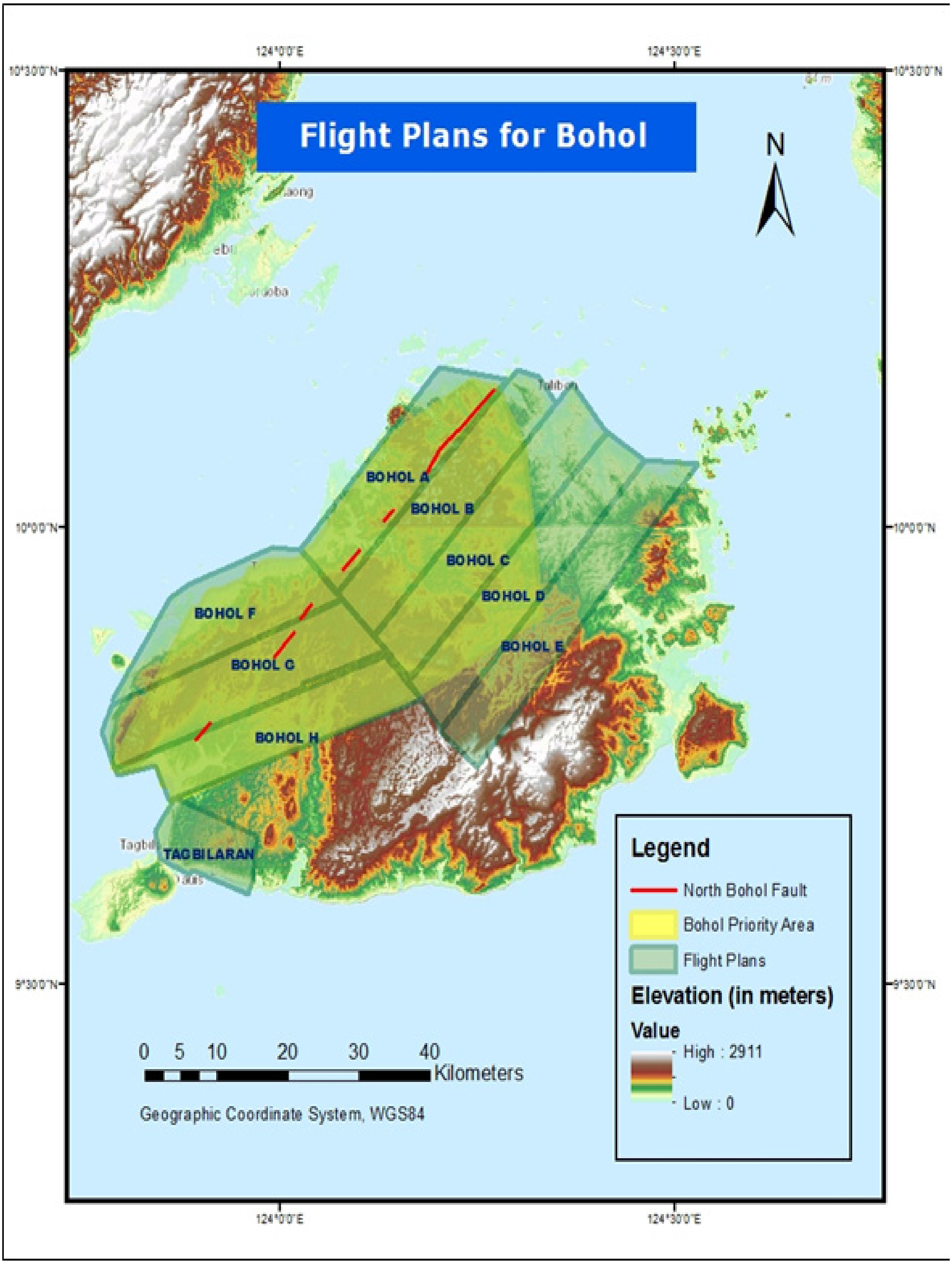

Figure 17. Bohol Floodplain Flight Plans

Results and Discussion

4.1.2 Ground Base Station

The project team was able to recover six (6) NAMRIA control stations (BHL-63, BHL-72, BHL-76, BHL-90, BHL-94, BHL-58) with second (2nd) order accuracy and three (3) (BHL-3074, BHL-3144 and BHL-3087) with fourth (4th) order accuracy. Simultaneous GPS observations were done and coordinates were re-processed in Trimble Home Business Center. The ground control point (GCP) was used as reference point during flight operations using TRIMBLE SPS R8, a dual frequency GPS receiver.

Table 8. Details of the recovered NAMRIA horizontal control point BHL-63 used as base station for the LiDAR Acquisition

Station Name	BHL-63	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	10°00'013.39821"
	Longitude	124°20'43.44094"
	Ellipsoidal Height	17.319 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	428232.164
	Northing	1106212.953
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	10°00'09.39110"
	Longitude	124°20'48.71189"
	Ellipsoidal Height	80.873 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	647621.975
	Northing	1106002.326
	Elevation (based on EGM96 Geoid)	16.264 m

Table 9. Details of the recovered NAMRIA horizontal control point BHL-72 used as base station for the LiDAR Acquisition

Station Name	BHL-72	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°57'18.13556"
	Longitude	123°57'29.41757"
	Ellipsoidal Height	3.672
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	385757.302
	Northing	1100937.073
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°57'14.10713"
	Longitude	123°57'34.69615"
	Ellipsoidal Height	66.381 m

Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°57'14.10713"
	Longitude	123°57'34.69615"
	Ellipsoidal Height	66.381 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	605191.43
	Northing	1100469.86
	Elevation (based on EGM96 Geoid)	2.701 m

Table 10. Details of the recovered NAMRIA horizontal control point BHL-76 used as base station for the LiDAR Acquisition with the re-processed coordinates

Station Name	BHL-76	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°53'26.7"
	Longitude	123°52'9.96678"
	Ellipsoidal Height	2.887 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	376001.503
	Northing	1093857.766
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°53'22.68039"
	Longitude	123°52'15.25182"
	Ellipsoidal Height	65.522 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	595482.6
	Northing	1093334.66
	Elevation (based on EGM96 Geoid)	2.022 m

Table 11. Details of the recovered NAMRIA horizontal control point BHL-90 used as base station for the LiDAR Acquisition with the re-processed coordinates

Station Name	BHL-90	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°42'07.54646"
	Longitude	124°02'37.87685"
	Ellipsoidal Height	78.268 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	395074.127
	Northing	1072931.147
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°42'03.59074"
	Longitude	124°02'43.17725"
	Ellipsoidal Height	141.756 m

Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	614672.369
	Northing	1072530.291
	Elevation (based on EGM96 Geoid)	77.471 m

Table 12. Details of the recovered NAMRIA horizontal control point BHL-94 used as base station for the LiDAR Acquisition with the re-processed coordinates

Station Name	BHL-94	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°41'18.69327"
	Longitude	123°55'11.57536"
	Ellipsoidal Height	65.876 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	381463.357
	Northing	1071470.853
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°41'14.73016"
	Longitude	123°55'16.87800"
	Ellipsoidal Height	129.088 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	601075.516
	Northing	1070990.185
	Elevation (based on EGM96 Geoid)	65.236 m

Table 13. Details of the recovered NAMRIA horizontal control point BHL-3074 used as base station for the LiDAR Acquisition with the re-processed coordinates

Station Name	BHL-3074	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°59'13.24854"
	Longitude	124°20'4.72905"
	Ellipsoidal Height	34.426 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	427049.438
	Northing	1104367.337
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°59'09.24478"
	Longitude	124°20'10.00158"
	Ellipsoidal Height	97.991 m

Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	646450.692
	Northing	1104149.838
	Elevation (based on EGM96 Geoid)	33.416 m

Table 14. Details of the recovered NAMRIA horizontal control point BHL-3144 used as base station for the LiDAR Acquisition with the re-processed coordinates

Station Name	BHL-3144	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	9°45'25.58044"
	Longitude	123°58'13.70763"
	Ellipsoidal Height	92.648 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	387039.17
	Northing	1079039.3
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	9°45'21.60408"
	Longitude	123°58'19.0074"
	Ellipsoidal Height	155.832 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	606604.218
	Northing	1078588.543
	Elevation (based on EGM96 Geoid)	91.714 m

Table 15. Details of the recovered NAMRIA horizontal control point BHL-58 used as base station for the LiDAR Acquisition with the re-processed coordinates

Station Name	BHL-58	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	10°02'12.58578"
	Longitude	124°02'37.87685"
	Ellipsoidal Height	78.268 m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	395074.127
	Northing	1072931.147
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	10°02'8.54469"
	Longitude	124°03'19.85079"
	Ellipsoidal Height	65.897 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	615673.14
	Northing	1109546.06
	Elevation (base on EGM96 Geoid)	2.109 m

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Table 16. Details of the recovered NAMRIA horizontal control point BHL-3087 used as base station for the LiDAR Acquisition with the re-processed coordinates

Station Name	BHL-3087	
Order of Accuracy	2nd Order	
Relative Error (horizontal positioning)	1 in 50,000	
Geographic Coordinates, Philippine Reference of 1992 Datum (PRS 92)	Latitude	10°03'10.47530"
	Longitude	124°03'30.06973"
	Ellipsoidal Height	3.629m
Grid Coordinates, Philippine Transverse Mercator Zone 5 (PTM Zone 4 PRS 92)	Easting	396774.658
	Northing	1111729.803
Geographic Coordinates, World Geodetic System 1984 Datum (WGS 84)	Latitude	10°03'6.43045"
	Longitude	124°03'35.33877"
	Ellipsoidal Height	66.363 m
Grid Coordinates, Universal Transverse Mercator Zone 51 North (UTM 51N WGS 1984)	Easting	616138.93
	Northing	1111325.66
	Elevation (based on EGM96 Geoid)	2.589 m

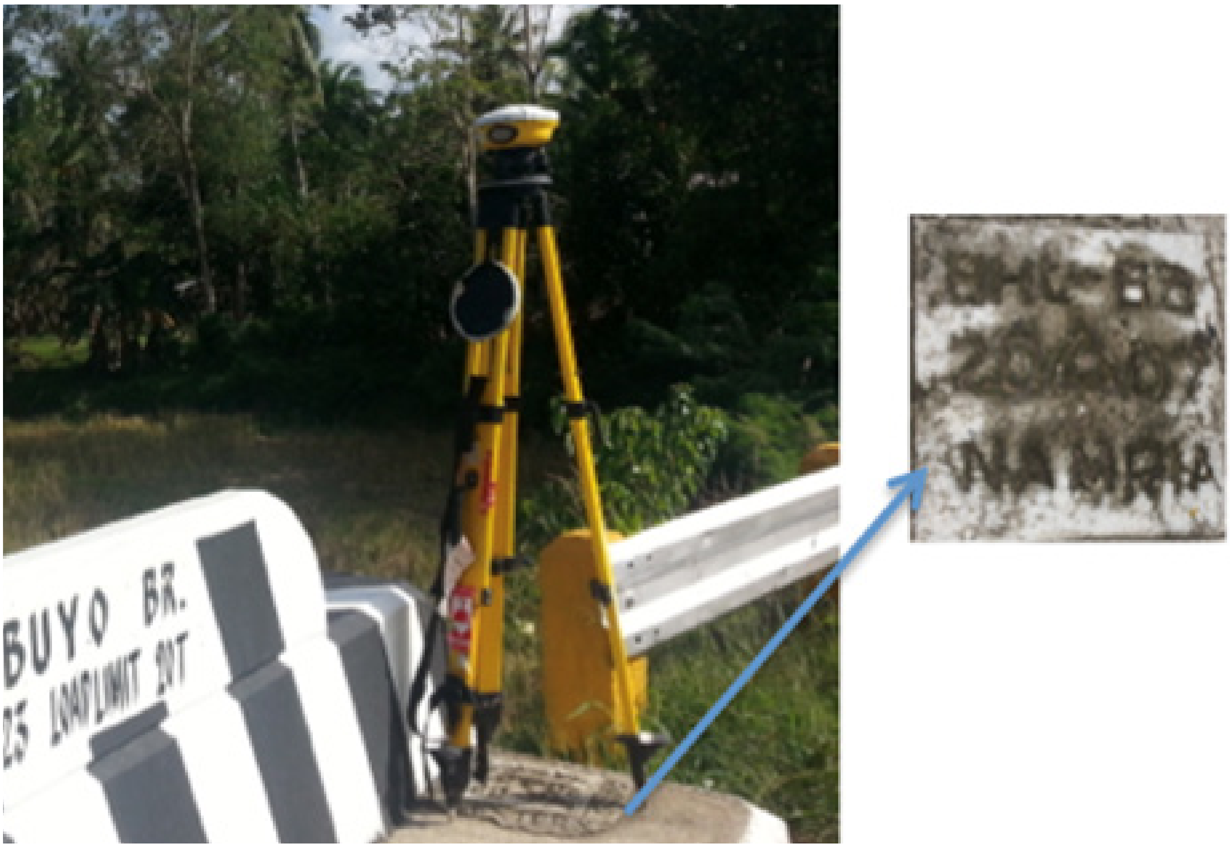

Figure 18. BHL 63 was recovered on Hagbuyo Bridge in the town proper of San Miguel, Bohol

Figure 19. BHL 72 was recovered on Port of Tubigon, Bohol

Figure 20. BHL 76 was recovered after the culvert on the stairs of Brgy. Desamparados Calape, Bohol

Figure 21. BHL 90 was recovered on the oval of Sevilla Central School in Bohol

Figure 22. BHL 94 was recovered at the back of Rizal Monument in Corella, Bohol

Figure 23. BHL 3074 was recovered in front of San Miguel Church in Bohol

Figure 24. BHL 3144 was recovered in front of Balilihan Justice Hall, Bohol

Figure 25. BHL 3087 was recovered on the left side of the road after Madaug Bridge in Brgy. Mandaug Tubigon, Bohol

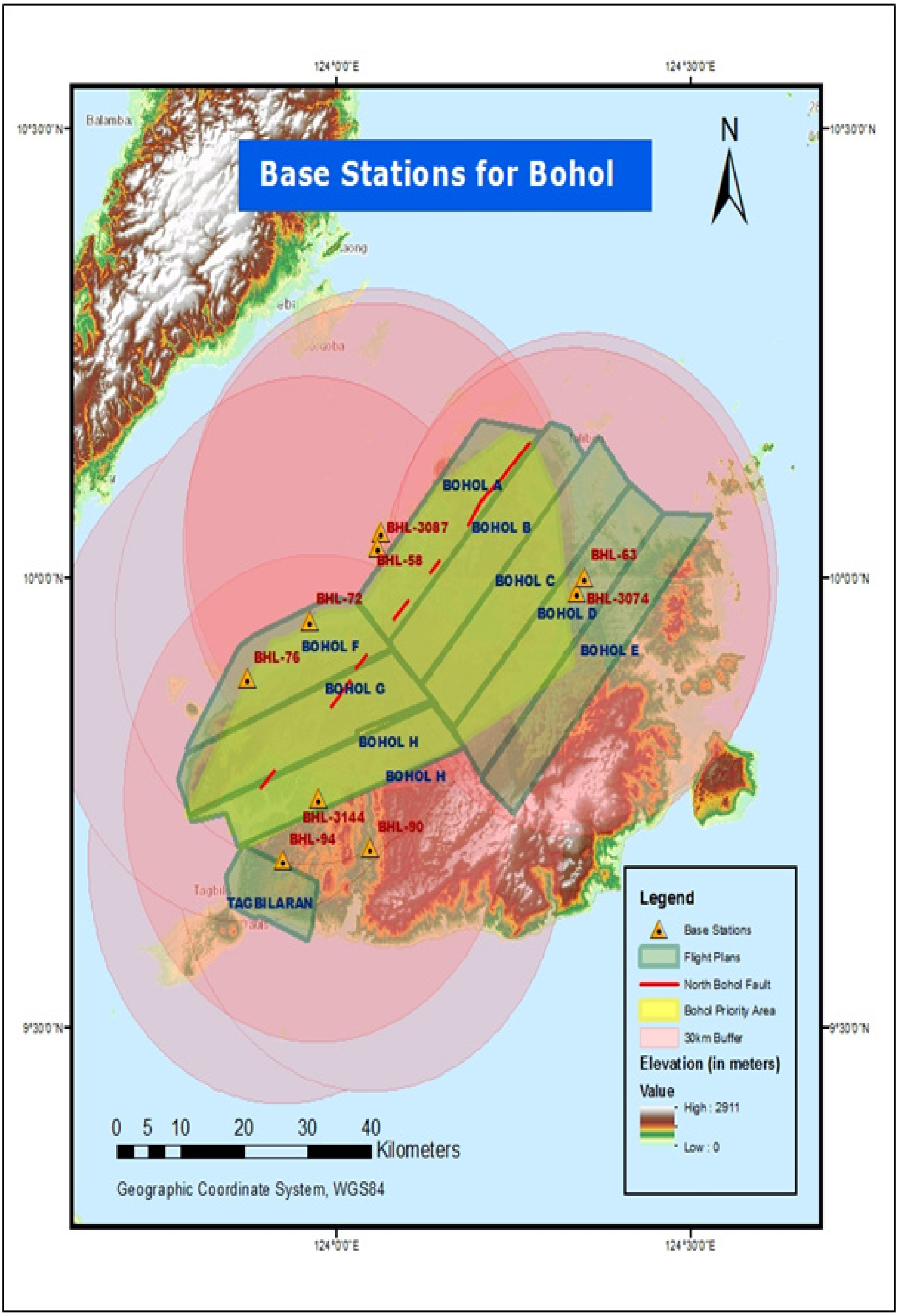

Figure 26. Bohol Floodplain Flight Plans and Base Stations.

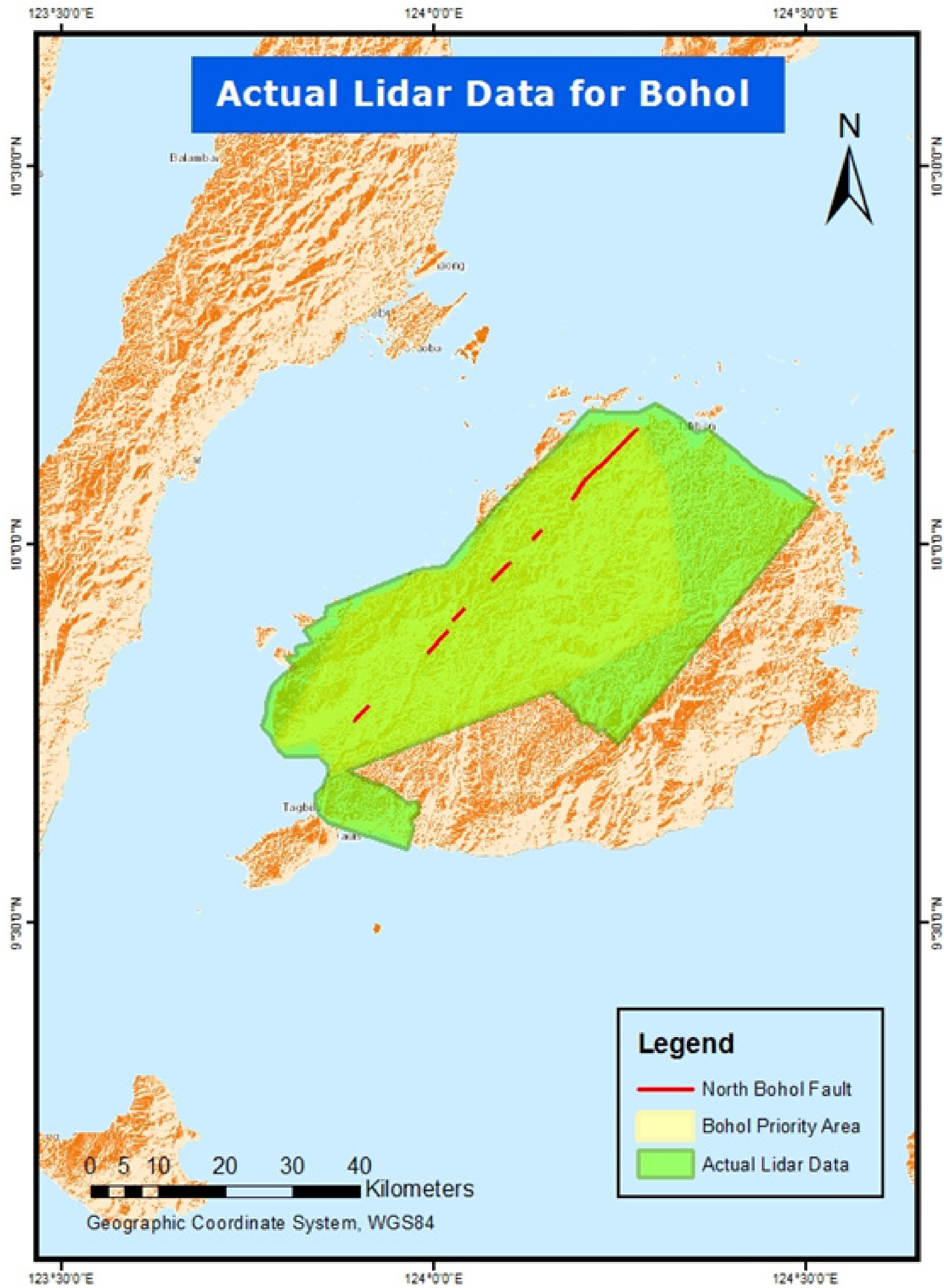

Figure 27. Bohol Floodplain Data Acquisition LAS Output.

Results and Discussion

Table 17. Flight Missions for LiDAR Data Acquisition in Bohol floodplain

Date Surveyed	Name	Flight Plan Area (km²)	Surveyed Area (km²)	Flying Hours	
				Hours	Minutes
Nov 11, 2013	TGB	78.72	96.8	4	17
Nov 13, 2013				4	29
Nov 15, 2013	BHL 1H	235.1	258.2	2	53
Nov 16, 2013				3	11
Nov 15, 2013				3	23
Nov 25, 2013	BHL 1G	261.2	268.65	1	59
Dec 2, 2013				3	23
Nov 17, 2013	BHL 1C	283.9	279.4	3	29
Nov 18, 2013				3	35
	BHL 1B	266	283.9	2	41
Nov 19, 2013					
Nov 24, 2013				4	17
	BHL 1D	266.3	284.3		
Nov 20, 2013				2	47
Nov 27, 2013				2	53
Nov 26, 2013	BHL 1A	213.2	229.2	3	17
Nov 27, 2013				2	53
Nov 29, 2013	BHL 1E	273.7	264.2	1	29
Dec 4, 2013				4	23
Nov 30, 2013	BHL 1F	220.5	203.55	0	0
Dec 3, 2013				3	47

Nineteen (19) missions were conducted to complete the LiDAR Data Acquisition of priority area in Bohol, for a total of sixty one hours and forty-seven minutes (61 hrs. and 47 mins.) of flying time for RP-C9022 including the LMS calibration flight over Tagbilaran City. All missions are acquired using the Pegasus LiDAR System. Table 17 shows the total area to be surveyed according to the flight plan and the total area of actual coverage per mission.

The priority area in Bohol with a total of 1,451 square kilometers (sq. km.) was completely surveyed from November 10 –December 6, 2013 by Pauline Joanne Arceo and Mary Catherine Elizabeth Baliguas as shown in Table 18.

Table 18. Area of Coverage of the LiDAR Data Acquisition in Bohol floodplain

Location	Date Surveyed	Operator	Mission Name	Total Watershed Area (km^2)
Bohol	Nov 11, 2013	P.J. Arceo & MCE Baliguas	1TGB315A	96.8
Bohol	Nov 13, 2013	PJ. Arceo	1BHL1H317A	159.8
Bohol	Nov 15, 2013	PJ. Arceo	1LMSBHL1HS319A	44.4
Bohol	Nov 15, 2013	MCE Baliguas	1BHL1G319B	147.7
Bohol	Nov 16, 2013	MCE Baliguas	1BHL1HS320A	98.8
Bohol	Nov 17, 2013	P.J. Arceo & MCE Baliguas	1BHL1C321A	157.7
Bohol	Nov 18, 2013	P.J. Arceo & MCE Baliguas	1BHL1BC322A	186.3
Bohol	Nov 19, 2013	P.J. Arceo & MCE Baliguas	1BHL1BS323A	69.4
Bohol	Nov 20, 2013	P.J. Arceo & MCE Baliguas	1BHL1D324A	79.3
Bohol	Nov 24, 2013	P.J. Arceo & MCE Baliguas	1BHL1BDS328A	111.5
Bohol	Nov 25, 2013	PJ. Arceo	1BHL1GS329A	Over the fault
Bohol	Nov 26, 2013	PJ. Arceo	1BHL1A330A	139.5
Bohol	Nov 27, 2013	PJ. Arceo	1BHL1AS331A	99.8
Bohol	Nov 27, 2013	P.J. Arceo & MCE Baliguas	1BHL1DS331B	261.0
Bohol	Nov 30, 2013	MCE Baliguas	1BHL1F334A	60.0
Bohol	Dec 2, 2013	PJ. Arceo	1BHL1GS336A	106.0
Bohol	Dec 3, 2013	P.J. Arceo & MCE Baliguas	1BHL1FS337A	140.0
Bohol	Dec 4, 2013	MCE Baliguas	1BHL1E338A	220.3

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4.2 LiDAR Data Processing

4.2.1 Trajectory Computation

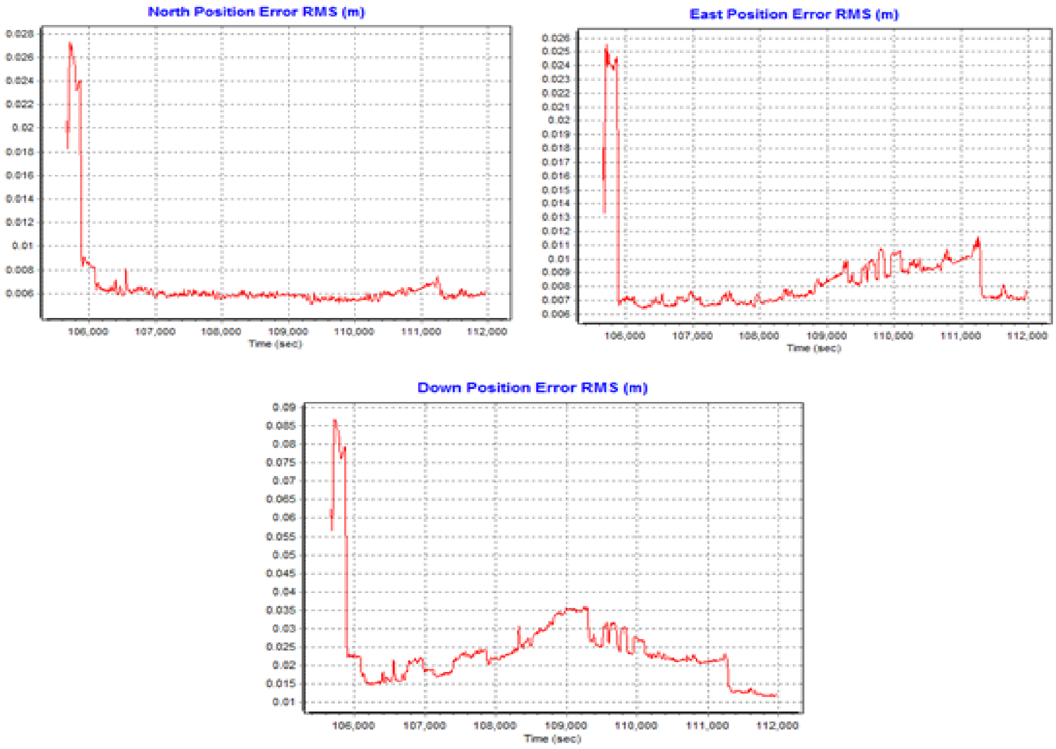


Figure 28. Smoothed Performance Metric Parameters of Bohol flight

The Smoothed Performance Metric parameters of the Bohol flight are shown in Figure 28. The x-axis is the time of flight, which is measured by the number of seconds from the midnight of the start of the GPS week. The y-axis is the RMSE value for a particular aircraft position with respect to GPS survey time. The North (Figure 28a) and east (Figure 28b) position RMSE values fall within the prescribed accuracy of 4 centimeter, and all Down (Figure 28c) position RMSE values fall within the prescribed accuracy of 8 centimeter.

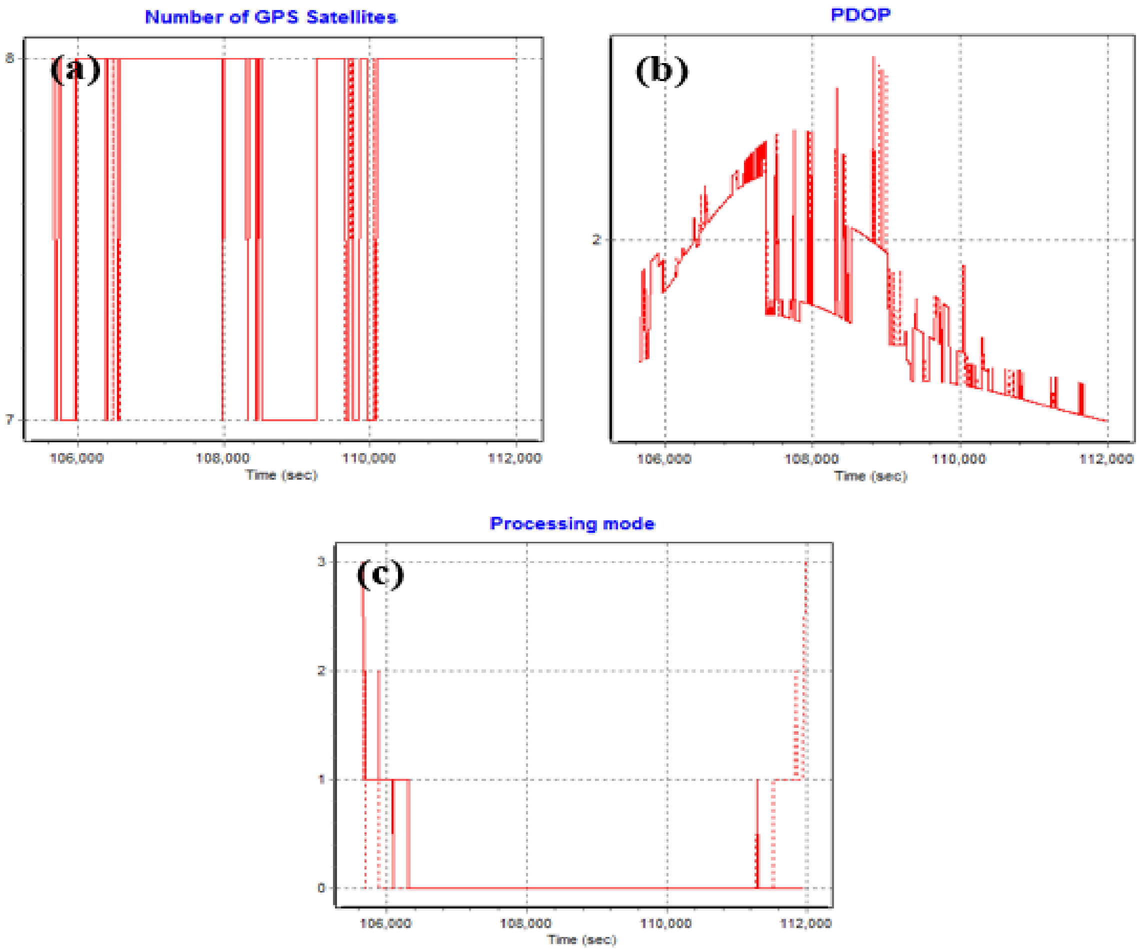


Figure 29. Solution Status Parameters of Bohol Flight.

The Solution Status parameters of the computed trajectory for Bohol flight, which are the number of GPS satellites, Positional Dilution of Precision (PDOP), and the GPS processing mode used are shown in Figure 29. The number of GPS satellites (Figure 29a) graph indicates that the number of satellites during the acquisition was between 7 and 8. The PDOP (Figure 29b) value does not exceed the value of 3, indicating optimal GPS geometry. The processing mode (Figure 29c) stays at 0, which corresponds to a Fixed, Narrow-Lane mode, which indicates an optimum solution for trajectory computation by POSPac MMS v6.2. All of the parameters satisfied the accuracy requirements for optimal trajectory solutions as indicated in the methodology.

4.2.2 LiDAR Point Cloud Computation

The LAS data output contains 14 flight lines, with each flight line containing two channels, a feature of the Pegasus system. The result of the boresight correction standard deviation values for both channel 1 and channel 2 are better than the prescribed 0.001deg. The position of the LiDAR system is also accurately computed since all GPS position standard deviations are less than 0.0066 meter. The attitude of the LiDAR system passed accuracy testing since the standard deviation of the corrected roll and pitch values of the IMU attitudes are less than 0.001deg.

4.2.3 LiDAR Data Quality Checking

The LAS boundary of the LiDAR data on top of the SRTM elevation data is shown in Figure 30. The map shows gaps in the LiDAR coverage that are attributed to cloud cover present during the survey.

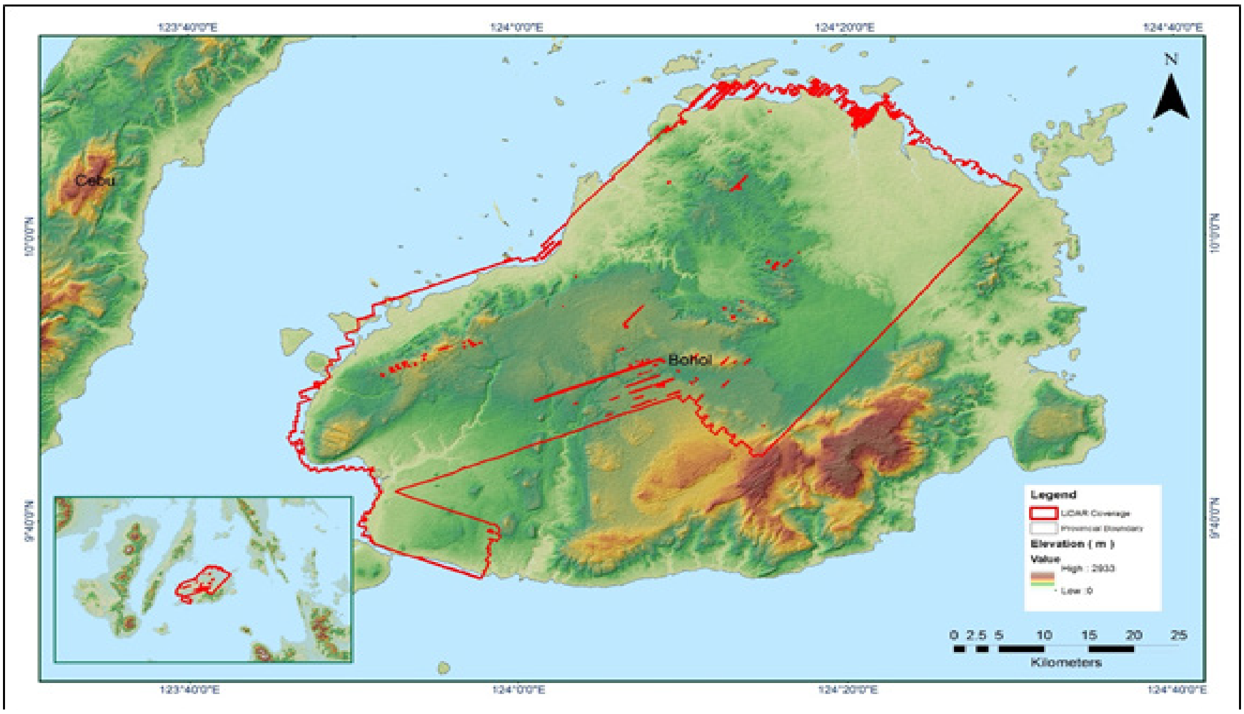


Figure 30. Coverage of LiDAR data for the Bohol mission

The overlap data for the merged LiDAR data showing the number of channels that pass through a particular location is shown in Figure 31. Since the Pegasus system employs two channels, an average value of 2 (blue) for areas where there are only two overlapping flight lines, and a value of 3 (yellow) or more (red) for areas with three or more overlapping flight lines, are expected. The average data overlap for Bohol is 52%.

The density map for the merged LiDAR data, with the red areas showing the portions of the data that satisfy the 2 points per square meter requirement, is shown in Figure 32. It was determined that 93.4% of the total area satisfied the point density requirement, and the average density for the entire survey area is 3.01 points per square meter.

Results and Discussion

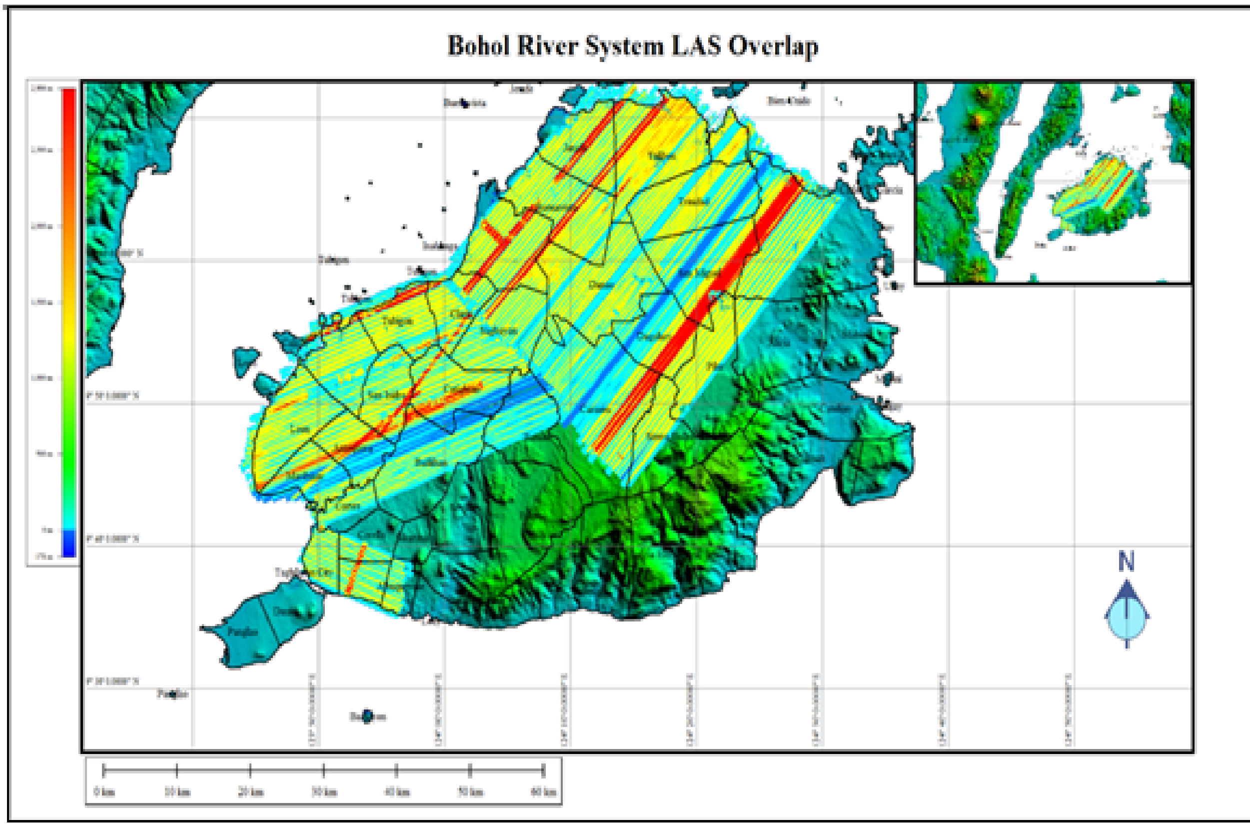


Figure 31. Image of data overlap for the Bohol mission

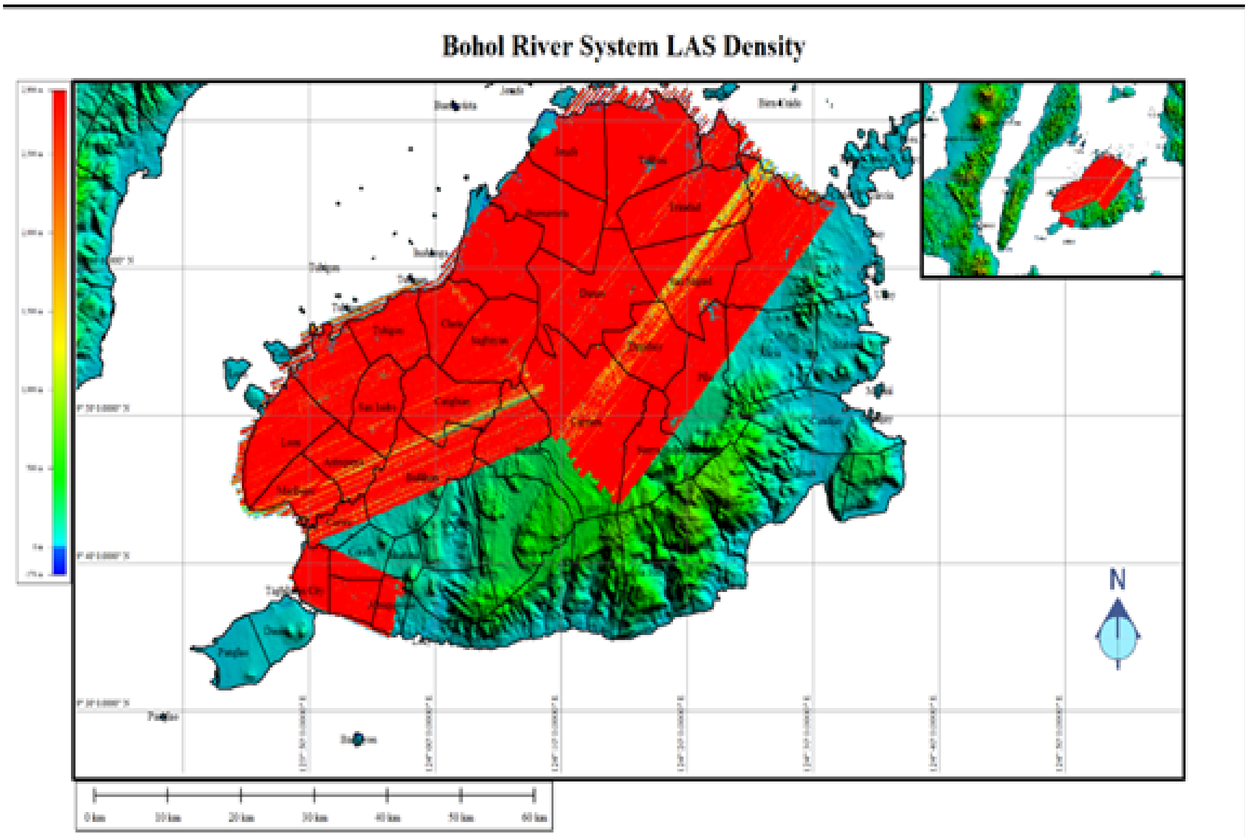


Figure 32. Density map of merged LiDAR data for the Bohol mission

The elevation difference between overlaps of adjacent flight lines is shown in Figure 33. The default color range is from blue to red, where bright blue areas correspond to a -0.20 m difference, and bright red areas correspond to a +0.20 meter difference. Areas with bright red or bright blue need to be investigated further using QT Modeler.

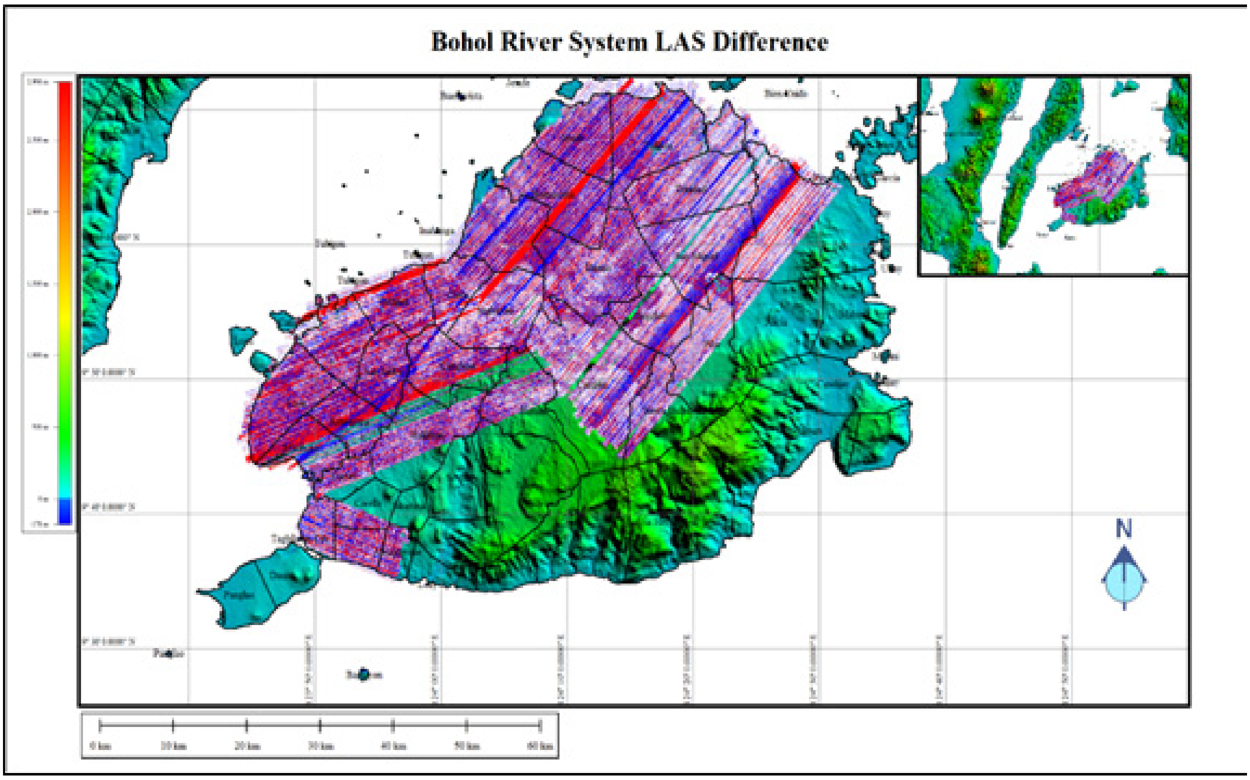


Figure 33. Elevation difference map between flight lines

A screen capture of the LAS data loaded in QT Modeler is shown in Figure 34a. A line graph showing the elevations of the points from all of the flight strips traversed by the profile in red line is shown in Figure 34b. It is evident that there are differences in elevation, but the differences do not exceed the 20-centimeter mark. No reprocessing was necessary for this LiDAR dataset.

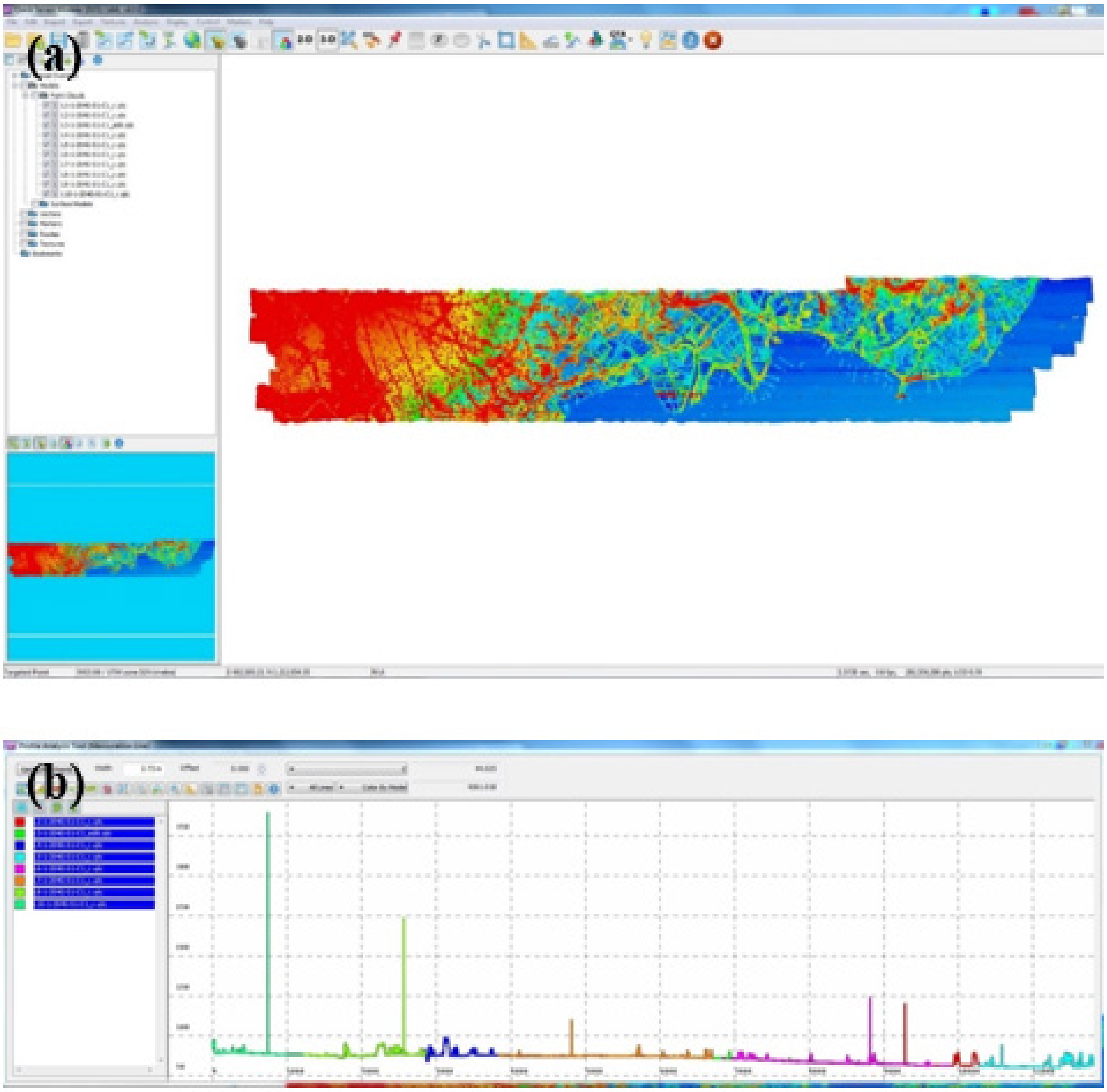


Figure 34. Quality checking with the profile tool of QT Modeler

4.2.4 LiDAR Point Cloud Classification and Rasterization

The block system that TerraScan employed for the LiDAR data is shown in Figure 35a generated a total of 4050 1 kilometer by 1 kilometer blocks. The final classification of the point cloud for a mission in the Bohol floodplain is shown in Figure 35b. The number of points classified to the pertinent categories along with other information for the mission is shown in Table 19.

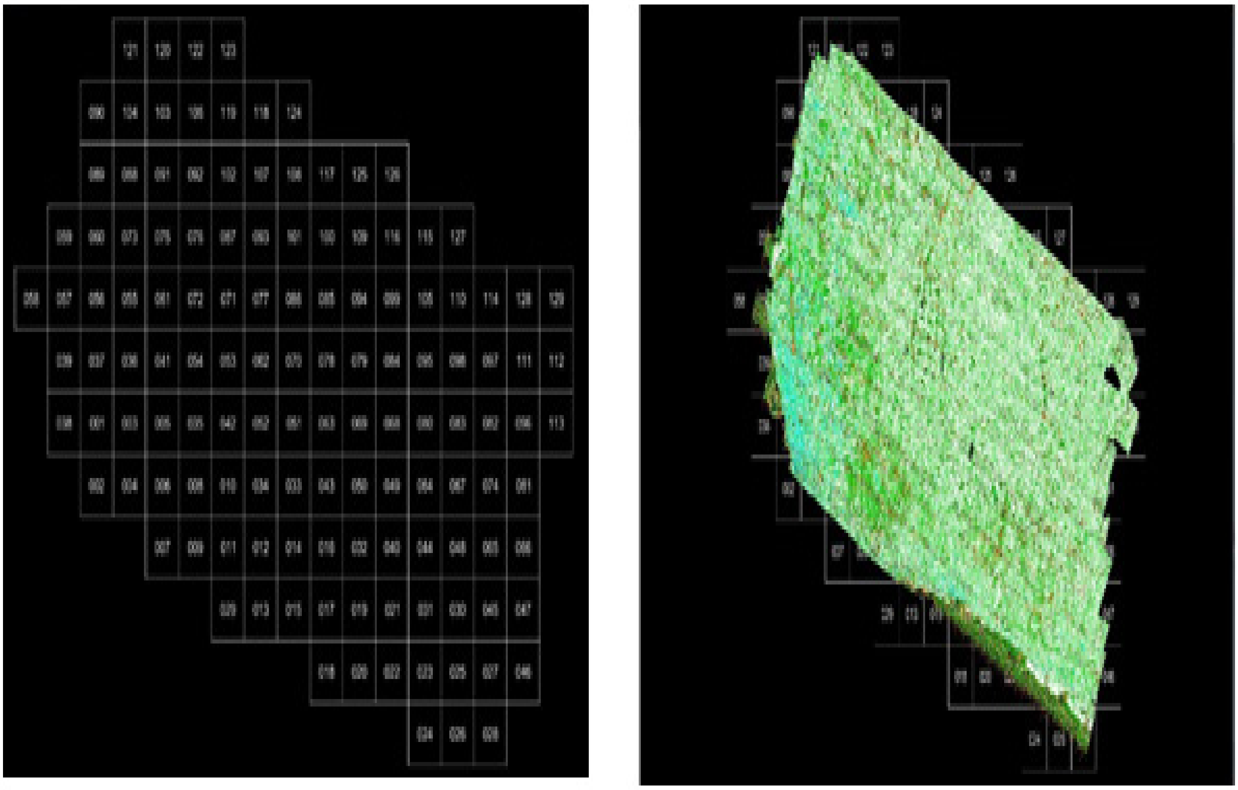


Figure 35. (a) Bohol floodplain and (b) Bohol classification results in TerraScan

Table 19. Bohol classification results in TerraScan

Pertinent Class	Count
Ground	107,098,445
Low Vegetation	190,657,457
Medium Vegetation	529,534,443
High Vegetation	395,174,539
Building	13,533,950
Number of 1km x 1km blocks	827
Maximum Height	589.22m
Minimum Height	28.78m

An isometric view of an area before (a) and after (b) running the classification routines for the mission is shown in Figure 36. The ground points are in brown, the vegetation is in different shades of green, and the buildings are in cyan. It can be seen that residential structures adjacent or even below canopy are classified correctly, due to the density of the LiDAR data.

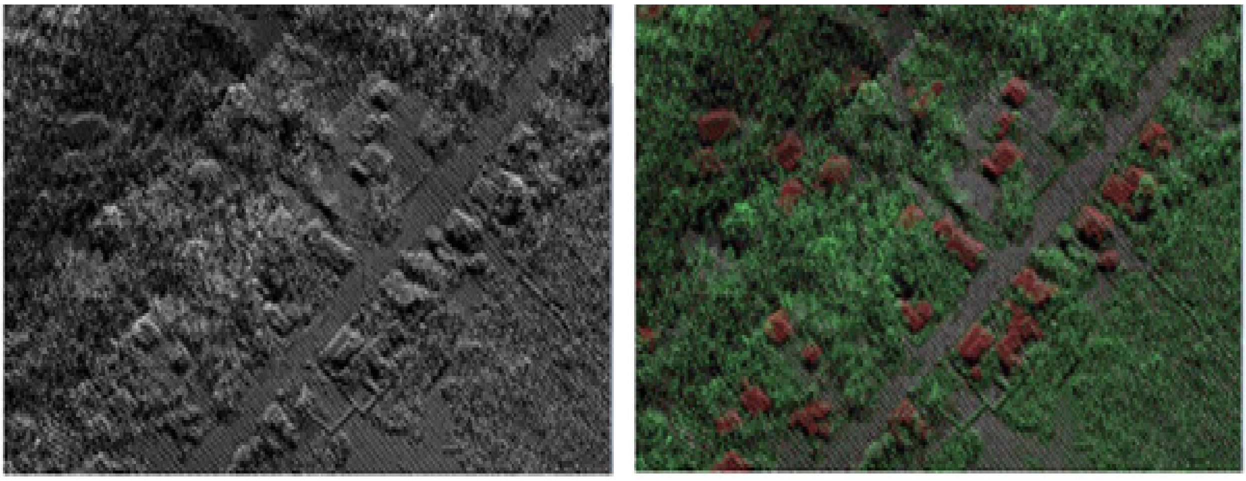


Figure 36. Point cloud (a) before and (b) after classification

4.2.5 DEM Editing and Hydro-correction

Portions of DTMs before and after manual editing are shown in Figure 37. It shows that the embankment might have been drastically cut by the classification routine in Figure 37a and clearly needed to be retrieved to complete the surface as in Figure 37b to allow to hydrologically correct flow of water. A small stream suffers from discontinuity of flow due to an existing bridge in Figure 37c. The bridge is removed also in order to hydrologically correct the flow of water through the river in Figure 37d.

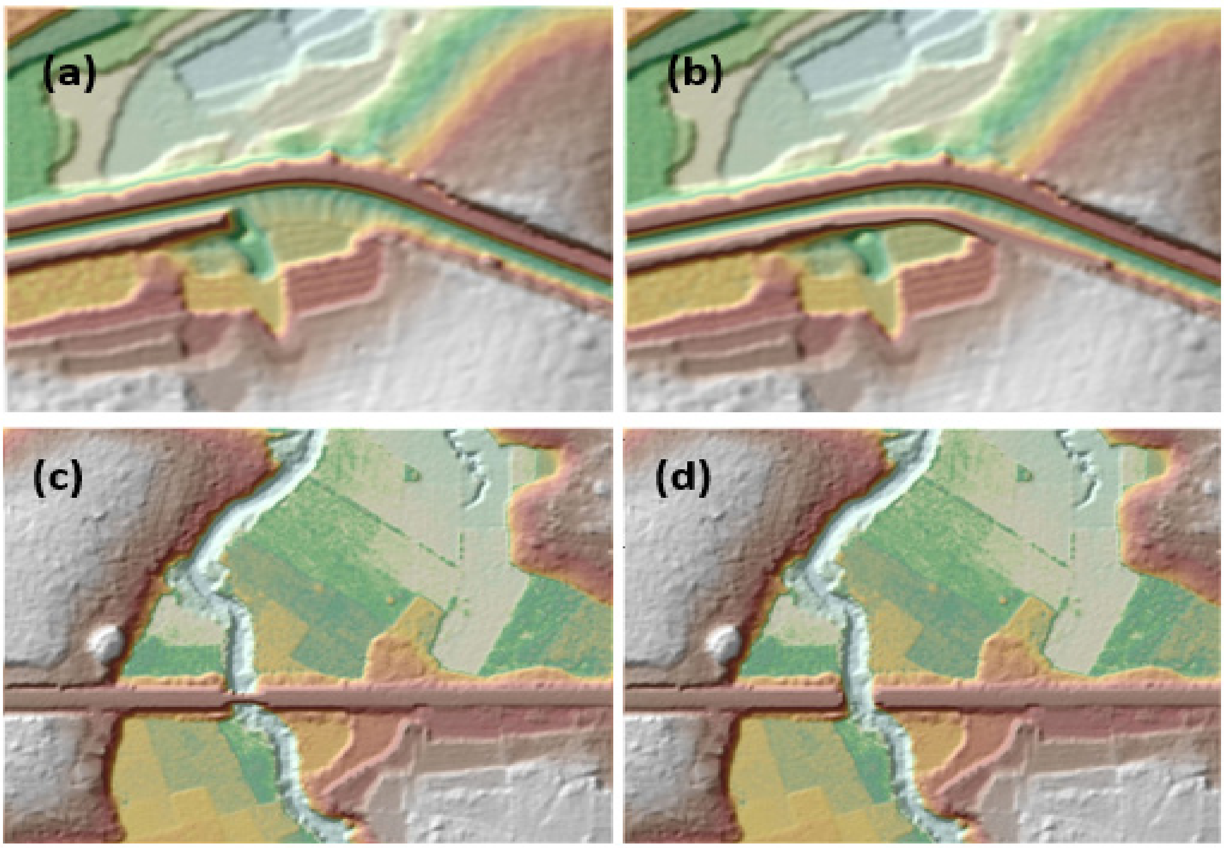


Figure 37. Images of DTMs before and after manual editing

Results and Discussion

The extent of the validation survey done by the Data Validation Component (DVC) in Bohol to collect points with which the LiDAR dataset is validated is shown in Figure 38. A total of 3889 control points were collected. The good correlation between the airborne LiDAR elevation values and the ground survey elevation values, which reflects the quality of the LiDAR DTM is shown in Figure 39. The computed RMSE between the LiDAR DTM and the surveyed elevation values is 25.225 centimeters with a standard deviation of 25.123 centimeters. The LE 90 value represents the linear vertical distance that 90% of the sampled DEM points and their respective DVC validation point counterparts should be found from each other. Other statistical information can be found in Table 20. The final DTM and extent of the bathymetric survey done along the river is shown in Figure 40.

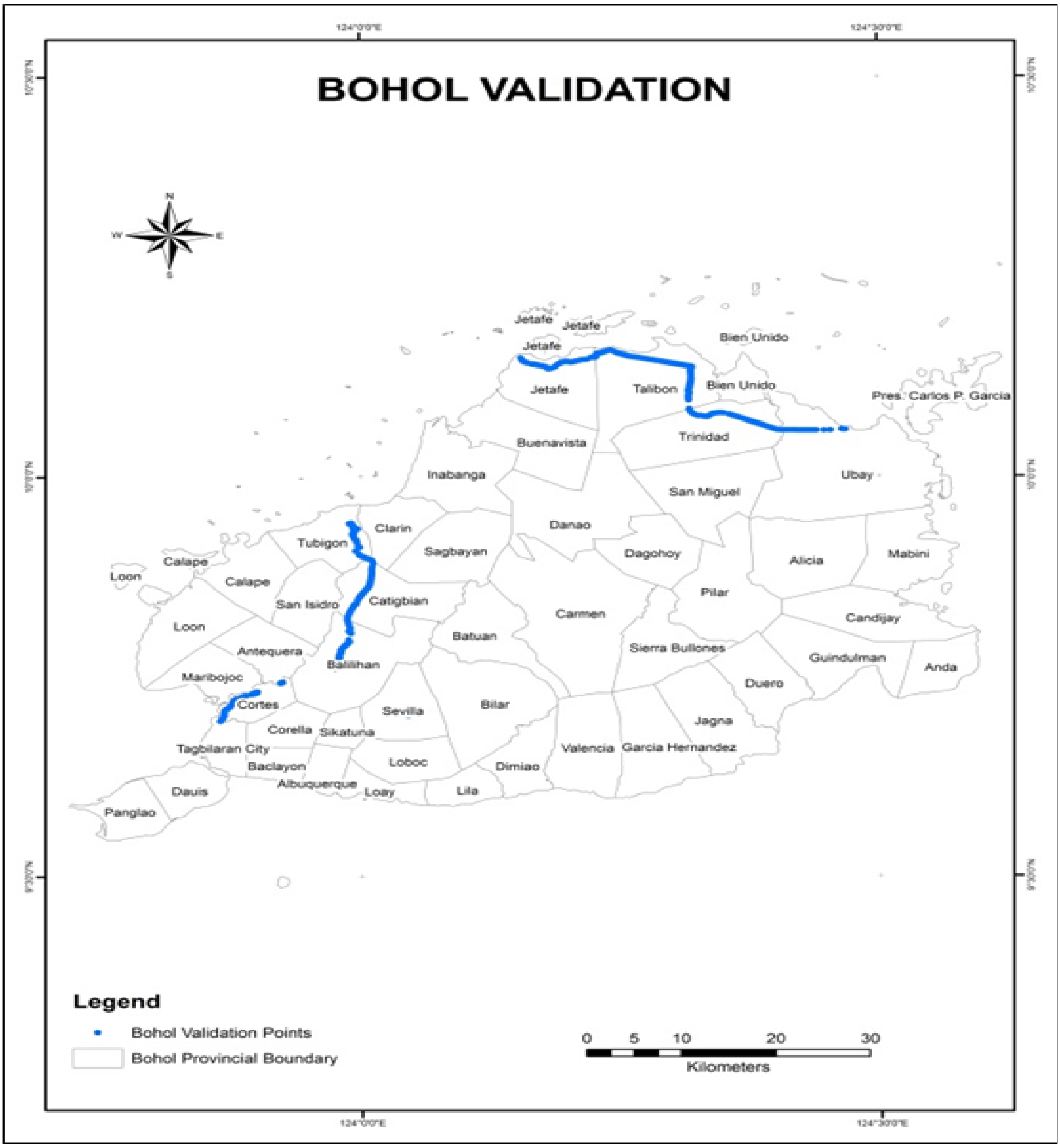


Figure 38. Map of Bohol River System with validation survey shown in blue

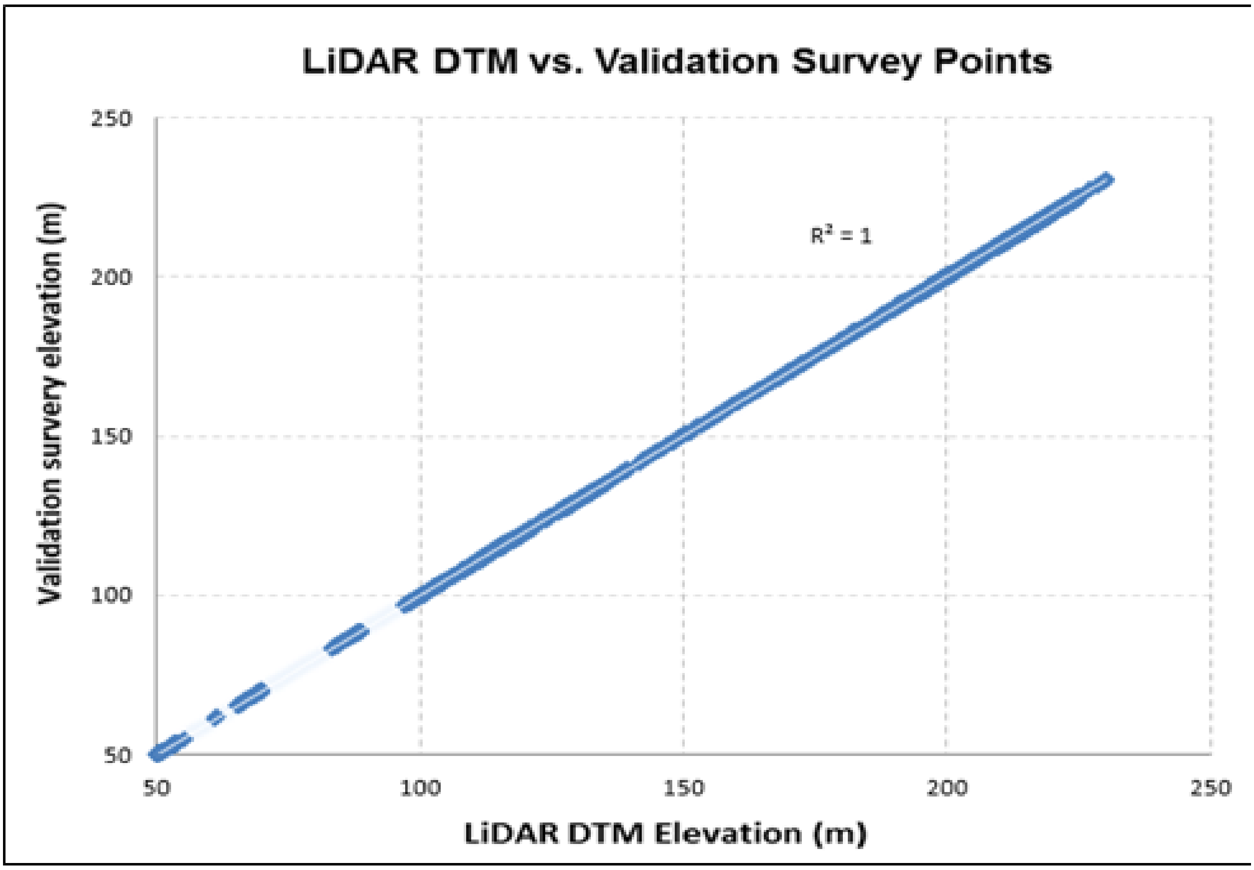


Figure 39. One-one Correlation plot between topographic and LiDAR data

Table 20. Statistical values for calibration of flights.

Statistical Information	Values (cm)
Min	-14.552
Max	14.310
RMSE	7.217
Standard Deviation	7.217
LE90	11.836

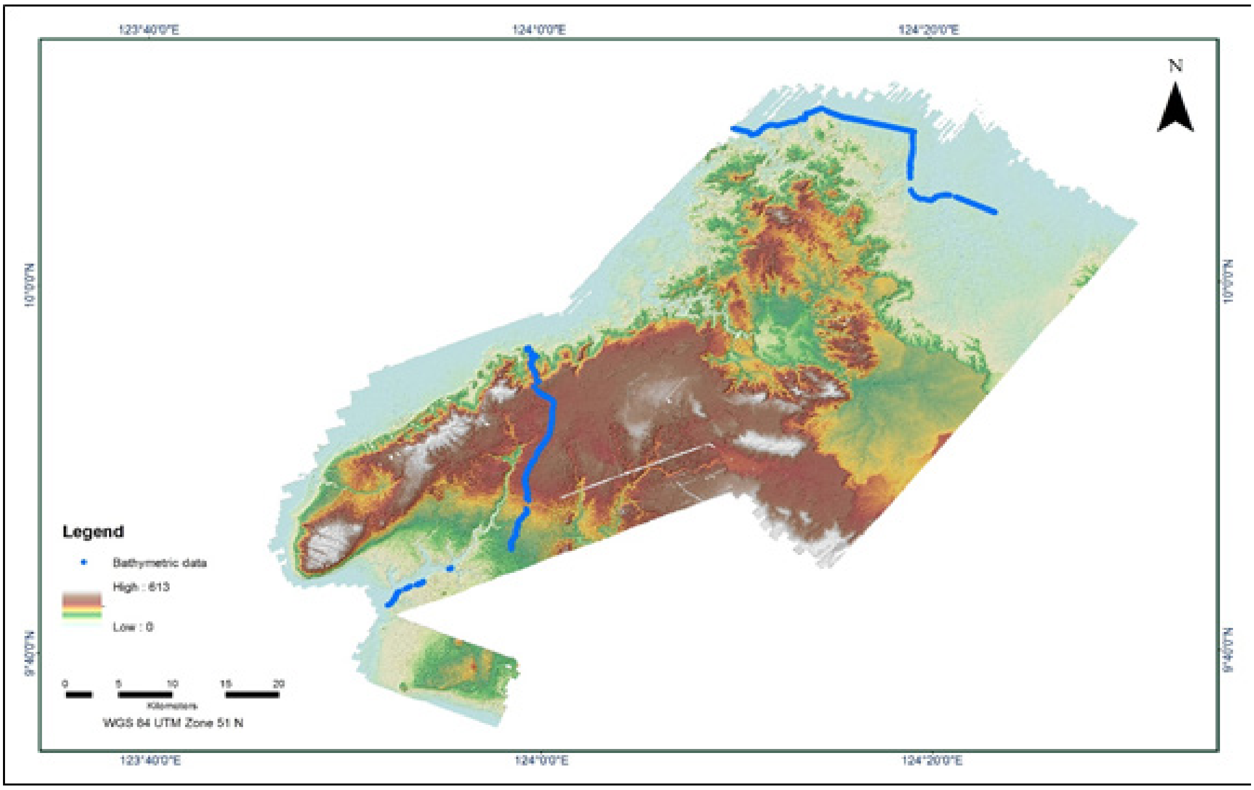


Figure 40. Final DTM of Bohol with validation survey shown in blue

The floodplain extent for Bohol is also presented, showing the completeness of the LiDAR dataset and DSM produced, is shown in Figure 41. Samples of 1 kilometer by 1 kilometer of DSM and DTM are shown in Figure 42 and Figure 43, respectively.

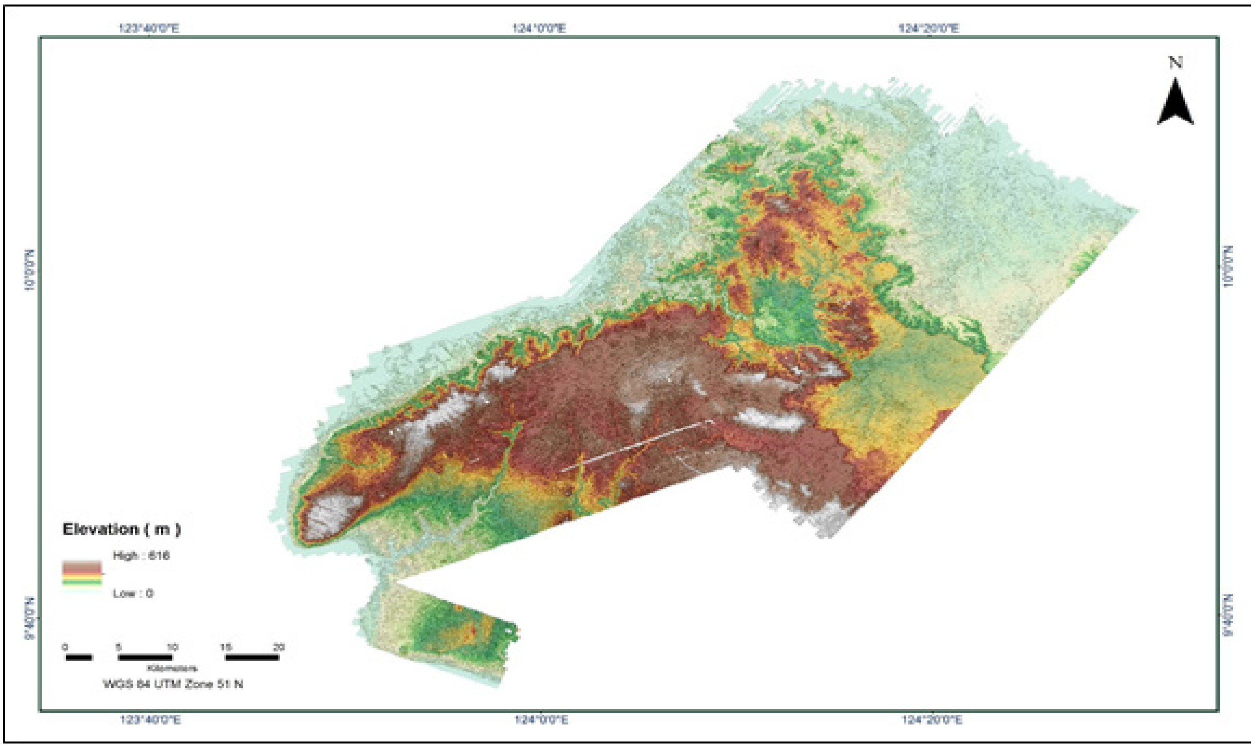


Figure 41. Final DSM in Bohol

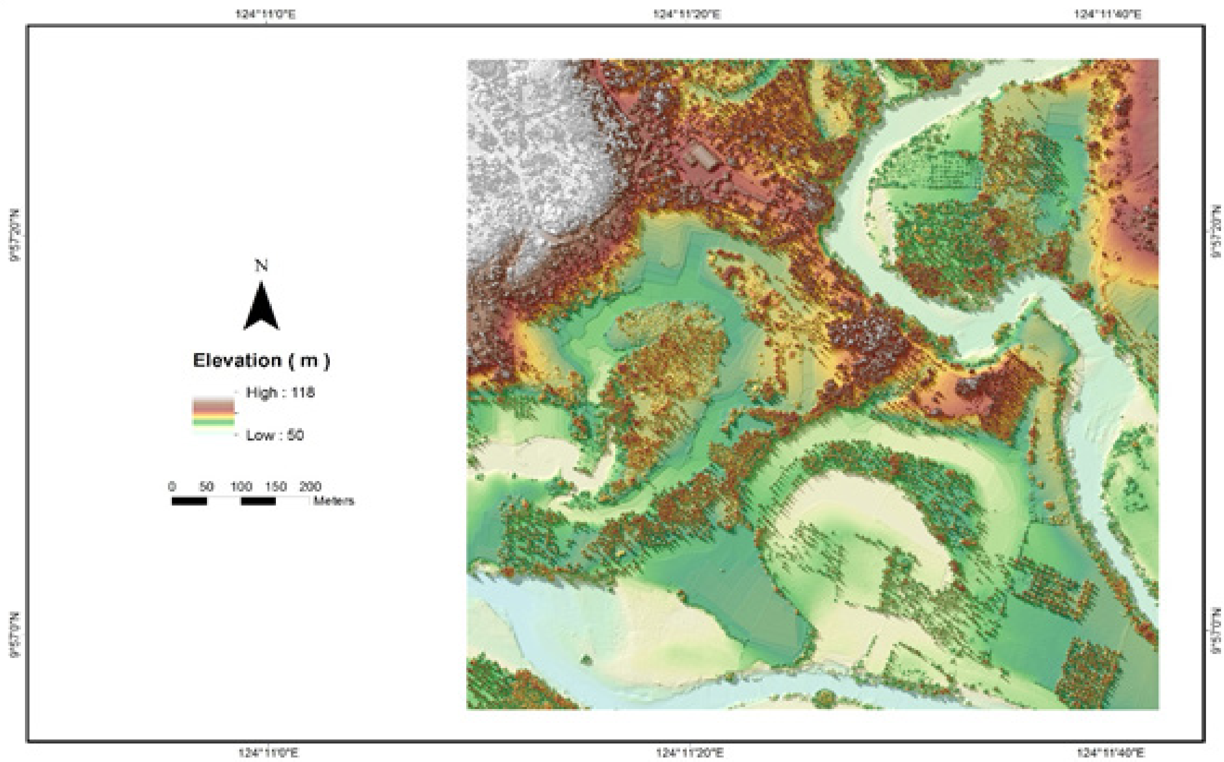


Figure 42. Sample 1x1 square kilometer DSM

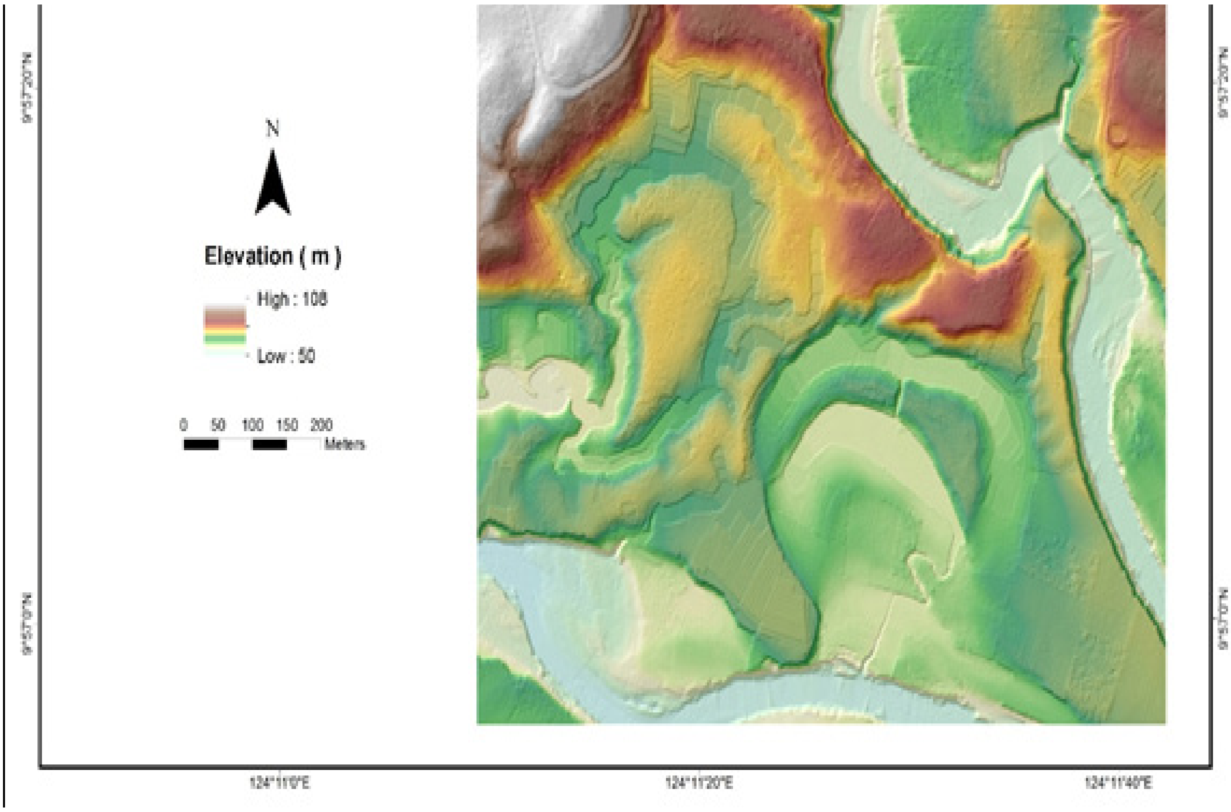


Figure 43. Sample 1x1 square kilometer DTM

Results and Discussion

The corresponding DSM and DTM for the area of Tagbilaran City are shown in Figure 44 and Figure 45. It is clearly shown that through the use of a dense LiDAR point cloud dataset, geologic structures (such as sink holes) that are even below canopy cover can still be detected, as evidenced by the sink holes that are not obvious in the DSM, but are clearly visible in the accompanying DTM. This proves the effectiveness of LiDAR as a tool for sink hole detection and mapping. The vicinity of the Inabanga fault line is shown in Figure 46 and Figure 47, which was a flat rice paddy area before the quake. The nearly 4m uplift in the yellow profile line caused by the quake can be clearly seen in the LiDAR DTM.

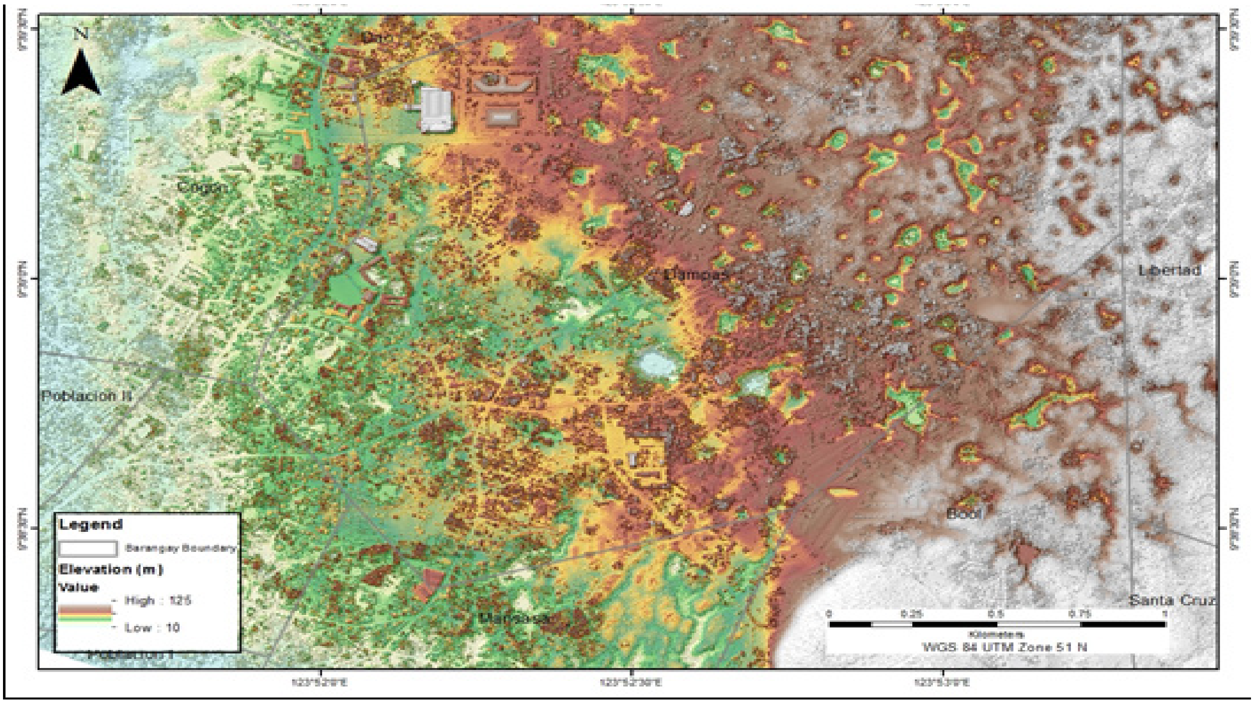


Figure 44. Final DSM in Tagbilaran

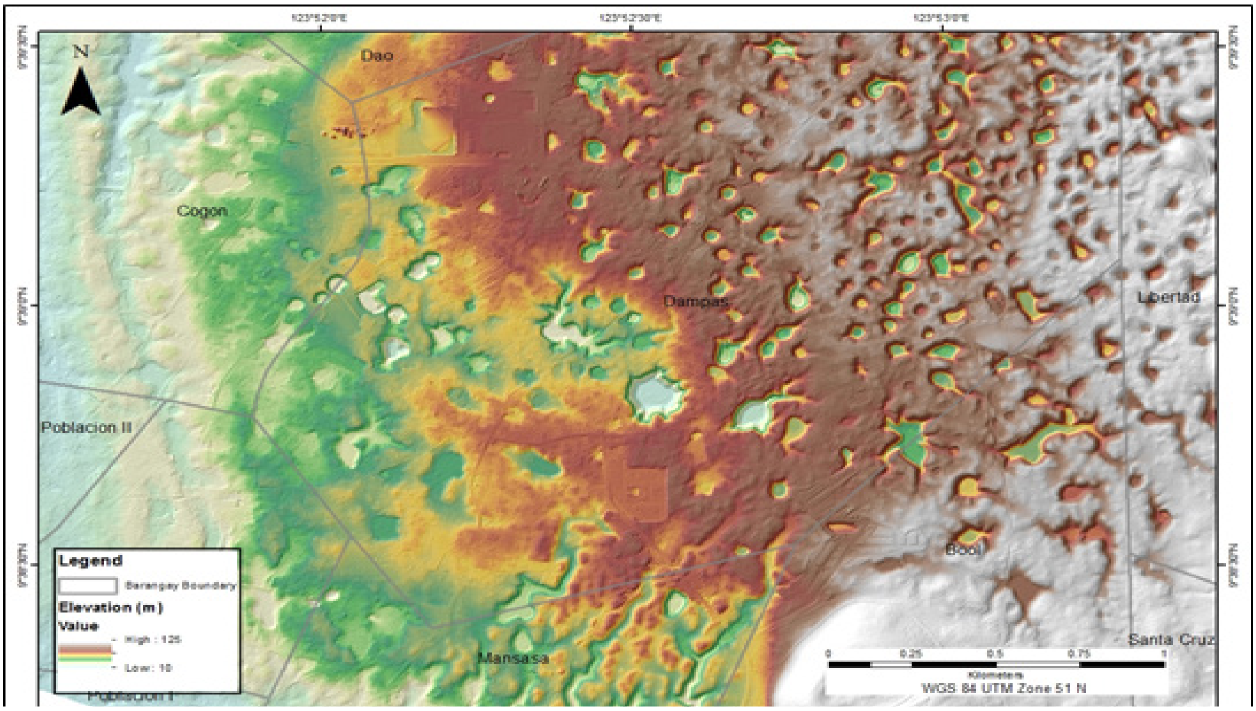


Figure 45. Final DTM in Tagbilaran showing presence of sink holes

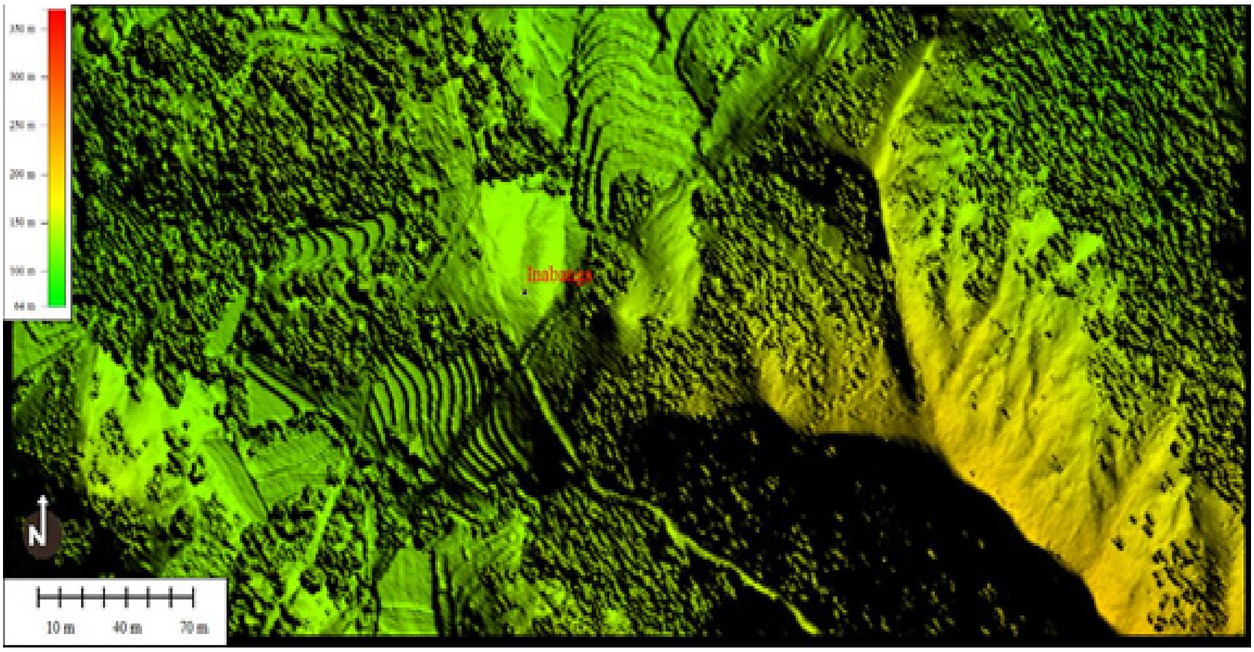


Figure 46. DSM in Inabanga, showing the uplift in the faultline

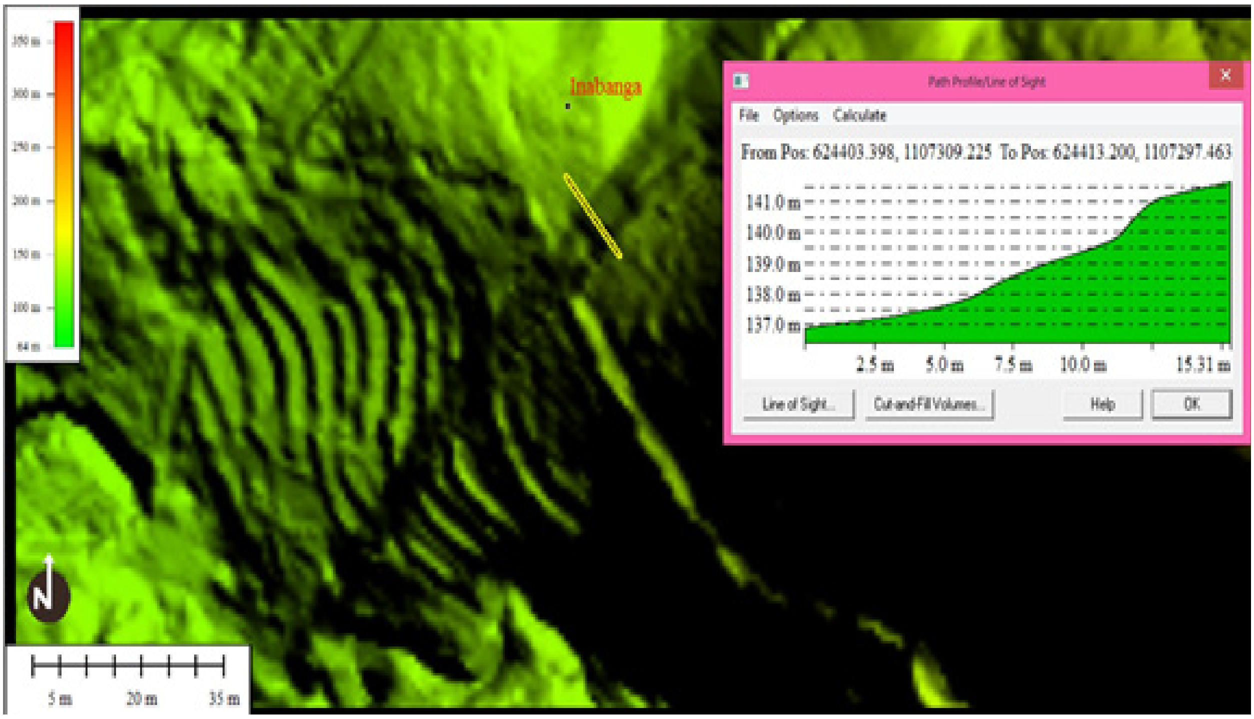


Figure 47. Profile view of the yellow line in the DTM, showing the 4m uplift in Inabanga

Annexes

Annex A

OPTECH TECHNICAL SPECIFICATION OF THE PEGASUS SENSOR

Parameter	Specification
Operational envelope (1,2,3,4)	150-5000 m AGL, nominal
Laser wavelength	1064 nm
Horizontal accuracy (2)	1/5,500 x altitude, 1σ
Elevation accuracy (2)	< 5-20 cm, 1σ
Effective laser repetition rate	Programmable, 100-500 kHz
Position and orientation system	POS AV ™AP50 (OEM)
Scan width (FOV)	Programmable, 0-75 °
Scan frequency (5)	Programmable, 0-140 Hz (effective)
Sensor scan product	800 maximum
Beam divergence	0.25 mrad (1/e)
Roll compensation	Programmable, ±37° (FOV dependent)
Vertical target separation distance	<0.7 m
Range capture	Up to 4 range measurements, including 1st, 2nd, 3rd, and last returns
Intensity capture	Up to 4 intensity returns for each pulse, including last (12 bit)
Image capture	5 MP interline camera (standard); 60 MP full frame (optional)
Full waveform capture	12-bit Optech IWD-2 Intelligent Waveform Digitizer
Data storage	Removable solid state disk SSD (SATA II)
Power requirements	28 V, 800 W, 30 A
Dimensions and weight	Sensor: 630 x 540 x 450 mm; 65 kg;
	Control rack: 650 x 590 x 490 mm; 46 kg
Operating Temperature	-10°C to +35°C
Relative humidity	0-95% non-condensing

Annex B

OPTECH TECHNICAL SPECIFICATION OF THE D-8900 AERIAL DIGITAL CAMERA

Parameter	Specification
Camera Head	
Sensor type	60 Mpix full frame CCD, RGB
Sensor format (H x V)	8, 984 x 6, 732 pixels
Pixel size	6µm x 6 µm
Frame rate	1 frame/2 sec.
FMC	Electro-mechanical, driven by piezo technology (patented)
Shutter	Electro-mechanical iris mechanism 1/125 to 1/500++ sec. f-stops: 5.6, 8, 11, 16
Lenses	50 mm/70 mm/120 mm/210 mm
Filter	Color and near-infrared removable filters
Dimensions (H x W x D)	200 x 150 x 120 mm (70 mm lens)
Weight	~4.5 kg (70 mm lens)
Controller Unit	
Computer	Mini-ITX RoHS-compliant small-form-factor embedded computers with AMD TurionTM 64 X2 CPU 4 GB RAM, 4 GB flash disk local storage IEEE 1394 Firewire interface
Removable storage unit	~500 GB solid state drives, 8,000 images
Power consumption	~8 A, 168 W
Dimensions	2U full rack; 88 x 448 x 493 mm
Weight	~15 kg
Image Pre-Processing Software	
Capture One	Radiometric control and format conversion, TIFF or JPEG
Image output	8,984 x 6,732 pixels 8 or 16 bits per channel (180 MB or 360 MB per image)

Annex C

THE SURVEY TEAM

Data Acquisition Component Sub-team	Designation	Name	Agency/Affiliation
Data Acquisition Component Leader	Data Component Project Leader -I	ENGR. CZAR JAKIRI S. SARMIENTO	UP-TCAGP
Survey Supervisor	Chief Science Research Specialist (CSRS)	ENGR. CHRISTOPHER CRUZ	UP TCAGP
LiDAR Operation	Senior Science Research Specialist	LOVELY GRACIA ACUNA	UP TCAGP
	Research Associate	PAULINE JOANNE ARCEO	UP TCAGP
Ground Survey	Research Associate	MARY CATHERINE ELIZABETH BALIGUAS	
Ground Survey	Research Associate	ENGR. LARAH KRISELLE PARAGAS	UP TCAGP
Data Download and Transfer	Supervising Science Research Specialist	LOVELY GRACIA ACU-NA	UP TCAGP

Annex D

DATA TRANSFER SHEETS FOR Bohol FLOODPLAIN

Data Transfer Sheets for 1BHL1GS336A, 1BHL1FS337A, 1BHL1E338A

DATA TRANSFER SHEET

Dec 11, 2013

DATE	FLIGHT NO.	MISSION NAME	SENSOR	OPERATOR	RAW LAS (RTLSC)	LOGS	POS	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)	OPERATOR COMMENTS (OPC LOGS)	FLIGHT PLAN	SERVER LOCATION
DEC 8, 2013	825P	1BHL1GS336A	Pegasus	P. Arceo	2.33 MB	6.72 MB	198 MB	N/A	N/A	16.8 GB	92.0 GB	13.7 MB	314 BYTES	N/A	Z:\Airborne_Raw\825P
DEC 9, 2013	829P	1BHL1FS337A	Pegasus	P. Arceo	2.46 MB	7.01 MB	219 MB	N/A	N/A	21.5 GB	74.5 GB	6.47 MB	366 BYTES	N/A	Z:\Airborne_Raw\829P
DEC 11, 2013	833P	1BHL1E338A	Pegasus	P. Arceo	4.17 MB	10 MB	262 MB	N/A	N/A	34.4 GB	78.5 GB	6.69 MB	565 BYTES	N/A	Z:\Airborne_Raw\833P

Received from

Name/Signature: Loida Paragas

Position: RA

Date: 12/11/13

Received by

Name/Signature: JOIDA PRIETO

Position: SSRS

Date: 12/11/13

Verified by

Name/Signature: JOIDA PRIETO

Position: SSRS

Date: 12/11/13

Page 1

Annex D

DATA TRANSFER SHEETS FOR Bohol FLOODPLAIN

Data Transfer Sheet for 1TGB315A, 1BHL1H317A, 1LMSBHL1H-S319A, 1BHL1G319B, 1BHL1HS320A, 1BHL1C321A

Nov 20

DATA TRANSFER SHEET

Nov 20, 2013

DATE	FLIGHT NO.	MISSION NAME	SENSOR	OPERATOR	RAW LAS (RTLSC)	LOGS	POS	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)	OPERATOR COMMENTS (DPC LOGS)	FLIGHT PLAN	SERVER LOCATION
Nov. 11, 2013	741P	1TGB315A	Pegasus	P. Arceo	1.56 MB	5.82 MB	220 MB	N/A	N/A	14.5 GB	41.5 GB	11.4 MB	574 BYTES	29.6 KB	Z:\Airborne_Raw\741PP
Nov. 13, 2013	747P	1BHL1H317A	Pegasus	P. Arceo	2.88 MB	9.48 MB	276 MB	N/A	N/A	27.2 GB	152 GB	11.3 MB	401 BYTES	N/A	Z:\Airborne_Raw\747P
Nov. 15, 2013	755P	1LMSBHL1HS319A	Pegasus	P. Arceo	1.15 MB	5.26 MB	165 MB	N/A	N/A	11.0 GB	56.5 GB	13.9 MB	399 BYTES	N/A	Z:\Airborne_Raw\755P
Nov. 15, 2013	757P	1BHL1G319B	Pegasus	C. Baliguas	2.26 MB	6.41 MB	196 MB	N/A	N/A	20.8 GB	49.9 GB	14 MB	439 BYTES	N/A	Z:\Airborne_Raw\757P
Nov. 16, 2013	759P	1BHL1HS320A	Pegasus	C. Baliguas	1.38 MB	4.95 MB	181 MB	N/A	N/A	16.5 GB	N/A	10.9 MB	536 BYTES	N/A	Z:\Airborne_Raw\759P
Nov. 17, 2013	765P	1BHL1C321A	Pegasus	no op log	2.76 MB	7.29 MB	201 MB	N/A	N/A	24.1 GB	43.9 GB	13 MB	N/A	N/A	Z:\Airborne_Raw\765P

Received from

Name/Signature MARY FUASTILOP

Position RA

Date 12/3/13

Received by

Name/Signature JOIDA F. PRIETO

Position SSRS

Date 12/3/13

Annex D

DATA TRANSFER SHEETS FOR Bohol FLOODPLAIN

Data Transfer Sheet for 1BHL1BC322A, 1BHL1BS323A, 1BHL-1D324A, 1BHL1BDS328A, 1BHL1GS329A, 1BHL1A330A, 1BHL1A-S3331A, 1BHL1GS336A

DATA TRANSFER SHEET

Jan 9, 2014

DATE	FLIGHT NO.	MISSION NAME	SENSOR	RAW LAS		LOGS	POS	RAW IMAGES	MISSION LOG FILE	RANGE	DIGITIZER	BASE STATION(S)		OPERATOR LOGS (OPLOG)	FLIGHT PLAN		SERVER LOCATION
				Output LAS	KML (swath)							BASE STATION(S)	Base Info (.txt)		Actual	KML	
November 18, 2013	769P	1BHL1BC322A	PEGASUS	N/A	3.22MB	8.14MB	214MB	N/A	N/A	27.6GB	23.6GB	BHL63 (.DAT +T02) - 2.82MB/ BHL3074-8.44MB	144 BYTES	383 BYTES	N/A	N/A	Y:\Airborne_Raw\769P
November 19, 2013	773P	1BHL1BS323A	PEGASUS	N/A	1.45MB	4.92MB	145MB	N/A	N/A	12.8GB	7.50 GB	BHL3074 (.DAT +T02) - 2.23MB/ BHL63-2.45MB	140 BYTES	485 BYTES	N/A	N/A	Y:\Airborne_Raw\773P
November 20, 2013	777P	1BHL1D324A	PEGASUS	N/A	1.60MB	5.20MB	155MB	N/A	N/A	14.3GB	70.3GB	BHL3074 (.DAT +T02) - 2.39MB/ BHL63-6.01MB	142 BYTES	366 BYTES	N/A	N/A	Y:\Airborne_Raw\777P
November 24, 2013	793P	1BHL1BDS328A	PEGASUS	N/A	6.10MB	6.00MB	251MB	N/A	N/A	27.5GB	144GB	BHL3074 (.DAT +T02) - 3.17MB/ BHL63-6.01MB	140 BYTES	494 BYTES	N/A	N/A	Y:\Airborne_Raw\793P
November 25, 2013	795P	1BHL1GS329A	PEGASUS	N/A	358KB	3.16MB	107MB	N/A	N/A	3.79GB	17.7GB	BHL72 (.DAT +T02) - 4.49MB/ BHL76-2.66MB	138 BYTES	162 BYTES	N/A	N/A	Y:\Airborne_Raw\795P
November 26, 2013	799P	1BHL1A330A	PEGASUS	N/A	2.83MB	7.26MB	191MB	N/A	N/A	24.5GB	129GB	BHL3087 (.DAT +T02) - 2.81MB/ BHL58-9.74MB	168 BYTES	492 BYTES	N/A	N/A	Y:\Airborne_Raw\799P
November 27, 2013	803P	1BHL1AS331A	PEGASUS	N/A	2.37 MB	6.49 MB	171MB	N/A	N/A	20.1GB	6.49 GB	BHL3087 (.DAT +T02) - 2.72MB/ BHL58-3.47MB	306 BYTES	406 BYTES	N/A	N/A	Y:\Airborne_Raw\803P
December 02, 2013	825P	1BHL1GS336A	PEGASUS	N/A	2.33MB	6.72MB	198MB	N/A	N/A	16.8GB	92.0GB	BHL3144 (.DAT +T02) - 2.22MB/ BHL90-11.4MB	129 BYTES	314 BYTES	N/A	N/A	Y:\Airborne_Raw\825P

Received from

Name Larah Paragas

Position RA

Signature

Received by

Name JOIDA F. PRIETO

Position SSRS

Signature

Verified by

Name JOIDA F. PRIETO

Position SSRS

Signature

Annex E

FLIGHT LOGS FOR Bohol FLOODPLAIN

1. Flight Log for 1TGB315A Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 7415

1 LiDAR Operator: BALICUAS ARCEO	2 ALTM Model: PEG	3 Mission Name: 1TGB315A	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: 9022
7 Pilot: R. SAMAR V	8 Co-Pilot: J. ALAJAR	9 Route:			
10 Date: Nov. 11, 2013	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 1226H	14 Engine Off: 1643H	15 Total Engine Time: 4H17	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					
20 Remarks: Mission completed.					

21 Problems and Solutions:

Acquisition Flight Approved by: LOVELY ACUNA — Signature over Printed Name (End User Representative)

Acquisition Flight Certified by: Antonio T Valenzuela Jr — Signature over Printed Name (PAF Representative)

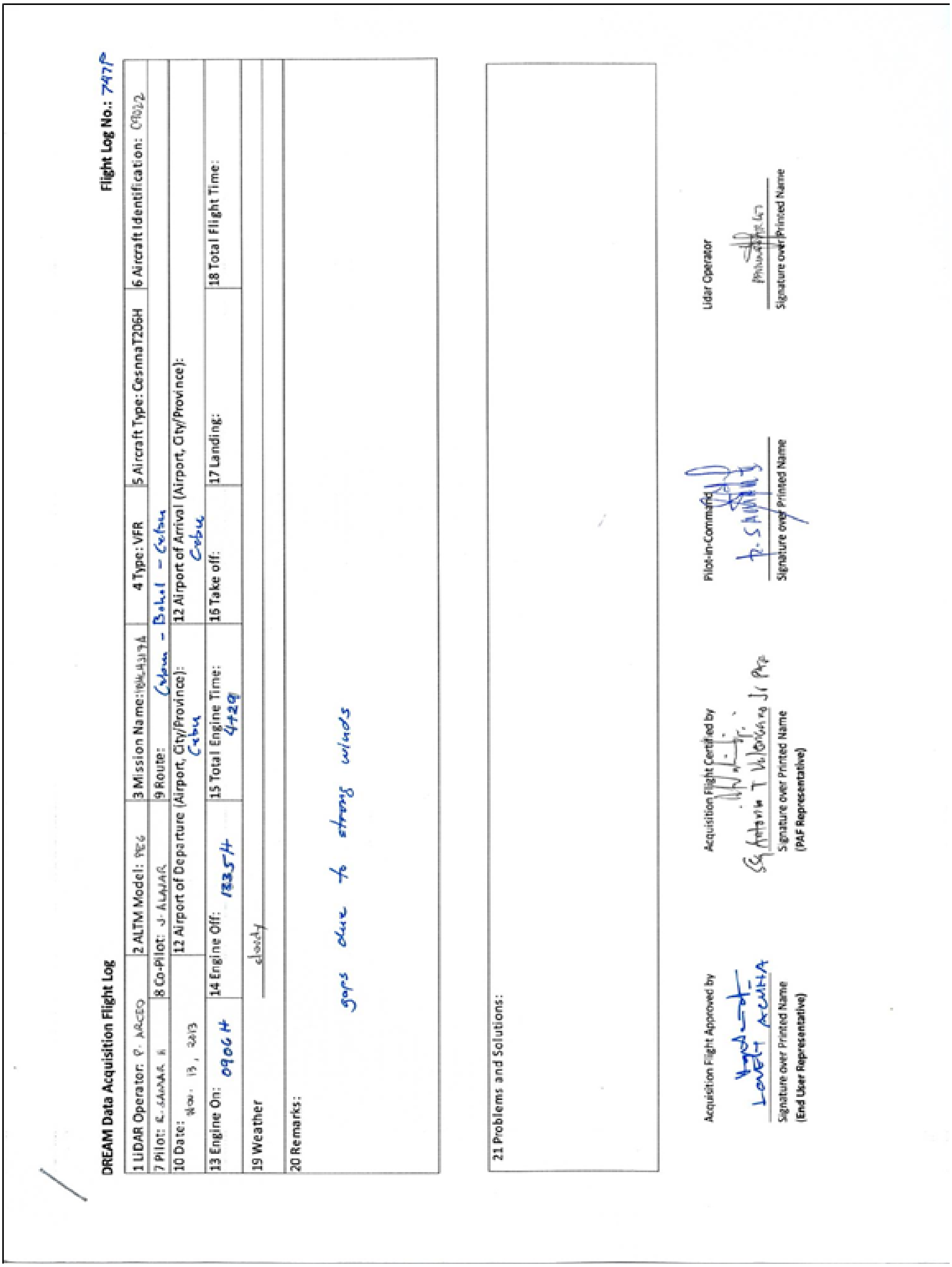
Pilot-in-Command: R. SAMAR V — Signature over Printed Name

Lidar Operator: MARY CATHERINE ELIZABETH BALICUAS — Signature over Printed Name

Annex E

FLIGHT LOGS FOR Bohol FLOODPLAIN

2. Flight Log for 1BHLH317A Mission



Flight Log No.: 797P

DREAM Data Acquisition Flight Log

1 LiDAR Operator: P. ARCEO	2 ALTM Model: PEG	3 Mission Name: 1BHLH317A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: R. SAMAR	8 Co-Pilot: J. ALAMAR	9 Route: Cebu - Bohol - Cebu			
10 Date: Nov. 13, 2013	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 0906H	14 Engine Off: 1335H	15 Total Engine Time: 4+29	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

gaps due to strong winds

21 Problems and Solutions:

Acquisition Flight Approved by
Signature over Printed Name
(End User Representative)

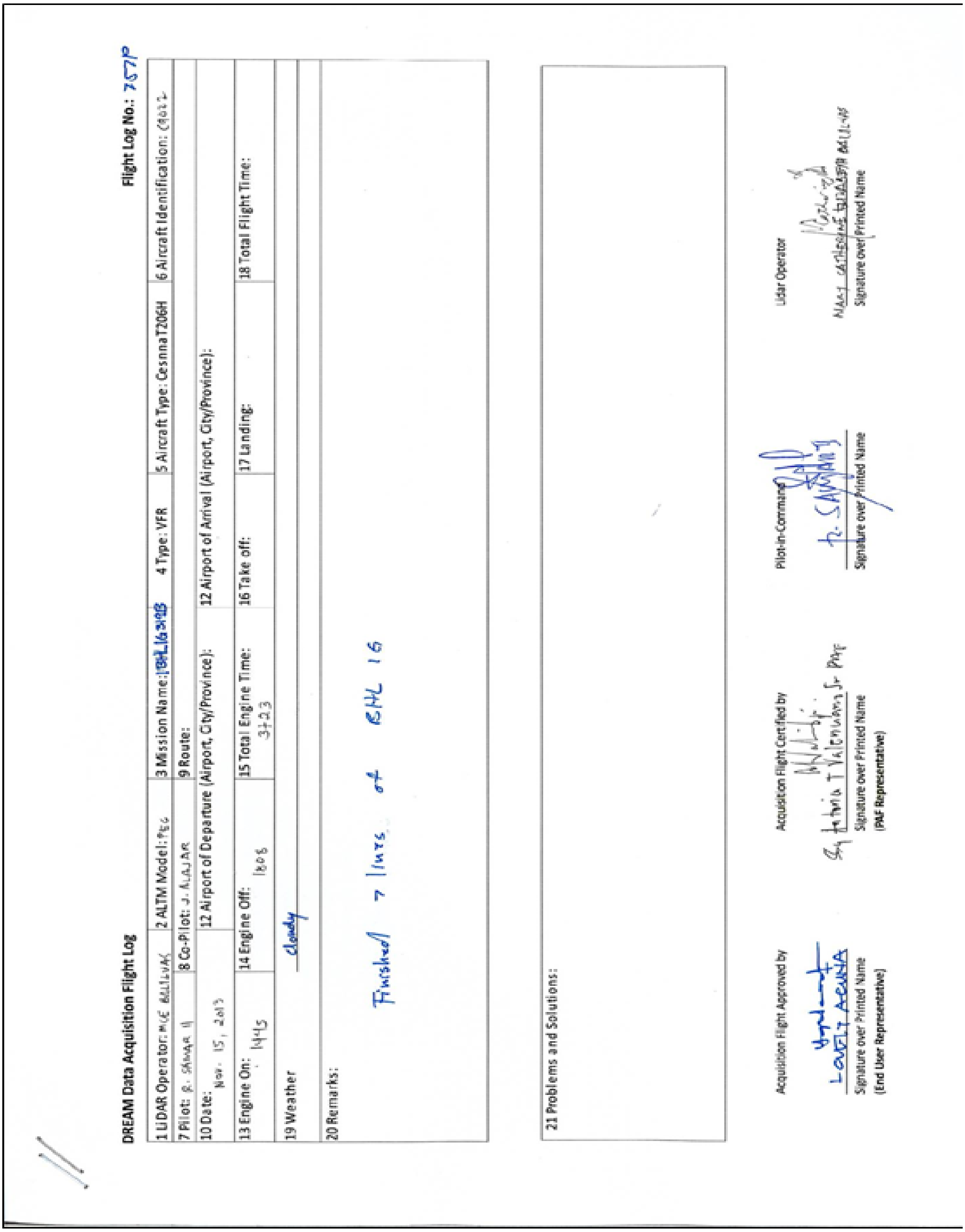
Acquisition Flight Certified by
Signature over Printed Name
(PAF Representative)

Pilot-in-Command
Signature over Printed Name

Lidar Operator
Signature over Printed Name

FLIGHT LOGS FOR Bohol FLOODPLAIN

3. Flight Log for 1BHL1G319B Mission



DREAM Data Acquisition Flight Log — Flight Log No.: 757P

1 LiDAR Operator: MCE BALUVAS	2 ALTM Model: PEG	3 Mission Name: 1BHL1G319B	4 Type: VFR	5 Aircraft Type: Cesnna T206H	6 Aircraft Identification: C9022
7 Pilot: R. SAMAR II	8 Co-Pilot: J. ALAJAR	9 Route:			
10 Date: Nov. 15, 2013	12 Airport of Departure (Airport, City/Province):		12 Airport of Arrival (Airport, City/Province):		
13 Engine On: 1445	14 Engine Off: 1808	15 Total Engine Time: 3+23	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: cloudy					

20 Remarks:

Finished 7 lines of BHL 16

21 Problems and Solutions:

Acquisition Flight Approved by: LOVELY ACUNA — Signature over Printed Name (End User Representative)

Acquisition Flight Certified by: Sg Antonio T Valenzuela Sr PAF — Signature over Printed Name (PAF Representative)

Pilot-in-Command: R. SAMAR II — Signature over Printed Name

Lidar Operator: MARY CATHERINE ELIZABETH BALUVAS — Signature over Printed Name

Annex E

FLIGHT LOGS FOR Bohol FLOODPLAIN

4. Flight Log for 1BHL1HS320A Mission

DREAM Data Acquisition Flight Log — Flight Log No.:

1 LiDAR Operator: MCE BALICUAS	2 ALTM Model: PEG	3 Mission Name: 1BHL1HS320A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: R. Samar	8 Co-Pilot: J. Alajar	9 Route: Cebu - BHL - Cebu			
10 Date: Nov. 16, 2013	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 0628	14 Engine Off: 0937	15 Total Engine Time: 3+11	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Cloudy					

20 Remarks:

Finished 4 lines of BHL 1A

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
LOVELY ACUNA	SSg Antonio T Valencia Jr	R. Samar II	MA. CATHERINE ELIZABETH BALICUAS
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Annex E

FLIGHT LOGS FOR Bohol FLOODPLAIN

5. Flight Log for 1BHL1G321A Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 7657

1 LIDAR Operator: PJ Arceo	2 ALTM Model: Peg	3 Mission Name: 1BHL1G321A	4 Type: VFR	5 Aircraft Type: Cessna T206H	6 Aircraft Identification: 9122
7 Pilot: R. Samar II	8 Co-Pilot: J. Alajar	9 Route: CEB - BHL - CEB			
10 Date: Nov. 17, 2018	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 1448	14 Engine Off: 1817	15 Total Engine Time: 3+29	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather	partly cloudy				
20 Remarks:	Finished 8 lines of BHL1C				

21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Lovely Acuna	Sgt Antonio T Valderrama Jr PAF	R. Samar II	PJ Arceo
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Annex E

FLIGHT LOGS FOR Bohol FLOODPLAIN

6. Flight Log for 1BHL1BC322A Mission

DREAM Data Acquisition Flight Log

Flight Log No.: 7695

1 LiDAR Operator: PJ Arceo & MCE Balicuas	2 ALTM Model: Peg	3 Mission Name: 1BHL1BC322A	4 Type: VFR	5 Aircraft Type: CesnnaT206H	6 Aircraft Identification: 9022
7 Pilot: R. Samar II	8 Co-Pilot: J. Alajar	9 Route: CEB - BHL - CEB			
10 Date: Nov 18, 2013	12 Airport of Departure (Airport, City/Province): Cebu		12 Airport of Arrival (Airport, City/Province): Cebu		
13 Engine On: 1446	14 Engine Off: 1821	15 Total Engine Time: 3+35	16 Take off:	17 Landing:	18 Total Flight Time:
19 Weather: Partly cloudy					

20 Remarks:

Finished BHL1C and 2 lines of BHL1B

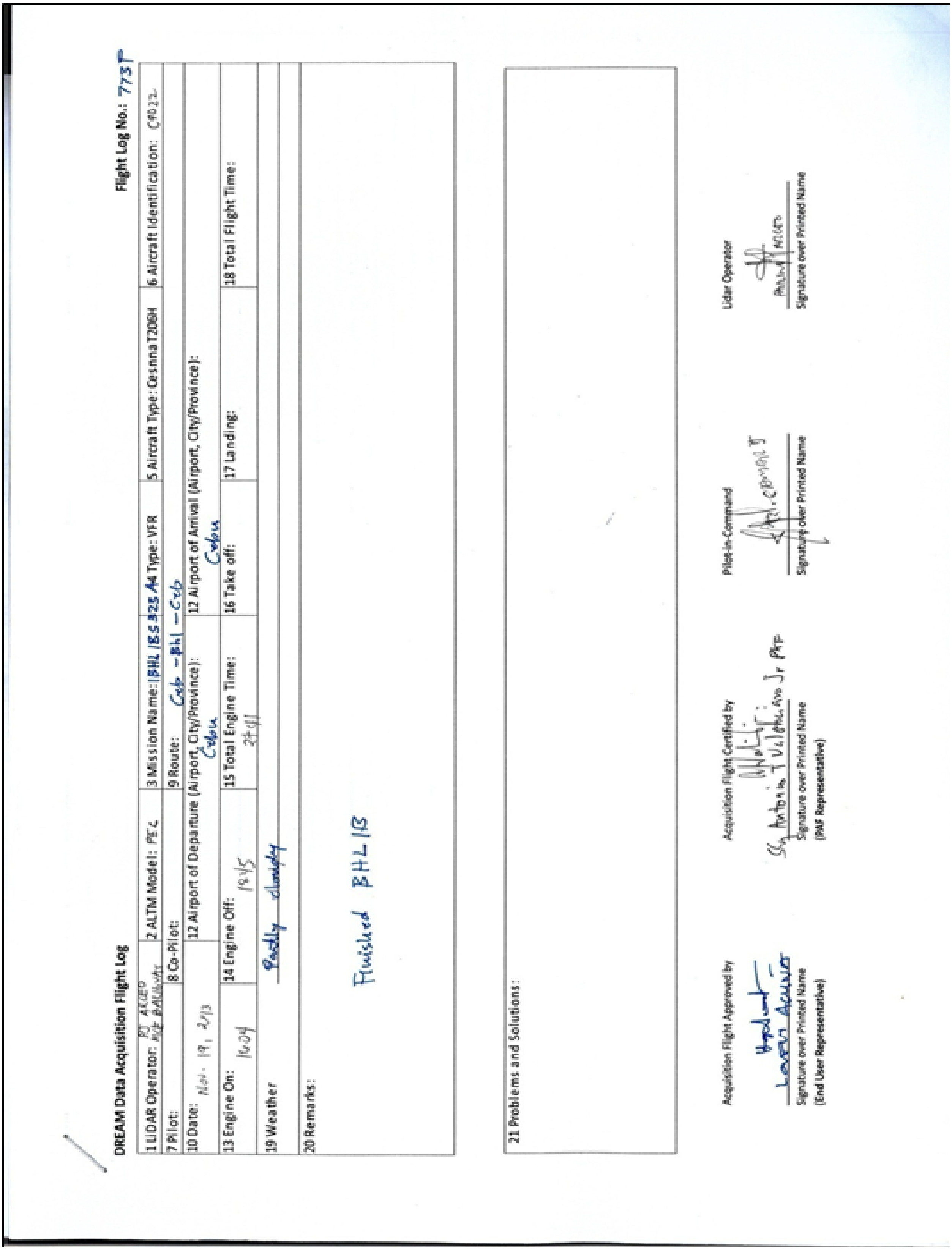
21 Problems and Solutions:

Acquisition Flight Approved by	Acquisition Flight Certified by	Pilot-in-Command	Lidar Operator
Lovely Acuña	SSg Antonio T Valenciano Jr PAF	R. Samar II	Phil Arceo
Signature over Printed Name (End User Representative)	Signature over Printed Name (PAF Representative)	Signature over Printed Name	Signature over Printed Name

Annex E

FLIGHT LOGS FOR Bohol FLOODPLAIN

7. Flight Log for 1BHL1BS323A Mission



DREAM Data Acquisition Flight Log — Flight Log No.: 773P

1 LIDAR Operator: PJ Arceo / MZ Baliuag	2 ALTM Model: PEG	3 Mission Name: 1BHL1BS323A 4 Type: VFR	5 Aircraft Type: Cesnna T206H
6 Aircraft Identification: C9022			
7 Pilot:	8 Co-Pilot:	9 Route: Ceb - Bhl - Ceb	
10 Date: Nov. 19, 2013	12 Airport of Departure (Airport, City/Province): Cebu	12 Airport of Arrival (Airport, City/Province): Cebu	
13 Engine On: 1604	14 Engine Off: 1845	15 Total Engine Time: 2+41	16 Take off:
17 Landing:	18 Total Flight Time:		
19 Weather: Partly cloudy			
20 Remarks: Finished BHL1B			
21 Problems and Solutions:			

Acquisition Flight Approved by — Signature over Printed Name (End User Representative)

Acquisition Flight Certified by — Signature over Printed Name (PAF Representative)

Pilot-in-Command — Signature over Printed Name

Lidar Operator — Signature over Printed Name

DREAM

Disaster RIsk and Exposure Assessment for Mitigation