

Procedures for Processing LIDAR Point Cloud Files to Create Digital Elevation Models, Contours, and Elevation Changes

Table of Contents

Introduction.....	3
Data Processing Workflow.....	3
Processing Software.....	4
Organize & Visualize.....	8
Metadata & Statistics.....	10
Filter & Subset.....	12
Transform.....	15
Gridding & Surface Analysis.....	17

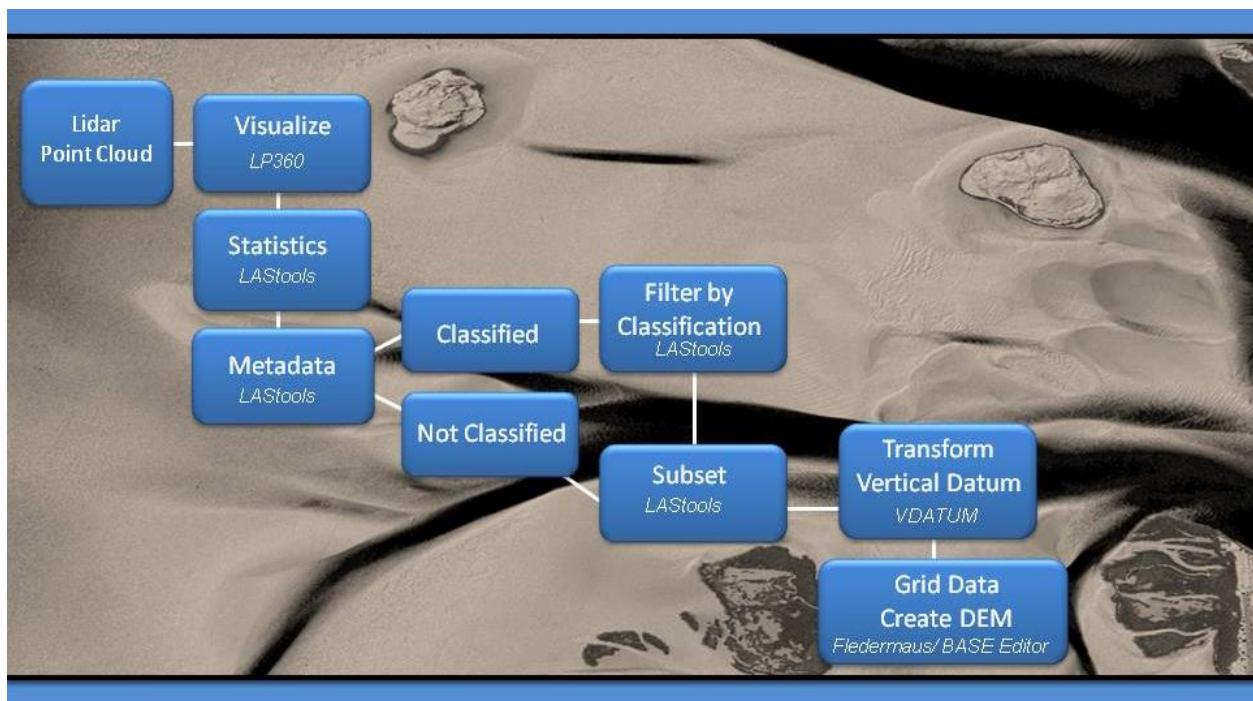
Software Used:

LP360 v 2013.2.49.1 (Qcoherent)
LAStools (Rapidlasso)
ArcGIS v10.2.2 (ESRI)
Fledermaus v7.4.0 (QPS)
VDatum v3.3 (NOAA)
Bathy DataBASE Editor v4.0 (CARIS)

Introduction

The purpose of this guide is to provide an overview of procedures and best practices for creating digital elevation models from bathymetric and topographic Lidar point clouds. There are several different programs and ways to grid data this document will list multiple software and several methods. Due to the limitations and licensing of each program a workflow combining the strengths of each program remains to be the most useful workflow for creating a number of different products serving different purposes. This guide does not represent an endorsement of any particular software package and only references software and licensing available to UNH CCOM at the time. All Lidar processing should start with recognizing what the desired goal and product is from using this data, this will dictate the scale, storage, as well as the appropriate gridding method.

Data Processing Workflow



Processing Software

LAStools

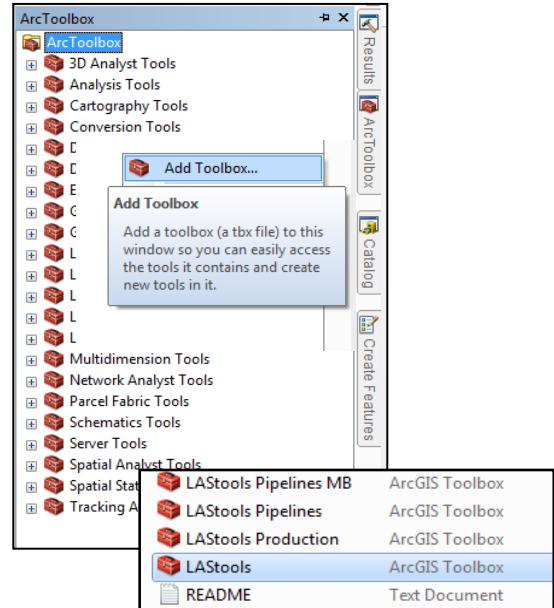
Download LAStools at <http://rapidlasso.com/>

Pros: LAStools are partially open source. LAStools are fast and have an easy to use graphical user interface (GUI) which is optimal for batch processing, the GUI can be found in the Bin folder under the main LAStools folder. LAStools also have an ArcToolbox available which can be added to your ArcMap by right clicking in ArcToolbox and adding a toolbox, however the LAStools in ArcToolbox will only process one file at time. LAStools are best for organizing and filtering LIDAR data.

Limitations: Only part of the tools included in the package can be used for free. To get full functionality of tools like las2dem you need to purchase a full license. LAStools lack visualization tools to truly understand the data.

The tools below are free to use:

<ul style="list-style-type: none">• Laszip• lasindex• lasvalidate• lasinfo• las2las	<ul style="list-style-type: none">• lasview• lasdiff• lasmerge• las2txt & txt2las• lasprecision
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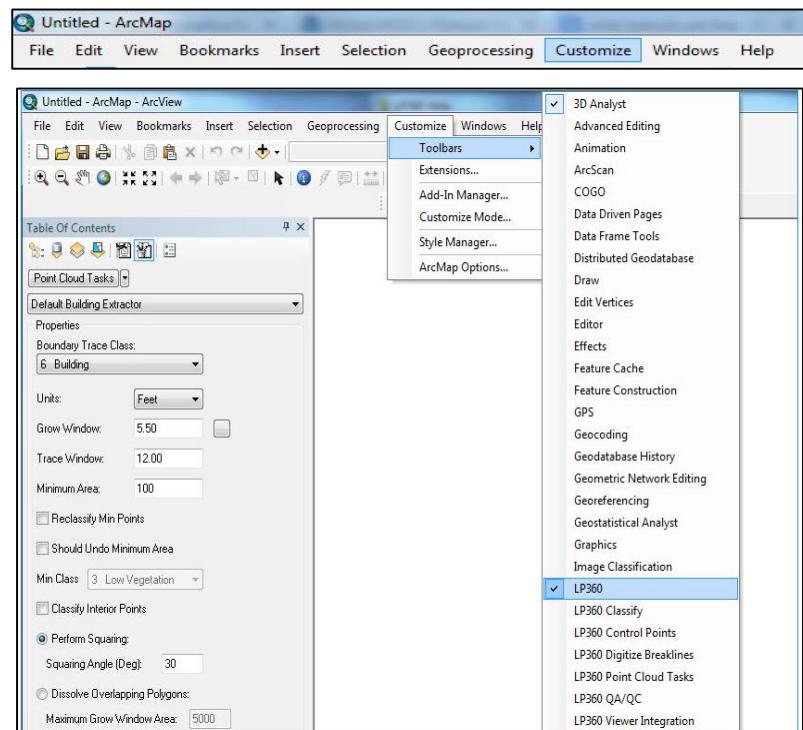
Tools not available without a license are listed below:

<ul style="list-style-type: none">• blast2dem• blast2iso• lasground• lasheight• lasclassify• lasgrid & lascanopy• lasboundary• lascontrol• lasclip• lascolor• las2shp & shp2las.	<ul style="list-style-type: none">• lasoverlap• lasoverage• lasduplicate• lassplit• las2tin• las2iso• las2dem• lasthin & lasnoise• lassort• lastile
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LP360

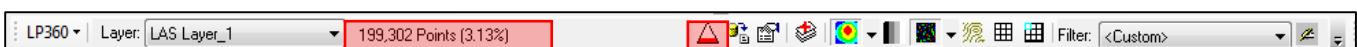
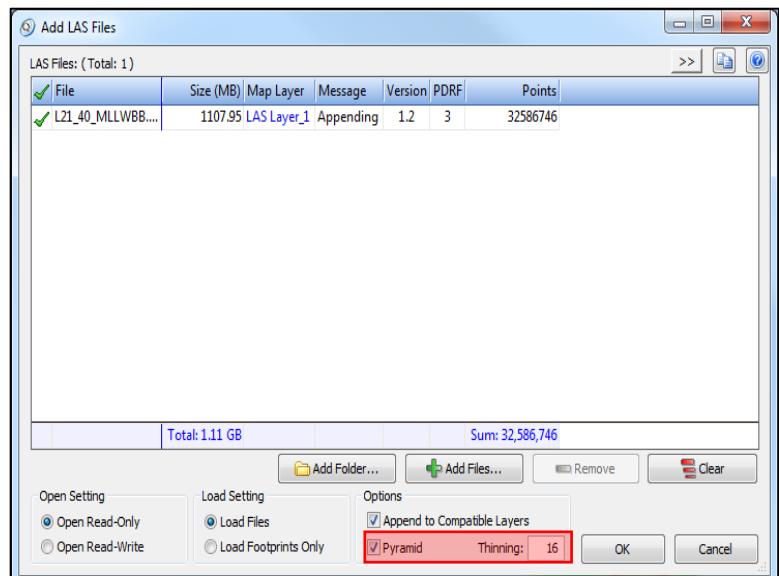
To use LP360 → Open a Session of ArcMap → Under Customize → Extensions → Turn on LP360, Spatial Analyst, and 3D Analyst.

Then under Customize → Toolbars → Add LP360 Toolbars. There is also an additional LP360 ArcToolbox for LAS File Management.



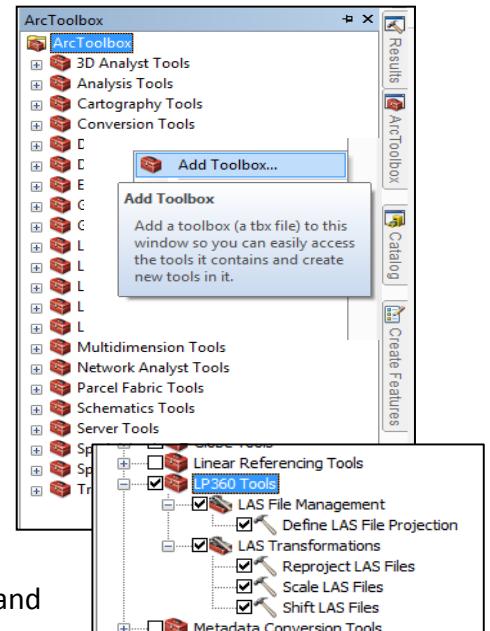
Pros: Fastest tool to view data, due to the ability to enter a thinning factor to determine the number of layers in the pyramid. An intermediate factor of 16 is recommended to improve performance. Pyramiding is used to improve display performance for large LAS Files. The higher the thinning factor the fewer levels in the pyramid file.

When viewing data using pyramids you will see in the main LP360 toolbar the percentage of points displayed compared to the full resolution data. Many point task and classification task require viewing data at full resolution and most tools will be grayed out or unavailable until full resolution is selected.



The visualization tools are the most useful, containing the most options for visualization. Having the ability to display the point cloud by elevation, colorband, classification, intensity, point source (to view flight lines), RGB value, point density, and elevation difference can be crucial for understanding the data. The profile and 3D tools are also a necessity when analyzing the point cloud data. With an easy to use ArcMap Toolbar the user can get a wealth of information by displaying different classifications. LP360 also has the ability to create and use breaklines which are surface constraints needed to create an accurate representational surface model.

Limitations: Bugs and issues prevent the user from exporting filtered point clouds that can be used in other programs, the vertical datum will not be recognized in other programs limiting the use of multiple exporting tools. The export tool also displayed a long processing time and additional issues were found when trying to export by using a polygon boundary. Advanced license is required for most filtering tasks, such as Low Isolated Point Filter, Statistical Noise Point Filter.



Fledermaus

Fledermaus is one of the best visualization tools. DMagic creates elevation models rapidly and is able to handle a significant amount of points which is crucial when working with large Lidar collections. DMagic is the fastest gridding program.

Different gridding methods available:

<https://confluence.qps.nl/display/KBE/Details+of+the+Weighted+Moving+Ave...+used+in+Fledermaus+and+DMagic+v7>

Weighted Moving Average – the default weighted average algorithm

The weight diameter controls the extent as to which smoothing takes places during the gridding operation. The weight field size will be the area over which each sounding will contribute to its neighboring cells. With a weight field size of 3, a sounding will contribute to the grid cell it is located in, and the 8 surrounding cells.

Shallow Biased – minimum value in the cell & Deep Biased - the deepest value in the cell

The shallow and deep gridding algorithms are the simplest of all the gridding options within Avggrid. Both algorithms simply store a max or min value within each bin while all the incoming data points are read. After the input data is finished, the grid values are then complete, with no further processing. This algorithm does not consider any values outside of each bin.

Median Filtered – median value in the cell

The median gridding algorithm is only slightly more complex than the shallow and deep algorithms. The biggest change is that all input depths are kept in a sorted list for each bin. Once all input values have been read, each list of depths (for each bin) is analyzed and the

median value chosen. The algorithm only works within each bin, so nothing is considered outside the bin boundary.

Root Mean Square - uses a RMS algorithm.

The RMS algorithm will create a root mean square value for each bin. During the gridding process each input value is squared and then added to the current total in the current bin. An input value is only ever added to the one bin it falls into. Once all the input values have been read, the sum of squares at each bin is divided by the total number of records in that bin, and then the square root of that value is taken.

Pro: Fast gridding tool that will not interpolate over areas with no data even without adding breaklines, creating an accurate surface representation. The user has an additional ability to use a polygon boundary when gridding and exporting. Very useful for surface profiling and volume comparisons and accepts LAS formats. Export surfaces that can be read by other programs and an option to export a BAG containing depth and uncertainty, by creating a Fledermaus PFM file with a Combined Uncertainty and Bathymetry Estimator (CUBE) surface.

Limitations: The user needs to have 64bit and 32bit available, only 32bit can export rasters to ArcGIS. This creates a lengthy workflow. Fledermaus also creates very large project files, not recommended for overall data storage.

Bathy DataBASE Editor:

Different gridding methods available:

TPU Weighted Mean: Use the Total Propagated Uncertainty (TPU) values for the soundings in the source files to compute a TPU-weighted mean depth for each node. (Note: the source must contain TPU values)

Basic Weighted Mean: Use the distance from the sounding to a node as the weight to compute the mean depth for each node

Shoalest Depth: Find the shoalest sounding near the node and assign the depth to the node.

Shoalest Depth True Position: Find the shoalest sounding near the node and assign the depth to the node. The original position of the sounding is retained as additional attributes on the node.

Pro: Best for creating depth areas and soundings selections, the best for nautical chart data workflows. Accepts LAS format, generalize features for contours, and very useful 3D and profiling visualization tools. CSAR designed to store grids and point cloud with billions of nodes, store multiple z attributes, and is multiresolution and scalable. CSAR is a portable file format for storage of terabytes of data. Shoal detection, volume computation, dredge analysis available and a Subset Editor tool to view bathymetric surfaces in 3D to identify and investigate problem areas.

Limitations: Long processing time for gridding surfaces, CSAR format only viewable in CARIS. TIN modeling has point limitations.

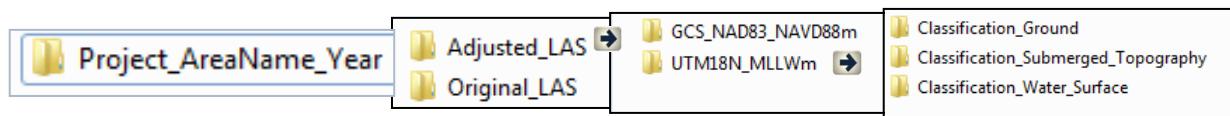
Organize & Visualize

Designed specifically for LIDAR, LAStools and LP360 are the most useful tools for viewing, converting, classifying, and tiling point cloud LIDAR data. Visualize data to help define areas of interest, subset grid size, evaluate extent and point spacing. Visualizing the point cloud is important for grasping actual survey coverage, as point cloud analysis has no interpolating. Viewing the point cloud is important for quality assurance, to view multiple points in the Z axis, and give the user an ability to view all points and vertical obstructions.

Note: While it is helpful to visualize data first, after visualizing, create metadata headers and calculate statistics to understand LIDAR attributes and then revisit the visualization of the data in the LP360 toolbar.

1. Organize

Create a folder systems to organize your outputs, whether they end up in a ArcGIS Geodatabase or in a folder structure, below is an example of a useful folder structure:



2. Visualize

a. If LAS files are Zipped (LAZ) use GUI LAStools laszip

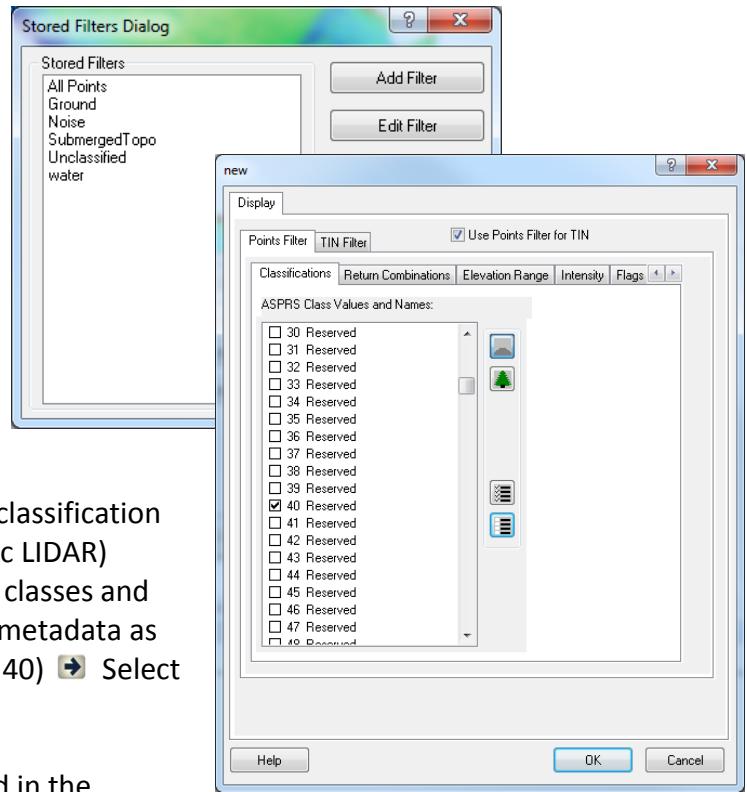
b. Use LP360 Toolbar in ArcGIS



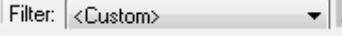
- i. Batch import raw LAS files through the import tool. Use the import button choose between folders and file import (if the files are broken into a large amount of subfolders this is the best tool for quickly importing and visualizing all las files in every subfolder).
- ii. Using the Display by elevation button toggle between different displays to highlight different features of your data. Some displays will not be applicable if the Lidar data does not contain those attributes, what attributes the data contains will be revealed through metadata and statistics in the next steps.

- iii. View each classification separately if the data is classification based. Using the filter dropdown on the toolbar  specify what classifications you would like to display  select the stored filter command.

- iv. Note: If there is no previously created metadata or the metadata does not specify classification; revisit this step after creating Lidar data headers to create accurate classification filters for your data. If metadata was created, classification information is located under Description  Abstract. Record the classes and the names of each class.



- v. Add filter  Name filter  Select a classification in your dataset (example Bathymetric LIDAR) In the display dialog  toggle off all classes and select only the class identified in the metadata as Bathymetric LIDAR (for this example 40)  Select okay and close stored filters dialog.
- vi. Repeat this for all classes represented in the metadata or edit filters to represent the appropriate class.

- vii. In the  use the drop down arrow to quickly view each class separately. Note: you can also create a custom filter to show multiple classes like water surface and submerged topography.

3. Inspect Data

- Next add imagery  from the same time period as the Lidar collection to your ArcMap, if not captured at the same time as the LIDAR as close to the date as possible, to QA/QC the point cloud and visually inspect the data.
- Also add in a NOAA nautical chart to visualize the point cloud and visually inspect the data.

Metadata & Statistics

http://www.asprs.org/a/society/committees/standards/asprs_las_format_v12.pdf

Las Format contains binary data consisting of

- Public header block (point numbers and coordinate bounds)
- variable length records (projection information, metadata)
- point data records (classification, returns, min max xyz)

1. LASTools - lasinfo

Note: After filtering data or transforming data run LASinfo after each step in the process to make sure your data is in the correct coordinate system and displaying the correct data or if the data is not loading in a program or displaying correctly run lasinfo to troubleshoot.

This tool will produce the header information shown below:

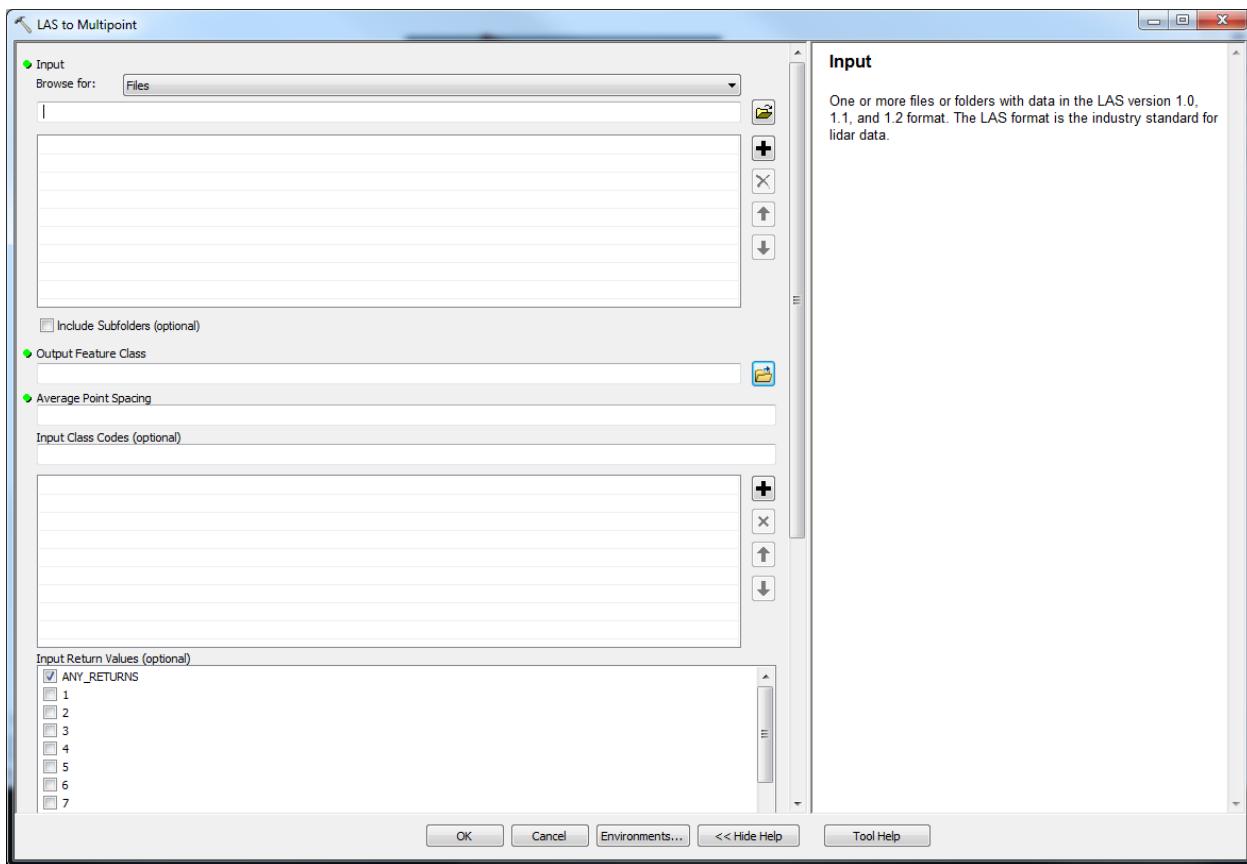
- File creation day/year
- header size
- offset to point data
- number of points
- number of points by return
- edge of flight line
- scan angle rank
- point source ID
- min xyz
- max xyz
- intensity
- return number
- number of returns
- scan direction flag
- classification
- gps time

2. Evaluate Point Spacing

- a. Use ArcGIS – Point Information Tool . This tool will give you point spacing, the average point spacing is the average distance separating sample points in the Lidar dataset. This will be used to determine cell size of your surface grid.

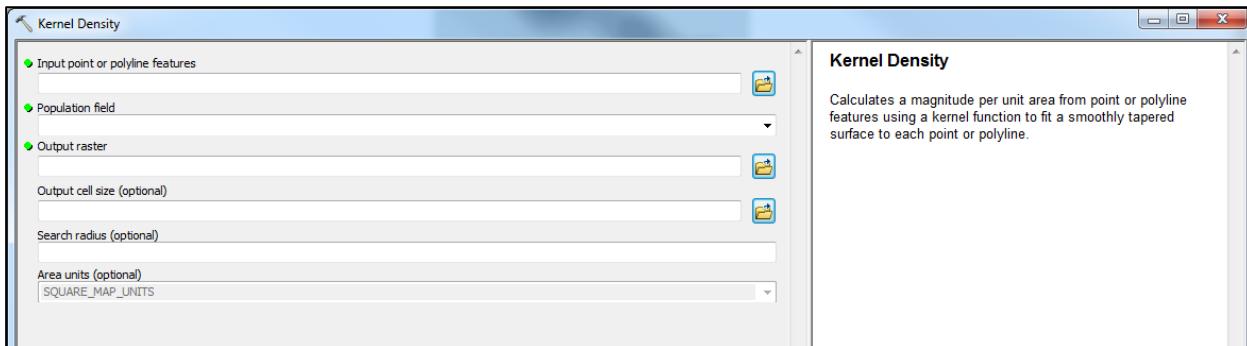
3. Evaluate Point Density

- a. Las to Multipoint tool
 - i. Add LAS Files ➔ Output Feature Class ➔ Enter Average point spacing (just calculated from the point to information tool) ➔ Select a single return, all returns, or single or multiple class codes ➔ Select OK



b. Kernel Density

- i. Input the Multipoint Feature → Enter population field as Shape Z → Enter 4x the average point spacing → Select out a single return, all returns, or single or multiple class codes → Select ok



4. Point Cloud Coverage Boundary File & No Data Boundary

Examine the point cloud coverage and create a boundary where only point coverage exist and create a boundary where no data exists. Breaklines and boundaries will be important when interpolating.

- a. LasTools – lasboundary tool exists which is the fastest way to extract a coverage boundary, however the lasboundary tool is not free.
- b. In ArcGIS you can manually digitize a boundary and breaklines if the dataset is not too large or complicated.
- c. If rasters were created use ArcMap  Raster to Polygon Tool or Raster Domain Tool to get a boundary file, this file may need to be simplified depending on the noise and outliers in the Lidar dataset.

Filtering & Subset

After viewing the Lidar metadata and statistics, knowing the number of returns and how many classes are in the dataset will help to decide which filtering still needs to be done. If there are multiple returns and classes, a classification based approach was used. If there is one class unclassified the data was already filtered to a certain extent.

Classification Based Approach

During the flight or afterwards the waveform is analyzed, all points are extracted, and each is assigned a classification, any filtering or editing will change classification on those points. Most vendors use TerraScan software with sophisticated algroithms to classify points into different classes.

Filter Based Approach

Experimental Advanced Airborne Research Lidar (EAARL) records the whole waveform during flight. Airborne Lidar Processing System (ALPS) is then used to process for a specific return; e.g. first surface, submegeed topography, and topography under vegetation. Only the point cloud for the specific return is provided. An automated filtering and manual editing is applied deleting noise and rejected points from the point cloud, instead of keeping all points and chaning classification only sginificant points are kept the rest deleted.

<http://coastal.er.usgs.gov/lsmr/tech/tech2-alps.html>

ALPS uses the following algorithms to differentiate between returns: the zero crossing of the second derivative is used to detect the first return and the trailing edge algorithm is used to detect the range to the last return; i.e., the algorithm searches for the location prior to the last return where direction changes along the trailing edge. In submerged environments, effects of refraction and change in speed of light as it enters the water column are accounted for in the “submerged topography” algorithm. The

exponential decay of the return signal through the water column is also determined based on the clarity of the water column. These corrections are performed by examining sample waveforms from spatially distributed locations in the survey area to define constants for exponential decay of the laser at the water surface and within the water column. A selection of constants is defined in ALPS for different water column and depth conditions: ranging from deep and clear water column to shallow and turbid water column. Data processed for submerged topography are referenced to an ellipsoid datum, which is independent of the elevation of the water surface (Nayegandhi and others, 2004).

Two Filtering methods within ALPS are used to extract ground (Bare-Earth) elevations from point cloud of processed last returns.

Random Consensus Filter is used in ALPs which applies semi automated statistical filtering methods to remove false bottom returns and other outliers from EAARL LIDAR data. The filter uses a grid of non-overlapping square cells of user-defined size overlaid onto the original point cloud. The user defines the grid cell size and vertical tolerance based on the topographic complexity and point sampling density of the data. The maximum allowable elevation range within a cell is established by the vertical tolerance. An iterative process searches for the maximum concentration of points within the vertical tolerance, and removes those points outside of the tolerance

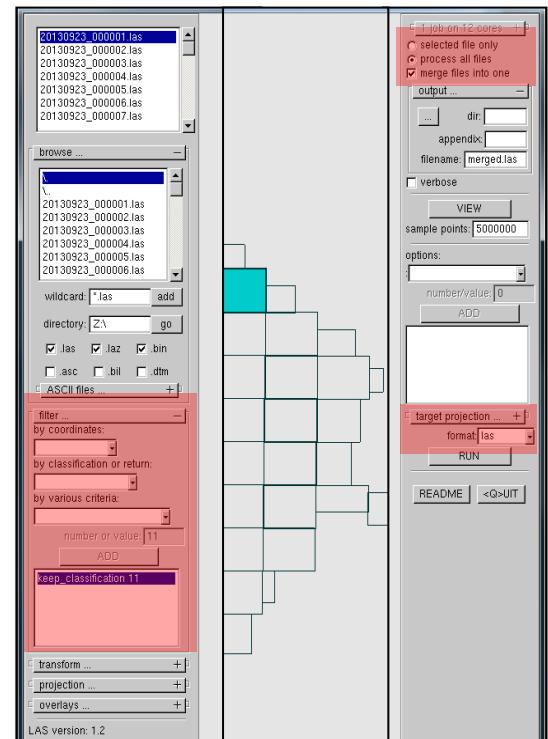
Iterative Random Consensus Filter (IRCF) The IRCF algorithm uses the RCF algorithm and a triangulated irregular network (TIN) model iteratively to progressively densify the output point cloud. The RCF paradigm is used to label the initial point cloud that represents the ground. All labeled ground points are triangulated using Delauney's Triangulation to create a TIN model. The points rejected from the first RANSAC iteration are treated as potential ground points. Each triangulated facet within the TIN model is defined as a three-dimensional plane, the equation of which is determined from the vertices of the triangulated facet. All potential ground points above or below each facet are classified as ground if they fall within the user-defined vertical range (also called the TIN vertical width) from the 3-D plane. The TIN model, created in the subsequent iteration with the new set of classified ground points, is further densified by adding all potential ground points within the vertical width for each triangulated facet. This process continues for a pre-defined number of iterations, or until less than 2% of potential ground points are added to the final population of ground points.

1. Filters

a. LAStools – las2las to Filter by Classification

(Extracts first/last returns, clips, reprojects, subsamples, translates, filters)

- i. Navigate to directory containing LAS files with full return point cloud.
- ii. Expand the filter tab on the left
Use the dropdown by classification or return → Select keep_classification → Enter a number or value of the classification to isolate and select add.



- iii. On the right side ➔ Choose to process all files individually or merge files into one output for a more manageable dataset ➔ Expand the output tab and navigate to directory for output and rename file
 - iv. On the right side column change format to LAS ➔ Select run
- c. LP360 Filters
 - I. Low/Isolated Points Filter(*Advanced license required*): used to find Low points and/or Isolated points.
 - II. Statistical Noise Point Filter (*Advanced license required*): used to find points that fit a "noise" criterion. These points are then moved to the specified Destination Class. The Statistical Noise Point Cloud Task is intended to be used for smoothing near-horizontal surfaces such as ground. It could be applied following ground classification where the resultant ground is "noisy" as a result of laser range precision ("noisy" range) or surface characteristics.
 - III. Basic Filter (*Standard license required*): classifies points based on definitions of basic point filters. Practical uses of this task include transferring or swapping points from one class to another.

2. Subset Data

Processing large amounts of data at one time is not recommended, processing times and storage increase significantly and usually lead to crashing programs. Tiling the data and subsetting data into more manageable files are better for QA/QC and processing times.

- a. LP360
Export Point Clouds by using a cook cutter polygon, some bugs were found in the program when trying to use this feature
- b. LAStools – lastile and lasclip
These are very good tools for filtering data however these tools are not free.
- c. LAStools – LasMerge
Is a good tool for creating more manageable files, after visualizing the data, break up files in groups or specific areas to be merged.

Transform

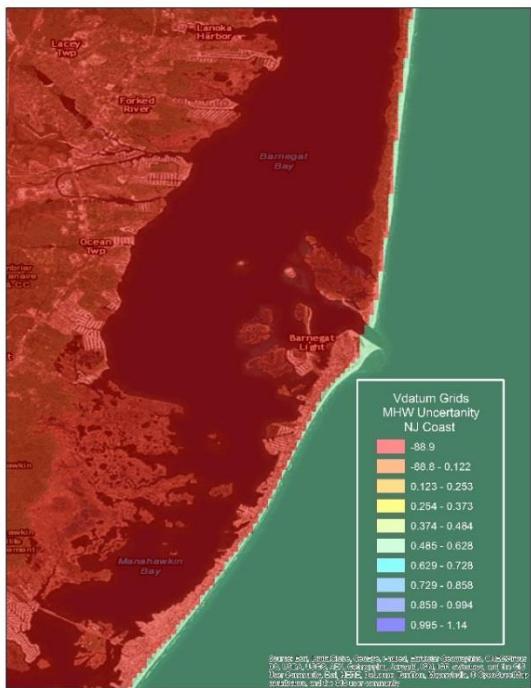
Download vdatum at <http://vdatum.noaa.gov/>

Create a consistent spatial reference for LAS files and the appropriate vertical datum dependent on the overall product. VDatum v3.3 only accepts ASPRS Lidar Data Exchange Format 1.0, 1.1, and 1.2.

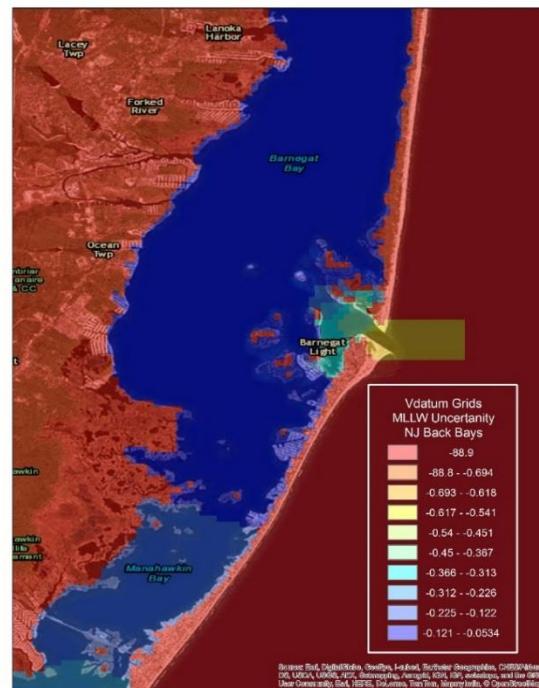
1. VDatum Boundaries

- a. Overlay LAS point cloud coverage boundary file with VDatum Boundaries
 - i. Within the VDatum folder is a list of VDatum regions using the MLLW Gridded data files (mllw.gtx) for the region of LIDAR data coverage.
 - ii. Add both .gtx file and the boundary shapefile to ArcMap ➔ Right click the color ramp of the mllw.gtx file in ArcMap and change the color ramp to a multicolored ramp to see the areas of VDatum coverage.

Coastal Barnegat Bay NJ

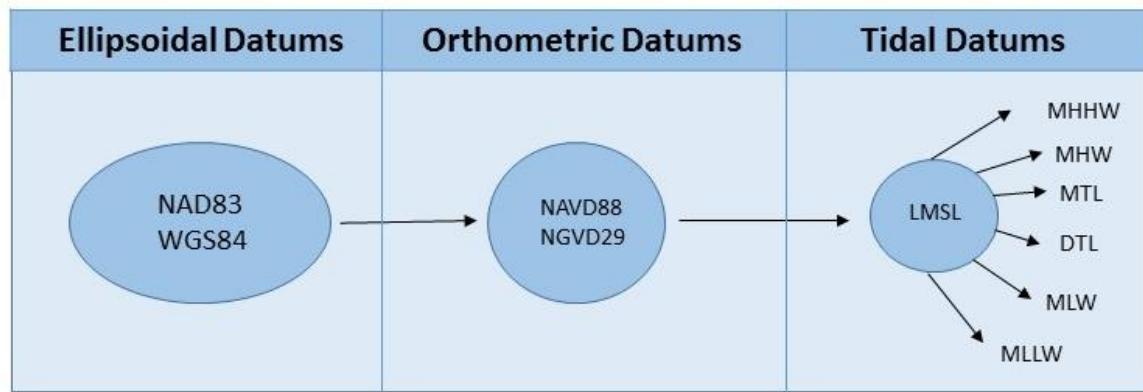


Back Bay Barnegat Bay NJ

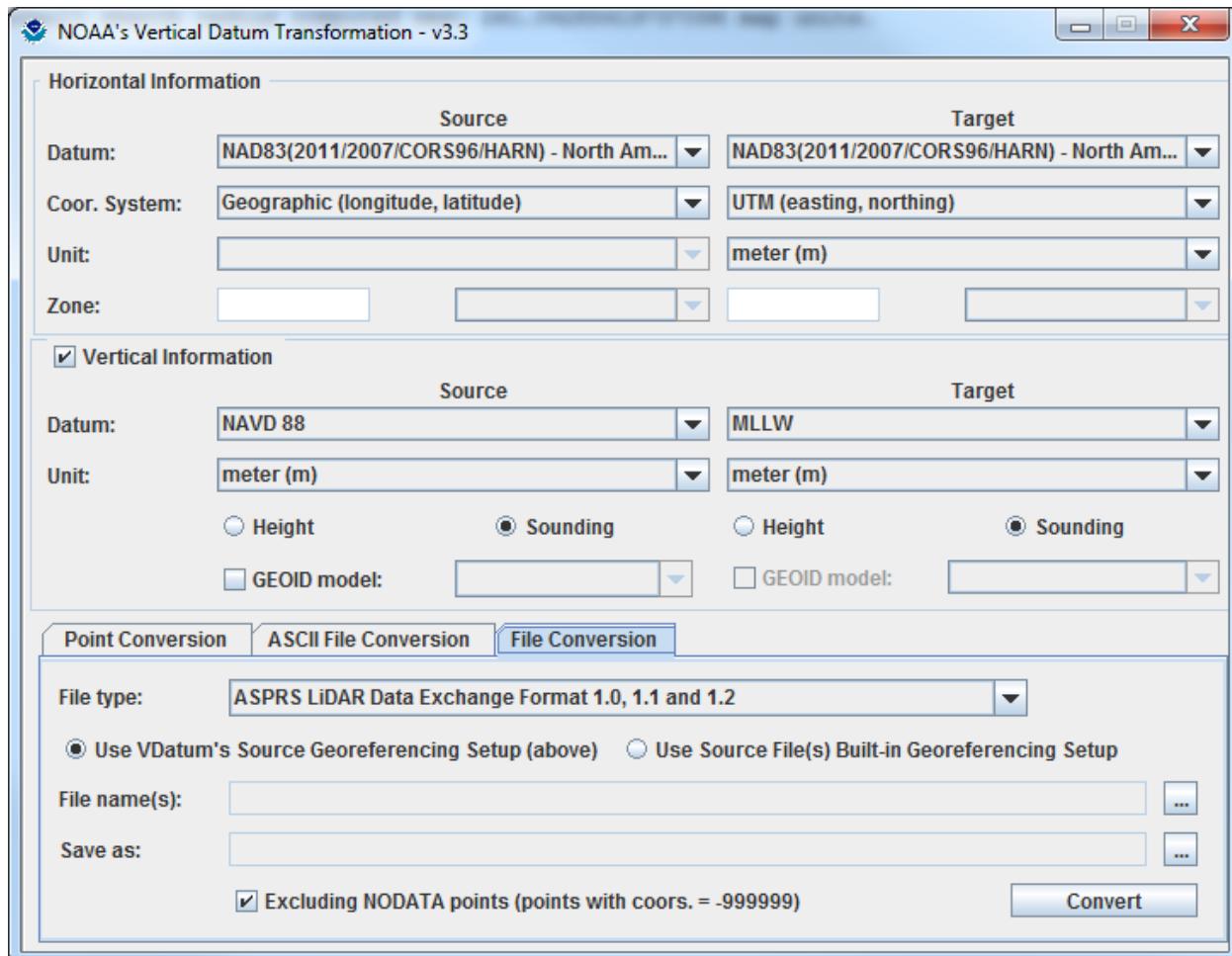


Note: Areas in red have no coverage.

2. NOAA's Vertical Datum Transformation v3.3 - VDatum Windows Batch File



- a. Add files → Input horizontal information → Input vertical Information → Select excluding no data points to remove any soundings that are not located within the VDatum transformation grid → Convert.



Gridding & Surface Analysis

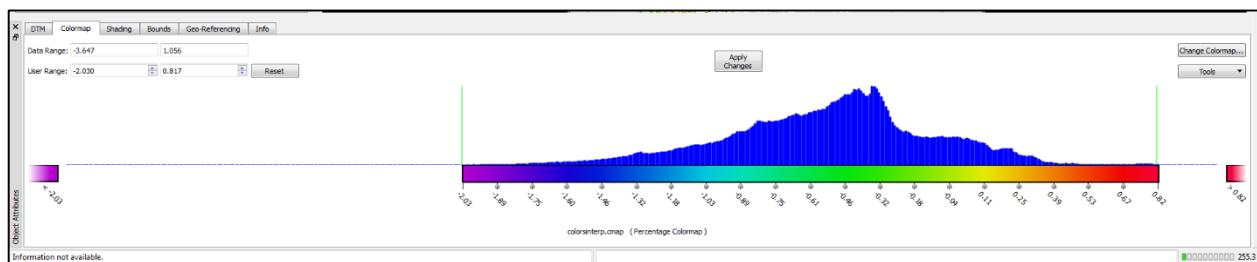
1. Fledermaus DMagic

a. Open DMagic

- i. File ➔ Create Project ➔ Set Horizontal Coordinate System
- ii. File ➔ Add Source Data ➔ Ungridded Data ➔ Add LAS Files ➔ Set Horizontal Coordinate System ➔ Finish
- iii. After Scanning ➔ Right click the las files ➔ Grid ungridded files ➔ Cell size = Point spacing ➔ Weighted moving Average = 3 ➔ Save SD ➔ Finish

<u>Weight diameter</u>	<u>Weight field size</u>
0.5	1
1.0	1
1.6	3
2.5	3
3.0	3
3.1	5
4.4	5

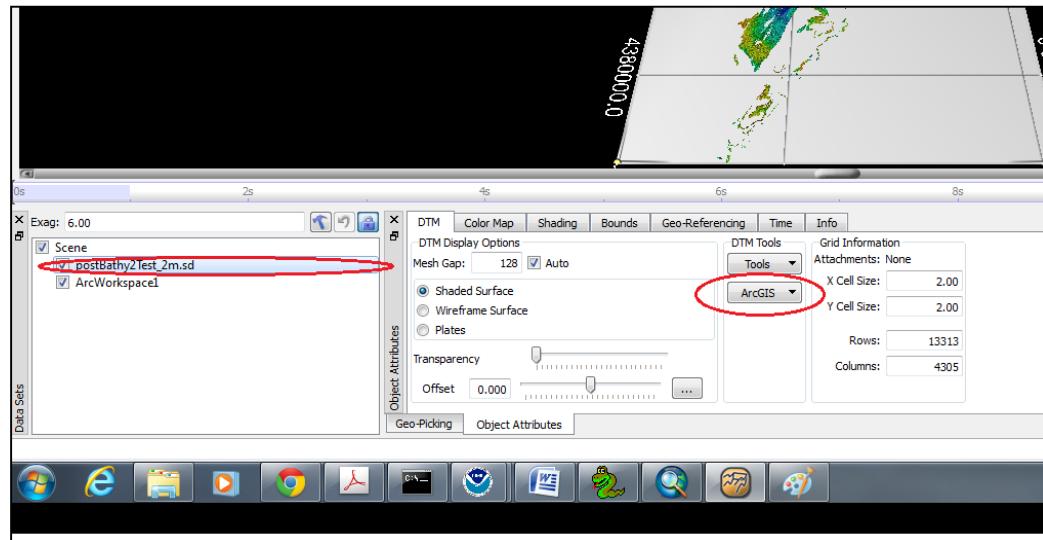
- iv. In the Colormap tab ➔ Change colormap for desired color ramp ➔ With left and right clicks on the mouse change data range to match depth ranges and better represent the data visually.



- v. Right click the SD file and Launch Fledermaus

b. Export DEM

- i. To export a DEM to ArcGIS you must be using 32bit version of DMagic.
- ii. After the SD is gridded under create ➔ Add ArcGIS Workspace ➔ Navigate to your GIS workspace Folder or Geodatabase ➔ Connect



- iii. Under the DTM Tab ➔ Dropdown menu for ArcGIS ➔ Transfer to Bathy Raster ➔ Click on the ArcWorkspace ➔ Finish

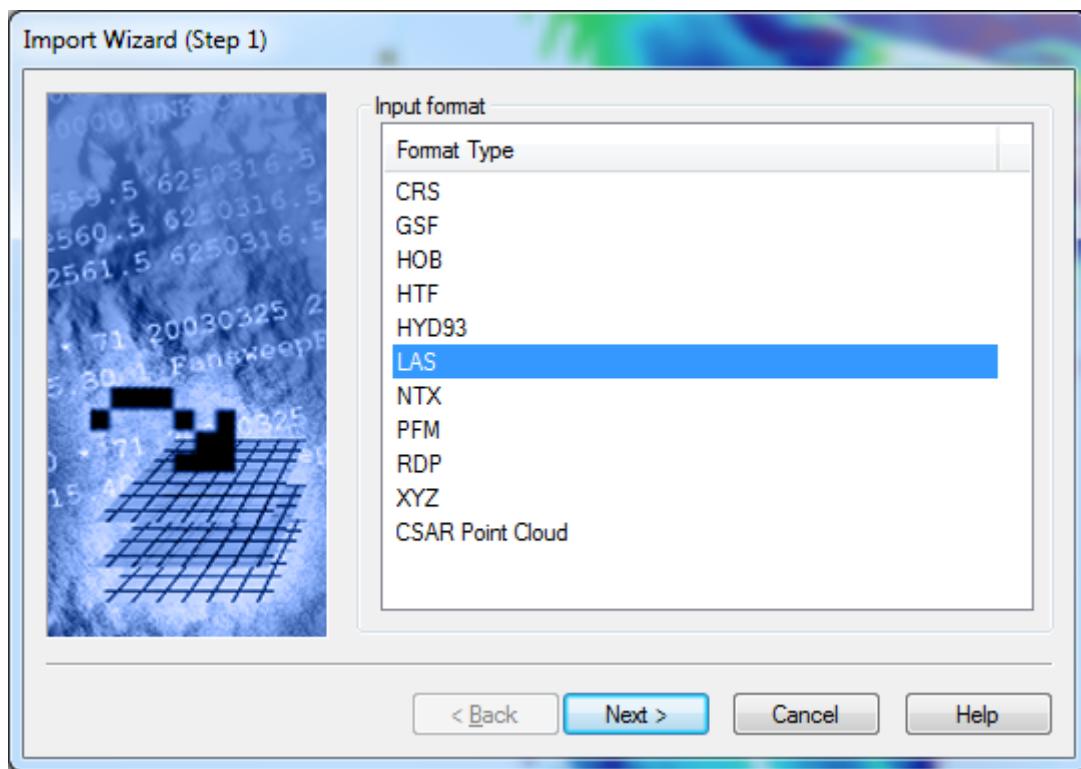
c. Surface Analysis

- i. Contouring Tool
- ii. Surface Difference Function - The volume is computed by summing the volumes of each individual cell in the resulting difference. The volume of each cell is computed by multiplying the height of that cell times the flat area of each cell. The flat area is simply horizontal cell size times the vertical cell size.

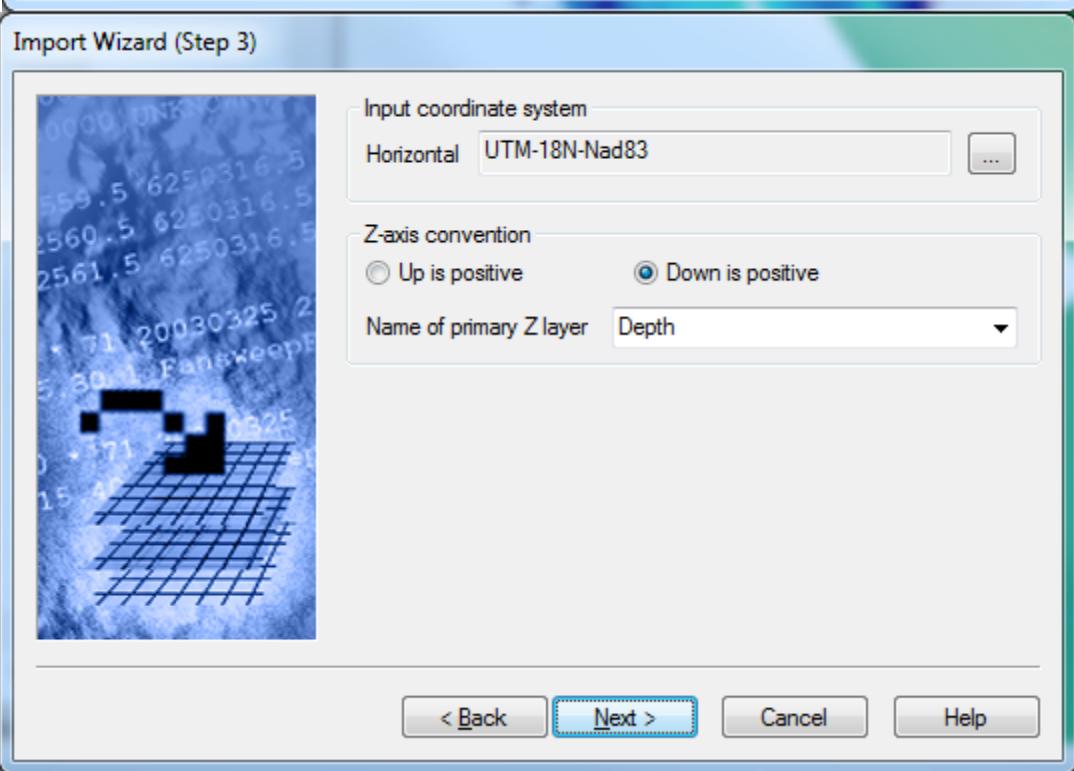
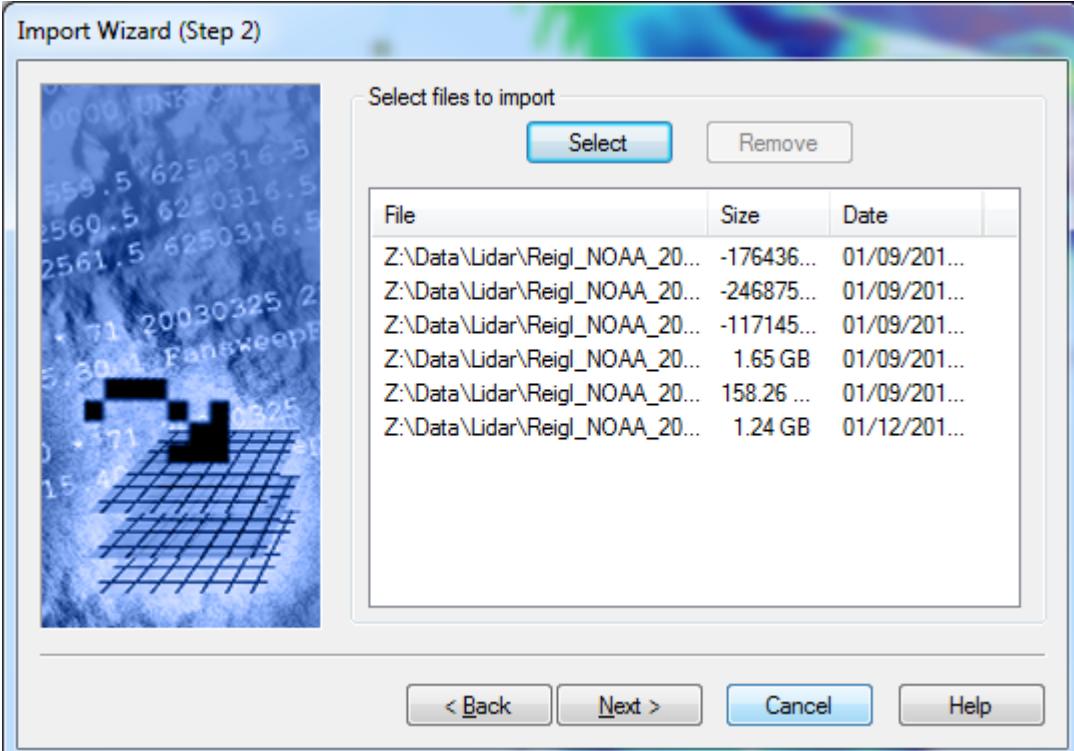
2. Bathy DataBASE Editor

a. Open Base Editor

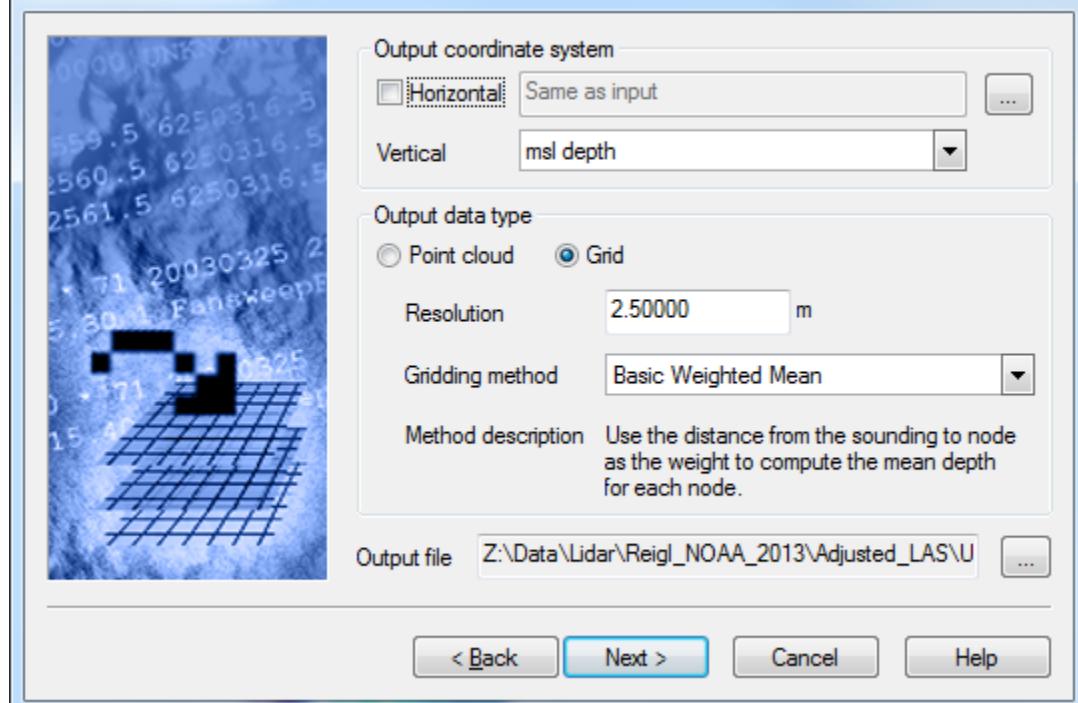
- i. Click on import wizard  Select LAS files



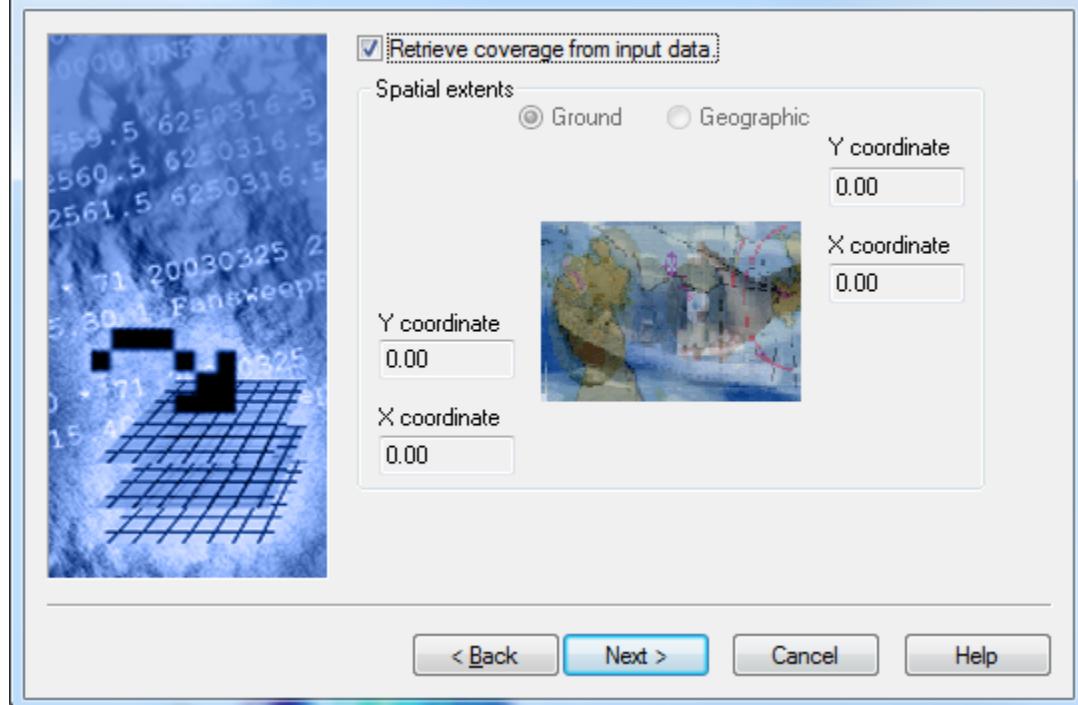
- ii. Run through the steps in the import wizard.



Import Wizard (Step 4)



Import Wizard (Step 5)



- b. Export formats
 - i. Bathymetry attribute grid (BAG)
 - ii. Bathymetric with Associated Statistical Error (BASE) – Surface is gridded data stored in CSAR format, additional attributes such as depth and Uncertainty are stored at each node.
 - iii. Sounding Set is un- gridded data points in the CSAR format, with additional attributes stored at each point.
- c. Surface Analysis
 - iii. Contour at multiple chart scales
 - iv. Surface Difference Function
 - v. Surface generalization Function

References:

http://www.asprs.org/a/society/committees/standards/asprs_las_format_v12.pdf

<http://rapidlasso.com/>

<https://confluence.qps.nl/display/KBE/Details+of+the+Weighted+Moving+Ave>
[Algorithm+used+in+Fledermaus+and+DMagic+v7](#)

<http://coastal.er.usgs.gov/lsmr/tech/tech2-alps.html>

<http://vdatum.noaa.gov/>

Caris Base Editor Reference Guide

LP360 Help Guide