

Case Study: Mapping Half Moon Caye's Reef Using the Adaptive Bathymetric System (ABS)

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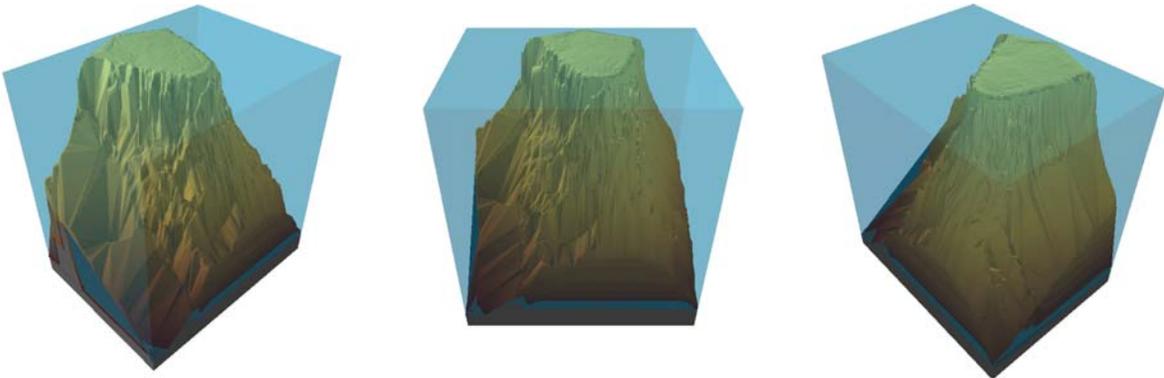
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Foreword: What is ABS and what can it do for me?

The Adaptive Bathymetric System (ABS) is designed to provide a simple, inexpensive system to map the small yet significant features of the ocean's bottom in three dimensions. With only a few days of fieldwork and limited investment of time, effort and post-processing, ABS offers the user an accurate 3-dimensional base map of reef areas. These maps may help tie the spawning patterns of different species to specific topographic features of the reef. The ABS 3-D maps allow us to investigate this relationship at multiple sites and compare among them. These maps will also help us develop understanding of changes in the distribution of target species over various reef features at different times of day and throughout the spawning season.

Since ABS is adaptive, users can add more geographic area or increased detail onto the map as time and resources become available. Initial surveys have proven extremely valuable in helping researchers, fishers, community members, decision-makers and donors to visualize reef promontories that harbor multi-species reef fish spawning aggregations. These maps can be updated with species abundance data to clearly illustrate the times and locations of various reef fish aggregations. We are only just beginning to realize the potential utility of this tool. This document offers a case study, which also serves as a step-by-step instruction guide for new users. The authors encourage new users to try the system and to provide feedback to us so that we can revise and clarify issues in subsequent revisions of this document, or of operations manuals that we may develop.

ABS is a new coral reef mapping technique¹ that is designed to rapidly create a 3-D model of a coral reef at a low cost. It is adaptive because the space between the lines of the survey grid varies based on a series of factors ranging from the predicted shape of the reef to the equipment used to record depth. This causes the survey grid to look different for each survey in contrast to traditional survey grids that consist of equally spaced lines. This results in shorter navigation times and costs. ABS consists of a three-step process:

1. Adapting a survey grid to various conditions (e.g. reef shape, equipment)
2. Conducting a field survey using an inexpensive fish finder
3. Manipulating the survey data to construct a digital elevation model of the reef

Most marine practitioners should focus on the second step of collecting data because this cannot be done remotely and partner with a GIS engineer to create the adaptive grids and 3D models.

As an example, the following chapters describe how the authors created a 3-D model of the Half Moon Caye reef in Belize in three days and at a cost of less than \$3,000. The reef is a site of multi-species fish spawning aggregation (FSA). Mapping what the reef looks like underwater helps to increase understanding of the FSA.

Figure 1 shows a diagram of the ABS process:

¹ The physics behind ABS are described in Adaptive Bathymetric System, Ecochard et al. (2003)

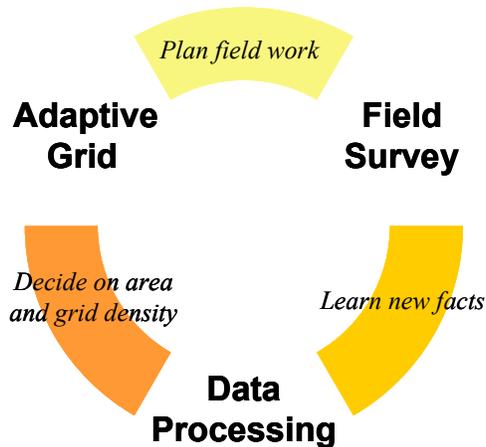


Figure 1 - The Adaptive Bathymetric System

The field survey was conducted from September 5th, 2003 to September 8th, 2003. Prior to this, the team had already conducted site visits and prepared an adaptive grid. The team used the following equipment and tools to create the 3D model of the reef:

Fish finder: Lowrance Electronics model LCX-15 MT² (~US\$1,000) with integrated GPS and MapCreate software

Transducer: Airmar TM260 50kHz (19° cone) 200Khz (6° cone) 1KW

Spreadsheet software: Microsoft Excel

GIS software: ESRI ArcView 8.3 and 3DAnalyst extension

Note that all the reef models are shown with the vertical axis measured in feet and the horizontal axis in meters. This creates visual exaggeration of heights that are useful for presentation. Geographically correct models are shown in Appendix C.

1 Preparing the Adaptive Grid

The ABS process starts with the preparation of a variable survey grid. This preparation consists of drawing a model of the reef, learning the limits of the fish finder and adapting the survey grid to the predicted depth and the limitations of the fish finder. This first step should take a GIS analyst less than half a day to prepare. All the maps refer to the Half Moon Caye reef where ABS was tested.

1.1 Drawing the Site Model

This consists of drawing a bird's eye view of the general shape of the reef with 'best-guess' depth curves using a LandsatTM satellite image (#7 in Figure 2).

² Lowrance offers a free emulator of the LCX-15 MT that runs on a PC available at <http://www.lowrance.com/Software/PCSoftware/demos.asp>

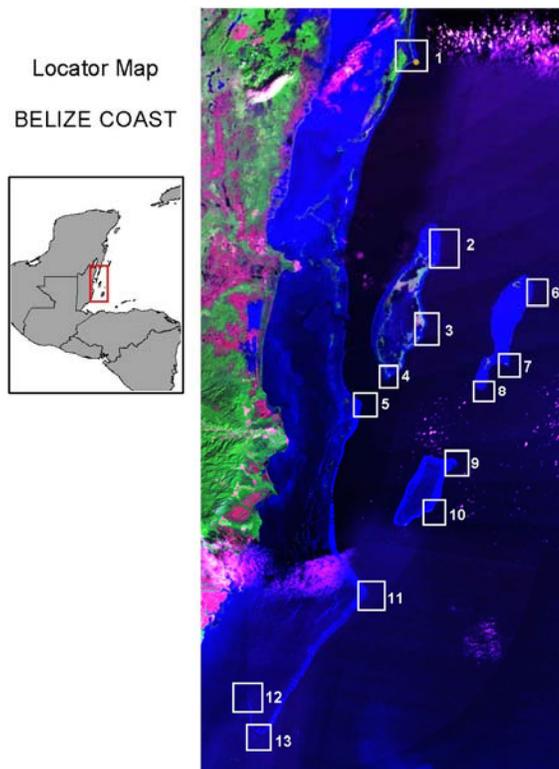


Figure 2 - Locator Map of the Belize Coast (Tim Boucher, The Nature Conservancy)

Building the Site Model includes locating the site on a map, drawing its shape, predicting depth curves and identifying the FSA location.

1.1.1 Locating the site

The Landsat™ satellite image of the reef in Figure 2 is referenced with latitude and longitude using the Universal Transverse Mercator (UTM) Zone 16N coordinate system. The location of the FSA was identified during past visits and depth transects recorded with a fish finder. This information will be used to start to draw the Site Model.

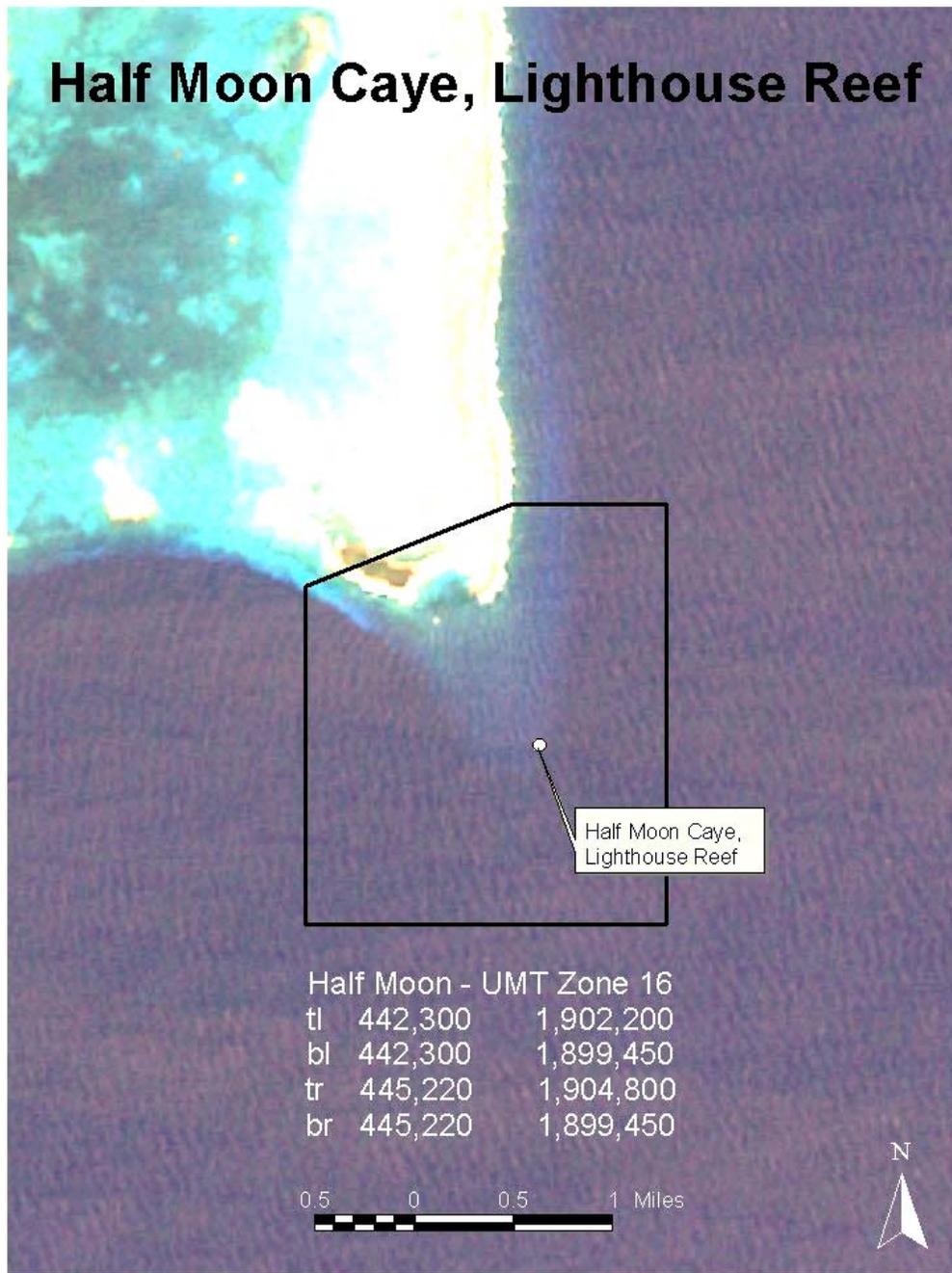


Figure 3 – Landsat™ Satellite Image of Half Moon Caye Reef (Tim Boucher, The Nature Conservancy)

1.1.2 Drawing the site shape

Drawing the site shape is not a precise task. The reef ridge is traced over the satellite image using the team’s “best guess” estimates.

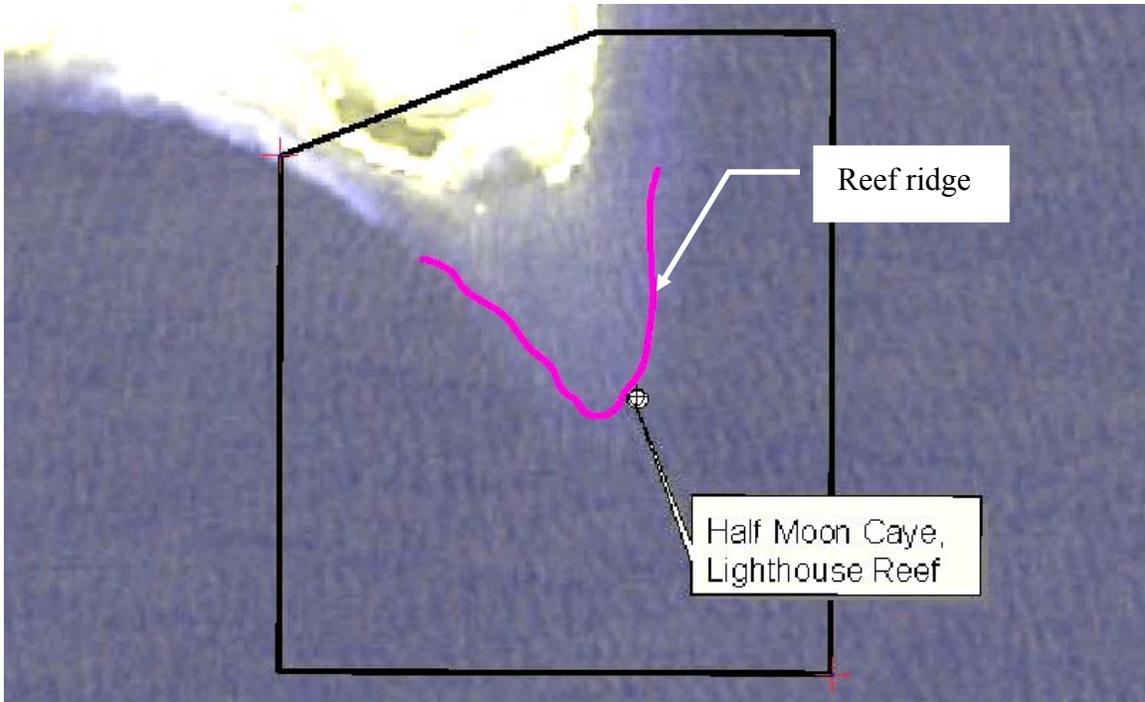


Figure 4 - Drawing the reef shape

1.1.3 Drawing predicted depth contours

A fish finder was used in 2002 to get depth samples along the top and East wall of the reef where fish spawning aggregation occurs. A 3D model of that information gives a gross idea of the reef shape.

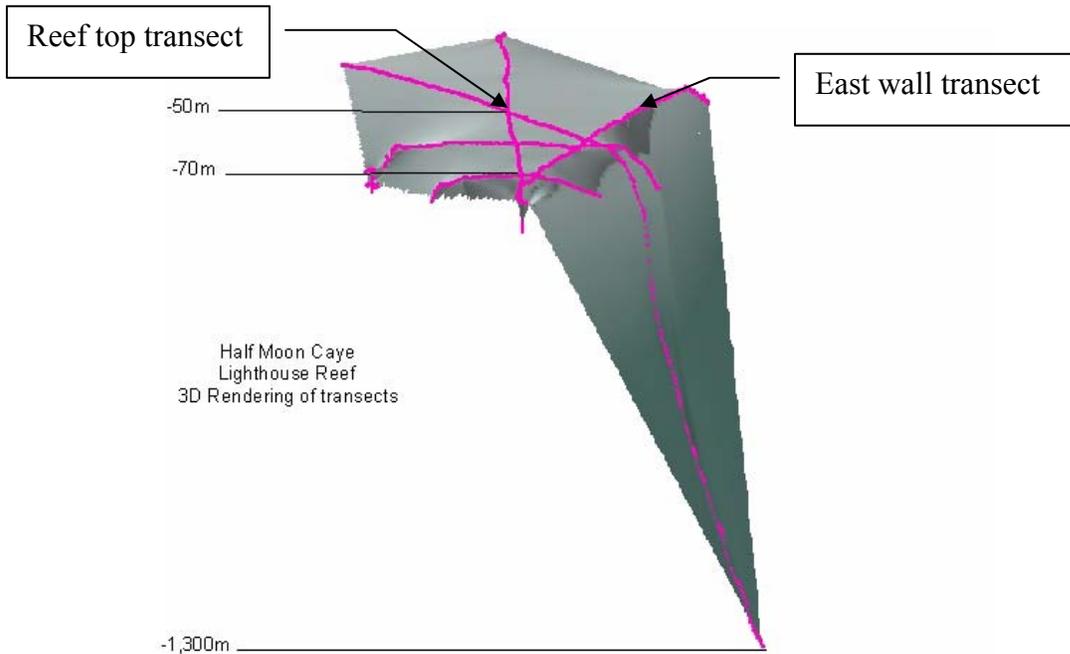


Figure 5 - A few transects can provide great insight on depth

The contours traced on a map show that the reef plateau is at about 30ft deep and slopes down to 75ft at the tip of the reef where it drops quickly to more than 1,300ft. This information helps estimate major contour lines as shown in Figure 7.

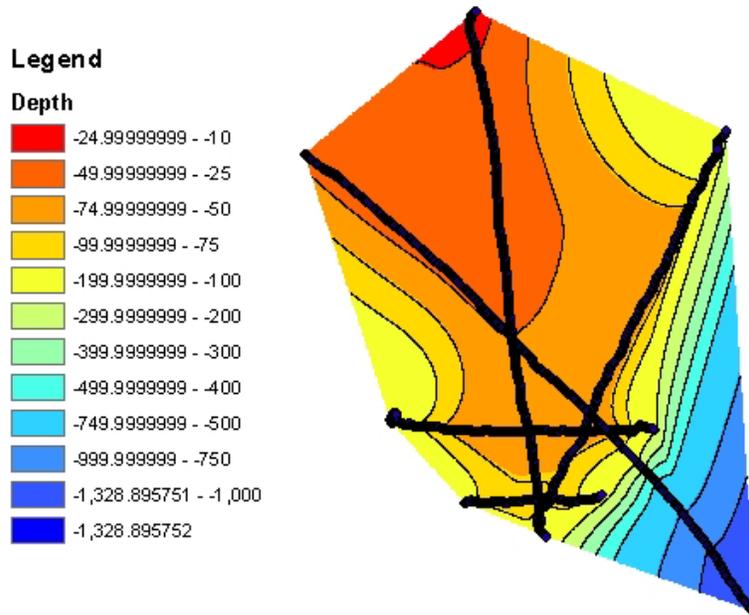


Figure 6 - Depth contour lines

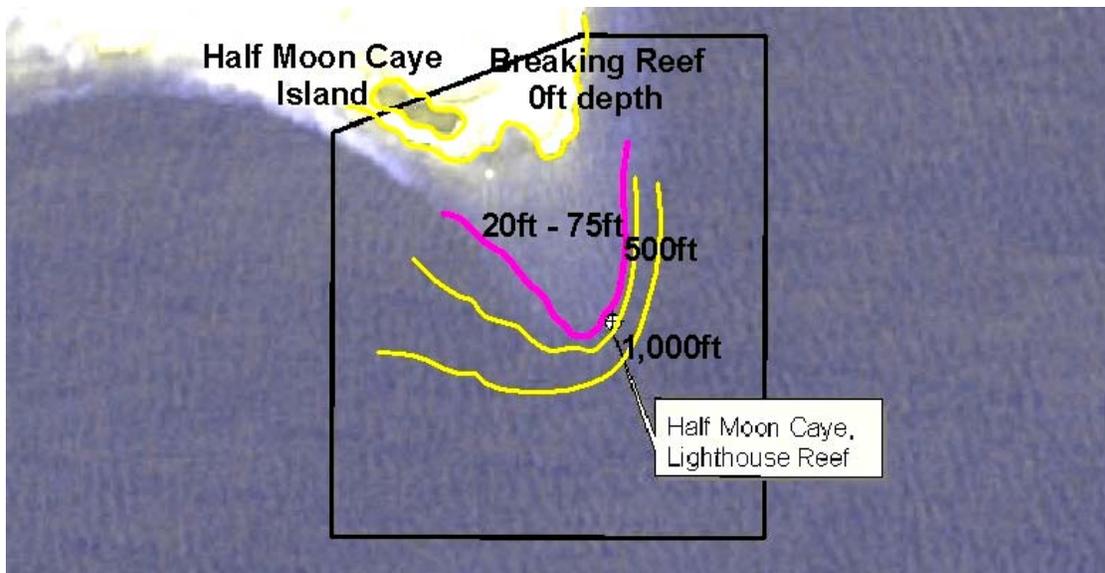


Figure 7 - Drawing the significant contour lines

1.1.4 Drawing the area of interest

The purpose of this survey is to gain a deeper understanding of the shape of the reef where fish spawning aggregation (FSA) has been observed, at the Eastern tip of the reef. The FSA area is identified with a hash pattern in Figure 8.

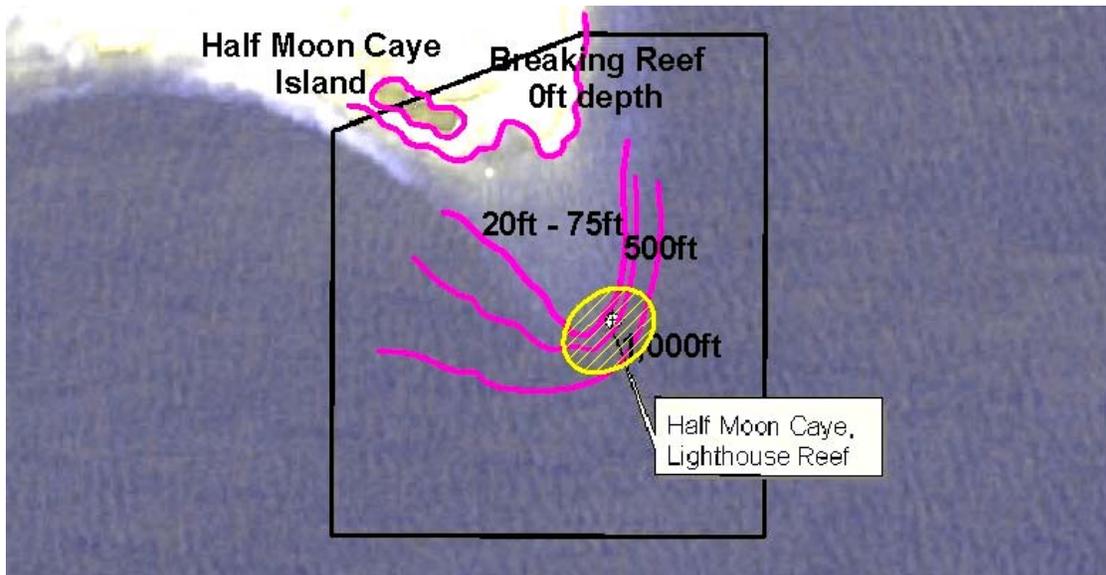


Figure 8 - Drawing the Fish Spawning Aggregation area

1.2 Learning Equipment Limits

The fish finder comes with a dual frequency 750Watts transducer. The 200 kHz transducer can penetrate depth up to about 100m and the 50 kHz transducer has a limit of about 300-600m. This is inadequate for the deepest parts of the reef that are expected to be around 1,000m deep; consequently the standard transducer has been replaced with a more powerful one from Airmar. This third party transceiver is twice as precise in the horizontal plane and can sample seafloor as deep as 1,800m.



1.3 Drawing the Grid

There is a simple rule to decide how far apart the survey lines should be: set the grid spacing to at half the size of the minimum seabed variation that needs to be recorded. The mathematical explanation for that division by 2 is in described in the ABS theory document.

The process of drawing the adaptive grid consists of setting the base grid size to half the size of the feature we want to record then adapting that grid to the equipment used, to the terrain features, to the areas of interest and to the availability of resources.

1.4 Setting the minimum base grid size

The team has decided to sample seabed slope variations that occur over at least 100 meters in length so the initial grid size is set at 50 meters (half of 100m). The grid starts at latitude 443500 and longitude 1901750 (UTM coordinates) and expands 25 lines East and 25 lines South as shown in Figure 9. At this stage the grid is identical to the one that would be used for a standard hydrographic survey.

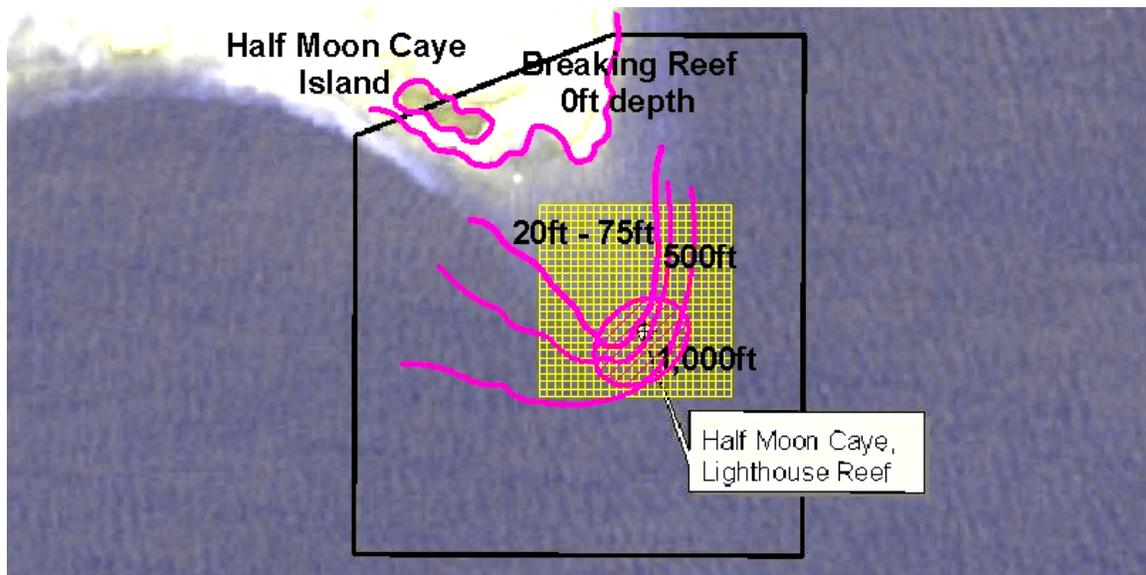


Figure 9 - Drawing the minimum base grid

1.4.1 Adapting the grid to the equipment

The grid is adjusted for the transducer capabilities. At 1,000m the transducer will record the shallowest seafloor feature in a circle of 167m radius (see table in Appendix A). At 500m it has a coverage radius of 84m. It is thus a waste to sample every 50 meters in these areas. In Figure 10 the grid is set to 150m (close to half the diameter of the transducer at 1000m) in the areas where the depth is expected to be 1,000m and to 100m in the 500m depth area. There is no need to adjust the grid GPS as it has an accuracy of 10m. Figure 10 shows the new 150m (thick yellow) and 100m (thin yellow) grid lines.



Figure 10 - Adapting the grid to the limits of the fish finder

1.4.2 Adapting the grid to the terrain features

The top of the coral reef is expected to be flat with little morphological variations. It can thus be sampled with a 400m resolution using a 200m grid (half of 400m as shown in Figure 11) without substantially distorting its features.

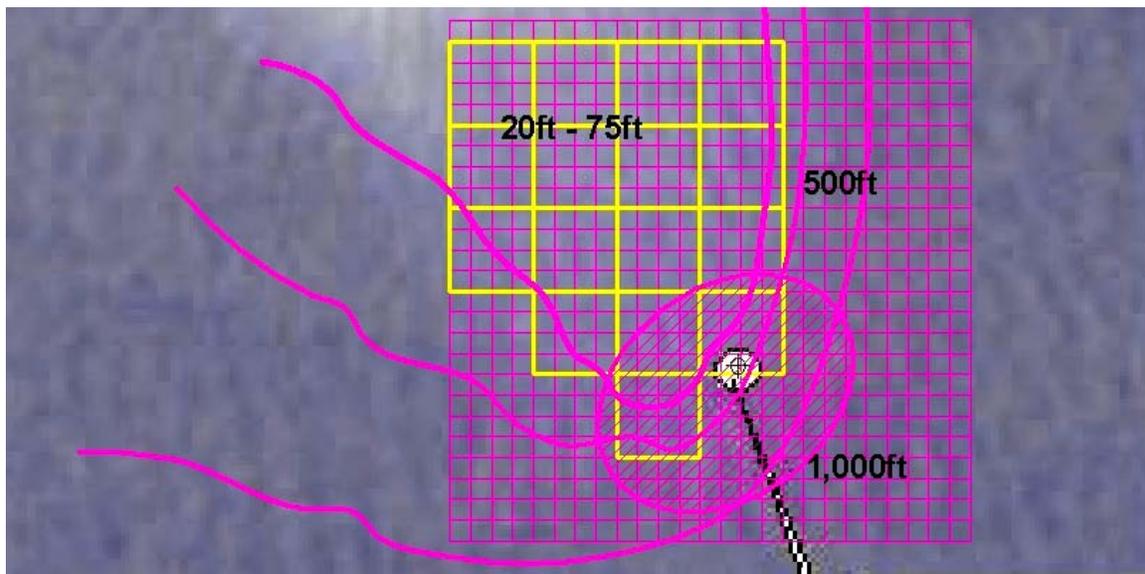


Figure 11 - Adapting the grid to the terrain feature

1.4.3 Adapting the grid to the area of interest

Scientists believe that there is a correlation between reef morphology and FSA activity and need more detailed information around the FSA area. The minimum 100m resolution (50m grid) is kept over the FSA area.

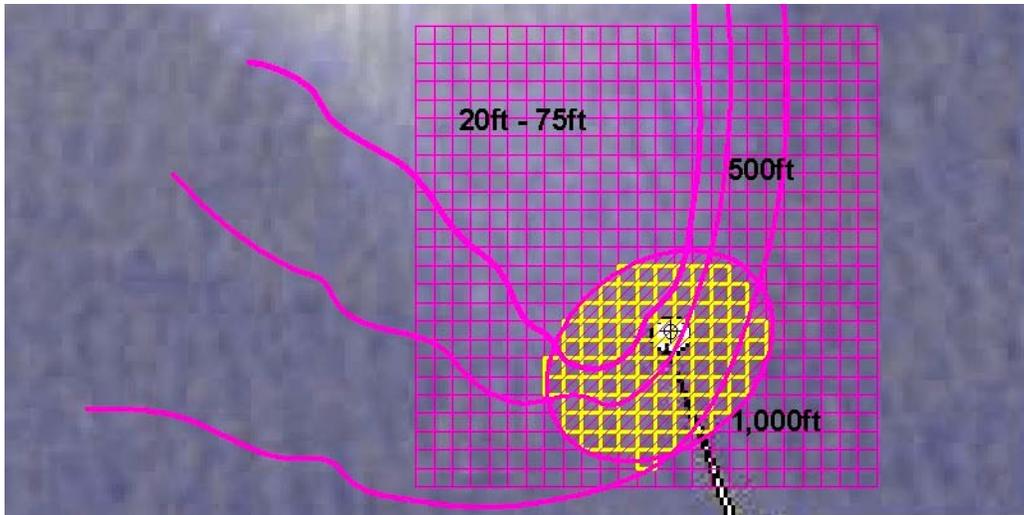


Figure 12 - Keeping a high resolution grid on the FSA site

1.4.4 Adapting the grid to the resources available

The budget of the project is limited. Most of the survey costs are tied up in fuel and field time. The plan is to conduct daily dawn-to-dusk surveys for 3 days from a camping base on an island near the reef. A 100m grid is used to cover the rest of the reef to accommodate these budget restrictions.

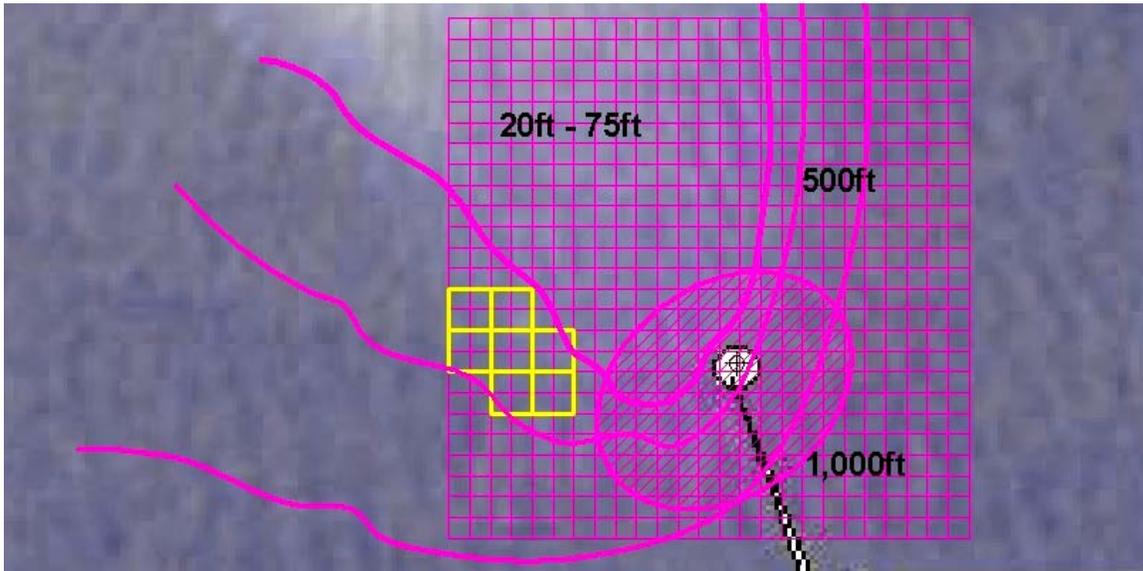


Figure 13 - Completing the grid based on resources available

1.4.5 Finalizing the adaptive grid

Figure 14 shows the adaptive grid. To simplify navigation, survey lines must be connected and grid cells closed (i.e. make sure they have 4 sides) (Figure 15).

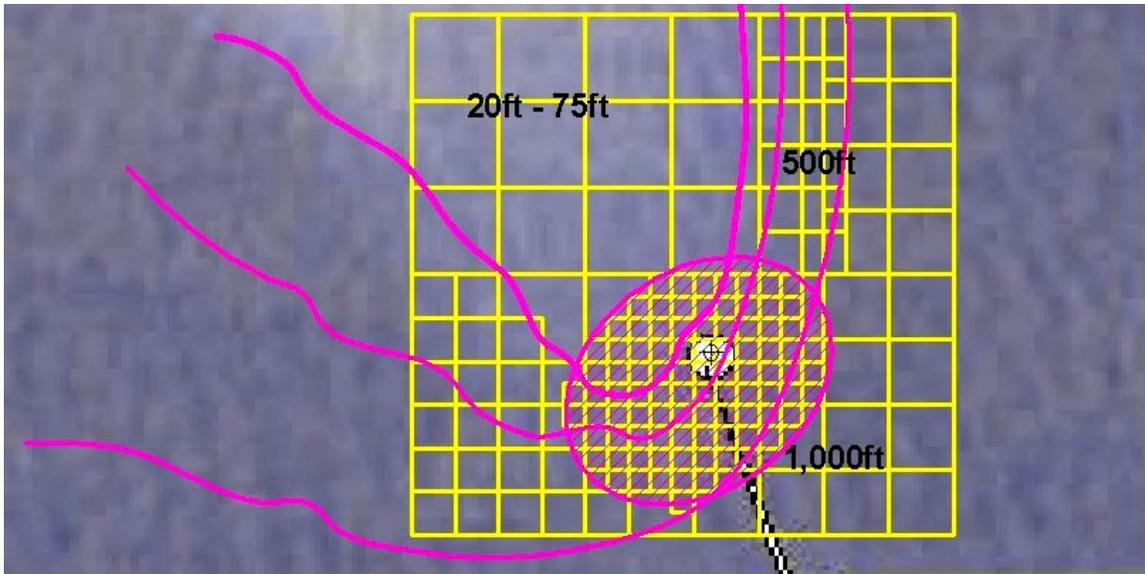


Figure 14 - Combining previous grid adaptations into one

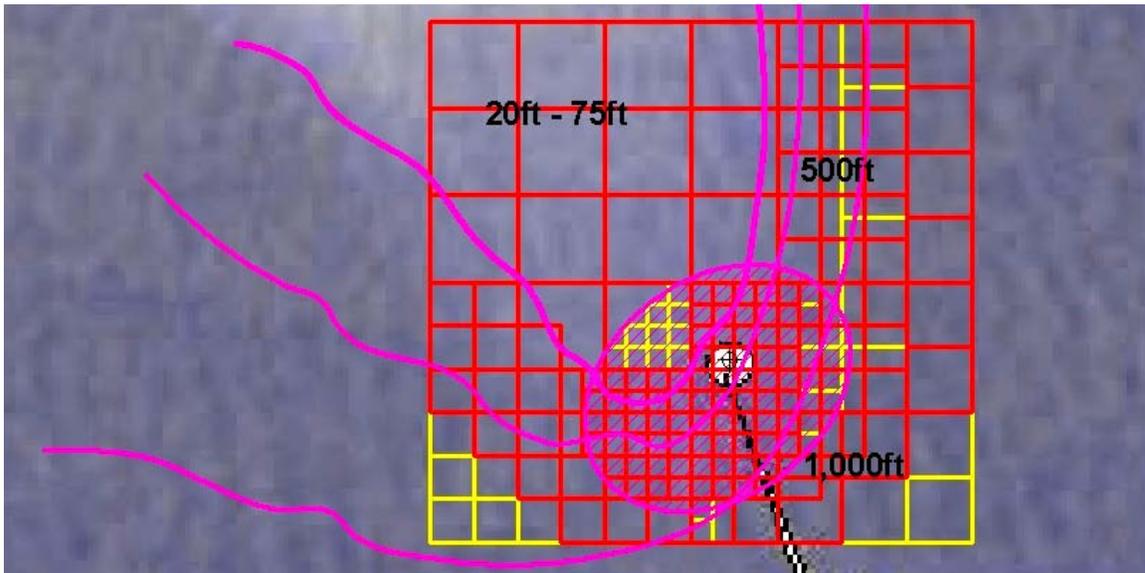


Figure 15 - Showing cleanup areas in yellow

Figure 16 shows the final adaptive grid for the site and how it differs from a traditional 50m grid. The adaptive grid is 59% less in length than the traditional grid and thus will be faster to navigate and cost less in fuel because the navigation route is shorter.

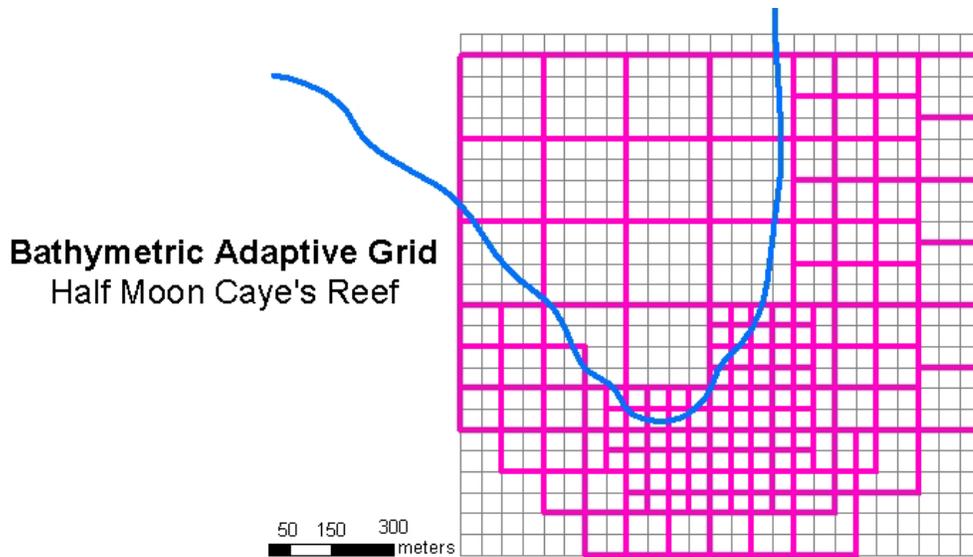


Figure 16 - Comparison of the ABS grid to a traditional 50m survey grid

2 Conducting a Field Survey

Conducting a field survey is the second step of the ABS process. Care must be taken to do that safely so planning is important.

2.1 Planning

Planning involves:

- Coordinating schedules and resources
- Securing a captain with a steady hand to navigate the grid straight
- Testing the equipment
- Checking the weather
- Packing the essentials (boat, fuel, supplies, generator, navigation map, etc.)

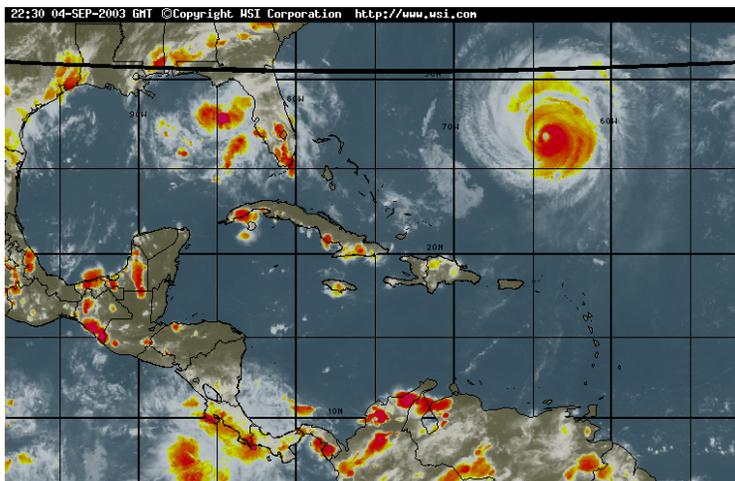


Figure 17 - Preparing to leave Belize City with equipment, food and good weather

Survey Tracks for Half Moon Caye Lighthouse Reef

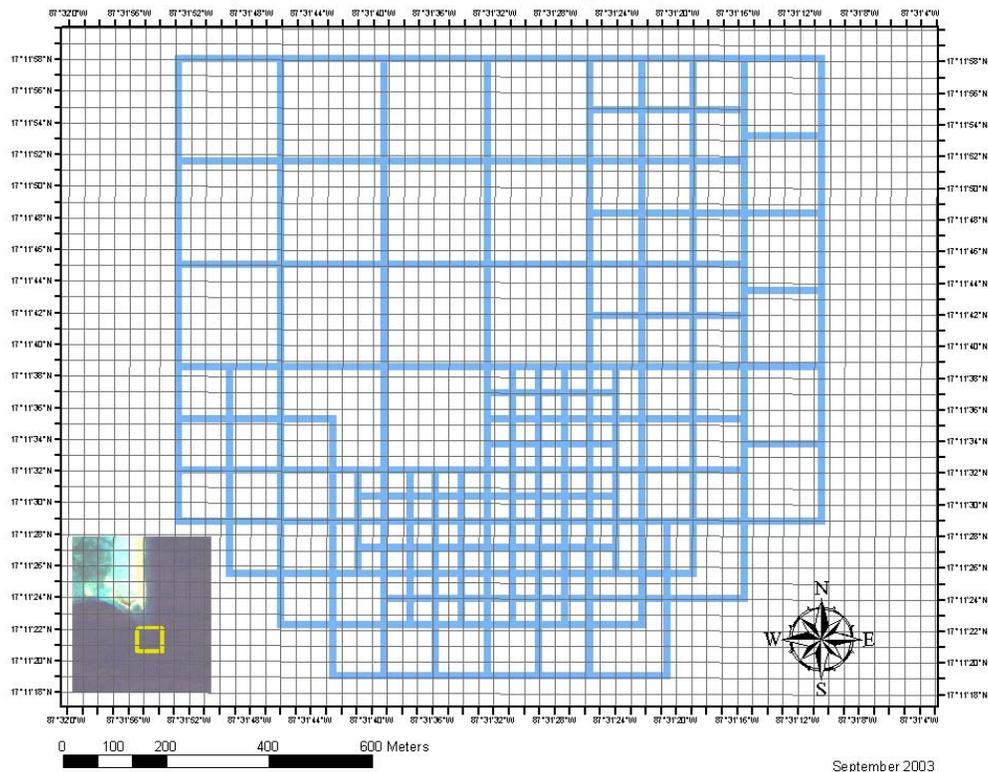


Figure 18 – Navigation map with survey tracks

2.2 Configuring the fish finder for bathymetric work

This section explains how to configure the fish finder for bathymetric work. Training should be conducted ahead of time with a free fish finder emulator running on a PC because it is easier to learn on land than in a tight rocking boat. This emulator is available at no cost from the Lowrance web site (www.lowrance.com).

2.2.1 Loading Data Points from Map Create

To facilitate navigation, some of the grid points can be loaded into the fish finder using the MapCreate software. This is done by typing the point's coordinates into a text file using Microsoft Window's Notepad and importing them as GPS points. The resulting file is exported as a .USR file, transferred onto a memory chip card and loaded in the fish finder. The fish finder user's manual explains how to perform this process in more detail.

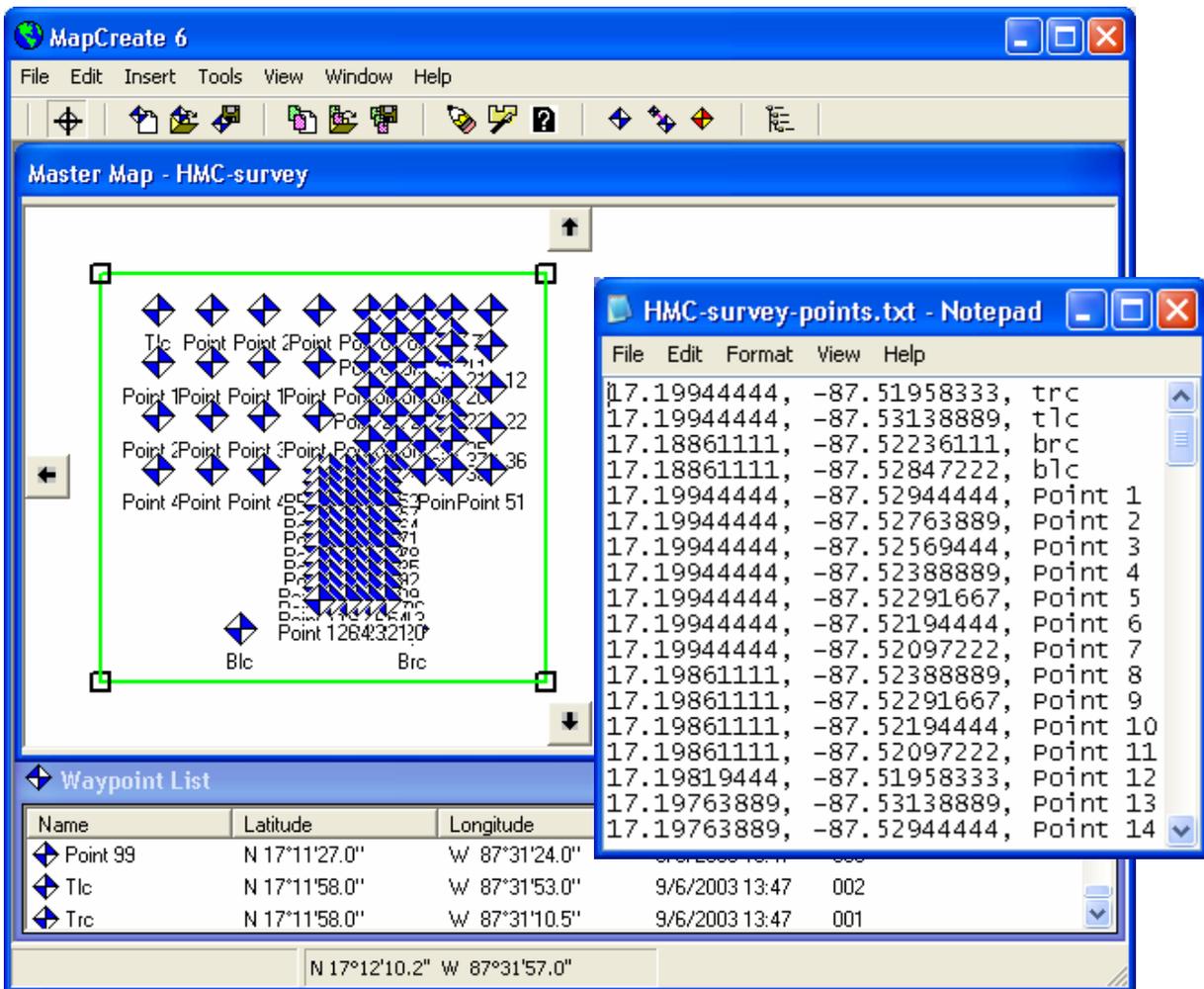


Figure 19 - MapCreate software and Notepad used to load grid points

2.2.2 Setting the Fish Finder Features

The fish finder is set in “chart manual mode” (Sonar Features menu) to disable the digital signal processing because it causes the fish finder to lose the bottom when there are large depth variations such as when going over a reef’s ridge. With the digital signal processing turned off the fish finder records the actual depth without interpretation.

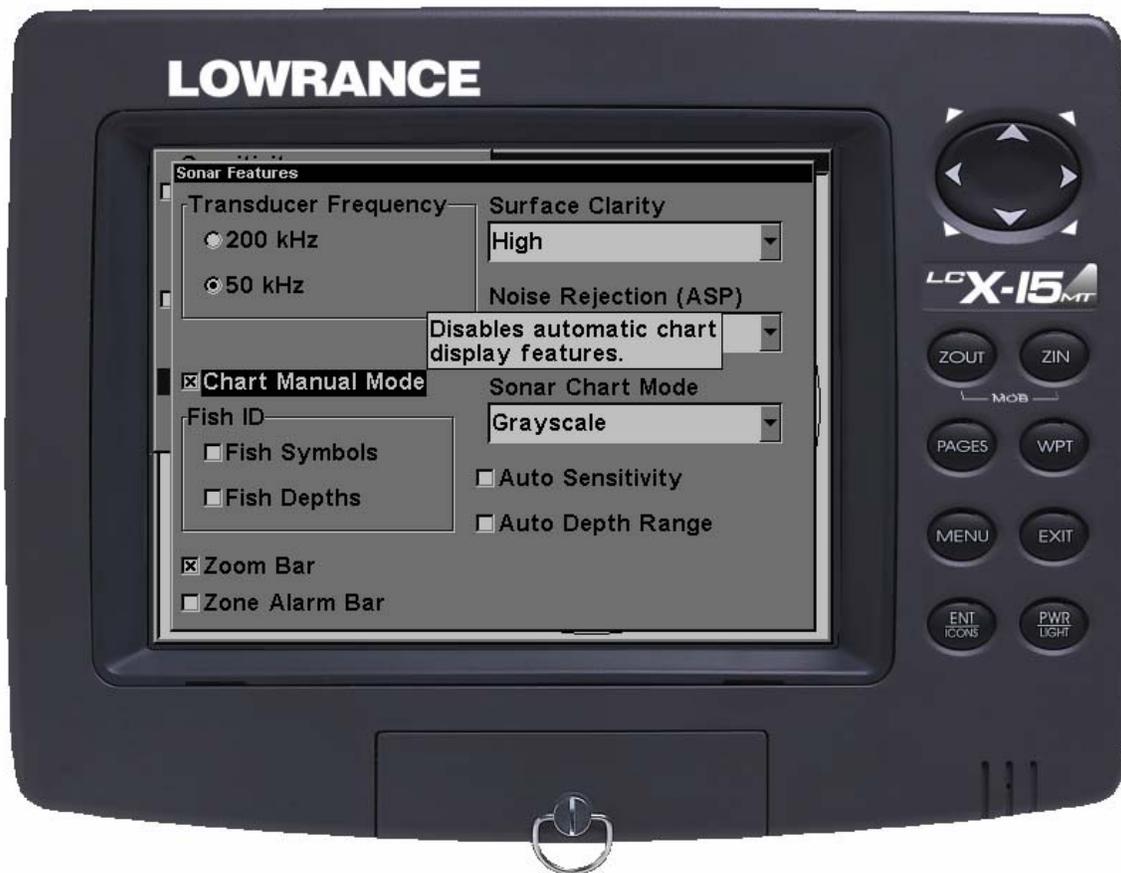


Figure 20 - Set the Chart Manual Mode in the Sonar Features menu

2.2.3 Selecting the Transducer Frequency

The fish finder records data for only one transducer frequency at a time thus the desired frequency must be selected manually. 200 kHz is best for shallow depths of up to 200m and 50 kHz to measure depths of up to 1,500m. In the “50 kHz and 200kHz” mode, the fish finder will only record the information from the 200 kHz transducer even though it will display the information from both frequencies on the screen. 50 kHz is selected when the depth will exceed 200m. This is done manually in the boat while monitoring depth readings.



Figure 21 - Selecting which transducer to use

2.2.4 Setting Depth Range

Setting the depth range is necessary in “Chart Manual Mode” to tell the fish finder where to stop looking for a bottom response. The Depth Range is periodically set to a limit close to the expected depth and in consideration of the reef slope. The fish finder operator should watch the depth readings on the screen, anticipate future depth readings and set the maximum depth level accordingly.





Figure 22 - Setting the depth range

2.2.5 Logging Data

The fish finder records depth information on a removable memory chip. Pressing “Menu” and selecting “Log Sonar Chart Data” starts the depth recording. The chart quality must be set to “High”. Recording should be stopped at the end of each track using the same screen to make future data processing easier. Deciding on a chart naming convention helps organize the files later on.

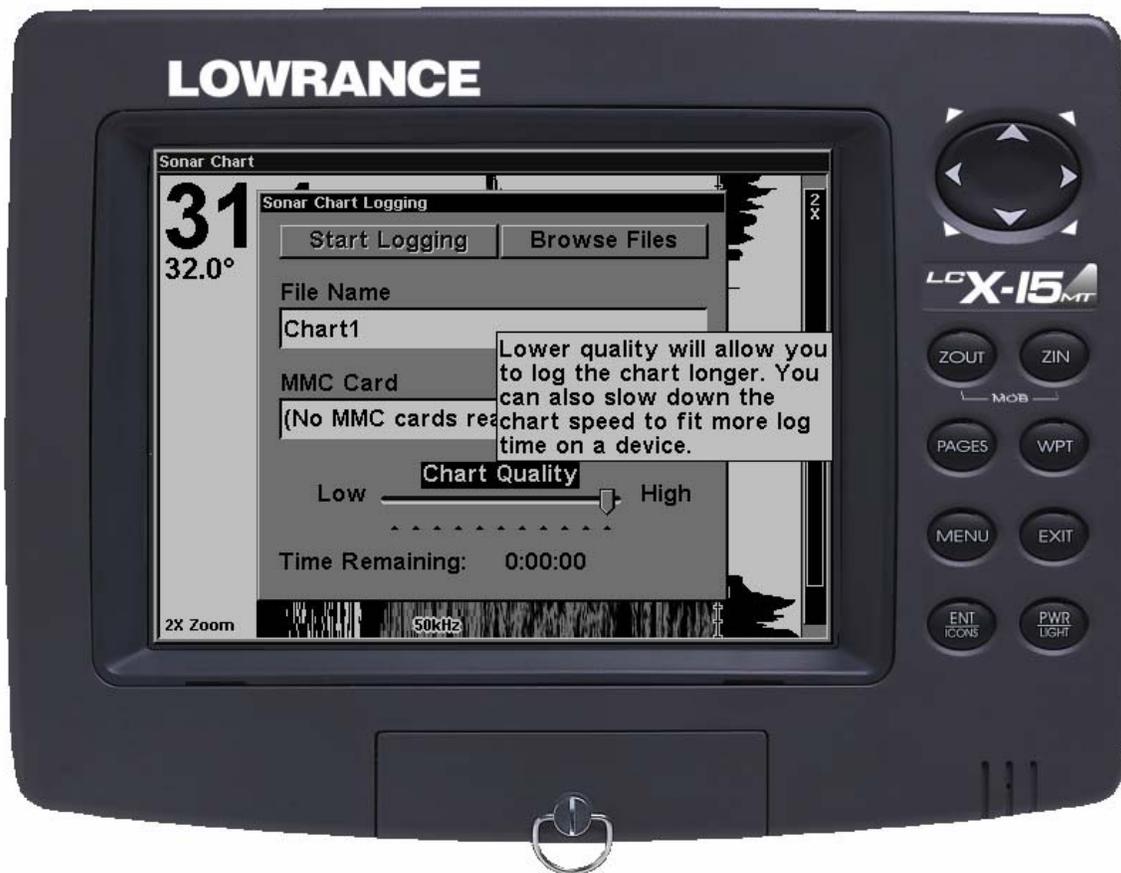


Figure 23 - Starting to record information on the MMC chip

2.2.6 Navigating the survey

It is best to select a “Dual Display Mode” that shows both the navigation map and the depth readings. The captain can navigate in a straight line from one point to another reading the map side of the screen while monitoring that the fish finder is reading valid depths. The map draws a line following the boat’s course and this facilitates maintaining a straight line between the navigation points. If the depth value starts blinking, the fish finder has lost the bottom and the boat must be stopped until the fish finder reads a new depth value. The captain should also be instructed to slow the boat to a crawl when going over the reef’s edge from shallow depth because these transitions are difficult for the fish finder to record.





Figure 24 - Using the dual display mode

3 Data Processing

Data processing is the third step of ABS. The information recorded during the field survey is converted into a visual 3D model.

The following programs are needed to process the information:

Program	Where to get it from
SLG2TXT.EXE	Part of MapCreate and included in the free Soundviewer program available on the Lowrance website at www.lowrance.com
Excel	Microsoft
ArcView 8.3	ESRI (www.esri.com)
3D Analyst	ESRI (www.esri.com)

ArcScene	ESRI (www.esri.com)
Content of the Case Study directory	Part of this toolkit includes the data collected at Half Moon Caye and files for each processing steps.

This is a summary of the data processing steps. The optional data cleanup process that results in visually smoother surfaces suitable for presentation is shown in italics:

Task	Program (filter)	Start File	Result File
Conversion of a single track from SLG to TXT	SLG2TXT.EXE	Chart1.slg	Chart1.txt
Conversion of a single track from TXT to XLS	EXCEL	Chart1.txt	Chart1.xls
Assembling all tracks into one file and removing null GPS values	EXCEL	Chart1.xls to Chart144.xls	f17-144 - step1.xls (35,055 points)
<i>Identifying values to remove by adding the formulas for all the filters</i>	<i>EXCEL</i>	<i>f17-144 - step1.xls (35,055 points)</i>	<i>f17-144 - step2.xls (35,055 points)</i>
<i>Removing depth values that are too low</i>	<i>EXCEL (TOO LOW filter)</i>	<i>f17-144 - step2.xls (35,055 points)</i>	<i>f17-144 - step3.xls (34,072 points)</i>
<i>Removing GPS errors</i>	<i>EXCEL (GPS ERRORS filter)</i>	<i>f17-144 - step3.xls (34,072 points)</i>	<i>f17-144 - step4.xls (34,064 points)</i>
<i>Removing depth errors</i>	<i>EXCEL (DEPTH ERRORS filter)</i>	<i>f17-144 - step4.xls (34,064 points)</i>	<i>f17-144 - step5.xls (28,215 points)</i>
<i>Identifying depth values outside the norm</i>	<i>EXCEL (SEGMENT ERRORS filter)</i>	<i>f17-144 - step5.xls (28,215 points)</i>	<i>f17-144 - step6.xls (28,215 points)</i>
<i>Removing depth values outside the norm</i>	<i>EXCEL</i>	<i>f17-144 - step6.xls (28,215 points)</i>	<i>f17-144 - step7.xls (27,965 points)</i>
Extracting X, Y, D information for GIS	EXCEL (save as dBASE IV)	f17-144 - step7.xls (27,965 points)	fxyd.dbf (27,965 points)
Creating a TIN	ArcMap 8.3 (3D Analyst)	fxyd.dbf (27,965 points)	tin
Converting the TIN to a raster	ArcMap 8.3 (3D Analyst)	tin	tingrid

Displaying the 3D model	ArcScene	tingrid	3D model
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3.1 Data Conversion

The data needs to be transferred from the memory chip to a PC using an adapter, cleaned up to remove errors desired and then converted for GIS use.

3.2 Converting the SLG file

The fish finder records data into SLG files. The SLG files are all converted to comma delimited text file using the SLG2TXT.EXE program.

Example:

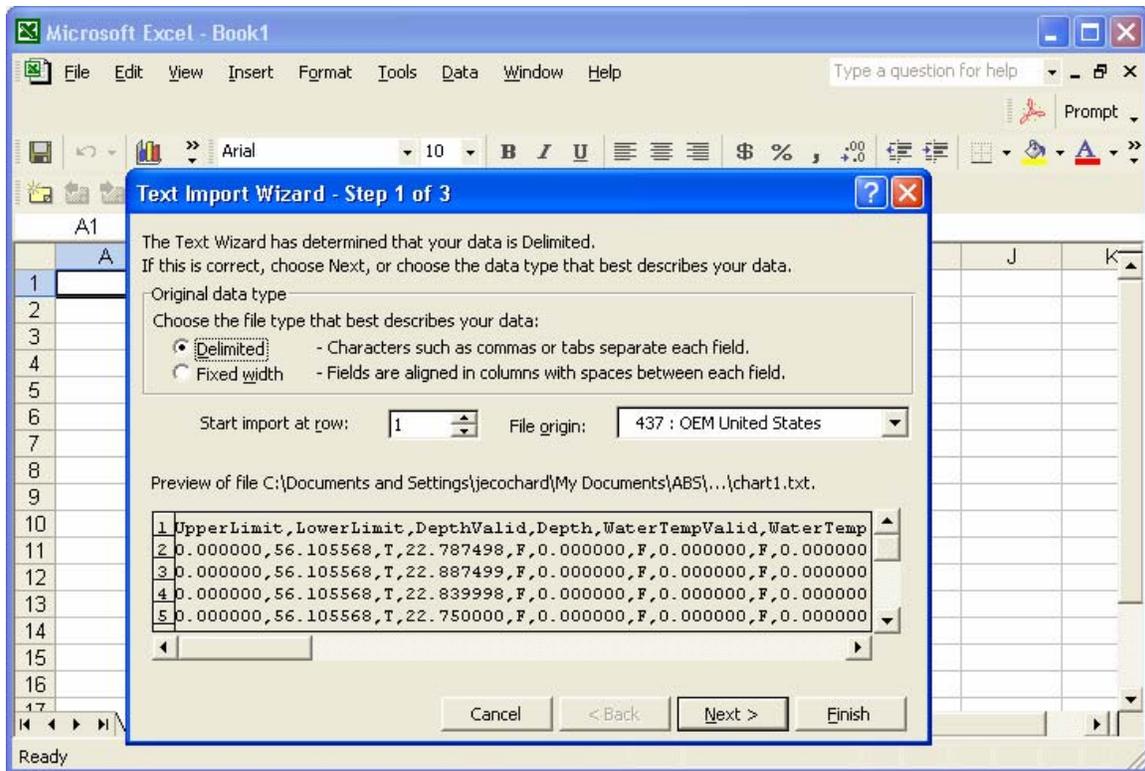
```
slg2txt Chart1.slg Chart1.txt
```

This will create the comma delimited text file Chart1.txt that can be imported into spreadsheet software.

3.2.1 How to Create the Spreadsheet

The file Chart1.txt is imported into the spreadsheet software, using a comma delimited format. The spreadsheet includes the columns:

UpperLimit, LowerLimit, DepthValid, Depth, WaterTempValid, WaterTemp, Temp2Valid, Temp2, Temp3Valid, Temp3, WaterSpeedValid, WaterSpeed, PositionValid, PositionX, PositionY, SurfaceDepth, SurfaceValid, TopOfBottomDepth, TopOfBottomValid, ColumnIs50kHz, TimeValid, TimeOffset[ms], SpeedTrackValid, Speed, Track, AltitudeValid, Altitude



The following columns are deleted from the spreadsheet as they do not include meaningful values for creating the 3D model:

WaterTempValid, WaterTemp, Temp2Valid, Temp2, Temp3Valid, Temp3, WaterSpeedValid, WaterSpeed, ColumnIs50kHz, SpeedTrackValid, Speed, Track, AltitudeValid, Altitude

The screenshot shows a Microsoft Excel spreadsheet with the following columns: A (Chart), B (LowerLim), C (Depth), D (Depth), E (WaterTemp), F (WaterTemp), G (Temp2), H (Temp2), I (Temp3), J (Temp3), K (WaterSp), L (WaterSp), M (Position), N (Position), O (Position), P (SurfaceD), Q (SurfaceD), R (TopOfB), S (TopOfB), T (Columns), U (TimeVal), V (TimeOff), W (SpeedTr), X (Speed), Y (Track), Z (Altitude), AA (Altitude). The data rows contain numerical values and text, with some cells highlighted in yellow. The status bar at the bottom indicates 'Ready'.

A new “Chart” column is added at the end and filled with the SLG file name or number. The spreadsheet is saved as Chart1 DATA.xls

All the “DATA” spreadsheets are combined into a single spreadsheet for easy processing³.

While this process seems complex it is not difficult to learn and practice. Two assistants learned how to do data conversion in less than an hour.

3.2.2 Data Processing

The fish finder takes 4 samples per second and the GPS one per second; consequently many data samples do not have GPS coordinates. Data points where the value is 0 in the columns **PositionX** and **PositionY** (i.e. no GPS data) are removed. The survey collected 34,955 data points with GPS coordinates.

To show the gross shape of the reef and prepare a new adaptive grid:

Remove the data points where DepthValid is “F”

Continue processing the data starting at section 3.7.1

³ Excel is limited to 65,535 data points so multiple spreadsheets may be needed.

To create smoother model of the reef, without data collection errors, follow all the steps described in section 3.7. This clean-up process is technical and only recommended to produce a final model of the reef with smooth surfaces.

3.3 Preliminary work – 2002

In 2002, a crew under the direction of Dr. Will Heyman recorded preliminary depth data on the top and Eastern edge of the reef. (Figure 25)

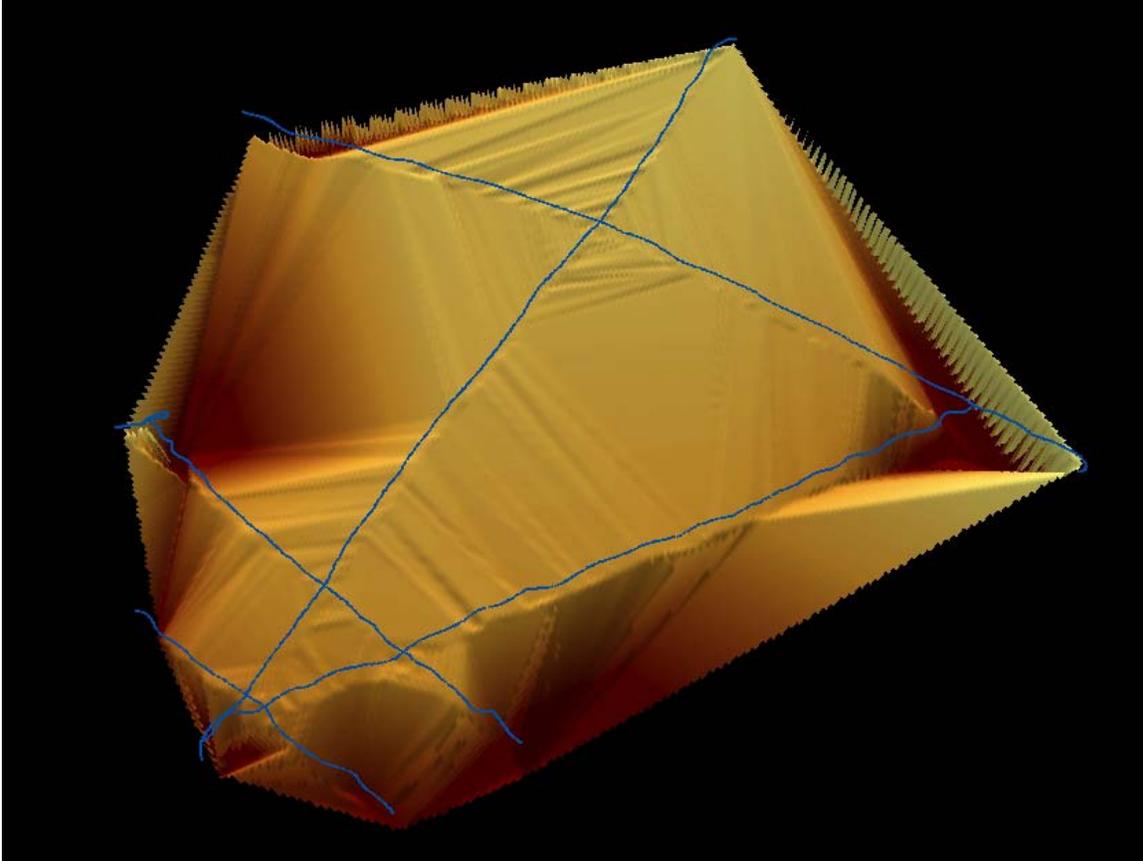


Figure 25 - Reef morphology from 2002 transect data

3.4 Day One

On Day One a single Mexican skiff boat was used to collect depth information by navigating portions of the adaptive grid. The sea was relatively calm for the area and time of the year.



Figure 26 - Mexican Skiff boat using fish finder sonar

At the end of Day One the team reviewed a 3D model of the reef made using the data collected (figure 27) and decided to extend the adaptive grid for the next day. This adjustment is part of repeating the ABS loop until satisfied with the results.

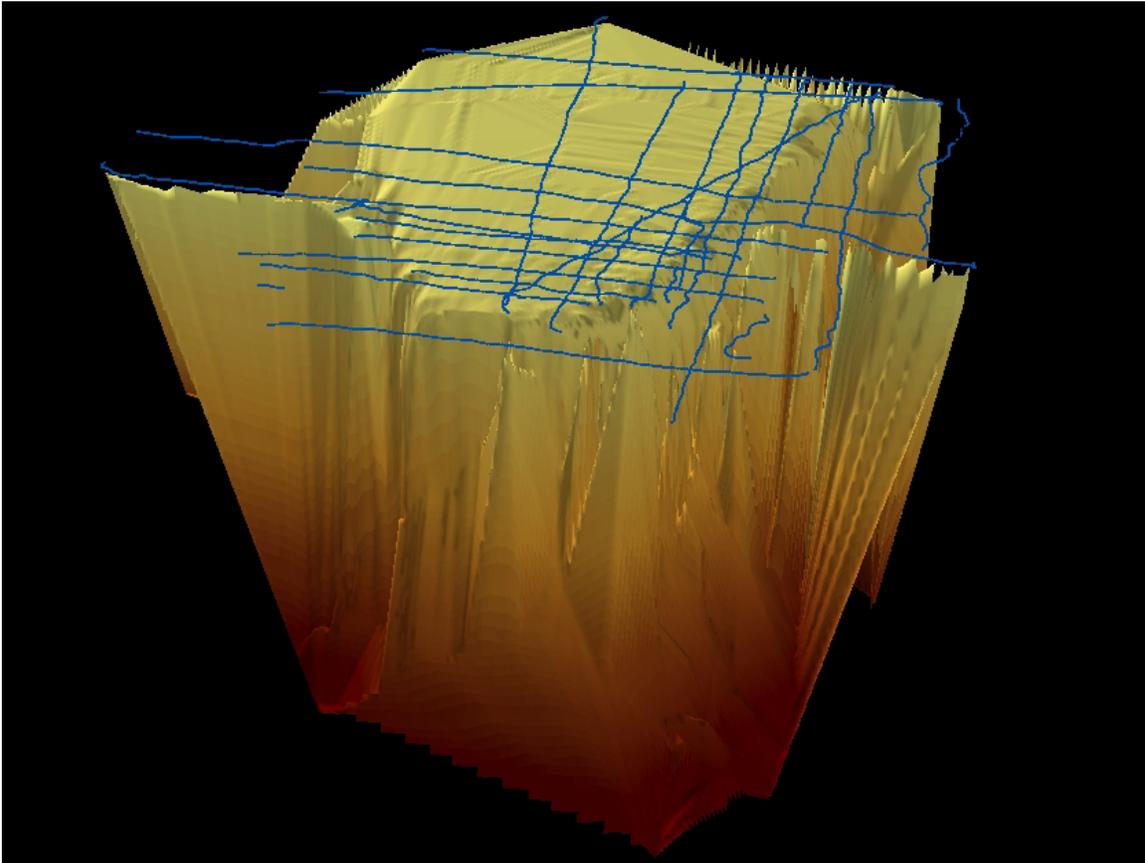


Figure 27 – 3D reef model from data collected on Day One showing navigation tracks

3.5 Day Two

Two boats were used on Day Two, each focusing on separate parts of the reef. The data collected on Day One shows that the reef is wider and deeper than initially expected. One boat focused on the FSA site while the other navigated tracks in front of the reef. The team was surprised to find that the depth exceeded 2,000ft. At the end of the day the team mapped the data obtained (figure 28) and once again adapted the grid based on these new findings (figure 29).

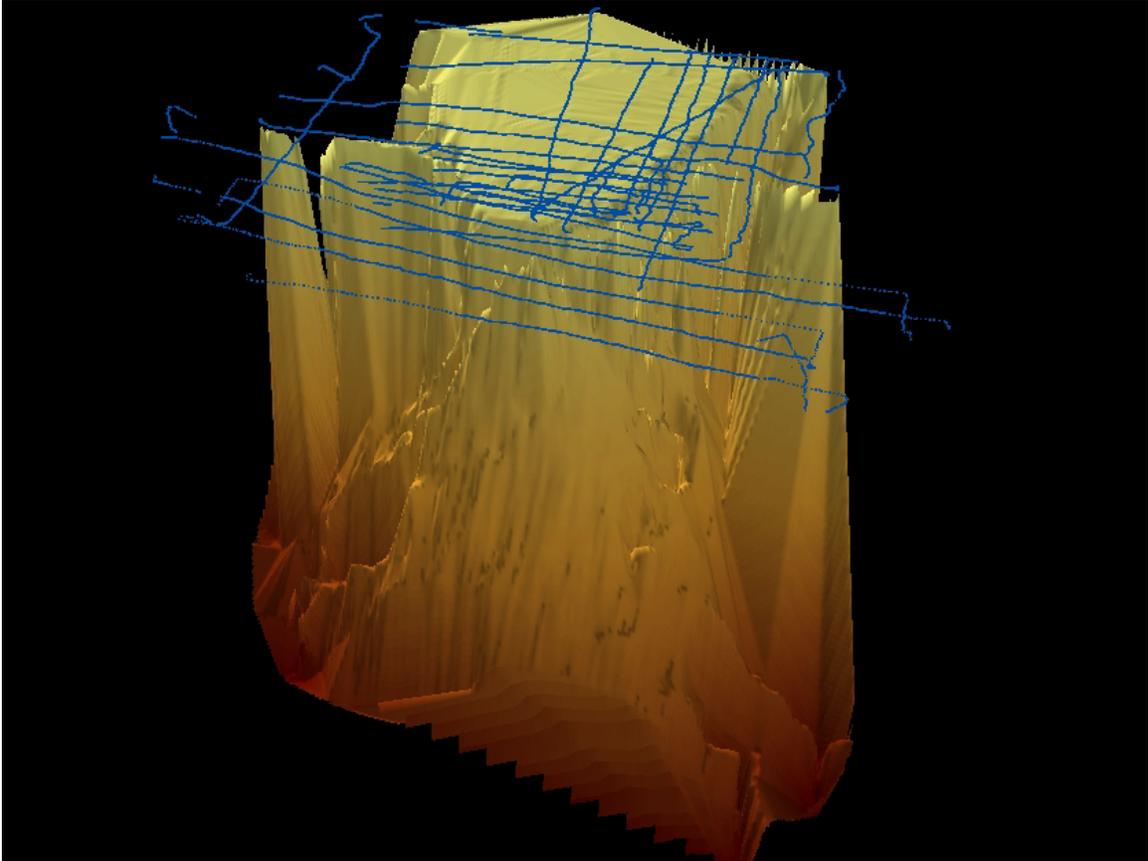


Figure 28 – 3D reef model from data collected on Day Two showing navigation tracks

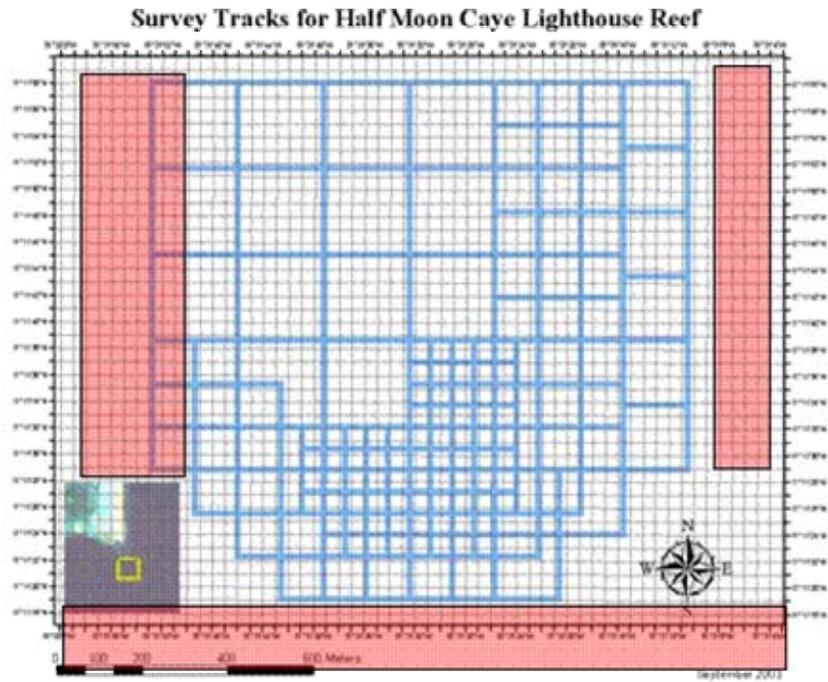


Figure 29 - Modified adaptive grid for Day Three

3.6 Day Three

On Day Three one boat navigated new lines to cover more of the West wall and the front of the reef. The reef is deeper than expected and more information is needed in these areas.

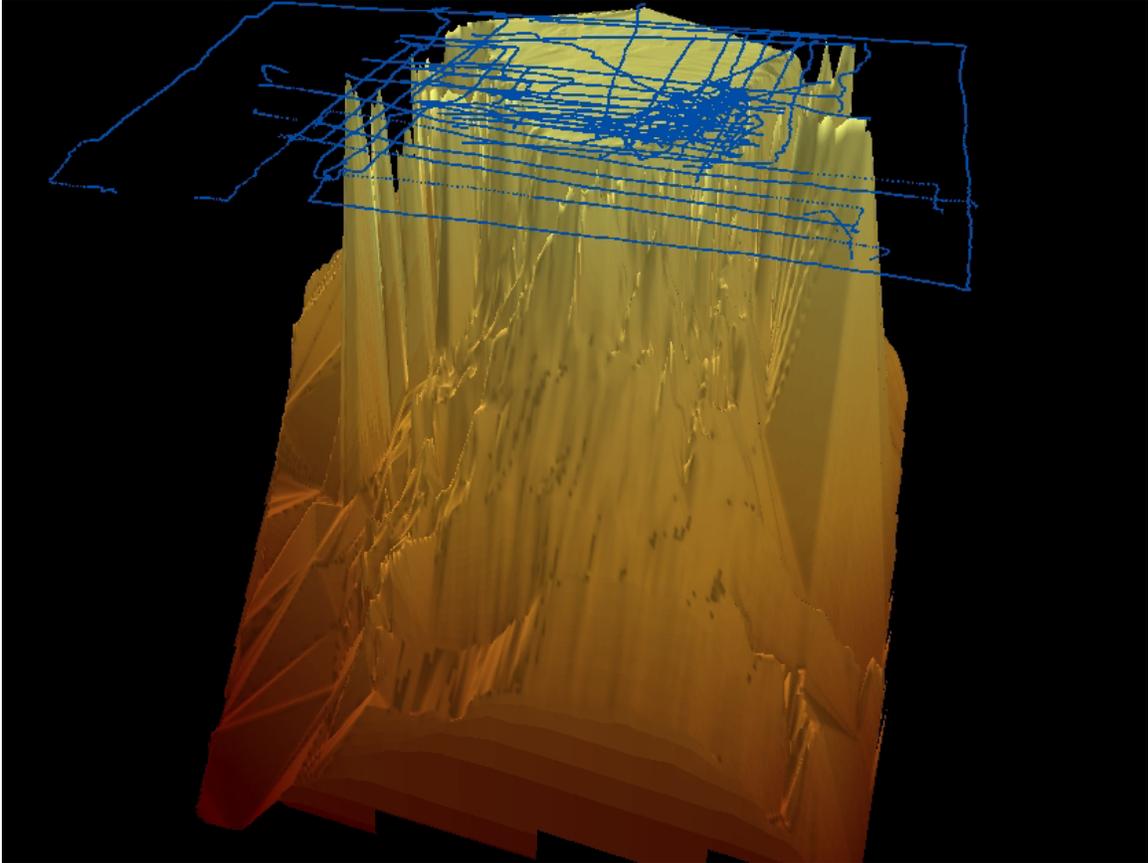


Figure 30 – 3D reef model from data collected on Day Three showing navigation tracks

3.7 Final Data Cleanup

The data collected has spurious errors that need to be cleaned up (Figure 30) to produce a smooth model for presentation. This is easily done with a spreadsheet program using some statistical analysis. The process is described in detail in Appendix B.

The following diagram shows the results of the data cleanup. Shapes displayed in red were the result of faulty information that has been corrected by the filters.

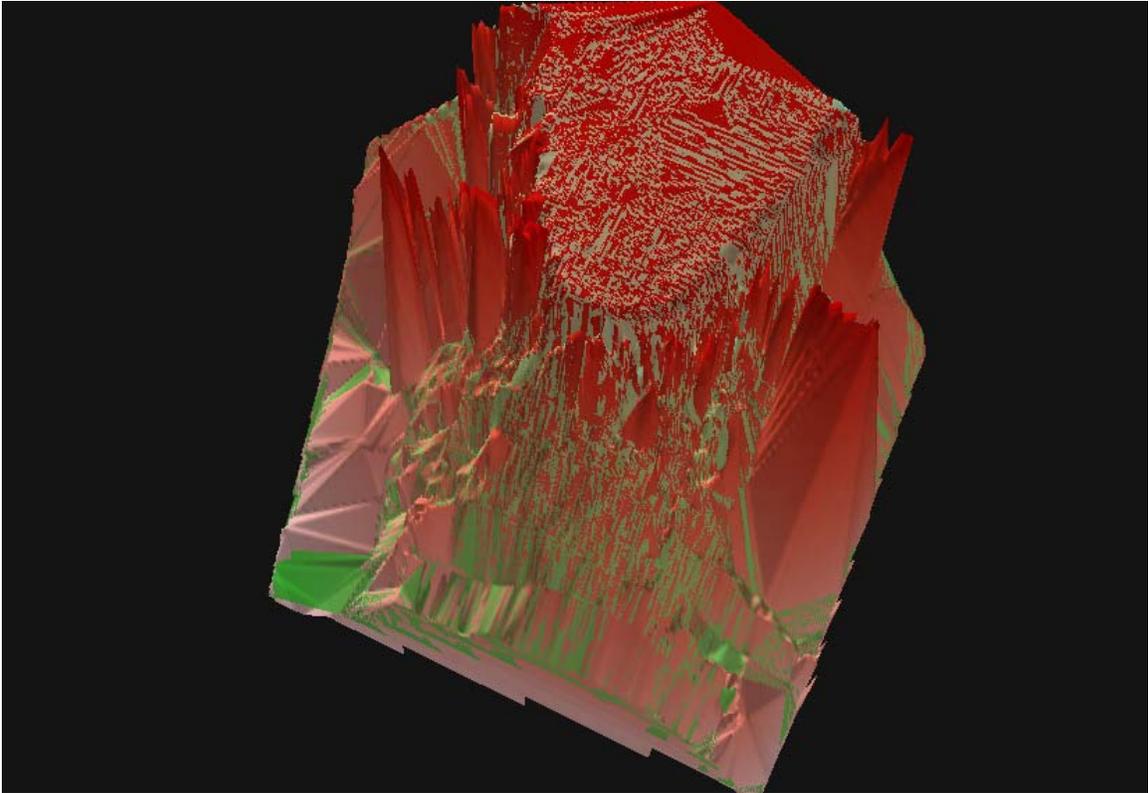


Figure 31 - Showing erroneous data corrected in red

3.7.1 Translating Values for Processing in ArcGIS

The information recorded by the fish finder uses proprietary Lowrance Mercator coordinates that need to be translated to standard Universal Transverse Mercator (UTM) coordinates with the following spreadsheet formulas because GIS software does not understand the Lowrance proprietary coordinate system.

A new column named “X” is created to hold the Easting coordinates. Cut and paste the following formula into the new X column at line 2 and copy it down to the end of the spreadsheet:

$$=180/PI()*F2/6356752.3142$$

A new column named “Y” is created to hold the Northing coordinates. Cut and paste the following formula into the new Y column at line 2 and copy it down to the end of the spreadsheet:

$$=180/PI()*(2*ATAN(EXP(G2/6356752.3142))-PI()/2)$$

A new column name “D” is created to hold depth. Cut and paste the following formula into the new D column at line 2 and copy it down to the end of the spreadsheet:

$$= - \text{Depth}$$

The fields Chart, X, Y and D are saved into a DBF file. This final file has 27,965 data points.

3.8 Creating a digital elevation model of the reef

Transforming X, Y, D coordinates into a three dimensional model requires the use of GIS software. ESRI products are the industry standards for GIS⁴.

3.8.1 Loading Data Points

In the GIS software the layer coordinate system is set to UTM and the dbf file containing the cleaned up data points is added. Selecting “display XY data” (figure 35) by using the right mouse click menu creates a series of point shapes for each XYD value.

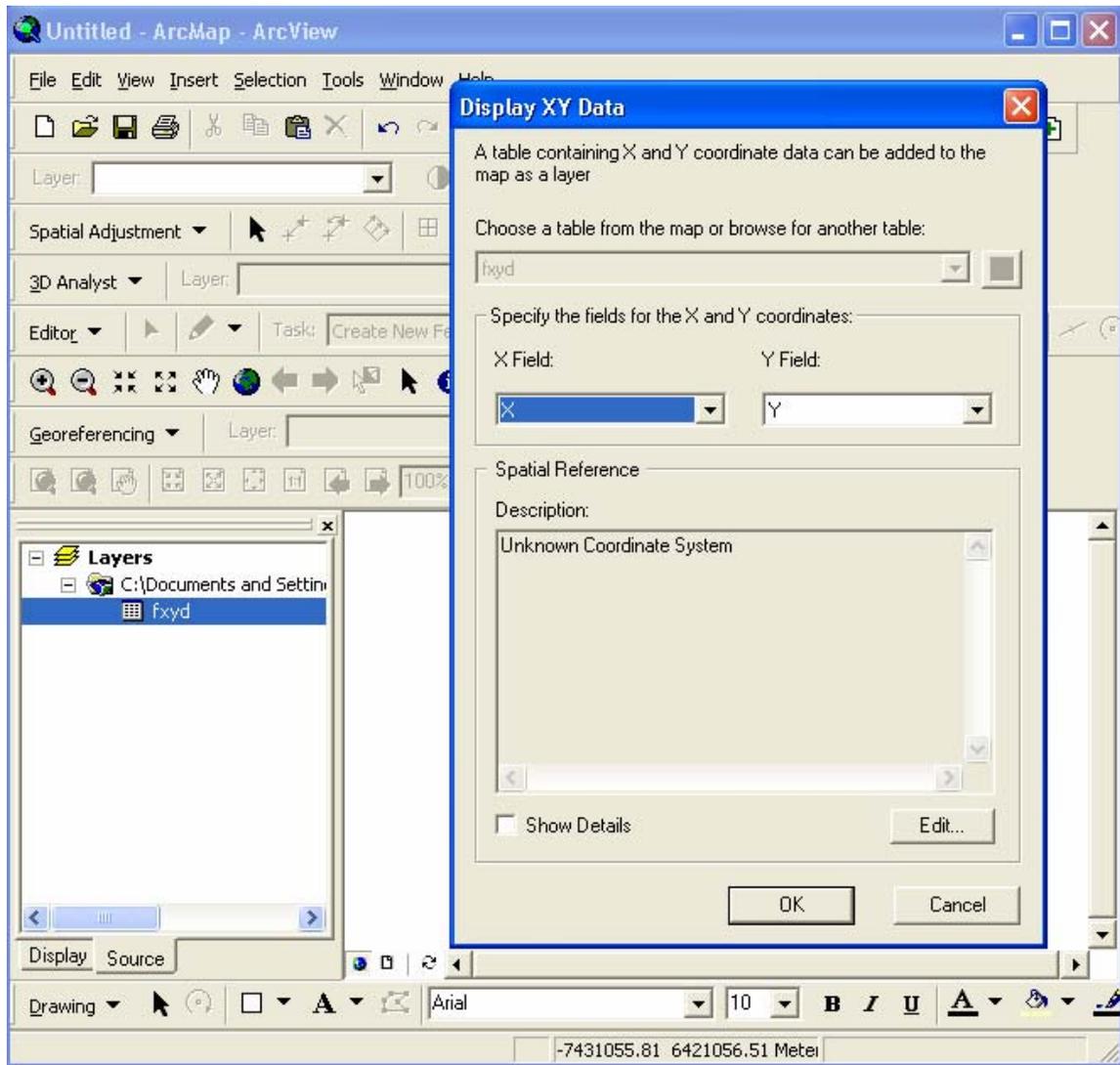


Figure 32 - Importing data points into ArcMap

⁴ Surfer and GMT are acceptable alternatives

3.8.2 Create Triangle Irregular Network (TIN)

The “Create/Modify TIN” option of 3DAnalyst is selected followed by the “Create TIN from features” option. The events layer is selected and the “D” field used as the height source (figure 36).

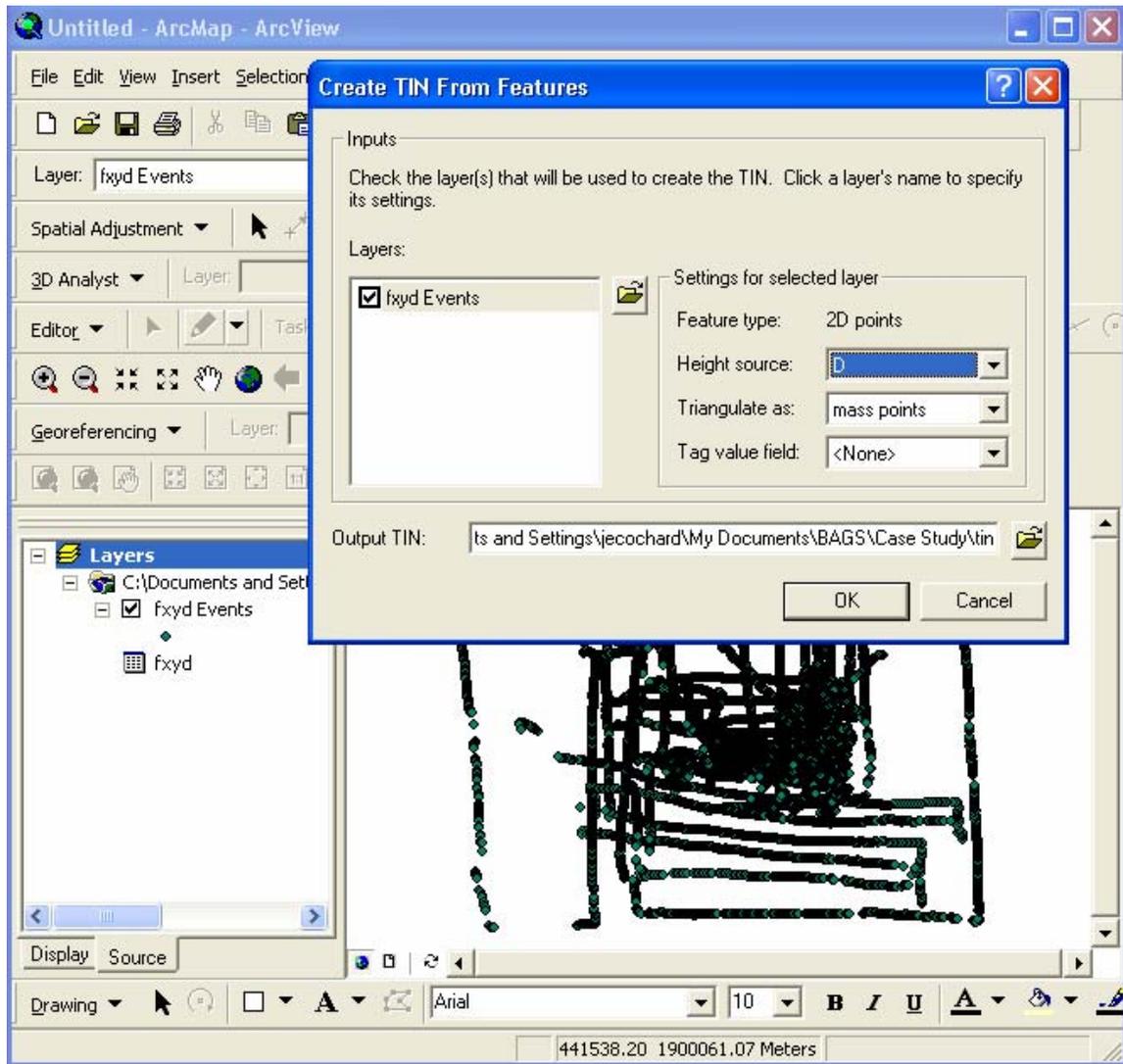


Figure 33 - Creating a TIN

3.8.3 Creating a raster from the TIN

At this point the TIN can be displayed in ArcScene but creating a raster leads to faster surface modeling. The “Convert” and “TIN to raster” options are used (figure 37).

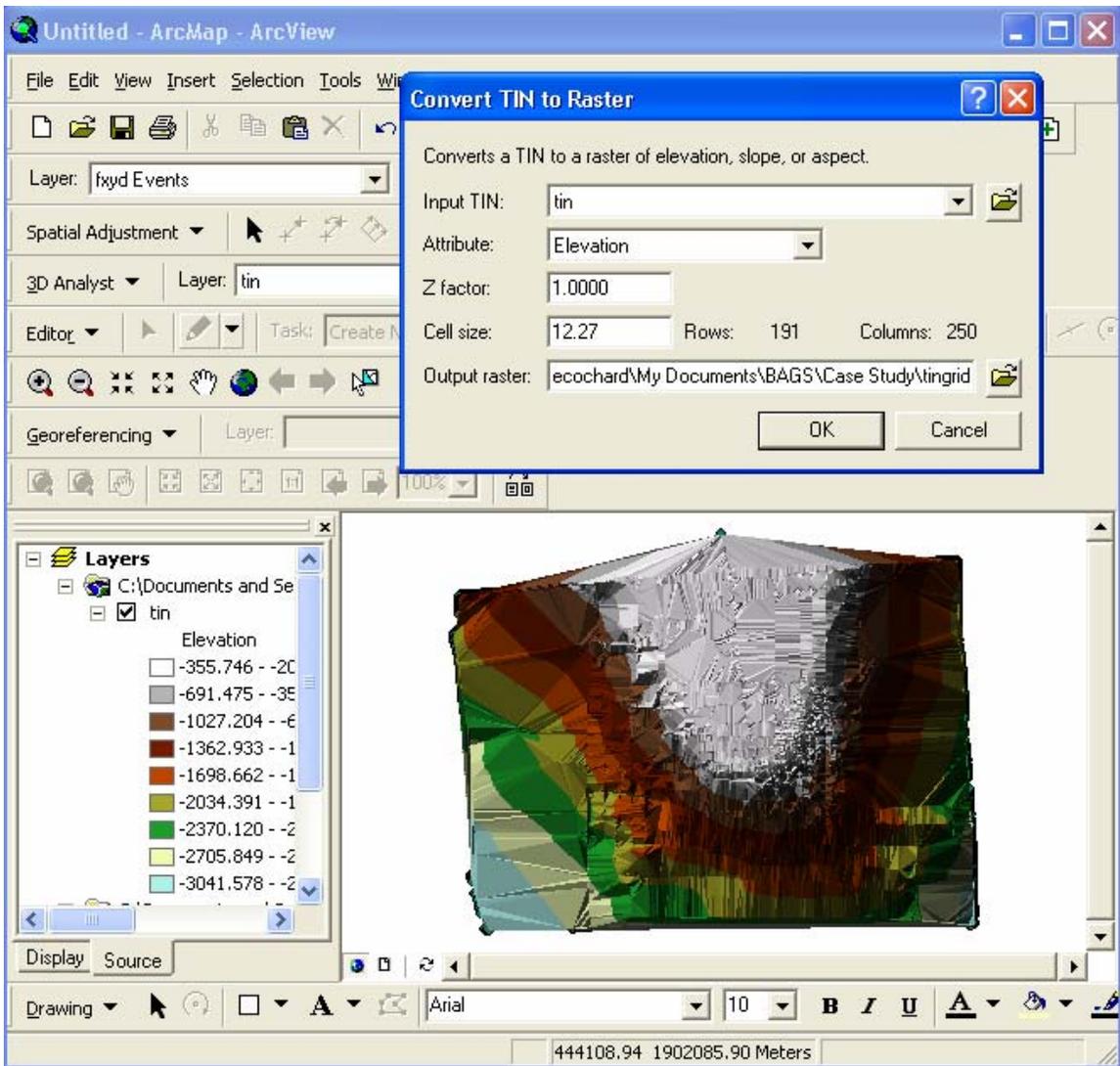


Figure 34 - Creating a raster from a TIN

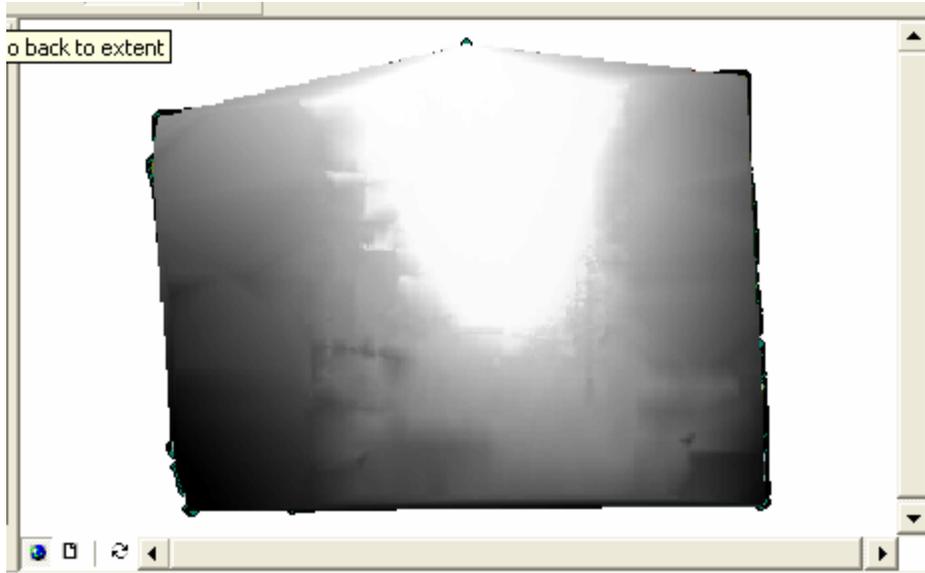


Figure 35 - Raster created from TIN

3.8.4 Viewing the reef in 3D

The raster is loaded in ArcScene to view the model of the reef in 3D (figure 39).

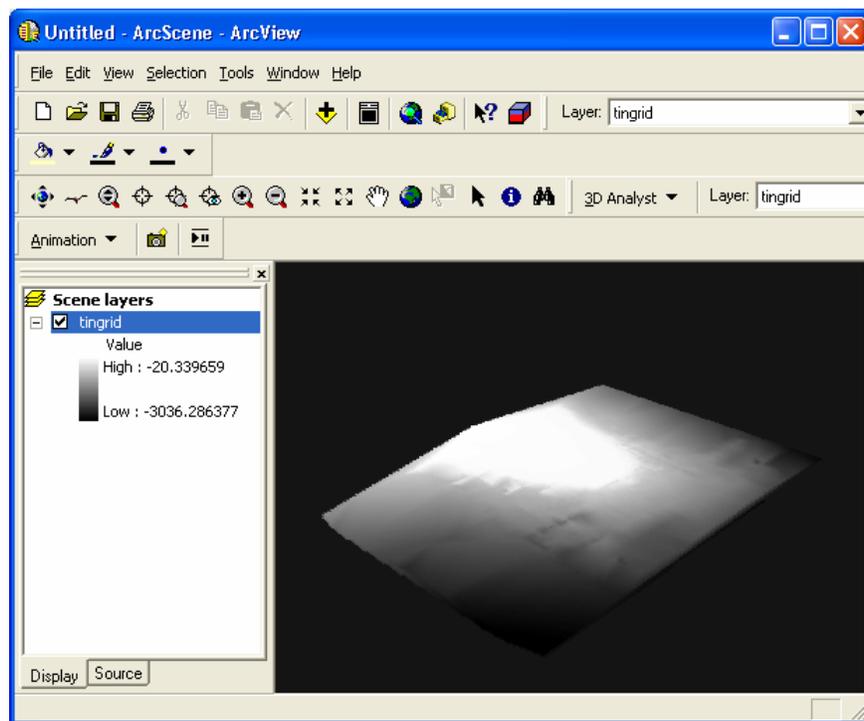


Figure 36 - Loading the raster in ArcScene

The right click “Properties” menu option and the “Base Heights” tab (figure 40) are selected followed by “Obtain heights for layer from surface”. The symbology can also be set to suitable colors and the lights turned on to create shadows.

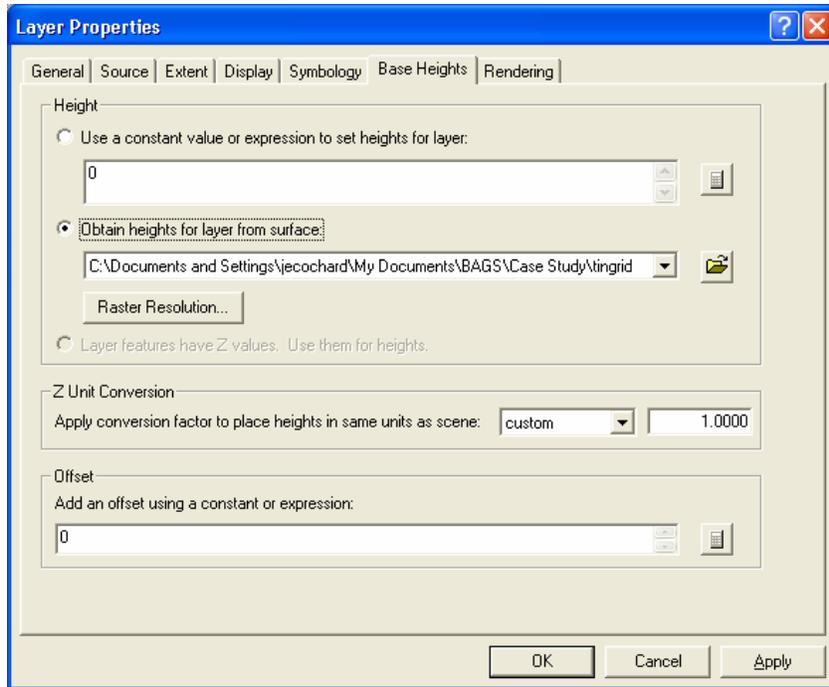


Figure 37 - Setting the raster's base heights

The raster appears in 3D and can be manipulated using the control tools.

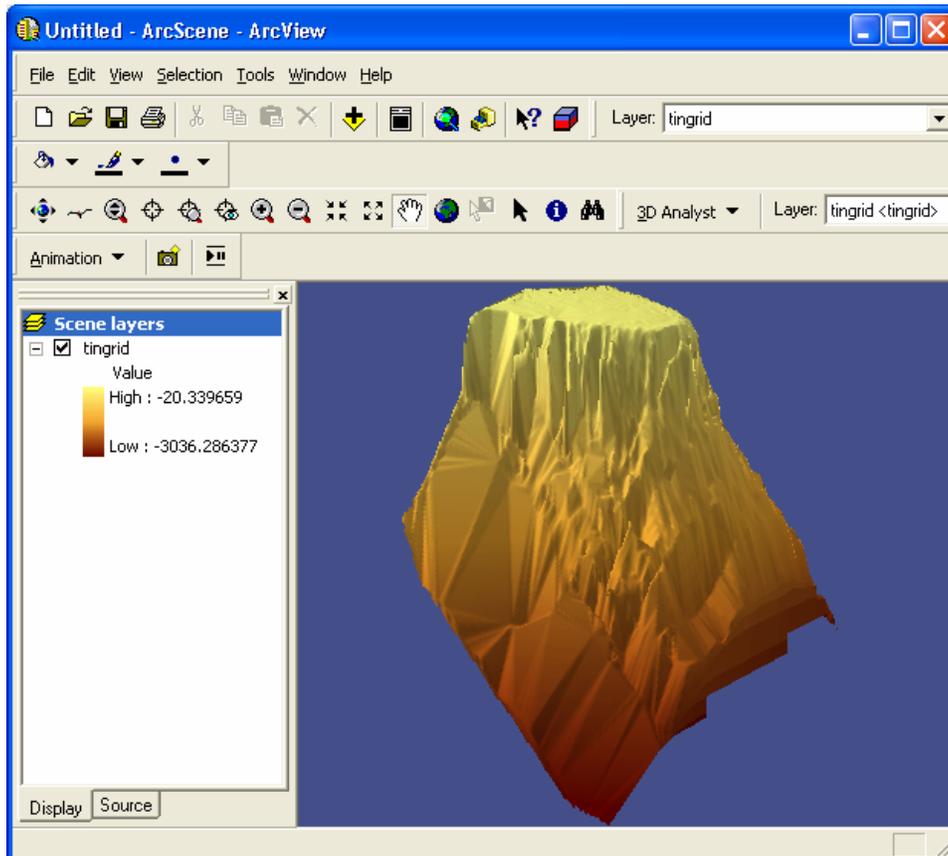


Figure 38 - 3D rendition of the reef in ArcScene

Incorporating a transparent satellite image leads to more realistic displays (figure 42 and 43). The model can also be colored and included into presentations (figure 44)

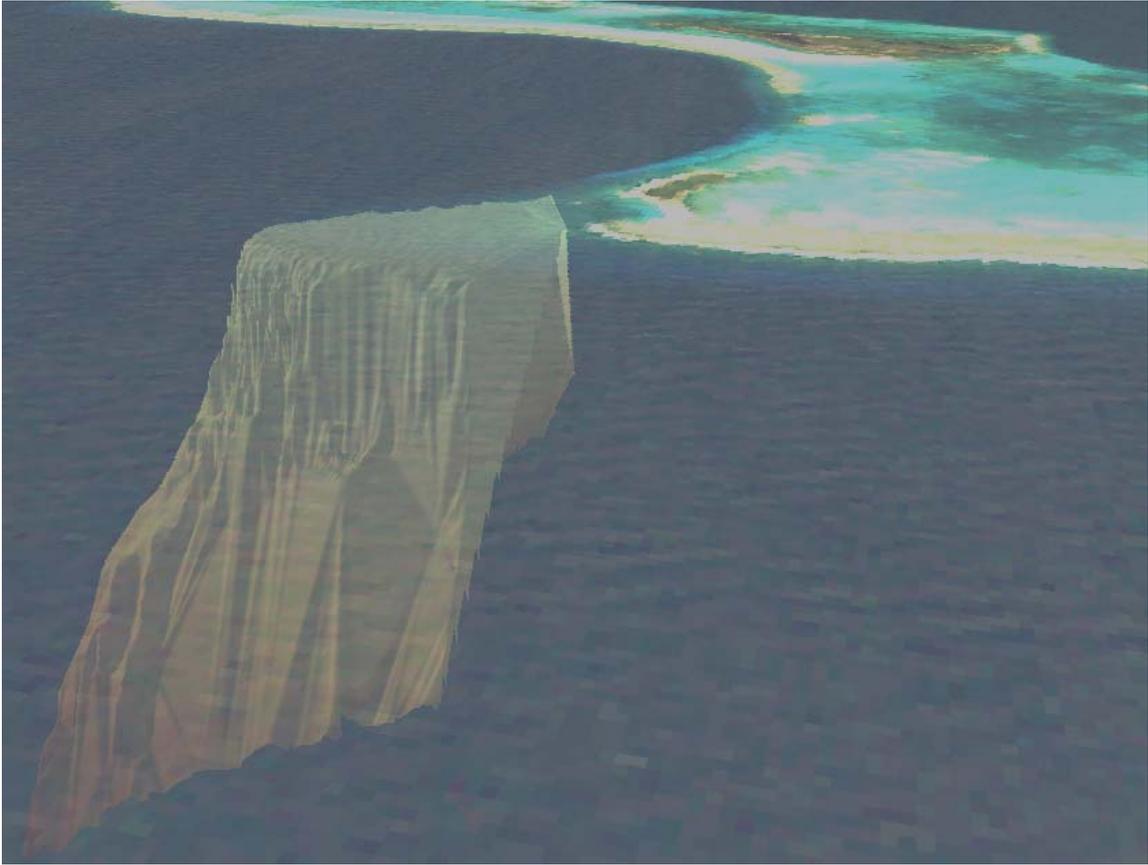


Figure 39 - East Wall of Half Moon Caye's reef

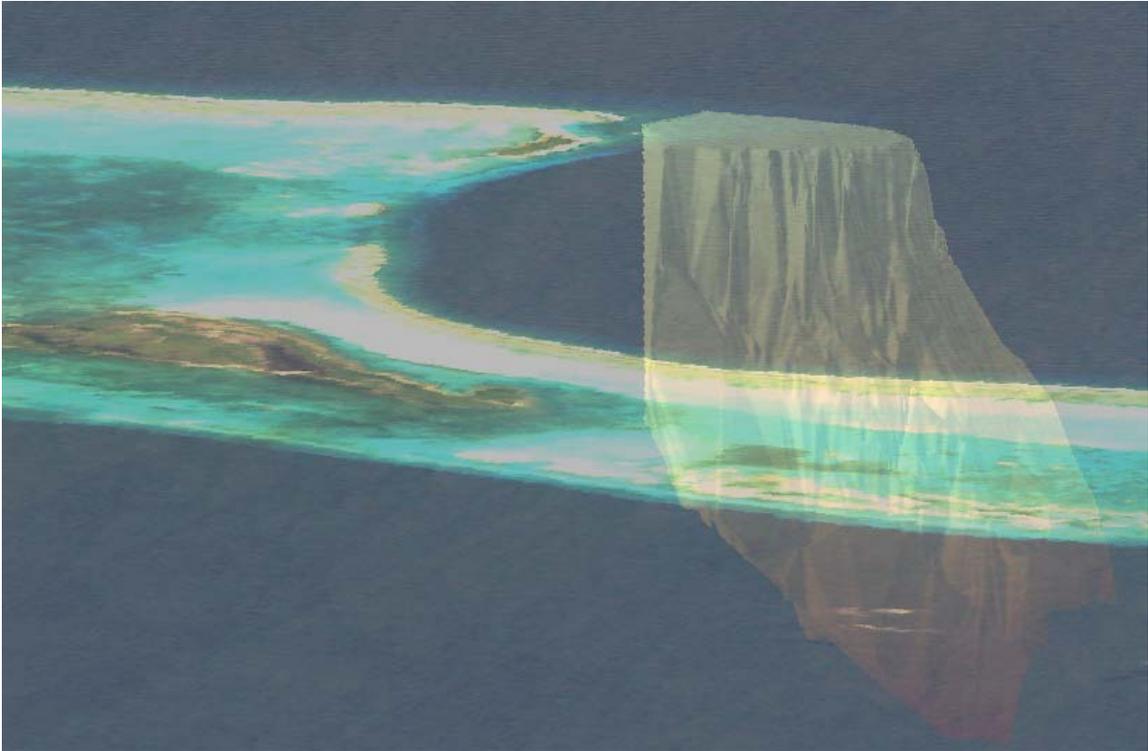


Figure 40 - West wall of Half Moon Caye's Reef

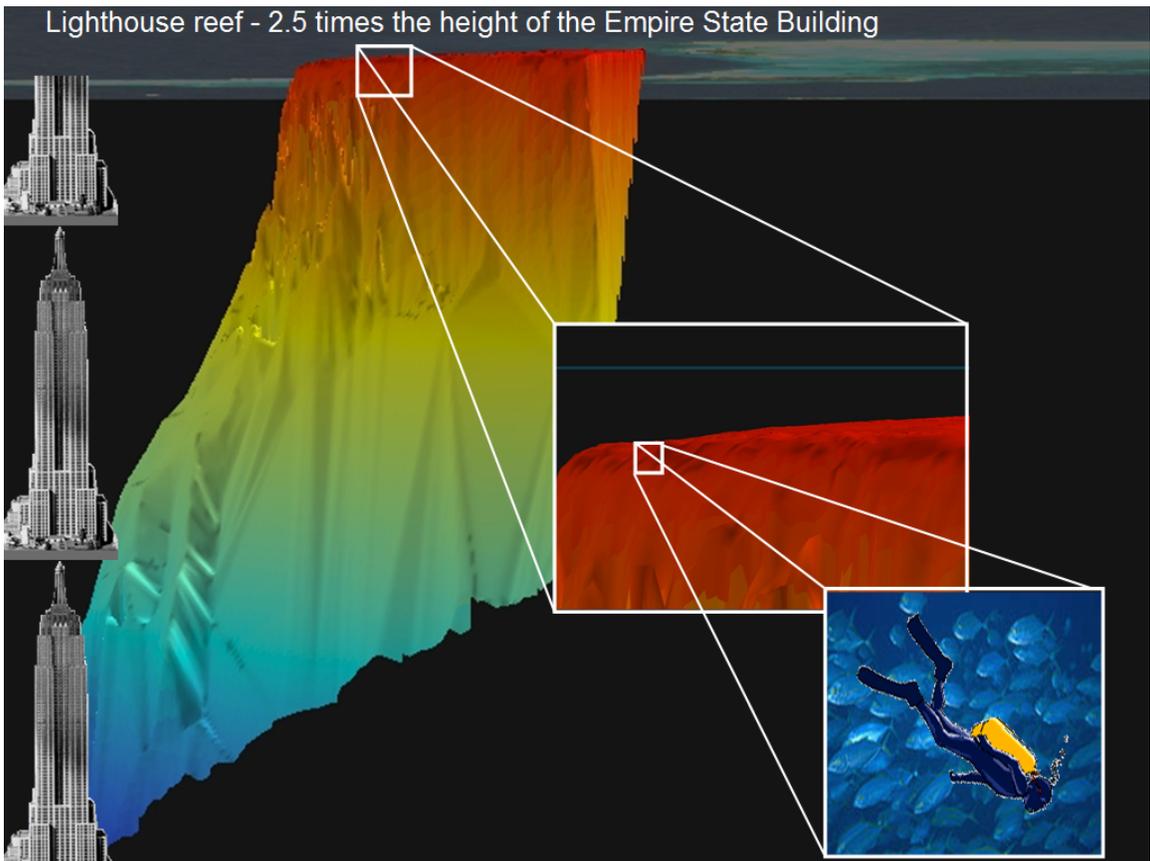


Figure 41 - Presentation of Half Moon Caye's Reef

4 Costs

ABS is designed to be affordable. It uses inexpensive technology and reduces the grid length required to map the reef. Ongoing survey costs are likely cost less than this first test case ... as ABS operators become more efficient.

4.1 Actual Costs and Time

Out case study costs were calculated from Belize City. The entire cost of the ABS process was \$2,810 and broken down as follows:

Initial Adaptive Grid Preparation: \$140 (4 hours of a GIS analyst @\$35/hr)

Field Survey: Staff: \$450 (2 surveyors @ \$75/day for 3 days). Equipment: \$2,080 (boat \$200/day for 3 days + 100 gallons @\$3.80 + Lowrance LCX 15 @\$1,100)

Data Processing: \$140 (4 hours of a GIS analyst @\$35/hr)

These costs were conservative. For example, the entire cost of the fish finder was included instead of some depreciated amount. Four hours of a GIS analyst was included. Once trained in ABS, a GIS analyst could easily do the same work in half the time.

The Airmar transducer, required for depth beyond 600m and up to 1,800m, was kindly donated by Airmar. It retails for less than \$800.

The ABS process took less than 4 days from start to finish. This test case was the first implementation of ABS in the field and the team had to learn the equipment in the process. Half Moon Caye's reef was also a very complex reef to map. Simpler reefs could be mapped in a day or two.

4.2 Commercial Estimate

To compare costs a price quote was obtained from a local hydrographic survey company. Our initial query reads:

"We want to make a bathymetric map of the Half Moon Caye promontory. I think the depth goes down to 3000 feet (1000 m), and the area of the box should be about 5 km2 and the contour intervals will be ok at about 100ft (35 m). We want to get a ball park figure of how much it would cost and about how much time it would take you to do it."

The hydrographic company provided the following estimate:

"I ran your numbers with my people and we can do the indicated job for US \$30,000. Price is a function of accuracy and depth. We need to use two different types of instruments to meet your TOR (depth in particular). Time frame for job would be about 1 week on the ground, and another week of data processing, to generate xyz dtm in dxf format readable in cad or gis. Weather window is up in the air, but we should be able to get reasonable data in < 4 ft seas. rolls being better than chop of course. We would need at least a 60-day notification, 60 % up front & balance on delivery of data."

The budget of the survey did not include the cost of executing a comparative commercial survey thus the ABS reef model cannot be evaluated against a commercial model. The question remains: Would a side-by-side comparison between a commercial model and an ABS model yield enough meaningful differences to justify the increase in cost and time?

5 Conclusion

The Adaptive Bathymetric System is a quick and cost effective way to map reefs. It provides models of reefs that motivate new thoughts and help clarify the understanding of processes like FSA that are hidden under the sea. ABS is also easy to learn. Trained assistants subsequently surveyed the Gladden Spit reef using ABS in one day (Figure 45). The ability for trainees to learn and apply the ABS process demonstrates that the method can easily be taught and thus can be deployed at scale.

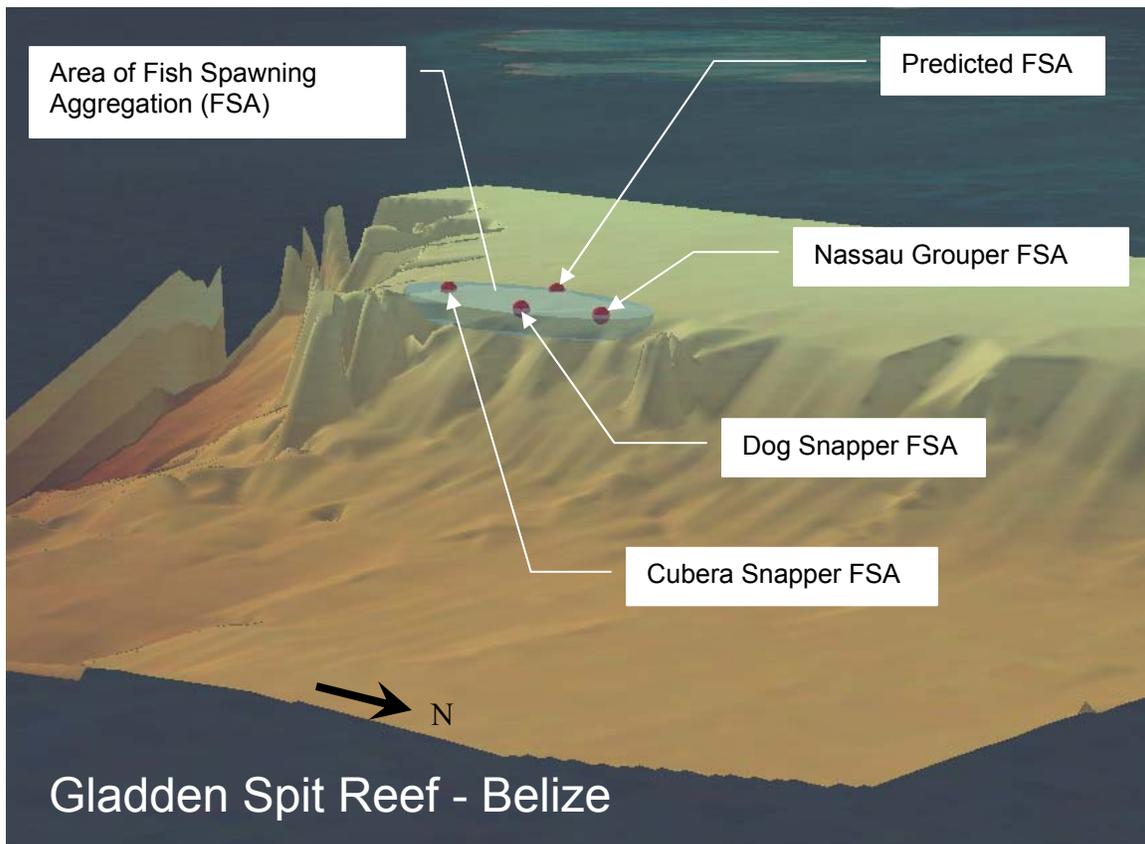


Figure 42 - Model of Gladden Spit resulting from ABS (1 day)

5.1 Lessons learned

This case study would not be complete without listing the major lessons learned:

ABS produces 3D reef models quickly and inexpensively. This study was the first application of ABS. A 59% potential in efficiency against a traditional survey had been calculated by comparing grid lengths. This case study shows that ABS can be 10 times cheaper, and twice as fast as a commercial survey. This makes ABS an attractive reef mapping alternative for projects with low budgets.

Equipment configuration. A lot was learned about the various configuration options of the fish finder. The users' manual was designed for fishing, not reef exploration and some options useful to identify fish impede the ability to obtain

reliable depth measurements. The best practices presented in this document were obtained by trial and error. Many times, the team had to stop the boat and test various settings in order to make progress, especially when depth levels were beyond 2,000 feet.

Slow boat to a crawl from shallow to deep. The equipment has difficulty continuously tracking bottom depth when going over a cliff's edge from its shallow end. To maintain bottom readings the boat must be slowed to a crawl during these depth transitions.

Make grids that join each other so that they are easier to navigate. When an adaptive grid is prepared the resulting pattern must be easy to navigate. It is best to use powers of 2 of the smaller grid instead of multiples of the smallest grid. The different grid cells should have been 50, 100, 200, 400 (2^0 , 2^1 , 2^2 , 2^3) instead of 50, 100, 150, 200, 400 (x2, x 3, x 4, x8).

Have a captain who can maintain a steady course. Navigational skills are a must when the sea is choppy and difficult to navigate. The skills of the captain are critical to navigate straight lines along the grid.

Memory chips are small. The memory chips used to record the depth information were very small and easily misplaced; consequently safekeeping in their protective case is advised.

ABS can be done in real-time. The team experimented using a laptop with GIS software on the boat, loading tracks freshly recorded for instant analysis and modeling.

5.2 Acknowledgements

This case study of ABS owes its success to the support and contributions from numerous people and institutions. The authors express thanks to the Fisheries Department of Belize who allowed this research to be conducted with permission from the Government of Belize. We thank the Belize Audubon Society for hosting us within the Half Moon Caye National Monument, for lending their power generator as our unit failed to function on the first day and for the valuable assistance of Kirah Foreman.

We are grateful for the support of Sonny Garbutt, second captain and culinary chef and Peg Heyman who provided helpful suggestions on the design of the study. Early graphics development was done with the assistance of Leo Sotomayor and Tim Boucher. We greatly benefited from the counsel of our reviewers, Judith Ecochard, Rod Salm and Soames Summerhayes. And special thanks go to Maya Gorrez and Mike Beck for their inspiration.

The authors are especially grateful to the ESRI Corporation for their generous donation of GIS software, to the Airmar Corporation for their donation of a TM260 transducer and to Luke Morris, Lowrance's international support engineer, for his help explaining the inner-workings of the LCX-15 and for providing the formula to convert Lowrance coordinates into UTM coordinates.

Appendix A - Transducers Coverage Radius at Depth (values in red italics may not be achieved)

Depth		50kHz Airmar		200kHz Airmar		50kHz Lowrance		200kHz Lowrance	
m	ft	m	ft	m	ft	m	ft	m	ft
10	33	2	5	1	2	3	11	1	3
20	66	3	11	1	3	7	22	2	7
30	98	5	16	2	5	10	33	3	10
40	131	7	22	2	7	13	44	4	14
50	164	8	27	3	9	17	55	5	17
100	328	17	55	5	17	33	110	<i>11</i>	<i>34</i>
150	492	25	82	8	26	50	165	<i>16</i>	<i>52</i>
200	656	33	110	10	34	67	220	<i>21</i>	<i>69</i>
250	820	42	137	13	43	84	274	<i>26</i>	<i>86</i>
300	984	50	165	16	52	100	329	<i>32</i>	<i>103</i>
350	1,148	59	192	18	60	117	384	<i>37</i>	<i>121</i>
400	1,312	67	220	21	69	134	439	<i>42</i>	<i>138</i>
450	1,476	75	247	24	77	151	494	<i>47</i>	<i>155</i>
500	1,640	84	275	26	86	167	549	<i>53</i>	<i>172</i>
550	1,804	92	302	<i>29</i>	<i>95</i>	184	604	N/A	N/A
600	1,969	100	329	<i>31</i>	<i>103</i>	201	659	N/A	N/A
650	2,133	109	357	<i>34</i>	<i>112</i>	217	714	N/A	N/A
700	2,297	117	384	<i>37</i>	<i>120</i>	234	768	N/A	N/A
750	2,461	126	412	<i>39</i>	<i>129</i>	251	823	N/A	N/A
800	2,625	134	439	<i>42</i>	<i>138</i>	268	878	N/A	N/A
850	2,789	142	467	<i>45</i>	<i>146</i>	284	933	N/A	N/A
900	2,953	151	494	<i>47</i>	<i>155</i>	301	988	N/A	N/A
950	3,117	159	522	<i>50</i>	<i>163</i>	<i>318</i>	<i>1,043</i>	N/A	N/A
1,000	3,281	167	549	<i>52</i>	<i>172</i>	<i>335</i>	<i>1,098</i>	N/A	N/A
1,050	3,445	176	576	N/A	N/A	<i>351</i>	<i>1,153</i>	N/A	N/A
1,100	3,609	184	604	N/A	N/A	<i>368</i>	<i>1,208</i>	N/A	N/A
1,150	3,773	192	631	N/A	N/A	<i>385</i>	<i>1,262</i>	N/A	N/A
1,200	3,937	201	659	N/A	N/A	<i>402</i>	<i>1,317</i>	N/A	N/A
1,250	4,101	209	686	N/A	N/A	<i>418</i>	<i>1,372</i>	N/A	N/A
1,300	4,265	218	714	N/A	N/A	<i>435</i>	<i>1,427</i>	N/A	N/A
1,350	4,429	226	741	N/A	N/A	<i>452</i>	<i>1,482</i>	N/A	N/A
1,400	4,593	234	769	N/A	N/A	<i>468</i>	<i>1,537</i>	N/A	N/A
1,450	4,757	243	796	N/A	N/A	<i>485</i>	<i>1,592</i>	N/A	N/A
1,500	4,921	251	824	N/A	N/A	<i>502</i>	<i>1,647</i>	N/A	N/A
<i>1,550</i>	<i>5,085</i>	<i>259</i>	<i>851</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,600</i>	<i>5,249</i>	<i>268</i>	<i>878</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,650</i>	<i>5,413</i>	<i>276</i>	<i>906</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,700</i>	<i>5,577</i>	<i>284</i>	<i>933</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,750</i>	<i>5,741</i>	<i>293</i>	<i>961</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,800</i>	<i>5,906</i>	<i>301</i>	<i>988</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,850</i>	<i>6,070</i>	<i>310</i>	<i>1,016</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,900</i>	<i>6,234</i>	<i>318</i>	<i>1,043</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>1,950</i>	<i>6,398</i>	<i>326</i>	<i>1,071</i>	N/A	N/A	N/A	N/A	N/A	N/A
<i>2,000</i>	<i>6,562</i>	<i>335</i>	<i>1,098</i>	N/A	N/A	N/A	N/A	N/A	N/A

Appendix B – Data Cleaning Filters

Four filters are created to remove data collection errors:

5.2.1.1 TOO LOW filter

The fish finder has a tendency to seek depth up once it has lost the bottom, resulting in recording ghost shallow values. TOO LOW is a high-pass filter that identifies values that are too low so that they can be removed. To set the value of this filter, calculate the distribution of depth values rounded to integer feet where DepthValid is true (“T”) (Figure 31). The TOO LOW filter is set at 20ft. This means that the filter will remove all values that have a depth lower than 20ft. The spreadsheet formula for the filter calculated at row 2 is:

```
=IF (D2 < 20,"REMOVE", "")
```

The TOO LOW filter removes 883 data points.

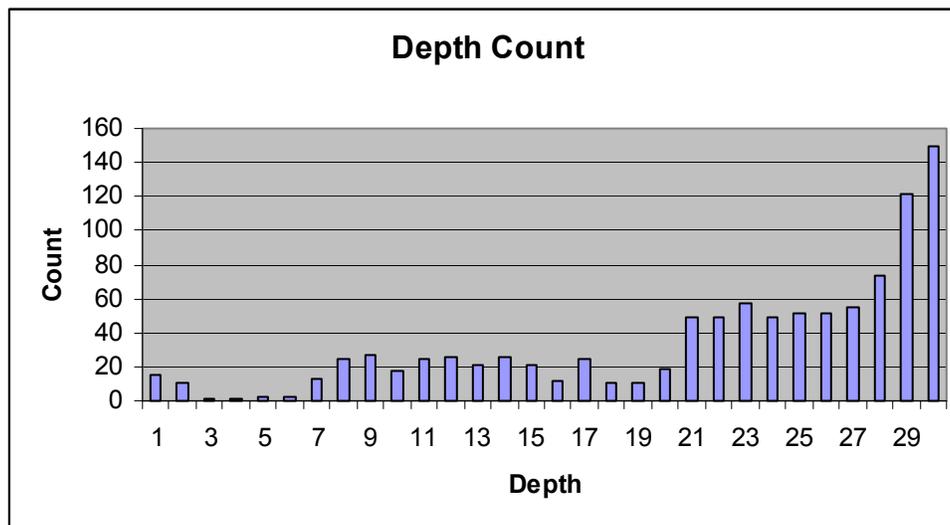


Figure 43 - Count of valid rounded depth values

5.2.1.2 GPS ERRORS filter

The GPS ERRORS filter identifies GPS coordinates that are more than two standard deviations from the mean of the ten previous points using a sliding window for both the X and Y positions. The Excel formula for the filter calculated at row 10 for X and Y are:

```
=IF (ABS(ABS(F11-F10)-1)>(2*STDEV(F2:F10)), "CHECK", "")
```

```
=IF (ABS(ABS(G11-G10)-1)>(2*STDEV(G2:G10)), "CHECK", "")
```

The GPS ERRORS filter removes 8 data points.

5.2.1.3 DEPTH ERRORS filter

The DEPTH ERRORS filter identifies and removes depth values that repeat more than 3 times and inconsistent depth values before a value with DepthValue set to “F”. DEPTH

ERRORS keeps the first value of a repeated series. The spreadsheet formulas for the filter calculated at row 10 are:

```
=IF (ABS(D11-D10)>(2*STDEV(D2:D10)), "CHECK", "")
```

```
=IF (D11=AVERAGE(D7:D10), "REMOVE", "")
```

```
=IF (OR(C12="F", C13="F", C14="F", C15="F", C16="F"), "SUSPECT", "")
```

The DEPTH ERRORS filter removes 5,850 data points.

5.2.1.4 SEGMENT ERRORS filter

This is a manual filter that consists of visually inspect the model and removing segments of information that are inconsistent with the surrounding data. The SEGMENT ERRORS filter removes 250 data points.

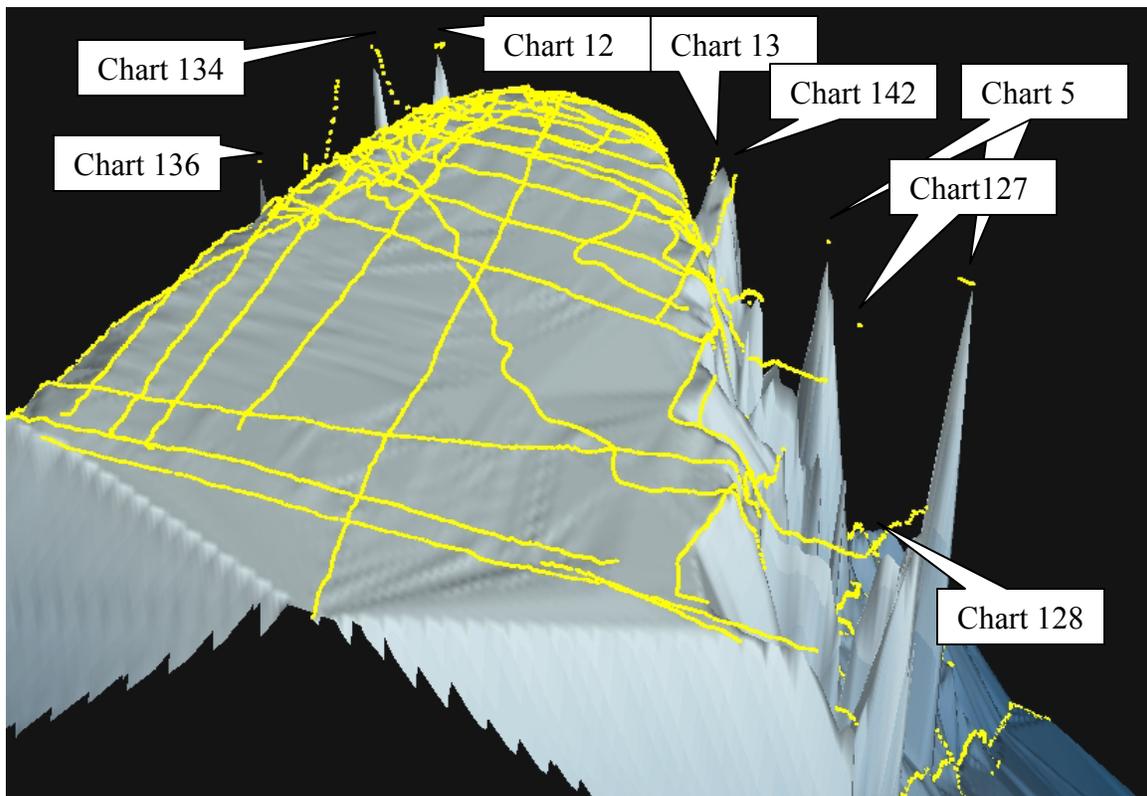


Figure 44 – Major segment errors

An example of inconsistency can be seen in Chart 33.

At the beginning of the data collection of Chart 33 the fish finder had difficulties obtaining a steady echo and recorded a shallower depth than expected. When the boat crossed the reef edge from shallow to deep the boat speed was too high and the fish finder had difficulties tracking the sudden drop accurately. It lost bottom and recorded a false ledge.

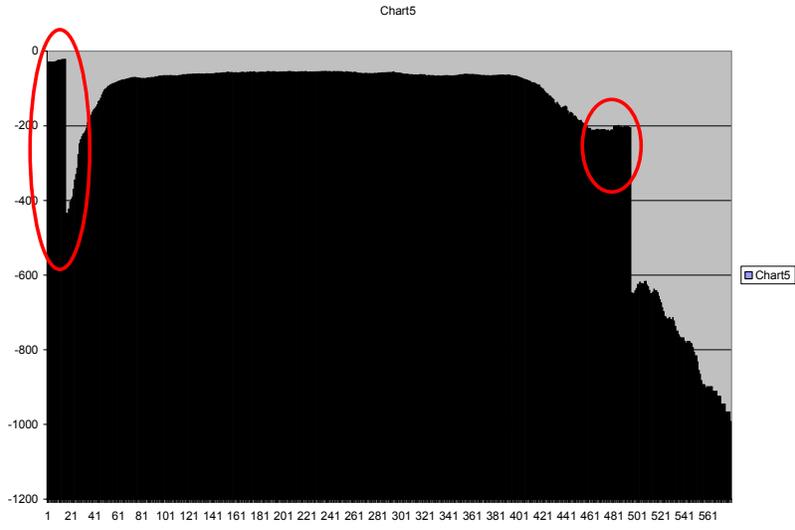


Figure 45 - Chart 5 before processing showing inconsistencies

Appendix C – Reef models with identical horizontal and vertical scales

Mapping reef models with vertical measurements in feet and horizontal measurements in meters results in vertical exaggerations. Displaying taller reefs is useful to position biological and hydrological phenomena because it leaves more space to draw them. However, sometimes there is a need to display real proportions. The following images have been corrected and use the same scale for horizontal and vertical measurements in order to display the reef without exaggeration.

