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Seamless Online Distribution of Amundsen Multibeam Data

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Abstract

Since 2003, all underway multibeam and sub-bottom data from the Canadian Coast Guard Ship Amundsen has been posted online within approximately six months of the end of each cruise. A custom interface allowing the user to access 15' latitude by 30' longitude mapsheets was implemented in 2006, allowing the user to download the bathymetric and backscatter data at 10 metre resolution. While this interface matched the underlying data management scheme implemented at the University of New Brunswick, the zoom and pan capability was at a fixed scale with limited contextual data.

In the past few years, with the introduction of web-based geographic information systems (GIS) (e.g. Google Maps, Yahoo Maps, Bing Maps), there have been thousands of maps published online. These online GIS programs are a suitable platform to display the seven years of Amundsen coverage within the context of the GIS-served satellite imagery and allow the user to freely browse all data in a familiar interface. The challenge, however, for serving up third party data through these map engines is to efficiently cope with the multiple zoom levels and changing resolutions.

Custom tiling software was developed to take all the raw data from the seven years of Amundsen (and others') multibeam coverage and convert it into multiple scale resolution images suitable for interpretation by Google Maps. The images were stored in a pyramid structure utilizing Google's map projection and uniquely named to reflect their georeferencing and resolution. This image pyramid is then accessed by Google Maps according to the user's current zoom level to optimize visualization. This multi-resolution data is served up on demand from the University of New Brunswick for dynamic overlay on Google's satellite data.

This web interface allows any interested parties to easily view multibeam and sub-bottom data from the Pacific Ocean through the Canadian Arctic Archipelago and into the Atlantic Ocean. The broad overview helps to understand regional trends and then focus on areas of interest at high resolutions to see particular features. The web interface also provides a link to the 15' by 30' mapsheet model with full source traceability.

Introduction

The Ocean Mapping Group at the University of New Brunswick has been working in the Canadian Arctic as a member of ArcticNet. ArcticNet is a collection of Universities and research institutes, made up of students, researchers and managers that work together with government, industry and northern communities to study climate change in the coastal Canadian Arctic. ArcticNet provides funding, and the CCGS Amundsen as a platform to perform marine research in the coastal Canadian Arctic. The ongoing mapping of the Amundsen has been divided into both seabed science investigation and geomatics engineering research which has inspired multiple thesis topics for members of the Ocean Mapping Group. The role of the Ocean Mapping Group in ArcticNet is to “map the bottom topography and geological structure of the Northwest Passage and other regions of the Canadian Archipelago as a first step towards the management of increased intercontinental ship traffic and resource exploration as ice conditions improve, and will contribute invaluable information to assess the economic, sovereignty and security implications of an ice-free NW Passage.” [Fortier, 2003].

The Ocean Mapping Group has been collecting data in the Arctic since 2003, on board the CCGS Amundsen, CCGS Nahidik and the CSL Heron, which is on loan to the University from the Canadian Hydrographic Service. As discussed by Bartlett et al. [2004], the Amundsen mapping platform consists of: a Kongsberg EM 302 (recently upgraded from an EM 300) 30 kHz multibeam echosounder, Knudsen 320R 3.5 kHz sub-bottom profiler, C&C Technologies CNav differential GPS receiver, Applanix POS/MV inertial navigation system, ODIM Brooke-Ocean (Rolls-Royce) MVP 300 moving vessel profiler, Seabird 911 CTD, Honeywell Barometer, and Applied Microsystems surface sound speed probe.

The Heron mapping instruments included: a Kongsberg EM 3002 multibeam echosounder, Knudsen 320B 3.5 and 28 kHz sub-bottom profiler, Knudsen 320B 200kHz single beam and sidescan echosounders, ODIM Brooke-Ocean (Rolls-Royce) MVP 30 moving vessel profiler, C&C Technologies CNav differential GPS receiver, CODA F-180 motion sensor, and AML surface sound speed probe.

The Nahidik mapping instruments included: a pole mounted Kongsberg EM 3002 300 kHz multibeam echosounder, CODA F-180 motion sensor, and C&C Technologies CNav differential GPS receiver.

Spending seven years in the Arctic has resulted in approximately 2,000 15' x 30' ArcticNet basemaps containing over 102,000 km² of bathymetric data. With each new field season, the Ocean Mapping Group will continue to build up multibeam and sub-bottom coverage in the Arctic providing safe passage for ship traffic as well as study the bottom topography and geological structure of the North West Passage. The Ocean Mapping Group also collects data about the salinity, temperature, and density of the water for oceanographic purposes, water column backscatter data and GPS positioning in the Arctic. The problem with collecting large datasets is managing each individual dataset and finding a suitable platform to display and link each dataset together.

Current Platform

The collection of multibeam and sub-bottom data in the Arctic has driven a strong demand for viewing and downloading the data online. In 2003 the Ocean Mapping Group was collecting multibeam and sub-bottom data during opportunistic surveys and short, dedicated site surveys. The data collected in the Arctic was sparse, which allowed the distribution method of multibeam and sub-bottom data to focus on corridors of data. As discussed by Beaudoin et al. [2008], in 2003 a Stripmap website (see figure 1) was developed which contained two different sun-illuminated bathymetry (across track and along track) images, a backscatter image and a correspondingly georeferenced sub-bottom image. To compliment these images, overview and location maps were added, providing the necessary contextual information. This online distribution provided users with the full picture of the sea floor (bottom topography and its underlying sediment layers) in 25km x 5 km mapsheets. For each year, users could walk through each 25 km stripmap viewing the multibeam and sub-bottom data.

In 2006, after four years of building up coverage in the Arctic, the multibeam distribution method was shifted to areas of coverage. As discussed by Beaudoin et al. [2008], in 2006 the ArcticNet Basemap Series (see figure 2) was developed which contained a set of tiled bathymetry and backscatter images. Each basemap covered 15' of latitude and 30' of longitude, at a resolution of 10 metres and in the Lambert conformal conic projection. These basemaps also contained an overview and location map to help place the data in geographic context.

The basemap website was a custom design, allowing users to view and download (as ESRI grid files) all of the bathymetry and backscatter information collected in the Arctic since 2003. For those concerned with data management and quality, it provided full source traceability, including details on all lines of all years that contributed to each mapsheet. New developments in web-GIS programs presented opportunities to improve upon this method and serve up multi-resolution imagery seamlessly, with more detailed contextual information.

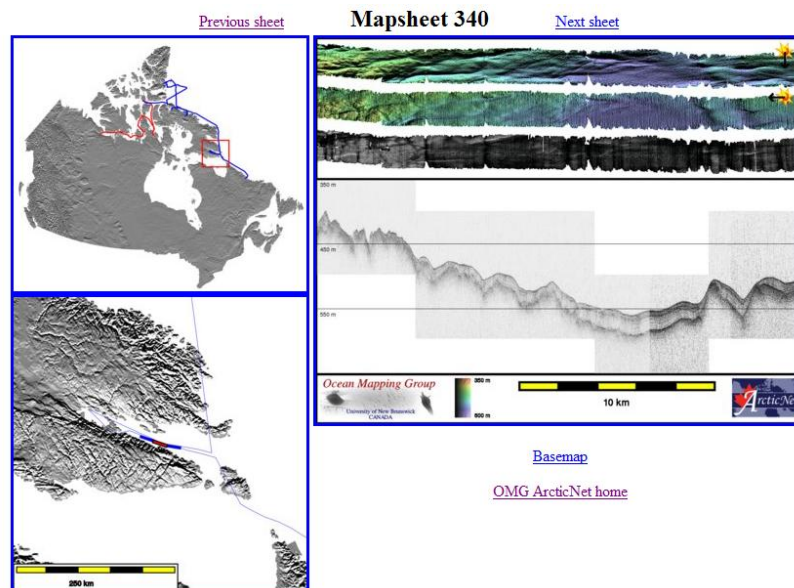


Figure 1. The ArcticNet Stripmap website [Ocean Mapping Group (2), 2010].

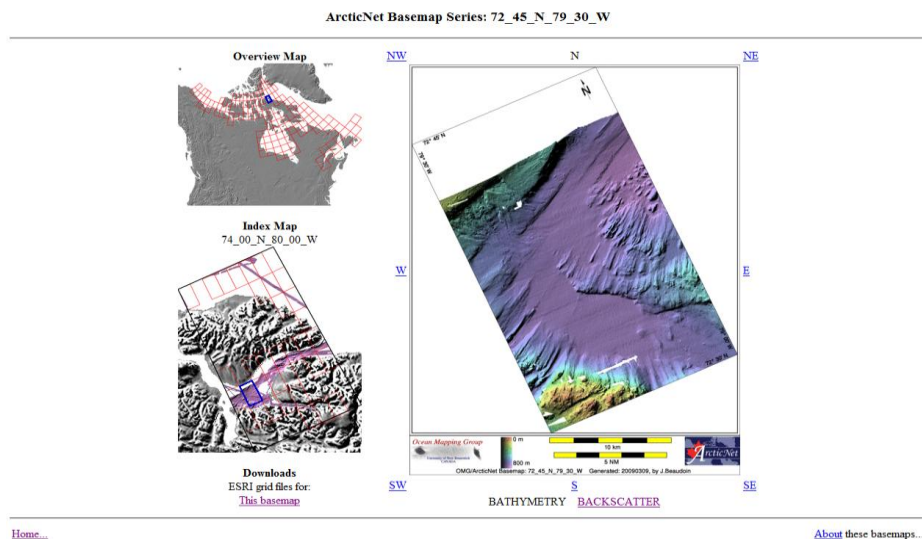


Figure 2. The ArcticNet Basemap Series website [Ocean Mapping Group (1), 2010].

Proposed Platform

The objectives for this project were to have the Ocean Mapping Group's data overlaid on a contextual background image, allowing users to pan and zoom to any area they choose. There was also a need for users to have the ability to download the multibeam data in the 15' latitude by 30' longitude, 10 metre resolution basemap format.

Geographic information systems (GIS) have been around since the 1960s, although they were typically expensive, difficult and proprietary, which limited their use. GIS systems have the ability to display the geographic area, at a user specified scale, viewed from above and also relate this geographic data with other information types [Geller, 2007]. Relating the geographic data to other information made GIS a suitable platform to display all of the Ocean Mapping Group's data.

Since 2004, there has been an increase in the development of free web-based geographic information systems, with Google Maps, Yahoo Maps, Bing Maps and MapQuest being the most common [Geller, 2007]. Developers have taken advantage of this and published hundreds of thousands of maps online. These web-based systems had a small set of GIS tools, however many

third-party “mash-ups” have been related to these GIS tools, allowing developers to add more functionality to their maps [Elias et al., 2008]. A mash-up is mixing two or more services from websites or web programs to create a new service. These web-based GIS systems allow developers and companies to display their data to anyone with access to the internet and an internet browser. These web-based GIS systems had a familiar user interface, making it easier for them to navigate and interpret the multibeam data.

The four main competitors (Google Maps, Yahoo Maps, Bing Maps and MapQuest) all have similar mash-ups implemented through JavaScript, and similar user interfaces. Google Maps was chosen as the web-based GIS system because it had a popular Application Programming Interface (API). The GIS tools available in the Google Maps API allow developers to add points, lines, polygons and custom overlays to the map, as well as geocode addresses [Google, 2009]. Google Map’s background imagery had a combination of satellite imagery and aerial photography with varying resolutions depending on the viewing location. Urban areas were typically covered with higher resolution imagery and rural or unpopulated areas were typically covered with lower resolution imagery. Google Maps also introduced Google ocean imagery, which was coarse (~10 km [Sandwell and Smith, 2010]) bathymetry for the ocean basins. The ocean imagery was created from the sea surface undulations, caused by sub-seabed gravity differences, which were recorded by satellite altimetry [Stewart, 1985]. The satellite and ocean background imagery was a suitable backdrop to provide the contextual data necessary for the Ocean Mapping Group’s data.

Google Maps was a suitable web-GIS platform, however it was still not the perfect solution to online data distribution. One of the disadvantages to using Google Maps was the use of the Mercator projection which does not show the poles. This was because a Mercator projection distorts the imagery as the latitude increases or decreases away from the Equator. As the imagery approached the poles, the distortion became infinite, which was why Greenland appeared to be larger than Africa, however it was the opposite. The Mercator projection was a standard map projection for nautical charting because it presented lines of a constant bearing as straight lines. Another disadvantage was the high resolution satellite imagery covered mainly the urban areas

(sparse in the Arctic). The high resolution satellite imagery and aerial photography was not commercially available in all areas of the world and it was expensive to purchase. This was not a major concern because the low resolution satellite imagery was comparable to most of the shorelines on electronic charts in the Arctic.

The last disadvantage was Google's ocean imagery was only available at lower resolutions and zoom levels. In areas away from the coast and at higher zoom levels (>10), the ocean imagery disappeared and was replaced with a grey background. This caused a few problems for the overlay of Ocean Mapping Group tiles, as they would not be displayed over areas with no ocean imagery. Displaying the Ocean Mapping Group tiles in these areas involved creating an array of overlays. The base layer was made up of white tiles. On top of the base layer was Google's satellite tiles, and the top most layer was the Ocean Mapping Group's custom tiles.

Methods Used To Overlay Data

The scale of the Ocean Mapping Group's dataset meant that an efficient method must be used to create, store and display the data online. Google Maps provides two types of custom overlays, ground overlays and tile overlays. While both types of overlays display images on top of the background data, they are very different in how they were implemented.

The ground overlay method was suitable for a small dataset covering a small area. It was relatively simple to implement, where developers only needed to have an image, with a transparent background, and the Southwest and Northeast latitude / longitude coordinates of the image. This overlay displays the image at one resolution, regardless of zoom level, making the loading time slow if more than one or two images were implemented this way or the resolution was finer than the current zoom level.

The tile overlay method was suitable for displaying all sizes of datasets. This overlay method was more complex in its design and implementation. Developers needed to create a pyramid structure (see figure 3) that varied the resolution according to the zoom level and latitude of the

overlay. At the lowest zoom level (zoom level 0), where the whole world was visible, the resolution of the data could be very low because of the map scale. At the highest zoom level (zoom level 19), where details such as vehicles and houses were visible, the resolution of the data needed to be high so the overlay did not become pixelated.

The tile overlay method involved creating a 256 by 256 pixel image, for each zoom level, everywhere multibeam data was collected. The number of potential tiles that needed to be created increased with the zoom level. For each subsequent zoom level, the image is divided into four tiles (see figure 4), thus giving the equation for the number of tiles necessary to cover the world as:

$$\text{Number of Tiles} = 4^n \quad (\text{where } n = \text{zoom level}).$$

Tiling the data drastically speeds up the load time of the online map because it only loaded the tiles, at an appropriate resolution, within the current user’s map bounds.

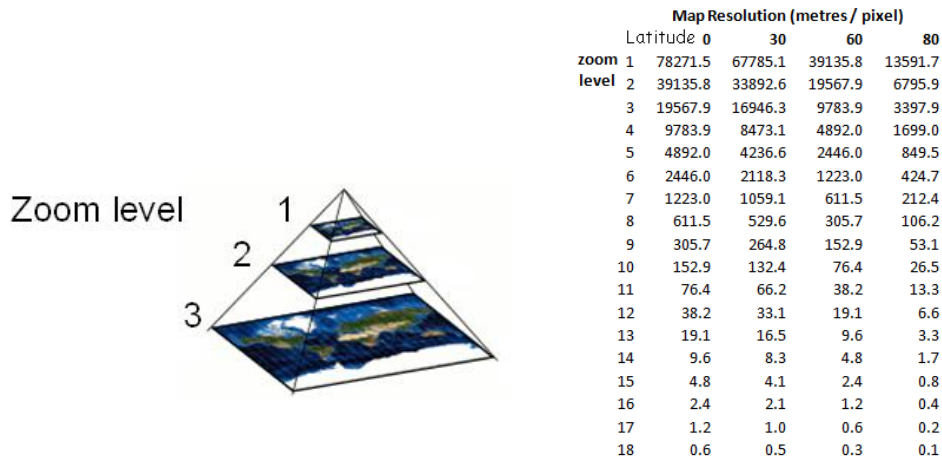


Figure 3. The pyramid structure used by Google Maps which varied the resolution of the image according to the zoom level and latitude [Pridal, 2008].



Figure 4. Tile creation for Google Maps, each tile was subsequently divided into four new tiles [Google Maps v2, 2010].

Creation of Tiles

Google Maps requires the tiles to be in a Spherical Mercator projection with a size of 256 pixels by 256 pixels. To create the tiles, the Ocean Mapping Group developed a custom software program. The program first needed to determine the latitude / longitude bounds of each 256 x 256 pixel tile covering the world. This was done using the following steps:

The Earth is divided into 360° of longitude and 180° of latitude. This represents a sphere, where the circumference at the equator is represented by 2π multiplied by the radius of the Earth ($R = 6378137$). Since a Mercator map does not show the poles, Google simplified their map by cutting off the poles to make the map square. To create the square map, Google used the circumference at the equator of $2\pi R$ to represent 360° of longitude and the total range of latitude. To calculate the upper latitude of the Google map, divide $2\pi R$ by 2 to give πR . Multiplying π by R equals 20037508.34 metres. Converting 20037508.34 metres to decimal degrees from the Mercator projection formula found in Maling [1973, p.153]:

$$y = \log_e \tan \left(\frac{\pi}{4} + \frac{\varphi}{2} \right)$$

rearranging to solve for φ :

$$\varphi = 2 \tan^{-1}(e^y) - \frac{\pi}{2}$$

$$\varphi = 2 \tan^{-1}(e^{20037508.34 \text{ m} / R}) - \frac{\pi}{2}$$

$$\varphi = 85.0511^\circ$$

This meant that the top latitude of Google's map was 85.0511°.

To calculate the lower latitude bound of the tile, the pole to pole latitude must be known ($2\pi R$) as well as the zoom level of the tile. The formula for calculating the lower bound:

$$\text{Lower latitude tile bound} = -2\pi R / 2^{\text{zoom level}} + (\text{upper latitude tile bound in metres})$$

The lower latitude tile bound was then converted to decimal degrees using the Mercator formula:

$$\varphi = 2 \tan^{-1}(e^y) - \frac{\pi}{2}$$

The upper latitude was then set to the lower latitude bound for the calculation of the next tile.

The left longitude tile bound was first set to the most Westerly longitude of the Mercator projection (-180°).

To calculate the right longitude tile bound, the circumference of the Earth must be known (360° of longitude) as well as the zoom level of the tile. The formula for calculating the right bound:

$$360^\circ / 2^{\text{zoom level}} + (\text{left longitude tile bound})$$

The left longitude tile bound was then set to the right longitude bound for the calculation of the next tile.

The program used the navigation tracks from the CCGS Amundsen, the CCGS Nahidik, the CSL Heron and other vessels to determine which tiles needed to be created. This was done by determining which tile the navigation track intersected at the highest zoom level (zoom level 14). For each tile that needed to be created, a list of the cleaned multibeam files that contributed to that tile was also created. The program then created each tile at the highest zoom level by gridding the multibeam data into each tile at a custom resolution and named the tile according to the latitude / longitude (row / column) position and zoom level (see figure 5). The resolution for each tile was determined using the following formula:

$$\text{Map resolution} = (\text{resolution (m/px) at Equator for zoom level 0}) * \cos(\text{latitude}) / 2^{\text{zoom level}}$$

*where resolution at Equator = $(2\pi R) / 256$ pixels per tile

*where R = 6378137.

After the multibeam data was gridded into the tiles, each tile was sun-illuminated to give the image a 3-dimensional appearance. The data was then colour shaded according to depth using the Ocean Mapping Group's custom bathymetric colour scheme. The colour scheme was deliberately chosen to be the same throughout the entire Arctic dataset with colour coded depths from zero metres to 1000 metres (everything below 1000 metres was a constant colour). The colour coded and sun shaded tiles were then converted to a PNG image, supported by Google, with a transparent background. The transparent background allowed Google's background imagery to be visible under the Ocean Mapping Group's tiles.

Following the creation of the highest zoom level (level 14), the tile images were collapsed to create the lower resolution zoom levels (zoom level 13, 12, 11... 3). For each lower zoom level (e.g. level 13), the four tiles in the original zoom level (level 14) were used to generate one tile in level 13. The collapsing was done using the name (row, column and zoom level, see figure 5) of each tile in zoom level 14 to determine the name of the tile for the level 13. This was done using the following calculations:

$$\text{Level 13 column} = (\text{Level 14 column} + 1 / 2^{\text{zoom level 14}}) * 2^{\text{zoom level 14} - 1}$$

If the level 14 column was odd, add 0.5 to the level 13 column and then subtract 1. If the level 14 column was even, subtract 1 from the level 13 column.

$$\text{Level 13 row} = (\text{Level 14 row} + 1 / 2^{\text{zoom level 14}}) * 2^{\text{zoom level 14} - 1}$$

If the level 14 row was odd, add 0.5 to the level 13 column and then subtract 1. If the level 14 row was even, subtract 1 from the level 13 row.

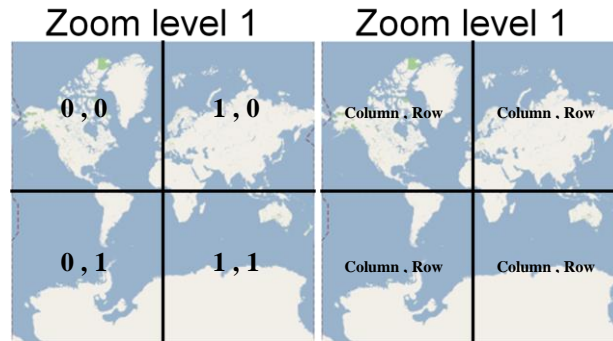


Figure 5. The naming (column, row, and zoom level) system for the Google Maps tiles (e.g. the top left tile name would be 0_0_1.png).

For each tile in level 13, the order (top right, top left, bottom right and bottom left) of the four tiles in the level 14 were calculated using the following steps:

Top left tile name = level 13 tile column * 2, level 13 tile row * 2, tile zoom level 13 + 1

Top right tile name = top left tile column + 1, top left tile row, zoom level + 1

Bottom left tile name = top left tile column, top left tile row + 1, zoom level + 1

Bottom right tile name = top left tile column + 1, top left tile row + 1, zoom level + 1

After the order of the four tiles in level 14 was determined, the program “imagemagick” was used to join the four images according to their order (see figure 6). The program created a new 512 x 512 pixel image which was then compressed to a 256 x 256 pixel image. This same method was used to collapse each subsequent level.

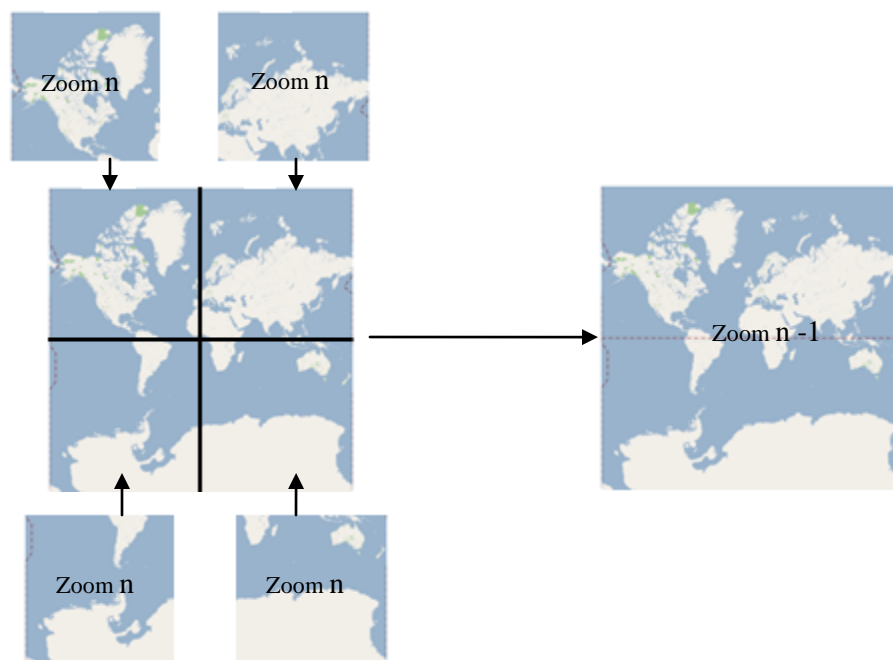


Figure 6. The four tiles from the higher zoom level (left) are joined to make the new tile in the lower zoom level (right).

Website

The creation of the website with Google Maps used Google's Application Programming Interface (API). The API is an interface that links Google's code to the web programming language Javascript. To embed Google Maps into a website, an API key was needed to register the website with Google. The API key can be obtained by registering and opening a Google account [Google, 2009].

The website with Google Maps compatible seafloor imagery was hosted on the Ocean Mapping Group's web-server at the University of New Brunswick. When the website was loaded onto a user's computer, satellite imagery tiles were loaded from Google's server to the website and the seafloor imagery tiles, stored on the Ocean Mapping Group's web-server, were served up on top of Google's satellite imagery. Only the tiles in the extent of the map window were loaded, which drastically improved the load time of the website as well as the load time when the user zoomed and panned.

Google Maps allows developers to customize the display of the map. In this project, map properties (map center and zoom level) were set when the website was first loaded and the satellite map type was chosen because Google added new low resolution ocean bathymetry to their satellite map. Standard Google controls: zoom and pan controls, map type control, scale bar, search bar, overview map and copyright information were added to the map to provide the user with a familiar interface. The following custom controls were added (see figure 7):

- Legend for the bathymetry
- Opacity control to make the satellite data transparent
- Checkbox to toggle the bathymetry on and off
- Map properties display to see the bounds of the map, the zoom level and the centre of the map
- The mouse: position on the map in latitude / longitude, position in pixels, the name of the tile the mouse is in, and the tile resolution
- A balloon with a link to download the multibeam grid files when the user left clicks
- Checkbox to toggle the strip maps on and off

The website was designed to allow users to continue to download the multibeam data in ESRI grid format. This was accomplished by linking the website to the ArcticNet Basemap series, where users could download the 15' latitude by 30' longitude mapsheets. This link was generated when the user left clicked anywhere on the map. The location of the mouse at the time of the click was passed to a function that calculated which ArcticNet basemap the mouse was in. To determine if there was basemap data where the user clicked, an xmlHTTP head request was sent in Javascript to determine if the basemap webpage existed. If the basemap webpage did not exist, no link to the corresponding basemap webpage was shown.

The strip maps (bathymetry, backscatter and sub-bottom data) were implemented into Google Maps as point overlays which were created from an xml file. The xml file had custom tags which contained the latitude and longitude of the centre of each 25 x 5 km mapsheet, the year the

stripmap data was collected, a link to the stripmap image, the name of the mapsheet and the colour of the custom icon (see figure 8). When the stripmaps were toggled on, users could click on the point marker and a balloon would pop-up showing the stripmap image with a link to the stripmap website (see figure 9).

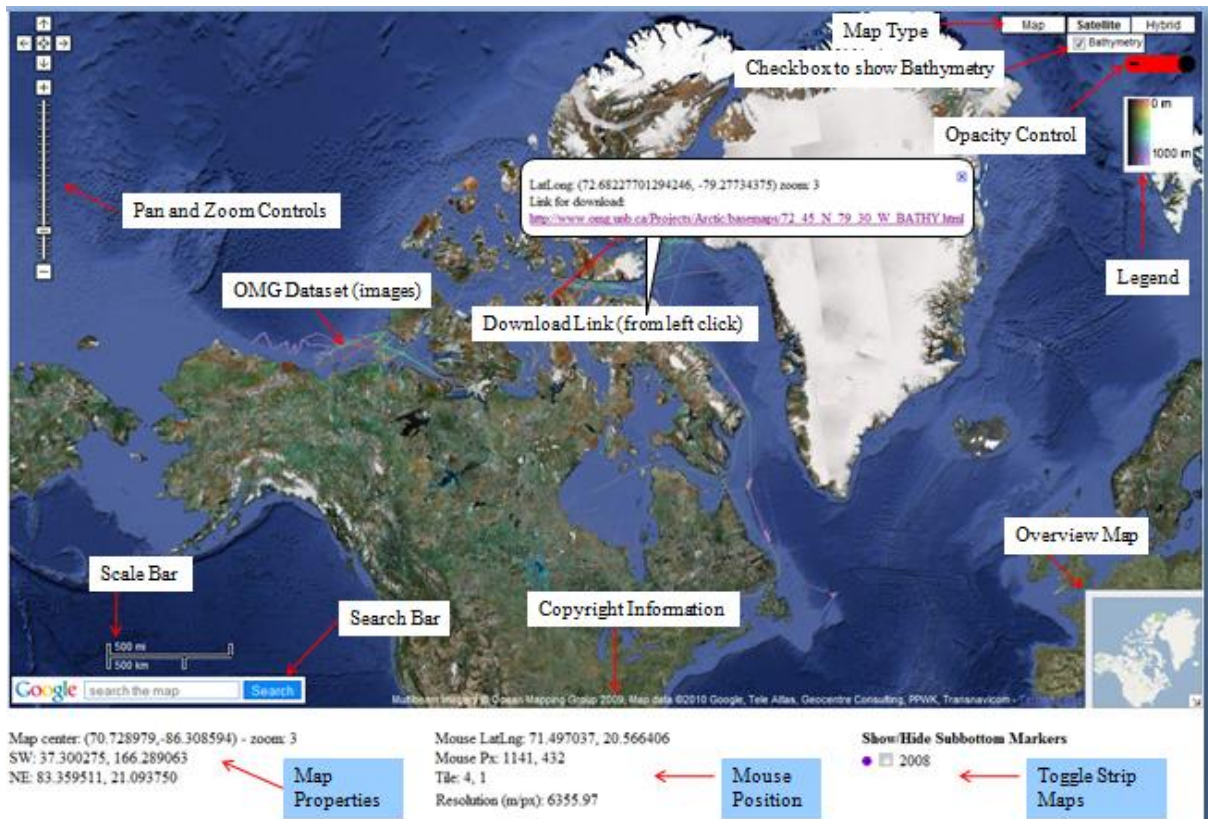


Figure 7. Standard map controls and custom map controls that were added to customize the map.

```
<markers>
<marker name="Mapsheet 0" address="http://www.omg.unb.ca/Projects/Arctic/stripmaps/nwp2008/img/strip_0.gif" lat="67.925121" lng="-114.973642" year="2008" icon="purple"/>
<marker name="Mapsheet 1" address="http://www.omg.unb.ca/Projects/Arctic/stripmaps/nwp2008/img/strip_1.gif" lat="68.020356" lng="-114.569748" year="2008" icon="purple"/>
<marker name="Mapsheet 10" address="http://www.omg.unb.ca/Projects/Arctic/stripmaps/nwp2008/img/strip_10.gif" lat="68.546710" lng="-109.808829" year="2008" icon="purple"/>
</markers>
```

Figure 8. A sample of the xml file used to generate the stripmap point overlays.

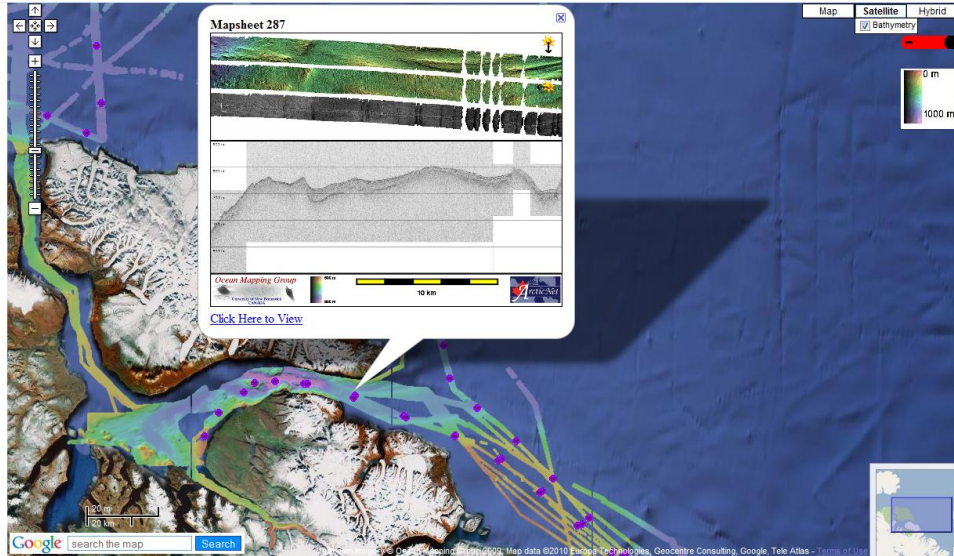


Figure 9. The stripmap image that pops-up when the point marker is clicked. The pop-up also has a link to the stripmap website.

Conclusion

The Ocean Mapping Group collects many different sources of data: multibeam bathymetry, backscatter, water column backscatter, sub-bottom, CTD and MVP casts for oceanography, GPS positioning and tidal information. Google Maps is a particularly agile platform for providing an alternate method to display the Ocean Mapping Group's large multibeam dataset, and it has the potential to provide a platform to link all other sources of data the Ocean Mapping Group collects. Rather than searching for data in many different locations, users can now go to one location (Google Maps) to search and link data both spatially and contextually. Users are able to get a broad overview of an Arctic region to understand the regional trends and then focus on areas of interest at high resolutions to see particular features.

Future Work

The current online distribution method, ArcticNet Basemaps, provided multibeam bathymetry and backscatter images to the users. Currently, this project only provides the multibeam bathymetry. Adding the backscatter tiles to Google Maps would help clients interpret the quality of the bathymetry and provide some rough seafloor classification.

The Ocean Mapping Group will continue to work in the Arctic, which means software needs to be developed to update the tiles after each field season. This update needs to be completed within a reasonable time span after each field season. The solution will be to create a tile for each year of data collection, and then combine the tiles from all years into one new tile.

As new developments and new versions of Google Maps API become available, the website will need to be maintained and updated. This is important to keep up-to-date with the ever evolving web-GIS industry.

Suggested Readings

- Google Maps API documentation [Google, 2009].

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