

Mapping Canada's Arctic Seabed: Collaborative Survey Processing and Distribution Strategies

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Abstract

There has been recent renewed political interest in mapping Canada's north, for example the October 2007 throne speech to Parliament stated that "As part of asserting sovereignty in the Arctic, our Government will complete comprehensive mapping of Canada's Arctic seabed. Never before has this part of Canada's ocean floor been fully mapped."

The Canadian Hydrographic Service, the Geological Survey of Canada and the ArcticNet NCE program have been mapping in the Arctic for many years and have amassed considerable amounts of data. Current clients require this data for all of navigation, engineering, natural resources and benthic habitat applications. Thus, products beyond "least depths", including geomorphology, surficial backscatter and shallow subbottom data, need to be processed and distributed simultaneously. Regarding future mapping efforts, there is a need to collate existing data sets and to make them available to the various parties that will be involved. This will facilitate their task by helping (1) to avoid redundant data collection and (2) to prioritize areas which should be remapped (e.g. due to low resolution or accuracy).

Through its involvement in ArcticNet, the OMG has developed an expandable data distribution model that allows for web-based perusal and retrieval of the ArcticNet data set. As the model was developed to serve the various needs of the many parties involved with ArcticNet, the ideas are adaptable to serving the various agencies that will be tasked with mapping Canada's Arctic seabed.

Introduction

In 2003, the decommissioned 1200 class icebreaker Sir John Franklin was brought back into service as a multidisciplinary science platform for research in the Canadian Arctic Archipelago (CAA). Renamed the CCGS Amundsen, the 98-meter vessel serves as a floating research platform that can access the ice-choked passages of the CAA. It plays an essential role in the ArcticNet program, a Network of Centres of Excellence of Canada (NCE) that studies the impact of climate change in the coastal Canadian Arctic (Fortier and Leblanc 2003). In combination with land based studies, the Amundsen provides critical research infrastructure that will facilitate the ArcticNet NCE to reach its goal of integrating the natural, social, and human health sciences to assess how climate change will affect the Canadian Arctic environment, and more importantly, the people that live there.

Of the many research areas covered by the ArcticNet program, seabed mapping falls under Project 1.6 -- The opening Northwest Passage. The ArcticNet NCE proposal lists one of the goals of Project 1.6 as building “a precise bathymetry for the Northwest Passage and other areas of the Canadian Arctic”. The mapping goals are to provide data and support for multi-disciplinary science, navigation, resource exploration and to aid decision making regarding security and sovereignty in the Northwest Passage. Project 1.6 deals with mapping the seafloor topography, surficial and underlying geological structure in the Northwest Passage (NWP) and other areas of the CAA. Mapping data is collected as an initial step towards the management of the expected increase in international ship traffic and resource exploration due to predicted improving ice conditions. It will also be used to help analyze the economic, sovereignty and security implications of an ice-free NWP. Mapping instrumentation currently includes:

- Kongsberg-Simrad EM300 30 kHz multibeam echosounder (MBES)
- Knudsen 320BR 3.5 kHz sub-bottom profiler
- Applanix POS/MV 320 inertial navigation system
- C&C Technologies CNAV Differential GPS receiver
- Odim/Brooke Ocean Technology MVP 300 moving vessel profiler
- Seabird 911 CTD
- Applied Microsystems Ltd. surface sound speed probe

To date, the Amundsen has completed five round-trips to the Canadian Arctic (refer to Figure 1), with approximately 80 days of continuous transit-style mapping completed annually (multibeam and subbottom). Ship-time onboard the Amundsen is shared amongst many research projects. As such, dedicated seabed mapping is restricted to a few locations per year; however, the EM300 system is operated continuously while in transit with the intent of slowly building coverage with each year’s transit through the NWP. Though the vessel’s seemingly random wanderings in any given field season may seem insignificant, the ArcticNet NCE has the potential to run as long as 14 years, thus a substantial amount of mapping can be completed, albeit in an unusual manner. Given the scarcity of available data in the region, the ArcticNet mapping program provides invaluable information for this new frontier: the data is currently being used to open up new potential shipping lanes and identify potential geohazards to oil and gas development including slope instability, shallow gas venting and iceberg scouring.

The Ocean Mapping Group (OMG) has been involved with the ArcticNet program since the very beginning and has been responsible for acquiring, processing and distributing the mapping data collected by the Amundsen. As with any project of this magnitude, there are challenges at each stage; these are compounded by the large geographic domain being mapped by the Amundsen. It is the intent of this paper to present the challenges encountered throughout the 2003-2007 period in the hopes that the experience gained by the OMG with this large scale project can be applied to the benefit of future large scale mapping campaigns in the Canadian Arctic.

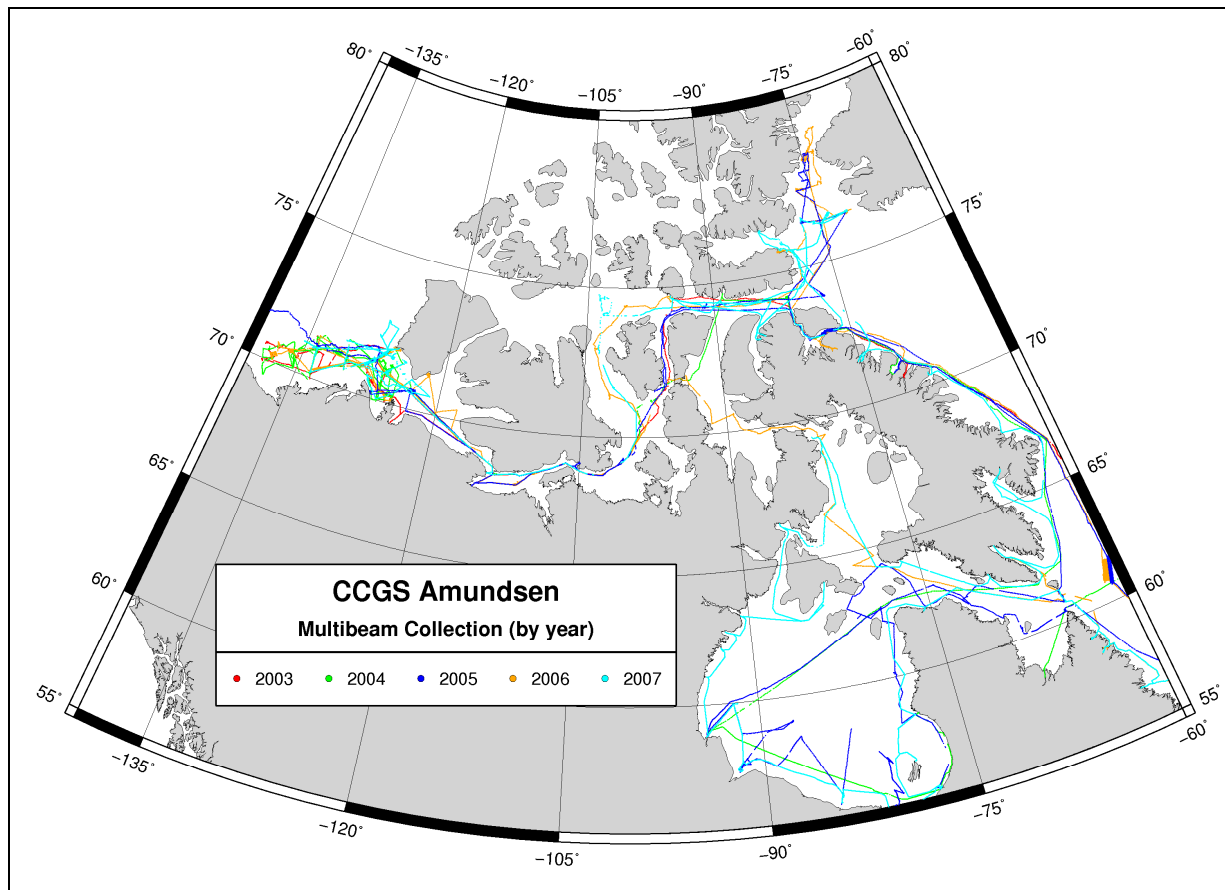


Figure 1. Ship track of the CCGS Amundsen, 2003-2007

Processing

Processing problems include poor or non-existent vertical control and sparse sound speed profiling while underway. Of course, there are other occasional problems, such as biases in surface sound speed due to ice clogging of the surface sound speed probe's pump (Beaudoin and Hughes Clarke 2004). These intermittent cases require focused post-processing on a very limited set of data. The vertical control and sound speed profile issues, on the other hand, are problematic throughout the entire data set and deserve more attention.

Vertical Control

The problem of vertical control is essentially this: the Amundsen transits thousands of kilometers each year through areas with very few tide gauges and very large distances between existing gauges. Other authors have examined using the height from the CNAV differential GPS antenna (Wert et al. 2004; Hughes Clarke et al. 2005). This approach has the drawback that satellite signals are often interrupted in areas of steep topography, which is very common in the eastern CAA (Church and Hughes Clarke 2007). Further to this, the tidal signal in many parts of the western CAA is at the noise level of the vertical component of the CNAV differential position (Hughes Clarke et al. 2005). Additionally, the ellipsoid antenna heights must be

reduced to a surface that is meaningful to navigators. This may be problematic as long wavelength errors may exist in the ellipsoid-geoid separation models in the CAA, though this has yet to be confirmed (Hughes Clarke et al. 2005).

Until these problems are resolved, an interim solution has been found in the WebTide hydrodynamic models for the Arctic, Hudson Bay and Northwest Atlantic regions. The WebTide models are 3D finite-element barotropic ocean circulation models which can be used to predict tidal currents and sea surface elevation at any point in the model mesh (Dunphy et al. 2005; Saucier et al. 2004; Dupont et al. 2002). The spatial domains of all the WebTide models are shown in Figure 2 and an example of the Arctic model mesh in the vicinity of Pond Inlet is shown in Figure 3. Note that all of the WebTide models are freely available online from the Department of Fisheries and Oceans' Ocean Physics Group website.

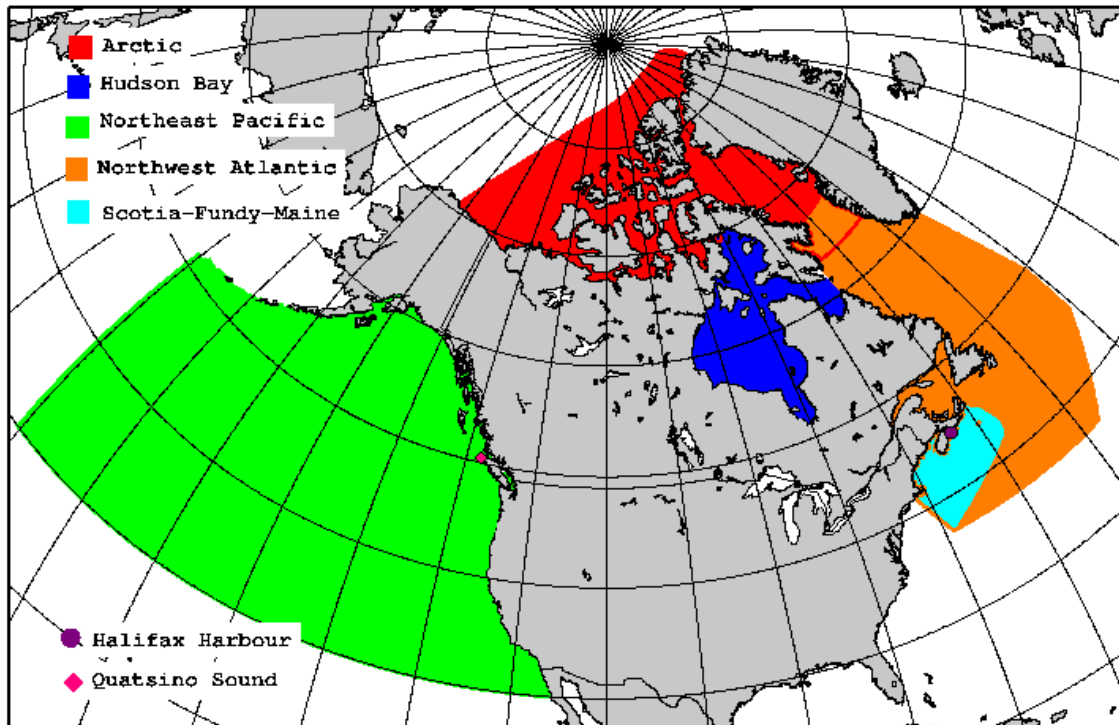


Figure 2. WebTide model coverage (after DFO, 2007)

Though WebTide provides a simple and elegant solution, this approach has its own set of problems. These are examined in turn below.

1. Working outside of model domains

There is a lack of coverage in some areas, notably Frobisher Bay leading into Iqaluit and many of the fjord systems on Baffin Island (see Figure 3). Furthermore, the representation of the coast is coarse and occasionally leaves out some of the shallower areas along the coastline, though this is less of a problem with the Amundsen in the Arctic as she is usually restricted to deeper waterways away from the coast. In all these cases, a tidal value is still required. In extreme cases such as Oliver Sound, an attempt has been made to create a higher resolution

hydrodynamic model, as discussed by Church and Hughes Clarke (1997). In simpler cases, this approach is overkill and a more straightforward line of attack is taken: use the tidal value of the nearest node of the mesh. This method has the drawback that a smooth, spatially interpolated solution is provided when within the mesh, but the solution locks onto the nearest node once outside the model domain and potentially introduces static shifts to the tidal height at the precise moment that the model domain boundary is crossed. This method can be refined by projecting the position onto the nearest edge and spatially interpolating between the vertices of the edge.

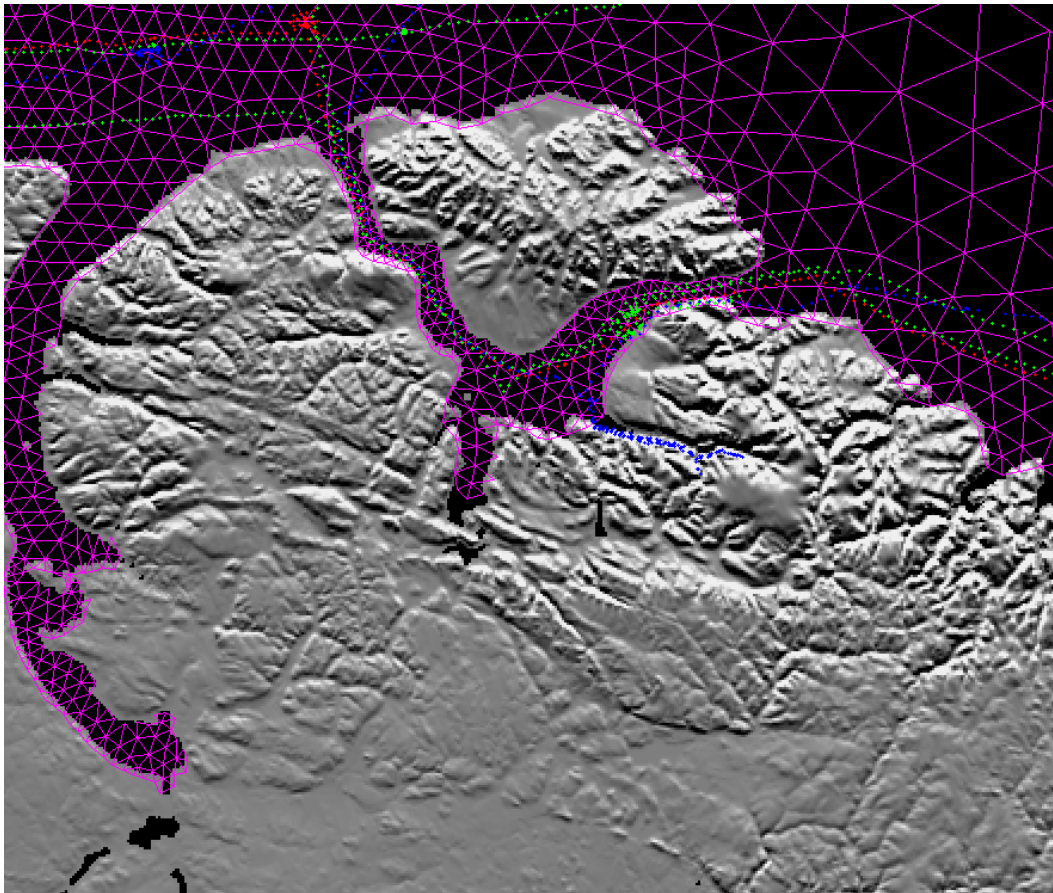


Figure 3. WebTide Arctic model mesh in the vicinity of Pond Inlet on northern Baffin Island, ship tracks for 2004-2005-2006 are plotted in red, green and blue, respectively. Note 2006 work in Oliver Sound was outside of the domain of the model (plotted in blue), refer to Church and Hughes Clarke (2007). Sun-illuminated topography was derived from the Can3D dataset.

2. Overlaps/gaps between model domains

There are cases of overlaps and gaps between the WebTide model domains. The overlap between the Northwest Atlantic and Arctic models in the Davis Strait region is clear in Figure 2, just east of the easternmost point of Baffin Island. Though not visible at the map scale in Figure 2, there is also overlap between the Hudson Bay and Arctic models in Fury and Hecla Strait, at the northern most extremity of Foxe Basin, north of Hudson Bay. More troublesome is the sliver gap between the Hudson Bay and Northwest Atlantic meshes, as shown in Figure 4. This is a variation of the “wandering off the mesh” problem discussed above in (1), and as before, the

elevation at the nearest node can be used, except perhaps in macro-tidal Frobisher Bay which is notably absent in the coverage of either model. In both cases of overlaps and gaps, the processor is faced with deciding where to switch from one model to the next.

In general, both of the problems discussed above reduce to choosing the most appropriate model for any given position. Choosing an appropriate model is not necessarily straightforward to automate since a requested position may:

1. Fall within one model domain only
2. Fall within overlap of two model domains
3. Fall outside of all model domains, but clearly near the edge of a single model (e.g. fjords on Baffin Island)
4. Fall outside of all model domains, but within a sliver gap between two models
5. Fall outside of all model domains, but at a far enough distance that it would be imprudent to use the water level of the nearest node (e.g. Frobisher Bay)

There are several thousands of survey lines collected to date, thus it is desirable to automate the model selection process. It is also desirable to remove any subjectivity in the decision making process as different processors may make different selections, or, the same processor may make different decisions from year to year.

Our solution is to define a coverage polygon for each model mesh that guides the WebTide lookup software into choosing an appropriate model, examples of polygon coverage are shown in Figure 5. The polygons are designed to (1) extend beyond the spatial coverage of the meshes in order to safely encompass all near shore areas that are not covered by the model, (2) extend and abut polygons from neighbouring meshes and explicitly define the boundary between adjacent model meshes (whether they overlap or not). Decisions about overlaps, gaps, edges are made only once, effectively removing repeatability issues. Further to this, the polygon map files serve as a form of metadata and can be readily provided along with any soundings or gridded data.

Turning to algorithmic details for a moment, the tidal lookup process begins by querying the desired position in the polygon map (the polygons are rasterized to facilitate lookup operations by avoiding point in polygon algorithms). One of two outcomes may occur: (1) the requested position falls within a polygon, or (2) the position falls outside the polygons. The second case can occur with gross outliers in navigation or when an area is deliberately omitted during the polygon construction process. The latter is the case with Frobisher Bay as it is not covered by the WebTide models. In this case, predicted tides at Iqaluit exhibit an increase of tidal range of approximately 4 m as compared to the nearest node of the WebTide mesh, located 250 km away at the mouth of Frobisher Bay. This large amplitude variation precludes a “nearest node” lookup, thus the bay has been deliberately omitted in the polygon coverage.

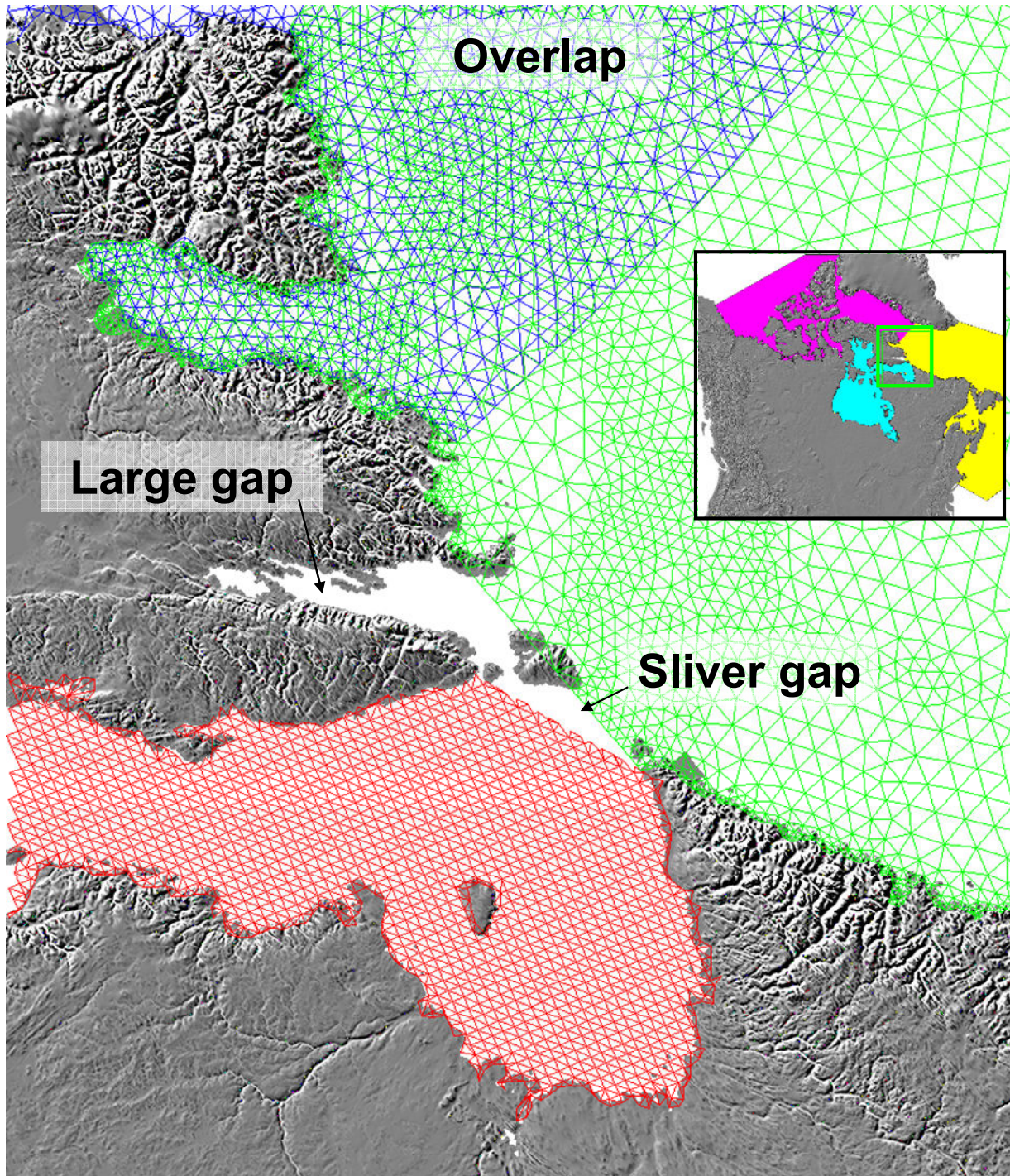


Figure 4. WebTide Arctic (blue), Hudson Bay (red) and Northwest Atlantic (green) model meshes in the vicinity of Iqaluit on southern Baffin Island.

Turning back to the first case, the polygon code is used to load the appropriate model data and lookup sea surface elevation at the desired position and time. If the position falls within the mesh, the elevation is spatially interpolated on the tilted plane defined by the elevation of the three vertices of the mesh element. If the position does not fall within the mesh, on the other hand, the elevation of the nearest node is used.

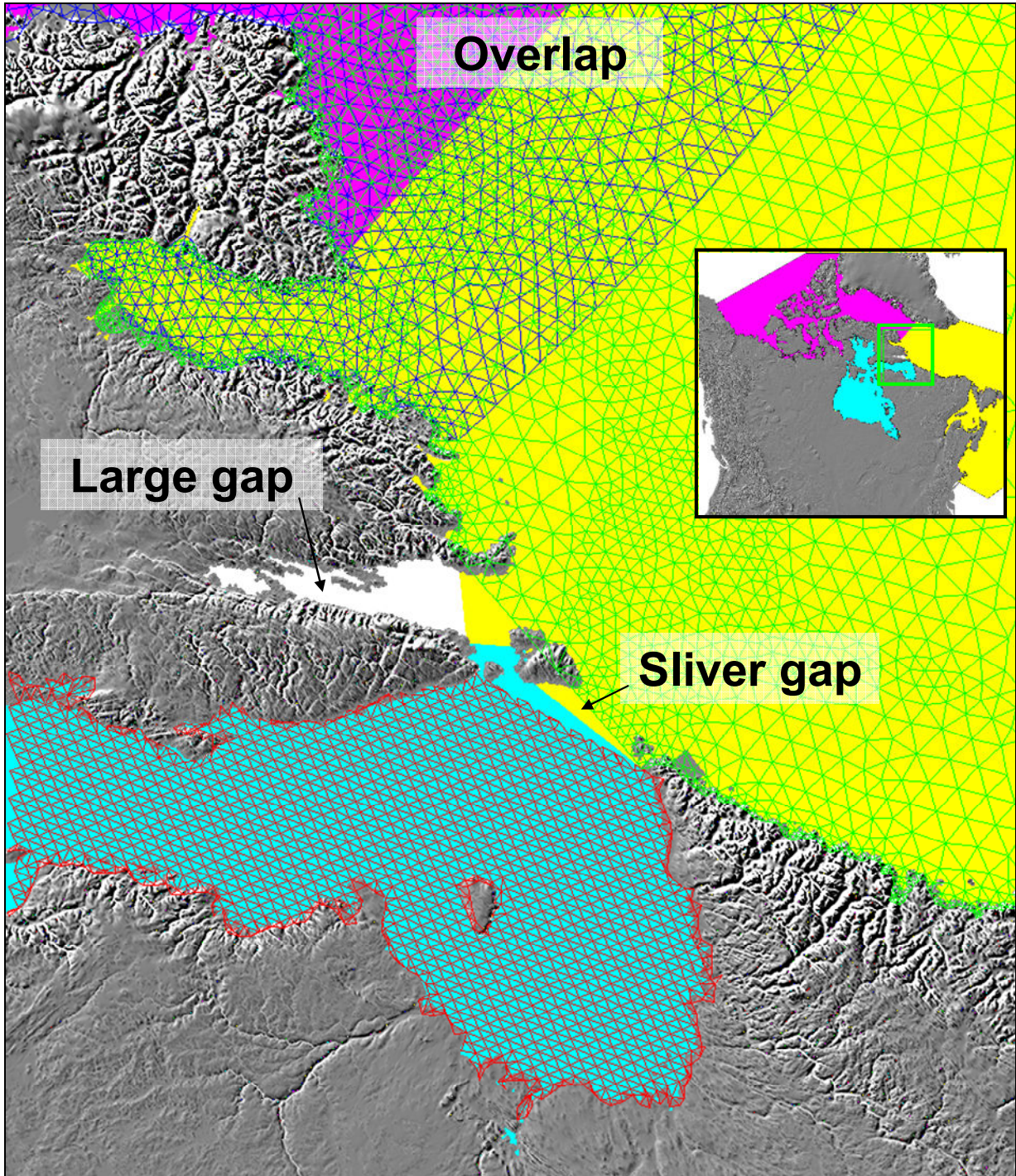


Figure 5. Polygon boundaries overlaid with WebTide model meshes.

3. Reduction to datum(s)

The sea surface heights provided by the WebTide models are referenced to mean sea level (MSL). For ArcticNet scientific bathymetric mapping, this vertical reference surface is adequate; however an alternate datum may be desired if the depths are to be used for navigation. No single chart datum can be used for the entire dataset as there are significant tidal amplitude

variations throughout much of the CAA. Church and Hughes Clarke (2007) have suggested using the four principal semidiurnal and diurnal tidal constituents provided by WebTide at each grid node to build a spatially varying datum. Though this approach may very well be appropriate for charting purposes, it adds a layer of complexity to the data in the sense that additional information must be recorded and provided to users in case they wish to remove the datum offset and reference depths back to MSL. As the majority of ArcticNet data users have scientific aims, the MSL reference has been left as the standard for data delivery thus the onus falls on the user to shift data to their own desired datum. As the lone “hydrographic” user of ArcticNet data, the CHS do not typically preserve the WebTide values provided with the ArcticNet data. They have expressed interest in applying WebTide to legacy CHS single beam transit data that has been collected over the years much in the same fashion that ArcticNet data is acquired while in transit.

Sound Speed Profiles

Though the Amundsen is equipped with state-of-the-art seabed mapping equipment, it must be remembered that mapping is NOT her primary mission. In fact, of the 80-120 days she spends in the Arctic each summer, only a handful of days are dedicated to regional mapping in areas of interest. Sound speed profiles are always collected at dedicated mapping sites, ensuring an accurate representation of the watercolumn. The remainder of the time, the Amundsen is in transit and multibeam data is collected simply because it can be. The data collected while underway are invaluable in previously unsounded areas; however, the accuracy of these data suffers as it is not feasible to collect more than a few sound speed profiles while in transit due to the tight ship scheduling. Though an MVP 300 is available onboard for the mapping and oceanographic teams, it is not always feasible to deploy due to the hazards posed by sea ice, as was the case in the 2003 field season. It was successfully deployed on numerous occasions in the first half of the 2004 field season, but mechanical wear rendered it inoperable for the second half of the season. Shortly after leaving Quebec City in 2005, the unit was lost during a dedicated site survey in the Labrador Sea (presumably caught in fishing gear). Unfortunately, it was not replaced until 2007.

An alternate source of sound speed information, in the absence of MVP profiles, is the CTD profiler used by the oceanographic team throughout the CAA. Without the MVP, the CTD casts provide the majority of sound speed information. Standard oceanographic operations involve intensive sampling over a limited geographic area, e.g. the North Water Polynya at the northernmost extremity of Baffin Bay or the Amundsen Gulf. In these areas, the soundings collected are very accurate due to the high sampling density along oceanographic sections. The oceanographic team collects CTD profiles intermittently throughout the NWP, mostly at the request of the mapping team. The number of profiles allowed is tied directly to how much the ship is behind schedule, with some field seasons enjoying a reasonable amount of casts while others are limited to only a few.

Two problems arise from the irregular collection of sound speed profiles. Firstly, and most obviously, there are insufficient profiles collected during some of the transits. This leads to systematic errors in the soundings. Secondly, the irregular profiling scheme demands that raytracing be done as part of post-processing, however, the irregular sampling scheme challenges simplistic profile selection routines (e.g. nearest in time, or nearest in distance). This introduces a substantial amount of pre-processing of the casts prior to re-raytracing the soundings.

1. Insufficient Sampling

It is imperative to find alternate sources of sound speed profiles in transit areas where the watercolumn is geographically undersampled. Since the speed of sound in water is a function of pressure, temperature and salinity, gridded oceanographic climatologies of average temperature and salinity values may be used to infer sound speed, an example of a commonly available climatology is shown in Figure 6.

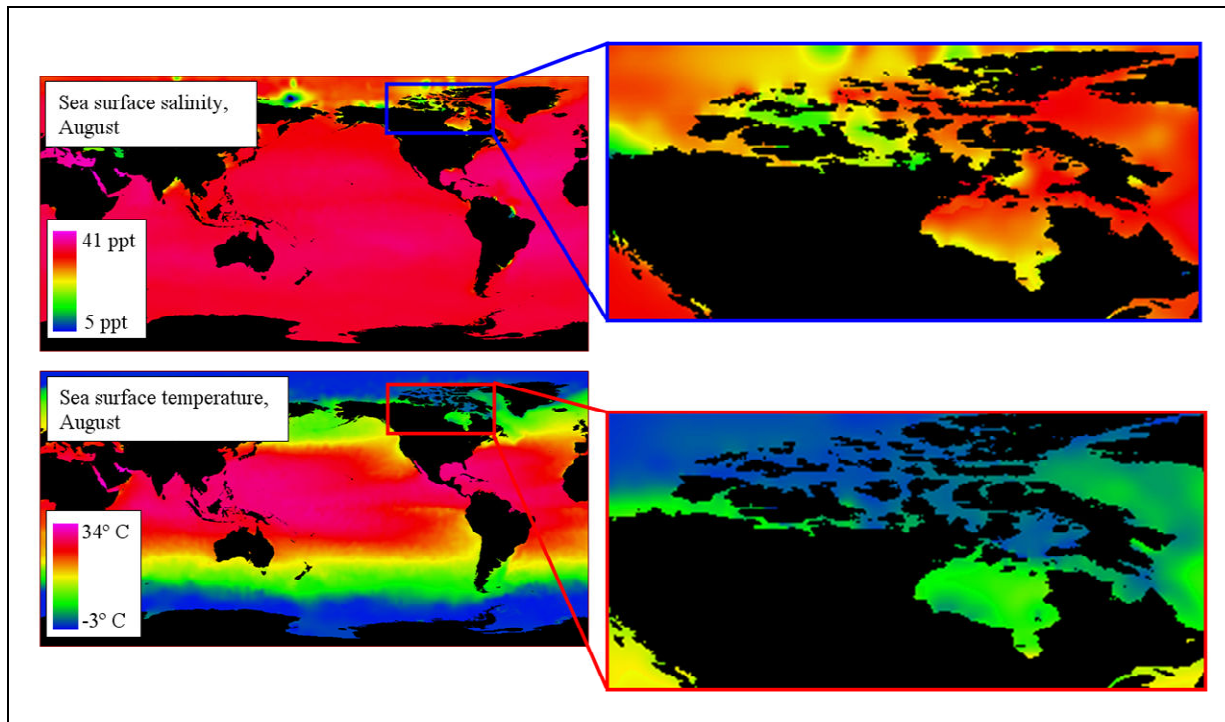


Figure 6. Sea surface salinity and temperature for the month of August, from the World Ocean Atlas (2001).

An oceanographic climatology is a regularly sampled grid of temperature and salinity and is meant to represent average oceanic conditions. A climatological grid is built from resampling from oceanographic databases of temperature and/or salinity profiles, for example, the World Ocean Database (WOD). Grids typically differ in horizontal, vertical and temporal resolution. For example, the World Ocean Atlas 2001 (WOA2001) is available with a horizontal resolution as fine as 0.25° whereas the vertical resolution varies with depth. The WOA01 grids are available as yearly, seasonal and monthly averages (see Figure 6). Though it is fully realized that the climatological profiles could not possibly replace actual measurements, it is expected that the derived profiles would prove to be “better than nothing” in the absence of adequate sound speed information during ship transit. The usage of climatologies is not without pitfalls. The paucity of oceanographic database observations in the CAA can potentially lead to biases in the average oceanographic conditions depicted by any given climatology, particularly in months where ship based oceanographic observations cannot be carried out (e.g. during formation and break up of ice cover). It is thus necessary to assess the suitability of a climatology for raytracing purposes before it can be used to reliably fill the gaps between sound speed profile sampling stations.

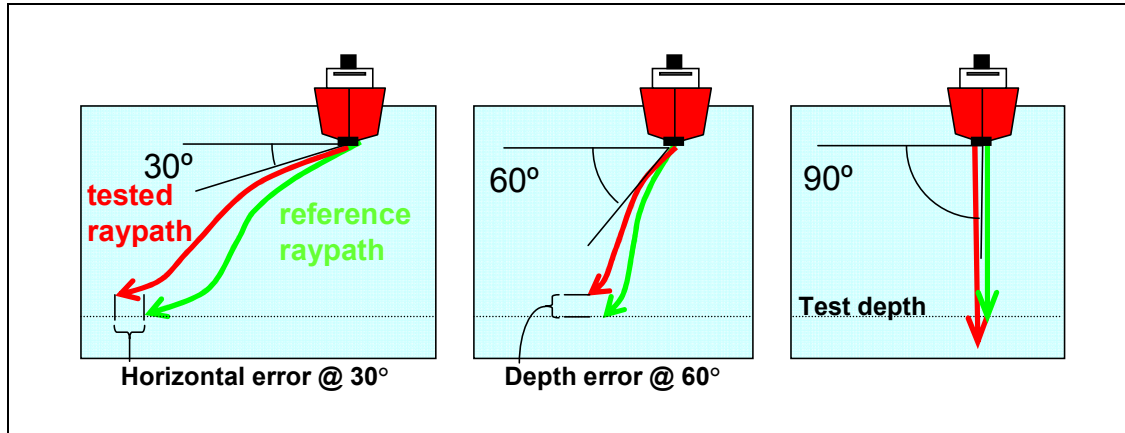


Figure 7. Cartoon depicting error evolution over a range of depression angles and a fixed test depth.

The difficulty then is how to assess a climatology as a source of sound speed information? This problem has been addressed in previous work (Beaudoin et al. 2006). Summarizing briefly, a raytracing simulation is used in which parallel raytracing solutions are computed for two sound speed profiles, one of which is considered a reference, or “truth” profile (refer to Figure 7). The raytrace simulation software can be used to investigate the discrepancy between the ray paths over the entire sounding space, i.e. from the outermost beam to nadir, and from depths immediately below the sounder down to the seafloor. Presented in the form of an image, it allows for an easily interpreted overview of the error resulting from use of the alternate profile (an example is shown in Figure 8).

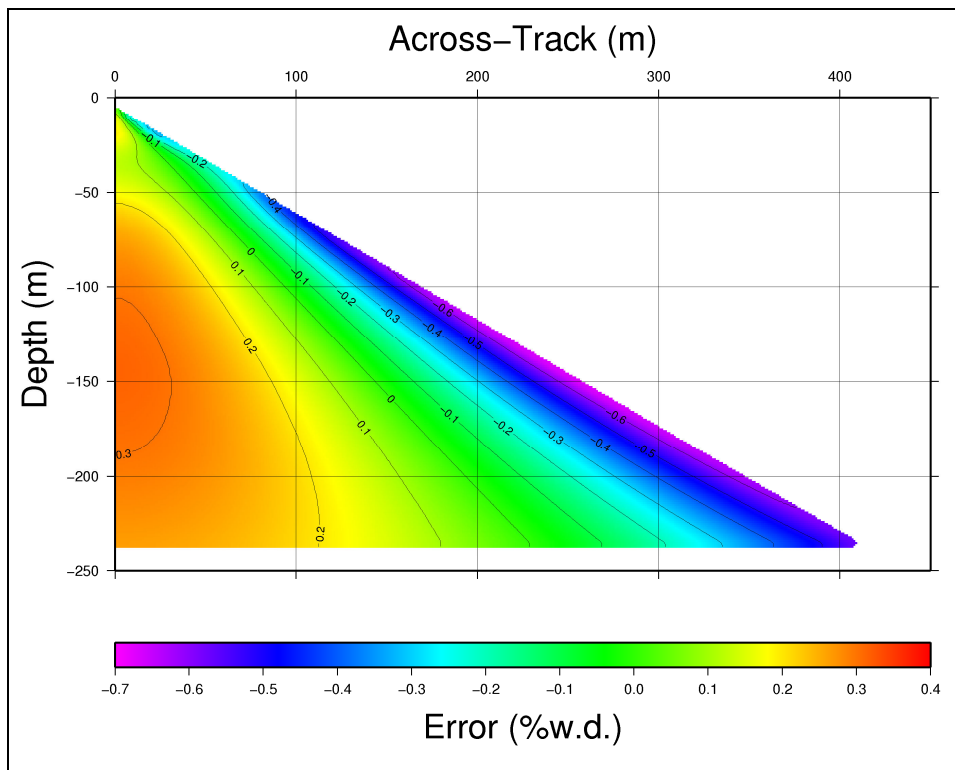


Figure 8. Example error wedge showing depth error across entire angular sector and full range of depths.

Alternate modes of operation of the software allow for the investigation of error across the swath at a fixed depth (Figure 9) and along any given ray path (Figure 10). In the first case, the discrepancies encountered across the entire swath (at a fixed depth) can be used to decide how much of the angular sector is within a tolerated specification at that depth, for example. Alternately, the worst case depth discrepancy encountered across the swath could serve as a simple scalar indicator of the general fitness of any of the alternate profiles in the immediate geographic area of the CTD collection site.

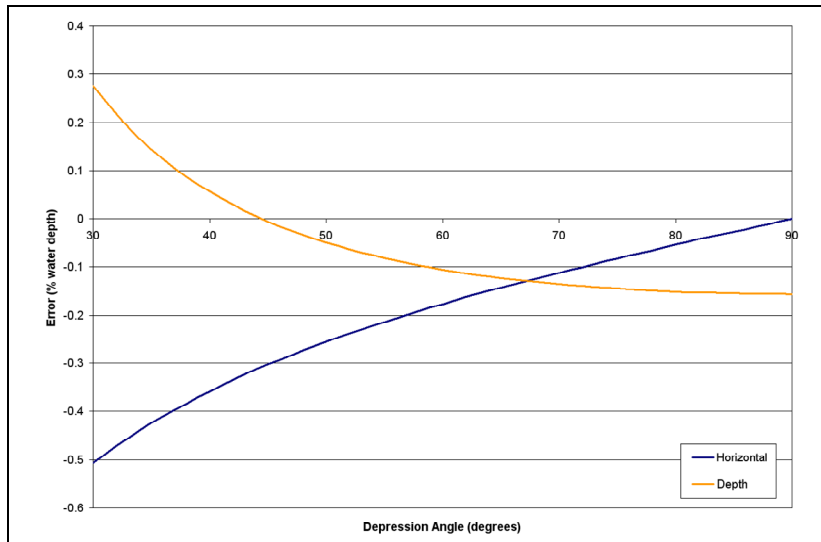


Figure 9. Example of variation of horizontal and depth error with depression angle.

The second case (Figure 10) investigates the depth evolution of error for a given raypath. Examining the raypath of the outermost beam (which typically suffers the most refraction error in wide swath systems) yields insight into the error evolution throughout the watercolumn.

Two benefits follow directly from a simulation approach. Firstly, it safely ignores all other sources of error, for example, vertical control, gridding artifacts in DTMs, or differences in sounding reduction methodologies

between real-time data acquisition software and post-processing software. Secondly, and perhaps the most important benefit, is that it requires no sounding data, thus it constitutes a generalized method that can be applied for any multibeam mapping system.

As pointed out by Beaudoin (2006), the several hundred ArcticNet CTDs serve as an independent source of reference profiles against which a climatology can be tested. In the 2006 work, the date and location of CTD derived sound speed profiles were used to lookup a climatologically derived sound speed profile. For each pair, a raytrace simulation provided an estimate of the error that would be incurred at that location if the climatological profile had been used instead of the true profile. Geographically plotting the worst case depth error at the end of the raytrace (the seafloor) gives an indication of spatial trends of climatology fitness, as is shown for a focused area of the NWP in Figure 11.

An alternative to using a climatology is to select proximal CTD casts from previous ArcticNet campaigns, where such information exists. A similar raytracing experiment was undertaken to gain an appreciation of the cost (in terms of sounding accuracy) of using profiles from previous field campaigns relative to the cost of using WOA01 profiles. The basic question being addressed was: given a section of undersampled ship transit, is it better to (a) use a profile from a previous year (collected in roughly the same location and day of year), or (b) use a profile generated from a climatology. It was found that, in general, using proximal CTD casts yielded a slight improvement in accuracy relative to WOA01 approach (~0.15% w.d.). Given the

complexity of selecting proximal CTD casts while respecting topographic and oceanographic boundaries, it is much simpler to use the WOA01 grid. Furthermore, there are many areas where no candidate neighbouring CTD casts exist, e.g. transits through Baffin Bay. Our approach has been to blend both solutions, i.e. neighbouring CTD casts are always preferred over WOA01 provided they exist within a reasonable time and distance.

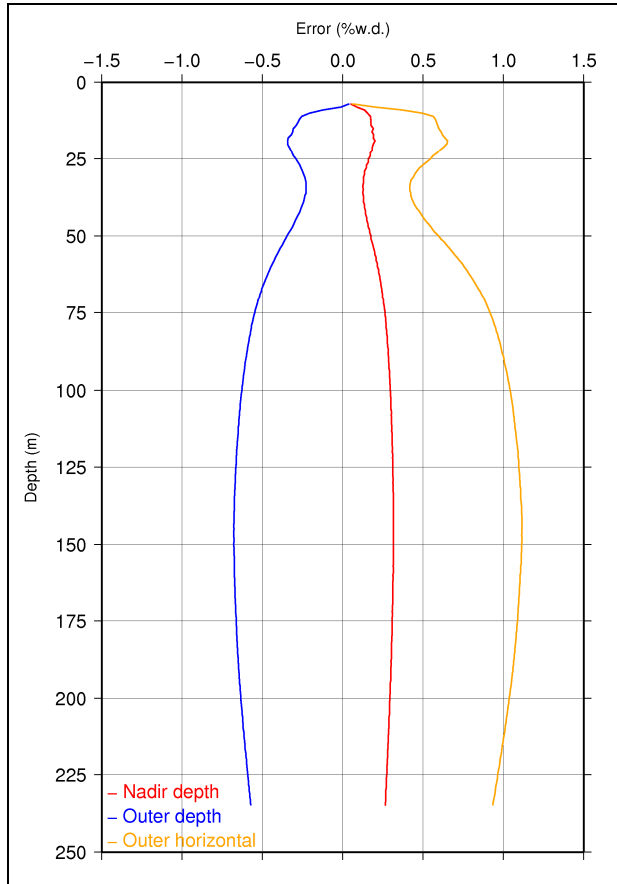


Figure 10. Example of depth variation of horizontal and depth error at nadir and at the outermost beam.

depths; for example, the HIPS raytracing algorithm simply holds the last sound speed value to the required depth (pers. comm.).

2. Steaming across an oceanographic sill with significantly differing conditions on either side of the sill. Depending on when/where profiles are collected on either side of the sill, a time or distance based algorithm may “accidentally” choose a profile on the other side of the sill. This situation is common in the central NWP and near Dolphin and Union Strait in the southernmost section of the NWP.
3. Retracing the ship track but only profiling in one direction, e.g. collection of oceanographic profiles while steaming into a fjord and then retracing the route on the way out. A “closest in time” approach is suitable on the way in to the fjord, however, “closest in distance” is preferable on the way out (otherwise the profile at the head of the fjord would be used for the entire transit out).

2. SVP pre-processing

Most, if not all, of the soundings collected by the Amundsen need to be re-raytraced in post-processing, however, the opportunistic mapping carried out during the Amundsen’s transits pushes the limits of traditional sound speed profile post-processing methods. Faced with up to a few hundred sound speed profiles collected over 80+ days of acquisition (spanning from Quebec City to the Beaufort Sea), it is unadvisable to re-raytrace all the soundings based on a “nearest profile in time” approach. Interesting refraction artifacts can occur in a few situations:

1. Steaming down a slope with a sound speed profiles collected at the top and the bottom of the slope. In this case, a “closest in time” or “closest in distance” selection would have the shallow profile used in deep water when it may be preferable to use the deeper profile. Sound speed algorithms may not necessarily balk at using a short profile for very deep

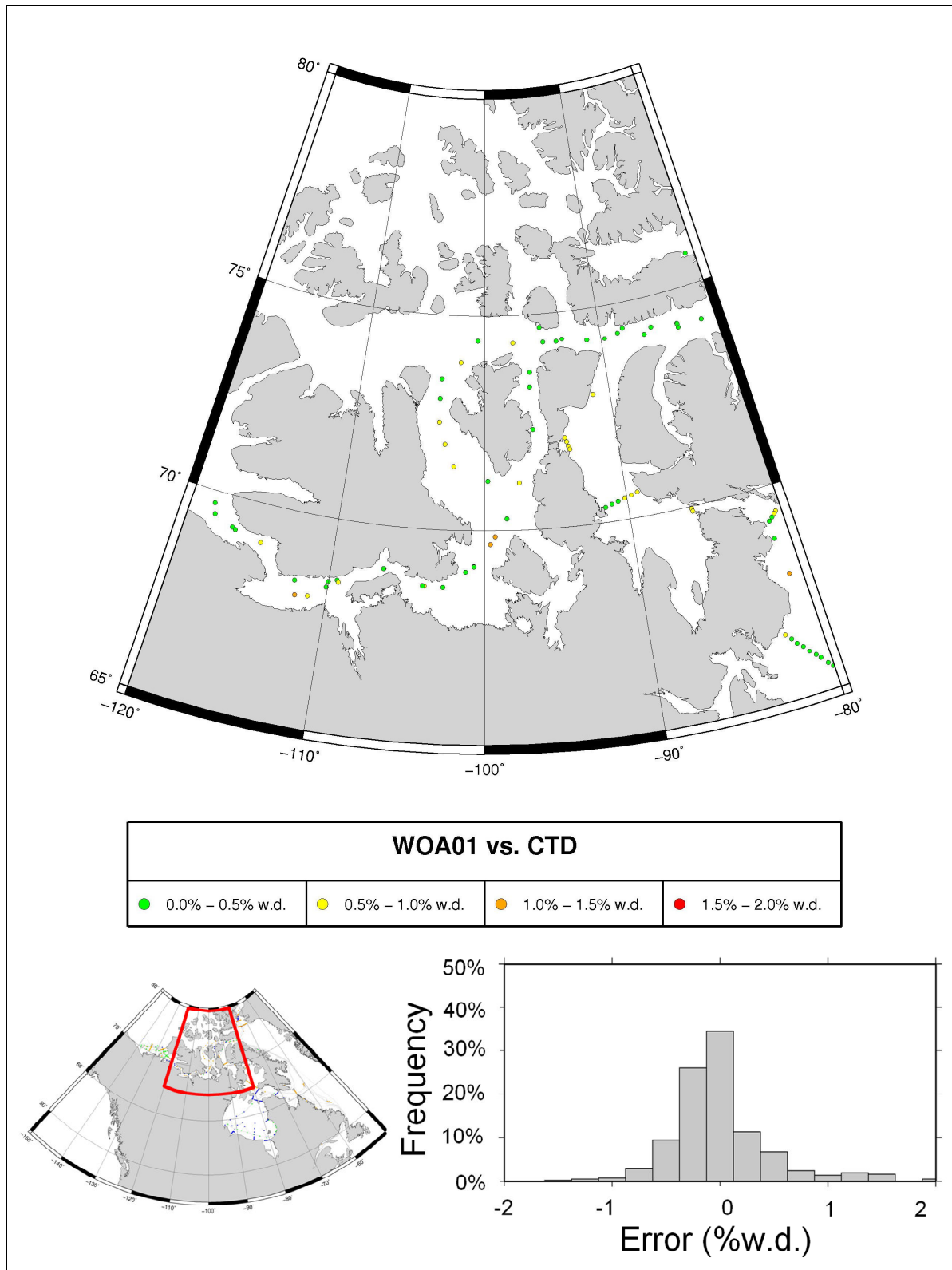


Figure 11. WOA01 depth accuracy degradation from spot-check analysis.

In cases like these, refraction artifacts can appear in the data after post-processing, leaving the operator wondering what went wrong (other than the fact that perhaps there were not enough profiles in the first place!). Some of these problems can be mitigated by simply choosing a more appropriate profile selection model, e.g. "closest in distance" instead of "closest in time". Again, this is a difficult decision to make without being able to visualize the watercolumn that the post-processing software is about to use to process the data. There is a distinct need, in the Amundsen's transit style mapping, to visualize all profiles along with the bathymetry to identify and correct these problems before post-processing.

To address these issues, a purpose-built graphical software tool was developed to post-process the Amundsen soundings. What began as a simple SVP editor tool grew into a sound speed profile decision management tool with three major components: (1) a sound speed profile editor, (2) geographic display, and (3) a time-series viewer.

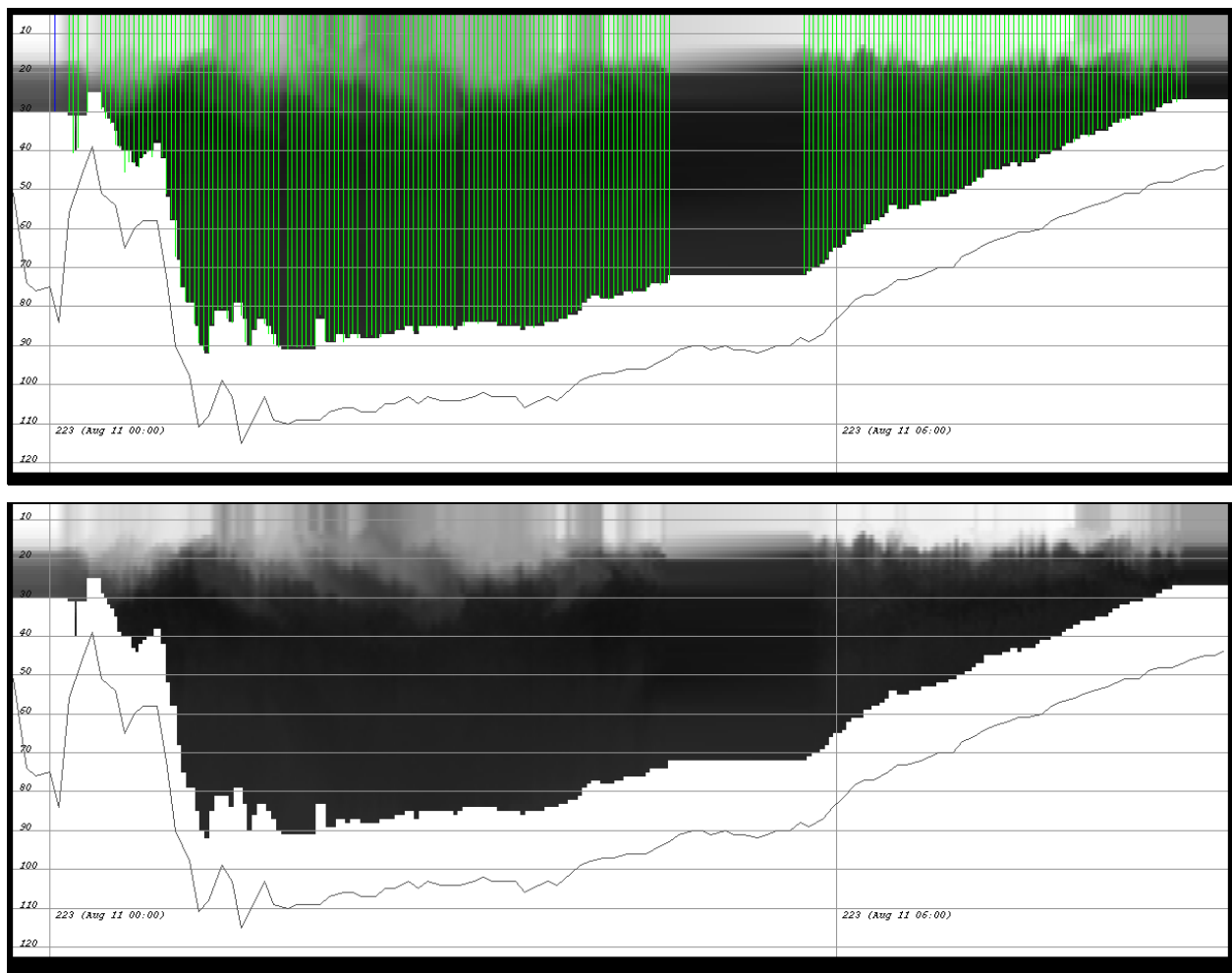


Figure 12. Example of sound speed field from an MVP300 cross section across the mouth of James Bay, collected in 2007. Individual profiles are indicated by green bars in the upper image, the same image is shown in the lower half without the profile markings. Note that the MVP300 cannot sample the upper 10-15 m of the watercolumn while underway, hence the blocky appearance in the upper portion of both images.

Arguably, the most important part of the software is the time-series viewer. The viewer shows the bottom depth (much like the real-time display of a single beam echosounder) along with the

sound speed profiles, which are marked as vertical bars extending from the surface to the maximum sampling depth of the profile. The sound speed profiles are used to generate an image of the watermass, referred to as a sound speed field, which is included as a backdrop. The sound speed field is re-generated whenever a profile is removed, added or edited in any manner. An example of a high resolution sound speed field is shown in Figure 12. Visualization of the sound speed field through time is perhaps the most important feature of the software as all other features would not be possible without visualization of the impact of user changes.

As mentioned earlier, the sound speed field is updated when a profile is edited; this includes the extension of profiles. By focusing on gaps between the bottom track and the sound speed field, the operator can identify problematic areas where sound speed profiles will not be deep enough. Referring to Figure 12 for example, the MVP300 is stopped from sampling 20 m from the bottom, leaving a noticeable gap between the sound speed field and the bottom track.

Profiles can be extended in the sound speed profile editor. There are three methods to extend the profiles: (1) manual addition of one or more points, (2) extension based on a user selected profile, or (3) extension based on a climatology profile at the profile location or at a user specified location (such as the deepest location in the basin). All of this is done graphically in the profile editor such that the operator can visually confirm the validity of the extension. Once a profile is extended, the sound speed field is updated immediately; this feature is essential in verifying that the profile is extended to the required depth.

The time-series viewer can also be used to help define a set of raytracing rules, which are a set of time-based rules that govern how sound speed profiles are to be selected. The rules are chosen in the sound speed field viewer; this allows the operator to change the selection behaviour to work around some of the problems listed earlier. Again, the sound speed field is updated immediately whenever the operator adds, modifies or removes a rule. An example of the sound speed field before and after application of raytracing rules is shown in figures 13 and 14, respectively.

Currently supported rules are:

1. closest in time
2. closest in distance
3. interpolated in time
4. last observed in time
5. next observed in time

The last two rules are especially useful in forcing the selection of profiles over oceanographic sills, essentially forming a breakpoint. It is important to note that the raytracing rules are a form of metadata as they document the output of the complex decision making process undertaken by the operator.

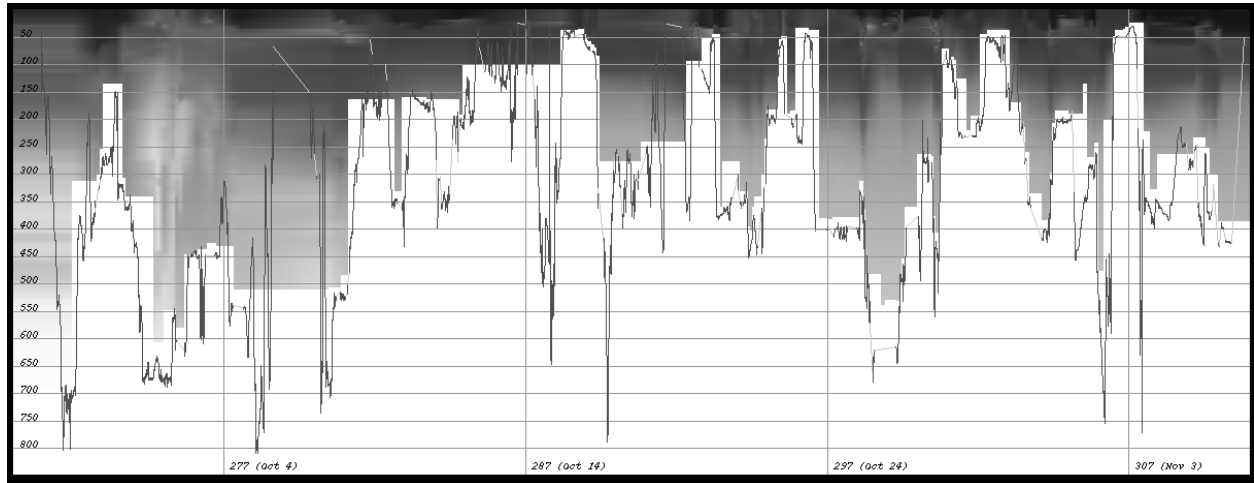


Figure 13. Raw sound speed field for a 42 day period in 2007. Note the gaps between bottom of sound speed field and bottom depth.

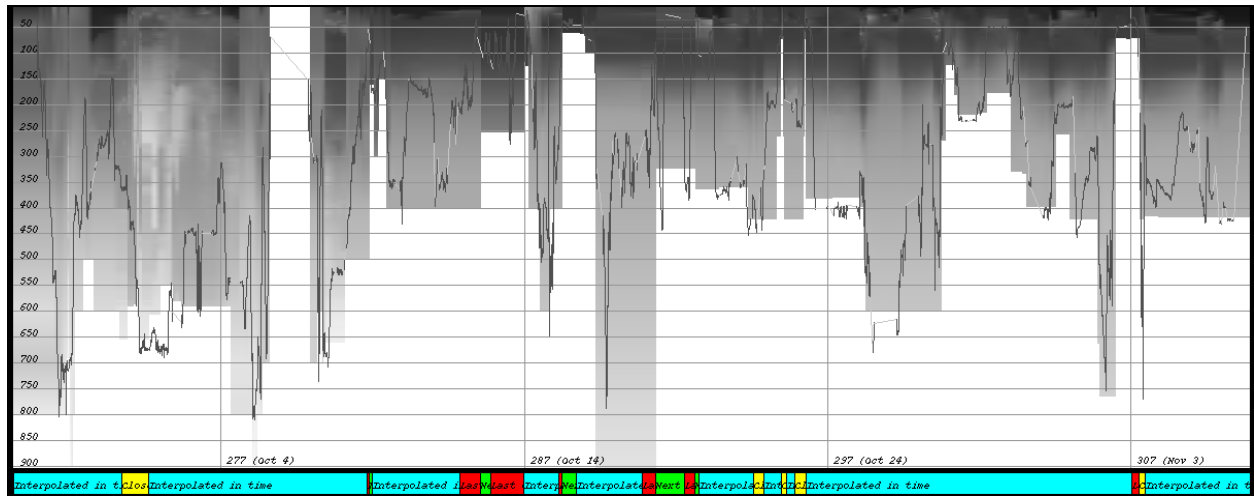


Figure 14. Sound speed field for same time period as shown in Figure 13 but with profiles appropriately extended and raytracing rules defined (colour coded bar at bottom of plot). Rule colour scheme is as follows: cyan=interpolated in time, yellow = closest in distance, red = next observed profile, green = last observed profile.

The two other major components of the software kit are a sound speed profile editor and a geographic viewer (figures 15 and 16, respectively). The sound speed profile editor allows for simultaneous visualization and editing of multiple sound speed, temperature and salinity profiles. Graphical extension of profiles is also performed in the editor. Being able to visualize multiple profiles is crucial to identifying break points over oceanographic sills, as is shown in the lower grayscale depth image of Figure 15. In this case the shoals in the central region (~150 m deep) present a barrier to the deeper water masses to the east and west. This results in distinct water mass characteristics on either side of the sill, something that the data processor must take into account during the generation of raytracing rules.

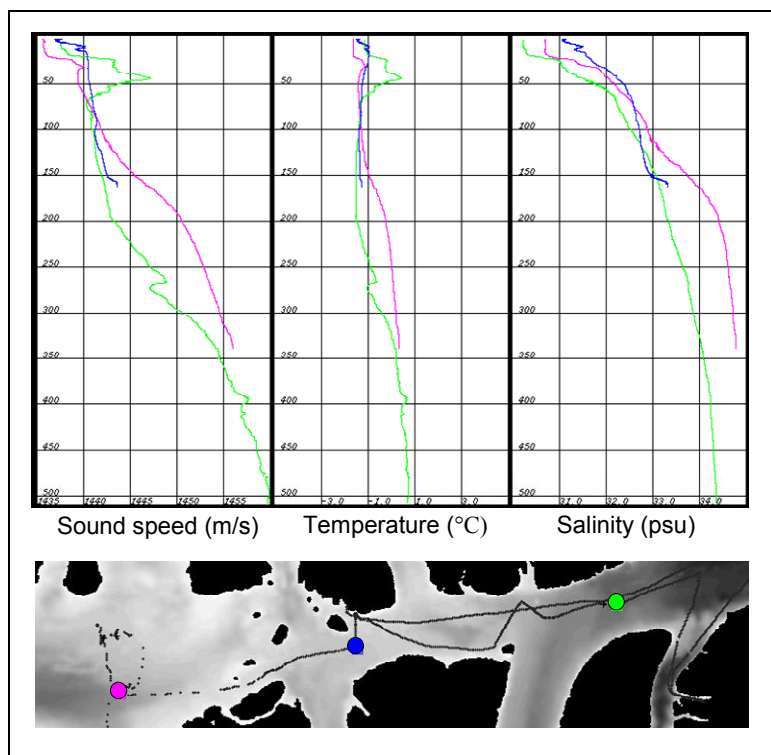


Figure 15. View of SVP editor. Sound speed, temperature and salinity profiles are plotted for three sampling locations spanning the central sills in the NWP. Note the differing watermass characteristics below 150 m water depth.

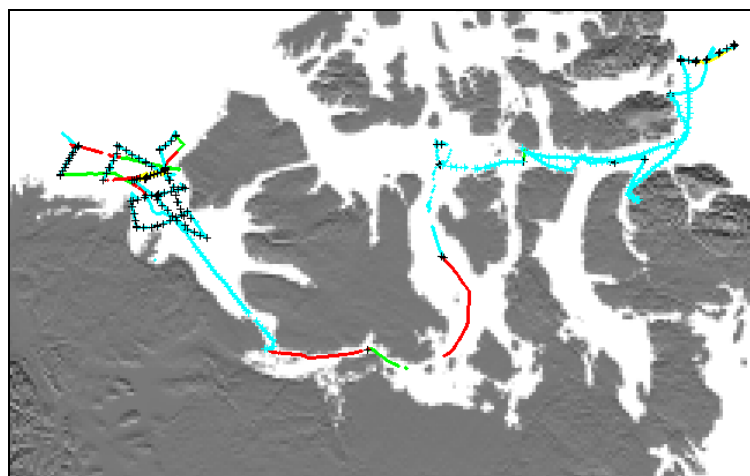


Figure 16. Plot of ship track corresponding to Figure 13 (CTD locations are marked with black crosses). Colour coding matches colour coding of raytracing rules from Figure 13.

ready for interpretation, i.e. no further processing would be required. It was realized at an early stage that it would be challenging to do so given the sporadic and seemingly random transit style mapping. In the few areas of dedicated and systematic mapping, bathymetry and backscatter data were presented in traditional map form whereas the sub-bottom data were presented in the form of fence diagrams. What of the data collected while in transit?

The geographic viewer plots the ship track, sound speed profile locations and raytracing rules over a user specified map. The underlying map can be whatever is deemed to be useful, e.g. bathymetry. Another example could be satellite derived sea surface temperature. The map can also be used to select sound speed profiles for plotting in the profile editor and for querying for climatology profiles. The climatology query can be point based, whereupon it provides a profile for the specified position. Alternately, a large section of ship navigation track for which there are no sound speed profiles can be selected and the query mechanism will return a set of climatology profiles along the track. This feature is particularly useful for the Amundsen's transits.

Distribution

The third and final challenge discussed in this paper is that of dissemination of bathymetry, surficial backscatter and sub-bottom profile data. The majority of ArcticNet mapping data users do not need access to raw soundings. Many have limited budgets to invest into specialized post-processing and/or visualization software. As such, the OMG took on the task of presenting the data to researchers in a format that is

The challenge was to present the bathymetry, backscatter and sub-bottom data in a format that is intuitive to the end users of the datasets. Our solution has been to present 25km x 5km “Stripmaps” that follow the ship track, as shown in Figure 17.

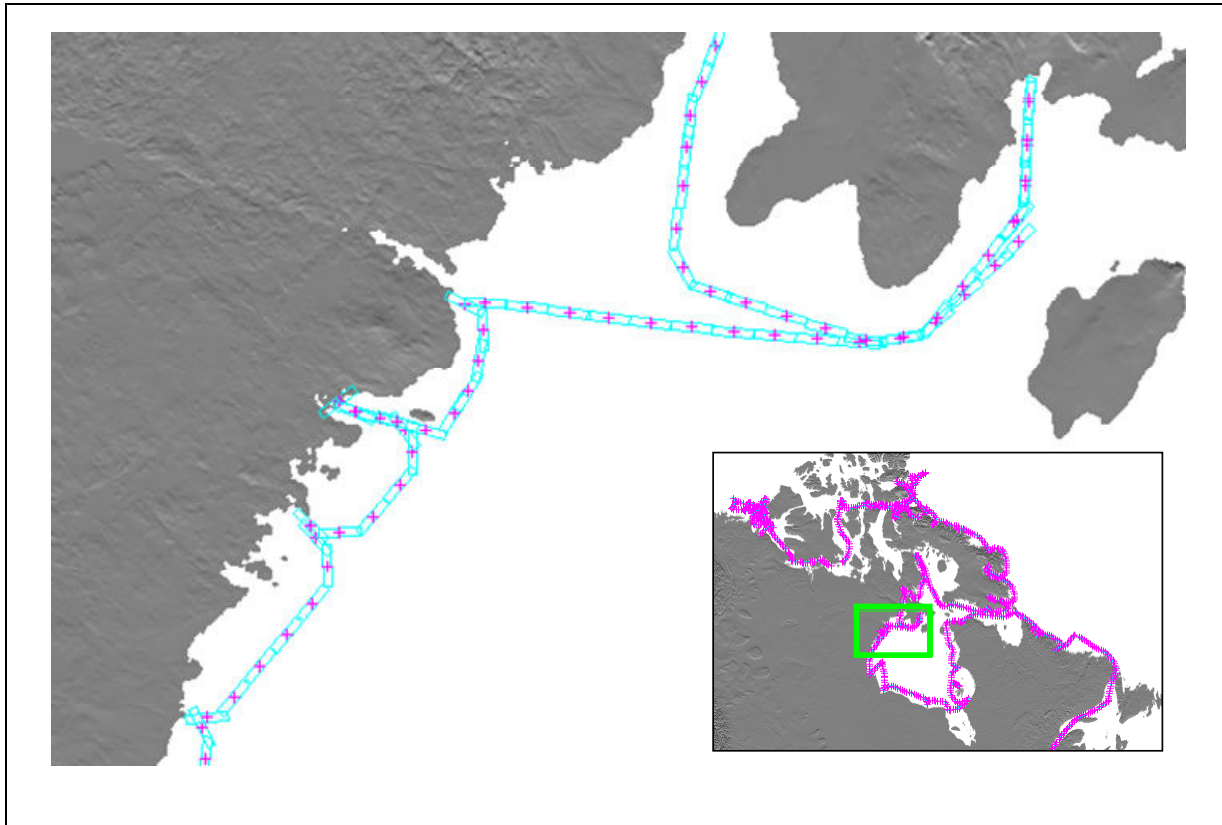


Figure 17. Plot of Stripmap locations along western rim of Hudson Bay for the 2007 field season.

A Stripmap image is built that contains four views of the mapping data in a single image: (1) sun-illuminated, colour coded bathymetry with sun-illumination across the ship track, (2) same as (1) but with sun-illumination along the ship track, (3) surficial backscatter, and (4) a 2-dimensional seismic plot that is geographically projected along the long axis of the strip map. The four images are combined together to form a standalone product that is useful for interpretation of the sub-bottom data, see Figure 18 for an example.

Stripmaps are delivered online along with overview and location maps to help place the data in geographic context. This initial presentation format, shown in Figure 19, was well received by ArcticNet data users and was used heavily in planning future mapping and coring sites for upcoming field seasons. After three years, however, a considerable amount of mapping coverage had been achieved in some areas and the Stripmaps failed to convey this as they focused solely on the data collected during a single year’s transit. The next logical step was to present the data as a set of tiled, high resolution map sheets, which are referred to as ArcticNet Basemaps.

The ArcticNet Basemaps combine bathymetry and backscatter data from multiple platforms collected over many years into a single map product, which is then made available through a web portal. The web interface is designed to allow users to geographically browse datasets and to download mapping products for Basemaps of interest (e.g. ESRI grid files). The web portal also

allows users to view the coverage achieved by the survey projects that contribute to the Basemap and to download metadata regarding each contributing data source. Figures 20 and 21 show examples of the Basemap website.

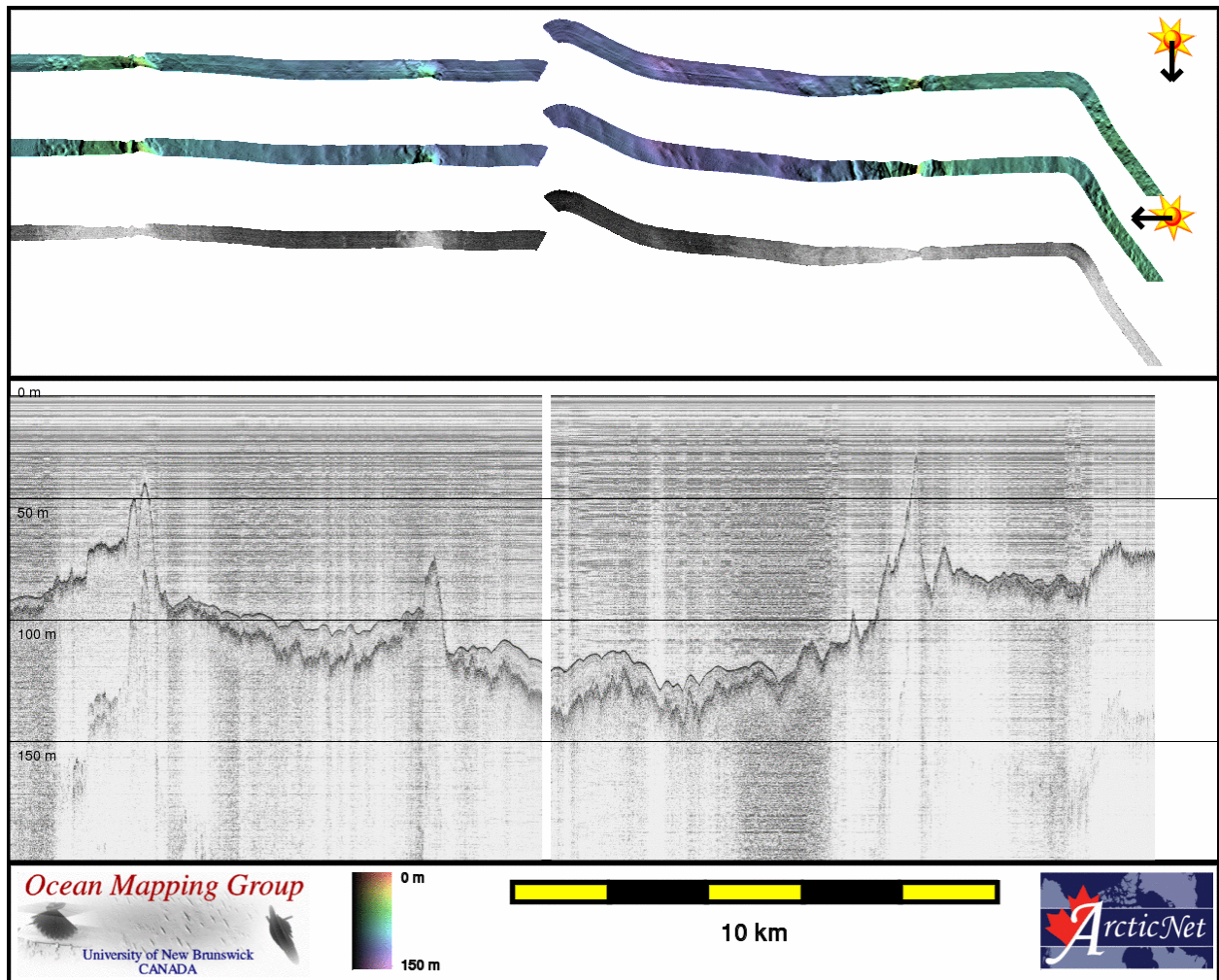


Figure 18. Example of Stripmap combination of four data views. The seismic plot in the lower half of the image is geographically registered along with the imagery in the upper portion of the figure. Features of interest can easily be identified in the other views, e.g. the shoal, high backscatter ridge towards the right end of the image

A semi-automated software toolkit was designed to generate the web portal from raw data in a four step process: (1) gridding/mosaicing data from a raw format (sounding x,y,z, or slant range corrected backscatter imagery) into map sheets, (2) combine map sheets from different sources into a single composite map sheet, (3) updating location maps with Basemap coverage, and (4) convert Basemaps and location maps into images for the Basemap website (including coverage thumbnails for each data source).

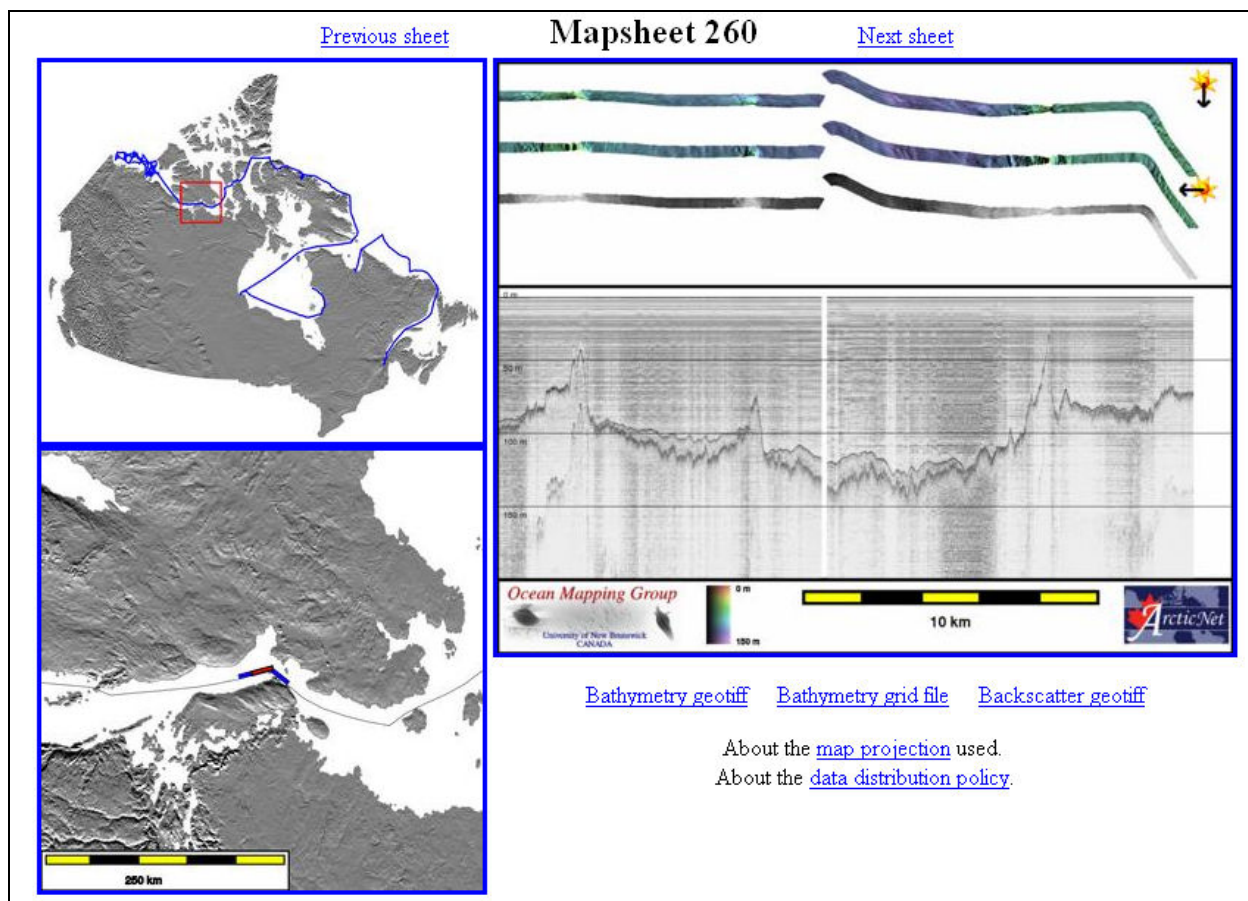


Figure 19. View of online Stripmap interface. Location maps on the left can be clicked to load the Stripmap at the click location.

The Basemap software toolkit is highly configurable and very portable to other projects. An initial configuration step is used to set up the Basemap project. It is at this stage that the user can specify the size, resolution and projection of Basemaps, etc. In the case of ArcticNet data, these are 15' latitude x 30' longitude, 10 m and a Lambert conformal conic projection with two standard parallels, respectively. User specified configuration settings are also available throughout the four stage process described earlier. For example, in the first stage, the behaviour of the software can be modified and tailored to different mapping platforms through the use of configuration files that specify, for example, weighting schemes for bathymetric gridding, or custom signal level shifts for backscatter imagery. In the second stage, the data are intelligently combined by, in the case of bathymetry, preserving any weighting schemes used in the initial gridding process such that sensors with poor performance can be given less weight in the combined grid.

The ability to configure and customize exactly what is done to source data allows for easy management of large multi-year and multi-platform data sets. For example, the ArcticNet Basemap series incorporates data from the Amundsen (Kongsberg EM300), the CSL Heron (Kongsberg EM3002), the USCGC Healy (Seabeam 2112) and the R/V Marai (Seabeam 2112). The Basemap toolkit is also being used by the OMG in the Bay of Fundy to manage data from several Kongsberg sensors (EM1000, EM3000, EM1002, EM3002, EM710), with some of the data dating back as early as 1992 (cf. Hughes Clarke et al., this conference).

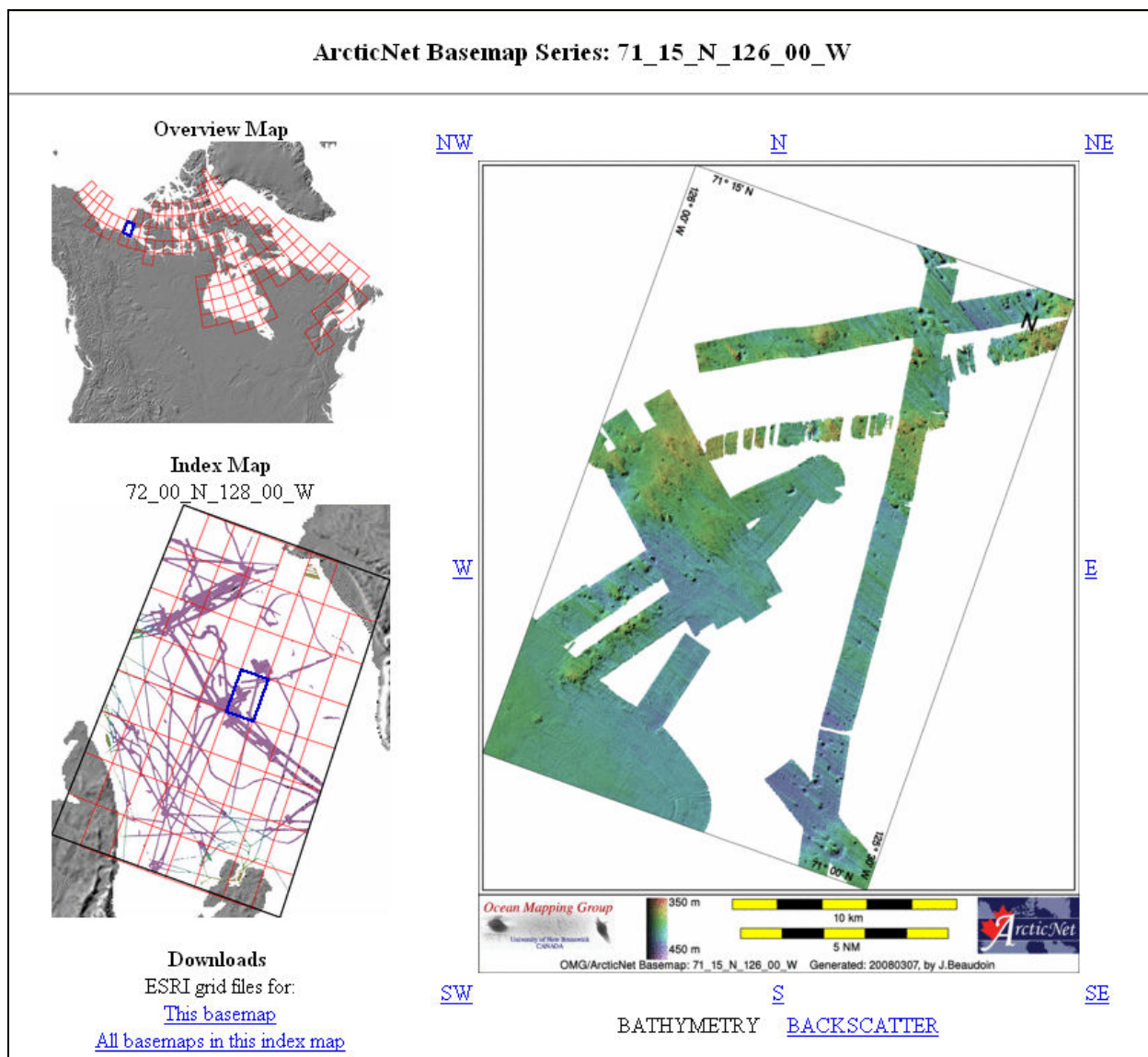


Figure 20. Example of Basemap bathymetric coverage in the Amundsen Gulf.

One of the most beneficial features of the Basemap Toolkit is the ease with which data from a new source can be added. A new source of data can be incorporated in the Basemaps and available for online distribution in a matter of hours for small data sets. The entire 2007 data set (16 weeks of continuous data acquisition) was incorporated at the end of the field season and available online to ArcticNet researchers within one work week, allowing timely access to the data for ArcticNet researchers.

The Basemaps are used on the Amundsen during data acquisition as well, mainly to avoid taking the exact same route twice. Raster images of Basemaps are uploaded to ship navigation software to display existing coverage and warn of impending rapid changes in depth. This soothes the bridge crew in “white chart” areas where the Amundsen has passed by before. In very shallow areas, the Amundsen tends to skirt the edge of previous coverage (see Basemap

Users & Clients

The Basemap and Stripmap websites represent one of the largest multibeam and sub-bottom datasets for the Canadian Arctic and as such these two sites are invaluable for geoscience research in the region. Issues that are addressed with this data include the nature and distribution of seabed geohazards (i.e. shallow gas and ice scour) as well as the recognition of potential hotspots for marine mammals and benthic organisms. Addressing these issues is important to protect the Arctic environment as human activity increases in the area.

Researchers at the Geological Survey of Canada (GSC) use the Basemap and Stripmap websites extensively for geological interpretation and survey planning. The Basemap site is the primary tool for the interpretation of multibeam bathymetry and backscatter data in the Northwest Passage. From the GSC's point of view, the two major strengths of the Basemap website are: (1) the individual map sheets contain several years of seamlessly integrated data, and (2) the maps are easily navigable which aids in geological interpretation. The Stripmap website is used to view and interpret the 3.5 kHz sub-bottom profiler data. This site is extremely useful for sub-seabed geological interpretation as the sub-bottom data and corresponding multibeam bathymetry and backscatter can be viewed simultaneously. These two websites are also essential tools for the planning of additional seabed mapping and for the selection of sediment sample sites (i.e. piston core locations). Without the multibeam and sub-bottom data, the sediment samples would lack context and would have limited value for geological interpretation. In addition to being data viewing and interpretation tools, the Basemap and Stripmap sites also function as a file transfer method between UNB and the GSC as the data is downloadable if necessary.

Another significant user of the ArcticNet data set is the CHS. To date, data has been used for planning and reconnaissance for future shallow water survey work. In rare instances, data has been incorporated into charts where no soundings have been previously collected or where sounding density is low. Examples of several charts that are in the process of being updated with ArcticNet data are listed below:

- 7184 (Broughton Island and Approaches) – ArcticNet data acquired during a community health visit in 2007 has been incorporated
- 7212 (Bylot Island and Adjacent Channels) – ArcticNet data will contribute significantly, most notably the Oliver Sound work of 2006 with the CSL Heron and CCGS Amundsen (cf. Church and Hughes Clarke (2007))
- 7566 (Cape Jameson to Cap Fanshawe) – ArcticNet will contribute significantly as Pond Inlet has nearly been entirely mapped with several transits since 2003 and some dedicated mapping time before and after a crew change in 2006.
- 7486 (Navy Channel to Fury and Hecla Strait) – A few transit lines collected by the Amundsen in 2006 and 2007 will contribute

ArcticNet data collected in the 2008 and 2009 field seasons will likely contribute as well if it falls within the bounds of the last three charts listed above since these charts are scheduled to be completed by the 2010/2011 fiscal year.

The data are heavily used by ArcticNet researchers either as a direct input to their research, or as contextual information to help understand biological or chemical processes under investigation. Other users of the ArcticNet Basemap series include:

- Canadian Navy: bathymetry, backscatter, sub-bottom profiler and CTD data collected by the Amundsen will help to plan naval exercises in the CAA
- Parks Canada: metadata provided through the Basemap website will be incorporated into a metadata database specifically designed for managing data collected in northern parks (namely Sirmilik National Park (Baffin Island) and the Torngat Mountains National Park (Labrador))
- DFO: improved bathymetric definition in the Arctic and Hudson Bay will help improve performance of the WebTide models in those regions

Mapping “Amundsen Style”

The location map in the lower left of Figure 20 gives an idea of the gradual build up of coverage that is achieved by the Amundsen’s “mapping while underway” philosophy. Though this may seem inefficient method of mapping compared to systematic mapping missions, it has been useful in other ways as it gives a wide geographic sampling of many of the areas of the CAA.

A perfect example of the benefits of casting a wide net comes from a recent paper published in Nature Geoscience (Lajeunesse and St-Onge 2008). From the Amundsen transit data collected in 2004 and 2005, Lajeunesse was able to deduce the drainage pattern of lake Agassiz–Ojibway, a large ice-dammed inland sea that existed towards the end of the last ice age and drained catastrophically ~8.47 kyr ago. Based on the distribution and orientation of relict iceberg scours, sand waves and drainage channels, Lajeunesse suggests that the outflow occurred underneath the Laurentide Ice Sheet, rather than over it. Had the Amundsen undertaken dedicated regional mapping programs in Hudson Bay, this conclusion could not have been reached.

Conclusions

As there currently is no deep water port operating in the CAA north of the Arctic Circle, the mapping endeavours hinted at by the Harper government will likely involve lengthy transits to and from southern Canada. It is proposed that much of the CAA and Canadian sub-Arctic seabed can be mapped “Amundsen style” if vessels assigned to Arctic mapping log data while in transit. The post-processing methodologies presented herein can be used to minimize errors due to tides and refraction; the ArcticNet Basemap Series can be used to warehouse the transit data and to help direct future transits to areas with little coverage.

There is much to be gained and much ground to cover. Cooperation between fellow modern day Arctic explorers will help to ensure the “complete comprehensive mapping of Canada’s Arctic seabed”. Log your transit data...we’ll happily take it.

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Author Biographies

 A photograph of Jonathan Beaudoin, a man in a grey hoodie with 'NEW FOUNDED' on it, standing on the deck of a boat. In the background, there is a large iceberg in the ocean under a cloudy sky.	<p>Jonathan Beaudoin is a PhD student studying with the Ocean Mapping Group (OMG) at the University of New Brunswick in Fredericton, New Brunswick. His main research interest is the application of oceanographic databases for multibeam surveying. Jonathan is also a research assistant for the ArcticNet project, which sees him involved in all stages of ArcticNet mapping operations in the Canadian Arctic. He holds bachelor degrees in Geomatics Engineering and Computer Science, both from UNB.</p>
 A black and white close-up photograph of John Hughes Clarke's face, smiling. The image is overlaid with a complex, wavy, grey-toned pattern that resembles a sonar or bathymetric map.	<p>John Hughes Clarke is the Chair of the Ocean Mapping Group at the University of New Brunswick. He has 20+ years experience working with swath sonar systems. He has degrees in geology and oceanography from Oxford, Southampton and Dalhousie and has been a post-doc at BIO and at James Cook University (Queensland). He has been at UNB for 13 years, working with and now leading the Ocean Mapping Group.</p>
 A photograph of Jason Bartlett, a man in a blue t-shirt and dark pants, standing next to a large piece of scientific equipment. The equipment is a tall rack with various components, including a red panel and a computer monitor. The t-shirt has 'CHASPS' on it.	<p>Jason Bartlett is a graduate of the Geodesy and Geomatics Engineering program at the University of New Brunswick. He is a registered Professional Engineer in the province of New Brunswick and currently employed by the Canadian Hydrographic Service. He also works in close cooperation with the Ocean Mapping Group on ArcticNet Project 1.6 – The Opening Northwest Passage.</p>



Steve Blasco has been marine geophysicist with the Geological Survey of Canada for over 25 years. Mr. Blasco's research focuses on marine environmental and engineering geology studies. These investigations are related to offshore oil and gas exploration in the Canadian Arctic, environmental problems in the Arctic, Great Lakes and Bermuda.



Robbie Bennett has been employed at the Geological Survey of Canada since 2004. His research is focused on the marine geology of the Canadian Arctic for the purpose of recognizing potential geohazards. Current activities include the investigation of mud volcanism, gas venting, slope stability, and ice scouring.