Lighthouse, No. 68 May 2006

USAGE OF OCEANOGRAPHIC DATABASES IN SUPPORT OF MULTIBEAM MAPPING OPERATIONS ONBOARD THE CCGS AMUNDSEN

J. Beaudoin (1), J. Hughes Clarke (1), & J. Bartlett (2)

1. University of New Brunswick, Fredericton, New Brunswick
2. Canadian Hydrographic Service, Burlington, Ontario

Introduction

Figure 1. Photo of the CCGS Amundsen after deploying scientists for surface ice sampling on the Arctic pack ice in the Beaufort Sea.

In 2003, through a joint CFI, NSERC funded program, the decommissioned 1200 class icebreaker Sir John Franklin was brought back into service as a multidisciplinary science platform for research in the Canadian Arctic (shown in Figure 1). Renamed the CCGS Amundsen, the ship was equipped with a variety of acoustic and supporting survey instruments to make her capable of state-of-the art seabed mapping. The 98-meter vessel is equipped with a 30 kHz Kongsberg-Simrad EM300 multibeam echosounder, which is a shallow to mid-ocean depth system (nominally 10m - 5000m). Further information about the mapping capabilities of the CCGS Amundsen is covered in Bartlett, 2004. The Amundsen plays an integral 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 [ArcticNet, 2006]. Of the many research areas covered by the ArcticNet program, seabed mapping falls under Project 1.6 -- The opening NW Passage. The ArcticNet 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, using the state-of-the-art EM300 multi-beam echo-sounder”. The word “precise” implies that due care must be taken to ensure that all soundings are as accurate as possible.

For the sake of brevity, a full discussion of the sources of errors in multibeam echosounding is avoided. Errors in orientation and position of the vessel are dealt with through adequate instrumentation: Applanix POS/MV 320 for orientation, heave and heading, and CNAV differentially corrected GPS for horizontal positioning. Vertical control is addressed by Hughes Clarke (2004). The remaining, and most worrisome, of all sources of error onboard the Amundsen is sound speed. Surface sound speed errors were a problem in 2003, but they have since been dealt with in post-processing (Beaudoin, 2004). The focus of this paper is the variation in sound speed throughout the watercolumn, which causes refraction of the acoustic ray path and introduces systematic errors in the depth and horizontal position of soundings.

Problem

The Amundsen is equipped with several sound speed profiling instruments, one of which is a moving vessel profiler (MVP) from Brooke Ocean Technology, specifically the MVP 300. The MVP was not used during the 2003 transit for fear of ice damage. It was successfully deployed for the first half of the 2004 field season, however, mechanical wear rendered it inoperable for the second half. Unfortunately, it was lost in 2005 while surveying in the Labrador Sea. Without the MVP, sound speed profiles must be performed while the ship is stationary; this is accomplished with a conductivity, temperature and depth (CTD) profiling instrument.

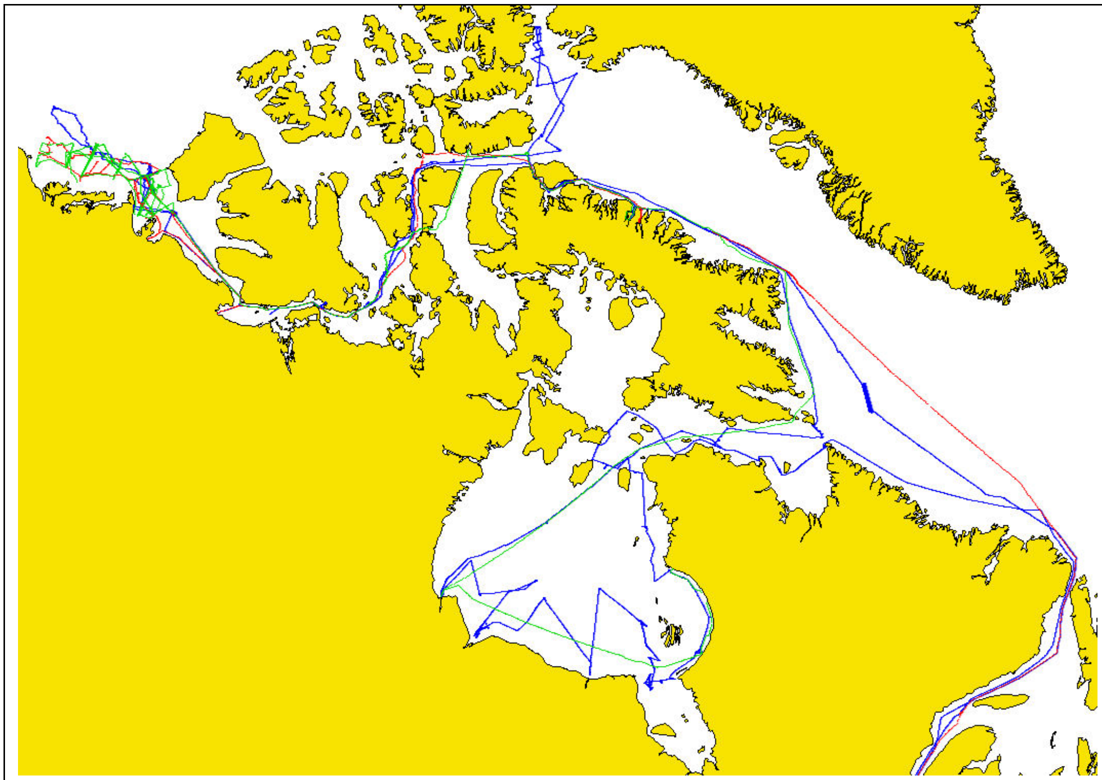

Figure 2. Shiptrack of the CCGS Amundsen over the 2003, 2004 and 2005 field seasons (in red, green and blue, respectively). After travelling north in 2003, the Amundsen overwintered in Franklin Bay in the western Amundsen Gulf and returned to Quebec city in 2004. The 2005 field season was the first round-trip to the Arctic accomplished in one year.

During ship transit, a tight schedule constrains the amount of time available for the collection of stationary sound speed profiles along the ship's track. Profiles are collected intermittently, though not frequently enough to resolve oceanographic boundaries, leading directly to systematic biases in the multibeam depth measurements. Given the lack of MVP data and the few opportunities for stationary profiles while transiting, there are two round trips from Quebec city to the Beaufort Sea for which there is little to no sound speed information available for the mapping data collected during transit (refer to Figure 2).

Proposed Solution

It is necessary to investigate the usage of other sources of sound speed information instead of limiting the post-processing to the few profiles collected during transit. Since the speed of sound in water is a function of pressure, temperature and salinity, oceanographic databases of temperature and salinity values may be used to infer sound speed. It is the purpose of this preliminary work to assess the suitability of the World Ocean Atlas 2001 (specifically the ¼° grid) as a source of sound speed information for undersampled sections of ship transit.

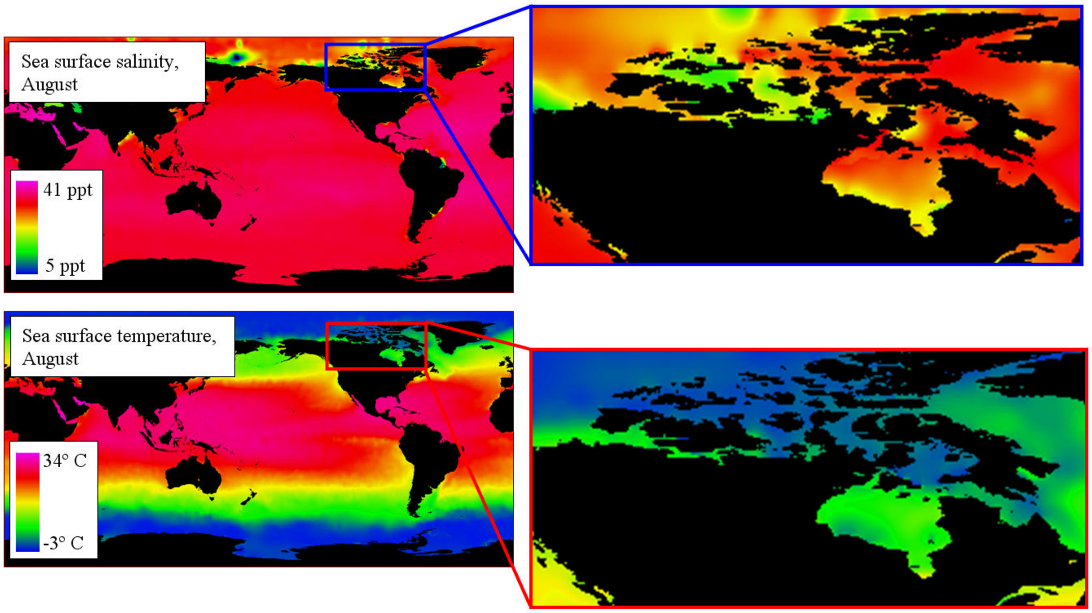

Figure 3. Sea surface salinity and temperature for the month of August, extracted from WOA01. Spatial resolution is ¼° in both latitude and longitude. Fluctuations in surface salinity are largely due to the presence of pack ice, which is quite variable from one season to the next.

The World Ocean Atlas 2001 contains temperature and salinity data for 1° and 5° grid (refer to Figure 3). The grids, which cover most of the vertical extent of the world's oceans, are resampled from profiles from the World Ocean Database 2001 data. A ¼° grid of temperature and salinity, generated using the same methods as the 1° and 5° grids, is also available [Boyer et al., 2005]. The ¼° dataset (referred to as WOA01 from this point on) is available as a set of yearly, seasonal and monthly averages; these grids may prove useful as sources of sound speed calibration in the absence of CTD and MVP profiles. Since the WOA01 grids represent average conditions (and are based on sparse datasets), there is a need to assess the robustness of the grids for raytracing purposes, this being the subject of this work.

Assessment of WOA01 grid robustness

Discrepancies (or errors) in sound speed profiles have non-intuitive effects on depth and positioning error. Figure 4 shows an example of the discrepancies between actual sound speed profiles and profiles from WOA01. A simple way to assess WOA01 is to use it for raytracing and compare the results to a "true" dataset. An experiment was performed in which parallel raytracing solutions were computed using (a) 362 actual sound speed profiles collected during the Amundsen's 2004/2005 field seasons (considered the "true" dataset), and (b) sound speed profiles corresponding to the 2004/2005 profile times/locations extracted from WOA01. The steps of the experiment are further described below.

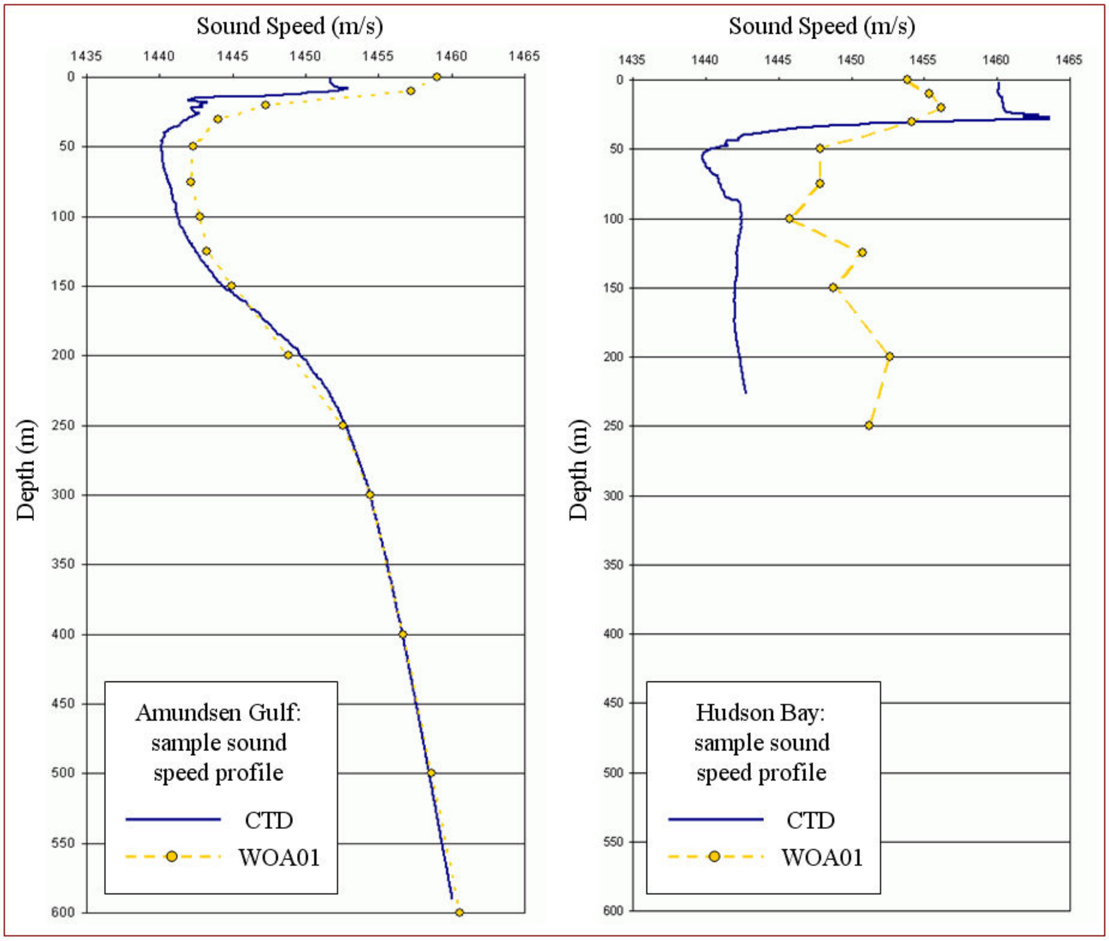

Figure 4. Comparison of actual sound speed profiles versus profiles extracted from WOA01 for Amundsen Gulf and Hudson Bay. Note that WOA01 vertical resolution decreases with depth.

Comparative raytracing solutions were computed using each profile pair ("true" profile and corresponding WOA01 profile) with depression angle ranging from 30° to 90°. For each depression angle encountered during the raytracing, the discrepancy between the two solutions was monitored, with the CTD profile generating a “true” solution against which the WOA01 raytracing solution was compared, as shown in Figure 5. The worst case discrepancy encountered over the range of depression angles was reported as the result, sample results from one of the profiles are shown in Figure 6. This generated a dataset of 362 assessments of the worst-case scenario errors incurred through usage of WOA01 profiles for raytracing.

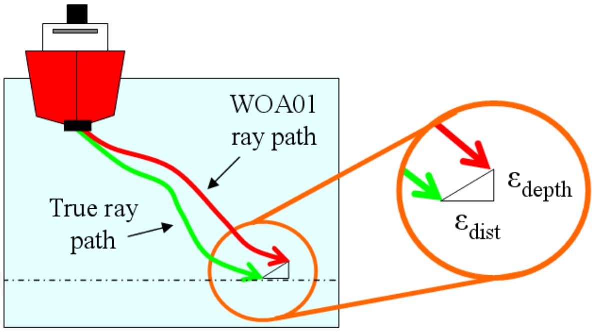

Figure 5. Cartoon depicting a comparative raytracing solution between an actual sound speed profile and a WOA01 sound speed profile for a given depression angle. Varying the depression angle from 30° to 90° allows for the investigation of the error behaviour across the nominal swath width of the EM300 as installed on the CCGS Amundsen.

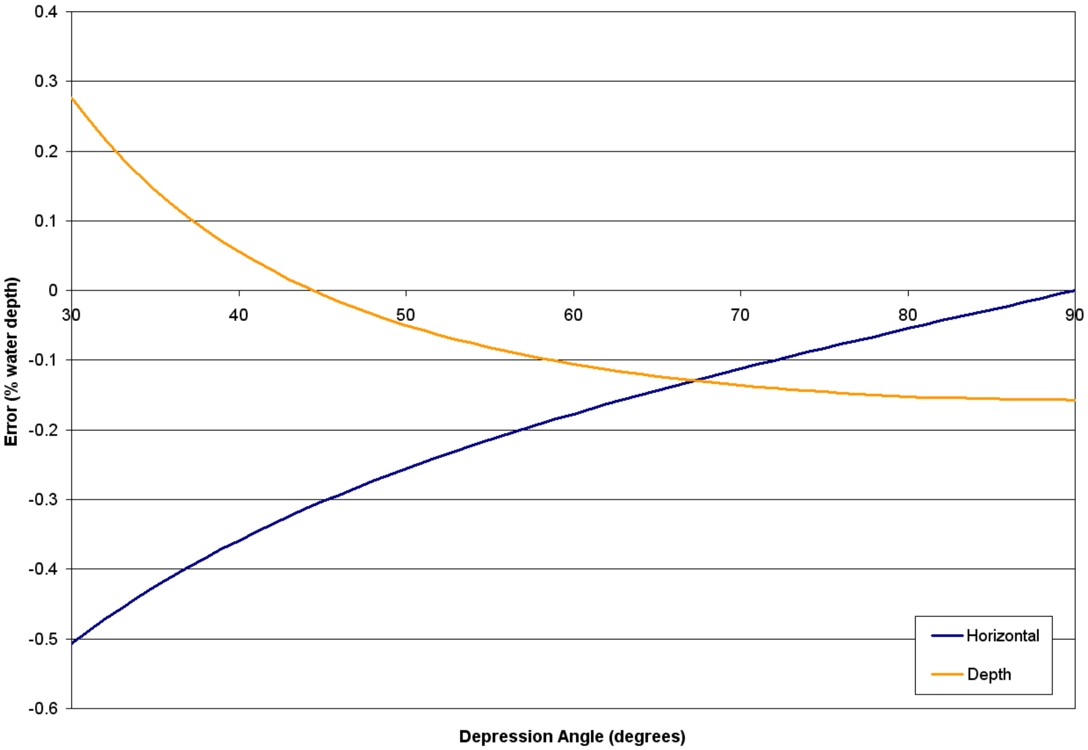

Figure 6. Sample results from comparative raytracing demonstrating variation in horizontal and depth error across the swath. As expected, errors are at their worst at the outer edges of the swath (corresponding to a 30° depression angle, far left on the x-axis). These results pertain to a profile collected in the eastern Amundsen Gulf.

Results

Of the 362 CTD profiles used in the experiment, the maximum observed errors due to WOA01 raytracing were less than 1% of water depth for depth and 2% for horizontal position, for 95% of the cases (refer to Figure 7). Several trends are apparent when the data are examined geographically, as in figures 8 and 9. For example, the western Arctic WOA01 profiles perform more than adequately most of the time, giving errors less than 1% of water depth in almost all cases. Lancaster Sound and Smith Sound suffer more horizontal error, though the depth error is quite tolerable. Hudson Bay, on the other hand, is likely the area of poorest applicability of the WOA01 profiles, though errors are still surprisingly small.

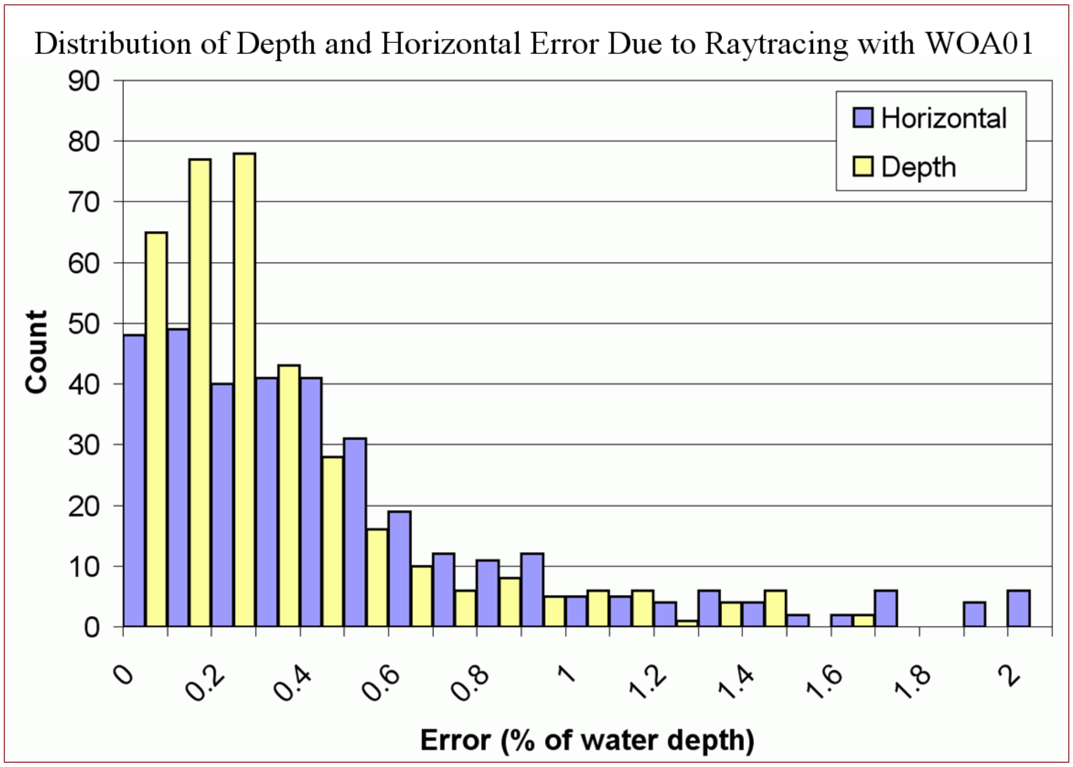

Figure 7. Histogram of results from comparative raytracing for all 362 profiles in the dataset. Of all errors, 95% are less than 1% and 2% of water depth for depth and horizontal components, respectively.

Interpretation

This approach has two saving graces: (i) the surface sound speed is measured continuously, and (ii) for the most part, the WOA01 profiles agree remarkably well with 2004/2005 profiles below the surface mixed layer. As observed by Dinn (1995) and Cartwright (2002), raytracing algorithms tend to recover gracefully when faced with outdated sound speed profiles that converge to reality at depth as long as one preserves the ray parameter (Snell's constant) through the measurement of the surface sound speed with a probe. By fixing the ray parameter at the surface, the true and computed raypaths will become parallel once the variable surface layer is passed. This is due to the fact that the ray parameter will maintain the correct departure angle at the deepest portion of the layer of surface variability regardless of the intervening sound speed structure in the watercolumn. An error in depth and across-track distance is introduced due to the poorly matching surface portion of the WOA01 profiles, however, this error is constant and becomes increasingly insignificant with depth, especially in the case where the thickness of the variable surface layer is small with respect to the entire watercolumn [Cartwright, 2002]. This is likely why the largest of errors (expressed as a percentage of water depth) are seen in Hudson Bay, a bay that is considerably shallower than the Amundsen Gulf and Lancaster Sound.

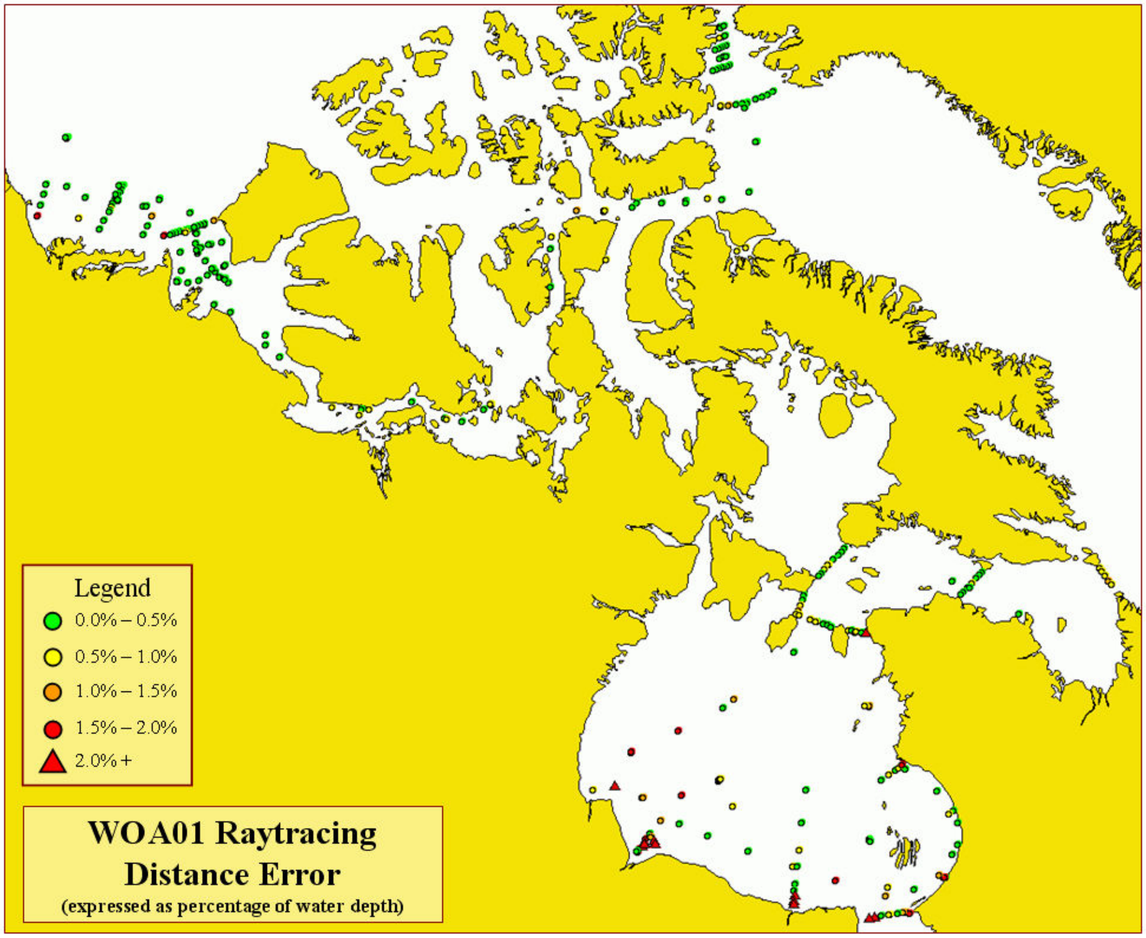

Figure 8. Geographic plot of horizontal component of error from comparative raytracing experiment.

Conclusion

The forecasted errors in this simulation suggest that WOA01 can be used for raytracing in the absence of MVP/CTD profiles without seriously impacting on sounding accuracy. The worst performance is realized in Hudson Bay, whereas the grid proves to be quite suitable for raytracing purposes in most of the western Arctic. The results obtained in this work are, of course, subject to several caveats:

1. They apply only to the geographic areas of CTD sampling in the 2004/2005 field seasons. A "leap of faith" is required to expand the conclusions drawn in this study to the areas between sampling stations.
2. They apply only to electronically beam-formed multibeam systems that measure the surface sound speed continuously. The same simulation was performed without surface sound speed matching between profiles; results were, as expected, very poor with errors approaching and occasionally surpassing 10% of water depth.
3. They are limited to multibeam systems with a 120° angular sector. The angular sector of the Amundsen's EM300 is limited to +/-60° due to the transducers being recessed in the hull for protection against ice (refer to Bartlett, 2004 for more details). The minimum depression angle examined was thus limited to 30° and a wider swath system should expect larger errors in the outer portions of the swath.

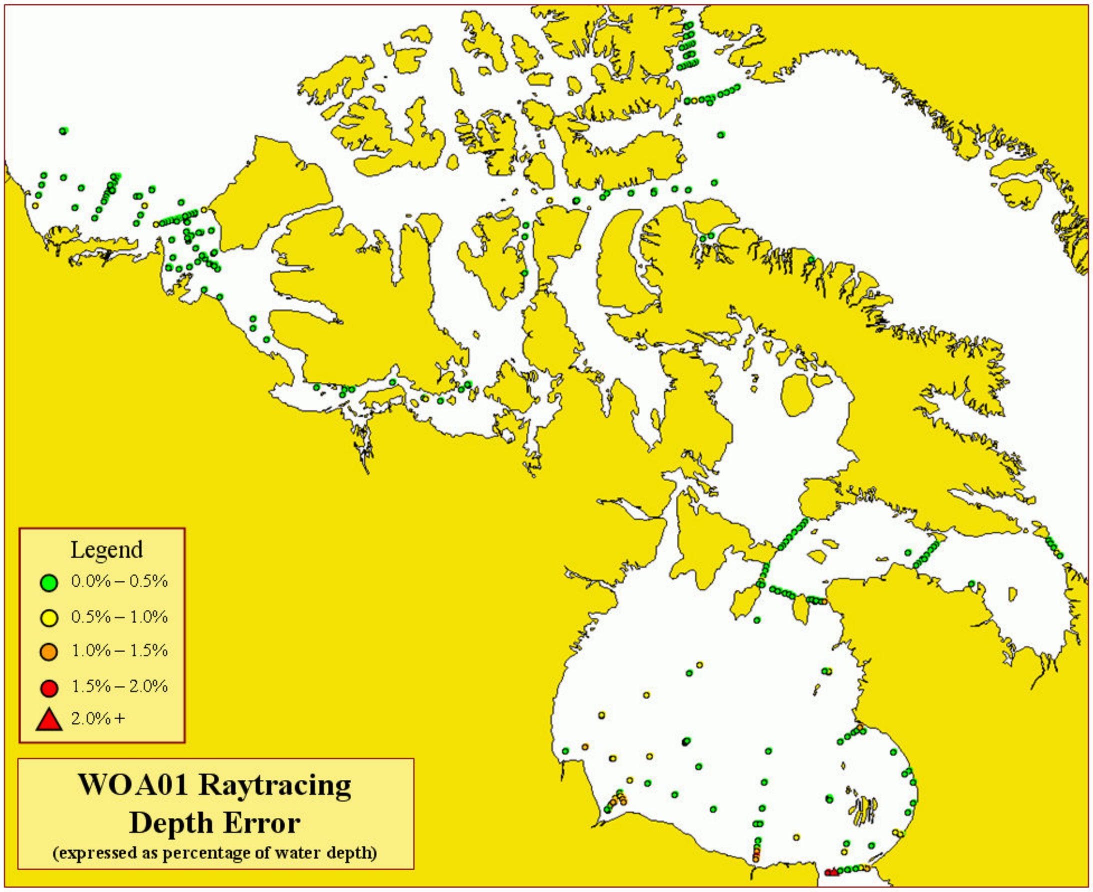

Figure 9. Geographic plot of depth component of error from comparative raytracing experiment.

Future work

Future sampling schemes onboard the Amundsen can focus on undersampled geographic areas to improve this assessment of WOA01 raytracing performance in said areas. In areas where WOA01 performed poorly (e.g. Hudson Bay), it would be useful to investigate the usage of the ArcticNet CTD profiles to improve the grid.

There is a need to incorporate WOA01 into ArcticNet multibeam post-processing. Based on this work, it is feasible that sound speed profiles, collected over several years of ArcticNet operations, can be used in conjunction with WOA01 to provide a reasonably correct approximation of the watercolumn. For raytracing purposes, spatial-temporal decision algorithms must be designed that intelligently choose amongst existing CTD profiles, and then fall back to the database when no CTD profiles exist within the search area/time.

Acknowledgements

The authors would like to acknowledge the Networks of Centres of Excellence Canada and sponsors of the Chair in Ocean Mapping as sources of funding. Furthermore, the Captains and crew of the CCGS Amundsen are thanked for their patience and professionalism while dealing with the motley collection of 40+ scientists, technicians and engineers that are entrusted to their care each field season onboard the Amundsen.

Literature Cited

ArcticNet, 2006. ArcticNet - Network of Centres of Excellence of Canada, http://www.arcticnet-ulaval.ca/, Visited March 29, 2006.

Bartlett, J., Beaudoin, J and Hughes Clarke, J.E., 2004, CCGS Amundsen: A New Mapping Platform for Canada's North: Lighthouse, Journal of the Canadian Hydrographic Association; Edition No. 65

Boyer, T., Levitus, S., Garcia, H., Locarnini, R.A., Stephens, C., and J. Antonov (2005), "Objective analyses of annual, seasonal, and monthly temperature and salinity for the World Ocean on a 0.25° grid". International J. of Climatology, v 25, n 7, Jun 15, 2005, Advances in Marine Climatology, p 931-945

Beaudoin, J. and Hughes Clarke, J.E., 2004, Retracing (and re-raytracing) Amundsen's Journey through the Northwest Passage: proceedings of the Canadian Hydrographic Conference 2004, Ottawa, CDROM

Cartwright, D.S. and J.E. Hughes Clarke (2002). "Multibeam Surveys on the Fraser River Delta, Coping with an Extreme Refraction Environment". Canadian Hydrographic Conference 2002, Proceedings, CDROM

Dinn, D.F., Loncarevic, B.D., and G. Costello (1995). "Effect of Sound Velocity Errors on Multi-Beam Sonar Depth Accuracy". Oceans Conference Record (IEEE). San Diego, CA, USA, IEEE, Piscataway, NJ, USA, 1995.V 1001-10.

Hughes Clarke, J.E., Wert, T., Dare, P., Beaudoin, J., and Bartlett, J. A stable vertical reference for bathymetric surveying and tidal analysis in the high Arctic. ArcticNet Annual Scientific Meeting, poster presentation, December 2004, Quebec, Canada.