Usage Of Oceanographic Climatologies And Databases In Support Of Multibeam Mapping Operations Onboard The CCGS Amundsen

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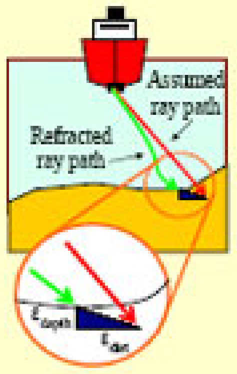
Introduction



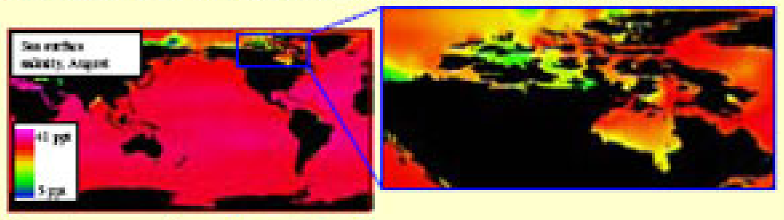
Background: Echo sounding relies on the measurement of elapsed time between the emission and the return of a pulse of acoustic energy. Knowledge of the speed of sound in the propagation medium allows for the reduction of the elapsed time to a range. Variations in sound speed throughout the watercolumn scale the measured travel time of the pulse and cause refraction of the acoustic ray path, introducing systematic errors in the depth and horizontal position of soundings. The speed of sound in water is a function of pressure, temperature and salinity, all of which may vary with depth, time and location. Sound speed profiles, derived from CTD measurements of salinity and temperature, can be used to correct for refraction of acoustic rays.

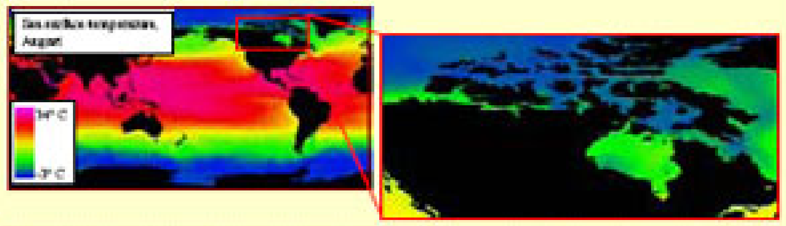
Problem: During ship transit operations, insufficient time is available for collection of multiple CTD casts along the ship's track. Sound speed profiles are collected intermittently, though not frequently enough to resolve oceanographic boundaries, leading directly to systematic biases in the depth measurements collected by the EM300 multibeam echosounder.

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. It is the purpose of this preliminary work to assess the suitability of the World Ocean Atlas 2001 (WOA01, specifically the 1/4° grid) as a source of sound speed information in sections of ship transit where the watercolumn is undersampled.

Project 1.6 The opening NW Passage

"Multibeam bathymetry, sub-bottom profiling and coring during multiple traverses through the NW Passage as part of the repetitive annual E-W transects will provide an unprecedented opportunity to map bathymetry and seabed geology". [ArcticNet NCE Proposal, March 2003]. One of the goals of Project 1.6 is "to build a precise bathymetry for the NW 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, i.e. sound speed profiles are an integral part of the success of Project 1.6.





The World Ocean Atlas 2001 (WOA01) contains temperature and salinity fields (among other data types) for 1° & 5° squares generated from World Ocean Database 2001 observed and standard level data. The WOA01 is available from the US National Oceanic and Atmospheric Administration's (NOAA) National Oceanographic Data Center (NODC). A ¼° grid of temperature and salinity, generated using the same methods as WOA01, is also available from the NODC [Boyer et al., 2005]. The 1/4° grid is available as a set of yearly, seasonal and monthly averages. Since sound speed is a function of temperature and salinity, these grids may prove to be useful sources of sound speed calibration in the absence of CTD profiles.

Methodology

Preparatory Work: Software was written to convert WOA01 grids into Ocean Mapping Group (OMG) format. After conversion, further programming produced software to extract temporally and spatially interpolated profiles for a user specified latitude, longitude and time. The software was extended to take OMG format sound speed profiles as input, in addition to navigation track data. The input data serves as a source of position and time; these values are then used to query the WOA01 grid from which a spatially and temporally interpolated sound speed profile is generated.

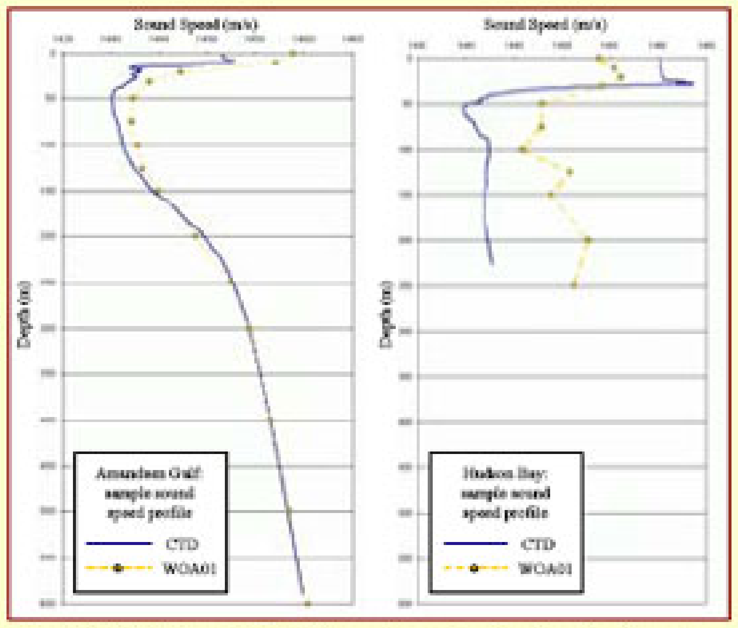
Assessment of WOA01 grid robustness: There is a need to assess the robustness of the WOA01 grid for raytracing purposes. Discrepancies (or errors) in sound speed profiles have non-intuitive effects on depth (and positioning) error. The best way to assess the WOA01 grid's performance is to use it for raytracing. An experiment was performed in which parallel raytracing solutions where computed using (a) 2004/2005 CTD profiles as truth, and (b) the WOA01 grid derived profiles corresponding to the 2004/2005 CTD times/locations. This is further described below and shown pictorially on the right. Steps 2-4 were repeated for all the 2004/2005 CTD profiles. This generated a dataset of 362 assessments of the worst-case scenario errors incurred through usage of WOA01 profiles for raytracing.

Step 1: CTD profiles from the 2004/2005 ArcticNet field seasons were used to generate sound speed profiles, yielding 362 "true" profiles against which the WOA01 grid would be tested.

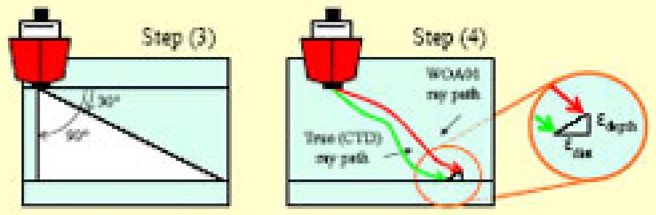
Step 2: For each CTD derived sound speed profile in (1), a corresponding WOA01 profile was generated based on the CTD cast's location and date.

Step 3: Raytracing solutions were then performed using each profile pair (CTD profile & WOA01 profile).

Step 4: 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.



Steps (1) & (2): Sample WOA01 sound speed profiles from the Amundsen Gulf and Hudson Bay (yellow) compared to sound speed profiles derived from 2004/2005 field seasons CTD casts (blue).

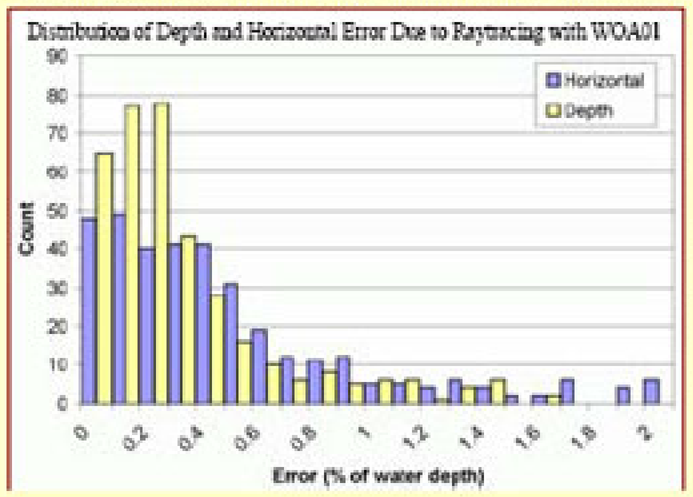


Steps (3) & (4): Raytracing was performed over a 60° range of depression angles. For each profile pair, the maximum error in depth and distance that was encountered over the range of depression angles was reported.

Results

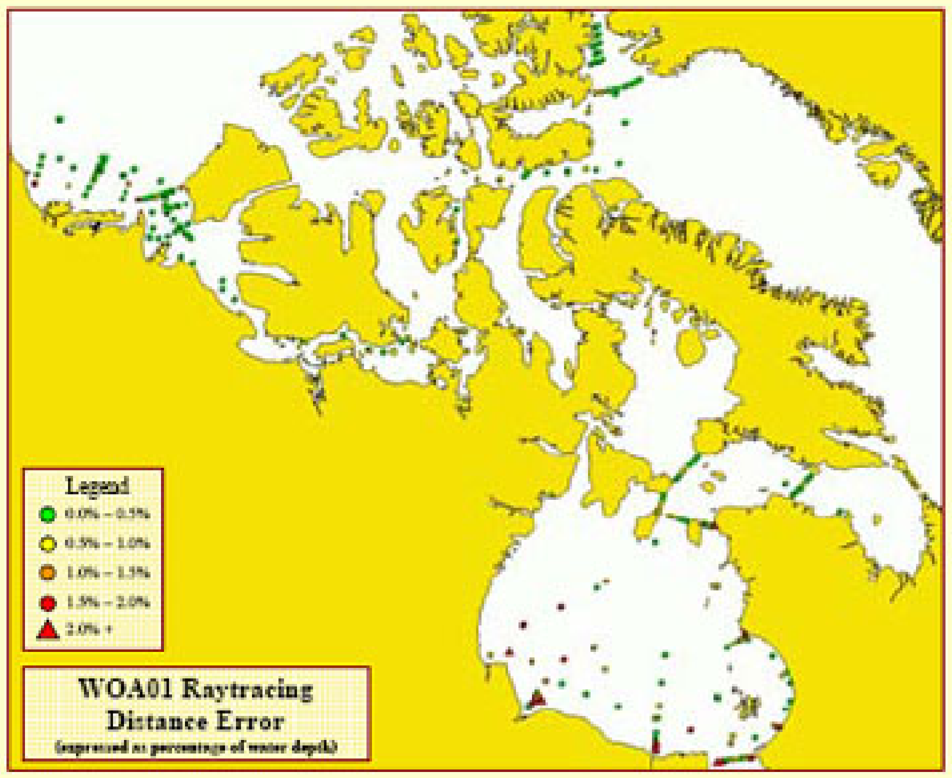
Results: Of the 362 CTD profiles used in the experiment, the maximum observed depth errors due to WOA01 raytracing were less than 1% of water depth for 95% of the cases. Examining the horizontal component of the raytracing solution, it was found that the horizontal error was less than 2% of water depth in 95% of the cases. Several trends are apparent when the data are examined geographically (shown in maps to the right). For example, the western Arctic WOA01 profiles perform more than adequately most of the time, giving errors that are 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.

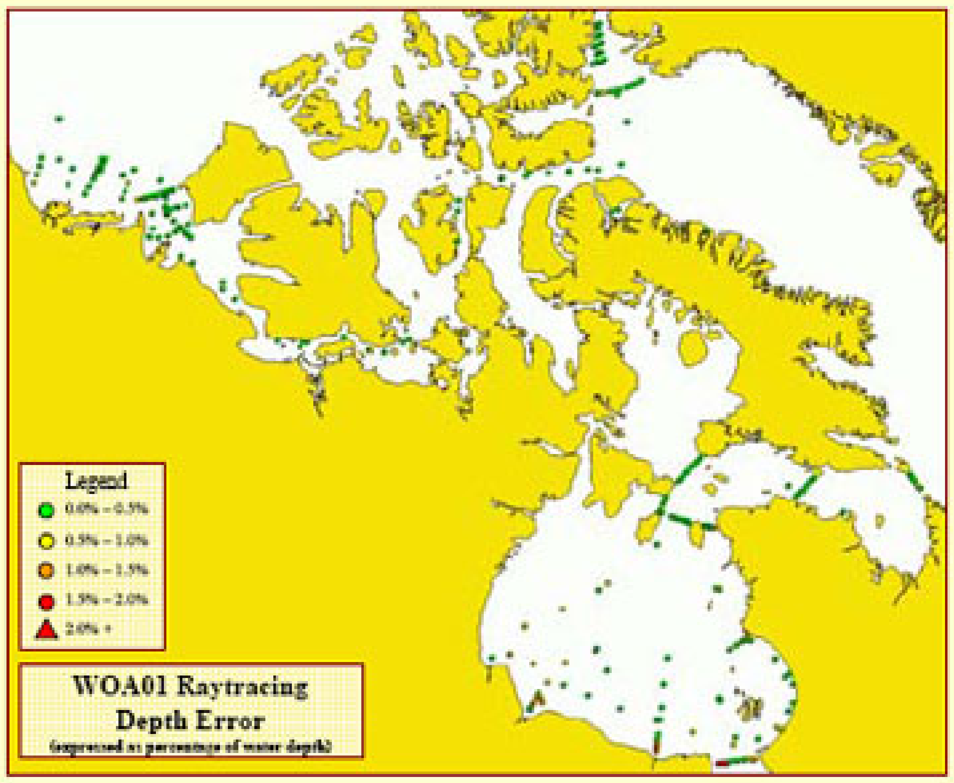
Analysis: How are we getting away with this? This approach has two saving graces: (i) the surface sound speed is measured continuously, and (ii) for the most part, below the mixed layer, the WOA01 profiles agree remarkably well with profiles collected in the 2004/2005 field seasons. As observed by Dinn (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.



Conclusion: The forecasted errors in this simulation suggest that the WOA01 ocean climatology grids can be used for raytracing in the absence of CTD information without seriously impacting on depth and horizontal errors of soundings. The worst performance is realized in Hudson Bay, whereas the grid proves to be quite robust in the western Arctic.

By raytracing with WOA01 (and ignoring other sources of error), sounding depth and horizontal positioning error would be within the allowable percentage of water depth error associated with Order 1 survey specifications of the International Hydrographic Organization (IHO). Note that this only applies to the geographic areas of CTD sampling in the 2004/2005 field seasons.





Leap of Faith: A "leap of faith" is required to expand the conclusions drawn in this study to the areas between CTD sampling stations. Perhaps in future years, sampling schemes can focus on undersampled areas to improve this assessment of the WOA01 grid raytracing performance in said areas.

Future work: There is a need to implement this database as part of ArcticNet post-processing. 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. A temporal analysis should also be performed to study the yearly variation in areas where the sampling density justifies such a study (e.g. western Amundsen Gulf).

Literature Cited

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