A Sound Speed Decision Support System for Multibeam Sonar Operations in the Canadian Arctic

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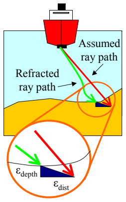
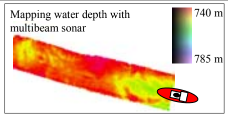
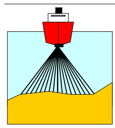
Introduction

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. Left unaccounted for, refraction can introduce systematic errors in the depth and horizontal position of the soundings.

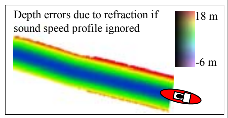


Multibeam sonars are very sensitive to refraction artifacts. As such, operators must ensure that profiles are collected often enough to account for the changing oceanographic environment. Under ideal survey conditions, profiles are collected with sufficient temporal and/or spatial frequency such that the underlying oceanographic processes that drive the changes in sound speed are captured.





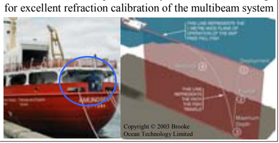
A multibeam sonar allows for the collection of a fan of soundings perpendicular to the ship's axis. The outermost soundings are the most sensitive to refraction and exhibit the largest errors when faced with an incorrect sound speed profile.



Sources of sound speed measurements on the Amundsen

Sound speed is measured by lowering a probe through the water column. The resulting sound speed profile is then used to correct the effects of refraction by computing the acoustic ray path for all soundings. The speed of sound in water depends on pressure, temperature and salinity, all of which may vary with depth, time and location. While oceanographers are primarily interested in salinity and temperature, hydrographers are interested in the resultant sound speed so that they may calibrate their sounding measurements. Onboard the Amundsen, several instruments are available to make such measurements. The primary system is the Moving Vessel Profiler (MVP) 300, which allows for the collection of sound speed profiles to depths of 300 meters while traveling at speeds up to 12 knots. Secondary systems for sound speed measurement include Conductivity, Temperature & Depth (CTD) instruments, deployed either on the rosette or as a standalone instrument.

MVP 300: Installed in the fantail of the Amundsen, the MVP 300 can collect profiles every few minutes, allowing for excellent refraction calibration of the multibeam system



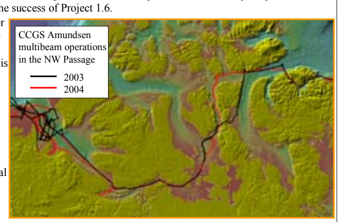
CTD

WHY IS THIS IMPORTANT?

Project 1.6 The opening NW Passage: Resources, Navigation, Sovereignty & Security

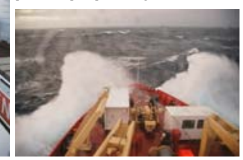
"Multibeam bathymetry, sub-bottom profiling and coring during multiple traverses through the NW Passage as part of the repetitive annual E-W transects will provide an unprecedented opportunity to map bathymetry and seabed geology". [ArcticNet NCE Proposal, March 2003]. One of the goals of Project 1.6 is to "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.

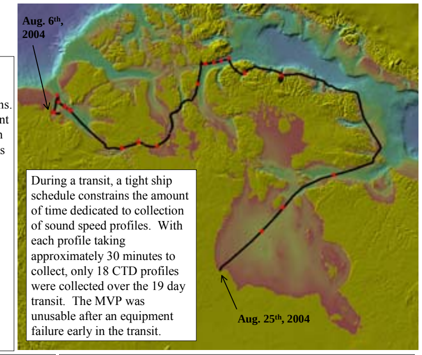
It is important to for mission planners to understand that ArcticNet research is always ongoing, even when the vessel is in motion. Time must be allocated for sound speed profile collection during transit as it is critical to the success of Project 1.6.



You can't always get what you want: The challenges of working with a sparsely sampled water column

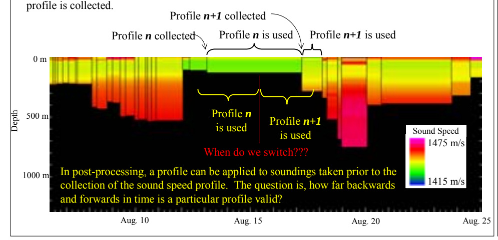
Bouts of high sea-states and icebreaking limit the deployment of the MVP. Stationary CTD profiles can also prove risky in these conditions. These factors, along with occasional equipment failure, lead to an under sampled watercolumn and force the operator to make tough decisions when it comes to applying the sound speed profiles in post-processing.





During a transit, a tight ship schedule constrains the amount of time dedicated to collection of sound speed profiles. With each profile taking approximately 30 minutes to collect, only 18 CTD profiles were collected over the 19 day transit. The MVP was unusable after an equipment failure early in the transit.

The sound speed field is modeled in real-time mapping operations by applying the profile immediately after its time of collection. The profile is used, whether it is valid or not, until another profile is collected.

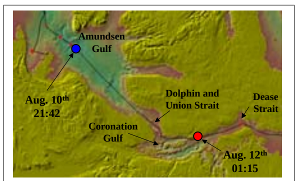


Challenges:

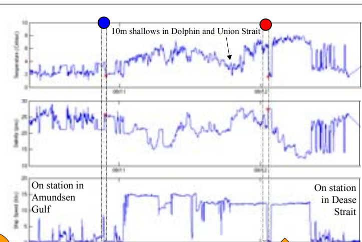
- Which profile is to be used for a given time?
- When should the switch be made to another profile?
- Should we choose profiles that are closest geographically or temporally?
- Does the profile in use cover the range of depths to which it will be applied? If not, how can we extend the profile beyond the collection depth?
- Can "hopeless" areas be identified where the data quality is clearly in error due to refraction artifacts?
- Can historic profiles be used in the areas identified as "hopeless"?

The sound speed profiles alone do not give enough information to address these challenges. Aiding information is required to assist the operator in making decisions when dealing with the challenges outlined above. A Decision Support System (DSS) can provide an environment where the operator can evaluate different forms of aiding information and make decisions based on the available data.

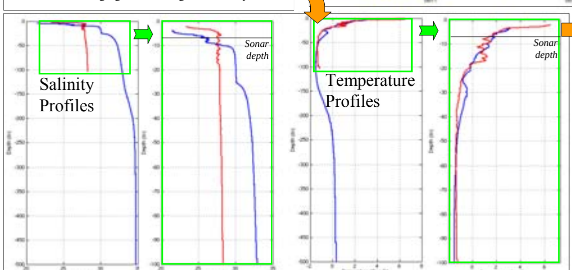
Decisions, decisions…Follow a hydrographer's decision process in post-processing application of sound speed profiles



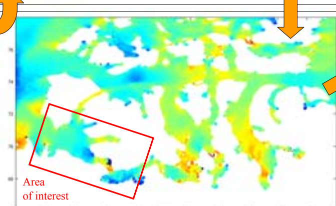
A profile was collected at the last scientific station in the Amundsen Gulf (blue). The next profile was collected approximately one day later in Coronation Gulf (red). When (or where) do we switch between them? Blue and red are used in the following figures to distinguish the two profiles.



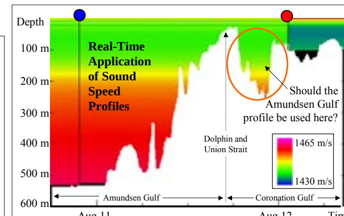
A surface temperature and salinity probe is installed on the CCGS Amundsen; it draws water from the same depth as the sonar transducer. It is important to plot surface temperature and salinity along with vessel speed since the hull draws surface water down to the probe while underway. While stationary, the temperature and salinity measurements are quite similar between the two stations, however, the measurements taken from the surface water that is drawn down while underway suggest that the waters warm while leaving Amundsen Gulf, and then cool again in Dolphin and Union Strait. This could be due to mixing of the shallow (10m) water mass through the strait, removing the surface stratification due to solar heating. Surface waters warm again as the vessel enters Coronation Gulf.



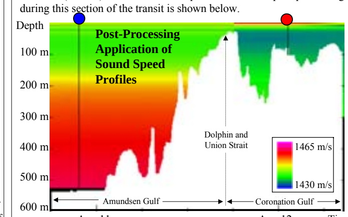
Examining the salinity and temperature profiles, it can be seen that both water masses share similar temperature characteristics though they differ markedly in salinity. Though useful, this information is not enough to indicate when or where to switch from one profile to the next. Note that the sonar head is at a depth of 6.5 meters, safely below the surface layer where temperature may vary diurnally.



While wind mixes the watercolumn from the top down, tidal currents have a similar effect but from the bottom up. The magnitude of tidal mixing is proportional to the cube of the tidal current speed over the water depth. The above map (current speed³/depth) has been prepared using currents from the WebTide[1] tidal model and shows that tidal mixing is likely a factor in Dolphin and Union Strait but is unlikely to have much effect in Amundsen or Coronation Gulf. [1. Kliem, Nicolai and Greenberg. 2003. Diagnostic Simulations of the Summer Circulation in the Canadian Arctic Archipelago. Atmos.-Ocean. 41.]



Application of the profiles in real-time would have the Amundsen Gulf profile being used well into Coronation Gulf. Examining the bathymetric trends through Dolphin and Union Strait, it is clear that a sill depth of a few tens of meters exists that limits the communication of waters deeper than the sill depth between Amundsen and Coronation Gulf. It is therefore reasonable to limit the profiles to the spatial extent of their respective water masses, and we should likely switch from the Amundsen Gulf profile to the Coronation Gulf profile while transiting through Dolphin and Union Strait. The ship track depth profile also allows us to determine the depth to which the Coronation Gulf profile must be extended (~250m). The final sound speed field used in post-processing during this section of the transit is shown below.

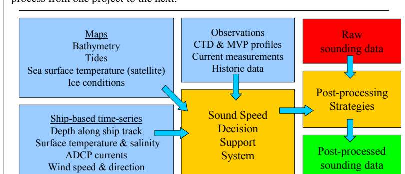


A decision is made…

Based on the following, it is unlikely that the Amundsen Gulf profile should be used once past Dolphin and Union Strait. The Coronation Gulf profile should be used instead, and should be extended to a depth of ~250m to accommodate the depth range along the ship track.

1. The surface temperature and salinity exhibit different trends to before and after passing through Dolphin and Union strait
2. The water column is likely tidally mixed in Dolphin and Union Strait due to the relatively strong currents and shallow depths and the stratification observed in the Amundsen Gulf profile does not likely survive the passage of Dolphin and Union Strait
3. A sill depth of 20-30 meters limits communication of deep waters between Amundsen and Coronation Gulf

A Decision Support System (DSS) for sound speed processing will help hydrographers make better decisions by integrating the various types of information into a single software application. The resulting workflow will be more intuitive, faster, and less error prone. The integrated design will allow for the documentation of decisions and their justifications, and allow the user to maintain consistency in the decision making process from one project to the next.



This research project proposes to develop a DSS in support of multibeam operations in the Canadian Arctic Archipelago. Research goals and questions include:

- Which types of aiding information may prove useful to the decision maker?
- How can aiding information be visualized such that it aids the decision process?
- Inclusion of "what if" scenarios that allow the decision maker to immediately evaluate the impact of their decisions in terms of correction or aggravation of refraction artifacts in the soundings
- Adaptation of the DSS to allow for planning, e.g. identify critical areas for sound speed profile collection for a planned ship track

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