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Real-time Monitoring of Uncertainty Due to Refraction in Multibeam Echo Sounding

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Abstract

A software toolkit has been developed to objectively monitor uncertainty due to refraction in multibeam echosounding, specifically mapping systems that employ underway sound speed profiling hardware. The toolkit relies on the use of a raytrace simulator which mimics the sounding geometry of any given echosounder, specifically array type, angular sector, draft, and availability of a surface sound speed probe. The simulator works by objectively comparing a pair of consecutively collected sound speed profiles and reporting sounding uncertainty across the entire potential sounding space. Real-time visualizations of the uncertainty as a function of time and space allow the operator to tune the sound speed profile collection regime to maintain a desired sounding uncertainty while at the same time minimizing the number of casts collected.

Introduction

Multibeam echosounders (MBES) collect oblique soundings, allowing for a remarkable increase in coverage compared to traditional downward looking single beam echosounders. The gain in coverage comes at a cost: the speed of sound varies with depth and can cause the oblique sounding raypaths to bend, much like light is refracted through a prism. If one assumes that the ray takes a straight path from sounder to seafloor, the deviation of the raypath due to refraction can introduce significant and systematic biases in soundings. This is readily corrected by measuring the sound speed variation with depth and using this additional information to model the acoustic raypath. Since the speed of sound in water is determined primarily by temperature and salinity, any significant spatial and/or temporal variations of these two quantities can significantly change the sound speed structure and could lead to sounding biases if an outdated sound speed profile is used for refraction correction. The surveyor must then take care to sample the watercolumn often enough to capture the important changes.

The problem is that there is no hard and fast rule to guide the hydrographic surveyor in deciding how often to collect sound speed profiles, especially in the oceanographically dynamic environment associated with coastal areas. Without *a priori* knowledge of the oceanographic factors at play in a particular survey area, the surveyor must take a monitoring approach to ensure that sufficient sound speed profiles are obtained. This is a highly subjective process and it is heavily influenced by the presence/absence of seabed topography and the experience of the operator. In the worst case scenario, the problem is not noticed until the post-processing stage, at which point there is very little

that can be done to rigorously rectify the situation (though there are empirical corrections that can be applied).

With static profiling systems, i.e. those which require the survey vessel to remain stationary during acquisition of a sound speed profile, survey operators must balance the loss of survey time taken to collect a cast against an improvement in sounding accuracy. This is a difficult balance to achieve given the subjective approach to monitoring sounding uncertainty due to refraction. Faced with indecision, the operator is often biased towards maintaining survey efficiency at the expense of collecting sound speed casts, potentially leading to an undersampled watercolumn.

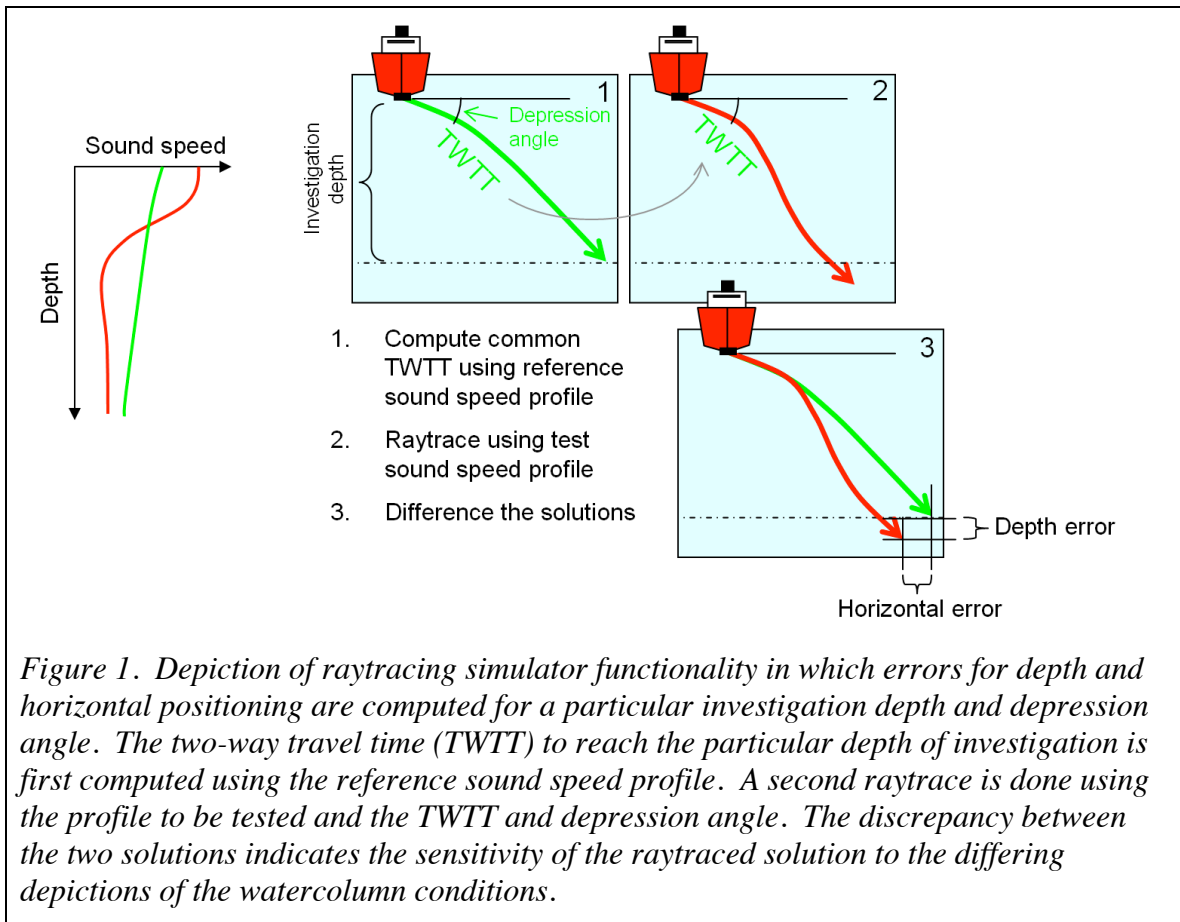
In the case of underway sound speed profiling systems (e.g. Furlong et al, 1997), the sampling problem becomes quite different: it is possible to oversample the watercolumn and collect far more sound speed casts than are strictly necessary to maintain a desired sounding accuracy. In this case, the profiling hardware (e.g. winches, cables) experiences accelerated wear and the towed instrumentation is unduly exposed to greater risk of fouling or grounding with each unnecessary cast.

In either case, there is a clear need for an objective, quantitative method to assess the impact of varying watercolumn conditions. A real-time objective approach is proposed in which sounding uncertainty is estimated based solely on the sound speed profiles themselves, i.e. no sounding data is required to estimate sounding uncertainty. This is done through the use of a comparative raytracing simulator which mimics the real-time raytracing geometry over the potential sounding space, i.e. the entire angular sector, from sounder to seafloor. Parallel raytracing solutions are computed over the potential sounding space for the pair of sound speed profiles that are being compared. The discrepancy between the solutions serves as a quantitative indicator of the uncertainty impact associated with the varying watercolumn conditions.

Raytracing Simulation

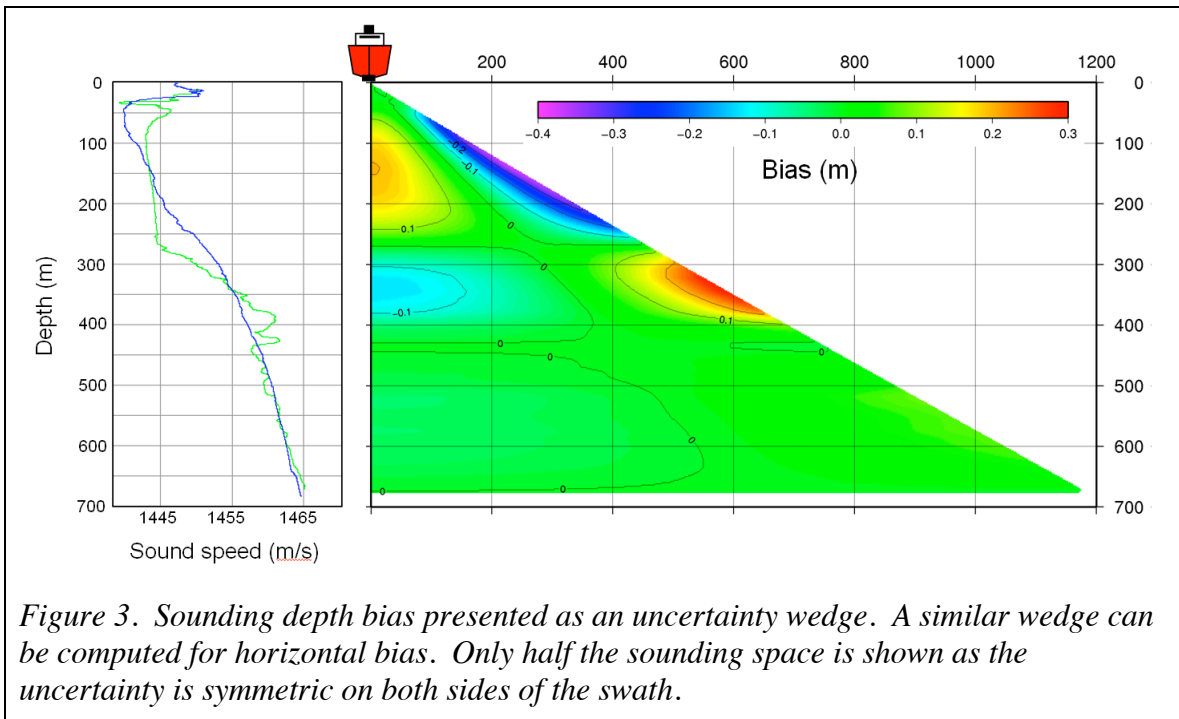
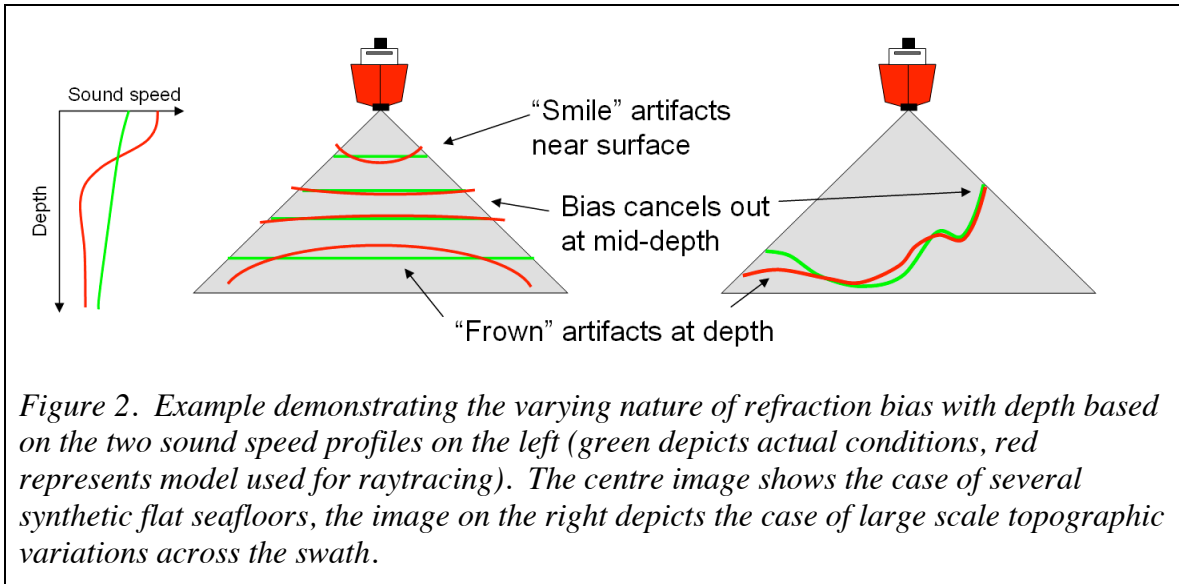
It is possible to objectively quantify the impact on sounding accuracy by post-processing sounding data with differing sound speed profiles (Hughes Clarke et al., 2000); however, this is not conducive to quick decision making as post-processing can lag significantly behind acquisition. The post-processing method is also limited to the range of depths which were actually sounded and gives no warning of mid-water discrepancies that can affect shallower soundings in areas that have not been sounded yet.

The simulation technique allows for rapid assessment of watercolumn conditions as it does not require sounding data, thus it circumvents the time lag associated with post-processing. It also has the potential to provide the whole picture instead of limiting itself to a nominal seafloor depth. As will be shown later in this work, this can be very important for real-time monitoring. Other researchers have also adopted a simulation approach for similar analysis problems, e.g. Imahori and Hiebert (2008). This work differs by specifically modeling the unique raytracing behaviour of MBES systems where *“transducer depth sound speed is used as the initial entry in the sound speed profile used in the raytracing calculations”* (Kongsberg, 2006, p. 63).



The simulation is based upon isolating the raytracing portion of depth reduction procedure, i.e. the reduction of a travel-time and depression angle into depth and horizontal distance, as shown in Figure 1. The simulator is a simple, yet powerful, tool which allows for a quantitative answer to the following question: “What would the bias be if sound speed profile B was used in the place of sound speed profile A?” In this case, profile A is meant to represent actual conditions whereas profile B represents an alternate model whose fitness is to be tested by a comparison to A. Such a comparison can be done for any location in the potential sounding space encompassed by the angular sector of the system. As shown in Figure 2, the discrepancy between the true and biased soundings can vary dramatically with depth and across-track position in the swath. In the example depicted in the center of Figure 2, a series of synthetic flat seafloors (green) are investigated over the depth range associated with the two sample sound speed profiles in the left side of the figure. The red seafloors show how depth varying discrepancies between sound speed profiles can influence refraction bias throughout the watercolumn. The soundings in the upper portion of the watercolumn would be affected by so-called “smile” type artifacts if the red sound speed profile were used in the place of the green. The nature of the refraction bias changes at full depth, becoming a so-called “frown” type artifact. Midway through the watercolumn, the transition from “smile” to “frown” artifact occurs, leading to a range of depths where the magnitude of the refraction artifact is minimal. The image on the right side of Figure 2 demonstrates how the depth varying nature of the refraction artifact would affect a

seafloor with significant across-track topography. In this case, the deeper portions of the swath are heavily biased by refraction whereas the shallower portions are relatively unaffected as they fall within the range of depths associated with the transition between “smile” and “frown” type artifacts.



As the refraction bias can vary dramatically with depth, it is imprudent to limit the raytrace simulator to investigating a single depth and across-track range. At the very least, it is important to investigate the subset of the sounding space covering the expected range of depths in a survey area. By systematically investigating the depth

and horizontal bias across a regularly spaced grid covering the entire potential sounding space, one can create a lookup table of bias for any position in the swath. The lookup table, referred to as an uncertainty wedge, can be presented in the form of a colour coded image, as in Figure 3. The uncertainty wedge format captures the location and magnitude of refraction type biases throughout the watercolumn in a single image. Presented alongside the casts that were compared, as in Figure 3, it is then a simple procedure to determine which portions of the watercolumn variability has the most impact on sounding accuracy.

An example best illustrates the benefit of examining the entire potential sounding space instead of limiting the investigation to the nominal seafloor depth. In the case of Figure 3, the two casts shown on the left side of Figure 3 were collected a year apart but at the same location in Lancaster Sound, the easternmost entrance to the Northwest Passage in the Canadian Arctic Archipelago. They were gathered during routine deep water multibeam mapping operations that are repeated on a yearly basis by the CCGS Amundsen, a Canadian icebreaker refitted for scientific research in the Canadian Archipelago (Bartlett et al, 2004). The raytrace simulator can be used to ascertain whether or not the second field season's mapping operations could have used the sound speed profile from the previous year without significant impact on sounding accuracy. Examining the uncertainty wedge computed from the raytrace simulator, it is obvious that the uncertainty associated with using a cast from the previous field season would be negligible at depths greater than 450 m. If the casts happened to be acquired in the deepest part of the survey area (standard practice for many hydrographic surveys) and significant portions of the survey area were significantly shallower than 450 m, then a small bias would have been incurred through use of the previous field season's sound speed profile but only for the depths shallower than 450 m.

The bias represented by the uncertainty wedge can be presented in other formats that are perhaps more useful for real-time monitoring. Figure 4 demonstrates two such alternate presentation formats, computed with different data than the wedge shown in Figure 3. The upper image presents the bias expressed in percentage of water depth whereas the lower image presents the same information but colour-coded using an arbitrarily chosen pass/fail schema. The second image is likely the most useful for real-time monitoring as it presents the information to the operator in such a manner that an immediate decision could be made, for example, regarding adjusting the survey line spacing to accommodate poor accuracy in the outermost sections of the swath.

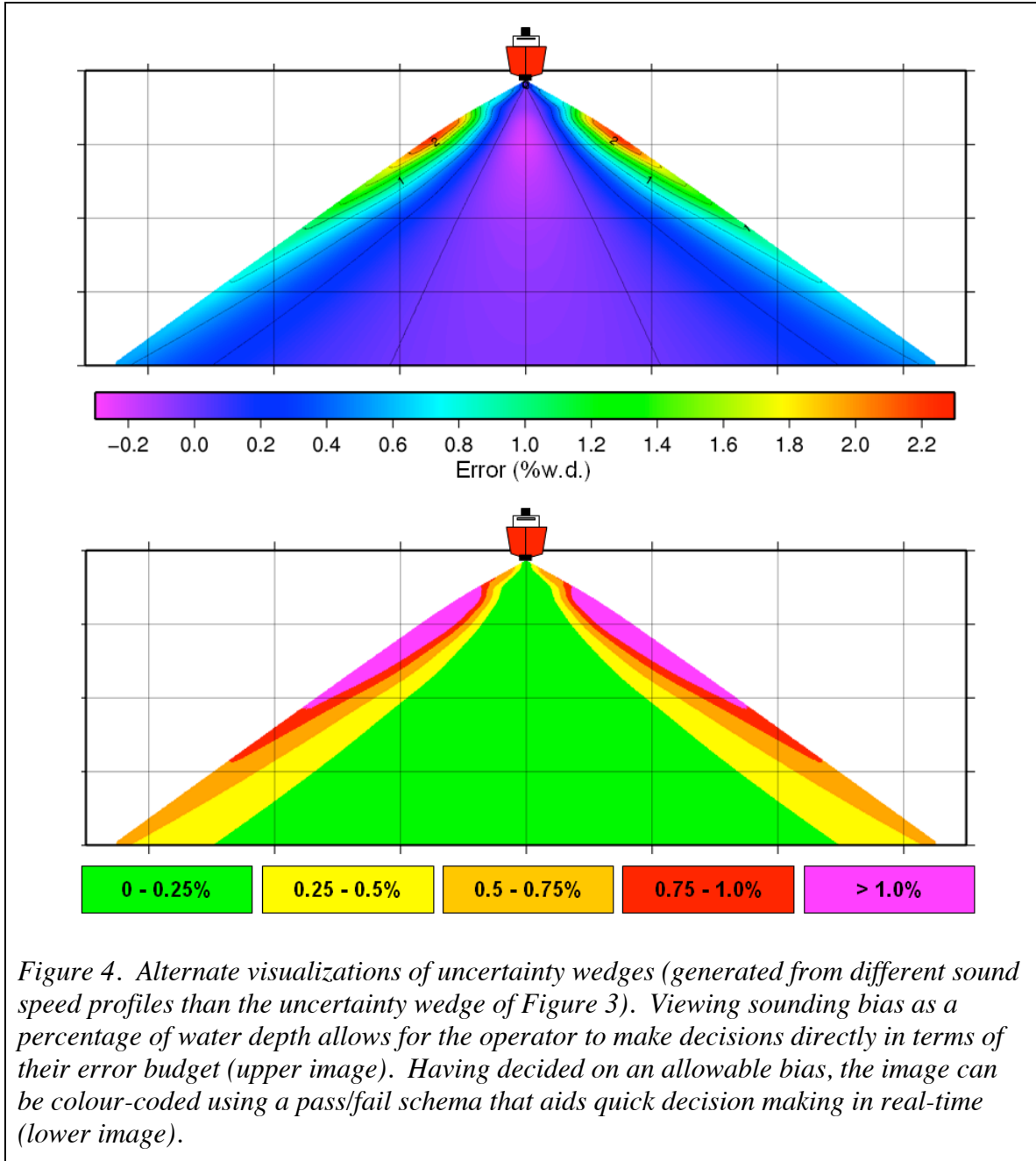


Figure 4. Alternate visualizations of uncertainty wedges (generated from different sound speed profiles than the uncertainty wedge of Figure 3). Viewing sounding bias as a percentage of water depth allows for the operator to make decisions directly in terms of their error budget (upper image). Having decided on an allowable bias, the image can be colour-coded using a pass/fail schema that aids quick decision making in real-time (lower image).

In order to serve as a reasonable predictor of sounding uncertainty, the simulator must honour the real-time sounding geometry as much as possible. The raytracing procedure thus requires reasonable estimates of several parameters some of which simply modify the range of depths and angles to be investigated, whereas others fundamentally change the behaviour of the raytracing algorithm. These are listed below along with explanation of how they affect the fidelity of the simulation.

Availability of a surface sound speed probe

A surface sound speed probe is often required to ensure correct beam pointing angles when using linear transducer arrays. This additional measurement may be used to supplement a sound speed profile during raytracing either by replacing the value at the transducer depth in the sound speed profile or by using it to set the ray parameter prior to raytracing (Beaudoin et al., 2004). As pointed out by Cartwright and Hughes Clarke (2002), the incorporation of the surface sound speed measurement has a significant effect on the behaviour of a raytracing algorithm, in some cases it allows for a graceful recovery from surface layer variability as long as the deeper portion of the watermass is relatively invariant. Figure 5 shows the result of an uncertainty wedge calculation using the same profiles as in Figure 3, but without the use of a surface sound speed probe (note that different colour scales differ between figures 3 and 5).

The real-time toolkit mimics the use of a surface sound speed probe by retrieving the sound speed at transducer depth from the reference profile and using this to compute the ray parameter for the test cast raytrace without modifying the test cast. One must take care, however, to only perform this additional step if the acquisition and/or post-processing software can accommodate the surface sound speed as an additional aiding measurement during sounding reduction, specifically the raytracing portion of the procedure. For example, a surface sound speed value may be input into a Reson 8101 MBES for use in pitch stabilization (Reson, 2000). Though this value is logged in the data stream, it is not used in subsequent raytracing calculations performed in post-processing in Caris HIPS (Wong, personal comm.). In this case, the simulator should not be configured to mimic a surface sound speed probe as this would give unreliable results, especially in the case where surface variability is significant.

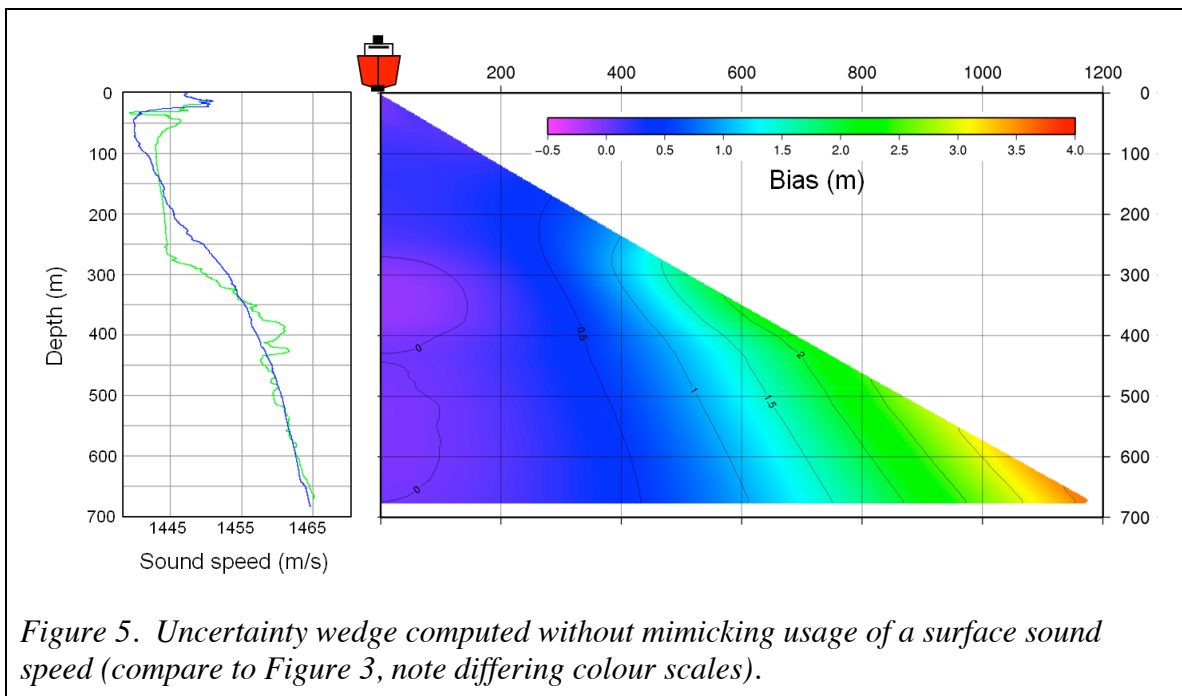


Figure 5. Uncertainty wedge computed without mimicking usage of a surface sound speed (compare to Figure 3, note differing colour scales).

Angular sector

The nominal angular sector that can be achieved by the sounder controls the shallowest depression angle that must be investigated and heavily influences a system's overall sensitivity to variable watercolumn conditions. As the outermost edges of the swath are typically the most sensitive to refraction, the predictive ability of the simulator depends heavily on having an accurate estimate of the outermost beam's depression angle. The outermost depression angle can be easily underestimated and overestimated in various conditions (see Figure 6). These two cases are examined in turn below.

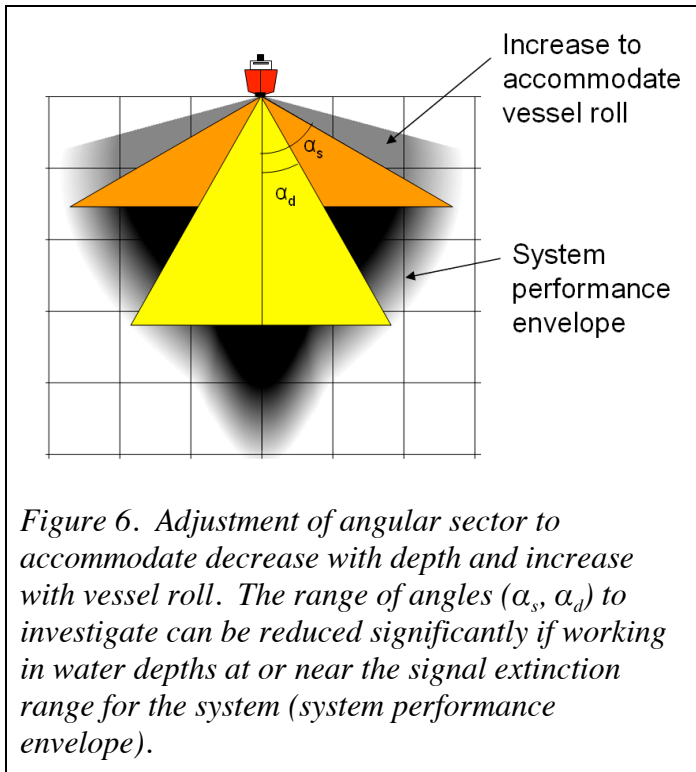


Figure 6. Adjustment of angular sector to accommodate decrease with depth and increase with vessel roll. The range of angles (α_s , α_d) to investigate can be reduced significantly if working in water depths at or near the signal extinction range for the system (system performance envelope).

In dynamic roll conditions, a system that is not roll-stabilized can experience larger refraction artifacts in the outer portions of the swath due to smaller than normal depression angles associated with extremes in vessel roll. By limiting the investigation to the nominal angular sector, the simulator would underestimate the refraction in the outermost beams during large roll events and the output would be overly optimistic (though this would only apply to one side of the swath). If the outermost soundings must be retained to maintain overlap between survey lines, then the simulator should allow for an artificial increase to the angular sector to allow for large roll events. It should be noted that in

particularly large roll events (10° - 15°) and with large angular sector systems (e.g. $\pm 75^\circ$), the outermost rays will tend to horizontal and will not likely have a bottom return. With an unstabilized system, the operator must make an effort to estimate the largest achieved angular sector instead of simply increasing the angular sector by adding the largest expected roll value. Vessel pitch can also reduce the outermost depression angles though the influence is not nearly as pronounced as that of vessel roll.

In the case that the outermost edges of the swath fall beyond the maximum range performance of the mapping system, the achieved angular sector can be significantly smaller than the nominal case. In this case, the simulator must allow for a reduction of angular sector with increasing depth, otherwise the uncertainty estimates would be overly pessimistic. This can be done manually by adjusting the angular sector to match the sector achieved under actual working conditions. This would also apply in the case where filtering applied in post-processing would artificially reduce the angular sector, e.g. filtering all soundings outside of $\pm 60^\circ$.

Transducer draft

A particular mapping system's susceptibility to surface variability can vary dramatically depending on the depth of the transducer in the watercolumn. The transducer draft should therefore be used as the start point of the raytrace. The simulator currently does not allow for vertical motion of the transducer through the watercolumn and all analyses are based on a static draft assumption.

Survey depth

For accurate predictions of sounding uncertainty, the simulator must investigate the range of depths encountered across the swath. As a first order approximation, the terminal depth of the sound speed profiles can be used as an approximate seafloor depth. In the case of highly varying topography across the swath, the terminal depth investigation can give a degraded estimate of uncertainty for portions of the swath which are significantly deeper or shallower than the investigation depth. It is thus important to investigate the entire potential sounding space to accommodate soundings which are significantly shallower than the depth of investigation. Accommodating soundings which are deeper than the investigation depth requires intelligent extension of the sound speed casts, something which may prove difficult in real-time. One potential solution would be to select a default deep cast for use in profile extension. In this case, the extension of the measured casts only allows for an estimation of how the uncertainty due to the surface variability decays or grows with depth; one cannot estimate the additional uncertainty due to deep variability unless one measures it.

Real-Time Application and Visualization

Application of the raytrace simulator to real-time monitoring simply involves comparing the most recently collected cast to its predecessor, the question being: "was the recently collected cast required to maintain sounding accuracy?" If the answer is "no", then the newly acquired profile could be considered redundant, i.e. it was not necessary to collect said profile as the previous could have been used in its place with only a small (and tolerable) bias being introduced. If the answer is "yes", then the change in the watermass structure between two casts was significant in terms of sounding accuracy and the second profile was absolutely necessary for the maintenance of sounding accuracy. Routinely comparing each cast against its predecessor allows the operator to assess if profile collection rate is adequately capturing the watercolumn variability. A hypothetical real-time monitoring scenario is shown in Figure 7 using a series of 6 sound speed casts.

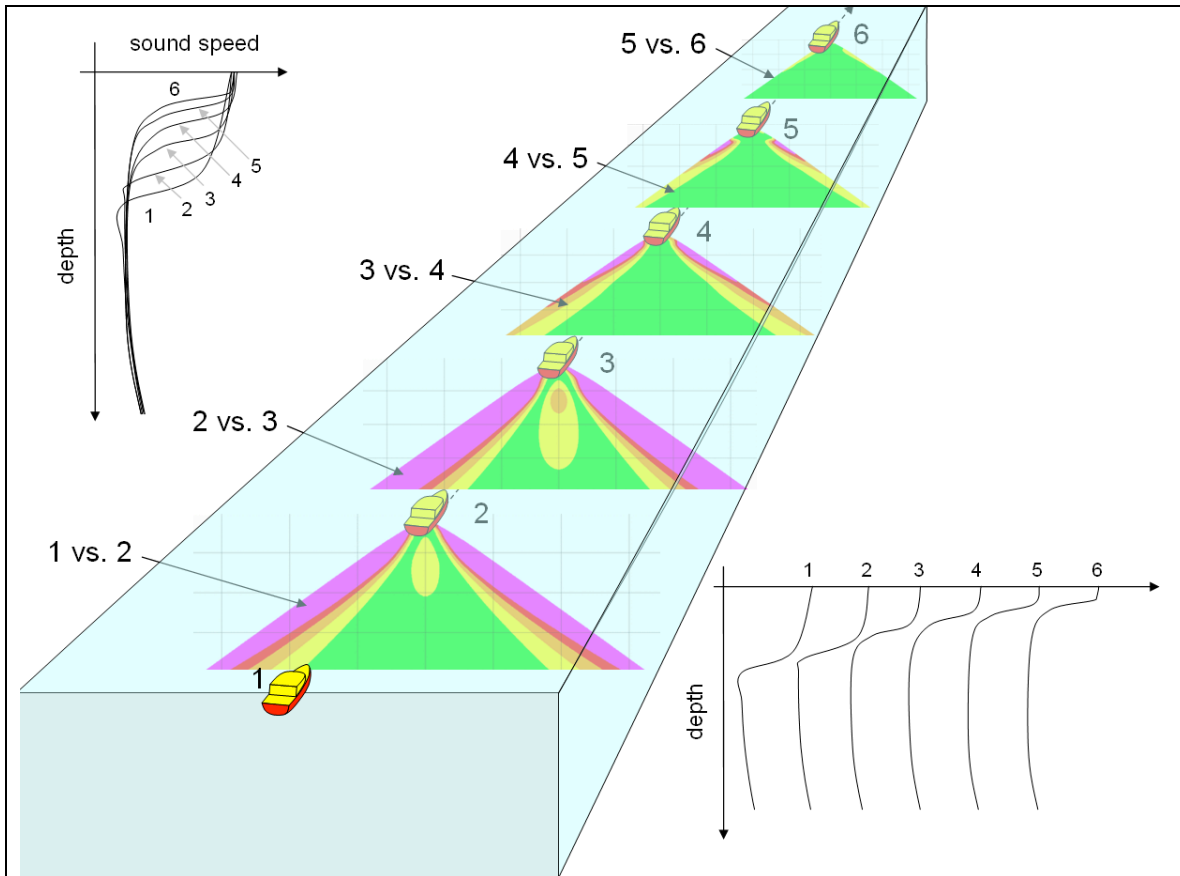


Figure 7. Snapshots of bias through an evolving watercolumn. A sequence of sound speed profiles indicates a gently rising thermocline (upper left, lower right is a stick plot of the same). Comparing each cast to its predecessor yields a set of uncertainty wedges; these indicate that the change in conditions between casts 2 and 3 was particularly penalizing (note that the rate of change in thermocline depth was at its greatest between casts 2 and 3). Conversely, changes in conditions between cast 3 and 4 had much less impact on sounding bias, with the impact diminishing between casts 4 and 5, etc.

For real-time monitoring of sounding uncertainty due to refraction, it is argued that one should investigate all positions in the potential sounding space instead of limiting the investigation to the nominal seafloor depth. Referring back to the example drawn from Figure 3, mid-water variability may introduce biases that become insignificant (or acceptable) with depth, however, if the survey line is steadily running up slope, the mid-water bias will eventually become significant once the water depth shoals to the depth associated with the troublesome variability. In this case, a sound speed cast sampling rate that is sufficient in deep water may prove deficient in shallow water if the nature of the watercolumn variability is the same in both locations. It is just as important to see the time history of the comparisons as this allows the operator to proactively adjust the watercolumn sampling rate before problems occur. A suggested visualization format, the uncertainty field, is suggested in Figure 8(d). The uncertainty field is built using the outer edge of the 3-D uncertainty wedge; this corresponds to the outermost regions of the potential sounding space. These are the most sensitive to refraction, thus the outer

edge of the 3-D uncertainty wedge acts much like a canary in a coal mine, providing an early warning of problems to come.

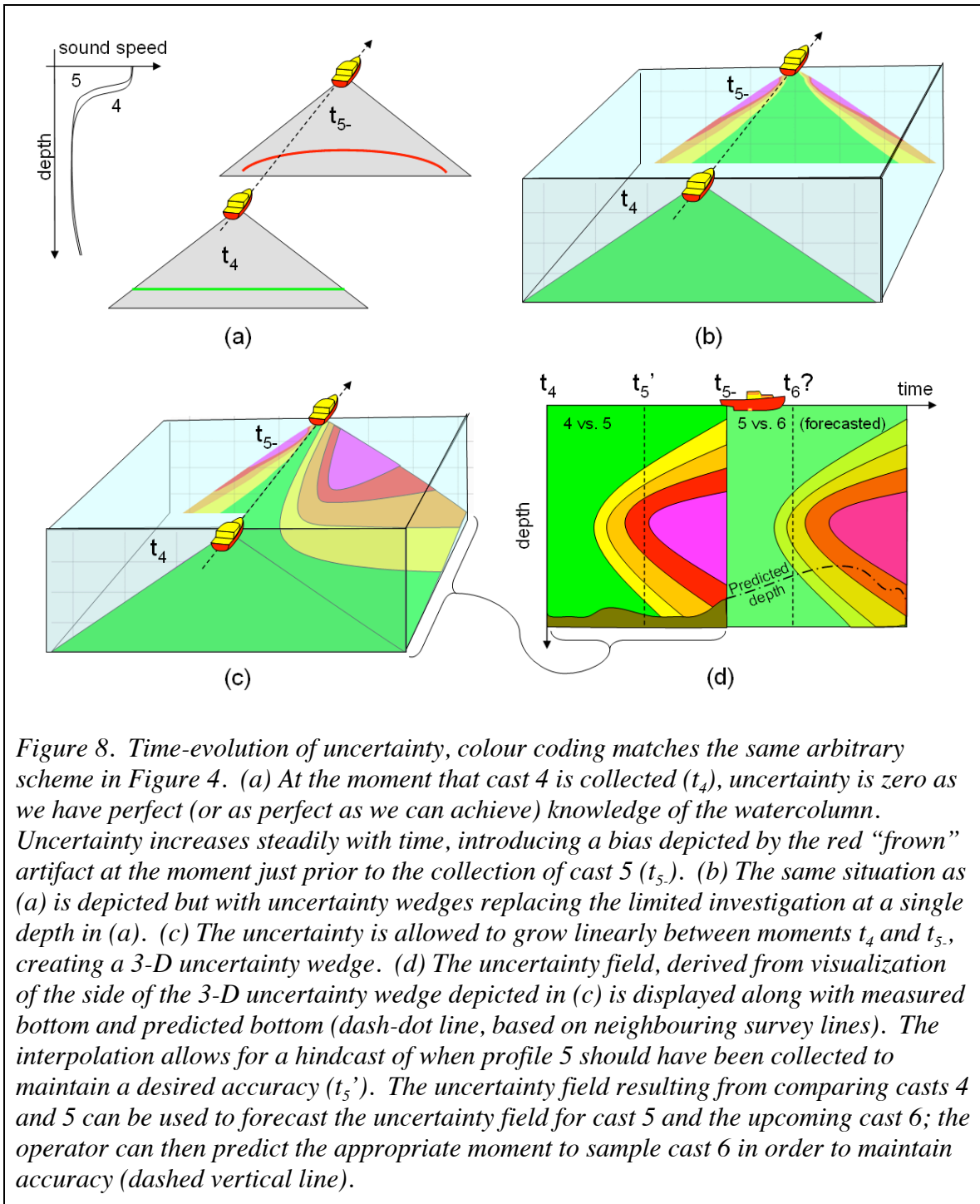
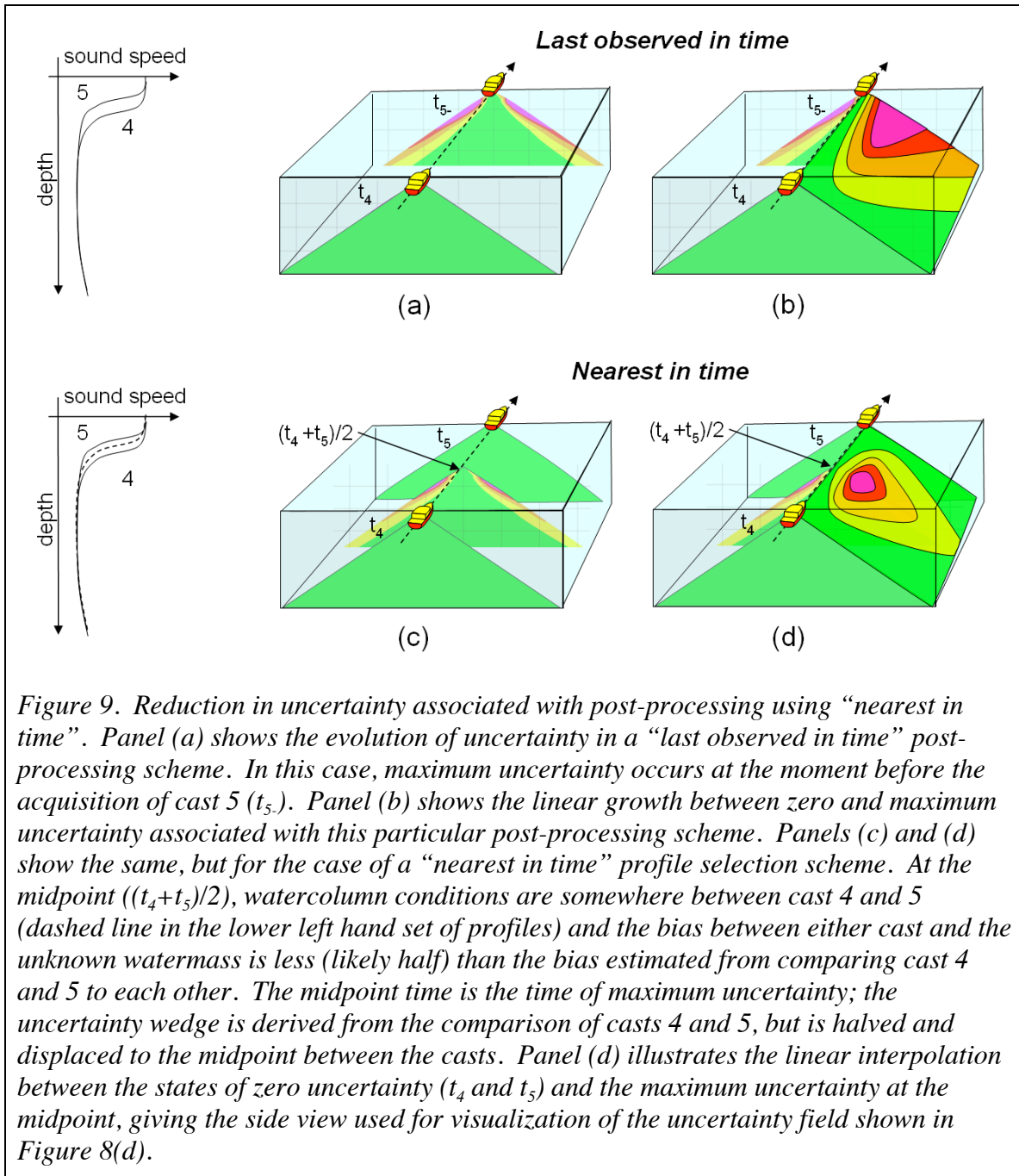


Figure 8. Time-evolution of uncertainty, colour coding matches the same arbitrary scheme in Figure 4. (a) At the moment that cast 4 is collected (t_4), uncertainty is zero as we have perfect (or as perfect as we can achieve) knowledge of the watercolumn. Uncertainty increases steadily with time, introducing a bias depicted by the red “frown” artifact at the moment just prior to the collection of cast 5 (t_5). (b) The same situation as (a) is depicted but with uncertainty wedges replacing the limited investigation at a single depth in (a). (c) The uncertainty is allowed to grow linearly between moments t_4 and t_5 , creating a 3-D uncertainty wedge. (d) The uncertainty field, derived from visualization of the side of the 3-D uncertainty wedge depicted in (c) is displayed along with measured bottom and predicted bottom (dash-dot line, based on neighbouring survey lines). The interpolation allows for a hindcast of when profile 5 should have been collected to maintain a desired accuracy (t_5'). The uncertainty field resulting from comparing casts 4 and 5 can be used to forecast the uncertainty field for cast 5 and the upcoming cast 6; the operator can then predict the appropriate moment to sample cast 6 in order to maintain accuracy (dashed vertical line).

It is important to note that the linear time-interpolation suggested in Figure 8(c) is strictly only applicable to high density watercolumn measurements typical of underway profiling systems. With sufficiently high sampling rates (or slowly varying conditions), it may be possible to use the interpolation to predict when the next cast should be taken in order to

preserve accuracy. Referring to Figure 8(d) again, the forecasted uncertainty field between times t_5 and t_6 suggests that accuracy would be maintained if cast 6 is collected much earlier than planned. Even though cast 5 was collected too late to preserve accuracy, the operator (or the control system) has the potential to learn from the mistake and increase the sampling rate such that cast 6 could be collected earlier than planned, avoiding further loss of accuracy.

It should also be noted that the uncertainty estimates correspond to the watercolumn model where every cast is used up to the moment of acquisition of the next cast, reflective of the real-time environment. If the soundings are post-processed and the casts are applied using a “nearest in time” selection algorithm, then the uncertainties predicted using the simulator may be overly pessimistic. Again, under the assumption that one is able to sample the watercolumn at a very high rate, the actual uncertainty at the midway point between profile samples is a fraction of the estimate from the simulation, likely half. This leads to an alternate view of the uncertainty field, as shown in Figure 9(c) and 9(d). More research is required to ascertain the validity of consistently halving the uncertainty estimates as this is highly contingent on having an adequately sampled watermass that is amenable to interpolation (cf. Hughes Clarke et al., 2000).



Real-Time Usage

A software toolkit has been developed to implement the raytracing simulation using the temporal visualization scheme suggested in Figure 8(d). The usage of the toolkit varies based on sound speed profiling capability; this examination is limited to the case of underway profiling systems, e.g. Moving Vessel Profilers (MVP), Underway CTDs, or expendable instruments. With these types of instruments, it is possible to sample the

watercolumn as often as desired and the goal then becomes to find the ideal sampling rate. Collecting too few casts will obviously impact on sounding accuracy. Collecting too many casts can be a problem as well: it is wasteful of potentially limited reserves of expendable probes whereas underway profiling systems experience unnecessary wear and are exposed to greater risk of fouling or grounding. In this case, the toolkit can be used to guide the surveyor to an ideal watercolumn sampling rate, somewhere between oversampling and undersampling.

An example of real-time usage during a short field trial with an MVP-30 onboard the CSL Heron in Saint John, New Brunswick is shown in Figures 10-12, (a follow-up paper is planned in which the field trial results will be fully presented). Briefly, the field trial took place above the reversing falls, a narrow and shallow constriction at the river mouth that experiences a dramatic reversal of current direction during a rising tide. The resulting twice daily injection of salty water from the Bay of Fundy makes for challenging survey conditions in a deep gorge above the falls. Figure 10 shows a time-series view of the bottom track and the watercolumn profiling rate (green vertical lines) acquired during a calibration run in which the real-time monitoring tool was used to identify problematic areas. The dotted and dashed boxes in Figure 10 represent two passes through the gorge above the reversing falls.

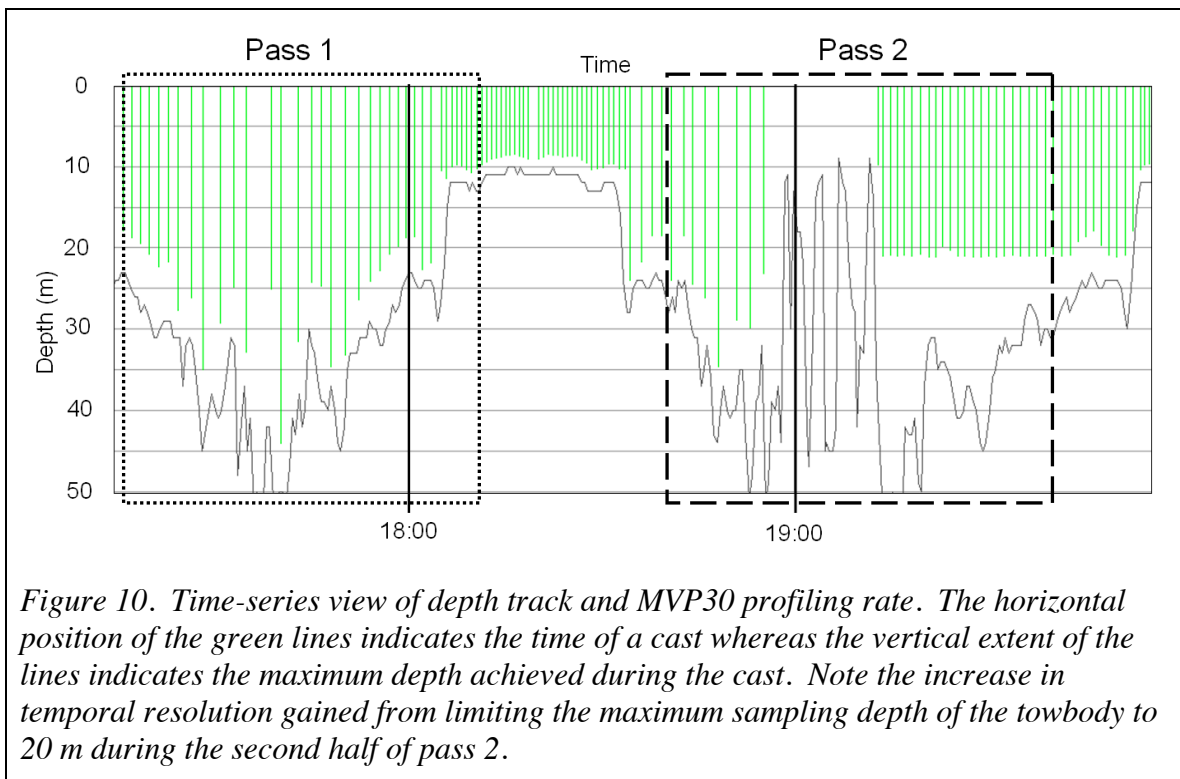


Figure 10. Time-series view of depth track and MVP30 profiling rate. The horizontal position of the green lines indicates the time of a cast whereas the vertical extent of the lines indicates the maximum depth achieved during the cast. Note the increase in temporal resolution gained from limiting the maximum sampling depth of the towbody to 20 m during the second half of pass 2.

During the first pass and half of the second pass, the MVP-30 was configured to profile as deep and as often as possible, this involved redeployment of the towbody immediately after recovery from the previous cast. Given the high degree of spatial variability, this scheme resulted in a several locations that exceeded 0.25% bias in the outermost portion of the swath at the nominal bottom depth, despite the MVP-30 sampling at the highest rate possible (refer to Figure 11, specifically the colour of the uncertainty field along the bottom track).

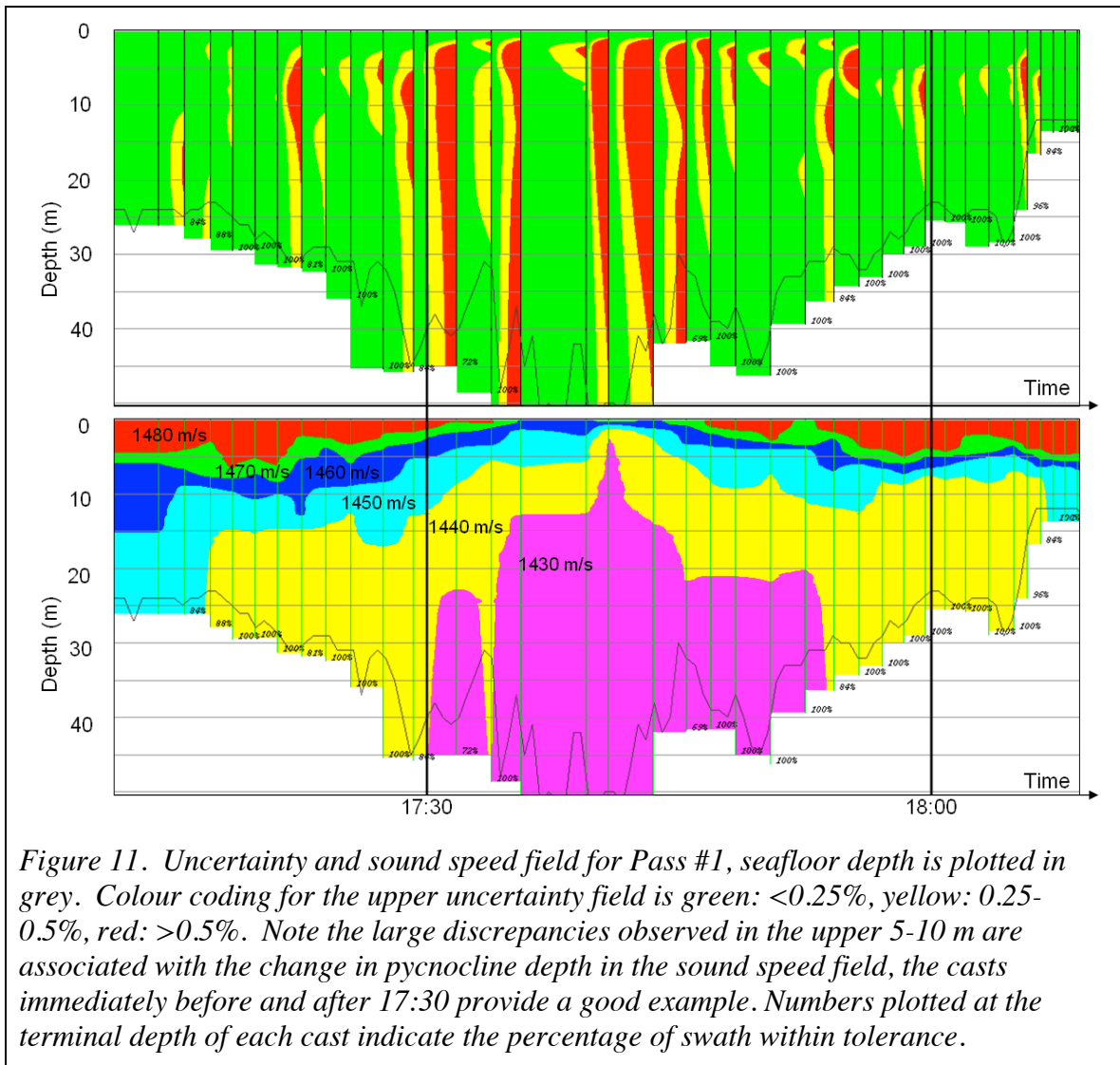


Figure 11. Uncertainty and sound speed field for Pass #1, seafloor depth is plotted in grey. Colour coding for the upper uncertainty field is green: <0.25%, yellow: 0.25-0.5%, red: >0.5%. Note the large discrepancies observed in the upper 5-10 m are associated with the change in pycnocline depth in the sound speed field, the casts immediately before and after 17:30 provide a good example. Numbers plotted at the terminal depth of each cast indicate the percentage of swath within tolerance.

The real-time view of the cast data allowed for the following observations:

- The bias resulted from a rapidly changing pycnocline depth between casts, this was associated with steaming through the salt wedge transition zone between predominantly fresh Saint John river water and salty water from the Bay of Fundy
- Watercolumn properties were typically invariant for any given cast below ~20 m and cast to cast variation was small

These two observations led to the conclusion that configuring the MVP to sample as deeply as possible to measure the deep and relatively invariant watermass was too costly in terms of sounding accuracy; efforts should have been focused instead on sampling the upper portion of the watermass as often as possible. As the system was already sampling as quickly as possible (no delay between retrieval and redeployment), only two options were available to improve resolution in the upper portion of the watercolumn: (1) reduce vessel speed, or (2) limit the maximum sampling depth. Reducing vessel speed helps in two ways. Firstly, less cable is paid out during

deployment (cable is paid out to accommodate forward motion of the vessel and the free fall of the towbody), this allows for a faster retrieval and redeployment. Secondly, the spatial sampling is improved by virtue of the reduced distance travelled between casts. The second option, that of limiting the sampling depth, helps much in the same way as reducing vessel speed: much less cable is paid out, so the towbody can be retrieved and redeployed much more quickly. To improve upon the poor performance observed during the calibration pass, the MVP was reconfigured during a turn to limit the maximum cast depth to 20 m. Combined with a reduction in vessel speed, this improved spatial resolution significantly and allowed for better control over uncertainty (see Table 1 and Figure 12).

Table 1. Increase of Accuracy due to Limiting Sampling Depth.

	Comparisons exceeding tolerance	Portion of survey time exceeding uncertainty tolerance (0.25%w.d.)
Pass 1	36 %	17.5 %
Pass 2 (before turn)	50 %	13.8 %
Pass 3 (after turn)	30 %	9.8 %

Note that casts were extended to bottom depth for the uncertainty and sound speed fields shown in figures 11 and 12, this was done by calculating sound speed at the desired depth based on the last observed temperature and salinity value at 20 m (recall that casts were largely invariant in their temperature and salinity below 20 m).

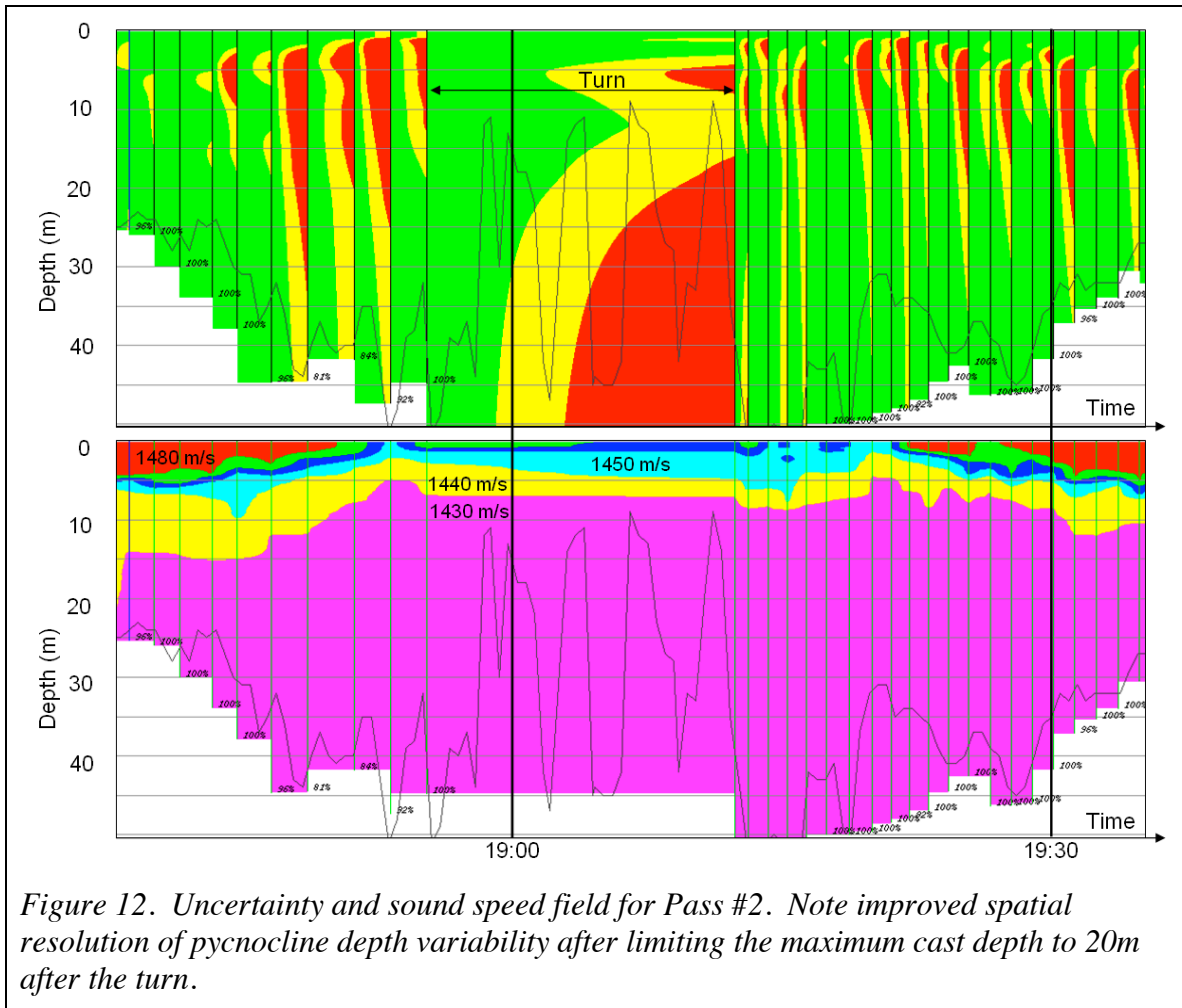


Figure 12. Uncertainty and sound speed field for Pass #2. Note improved spatial resolution of pycnocline depth variability after limiting the maximum cast depth to 20m after the turn.

With stationary profiling instruments, it is often impractical to sample the watercolumn at the high rates that are sometimes necessary in a dynamic environment. In this case, the toolkit can, at the very least, provide a real-time estimate of the portion of the angular sector that is within specification, allowing the surveyor to dynamically adjust survey line spacing to counteract intolerable uncertainty in the outer edges of the swath due to their limited ability to sample the watercolumn. The real time visualization depicted in Figure 8-d can still be used to indicate the depth, nature and magnitude of uncertainty associated with watermass variability, however, the linear time-interpolation is not valid: using the temporal interpolation to help predict the time of the next required cast would yield highly unreliable (and likely frustrating) results.

Future Work

Comparing two sound speed profiles collected in succession can provide a snapshot of uncertainty; this serves as a useful metric to gauge the average uncertainty when several comparisons can be made amongst a set of several casts. This is particularly useful for estimation of refraction based sounding uncertainty, a current weakness of commonly used total propagated uncertainty (TPU) models, e.g. Hare et al. (1995) as implemented in CUBE (Calder, 2003). Current research includes investigating methods

to examine sets of uncertainty wedges derived from a survey and using them to quantify sounding uncertainty due to varying watercolumn conditions.

As the raytrace simulator does not require sounding data, the toolkit can also be used to tackle difficult analysis problems in pre-cruise planning. For example, a high density set of casts can be collected and analyzed prior to a survey to provide direction to field personnel. Future work will focus on establishing pre-analysis observation and analysis procedures to aid in this effort to deliver meaningful and practical advice to field personnel.

Conclusion

The ability to monitor watercolumn conditions as a source of uncertainty gives unprecedented control over refraction type biases: the hydrographic surveyor can assess their sensitivity to refraction bias in real-time and react accordingly in the field to correct the problem. Corrective measures include, but are not limited to, increasing the profile sampling rate, reducing the sensor maximum deployment depth to allow for higher sampling rates, or accepting the loss of accuracy and reducing survey line spacing accordingly to mitigate the effects of refraction.

The most obvious benefit of such a software toolkit is a decrease in refraction biases. Another benefit, not as obvious but perhaps more important, is the surveyor's real-time ability to state with confidence that sufficient sound speed profiles were collected in order to maintain a desired sounding accuracy.

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Biography

Jonathan Beaudoin obtained a PhD in Geodesy and Geomatics Engineering from the University of New Brunswick (UNB) earlier this year after studying with the Ocean Mapping Group (OMG). He also holds Bachelors degrees in Geodesy and Geomatics Engineering (2002) and Computer Science (2002) from UNB.

Having recently joined the Center for Coastal and Ocean Mapping (CCOM) at the NOAA-UNH Joint Hydrographic Center, University of New Hampshire he plans to continue working in the field of his PhD research, estimating sounding uncertainty from measurements of water mass variability. His research plans include an examination of oceanographic databases such as the World Ocean Atlas and the World Ocean Database to see how the data contained in these comprehensive collections can be turned into information that is meaningful to a hydrographic surveyor. Other plans involve assessing how to best acquire, visualize, process and analyse data from sound speed sampling systems, again, in terms that are meaningful to a hydrographic surveyor.