Multi faceted advances in underwater operational sonar prediction systems

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ABSTRACT

Over the past twenty years there have been a number of advances in underwater acoustic range prediction systems namely: - increased spatial and temporal fidelity of the underwater environmental data sets, the ability to include more insitu measurements, additional input parameters data and the increase in available computing power.
This paper describes an initial assessment of the role of glider data as an input into a nowcast acoustic range prediction model. It includes an analysis of the temporal and spatial variability of the water column data measured by a glider in shallow Australian waters.

INTRODUCTION

One of the difficulties in underwater nowcast predictions for acoustic detection ranges has often been the paucity of available water column data which can also have a very inhomogeneous distribution in both space and time.
A number of papers (Jones 2002, Jones 2009) compare calculated transmission loss with at sea measurements in Australian waters. The collecting of the necessary data within the time scale required for these calculations has been an expensive logistic exercise requiring support equipment in the form of aircraft or support vessels collecting SVPs across the required range and bearing/s.
For an operational system it has not been practical to expect access to this level of data collection on a regular ongoing basis, instead for nowcast sonar range predictions it has been the practice to use an insitu bathy drop supplemented with climatology data to characterize the water column. This situation changed about four years ago with the increasing availability of 3D gridded water column oceanographic data sets (BLUElink, 2008) sampled on an hourly basis.

In parallel with the development of regional water column oceanographic models has been the enhancement of embedded sonar range prediction systems. These systems include pseudo real time update of the self noise for each bearing and processed band. The update rate is optimized through multi threading per beam of transmission loss calculations. With this reduction in the range prediction temporal sampling comes the challenge of measuring or estimating the water column sound speed characteristics.

An obvious source of water column data which has recently become available is from autonomous gliders. These have the ability to measure the water column ahead of the vessel, albeit slowly and to provide this data in a reasonably short time period. In addition, there can be multiple gliders concurrently collecting data so that many bearings can be covered simultaneously.

Autonomous gliders follow an up and down sawtooth profile through the water column sampling the water column for temperature and salinity approximately every 5 seconds. As the glider is driven by variable buoyancy it travels at approximately 1 km/hour.

Initial data assessment

An initial assessment of the role of glider data as an input into a nowcast acoustic range prediction model has been carried out by the author.

The data was collected by DSTO using two Slocum gliders over five days from 11th - 15th July 2011 at the top end of the Capricorn channel in the southern Great Barrier Reef area (Jackson, 2012). Figure 1 plots the route of the two gliders, named, glider “k85” which traversed further from the coast than glider “k90”. Cape Clinton is the nearest coastal feature spanning from 22.55°S to 22.65°S.

The Temperature-Salinity (TS) diagram of all the data points for both gliders is shown in Figure 2. The features displayed in these plots differ due to the different glider routes with glider k85 traversing deeper water than glider k90. The maximum temperature was recorded by the k85 which was slightly less than 21°C compared to glider k90 which recorded a maximum temperature 0.05°C lower. The salinity range is greater for k85 than k90.

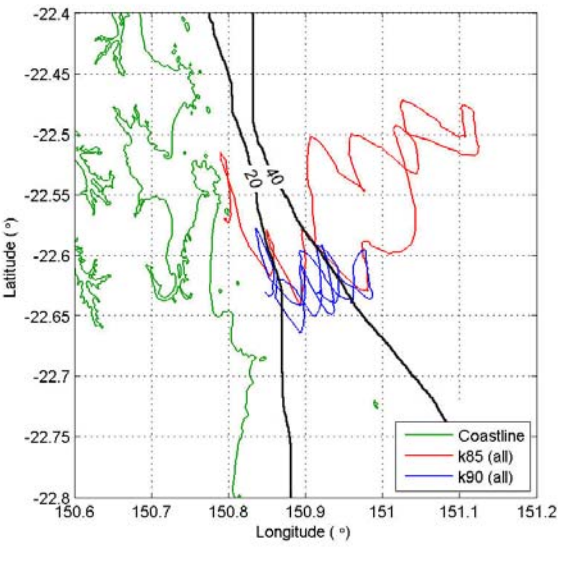


Figure 1: Route taken by the two gliders over a three day period starting late 11th July 2011

There are obvious differences in the features between the two glider TS plots which could be due to the time of measurement and/or the location. When the glider data was reviewed in hourly time increments it became apparent that a parcel of cold water was traversed by glider k90 on the early morning of the 15th July. The maximum surface temperature was then reduced by 0.8 °C in a 2 hour time period (see Figure 3). The second glider traversed the same area 8 hours later and the temperature profile exhibited similar changes symptomatic of a sustained front. For the salinity profile, there is a delay of some two hours after the temperature dropped when the salinity initially increases prior to stabilizing to a small range of values between surface and maximum glider depth. This is indicative of a well mixed water column. Typical results are shown in Figure 4.

Thus the complexity of the two temperature/ salinity profiles shown in Figure 2 is partially due to the overlaying of two parcels of water, one with a maximum temperature slightly below 21°C and the second with a maximum temperature at approximately 19.7°C.

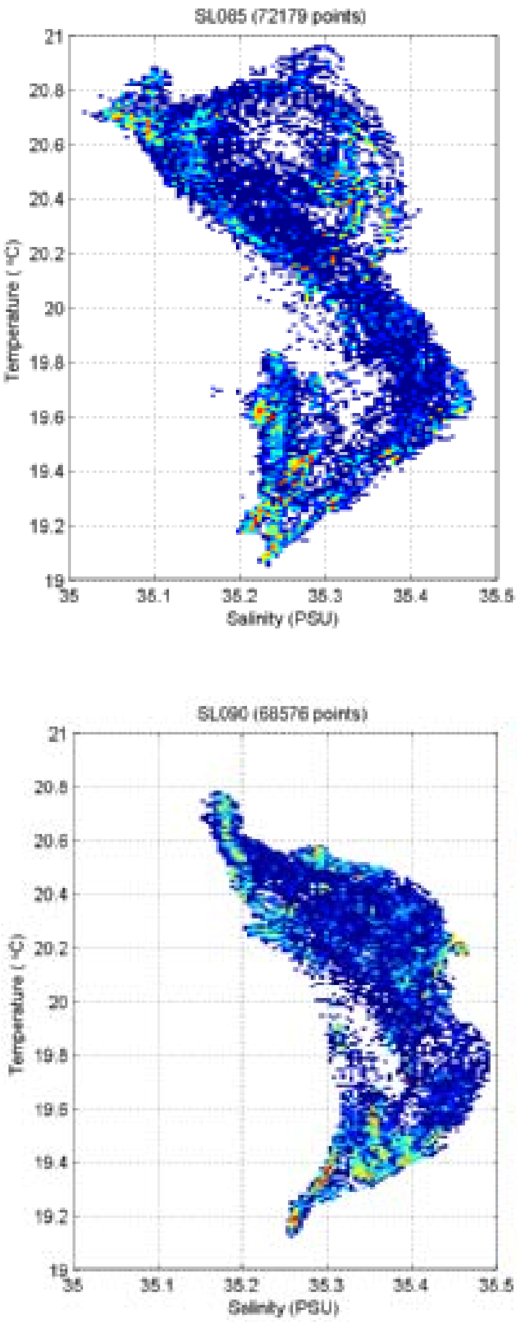


Figure 2 Temperature Salinity diagram for the two gliders. The colour intensity scale shows the number of points which recorded each temperature salinity pair

Ocean Currents

Previous studies conducted in the area of the Southern Great Barrier Reef based on satellite thermal imaging (Burrage 1996), have concluded that there is a persistent frontal feature, called the Clinton Cape front, caused by the impact of the change in coastal orientation on a northward, well-developed boundary current. This front was described as a mushroom shaped jet of cold water starting from the coast, and extending eastward 245 km. Along the coast line the width of the root was 85 km and tapered at the throat to 18 km before expanding at the head to 105 km. An earlier reference (Kleypas 1994) found that the front was smaller, extending out 100 km. The jet temperature was generally 1° to 2°C cooler than the surrounding water. It is hypothesized that the routes of both gliders crossed this frontal boundary. As there is no open source high resolution satellite SST imagery for this time and area this cannot be independently verified. It is also assumed that waters within the jet are well mixed based on the TS diagrams.

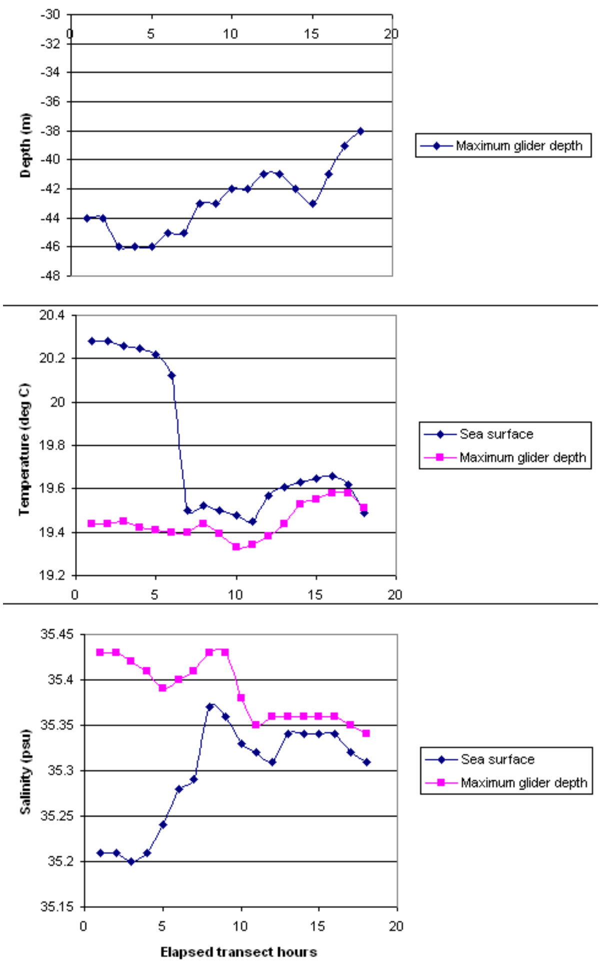


Figure 3 Temperature, Salinity and maximum glider depth during a 20 hour transit time for glider "k90"

The boundary delineation can be estimated by viewing the TS diagrams which have been clustered into three different types, typical examples are shown in Figures 4 to 6. Figure 7 plots the different TS types on the glider routes.

Figure 4 shows that the water column was generally well mixed in the bathymetry range of 0 -20m and in deeper water during the start of glider “k90” transit when it was between -22.5° and -22.55°S. Generally, as the water depth increased the TS diagram showed a greater range of temperature and salinity values and the resulting plot varied from a curve as shown in Figure 4 to an L or hook shape over a small temperature and salinity range. In the 41-60m water depth the TS data often included a hysteresis as shown in Figure 6 which is a 3D temperature salinity depth profile. The data in this figure shows that the TS hysteresis is due to the salinity measurements. There are two possible causes for the hysteresis: firstly, it maybe due to different sensor measurement latency times during the downcast/upcast cycle or secondly, it may reflect an actual water column event. There are no independent measurements to clarify this. If the cause is due to a latency issue then either a correction needs to be applied to the measurement depth or some of the data is excluded in the speed of sound calculation.

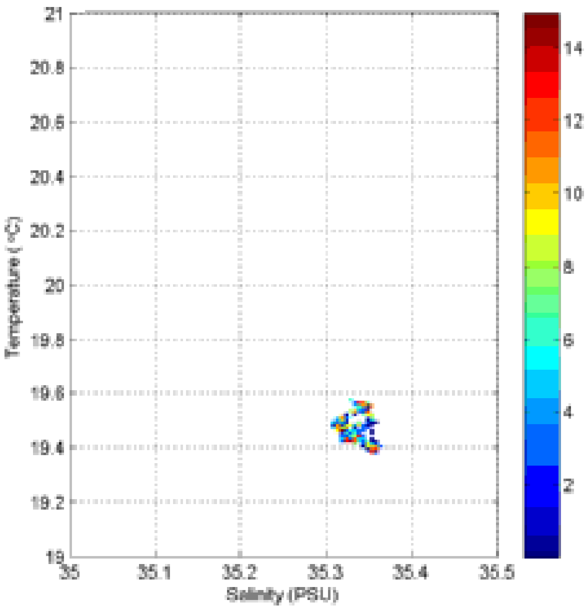


Figure 4 TS diagram of well mixed water based on 1 hour of data. The colour intensity scale shows the number of points which recorded each temperature salinity pair

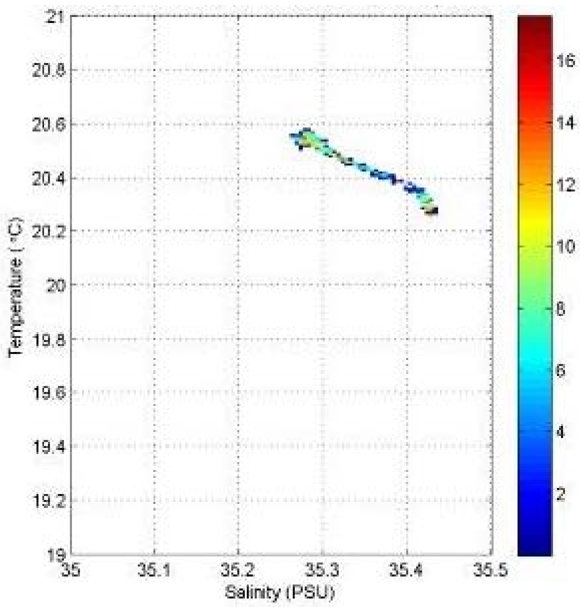


Figure 5 TS diagram for water column with a distinct profile based on 1 hour of data. The colour intensity scale shows the number of points which recorded each temperature salinity pair

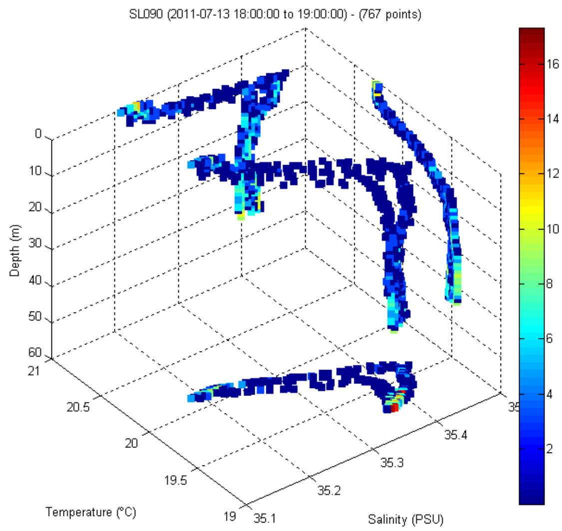


Figure 6 3D Temperature Salinity Water Depth diagram for 1 hour of data which displayed hysteresis. The colour intensity scale shows the number of points which recorded each temperature salinity pair

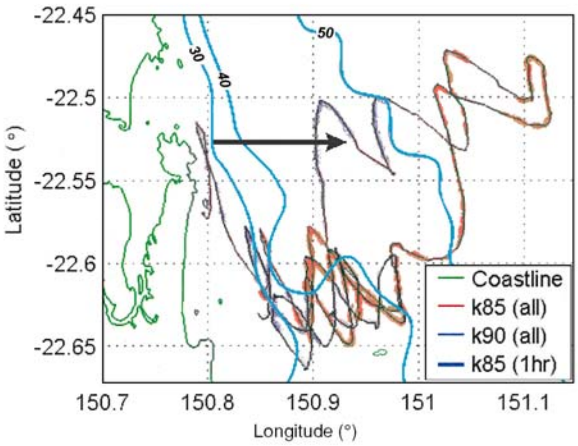


Figure 7 Cluster analysis of the TS data based on 1 hour sampling. The arrows indicate the reported current flow. The purple overlay of the routes indicate the possible southern edge of a cold water jet and is based on TS diagrams which are similar to Figure 4. The brown route overlay is for locations where the TS diagram is similar to Figure 6. The pink route overlay is for locations where the TS diagram is similar to Figure 5

Tidal Analysis

This area of the Great Barrier Reef is noted for its macro tidal ranges (Australian Bureau Statistics, 2012). Table 1 shows the tidal information for 3 days of the trial. During the time of the significant change in the TS plots, the night of Thursday 14 th and Friday 15th morning the tidal heights were at a maximum due to the new moon as indicated by the open circle next to the “Friday 15” caption.

Port Alma - Times and Heights of High and Low Waters
July - 2011

(Peaked Island, add 3 minutes for approximate tide times)

Wednesday 13		Thursday 14		Friday 15	
Time	Height	Time	Height	Time	Height
0209	0.98	0255	0.87	0336	0.82
0744	4.19	0829	4.27	0909	4.32
1408	0.87	1451	0.81	1529	0.80
2027	5.25	2107	5.29	2143	5.26

Table 1 Local tidal information for the (extract BOM 2011)

Griffin states that the tidal flow has a strong longshore component but previous studies of the area do not mention a tidal signal as a significant component in the TS water column characteristics. (Griffin 1984).

Glider Temperature Profiles

Figure 8 shows a comparison between the temperature profiles recorded for some typical gliders upcasts against climatology (CARS 2000) for the month of July. These plots indicate that the sea temperature levels over the shelf are less than the climatological profile. This finding is in agreement with the findings for the same region although for the month of May (Middleton 1994). Middleton considers that the reason for this difference is due to the shelf (glider) and ocean (climatology) water masses. In the former case there is a negative net heat budget during the winter with the shelf waters cooling whereas in the deeper waters there is an upward transport of heat from below.
As temperature is the primary driver of the sound speed equation, the differences indicated in Figure 8 will result in different Sound Velocity Profiles (SVP) profiles.

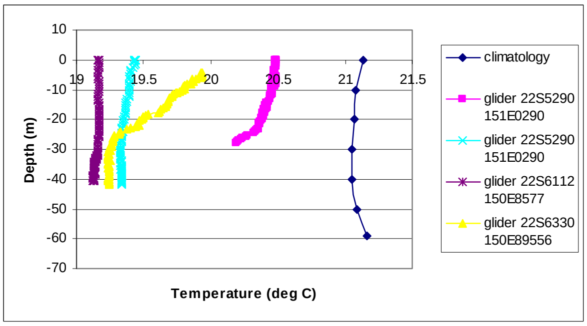


Figure 8 Comparison between the temperature profiles recorded at different glider locations against climatology database

Middleton also notes that the surface temperature increases from the coast across the shelf and the salinity decreases across the shelf. Both of these findings are supported by the data for the eastward leg from location 22.55°S 150.9°E where the maximum surface temperature was 20.1°C with a steady increase until 22.5°S 151.1°E where the maximum surface temperature was 20.8°C. After this time, the glider apparently moved away from the cool water jet and the maximum surface temperature remained stable down to location 22.6°S 151°E.

Single glider up and down cast

Figure 9 shows the calculated SVP of a single up and down cast by one of the gliders. The single glider up/down cast took eleven minutes to complete and starts with the upcast data. The maximum time difference between measurements at a given depth occurs between the maximum depth of the profiles. The minimum time difference is at the surface. During the up/down cast the glider maintains a constant bearing (within 2 degrees) and the distance travelled from the first measurement point to the last is 167 metres.

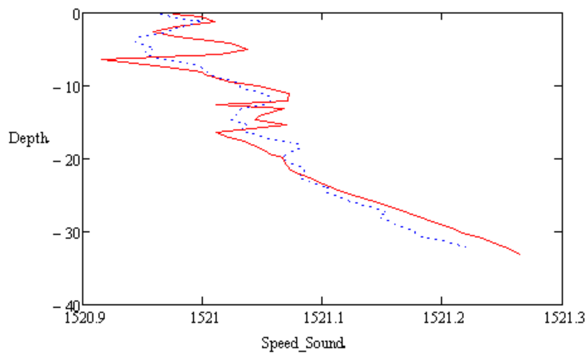


Figure 9 SVP (m/sec) calculated for a single down and upcast from a glider measuring temperature, salinity and depth (m). The solid red curve is the downcast and the dotted blue curve the upcast

It is noted that the two SVPs do not coincide indicating a dynamic ocean environment. From an acoustic point of view the average SVP gradient varies from -0.01 /sec for the upcast to -0.015/sec for the downcast. Assuming that the data truly reflects only the water column characteristics and that the glider data can be spatially aligned to a single location, then an understanding of the local oceanographic dynamics may be postulated by plotting the data as a density versus depth graph as given in Figure 10.

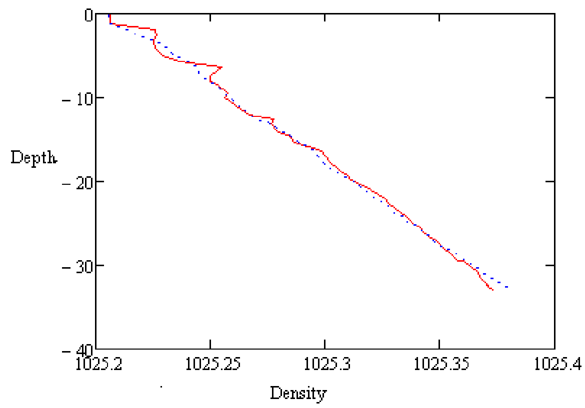


Figure 10 Density (kg/m^3) calculated for a single down and upcast from a glider measuring temperature, salinity and depth (m). The red solid curve is the downcast and the blue dotted curve the upcast

Figure 10 shows that the water column transversed during the glider upcast is stable as the density is monotonically increasing with depth however the glider down cast density profile shows two depth ranges where the density is decreasing with depth indicating potential water column instability.

Water Column range dependent model input

Temperature and salinity data can be entered into a range dependent prediction model as single columns in a range versus depth matrix, prior to the SVP calculation. Glider data, on the other hand, would be entered in a “staircase” manner with the gradient of the data in the matrix driven by the distance which the glider traverses in a given measurement cycle. Assuming that the grid size of an individual cell of the matrix is 2 metres in depth by 100 metres in range, then the data shown in Figure 11 would cover one fully populated column of the matrix and one partially populated with values in the deeper depths. Additionally each column would have a number of SVP measured values as the glider samples the data at approximately 0.5 metre in depth. The data can be stored as a function of the original depth and range, the time at which it was collected and whether it is a down cast or upcast measurement.

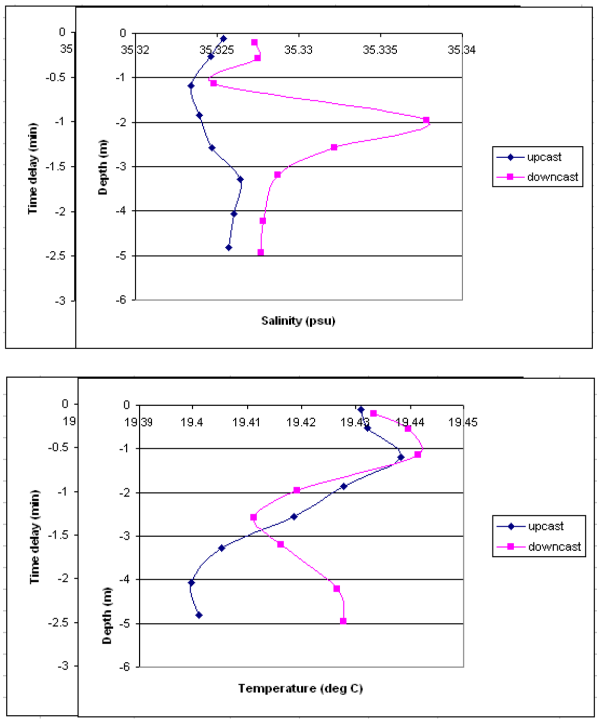


Figure 11 Near surface salinity and temperature profiles as a function of depth and time delay between measurements at a given depth

The determination of the actual profile which is to be run in the model can be through filtering the data as a function of time, spatially or both. Another approach which can be considered is a statistical approach where the mediod profile is generated from the data as well as those at a certain number of percentiles. With any of these approaches a range of detection ranges may eventuate which is reflective of the inherent dynamic nature of the ocean.

Consecutive glider up and down casts

If the data is collected in a temporally stable region, then it is expected that consecutive glider up and down cast data would reasonably coincide and thus the selection of the data reduction method would be reasonably irrelevant, but in regions, as shown in Figure 1, which are strongly affected by tides, this is not the case. The data reduction selection methodology must adequately deal with both cases.

A reasonably benign area was selected from the dataset as shown in Figure 7. The 7.5 km northerly route starting from approximately 150.9°E 22.6°S and ending at approximately 150.9°E 22.5°S was chosen. The TS characteristics of this route are of well mixed water similar to those given in Figure 4. Figures 12-15 show the raw temperature and salinity concatenated profiles as a function of depth. The profiles have been divided into a sequence of contiguous upcasts and downcasts. The average distance travelled and the elapsed time from the start of the route for each upcast is given in Figure 16.

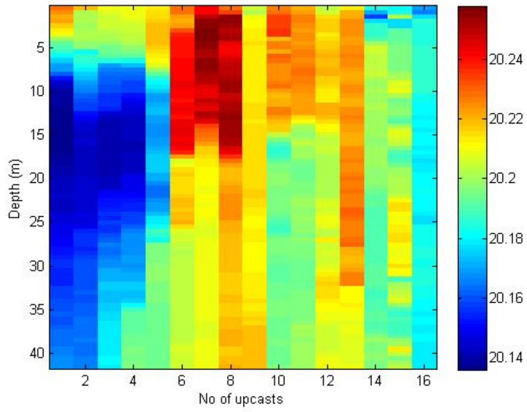


Figure 12 Sequence of contiguous upcast temperature profiles (°C) as a function of depth

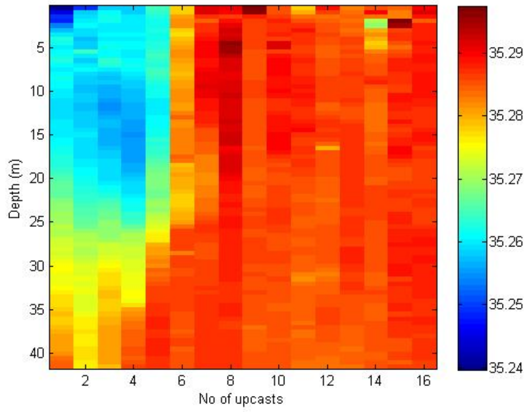


Figure 13 Sequence of contiguous upcast salinity profiles (psu) as a function of depth

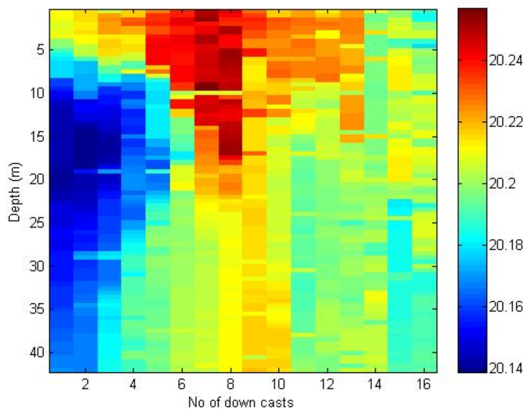


Figure 14 Sequence of contiguous downcast temperature profiles (°C) as a function of depth

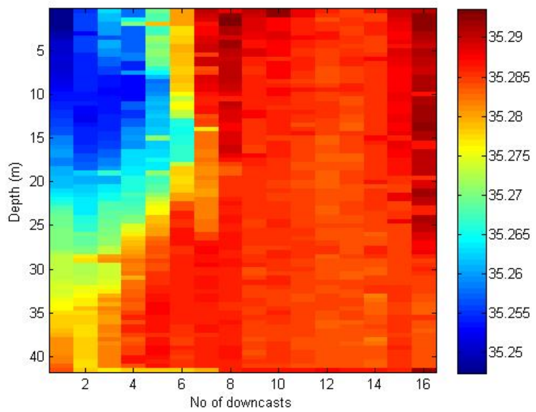
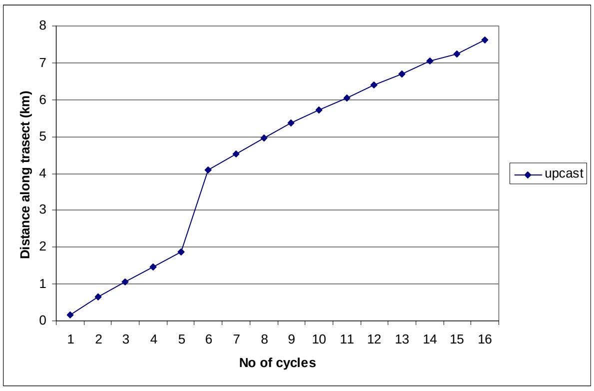


Figure 15 Sequence of contiguous downcast salinity profiles (psu) as a function of depth



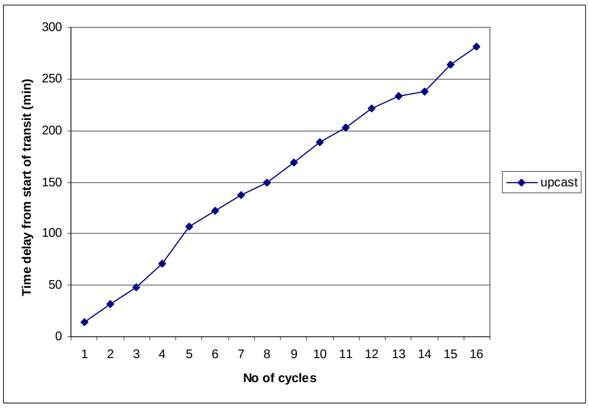


Figure 16 Distance and time delay along upcast route

Although the temperature and salinity ranges are small for each of the plots, there is evidence of the dynamics of the water column present in the figures. For example, there is a parcel of warm water present near the surface in both the upcast and downcast plots from cycle 6-8 in Figures 12 and 14. The upcast and downcast salinity plots (Figures 13 and 15) both show an evolution from slight stratification at cycle 1 to well mixed from cycle 9 onwards.

The jump in distance between cycle 5 and 6 in Figure 16 is assumed to be due to a GPS adjustment and the range along the route would need to be reduced accordingly.

Finally the temperature and salinity profiles have been converted into sound speed profiles for three ranges as indicated in Figure 17. Although, the temperature and salinity ranges for this route are small, the resulting sound velocity profiles are significantly different, particularly in the first 5 to 10 metres.

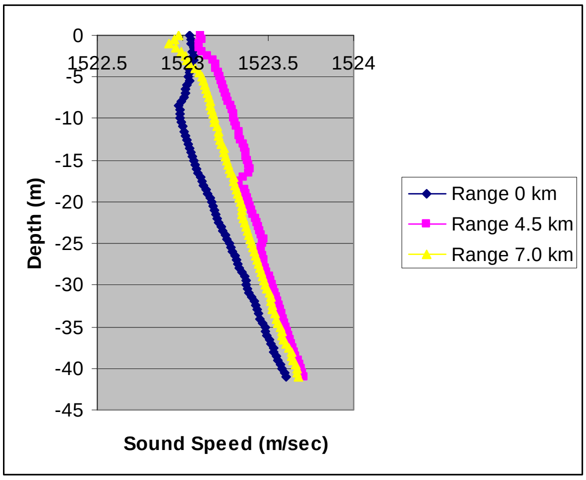


Figure 17 Sound speed profiles based on concatenated upcast glider measurements using the raw ranges given in Figure 16

DISCUSSION

The goal of this preliminary study was to look at the suitability of glider data as an input for nowcast range dependent acoustic transmission loss calculations. The conclusion reached based on the dynamic datasets reviewed is that if one uses this data directly to calculate sound speed profiles then a number of caveats would need to be applied. In the first instance there is the issue of the salinity hysteresis to be resolved. In the second instance, the profiles need to be aligned in time for the different upcast/downcast time delays noting that the data has the finest time resolution in depth compared to the coarser and variable time resolution in range. In the third instance, the location of the measurement may require correct due to GPS adjustments. Finally, there is the need to include the differences between individual upcast/downcast. A solution to the latter issue is to separate the data into two sets. One set would consist of upcasts and the other down casts. These could each be used to predict the transmission loss and detection range. This may result in different detection ranges being calculated and the concept of “range of ranges” needs to be invoked for the detection range calculations.

Rather than directly using the glider data after applying suitable corrections, a more preferred approach is to use it in conjunction with a priori knowledge or as an input into a local regional oceanographic model. As indicated in this study, the general location of oceanographic features, such as the tidal data and the northerly boundary current can be given as existing knowledge. The role of the glider data could be to refine this information for nowcast predictions. In particular, the glider data can be used to infer greater detail, such as steric height, which could supplement existing satellite observations. The given set of glider data has a limited lifetime which can be extended with the inclusion of an afternoon effect model, but at the expense of requiring a number of additional inputs such as wet and dry air temperature. The use of the afternoon effect model can also allow the glider data to be aligned to a particular instant in time. The concept of “range of ranges” is also suitable in this context as a means of including the variability of the measured parameters in the range prediction result.

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