AN INVESTIGATION INTO SPATIAL VARIATION OF THE DEEP SOUND CHANNEL AXIS OFF THE CENTRAL CALIFORNIA COAST

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OC3570 Cruise Report

1. Introduction

The littoral ocean environment is quickly establishing itself as the focal point of research and development for the 21st century Navy. Quantification and prediction of small scale spatial and temporal ocean variability is becoming more valuable as operational areas of interest to the United States concentrate on coastal locales. In the arena of undersea warfare, sound velocity profile characterization and accurate prediction of it provides a stable foundation for the undersea warfighter to operate with a significant advantage over adversaries.

Most of the oceanographic forecasting products available to the warfighter today are driven by sparse climatology databases. These products, when validated, more than often prove to be a poor prediction of the acoustic environment. Resolution of these models is equally inadequate to meet the high spatially sensitive needs of today's operations in the littoral zones. A more detailed investigation of sub-mesoscale spatial variation of sound velocity with depth is discussed in this paper. More specifically, data is analyzed to determine spatial and seasonal trends of the deep sound channel axis off of Monterey, California.

2. Measurements

Data for this analysis were gathered over the period of 34 different cruises to include the first leg of the OC3570 Winter 2004 cruise from Jan 27th to Jan 30th, which represents the newest data collected. Conversely, the first data set dates back to February 1997. Data from these various cruises were meticulously taken at specific points on a carefully studied East/West track called Line 67 (fig. 1.

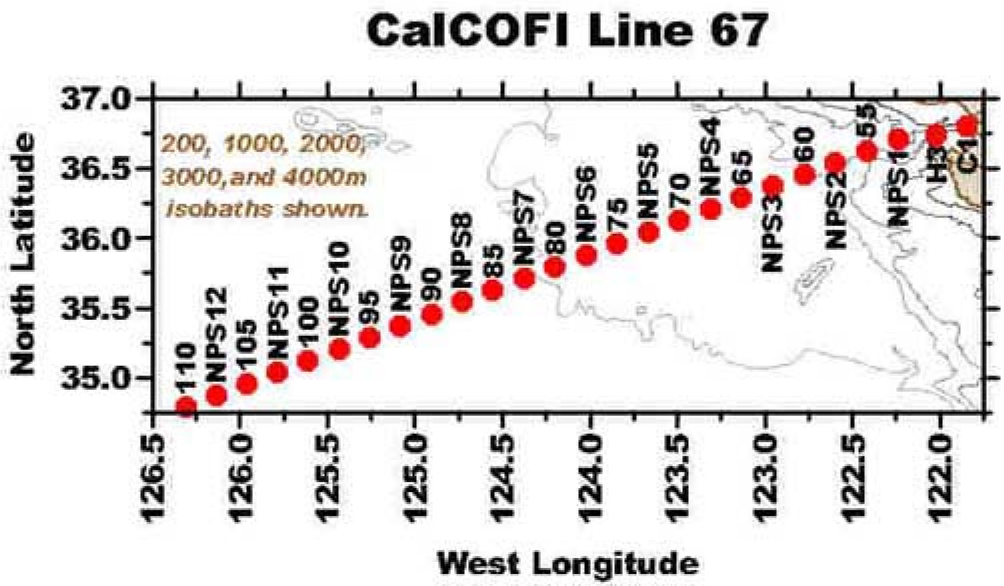

Fig. 1 Line 67 map

The data consisted mainly of CTD casts. Ship location was also recorded at each CTD cast for spatial accuracy. CTD stands for conductivity, temperature and depth, which represent quantities that can be converted to values that are integral to sound speed derivation. Note that since the analysis focused on the littoral, only the first six data points in figure 1 were analyzed in this paper.

3. Data Processing

The first step in making the CTD data useful was to convert the conductivity and depth into values that are functions of sound speed. Conductivity was converted into salinity, and depth into pressure. Sound velocity is a function of salinity, temperature and pressure.

$$C = f(S, T, P)$$

The above conversions were conducted using a MATLAB code that simutaneously calculated sound velocity for each depth in 2 meter increments. Plots of this resultant data are classic sound velocity profiles (SVP's). Minimum speeds on these SVP's were recorded. Each data set contained five to six SVP's and was truncated to look only at the depths of interest to the deep sound channel (200-900 meters). Shallow waters and extreme deep waters were not examined. In order to view the different locations within each data set, a waterfall plot (fig. 2) was produced by adding an incremental scaling factor to each profile. The leftmost sound velocity profile represents the station furthest east for the data set.

The SVP's produced had significant high frequency noise. Those fluctuations resulted in false sound speed minimums for some locations. In order to correct for this, a fourth order Butterworth filter was applied with cutoff coefficient of .1. Note that the coefficient was picked by inspection of the SVP. When visible smoothing took place as to not reduce key variations in the profile, the coefficient was chosen. This Butterworth filter would not be acceptable for all situations. Sound will react to small, high frequency changes in speed depending on its frequency. Further operational experiments should choose different filters depending on the frequency of interest. Data sets were smoothed for this experiment for the sole purpose of determining accurate spatial trends in the deep sound channel axis.

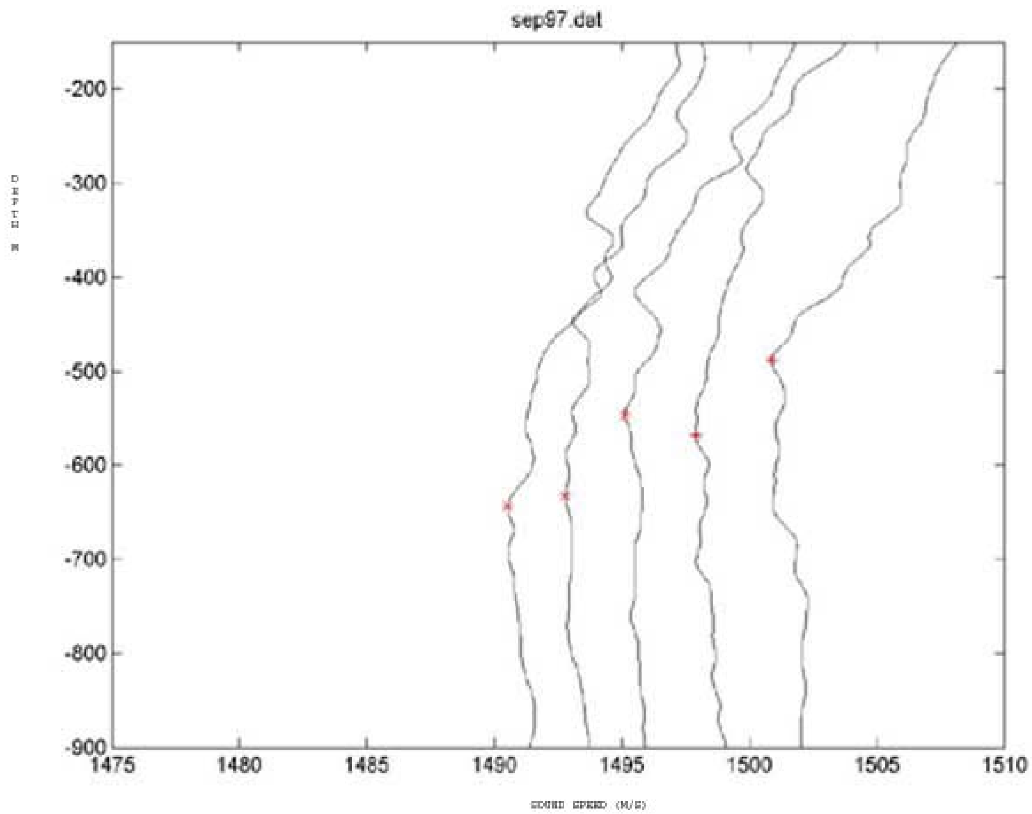

Fig. 2 Waterfall plot (Depth vs. Sound Speed)

While each of the cruises maintained strict discipline as to the location of the predetermined stations, there was some variation and some bad data. Even GPS has some error. MATLAB was used to find each sound speed minimum for a given longitude for all of the data sets. This data was placed into a scattergram (fig. 3) and was analyzed visually to determine the possibility of any trends in the data.

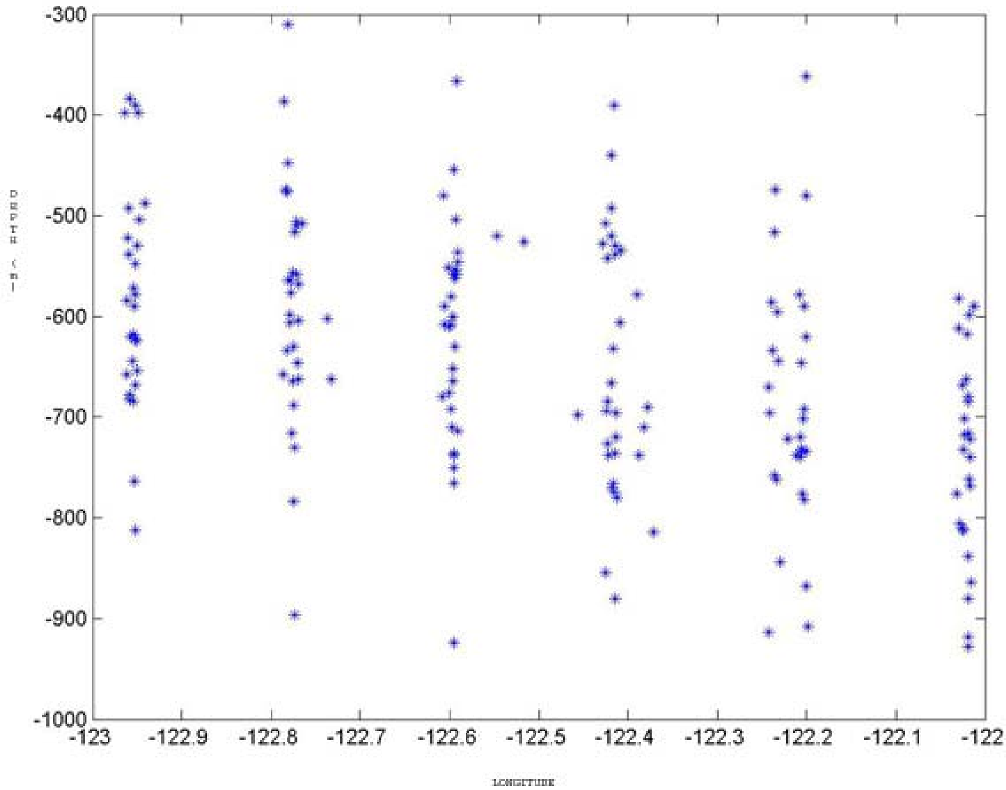

Fig. 3 Scattergram (Sound speed minimum depth vs. Longitude)

A general trend of sound speed axis shoaling can be seen with some degree of certainty. However, in order to more accurately determine a possible trend, the mean sound minimum of each of the longitude bins was plotted for the seven year data ensemble (fig 4) to facilitate a more rigorous analysis.

This complete data processing path was performed for the entire ensemble, for different seasons (months) based on duplicate monthly data, and for the 1998 El Nino year.

4. Results

The deep sound channel axis trend for the entire ensemble of data produced interesting results. The data collected represented a statistically significant amount of sound speed minimums and showed an obvious trend in the seven year averaged ensemble (fig. 4). A clear shoaling of the deep sound channel occurred from nearshore to offshore. Average axis depth ranged from 740 meters to 580 meters at the far west station. This basic trend can again be seen in the scattergram plot above (fig. 3).

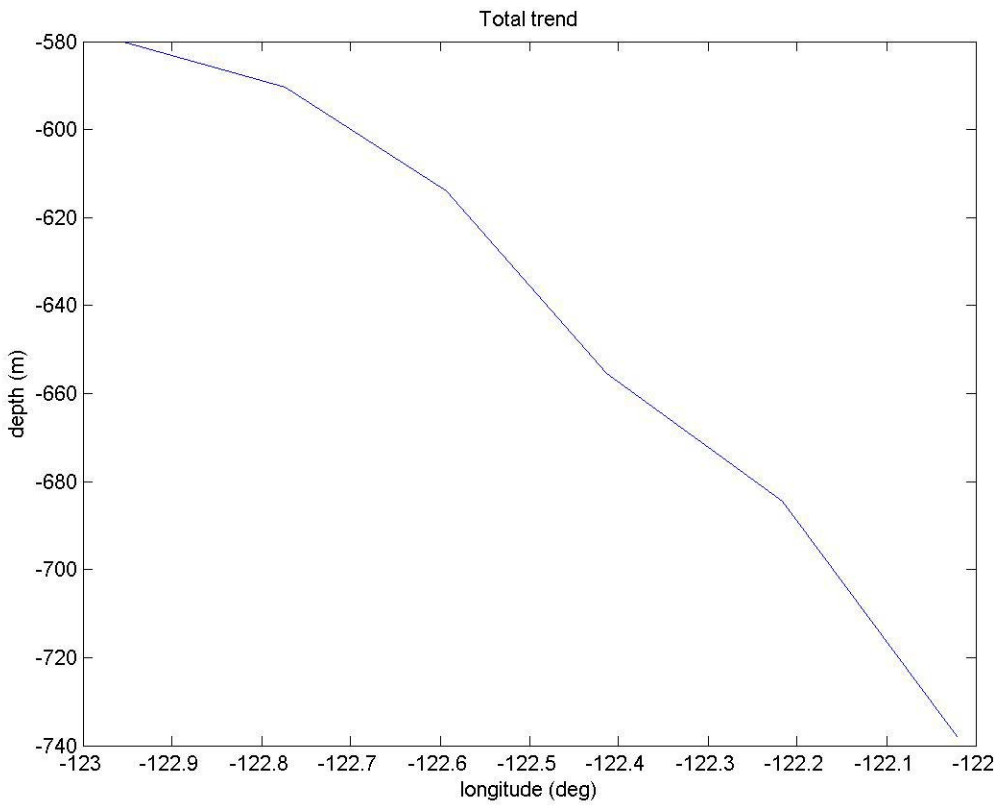

Fig. 4 (Offshore deep sound axis trend)

This data trend helped validate a plot produced by Professor Curt Collins of the Oceanography Department at the Naval Postgraduate School. His plot (fig. 5) varies from the above in statistical approach. Figure 5 is an Empirical Orthogonal Function

(EOF) plot of the entire Line 67 data minus the most recent Jan 2004 data set.   EOF's show the percentage of variance described by each mode. The similarity was easily seen and helped to support that the initial trend upward in the EOF is statistically significant compared to the remainder of offshore data fluctuations

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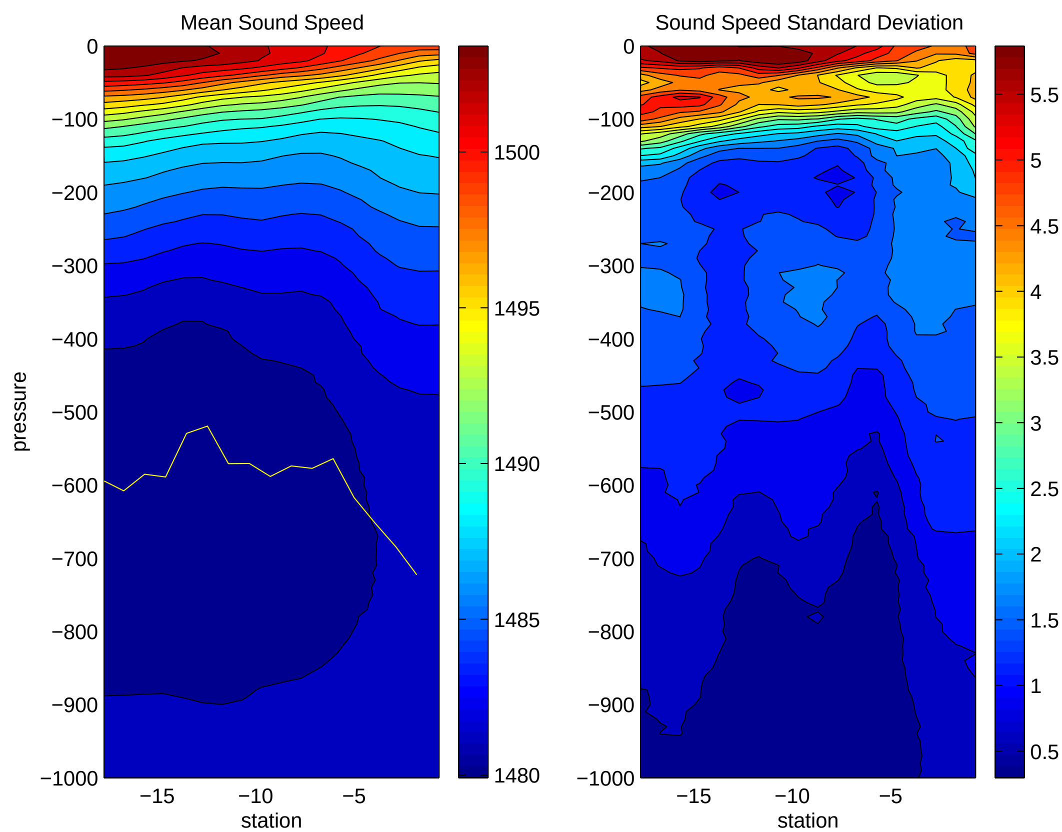

Fig. 5 EOF

The analysis of various months proved to be less significant statistically although some results did match the complete data set in principle. This result was expected as individual months only had three to four different data sets to work with over the seven year span. Months that had less than three sets were not explored. Monthly data sets will be discussed in relation to the overall ensemble as the data is sparse and individual comparison with other months would be moot.

January showed a trend similar to the ensemble except for the sixth station (fig. 6). That station was nearly not included in the total as it was obvious from the initial scattergram that it was nearing the edge of the shoaled deep sound channel axis. Disregarding the sixth, January displayed a trend that correlates well to the total and had a range of depths between 720 and 575 meters.

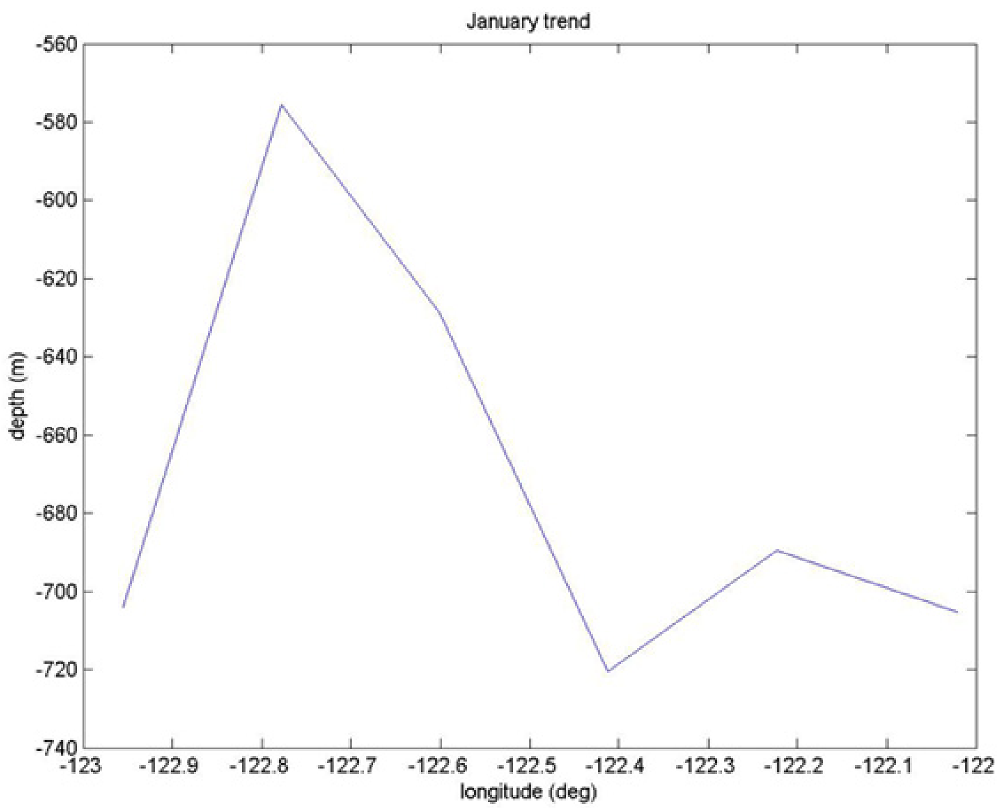

Fig. 6 January Deep Sound Channel Axis

February also showed a similar trend compared to the total with a drop off at the sixth station (fig 7). The initial two stations showed little significant shoaling. However, the second two stations displayed a very steep gradient in the average axis depth. The range of fluctuations was from 710 to 560 meters.

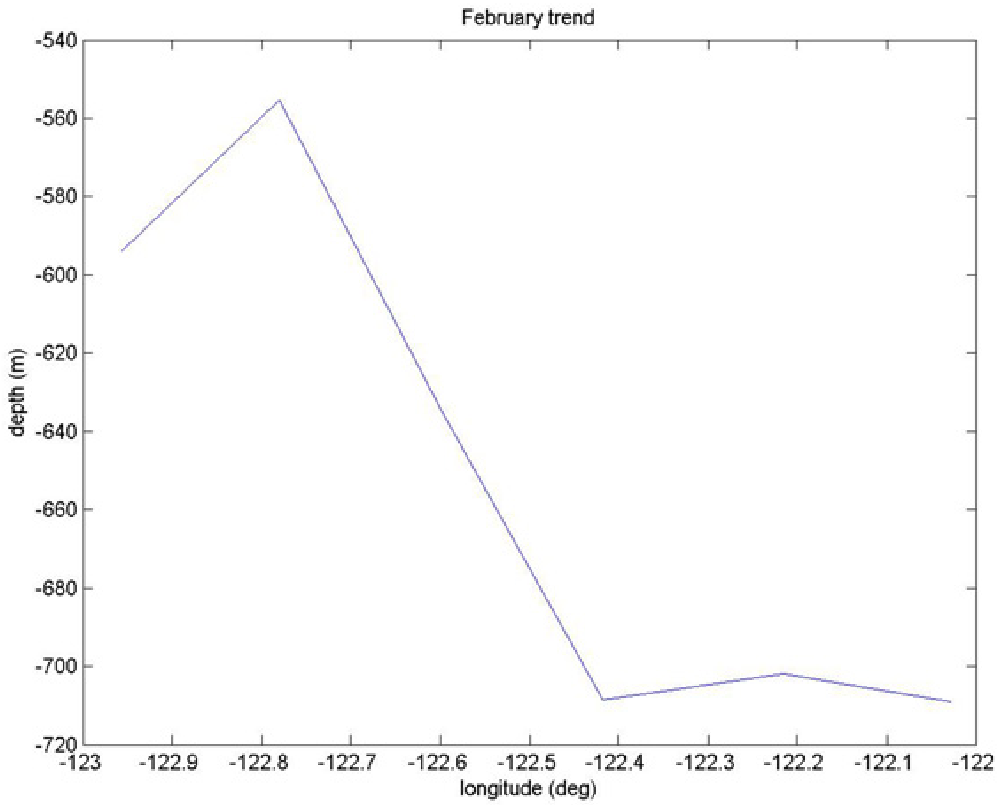

Fig. 7 February Deep Sound Channel Axis Depth

March data showed the steep gradient between the first and second stations with no statistical change over the remaining plot (fig. 8). Axis depth range was high, going from 790 to 560 meters.

April peaked much earlier than the ensemble and dropped off equally as fast (fig. 8). The data did not correlate well to the ensemble. The range was significantly more succinct as well, ranging from 650 to 525 meters.

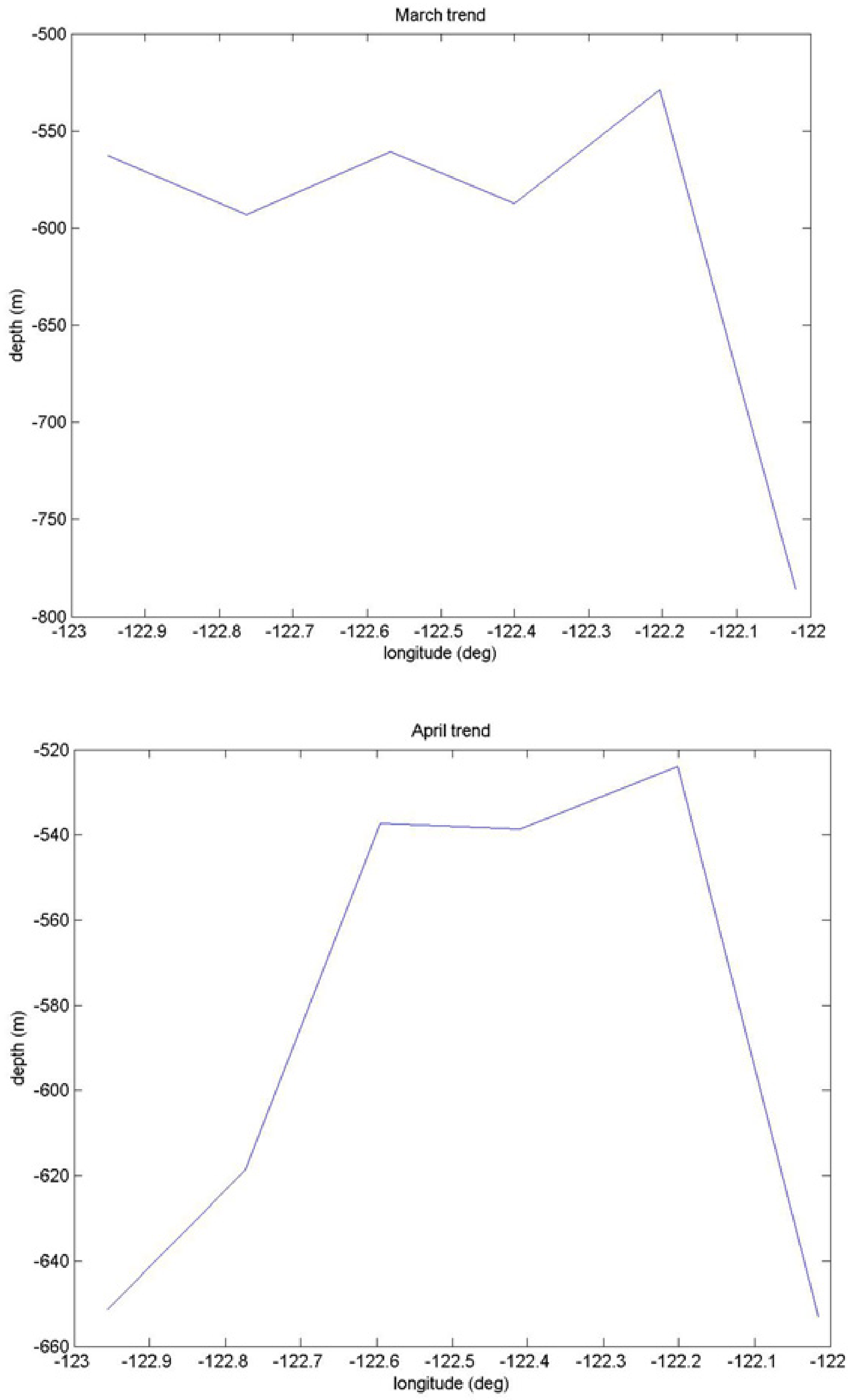

Fig. 8 March/April Deep Sound Channel Axis Depth

May correlated well with the ensemble. It showed a gradual shoaling with little significant variation spatially (fig. 9). The range was large, from 680 to 490 meters

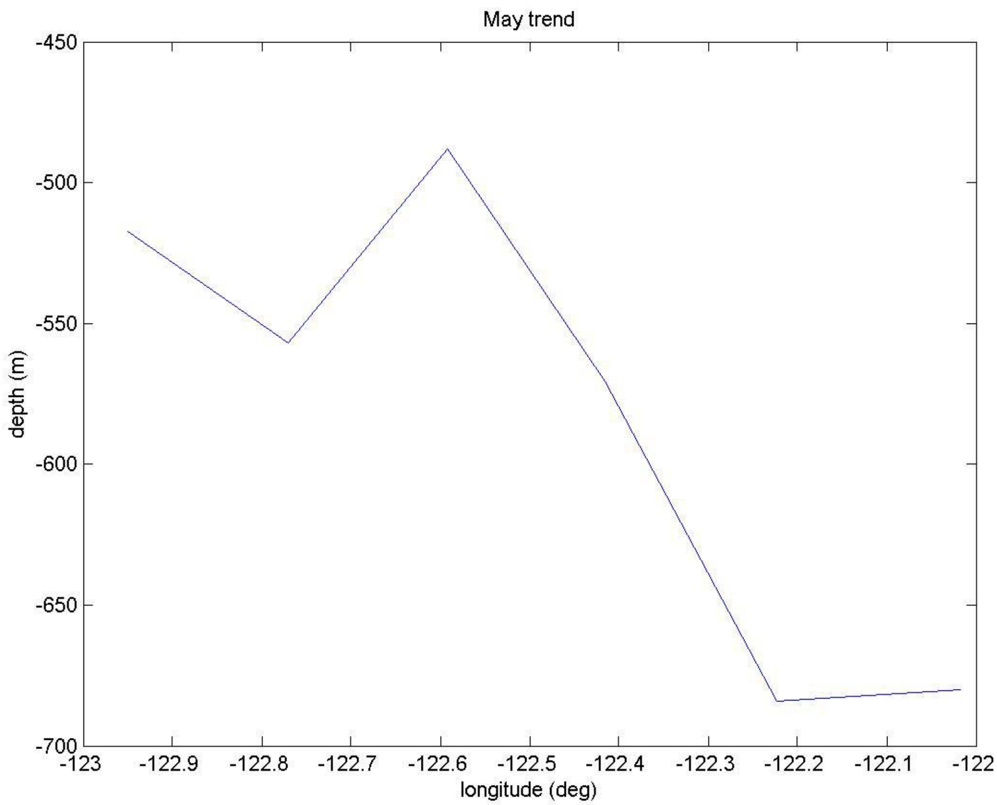

Fig. 8 May Deep Sound Channel Axis Depth

Summer data was sparse as most of the cruises took place in the winter/spring time. July is the only month that had enough readings to make a somewhat reasonable chart. Even though the majority of data from the ensemble came from winter and springtime data, July fit very well (fig 9). A very gradual shoaling affect was observed with the main difference in the extreme depth variation of the axis. It ranged from 760 to 490 meters, by far the greatest of the months and certainly greater than the ensemble.

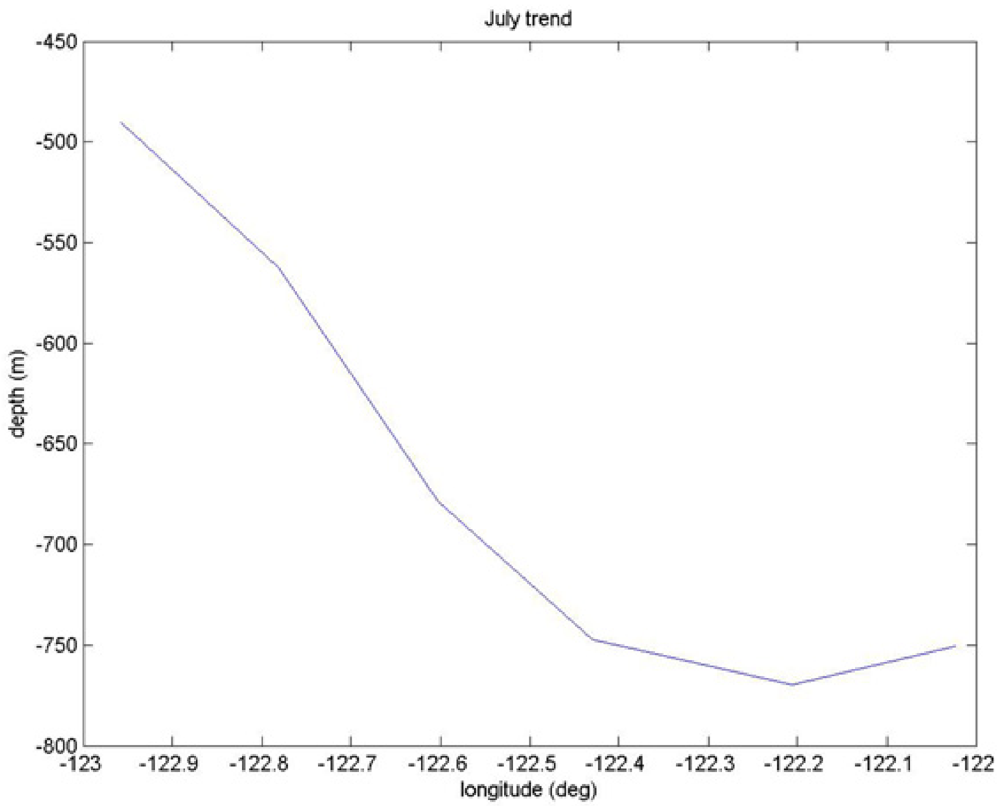

Fig. 9 July Deep Sound Channel Axis Depth

Similarly, November was the only fall month that was examined (fig. 10). It was not as well behaved and displayed all shoaling characteristics between the fourth and fifth data points. Range of axis depth was 200 meters.

Some of the above months contained data from the oceanographically anomalous El Nino year of 1998. After seeing the rough fits of the various months, those years were analyzed without 1998 data to determine if perhaps a better fit could be obtained. It was observed not to significantly change the trends. When 1998 data (five sets) were plotted in similar fashion to the months the fit was quite good to the ensemble (fig. 10).

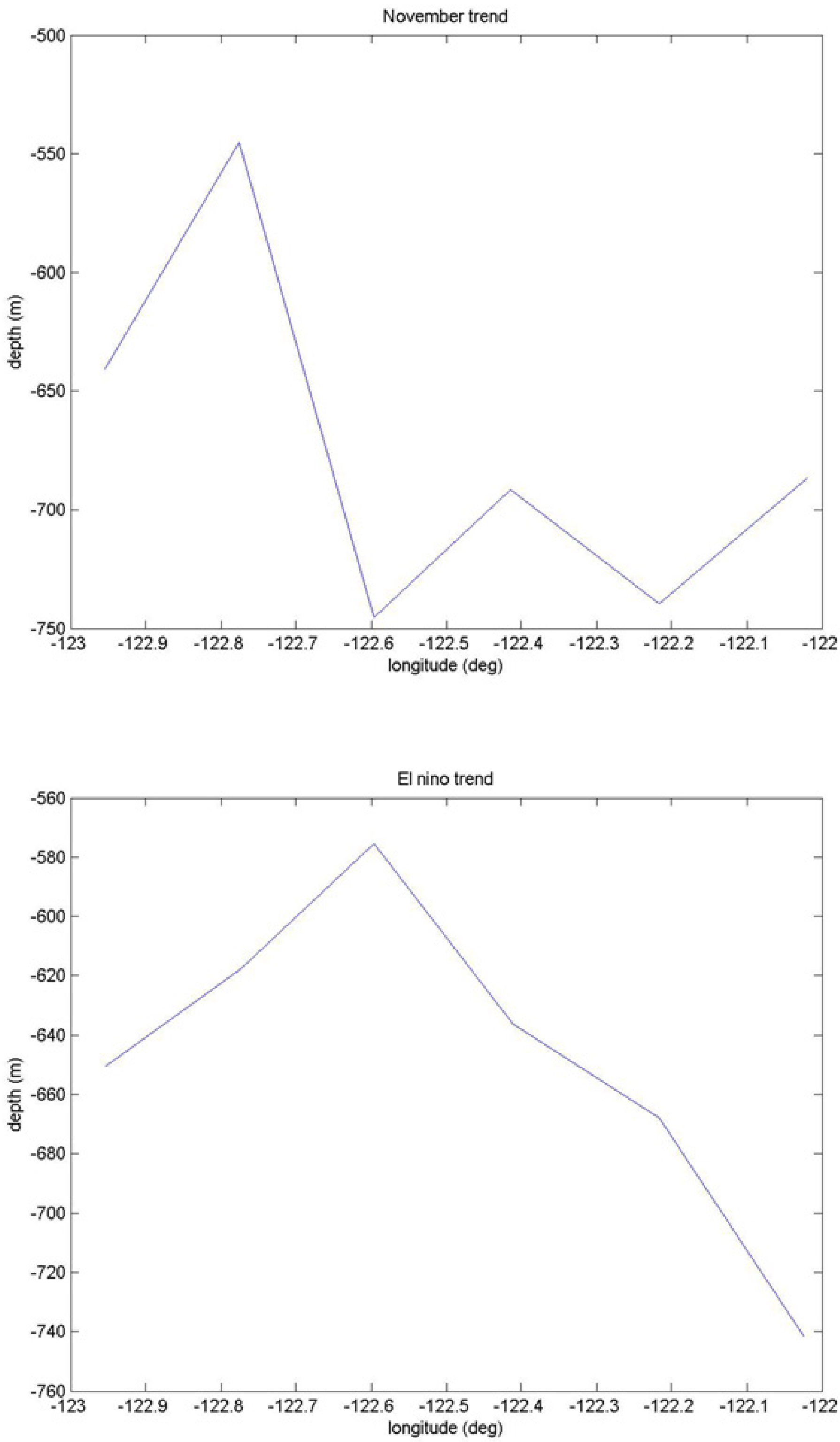

Fig.10 November and El Nino (1998) Deep Sound Channel Axis Depth

5. Conclusions

A definite, statistically sound, shoaling of the deep sound channel axis is observed on Line 67 from the Monterey Bay to approximately 123 degrees west longitude. Monthly investigation yielded limited results as to seasonal variation of this shoaling effect. The anomalous El Nino year produced little change in deep sound channel axis depth compared to the ensemble based on limited data input.

Continued research could take many forms. Explanation is needed as to what causes the obvious shoaling of the sound axis. Possibilities include the influence of the northward flowing Davidson current bringing Equatorial waters north in stark contrast to the southward flowing California Current directing Arctic Deep waters south. Does this effect extend further to the north and south or is it amplified by the unique bathymetry of the origins of Line 67 in Monterey Bay?

Data scarcity makes the job difficult. The ability to predict the underwater environment rests on our understanding of the dynamics that drive sub-mesoscale variations like this one. These are the questions that we are needed to answer as a community and these are the questions that will be asked.