



**SoVeAt - A tool for visualizing
sound velocity data for Naval applications**

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Abstract

This report discusses various functionalities of Sound Velocity Atlas (SoVeAT) tool developed for use by Naval Operations Data Processing and Analysis Centre (NODPAC) a wing of Indian Navy. The subsurface

profile data of temperature and salinity (T/S) used in developing this tool is the Argo data which is obtained from INCOIS Argo mirror archives which is obtained from two Global Data Assembly Centre's (GDAC) namely Coriolis in France and USGODAE in USA. These data sets are processed, quality controlled and merged to form a unique data set for enhancing the Sound Velocity climatology of Indian Ocean (30E - 120 E and 69 S - 30 N). With this sound velocity data derived from Argo T/S, Graphic User Interface (GUI) based tool is built for visualizing parameters viz., Sound Velocity, Temperature, Salinity and bathymetry. This tool has capability to generate climatology dynamically between any chosen periods apart from visualizing various plots which are useful for Navy while at sea. Also provision for adding newly observed T/S data is provided making this most robust sound velocity tool for use by the Indian Navy.

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ABSTRACT

This report discusses various functionalities of Sound Velocity Atlas (SoVeAT) tool developed for use by Naval Operations Data Processing and Analysis Centre (NODPAC) a wing of Indian Navy. The subsurface profile data of temperature and salinity (T/S) used in developing this tool is the Argo data which is obtained from INCOIS Argo mirror archives which is obtained from two Global Data Assembly Centre's (GDAC) namely Coriolis in France and USGODAE in USA. These data sets are processed, quality controlled and merged to form a unique data set for enhancing the Sound Velocity climatology of Indian Ocean (30E - 120 E and 69 S - 30 N). With this sound velocity data derived from Argo T/S, Graphic User Interface (GUI) based tool is built for visualizing parameters viz., Sound Velocity, Temperature, Salinity and bathymetry. This tool has capability to generate climatology dynamically between any chosen periods apart from visualizing various plots which are useful for Navy while at sea. Also provision for adding newly observed T/S data is provided making this most robust sound velocity tool for use by the Indian Navy.

1. Introduction

Spatial variations of sound speed cause acoustic rays to bend according to Snell's law (Urick, 1983), and sound is partially reflected and refracted as the sound speed varies sharply. This results in formation of "shadow zones" where sound waves cannot penetrate. In general the maximum mean sound speed values are observed in the surface layers of 0 – 50 m in the ocean, the sound speed values decrease in the deeper layers. This could be attributed to the fact that the deeper water is relatively cooler than that at surface. Temperature being a major contributor, this accounts for the low sound speed values in the deeper layers. The high sound speed core that is well formed till 100 m depth, starts dissipating, and the contours of sound speed of then found to increase from equator towards north. Beyond ~100 m the meridional gradients in sound speed start changing into zonal gradients.

Acoustical properties of the ocean environment largely determine the submarine operations and operational characteristics. Sonic Layer Depth (SLD) derived from Sound Velocity is having important potential applications for global underwater communications and for the anti submarine warfare (ASW). SLD is defined as the depth of maximum sound speed above the deep sound channel axis and is obtained from Sound Velocity Profile (Jain et al. 2007; Etter 1996). A submerged object goes undetected by surface sonar at a depth of SLD plus 100 m and beyond (<http://www.fas.org/man/dod-101/sys/ship/deep.htm>). SLD plays an important role in determining the angle of refraction of sound rays traveling in the ocean and hence in identification of the shadow zones. In general, the deeper the sonic layer, the stronger and wider the duct and the less steep the angle of refraction. Due to this, more of the sound is trapped producing longer detection ranges. A decrease in sea state results in less mixing. This causes the SLD to shallow, which in turn refracts the sound rays at a sharper angle, thus producing shorter detection ranges. Conversely, an increase in sea state results in more of the mixing and deepening the SLD. Sound rays then refract at a less steep angle and Sonar detection ranges increase (Figure 1).

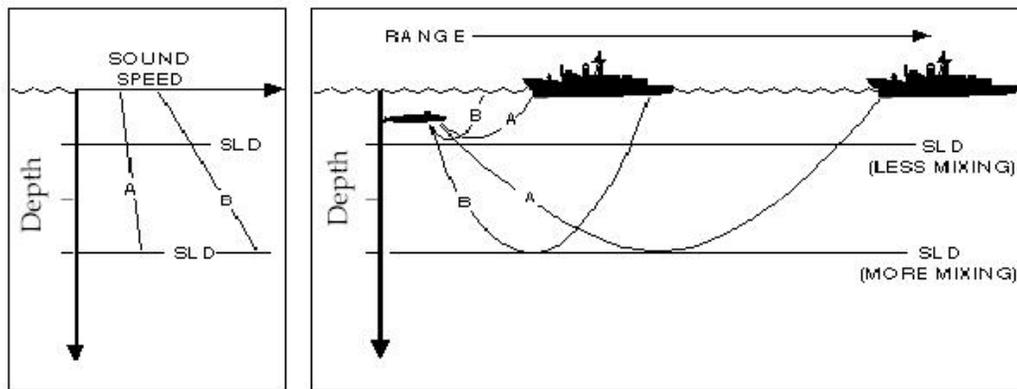


Figure 1: Effects of SLD and sound speed on propagation paths (source: http://www.fas.org/man/dod-101/navy/docs/es310/SNR_PROP/snr_prop.htm)

The usefulness of the sound channels greatly depends on the thickness of channel and the frequencies of interest. All sound channels are frequency limited. Only higher frequency sound rays are trapped in that. If the frequencies are above the low frequency cut off, they are trapped in the channel making the channel useful. This cut off frequency can be determined from the width of the surface duct, frequency of interest and the rate of change in sound speed with depth. Surface duct width depends upon the depth of the sonic layer (Figure.1). Hence, SLD affects the cutoff frequency, which is a significant factor in the sound channel propagation path (U.S. Navy Website).

The actual range of direct path propagation of sound velocity depends upon the source and receiver depths, sound speed gradient and SLD. If the source and the receiver are both within the SLD, the strength of the sound speed gradient and the depth of the sonic layer determine the range. The weaker the positive sound speed gradient and the deeper SLD, the greater the direct path ranges. Figure 2(a) shows direct path rays in a stronger positive gradient with the SLD at less depth than in Figure1(b). Path ranges are greater in Figure.1(b) as there is less refraction of the rays. If the source is below the SLD, the temperature gradient in the thermocline region determines the range.

Studies relating to sonic layer depth are limited owing to lack of continuous subsurface profiles. Some investigators have made attempts to study the sonic layer dynamics based on available observations while others obtained SLD from surface parameters using artificial neural network (ANN) techniques. Using a global set of in situ temperature and salinity profile observations, Helber et al, (2008) analyzed the sonic layer depth and compared it with mixed layer depth over the annual cycle. Using the recently deployed Argo floats data Jain et al, (2007) estimated SLD using ANN technique from surface parameters obtained from Woods Whole Oceanographic Institution mooring deployed at 61.5 E and 15.5 N in Arabian Sea.

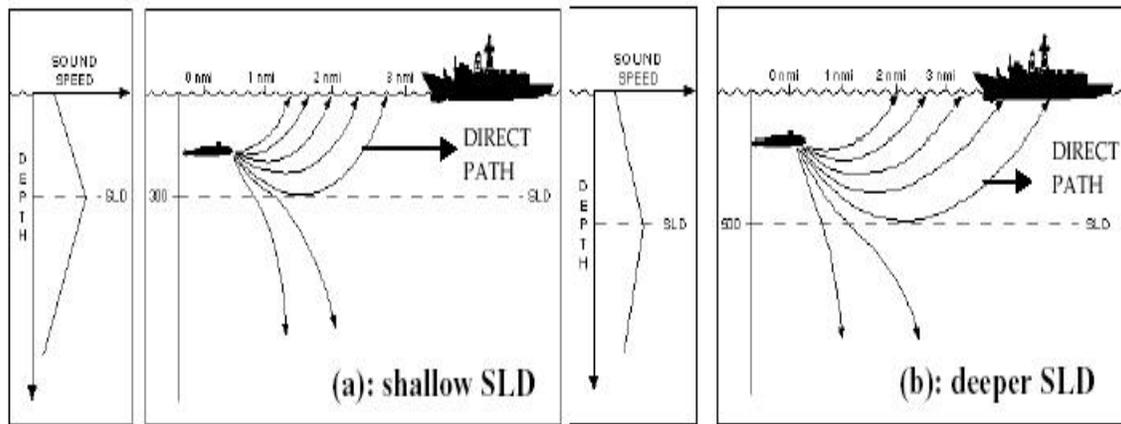


Figure 2: Direct path sound rays (source and receiver are in the sonic layer). (source: http://www.fas.org/man/dod-101/navy/docs/es310/SNR_PROP/snr_prop.htm)

All the above mentioned studies have used either climatologies or historical hydrographic data or limited in situ observations obtained before the Argo project started, they suffer from large uncertainty due to sparse observation in those regions away from major shipping routes. In addition, since a major portion of the historical data consists of temperature profiles, some of the studies used temperature profiles to infer the mixed layer depth from the isothermal layer depth (de boyer montegaut, 2004; Lorbatcher, 2006). Since the year 2000, the number of Argo floats in the world oceans has been increasing year by year and the projects goal was reached in November 2007, i.e., more than 3000 floats are now in operation in the world oceans. The number of profiles obtained annually by Argo in the world oceans was more than 30,000 in 2003 and this number tripled to about 90,000 in 2006. Thus, the annual total of Argo profiles obtained

every year is now equivalent to three quarters of the total number of historical Conductivity-Temperature-Depth (CTD) profiles deeper than 2000 m archived in the world ocean data base 2001.

Thus this large quantity of Argo data enables us to estimate sound velocities and sonic layer depth with a quality that must be better and much more homogeneous in space and season than previous climatologies. In the present work a GUI tool is developed to visualize the Sound Velocity which is dynamically computed from all the Argo observations and various visualization capabilities are presented.

2. Data and Methodology

The data set mainly used in this tool are subsurface temperature and salinity profiles obtained from Argo profiling floats encompassing the period 2000 - 2018. All the profiles are passed through 19 automatic Real Time Quality Control (RTQC) procedures as prescribed by the Argo Data Management Team (ADMT). All the eligible profiles were passed through Delayed Mode Quality Control (DMQC) and corrected mainly for the salinity degradations. In addition to these, all the profiles are visually checked for any leftover spikes and unusual gradients using VQC tools developed in house (udaya bhaskar, 2012). Leroy et. al., (2008) equation is used derive sound velocity from these temperature and salinity profiles. As claimed by Leroy this equation is applicable to latitude in all oceans and open seas, including the Baltic and the Black Sea. The detailed equation is as given below.

$$\begin{aligned}
 c = & 1402.5 + 5T - 5.44 \times 10^{-2}T^2 + 2.1 \times 10^{-4}T^3 \\
 & + 1.33S - 1.23 \times 10^{-2}ST + 8.7 \times 10^{-5}ST^2 \\
 & + 1.56 \times 10^{-2}Z + 2.55 \times 10^{-7}Z^2 - 7.3 \times 10^{-12}Z^3 \\
 & + 1.2 \times 10^{-6}Z(\Phi - 45) - 9.5 \times 10^{-13}TZ^3 \\
 & + 3 \times 10^{-7}T^2Z + 1.43 \times 10^{-5}SZ.
 \end{aligned}$$

3. Overview of the SoVeAT tool

Once the required Sound Velocity profiles are derived from quality controlled temperature and salinity data, these data are ready for use with the SoVeAT tool. Using these profiles data Graphical User Interface (GUI) is designed to visualize the data in various forms. As per the request of NODPAC, the following visualization functionalities are designed and incorporated into the SoVeAT tool.

S. No	Parameter	Visualization forms
1.	Sound Velocity Profiles	<ul style="list-style-type: none"> a. Time series plots for a point and averaged over an area. b. Climatology generation and visualizing spatial contour Plots (2D plots). c. 3D plots of Sound Velocity which includes full Indian Ocean extent and along a pie wedge. d. Plots along a designated ship track, which include the curtain plot over laid on 3D bathymetry. e. Data density statistics plots.
2.	Temperature and Salinity	<ul style="list-style-type: none"> a. Time series plots for a point and averaged over an area. b. Climatology generation and visualizing spatial contour plots. c. Plots along a designated ship track which include the curtain plot over laid on 3D bathymetry. d. Data density statistics plots.

Table 1. List of functionalities for each of the parameters provided in SoVeAT tool



Figure 3. Home interface of the SoVeAT tool.

The default interface (home page) to visualize the sound velocity data is given in Figure 3. Here the user is given the option to choose one among the available visualizations of SVP and temperature and salinity data sets. The available options are given on the top left hand corner. The options are "Home", "Line Plots", "Maps", "Analytics", "User Guide". Once the functionality is chosen, the user is shown with multiple options to plot the graphs on the fly. The rest of the section describes the individual plotting options available in the GUI.

3.1 Line Plots: Choosing this option allows the user to plot the line plots along (i) a fixed point that is time series, (ii) vertical profile along a depth that is position and time are fixed (iii) data along a trajectory of ship.

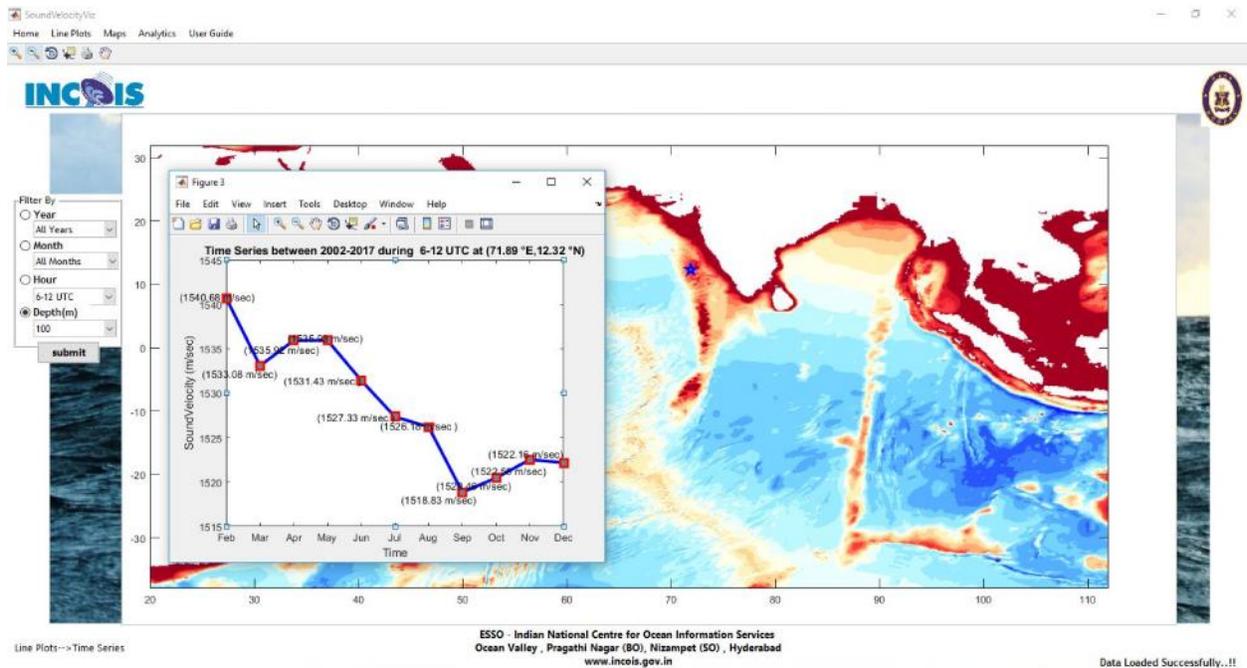


Figure 4. Time series plots of Sound Velocity at 70.10 longitudes and 10.12 latitude in the Arabian Sea. Sound velocity variability for all months and time zone of 06 - 12 Hrs.

3.1.1 Time series plots: To generate time series plots the user is given the option to choose his desired months (Jan - Dec) and the time zones of the day vis., 00 - 06 Hrs, 06 - 12 Hrs, 12 - 18 Hrs, 18 - 24 Hrs. Figure 6 shows that selection of years range, month and time zone from the dropdown menus for generating the time series plots. Once the user selected the year range, month and the time zone, he can select any location in the map which executes a query from the data stored, which results in filtering the data so as to match the query and the output is

generated in the form of a line plot. The user is also provided with an option to choose and plot the sound velocity variations for all the months and one specific time zone and for a specific month and all time zones with varying depths respectively. The tool is also capable of throwing errors if the choice of filtering is wrong Ex: choice of all months all time zones. This type of choice results in an error box indicating "invalid selection" and the user is asked to recheck his selection and change it for getting a valid output. Figure 4 shows the time series plots for a choice of all month and time zone 06 - 12 Hrs.

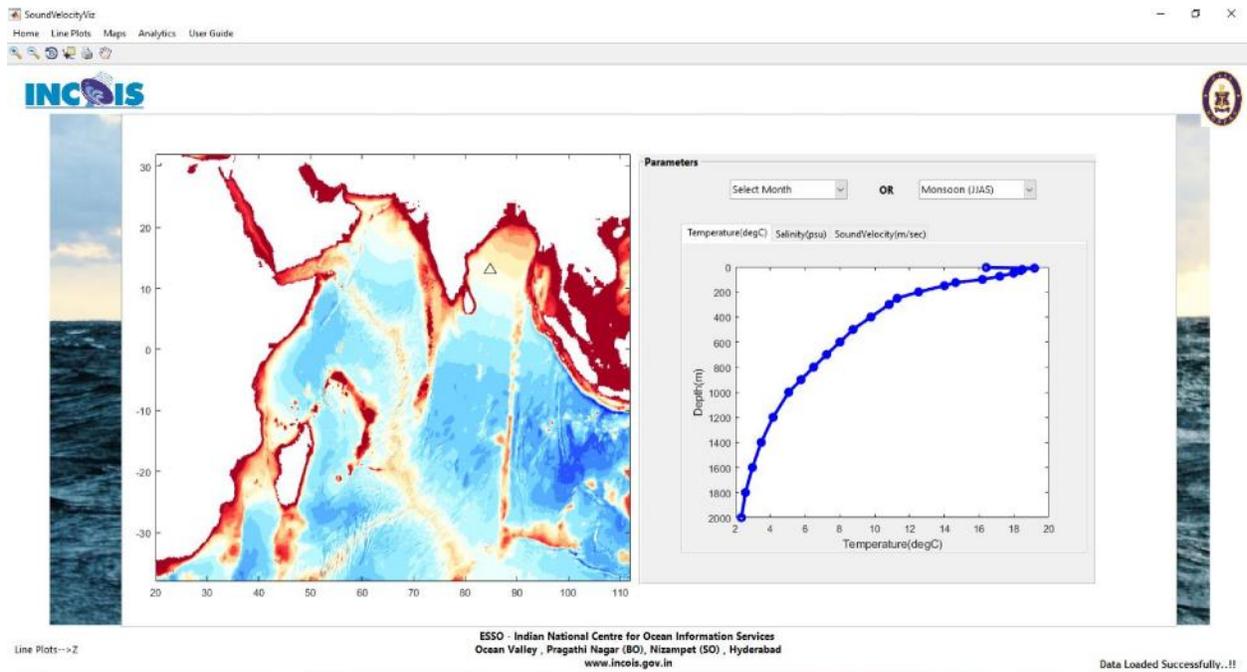


Figure 5. Sound Velocity at 84.17 longitudes and 13.18 latitude in the Bay of Bengal. Sound velocity variability for all depths is provided for the month of August.

3.1.2 Profile (Z) plots: Visualization of sound velocity along different depths is done by selecting “Z” submenu item under Line Plots. By selecting Z user is requested to select a point on map to fetch the corresponding data and plotted in adjacent pane. Here, user is provided with two choices i.e., filter by month and filter by season for the selected location which results in new plot. Figure 5 provide the snapshot of sound velocity profile for the chosen location for the month of August. The user can play with the month and season but to get see the profile variability.

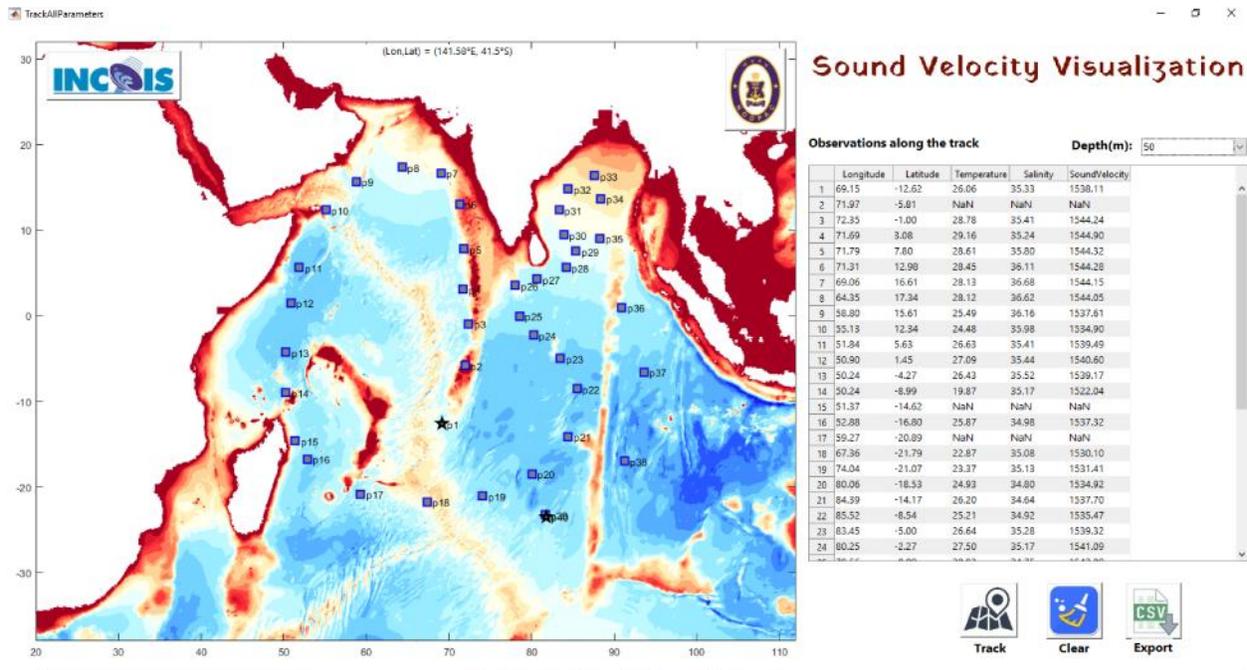


Figure 6. Manual selection of cruise positions to obtain the sound velocity along this track. Temperature, salinity and sound velocity for the positions are given in right pane.

3.1.3 Trajectory plot: In addition to the time series and depth/profile plots, the user is also given an option to generate the line plot of sound velocity along any specified ship tracks for any specific month or season. The user can create a cruise track file beforehand and uploaded it or the track of his choice can also be created with manual selection of (longitude, latitude) points which can be eventually saved into the desired locations and can be used at a later stage. Figure 6 shows the available options to give the track positions. After selecting the option and the locations the user is given an option to save this cruise track for later use. The positions of the cruise track are shown as $P_1, P_2 \dots P_n$ where P_n is the n th location of the track. The values along these positions are computed from the data and then displayed in the left hand side frame which can be copied and used for any purpose. Also the line plot of the parameter chosen is shown for all the position along the track. User can also export the track locations data as excel.

3.2 Map view of sound velocity: Choosing this option allows the user to plot and visualize the filled contour plots along (i) Longitude Vs Latitude (2D spatial) , (ii) Longitude Vs Latitude and Depth (3D Spatial) (iii) Animated 3D along Longitude, Latitude and depth (iv) 3D pie wedge view (v) 3D curtain view.

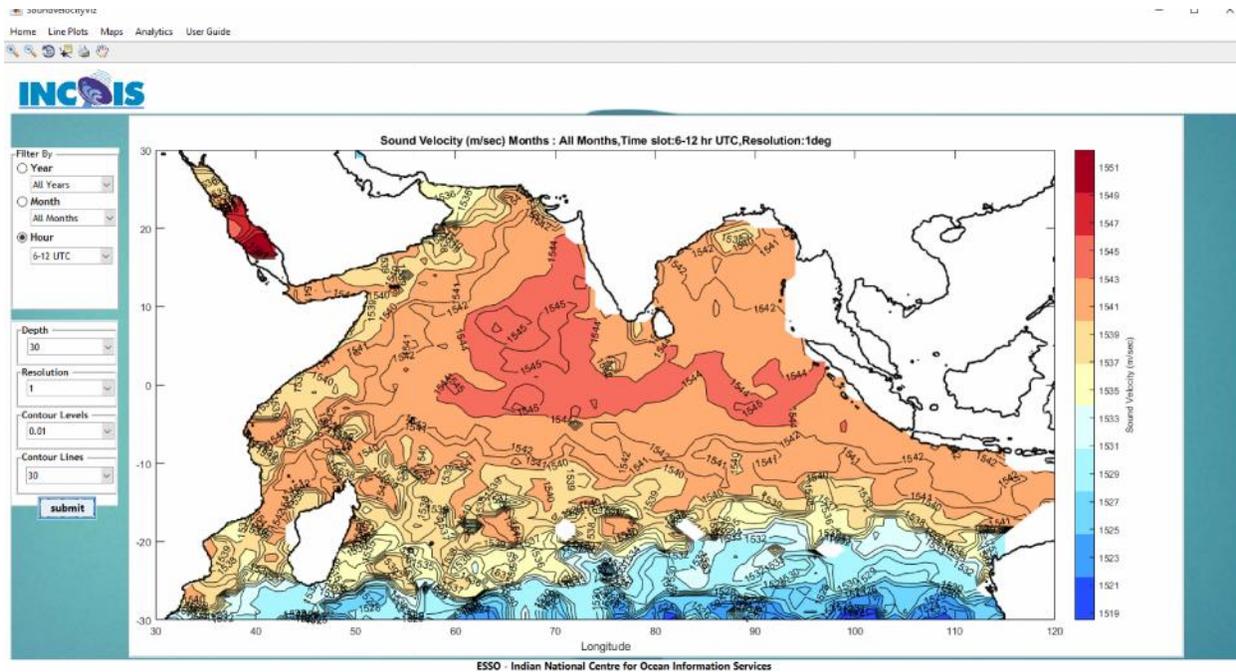


Figure 7. Sound velocity at 30 meters (dynamically generated from the data) for the time slot of 6 - 12 hrs.

3.2.1 2D Spatial plots: This option gives the feasibility of generating sound velocity climatology dynamically from all the available data. Unlike climatologies which are generated once and all the analysis is based on it, here the climatology generation is made dynamic. The user is given an option to generate climatology for any resolutions like, 1.0° , 0.75° , 0.50° and 0.25° degrees and also for period of his choice. Also, the option for choosing the number of contour lines and levels in the spatial plot that would be produced is provided. By default the climatology uses all the data for all the years available. However an option is given to the user to choose the time range (year x - year y) so that all the data available between this period is obtained and climatology is generated. Also provision for updating the data for years to come is also provided, so that this tool is not limited to the current climatology but also caters to all upcoming years too. Figure 7 shows spatial climatology of sound velocity at 30 meters depth based on data of all years, all months for 6 - 12 UTC, for a grid resolution of $1^\circ \times 1^\circ$ with contour level 0.01 deg Celsius and with 25 contour lines.

3.2.2 Animated 3D along longitude, latitude and depth: In this the user is given a option to view the 3D structure of sound velocity and the variation can be seen along longitude, latitude and

depth by providing the options which create an animated sound velocity picture, giving its variability along the chosen axis viz., longitude, latitude and depth. Figure 8 shows a snap shot of the 3D structure of sound velocity showing its variability along the longitude.

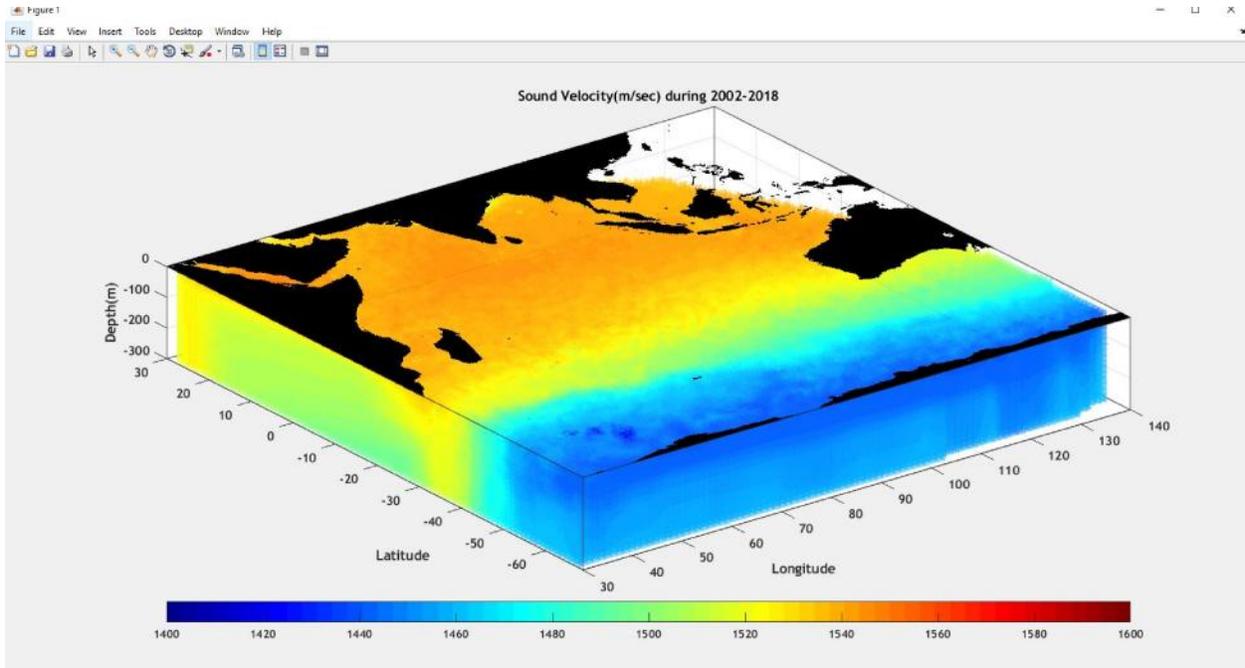


Figure 8. Animated sound velocity along longitude based on all the data.

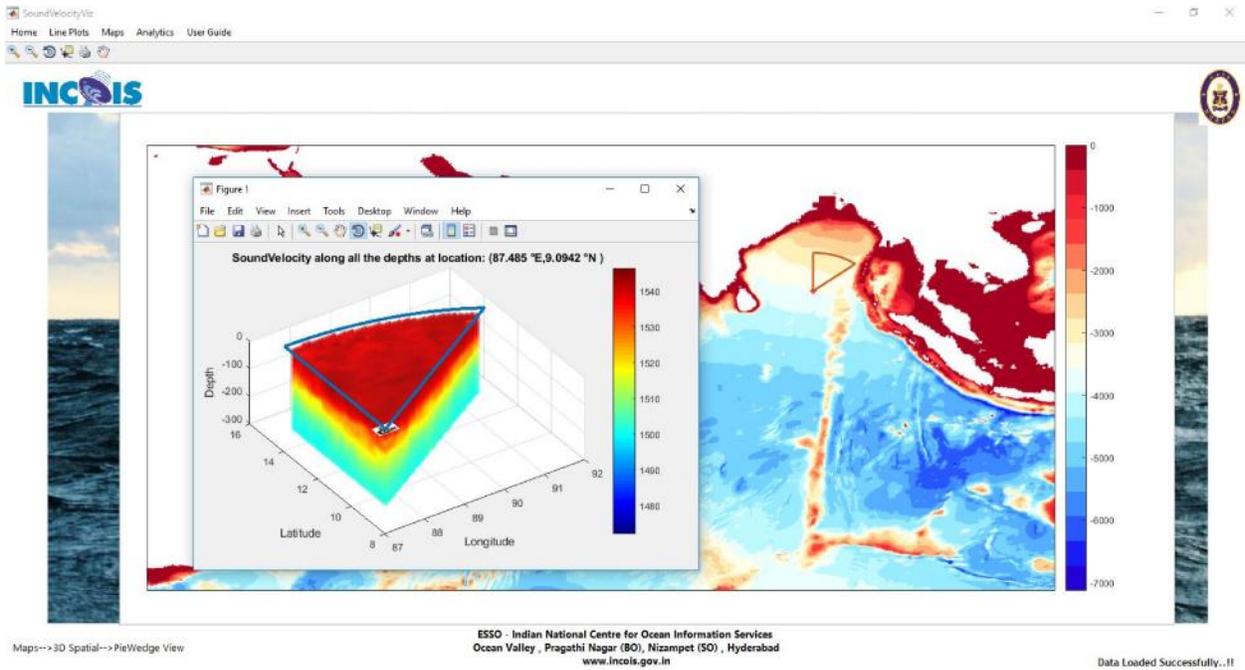


Figure 9. 3D pie view of sound velocity at a specified location in Bay of Bengal.

3.2.3. 3D pie wedge plots: This option gives a provision to view the sound velocity along a pie region with a angle of 30 degree with the head of the submarine/ship. The resulting plots gives visibility from the selected location on map along with angle of elevation (30 degrees). When user selects a location on map, a pie is drawn and corresponding sound velocity data along all the available depths is fetched from the database and a 3D pie wedge diagram is generated on the fly. Figure 9 explains about the above scenario and this 3D pie can be rotated and view in any direction and also the depth levels can be manipulated to view only at specified depth of user's interest.

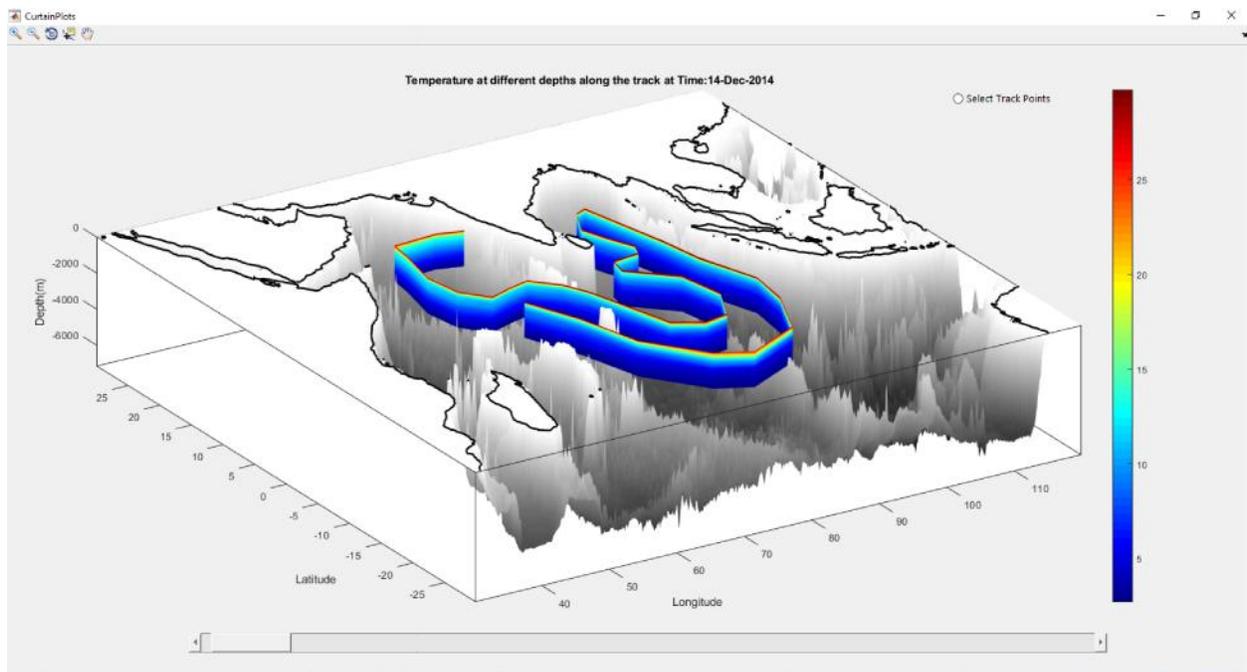


Figure 10. Curtain view of temperature on 3D bathymetry.

3.2.3. Curtain view (on 3D bathymetry): In this option the user is provided the choice of visualizing sound velocity, temperature and salinity data along with the 3D bathymetry view. For a chosen track it extracts the sound velocity, temperature and salinity along the given track with respect to bathymetry as base layer. Bathymetry is displayed as gray color and on top of it sound velocity is plotted in color. Figure 10 shows a sample visualization of the above case. In this an option is provided to the use to give locations and depth of choice for which the sound velocity is extracted and displayed as cross section plot.

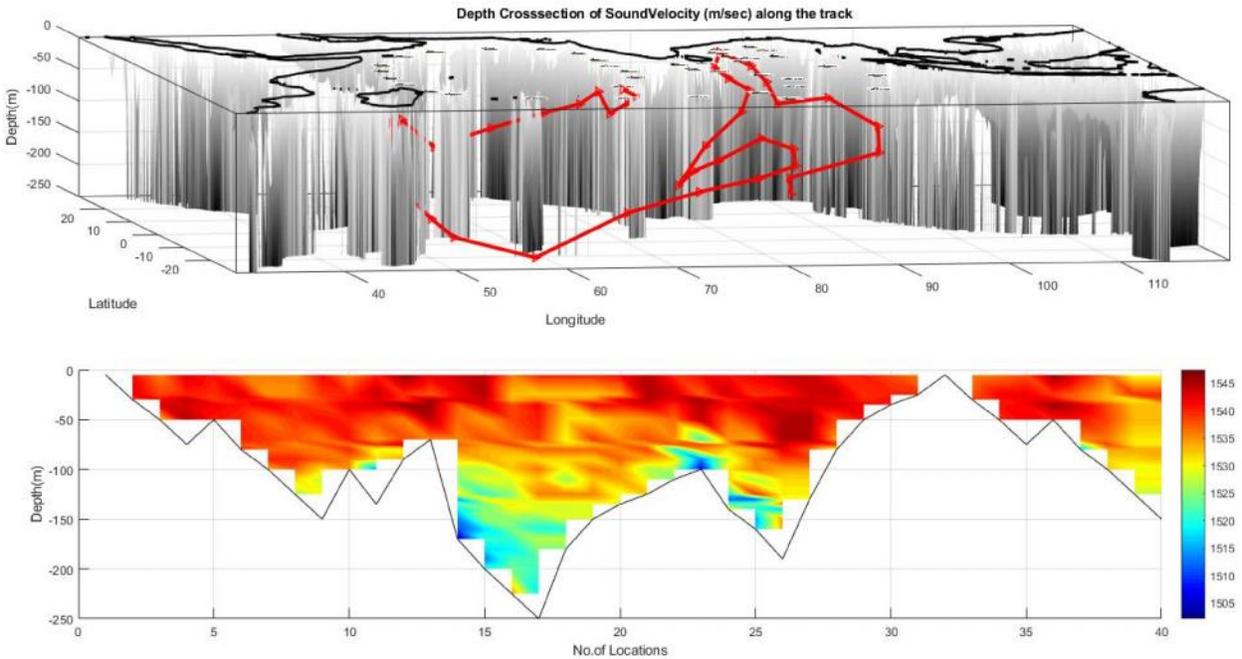


Figure 11. Cross section view along z of sound velocity along the track on 3D bathymetry.

3.2.3. Depth Cross-section 3D along the track (on 3D bathymetry): In this option the user is provided the choice of visualizing sound velocity, data along with the 3D bathymetry view for a specified trajectory indicating the dive of Submarine. For a chosen track it extracts the sound velocity, along the given track up to the specified depth and both the trajectory on 3D bathymetry along with the sound velocity cross section plots up to indicated depth is shown. As in the case of curtain plot, Bathymetry is displayed as gray color and sound velocity is plotted as a cross section plot. Figure 11 shows a sample visualization of the above case. In this an option is provided to the use to give locations and depth of choice for which the sound velocity is extracted and displayed as cross section plot.

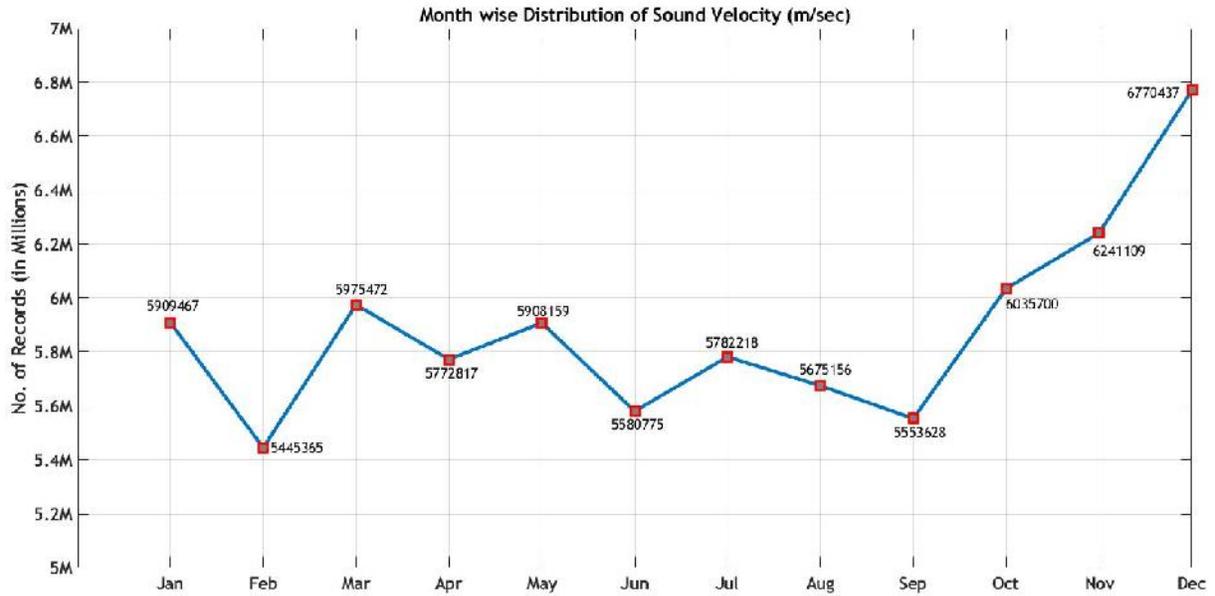


Figure 12. Monthly distribution of sound velocity data for the years 2002 - 2018.

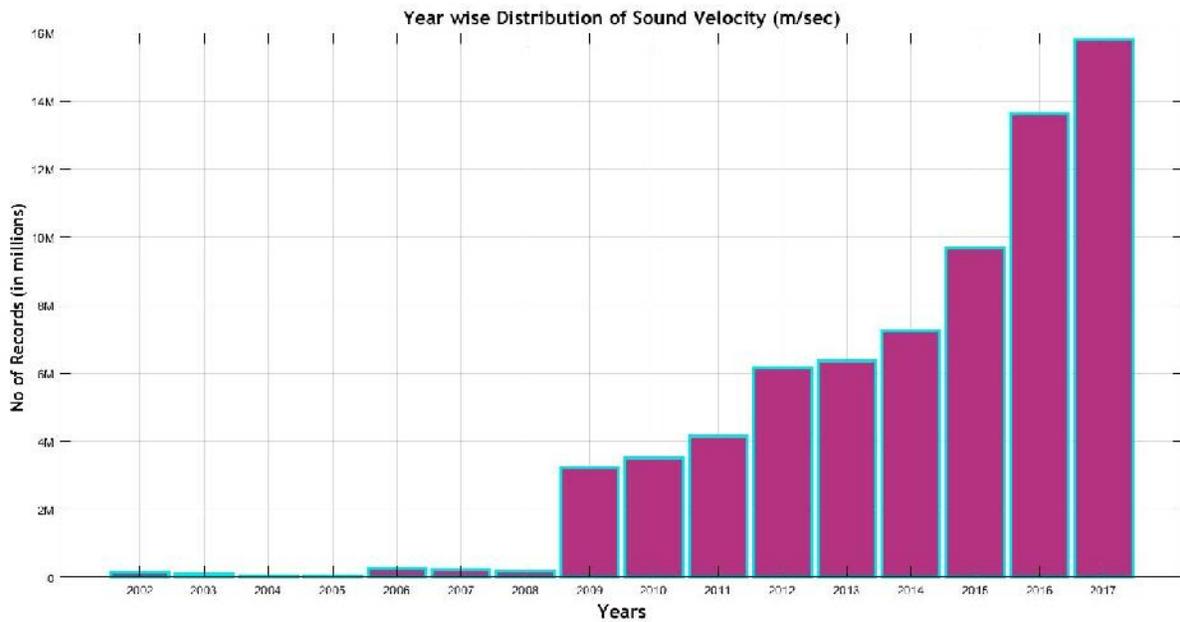


Figure 13. Yearly distribution of sound velocity data for the month of October.

4. Analytics tool

This option is given to the user to check the spatial and temporal coverage of data which is used in generation of the plots and also to know that amount of data that has gone into generation of climatology. There are options like (a) to see the distribution of data varying each month between the chosen year(s) and (b) to see the distribution of data for a chosen month varying for all the years and (c) to see the spatial distribution of data corresponding to the parameter which give a confidence of the spatial contours drawn for the parameter based on the data. The first option of monthly distribution of data is given in figure 14. Here a sample year 2002 - 2017 are chosen for which the monthly distribution of the data is given in the figure. The second option of yearly variability of data for a chosen month is shown in Figure 12. Here the distribution of sound velocity data for the month of October for all the years 2001 to 2018 is given. One can clearly see the increase in the amount of data records with the passage of time from more and more Argo floats. The third option of plotting and checking the spatial distribution of sound velocity data is shown in Figure 13. For this the user need to choose both the Year and Month which will result in the generation of spatial distribution plot. The sample plot of spatial distribution is given in Figure 14 for the years 2002-2017 and all months. Finally any option is given to use to see the monthly distribution of all the available data on a cob-web plot. This plot gives the data availability on spiral view with each corner of the spiral (cob-web) representing the month of data availability. The cob-web plots for data availability for all the months are given in figure 15.

5. Dynamic climatology generation.

One of the biggest attractions of this SoVeAT tool is that it is dynamic. Unlike climatologies which are generated once and all the analysis is derived based on it, here the climatology generation is made dynamic. The user is given an option to generate climatology for any resolutions like, 1.0° , 0.75° , 0.50° and 0.25° degrees and also for period of his choice. By default the climatology generation uses all the data for all the available years. However in this tool an option is given to the user to choose the time range (year x_1 - year x_2) so that all the data available between these periods is obtained and climatology is generated. Figure 13 shows the option of generating climatology for a grid resolution of $1^\circ \times 1^\circ$. Also provision for updating the data for years to come is also provided, so that this tool is not limited to the current climatology but also caters to all upcoming years too. The GUI pages corresponding to the updating of the new data measured by the Argo floats.

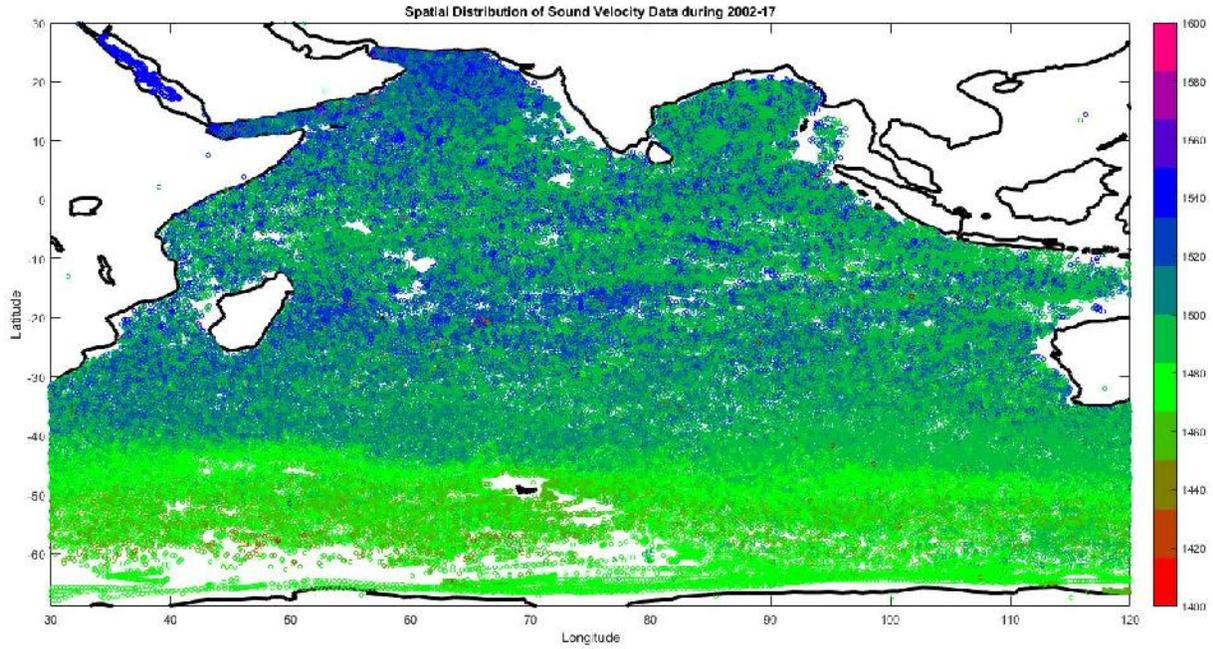


Figure 14. Spatial distribution of sound velocity data for the year 2015 and all months.

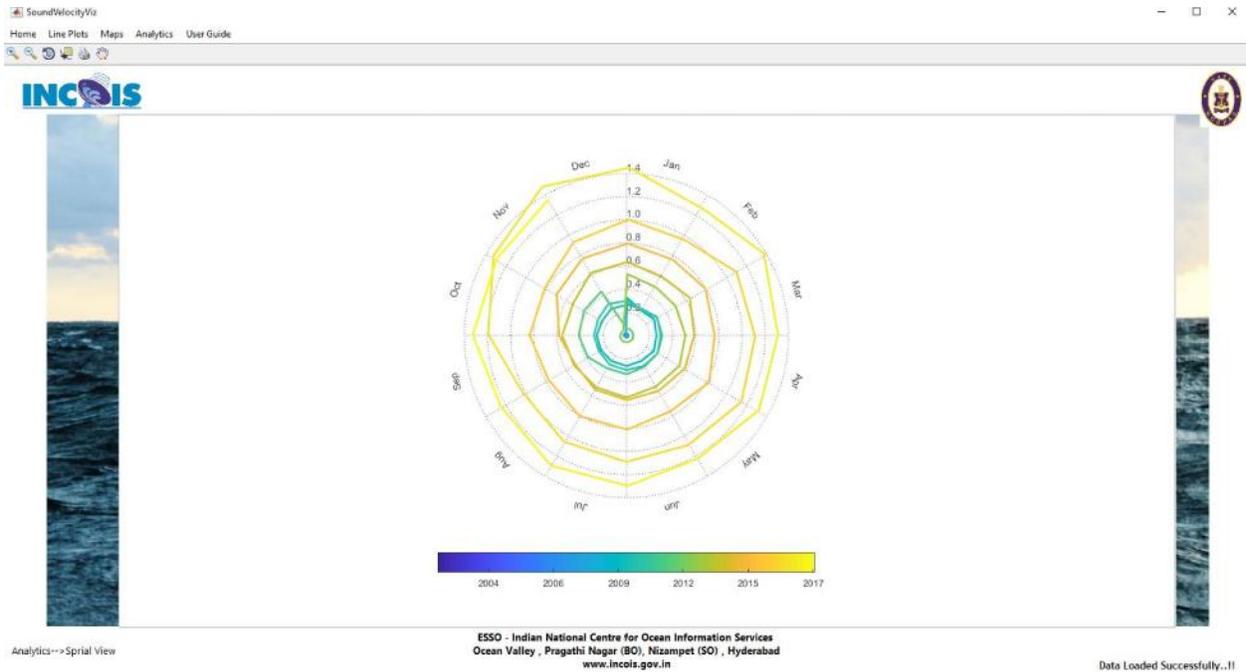


Figure 15. Cob-web plot of data availability for the months between chosen years.

6. Summary and conclusion

In this work a GUI tool developed for use by Naval Operations Data Processing and Analysis Centre (NODPAC) a wing of Indian Navy was described. Data from all Argo floats deployed by various countries in the Indian Ocean are all together used for generating database and visualization purpose. The data from these floats are processed, quality controlled and merged to form a unique data set for generating sound velocity climatology of Indian Ocean. With the use of this base data (temperature and salinity), Graphic GUI tool is built for visualizing parameters viz., sound velocity, temperature and salinity. This tool is capable for generating climatology dynamically between any chosen periods apart from visualizing various plots which are useful for Navy while at sea. Also provision for adding newly observed temperature and salinity data is provided making this most robust tool for use by the Indian Navy.

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We are grateful to Dr. SSC Shenoi, Director, INCOIS for his encouragement and providing the facilities to carry out the work. We are also grateful to various Data Assembly Centre's (DACs) for providing temperature and salinity data for generating the sound velocity atlas which was subsequently used for visualization in this tool.

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