

Ocean Acoustic Tomography - A Modern Tool for Ocean Measurements

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Introduction

Ocean Acoustic Tomography is a new promising technique to measure the interior structure of the ocean using the principles of sound transmission in the sea. This is similar to a technique used in medicine called Computer Assisted Tomography (CAT), a method of observing an object slice by slice and studying the interior. The tomogram is a picture of a slice. Multiple tomograms are used to reconstruct a three dimensional image. The CAT scan employs X-rays for imaging the parts of the body, usually the brain for locating the tumours inside. Ultra Sound, Radio Isotope, Nuclear Magnetic Resonance (NMR) also find application to form tomographic images.

Tomography has its parallels in seismology too where the structure of the earth is inferred from a knowledge of the attenuation and arrival times of seismic waves transmitted from a transmitter and received at distant receivers, located at different places in an array.

Similarly in the ocean, the phenomenon of propagation of sound waves is utilised to produce a picture of the interior structure of the water column. It is a technique that has been proposed recently by Walter Munk of the Scripps Institute of Oceanography and Carl Wunsch of the Massachusetts Institute of Technology of the United States. From the existing basic knowledge of the ocean and sound propagation characteristics in the interior of the ocean, they proposed a practical measuring tool which has come to be known as 'Ocean Acoustic Tomography'.

The need for such a system

The oceans are extraordinarily complex systems. The observed distribution of temperature, salinity etc. and their variability in time & space is due to the complex mingling of the water-masses, circulation and mixing processes in the ocean. Recent observations have demonstrated that most of the Kinetic energy (about 99%) of the ocean circulation is associated with meso-scale eddies having horizontal length scales of a few hundred km and periods of 10 to 150 days. Some of the interesting phenomena yet to be investigated in detail are the swiftly moving large scale current systems, slow rotating gyres, warm and cold eddies (diameter ranges from 25-500 km), upwelling regions, etc. The mixing processes associated with tidal currents, internal waves, influx of saline and fresh water, of warm and cold water etc. need to be understood. The interaction of these and the other processes creates the observed patterns of the distributions.

The heat content in the upper ocean vitally affects the climatic conditions over the continent. Measuring the ocean weather poses a formidable problem. Even for an area as small as 1 square mega meter (1000 km x 1000 km), several fully dedicated vessels or several moorings are required. Tomography provides a good alternate method of obtaining data at a snap shot. The additional advantage of this system is that with 'm' moorings consisting of 'r' receivers and 's' sources yield r.s pieces of information rather than r+s=m pieces as obtained from traditional methods.

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Methodology

Sound speed profile over most of the open ocean shows a minimum at a depth that varies with geographical location, but is typically about 1 km, forming a deep sound channel (SOFAR channel). This is due to the opposing effects of temperature which dominates in the upper layers and causes a rapid decrease in sound speed with depth and of pressure whose increase eventually results in an increase of sound speed. Sound is trapped in the sound channel. Sound waves are refracted downward when propagating in the region of negative sound speed gradient above the sound channel and upward when propagating in the region of positive gradient below it. Acoustic energy thus cycles through the water column in the sound channel. The major effect of SOFAR channel propagation is that sound can propagate over a great distance along wholly refracted paths where it suffers only attenuation and geometric spreading losses. Scattering and absorption losses associated with boundary interaction are avoided. The geometric spreading is essentially cylindrical, and energy density decreases inversely proportional with range.

Ray paths can be computed using Eikonal or geometrical optics approximation where the field transmitted from a source is described in terms of rays whose characteristics are determined by the sound speed as a function of position. Each ray travels along a unique path determined by the angle with which it leaves the source. The time required for a pulse to pass from source to receiver along a particular path is called the travel time for that path. The single pulse at the source is split into an ensemble of pulse arrivals at the receiver, spreading over a second or more. For a 1000 km range typically about 10 rays intersect the receiver. These acoustic rays passing through different layers contain the history and memory of these layers they pass through. One needs decoding the arrival time signals to arrive at the oceanic structure.

The tomographic study includes (1) forward problem and (2) inverse problem. The forward problem consists of understanding the propagation of sound from a given source to a given receiver. The inverse problem is to use the travel time data and any other data along the resolvable

acoustic paths to obtain an estimate of the perturbation in sound speed to a reference sound speed.

Studies at National Institute of Oceanography

Sound ray paths have been computed along several meridional and zonal sections to study the aspects of ray geometry in relation to general oceanographic characteristics (forward problem). These computations are based upon hydrographic data from INODC archives. Along the transmission path 10 to 15 sound speed profiles have been utilised to construct the range dependent sound ray paths. The ray geometry has been studied in relation to the vertical sound speed structure. Fig. 1 shows ray path geometry for a hypothetical sound source located in the deep sound channel. The ideal locations of a receiver have been indicated by circles A and B where many rays intersect at these points. Besides the rays shown, some more rays may reach these points. The travel times of different rays reaching such a point will be used to deduce sound speed perturbations w.r.t. a reference sound speed profile.

The analysis of computed parameters such as travel time, ray looping, depth of scanning, etc. of different rays, along several sections have shown important features. A comparison of the parameters obtained for different regions of the Indian ocean has revealed considerable dependence of these quantities on the sound speed profiles.

Inversion techniques have also been developed to process the travel time data received at the receiver to obtain the sound speed perturbations from standard reference profile.

Future Developments

The long term objective of a tomographic system is to provide a complete coverage of the oceanic area to obtain uniform data sets on temperature and density fields. This system is fully complementary to the remote sensing of the oceanographic parameters from space. When coupled with other systems like satellite altimetry for the measurements of sea level and scatterometry for obtaining the wind distribution over sea surface, this can provide all the needed information on the interior structure of the ocean and the forcing parameters at the sea surface.

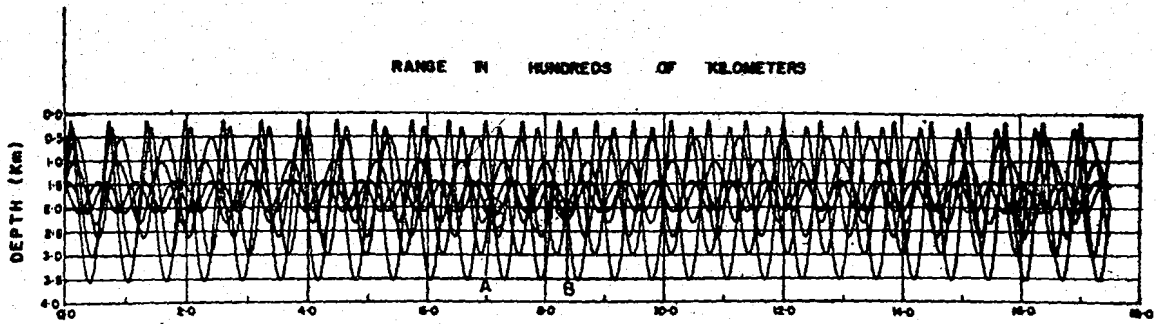


FIG. 1. RAY PATH GEOMETRY FOR A HYPOTHETICAL SOURCE LOCATED IN THE DEEP SOUND CHANNEL ALONG 87° E (BAY OF BENGAL) POSITIVE RAYS

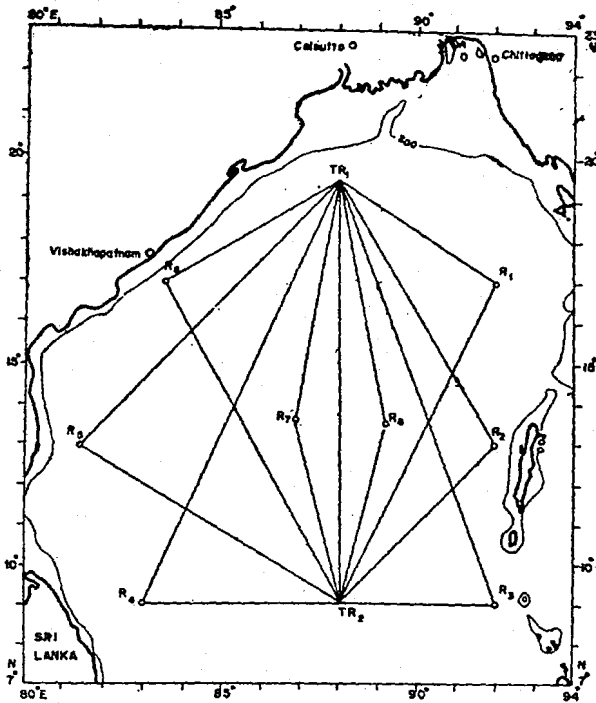


Fig. 2: A PROPOSED ACOUSTIC TOMOGRAPHIC SYSTEM FOR THE BAY OF BENGAL

Fig. 2 shows an arbitrary schematic tomographic network proposed for the Bay of Bengal. It contains 2 transmitters and about 8 receivers. A similar network may be useful to monitor the Arabian Sea. South of equator 2 or 3 such array systems when laid out with thought and care might cover the entire area.

Ocean Acoustic Tomography though appears to be simple in principle, development of the system involves comprehensive understanding of the distributions and their variability in the ocean. Several field and laboratory experiments on sound transmission have to be carried out to understand transmission characteristics in relation to hydrographic features to establish the system.

Suitable low frequency acoustic transmitting and receiving systems and mooring systems have to be developed. All this involves a very high level of sophisticated technology.