

CHALLENGES IN MARINE INSTRUMENTATION

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Abstract

The problems of ocean science are technology intensive as the area to be surveyed is vast, complex and hostile. The accessibility of most of the areas too, puts severe constraints on the design methodology, specially the power source of the systems. Also the parameters involved are interdependent on many factors which may be natural or influenced by man. As the area involved ranges from local to truly global, the technology requirements have to be tailored for specific applications. For surface parameters such as color, temperature etc. satellite technology has proven to be of good value though much greater emphasis is still needed in the area of algorithm development. Underway data collection techniques mostly revolve around acoustic techniques and have traditionally yielded good results. With enhanced signal processing capabilities, data acquisition and instant processing has improved but much still needs to be addressed. Deep sea micro-level biological phenomenon need reliable optical systems, an area which is currently being greatly improved. For biological observations these camera systems are essential though the presence of the experimentalist has distinct advantages. The area of biology has seen good development but still poses a very strong challenge for technology. Biosensors which can detect bioluminescence and other biological activities would play a major role. Autonomous instrumentation outfitted with different types of in-situ sensors would collect data without disturbing the system. Acoustic and optical instrumentation combined on the same platform would be able to address these problems. For this autonomous vehicles with extremely low power requirements, long term deployment and data transmission capability via satellites after surfacing, needs development. As the data collected in a typical oceanographic expedition is large, onboard processing of that data becomes important. Fortunately computers today are highly advanced and capable of extremely high speed number crunching and major bottlenecks rarely occur in the on-line transfer of data from ship to shore. Improvements in this area need only consolidation of the various techniques available to optimize the use of ship time.

Introduction

Oceans form a dynamic, complex system with a large number of processes and parameters interacting continuously under the influence of many external factors. Some of these are the weather, gravity tides, geological upheavals on long and short time scales. Even extraterrestrial influences have been associated with the evolution of the oceans. As mankind is dependent and to a large extent influenced by the happenings in the oceans, it becomes important to determine

these effects and improve our understanding of various processes to the level of predictability and effective mitigation measures.

Man has, since eons, used the ocean for his food resources, recreation and travel among other applications. His scientific curiosity led to technological innovations which in turn allowed him to better understand the oceans complexity. World War II gave impetus to application of the prevailing technology to ocean system understanding and consequently fueled rapid development in the field of marine instrumentation.. The need of superpower states to project their military power at great distances placed emphasis on naval development and in turn to the development of systems to better understand the behavior of the oceans. The result was more accurate navigation, bathymetry, water characteristic's measurements and the prediction of weather amongst other aspects. The area of acoustics was a major gainer during this period.

The early sixties also saw the emergence of solid state electronics which affected the overall pattern of scientific research and the oceanographic community used the emerging technology to improve the quality of its science allowing the addressal of many new issues, new discoveries and understanding of oceanic evolution. Two notable examples are the spreading ridges and trenches confirming the theory of plate tectonics and Hydrothermal vents with their strange and exotic life forms. This was possible because of the development of sophisticated instrumentation and manned submersibles notably the submersible ALVIN (Edmond and Von Damm, 1983). The presence of life forms at great depths and pressures in the absence of light and oxygen has led to radical changes in biological concepts related to life at sea. This in turn has catalyzed the development of technology that has delivered many useful products to mankind, such as drugs from the sea.

In earlier times, it was science which drove technology but it seems now that the new electronic revolution is driving science and the scientific community to address difficult global questions. Marine research at sea has a high price tag in terms of acquisition, operation and maintenance of research vessels and advanced scientific instrumentation and it is necessarily becoming an international endeavor throwing up new challenges in marine instrumentation which are addressed here.

Acoustics

Acoustical techniques to study oceanic behavior are the primary non invasive methods for geological, geophysical, biological, physical and engineering aspects of ocean research as well as for resource location, evaluation and exploitation. Acoustical methods are currently used for detection and addressal of localized, regional and global problems especially and could become an extremely important tool for world climate research. In a parallel to satellite technology which gives surface synoptic coverage of the ocean surface, acoustical methods integrate the variability of the vertical column. As the speed of sound is dependent on the ocean structure, it allows scientists to study the water column as well as the seabed and the subsurface. Major advancements have taken place in the field of bathymetry, seabed coverage and the structure of the ocean bottom with the help of new tools such as Multibeam swath bathymetry systems (de Moustier, 1986) (See Fig 1a and 1b), long range side scan sonars and 3 D seismic systems.

These tools have led to increased understanding of the geological and geophysical structure of the earth. The multibeam system has been successfully used in generating contour maps. With the rising cost of research vessels effective utilization of ship time is critical and these aspects now dominating exploration and exploitation of ocean resources. Modern post processing techniques allow us to extract backscatter information from the reflected signal giving information such as sediment density and variation, soil strength etc. The major challenge here is in enhancing the reliability of the data collection along with proper classification of sediments. This information, especially in the near coastal zone, would be of importance as man starts to colonize the sea. Acoustics are also being increasingly looked at in tomographical and thermometric applications.

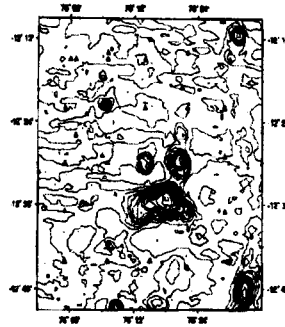
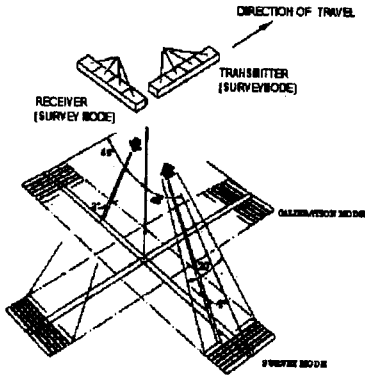


Fig. 1a. Hydrosweep Transmission / calibration and reception.

Fig. 1b. Bathymetry Contour map-Nodule Area, Central Indian Basin

In determining the role of the oceans in moderating and responding to global climate change, Acoustic Thermometry of Ocean Climate (ATOC) experiments can play a key role. Here a low frequency sound pulse transmitted omnidirectionally, is received by a number of hydrophone receivers placed at strategic locations. (Figure 2). As the velocity of sound is a function of water temperature, salinity and pressure, variations will take place in its travel time in response to variations of any of these parameters (Desa et. al, 1997). When monitored over long time scales actual variations of the sea temperature can be spatially monitored in the oceans. Analysis of the data from the first series of experiments in the Pacific obtained has revealed the variation of sea water properties such as temperatures etc. and their implication on the heat budget and heat flux of the ocean-parameters critically related to world weather patterns. (Munk and Forbes, 1989)

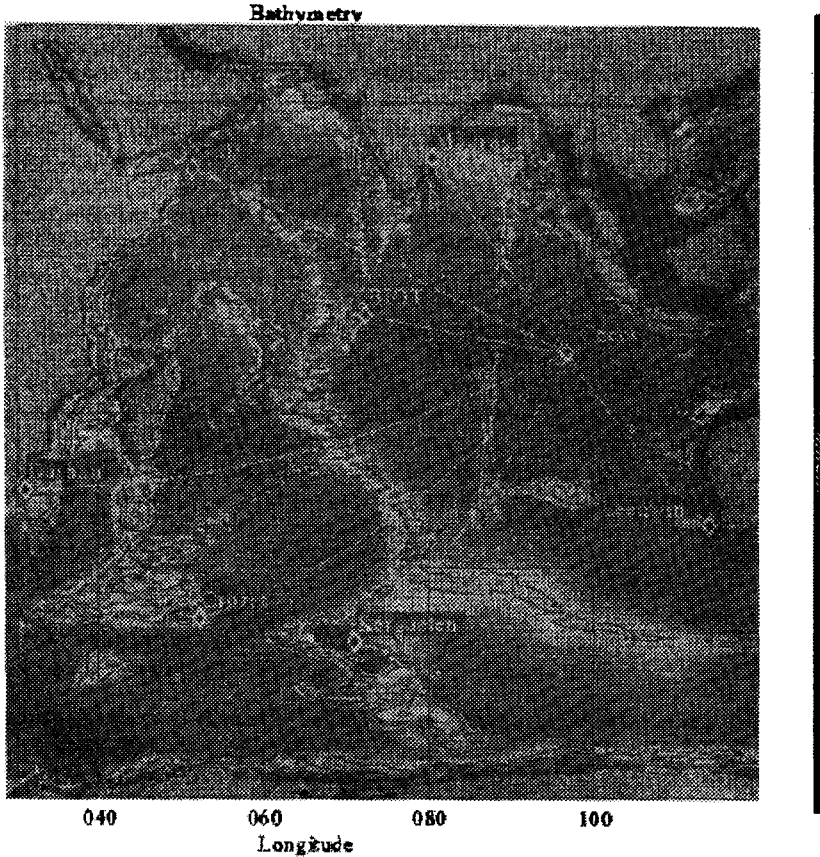
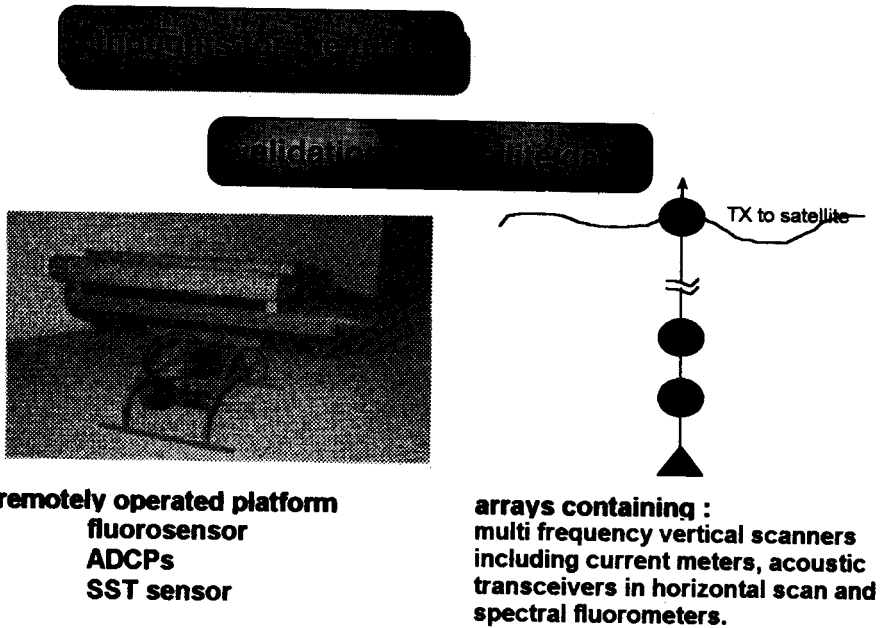


Fig 2. Indian Ocean ATOC experiment.

A study of water masses on a large and regional scale would benefit greatly from operational tomographic experiments. Water masses carry huge amount of salts, nutrients, oxygen, suspended sediment loads and the stored heat and their movements affect the productivity of the oceans and climate. Acoustic tomography experiments are prime candidates in man's search to routinely, continuously and cost effectively monitor the oceans. A suite of moorings in a large area with appropriate spacing having acoustic transceivers, current meters, thermistors and other sensors would be able to uniquely determine the various factors at play. This is conceptually depicted in figure 3. To enhance the interpretation it will become necessary to put sea truth validation buoys with these moorings to collect surface data and precise position of these buoys with GPS / DGPS methods.



**remotely operated platform
fluorosensor
ADCPs
SST sensor**

**arrays containing :
multi frequency vertical scanners
including current meters, acoustic
transceivers in horizontal scan and
spectral fluorometers.**

Fig. 3. Tomographical studies with sea truth validation.

Acoustical methods can also help in qualitative and quantitative studies of biomass. Acoustic techniques in the form of sonars and fish finders have led to gross over-fishing and no major refinements are expected in this area. What is now being realized to be of major significance is that sustainable fish offtake levels are limited effectively by productivity of the food chain. The acoustic estimation of zooplankton biomass upto 500 micrometer size, and further down the size scale in conjunction with optics, will become a major challenge in the years ahead.

An example of the advances in the realm of identifying individual zooplankton as well as the 3D spatial structure of biomass in the oceans (Wiebe and Green, 1994) is shown in Figures 4 and 5. The capability of dual beam and split-beam is clearly seen in the ability to uniquely determine position and direction of movement of zooplankton (Fig 5). In figure 6 is seen the possibility of distinguishing types of micro-organisms with a swept frequency beam. Clearly many challenges lie ahead, but it is on evolutionary rather than revolutionary scales.

Such understanding of the biomass, which has spatial and season variability is important if true sustainable yields are to be achieved. Acoustical sampling methods for biomass estimation have many advantages over nets, particle counters, photography, fluorometers etc., in case of analysis, minimum platform time for observation and largest frequency of sampling. This area is bound to see increasing improvements in transducer and software technology.

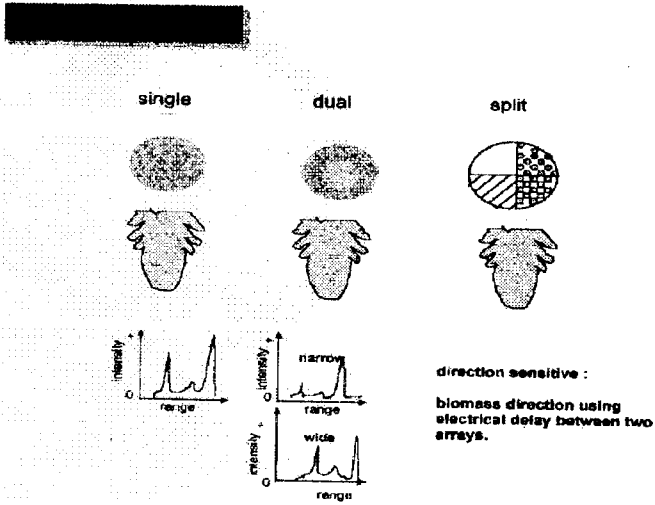


Fig. 4. Acoustic signatures with single, dual and split beam methods.

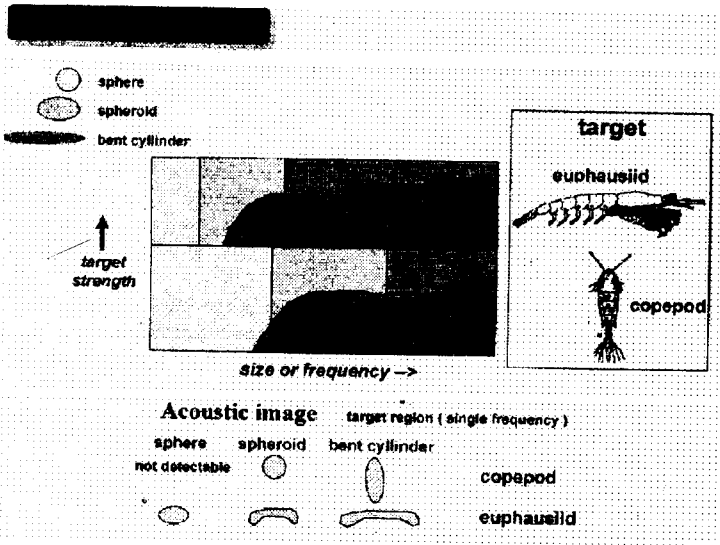


Fig 5. Acoustic signatures of Benthic creatures

Optics

Even though acoustic techniques have aided the understanding of various oceanic processes, the need to optical capture certain processes still exists. Photography techniques are used to for long term observation of biological benthic activities, search and recovery operations of sunken objects, and documentation of underwater objects as in case of marine archaeological finds (Ballard, 1993). The need to view the geological and biological processes has led to development of underwater television systems giving the scientific community a telepresence on the location. Information obtained can be transmitted in real time giving rise to wide ranging applications. Currently these are "routinely" employed in the finding of hydrothermally active zones, spreading ridges and other geological phenomenon. Detection of mineral resources, seabed features and sunken objects are areas where optical systems advantageously couple with acoustic systems and remotely controlled platforms. Such a system was used by the National Institute of Oceanography for large scale photography of sediment overlaying nodule fields in Central Indian Basin as shown in figure 5a and 5b. These optical and robotic combinations have been used in some famous rescue operations and as the intensity of operations in the coastal zone and the outer shelf areas increase, these capabilities will have to be enhanced.

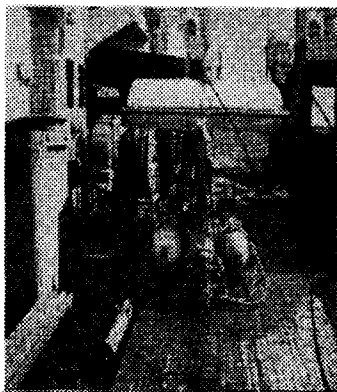


Fig 5a. ABBISAL Photography system.

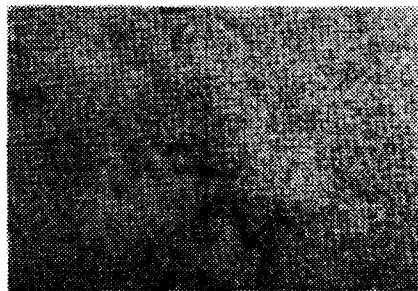


Fig 5b. Nodule on sea floor (ABBISAL).

Manned submersible, though expensive, still have a role to play in certain areas. These are mainly in the search of hydrothermal vents, spreading regions and deep sea biological observations. It is possible that with better television systems, fiber optic cables and high bandwidth data transmission systems, artificial intelligence based systems with low power and three dimensional movement capabilities will eventually marginalised manned submersibles.

Hydrothermal vents support extremely strange life forms which sustain in low light, very low oxygen and under extreme pressure. Some of these life forms thrive on sulfur based system and in high temperatures. Submersible ALVIN has undertaken many dives for hydrothermal field studies. In recent dives over Mid Atlantic Ridge hydrothermal fields, a scientist from the National Institute of Oceanography was the first Indian to dive in deep sea and was witness to

intense venting and biological activities. The samples recovered are shown in Fig 6a and 6b. The first photo shows a hydrothermal chimney recovered. This has an opening of about 15 cm diameter while the second shows the various metal sulfides precipitated from the hydrothermal solution. The color variation in the samples reflects the presence of various minerals.

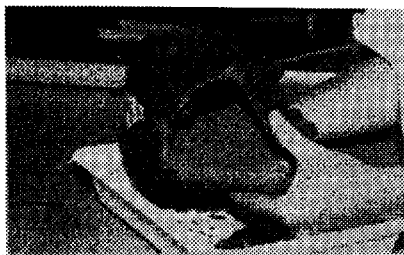


Fig. 6a. Hydrothermal Chimney.

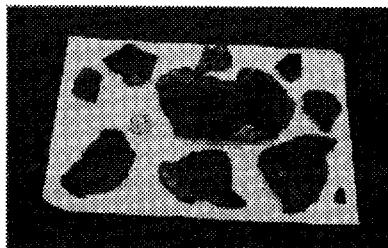


Fig. 6b. Rocks with mineral precipitations.

As biological interest in small marine organisms grows, the sampling frequency has to be increased to detect them. For large fishes and zooplanktons, acoustical methods suffice. But these techniques fail for phytoplanktons and still smaller particles. The detection of algae (picoplankton, nanoplankton and phytoplanktons) is best done by active and passive optical methods using fluorometers, backscatter, particle sizers, optical radiometer and lasers etc. as shown in figure 7 (Desa Ehrlich et. al, 1997) Generally optical methods of biomass estimation are adopted for particle sizes smaller than 200 microns.

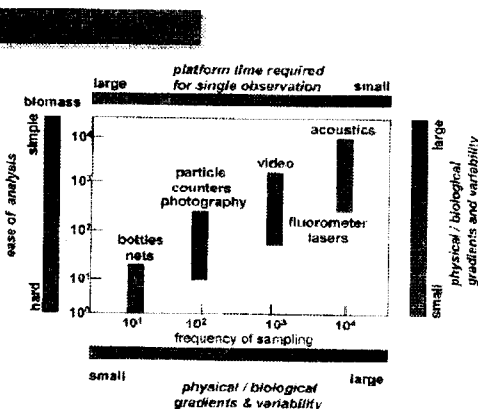


Fig. 7. Sampling techniques for biomass detection.

The insitu study of the various elements of the food chain by optical techniques is essential in this understanding. Passive and active techniques using fluorometers and particles sizers and insitu optical radiometers and absorption meters are perfect compliments. The fluorescence measured by satellites at 680 nm wavelengths that can be detected by satellite range from ultra-violet to infra-red, covering the absorption and fluorescence of phytoplanktons as well as the

detection of dissolved yellow substances and suspended sediments. The challenges in this area will be the development of regional algorithms especially for coastal regions -such as they are in biomass and complex in structure.

Satellites

The single most effective impact on synoptic understanding of some large scale surface oceanographic features has undoubtedly been through satellite remote sensing. This mode of viewing has made invaluable contributions to our understanding of surface circulation patterns, sea surface temperatures (SST), productivity of the oceans, waves and wind fields, geoidal determination and in more recent times to bathymetry and gravity in shallow regions. We are also beginning to understand the synergy possible from suites of satellite sensors to synoptically record allied oceanographic features. The challenges in this area will come from the development of algorithms that have evolved from a deep understanding of the processes being mapped and in the allied effort of accurate sea truth validation. Table I gives a fairly comprehensive idea of satellite sensors and the fields of application.

Table 1.

Sensor	Data	Science	Application
Ocean Color Sensor	Ocean Color	Phytoplankton, ocean current, surface temp. pollution and sediment	Fishing, ship routes monitoring coastal pollution
Scatterometer	Wind speed Wind Direction	Wave structure, currents Wind patterns	Ocean waves, ship routes, currents, ship safety
Altimeter	Altitude of Ocean surface, wave height wind speed	El Nino onset / structure	Wave and current forecasting
Microwave Imager	Surface wind speed Ice edge, precipitation	Ice thickness, cover, stress ice growth and ablation	Navigation Info ship routes
Microwave Radiometer	SST	Ocean air interaction	Weather forecasting

(Source : Report on Ocean Science and its Technology, W Andahazy, P.J. Cook and members, IWCO Committee and US Congress, Office of Technology Assessment, 1994).

The remote sensing satellite of the future play a significant role in helping us understand atmosphere-ocean interaction and its effect on global climate. A major challenge would be the complementary role of computer models in assimilation of real time satellite data to predict major events at sea.

A comprehensive program to augment the capability in this direction has been launched by Indian Space Research Organization (ISRO) under the umbrella of National Natural Resources Management System (NNRMS) by Department of Space. The present Indian Remote Sensing (IRS) satellite IRS -P3 carries a Wide Field Sensor (WiFS) and a Modular Optoelectronic Scanner (MOS). MOS is providing useful data on ocean biology such as chlorophyll pigments

and primary productivity. IRS-P4 would also being called OceanSat 1 will carry an Ocean Color Monitor (OCM) and a Multi-frequency Scanning Microwave Radiometer (MSMR). The OCM will be an unique regional and global observation platform for chlorophyll pigments and primary productivity while MSMR will provide data on SST, atmospheric water vapour and sea surface winds. IRS - P7 expected to be launched early in the 21 st century will be an integrated mission with capabilities to globally monitor the ocean and atmosphere. The mission is expected to provide comprehensive data on wind field, wave spectrum, sea surface topography, ocean surface currents, internal waves, SST, chlorophyll pigments etc. (Private Communication)..

Autonomous Systems

Oceanography is an expensive science done at sea, and growing increasingly so as the cost of operating ships rises continuously. Acoustics and satellite techniques provide the large synoptic complementarity essential to our understanding of this vast inter-related systems-the oceans. But precise point measurements are still required, and autonomous vehicles provides a low cost alternative to ship data. Mentioned below are the challenges in the area of drifter technology, long term unattended underwater platforms and moorings, and long term globally roving profilers.

Surface parameters such as sealevel variations, winds, waves, SST, air pressure, currents etc., can be measured by autonomous drifting buoys. Sensors for current, temperature and the light field can also be installed to determine water column properties. Major challenges in this area would be the development of more accurate wind and wawv sensors.

Autonomous systems capable of being installed on shelf and slopes can be utilized to obtain specific information related to biomass, water circulation, sediment transportation and other chemical properties. For these the sensor suites have to necessarily be robust to withstand long term deployment and must be miniature and power conscious. They can be programmed to record seasonal and long term data. In this class too, belongs the long-term acoustic moorings for tomography and thermometry. The data obtained from these systems can be recorded on high capacity hard drives stored on multiple popup buoys (Foden and Spencer, 1995). A 2.1 Gb capacity popup databuoy module, as shown in figure 8, has been developed and deployed for ATOC experiments.. A built in satellite link can transfer the data to desired location or the module may be recovered by surface vessels. This technique can be used for many long term submerged experiments including biomass estimation, acoustic tomography etc. Major constraint here would be the power source, and this would be a major challenge in this area.

Long -term Ocean Observatories (LEO) program is the first such program designed to acquire data on these aspects and installed off the coast of USA. (Andahazy et. al). These systems have the potential to fulfill the necessary regional scale requirements yet can integrate with futuristic global observation systems and platforms.

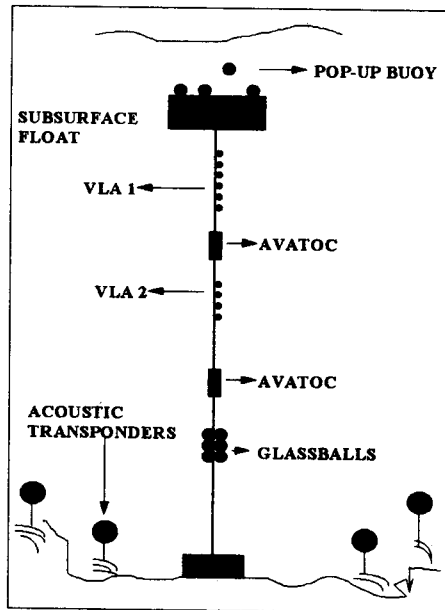


Fig. 8. Pop up buoy for data modules.
 (Modified from Worcester P F et al, 1997. Deep Ocean Data Recovery
 Module. Sea Technology, Vol 38, no 2).

Autonomous Lagrangian Circulation Explorer (ALACE) is a subsurface buoy which periodically rises to the surface and transmits data via ARGOS satellites. (Davis, 1996). During its submergence it measures time averaged absolute current velocity near 1000 meters for weeks. As every few weeks it ascends to the surface, it is being used to obtain data on temperature and salinity in upper ocean. This data will help in world climate modeling experiments. This and similar systems, developed and deployed, can probably notify oceanic events such as disasters and trigger quick reaction for safety measures. As mentioned earlier, new battery developments will have to support this.

ROSS-a remotely Operated Surface Skimmer is a platform under development at the National Institute of Oceanography. It is a simple surface driven device moving under radio control and capable of carrying sensors for sea truth validation. Satellites give large scale coverage while in-situ ship based data collection is a point measurement. A single pixel in the large field covered by a satellite measures several hundred square meters. The extrapolation of ship based point data to large satellite scanned areas result in errors. The ROSS would be capable of continuous measurement in areas of about few square kilometers during a station coincident with a satellite pass (Elgar Desa et. al, 1997).

Bio Sensors

Biosensors, built naturally, are highly sensitive as they are used by various sea creatures to detect the food or arrival of danger in form of other life forms. The electroreceptors of sharks or skates can be synthetically reproduced and placed in appropriate carriers. This then can detect the arrival of other biota / life form or possibly other processes such presence of dangerous pollutants and biologically toxic substances discharged by industries. It can also have military applications in detection of chemical warfare substances. Another example is the use of animal phosphors. In conjunction with lasers they may be employed in tagging of certain organisms for ecological and other type of studies (Andahazy and Cook).

These biosensors, especially the genetically altered ones, can significantly contribute to pollution monitoring aspects, for example, dumping of toxic wastes by coastal industries into estuaries. The fusing of lux or light emitting genes along with genetic regulatory elements into genetically modified *Escheria coli* cell made these cell to emit light in response to mercury or copper ions (Dubey et. al, 1993). This response can be used to quantify the presence of such toxic ions and probably be investigatively linked to the source. Further development in this field would lead to development of biosensor capable of detecting large number of such chemical and possibly biological contaminations.

Conclusions

We have mentioned what we foresee as the major challenges in areas of technology that will unfold in the decade ahead. The imperatives driving this demand will be important science aspects that have a bearing on our economy and our lives. It is obvious therefore that climate related programs must be given priority. For a country which is dependent on monsoon agriculture, it is important that application of satellite technology and development of appropriate algorithms and models for regions close to the country must be taken up. As climate variations may also lead to large fluctuations in sea level, such studies would have to be addressed at enhanced technological levels. These would have a direct bearing on the coastline of the country. Another area which could demand technological attention is the effect on fisheries, coastal zone processes and the management of coastal zone. Long term moorings, biosensors and satellite sensing would be the major tools that will be employed in this challenge. The years ahead are exciting for the promise and the challenges that they hold.

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