

3rd Prof. Satish Dhawan Lecture

**TOWARDS COASTAL OCEAN OBSERVING
AND
PREDICTION SYSTEM FOR INDIA**

By

Satish R. Shetye

Director

National Institute of Oceanography, Goa

December 20, 2004



Indian Meteorological Society
Ahmedabad Chapter

IMSA Thanks Dr. S. R. Shetye for 3rd Prof. Satish Dhawan Lecture...



About the Speaker...



Dr. Satish R. Shetye was born on 25 October, 1950, at Panaji in Goa. He received his M.Sc. in Physics from the Indian Institute of Technology, Bombay, and Ph.D. in Physical Oceanography from the University of Washington, Seattle, USA. Since 1982 he has been working at the National Institute of Oceanography, Dona Paula, Goa, and started serving as its Director earlier this year.

Dr. Shetye has worked on many aspects of physical oceanography of the waters around India, including tidal dynamics along the coast and in estuaries, coastal currents, large-scale circulation in the North Indian Ocean, mixed-layer dynamics, and ocean-monsoon coupling. His work is based on both observations and model studies. This experience in dealing with many different aspects of ocean sciences by using different tools, and the desire to make the scientific enterprise of the country relevant to its needs, have prompted Dr. Shetye to choose the topic of this lecture. It deals with the issue of putting together a system of observing platforms and models that will enable prediction of marine environment some days in advance.

Dr. Shetye's work has earned him a number of honours, including the Shanti Swarup Bhatnagar Prize (1992) and fellowships of all the three national science academies of the country. He serves on a number of national and international policy and planning bodies, and since 2001 has been serving as the Editor of the *Proceedings of the Indian Academy of Sciences (Earth and Planetary Sciences)*.



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1st Lecture : September 25, 2002
by Dr. K. Kasturirangan
Chairman, ISRO

2nd Lecture : November 07, 2003
by Dr. R. R Kelkar
Director General, IMD



TOWARDS A COASTAL OCEAN OBSERVING AND PREDICTION SYSTEM FOR INDIA

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1. Introductions

According to the Handbook on Fisheries Statistics of India for the year 2000, the total number of fishing crafts in the coastal states and union territories of India is over 280,000. These include traditional craft, motorized traditional craft, mechanized boats and other assorted craft used in fishing. There are close to 750,000 full-time and a similar number of part-time fishermen in India. Most of them live in well over 3500 fishing villages scattered along the 7,500 km coastline of the country. While the fishing skills of the fishermen are formidable, most take the physical state of the seas that they venture to every day as a part of the unpredictable Nature. They often use folklore to make predictions about the seas, but are not aware that such predictions are now in the realm of routine business of the establishment dedicated to the science and technology of the coastal marine environment.

While the fisher-folk form one end of the spectrum of “technology-savvyness” of those using the Indian coastal regime, at the other end of the spectrum are the explorers for oil and gas in the 2 million square kilometres of Indian Exclusive Economic Zone (EEZ). The Oil and Natural Gas Commission (ONGC) of India announced last year that it expects to spend in the





near future about 1.2 billion US dollars every year towards exploration to increase oil and gas production from deepwater fields. The exploration for oil uses high-technology and expensive offshore platforms, ships, and a myriad other systems. These often include environmental prediction and forecasting systems for the region of interest.

In between these two extremes of technology-savyness are those who use the coastal region of India for a number of purposes: transportation, dumping of industrial waste and sewage, laying telecommunication cables, operations related to activities of ports located along the Indian coast, recreational activities at the beaches along the coast, etc.

All those who venture out into the seas around India would benefit if there were a coastal environmental prediction system that would routinely provide forecasts on how it is going to be out there during the time they are at sea. In fact, plans have already been mooted to put such a forecasting system in place. I am going to focus today on the physical processes that such a system will need to address. The science behind these processes will need to be put in place, so that predictions in and for the coastal zone are based on firm, scientific foundations.

I chose this topic for the Third Prof. Satish Dhawan Lecture because one passion that Prof. Dhawan had was putting publicly funded science and technology in the service of the country and its people. He also loved experimental studies and enjoyed the science that underlies day-to-day natural phenomena: the only



monograph that he could find time to author was on bird flight. In this lecture, I am going to piece together a description of the way important variables (velocity, surface waves, tides, etc.) in our near-shore region behave, using data that have been collected in the past for a number of projects taken up at the National Institute of Oceanography (NIO), Goa. One of Prof. Dhawan's passions was bringing into public domain data collected by public institutions in India. I got a first-hand flavour of the passion that he brought to anything that he worked on while serving with him on a panel that was dedicated to public access to scientific data collected in India. In this tribute to that passion, I am going to piece together information on how one near-coastal regime of India behaves. I will also comment on aspects of this behaviour that we understand and on aspects that we don't. The intent here is to evolve a research agenda that makes reliable coastal ocean prediction the ultimate goal. The region I will examine is off Goa. With NIO located here, it has emerged as one of the best observed regions of the Indian coastal regime.

Let me start with an overview of the temporal and spatial scales of motion that occurs in the ocean. Figure 1 provides a pictorial summary. At the low end of both the scales are wind waves. Typically they have temporal and spatial scales of the order of seconds and meters respectively. Next come motions known as internal waves, whose lower temporal bound is determined by the local density stratification, i.e. by the Brunt-Vaisala frequency. The lower bound on these motions is of the order of hours. The next set of important temporal scales are approximately half a day and a day, corresponding to semi-diurnal and





diurnal forcing due to astronomical tides. These temporal scales are the most important in the shallow regime (depths ~ 10 m) along the Indian coast. The next important temporal scale is the inertial period, which is a function of latitude; off Goa the inertial period is about two and half days. The larger scales depicted in Figure 1 are due to the large-scale wind field. These scales form a broad spectrum with temporal scales ranging from days to weeks. The largest of this band of scales is associated with the seasonal monsoon winds and has a range from weeks

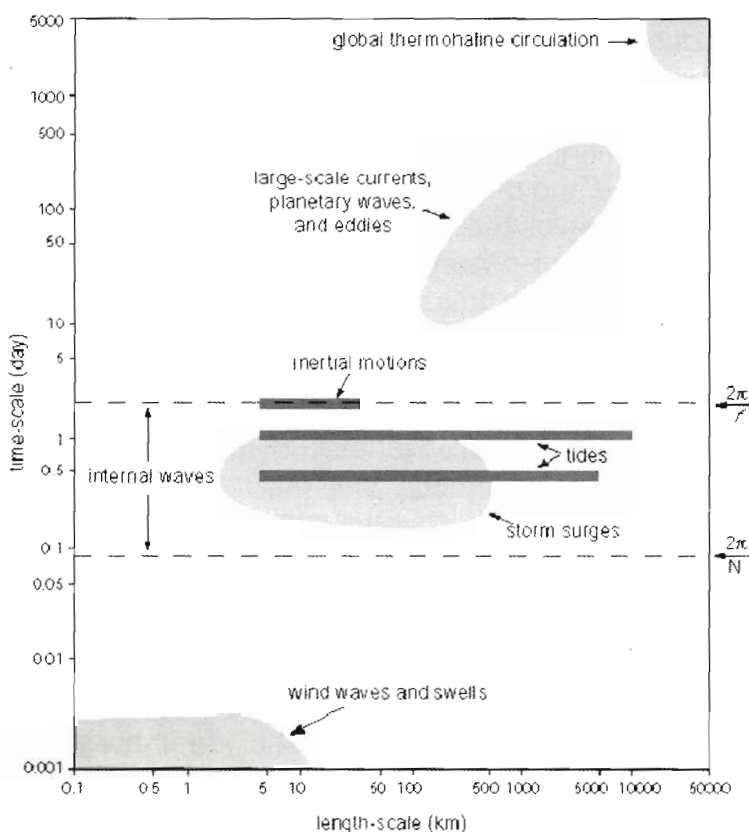


Figure 1: Important scales of motion in the seas around India

to months. The largest of the scales depicted in the figure refers to the global thermohaline circulation, often called the “conveyor-belt” circulation. We will not discuss such scales in this talk.



The scales most important to this talk are those associated with three types of motion: surface wind waves (small temporal and spatial waves), tides and tidal currents (temporal scale of half a day and a day), and coastal currents with periods ranging from a few days to weeks. The region from where these motions will be discussed is depicted in Figure 2. The

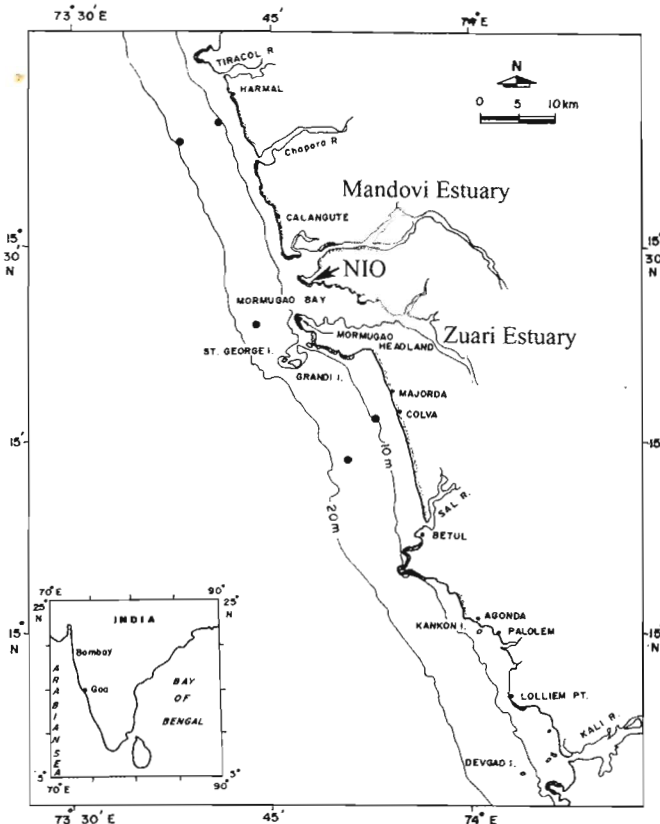


Figure 2: Location where observations were carried out.



discussion is based on the following observations. Wind waves were measured and their spectra computed once every three hours during June 1996 to May 1997 in 23 m deep water off Mormugao Bay. During this period, winds were measured (10-minute average of magnitude and direction) from the terrace of the NIO building. Coastal currents were recorded at five locations (shown with solid circles in Figure 2) for a month during March-April 2003. During the two months sea level was measured at five locations within the channel of the Mandovi Estuary and at six locations in the Zuari Estuary. The locations where the measurements were made stretched from the mouth of the two channels to the inshore distance up to which tidal influence is felt. Simultaneously, winds were measured from the terrace of the NIO building. Yet another set of measurements that will be discussed are currents measured at the shelf break during May 2001 to November 2003. I begin with the surface wave field.

2. Surface wave field

To anyone who is going out to sea for a few days for either pleasure or work, the most important question is the following: how rough is it going to be? The roughness depends on the kind of waves on the ocean surface. The waves are generated by winds blowing on the ocean surface. The most convenient form for representing them is the wind spectrum. Figure 3 gives two typical spectra that have been observed; the first on 8 July 1996 and the other on 4 April 1997 at 1500 hours. The winds that were measured from the NIO terrace during the period of wave measurements are shown in Figure 4. The abscissa in each of the



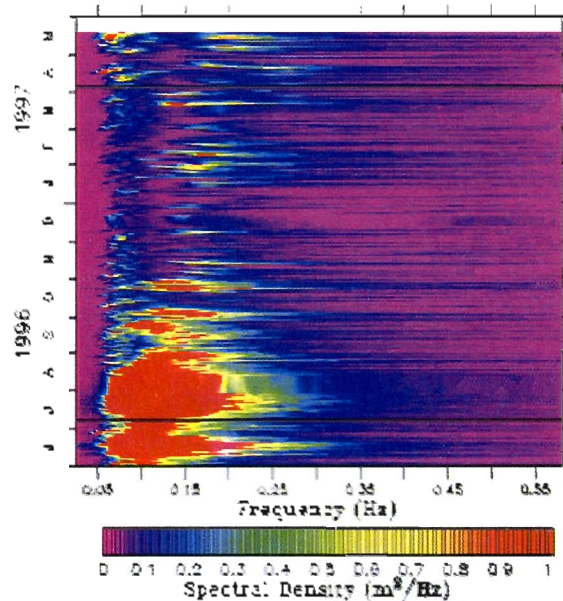
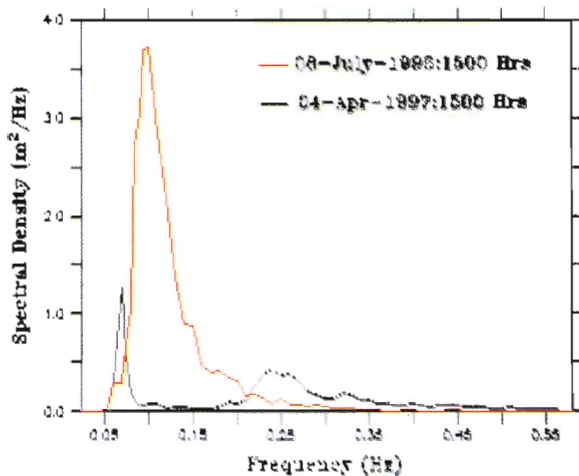


Figure 3: Spectra of wind waves of Goa.

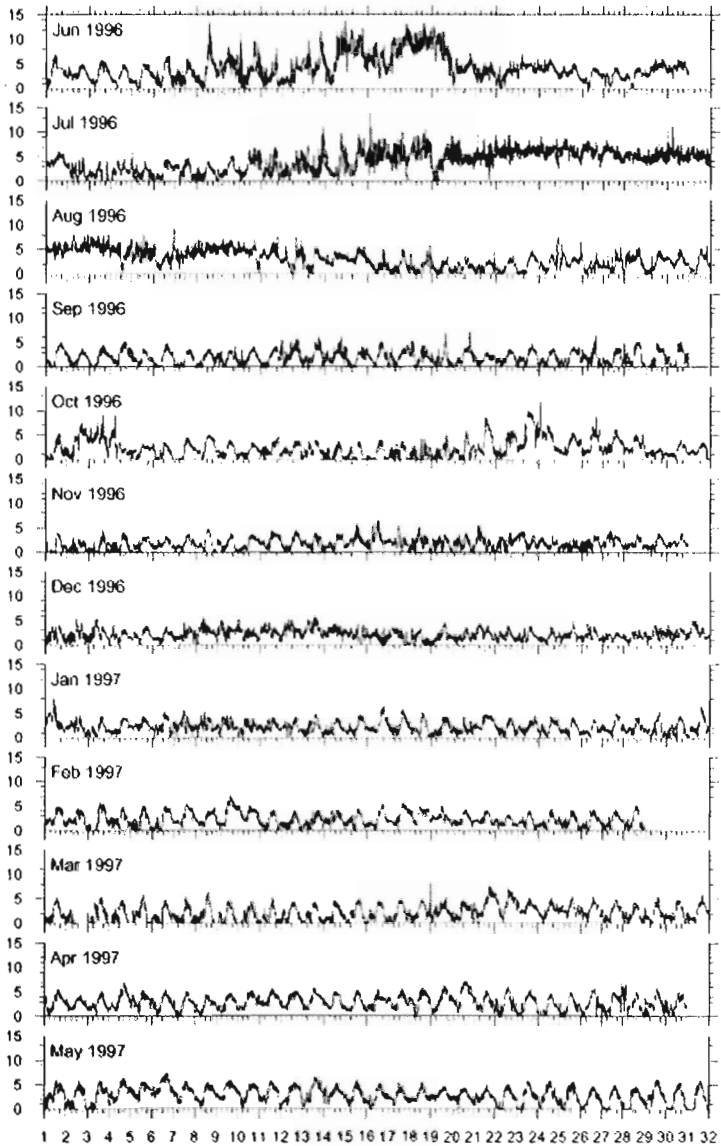


Figure 4: Wind speed (m/s) during June 1996 to May 1997 on the terrace of NIO, Goa

twelve panels in the figure covers one month. This figure brings out the kind of winds that blow over the coastal region off Goa. When the southwest monsoon is not active, the wind field is dominated by the diurnal cycle due to the sea breeze, a phenomenon common along the entire Indian coast. When the southwest monsoon is active, winds are much stronger and have no particular periodicity.



Figure 4 helps to understand the differences in the two spectra that are depicted in the upper panel of Figure 3. During the southwest monsoon, strong winds generate much more energetic waves than one seen during April 1997 when the local wind field was primarily due to the sea breeze. Another difference between the two spectra is that the July spectrum has a single peak whereas the April spectrum has two peaks. The difference seems to arise from the following: the spectrum during July seems to have been primarily due to waves that were generated elsewhere, perhaps far away, and have travelled to the location where the waves were measured. The low frequency part of the April spectrum is perhaps due to similar waves (often described as “swell”), whereas the high frequency part seems to be generated locally by the coastal sea breeze.



Notice that my explanation above is dotted with “perhaps” and “may be”. This is so because of a lacuna in the available literature. There is hardly any study that gives reliable observations and links the observed waves to the observed wind field over the north Indian Ocean. The literature does have reports on observations or results of model studies, but it is difficult to find a careful analysis that establishes a



causal link between the observed wave field and the wind field that might have caused it. Such an analysis must have both observations and model studies, and they must aim at answering questions like the following: are there typical regions where the swells seen along the coast of India get produced? If yes, how far and large are these region? We will need to address these issues as we progress towards a coastal ocean prediction system.

The lower panel in Figure 3 shows the evolution of the wind-wave spectrum (using colour for spectral energy) during a year. The figure shows how energetic the wave field is during the southwest monsoon in comparison to the rest of the year. We need data of this kind along other locations of the Indian coast. The observations then would provide the food for thought necessary to pose questions of the kind raised above. An observational database must emerge to describe what goes on in the Indian coastal region, and this must be followed by analysis to define why it goes on. Many such “whats” and “whys” would then pave a way to a reliable prediction system.



3. Tides and Tidal currents

One of the most visible manifestations of the dynamic nature of the ocean is the variation of sea level due to tides. Its importance is particularly noticeable in shallow waters near a coast because here the tidal influence generally dominates over other influences. The tides along the coast of Goa are mixed with both semi-diurnal and diurnal constituents contributing to the field. This can be appreciated from the variation of tidal elevation in the Mandovi during March-April 2003

(Figure 5). Tides and tidal currents are of particular interest in the estuaries of India. A large number of estuarine channels of varying sizes line the country's

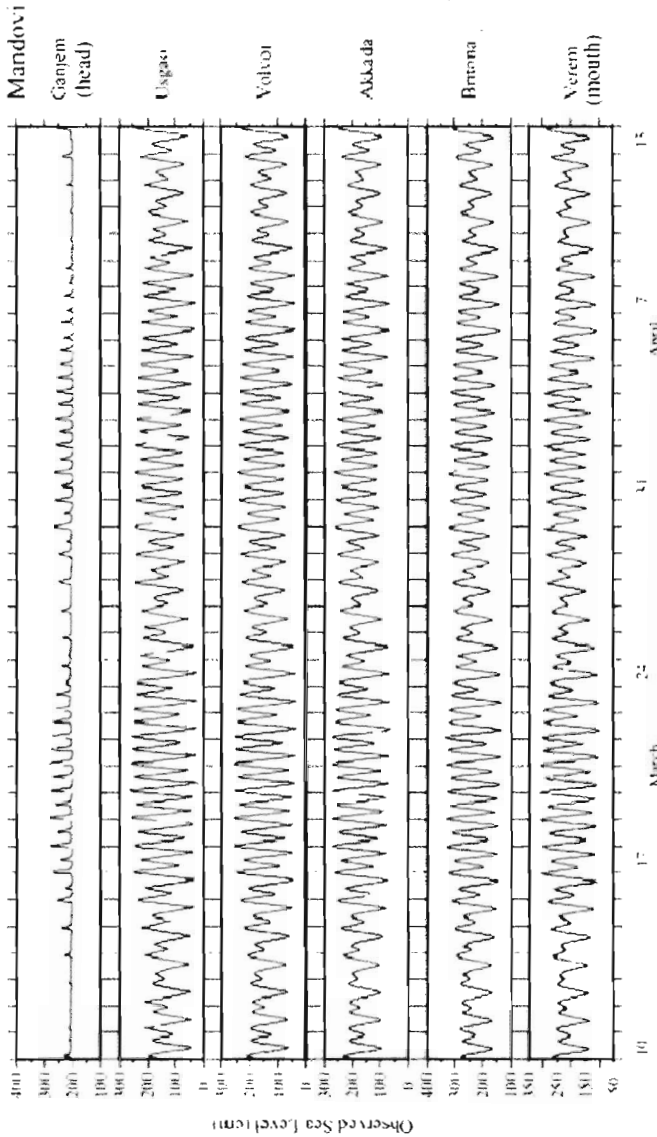


Figure 5: Sea level variation in the Mandovi during March-April 2003.





coast, and here the tide is the main forcing. The estuaries are used extensively for fishing, navigation, to dump domestic and industrial waste, and for recreation. Hence understanding their behaviour and developing means of predicting their state (is the water safe to swim in?) is important. I will examine the Mandovi estuary from two angles: variation in tidal amplitude and characteristics of vertical mixing. The former determines the distance from the mouth up to which tidal influence is felt in the estuarine channel, and the latter is important to appreciate the ability of the estuary to cleanse itself of pollutants dumped into it.

Analysis of observations shown in Figure 5 show that amplitudes of the major tidal constituents increase from mouth to head until increase in height of the channel bottom prevents the tide from progressing farther. The degree of amplification, however, differs from constituent to constituent. Each constituent of the tide in such a channel can be looked at as a wave that is forced at the mouth by the large-scale astronomical tide. The tide in the channel is a consequence of the propagating wave and a reflected wave generated within the channel. Both the incident and the reflected wave experience frictional decay, and undergo change because of variation in the cross-sectional area of the channel from mouth to head. Hence there are interesting dynamics in action. However, there are no estuaries along the coast of India where this sort of dynamics have been examined. One reason for this is, of course, a dearth data on how the tide varies within a channel for a period long enough to carry out a careful analysis (i.e. roughly a month). This has prevented posing of



questions related to the dynamics.

Let me now turn to another interesting aspect of our estuaries. Figure 6 shows observations that were carried out on vertical stratification in the Mandovi, first during the spring tide and then during the neap tide. It

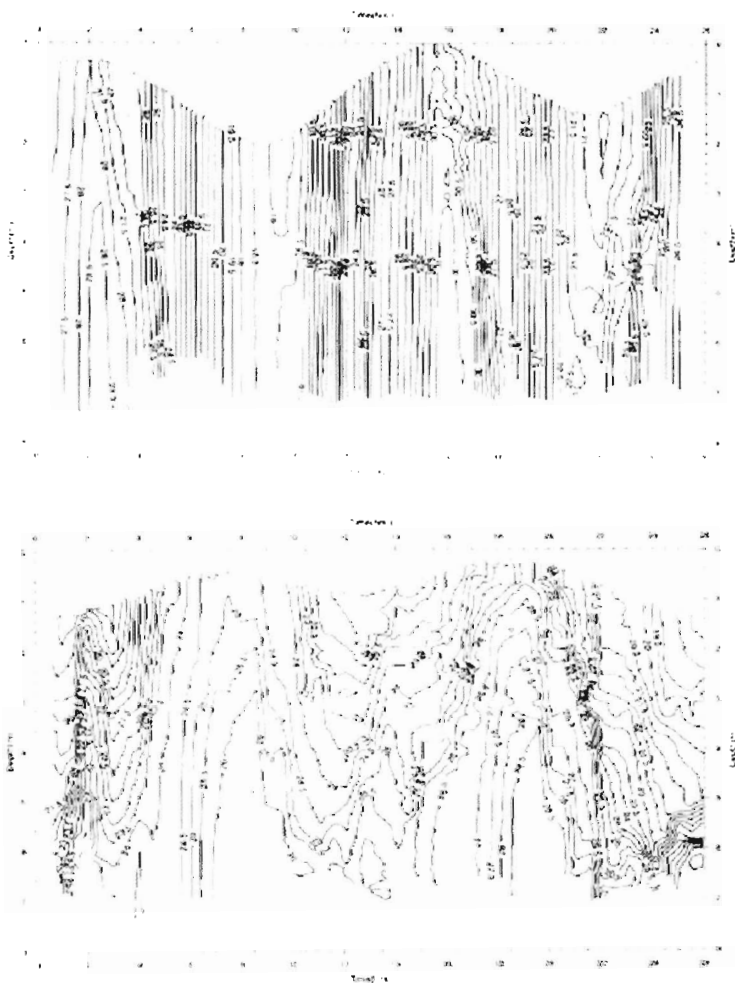


Figure 6: Salinity (ppt) at a location in Mandovi during spring (upper panel) and neap (lower panel) tides.



is very clear that the mixing in these estuaries is a function of the tide. The literature on Indian estuaries is completely silent on this issue, in spite of the fact that mixing characteristics determine the ability of the estuary to transport pollutants off to the sea. We need to carry out such observations and then model them.

A coastal prediction system needs to take the estuaries into account because their banks are often the most preferred locations for human settlement. Many of our major cities are located on the banks of estuaries. Hence our estuarine channels offer issues relevant to society, interesting dynamics, and considerable ease in setting up observing systems. In spite of these advantages, the estuaries remain little studied. The time is perhaps right to ask the question: *do we need a re-examination of our priorities?*

4. Sub-tidal motions

Since tidal motion has precisely defined frequencies, it is possible to remove accurately the tidal component from the observed current. This makes it possible to examine the variation that is not linked to tides. Let me now look at the kind of motion that occurs in near-coastal waters off Goa at frequencies lower than the tidal frequencies. Figure 7 summarizes the de-tided alongshore current in about 15 m of water off Mormugao. The current along the coast shows variations on temporal scales varying from days to weeks. Analysis to determine the correlation between de-tided currents, detided sea-level in the Mandovi and Zuari estuaries, and low frequency winds (low-pass filtered to remove diurnal variability to filter out the effect of the sea breeze) measured during March-



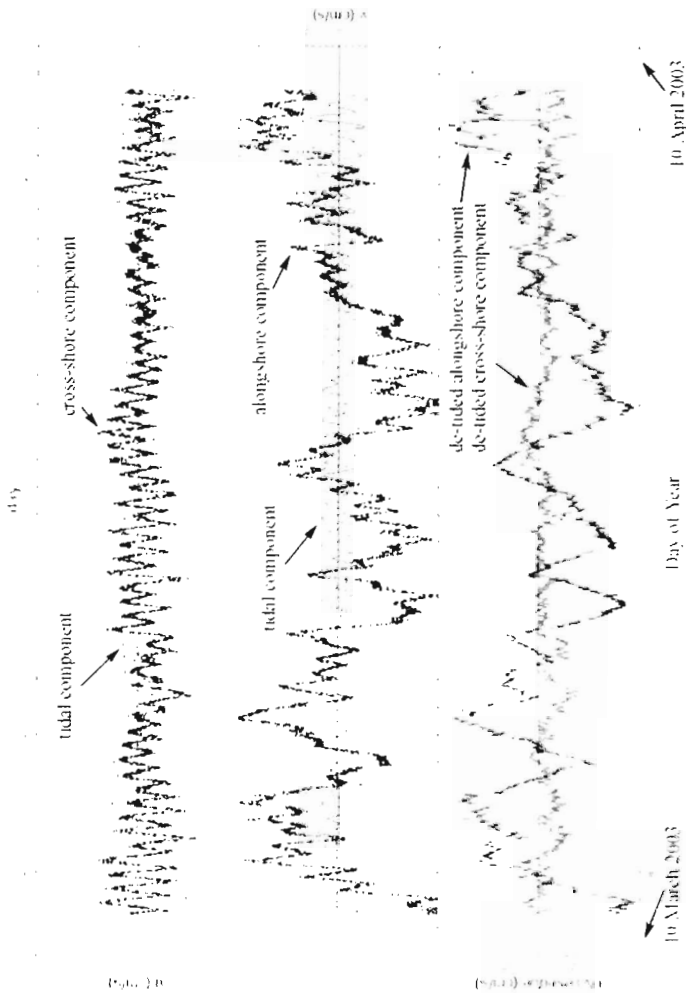


Figure 7: Current (cm/s) measured off Mormugao Bay.

April 2003 showed the following:

- (a) When the alongshore current is northward (southward), the sea level along the coast and in the Mandovi and Zuari estuaries rises (drops). This result is expected from large-scale oceanographic analysis, and implies that the alongshore current is in 'geostrophic balance'.





(b) Alongshore winds and alongshore currents are highly correlated. In essence, at the time when the observations were carried out, this coastal region was behaving like a typical “wind-driven eastern boundary current”. We know from other data that this is not always the case along the Indian west coast.

Let me conclude this talk with one more observed record of alongshore current (Figure 8). This shows

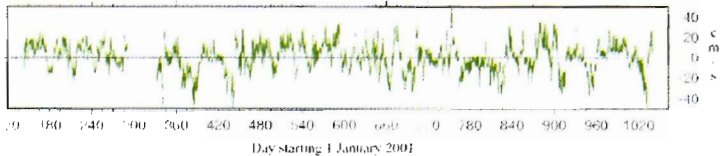


Figure 8: Alongshore current (cm/s) at the shelf-break during 22 May 2001 – 7 November 2003. 1 January 2001 corresponds to day 0.

near-bottom currents near the shelf-edge, where the depth is approximately 200 m. Most striking is the variability with periods ranging from days to weeks. A seasonal cycle is not particularly obvious in this almost two and-half-year record. It is expected that the variability arises because of the presence of similar variability in the winds. Hence, any prediction system that aims at simulating the sub-tidal currents in the coastal region must have a good predicted wind field available from atmospheric forecast models.

5. Epilogue

In this talk, I have shown observations that have been made on the shelf off Goa and in the estuaries in Goa.



These observations trigger research issues related to the dynamics of the region. We need to address these issues to gain an understanding of the Indian coastal regime. Such an understanding will help to put the country in a strong position to develop a coastal ocean prediction system. It is expected that such a prediction system has societal relevance because of the large number of citizens who venture out to sea every day and because of the large investment that is being made in the coastal region.



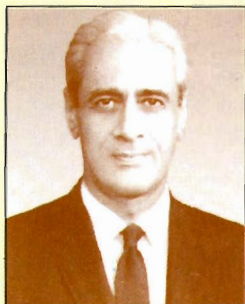
The goal of assembling a reliable prediction system will require a science plan with two essential components: observations and modelling. We need both components to make progress. The coastal ocean prediction system provides a goal that justifies a long-term project, which will give the country a programme that is relevant to society: publicly funded science for the good of the public.

It is this kind of science that Prof. Dhawan advocated. I believe he would have approved the project to set up a coastal ocean observing and prediction system because it may well bring some security to the close to a million fishermen who venture out to sea without any scope for pre-warning on what is out there. I also believe he would have approved because there is very interesting science there waiting to be studied.





Professor Dhawan -a Brilliant Scientist



Professor Dhawan was born on 25th September 1920 in a distinguished family. His father was a high-ranking civil servant of undivided India and retired as the resettlement Commissioner of Government of India at the time of partition.

Professor Dhawan graduated from the University of Punjab with an unusual combination of degrees: BA in Mathematics and Physics, MA in English Literature and a BE in Mechanical Engineering. In 1947 he obtained an MS in Aeronautical Engineering from the University of Minnesota, and moved to the California Institute of Technology, where he was awarded the Aeronautical Engineer's Degree in 1949 and a Ph.D. in Aeronautics and Mathematics in 1951 with Professor Hans W Liepmann as adviser.

Professor Dhawan joined the Indian Institute of Science in 1951 and became its director in 1962. He took over as chairman of space commission and chairman, Indian Space Research Organisation (ISRO), Secretary to the Government of India in the Department of Space in 1972.

The superb technology development organisation ISRO has now become has been professor Dhawan's loving creation. As an architect of space mission profile, he brought out the blue prints for the Indian National space programme, which gave out a stable of various launch vehicles (SLV, ASLV, PSLV and GSLV) and satellite series (IRS and INSAT) during the period 1980-1995. As chairman, ISRO, he guided ISRO in developing effective ways of accessing growth strategies for the future and monitoring the progress of the ongoing projects. His project management methods allowed work to be coordinated across different groups and work centers within ISRO, and even in industry and academic institutions. He developed a promotion and assessment system that had some unique features, enabling the more productive engineers to move ahead of their colleagues but not too rapidly, retaining the confidence of bulk of the staff in the fairness of the system. He directed the Indian Space Programme through a period of extra ordinary growth and spectacular achievement during his tenure. Various awards conferred on professor Satish Dhawan include Padmashri (1966), Padmabhushan (1971), Padmavibhushan (1981), Indira Gandhi Award for International Integration (1999)



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