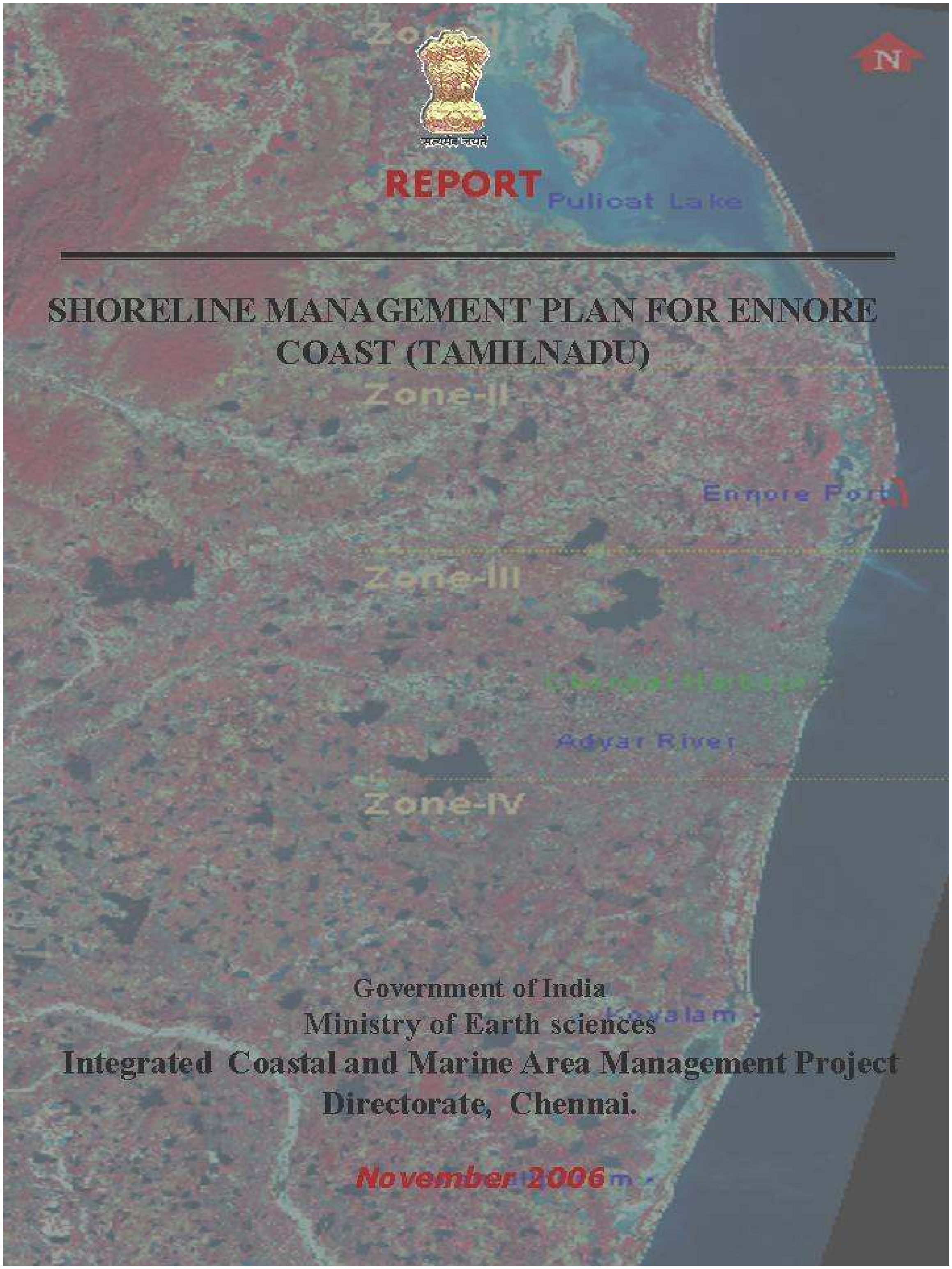

REPORT

SHORELINE MANAGEMENT PLAN FOR ENNORE COAST (TAMILNADU)

Government of India
Ministry of Earth sciences
Integrated Coastal and Marine Area Management Project Directorate, Chennai.

November 2006

EXECUTIVE SUMMARY

The coastline of Chennai with a hinterland of 20km offer a variety of environmental issues and problems, which need integrated management. These include the coastal erosion and accretion, pollution from human settlement and industries, loss of aesthetics in tourism beaches and declining fishery resources. The ICMAM Project Directorate undertook the task of analysing above problems and prepared integrated management solutions, which will help to solve these problems and also avoidance of occurrence of such problems in future.

It is well known that the shoreline along Chennai coast is subjected to oscillations due to natural and man made activities. After construction of Chennai port, coast north of port is eroded and 350 hectares land is lost into sea. The river Cooum that carries domestic sewage is closed due to accretion of sand south port. State Government resorted to short term measures for protecting coastal stretch of length 6 km at Royapuram with sea wall and the erosion problem shifted to further north. Now with the construction of Ennore port, 16 km North of Chennai port, another erosion problem was emerged and similar issues like Chennai port are on the way. If, no intervention is planned, threat to ecologically sensitive Pulicat Lake is inevitable. North Ennore Coast is already experiencing increased wave action and the naturally formed protection barriers, the “Ennore Shoals”, may likely to be disturbed by construction of Port. Baseline data reveal that the Ennore creek on south of Ennore port is experiencing increased siltation.

Since the available information on Ennore coast is not sufficient for working out suitable measures, a research project entitled “Shoreline management along Ennore” has been formulated to conduct detailed field and model investigations on various dynamical aspects (water level variations, currents & circulation, tides, waves, bathymetric variations, sediment transport, shoreline changes etc) of Ennore coast covering Ennore creek to Pulicat mouth. The objective of the project is to develop hindcast, nowcast and forecast models on shoreline changes in priority areas for identification of vulnerable areas of erosion/ accretion to arrive at remedial measures for protection of coastline from natural and human perturbations. The strategy proposed in the present study aims at obtaining a comprehensive picture on shoreline changes along Ennore coast and to take remedial measures for shoreline management along the stretch.

Coastal processes responsible for shoreline changes were monitored in 4 phases during the period 2004-2006. Field measurements on winds, waves, tides, currents, sediments, beach profiles, bathymetry etc were conducted at selected locations between Pulicat and Ennore creek. Seasonal variations on water levels, wave climate, currents and circulation, sediment transport, shoreline changes etc were studied. The measurements indicate that the tide propagates from south to north and variation of tide range along the coast is insignificant. Currents are seasonal, northerly during SW monsoon and southerly during NE monsoon. Wave climate indicate that 90% of the waves approach the coast from SE direction and the remaining 10% from NE direction. Sediment characteristics monitored at Ennore shoals indicate that the coarse sediment occupied along the offshore boundary of the shoal and finer sediments adjacent to the coastline. This aspect clearly demonstrates that the shoals while interacting with large waves, reduces the energy of the incoming waves which results in deposition of coarser sediment along the offshore boundary of the shoals. Finer fragments of the sediment are carried over the shoal by relatively low energy waves and deposit adjacent to the coastline. The simultaneous wave observations at shoals indicate the wave energy is attenuated when they travel over shoals and the adjacent coast is naturally protected by shoals. Beach profiles and shoreline positions were monitored for two years for the coastal stretch between Pulicat and Ennore creek. The observations at Pulicat indicated complete closure of bar mouth due to failure of monsoon in recent years. The immediate 1 km length of coastal stretch abutting south breakwater (updrift coast) accreted at a rate of 45 m per year, a 300 m wide beach formed at south breakwater. The zone of accretion extended south upto 2.6 km that eventually lead to rapid silting of Ennore Creek used to draw cooling water by power plants mentioned earlier. North of Port, the coastline (beach fill area) eroded at 50 m per year upto 1 km from the north breakwater and showed accretion thereafter due to material originating from the fill region. After 2003, the coastline beyond nourishment area (3 km) near Kattupalli village underwent readjustment that resulted in moderate erosion of the order of 50 m.

Keeping in view of processes identified from filed investigations, model investigations on hydrodynamical aspects, nearshore wave transformation processes, sediment transport pattern and shoreline changes have been carried out. The models are calibrated with the field data collected during the four phases of project work. By integrating the results of field and model investigations, the sediment budget for Ennore coast was estimated. The existing sediment transport rates of the coast were also determined. The areas prone to erosion and deposition (hot spots) have been identified. Possible interventions for protection of Erosional hot spot located just immediate 1.5 km north of Ennore port were tested for preparation of shoreline management plan.

Earlier, by anticipating erosion on north coast, the Ennore port authorities have adopted the soft shore protection measure the “beachfill”, over a length of 4 km and width 500 m. The present study indicated that the measure taken by port authorities worked well. Modelling studies indicate that beach fill with a length of 1000 m plus transitional length of 800m and width 600 m, resulted in increase in the life of the project by one more year.

As a part of the study, the functional performance of the hard protection measures like groins were tested through model simulations. Adoption of these options helps to prevent erosion along the stretch under consideration, but the erosion problem may likely to be shifted further north as there is no adequate sediment supply available to north of Ennore Port due to trapping of sediments in the entrance channel.

Finally, the submerged reefs with sand bypassing seems to be a good option for protection of Ennore coast since it not only reduced the wave energy but also provides wave rotation which reduces convergence of energy on lee side of the reef. There may not be a problem of shifting in erosion zone, that too, the option is more environmental friendly. The present study recommends fabrication of submerged reefs with periodical renewal as a long term solution to deal with the present and future problem of erosion on north of Ennore coast. It is also strongly suggested that immediate initiation of such remedial measures will help in non-repentance of delayed response leading to large loss of land as occurred along the Royapuram coast of Chennai. The detailed structural design of finalized option needs to be taken up, as it is not included under the present scope of study.

Acknowledgements

We are thankful to the support extended by Ennore Port Authorities in terms of utilizing their facilities for operation of survey vessels and the Public Works Department, chennai for providing crest of berm data for the present work.

Contents

1. INTRODUCTION

Environmentally friendly solutions that are compatible with ever-changing needs of the society are major challenges in coastal zone management today. Political, social and technical issues must be considered, and possible solutions must balance the likely positive and negative impacts. For centuries, the coastline has been a focus for a variety of activities including industry, agriculture, recreation and fisheries. These national economic assets have been developed and flourished despite constant changes in the physical characteristics of the coast. The coastline is a national heritage and in order to sustain it for future generations, proper management of coastal zone is essential. 'Coastal defence' means protecting the coastline from erosion by the sea and defending low lying ground from flooding by the sea.

Traditionally, coast and flood protection works have been implemented in a piecemeal fashion, either in response to a recognized threat to an existing village or town, or as part of a new development scheme. The authorities responsible for coastal defence and flood protection tend to look at the issue within their own boundaries. The measures taken in response to a problem, sometimes lead, often unintentionally, to adverse effects on both adjoining and distant stretches of coastline.

Therefore, there is need for a well-defined plan that seek to treat the shoreline and the defence requirements in a more integrated, sustainable and strategic manner. This can be achieved by Shoreline Management Plan (SMP), which considers the issues at a reasonable scale. The policy adopted should ensure adequate protection against flooding and erosion in a manner that is technically, environmentally and economically acceptable, both at the time any associated measures are implemented, and in the future.

For preparation of SMP, the boundaries of the region have to be identified properly to avoid adverse impacts, arising from the interventions planned as a part of the Plan. The processes along the shoreline vary spatially and temporarily. The inputs and outputs of the region have to be assessed carefully depending on underlying processes. There are few questions which still need to be answered by scientific experiments. They are

i) The coastal stretch considered is dominated by onshore - offshore transport or along shore transport

ii) The magnitude of the sediment transport in onshore, offshore and along shore

iii) The modification of sediment pathways along the coastal stretch resulting from man made interventions. These include construction of dams on upstream of the river, major harbour installation along the coast, sand mining etc.

1.1 Coastal Protection Measures - Experiences from other countries

The mitigation measures implemented along the coastal areas in Europe and USA clearly indicate that the functional performance of the measures could not be met due to lack of understanding of underlying of coastal processes, as it requires continuous monitoring of various parameters (tides, waves, currents, sediment transport etc.). The key environmental and structural parameters governing shoreline response to structures are yet to be elucidated. Before engineering design guidelines can be developed for coastal protection structures, a fundamental research challenge is to establish the mechanisms that cause erosion or accretion in their lee or adjacent to the structure. The experiences from the few cases where structures (Groins, Offshore breakwater) built for the coastal protection are briefed below:

The groins are built to stabilize a beach, where erosion is generated by a net longshore loss of sand. Groins are most effective where the longshore transport has a strong predominant direction and where this action will not create unacceptable downdrift erosion **(USACE, 2001**). A well-designed groin field will fill and allow natural sand bypassing at nearly pre-groin conditions, thus reducing downdrift erosion. Nonetheless, groin projects have met with varied success in part because of vague definitions of functional design criteria (**CERC, 1984**). With few exceptions, functional design criteria are defined in relative terms. Furthermore, earlier design practices were limited because ascertaining proper functional design was usually an exercise in trial-and-error. However, recent advances in numerical computer simulation can be used to approximate performance and shoreline behaviour in response to discrete groin design characteristics (**USACE, 1995**), for which information on coastal processes and shoreline changes is required.

Functional design criteria refer to those critical design factors that must be considered in order for a groin system to offer an acceptable solution to a discrete erosion problem; yet not instigate accelerated erosion along adjacent beaches (**USACE, 1995).** According to **BALSILLIE and BERG, (1972)** there are three groin design considerations; i) littoral processes (wind and wave data, beach slope, sediment type etc.); ii) functional design criteria (length, height, spacing etc.); and iii) structural design criteria (material types, construction procedures etc.). Among the three design considerations, the first part was addressed completely as part of this project and second aspect which deals with dimensions of the structure was partially dealt. Structural design was not addressed in the present scope of the project.

Shoreline response to the structures along different parts of the world was reviewed by **Turner (1994)** in terms of its functional performance. Six such cases were reviewed based on the field monitoring studies conducted at respective places. The objective of this review is to assess the critical parameters for design of coastal structures. Of the reported parameters of breakwater length, crest submergence level, crest width, nearshore slope, littoral drift rates, and the presence or absence of concurrent sand nourishment, none appears to be critical in governing shoreline response characteristics of submerged breakwaters. It may be specific combinations of these parameters that are important, but it is reported that additional design and environmental factors must be considered.

1.2 Status of coastal protection measures along the Chennai and its relevance to study area

Sediment inputs to the Ennore coast depends on the geomorphology of the coast and man-made interventions made on adjacent coast. The status of coast, south of Ennore creek to Adayar river (**Fig. 1.1)** was studied for shoreline changes. The 11 km in length of the coast extending from fishing harbour to Ennore creek is under enormous stress due to an increased industrial growth combined with harbour facilities, resulted changes in coastal dynamics. The rate of sediment transport (**Chandramohan et al. 1990**) is towards the north from March to October and towards the south from November to February. The net drift towards north is in the order of 0.3×10^6 m^3 per year. Ever since the Chennai harbour was constructed, the coast north of the harbour has been experiencing erosion at the rate of about 8 meters per year. It is estimated that 500 meters of beach has been lost between 1876 and 1975 and another 200 meters between 1978 and 1995. History reveals that in the year 1876 a jetty projecting into the sea was constructed at Chennai for unloading of the cargo. Later, breakwaters were constructed on either side of the jetty (with the harbour entrance located on the eastern side), to protect the facility from wave disturbance, without realizing the effect of east entrance on tranquility in the harbour basin. Subsequently, the entrance to the harbour was shifted to the north and the harbour expanded further parallel to the coast for operational reasons. Schematic diagram (**Fig. 1.1**) shows the present day configuration of the Chennai port and the growth of the beach on the southern side over the years. Marina Beach has been formed as a result of arresting the littoral drift by the breakwater. The north Chennai coast, extending from the fisheries harbour is fragile and is very sensitive for change in the environmental conditions. One of the main reasons for this delicate response of the coastal stretch is the disruption in sediment supply induced by the Chennai port causing extensive erosion over the years. This has been aggravated by the rough sea conditions during the northeast monsoon. Wave overtopping and undermining of the coast due to unprecedented wave actually has caused substantial damage to the coastal region.

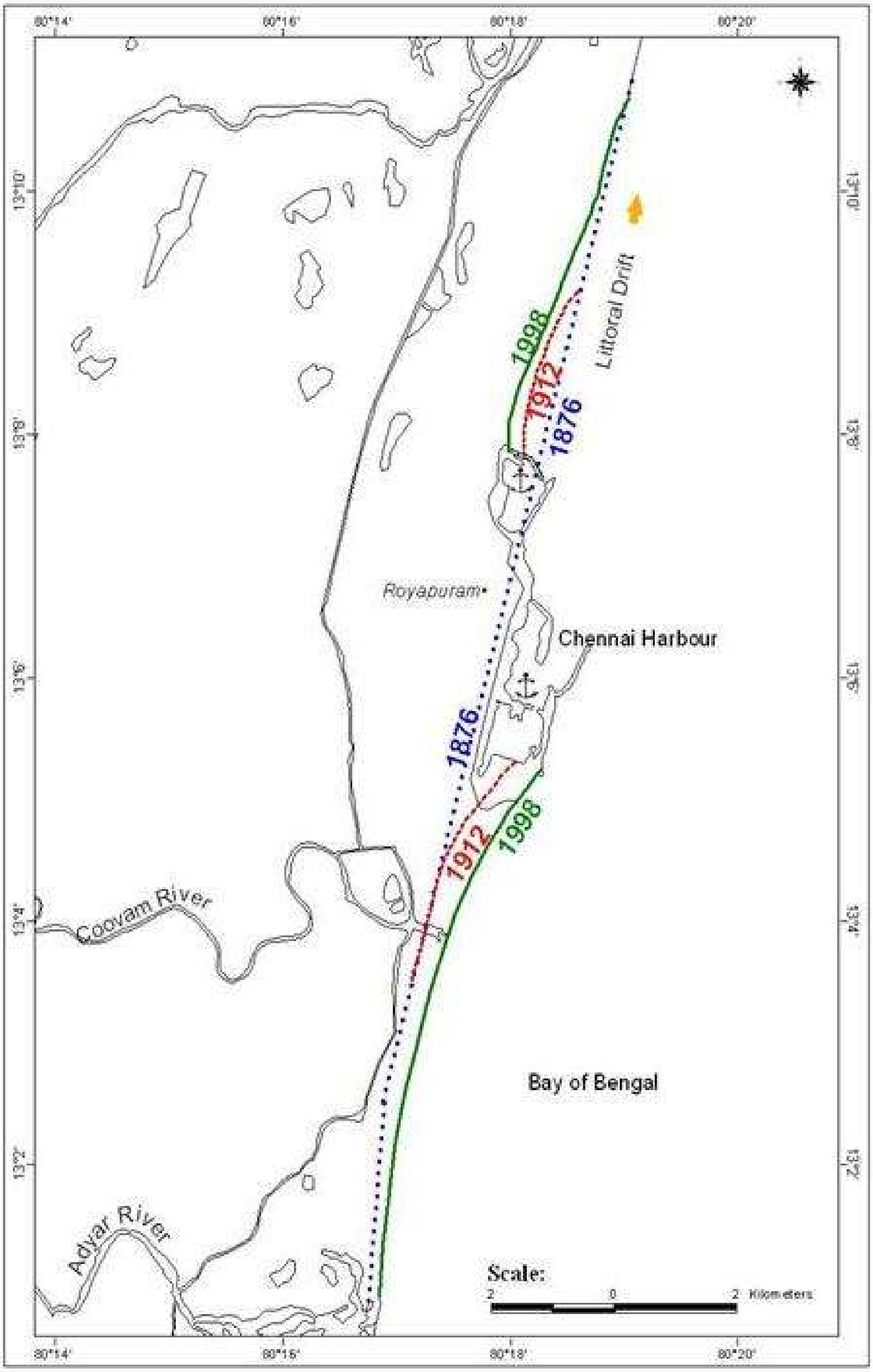

Fig. 1.1 - Present day configuration of Chennai coast

The consequences of the construction of Chennai port and Fishing harbour on the North Chennai coast are detailed below.

The shoreline has recessed by about 1000 m with respect to the original shoreline in 1876. The villages, hutment and the Royapuram-Ennore express highway connecting the Manali Refineries and Thermal Power Station to Chennai are subjected to sea erosion during both Southwest and Northeast monsoons every year. The erosion in the coast which became very pronounced, affected the coastline up to the 13/150 KM stone near Bharathi Nagar and necessitated constant attention and protective works in response to the cry of the fishermen living in this stretch.

In order to protect the coastline, the State authorities resorted to construction of short-term protective structures. They have recommended the use of sand dredged at Chennai port to nourish North Chennai-Royapuram as a long-term measure and construction of Rubble Mound Stone wall and groins as short-term measures. Part of this protected coastal stretch experiences undermining of the seabed due to large-scale wave action. The erosion along this coast has reached an alarming stage requiring immediate attention (**Kalisundram et. al, 1991**). It is estimated that an area of 260 hectares of land was lost between the years 1893 and 1955 and that an area of about 30 hectares was destroyed by the wave action between the years 1980 and 1989. Overall loss between the period 1893 and 1989 is estimated to be of the order of 350 hectares. The cost of land alone, lost to the sea, is of the order of approx. Rs.200 crore (US $40 million). During and after 1990 this stretch of coastline was threatened by severe waves and the authorities resorted to new techniques involving erection of concrete pipes to protect the shoreline. However, this did not provide much of remedy and about 50m wide beach must have been lost after 1990. Devastating effects due to the wave overtopping and severe erosion led to the destruction of the coastal highway and compulsory rehabilitation of fishermen (about 200 families) to safer places. The shoreline receded by about 100 m between 1978 and 1995.

Though the short-term measures taken up by authorities gave temporary solution to the villages in protected areas, the problem is not resolved completely. Due to the construction of stone wall (**Fig. 1.2**), the natural beach available is lost and the downdrift villages, north of protected areas started experiencing erosion. The village Chinnakuppam near Ennore fly ash outfall is experiencing severe erosion.

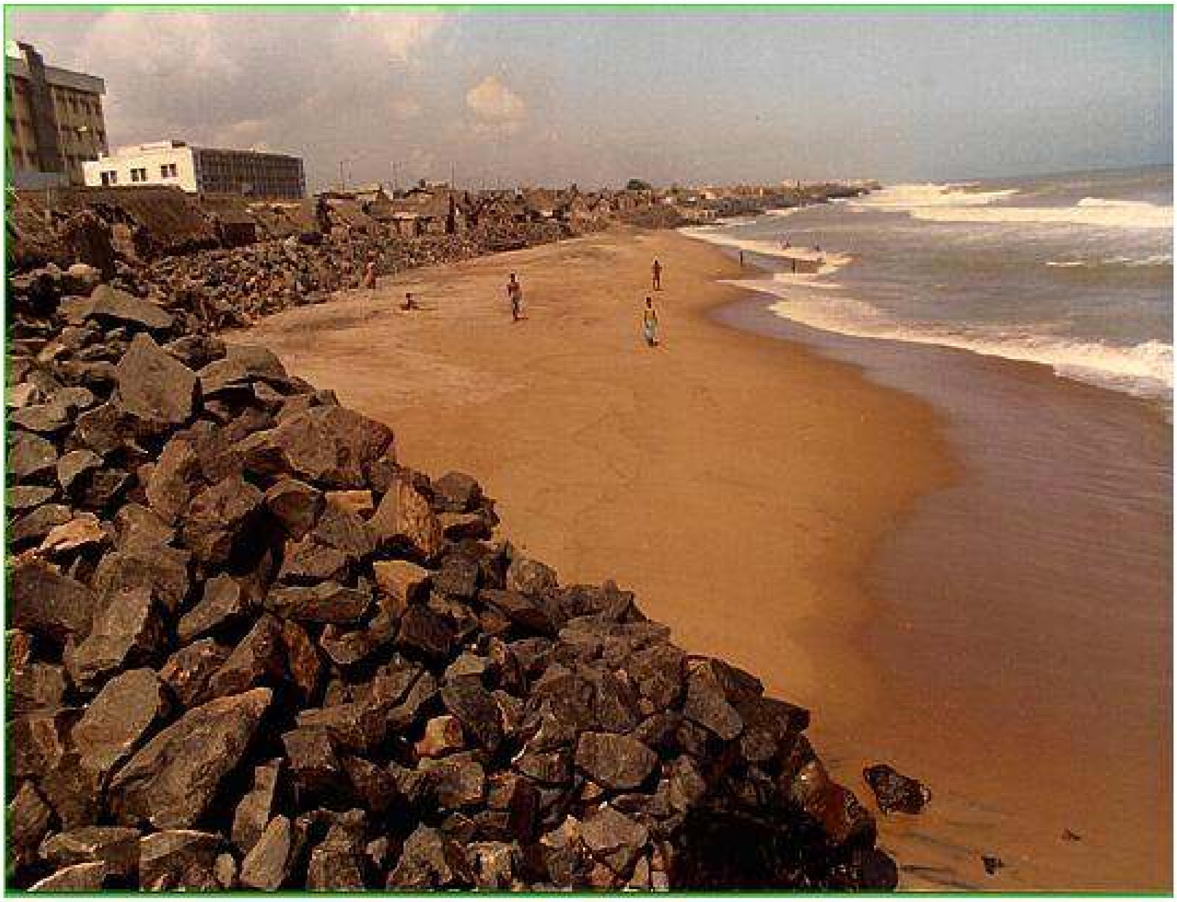

Fig. 1.2 - Sea wall along Rayapuram Highway

The figures of dredging quantities provided by the Dredging Corporation of India indicate a variation between 0.27 million m^3 and 1.10 m^3. It has been reported that the annual maintenance dredging at Chennai port is in the order of 0.5 million m^3. This dredged material is being dumped to the east of harbour, as dredgers are unable to reach nearer to the shore due to shallow draft.

The short-term protection to the coastline by dumping stones is found to be ineffective for the reasons that (i) the nearshore coastal processes in the region are not clearly understood, (ii) inadequate funds usually restrict the required quantity of rubble for the protection and maintenance, which make remedial measures as ineffective and (iii) lack of continuous monitoring (**Mani, J.S 2001**).

The above case, clearly stressed the need for a shoreline comprehensive plan to manage the multiple resources and uses of shorelines in a manner that is consistent with requirement and purposes and addresses the needs of the public. The management plan should ensure a balance that supports local economic interest, protect environmental resources and allows the public to enjoy those resources and all these are vital for the long-term success of a Shoreline Management Plan (SMP**)**.

Similarly, due to the newly emerged Ennore satellite port, the north coast near Kattupalli village is under severe erosion and the Ennore creek located 2.6 km south of port is experiencing siltation. Ennore creek carries industrial effluents generated from adjoining land based activities. The decreased flushing characteristics due to siltation leads to degradation of water quality and causing major environmental problems and the Enore coast has become a hot spot in relation to coastal zone management.

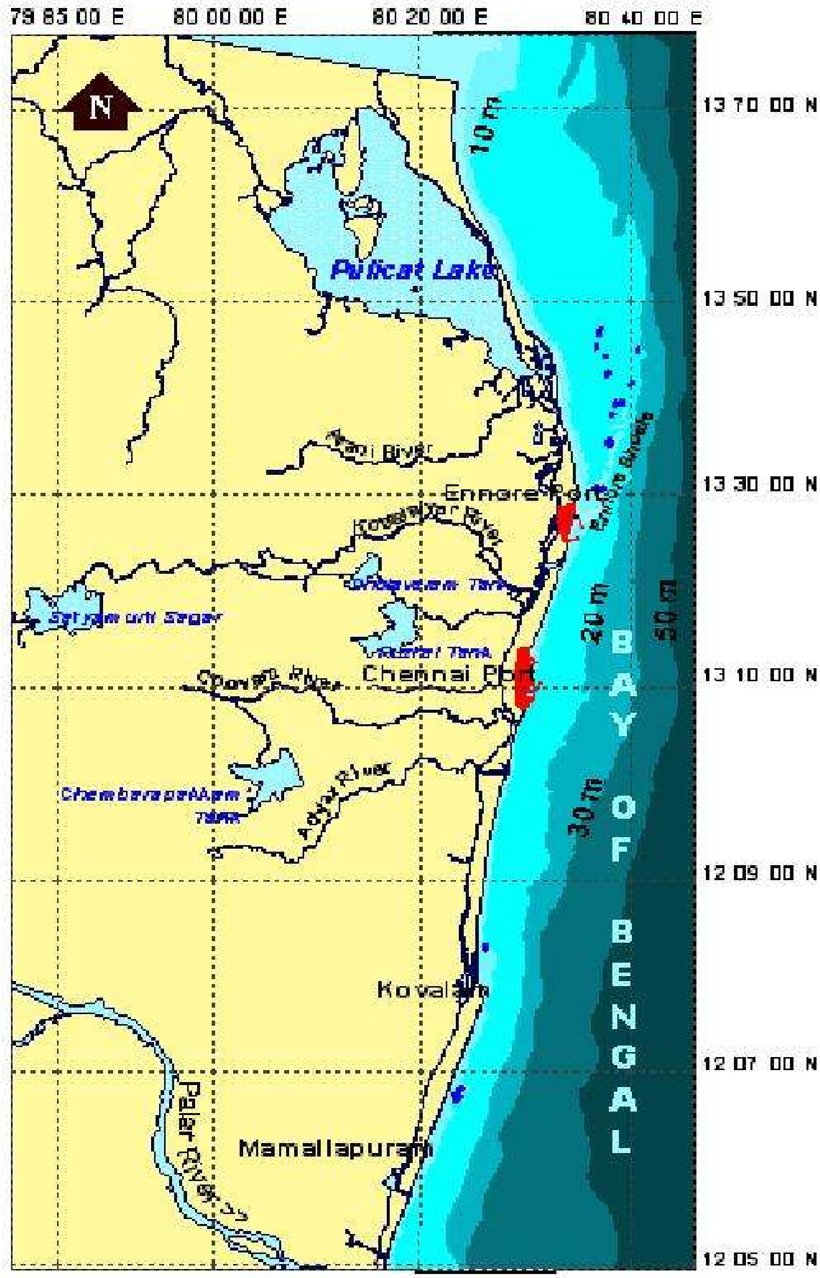

Fig. 1.3 – Chennai – Ennore coast

1.3 Brief Description of the project

The critical analysis of issues related to shoreline management along the chennai coast reveals that the impacts are due to natural aspects, e.g. change in wave climate, failure of monsoon and sediment depletion and man made activities viz., development of ports, coastal structures and activities at upstream of estuaries. Measures attempted to protect the coast from erosion and free from siltation could not give fruitful solutions due to lack of understanding of coastal processes. Creation of another (Ennore) port in a region that is already highly sensitive to sediment transport is bound to lead to further complexities in terms of coastal erosion and/or accretion. At present, the southern coast of Ennore is witnessing accretion (attributable to breakwater) and, a tidal creek some 2.6 km away is silting up rapidly causing concern to nearby Power Plants drawing cooling water from it. Artificial beach nourishment (to prevent downdrift erosion) was therefore taken up in the year 2000 by placing $3.5x10^6$ m^3 of sand dredged from the harbour basin and the approach channel through capital dredging. Under these circumstances, a careful assessment of shore protection measures for optimum performance and likely cross impacts on adjacent coast would appear essential for any judicious implementation of coastal zone management practices.

The coastal stretch considered for the study (**Fig 1.3**) is located in north Chennai coast and is highly sensitive to the sediment transport. Ennore Port, constructed 16 km North of Chennai port would also result in similar issues like Chennai port. If, no intervention is planned, threat to ecologically sensitive Pulicat Lake is inevitable. North Chennai Coast is already experiencing increased wave action and the naturally formed protection barriers " Ennore Shoals" may likely to be disturbed by construction of the Port. In view of this a research project entitled "Shoreline management plan for Ennore coast" was formulated for a detailed study on various coastal dynamical aspects. The objective of the project is to develop hindcast, nowcast and forecast models on shoreline changes in priority areas for identification of vulnerable areas of erosion/ accretion and to predict changes in the future to develop appropriate remedial measures for protection of coastline from natural and human perturbations.

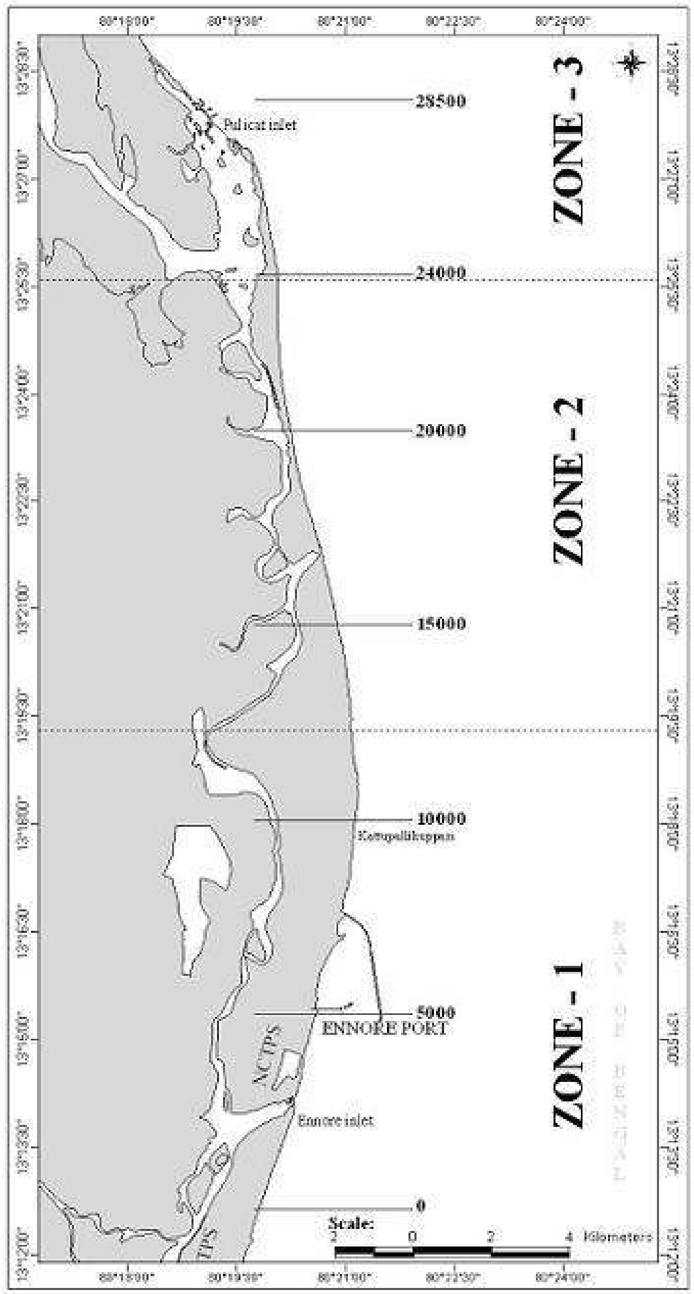

Fig. 1.4 – Study area and station locations

The study area comprises mainly 3 zones i.e. a) zone **I** – the 5km coastal stretch each on North and South side of Ennore port including Ennore creek (**Fig 1.4**). b) Zone **II** – the coastal stretch in between North Kattupalli and south Pulicat mouth which occupies mostly sand dunes and c) Zone **III** – the 2km coastal stretch on North and South of Pulicat mouth which occupies a narrow channel opening into the sea . The study area extends from shoreline to 25m depth contour.

1.4. Objectives

- To identify the areas which are vulnerable to erosion/ accretion due to shoreline changes caused by construction of Ennore port through field studies
- Identification of dominant forcing functions and evaluation of earlier preventive measures.
- To develop hindcast and forecast models for prediction of shoreline changes using the primary data
- Validate Numerical Models for field conditions to address issues in Nearshore - Erosion & Siltation at Inlet
- To prepare a shoreline management plan suggesting measures for protection of the coast from erosion / accretion

1.5. Project components/tasks

The study involved both field and model investigations. Major project components are

- Assessment of present status and detect shoreline changes at Ennore port by using past data
- Identification of vulnerable areas for erosion/ accretion
- Monitoring of processes responsible for shoreline changes such as waves, tides, currents, sediment characteristics, beach profiles and morphology, etc.
- Monitoring of Ennore shoals and its role in protection of North Chennai coast
- Development of Impact models and prediction of future changes using MIKE 21 & LITPACK models
- Integration of results for mapping of vulnerable areas for erosion/accretion through GIS
- Recommendations of Interventions like sand bypassing/ groins/ offshore breakwater/ submerged reefs for protecting the coast from erosion/accretion

The monitoring scheme for understanding the processes responsible for shoreline changes covers two seasons i.e. NE monsoon (Phase I & III periods) and SW monsoon (Phase II period) and measurements were made at 7 stations (**Fig 1.5**) that include measurements of

- Tides/water levels at 7 stations (D1 to D7) by deploying tide gauges in coastal waters and harbour

- Current meter recording at 6 stations (D1 to D7 except at D4) - 3 in mooring and 3 from boat
- Wave measurements at 7 locations by pressure gauge and 6 months from NDBP Buoy
- Littoral Environmental Observations (LEO) between Ennore and Pulicat (2 seasons)
- Measurement of current profiles along 3 transects using ADCP, ADP and ADV
- Weather data recording at Ennore Port by installing weather station
- Random water and sediment sampling at 34 stations (sts R1 to R34) for 3 phases
- Beach sediment sampling at upper and lower foreshore along the transects T1 to T7 (2 phases - NE and SW)
- Beach profile and bathymetric profile across the shore along each transects T1 to T7 (2 phases - NE and SW)
- Shoreline mapping between Ennore and Pulicat (quarterly during study period and annually from 1999)
- Bathymetry for the year 2000 & 2005 (20 km coast)

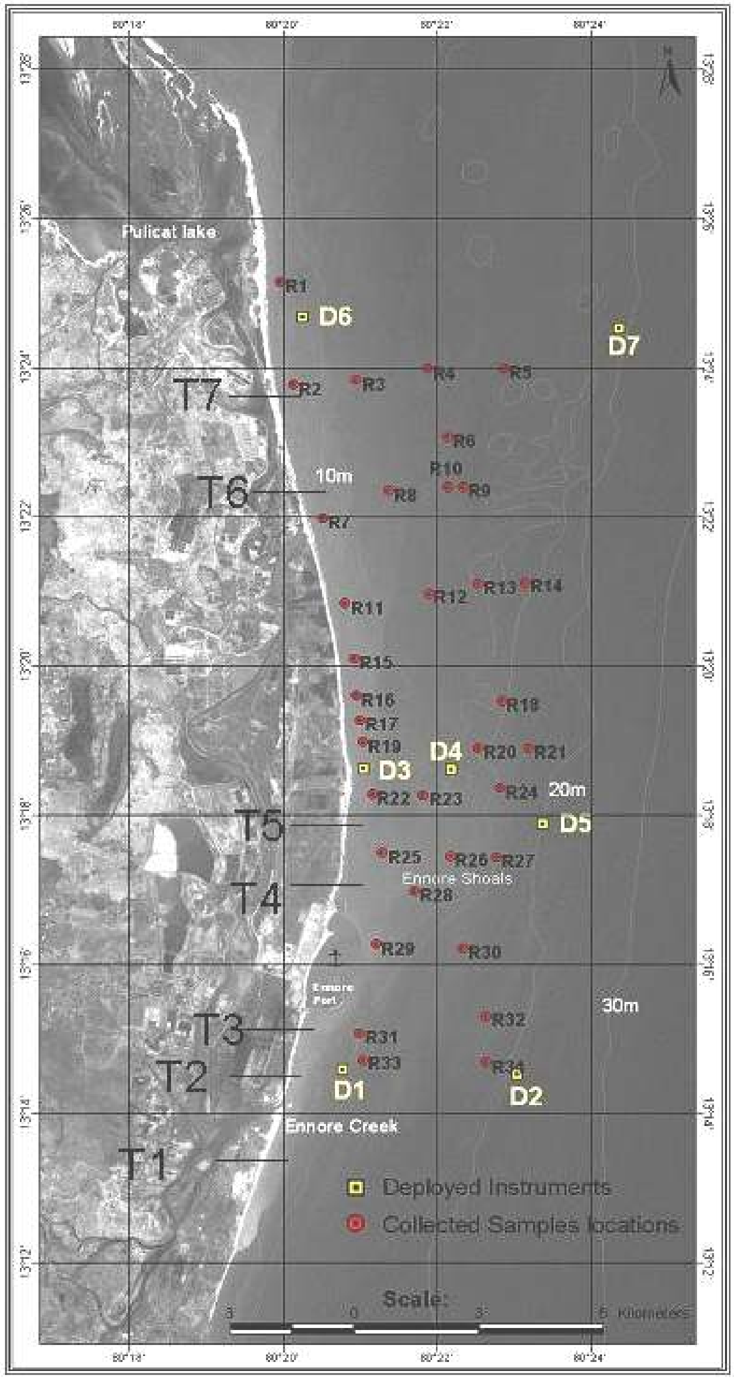

Fig. 1.5 – Study area with zones

1.6. Participating Institutions and their responsibilities

ICMAM Project Directorate	Responsibilities
Shri M. V. Ramana Murthy, Sci.E	Co-ordination of project activities, project design; Organizing field campaigns and collection of field data on hydrodynamics; Periodical review of field data and models and preparation of Shoreline Management Plan
Dr V. Ranga Rao, Sci.D	Organizing field campaigns, beach profile survey, analysis, first level modeling and preparation of report
Dr.Manjunath Bhat, RA	Deployment/ retrieval of field equipment, bathymetry & ADCP survey, analysis of data, shoreline change modeling
Edwin Rajan, T.A	Setting and operation of Instruments, deployment and bathymetry survey
Y.Pary Vallal, SRF	All GIS work related to mapping of shoreline changes, bathymetry & ADCP survey
M.Padmanabham, JRF	Analysis of tide, current and ADP data
Dr. B.R. Subramanian, Sci,G and Advisor (Project Director)	Overall in-charge of the project, Project conception, review of draft Shoreline Management Plan

NIOT	Responsibilities
Dr Rajat Roy Chaduary, Sci. F	Overall logistic and administrative support for project activities
Dr B.K.Jena, Sci. D	Support in organizing field data collection, timely support for logistics and deployment
Mr.Jaiprakash, T.A	Assistance in deployment and survey

1.7. Present report

The present report deals with the entire work carried out (**Table 1.1**) during the four phases i.e. Phase I (Nov/Dec 2004), Phase II (Apr/May 2005), Phase III (Dec 2005) and Phase IV (Aug 06) of project duration. Secondary information on shoreline changes from **PWD, Chennai**; weather data from **IMD**, **Chennai** were also collected and analyzed. All the field data collected during the above four phases were processed and analyzed. Spatial as well as temporal variations of various coastal oceanographic parameters and the features identified were thoroughly discussed and presented.

The coastal process studies include the monitoring of hydrographic, sediment and shoreline changes. The parameters monitored and type of instrumentation deployed and analytical instruments used for data analysis, are detailed below:

Table 1.1 - Details of parameters monitored and instruments used

S No.	Parameter	Instrument	No. of locations
1.	Tides/waters inside the harbour and open coast	Directional and non-directional tide gauges, Valeport	7
2.	Waves (directional/ non-directional)	Directional and non-directional tide gauges, Valeport	3
3.	Coastal currents	RCM 9 Current Meters, Aanderaa	6
4.	Nearshore current profile	Acoustic Doppler Profiler (ADP), Sontek	1
5.	Wave orbital velocities and mean nearshore currents	Acoustic Doppler Velocimeter (ADV) with optical back scatter (OBS), Sontek	1
6.	Bathymetry survey	Echosounder, Odom and Heave Sensor, TSS	--
7.	Bed sediments	Mud Grab Samplers, Hydrobios	34
8.	Suspended sediments	Water Samplers, Niskin	34
9.	LEO observation (longshore current, brim height and surf zone width)	Floats	5
10.	Beach profiles	RTK GPS SR 530, Leica and Total Station, TPS 1100, Leica	20 km coastline at 500 m transects
11.	Shoreline mapping	Arc Pad, GS 5+, Leica	20 km coastline
12.	Meteorological parameters	Automatic Weather Station, R.M. Young	--

Laboratory Analysis

S No.	Parameter	Instrument
1.	Grain size distribution (coarser sediments)	Analytical Sieve Shaker(Retsch)
2.	Particle size distribution (finer sediments)	Particle Size Analyser, Master Sizer 2000 (Malvern)

The observations were made in 4 phases between November 2004 and August 2006. The Wave and Tide Gauges were deployed in coastal waters to measure tides and waves simultaneously. Currents were measured using automatic current meters at some of the locations, where waves were measured. A typical mooring design adopted for simultaneous monitoring of tides, currents and waves is shown in **Fig 1.6**. Acoustic Doppler Profiler (ADP) and Acoustic Doppler Velocimeter (ADV) were deployed in nearshore between 0 m and 8 m water depth at selected transects. At some locations, the data on tides and waves could not be retrieved due to malfunctioning of the equipment (2 Nos.) and loss of the mooring (1 location) due to rough weather condition inspite of several test checks conducted on functionality of equipment.

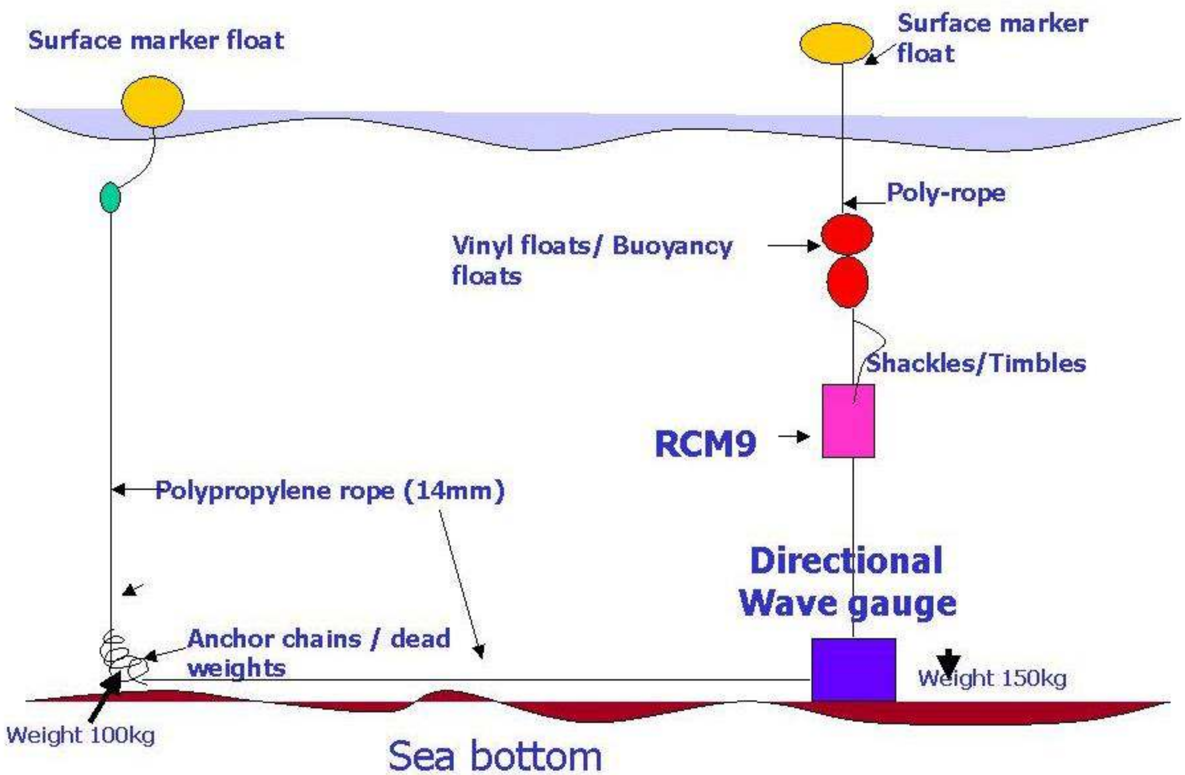

Fig 1.6 a) - Mooring used for deployment of Wave and Tide gauge and current meter

Fig. 1.6 b) - Instruments used for Monitoring Nearshore parameters

It was proposed to collect wave data for 1 year using Directional Wave Rider Buoy, NIOT, at a water depth of 23 m for assessing annual wave climate and for validation of numerical model. But, due to vandalism and delay in redeployment, the data could be collected only for 6 months (**Table 1.1**) against intended plan of 1 year. Phase IV observations with three directional wave gauges on north of port were undertaken to validate the numerical models and partially to bridge the data gap in Directional Wave Rider Buoy data. Field experiments forms an essential part for the ocean/ coastal processes and for validation of numerical models. Undertaking oceanographic measurements is challenging task, requires enormous efforts in terms of deployment, retrieval and maintenance of instruments during deployment period. Coastal measurements along Indian coast are sparse and maintaining instruments at site is labour intensive. Most of observations are discontinued prior to intended period due to logistic problems and severe weather conditions. During the field experiment conducted at Ennore, enough care was taken while collecting the coastal data in terms of deployment, maintaining the equipment through watch and ward and retrieval. Details of deployment such as location, parameter, measuring interval and duration of observations at each station for four phases of observation are shown in **Tables 1.2 - 1.5**.

Table 1.2 – Details of data collection during phase I period (Nov/ Dec 04)

			Phase I (Nov/ Dec 04)						
S. No	**Parameters**	**Record Interval**	**St D1-** (0429169 &1464110)	**St D2-** (0433248 &1463990)	**St D3-** (0429674 & 1471558)	**St D4-** (0431740 & 1471516)	**St D5-** (0433880 & 1470184)	**St D6 –** (0428284 & 1482723)	**St D7 –** (0435689 & 1482429)
1	Tides/water level	Sampling frequency of 4 Hz for 60 sec & measuring interval of 10 Min.	17/11/ 04 to 3/12/04 17/11/04 to 26/11/04 & 28/11/04 to 3/12/04 TG-19036	17/11/04 to 26/11/04 17/11/04 to 26/11/04 TG-19030	19/11/04 to 26/11/04 19/11/04 to 26/11/04 TG-21164	19/11/04 to 26/11/04 19/11/04 to 26/11/04 TG-21163	19/11/04 to 26/11/04 19/11/04 to 26/11/04 TG-21170	18/11/04 to 17/12/04 18/11/04 to 17/11/04 TG-21165	18/11/04 to 26/11/04 18/11/04 to 26/11/04 TG-19034
2	Waves	Sampling frequency of 4Hz with 1024 samples & Measuring interval of 60 Mts.	17/11/ 04 to 3/12/04	17/11/04 to 26/11/04	19/11/04 to 26/11/04	19/11/04 to 26/11/04	19/11/04 to 26/11/04	18/11/04 to 17/12/04	18/11/04 to 26/11/04

Phase I (Nov/ Dec 04)									
S. No	**Parameters**	**Record Interval**	**St D1-** (0429169 &1464110)	**St D2-** (0433248 &1463990)	**St D3-** (0429674 & 1471558)	**St D4-** (0431740 & 1471516)	**St D5-** (0433880 & 1470184)	**St D6 –** (0428284 & 1482723)	**St D7 –** (0435689 & 1482429)
3	Currents	10 Mts.	17/11/ 04 to 3/12/04 CM-1060	17/11/04 to 27/11/04	19/11/04 to 27/11/04	No cur meter	19/11/04 to 27/11/04	19/11/04 to 27/11/04	18/11/04 to 27/12/04
4	Weather	60 Mts.	15/11/04 to 25/11/04 & 28/11/04 to 6/12/04						
5	Current profile	20 Mts.	20/11/04:1132 to 26/11/04:1912; At 8m depth; st1 (429630&1469120); st2(429414&1473472) ;st 3(428454&1464976)						
6	Discharge		NIL						
7	Wave orbital velocity		NIL						
8	Bathymetry survey		--						
9	Shoreline survey		Entire shoreline between Ennore creek and Pulicat confluence – Nov 04 to Jan 05						
10	Beach profiles		Entire shoreline between Ennore creek and Pulicat confluence – Nov 04 to Jan 05						
11	Beach sediments		Beach Sediment samples at high tide line and low tide at selected locations along the shoreline between Ennore creek and Pulicat confluence – Nov 04 to Jan 05						
12	Bed load sediments		Offshore bed sediment samples at 34 sts (R1 to R34) between 3m and 25m depth contours - Nov 04						
13	Suspended sediment concentration		Surface water samples at 34 sts (R1 to R34) between 3m contour to 25m contour - Nov 04; Time series measurements at 3hr intervals over 24 hours for surface, mid-depth & bottom levels						

Table 1.3 – Details of data collection during phase II period (Apr/May 05)

			Phase II (Apr/ May 05)						
S.No	**Parameters**	**Record Interval**	**St D1-** (0429169 &1464110)	**St D2-** (0433248 &1463990)	**St D3-** (0429674 & 1471558)	**St D4-** (0431740 & 1471516)	**St D5-** (0433880 & 1470184)	**St D6 –** (0428284 & 1482723)	**St D7 –** (0435689 & 1482429)
1	Tides/water level	Sampling frequency of 4 Hz for 60 sec & measuring interval of 10 Min.	30/3/05 to 30/4/05 30/11/05 to 30/4/05	Instrument lost	31/3/05 to 18/4/05 31/3/05 to 17/4/05	Instrument lost	31/3/05 to 20/4/05 31/3/05 to 20/4/05	31/3/05 to 30/4/05 31/3/05 to 30/04/05	31/3/05 to 8/5/05 31/3/05 to 8/5/05
2	Waves	Sampling frequency of 4Hz with 1024 samples & Measuring interval of 60 Mts.	30/3/05 to 30/4/05	- do -	30/3/05 to 18/4/05	Instrument error	31/3/05 to 20/4/05	31/3/35 to 30/4/05	31/3/05 to 8/5/05
3	Currents	10 Mts.	30/3/05 to 30/4/05	- do -	31/3/05 to 18/4/05	-do -	30/3/05 to 20/4/05	30/3/0 to 30/4/05	31/3/05 to 30/4/05
4	Weather	60 Mts.	25/4/05 to 6/5/05						
5	ADP vertical profiles	20 Mts.	6/4/05:1300 to 15/4/05:1700 (6mdepth (428960&1464783); 7m depth(43015&1469611); 8m depth(429637&1473514 & 9m depth(426950 & 1488441)						
6	ADCP discharge		nil						
7	ADV orbital velocities		6/4/05:1400 to 6/4/05:1500 5m depth(428735 & 1464960); 4m depth(429485&1469576); 5m depth(426536&1488316) 6m depth (429379 & 1473486)						

			Phase II (Apr/ May 05)						
S.No	**Parameters**	**Record Interval**	**St D1-** (0429169 &1464110)	**St D2-** (0433248 &1463990)	**St D3-** (0429674 & 1471558)	**St D4-** (0431740 & 1471516)	**St D5-** (0433880 & 1470184)	**St D6 –** (0428284 & 1482723)	**St D7 –** (0435689 & 1482429)
8	Bathymetry survey		Bathymetric survey between 3 and 25m depth contours. Area covered between Ennore creek and Pulicat mouth						
9	Arcpad survey		Entire shoreline between Ennore creek and Pulicat confluence – Apr 05 to May 05						
10	RTK beach profiles		Entire shoreline between Ennore creek and Pulicat confluence – Apr 05 to May 05						
11	Beach sediment		Beach Sediment samples at high tide line and low tide at selected locations along the shoreline between Ennore creek and Pulicat confluence – Apr 05 to May 05						
12	Bed load sediment		Offshore bed sediment samles at 34 sts (R1 to R34) between 3m and 25m depth contours - Apr 05						
13	Suspended sediment		Surface water samples at 34 sts (R1 to R34) between 3m contour to 25m contour - Apr 05;						

Table 1.4 – Details of data collection during phase III period (Dec 05/Jan 06)

			Phase III (Dec 05/Jan06)						
S.No	**Parameters**	**Record Interval**	**St D1-** (0429169 &1464110)	**St D2-** (0433248 &1463990)	**St D3-** (0429674 & 1471558)	**St D4-** (0431740 & 1471516)	**St D5-** (0433880 & 1470184)	**St D6 –** (0428284 & 1482723)	**St D7 –** (0435689 & 1482429)
1	Tides/water level	Sampling frequency of 4 Hz for 60 sec & measuring interval of 10 Min.	17/1/06 to 7/2/06	nil	19/1/06 to 31/1/06	19/1/06 to 31/1/06	nil	20/1/06 to 26/1/06	nil
2	Waves	Sampling frequency of 4Hz with 1024 samples & Measuring interval of 60 Mts.	17/1/06 to 7/2/06	nil	19/1/06 to 31/1/06	19/1/06 to 4/2/06	nil	20/1/06 to 27/1/06	nil
3	Currents	10 Mts.	17/1/06 to 14/2/06 CM-1110	nil	18/1/06 to 31/1/06 CM-664	19/1/06 to 31/1/06 CM-1120	nil	20/1/06 to 27/1/06 CM-1116	NIL
4	Weather	60 Mts.	Weather data monitored during 1/2/06 to Feb06						
5	ADP vertical profile	20 Mts.	17/1/06:1716 TO 22/1/06:1056 AND 22/1/06:1144 to 8/1/06:1050						
6	ADCP discharge		Cross-shore profiles at selected cross-section from Marina beach to Kalanji along ennore during 7-13 feb06						

			Phase III (Dec 05/Jan06)						
S.No	**Parameters**	**Record Interval**	**St D1-** (0429169 &1464110)	**St D2-** (0433248 &1463990)	**St D3-** (0429674 & 1471558)	**St D4-** (0431740 & 1471516)	**St D5-** (0433880 & 1470184)	**St D6 –** (0428284 & 1482723)	**St D7 –** (0435689 & 1482429)
7	ADV orbital velocities		23/1/06:1017 TO 23/1/06:1121 AND 18/1/06:1758 to 18/1/06:1902						
8	Bathymetry survey		Bathymetric survey between 3 and 25m depth contours. Area covered between Ennore creek and Pulicat mouth						
9	Arcpad survey		selected bathymetry track were made along Ennore-pulicat coast jan06						
10	RTK beach profiles		Entire shoreline between Ennore creek and Pulicat confluence – Jan-feb06						
11	Beach sediment		Beach Sediment samples at high tide line and low tide at selected locations along the shoreline between Ennore creek and Pulicat confluence – jan06-feb06						
12	Bed load sediment		Offshore bed sediment samples at 34 sts (R1 to R34) between 3m and 25m depth contours – feb06						
13	Suspended sediment		Surface water samples at 34 sts (R1 to R34) between 3m contour to 25m contour – jan06						

Table 1.5 – Details of data collection during phase IV period (Aug. 06)

			Phase IV (Aug. 06)		
S.No	**Parameters**	**Record Interval**	**St D3-(**0429674 & 1471558)	**St D4-(**0431740 & 1471516)	**St D5-(**0433880 & 1470184)
1	Tides/water level	Sampling frequency of 4 Hz for 60 sec & measuring interval of 10 Min.	19/08/06 to 01/09/06	19/08/06 to 05/09/06	19/08/06 to 05/09/06
2	Waves	Sampling frequency of 4Hz with 1024 samples & Measuring interval of 60 Mts.	19/08/06 to 01/09/06	19/08/06 to 05/09/06	19/08/06 to 05/09/06
3	Currents	10 Mts.	19/08/06 to 01/09/06 C-1116 & 1064	19/08/06 to 05/09/06 C-1064 & 1116	19/08/06 to 05/09/06 C-1059
4	ADP vertical profile	20 Mts.	09/08/06 to 25/08/06 (south of Ennore Port), 25/08/06 to 25/08/06 (at D3 location) and 25/08/06 to 04/09/06 (D5 location)		
5	ADCP discharge		26/08/06 offshore Kalanji		
6	ADV orbital velocities		21/08/06 to 04/09/06 at 4 m depth off Kalanji		
7	Bathymetry survey		Bathymetric survey between 3 and 25m depth contours. Area covered between Ennore creek and Pulicat mouth		

8	Arcpad survey		selected bathymetry track were made along Ennore to Kalanji (Aug. 06)
9	RTK beach profiles		Entire shoreline between Ennore creek and Kalanji – Aug. 06
10	Beach sediment		Beach Sediment samples at high tide line and low tide at selected locations along the shoreline between Ennore creek and Kalanji – Aug. 06
11	Bed load sediment		Offshore bed sediment samples at 34 sts (R1 to R34) between 3m and 25m depth contours – Aug. 06
12	Suspended sediment		Surface water samples at 34 sts (R1 to R34) between 3m contour to 25m contour – Aug. 06

2. FIELD INVESTIGATIONS

2.1 Seabed Morphology/ Bathymetry

Seabed morphology of the Ennore region (Ennore creek to Pulicat) was mapped using surveys conducted during May 2000 and April 2005. The bathymetry survey was carried out for the area of 20-km on parallel (north to south) and 4km on perpendicular (east to west) to the coast. The data was collected upto a water depth of 25m. Single beam (ODAM) echosounder was used. The single beam echo sounder, (ODOM Hydrotrac, USA) was fixed in the boat along with heave sensor and DGPS. Potential errors, such as vessel roll, pitch, and yaw, and time lag between the positioning sensor (GPS) and the sonar measurement, are recorded with on board instrumentation and incorporated into the post-processing procedure (**USACE, 2001**). Care was taken to prevent/minimize other errors such as inaccurate alignment of sensors, transducer draft depth, and sound velocity measurements (**USACE, 2001**). The area to be surveyed was marked with grid spacing of 100 m on the background of satellites map (IRS 1D Pan) and the line position was maintained by interfacing DGPS to PC based software (HYPACK 4.0). Since the coastal environments display more variation in the cross-shore direction than the alongshore direction the transect survey was performed perpendicular to the shoreline. Tidal corrections have been applied to the data in post processing mode by using the simultaneously recorded tide at Ennore and Pulicat. It is necessary to interpolate survey data in order to produce a continuous bathymetric map. Hence the observed data was post processed, analyzed and interpolated using HYPACK MAX survey software and the seabed elevation with respect to chart datum was prepared using ArcGIS software.

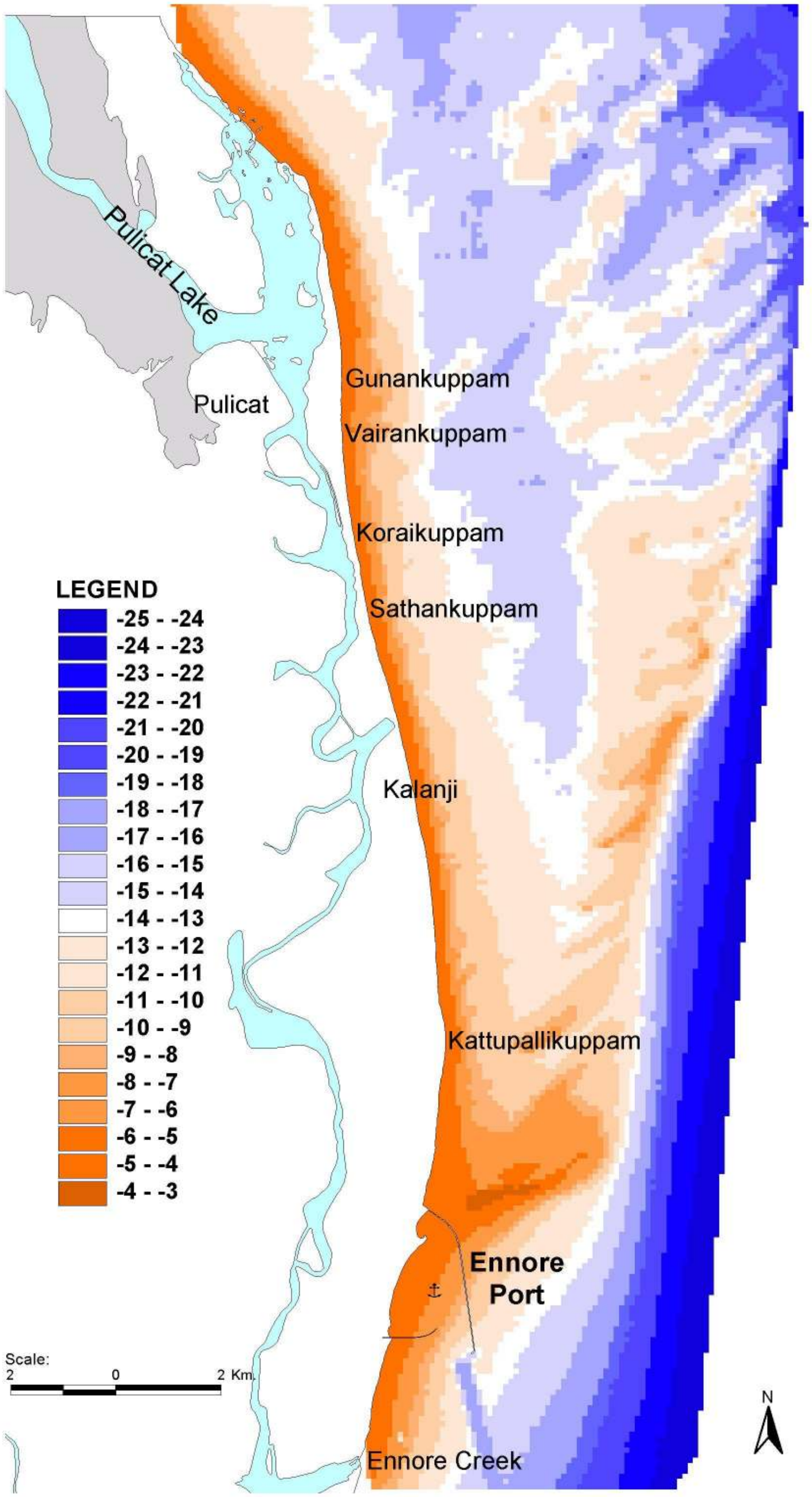

Fig 2.1 – Bathymetry of Ennore coast

The seabed morphology at Ennore coast **(Fig 2.1)** is complex with varied slope between Ennore creek and Pulicat lake. The slope at south of Ennore Port is relatively steep (1 in 300) at Ennore creek, while the slope on northern side is flat (1 in 500) with submerged shoals extending in northeasterly direction. It has been hypothesized that shoals might have formed due to interaction of northerly coastal currents and sediment supply through Ennore creek (Kosattalaiyar river) when it was active. The cross-sectional profiles made at 1 km interval between Ennore creek and Pulicat lake (-2, 0, 1, 2, 3, 4, 5, 6 km) and are shown in **Fig 2.2**. Positive distances indicate the profiles on northern side of Ennore port, '0' represents the profile at port cross-section and the negative distances represent the profiles on southern side of the port.

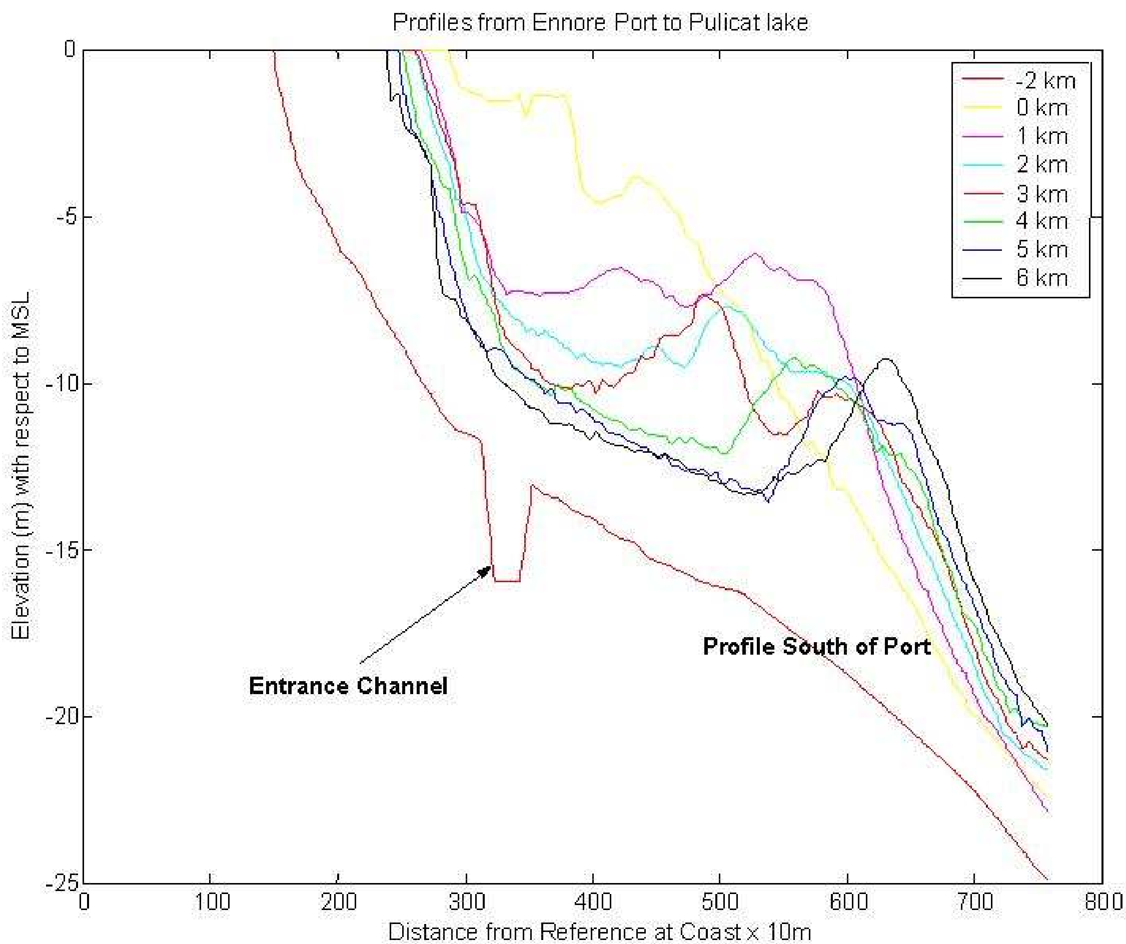

Fig 2.2 – Cross-shore profiles at different distances on North and South of Ennore Port

2.2 Winds

Continuous monitoring of weather parameters (wind speed and direction, air temperature, humidity etc) was made by installing the automatic weather station at Ennore port during phase I (Nov 04), phase II (Apr 05) and phase III (Jan 06). The recorded data (**Fig 2.3**) indicate that during Phase I & phase III (**Fig 2.3 a & c**) periods the winds are mostly from 30-110^o (NNE & ESE) and speeds are 0.9 to 11 m/s. However in Phase II (**Fig 2.3 b**) the directions are from 150^o (ESE) to 210^o (SSW) and the speeds are 0.6 to 2.4m/s. It is noticed from the figure that strong winds usually blow from E-SE direction during NE monsoon period and from S-SSW during SW monsoon. The annual wind pattern derived from NCEP (National Centers for Environmental Prediction, NOAA) data for Ennore region for the year 2004 is also shown in **Fig 2.3**. Winds reversed with reversing season. They blow predominantly from ENE-ESE direction during NE monsoon period and from SSW-SSE during SW monsoon period. On the whole for Ennore coast, wind speeds varied from 3.5 to 12 m/s and the directions are mostly between NNE and SSW.

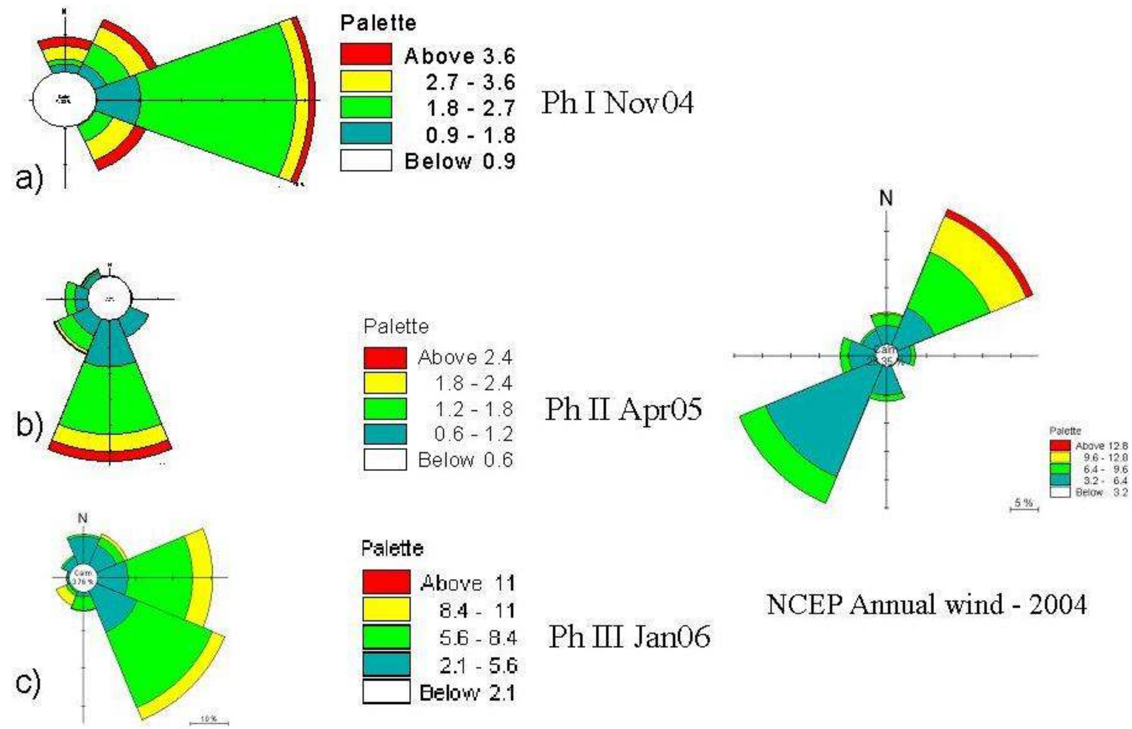

Fig. 2.3 – Wind roses during phase I Nov 04), Phase II (Apr 05) and phase III (Jan 06)

2.3 Waves

Directional waves are monitored using Directional Wave Rider Buoy (NDBP) from Sep. 2004 to Aug. 2005. There are few data gaps during the above period due to damage caused to the buoy by local fishermen and delay in redeployment. Since the directional wave data was not available for the observations of phase I (Nov. 2004), phase III (Jan. 2006) and phase IV (Aug. 2006), the directional wave gauge deployed at north of Ennore Port (D5) was considered for directional wave analysis. Waves were sampled at frequency of 4 Hz with a measuring interval of 1 hour at all the locations. Except, the station D5, all the wave gauges are non directional and hence, the measured wave direction at D5 is considered for analysis.

The wave directions recorded at St D5 with Directional Tide Gauge during the phase I (Nov 04), phase II (Apr 05) and phase III (Dec 05) periods are shown in **Fig 2.4**. Wave directions are highly variable depending up on the season. In phase I (**Fig 2.4 a**) the predominant directions are between 130^o and 230^o, in Ph II (**Fig 2.4 b**) 70^o-260^o and in phase III (**Fig 2.4 c**) 120^o-220^o. Wave heights are high (0.6 to 1.7m) during phase I period compared to that (0.2 to 0.8m) during Phase II & III periods due to active northeasterly winds. It has also been noticed that local wind gust made sea conditions rough on 2nd December, 2004 and all the mooring were retrieved after 8 days due to the rough sea conditions against the intended period of 15 days. During phase II (Apr. - May. 2005), the wave heights are very low and increased wave heights observed on 8th April, 2005 can be attributed to local sea state conditions. Comparison of simultaneously recorded wave heights for sts D1 to D7 during Phase I (Nov 04), Phase II (Apr 05) and Phase III (Dec 05) periods are shown in **Fig 2.5**. A preliminary analysis made on comparison of significant wave height between different stations and NDBP (National Data Buoy Program, NIOT) wave heights (**Fig 2.5 a & b**) indicate increasing trend in wave heights during Phase I and decreasing trend in Phase II. Wave heights from NDBP increased from 0.9m to 1.9m (**Fig 2.5 a**) and the corresponding waves heights at other stations ranges from 0.5 to 1.6m during Phase I. In Phase II, the NDBP wave heights decreased from 1.1 to 0.4m (**Fig 2.5 b**), the corresponding heights at other stations ranges from 0.8 to 0.2m. A detailed wave spectral analysis for different stations is being taken up to study the variation in wave energy among the stations.

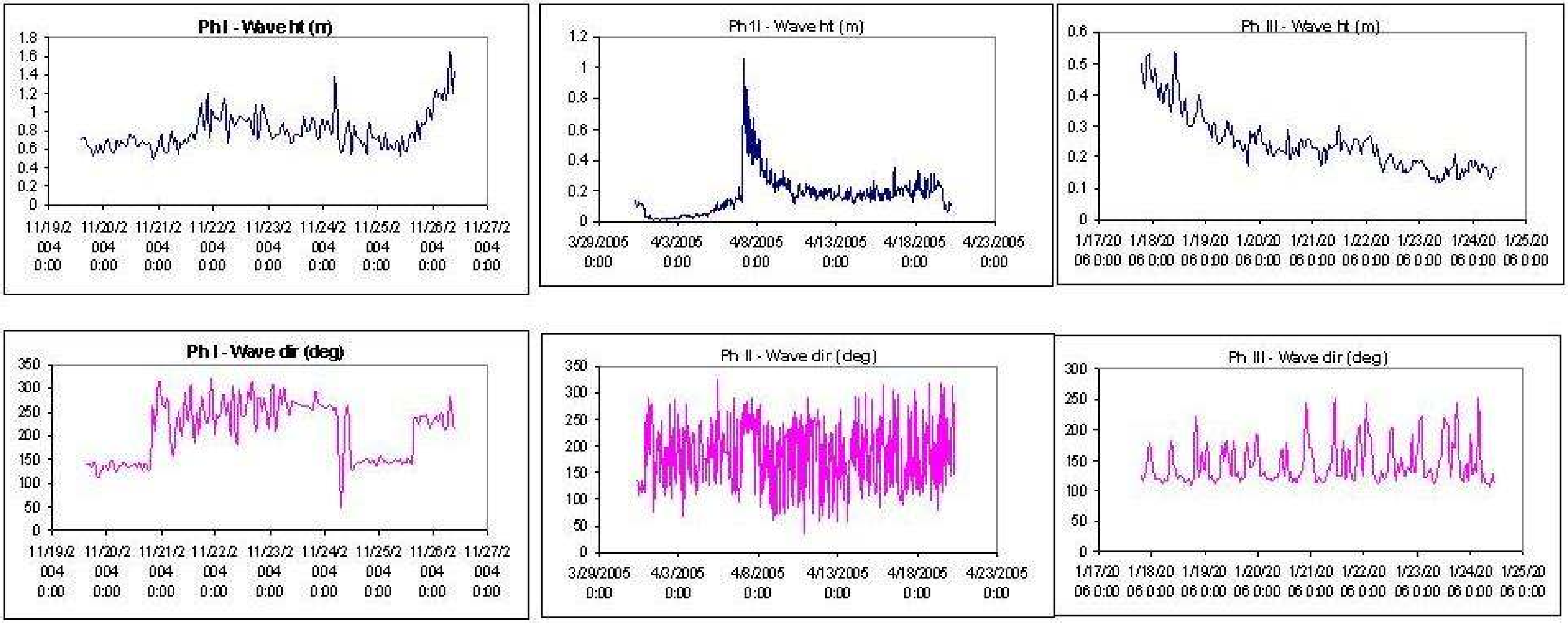

Fig 2.4 - Wave heights and directions at st D5 for a) Phase I (Nov 04), b) Phase II (Apr 05) and c) Phase III (Jan 06)

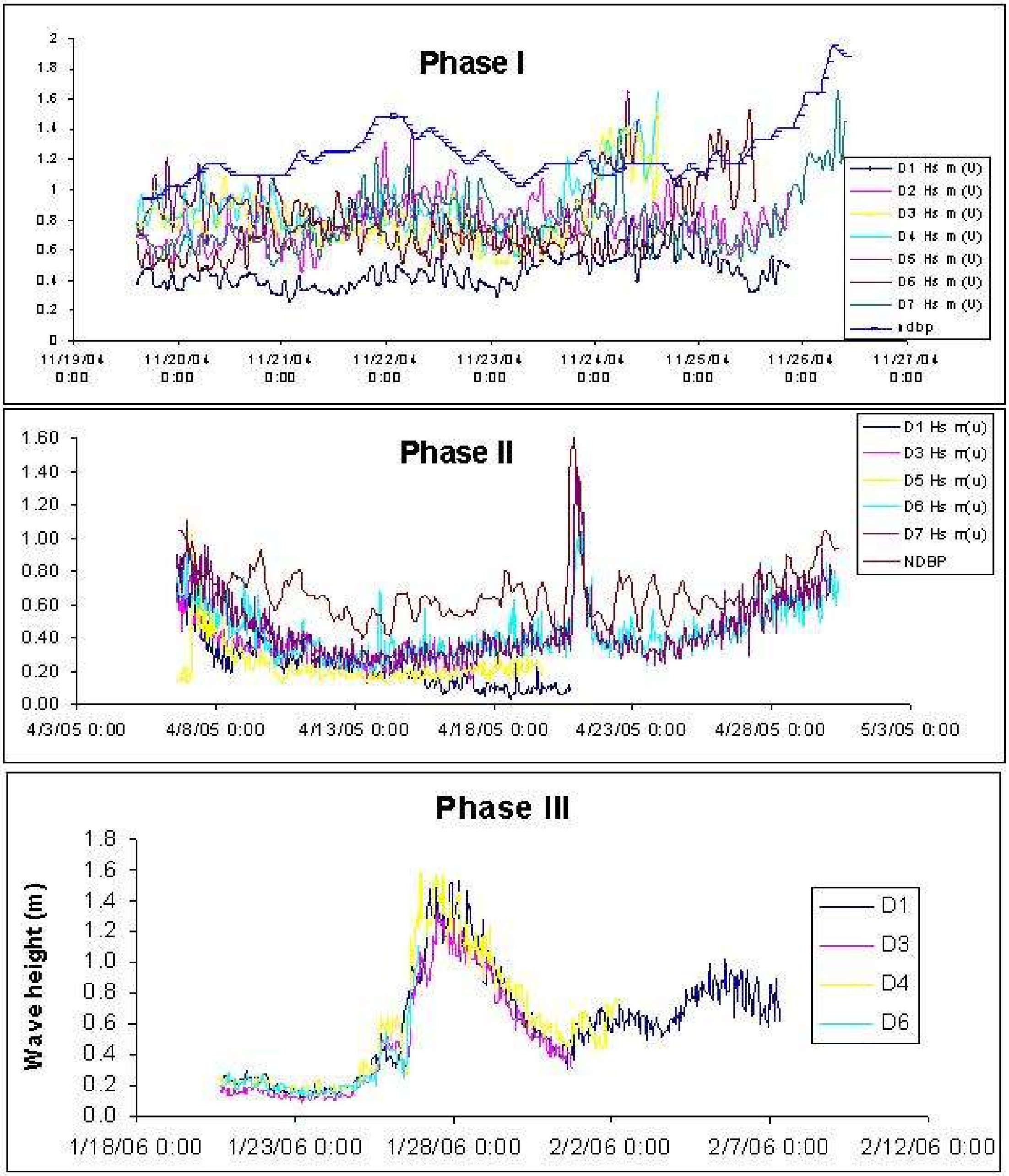

Fig 2.5 - Wave records under a) Phase I (Nov 05) b) Phase II (Apr 05) and Phase III Jan 06) periods

Table 2.1 - Wave amplification at stations D1 to D7 under phase I (Nov. 05), phase II (Apr. 05) and phase III (Jan. 06) periods

Period	D1	D3	D4	D5	D6	D7
Phase I	0.60	1.10	1.10	1.10	0.80	0.90
Phase II	0.40	0.50	0.53	0.59	0.59	0.62
Phase III	0.97	0.80	--	--	0.92	--

Computation of wave height amplification (**Table 2.1**) between shallow water stations (sts D1, D3, D4 & D5) and deep water station (st. D2) indicate that in Phase I and III periods (NE monsoon) the nearshore wave heights are amplified by a factor of 0.8 to 1.1, which can be attributed to shoaling. During phase II (SE Waves) period, waves approach the coast from the SE direction resulted in reduction in nearshore wave height by a factor of 0.5 due to dissipation of energy by shoals. The above analysis clearly indicted that coast north of Ennore Port is protected from SE waves (last for 8 months).

Nearshore wave parameters were also monitored on either side of the port using Acoustic Doppler Profiler, which is fitted with pressure sensor. Preliminary PUV analysis was conducted to study along shore variability of nearshore waves at three stations. Wave energy distribution from the spectral analysis of PUV records for phase I (November 2004), phase II (April 2005) and phase III (January 2006) periods are shown in **Fig 2.6** and **Table 2.2**. The directional trend with season is seen at station III, which is 7 km from the port, while station I and II are influenced by the port. All the field observations indicted that nearshore circulation is modified by port upo 4 km on northern side and 3 km on southern side with present configuration of port and intervention (artificial nourishment on north). Attempts were made to asses the variability of nearshore circulation using numerical model.

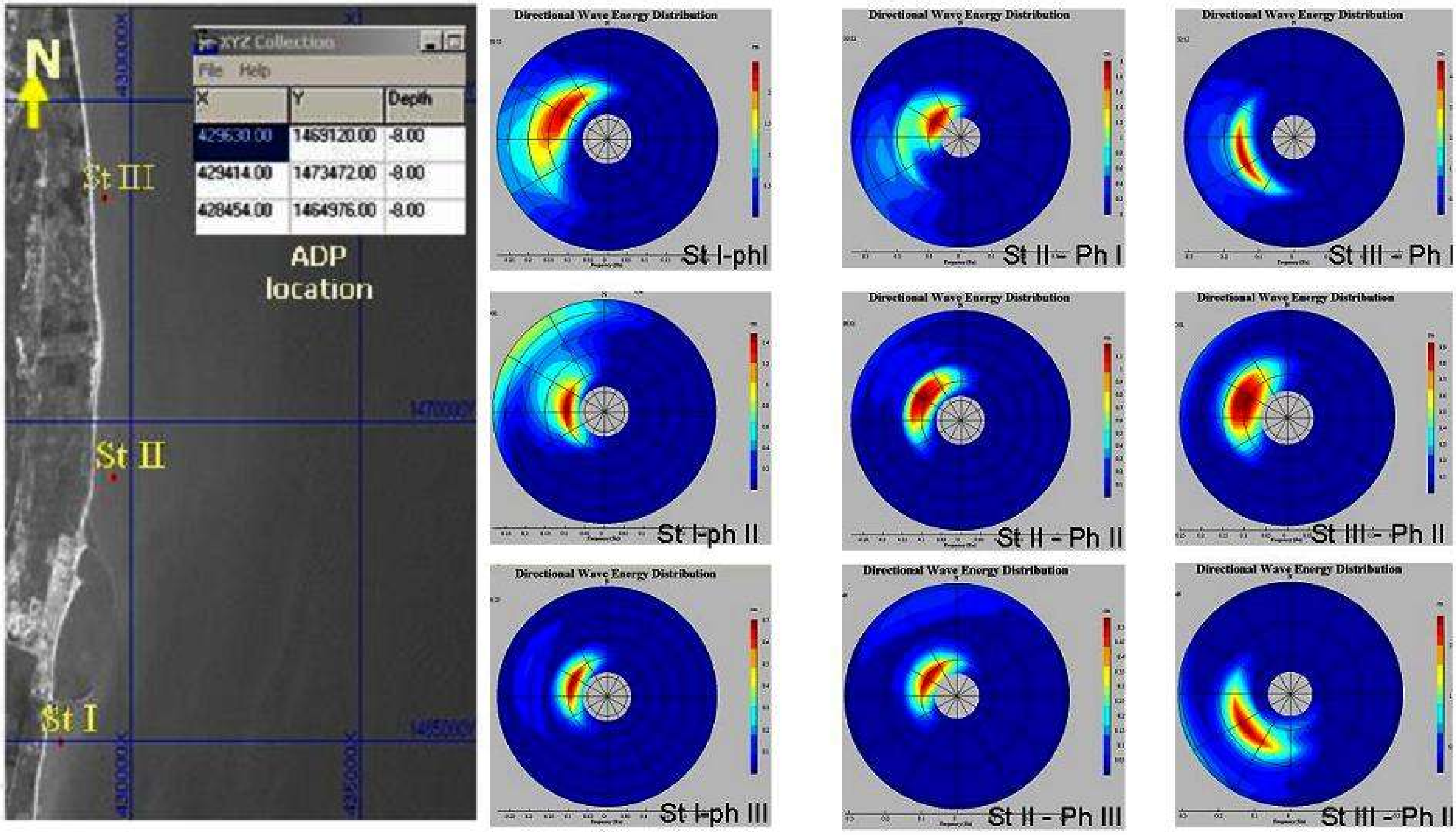

Fig 2.6 - Spectral wave characteristics of nearshore waves during phase I (Nov 04), Phase II (Apr 05) and Phase III (Jan 06)

Table 2.2 - Wave parameters obtained from ADP data for the phases I, II & III

	Station I			Station II			Station III		
	Wave height	**Wave pressure**	**Wave direction**	**Wave height**	**Wave pressure**	**Wave direction**	**Wave height**	**Wave pressure**	**Wave direction**
Phase 1	0.95	6.4	304	0.77	8.7	305	1.46	6.0	249
Phase 2	0.59	9.0	273	0.38	8.4	306	0.32	8.7	291
Phase 3	0.24	9.4	283	0.21	9.4	308	1.15	6.6	232

In Ph I (Nov 04) and Ph III (Apr 05) periods, the waves approach the coast from NE direction with most of the energy is concentrated in 0.16Hz (6-7sec). During Ph II (Feb 06) the waves approach the coast from SE with wave energy concentrated at 0.1 to 0.28Hz (4s & 11s period)

In order to bridge the gap in the wave data of Directional Wave Rider Buoy, NDBP, annual wave climate derived from Hindcast data was used. NCEP winds at 0.5^o grid was used in Offshore Spectral Wave Model to arrive at wave climate. Predicted waves are compared with observed data at Ennore and model prediction agrees well in wave heights and direction but wave periods are under predicted by 15 %. Annual wave climate for the year 2004-05 is shown in **Fig. 2.7**.

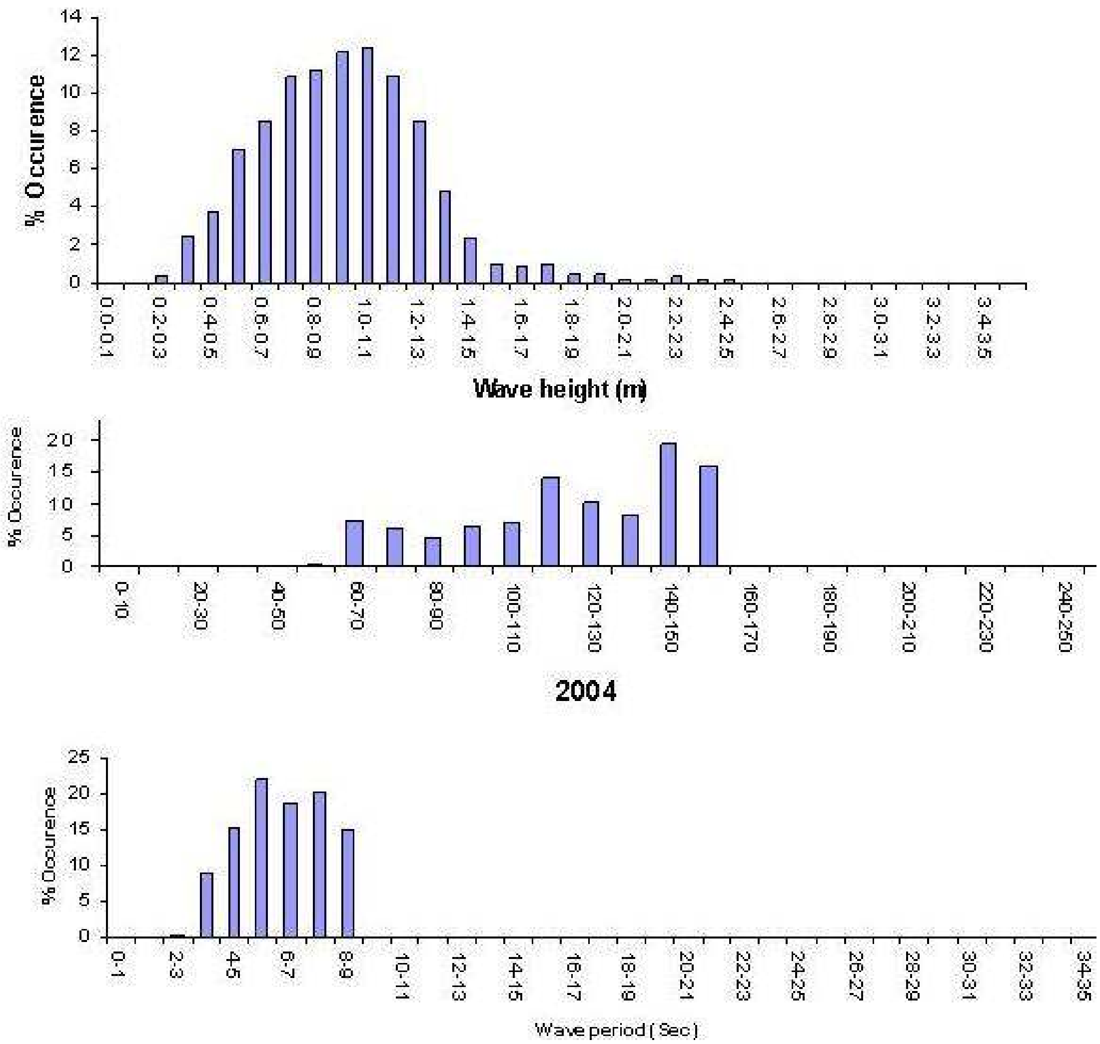

Fig 2.7 – Annual wave climate for Ennore coast predicted from NCEP winds

2.4. Tides

Tides in the Bay of Bengal originate in the Indian Ocean and get amplified at the head bay due mainly to nonlinear shallow water effect and the northward convergence of Bay of Bengal. The bay tides are semidiurnal in nature with the period of 24 hrs and 52min. The highest tide is seen where the influence of bottom relief and the configuration of the coast are prominent i.e. in the head bay region. The main tidal constituents in Bay of Bengal are M2, S2, K1 and O1 (**Table 2.3**) and out of these the tide is dominated by the M2 and little extent by the S2. The amplitudes of M2 constituents at various places (Colombo, Cuddalore, Chennai, Visakhapatnam and Calcutta) reveal that the tidal amplitude gradually increased from south to north in Bay of Bengal i.e. from Colombo to Calcutta. Near Colombo the tidal amplitude is 0.18m which gradually raised to 0.33m at Chennai, 0.48m at

Visakhapatnam and 2.4m at Calcutta. Occurrence of lower tidal amplitude in southern region of Bay of Bengal is due to presence of amphidromic point (the region of zero tidal range) around SE corner of Sri Lanka. The phase of the tide also varies from south to north along Bay of Bengal. At Colombo the phase of the tide is around 50^o indicating the tide is propagating northeastward. From Cuddalore to Visakhapatnam the phase is around 240^o indicating the tide pattern is more or less same and is perpendicular to the coast along Andhra and Tamil Nadu. Thus the tide propagates from south (Sri Lanka) to north (Calcutta) in anticlockwise direction once crosses the Sri Lanka region. Very small amplitude of S2 (**Table 2.3**) compared to M2 indicates the dominance of semi diurnal tidal component along southern part of East Coast. Thus for Ennore coast the tides are predominantly the semi-diurnal type with a phase velocity perpendicular to the coast which lead to large scale seasonal residual circulation along the coast.

Table 2.3 - Amplitudes and phases of tidal components M2, S2, K1 and O1

Places	Mean level	M2		S2		K1		O1	
		Ampli-tude	Phase	Ampli-tude	Phase	Ampli-tude	Phase	Ampli-tude	Phase
Colombo	0.38	0.18	50	0.12	101	0.07	36	0.03	59
Cuddalore	0.63	0.26	241	0.11	284	0.10	344	0.02	308
Chennai	0.65	0.33	239	0.14	274	0.09	339	0.03	321
Visakhapatnam	0.84	0.48	239	0.21	274	0.11	336	0.04	320
Calcutta	--	2.41	--	--	--	--	--	---	---

The tidal characteristics for Chennai coast provided by the Chennai Port Trust are shown in **Table 2.4**. All the levels are with respect to chart datum specified by the Naval Hydrographic Office, India. The change in water levels combined due to astronomical tide, wind setup, wave set up, barometric pressure, seiches and global sea level rise were estimated as 1.57m, 1.68m and 1.8m at 15m, 10m and 5m depth contours respectively. Analysis of the tidal record for Chennai coast reveal that the mean tidal range during spring tide is 1.0m and during neap tide is 0.4m.

Table 2.4 - Tidal characteristics for Chennai coast

Highest High Water	H.H.W	1.50M
Mean High Water Spring	M.H.W.S	1.10M
Mean High Water Neap	M.H.W.N	0.80M
Mean Sea Level	M.S.L	0.54M
Mean Low Water Neap	M.L.W.N	0.40M
Mean Low Water Spring	M.L.W.S	0.10M
Mean Spring Range	M.S.R	1.00M
Mean Neap Range	M.N.R	0.40M

Coastal structures are designed based on wave condition, which is depending on fluctuation of water levels. They control both flooding and wave exposure. Coastal areas/structures are subjected to larger waves when water level increases. Water level fluctuation in coastal areas could be due to tides, storm surges, barometric changes and climatic fluctuations. For modelling of coastal circulation, the role of each forcing function like tide, wind, wave etc. has to be identified and analysed.

Water levels were monitored at 6 locations in coastal waters and one location inside the port. The station located inside the port (new finger jetty) was monitored for a period not less than 30 days in phase II, phase III and phase IV. The data was analysed for harmonic analysis (**Piorewicz, 2002**). The pressure data was analysed for separation of tide from non-tidal components of the signal. The residual time series, amplitudes of various constituents, spatial contribution of tidal and non-tidal energy are shown **Fig. 2.8, Fig. 2.9** and **Fig. 2.10** respectively. Analysis of residual time series (detided signal) at Ennore indicate that a signal with a periodicity of 20days (0.04 to 0.05 cycles per day (cpd)) was observed in all seasons but during Ph3 and Ph4 a periodicity of 2 cpd was also noticed. In order to study the influence of meteorological forcing on water level, a continuous observation of meteorological data (wind speed &direction and pressure) is required. Though, automatic weather station was deployed at Ennore, continuous data could not be collected due to frequent failure of power supply at port. Major diurnal, semi-diurnal and quarter-diurnal constituents derived for the 3 sets of data are shown in **Table 2.5**.

Spatial variation along tides can be attributed to coastal configuration and presence of shoals. Asymmetry in tides are seen among different stations (**Fig. 2.11**) and it is more predominant during neap phase of the tide.

Table 2.5 - Frequencies of selected diurnal, semi-diurnal and quarter-diurnal tidal constituents for phase 2 (Apr. 05), phase 3 (Jan. 06) and phase 4 (Aug. 06)

Type	Tide constitute	Freq (cycle/hour)	Phase 2		Phase 3		Phase 4	
			Amplitude	Phase	Amplitude	Phase	Amplitude	Phase
Diurnal	K1	0.041781	0.1018	334.43	0.0856	326.72	0.1006	337.38
	O1	0.038731	0.0331	322.62	0.0268	319.13	0.0281	326.87
	P1	0.041553	0.0337	341.5	0.0283	333.79	0.0333	344.45
Semi diurnal	M2	0.080511	0.3305	235.17	0.3029	219.73	0.32	239.36
	S2	0.083333	0.1404	271.89	0.18	259.1	0.1549	271.27
	N2	0.078999	0.0629	224.95	0.0765	220	0.0823	241.92
	K2	0.083562	0.0382	294.29	0.049	281.5	0.0422	293.67
Quarter diurnal	M4	0.161023	0.0018	7.6	0.0021	47.81	0.0008	119.36
	S4	0.166667	0.0014	281.07	0.0011	163.76	0	320.72
	MS4	0.163845	0.0008	146.67	0.0021	102.16	0.0038	149.52
	MN4	0.159511	0.0007	277.4	0.0025	42.01	0.001	356.43

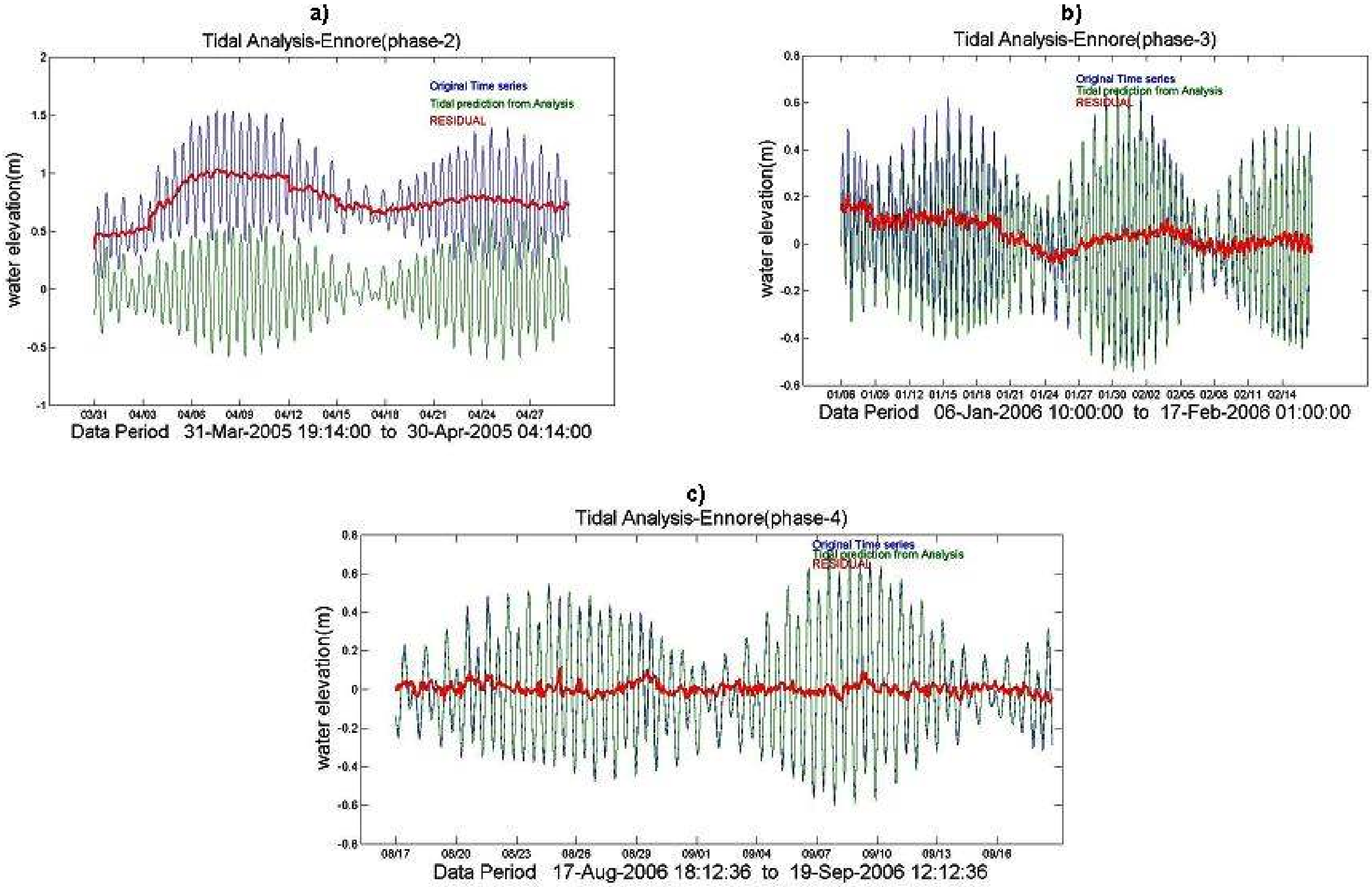

Fig. 2. 8 – harmonic analysis of tide at Ennore for ph 2 (Apr 05), ph 3 (Jan 06) and ph 4 (Aug 06)

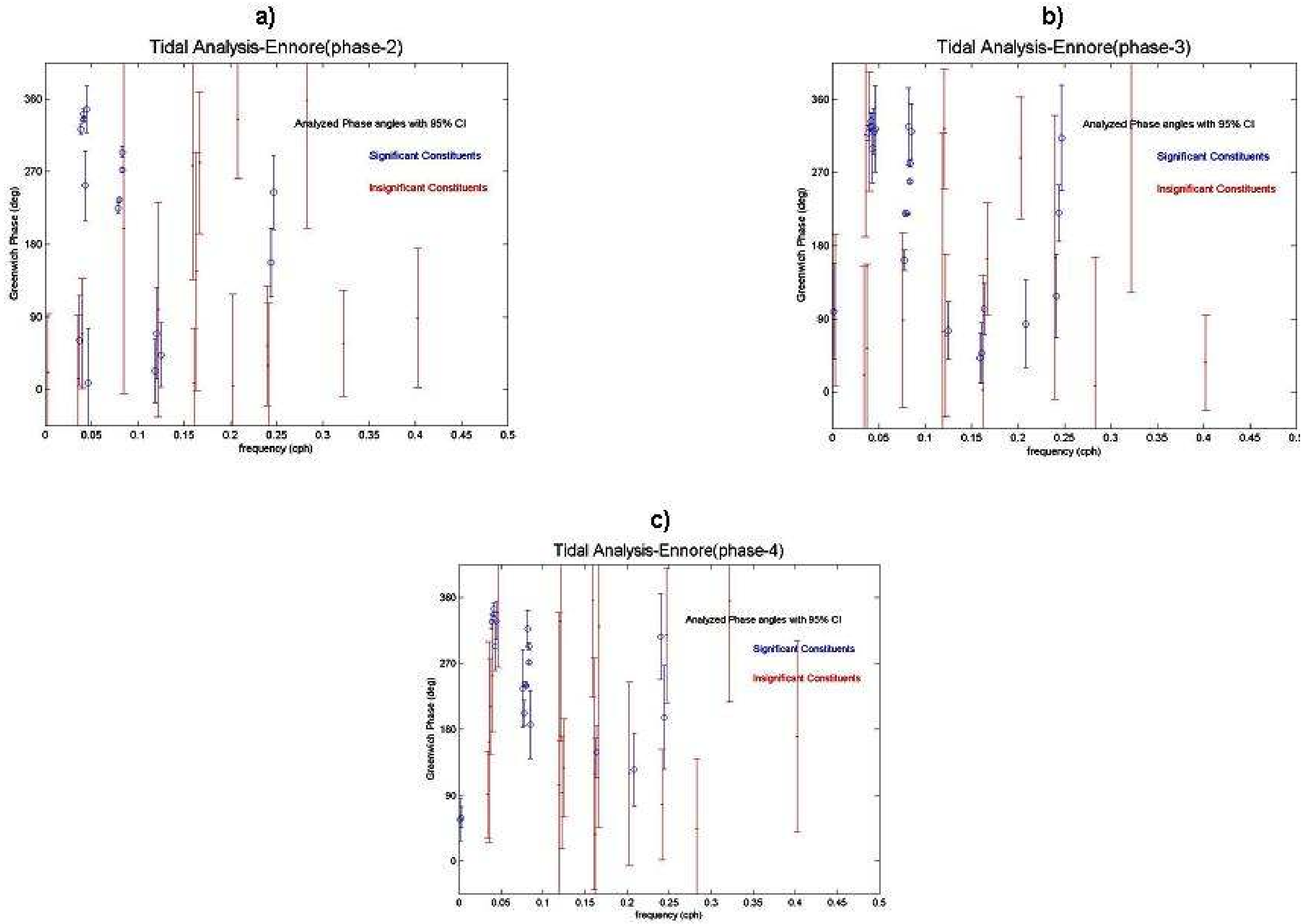

Fig. 2. 9 – Amplitude of analysed tidal constituents with 95% significant level

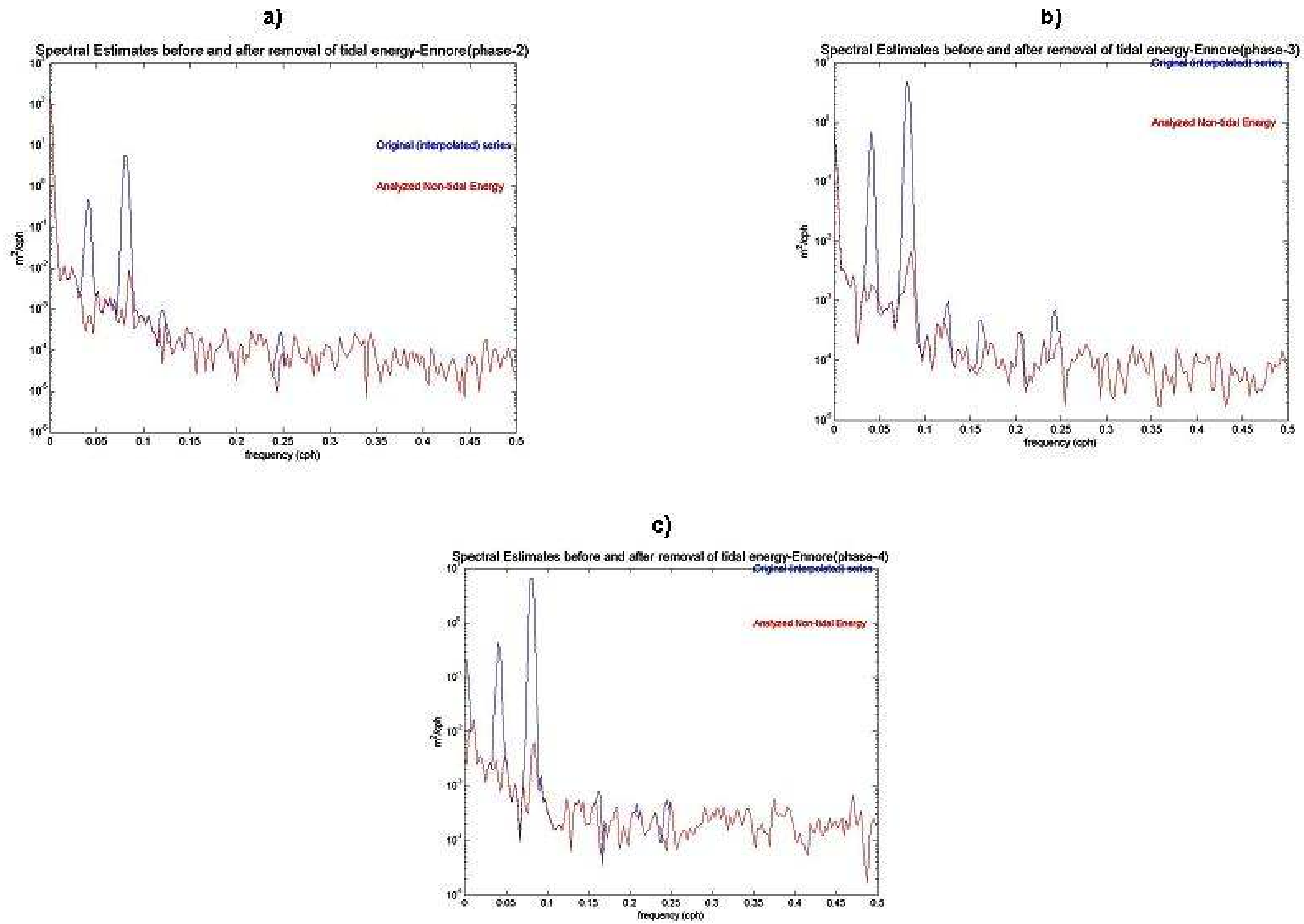

Fig. 2.10 - Spectral estimates of tidal and non-tidal energy

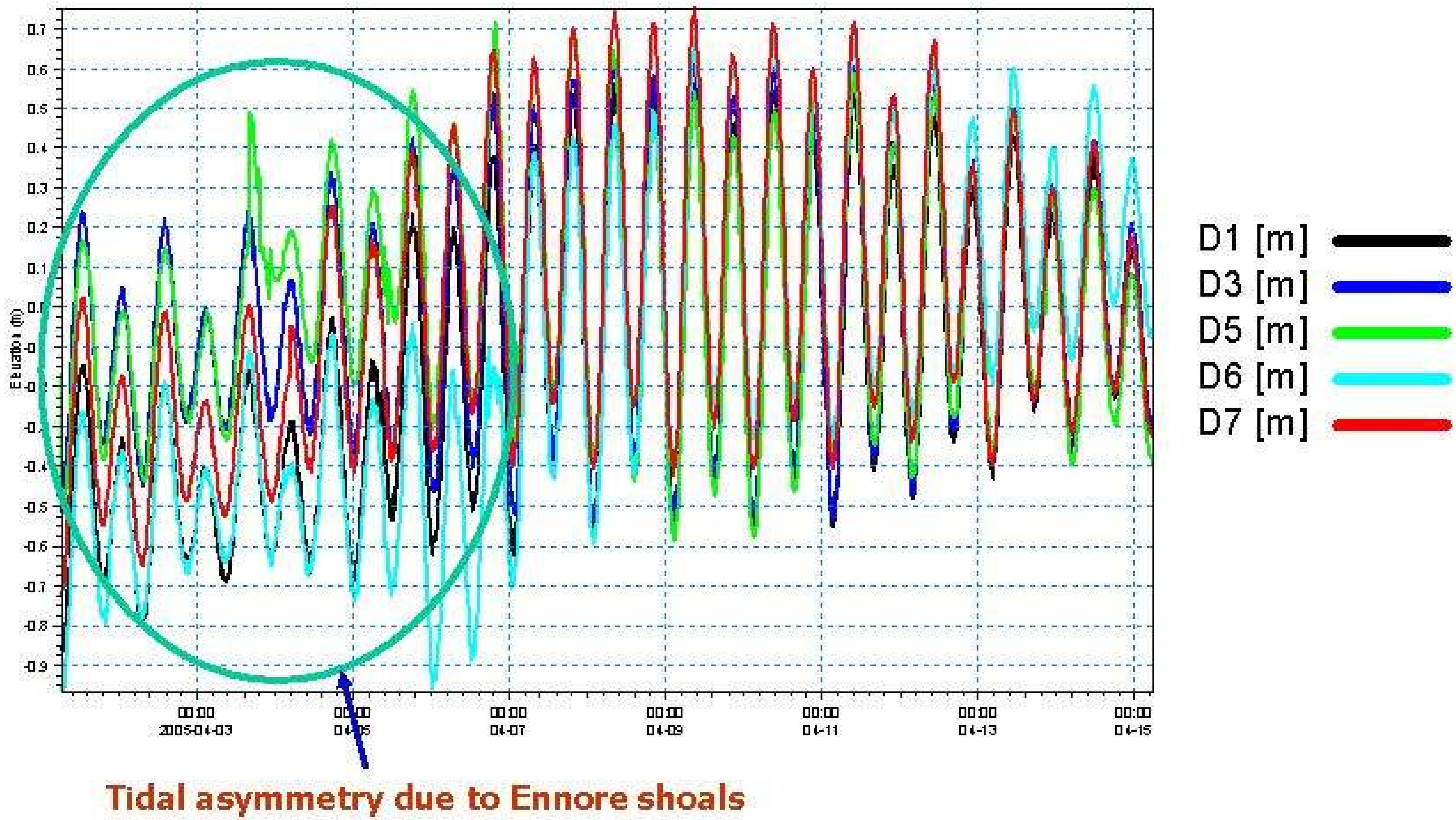

Fig. 2.11 – Water level variations at different stations (Sts D1, D3, D5, D6 and D7) during Phase I (April 05)

2.5 Currents and Circulation

Circulation at Ennore is seasonal and predominantly forced by tide and wind components. **Shankar et al (1996)** have studied East Indian Coastal Currents (EICC) and reported that EICC reverses direction twice a year, flowing Northeastward from February till September with a strong peak in March-April and Southwestward from October to January with strongest in November. Major driving mechanism of its variability was attributed to wind in the Bay of Bengal, which reverses with monsoons. It has also been reported that periods of peak monsoons do not coincide with times of maximum current speed. Under these uncertainties, it is difficult to assess the coastal circulation in East Coast. Observations made under the project on "Waste Load Allocation at Ennore" indicate a sudden reversal in current direction during the month of March 1999 from south to north.

Based on collated information from other sources and experiences of ICMAM-PD, a field experiment was designed to monitor the currents at 6 locations between Ennore and Pulicat. Out of 6 locations, at three locations, the current meters were moored with tide gauges and rest of the locations were monitored by hanging the instrument from the boat at water depth of 2 m from surface. All the currents observed at different locations were analysed.

The stick plot showing the current magnitude for the three phases of observations are shown in **Figs. 2.12 - 2.20**. Currents are southerly during NE monsoon i.e., Nov. 04 and Jan. 05 and northerly for SW monsoon i.e., April 05 and August 2006. The magnitude of the maximum and mean currents for four phases are given in **Table 2.6**.

Table 2.6 - Spatial Distribution of Current Magnitude and Direction at various stations (for the 4 phases of observations)

Location/ Station	Phase I			Phase II			Phase III			Phase IV		
	Average (cm/sec)	Maximum (cm/sec	Direction	Average (cm/sec)	Maximum (cm/sec	Direction	Average (cm/sec)	Maximum (cm/sec	Direction	Average (cm/sec)	Maximum (cm/sec	Direction
D1 h=2.5, H=10	20	45	SW	20	32	NE	4	6	NE & SW	--	--	--
D2 h=9.2, H=20	15	25	SW & NE	--	--	--	--	--	--	--	--	--
D3 h=4.2, H=6.5	25	48	S	20	30	N	18	25	N	--	--	--
D5 h=2.7, H=22	30	50	S	45	70	N	25	35	NNE	40	55	N
D6 h=2.6, H=10	25	65	S	30	35	N	15	22	N	--	--	--
D7 h=9.0, H=19	35	60	S	40	55	N	--	--	--	--	--	--

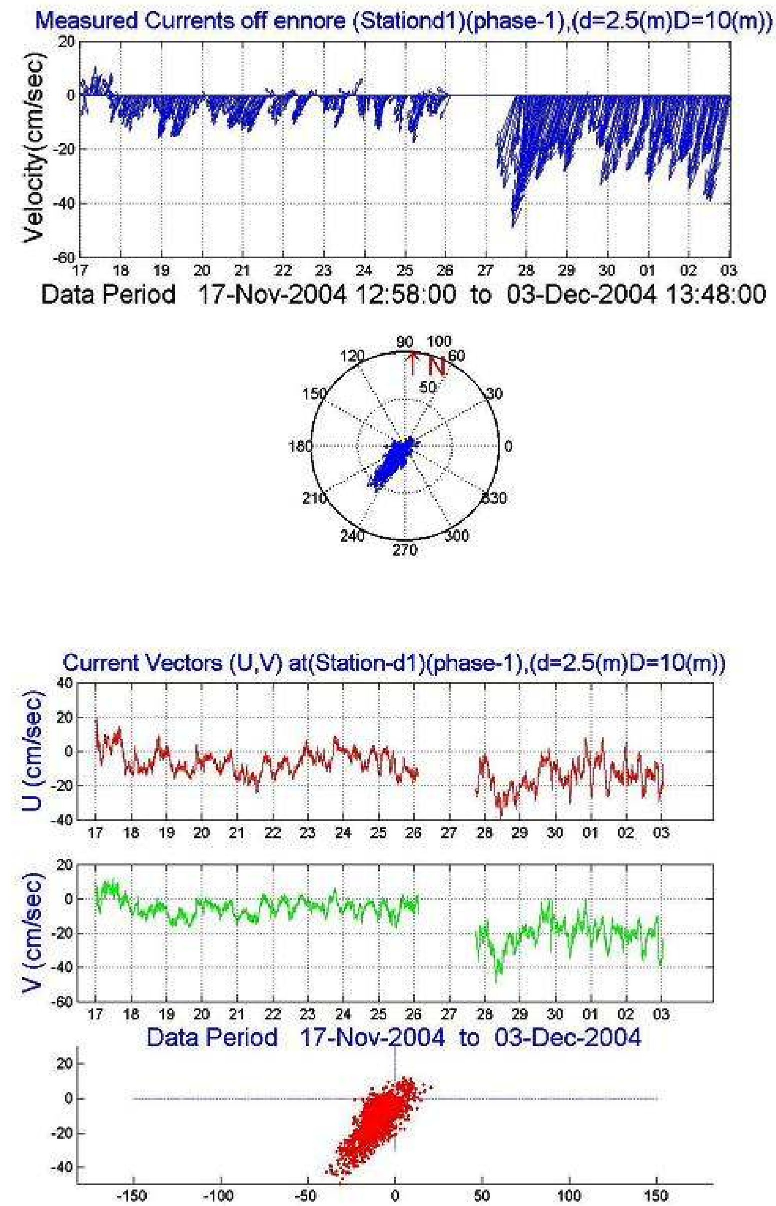

Fig 2.12 - Measured currents at Station D1, South of Ennore Port (Phase 1 - Nov. 04)

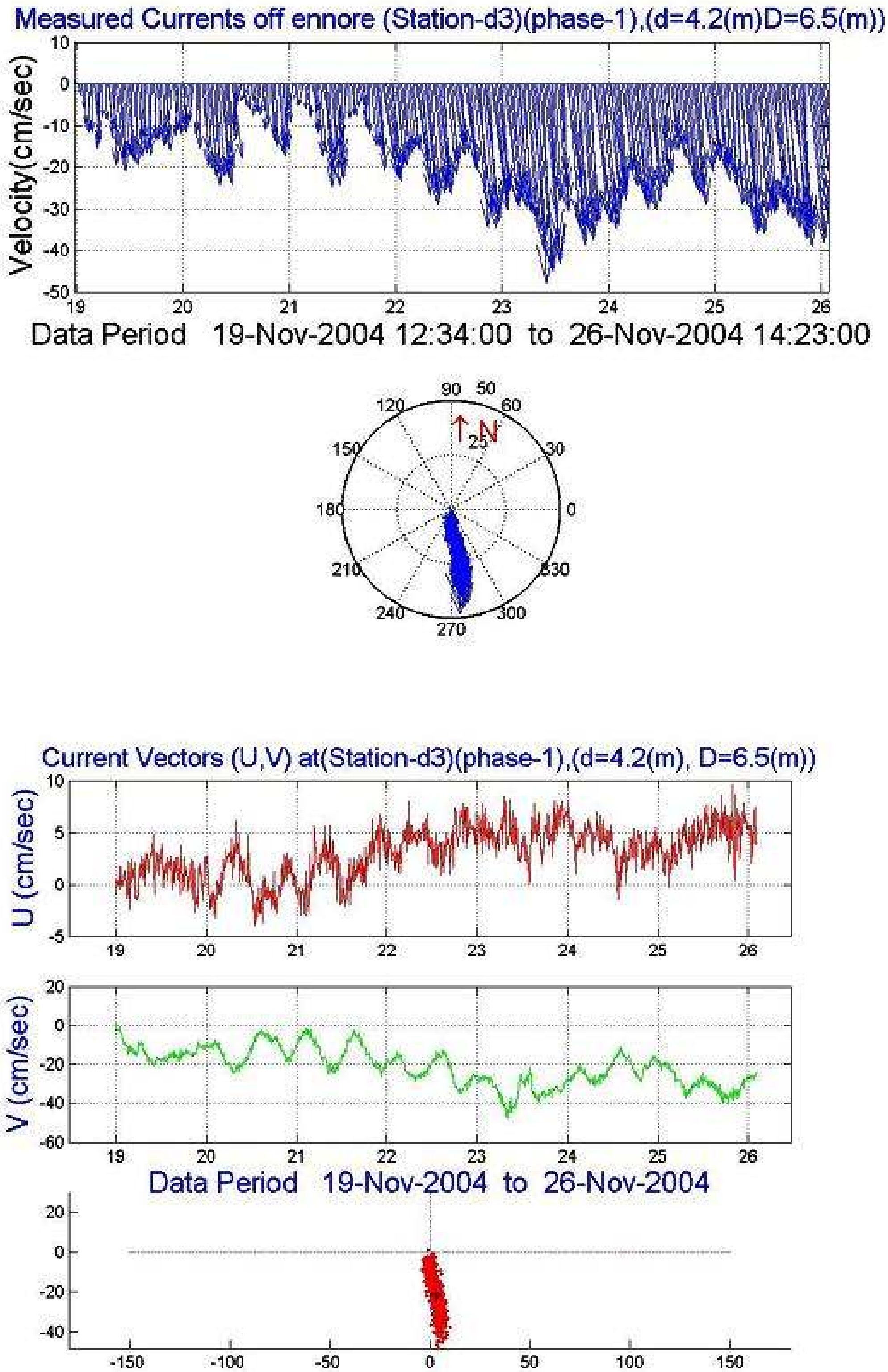

Fig. 2.13 - Measured currents at Station D3, North of Ennore Port (Phase 1 - Nov. 04)

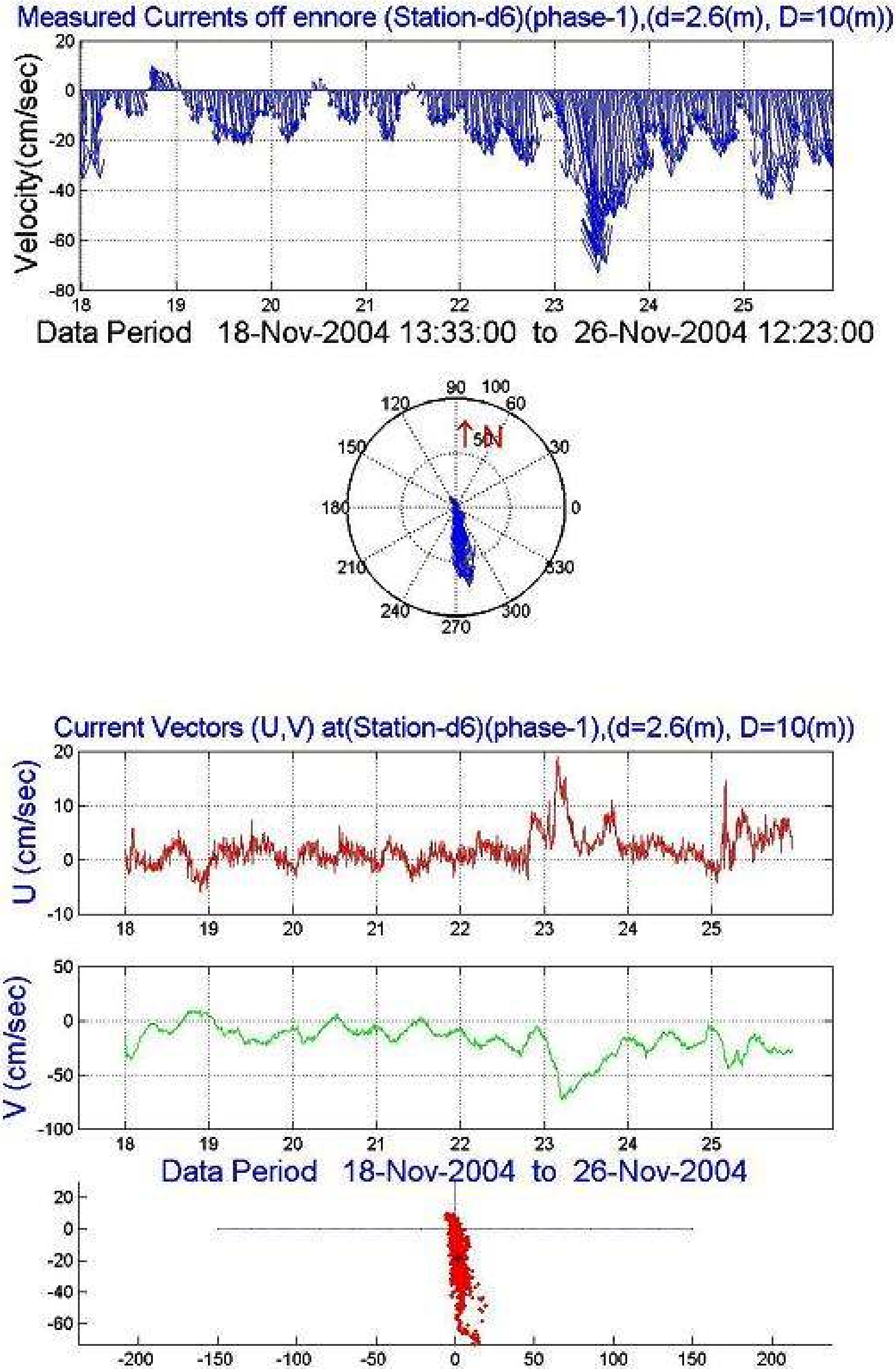

Fig. 2.14 - Measured currents at Station D4, North of Ennore Port (Phase 1 - Nov. 04)

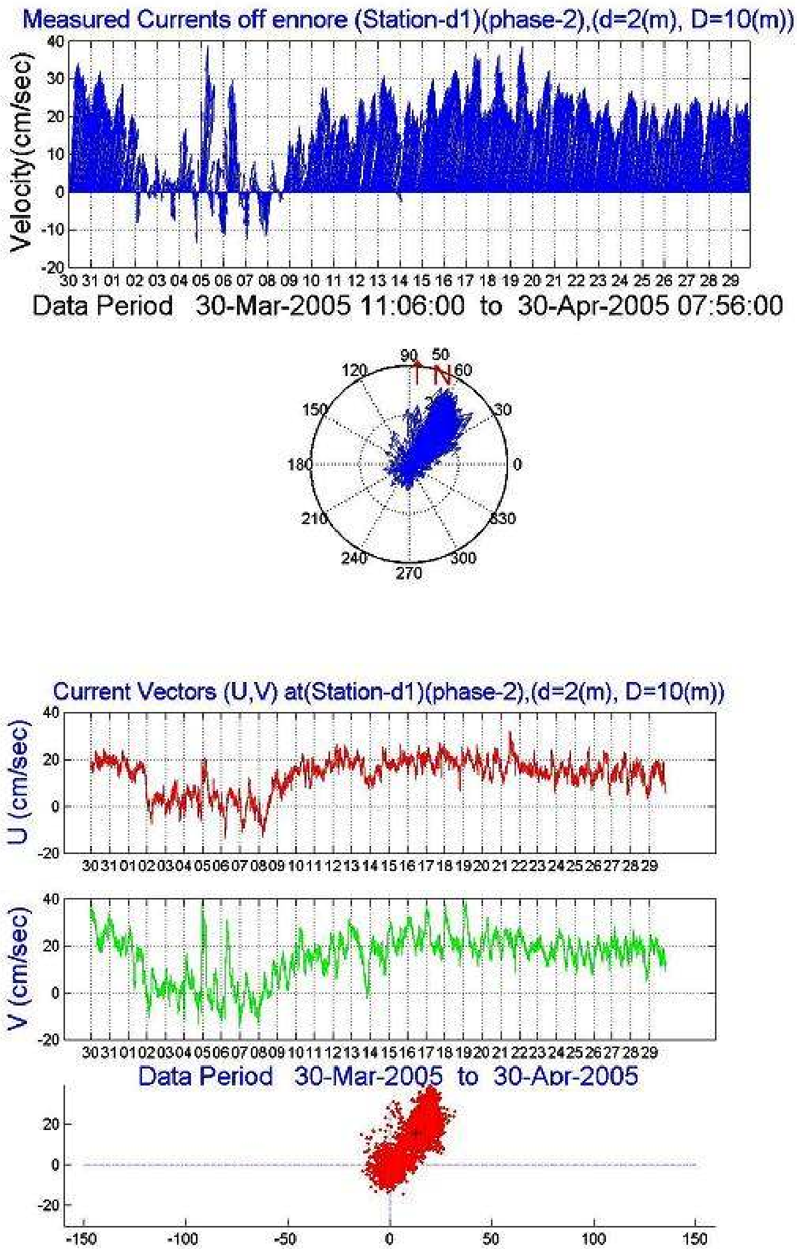

Fig. 2.15 - Measured currents at Station D1, South of Ennore Port (Phase 2 - Apr. 05)

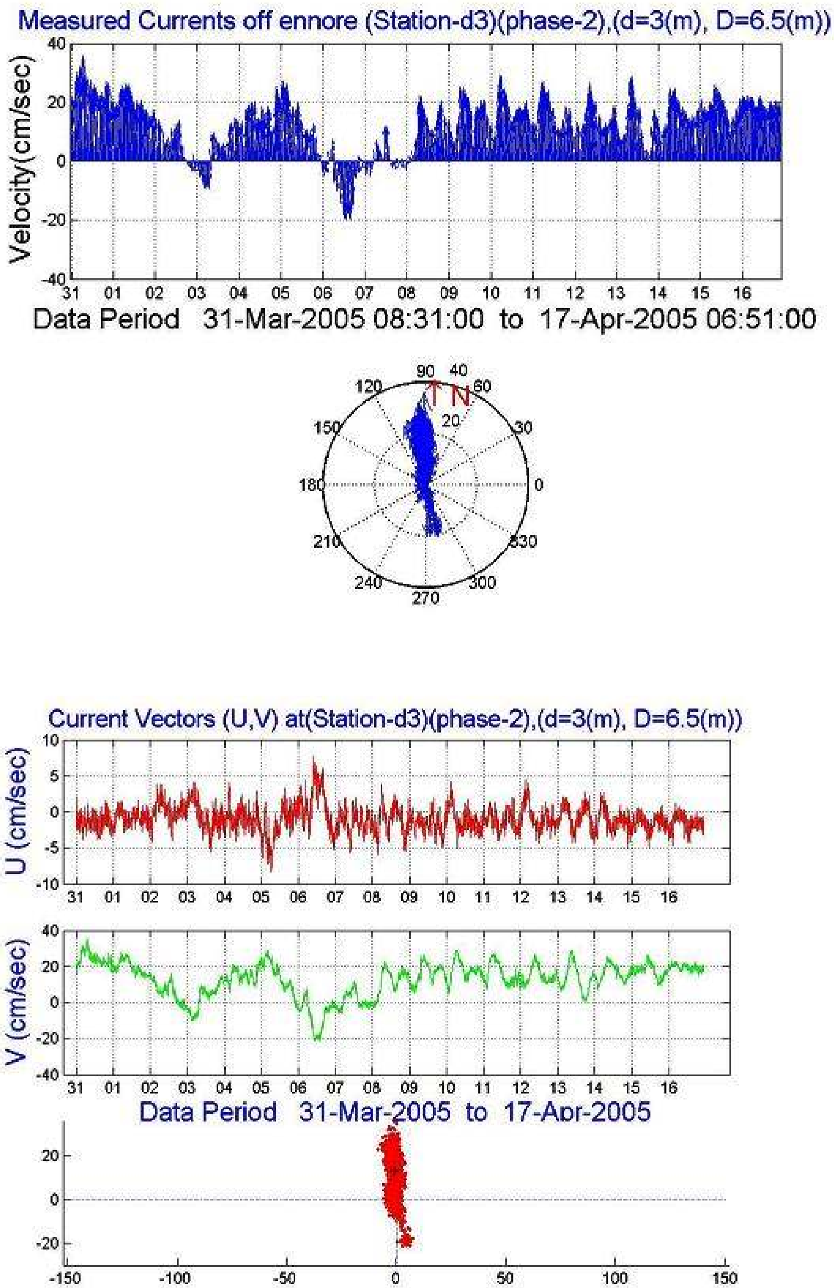

Fig. 2.16 - Measured currents at Station D3, South of Ennore Port (Phase 2 - Apr. 05)

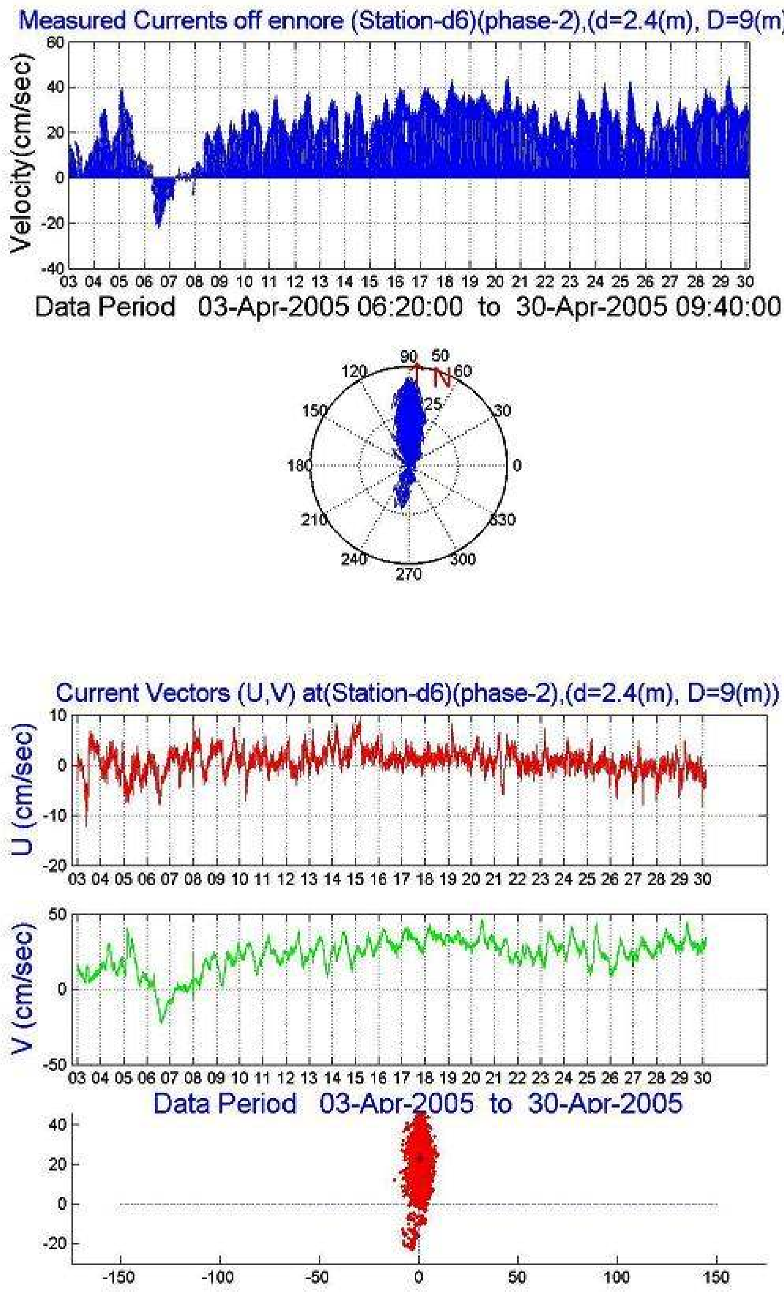

Fig. 2.17 - Measured currents at Station D6, South of Ennore Port (Phase 2 - Apr. 05)

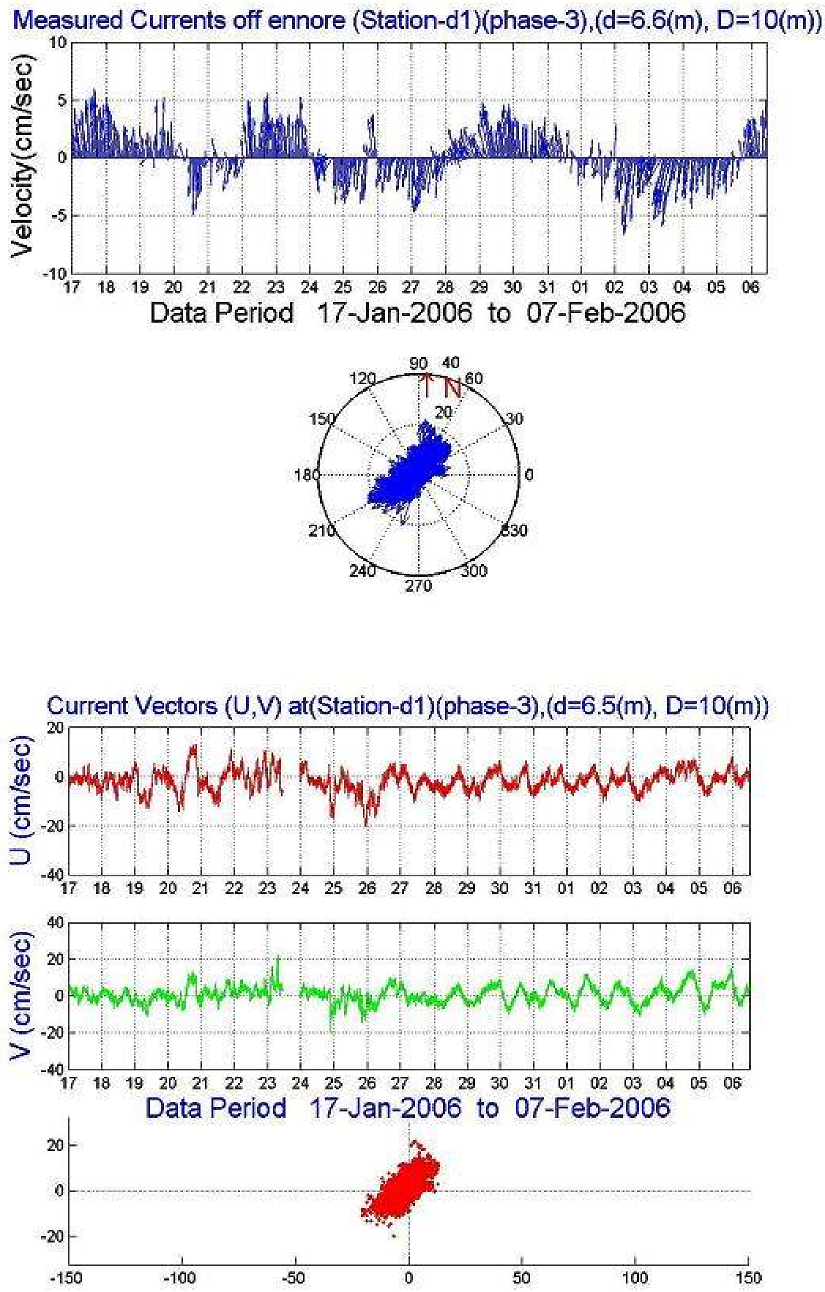

Fig. 2.18 - Measured currents at Station D1, South of Ennore Port (Phase 3 - Jan. 06)

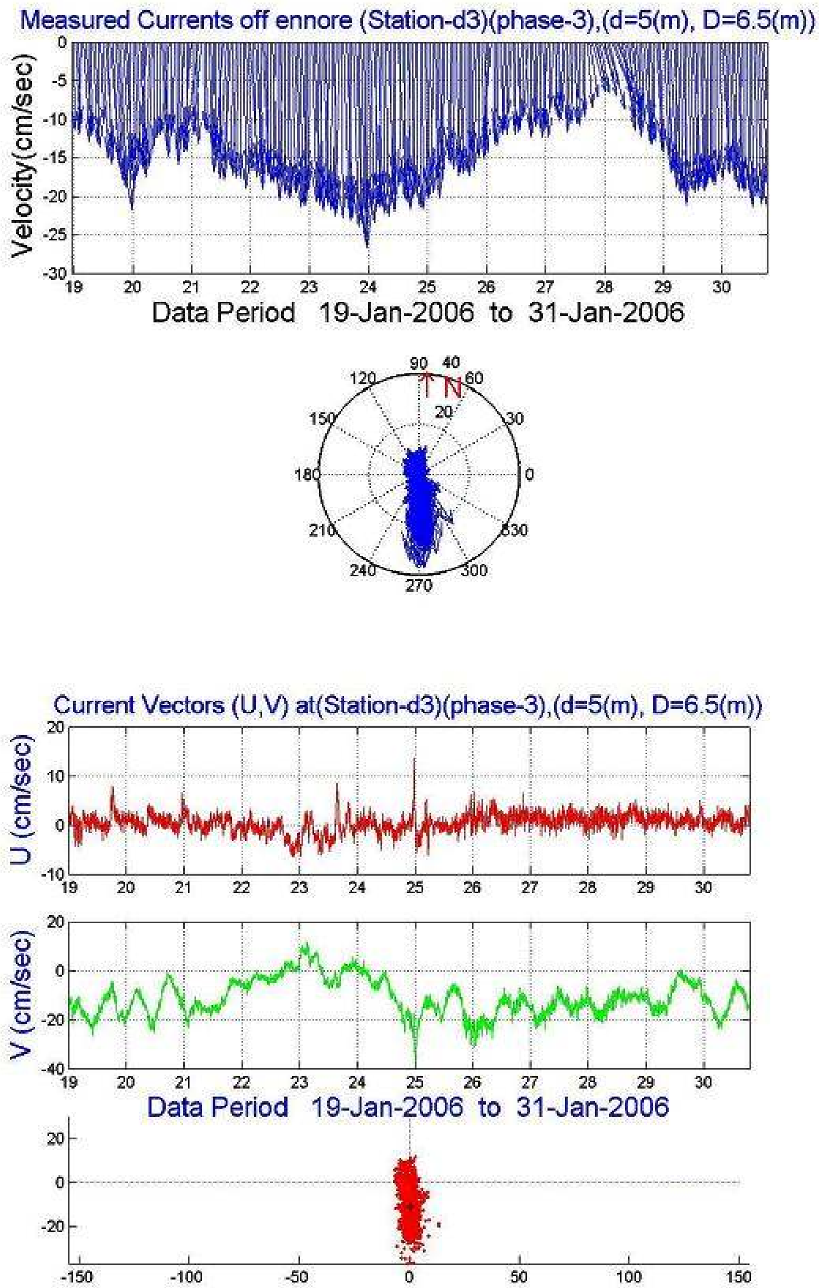

Fig. 2.19 - Measured currents at Station D6, North of Ennore Port (Phase 3 - Jan. 06)

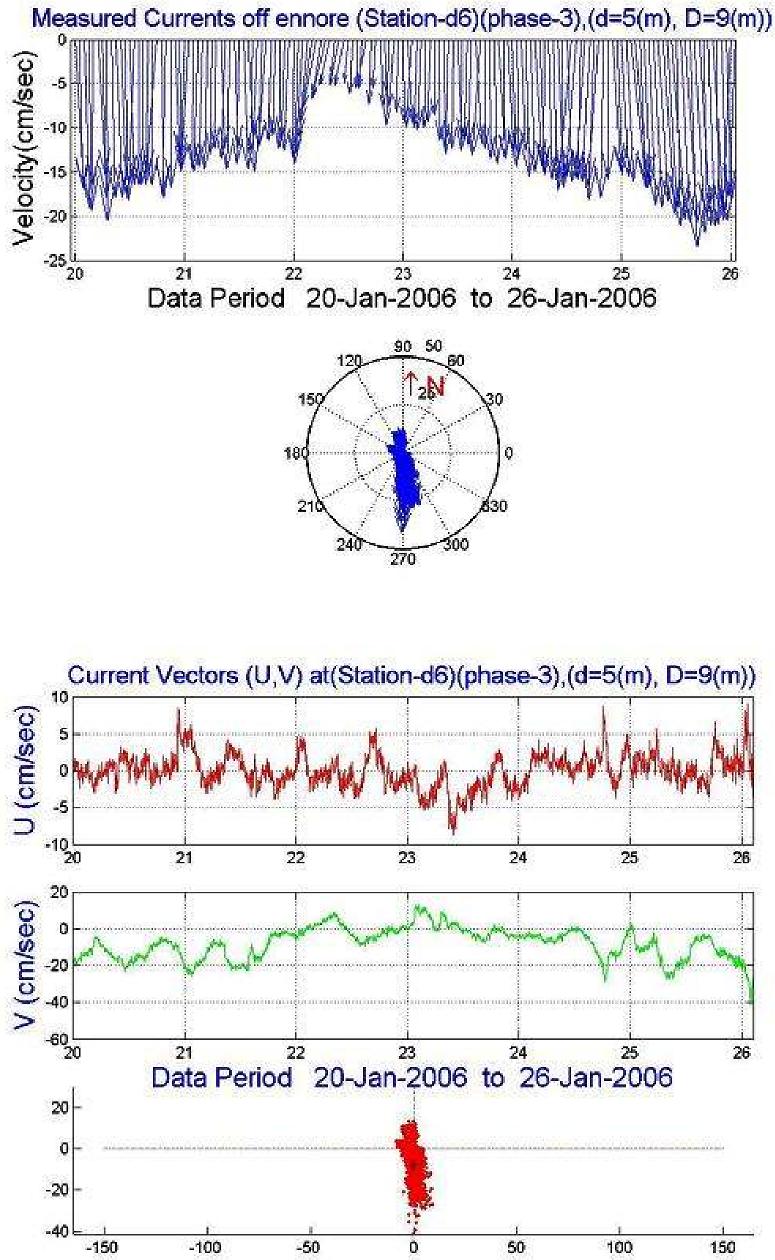

Fig. 2.20 - Measured currents at Station D6, North of Ennore Port (Phase 3 - Jan. 06)

Acoustic Doppler Velocimeter (ADV) (5 MHz) was deployed in nearshore area at a water depth of 3 - 6 m on either side of the Port to monitor mean currents, wave orbital velocities and turbulent velocities. The directional spectrum derived from p, u, v analysis based on Extended Maximum Entropy Principle (EMEP) method (**Hashimoto, N, 2002**). The three parameters required for the analysis are sampled at 4 Hz with 1024/2048 samples with a measuring interval of 30 minutes. The parameter 'p' from the pressure sensor and 'u, v' from the velocimeter located at a height of 1.1 m from the seabed. The result from the directional spectrum analysis at 3 stations, namely, station 1 (south of Ennore Port), station 2 (immediate north of Ennore Port) and station 3 (2 km from north of station 2 at Kalanji) are shown in **Fig.2.21**. Stations 2 & 3 show nearshore currents coincided with coastal currents and its direction is northerly during southwest monsoon and southerly during northeast monsoon. But, station 1, which is located at 500 m south of Ennore Port, is influenced by Ennore breakwaters, do not show any particular trend in the direction.

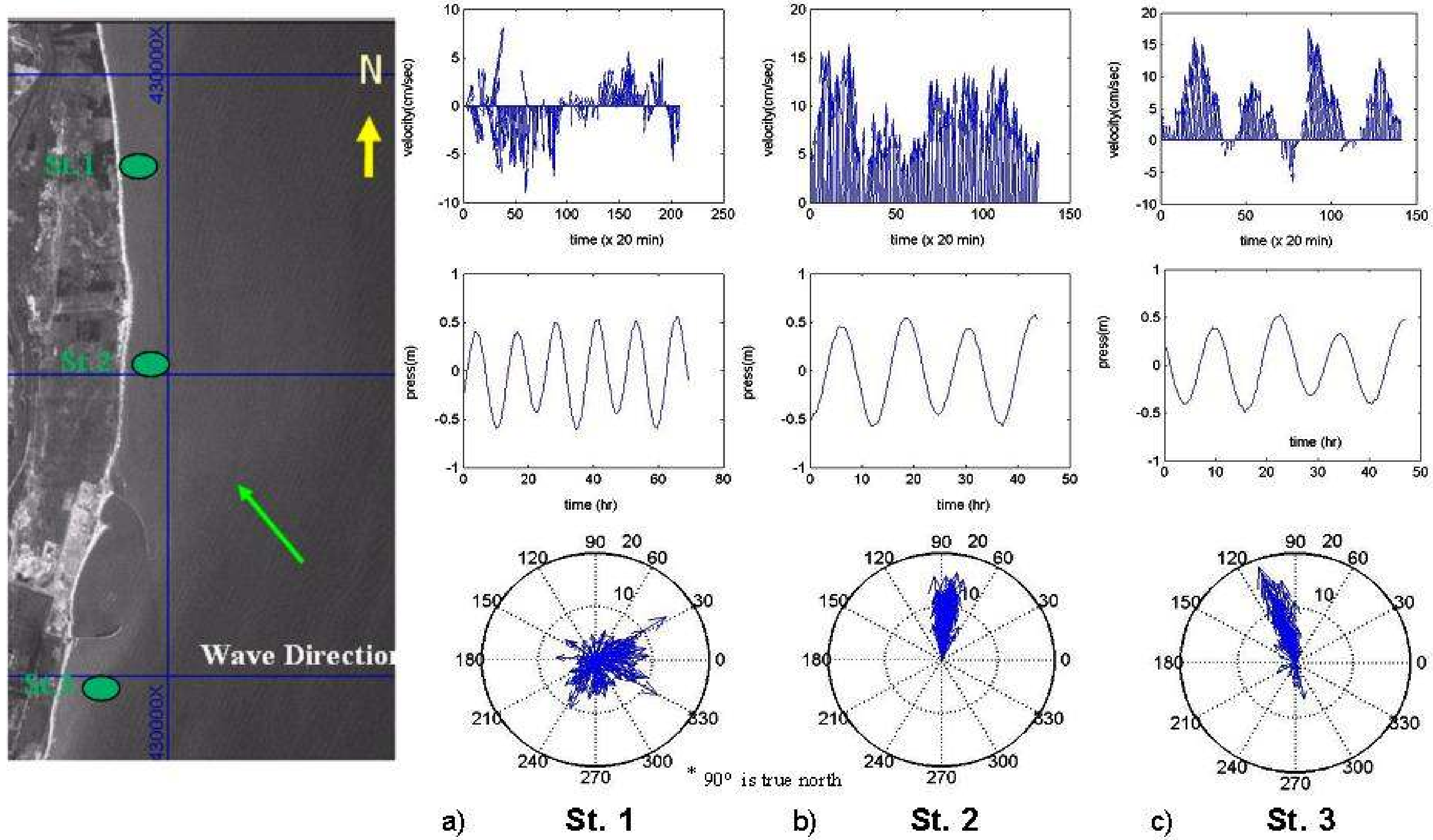

Fig 2.21 – ADV recorded currents at sts 1, 2 and 3 during Phase II (Apr 05)

2.6 Suspended Sediment Distribution

Plot of suspended sediment concentrations for phase I (Nov 04), phase II (Apr 05) and Phase III (Jan 06) periods is shown in **Fig 2.22.** In phase I & II (**Fig 2.22a**) the isolines are more closely packed in the region just immediate N & NE of northern breakwater (Ennore port), indicating the presence of high concentration of suspended sediment. Presence of high concentration (12 – 18 mg/litre) on north of Ennore port may be due to generation of turbulence related to the presence of Ennore shoals or port structures. It is observed that the suspended sediment concentration decreased offshore i.e. as one goes away from the port region. Near the shoreline, the concentration is about 8.5-18.1 mg/litre while at 20m depth contour (around 7km offshore) the concentration reduced to 6.6 – 8 mg/litre. It is also noticed that the suspended sediment concentration decreased along the coast as one goes away from the port region; on northern side the concentration decreased from 18.1 mg/litre (near northern breakwater) to 8.5mg/litre (near Pulicat mouth). On southern side it decreased from 12.3mg/litre (southern breakwater) to 10mg/litre (near Ennore creek). It is clearly noticed that the suspended sediment movement has a tendency to move along the coast northward during phase II and southward during Phase I & III periods. Thus the suspended sediment movement is driven by the seasonal coastal currents.

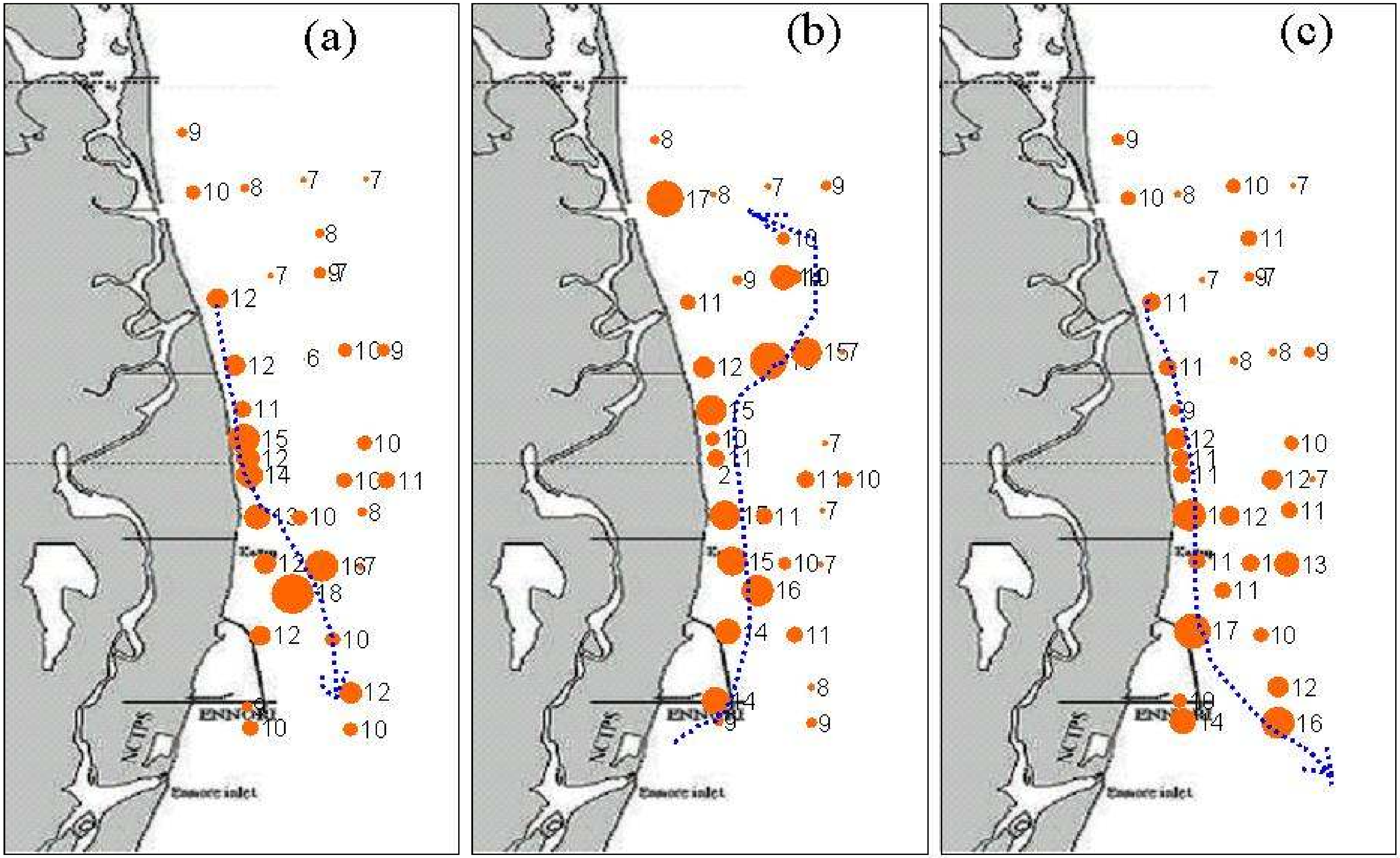

Fig. 2.22 - Suspended sediment concentration (mg/l) a) Phase I, b) Phase II and c) Phase III (Hypothetical track of ssd movement)

Comparison of suspended sediment concentration for 34 locations (R1 to R34) between phase I, II & III periods is shown in **Fig 2.23.** Suspended sediment concentration values during Phase I and Phase III show almost similar variation because the phase I & III periods lies in the NE monsoon conditions. A different trend in the distribution of suspended sediment concentration in phase II period is attributed to either SW monsoon condition or tsunami occurrence.

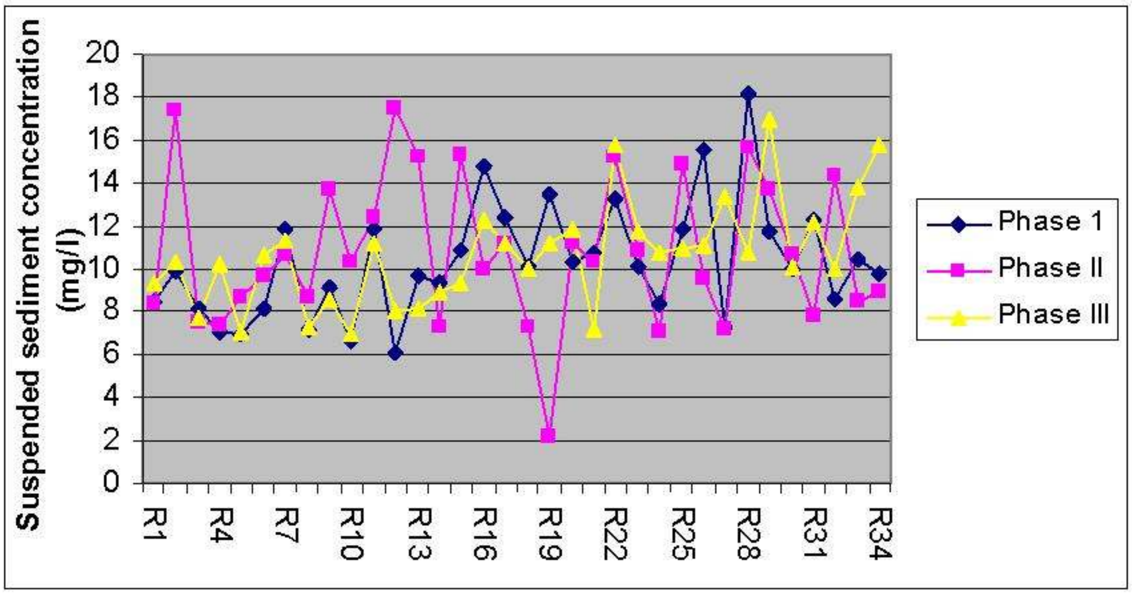

Fig 2.23 – Comparison of suspended sediment concentration (mg/l) during Phase I (Nov 04), Phase II (Apr 05) and Phase II (Jan 06)

2.7 Beach and Bed load sediment distribution

To understand the sediment distribution pattern along the Ennore coast, bottom sediment samples (R1 to R34) in offshore waters (upto 25m depth contour) and beach sand samples at selected locations were collected and analyzed **(Figs 2.24 and 2.25)**. Beach sand samples were treated **(Inman, 1949)** and subjected to sieve analysis using ASTM sieves at ½ phi interval for 15 minutes. Sediments were classified and analysed by following **Wentworth (1947)** and **Folk and Ward (1957)**. Underwater sediment samples were analysed for size by using Particle Size Analyzer for phase I, II and III and presented.

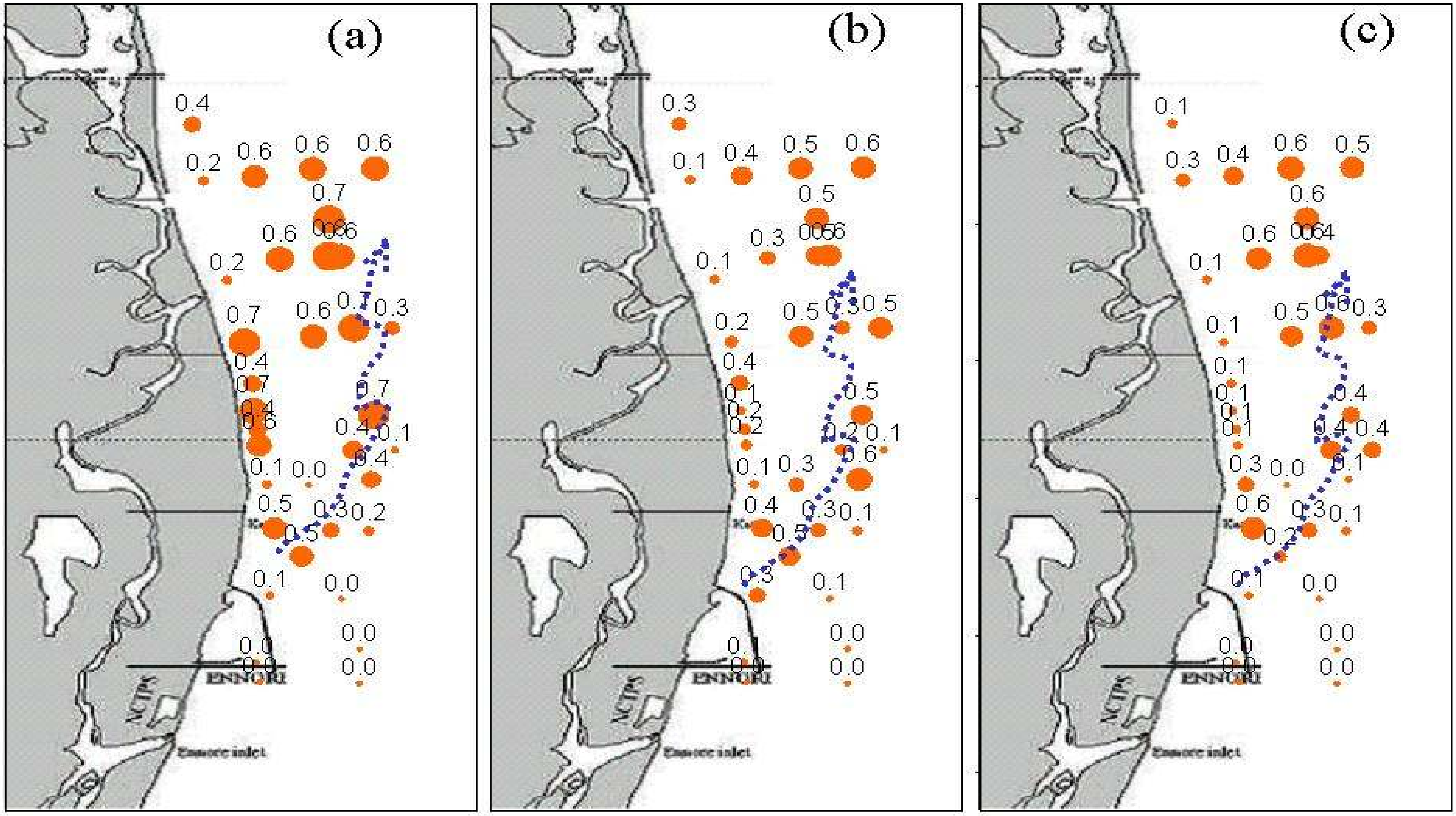

Fig. 2.24 - Bedload sediment size (mm) a) Phase I b) Phase II and c) Phase III

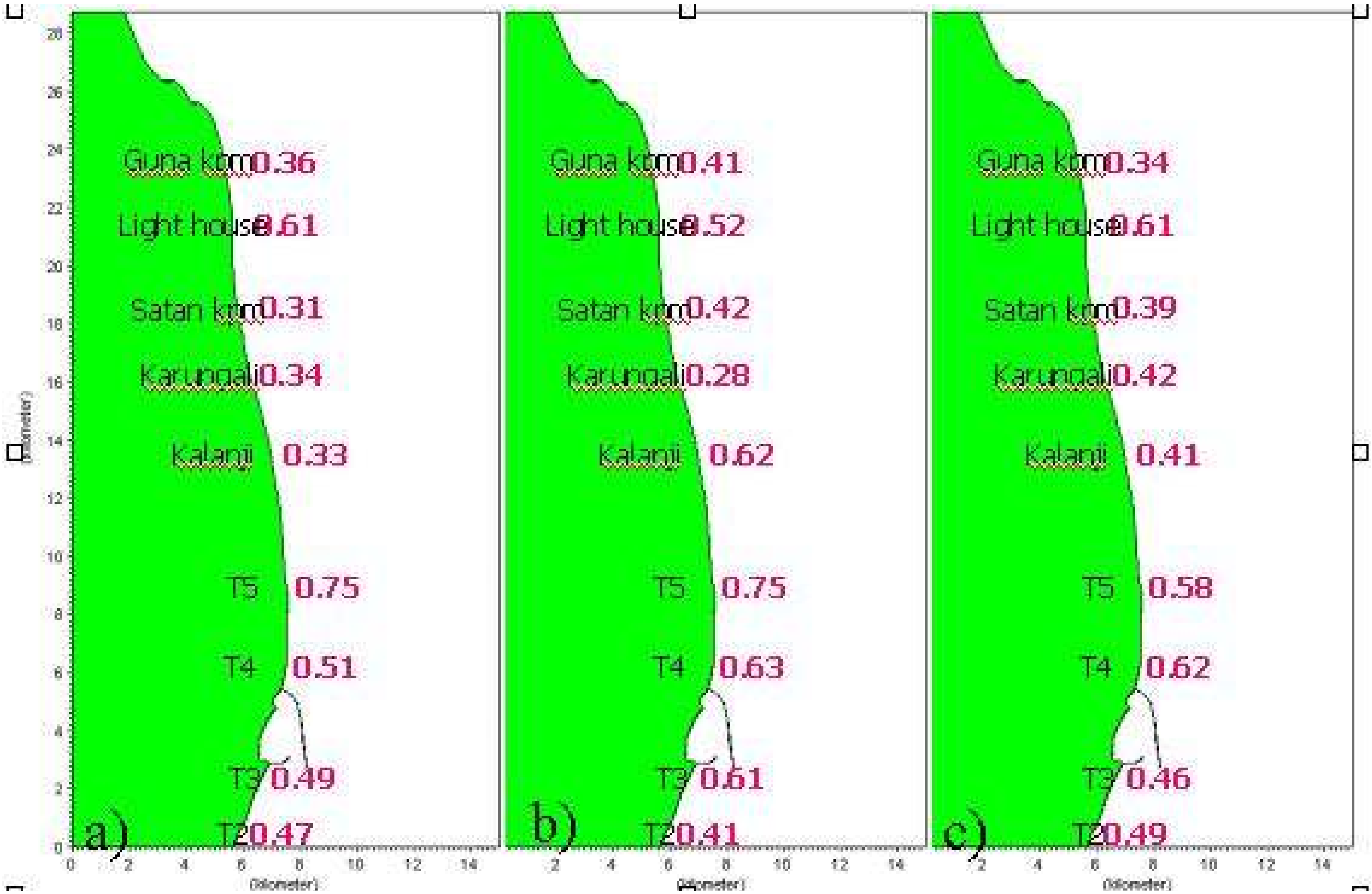

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Fig. 2.25 – Beach sand size (mm) along Ennore coast for a) Phase I (Nov 04), Phase II (Apr 05) and Phase III (Dec 05)

Ennore sediments fall under coarse (1.0 - 0.5 mm) to medium (0.5 - 0.25 mm) sand class where medium grained sand is predominant. In general, the sands are moderately well sorted to moderately sorted, positive to negatively skewed but predominantly symmetrical during SW monsoon and negatively skewed during NE monsoon indicating excess of fines, platykurtic to leptokurtic, majority being mesokurtic. In general, the sand characters indicate a relatively medium energy environment along this stretch.

Alongshore and cross-shore variations in sand characters are not showing any particular trend in relation to littoral drift. This could be attributed to varying levels of wave energy and alternative zones of convergence and divergence along the shore and it may also be due to the reversal of nearshore currents owing to NE and SW monsoons.

In general, the grain size of bottom sediment varied between 0.01 to 0.7 mm with an average of 0.32 mm. Bottom sediments in offshore waters are predominantly of silt and to a lesser extent clay except in the region of shoal where medium size sand was noticed. Relatively higher grain size probably derived from beach fill area and may be transported and got deposited in the direction of NE where they come across shoals. Higher size may also be due to the lifting of fines and leaving behind the coarse when waves encounter the shallow depths (shoals) suddenly which leads to turbulent effects. However, both the reasons need confirmation based on detailed mineralogical studies.

The Coarser and moderately sorted sediments with symmetrical nature at north of the port are favorable for longevity of nourishment. However all along the beach, the sand is mainly medium to coarse grained and moderately sorted and their size varied from 0.31 to 0.75mm.

Comparison of sediment size for different stations (R1 to R34) for three phases (**Fig. 2.26**) show more or less similar features except in the region from Kalanji to Satankuppam stretch (sts R11 to R21) where the orientation of the coast and relatively more deeper depths compare to adjacent nearshore areas may influence the pattern of sand. On the whole the sediment sizes of 0.22mm (2.1ϕ) to 0.33 mm (1.32ϕ) are most predominant along the beach and 0.11mm (3.14ϕ) in offshore areas.

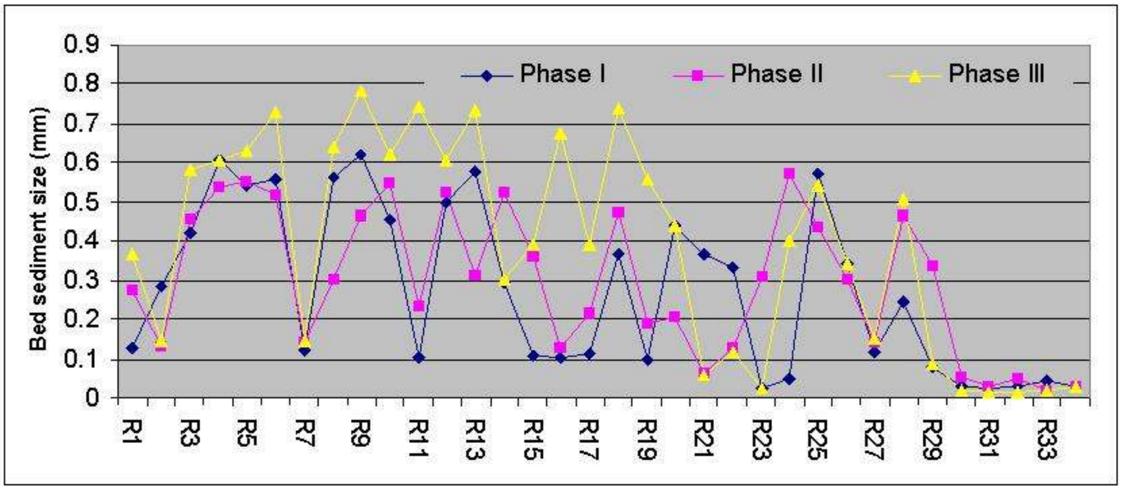


Fig 2.26 – Comparison of grain size (phi) for Sts R1 to R34 for a) Phase I (Nov 04), b) Phase II (Apr 05) and Phase III (Dec 05)

In order to study the qualitative and quantitative aspect of sediment deposition, locally made sand traps were deployed at 4 stations (Sts D1, D3, D5 & D6) during phase III (Dec 05) period. Analysis of the sediment collected in sand traps (**Fig 2.27**) reveal that St D6 shows entirely different trend in sedimentation than the other 3 stations. Sts D1 and D5 (**Fig. 2.27**) show similar characteristics of sediment which indicate that most of the sediment transport is by passing from south of Ennore port (from St. D1) to offshore area in the NE direction where St D5 is located. St D3 shows mixed trend of sediment distribution pattern which may be due to erosion and spreading of beachfill material. Distribution of settling rates of sediment at different stations (**Fig 2.27b**) indicate that sts D1 and D5 show more or less similar rates. St D6 show more sediment settling rate compared to the other stations.

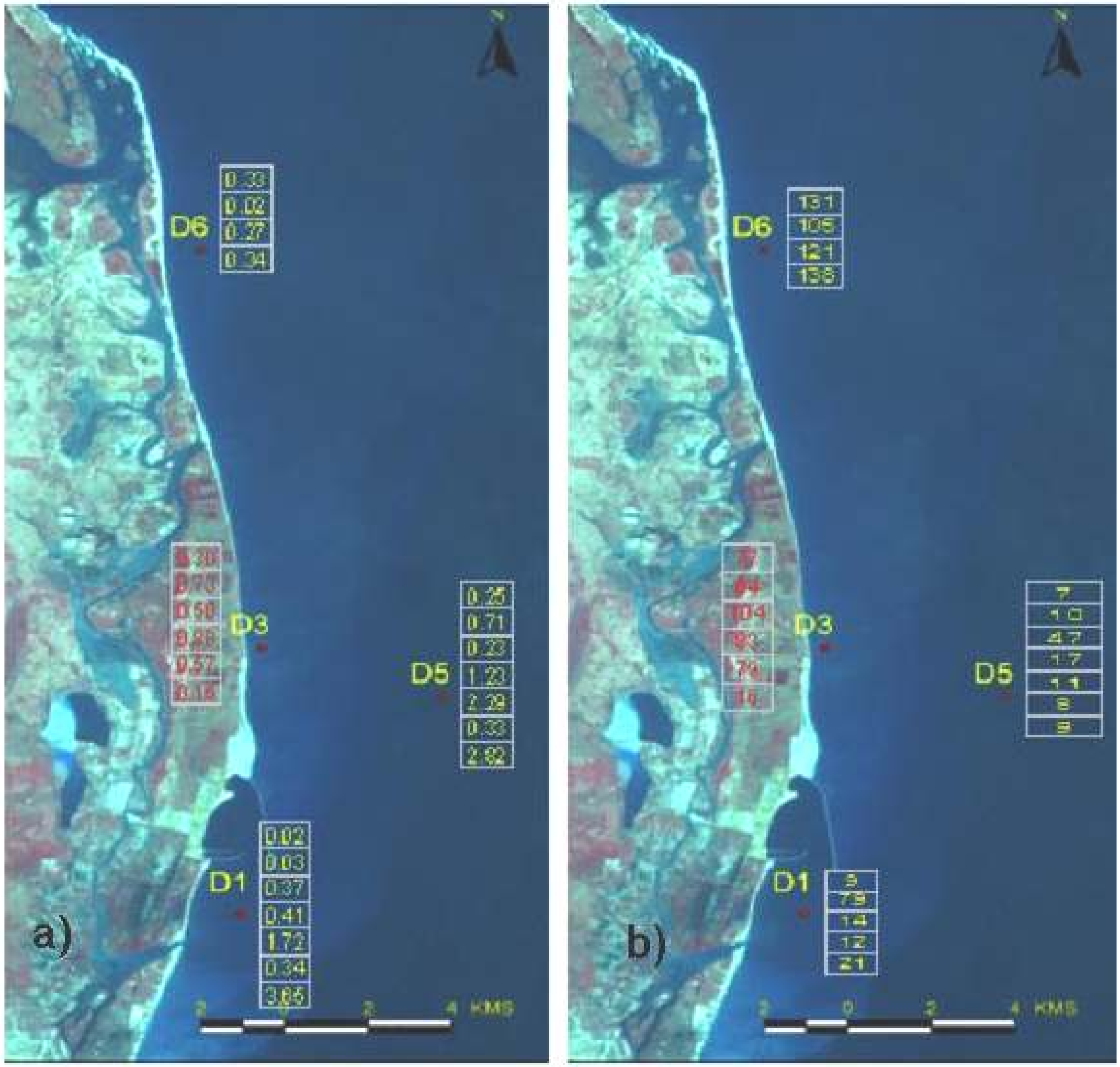


Fig 2.27 – Distribution of a) settling rate (grams/hr) and b) sediment size (microns) at different stations during phase II (Dec 05)

2.8 Littoral Environmental Observations

Field observations on littoral parameters (Breaker ht, period, longshore current speed and direction, breaker angle etc.) along Ennore coast were made during phase I, Phase II and Phase III periods. Results are presented and discussed below.

Zone I (Ennore port area): Field observations on Littoral Environmental parameters along north and south of Ennore port during Phase I, Phase II and Phase III periods (**Table 2.7**) are presented below.

North of Ennore port: The northern shore of Ennore port is occupied predominantly with spill breakers of height 0.2-1.7m under Phase I, 0.3-1.3m under Phase II and 0.2-1.0m under phase III. Much of the incoming wave energy is expended in breaking before it reaches the shoreline indicating dissipative beach. Surf zone is wide along this zone due to the presence of shoals. Occasionally, wave breaking is noticed on immediate north due to the shoals. The strength of the longshore currents is 0.01-0.14m/s under Ph I; 0.08-0.24m/s under Ph II; and 0.05-0.12m/s under Ph III. The direction of longshore current is predominantly southward during Ph I & III (NE monsoon condition) periods and northward during Ph II (SW monsoon condition) period even though at some places bi-directional longshore current occur.

South of Ennore port : The southern shore is predominant with plunging type of breakers, having heights of 0.3-2.0m under Phase I, 0.3-1.3m under Ph II and 0.3-1.6m under Phase III. Along this stretch within 1 km from south breakwater, the waves break almost on the beach leading to reflective beach. Surf zone is very narrow along this stretch. Beyond 1km south, breaking of waves occur before reaching the coast indicating dissipative beach. The strength of the longshore currents are 0.02-0.14m/s under Ph I; 0.07-0.15m/s under Ph II; and 0.10-0.15m/s under Ph III. The direction of Longshore current is southward under Ph I & III (NE monsoon condition) periods while northward under Ph II (SW monsoon condition).

On the whole the beach on the northern side of port is dissipate beach occupying with spill breakers. However, the beach on southern side is reflective beach predominant with plunging breakers. Along north coast the spillers run long distance before reaching the shore while on south coast plungers breaking almost at shore. Thus Breaker zone is wider on north while narrow on south; Wave crests approaching shore with higher angle on north when compared with that on south; On north, much of the incoming wave energy is expended in breaking before it reaches the shoreline indicating dissipative beach, However on south the waves breaking almost nearer to shoreline with grater height indicating reflective beach.

Table 2.7a– Littoral environmental observations along Ennore coast during Phase I (Nov 04)

Phase I						
Location	**Breaker type**	**Breaker height (m)**	**Breaker period (Sec)**	**Breaker angle**	**LSC Speed (m/s)**	**LSC dir**
		Zone I				
North of Ennore port	spilling	1.0-1.7 (foreshore) 0.2-0.8 (nearshore)	6 to 11	10-15^{o}	0.01 – 0.14	south
South of Ennore port	Plunging &Spilling	1.5-2.0 (foreshore) 0.3-1.0 (nearshore)	6 to 11	5-7^{o}	0.02 – 0.12	south
		Zone II				
North Kattupalli to light house	Plunging & spilling	1.2-2.5 (foreshore) 0.2-0.7 (nearshore)	5 to 12	3 to 7^{o}	0.02-0.21	Oscillatory
		Zone III				
South of Pulicat mouth	Plunging & spilling	1.8-2.5 (foreshore) 0.2-0.4 (nearshore)	6 to 9	3 to 7^{o}	0.02-0.3	Oscillatory
North of Pulicat mouth	spilling	0.8-1.5 (foreshore) 0.2-0.4 (nearshore)	4 to 9	5 to 9^{o}	0.02-0.04	north

Zone II (Between Kalanji & Satankuppam): The region is usually occupied with submerged shoals in the surf zone. Initially the breakers start as plungers at seaward end of surf zone, once they reach the shoal area they become spill breakers. Along this stretch the breakers (wave crests) approach the shoreline in bidirections from SE and NE. Breaker height varied from 0.2 to 2.5m in phase I, 0.4 to 1.0m in phase II and 0.2 to 0.8m in phase III. The bi-directional approach of waves leads to an oscillatory long shore current that runs sometimes northward and southward with varying speeds between 0.02 and 0.21m/s. The shoreline is occupied with sand backed shore line and there is no sand dunes. Since the majority of the surf zone occupied with spill breakers of varying heights this beach is also dissipative beach.

Table 2.7b – Littoral environmental observations along Ennore coast during Phase II (Apr 05)

Phase II						
Location	**Breake r type**	**Breaker height (m)**	**Breaker period (Sec)**	**Breake r angle**	**LSC Speed (m/s)**	**LSC dir**
			zone I			
North of Ennore port	plungin g	1.2 - 1.7(foreshore) 0.3-0.5(nearshore)	7 to 10	10 to 15	0.08 - 0.24	north
South of Ennore port	spilling	1.0 - 1.3 (offshore) 0.3 – 1.0(nearshore)	6 to 8	8 to 9	0.07 - 0.15	north
			Zone II			
North Kattupalli to light house	plungin g	1.3 - 1.5 (foreshore) 0.4-0.7(nearshore)	7 to 8	13 to 17	0.12 to 0.13	north
			zone III			
South of Pulicat mouth	plungin g	1.2 - 1.5 (foreshore) 0.3 – 0.5 (nearshore)	8 to 9	15 to 18	0.1 - 0.3	north
North of Pulicat mouth	spilling	1.0 - 1.2 (foreshore) 0.2-0.5 (nearshore)	7 to 9	15 to 20	0.12 - 0.24	north

Zone III (Pulicat confluence): The north shore is very flat and wider and occupied with mostly spill breakers of heights 0.2-1.5m. Littoral currents speeds of the order of 0.02 to 0.3m/s moving in north direction. The south shore of Pulicat confluence is mainly depositional shore and occupied with a small bay like formation. Plunging wave heights of 2-2.5m at Seaward end of breaker zone and spillers of height 0.2-0.4m in the surf zone are noticed. Longshore current is oscillatory i.e. northward sometimes and southward in other times because of bi-directional approach of wave crests from NE & SE directions.

Table 2.7c – Littoral environmental observations along Ennore coast during Phase III (Dec 05)

Phase III						
Location	**Breaker type**	**Breaker height (m)**	**Breaker period (Sec)**	**Breaker angle**	**LSC Speed (m/s)**	**LSC dir**
			Zone I			
North of Ennore port	spilling	0.5-1.0 (foreshore) 0.2-0.5 (nearshore)	5 to 7	10-15o	0.05 – 0.12	southwar d
South of Ennore port	Plunging &Spilling	1.2-1.6 (foreshore) 0.3-1.0 (nearshore)	7 to 9	10 to 12o	0.10 to 0.15	southwar d
			Zone II			
North Kattupalli to light house	Plunging & spilling	0.7-1.0 (foreshore) 0.2-0.8 (nearshore)	6 to 8	5 to 10	0.05 to 0.12	southwar d
			Zone III			

Phase III						
Location	**Breaker type**	**Breaker height (m)**	**Breaker period (Sec)**	**Breaker angle**	**LSC Speed (m/s)**	**LSC dir**
South of Pulicat mouth	Plunging & spilling	0.5-0.9 (foreshore) 0.2-0.4 (nearshore)	6 to 9	3 to 7 o	0.02-0.09	southward
North of Pulicat mouth	spilling	0.8-1.0(foreshore) 0.2-0.6(nearshore)	4 to 9	5 to 9 o	0.02-0.04	oscillatory

On the whole it is observed that during SW monsoon period the longshore current velocities are relatively high compared to that during NE monsoon period. The littoral currents are directed to north along the coast during SW monsoon conditions and south during NE monsoon conditions (**Fig 2.28**).

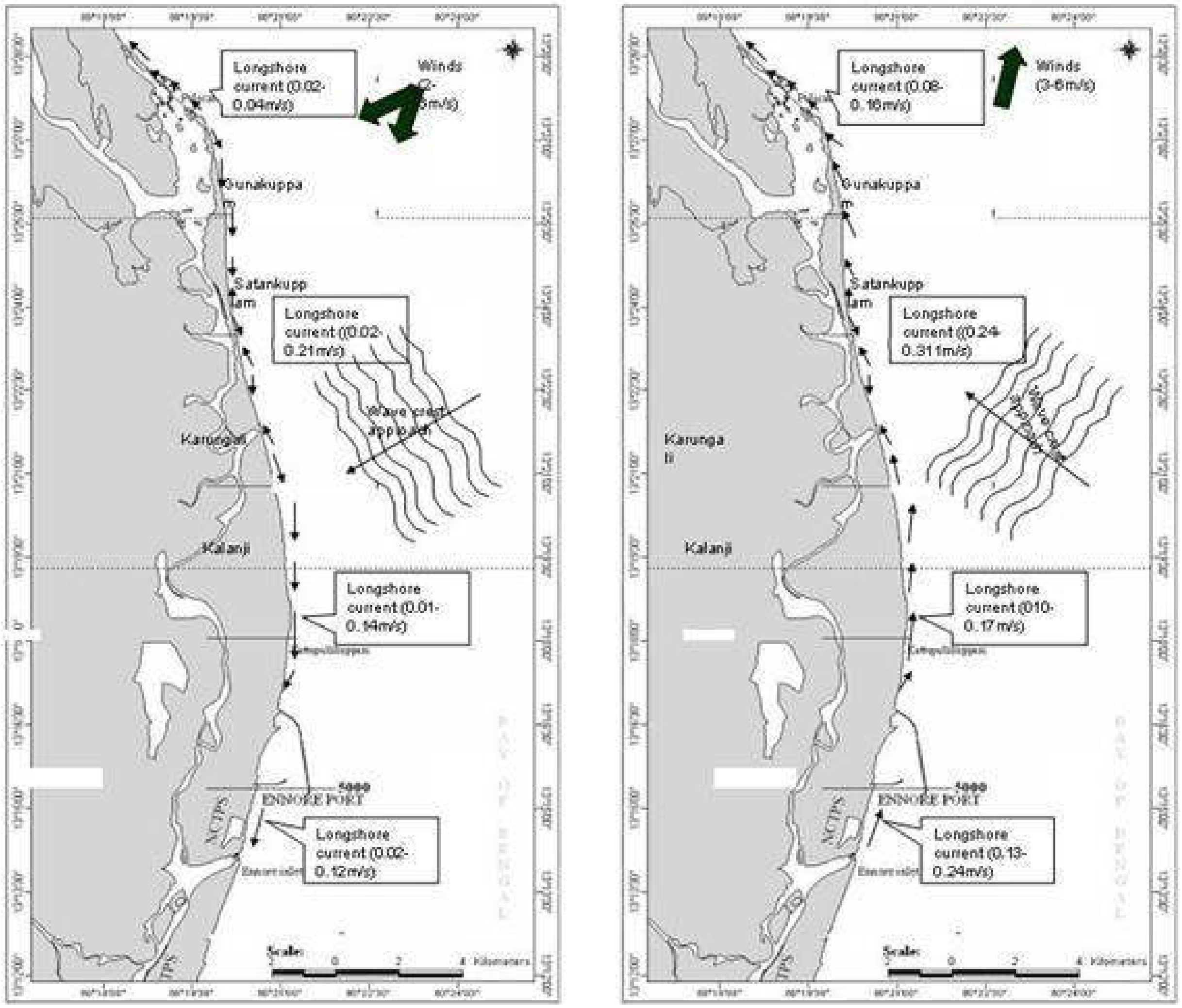


Fig 2.28 – Hypothetical picture of littoral processes during a) NE monsoon (Nov 04) and b) SW monsoon (Apr 05)

2.9 Beach Profile Changes

The Ennore coastline is typical in its orientation. From Ennore creek to Kattupalli the shoreline orients in the direction of 17^0 N where as from Kattupalli onwards it orients in 350^oN. This 27^o change in shoreline orientation may lead to wide variation in nearshore sediment transport pattern. In order to study the seasonal variation in sediment transport pattern and to identify the erosion/ deposition cells, number of cross-shore beach profiles (Tn3 to Tn25) at a number of transects along Ennore coast (**Fig 2.29**) were measured with RTK. These profiles were then reduced to chart datum and the variation in cross-sectional volume across 25 profiles were computed for phase I (Nov 04), phase II (Apr 05) and Phase III (Dec 05) periods (**Table 2.8).**

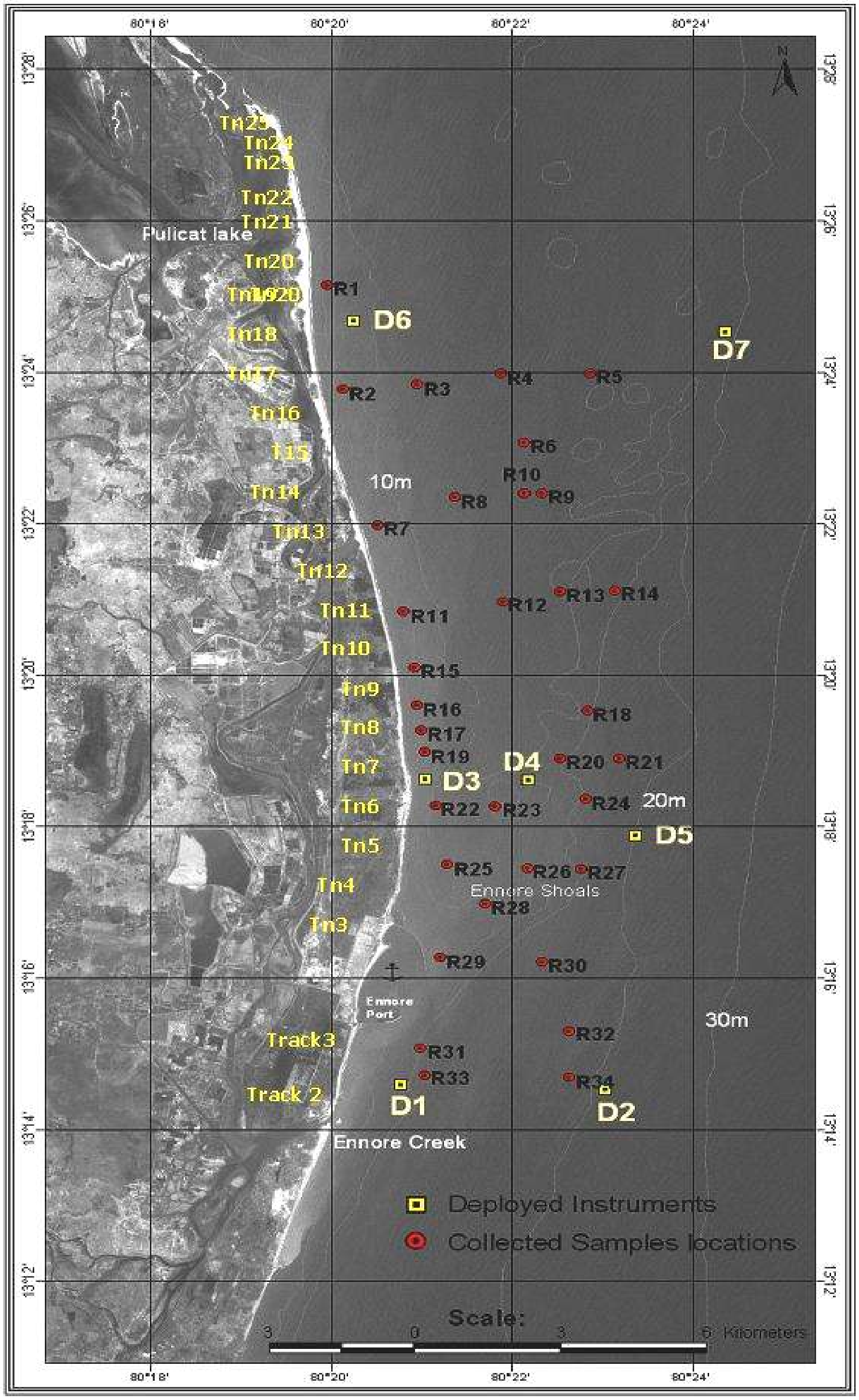


Fig 2.29 a – Station locations for beach profiles along Ennore coast

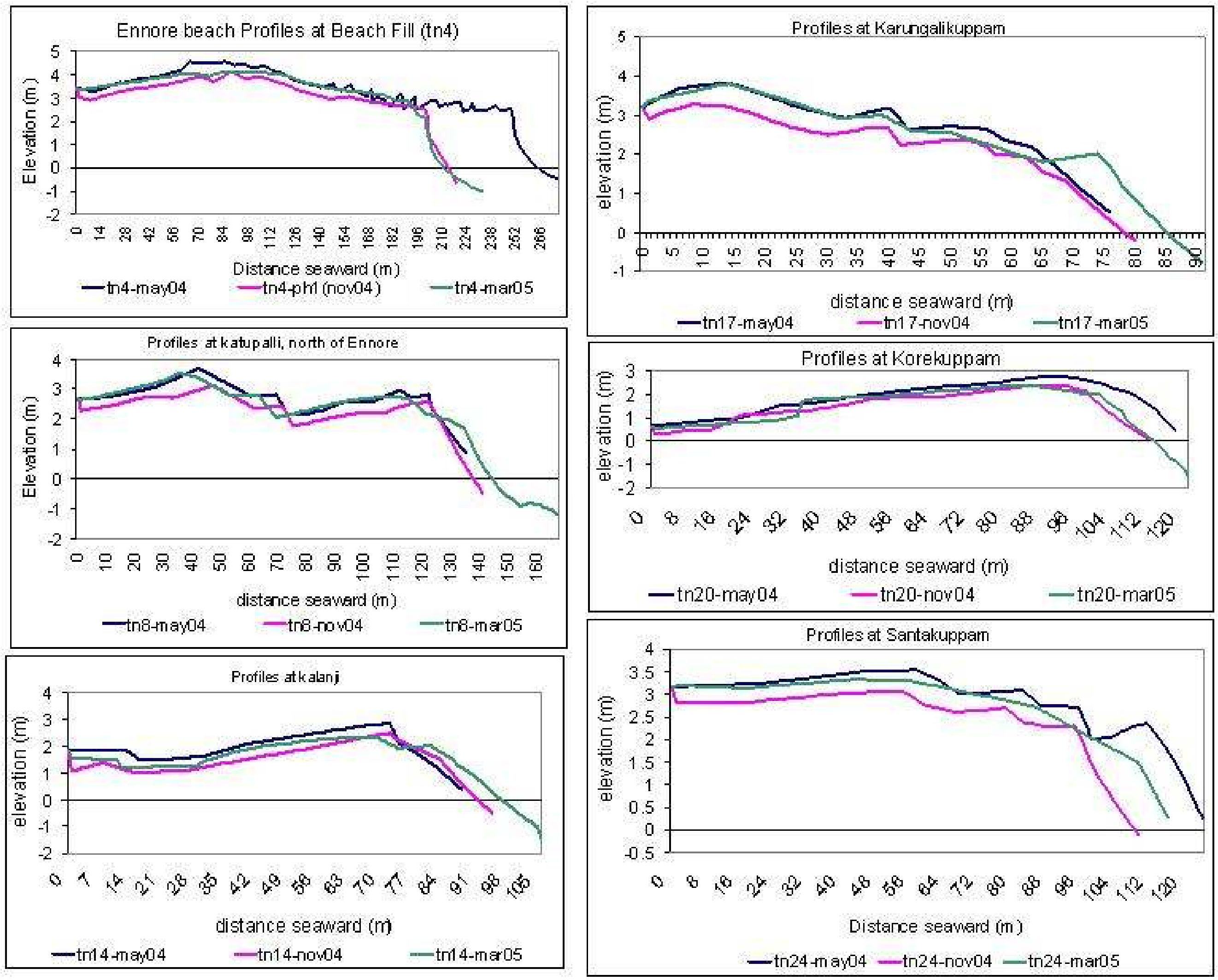
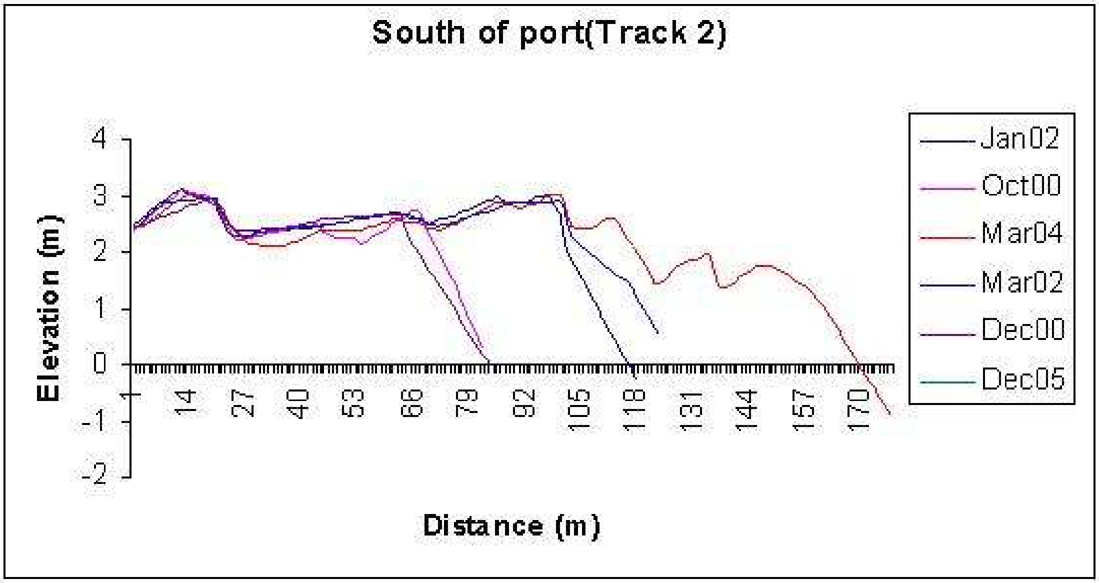


Fig 2.29b – Beach profiles at selected locations along Ennore coast



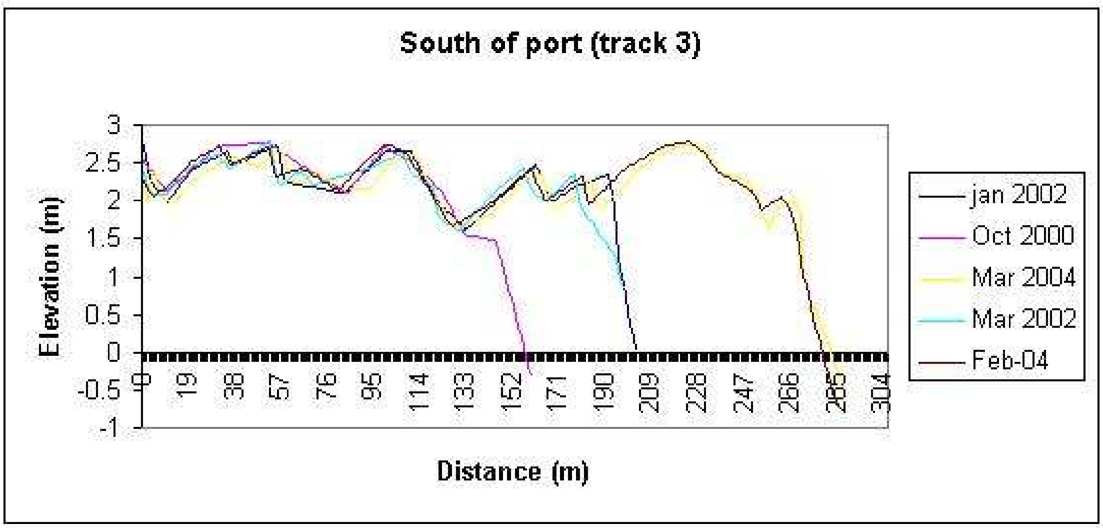


Fig 2.29c – Beach profiles at selected stations along north coast of Ennore port

Seasonal variations as well as role of tsunami run up on beach sediment volume changes were studied. The main features identified were i) From November 2004 to December 2005, occurrence of series of erosional and depositional zones on north coast beyond beach fill (Tn 7 to Tn 25) indicate that the beach changes resembles more natural phenomena. However the Kalanji shore (tn13 to tn17 transects) showing continuous erosion by showing decreased sediment volume and ii) The cross-sectional sediment transport varied from 2 to 117 cu.m/m/year depending upon the location.

Table 2.8 – Sediment volumes (cu.m/m) at selected transects along Ennore coast

Track	Latitude	Longitude	Nov 04	Mar 05	Dec 05	Nov 04-Mar 05	Mar 05-Dec 05	Annual Variation
TN25	1483910	427286.9142	266	270	256	4	-14	-10
TN24	1483159	427270.4882	313	325	418	12	93	105
TN23	1481491	427472.8466	102	99	89	-3	-10	-13
TN21	1480699	427465.2483	287	270	255	-17	-15	-32
TN20	1480033	427758.7453	76	66	69	-10	3	-7
TN19	1479435	427824.6185	99	109	117	10	8	18
TN18	1478992	427914.1009	114	129	164	15	35	50
TN17	1478560	428011.9487	215	238	211	23	-27	-4
TN16	1478134	428202.5162	105	97	90	-8	-7	-15
TN15	1477628	428261.9114	215	194	190	-21	-4	-25
TN14	1477191	428397.0448	170	162	150	-8	-12	-20
TN13	1476654	428548.9997	185	172	146	-13	-26	-39
TN12	1476085	428656.9478	170	165	168	-5	3	-2
TN11	1475426	428811.7162	17	60	29	43	-31	12
TN10	1473536	429059.6449	82	64	59	-18	-5	-23
TN9	1470809	429106.3154	344	405	364	61	-41	20
TN8	1470523	429131.1599	367	369	373	2	4	6
TN7	1469983	429136.4404	275	314	283	39	-31	8
TN5	1469026	428870.4828	1095	1243	1212	148	-31	117
TN4	1468896	428812.8325	972	1155	896	183	-259	-76
TN3	1468565	428874.9552	319	366	373	47	7	54
TN2	1468474	428832.4553	344	407	364	63	-43	20

In order to understand the role of recent tsunami (26 th Dec 04) run up on sediment transport along the Kattupalli area, the available 4 beach profiles (**Fig 2.30**) before (Nov 2004) and after tsunami (Feb 2005) were analyzed. The increase in sediment volume in post-tsunami period (**Table 2.9**) indicates adding up of the sediment to the shore which may be due to normal seasonal sediment transport pattern or tsunami run up (occurred just one month back). The beach profiles comparison in **Fig 2.30** clearly reflect that the backshore region faced accumulation of sediment in all profiles and the foreshore region shows erosion trend. Thus It is believed that the foreshore sediment is lifted by tsunami run up and deposited on the backshore. An amount of 0.2 to 18 m^3/m of sediment was added along the back shore of Kattupalli area.

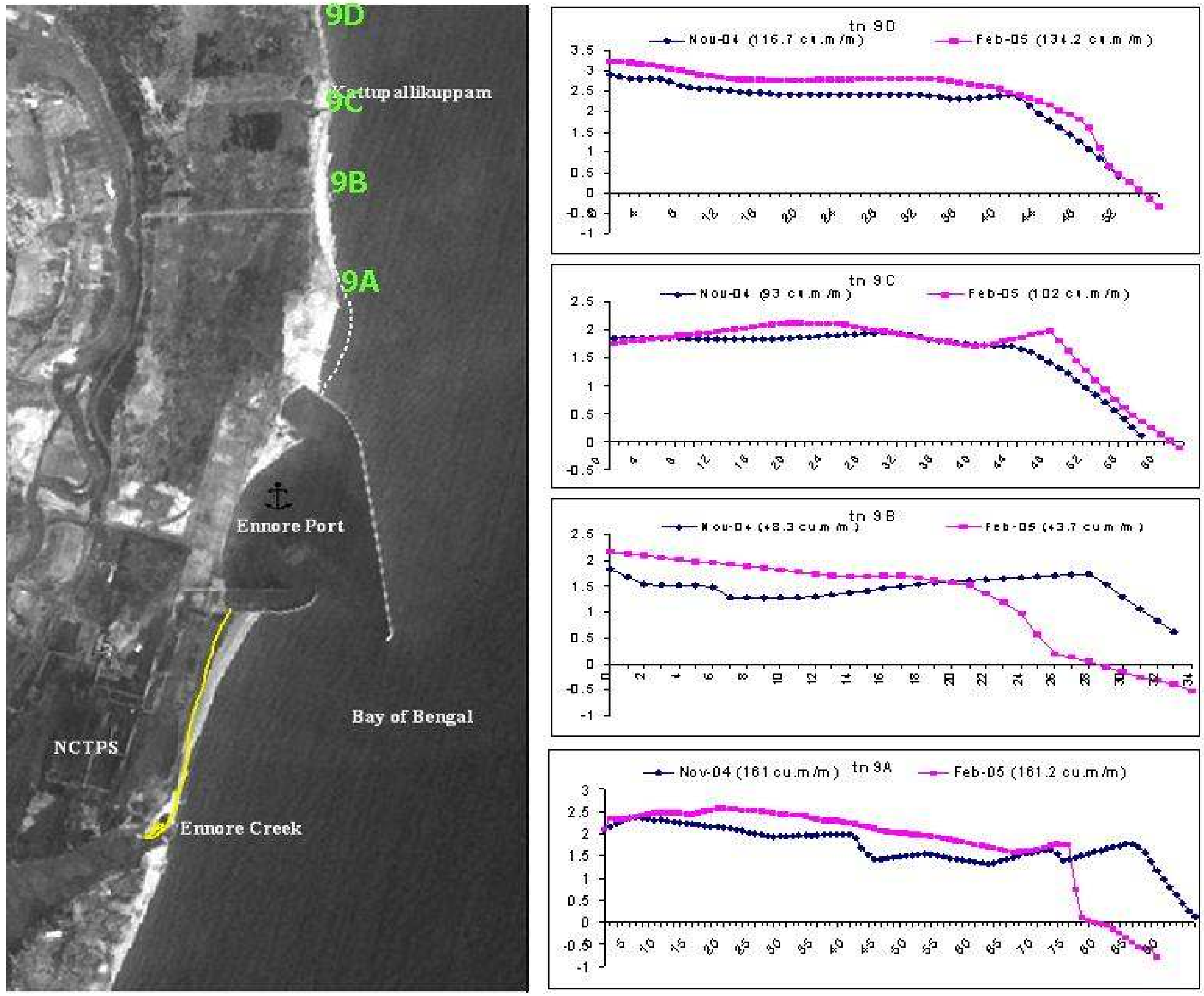


Fig 2.30 – Comparison of beach profiles at 4 transects before and after tsunami run up along north Kattupalli coast

Table 2.9 – Cross-sectional volumes (m^3/m) at 4 transects before and after tsunami along Kattupalli coast

Profile Id	Nov. 04	Feb. 05	Volume change
9A	161	161.2	0.2
9B	48.3	43.7	-4.6
9C	93	102	9.0
9D	117	134	18.0

2.10 Shoreline Changes

To study the historical as well as seasonal variations in shoreline changes along Ennore coast, the shoreline position data collected by PWD, Chennai during 1984 – 2004 and the field data collected by the ICMAM-PD from 1999 onwards were analyzed and the results are presented below.

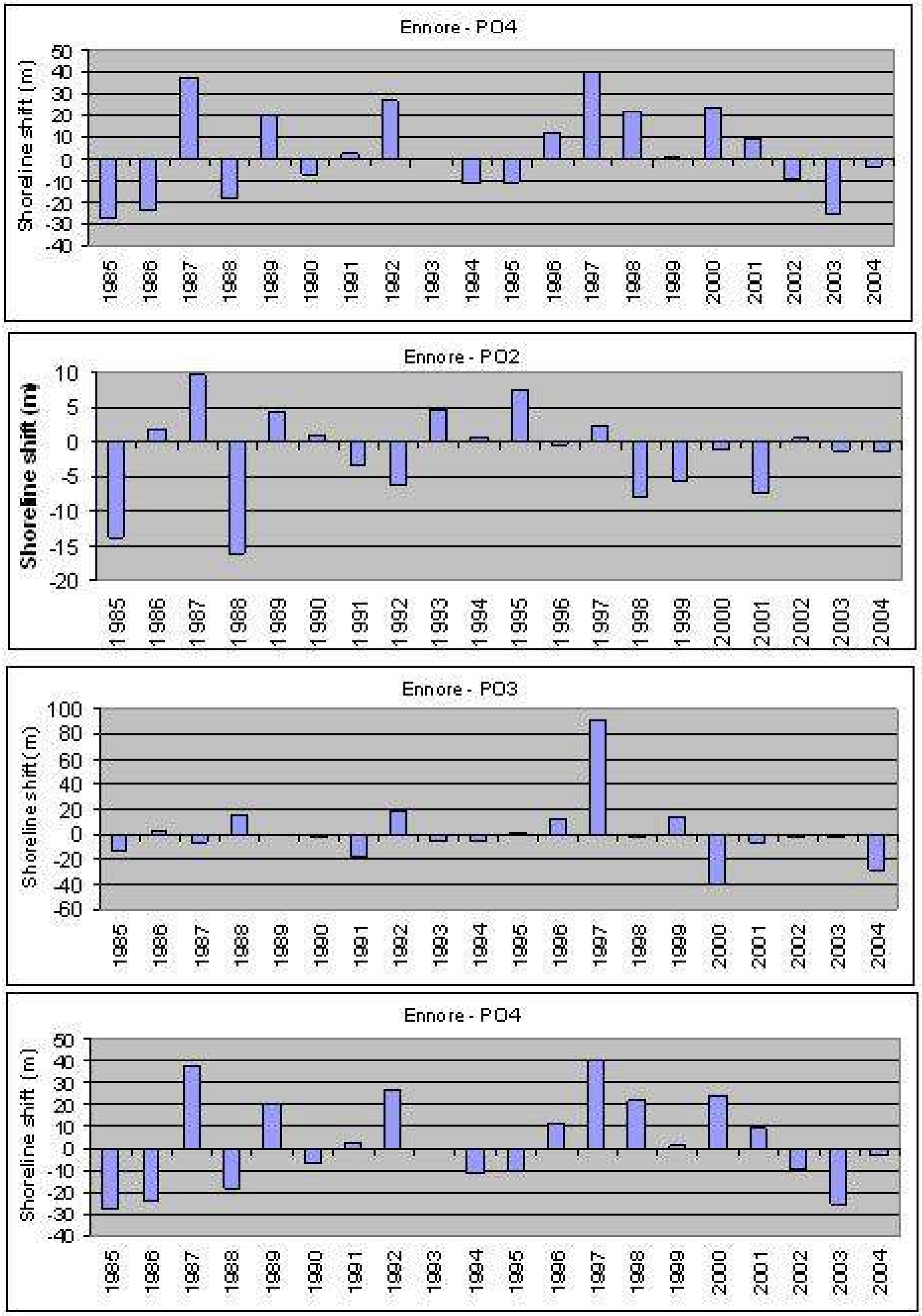


Fig 2.31 – Historical changes in shoreline position

Table 2.31 – Historical changes in shoreline position

Tracks	Range of shift (m/year)
PO1	-19 to +17
PO2	-30 to +24
PO3	-35 to 54
PO4	-81 to 89

Historical trend: The concept of setback line has been adopted in many countries to regulate the developments in near coast. State Public Works departments, Tamil Nadu is monitoring the shoreline oscillations along the Tamilnadu coast under the monitoring program called "Crest of the Berm". The crest berm is seaward end of the beach profile, formed by the action of waves and found to be ideal feature for assessing the shoreline change. The crest of the berm data from 1984 to 2004 (20 years) was analysed to compute the shoreline oscillation along the Ennore coast. The shoreline changes at 4 selected sts PO1, PO2, PO3 & PO4 (**Fig. 2.31**) along Ennore coast reveal that from 1984 to 1993 the shoreline oscillates mostly both seaward or land ward where as from 1994 onwards the shore shifted mostly to landward at PO1, PO2 & PO3 and seaward at PO4. On the whole the historical changes in shoreline data indicate that the shore usually migrates from –20 to +90 m per annum (**Table 2.31**) along Ennore coast depending upon the location.

Recent trend: The recent field observations of shoreline position for different periods during 1999 to 2006 were shown in **Fig. 2.32.** The positions were measured based on berm crest location using RTK GPS. The shoreline positions were plotted on a rectified satellite image in Arcview software and the changes, if any, in shoreline position and the corresponding erosional/ depositional trends were identified. The distance of migration either seaward (deposition length) or landward (erosion length) were measured with the help of Arcview GIS software. In determining the exact rate of erosion or deposition, care was taken whether the coast was exhibiting any abnormal variation other than seasonal variation. In determining the erosion zone the continuos migration of shoreline landward was taken into account. The shoreline changes obtained in this way reveal the following features.

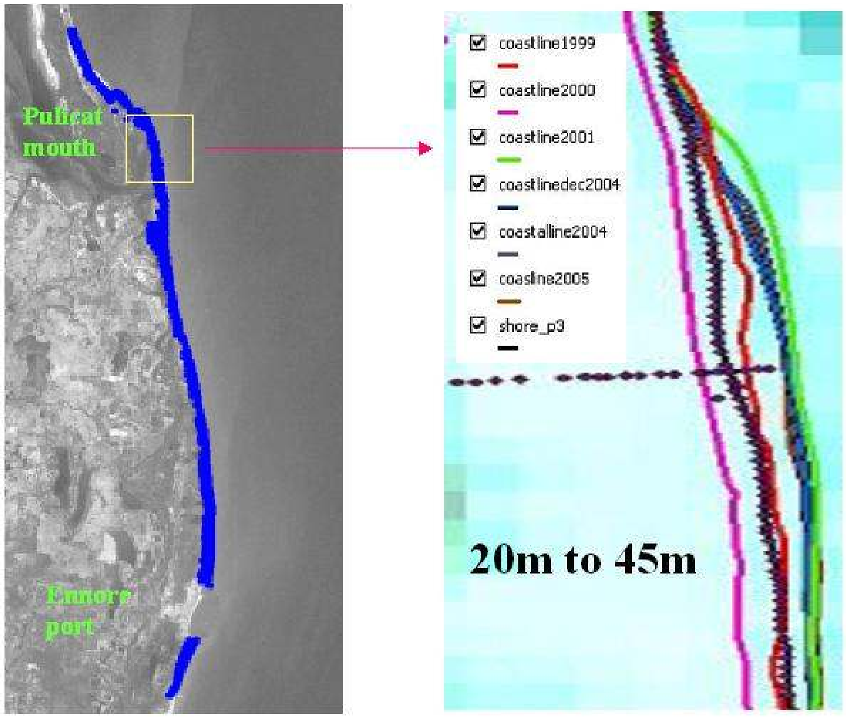


Fig 2.32a – Shoreline migration near Pulicat mouth during 1999 to September 2006

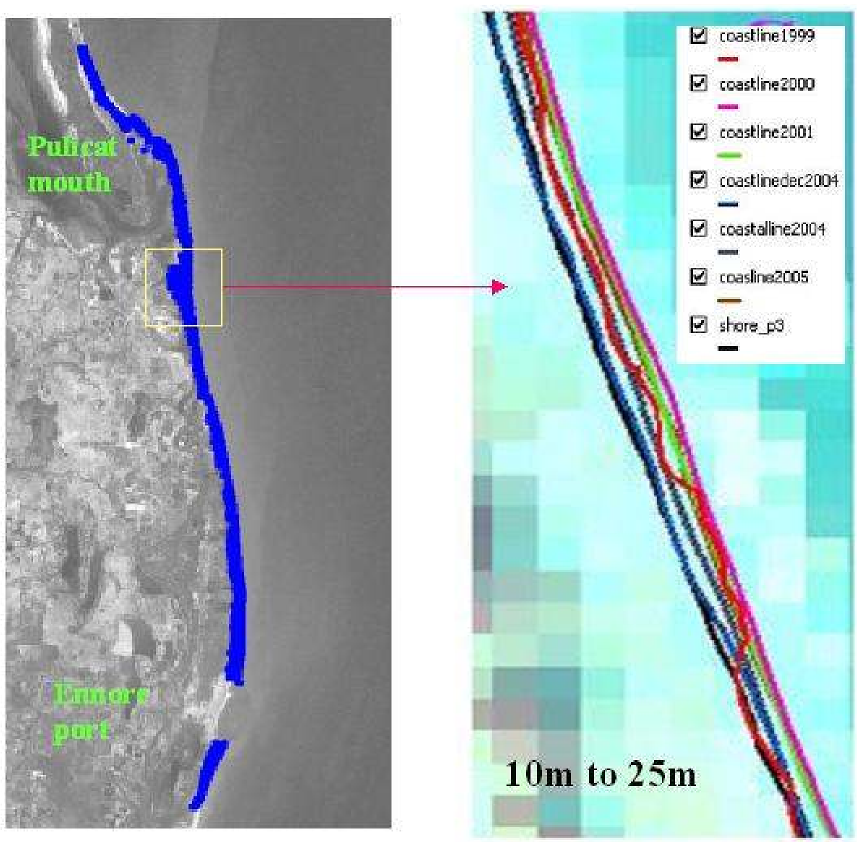


Fig 2.32b – Shoreline migration at south of Pulicat mouth during 1999 to September 2006

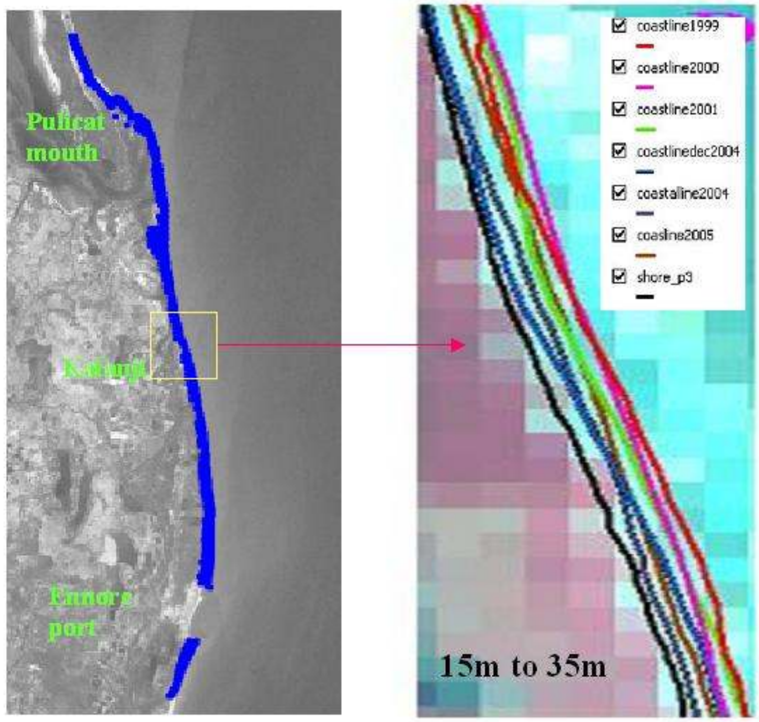


Fig 2.32c – Shoreline migration at Kalanji during 1999 to September 2006

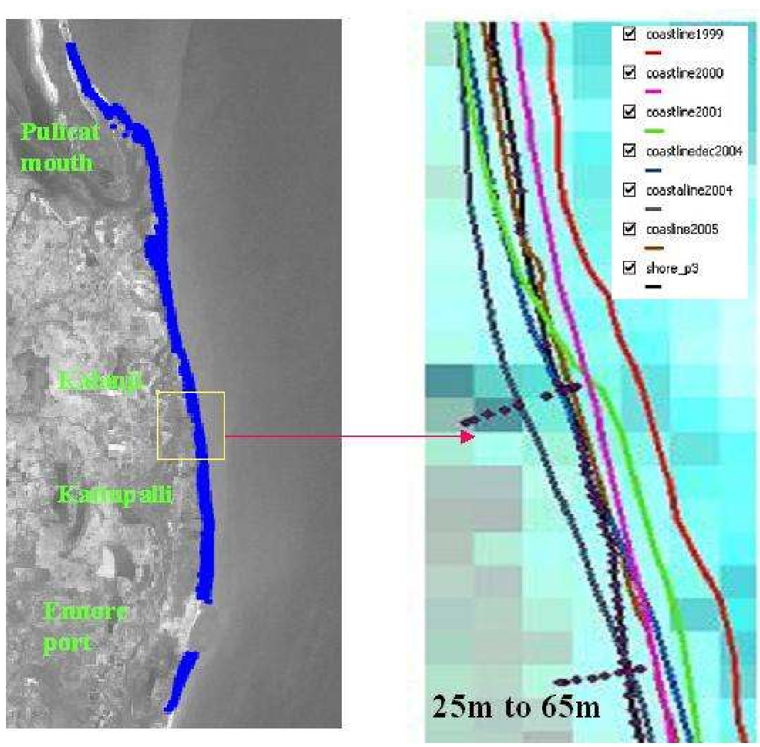


Fig 2.32d – Shoreline migration at south of Kalanji during 1999 to September 2006

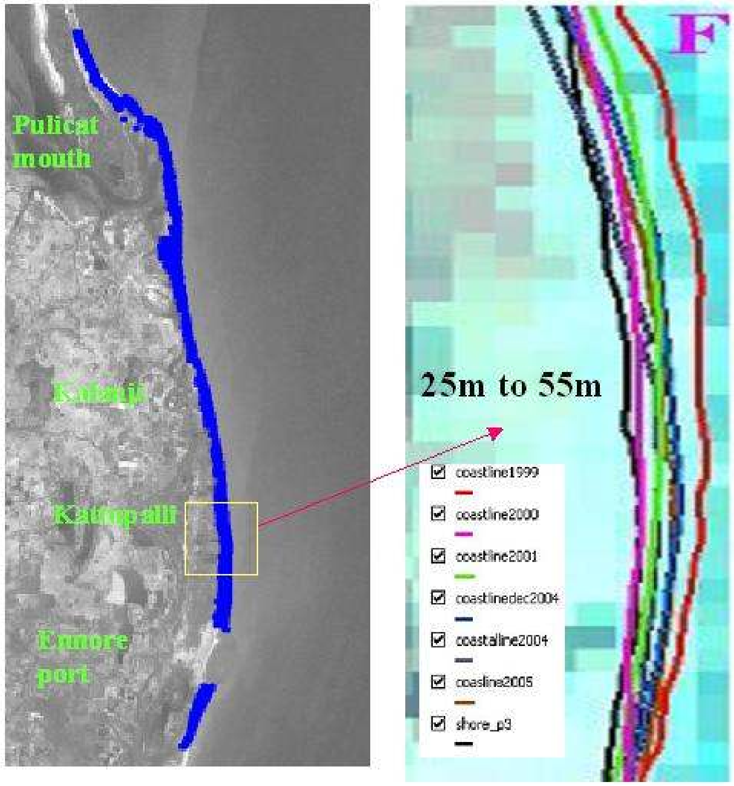


Fig 2.32e – Shoreline migration at south of Kalanji during 1999 to September 2006

Near the mouth of Pulicat (**Fig 2.32a**) the shoreline migration is highly variable and an oscillation of 20 to 45m was noticed during 1999-2006 period. From south of Pulicat to Kalanji (**Figs 2.32b & 2.32c**) the landward migration of shoreline is of the order of 30-40m. From Kalanji to Kattupalli (**Figs 2.32d & 2.32e**) the shoreline getting severe erosion of the order of 25 to 65m and the shoreline migrating landward.

Along north coast of Ennore port (**Fig 2.32f**), the beachfill area is undergoing severe erosion at the rate of 50m per annum (Even though the coast was protected with beachfill of 500m offshore). The erosion length was extended up to 1500m alongshore and 400m onshore (i.e. 400m receded back from 2000 beachfill shoreline).

The shore, south of the Ennore port (**Fig 2.32f**) is accreting at a rate of 45m per annum, extended offshore 300m to 400m (during 2000-2006) and alongshore 2.6km causing increased siltation in Ennore creek (about 90m).

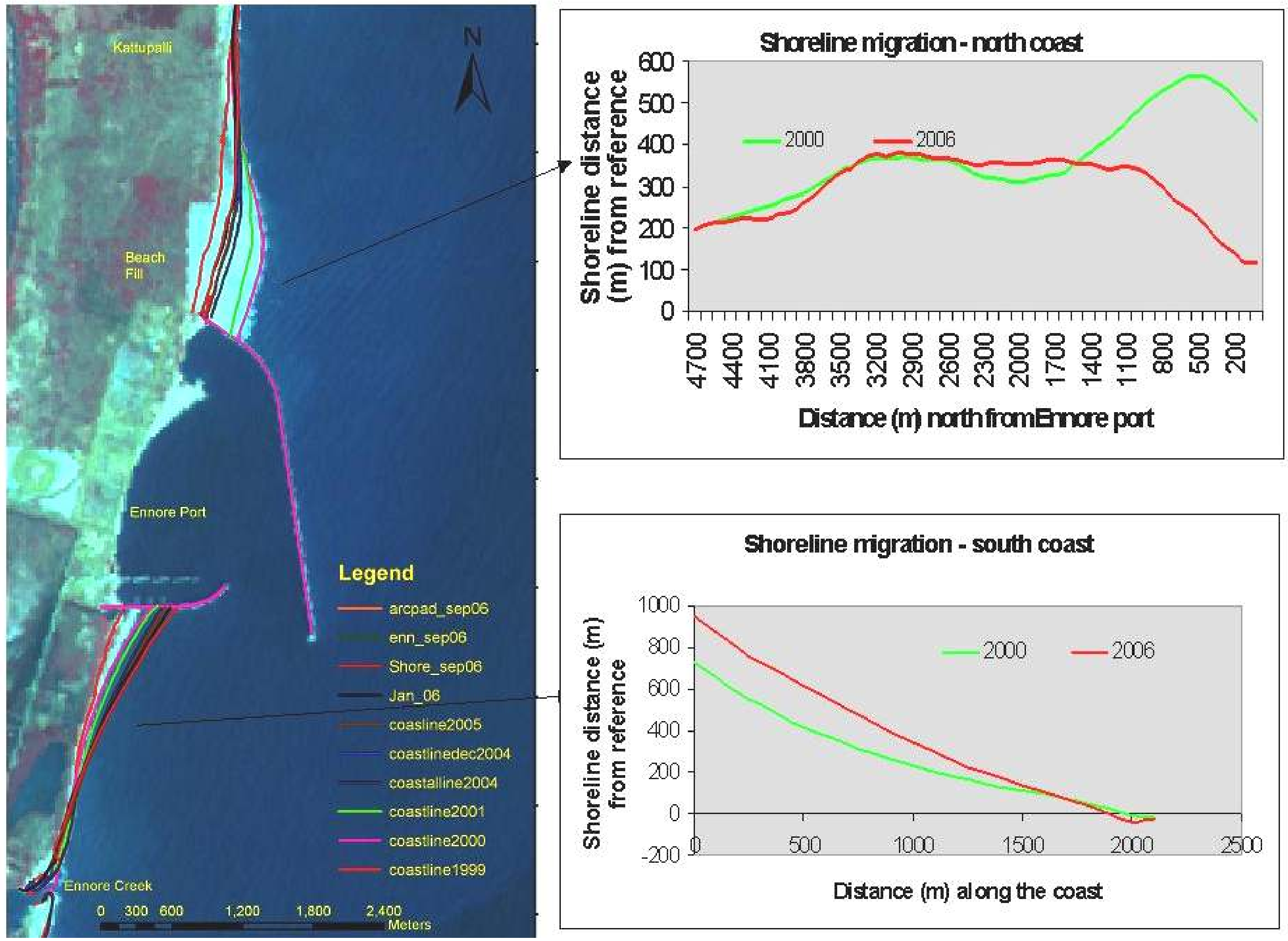


Fig 2.32f – Shoreline migration on north and south of Ennore port during 1999 to September 2006

3. MODELING

The objective of modelling is develop impact models to evaluate various management options in terms of its functionality and cross impacts resulted from the interventions proposed under each management strategy. The dynamics of the coastal waters were analysed based on the field observations conducted for a period of one year, covering all seasons on various parameters such as water levels, currents, wave climate, sediment transport, shoreline oscillations etc. The following models are being used to generate impact models

i) Hydrodynamic Model to simulate flow pattern

ii) The Offshore Spectral Wave and Parabolic Mild Slope wave models for deriving wave climate

iii) MIKE 21 ST module for sediment transport pattern and bed level changes and

iv) LITPACK model for prediction of shoreline changes. The preliminary results of the model investigations are summarized and presented below.

3.1 Hydrodynamic Model

In order to simulate water levels and current pattern for Ennore coast, the hydrodynamic (HD) module of MIKE 21 was setup. The HD model simulates water level variations and flows in coastal regions. The model can account bottom friction, wind effect, coriolis force, sources and sinks and wave radiation stresses. For Ennore coast, the model area considered for the simulation is 14km x 8km (**Fig. 3.1a**), covering 7 km coast on north of Ennore Port and 4 km on south. The seaward boundary is extended upto 25 m depth contour and the landward boundary upto shoreline. A 10m x 10m grid was discretized from the measured bathymetry. Three open boundaries were considered in the simulation i.e. the north and south boundaries are provided with water levels and the eastern boundary with water flux as a function of time. Since the coast, experiences seasonal reversal of circulation pattern, the model simulations were carried out for NE and SW monsoon conditions (**Fig 3.1 b & c**). The model was calibrated with field data for phase I, II & III periods and the circulation pattern around port area was simulated.

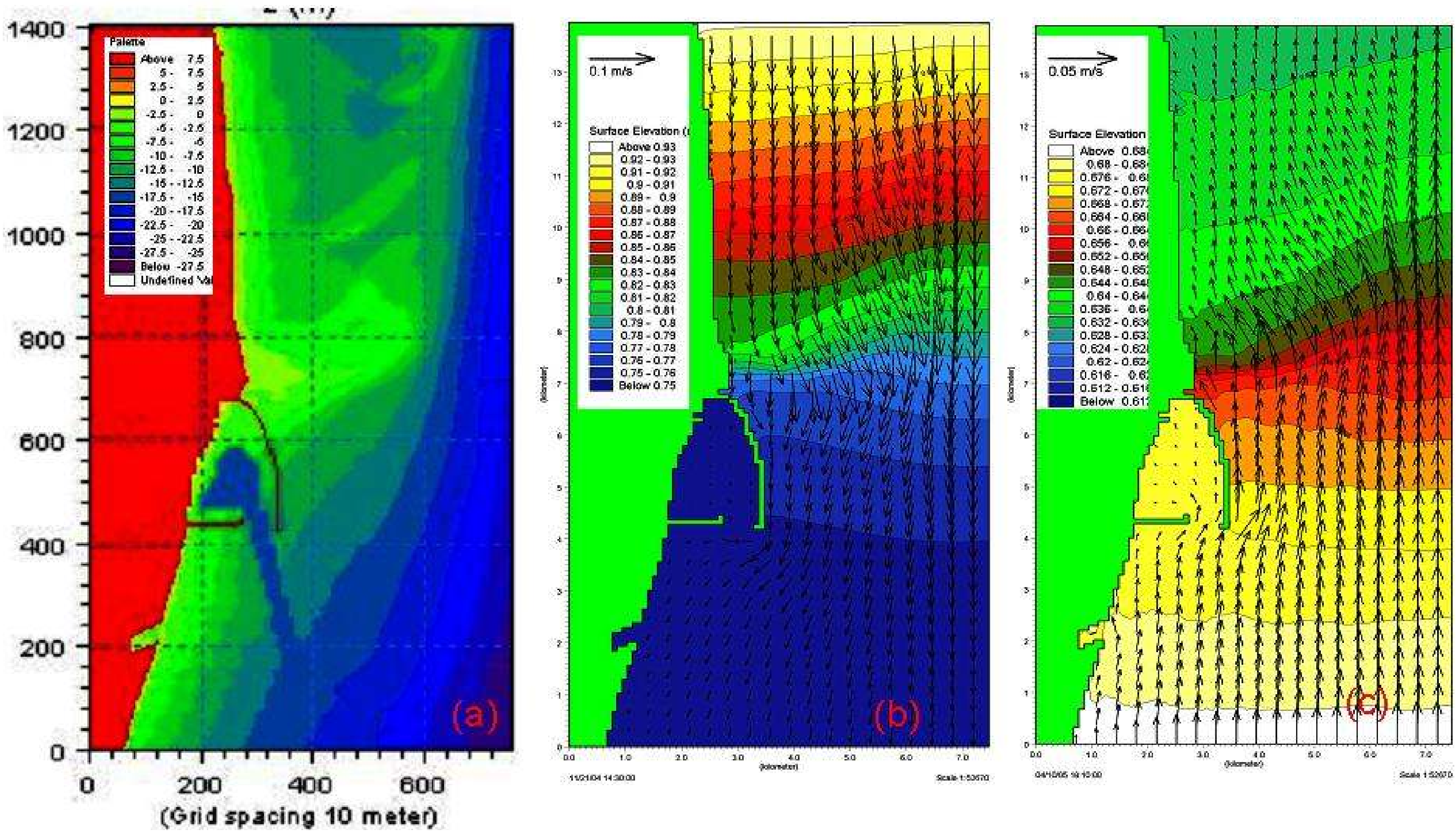


Fig. 3.1 - a) Bathymetry and b) & c) Simulated water levels and currents under NE monsoon (Nov. 04) and SW monsoon (Apr. 05) respectively

The simulated water levels are well correlated with observed ones (**Figs. 3.2 & 3.3**). The two major forcing functions, i.e., tide and wind, influence the circulation pattern, latter being a dominant forcing function, which control the direction of current. The flow field south of Ennore Port is complex and field observations indicate no distinct pattern. The circulation north of Port is influenced by long north breakwater and presence of shoals.

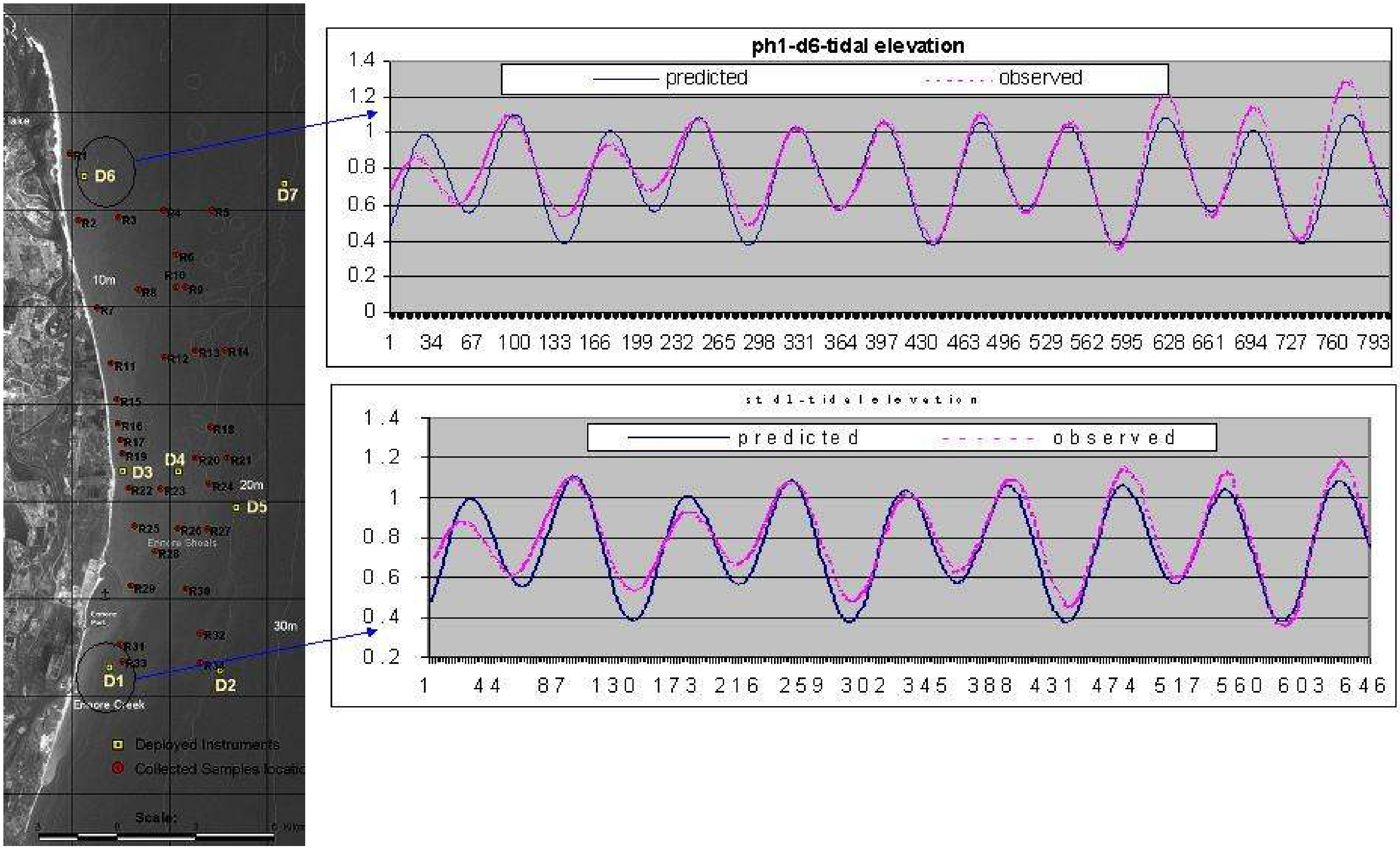


Fig. 3.2 - Comparison of predicted and observed tide under NE monsoon (Nov. 04)

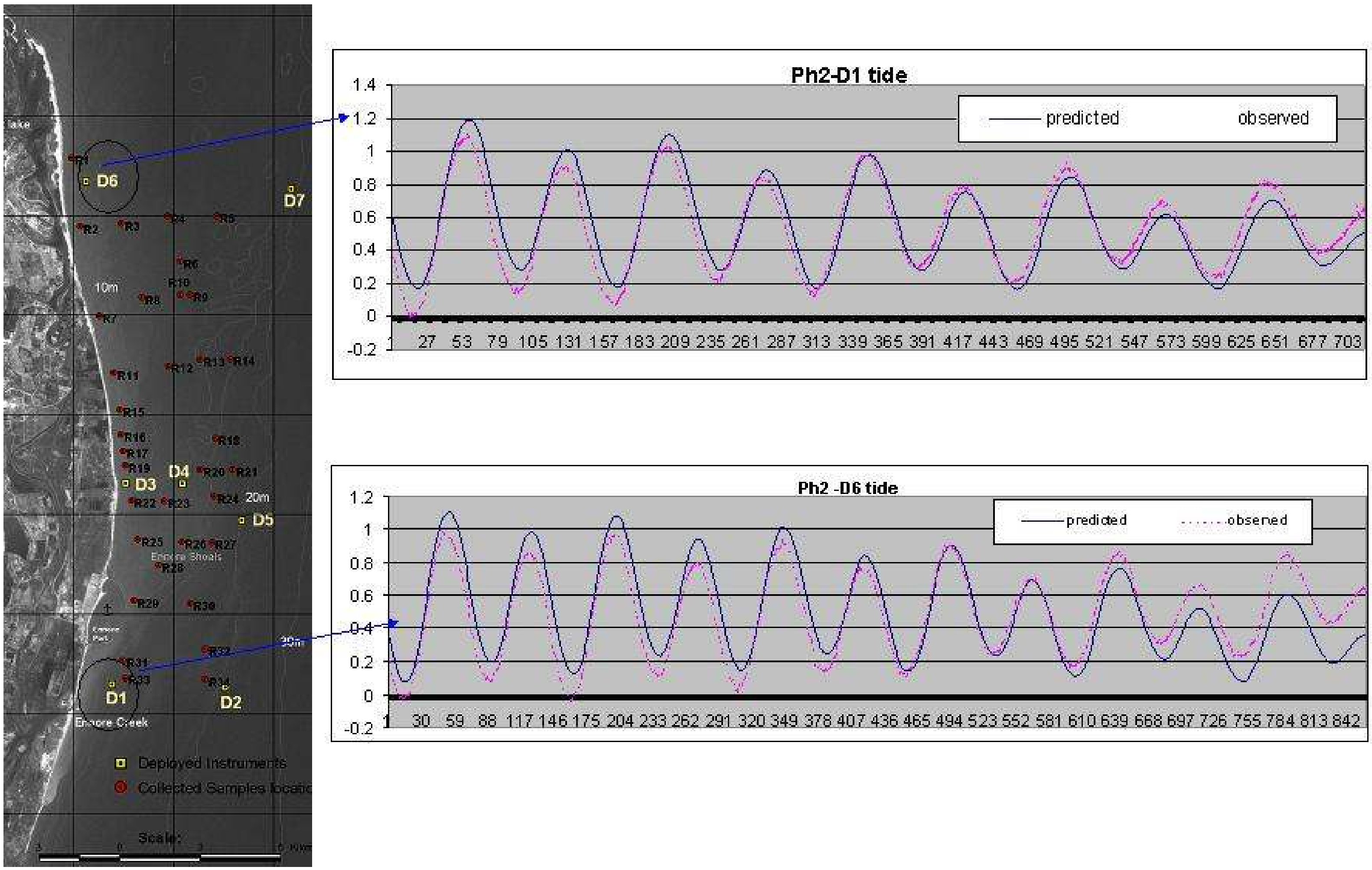


Fig. 3.3 - Comparison of predicted and observed tide under SW monsoon (Apr. 05)

3.2. Wave Model

Spectral wind–wave model (OSW): In order to predict the annual wave climate for Ennore coast, the spectral-wind wave model, the OSW was used. The basic requirement for the model are i) wind data, which was obtained from NCEP winds and ii) the bathymetry, which was derived from C-MAP. The model was run initially by using the NCEP winds to get global wave climate. Boundary wave climate for Ennore coast was extracted and provided as input to PMS model to simulate nearshore waves by giving the extracted waves as offshore boundary. Finally the model was calibrated with the field observations **(Fig 3.4)** and utilized to study the annual variations in nearshore wave climate.

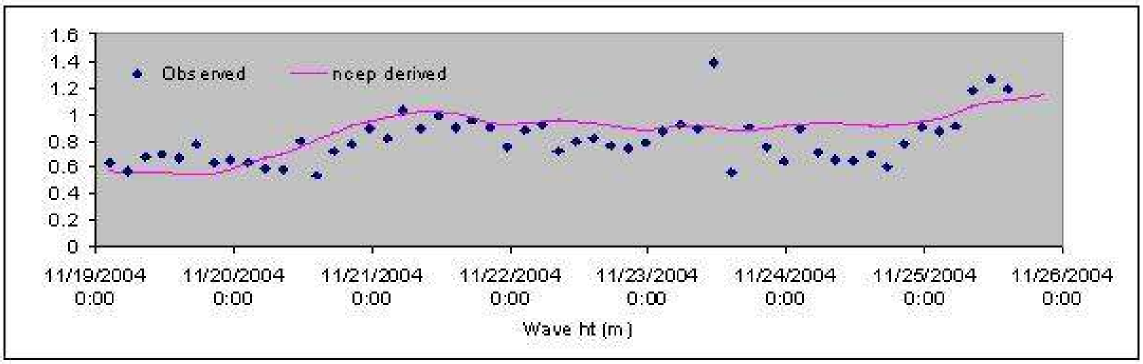


Fig 3.4 – Comparison of OSW predicted waves with observed ones

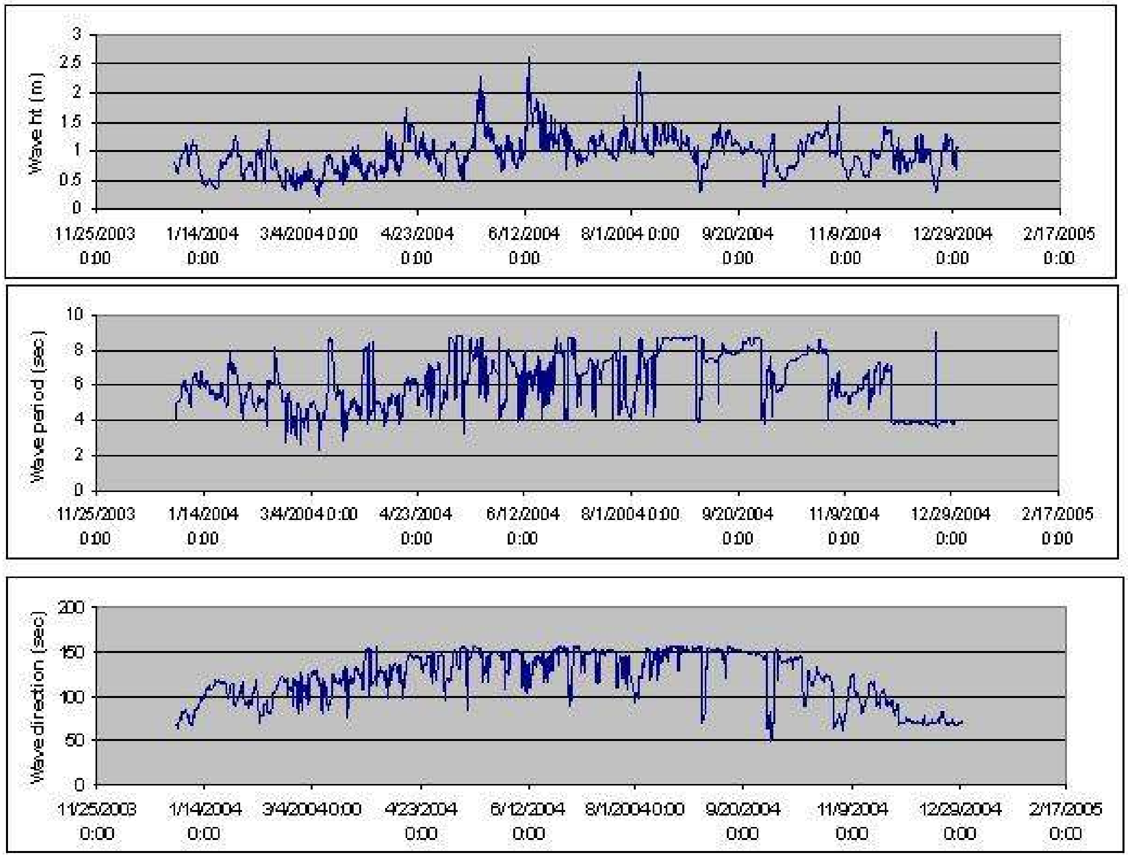


Fig 3.5 – Predicted annual wave record for Ennore offshore waters (OSW model)

The annual distribution of wave record **(Fig 3.5)** indicates that during Nov – Dec the waves are mostly from 60°-70° in other months from120-140°. Percentage distribution of wave directions **(Fig 3.6)** clearly shows that almost 85% of waves are coming from E-SE (90-160°) direction and the remaining 15% are from NE-ENE (40-80°). Thus the annual Ennore wave climate leads to a net northward littoral sediment transport pattern over a year. Wave periods varied between 3 to 9 sec and heights from 0.5 to 2.0m. Most percentage of waves occurs in the height range 1.0 to 1.5m and in the periods of 4-9 sec.

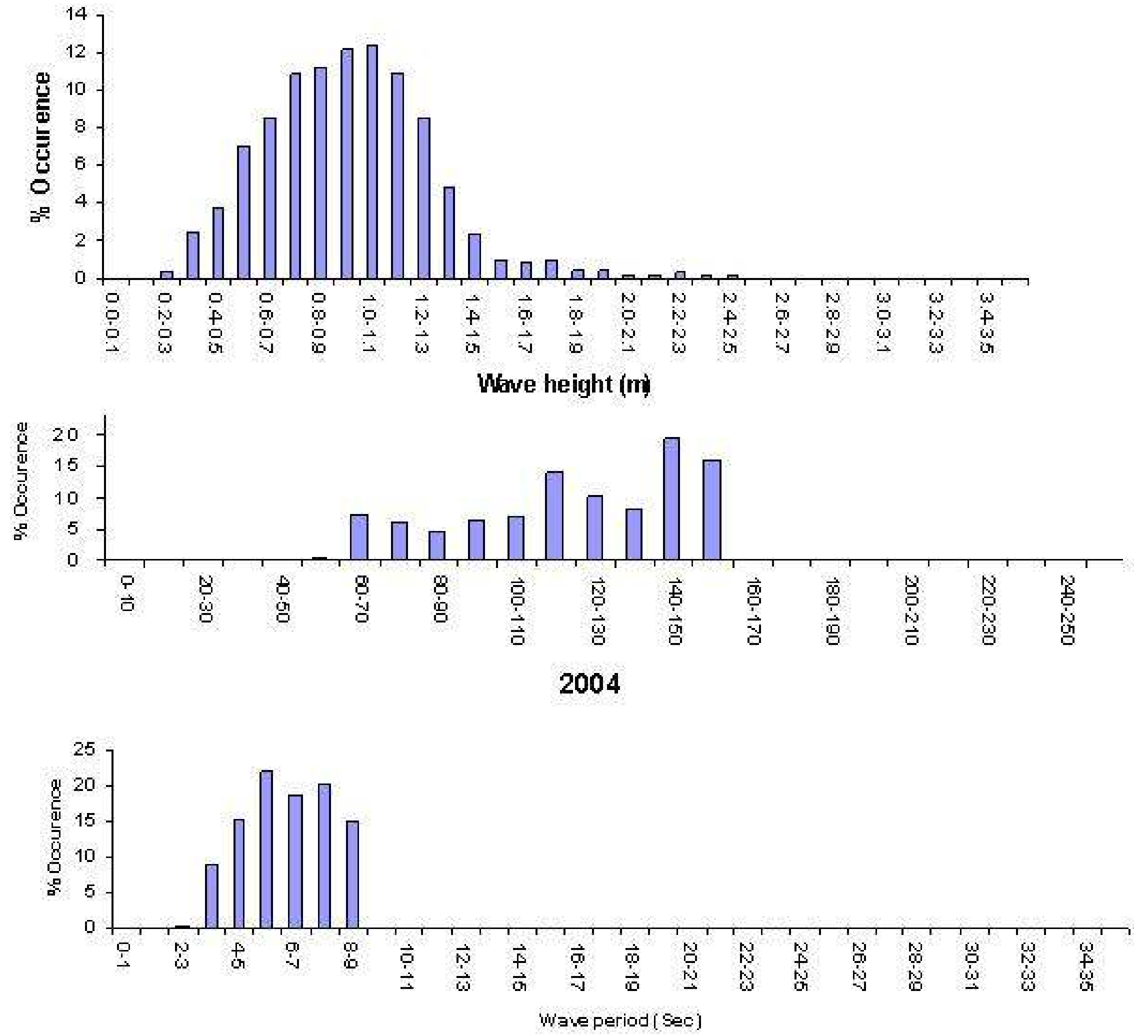


Fig 3.6 – Percentage occurrences of a) wave ht (m), b) Wave dir. (deg) and c) wave pr. (s) for annual wave record of Ennore coast

Nearshore Wave Model: To study the wave transformation from offshore to nearshore region in the Ennore coastal waters is simulated using Parabolic Mild Slope (PMS) wave model of MIKE 21. The model is a linear refraction-diffraction model based on a parabolic approximation to the elliptic mild slope equation. The model takes into account the effects of refraction and shoaling due to varying depth, diffraction along the perpendicular to the predominant wave direction and energy dissipation due to bottom friction and wave breaking. The presence of shoals on north of Ennort Port requires diffraction model. The model also considers the effect of frequency and directional spreading using linear superposition. For Ennore coast, the model was run to study the wave transformation from 25 m depth to nearshore coast. The study area and the bathymetry are the same as that used in HD simulation. The offshore boundary is specified with time series of observed wave parameters (RMS wave ht, mean wave direction and peak period). The two lateral boundaries (North & south) are considered with the symmetry type of boundary condition, for which the depth contours are assumed to be straight and parallel at the boundaries. Model simulations were conducted by using the field data of Phase I, Phase II and Phase III periods. The results are presented in **Fig 3.7**.

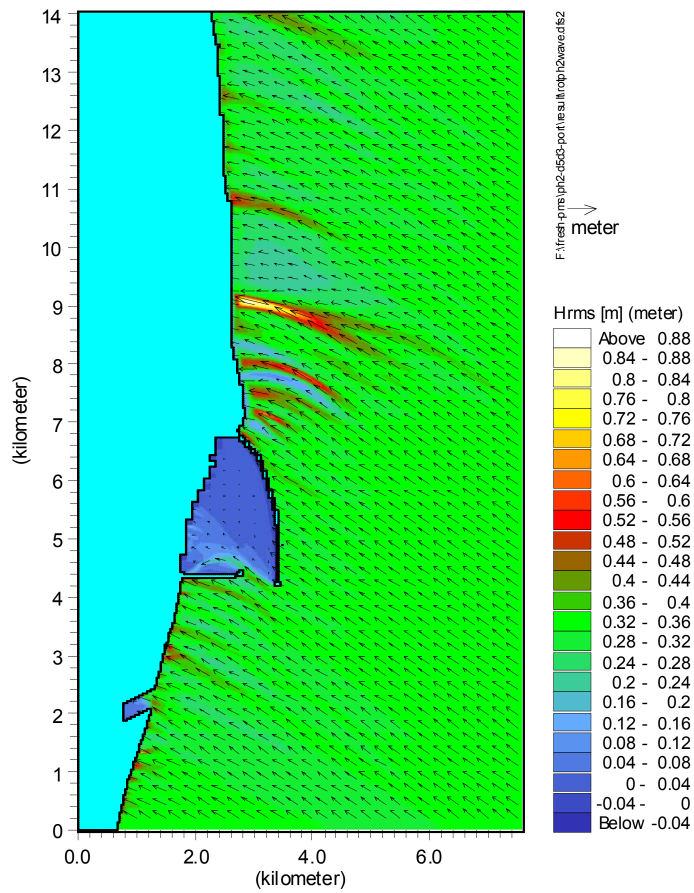


Fig 3.7a – Simulated wave ht (m) and direction for SE waves

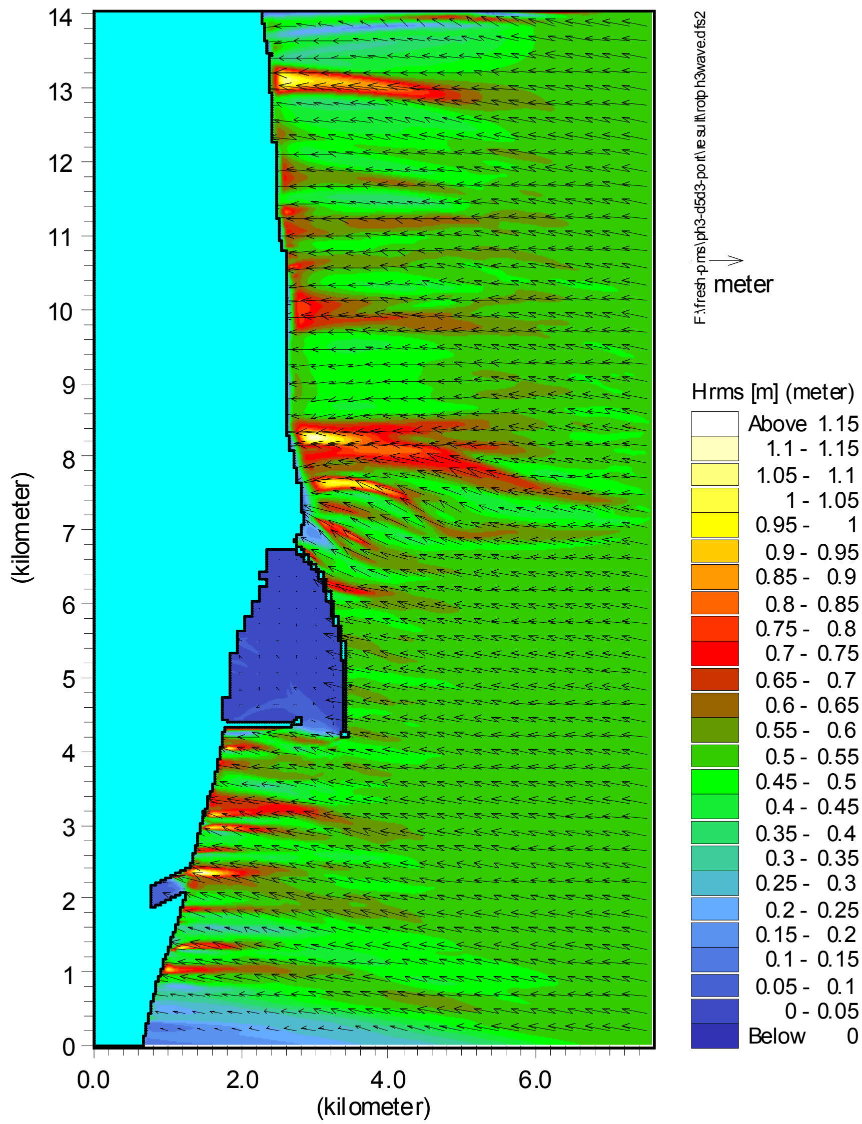


Fig 3.7b – Simulated wave ht (m) and direction for E waves

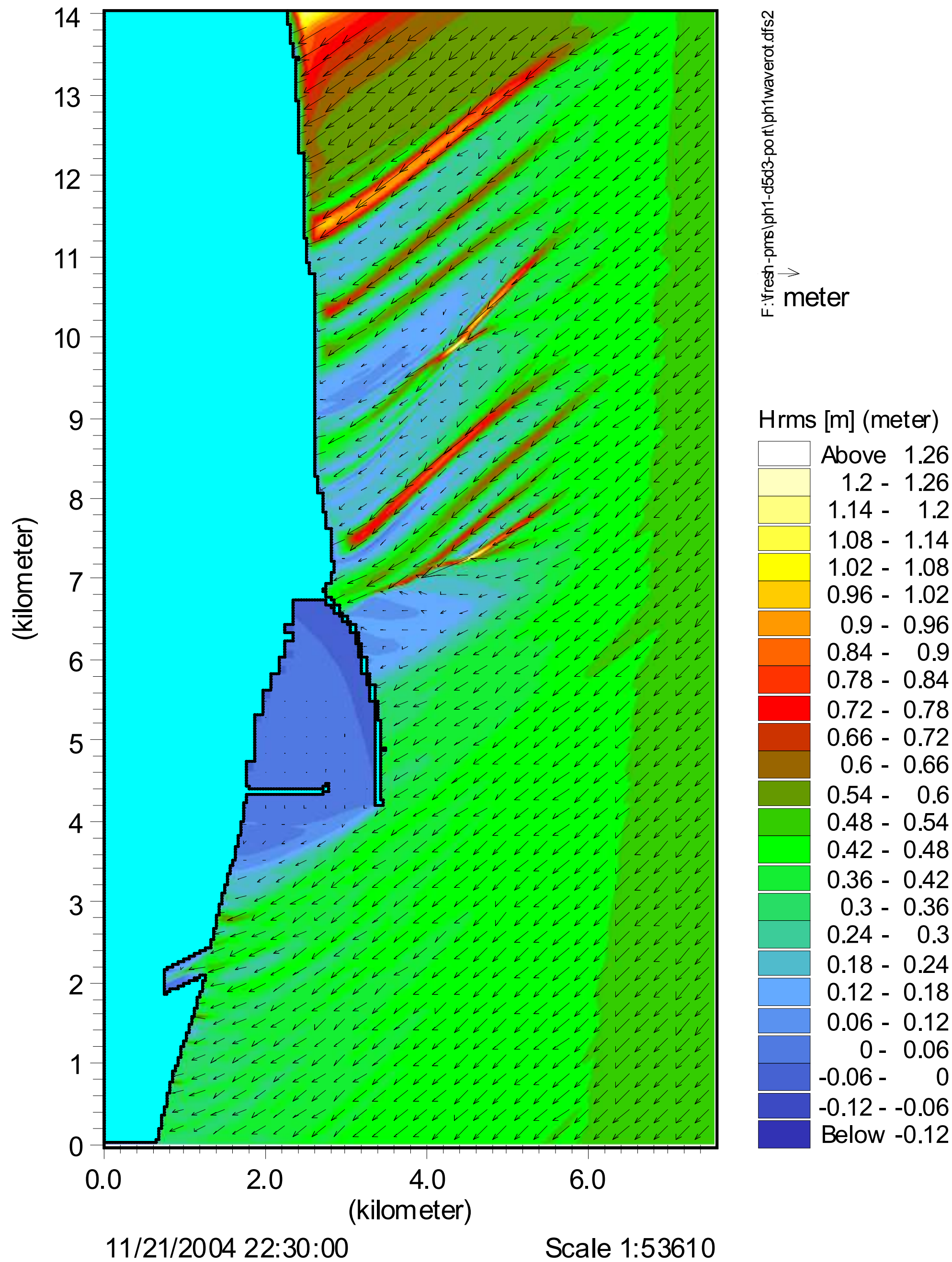
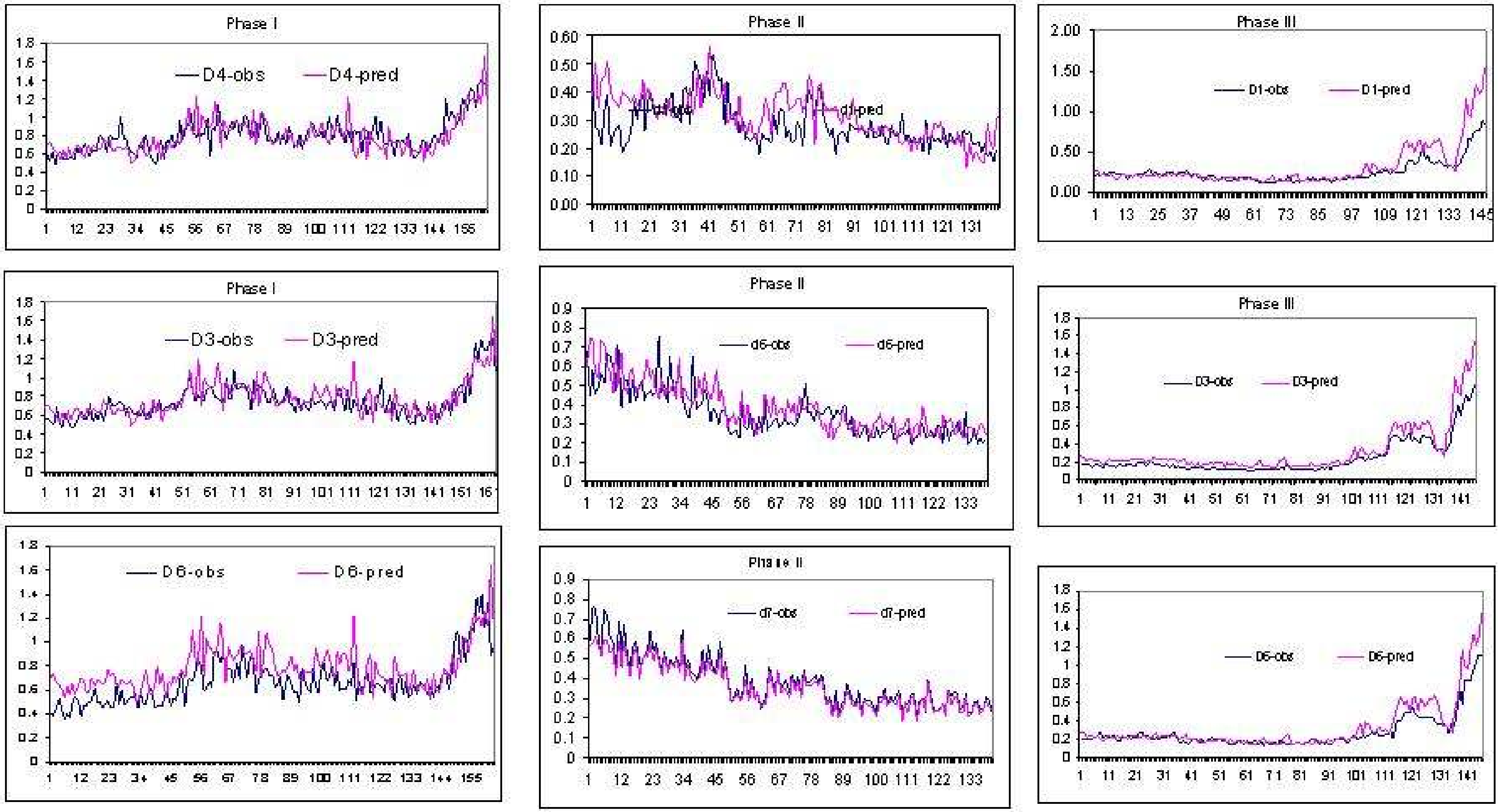


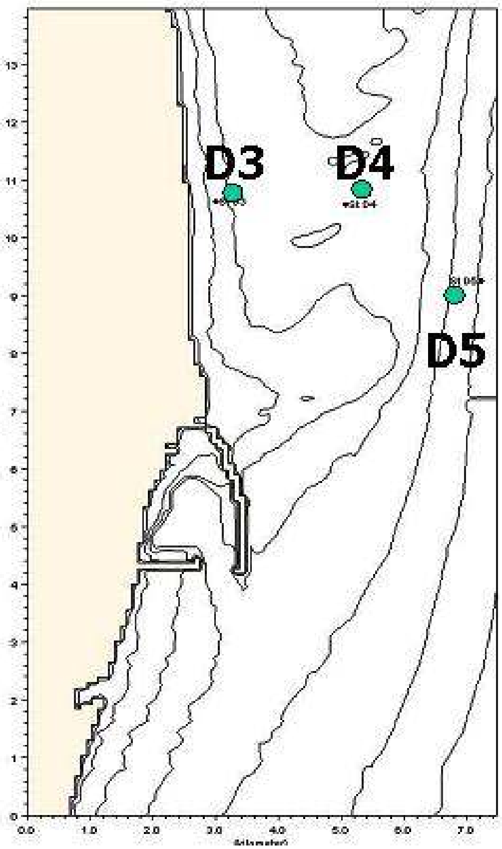
Fig 3.7c – Simulated wave ht (m) and direction for NE waves

Simulations were conducted for predominant wave directions prevailing at Ennore, namely, ENE-60^o, E-90^o and Southeasterly waves (135^o) (**Fig. 3.7**). The coast south of Port experiences diffracted waves during NE monsoon and refracted waves during SE monsoon. High concentration of wave energy is noticed at south of Port during SW monsoon. The coast north of Port experiences concentration of wave energy at some places due to convergence of wave rays resulting from complex bathymetry (shoals). Simulated wave heights were compared well with the observed heights with an rms error of 0.1 and correlation coefficient greater than 0.76 (**Figs 3.8 and 3.9**).



(a) (b) (c)

Fig 3.8 – Comparison of observed and simulated wave heights a) Phase I (Nov 04), b) Phase II (Apr 05) and c) Phase III (Dec 05)



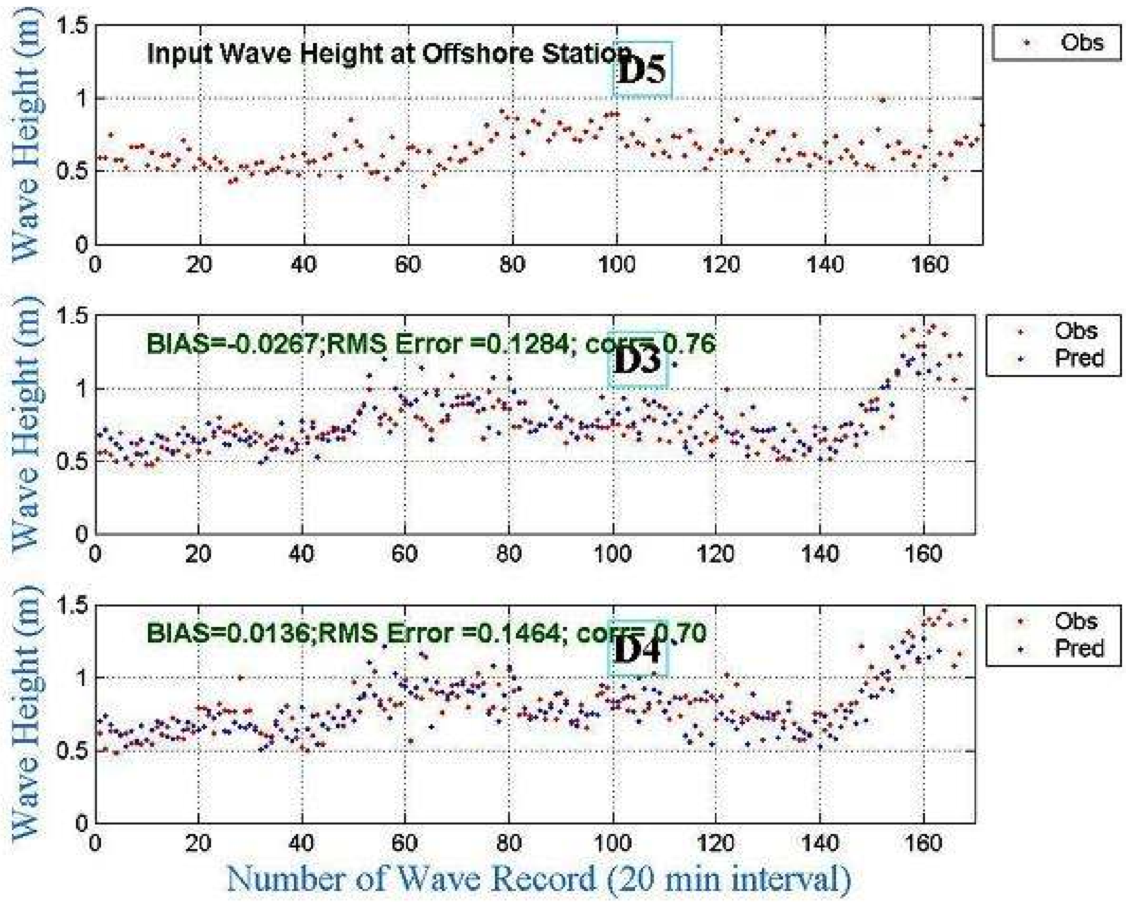


Fig 3.9 – Comparison of observed and simulated wave heights at sts D3, D4 and D5

3.3 Sediment Transport Model

MIKE 21 ST (Sediment Transport) module is used for simulation of sediment transport rates along the Ennore coast. The model calculates the rates of non-cohesive sediment (sand) transport for combined waves and current situations. Apart from the sediment transport components, the model also simulates the initial rates of bed level changes. The basic requirements for the model simulation are i) the Wave climate and radiation stresses derived from MIKE 21 PMS model results (**Fig. 3.7**) of section 3.2, ii) The flow pattern derived from MIKE 21 HD simulation **(Fig 3.10)**, and iii) Preparation of sediment table based on sediment size distribution of the model area. By giving the appropriate inputs, ST model was run for Phase I, II & III periods and the results were used to identify the potential areas of erosion and deposition and the initial rate at which bed level changes **(Fig. 3.11).**

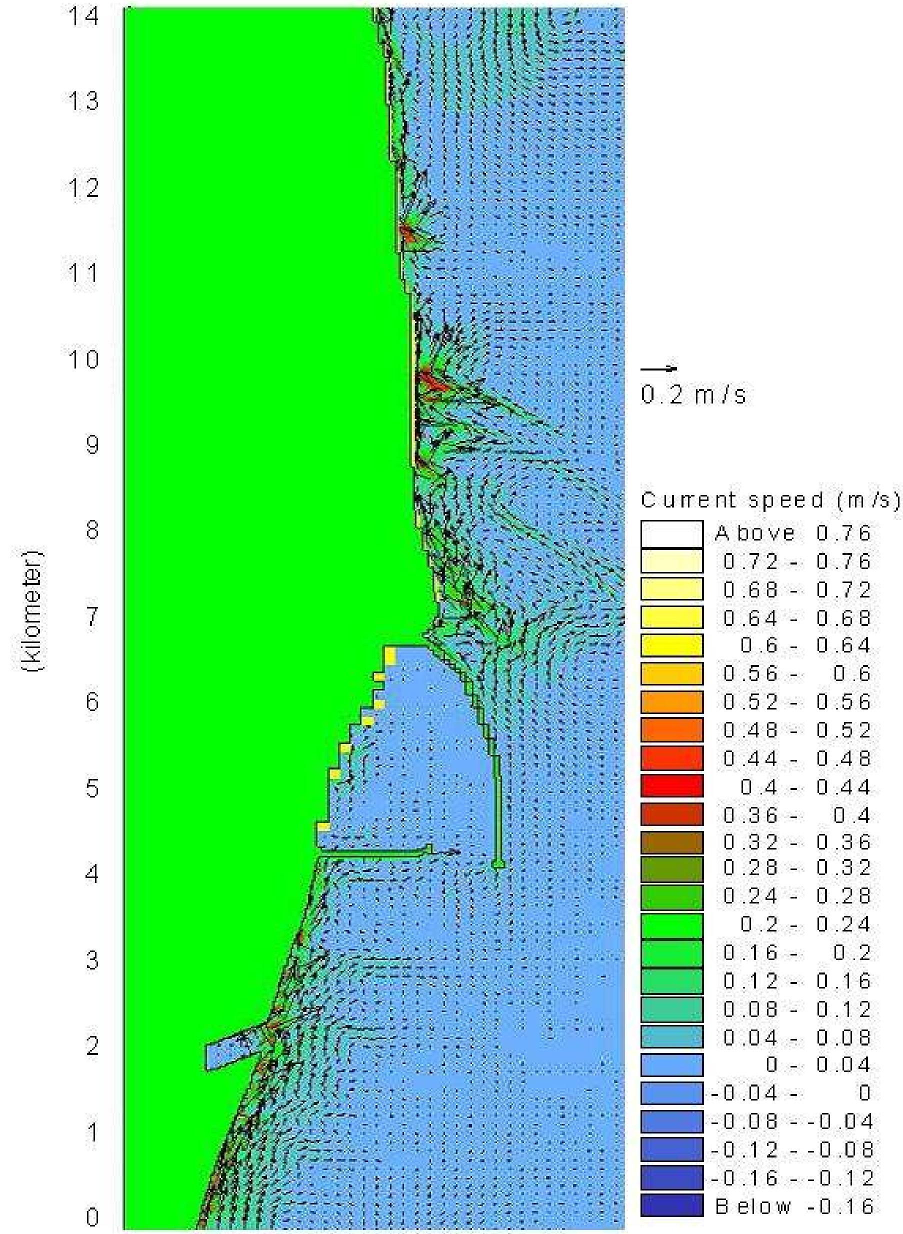


Fig 3.10a – Wave induced currents (cm/s) under SE waves used in ST model

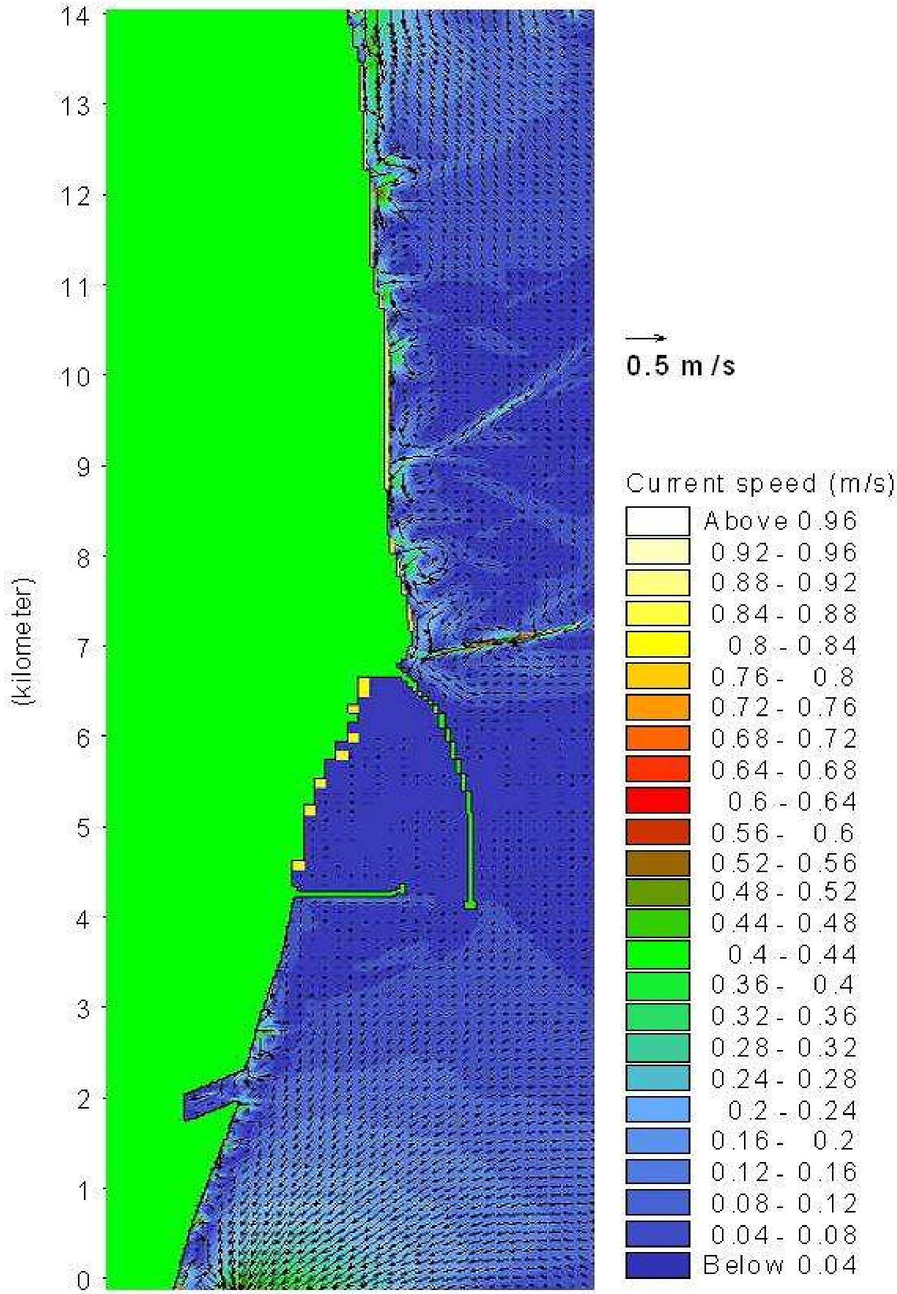


Fig 3.10b – Wave induced currents (cm/s) under NE waves used in ST model

The model results indicate that the nearshore waters of beachfill area are experiencing maximum sediment transport (of about 183 cu.m/yr/m) rates compared to other regions. This may be due to concentration of wave energy associated with wave convergence in the presence of port structures. At other places the sediment transport is of the order of 20-50 cu.m/yr/m.

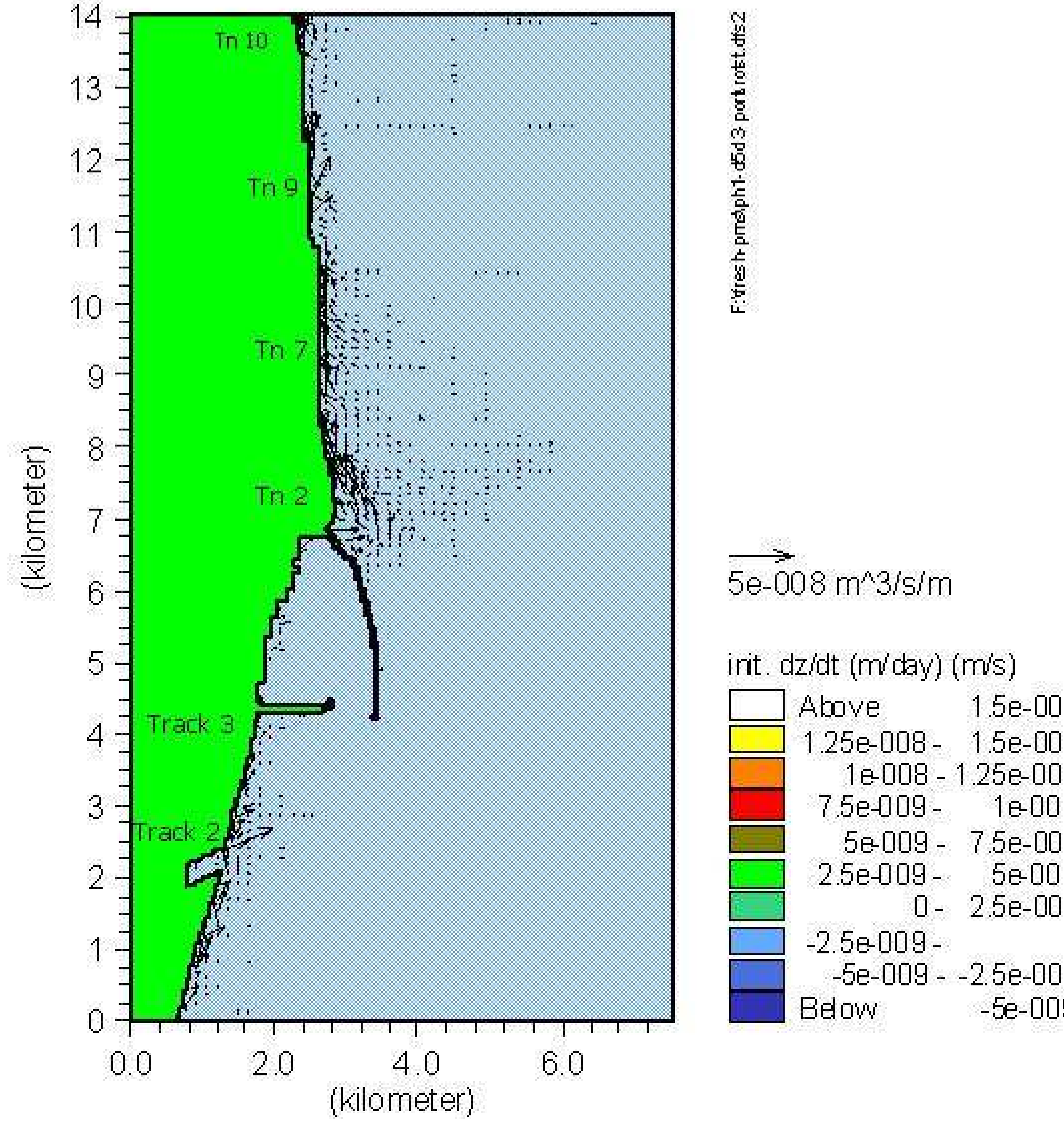


Fig. 3.11a – Domain of sediment transport rates and initial bed level changes under SE waves

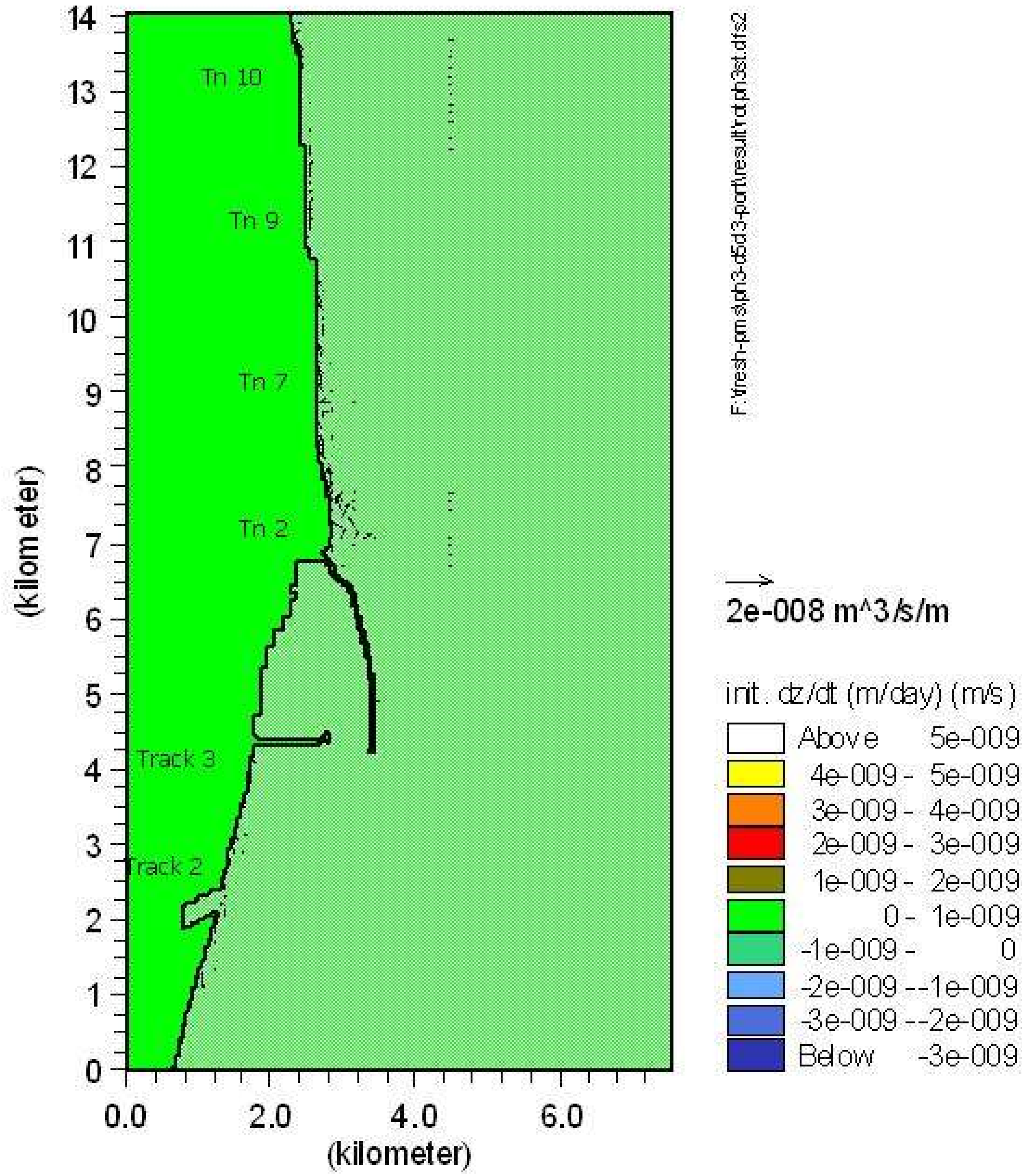


Fig. 3.11b – Domain of sediment transport rates and initial bed level changes under NE waves

The offshore extension of sediment transport zone is also varied from place to place depending upon the wave convergence and divergence zones. The transport zone extended upto 0.5 to 1.5km offshore near beachfill area and upto 0.1 to 0.3km in other places. However, a detailed modeling investigations are required, when an appropriate intervention is finalized.

3.4 Shoreline model (LITPACK)

To simulate shoreline evolution along Ennore coast, the one dimensional model LITLINE of LITPACK system was used. The model has the capacity to simulate the influence of structures like groin, breakwater, jetties etc on shoreline evolution and has the facility to include sediment source and sinks. The model predicts variations in shoreline position with in a stipulated period of time under the combined action of waves and currents. The input data required for the model are cross-shore profile, initial shoreline position along the coast, sediment size, annual wave climate etc. The required annual wave climate for Ennore coast is derived from the OSW/PMS model simulations discussed under section 3.2. The cross-shore profiles and the shoreline positions used in LITPACK model were derived from the RTK field data collected on different occasions during 1999-2005. As the Ennore coastline is subjected to changes due to natural and man-made activities (historical changes of Ennore coast is discussed section 3.0), the LITLINE simulations (**Fig 3.12**) were carried out for 3 Cases – I) shoreline evolution under the condition of no port structures i.e. with the1999 shoreline as base; ii) Shoreline evolution under the presence of port structures with 1999 shoreline as base and iii) Shoreline evolution of beach filled shore with 2001 shoreline as the base.

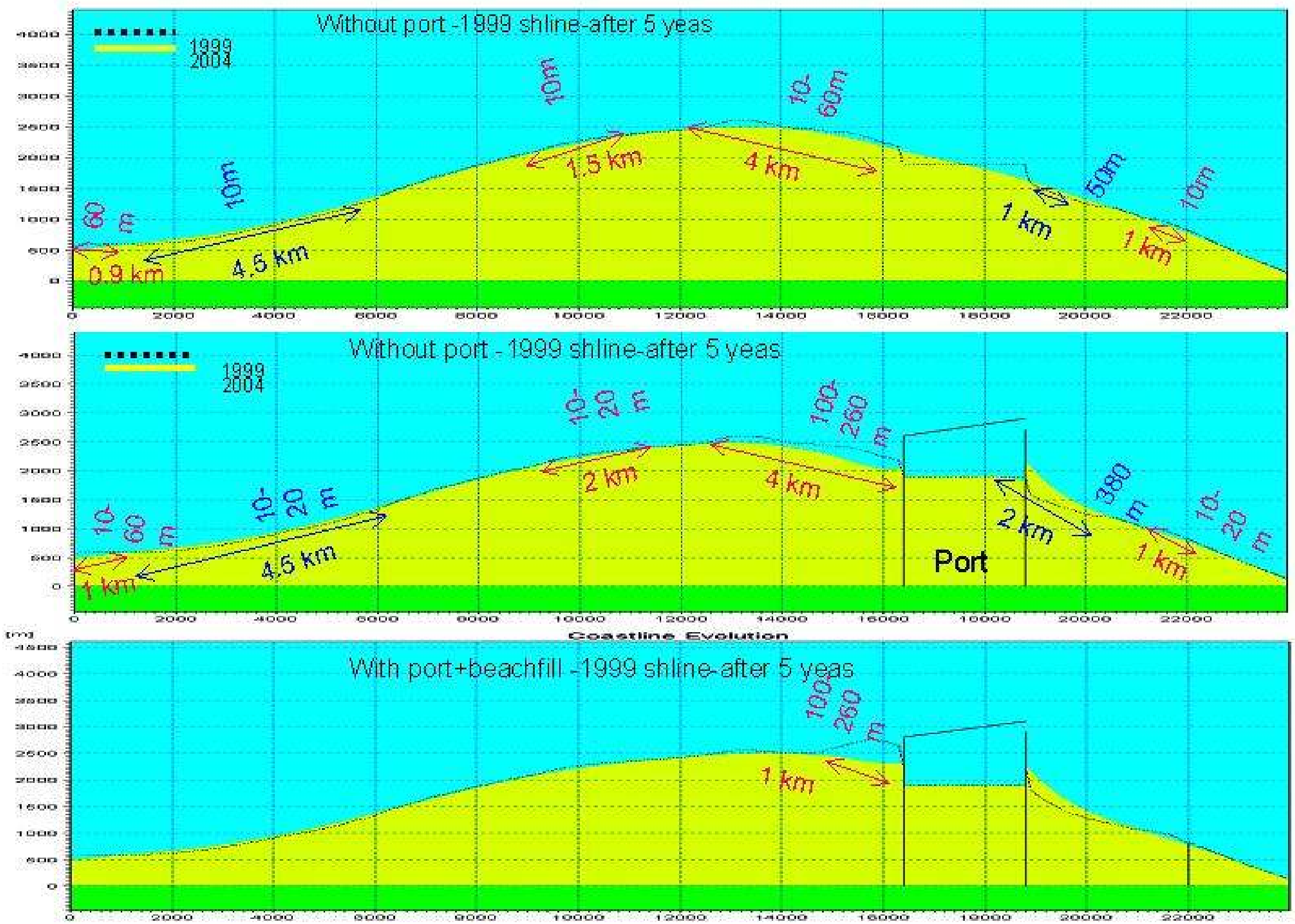


Fig. 3.12 - Shoreline changes under a) No Port, b) Port and c) beachfill

Simulations and field observations indicate that the beachfill placed north of Port was lost upto an extent 70% and the prediction indicates entire beachfill be subjected to erosion by the year 2007 **(Fig 3.13)**. After 2007, the natural coast will start eroding **(Fig 3.14)** if no sand is supplied. Simulations also indicate that shallower parts of the shoals (water depth of less than 6 m) are also likely to be eroded.

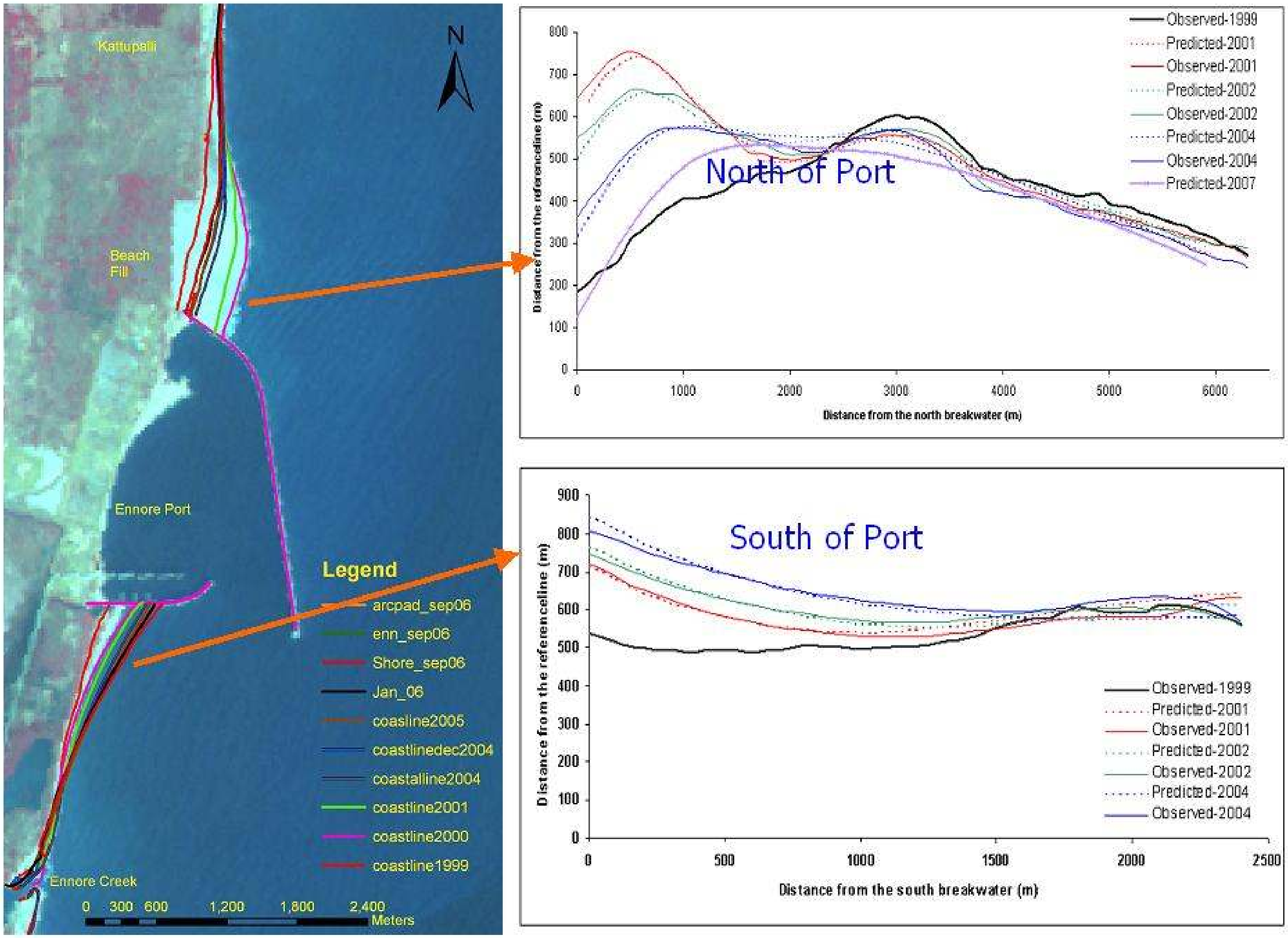


Fig 3.13 – Predicted and observed shoreline along north and south coast of Ennore

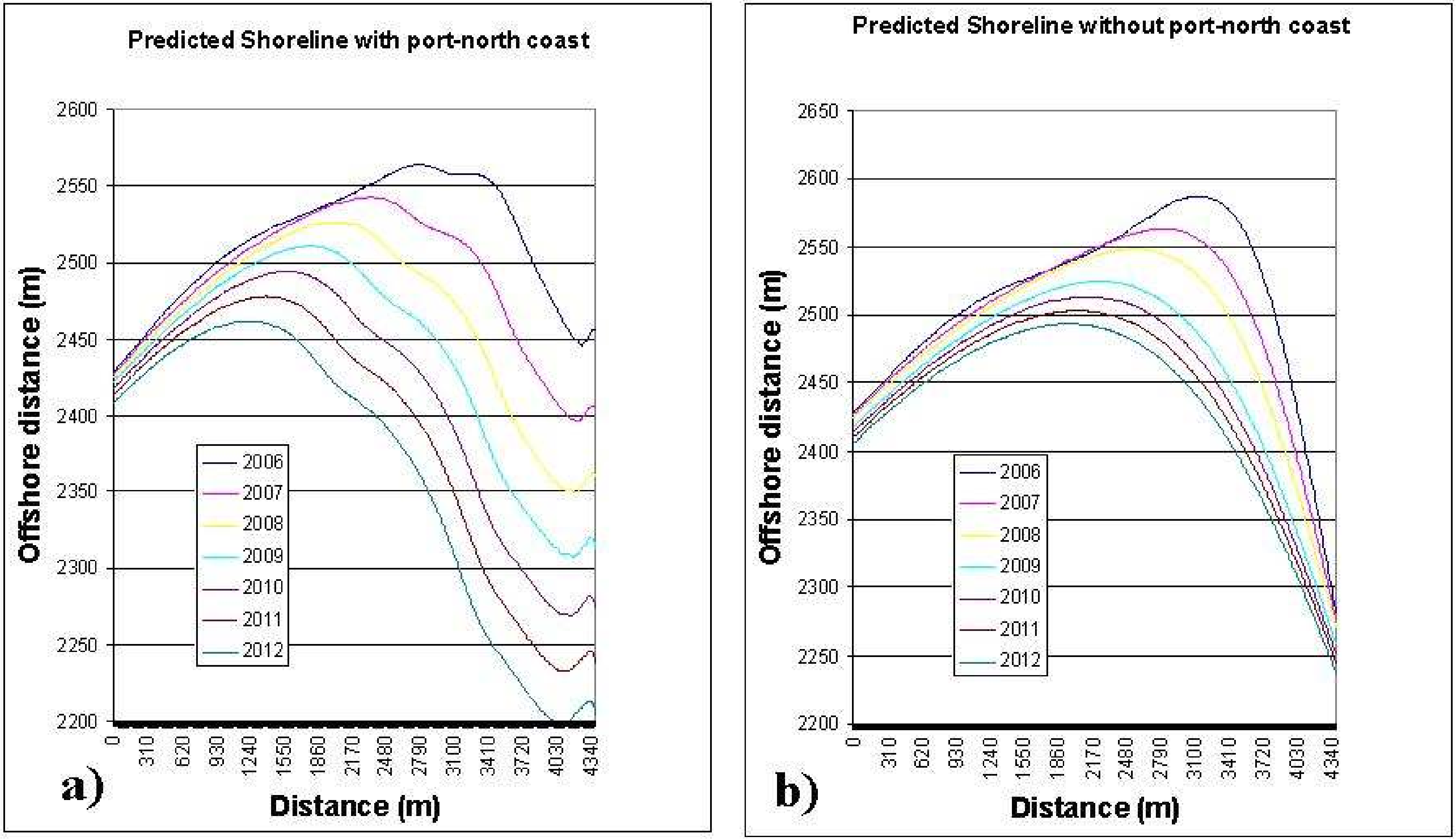


Fig 3.14 a– Predicted shoreline along north coast of Ennore a) with port and b) with out port

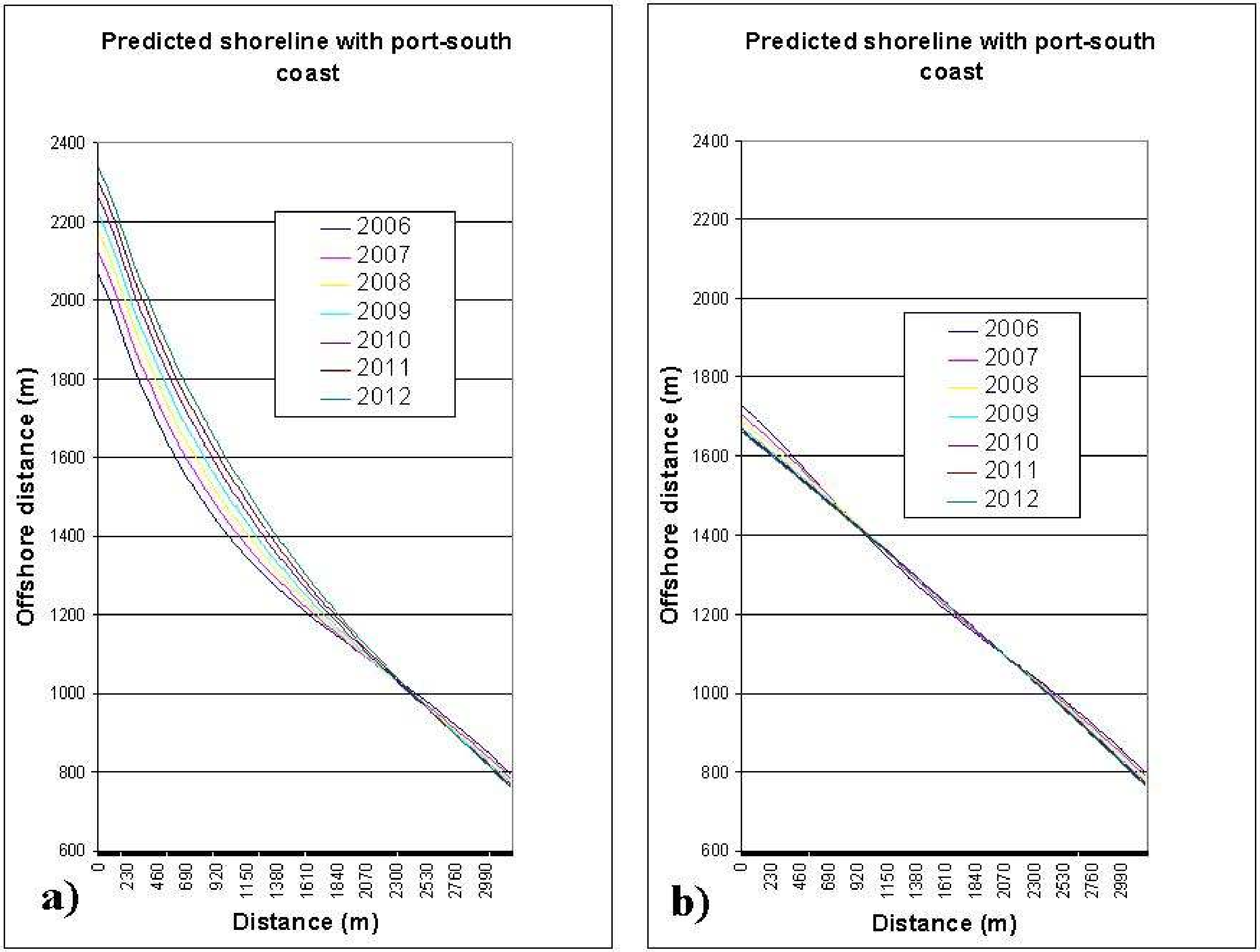


Fig 3.14b – Predicted shoreline along south coast of Ennore a) with port and b) with out port

On the whole, the south coast is accreting at an average rate of 45 m / year and north coast eroding at a rate of 50 m/year as discussed in Section 2.10. Since the port authorities adopted beachfill option by anticipating the erosion on north coast in 2001, the present erosion length was reduced to 1.5km. In order to prevent the erosional hot spot of 1.5km north port coast, different structural interventions were tested through model simulations. Necessary budget estimations on sediment transport along Ennore coast were made and presented below.

4. INTERVENTIONS

The field measurements of shoreline position along Ennore coast indicate that the 1.5km north coast of Ennore port is eroding at the rate of 50m/yr while the 2.0 km south coast accreting at the rate of 45m/yr (section 3). In order to prevent the erosion in north coast different interventions and the consequent impacts on shoreline management along the coast both soft (sand bypassing) and hard measures (groins, offshore breakwater and submerged reefs-geotube) were tested with appropriate model simulations. The interventions considered for the protection of coast north of Ennore Port are

(a) Artificial beach nourishment
(b) Disposing of dredge spoil (sand bypassing)
(c) Groins
(d) Submerged reefs

4.1. Artificial beach nourishment

"Soft" engineering measures such as beach nourishment are widely used for shore protection due to lack of negative impacts like erosion and also advantage over "hard" measures (seawalls, groins and breakwaters) in terms of performance, aesthetics and restoration of natural beach (**CAPOBIANOCO *et al.* 2002**). As a result, nourishment has become an integral part of coastal zone management strategy. Several approaches are available in this regard (**CAPOBIANOCO *et al.* 2002**) and **Table 4.1** shows a broad classification based on cross-shore dimension.

Table 4.1 – Different approaches of sand nourishment

Nourishment approach	Description
Dune nourishment	placing all the sand as a dune behind the active beach
Nourishment of subareial beach	using the nourished sand to build a wider and higher berm above the mean water level
Profile nourishment	distributing the added sand over the entire beach profile
Bar or shoreface nourishment	placing the sand offshore to form an artificial bar

At Ennore, an alternate option namely "nourishment of subareial beach" was implemented. The material dredged from Ennore port through capital dredging (3.5×10^6 m^3) was transported through pipeline to the project site immediately north of port. Out of total quantity of dredged material, 0.7×10^6 m^3 was placed over the existing beach to rise the berm height from 2.5 to 6.0 m above mean sea level and the rest is spread nearshore to widen the beach by 500 m **(Fig.4.1)**. Fill started supplying material to the downdrift coast from the inception of the project and a 250 m wide beach was lost between 2000 and 2004, forming a steep cut at the beach fill location.

Hanson and Kraus (1995) reported that improvement in design of nourishment projects and its life requires consistent evaluation criteria. In this context, while the behaviour of beachfills without a structure was well studied using a number of analytical methods (that take into account uniformity in topography, hydrodynamic and sediment-transport processes), there are comparatively fewer studies that deal with beachfills having a structure **(Kraus, 1995**). Predictive capability at places where uniformity does not occur near structures and complex bathymetry, is required for engineering design of coastal protection schemes. In the present study, extensive field data were used to evaluate the performance of the fill and improvements in design suggested based on numerical experiments.

The overall performance of the beach fill to protect the downdrift coast appears satisfactory. Simulations conducted using coastline evolution model indicated that the expected life of survival of the beach fill would be 3 years and the north coast needed maintenance after 2007. Minor deviations in the predictions (~ 6 months) are anticipated due to occurrence of tsunami. If no intervention is planned by then, north of Ennore Port will erode due to deficit sediment supply, as there is no possibility of sediment bypassing from south due to presence of entrance channel. An extent of 250 m wide beach was already lost against 500 m **(Fig.4.1)**, provided under nourishment. Beach fill of length 1000 m with 500 m transition length, as provided in the project, is not sufficient to make integrity of fill with adjacent coastline. Less transition length resulted in erosion of the coast beyond 1000 m and the village, Katupalli, located immediately north of fill is experiencing accelerated erosion of the order 50 m, three years after placement the beach fill. In order to improve the performance of nourishment and minimize its impact on adjacent coast, dimensions of fill should be of length 1000 m, width 600 m with a transition length of 800 m. On the southern side at the breakwater the average rate of accretion was 45 $m.yr^{-1}$ until 2003 and no significant accretion was noticed after that. The possible reason for maintaining the constant shoreline above waterline could be as a result of accumulated sand sliding into the port approach channel sustaining slope stability, which was confirmed by the sediment budget made at Ennore Port. Therefore, the Port Authorities have to continue dredging to maintain the navigation channel and these materials can be bypassed to the north of Port to nourish the beach.

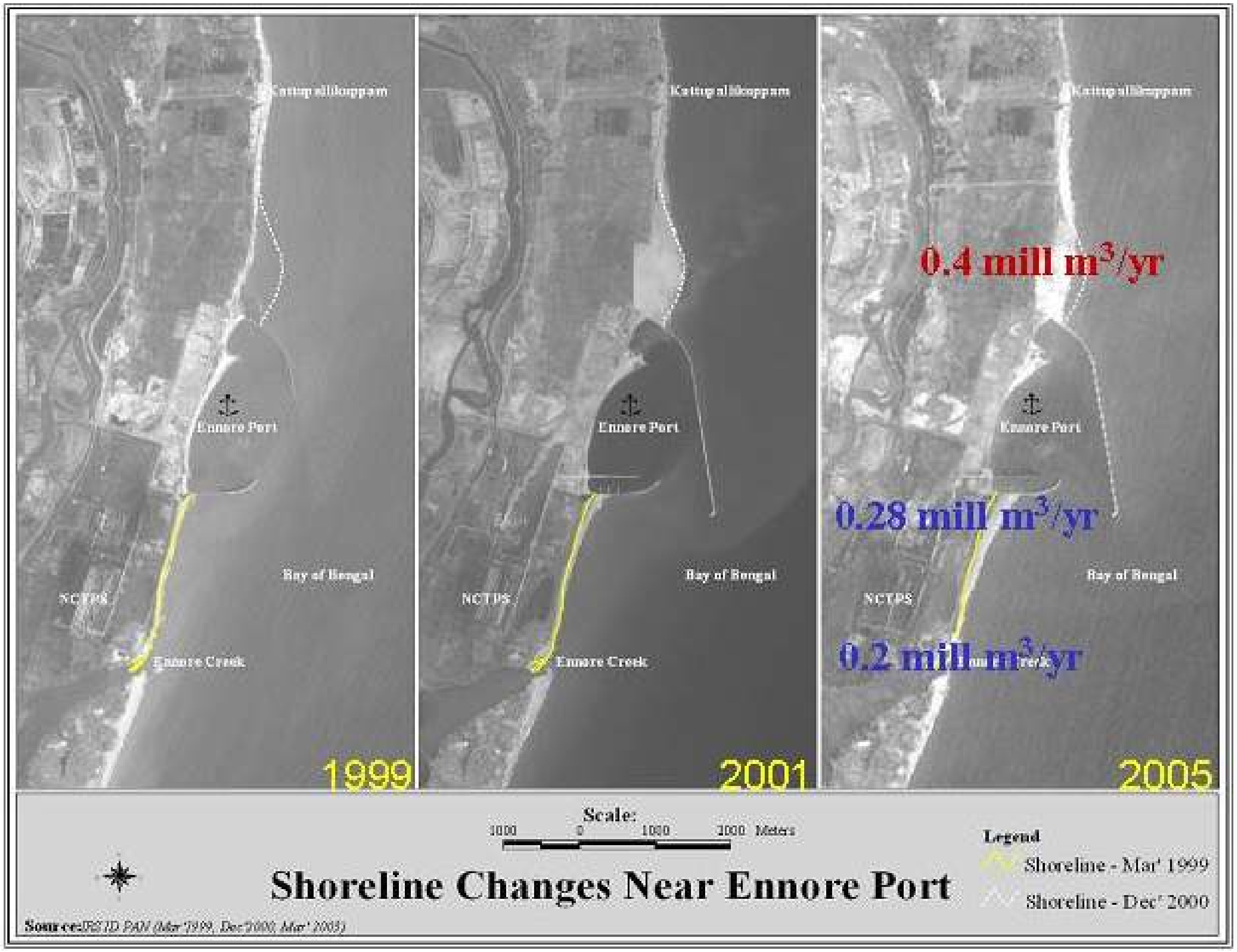


Fig 4.1 – Changes in beachfill

4.2 Sand Nourishment

By anticipating erosion on northern side, Ennore port has adopted the soft coastal protection measure “The beachfill” within 4.5km stretch upto 500m **(Fig. 4.1)** offshore distance in 2001. Alternatively, sand can be bypassed to northern side through pipeline (**Fig 4.2**). It is estimated that 0.25 x 10^6 m^3 of sand is being dredged annually from Ennore creek to maintain the power plants. The option of bypassing this sand to northern side will help in beach nourishment. The disposal can be done during southwest monsoon so that possibility of material entering into the entrance channel can be avoided. It is estimated from the simulation that a dump area of 1.5 km x 1.0 km (at beachfill, the north of Ennore port upto 1.5km distance from north breakwater) could build the sand mound to an extent of 0.4 m. The whole dredging operations with dredger capacity of 7000 cum hopper capacity take 3 months period.

Here, in this context, the sand bypassing technique has a limitation. Actually, in the beachfill area the amount of sediment eroding per year is 0.4 million cu.m (**Fig. 4.1**) which is more than the amount available from Ennore creek (0.25 million m^3/yr) to mitigate the erosion problem. Hence the alternative approach is adoption of sand by passing technique together with construction of submerged reef by which the erosion rate can be diminished.

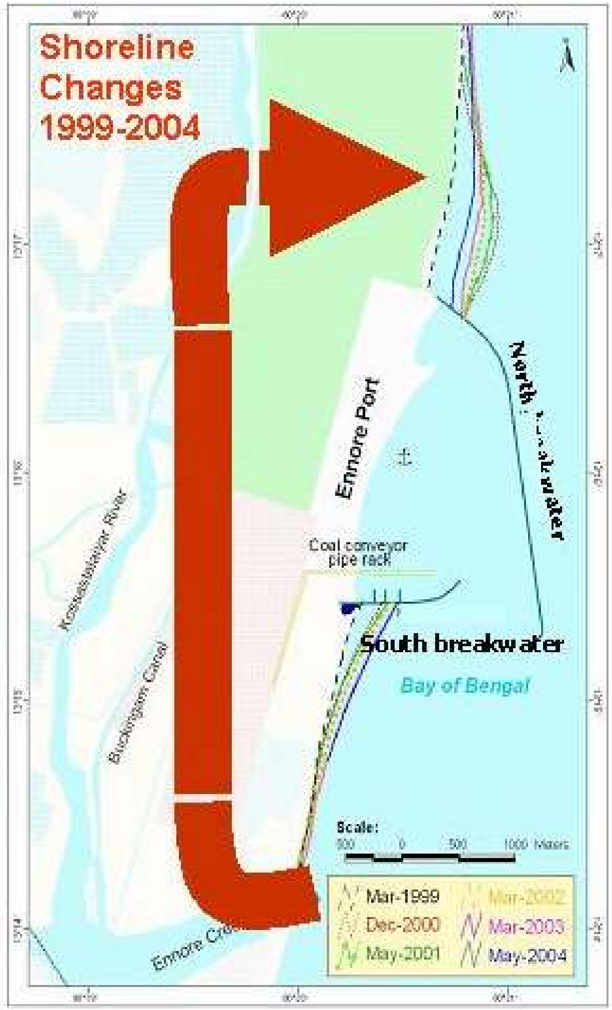


Fig 4.2 – Sand bypassing along Ennore coast

4.3 Groins

Groins and their massive relatives, artificial headlands, are coastal structures built of similar materials as seawalls, but oriented approximately shore-normal. They form a cross-shore barrier that traps sand that moves alongshore, thereby increasing the width of the beach on the upstream side. Thus, they function best on beaches with a predominant alongshore transport direction (***Basco and Pope, 2004***). Groins are built to serve three purposes. i) To build or widen a beach, by trapping sand, ii) To stabilize a beach, which is subject to excessive storms or periods of episodic erosion and iii) to reduce or prevent the movement of littoral materials out of an area. This final case may be best applied at the terminus of a littoral cell to prevent sand from entering a sediment sink (**CERC 1984**). When groins are placed within a littoral cell, the usual outcome is to 'shift the problem down the coast'. Indeed, groins form an artificial headland that results in erosion on the downcast side of the structure. Use of groins to stabilize beaches has generated much controversy, triggered by a few, well documented examples in which adjacent beaches and communities were placed at risk because of severe downdrift erosion (***Leatherman, 1991***). Groin design characteristics were not always well understood and their design was as much an art as it was a science (**CERC, 1984**). There are three groin design considerations i) Littoral processes (wind and wave data, beach slope, sediment type etc); ii) Functional design criteria (length, height, spacing etc) and iii) structural design criteria (material types, constructional procedures etc). For Ennore coast even though there is predominant alongshore sediment transport but at immediate north of port there is considerable onshore/offshore movement of sediment. In order to find suitability of groins to arrest erosion north of North Port, 7 groins (each 20m width and 600-700m length) were considered and their possible response along the shore was studied with the help of MIKE 21 st model.

Simulations on effectiveness of groin structure under different wave directions (**Fig. 4.3**) indicate that the groin effect is completely negligible when waves approach the coast from E direction i.e. parallel to coastline. It is evident from the studies that the bypassing of sediment to north of port is not possible due to presence of entrance channel on southern side of port, which traps the sediment. A question arises in this context is when groins in the Royapuram area building the beaches why not at the Ennore shore?. To answer to this, the following reasons are more adoptive i) Orientation of coast along Ennore is typical compared to that along Royapuram. Along Royapuram the sediment transport will takes place along the coast where as at Ennore coast most of the sediment is by passing by Ennore port in NE direction (discussed in section 2.7), ii) On south of port, most of the sediment was getting trapped at Ennore creek and at south breakwater and hence supply of sediment near beachfill area is reduced and iii) because of Convex projection of coast onwards and presence of port structures, the wave refraction pattern leads to more concentration of energy at the Ennore coast compared to that at Royapuram coast. Since the waves approach the shoreline most of the time from SE direction the simulated MIKE 21 ST model results for the SE waves is shown in **Fig 4.4** to study the possible nearshore current pattern and associated sediment transport. The simulation results indicate that the wave heights on the downdift side were drastically reduced and the wave induced current strengths deceased and considerable amount of sediment is accumulated. Under varying annual wave conditions the LITPACK predicted shoreline by the nearby 5 years (2006 to 2011) is shown in **Fig 4.5**. 8 nos of trained set of groins were tested with LITPACK model. The model was run by constructing 8 groins of varying size (150 to 250m length) and the prediction of shoreline next 5 years period (2006 to 2011) was made (**Fig 4.6)**. The predicted shoreline clearly indicate that the coat is under going severe erosion on its northern side of groin field event though the beach was built up in the field of groins. In order to compensate the loss of north beach of groin field an amount of 1.2 x 10^6 cu.m/yr (**Fig 4.7**) sediment supply is need by artificial nourishment of the lost beach. But the main problem regarding groin construction is downdrift erosion, which is extended further north. Further, the normal sediment transport along Chennai coast of the order of 0.7 x10^6 m^3 / yr may be insufficient to build beaches to protect the shoreline. Hence, groins seems not to be a good viable option for coastal protection for Ennore coast.

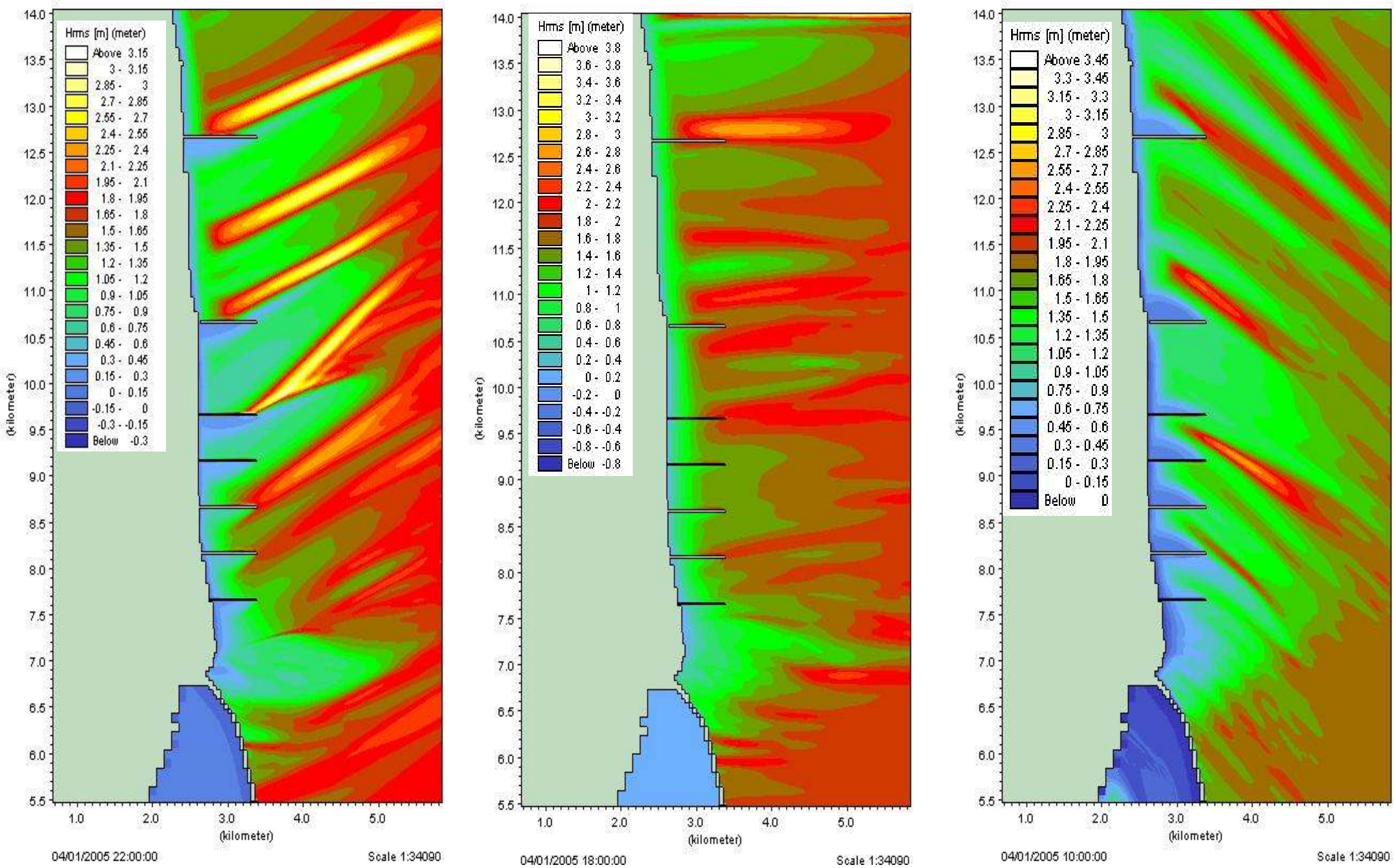


Fig 4.3 – Wave height variation in the presence of groins when waves approach from a) NE b) E and c) SE directions

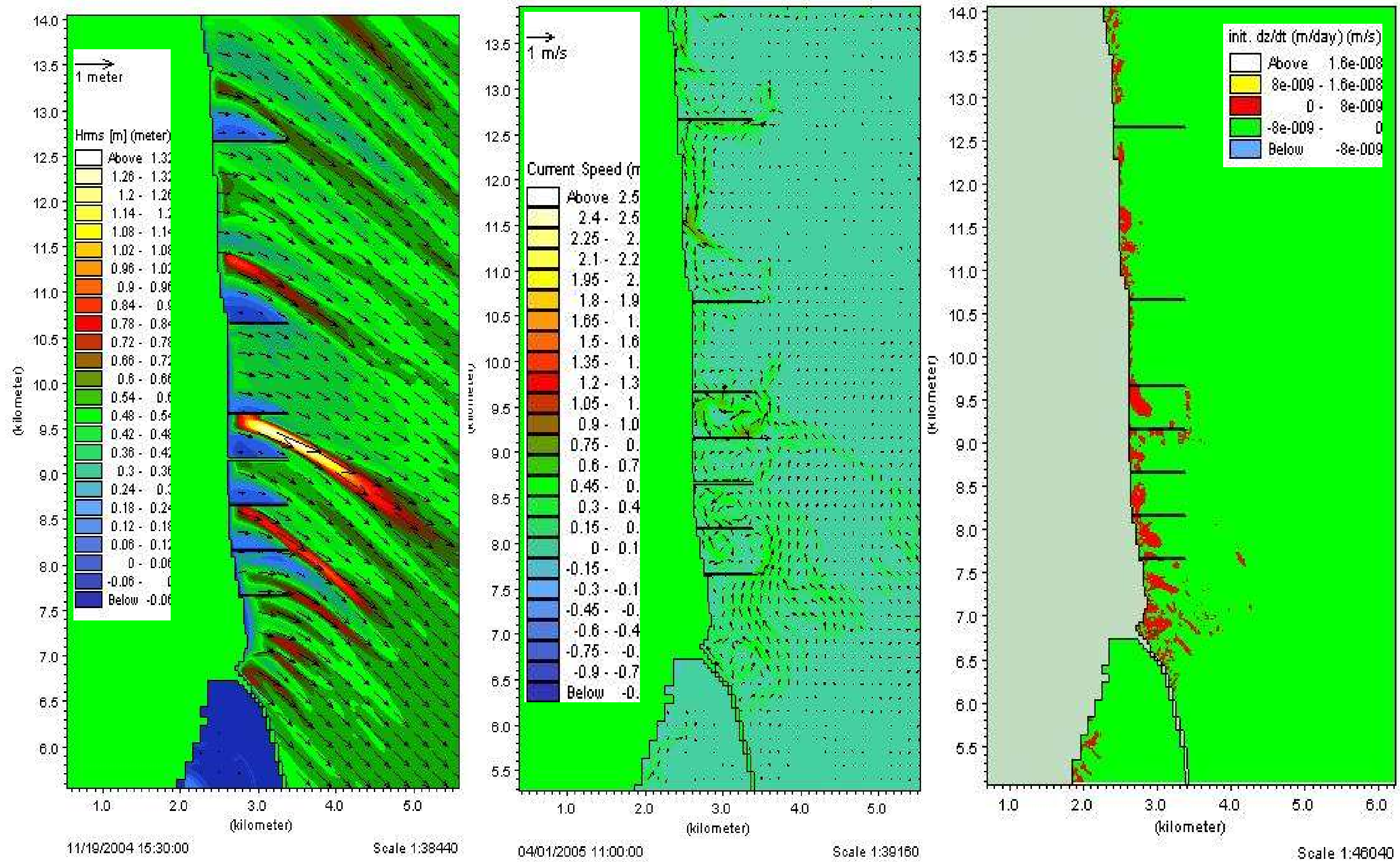


Fig 4.4 – Simulated a) wave ht (m) b) wave induced current and c) alongshore sediment transport under groin construction

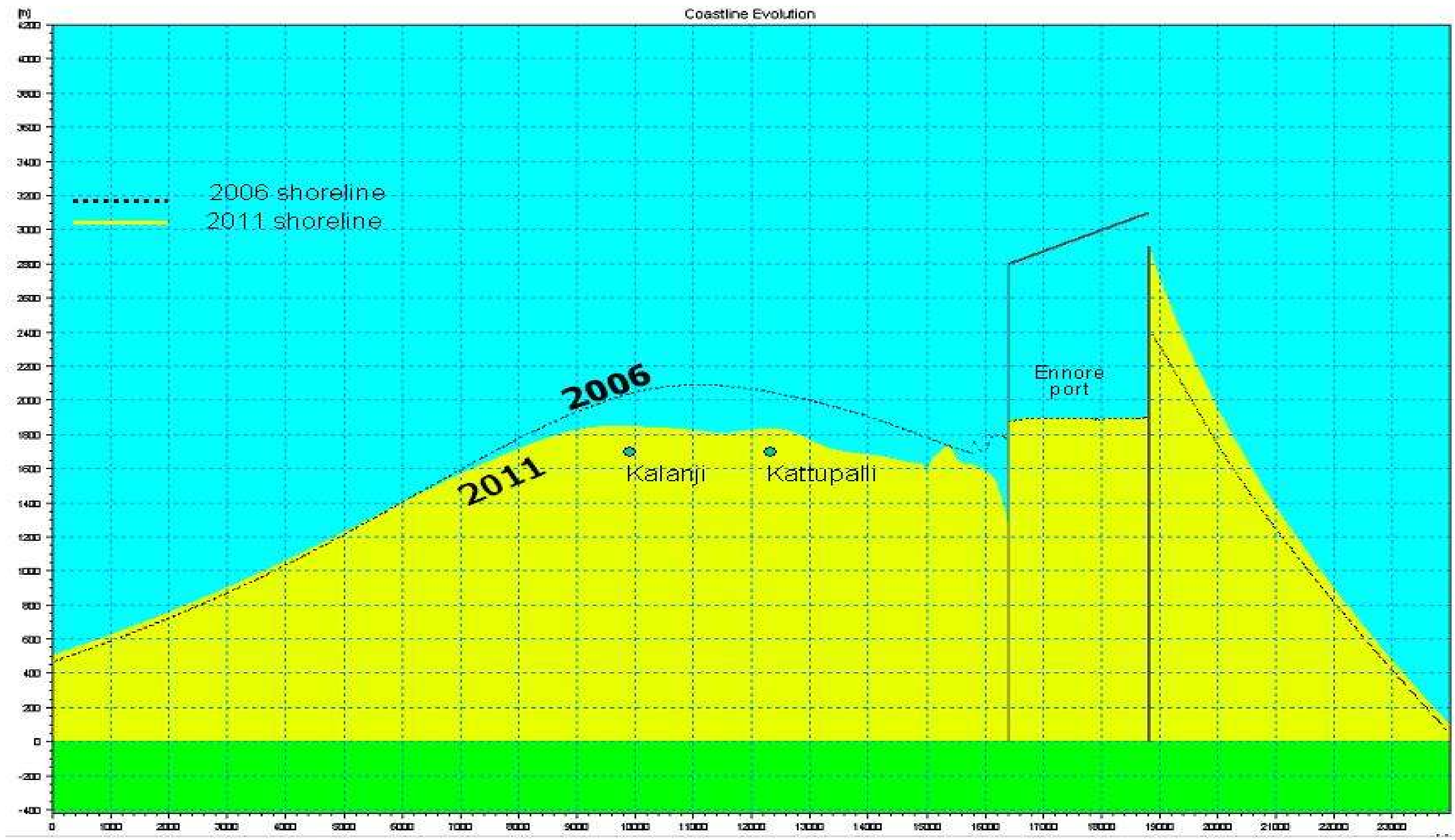


Fig 4.5 – Predicted shoreline change between 2006 and 2011

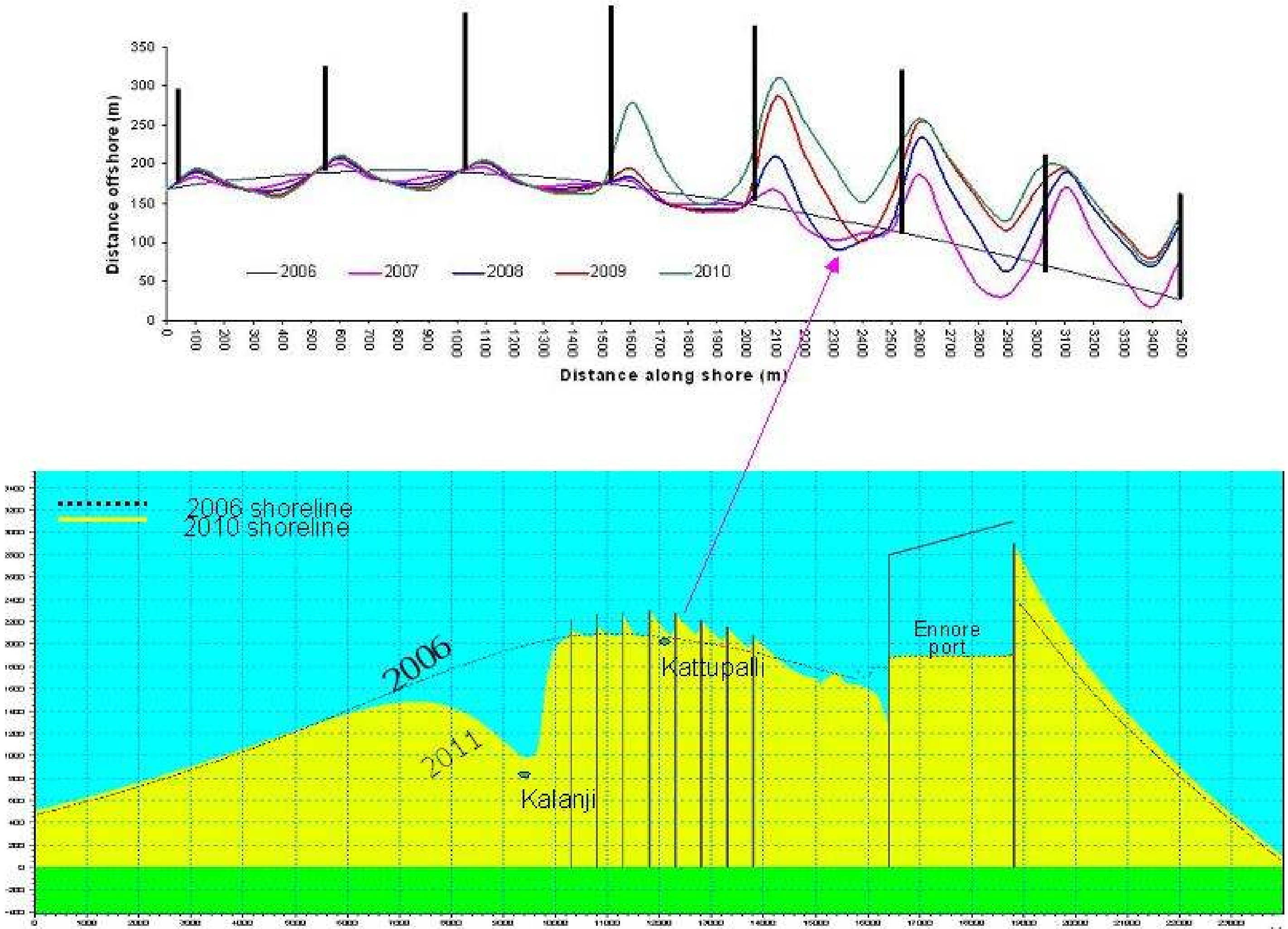


Fig 4.6 – Shoreline migration under groin field based on annual wave conditions

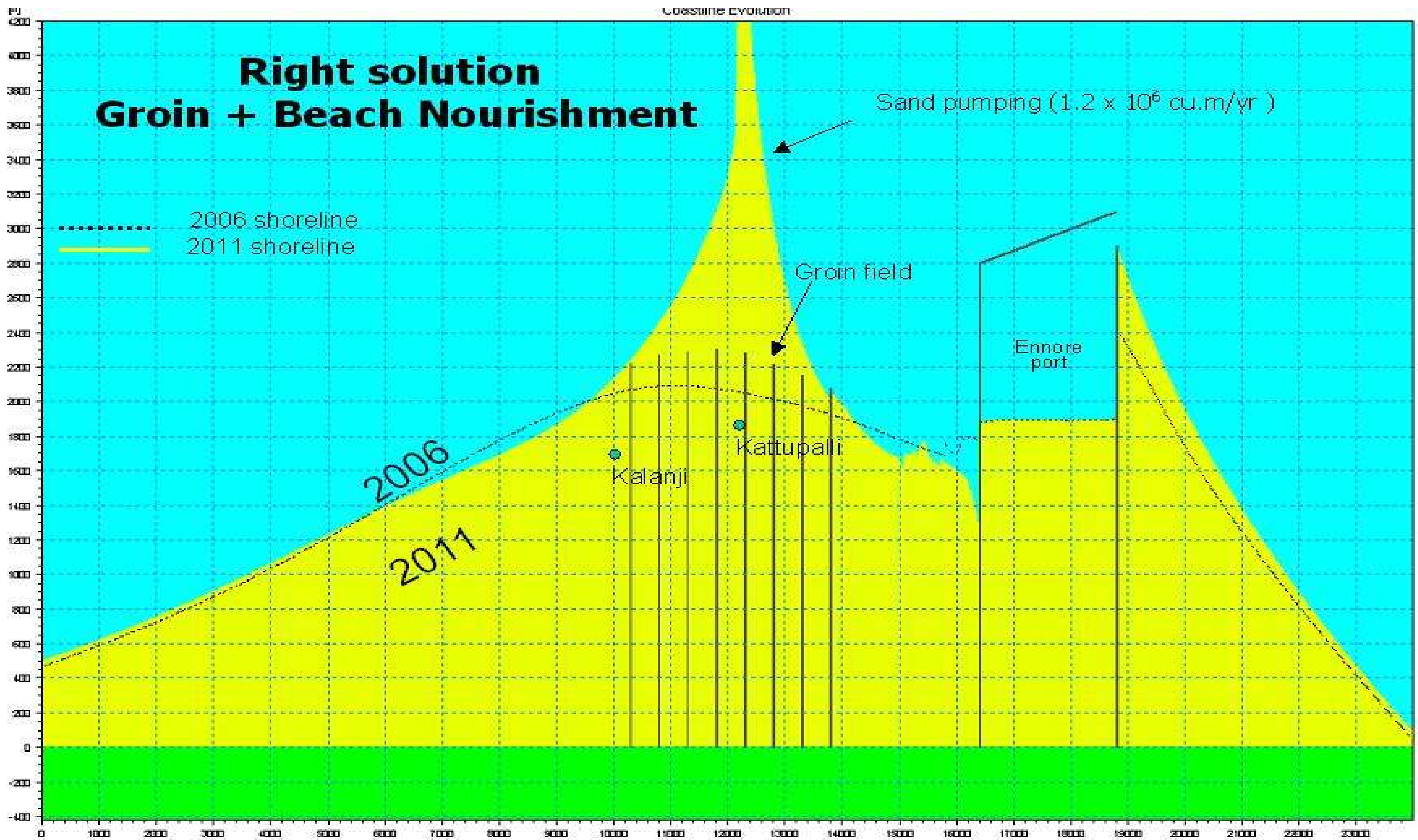


Fig 4.7 – Beach nourishment and groin field for shorelien protection on erosional hot spot of Ennore coast

4.4 Offshore Submerged Reefs

Offshore, or multi-purpose, submerged reefs are a relatively new coastal zone management concept which will work by breaking the waves offshore and eliminating the power of the waves at the shoreline. There are many examples of submerged reefs for coastal protection worldwide, although the majority are not multi-purpose and do not incorporate rotation functions – these structures are mostly designed for wave attenuation. Even so, these existing structures give a good indication of reef effectiveness and wave transmission for different depths of water above the crest, which is also relevant to tidal range. Anecdotal evidence suggests that submerged reefs are more effective in areas with small tidal ranges. Submerged reefs function through wave dissipation and wave rotation, which leads to salient growth in the lee of a reef. Wave energy is dissipated on the reef resulting in less energy at the beach in the lee of the reef and the consequent deposition of sediment. The depth of the reef, its size and its position relative to the shoreline determine the level of coastal protection that may be provided by the reef **(Black and Andrews, 2001a, b; Black, 2003**). This ability to vary the protection level as part of the reef design is a feature of the offshore reefs and allows far greater flexibility in their design function compared to other types of coastal protection device. It is well accepted (**Brampton et al., 1995**) that a submerged reef will reduce wave heights in its lee, and cause a re-orientation (or "rotation") of the beach contours and waves for some distance up and down the coast on either side of the sheltered area. Most commonly an offshore obstruction, such as a reef or island, will cause the shoreline in its lee to protrude in a smooth fashion, forming a salient or a tombolo. This occurs because the reef reduces the wave height in its lee and thereby reduces the capacity of the waves to transport sand. Consequently, sediment moved by longshore currents and waves builds up in the lee of the reef (**Black, 2001**). Providing habitat for marine species to develop marine biodiversity and the seaweeds grow after 6 weeks. In terms of construction costs, the use of sand-filled geotextile containers as reefs has proven to be significantly lower than land-based, hard rock, solutions (in terms of cost per protected meter of shoreline). These factors are considered in relation to the suitability of reefs for solving coastal erosion problems and meeting modern expectations for the environment.

Submerged reefs have low impact on the aesthetics of the beach environment since they don't encroach on the beach or protrude from the water and they have many multiple uses like surfing, sea bathing, swimming, fisheries, tourism etc (**Fig 4.8)**. In ecological terms, the hard stable substrate (such as reefs) results in greater biodiversity and species abundance than mobile sandy substrates (**Pratt, 1994; Mead et al., 1998**). Comparatively few species (mostly worms and bivalves) inhabit the abrasive, mobile sandy sea-beds. Abundance increases on topographically more complex substrates (i.e. a higher number of different niches are available) and when the reef is larger (**Pratt, 1994**). Artificial reefs provide the opportunity to create designed habitat and to 'seed' specific species that may be of commercial or cultural value (**e.g. Saito, 1992**). Therefore, the biological enhancement may include increased environmental value (increases in bio-diversity and abundance), increased amenity in the form of a diving and snorkelling venue and enhanced fisheries by the incorporation of specific habitat.

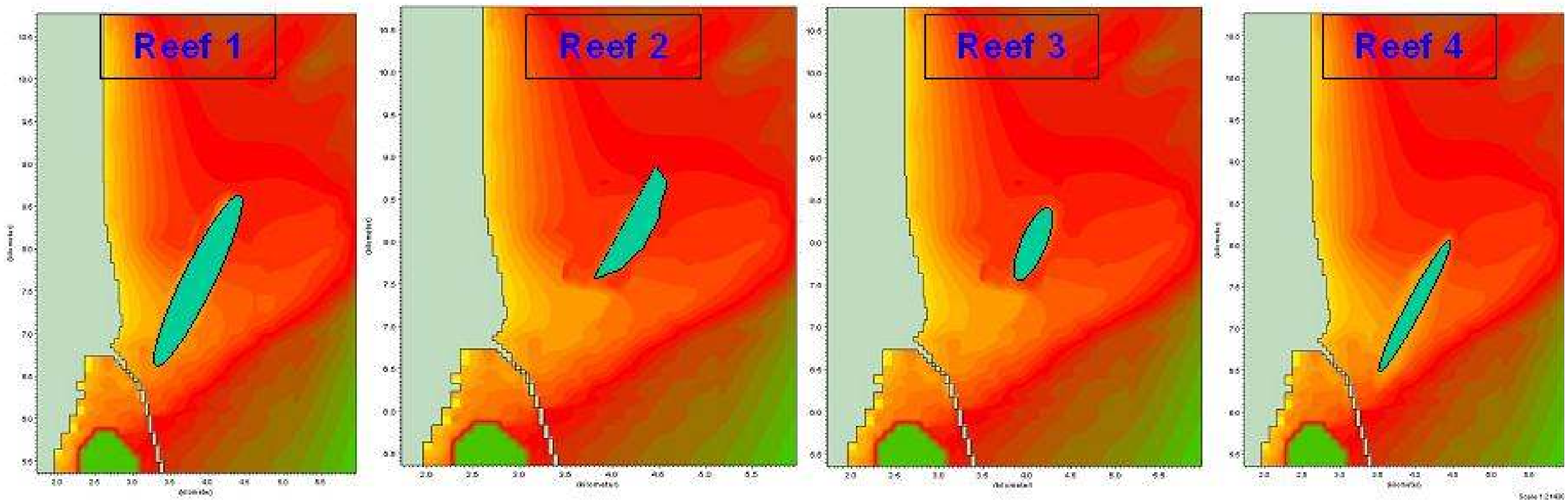


Fig 4.9 – Reef under different configurations and shapes

Table 4.2 – Configurations and shapes of different reefs considered for model simulation

Reef ID	Major axis length (m) L	Minor axis length (m)	Depth (m) of Reef Surface	Distance (m) from shore X	X/L
Reef 3	800	200	2.5	1300	1.6
Reef 2	1000	200	2.5	1300	1.3
Reef 4	1500	200	2.5	1200	0.8
Reef 1	2000	300	2.5	1200	0.6

Numerical Investigations are conducted with various configurations of reefs (length, width and crest height - depth) and distance from the coast. Optimum configuration in terms of its dimensions and distance from the coast was arrived.

For Ennore coast, four different types of reef designs (**Fig. 4.9 and Table 4.2)** were considered for model simulations and the effectiveness of these reefs on Ennore wave climate were tested (**Fig 4.10**). Based on the model results, reef 4 showed reasonably good results in the context of wave attenuation (**Fig 4.11**) on the lee side of the reef. So keeping in view of protection of about 1.5 km length of northern shore of Ennore port, finally the size and shape of reef 4 (length: 2 km & width: 300 m) is considered for further detailed studies on the effectiveness of the reef 4 design.

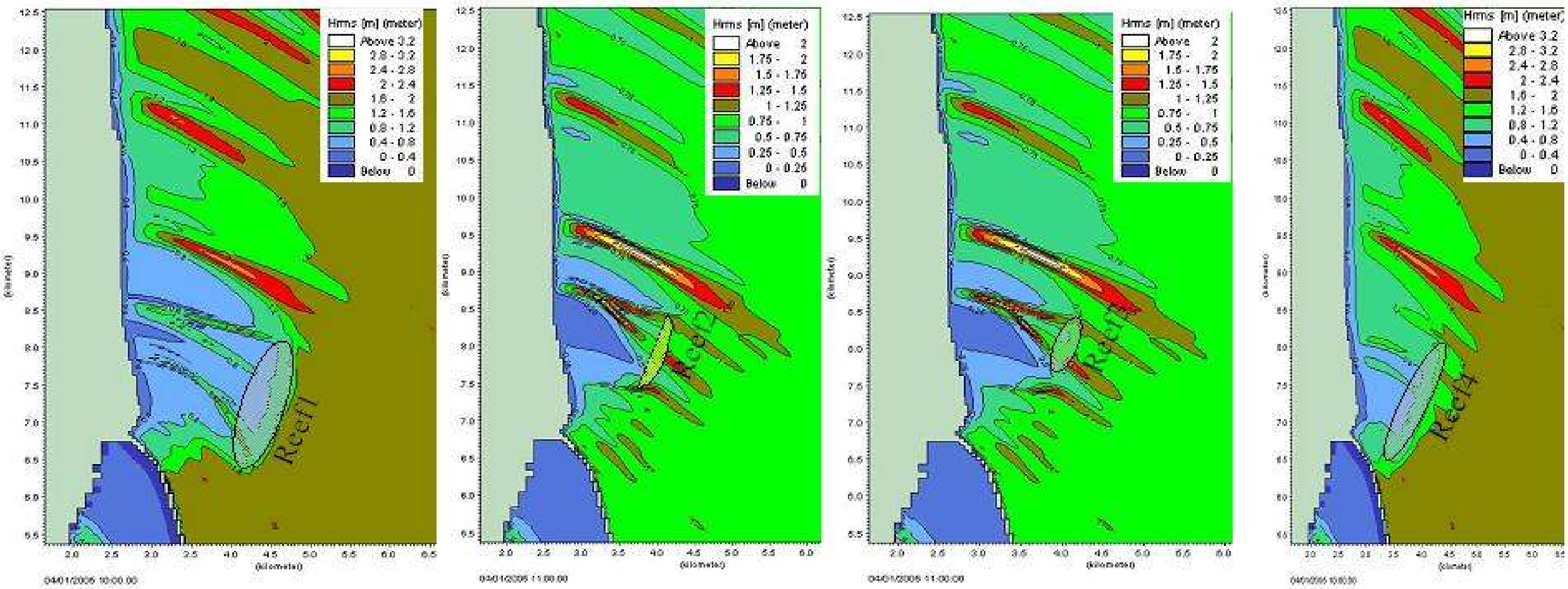


Fig 4.10a – Reef effectiveness under SE waves

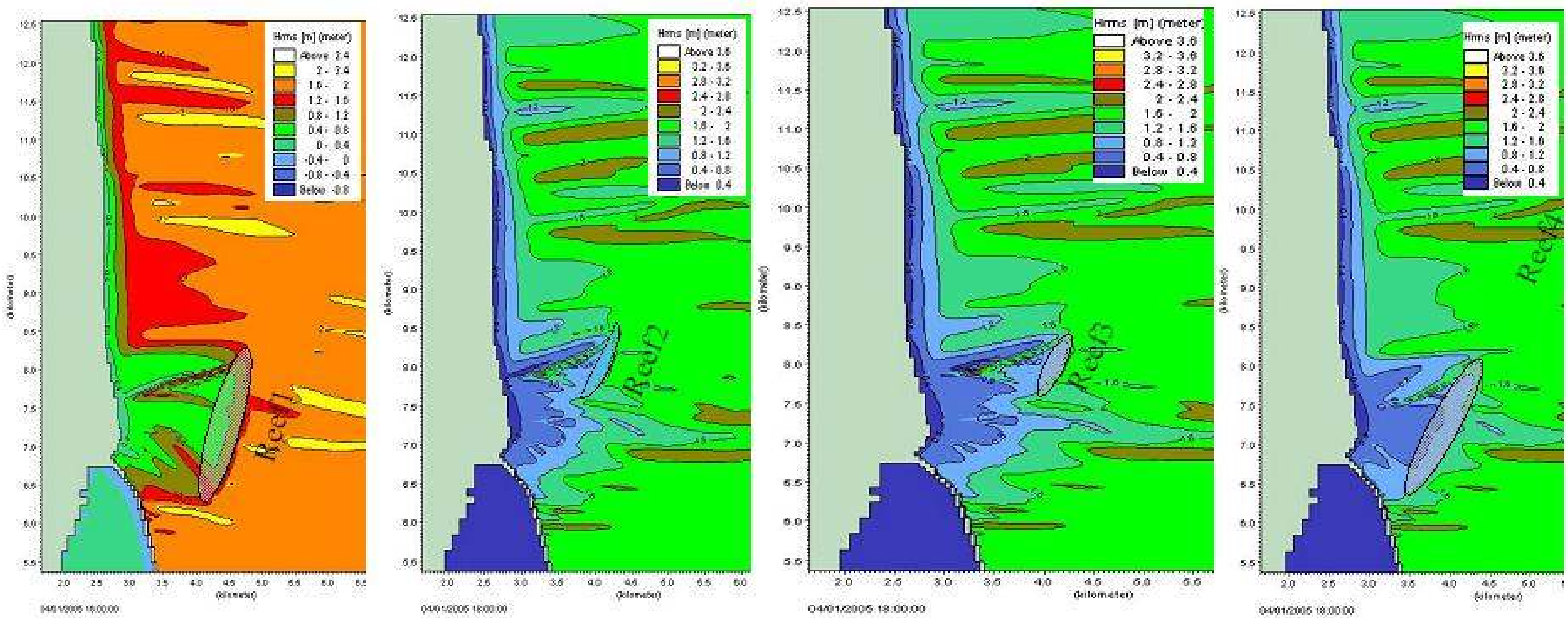


Fig 4.10b – Reef effectiveness under SE waves

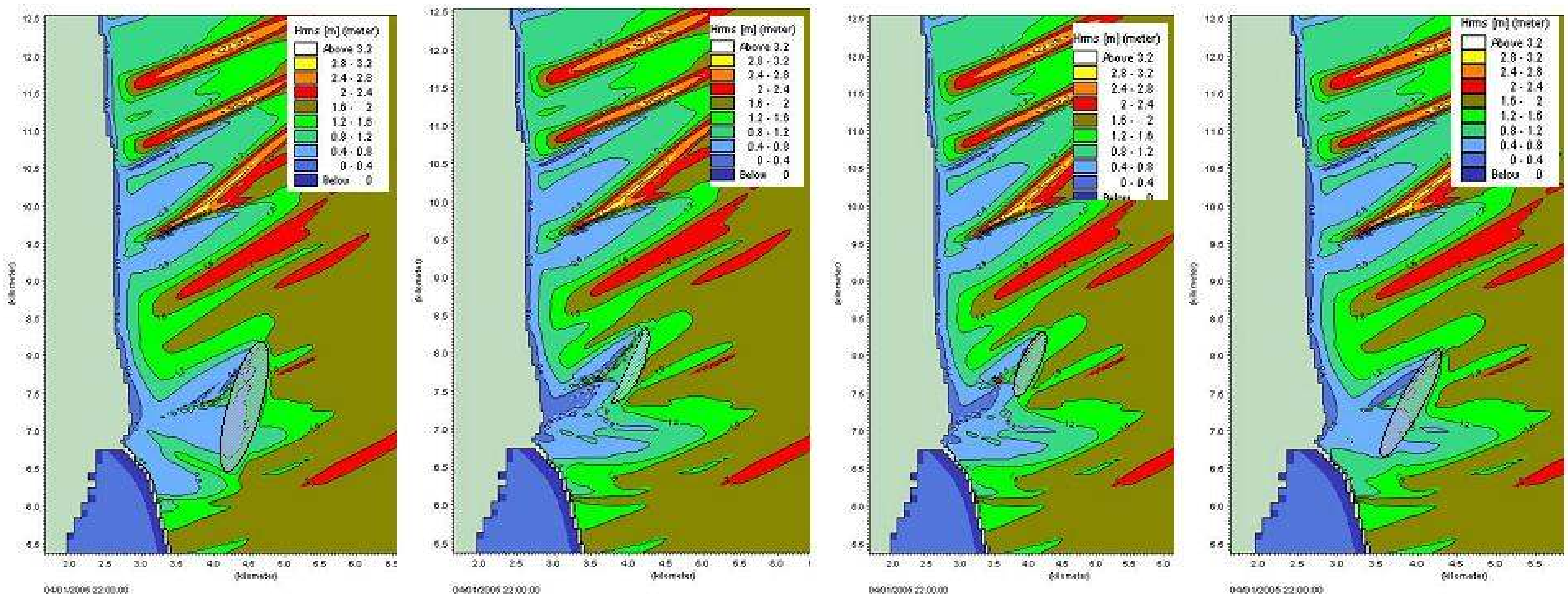


Fig 4.10c – Reef effectiveness under SE waves

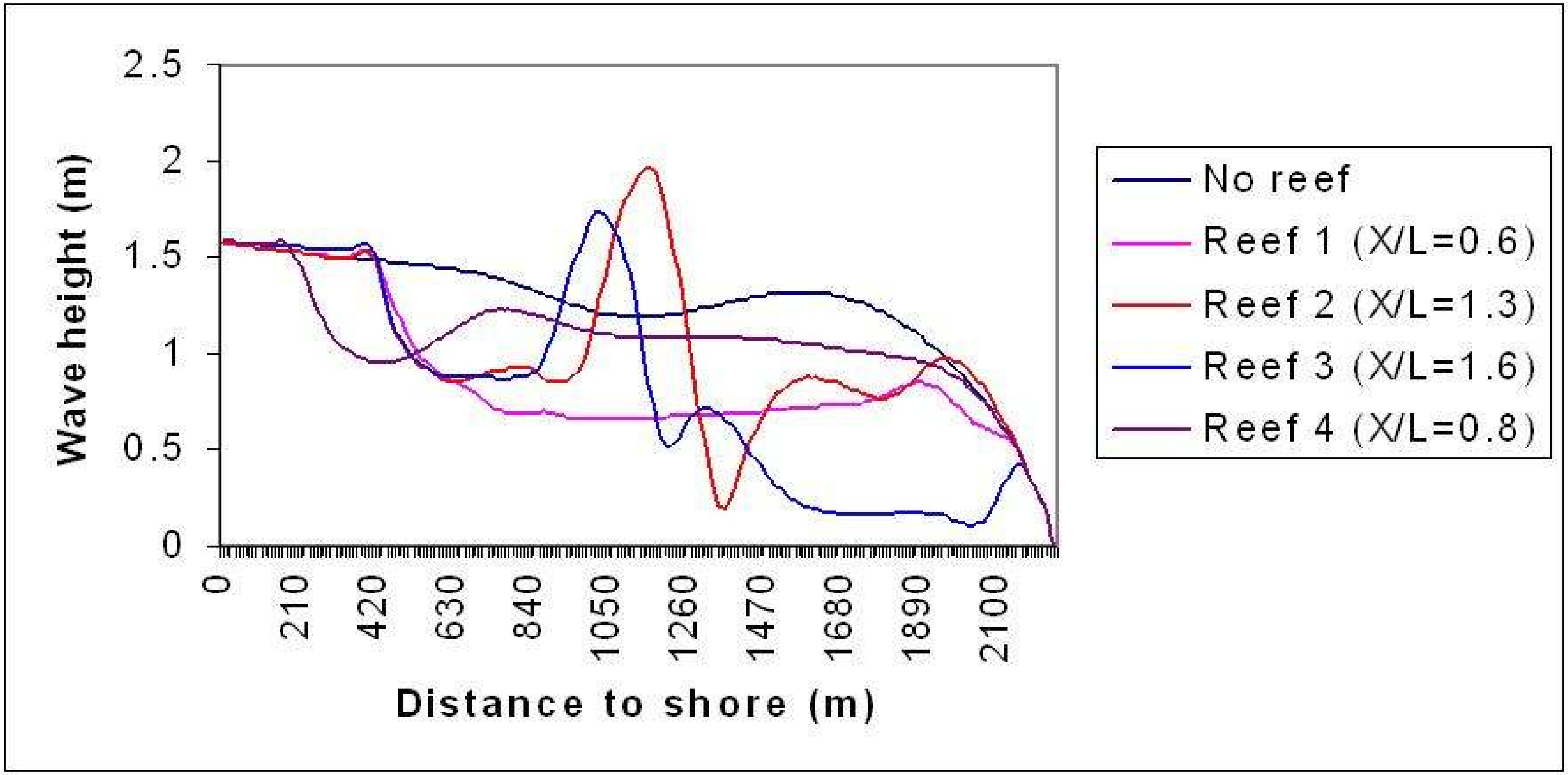


Fig 4.11 – Reef effectiveness under different configurations

The results indicate that reefs reduces wave energy upto 20 to 40% on nearcoast, there by helps in accumulation of sediments due to reduction in wave intensity. The cross impacts of these reefs is also minimum when compared to other options. The reef breakwater was tested with varied crest elevation (depth of water) and simulated wave height distribution on leeside of reef breakwater is shown in **Fig 4.12**. Maximum reduction in wave height is observed when the depth above shoal is 2.5 m.

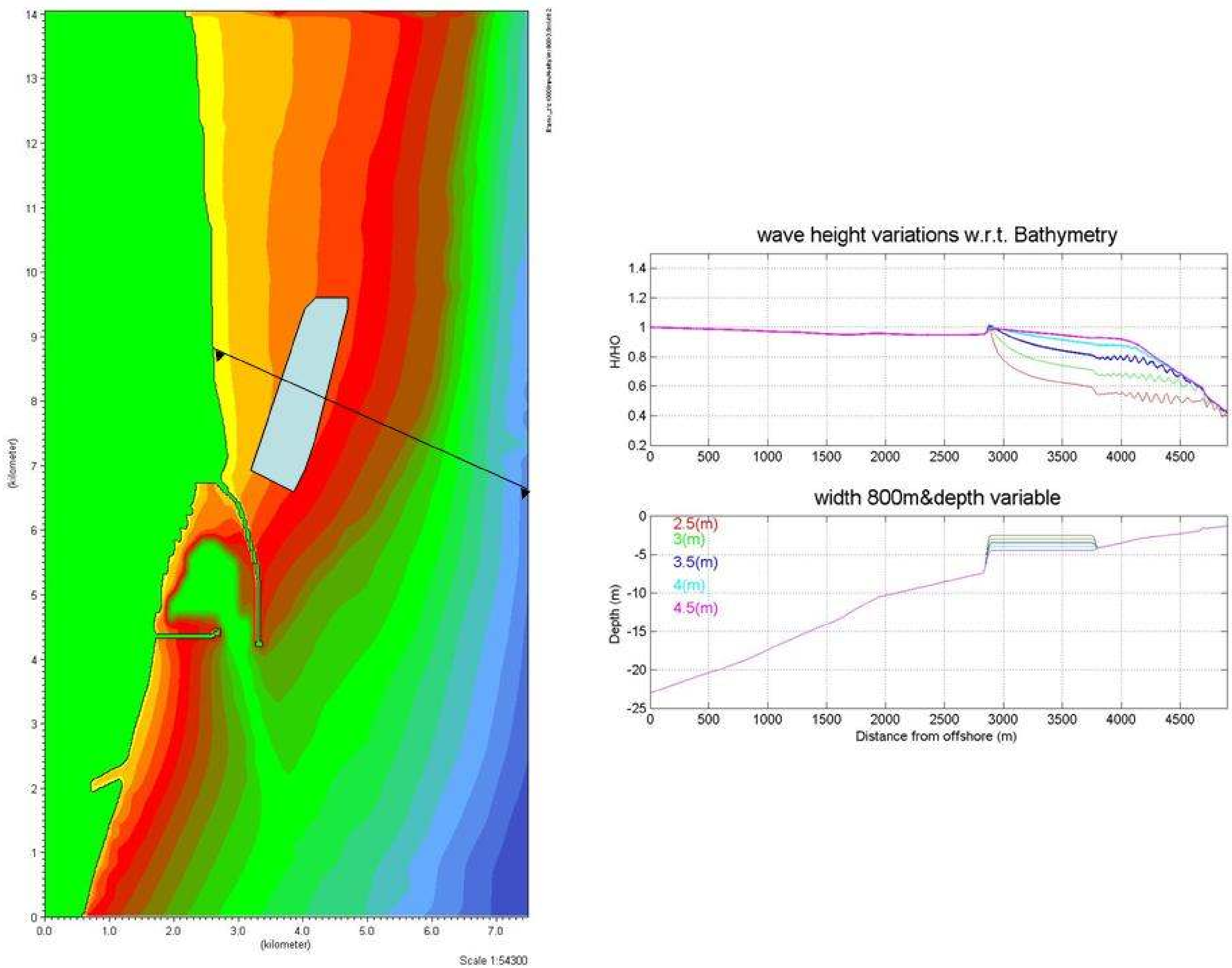


Fig. 4.12 - Configuration of reef breakwater and wave height distribution along the transect taken across the reef

In order to find out suitable location and reef optimization the dimensions of reef were varied in terms of its depth of location and its width **(Figs 4.13 and 4.14)**. Initially the reef was tested for different depths and found that 2.5m depth (below sea surface) is the most optimization for construction of reef. Later by varying widths of the reef the design was tested. Ultimately it was found that the depth of 2.5m and width of 600m will give reasonably good results for reduction in wave energy and to build the beach .It is also observed that when the width of the reef increased more, better results are reproduced in terms of reduction in wave height but one should aware the construction cost of a wider reef.

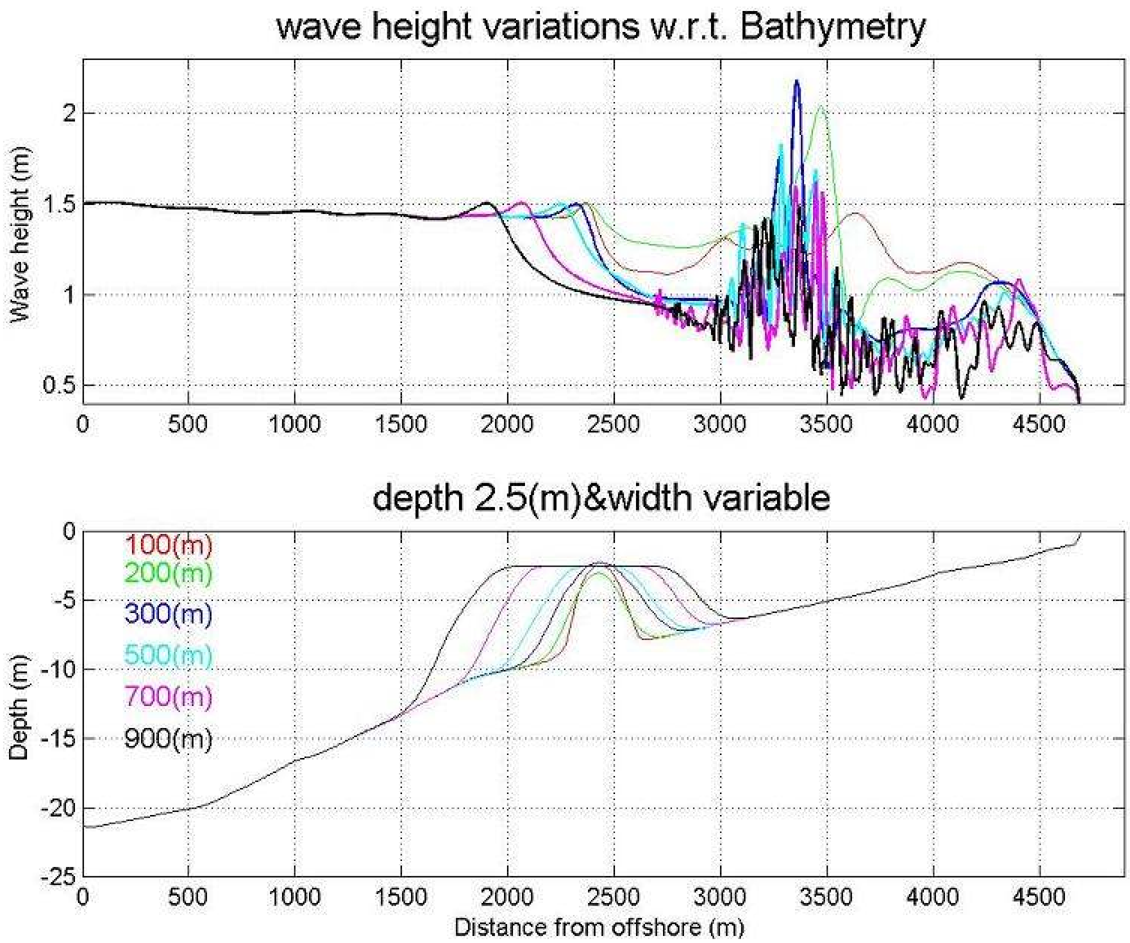


Fig 4.13a – Wave height variation for different reef widths (l;ocated at 2.5m depth)

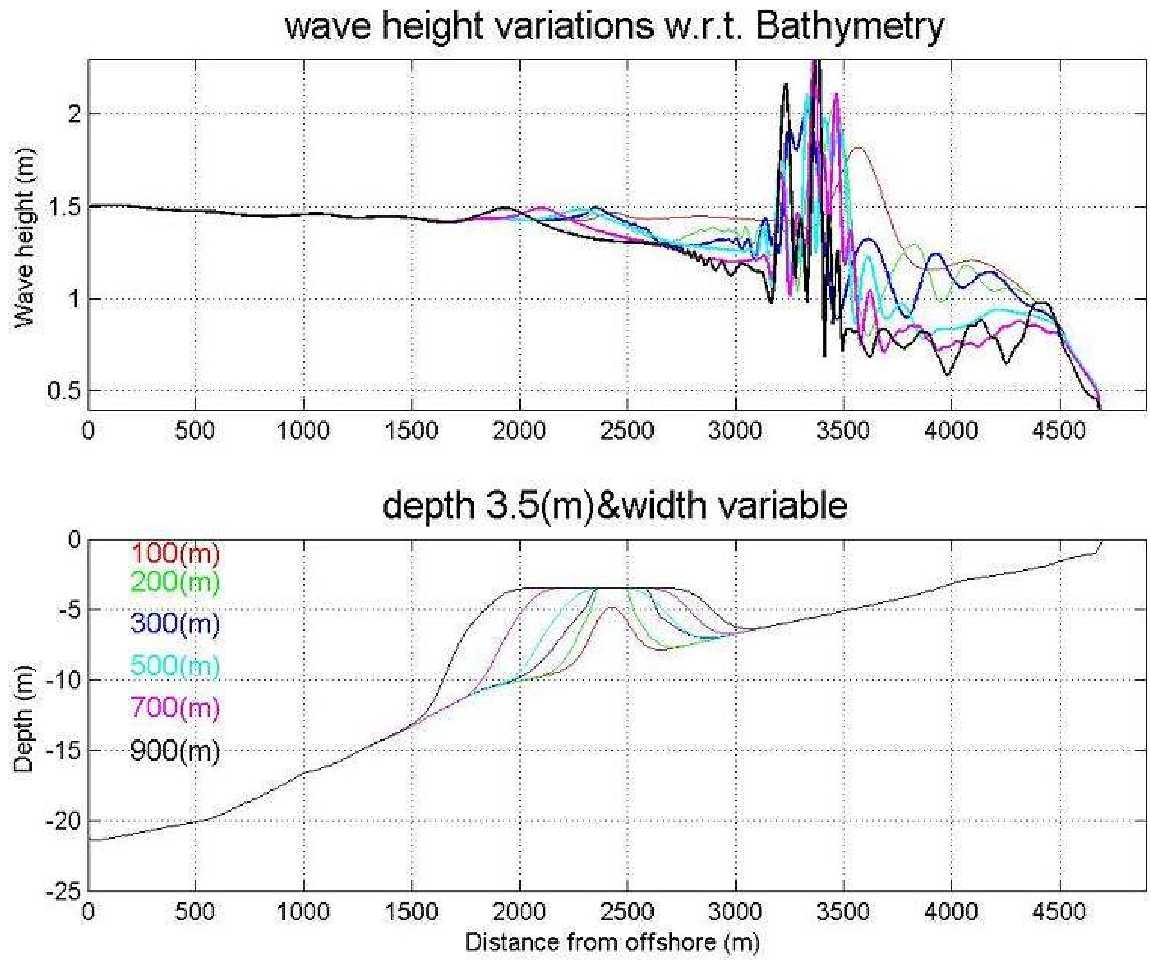


Fig 4.13b – Wave height variation for different reef widths (located at 3.5m depth)

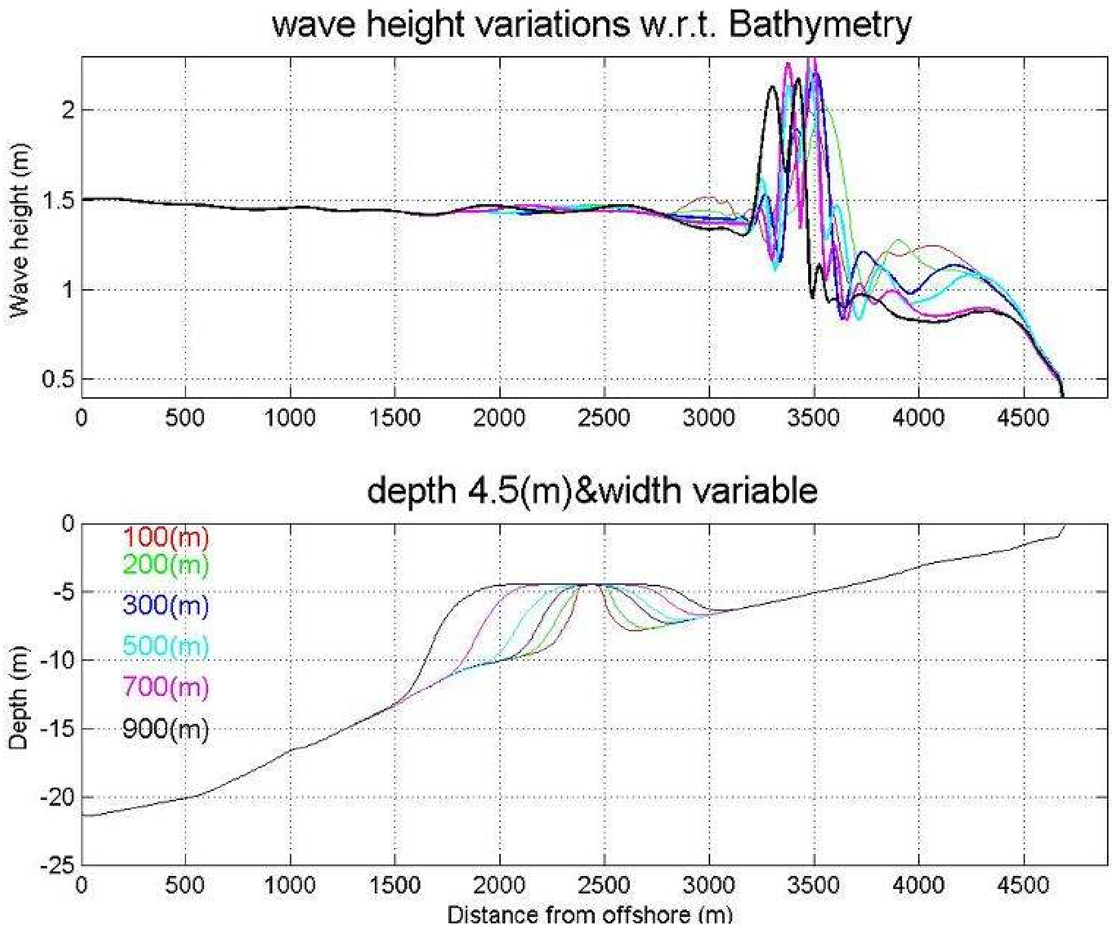


Fig 4.13c – Wave height variation for different reef widths (located at 4.5m depth)

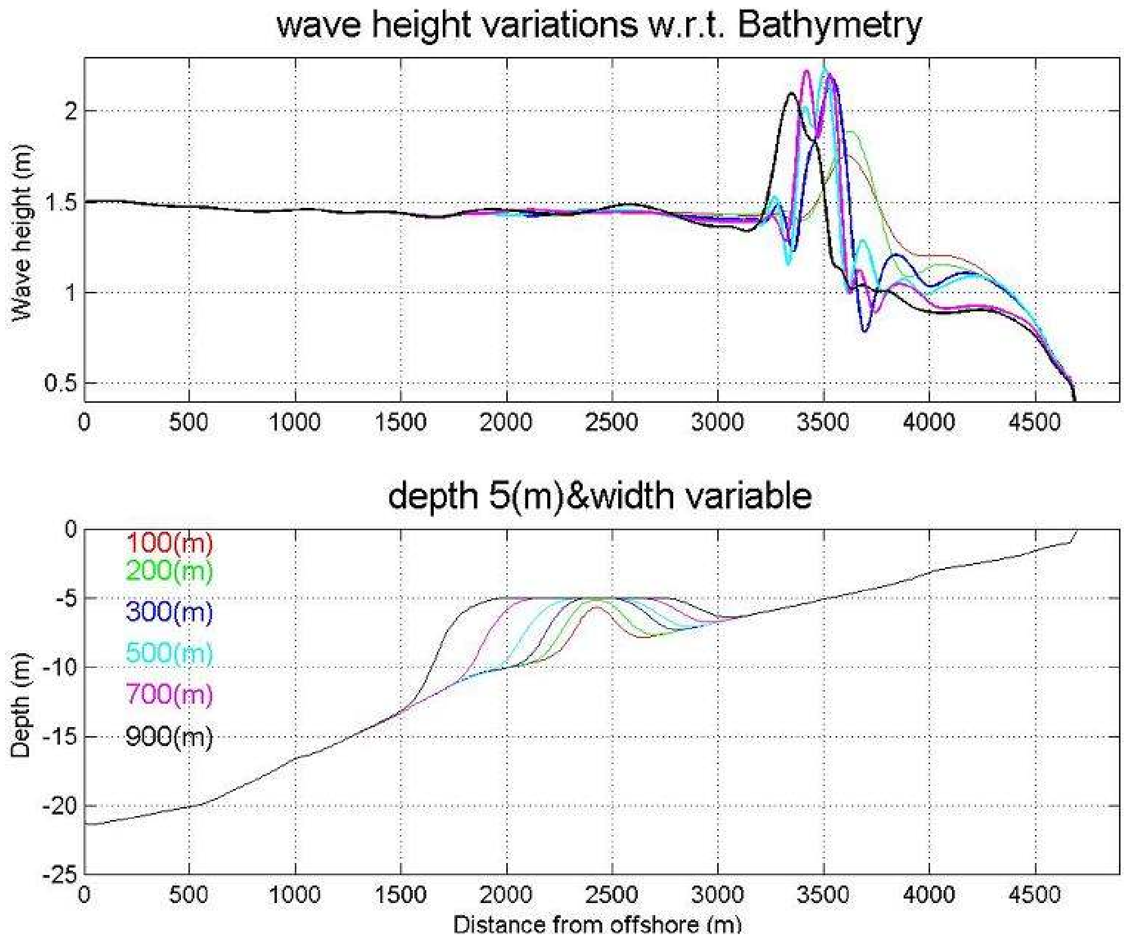


Fig 4.13d – Wave height variation for different reef widths (located at 5.0m depth)

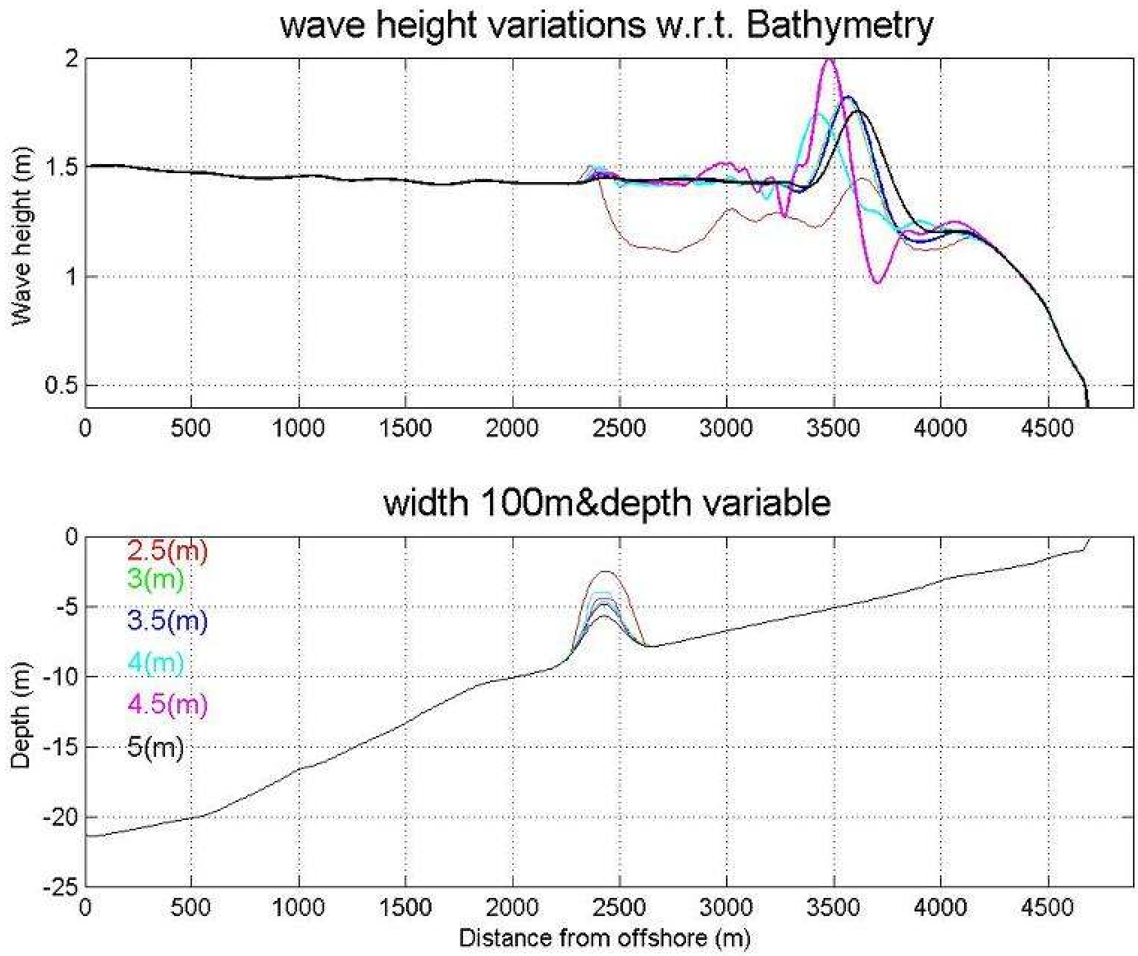


Fig 4.14a – Wave height variation for different reef depths (of constant width 100m)

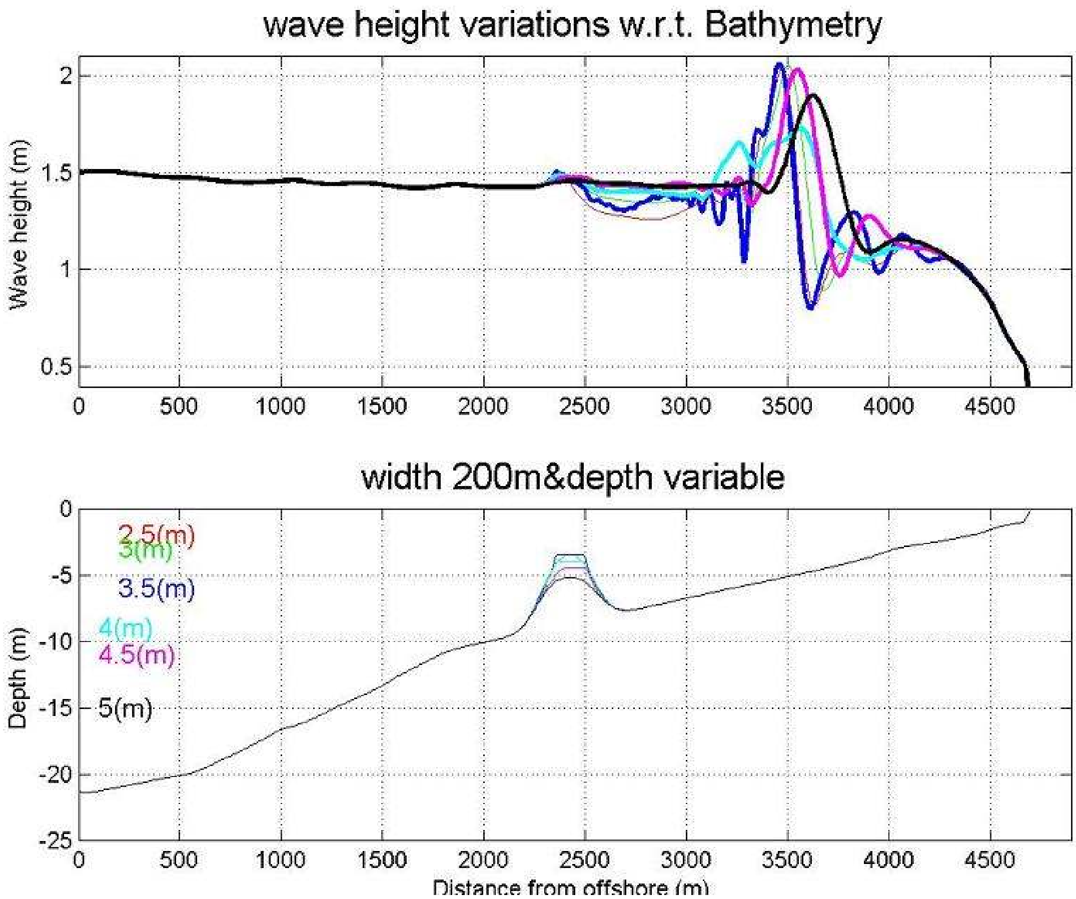


Fig 4.14b – Wave height variation for different reef depths (of constant width 200m)

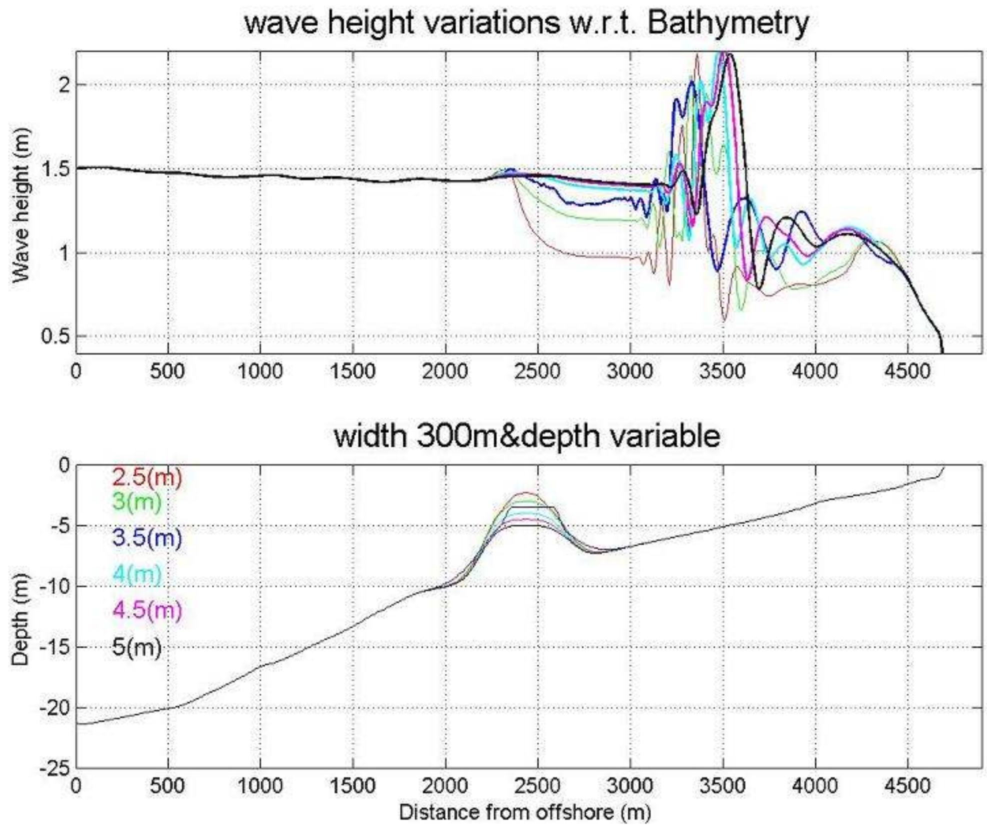


Fig 4.14c – Wave height variation for different reef depths (of constant width 300m)

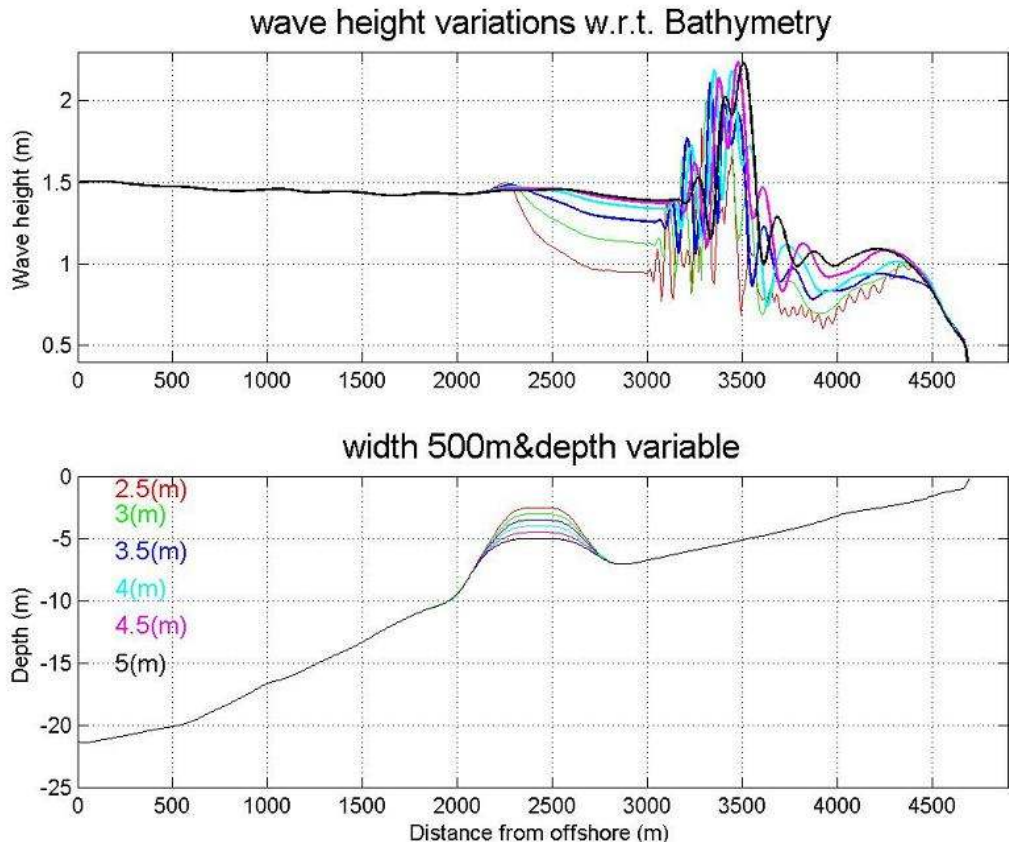


Fig 4.14d – Wave height variation for different reef depths (of constant width 500m)

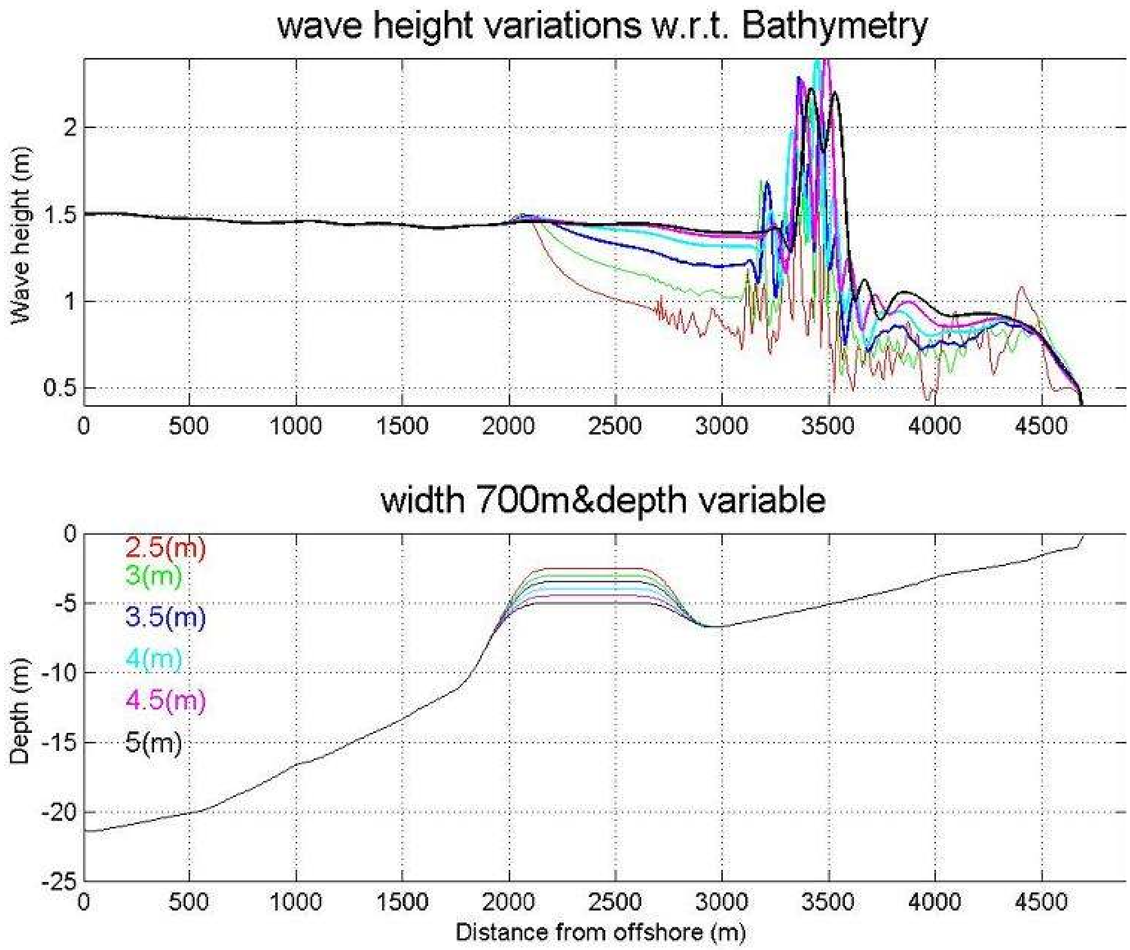


Fig 4.14e – Wave height variation for different reef depths (of constant width 700m)

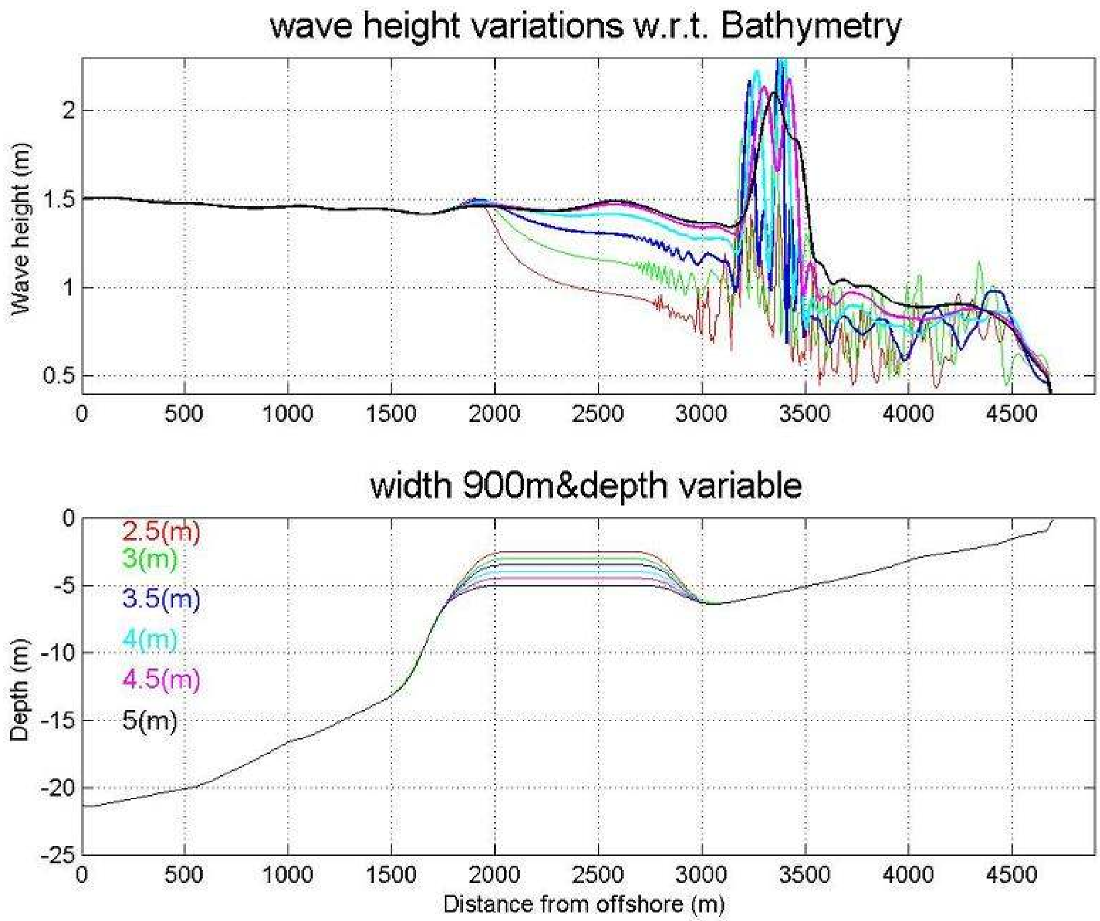


Fig 4.14f – Wave height variation for different reef depths (of constant width 900m)

5. RECOMMENDATIONS

The information on hydrodynamic (Tide, wave, current) conditions, shoreline changes and sediment characteristics was used to estimate sediment budget for the coastal stretch from Chennai port to Pulicat mouth. Analysis brings out following inferences.

- Sediment is bypassed to north at Chennai port through south breakwater. Construction of groin field at two coastal stretches along Royapuram coast has blocked part of sediment during year 2004-2005. Recent observations indicate that the accretion was reduced.

- The Beach, south of the port, is accreting at a rate of 45 m per annum, extended offshore 320 m, and alongshore 2.6 km, causing increased siltation in Ennore Creek. On north of port, 600 m length of beach fill is eroding at the rate of 50 m and the zone of erosion is shifting further north. During 2003 - 2004, the erosion length was extended up to 1500 m and 100-m width of beach was lost outside the nourishment area. Coastline adjacent to beach fill underwent readjustment and a village Katuppali located 2.5 km from the north breakwater is experiencing erosion to an order of 30 m per year.

- Predictions made using numerical model indicated that beach fill placed by port authorities would be completely lost to sea by 2007 and original coast will be under threat if no intervention is planned.

Four interventions are worked out based on the field investigations and numerical experiments – Artificial beach nourishment, Sand bypassing, Groins/Offshore breakwaters and Offshore submerged reefs. The advantages and limitations of each intervention are discussed below.

- Artificial beach nourishment, which was implemented by port authorities by dumping 3.5×10^6 m^3 of sand obtained from capital dredging performed well in controlling the erosion on northern side by way of supplying sediments to north. The detailed analysis made from the beach profiles and numerical modeling indicates that life of the project can be increased by arriving suitable dimensions of beachfill and transition length. Beachfill with a of length 1000 m, width 600 m with a transition length of 800 m would result in increase in the life of the project by one more year and the impact on adjacent coast can also be minimized.
- Sand bypassing is also proven to be better option for coastal protection along east coast of India, but requires periodic maintenance of equipment like pumps and pipes. Alternatively disposing of sand dredged from maintenance dredging to north of port through rainbow disposal, which is being currently implemented in Visakhapatanam port. The annual maintenance dredging expected at Ennore port would be around 0.3×10^6 to 0.5×10^6 m^3.

- Though option of groin field was worked out, it may not be efficient at Ennore port, as the sediment supply to north of port is limited by configuration of entrance channel. Observations indicate that coarser sediments coming from south are trapped into entrance channel of Ennore port. As a result, the finer sediments are only bypassed to north as suspended load, which may not be useful in building the beach. Construction of groins will also result in erosion of the coastal stretch further north of groin field.

- Offshore submerged reefs are one of the soft option which is implemented in New Zeeland, Australia and US and results of this option was more environmentally friendly and adaptive. Numerical Investigations are conducted with various configurations of reefs (length, width and crest height) and distance from the coast. Optimum configuration in terms of its dimensions and distance from the coast was arrived. The results indicate that reefs reduces wave energy upto 20 to 30% on nearcoast, there by helps in accumulation of sediments due to reduction in wave intensity. The cross impacts of these reefs is also minimum when compared to other options.

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